CLIMATE RESEARCH AND SEISMOLOGY DEPARTMENT

KNMI

Biennial Scientific Report 1999 - 2000

Koninklijk Nederlands Meteorologisch Instituut

CLIMATE RESEARCH AND SEISMOLOGY DEPARTMENT

Biennial Scientific Report 1999-2000

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Appendices

Preface • Two important events mark the activities of KNMI's Climate Research and Seismology Department in the years 1999 and 2000.

In 1999 an international Review Board reviewed the research of the Department. It was concluded that the quality and productivity of the research meet high international standards. Of course I am proud of this result.

The important public task of KNMI regarding climate change was emphasised by contributions of the Department to various reports and meetings. The recent report of the Intergovernmental Panel on Climate Change underlines the impact of research on public awareness of environmental problems and climate change. It also underlines the necessity of national and international co-operation in research to realise progress in climate research. Our scientific work is firmly embedded in international programmes and networks.

In this third biennial report of the Climate Research and Seismology Department an overview of the results and some highlights of experimental research in 1999 and 2000 are presented.

Prof. Dr. Joost de Jong
Director KNMI

Introduction • KNMI's research programme is a balanced combination of experimental, modelling and theoretical research, covering a wide range of aspects of the climate system. The central theme of this third Biennial Scientific Report of KNMI's Science Department is our experimental research. Five articles highlight various experimental and observational studies and facilities. Together they emphasise the importance of this aspect of KNMI's climate research.

Bernard Dost and Läslo Evers describe a project aiming at improving the assessment of seismic risks by the Seismology Division's work on 'unearthing' palaeoseismic information.

Fred Bosveld reviews research on the micrometeorology of a forest and its interaction with the free atmosphere, contributing to a better understanding of the role of forests in the climate system.

The Oceanographic Research Division has a long tradition in research of the microscale aspects of air/sea interaction. Cor Jacobs and co-workers present the first promising results obtained with a wave-following device that has been tested and will be deployed from the platform Noordwijk off the Dutch North Sea coast.

The greatest uncertainty in future projections of climate probably arises from clouds and their interactions with radiation, as is reaffirmed by the Third Assessment Report of the Intergovernmental Panel on Climate Change

(IPCC). André van Lammeren and his colleagues describe their work on simultaneous ground based and satellite detection and observation of many relevant cloud characteristics. To further extend and improve this work, a cloud radar has been purchased during the reporting period, which will be installed in the course of 2001.

The tropics are almost void of upper-air ozone stations. The recent establishment of such a station in Paramaribo, Surinam, with generous financial support from the Netherlands Organisation for Scientific Research, was greeted with enthusiasm by the research community. Paul Fortuin and his colleagues report in the last highlight on the technical aspects of this station and on the first results.

In addition to these highlights, all Divisions present their progress during the past two years, followed by an overview of our national and international policy related activities. The final chapter describes the work of the model support group.

At the end of 1999 an international Review Board reviewed the productivity and quality of our research. The Board concluded that our research has been very productive and has reached a high quality level by international standards. Of course the Board made some critical comments, some of which have already led to the implementation of proposed changes. We are working on a Research Strategy for the forthcoming years, in which the Board's suggestions for improvement will be taken into account.

KNMI's Research Department is the largest climate research group in the Netherlands. It is vital for the Department to have access to young scientists and to funding offered by the National Science Foundation and by national programmes. It is therefore essential to maintain excellent relations with universities with a climate research related curriculum. We offer research opportunities at graduate and post-graduate level and encourage part-time professorships of KNMI staff at Dutch universities. This policy has been fruitful. Three Heads of Divisions became part-time professor during the reporting period: Hennie Kelder at the Technical University of Eindhoven, Theo Opsteegh and Gerbrand Komen at the University of Utrecht. Bert Holtslag moved to Wageningen as a full-time professor. Many projects are carried out in co-operation with these universities.

One of the Department's public tasks is its close involvement in IPCC. We represent the Netherlands on the Panel and in Working Group I. Moreover, KNMI scientists contributed to IPCC's Third Assessment Report as lead author, contributors or reviewers. A substantial part of our scientific output was assessed by IPCC.

A pleasant working environment stimulates productivity: in 2000 Climate Research moved back to the refurbished east wing of KNMI's premises and our Seismology division moved to their great satisfaction into the beautifully restored old Villa, KNMI's former Headquarter since 1897. Unfortunately the hall with its beautiful stairs, which figured so prominently on the cover of the previous Biennial Reports, fell victim to this restoration.

The Ministry of Transport, Public Works and Water Management, of which KNMI is an Agency, funds our work in the first place. Additional funding is obtained from various funding agencies listed in an Appendix. I hope that this Report is convincing evidence that we made efficient, productive and grateful use of all funding provided.

Dr. Fons Baede
Head of Climate Research and Seismology Department

Recent highlights

Palaeoseismology: in search of large earthquakes

Palaeoseismological research along the Roer Valley Graben

by Bernard Dost and Läslo Evers

Introduction • The Netherlands is generally regarded a low seismicity area. This means that large earthquakes are rare, but not necessarily absent. Seismic hazard analysis for the Netherlands and immediate surroundings is based on the historical occurrence of seismicity in the region. Unfortunately, the historical catalogue is limited in time and moreover the magnitude of most events before 1960 is poorly known. Instrumental observations started around 1900 and it was not before 1935 that Richter designed a magnitude scale that was accepted and generally used. However, even though we have only access to a catalogue of events over a limited time frame, a statistical analysis of the historical dataset enables a hazard estimation [1]. In this analysis, based on Poisson statistics, a reference return period of earthquakes of 475 years is adopted, corresponding to an exceedence probability of 10% in 50 years. The south-eastern part of the Netherlands shows the strongest hazard, related to the Roer Valley Graben (RVG). There is interest from the (re)-insurance companies considering the economic importance of the region. Calculations of the potential losses for a hypothetical earthquake of magnitude 6.4 near Cologne at 10 km depth amounts to a loss of 55 billion US $ [2].

Fortunately there are methods to extend the observation period. One way is to use written historical data, though the interpretation will not always be easy. In some cases, like a reported historic event in the Northern part of the Netherlands in 1262 [3], earthquake phenomena are reported in combination with strong winds and the association of three reported

phenomena with an earthquake is doubtful. The help of a historian is indispensable for the evaluation of the written sources. In this way the observational period can be extended from 100 years to approximately 700 years. Looking at an even longer timescale, palaeoseismology, the study of prehistoric earthquakes, may add additional information. Looking in detail at the near surface geology of large faults, a search is made for traces of movements at the surface (surface rupture) that may be interpreted as being caused by large earthquakes.

There is a strong indication of surface rupture for 3 events in the last 30.000 years

The Roer Valley Graben is the main active tectonic feature in the Netherlands and did produce earthquakes of moderate size (Uden, 1932, local magnitude $M_L = 5.0$, Roermond 1992, $M_L = 5.8$). Both events are located at the Peel boundary fault (PBF), the north-eastern boundary of the RVG (Figure 1). This fault was selected as a target for the first palaeoseismic investigation in the Netherlands. Since the average depth of earthquakes around the PBF is 17 km, a surface rupture requires an event of a large magnitude. The recent Roermond event (April 13, 1992) of local magnitude 5.8 (moment magnitude $M_w = 5.3$) left no traces along the fault at the surface, although earthquake related phenomena like liquefaction (sand boils) and triggered landslides were observed in the region.

The south-western bordering fault of the RVG, the Feldbiss fault, has been investigated previously in a series of palaeoseismological studies [4]. Five trenches have been excavated in the period 1996 - 1999, sampling a fault segment of 5 - 10 km. Although not all trenches show the same events, there is a strong indication of surface rupture for 3 events in the last 30.000 years (30 kyr). Inferred magnitudes for these events are between 6.2 and 6.8, which is a full magnitude higher than the 1992 Roermond event. These studies triggered interest in the subject of scientists in the neighbouring countries and resulted in a European project (PALEOSIS), which was carried out in the period 1998 - 2000. For the RVG area a German group focussed its attention on the Rurrand fault, the extension of the PBF, while KNMI and the Netherlands Institute of Applied Geosciences (NITG-TNO) focused on the PBF. The third partner, the Royal Observatory in Brussels (ORB), acted as co-ordinator and assisted in the research of the other partners.

Site selection • The Peel boundary fault has a visible surface expression in the Netherlands. On aerial photographs the fault can be identified in the south-eastern part of the country as a small scarp. This is confirmed by geodetic levelling data and mapping of tectonic lineaments [5].

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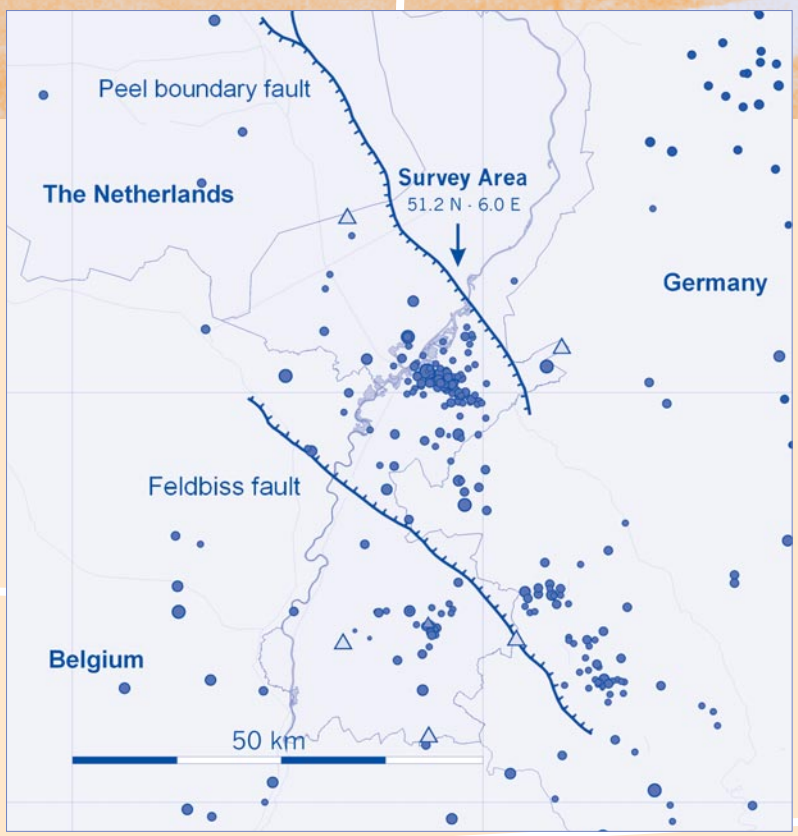

Figure 1.Overview of seismicity in the southern part of the Netherlands and surrounding region (1900-2001). The Peel boundary fault is the north-eastern boundary of the Roer Valley Graben while the Feldbiss fault bounds it to the south-west. The dots represent earthquakes and the triangles denote seismological stations.

Zooming in on the fault, the following criteria were used to define a target area for palaeoseismological research:

1. The fault zone should be simple in its configuration, preferably consisting of a single fault plane.
2. A visible step in the terrain should allow geomorphological modelling, providing additional constraints for the interpretation.
3. Dating of Holocene (< 12 kyrs Before Present) events is of crucial importance and can best be done if the trench could be related to well dated terraces of the Maas river.
4. Ground water level should be lower than the projected depth of the trench (3 m) to avoid expensive pumping during the excavation.
5. The survey area should not fall under laws preventing trenching (nature reserve).

On this basis, two potential sites were selected near the village of Neer, close to Roermond. A detailed survey using Ground Penetration Radar (GPR) was carried out at the two sites to find the exact position of the Peel boundary fault (Figure 2) and to image the fault zone close to the surface. This method shows high resolution pictures of the first few meters, but is limited by the depth of the groundwater level. The first site, where a clear step in the terrain was observed, gave no results, since the groundwater level was close to the surface. The second site, close to the village, showed at the GPR sections clear evidence of the fault scarp at depth and this site was selected to carry out additional geophysical surveys. The selected area is a square of 100m by 100m and shows a small step in the terrain (2 - 3 m) trending NW-SE.

A detailed survey using GPR was carried out at the two sites to find the exact position of the Peel boundary fault

After the initial GPR profiles electrical tomography (ET) was applied, an independent measure to add information on possible compositional changes in the subsurface. Lateral variations in resistivity were found to coincide with variations in the depth of the reflectors in the GPR sections, indicating a fault. Since these results were very promising, a full 3D survey was carried out to follow the fault in detail with both GPR and ET measurements [6].

Although the terrain was quite smooth, less than 3 m variation in altitude over a horizontal section of 150 m, a detailed levelling profile was measured by the ORB. If the present shape of the fault scarp is due to erosion from an initial situation where a fault step was created, the original vertical offset can be inferred from geomorphological modelling. This was investigated

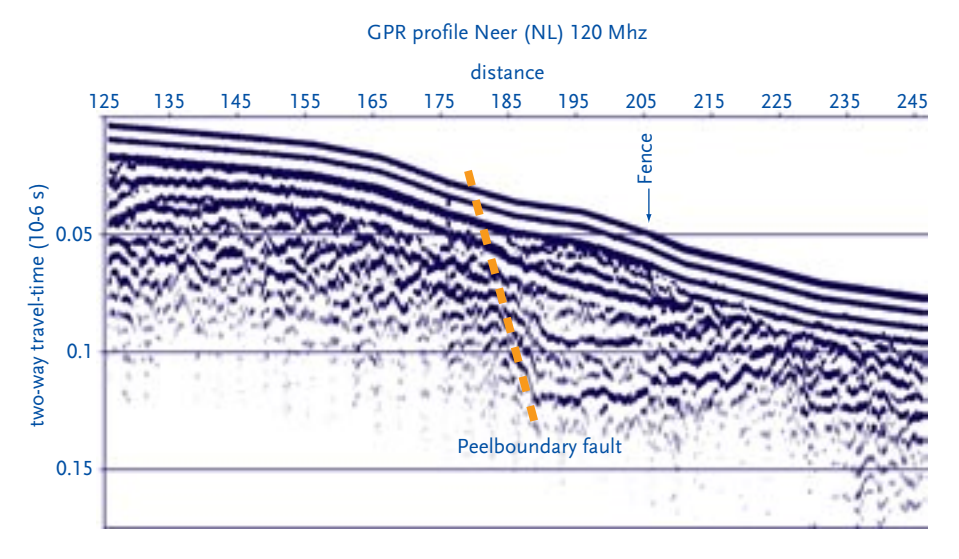

Figure 2. Ground Penetrating Radar (GPR) section in the survey area, running from NE to SW over a total length of 120 m.

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at both the trenches along the Feldbiss fault and the PBF, resulting in comparable figures for both faults. Since the last glacial maximum (14 - 19 kyrs BP) a total vertical offset of more than 1 m is inferred.

Trench analysis • After site selection a trench of 60 m in length, 3 m deep and 3 - 4 m wide was made (Figure 3). As expected on the basis of GPR and ET measurements, the fault was captured within the trench and a detailed geological survey was carried out by geologists of the NITG-TNO in co-operation with colleagues from the ORB. The survey focused on recent geological history (< 25 kyrs BP) exposed in the trench. A typical horizon clearly present in the trench is the Beuningen gravel bed, which is dated at 16 kyrs BP. This horizon showed displacements of 55, 30 and 5 - 10 cm, corresponding to three postulated events. Other geological horizons deeper in the trench show the same displacements as the Beuningen horizon, suggesting no additional movements between 25 and 16 kyrs BP. The most recent history is disrupted by human activity, like ploughing, and detailed soil analysis was needed to study the faulting process in detail. The two main events are postulated to have taken place in a period of less than 2 kyrs between 16 kyrs BP and 14 kyrs BP. The third, most recent and smallest event cannot be dated, but occurred presumably in the late Holocene (< 12 kyrs).

It should be noted that the results described are based on a number of assumptions. First of all the nature of the displacements found in the trench is assumed to be co-seismic. This is based on circumstantial evidence, like the identification of liquefied sands close to the fault zone. It

The two main events are postulated to have taken place in a period of less than 2 kyrs

may be that part of the displacement found was generated by a-seismic movement. A further assumption is that all events did generate surface displacement in one large earthquake. However, the displacement may be caused by more than one earthquake within a period of e.g. 100 years, which could diminish the size of the postulated events. These assumptions introduce an uncertainty in the results and one should keep these in mind.

Inferences • Based on the measured displacements at the surface, an estimate can be made of the magnitude of the events. Empirical relations have been developed between surface displacement, rupture length, rupture area and magnitude [7]. Because data from only one trench are available, two methods can be used. The first method is based on an estimate of the fault rupture length. This estimate is made on the basis of regional

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Figure 3. View on the trench looking to the south-west.

Magnitudes. The original definition of magnitude by Richter in 1935 was intended for epicentral distances up to 600 km. The scale was based on the measurement of amplitudes from recordings of a standard short period seismometer and as a result saturates for large earthquakes that generate longer periods outside the pass band of the instrument. In order to extend this definition to larger distances and to overcome saturation, new definitions were added: body wave magnitude (m_b) and surface wave magnitude (M_s). All these measures, however, are based on amplitudes of seismic waves and suffer saturation for the larger events. The moment magnitude (M_w), however, is based on the measurement of the seismic moment, which more directly represents the amount of energy released at the source. The moment magnitude does not saturate and is the reference magnitude in palaeoseismic research.

geology- the lateral extend of the single fault plane as can be followed in seismic reflection lines- and on the basis of regional subsidence data. The estimated rupture length at Neer is 10 - 20 km which implies a magnitude of M_w= 6.2 (10 km) to 6.6 (20 km). The second method is based on an estimate of the maximum surface displacement. At Neer the maximum displacement measured in the trench is 10 - 50 cm. These values relate to a magnitude of M_w= 6.0 (10 cm) and 6.5 (50 cm). Both methods give comparable results. However, accuracy is limited and can only be improved when more trenches are opened along the fault zone. Then average displacement can be used and the continuation of the events can be traced. The magnitude estimates for the largest events are more than one magnitude unit higher that the values for the Roermond event (M_w= 5.3).

Apart from the magnitude, also recurrence times of large earthquakes are important for hazard estimation. Although results from the trench at Neer provide a first view on the activity of the PBF at longer time scale, the fact that only two events were observed at a relatively short time scale (2 kyrs) is a complicating factor. There is a need for more trenches to correlate events and to obtain a better understanding on the recurrence times.

There is a need for more trenches to correlate events and to obtain a better understanding on the recurrence times

General picture • The findings along the Peel boundary fault are comparable to the findings of palaeoseismic research along the Feldbiss fault. The recent geological history shows traces of possible large events. Recurrence times are not yet accurately known, but the findings at Neer suggest that the occurrence of large events is irregular in time. The Feldbiss fault is investigated in more detail [8]. Five trenches have been opened in the period 1996 - 1999 enabling a correlation of events sampling 5 km fault length. Three events in the last 30 kyrs are identified. The most recent event is dated 600 - 900 AD and is visible in three trenches.

Trenching along the continuation of the Peel boundary fault, the Rurrand fault in Germany, close to the city of Jülich unfortunately showed little results. This is due to the fact that the trench did not show recent deposits, due to the presence of a plough layer disrupting the geology record. However, the trench showed on a longer time scale (250 kyrs) episodic faulting [9].

Palaeoseismic research applied to active faults in a low seismicity area sheds some light on the existence of large earthquakes that occur on a longer timescale. In order to get a more complete picture, more trenches are needed enabling a correlation of events over the rupture front of a postulated

palaeo-earthquake. Since the region is either densely populated or part of a nature reserve where trenching is not permitted, the possibilities of further research is limited. However, in view of the increased vulnerability of modern society to hazards it is worthwhile to continue the search for large earthquakes in a low seismicity area like the Roer Valley Graben.

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Sensing the forest: a micro-meteorological study

by Fred Bosveld

Introduction • Entering a forest is always a special experience for a meteorologist. Forests form one of the few canopies of which the interior can be entered and experienced without special instruments. Wind speeds and radiation levels are lower than in the open field. And, when listening carefully, the development of wind gusts into the forest canopy can be followed by ear. Geiger was one of the pioneering forest meteorologists [1]. He showed that the actual microclimate depends on the density of a forest. In general the air in the interior of the forest is cooler and more humid than aloft during daytime. This effect is more pronounced for a dense forest. Although the large size of trees compared to other vegetation types is not a principle difference, the influence of forest on atmospheric and hydrological processes differs substantially from the influence of low vegetation. Most notable forest characteristics are a low albedo, a large rainfall interception reservoir and high aerodynamic roughness [2].

As an example, Figure 1 shows typical measurements of the components of the energy balance for a grassland site (Cabauw, the Netherlands) and a Douglas fir forest (Garderen, the Netherlands) for the same clear day (May 21, 1989). The figure shows that for the same short wave downward radiation (SWD), higher net radiation (QN) occurs at the forest site. This is related to the difference in albedo, 0.11 for the forest and 0.23 for the grassland site. But also, daytime surface temperatures (not shown here) are much lower for the forest site, due to the high roughness of the forest, leading to a smaller upward long wave radiation as compared to the grassland site. Transpiration rates (LHF) are very different. At the grassland site transpiration

is so high that the afternoon change of sign of the sensible heat flux (SHF) occurs 3 hours earlier than at the forest site. The diurnal variation of the storage heat flux (G) is much larger at the forest site due to the significant amount of standing biomass. The large difference in sensible heat flux between the sites suggests that the atmospheric boundary-layer height will be higher over forest than over low vegetation.

Air-pollution and the Dutch forests • Concern for the hazardous effect of air-pollution on natural ecosystems in industrialised countries has initiated much research over the last decades. In the Netherlands this concern resulted, among others, in the Dutch Priority Program on Acidification. As part of this program the ACIFORN project (Acidification research on Douglas fir Forest in the Netherlands) aimed at assessing the impact of air pollution on tree vitality. The experimental part of this project culminated in a co-ordinated experimental effort in 1989 by a number of Dutch institutes at the Speulderbos research location, near the village of Garderen, the Netherlands. The experimental site was a Douglas-fir stand *(Pseudotsuga menziesii)* situated in an extended forested area. The co-operating institutes were the Agricultural University of Wageningen (air-pollution concentration, root density), the Research Institute for Forestry and Urban Ecology, Wageningen (bio-geometry), University of Amsterdam, Environmental Sciences (hydrology), University of Leiden, State Herbarium (bio-geometry), TNO Delft (Ammonia concentrations), KEMA Arnhem (tree sapflow) and KNMI De Bilt (micro-meteorology). After this period more experiments have been performed on this location. Among others the Speulderbos site has been one of the two landsurface stations for the KNMI Tropospheric Energy Budget Experiment (TEBEX). Since the beginning of the 1990's the site is managed by the Netherlands Institute for Public Health and the Environment (RIVM) and is part of their air-pollution monitoring network.

To study the impact of air pollution on tree vitality one has to estimate the amount of air pollution that is deposited onto the forest. For many air pollution components no direct flux measurement methods are available since these require fast response concentration measurements to apply the so-called eddy-covariance method. However, vertical concentration differences can be measured for many species with high accuracy. To apply this type of measurements the relation between the vertical concentration difference and the vertical flux close to the forest has to be known. For low vegetation well established relations for the turbulent transport resistance exists which hold well away from the surface. Theoretical and experimental studies suggest that by taking the low vegetation relations as a reference, a decreased resistance occurs in the air layer just above forests (typically lower then a few times the vegetation height). By lack of a good theory about the relation between forest geometrical parameters and this decreased resistance it appeared to be necessary to determine the turbulent transport resistance over the Douglas fir forest experimentally. To this end the transport properties for heat were derived on the basis of direct turbulent flux measurements and accurate temperature

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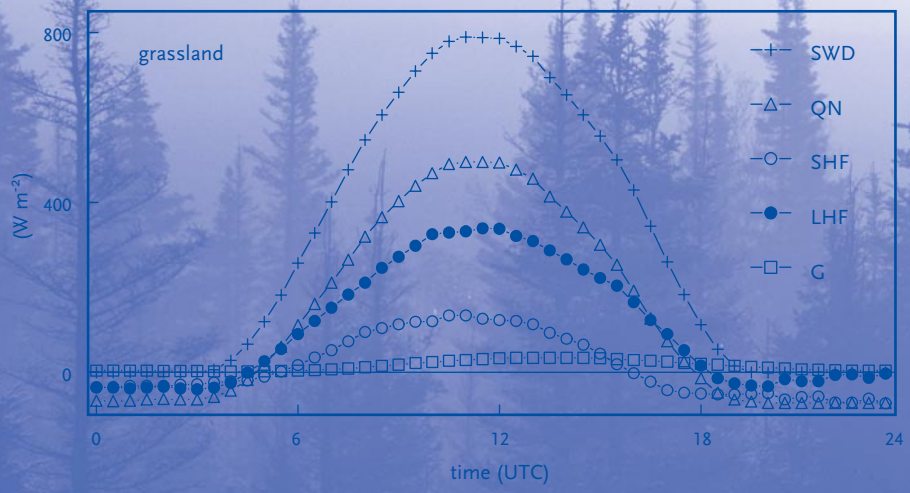

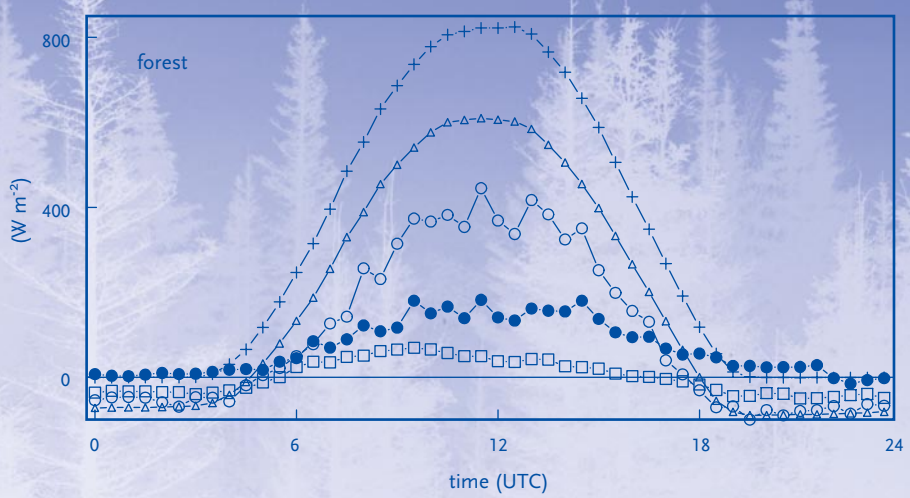

Figure 1. Surface fluxes of short wave incoming radiation (SWD), net radiation (QN), sensible heat flux (SHF), latent heat flux (LHF) and storage heat flux (G) for a forest and a grassland site for the same day.

difference measurements [3]. Figure 2 shows the decreased transport resistance (again relative to the low vegetation value) as function of height (scaled on the vegetation height) for the Douglas-fir forest (full circles). Also shown are the results for a number of other forest studies. In general the transport resistance approaches the low vegetation value above approximately two times the forest height and decreases when going down to the forest. However, the differences between forests are large, partly related to the density and other geometrical characteristics of the forests. Having established the site specific exchange coefficients the observed air pollution concentration gradients could be interpreted in terms of deposition fluxes. The results of the deposition estimates produced within the ACIFORN project has played an important role in the national debate about air-pollution reduction measures.

Forests in weather and climate • The Earth's surface forms the lower boundary condition of the atmosphere. As such it strongly modulates the internal dynamics of the atmosphere. The distribution of land and sea and the location of mountain ridges are of importance for the large-scale variations in weather and climate, as is the distribution of sea surface temperature. But also land surface types and their variation over the globe have an important impact on global and regional climates. Forests form one of the important ecosystems of the Earth's land surface.

Predicted climates are sensitive to the model treatment of surface albedo, soil water availability, surface roughness and stomatal control [4]. Feedbacks on the diurnal scale occur through the coupling between evapo-transpiration on one hand and boundary-layer development and boundary-layer cloud formation on the other hand [5]. On the seasonal scale the coupling of soil water availability with atmospheric precipitation is important [6]. At still longer time scales, changes in vegetation cover are to be considered. For weather prediction in the short range (3 days) the impact of land-surface cover is less important due to the process of continuous assimilation of observations. However, a correct representation of surface processes is still of great importance for the translation of large-scale weather characteristics to phenomena close to the surface, where most human activities takes place.

Comprehensive observational data sets of surface fluxes of precipitation, radiation, sensible and latent heat and momentum covering at least one hydrological year, can contribute significantly to the evaluation of climate and weather models. But also process studies can shed light on deficiencies in the model formulation. For the Speulderbos a data set is available which can be used to evaluate land surface models. The time series are made continuous with an intelligent time gap-filling procedure [7]. As an example of a process study we discuss the results on evaporation and transpiration and their interaction for the Speulderbos site.

Transpiration is the loss of water through the stomata of the tree leaves. For dry days this is the dominating process of water loss from the

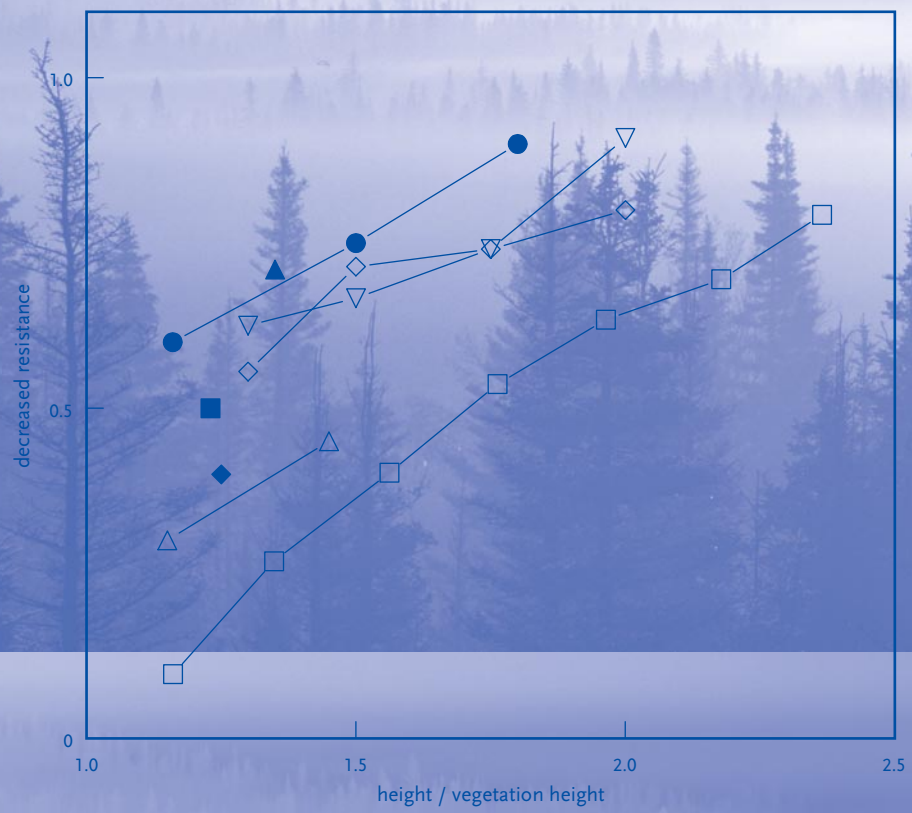

Figure 2. Decreased transport resistance for Speulderbos (full circles) and various other forests as function of height scaled on vegetation height.

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forest. The magnitude of transpiration is determined by the atmospheric conditions (available energy, temperature, humidity and wind speed) and by the control of the trees on the stomatal aperture. This control itself is a feedback on atmospheric conditions and on the soil water conditions. In the 1960's a concept was developed to separate the atmospheric influence from the vegetation influence by the introduction of the surface conductance for water vapour. From this concept the so-called Penman-Monteith equation was derived [8]. This concept was applied to the Speulderbos forest observations [9]. Figure 3 shows the observed surface conductance (based on eddy covariance transpiration rates) for water vapour as a function of specific water vapour deficit (a measure for the dryness of the air). There is a dramatic decrease of conductance with increasing dryness. For this forest the control is so strong that it fully counteracts the atmospheric influence of increased drying power of dryer air. The figure also shows that with increasing short wave downward radiation (SWD) the conductance increases. This is a well known effect that is related to the need of a plant to take up more carbon-dioxide through the stomata when assimilation potential is high at high irradiation levels.

The forest control fully counteracts the atmospheric influence of dryer air

During rainy episodes the crown layer of the forest intercepts part of the precipitation. This intercepted water is then evaporated back into the atmosphere. Trees have no control over this process; it is almost fully regulated by the atmospheric conditions. Interception amounts are especially high in maritime climates where the yearly rain amounts fall with relatively low intensities spread over the whole year. The other determining factor for interception loss is the evaporation rate itself. This determines how quick the canopy dries out and how precipitation is partitioned between drainage and the evaporation of intercepted water. By using a novel technique based on microwave attenuation, Bouten from the University of Amsterdam was able to measure the interception process in great detail [10]. Due to the energy consumption by the evaporation process and due to the blocking of stomata by free liquid water on the needles the transpiration rate is suppressed. With the so-called heat pulse velocity technique long time series of the sapflow velocity in the trunks of trees were obtained. This sapflow velocity is a measure for the transpiration rate. However, due to storage of sap in the tissue between the trunk and the crown of the tree the two may differ in timing. The combination of measurements enabled us to distinguish transpiration from evaporation during wet conditions [9]. The Penman-Monteith equation was extended to describe both processes and their interaction. Figure 4 shows for one day observed evaporation (microwave attenuation) and transpiration rates (sapflow),

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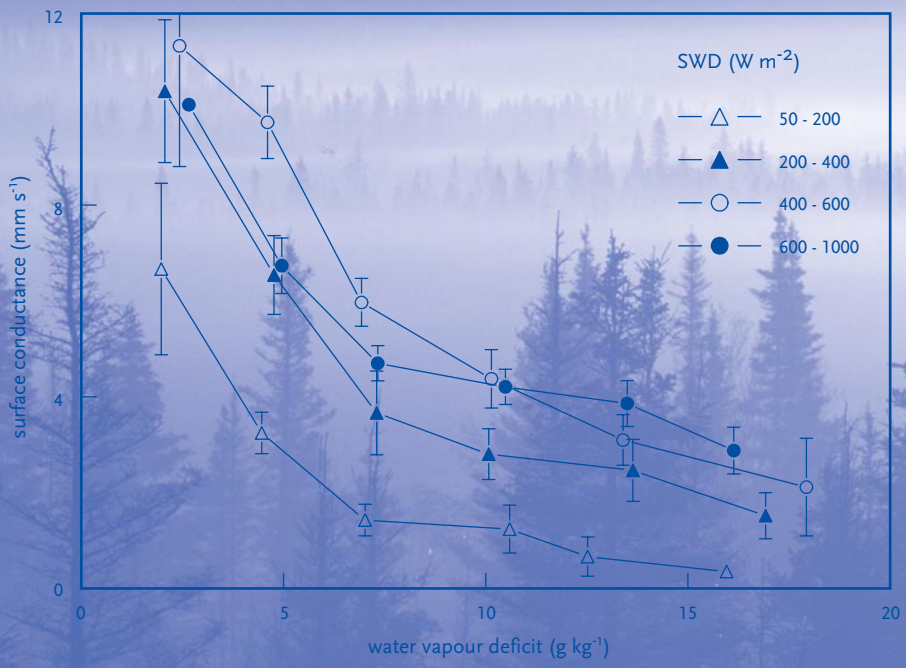

Figure 3. Observed forest surface conductance as a function of water vapour deficit, stratified into classes of short wave downward radiation (SWD).

Figure 4. Evaporation (Evap) and transpiration (Trans) both observed (obs) and modelled (mod) for one day with a drying episode. Also shown is the reference transpiration for dry days (Trans(ref)). The sapflow (Trans(obs)) deviates at night.

together with the modelled values based on the observed meteorological conditions. The transpiration reference line shows the model transpiration that would occur with the same atmospheric conditions when the canopy would have been dry. In the morning a clear transpiration reduction is observed. The deviation in the late afternoon is related to the difference in timing between sapflow and transpiration

Forests and satellite based remote sensing • With the advent of satellite based observational systems, global observations of the Earth's surface become available. Characterisations of various parameters related to land surface type can be obtained on a global scale by using radiance observations. Although still hampered by various problems, (atmospheric transmission, cloud detection, linking observed parameters to canopy parameters) satellite based observations seems to be the way forward to improve on describing the lower boundary condition of the atmosphere quantitatively on a global scale. Ground-based observations are essential to interpret these remote sensing data.

The surface radiation-temperature plays an important role in the surface energy budget and it is one of the important surface parameters that can be observed from satellite-based observational systems. The temperature difference between the surface and the atmosphere is related to the partitioning of the available energy into its components. Various methods to estimate the evapo-transpiration from observations of infrared radiation temperature are investigated [11]. For a good interpretation of these observations, we need a thorough understanding of the various processes that determine the surface temperature.

During daytime the surface radiation temperature for the Speulderbos forest appeared to behave in a predictable way. Given the atmospheric conditions and the forest geometrical characteristics the surface radiation temperature could be predicted by extrapolating the atmospheric temperature profile to the forest crown layer [12]. However, when turning to night-time conditions, at times unexpected behaviour was found. Deviation from theory occurred during low wind and clear sky conditions [13]. These are

Deviation from theory occurred during low wind and clear sky conditions

typical conditions for canopy convection to occur as already described by Geiger in the 1930's. Figure 5 shows for two nights potential temperature differences relative to the temperature at 24 m height. The temperatures indices are (i) interior of the forest (4 m) and (c) crown radiation. The left panel is a high wind speed case and it is observed that the interior temperature is close to the air temperature aloft, whereas the crown radiation temperature is somewhat lower due to long-wave cooling of the crowns. The right panel is a low wind

Discovering the forest

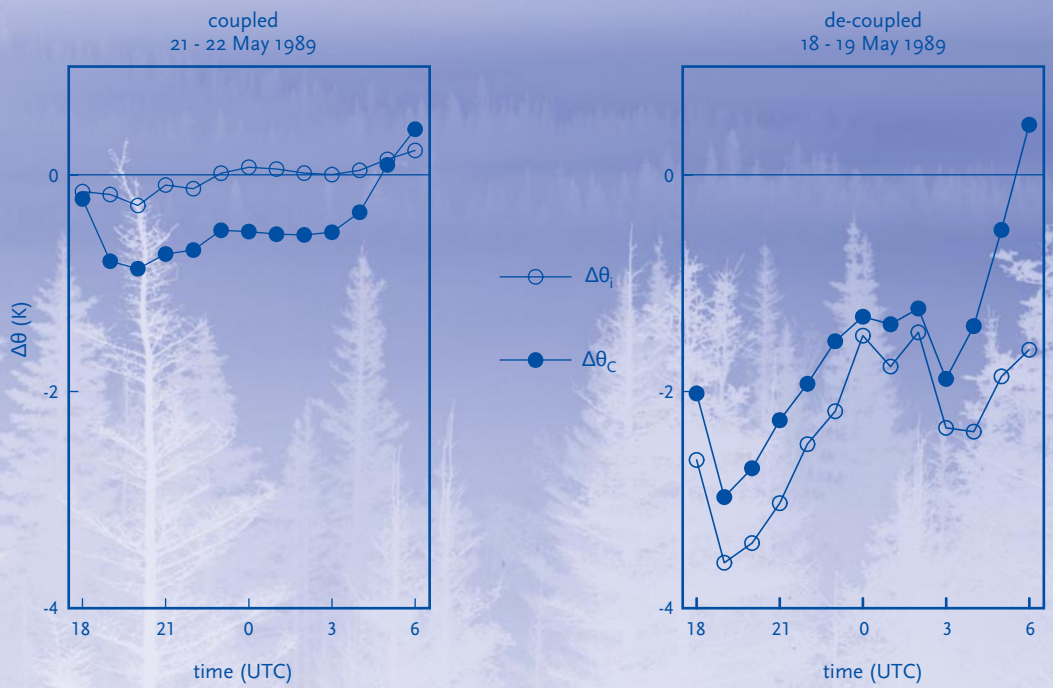

Figure 5. Observed potential temperature differences relative to the 24-m level, for two clear nights. Left panel - high wind speeds (coupled case). Right panel - low wind speeds (de-coupled case). (i) in forest interior and (C) crown radiation temperature.

speed case although later in the night wind speed increases. Here we see that the interior temperature follows the crown radiation temperature. This shows that at high wind speeds the interior temperature is coupled to the air temperature above the forest. At low wind speeds and clear sky conditions both the interior temperature and the crown radiation temperature are decoupled from the temperature above the forest. Due to long wave cooling, we would expect for the decoupled case the crown temperature to be lower than the interior temperature. In reality the crown radiation temperature is a mixture of temperatures along the depth of the crowns. In low wind conditions the temperature in this layer increases with height and the mean crown temperature is higher then the minimum temperature in the deeper layer. When correcting for this effect a well defined relation was found between the amount of storage heat transported through the air in the forest interior to the crown layer and the difference between the crown temperature and the forest interior temperature. This relation appeared to be of the same form as the relation between vertical temperature differences and transported heat in the convective atmospheric boundary-layer. These studies show that the interpretation of satellite-based infrared surface radiation observations of forests can be quite complex especially during night time.

These studies show that the interpretation of satellite-based infrared surface radiation observations of forests can be quite complex

Probably, the Speulderbos forest site is the best investigated forest in the Netherlands. Thanks to the co-operation of many national institutes at one forest site many interdisciplinary studies could be performed related to forest growth, air pollution, hydrology and meteorology. The data sets and research results have found their way into both the scientific and the policy maker's communities. The estimates of air pollution loads have played an important role in the political debate on air-pollution regulations. Recently the data have been used, among other data sets, in the evaluation of the new land surface module of the model of the European Centre for Medium-Range Weather Forecasts (ECMWF). At the moment the data are used to evaluate a satellite-based method for deriving evapo-transpiration maps.

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Dances with waves: the KNMI wave follower

by Cor Jacobs, Wiebe Oost, Cor van Oort and Ed Worrell

Air-sea interaction • The generation and growth of waves due to wind blowing over water, is a well-known example of air-sea interaction. Momentum transported downwards from the air to the sea causes the waves to grow until equilibrium is reached between input and dissipation of energy. The most obvious manifestation of wave energy dissipation is breaking waves, often visible as whitecaps. If growth or an equilibrium situation cannot be sustained anymore by the input from the wind, the waves decay again. This form of air-sea interaction has a variety of practical consequences, ranging from the design and construction of dikes to the pleasure - or dangers - that surfers or swimmers experience in the surf zone.

But air-sea interaction goes far beyond generation, growth and decay of waves. Air-sea exchange processes, taking place at over two-thirds of the Earth's surface, are of paramount importance to our weather and climate. The exchange of heat, moisture and momentum between the oceans and the atmosphere fuels to a large extent the atmospheric and oceanic circulation. The release of water vapour and cloud condensation nuclei by the oceans affects the formation and distribution of clouds. Trace gases, such as CO_2 and many other natural or anthropogenic constituents are exchanged continuously between the ocean and the atmosphere. This affects the distribution of such substances between atmosphere, hydrosphere, cryosphere, biosphere and lithosphere, and therefore atmospheric trends of, for example, greenhouse gases. On smaller scales air-sea interaction influences the dynamics and chemical and biological processes of the upper ocean.

Thus, any type of coupled ocean-atmosphere model aiming at wave and surge prediction, weather prediction, climate studies or studies of other environmental issues should contain a correct description of air-sea exchange. This in turn requires a fundamental knowledge of air-sea interaction processes.

Wave-turbulence interaction • The exchange of momentum, heat, moisture and gaseous substances between the air and the sea, driven by differences in wind speed, temperature, humidity and concentration, respectively, is predominantly controlled by turbulence. Just above the wavy water surface, the waves interact with the atmospheric turbulence. Wave motions initiate pressure fluctuations and motions in the air, resulting in what we will call wave-coherent features. For example, air is forced upwards if it approaches a wave crest, and flows downwards again if it enters the through. Thus, while the spatial average of the vertical velocity is approximately zero near the surface, the vertical velocity is in this case on average positive at the backward faces of the crests, and negative at the forward faces. In other words, choosing the wave-phase as the frame of reference, we may anticipate phase-related systematic differences in the vertical velocity. In the case of fixed obstacles (a 'frozen' wave field) such differences would turn out to be systematic, spatial differences. Waves will also induce differences in other quantities, such as horizontal wind speed, pressure and turbulent transport [1].

The closer to the sea surface, the more intense we expect the interaction between waves and turbulence to be. The atmospheric layer in between and just above the waves, with a noticeable influence of wave motion on turbulence is called the wave boundary-layer (WBL). It is often assumed that the wave-induced motions decrease exponentially with height, but the exact vertical decay function is still uncertain [2].

The closer to the sea surface, the more intense the interaction between wind and waves

Within the WBL, the fluxes are generally assumed to be constant with height. Three mechanisms contribute to the momentum fluxes: viscous, turbulent, and wave-induced transport. The latter mechanism contributes to the flux by wave-induced motions of the air. The relative contribution from the various mechanisms changes with height. At the water surface, the momentum transport is entirely due to viscous transport plus the wave-induced momentum transfer. Above the surface, turbulence soon dominates the viscous transport. The relative contribution from the wave induced transport decreases with height. At the top of the WBL, the influence of the waves has disappeared so that the momentum transport is almost entirely due to turbulence. The

situation for the sensible heat and moisture fluxes is somewhat different. In this case, a direct impact of wave-induced air motions is supposed to be much smaller. However, indirect wave-induced fluxes occur, for example, due to the production of sea spray [2].

The structure of the WBL has important implications for air-sea interaction processes. The wave growth rate can be shown to depend on the turbulent structure of the WBL, as influenced by wave coherent structures [1]. Wave-induced fluctuations in the WBL are considered to be a key parameter in our understanding of the sea surface roughness and in the parameterisation of the air-sea momentum flux as a function of the wave field [2,3]. Wave-turbulence interaction may introduce additional length and velocity scales in the atmospheric surface layer. The almost universally applied Monin-Obukhov similarity theory, describing the structure of this layer, is probably not applicable within the WBL, and, if used, it must be applied above the WBL [4]. Similarity relations and flux-profile relationships within the WBL will have to be reconsidered [5]. In a recent modelling study, Kudryavtsev and Makin [6] showed that breaking waves can have a significant impact on momentum transport by means of wave-coherent structures induced by airflow separation. The estimated contribution from such structures in the WBL was up to ~ 40% of the momentum flux, at wind speeds greater than 10 m/s. Breaking waves also generate spray, which affects the heat and moisture fluxes [2]. Such effects will be visible mainly within the WBL. Finally, gas transfer might be affected as well.

The need for a wave follower • Fundamental knowledge of the WBL structure is needed to quantify the impact of wave-turbulence interaction on wave growth and turbulent transport. Unfortunately, obvious practical problems have precluded turbulence observations at sea below the level of the wave crests, where wave-turbulence interaction is most intense. Until now, field observations are restricted mainly to estimates of the wave growth due to wave-induced pressure perturbations and to observations at fixed heights, above the wave crests [5,7]. Knowledge about the WBL has therefore been obtained basically from theoretical and model studies, and a few laboratory experiments. Models of the WBL are mostly evaluated using the limited number of data from laboratory experiments, but results from such experiments still need to be confirmed at sea.

In order to contribute to a fundamental understanding of the WBL, the Oceanographic Research Division decided to develop a wave following system that allows turbulence measurements very close to the sea surface, in between the waves. In the year 2000, the wave follower was used at sea for the first time. This campaign was primarily intended to test and operationalise the wave following system. Furthermore, we wanted to show that it actually is possible to perform high-quality turbulence measurements at sea below the level of wave crests. In the present contribution we describe our wave follower, and present results from a pilot experiment conducted in November 2000.

Basic design and development • The wave follower, shown schematically in Figure 1, consists of a tall vertical pole, on which micrometeorological instruments can be mounted and that can be moved up and down by means of a strong electromotor. A water level sensor at the lower end of the pole detects the position of the system relative to the instantaneous water surface at a sampling frequency of 60 Hz. The signals from the water level sensor are transferred to the digital motion control system, consisting of the electromotor, a PC interface card, and a servo amplifier. These signals are processed by means of a Kalman filter, implemented on the servo system, which predicts the position of the water surface one timestep ahead. The servo system then moves the pole towards a position in accordance with the predicted one, so as to maintain the pole at a fixed distance from the water surface. The cycle is repeated using a new signal from the water level sensor. In this way, instruments mounted on the wave follower are kept at a more or less constant distance from the water surface, as low as some 20 - 30 cm above it, even if the waves are up to three meters high.

The wave follower is attached to a special boom, which in turn is attached to a stable platform (Figure 2). The motion of the wave follower is purely vertical and the area in contact with the water surface is minimal. These characteristics imply great advantages over, for example, a pole supported by a float. The delay in the wave following motion is much smaller, so that the data are obtained in an almost perfect wave following co-ordinate system. Furthermore, the distortion of the local wave field will be much less than the distortion introduced by a floating system. Also, due to the purely vertical motion, no pitch-and-roll corrections to the turbulence data need to be made. Another favourable characteristic is the limited diameter (7.6 cm) of the circular part of the pole that carries the sensors, which minimises flow distortion.

Special provisions • A software package that provides the man-machine interface of the wave follower and the control of the servo system has been developed. It allows to switch between computer control and remote, manual control. A visual interface shows the signal from the level sensor, and the performance of the Kalman filter can be checked. Furthermore, a display of real-time video images from a camera at the lower side of the wave follower boom enables a continuous visual check on the wave follower and the surrounding wave field.

The instrument is designed to follow waves with frequencies less than 1 Hz, and to ignore smaller waves of higher frequencies. It has a vertical stroke of somewhat more than 3 m, and the electromotor is able to move 50 kg at a maximum acceleration of 6 m/s^2. Although the acceleration of the water surface is usually less, the servo system might not be capable to follow very steep or vigorous, actively breaking waves. Special provisions safeguard the functional use of the wave follower under such adverse conditions. First, the software checks whether or not the water surface approaches either the lower

Discovering the sea surface

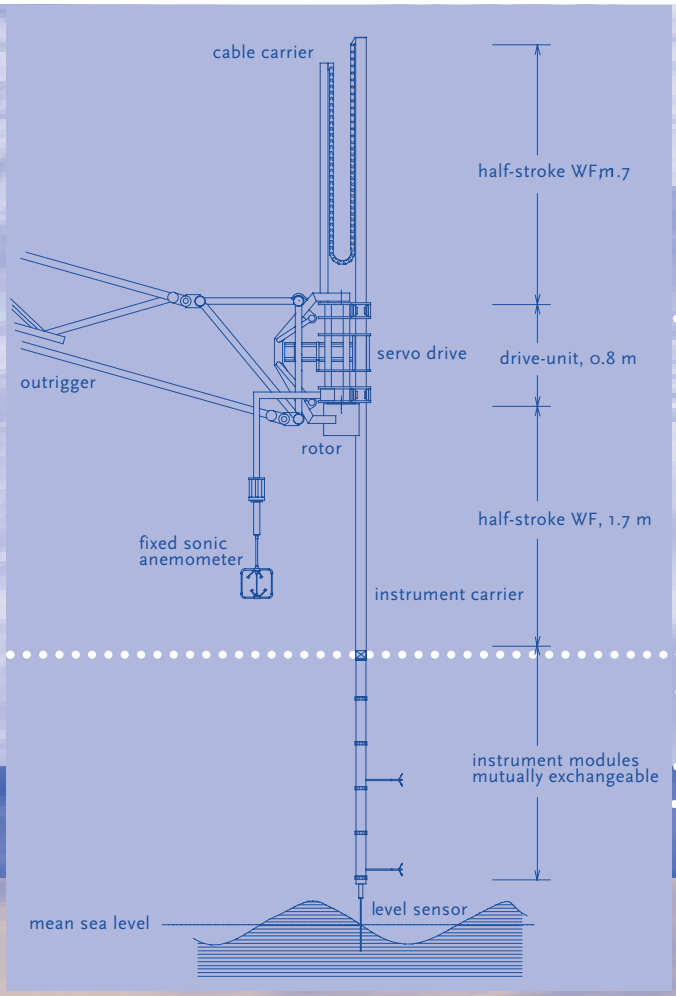


Figure 1. Schematic representation of the wave follower (WF) attached to the outrigger at Meetpost Noordwijk.

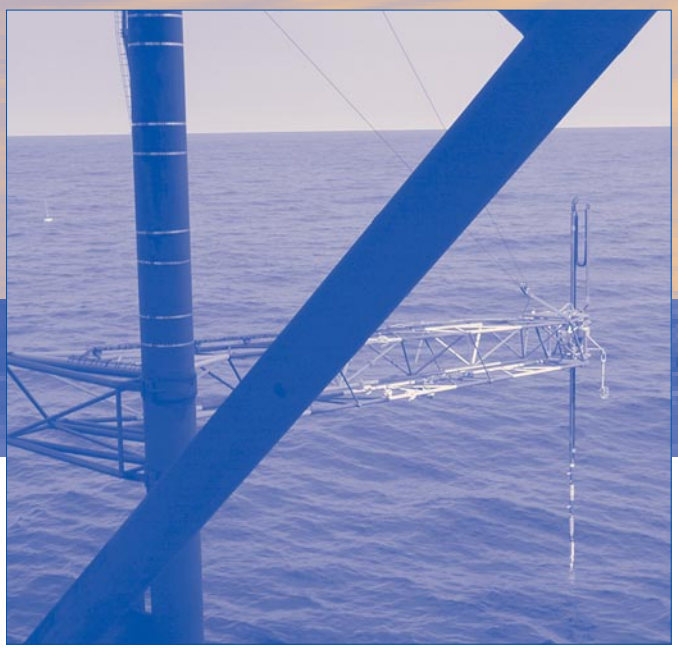


Figure 2. Photograph of the wave follower in action. The photograph was taken below the main body of Meetpost Noordwijk. The black structures in the foreground are part of the jacket construction that supports Meetpost Noordwijk, and to which the wave follower boom is attached.

or the upper boundary of the measurement range of the water level sensor. Second, a special, small sensor just above the level sensor will detect the presence of liquid water at the lower side of the instrument pole. If any of these conditions occurs, an emergency signal is sent to the servo system and the wave follower is pulled up towards a safe position, using maximum acceleration.

The wave follower is constructed to be deployed at Meetpost Noordwijk (MPN), a research and monitoring platform owned by Rijkswaterstaat (Directorate-General of Public Works and Water Management). The special outrigger on which the wave follower is mounted will always keep the pole in an accurately vertical position. The boom has a length of 12 m and is pointing towards the North. This allows meaningful observations to be made if the wind is blowing from a direction between south-west and north-east, over north (225°-360°/0°-45°). For other wind directions, flow distortion by the platform will induce irrecoverable measurement errors. During operation, the wave follower can be aimed at the mean wind direction by means of a rotor, fixed at the end of the outrigger. A small plateau, integrated in the system, provides a stable position for reference measurements without motion. To attach or detach the instrument modules (see below) and for maintenance the boom can be hoisted up, using a winch. The wave follower still maintains its vertical position during this operation.

Mounting the sensors • Micrometeorological instruments are mounted on the wave follower using a modular system of mutually exchangeable hollow tubes. Figure 3 schematically depicts one of these modules, designed to carry a pressure anemometer (see below). Each module, with a length of about 34 cm, has one or two positions where specific instruments can be attached. The inside of the tubes contains processing boards, signal cables, and an air conduit that allows maintaining some overpressure at the specialised anemometers. The connectors integrated in the modules allow signal transfer from one module to the other. At present, the wave follower can carry up to five modules. The set of instrument modules makes up the lower part of the pole. Because the tubes are interchangeable, there is some flexibility in our choice of the actual experimental configuration during field experiments.

The pressure anemometer • For turbulent flux measurements on the wave follower we deploy pressure anemometers (PA's) [8]. It is at present probably the only anemometer that can be used for reliable turbulence measurements as close to the sea surface as desired during a prolonged period of time. Figure 4 shows a photograph of a special version of the PA, designed specifically for use on the wave follower.

The PA is based on the principle that wind exerts a pressure on an object that depends on both the strength and the direction of the wind [8]. The pressure differences between the components of four pairs of flow outlets,

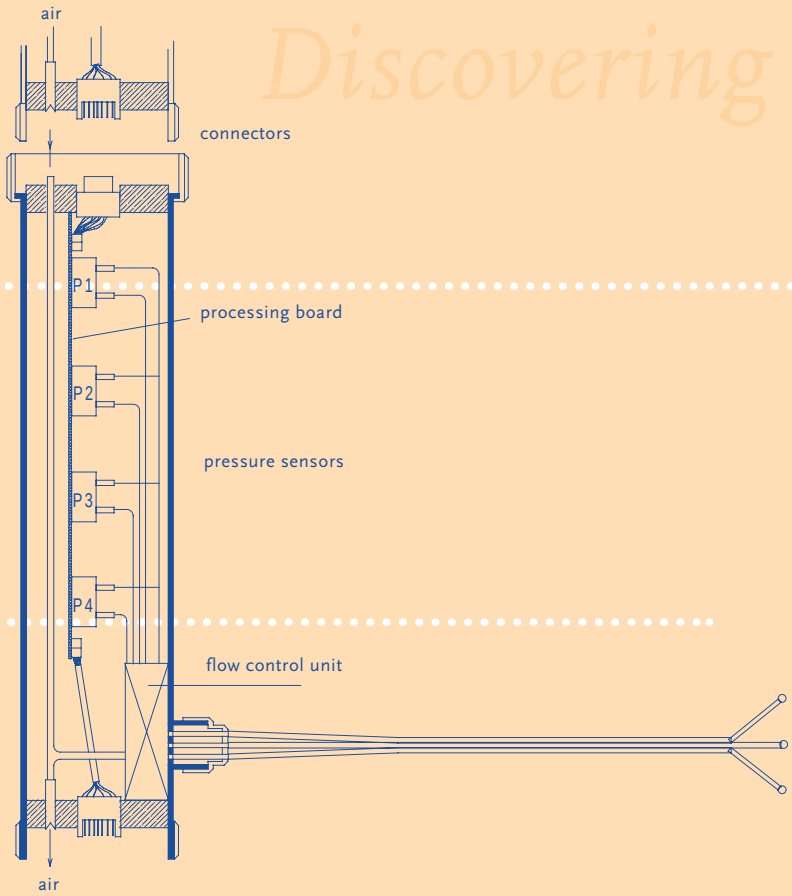


Figure 3. Schematic representation of the anemometer-module, used to mount the pressure anemometer on the wave follower. A thermistor and a pressure probe can be mounted on another, slightly different version of the module.

the

Figure 4. Photograph showing a pressure anemometer (PA). The version of the PA shown here was constructed especially for use on the wave follower. The flow outlet tubes can clearly be seen.

sea surface

placed in an arrangement that provides the widest possible angle of acceptance, are measured. Combining the signals yields the wind vector. The wind can be sampled at a frequency of 40 Hz. Because the PA is kept under a slight overpressure the sensor is self-cleaning, which is important in particular over the sea. Furthermore, the sample volume of the PA is smaller than that of most wind sensors that are commercially available to date. The small sample volume allows measurements close to the surface without losing a significant part of the contribution of small turbulent eddies to the flux.

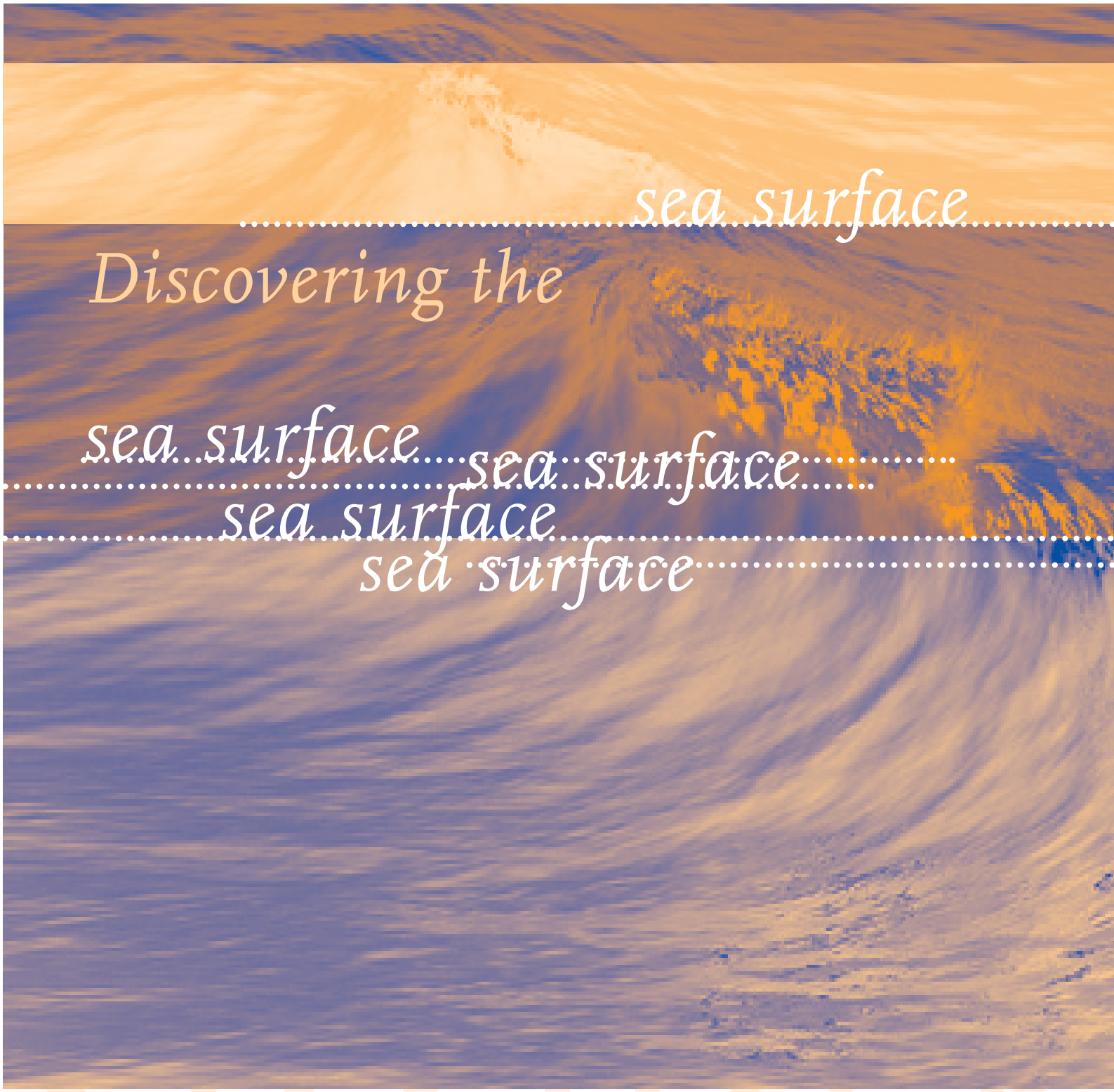
Initial tests • The wave follower has now passed through various stages of testing. Initial tests were performed at KNMI. The wave follower was attached to a container, and special simulation devices allowed dry system tests in our laboratory. The first emerging growing pains could be cured.

Hereafter the wave follower was ready to be tested in a wave flume facility. Here, realistic wind-wave spectra can be created, allowing tests under quasi-natural conditions. The first tests in the wave flume facility revealed that the design of software that allows the wave follower to keep track of the water surface is far from trivial. This led to the development of the predictive Kalman filter, a piece of real-time software running on the motion controller, presently in use. Additional tests in the wave flume facility demonstrated the wave follower to be able to follow a realistic wave spectrum, containing waves with heights up to 2.5 m.

The following tests at sea, without micrometeorological sensors, showed that the special provisions at MPN, such as the specialised boom and the mechanical part of the wave follower, the servo system and the rotor, functioned well. Also, the software and the arrangements that safeguard the instrument functioned well. The instrument was now found ready to be tested with instruments mounted.

Tests in a wave flume facility showed the wave follower to be ready for the real waves at sea

November 2000: a pilot study • A first, orientative field experiment with our wave follower was conducted in November 2000. The primary goal of this pilot experiment was to operationalise the wave follower, and to demonstrate that turbulence measurements within the WBL and in a wave following frame of reference are actually possible. Furthermore, we wanted to get an impression of the behaviour of the sensors on a moving platform and of the effects of motion on the signals.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We mounted two PA's and a fast thermistor on the wave follower. The instrument modules were placed in a way that put the PA's at 49 and 152 cm above the actual local water surface if the system would follow real waves. The thermistor then was at 134 cm above the sea surface. Reference signals for wind speed and temperature at a fixed position were obtained from a conventional sonic anemometer (Gill, Solent R3A), mounted on the special plateau at the end of the boom. Upon descent of the boom, this instrument was located about 3 m above the mean sea level.

Because of the unfavourable wind conditions (the wind was blowing from the south during most of the experiment, a direction outside the acceptable range), we first conducted measurements with the wave follower well above the mean sea level (~5 m). Some of these runs were performed with the wave follower in a fixed position, while we let the wave follower move independently from the actual surface in other runs. In one set of the latter runs we applied a perfectly sinusoidal motion (about 0.17 Hz). Another set was performed in which we used wave data from an earlier field experiment to drive the wave follower motion.

Some preliminary results on the wind observations from the pilot experiment are presented next.

Results with surface-independent motions • Like we had hoped, the measurements during runs with surface-independent motions revealed that the first-order effect of motion is simply the registration by the sensors of the vertical speed due to the motion of the wave follower, which is a feature that can easily be corrected for. This is illustrated most clearly using the results from runs with the sinusoidal motion, shown in Figure 5. The graph depicts the raw power spectral density of the measured vertical wind speed in this case, along with the one corrected for the wave follower motion, the one obtained with the motionless sonic anemometer, and the observed surface wave spectrum. The large peak in the raw spectrum, at 0.17 Hz, is clearly due to the motion of the wave follower. When the vertical speed of the wave follower was subtracted from the samples, the remaining spectrum of the turbulent motion showed a good correspondence with the one obtained with the fixed sonic anemometer. In both spectra, a small peak at about 0.2 Hz remains, which is presumably due to the influence of the waves, as the peak in the turbulent spectra coincides with the peak in the surface wave spectrum. The smaller peaks at the higher frequencies in the spectrum from the PA are probably due to resonance from the outrigger: in the case of strong wave follower movements concurrent motions from the outrigger were observed. Similar results were found using the wave data from an earlier experiment and for runs in which the actual waves were followed.

An important conclusion from these tests is that it is possible to measure turbulence on the wave follower with reasonable confidence if a simple, first order vertical motion correction is applied. However, some work

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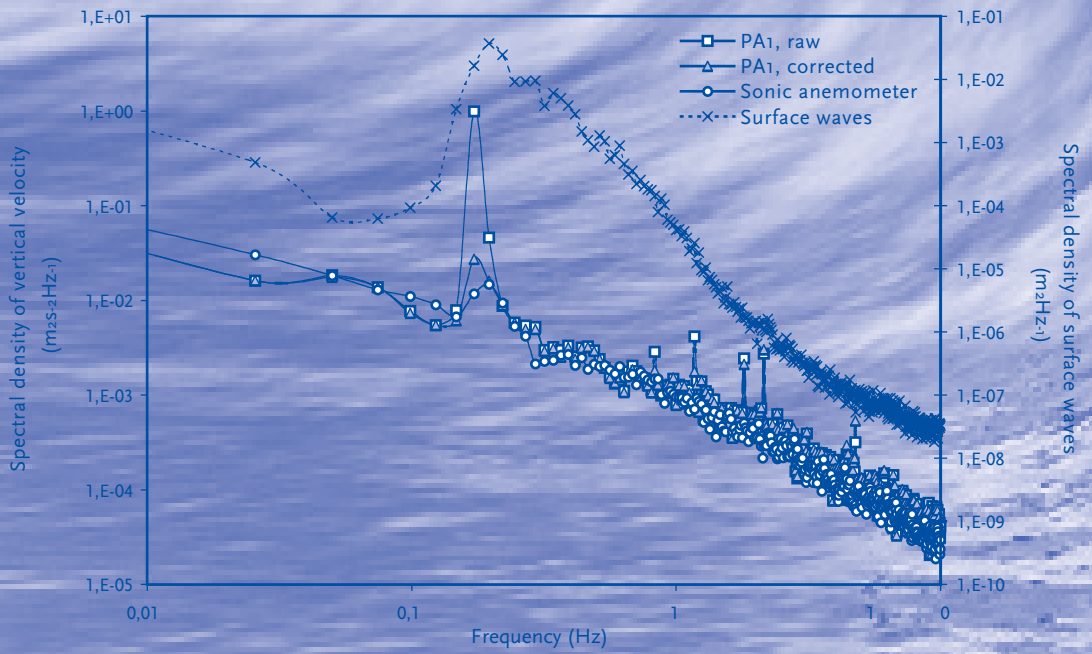

Figure 5. Power spectral density of vertical velocities (left scale) measured by the lower pressure anemometer (PA1), and the stable sonic anemometer attached to the plateau at the end of the outrigger. Also shown is the surface wave spectrum (right scale). For PA1 the raw signal contains the effect of a sinusoidal motion at 0.17 Hz. After correction for the wave follower motion the peak in the velocity spectrum is largely removed. In both the corrected spectrum from PA1 and the spectrum from the sonic anemometer a small peak that coincides with the peak of the surface wave spectrum remains, which suggest an influence of the underlying wave field.

has to be done to stabilise the outrigger. Furthermore, small sensor effects related to motion can not be excluded at present.

Turbulence measurements within the WBL • On the very last day of the experiment music was in the air. The wind turned and started to blow from a favourable direction (west to north-west). Waves reached maximum heights up to 2 m near MPN. Using the instrument configuration described above, the wave follower descended to follow the actual water surface, and measurements were performed well below the level of most wave crests. The average wind speed was about 6 m/s at the level of the wave follower. Occasionally, the wave follower lost track of the water surface due to the strong accelerations upon the approach of a very steep or breaking wave. Furthermore, after some time the signal from the water level sensor was corrupted due to dirt attached to the sensor. It will be attempted to address these problems by substituting the present level sensor by an acoustic one at the end of the outrigger. The measurement range of the sensor will furthermore be extended.

Despite the problems, the first dance with the waves yielded about five 18-minute runs of turbulence measurements deep within the WBL. Afterwards, two of these runs appeared to contain usable information and their data were combined into a 25-minute record for further processing. An important, challenging step in the processing of the data is the extraction of wave-coherent signals. Information induced by waves that are part of a wide spectrum is incorporated in randomly varying turbulent signals. To extract wave-related information buried in turbulence we applied a method proposed by Hristov et al [9]. Alternative methods to extract wave-coherent information will be tested later.

A challenging step is to extract the wave-coherent signals buried in turbulence

The important first step in the analysis involves the reconstruction of wave-phase information from the measured surface elevation record. This information allows relating the observations to wave-phases, and subsequent averaging over wave-phase bins, so as to obtain the so-called phase-locked signals. The result of the phase averaging of surface elevation can be considered as a definition of the average wave during a run. For our run, this average wave is depicted as the bold line in Figure 6. It can be seen that a nice, smooth average wave is extracted from the wave spectrum. In what follows, it is important to keep in mind that the wave travels from the left to the right in the figure.

Next, we computed the phase-locked vertical wind speed for all three sensors used. The open squares and the pluses show the uncorrected,

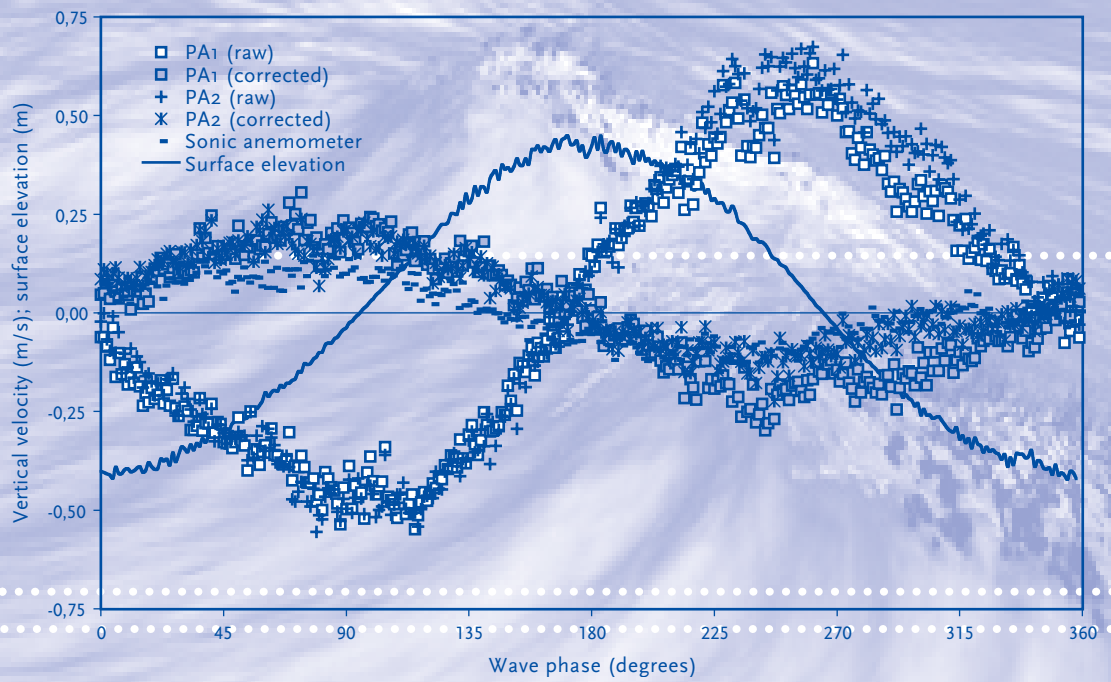

Figure 6. Phase averaged signals of the surface elevation (the 'average wave', travelling from the left to the right), the vertical velocities from the pressure anemometers (PA1 at 49cm above the sea surface and PA2 at 152 cm above the sea surface, respectively), and the sonic anemometer (at 3 m above mean sea level). The raw signals from the PA's still contain the wave follower movement. After correction, clear phase-locked patterns remain, which are consistent with the phase-locked pattern from the stable sonic anemometer. The patterns suggest that, on average, the air overtakes the waves during this run.

phase-locked vertical wind speed of PA1 (height 49 cm) and PA2 (height 152 cm). These results are included to demonstrate that the algorithm to extract wave-related information works well. The main contribution to these signals comes from the wave follower motion. This motion can clearly be seen. If a wave crest approaches, the wave follower moves upward and it descends again if the wave travels away. As expected, the speed, up or down, is at its maximum over the steepest parts of the surface, while it is about zero right on top of the waves.

Next, we computed the phase-locked, motion-corrected vertical velocity signal of the PA's and that of the vertical speed observed with the stable sonic anemometer. First, it can be seen that the magnitude of the signals is similar, which again demonstrates that the first-order motion correction yields reasonable results. All signals show clear, phase-related differences. This is an indication of wave-coherent motions at all levels. The influence tends to decrease with height, and a phase-shift occurs among the wave-coherent signals. This kind of information is important, because it can be used to check and improve models of the WBL [1,2]. Such an exercise is beyond the scope of the present contribution.

The present results are consistent with a situation in which air, on average, overtakes the waves: the air moves upward to flow over the crest and moves downward to enter the trough. In principle, an effect on the PA's due to the strong wave follower motions cannot be excluded at present. However, because the stable sonic anemometer revealed similar wave-coherent information, we feel that the results obtained with the PA's truly indicate the presence of wave-coherent fields, and are not an artefact of measurements on a moving platform.

The future • The most important conclusion from the results presented in previous sections is that the wave follower sounds promising. We are able to perform over sea turbulence measurements at heights below the level of the wave crests, in a wave-following frame of reference, and to extract important information about wave-induced processes in the WBL, a so far unprecedented feat.

We can now obtain at sea information about wave-induced processes far below the level of the wave crests

Possibilities emerge to perform basic tests of crucial assumptions. Can the logarithmic wind profile be extrapolated to a level near the waves in a way that makes sense? Are the fluxes really constant with height and what is

the contribution of wave-induced fluxes? Can we understand wave growth in terms of the WBL structure? How can we improve models of the WBL and parameterisations for wave growth? Is there experimental evidence of airflow separation due to wave breaking at sea and, if so, how often does it occur and what might be the contribution of the resulting wave-coherent structures to the total flux?

The tests revealed some remaining growing pains of the instrument, such as pollution of the level sensor and resonance of the outrigger. We will be working hard to alleviate them. Furthermore, the preliminary results presented above just mark the very beginning of our analysis and learning process at the time of writing. Further analyses of wave-coherent structures will be performed on other signals and their combination. Independent, alternative methods to extract wave-coherent signals will be tested as well. Given the limited number of data from the pilot experiment, the main goal of these analyses will be to check experimental procedures and algorithms. In the spring of 2001, we hope to be ready to perform more extensive and high-quality, near-surface observations during our next measurement campaign at sea, using a unique instrument: the KNMI wave follower.

Acknowledgement • The wave follower research is conducted on a unique facility: Meetpost Noordwijk. We would like to thank the owner of the platform, the North Sea Directorate of the Directorate-General of Public Works and Water Management of the Ministry of Transport, Public Works and Water Management, for granting us permission to install and use the wave follower on the platform.

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New ways of observing clouds: a tour along satellite based and ground based remote sensing techniques

by André van Lammeren, Dave Donovan, Arnout Feijt, Robert Koelemeijer and Piet Stammes

Introduction • On average, more than 60% of the Earth's surface is covered by clouds. Clouds strongly affect atmospheric radiative fluxes and heating rates. Therefore it is crucial that climate models produce realistic cloud fields with the correct cloud properties and feedbacks. This is a challenging task. The underlying difficulty is that many different processes contribute to cloud formation and cloud-radiation interactions at very different scales: e.g. dynamical forcing (large-scale or sub-scale), microphysical processes and cloud geometry with possible overlapping of cloud layers. Although there has been considerable progress in the physical content of the models, clouds remain a dominant source of uncertainty. The Intergovernmental Panel on Climate Change (IPCC) concludes in its latest report [1]: *' ..... there has been no apparent narrowing of the uncertainty range associated with cloud feedbacks in current climate simulations'*. It is recognised that the only way to make progress in this complex area of atmospheric science is by consistently combining observations with models. This asks for a strong interaction between those making observations and those using climate models [2].

The above implies that cloud observations have to match the modeller's needs. Presently, the available observations are not accurate and detailed enough and do not cover all relevant cloud and aerosol parameters to constrain models adequately.

In this highlight the work within the Atmospheric Research Division on improving cloud observations is presented. This observational programme has been developed in close co-operation with modellers from

KNMI and other institutes. The work includes the development of new ground based remote sensing techniques and the improvement of cloud parameter retrieval algorithms for satellite observations. The measurements are used to derive various cloud parameters such as: cloud base and cloud top height, liquid/ice water path, extinction profiles, total optical depth, albedo and particle size. The retrieved cloud properties are used for a wide spectrum of applications, like model evaluation, monitoring, study of cloud processes, operational use by forecasters, and to improve retrievals of the chemical composition of the atmosphere (e.g. ozone).

In the first part an overview of the retrieval of cloud parameters from operational meteorological satellites is given. Next, a new algorithm for the retrieval of cloud top pressure and effective cloud fraction is presented, based on Oxygen A-band observations of the Global Ozone Monitoring Experiment (GOME). In the last part an innovative synergetic lidar-radar algorithm for the retrieval of particle size and water content for ice clouds is described.

Cloud parameter retrieval with meteorological satellites • Operational meteorological satellites measure reflected sunlight and emitted radiation. These measurements can be used quantitatively to derive cloud properties like: cloud amount, cloud top temperature, optical thickness and water content. In order to derive these cloud characteristics an analysis environment with retrieval algorithms was developed. A large effort was put in the evaluation of the results with synoptic observations and measurements from two measurement campaigns. The satellite platforms used for this study were: the European geostationary satellite Meteosat and the Advanced Very High Resolution Radiometer (AVHRR) on board of the NOAA polar orbiters.

To detect the presence of clouds in the half-hourly METEOSAT images the METEOSAT Cloud Detection and Characterisation KNMI method, MetClock, was developed. The method includes the use of the surface temperature fields of a Numerical Weather Prediction (NWP) model as a dynamic threshold value. Over 2 million synop reports from human observers from all over Europe were used to assess the skill of the method. It was shown that the use of NWP data improves cloud detection significantly.

It was shown that the use of NWP data improves cloud detection significantly

The NWP model surface temperatures are also used in the AVHRR (Advanced Very High Resolution Radiometer) analysis environment called KLAROS (KNMI Local implementation of Apollo Retrievals in an Operational System), developed at KNMI. For the interpretation of the 0.6 mm channel


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reflectivity, extensive radiative transfer calculations were done with the Doubling-Adding KNMI (DAK) radiative transfer code. The results were put in Look-up tables (LUT). The LUT's are used to obtain the following cloud field properties: cover fraction, optical thickness, emissivity, temperature and liquid water path. In order to assess the quality, the retrieved properties were compared to measurements from two campaigns: the Tropospheric Energy Budget Experiment, TEBEX, and the Clouds and Radiation intensive measurement campaigns, CLARA96, in which the 3GHz radar of Delft Technical University played a central role. The comparison shows that the retrieval algorithms yield results that agree with independent ground based measurements.

The presented case study shows the KLAROS analysis of a frontal zone passage on April 17, 1996. The front passed the Netherlands from the south-west to the north-east. The AVHRR 10.8 mm channel temperatures are displayed in the left panel of Figure 1. The vertical profiles of the 3GHz radar at Delft are shown in Figure 2. The radar measurements support the conceptual model of a warm front. From the overpass of the edge of the front at 8:00 UTC until the time of overpass of the AVHRR (13:00 UTC) the cloud base height decreases from about 7 km to 5.5 km. The clouds at the edge of the cloud field are expected to have a high altitude and a relatively small vertical extent. The AVHRR 10.8 mm channel temperature, however, shows warm clouds at the edge of the frontal zone. This is due to the semi-transparency of thin clouds that causes the signal to be composed of contributions from the cold cloud and the warm surface. KLAROS is employed to correct for the semi-transparency. The retrieved cloud temperatures are presented in the right panel of Figure 1.

From the radar data we estimate the minimum and maximum cloud top height to be 6 and 8 km respectively, which according to radiosonde temperature profiles correlate to cloud top temperatures of 248 K and 233 K. From the cloudy pixels a frequency distribution of measured equivalent black body temperatures at 10.8 mm is made (dashed line in Figure 3). The temperatures range from 240 - 270 K. The average temperature is 259 K, which is well outside of the range of the radar derived temperatures (233 - 248 K). The measured temperatures indicate clouds that occur at altitudes from the ground up to 6.5 km height. Obviously, the 10.8 mm equivalent black body temperatures are not representative for the cloud layer. The solid line in Figure 3 indicates the distribution of corrected cloud temperatures. The values range from 230 to 250 K, which corresponds well with the radar observations. On average the difference between measured and retrieved cloud top temperature is 17 K. In conclusion: KLAROS largely improves the estimate of cloud temperature based on AVHRR data.

The work described above is preparatory to the launch of Meteosat Second Generation (MSG) in January 2002. The passive imager onboard of MSG, the Spinning Enhanced Visible and Infrared Imager, SEVIRI, includes 11 spectral channels, of which 8 are similar to current AVHRR and Meteosat

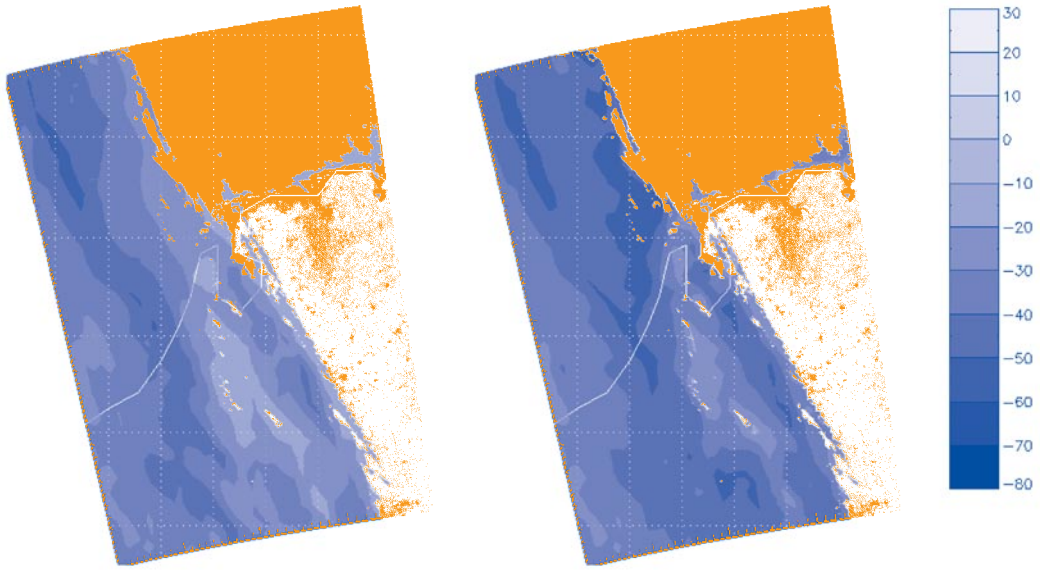

Figure 1 . Measured temperature (left) and retrieved cloud temperature (right) for a frontal zone over the Netherlands. At the eastern edge the temperature difference is 10 to 30 degrees.

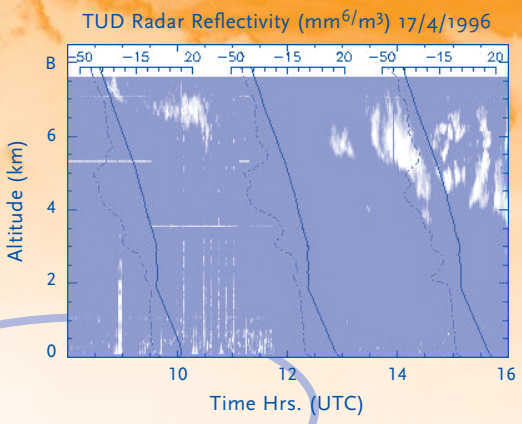

Figure 2. Time series of radar reflectivity. White indicates the presents of cloud particles. The cloud height decreases from 7.5 to about 6 km, which corresponds to temperatures of 233 - 248K.

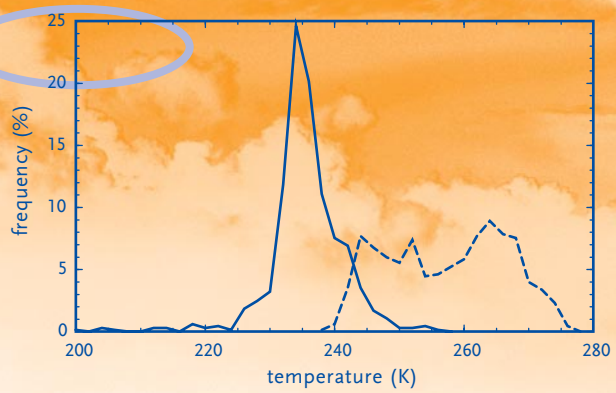

Figure 3. Frequency distributions of retrieved (solid) and measured (dashed) temperatures near the radar station.

channels. SEVIRI enables the retrieval of cloud and surface parameters that are currently derived from Meteosat and AVHRR at a rate of 4 times per hour. This is expected to have a major impact on the meteorological practice and climate research.

Global cloud monitoring with GOME • Global ozone measurements are needed for the study of the chemistry of the atmosphere. To obtain accurate ozone measurements, information on cloud properties is needed because clouds have disturbing effects on the retrieval. Global ozone and cloud observations are obtained from the Global Ozone Monitoring Experiment (GOME) on board ESA's (European Space Agency) ERS-2 (Earth Remote Sensing) satellite. GOME is a spectrometer measuring between 240 - 790 nm. GOME will be succeeded by SCIAMACHY in 2001, and by the GOME-2 instruments in the period after 2005. In the long term, this will yield a measurement record from 1995 till 2015.

Cloud measurement principle • A method has been developed at KNMI to derive effective cloud fractions and cloud top pressures from the spectral reflectivity measurements of GOME. This method, called Fast Retrieval Scheme for Clouds from the Oxygen A-band (FRESCO), makes use of reflectivity measurements in and around the oxygen A-band 3). The oxygen A-band is an absorption band of O_2 near 761 nm, which can be clearly observed in the Earth's spectrum.

The retrieval is based on minimising the difference between a calculated and measured spectrum of the oxygen A-band, by varying the cloud fraction and cloud top pressure in the calculations. In this process cloud optical thickness plays a role. Unfortunately, it is impossible to derive both the cloud fraction and cloud optical thickness independently, because clouds with different optical thickness' and different cloud fractions may give rise to the same spectral reflectivity. Therefore, we assume a cloud albedo of 0.8 (optically thick cloud), and then derive an effective cloud fraction.

The effective cloud fraction is derived from the brightness of the scene with respect to a clear sky scene. The air pressure at the top of the cloud (cloud top pressure) is derived from the depth of the oxygen A-band, which depends on the amount of oxygen above the cloud. For example, if the band is deep, much oxygen is present above the cloud and therefore the cloud top pressure must be high (low altitude cloud). Note that this effective cloud fraction is thus the equivalent cloud fraction holding for an optically thick cloud.

Validation • To validate the effective cloud fractions and cloud top pressures derived using FRESCO, we compared them to cloud properties derived from Along Track Scanning Radiometer (ATSR-2) data that have a smaller pixel size and can well serve as reference. This comparison was made using data acquired over north-west Europe on July 23, 1995. We found that


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differences in effective cloud fractions are small, and are mainly introduced by errors in the assumed surface reflectivity. The cloud top pressures derived with FRESCO have an average bias of 65 hPa. This is probably due to absorption by oxygen inside the cloud, which is presently not accounted for in the FRESCO method. Radiative transfer calculations show that this effect can account for this bias [4].

Global monthly average effective cloud fractions and cloud top pressures derived using the FRESCO method for July 1995 are shown in Figures 4a and 4d. For comparison, monthly averaged effective cloud fractions and cloud top pressures from the International Satellite Cloud Climatology Project (ISCCP) are shown in Figures 4b and 4e. The ISCCP data are not yet available for 1995 and onwards, and therefore, a comparison is shown using ISCCP data averaged over the July months of the period 1989-1993. Missing data, e.g. over snow/ice covered surfaces and over high-latitude areas, are shown in black. Figure 4c shows the zonally averaged effective cloud fractions obtained from FRESCO and ISCCP, as well as their difference. Figure 4f shows the zonally averaged cloud top pressures and their difference. The effective cloud fractions of ISCCP are calculated from the cloud fraction and cloud optical thickness, as reported in the ISCCP data set. Clearly, there is agreement between the FRESCO and ISCCP results regarding the main global cloud features, such as low-altitude marine stratus clouds off the west-coasts of large continents, and high altitude convective clouds in the inter-tropical convergence zone (ITCZ). By analysis of time series, seasonal movement of global cloud structures, such as the ITCZ, can be studied.

FRESCO can contribute to the monitoring of cloud top pressures on a global scale

Differences between cloud properties derived using FRESCO and ISCCP are due to various reasons. First, annual (and diurnal) variations explain part of the differences between FRESCO and ISCCP effective cloud fractions and cloud top pressures. Secondly, we want to emphasise that the methods to derive cloud top pressure by FRESCO and ISCCP are very different: FRESCO makes use of near-infrared wavelengths (around 0.76 micron), whereas ISCCP makes use of thermal infrared wavelengths (around 11 micron). Clouds are more opaque at thermal infrared wavelengths than at near-infrared wavelengths. Consequently, the cloud top pressure values derived by FRESCO will be biased towards higher values, because absorption associated with penetration of light into the cloud is not taken into account in the FRESCO retrieval method at present. When further improved, the cloud top pressures derived using FRESCO can be an important contribution to the monitoring of cloud top pressures on a global scale. Knowledge of cloud properties in the atmospheric scene observed by GOME is used to improve column density retrievals of ozone and other trace-gases.

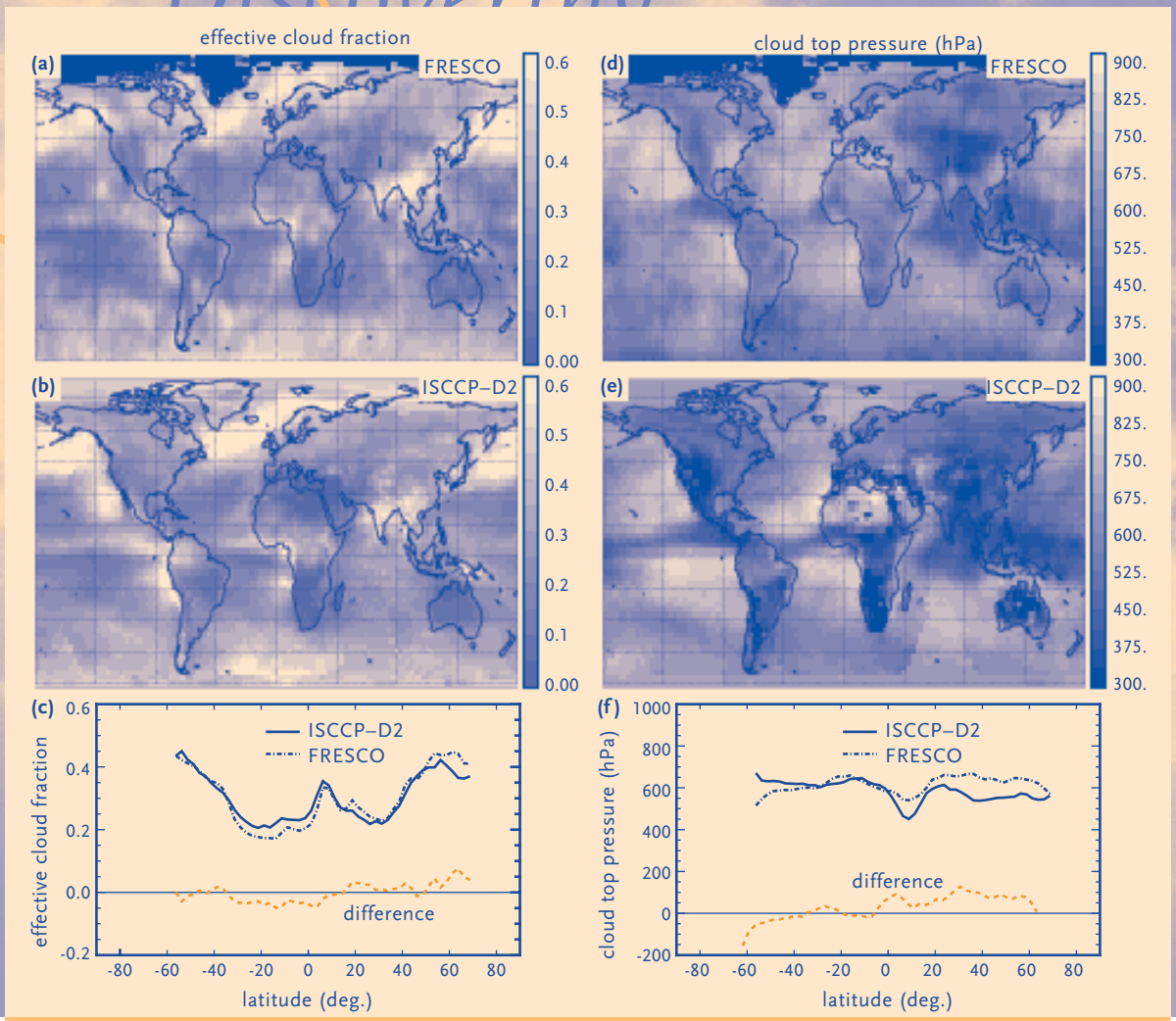

Figure 4. Monthly averaged effective cloud fractions and cloud top pressures derived from GOME using the FRESCO method and from ISCCP. Left: effective cloud fractions, right: cloud top pressures (hPa). Top: FRESCO results, middle: ISCCP results, bottom: zonal averages. The FRESCO results are for July 1995 and the ISCCP results are July-averages of 1989 - 1993.

Combined lidar/radar cloud remote sensing • The present generation of operational meteorological satellites provides insufficient information on the vertical structure of important cloud properties such as cloud cover, optical properties and microphysics. This information can be obtained from ground-based measurements by combining different active and passive remote sensing techniques. In this section we present an example of such a new technique based on the synergy of lidar and radar measurements. It is expected that this newly developed technique will be used for new research satellites in the near future.

Cloud radars and lidar systems operate in a conceptually similar manner. They both transmit a pulse of electro-magnetic radiation into the atmosphere and detect the radiation scattered back to the receiver as a function of time after the pulse has been launched. The key difference between lidars and radars is the very different frequency at which they operate. Lidars usually operate in the wavelength range between 300 and 1000 nm while cloud radars operate in the mm - cm region. This difference in operating wavelength means that a cloud lidar and a cloud radar will be sensitive to different sizes of cloud particles. Roughly speaking, depending on the radar's operating wavelength and sensitivity, cloud radars are mainly sensitive to cloud particles whose characteristic size is greater than 20 - 30 microns, while lidars are mostly sensitive to particles whose characteristic size is below 10 microns. Note in this context that radar reflectivity is proportional to the 6^{th} power of the particle size, and lidar reflectivity only to the second power of the particle size.

Due to the different response to different particle sizes, simultaneous cloud soundings made with a lidar and radar are complementary. For instance, if the particles near the bottom of a cloud happen to be small they may not be detected by the radar, while the lidar will easily detect them. On the other hand, the lidar signal may not reach to the cloud top due to optical attenuation, while the radar signal, being much less attenuated, will reach the cloud top. Putting both the radar and lidar signals together thus often gives a much more complete picture of the structure of clouds.

In parts of the cloud where both the lidar and radar signal is sufficiently strong, the ratio of the optical extinction to radar reflectivity may be determined and used to determine the cloud lidar/radar effective particle radius (R'_{eff}). If assumptions concerning the distributions of particle size and shape are made, the normal effective radius (R_{eff}) used in radiative transfer models of clouds may be determined. At the same time the water content and particle number density may be estimated. These quantities are important in determining the cloud's physical state and how it will interact with solar and thermal radiation within the Earth's atmosphere.

This new procedure to invert combined lidar and radar cloud data has been recently developed at KNMI [5, 6]. Figure 5 shows results obtained during the Clouds and Radiation experiment, which was conducted in the

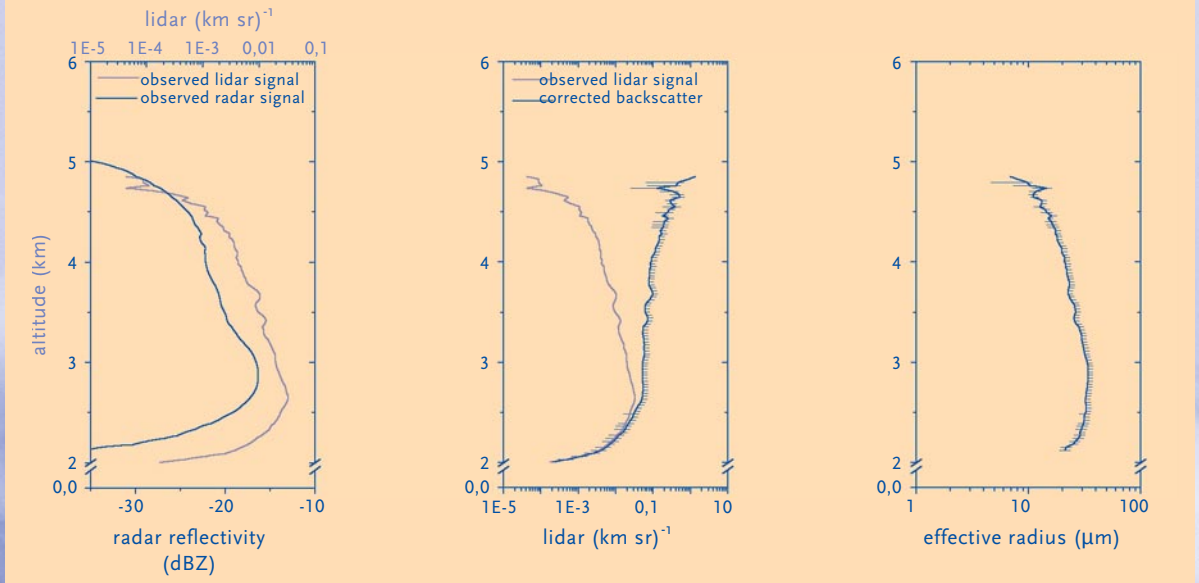

Figure 5. Lidar and Radar signal profiles as well as retrieved optical extinction, water content and effective particle sizes for data obtained during the CLARA campaign.

Discovering clouds

Netherlands in 1996 (CLARA'96). The Figure shows the signal profiles obtained from a mid-level ice cloud together with the retrieved optical extinction, ice-water content and effective radius. The same inversion procedure can be applied to successive signal profiles at fairly high temporal resolution. Figure 6 shows a two-dimensional density plots of the lidar and radar signal fields as well as the retrieved particle sizes and water contents for a 5-hr period on the same day as for the data shown in Figure 5.

The procedure has been applied to a number of situations and a comparison with the results of in-situ aircraft mounted particle probes is very encouraging. Further work is underway to improve the procedure and apply it to large cloud data sets. The results will then be used to develop a better understanding of cloud processes and to improve cloud radiation parameterisation used in atmospheric models. Work is also underway to extent the procedure so that it may be applied to data obtained by space-based lidars and radar missions such as the joint CloudSat (cloud radar) and Picasso (cloud/aerosol lidar) missions of the National and Oceanic Space Administration (NASA) and the proposed EarthCARE (Earth Cloud Aerosol Radiation Explorer) mission of ESA and the National Space Development Agency of Japan (NASDA).

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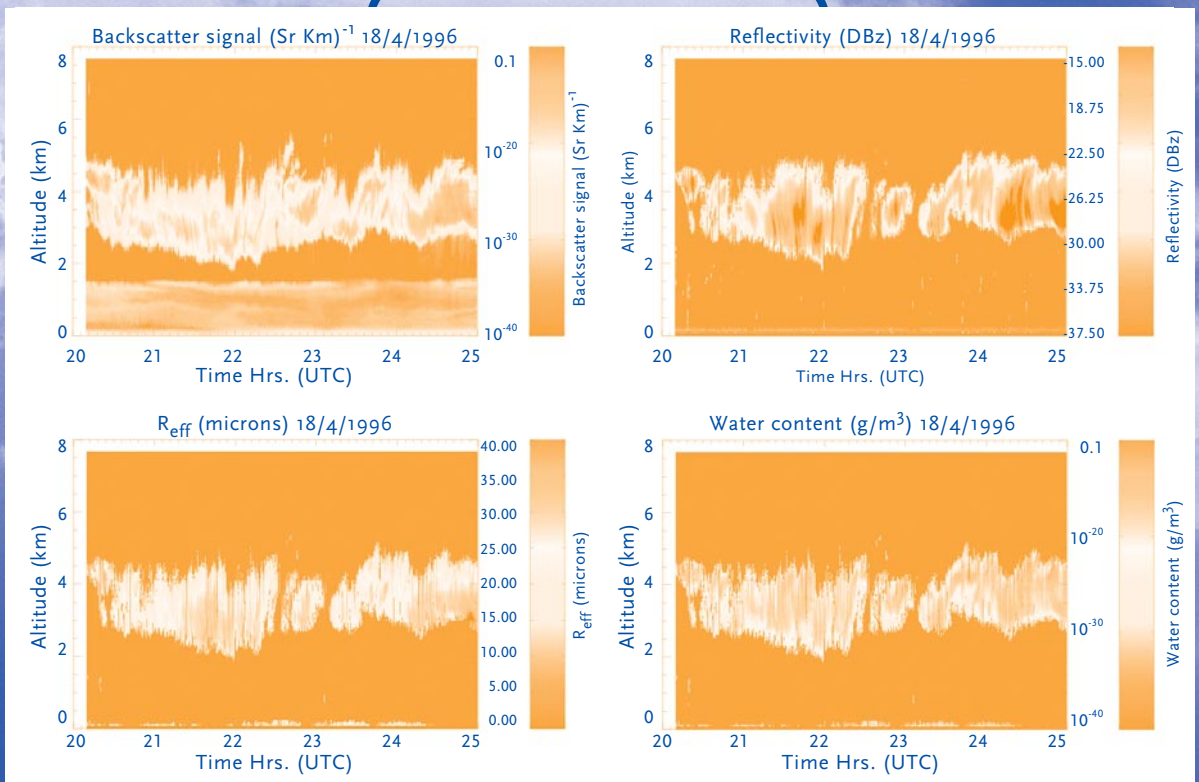


Figure 6. Radar reflectivity (top left), lidar signal (top right), retrieved particle effective radii (bottom left) and Ice water content (bottom right) for April 18th, 1996.

South meets north over Suriname: ozone observations in Paramaribo

by Paul Fortuin, Ronald van der A, Renske Timmermans, Michiel van Weele and Hennie Kelder

Introduction • The Inter-Tropical Convergence Zone (ITCZ) plays a vital role in determining the atmospheric circulation in the Tropics. Here, air from the south and the north meet, undergo various dynamical and chemical processes, rise through convection to higher altitudes and then flow out to extratropical latitudes. Over large regions in the Tropics, the ITCZ can be discerned as a cloudy band parallel to the Equator. Its latitudinal structure is quite narrow over the oceans on either side of the South American continent, so its annual migration between the Equator and approximately 10° north can be well followed. This migration also largely determines the seasonal variations of the areas within its range. In Suriname, for example, the two wet seasons coincide with the periods that the ITCZ is right overhead (December to January, April to July), the dry seasons occur when it is south or north of Suriname (respectively February to March and August to November). An observation site in Suriname therefore samples air from both the Northern and Southern Hemisphere, as well as air within the ITCZ itself, depending on the ITCZ position. Furthermore, due to the relatively flat orography of the north-eastern coastal region of South America, the air remains largely unperturbed when advected over such a site. Hence the orographic influence on the transport of air is minimal which greatly simplifies efforts to trace the air back to its region of origin. The tropical atmosphere comprises about half the global atmosphere, yet there are currently few systematic observation posts to study its behaviour.

All these features combined prompted a joint Suriname-Netherlands research initiative that led to the project RADCHiS (Research on the Atmospheric Dynamics and Chemistry in Suriname) and the establishment

of an ozone observation station in Paramaribo. Besides increasing our understanding of the atmospheric dynamics and chemistry in the Tropics, these observations play an important role in the validation of ozone products from the satellite instrument GOME (Global Ozone Monitoring Experiment).

Paramaribo station has received international recognition, as can be seen from the regional GAW (Global Atmospheric Watch) status it received from the World Meteorological Organisation (WMO), and its membership of the Network for Detection of Stratospheric Change (NDSC) and the project SHADOZ (Southern Hemisphere Additional Ozonesondes) of NASA (National Aeronautic and Space Administration).

The project RADCHiS • As the name suggests, the programme outline of RADCHiS is essentially to study the atmospheric dynamics and chemistry in the Tropics based on the following routine observations:
- continuous total ozone and UV (Ultra Violet) observations with a Brewer MKIII spectrophotometer,
- regular (weekly) balloon soundings measuring profiles of ozone, temperature, moisture and wind.

The research project is an initiative of KNMI, in co-operation with the Meteorological Service of Suriname (MDS). KNMI provides its expertise (a similar observation programme is being run in De Bilt, the Netherlands), whereas MDS provides the infrastructure and personnel needed to carry out this project. The Institute for Marine and Atmospheric Research of the University of Utrecht (IMAU) and the Max Planck Institute for Chemistry in Mainz (MPI-Mainz) are co-submitters, and therefore research partners, in this project. The corresponding principal investigators are Prof. Dr. J. Lelieveld and Nobel Prize winner Prof. Dr. P.J. Crutzen, who is one of the very first instigators of atmospheric research in the Tropics. The project was approved for funding by the Netherlands Organisation for Scientific Research (NWO), for a four-year period starting September 1998. Additional funding comes from the Netherlands Earth observation community - the Netherlands Institute for Aviation and Space Research (NIVR) and the Netherlands Foundation for Space Research (SRON) – and from KNMI. WMO kindly arranged an agreement between the Suriname and Netherlands governments so that the project could be implemented under the WMO Voluntary Co-operation Programme (VCP). The VCP status greatly simplifies the procedures needed to import scientific equipment into Suriname and furthermore gives WMO membership countries the opportunity to support and participate in the RADCHiS project.

The observation site • The selection of an observation site proved to be easy as the premises of the MDS in Paramaribo provides the ideal setting. The MDS building has a platform extending above the roof that offers an undisturbed view to all sides and more than enough space for the Brewer instrument and the sounding antennas (Figure 1). MDS also offered ample office space, along with a spacious operator room with a view on an open field

Discovering the tropical atmosphere

Figure 1. The observation platform on top of the Suriname Met Office building, with (left to right) an outdoor video camera, the GPS antenna, UHF antenna and the Brewer MKIII.

where balloons could be launched and a filling hut constructed. The site is located at 5.8° N 55.2° W, at a latitude that is just about in the middle of the annual migration range of the ITCZ in this region. In fact, the meteorological equator – defined as the global average latitudinal position of the ITCZ – corresponds with this latitude.

An operator crew consisting of five MDS employees was selected and trained during the following two installations: the Brewer MKIII spectrophotometer in March and then the Vaisala sounding equipment in September 1999. Along with the second installation, an outdoor video camera was installed, pointing to the south-east and taking wide-angle pictures of the sky every two minutes. These pictures can be used to complement the Brewer and sonde observations, and when combined into an animation they can provide valuable information on the spatial and temporal scales of cloud processes.

The observational programme is now fully operational, with the Brewer performing continuous total ozone and UV measurements, besides so-called Umkehr measurements during sunrise and sunset. The German word 'Umkehr' refers to a technique through which an ozone profile can be derived from zenith-sky irradiation measurements when the Sun is skimming the horizon. On cloudless occasions, these Umkehr profiles can be used to extend the ozone profiles above the height level reachable with a balloon sonde (around 32 km). The balloon sondes are released on a weekly basis, measuring ozone with the Electrochemical cell (ECC) technique, along with temperature, moisture and wind speed plus direction.

The main focus is the study of atmospheric transport and dynamics in the Tropics

Research • The Paramaribo observations are used for various areas of research within KNMI. Apart from the main focus, the study of transport and dynamics in the Tropics, the observations are used for radiative transfer and UV research, and have found an important application in the field of satellite validation. First results on this research have recently been presented at international symposia and will be briefly discussed.

Transport and dynamics • Figure 2 shows 1.5 years of Brewer total ozone values (starting March 1999), along with sonde humidity and meridional wind measured at 1 km height (starting September 1999). Clearly, the wet seasons occur during transitions in the meridional wind direction, when the ITCZ migrates overhead. First analyses [1)] indicate that photolysis of

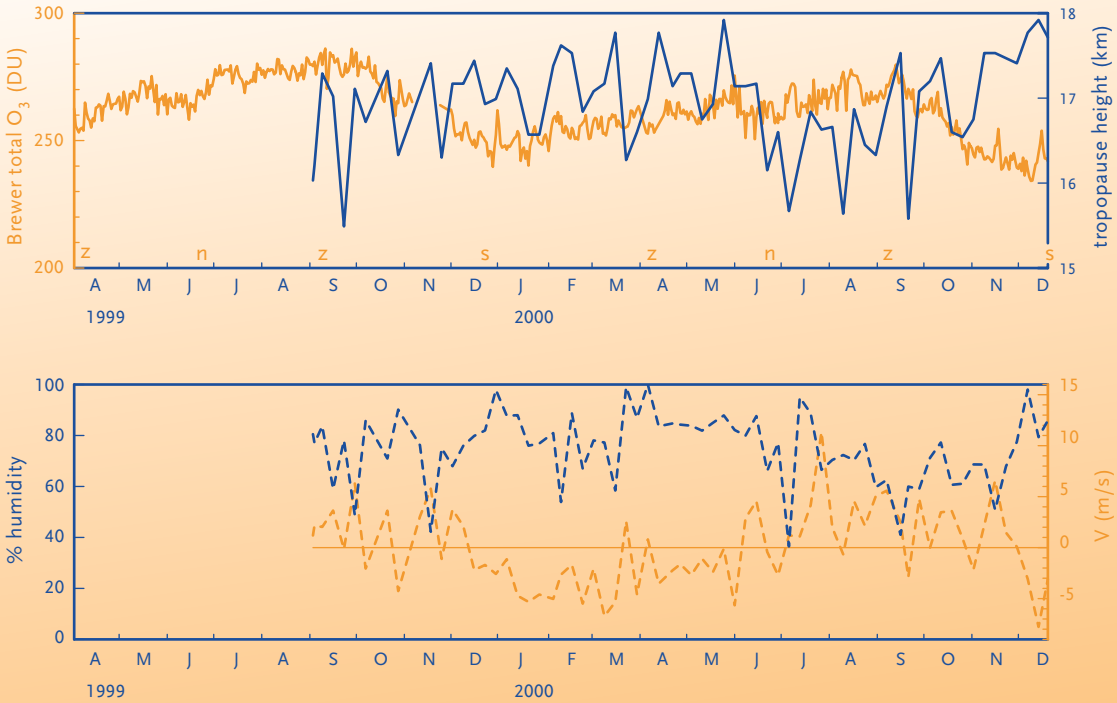
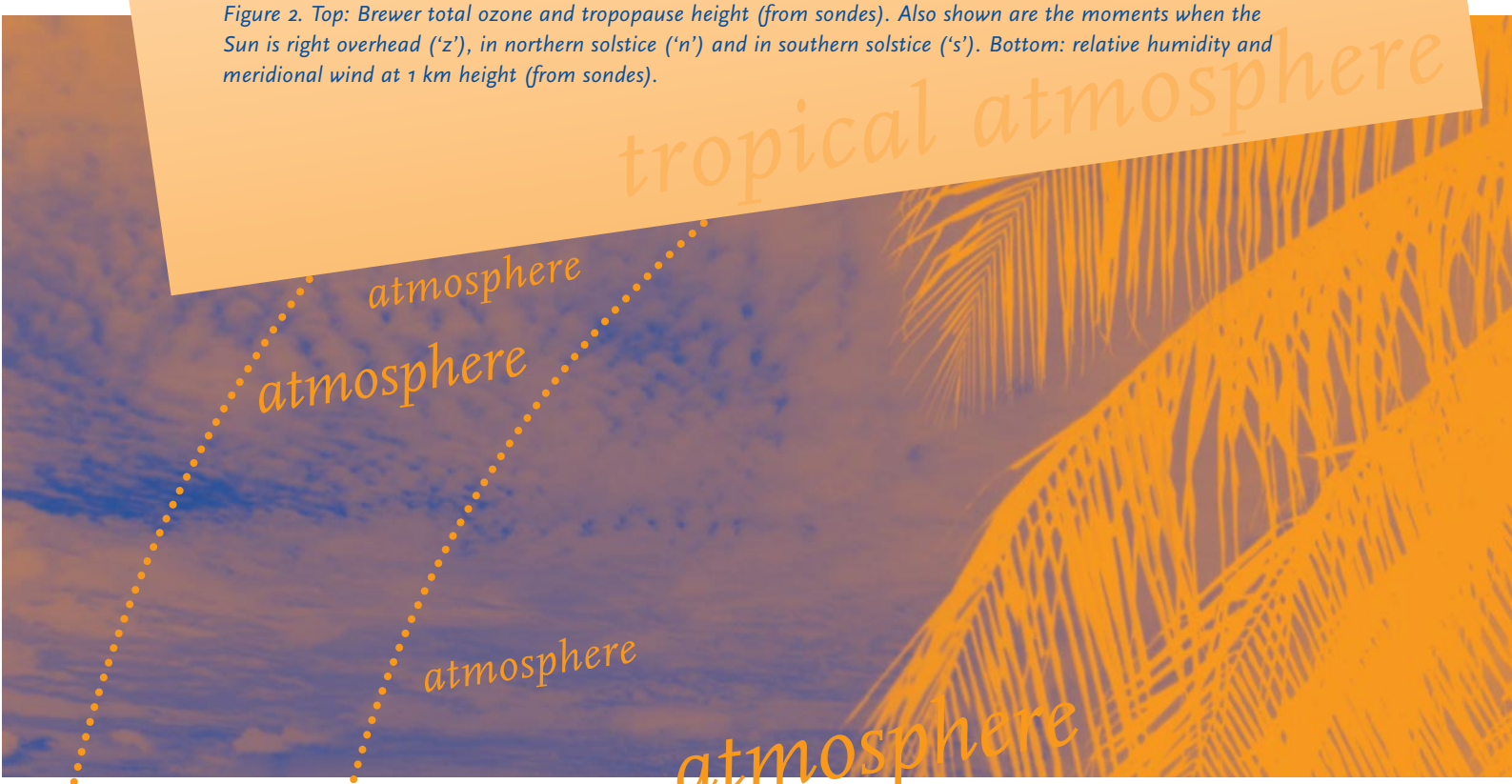


Figure 2. Top: Brewer total ozone and tropopause height (from sondes). Also shown are the moments when the Sun is right overhead ('z'), in northern solstice ('n') and in southern solstice ('s'). Bottom: relative humidity and meridional wind at 1 km height (from sondes).



ozone in the stratosphere as well as vertical motion are the prime factors influencing seasonal changes in total ozone. The tropopause height (Figure 2) is an indicator of the strenght of the vertical motion. Maximum total ozone values are reached around September when the Sun is at zenith during the long dry season, causing high photolysis of ozone. Minimum total ozone values occur when the Sun is in southern solstice, and coincides with the short wet season (December - January) when the ITCZ passes overhead. The long wet season (April - August) causes only a local minimum in total ozone as the increased ascent rate is now compensated by increased ozone photolysis as the Sun passes overhead. The ozone maximum in the year 2000 is about 10 DU (Dobson Unit) less than the 1999 ozone maximum. This is most likely due to the descending easterly phase in the quasi-biennial oscillation (QBO) [1], which induces a mean ascending motion [2]. Previous studies have shown that the QBO is caused by momentum transfer of equatorial waves that propagate into the stratosphere. From a first analysis of the Paramaribo wind fields, these waves seem to be mostly generated by deep convection up to 12 - 14 km, corresponding to the level where the equivalent potential temperature equals that of the Earth surface. First analyses also reveal that the ITCZ over Suriname has a structure similar to a cold front, with cooler air coming from the north-east trade winds. Also, there are indications that the annual cycle of accent rates over Suriname are the result of local - rather than extratropical - wave driving.

Satellite validation • The ozone profiles and column values recorded at Paramaribo station are also used for validation of ozone retrieval products from GOME. In 1995, GOME was launched on ERS2 (Earth Remote Sensing), to measure the spectrum of back-scattered sunlight from the atmosphere in nadir direction. From this spectrum both the total ozone column and a collocated ozone profile is retrieved, which is unique for satellite measurements. In Figure 3 the ozone column measurements from the Brewer at Paramaribo are compared to collocated ozone columns retrieved from the

Both TOMS and GOME ozone columns show overall good agreement with the Brewer measurements

GOME and TOMS-EP (Total Ozone Mapping Spectrometer-Earth Probe) satellite instruments. Both TOMS and GOME ozone columns show overall good agreement with the Brewer measurements. The long-term variations are followed very well. The values from TOMS and GOME are on average respectively 3% higher and 1% lower than the Brewer values. The temporal short term variance in total ozone is better captured by TOMS, due to its smaller ground pixel: 40 by 40 km for TOMS versus 40 by 320 km for GOME.

Discovering the tropical atmosphere

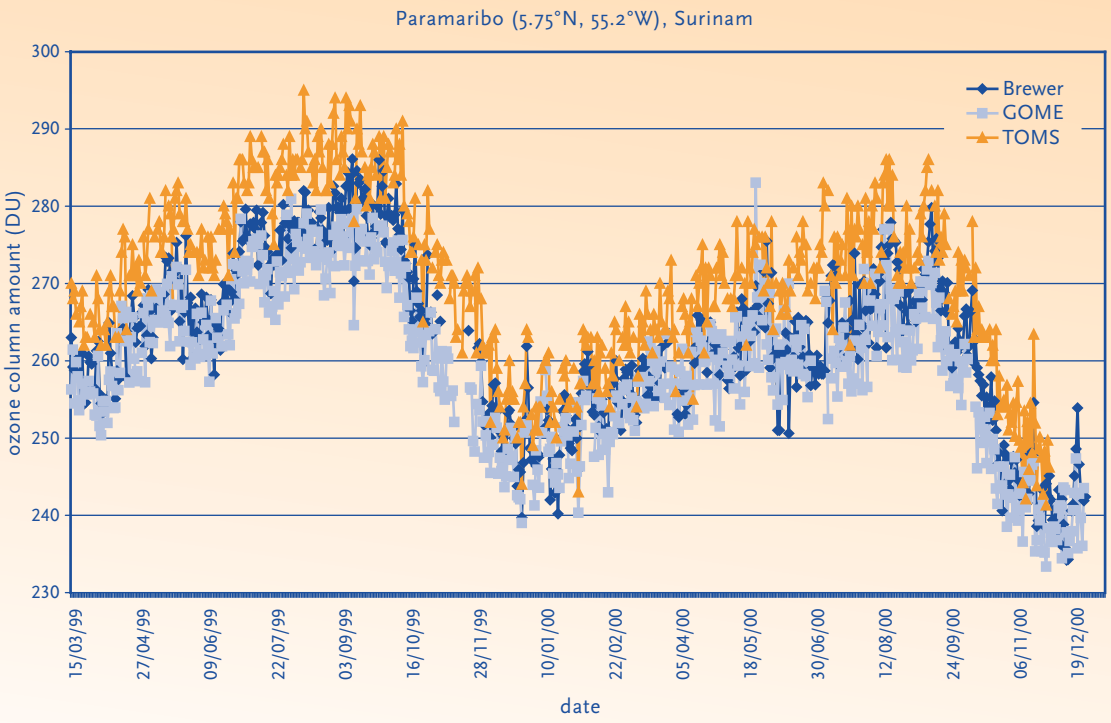


Figure 3. Brewer total ozone values at Paramaribo compared with TOMS and GOME satellite instruments.

The steep rise of ozone absorption from 340 to 260 nm in the observed back-scattered radiance offers the possibility to infer height-resolved information on the ozone concentration in the stratosphere as well as in the troposphere [3,4]. Every 12 seconds the GOME instrument makes an observation in the UV spectrum suitable for profile retrieval. This observation has a ground pixel size of 960 by 100 km, resulting in global coverage in a period of 3 days. The ozone profile retrieval is performed with the optimal estimation method [7], where the information of the observation is combined with a-priori information. The a-priori ozone profile is taken from the climatology of Fortuin and Kelder [5]. The GOME ozone profiles are compared to local ozone sonde measurements at Paramaribo for the period of October 1999 till July 2000. In Figure 4 an example is given of ozone sonde measurements and collocated retrieved GOME profiles for November of 1999. The retrieved ozone profiles in Paramaribo follow the sonde profile very well. The deviations of the stratospheric values between GOME and the sonde are usual within the retrieval error (indicated with a horizontal bar in Figure 4). While deviations found at stations at mid-latitudes are usually within the retrieval errors, the GOME ozone profile at Paramaribo shows systematic deviations at certain layers. This shows the importance of ozone validations at a tropical station, also for satellite instruments to be launched in the near future, like SCIAMACHY (Scanning Imaging Absorption Spectrometer for Atmospheric Cartography), OMI (Ozone Monitoring Instrument) and GOME-2.

UV radiation • As can be expected, the Brewer UV measurements can show very high damaging UV (DUV) values. In the Netherlands, for example, the DUV-scale maximum lies at a value of 8, corresponding with 200 mWm^{-2}. In Suriname, this value is almost always exceeded around noon, the typical range is around UV index value 12. The UV insolation at Paramaribo is surprisingly constant over the year with typical maxima of UV index of 13 or 14 on a cloudfree day. The annual variation in UV insolation at Paramaribo is modulated by the variation in solar zenith angle (sza), Sun-Earth distance, ozone column and cloudiness [6]. The bimodal distribution due to the variations in solar angle is partly compensated for by the annual cycle in the ozone column: the maximum ozone column in

The UV insolation at Paramaribo is surprisingly constant over the year

September coincides with the minimum sza. At Paramaribo the Sun crosses the zenith at local noon twice a year: in April and September (see Figure 5). The difference in UV insolation between both cycles is partly compensated by the Sun-Earth distance, which is smallest in January and yields about 6% more UV in January than in July. The scattered UV measurements show that a cloud-free noontime is the exception at Paramaribo, even in the dry seasons

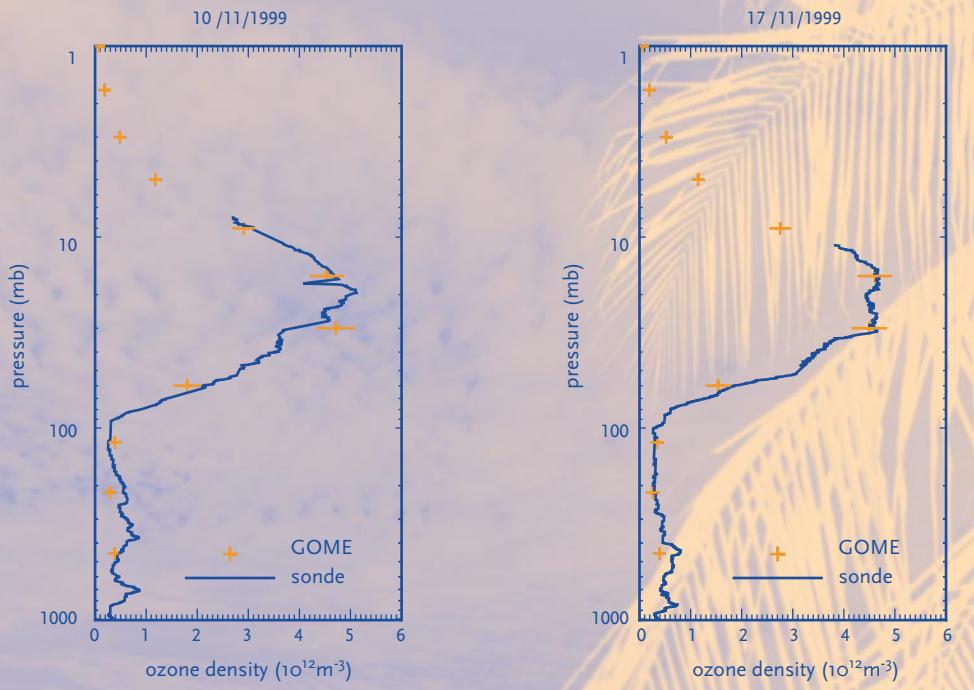


Figure 4. Collocated and coincidental ozone profiles at the ground station Paramaribo measured by an ozone sonde and the GOME satellite instrument.

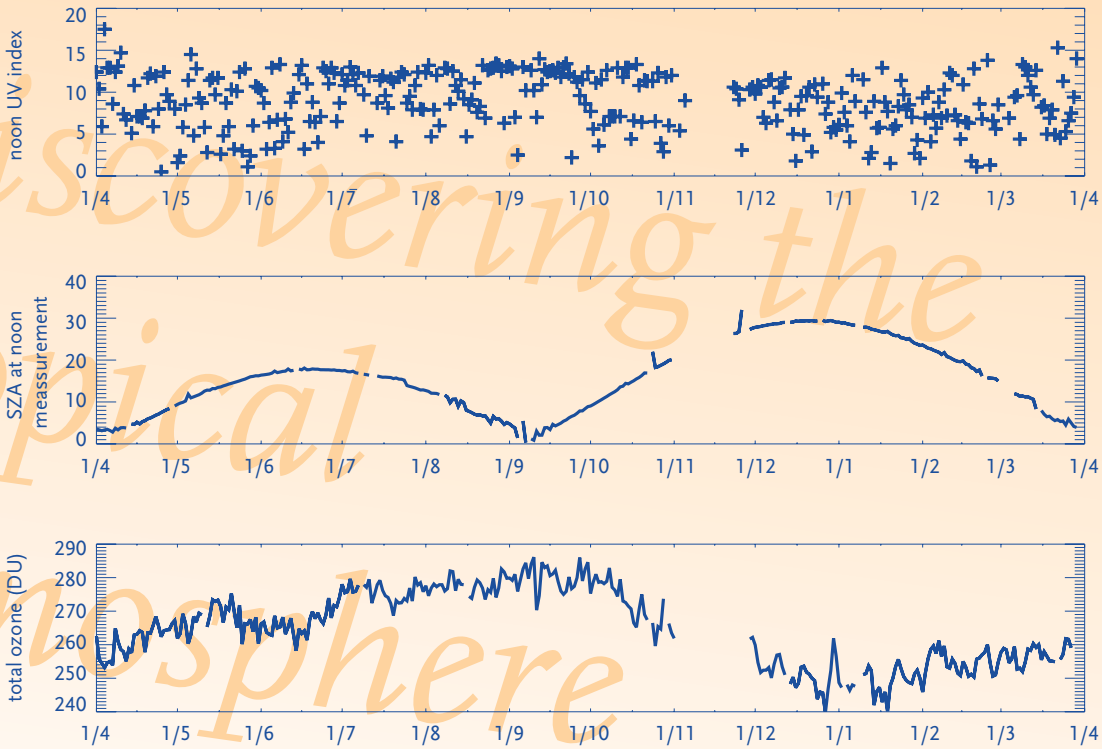


Figure 5: One year (1 Apr 1999 - 1 Apr 2000) of UV Index (top) and total ozone (bottom) measurements at Paramaribo. The figure in the middle gives the solar zenith angles of the spectrum for which the UV Index was determined, which is the first spectrum after noontime on each day.

Discovering the tropical atmosphere

(February - March; August - November). The maximum UV Index measured in Paramaribo thus far is 17.5 on 4th of April 1999, in partly cloudy conditions.

Outlook • In its short existence, Paramaribo station has yielded a valuable set of observations which already has lead to new insights in atmospheric research and holds promise for future discoveries. Its strategic location under the migrating ITCZ provides a unique insight into many key features of the atmospheric circulation in the Tropics. Some of these dynamic features, like the El Niño event, which recurs every two to five years and has an influence on climate world-wide, act on long time scales. To study these features years of observations are required. It therefore would serve many interests to maintain and if possible expand this observation programme in the future, beyond the duration of the RADCHIS project. Also, new satellite instruments will be launched in the coming years which need to be validated in the Tropics. Prospects for expansion of the observation programme are good and first plans are being realised: the RIVM (National Institute of Public Health and the Environment) has donated an ozone monitor to sample smog levels in the boundary-layer over Paramaribo, and also intends to install a back-scatter LIDAR (LIght Detection And Ranging) instrument in Paramaribo within the next year together with KNMI. With this highly advanced instrument, the distribution of aerosols in the atmosphere can be monitored continuously, providing insight into many aspects of atmospheric transport and cloud formation. This combined set of instruments will provide an invaluable insight to atmospheric dynamics and chemistry in the Tropics.

We thank NWO, NIVR and SRON for their generous support of this project. More specifically we like to thank the personnel of NWO-ALW for their positive and serviceable attitude in many matters.

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Current projects

Predictability Research

General • The Predictability Research Division investigates the predictability and natural variability of weather and climate. The research covers a wide range of topics, which can be summarised in a number of themes.

The Division started with the theme 'Skill prediction and ensemble forecasting'. In a joint project with ECMWF (European Centre for Medium-Range Weather Forecasts) an ensemble prediction system for the European area has been developed for the short and early medium range. A second theme is 'Dynamics of weather and climate'. In this theme predictability is studied in the more theoretical context of isentropic contour dynamics models and low-dimensional models of climate. Finite predictability may be intrinsic or related to model limitations.

Research on climate variability and climatic change is the third main theme of the Division. It is centred around ECBILT, an intermediate-complexity climate model developed within the Predictability Research Division. In climate modelling we co-operate with various Climate Research Divisions (Atmospheric Research, Oceanographic Research and Climate Analysis), with our partners in CKO (Netherlands Centre for Climate Research) and with foreign institutes like the University of Louvain-La-Neuve, Belgium, and the Meteorological Institute of the University of Hamburg, Germany. The second version of ECBILT, containing an improved radiation scheme, became available in 2000. ECBILT has been applied to the study of a large number of scientific questions described in 'Predictability and natural variability of climate' and 'Reconstruction and modelling of past climate'. Topics include decadal climate variability, the effect of a variable solar forcing, ensemble scenario studies, modelling of low-frequency variability and the comparison to palaeo data, and the interpretation of recorded signals at Milankovitch timescales.

Part of the Division's funding comes from external agencies. The EU funded project SINTEX (Scale INTeractions EXperiments) ended in 2000. In SINTEX the interaction between various timescales of natural variability has been studied. Two projects with respect to low-frequency variability and the comparison to palaeo data were funded by NOP (National Research Programme on global air pollution and climate change). Both involve a direct collaboration with geologists and palaeo-ecologists. A joint project with the Department of Mathematics of the University of Utrecht, funded by NWO (Netherlands Organisation for Scientific Research), is concerned with the fundamental properties of simple climate models. We actively participate in the Dutch

CLIVAR (Climate Variability and Predictability Research) programme called CLIVARNET.

Two international workshops were organised by the Division. In March 1999 about 30 scientists from Europe and the USA came to KNMI to discuss how climate modelling and palaeodata can be combined in the analysis of low-frequency climate variability. Co-organiser of this workshop was the GKSS Research Centre, Geesthacht, Germany. A workshop on dynamical system concepts in climate research was held in De Bilt in April 2000. This workshop was attended by about 50 scientists from Europe, Russia and the US.

Skill prediction and ensemble forecasting

Hersbach, Mureau, Opsteegh

The skill of a weather forecast varies from day to day. Information about the skill can be retrieved from the probability distribution function (PDF) of the forecast errors. Ensemble prediction systems are the most straightforward tools to generate such probability distributions. In an ensemble system the same forecast is repeated a large number of times from perturbed initial conditions. In order to limit the size of the ensemble a special type of perturbations is calculated which has optimal growth characteristics. An example of such optimal perturbations are the so-called Singular Vectors. The Singular Vectors with largest eigenvalues are the directions in phase space in which initial errors grow fastest during a predefined integration period and for a predefined area of interest. The area of interest can be the whole globe, but also a more restricted area like Europe. Singular Vectors, which are computed for a restricted area, are called Targeted Singular Vectors. In order to measure error growth properties a metric is needed. Here we have a choice. The Singular Vector properties will depend on this choice. Usually total energy is taken to measure differences.

In a joint project with ECMWF an ensemble system has been developed for the short and early medium range (up to day 5). This system is different from the operational ensemble prediction system (EPS) of ECMWF in that it makes use of Targeted Singular Vectors for the European area (TEPS). Such a system has a clear advantage: the full PDF of the forecast errors for Europe is generated more accurately. This especially applies for weather parameters (such as precipitation, 2-metre temperature and 10-m wind speed), for which the skill is lower than for the large-scale flow. The Singular Vectors are generated with the T42 adjoint/tangent linear model, whereas an ensemble, consisting of 50 members, is integrated with the full T159 ECMWF non-linear model. Experiments have shown that an optimisation of the perturbations in terms of total energy results in the winter season in a modest improvement of the TEPS ensemble system with respect to the ECMWF EPS. However, in the autumn and spring cases, the impact of the targeted ensembles is significantly positive. This is caused by a better performance of TEPS with respect to low probability extreme-weather events. As a result, the range of cost/loss ratios for which a user has benefit is substantially larger for the targeted ensembles. The impact is maximal for day two and three and decreases thereafter. In 1999 TEPS was run on Fridays and Sundays. At those times evolved singular vectors were added operationally to the EPS system of ECMWF. These additional perturbations appear to dominate the performance of EPS, and therefore also the performance of TEPS for the first few forecast days. As an alternative, targeted singular vectors with an optimisation time of 12 h were introduced in TEPS. Although impact in scores with respect to EPS was more modest than for the cases considered in 1997, the frequency of outliners improved considerably. A paper has been submitted.

It was shown how the continuous ranked probability score (a rather new verification tool for probabilistic forecasts) can be decomposed into three parts and how each part is related to other well-known verification tools. A paper on this verification tool has been published in Weather and Forecasting.

Dynamics of weather and climate

Verkley, Pasmanter, Trieling, Vosbeek, Achatz, Crommelin, Timmermann, Opsteegh

Contour dynamics

In the summer of 1999 the post-doctoral research project `The predictability of two-layer contour dynamics systems', funded by NWO came to an end by the departure of Dr. Trieling to the Vortex Dynamics Group of the Technical University Eindhoven. The project aimed at investigating to which extent it is possible to describe the process of atmospheric cyclogenesis (synoptic development) using isentropic contour dynamics models. In isentropic contour dynamics models the vertical structure of the atmosphere is represented by one or more layers of uniform potential temperature (isentropic layers) and the horizontal structure (within the layers) by two or more regions of uniform potential vorticity (PV). Assuming hydrostatic and geostrophic equilibrium(simplified linear balance), the models are defined completely in terms of the positions of the potential vorticity fronts and can be integrated in time using the technique of contour dynamics.

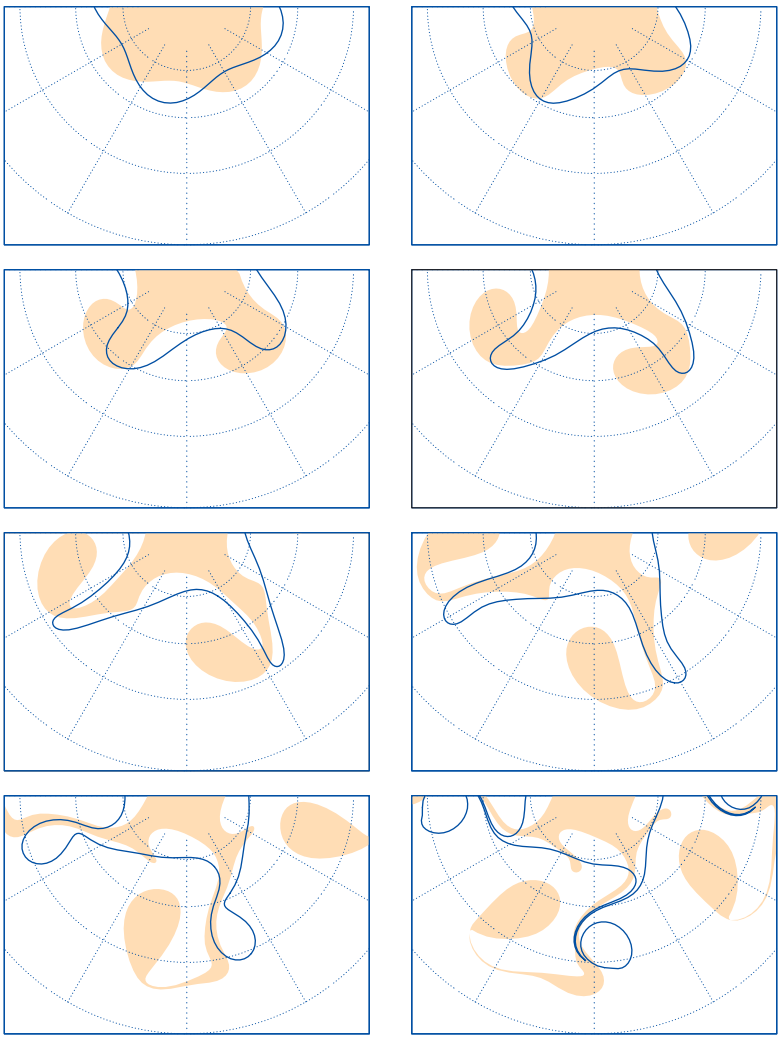

Figure 1. Life cycle of a cyclone in a two-and-a-half layer contour dynamics model. The panels (from top-left to bottom-right) show the state of the model at intervals of one day. The shaded region corresponds to low values of the potential vorticity in the lowest layer. The region north of the contour corresponds to high values in the middle layer. The top layer is motionless.

The work has evolved into a state in which it has become clear that a so called two-and-a-half layer contour dynamics model with a single front of potential vorticity in each of the two active layers is sufficiently versatile to produce cyclogenesis. This model, consisting of three layers of uniform potential temperature - the upper layer assumed to be at rest - was investigated extensively. The project has resulted in two studies on baroclinic life cycles in a two-and-a-half layer contour dynamics system: one on the structure of zonal flows and another on infinitesimal and finite-amplitude perturbations of zonal flows.

Figure 1 shows an example from the second study. The shaded area marks the region in the lower layer in which the potential vorticity is lowest. The curve (contour) marks the potential vorticity front in the middle layer, with the higher value to the north of the contour. The initial state (shown in the first panel) is a zonal state in which both fronts are at 50 degrees north, with an amplitude of 5 degrees (north-south) and a phase difference of 50 degrees (east-west). The other panels show the states at intervals of one day. The figure shows an evolution that is typical of a baroclinic life cycle.

Monitoring atmospheric analyses

This project, begun in the summer of 1998, was funded by the BCRS (Netherlands Remote Sensing Board). The aim of the project is to devise a method by means of which it is possible, using a graphical interaction procedure, to modify the

analysis of HIRLAM (High Resolution Limited Area Model) used at KNMI and to study the consequences of the modification in terms of the resulting forecast. The analysis is adjusted in terms of PV (potential vorticity) and a three-dimensional variational data-assimilation system (3DVAR) is used to obtain a dynamically consistent modified analysis from the modified PV.

To give an idea of the present state of affairs we present an example of an analysis that is modified using this method (Figure 2). In panel (a) of the

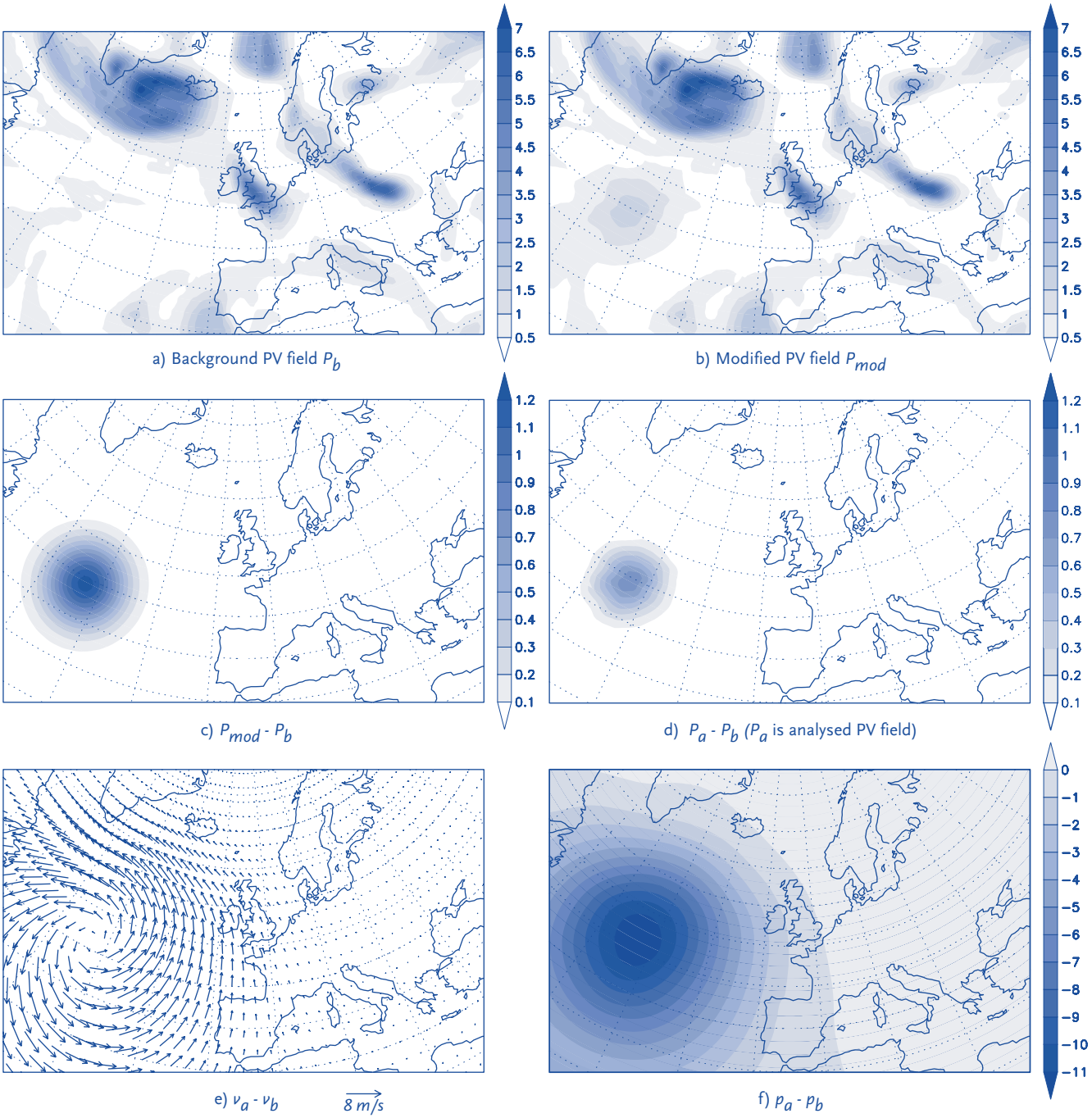

Figure 2. The background PV field (a), the modified PV field (b), the difference between the modified and the background PV field (c), the difference between the analysed and the background PV field (d), all on model level 15. The last two panels show for model level 31 (the surface) the difference in velocity (e) and in pressure (f) between the background field and the modified analysis. The potential vorticity is shown in PV-units, the velocity in ms^{-1} and the pressure in hPa.

figure we show a PV field (background field) as analysed by HIRLAM. In (b) we show the modified PV field and in (c) the difference between the modified and background fields. Note that the difference is a rather large but localised source of PV. In (d) we show the modified analysis in terms of PV; the fact that (d) and (e) resemble each other to a considerable degree means that the procedure was able to modify the underlying dynamical fields in such a way that they reproduce the modified PV field. In (e) and (f) we show the difference between the analysis and the background of two of these underlying fields: the velocity and pressure field at the surface. The modified analysis can be used as an alternative initial state in a numerical forecast by HIRLAM.

In December 2000 the project was completed in terms of the BCRS report 'Manually adjusting a numerical weather analysis in terms of potential vorticity using three-dimensional variational data-assimilation'. The project has resulted in a system that functions as expected, although it needs further fine-tuning and optimisation. It has been established that the concept of potential vorticity in combination with variational data-assimilation can handle human interventions in the numerical forecasting process in a natural and effective way. It is intended to continue the work by testing the system on a few selected meteorological cases and to optimise the system in terms of computational speed and user-friendliness. In the future we expect to test the system in an operational forecasting environment to assess its effectiveness in daily operational practice.

Isentropic models
The main goal of this project is to provide a solid physical foundation for isentropic contour dynamics models of the atmosphere. The study of the dynamics of an isentropic layer in hydrostatic equilibrium - with the emphasis on the vertical profile of vertical velocity - appeared in the January 2000 issue of the Quarterly Journal of the Royal Meteorological Society. As a result of a referee's suggestion it was shown that the derived profile of vertical velocity is an exact solution of Richardson's equation when specialised to an isentropic layer.

In contrast with hydrostatic balance, geostrophic balance is not trivially applied to flow on a global domain. The problem was studied in the context of the simplest isentropic model that one can imagine: a single hydrostatic layer of air with uniform potential temperature. Such a model behaves very much like a single-layer shallow water model, but is more appropriate as a simplified model of the atmosphere than a shallow-water (constant-density) model. The assumption that deviations of the Montgomery potential (or geopotential) from the state of rest are equal to the Coriolis parameter times the streamfunction was found to give a form of geostrophic balance that can be used globally. This simplification of linear balance can be used to derive, e.g., the equivalent barotropic vorticity equation on the sphere in a conceptually clear and physically consistent way.

The form of balance just mentioned was also used as a starting point in a Hamiltonian method, developed by Salmon, to construct global balanced models of the atmosphere that conserve energy, mass and potential vorticity. The method was applied to the single-layer isentropic model mentioned above. A comparison of the balanced model with the original unbalanced model makes clear that the balanced model is a very accurate approximation of the original model. The corresponding paper is now in press at the Quaterly Journal of the Royal Meteorological Society. It is planned to apply the method to isentropic models with more than one layer including the case in which the lowest layers are infinitesimally thin locally.

Statistical mechanical approach to 2D coherent structures
This concerns the study of the effects of the ever present and often neglected microscopic fluctuations on the macroscopic behaviour of the system under consideration. Three papers were published on the so-called statistical mechanics approach to the coherent structures observed in the asymptotic regime of two-dimensional flows. A fourth paper is in preparation. In this paper it is explained how and when it is possible that the inviscid theory correctly predicts the coherent structures generated by viscous two-dimensional flows. This represents an important step in bridging the gap between the theory and the behaviour of realistic, dissipative flows. A collaboration with Dr. A.H. Nielsen, RISØ Institute, Denmark, was started in order to apply some of the techniques developed in these papers to the results obtained in high-resolution numerical simulations.

Low order statistical-dynamical climate models
For two reasons it is an interesting objective to formulate low-dimensional models of the atmosphere which, in spite of their simplicity, retain

a considerable degree of realism in the description of mean states as well as internal variability. First, they are more transparent than the ever more complex state-of-the-art GCM's and thereby serve as tools for deepening our understanding of the behaviour of GCM's and the atmosphere itself. Furthermore, they are fast so that they can be used as part of intermediate complexity models by which we can examine the ultra-long timescales of the climate system. With this in mind, and based on previous encouraging work during the stay of Achatz at KNMI and after his return to the Leibniz-Institut für Atmosphärenphysik (Germany), a reduced model has been developed which is based on empirical orthogonal functions (EOF). Such models are able to describe complex systems with high efficiency. The novelty of the work undertaken here was that the non-linear dynamics of the model is based on the primitive equations (PE) so that also tropical dynamics is captured well. Furthermore the model goes beyond its predecessors by also describing a seasonal cycle. Basis is a new numerical PE algorithm, which retains internal gravity waves but is filtered with respect to the external wave type. This serves as framework for the definition of a PE-based total energy metric for the determination of the EOF's from some data set. The dataset used is a long run of ECHAM3 (Hamburg Version of the ECMWF Model). External forcing and linear dynamics of the model are empirical. They optimise instantaneous tendencies in the ECHAM3 data. Investigations of the behaviour of the model show good simulations of first and second moments in the ECHAM3 data and their respective seasonal cycles. Recurrent anomalies can be reproduced. This is especially the case for a small model version, based on as few as 30 patterns. The model is presently employed in studies on atmospheric dynamics. The possibility of using them as a dynamical core of an intermediate complexity climate model is presently under investigation.

By studying the properties of a two-layer quasi-geostrophic version of a low order dynamical-empirical EOF model, a link is established between atmospheric ultra-low frequency variability (ULFV) and the occurrence of homoclinic dynamics. Uncoupled atmosphere models possess significant variability on very long time scales (years to decades), which must be generated by internal atmospheric dynamics. The mathematical structure of this long-timescale variability is investigated. The ten-dimensional (10D) version of the model possesses both nonzero ultra-low frequency variability and some realistic short timescales. The essence of the ultra-long timescale behaviour of the 10D model, which manifests itself as bursts in the atmospheric turbulent energy, can be represented by a 4D subsystem. In this subsystem, strong evidence for the existence of a homoclinic orbit is found. The chaotic dynamics generated by the homoclinic orbit explains the observed long-timescale features of the model. It is shown that hints of homoclinic dynamics can also be found in more complex models.

Low-order empirical climate models

The recurring theme in the investigations listed below is the construction, when possible, of empirical, low dimensional models. Another question is that of predictability, be it intrinsic or related to model limitations. In the empirical modelling of the dynamics of El Niño - Southern Oscillation (ENSO) a novel, nonparametric regression analysis was used to derive a set of reduced models from an intermediate-complexity atmosphere-ocean model of the tropical Pacific and from a state-of-the-art GCM. The analysis performed was focused on the dimensionality issue as well as on the role of nonlinearities. This empirical technique helps to identify key processes and to explain physical peculiarities of simulations. A publication will be published in the Journal of Physical Oceanography.

The results of a 330-year long model simulation performed with a coupled GCM as well as results from the simpler Zebiak-Cane ENSO model were used in order to compute the corresponding season-dependent, cyclic Markov chains. In this way, one obtains a lower bound for the predictive skill of dynamic ENSO models as well as the dependence of the ENSO predictability upon the initial state and the initial month. These calculations are now extended using longer simulations and available measurements. A collaboration was started with the Physics Department of the University of Rome in order to extract more information from these Markov chains.

The role of noise-induced transitions in the thermohaline circulation was studied using a multiplicative Langevin equation. It was shown that the intensity and other characteristics of the ubiquitous noise can lead to clear-cut changes in the mean state of the thermohaline circulation. The corresponding publication appeared in the Journal of Physical Oceanography.

Using a relatively simple threshold-model of ice volume forced by the envelope of the eccentricity modulated solar insolation it was possible to reproduce the 100 ky cycles of the Late Pleistocene. A publication on this work has been submitted.

ECBILT: an intermediate-complexity climate model

Haarsma, Selten, Schaeffer, Wang, Weber, Opsteegh, Beersma

Models are an important tool in climate research. In recent years the so-called intermediate-complexity climate models are emerging to bridge the gap between comprehensive coupled GCM's on the one hand and low-order, conceptual models on the other hand. The Predictability Research Division has developed such an intermediate-complexity climate model (ECBILT), primarily for the investigation of extratropical climate variability on decadal and longer time scales. ECBILT contains a number of (subgrid-scale) processes in a parameterised form. In this respect it is similar to GCM's, albeit with a coarse spatial resolution and a high degree of simplification in its parameterisation package. Contrary to conceptual models, the number of degrees of freedom is much larger than the number of adjustable parameters. Tuning has to be done mainly on the level of the included processes. The simulated climate in the extratropics is reasonably realistic, with a good qualitative agreement to the observed location of the stormtracks and the dominant patterns of variability. Due to the coarse resolution the intensity of the variability is underestimated. ECBILT is computationally very efficient. It is possible to perform climate simulations in ensemble mode or to perform ultra-long simulations. Since it was first developed ECBILT has been applied for the study of a wide range of scientific questions. This will be described in the following paragraphs 'Predictability and natural variability of climate' and 'Reconstruction and modelling of past climate'.

ECBILT is being modified and improved in a continuing process. Here we co-operate with various Climate Research Divisions (Atmospheric Research, Oceanographic Research and Climate Analysis) as well as with (inter-) national partners. ECBILT has been coupled to the CLIO (Coupled Large-Scale Ice Ocean Model) ocean/sea-ice model of the University of Louvain-La-Neuve, Belgium. We participated in the workshop on Earth System Models of Intermediate Complexity (EMIC's) held at the Conference of the European Geophysical Society (EGS) in Nice, France, in April 2000. A paper on the spectrum of climate models, ranging from comprehensive GCM's via EMIC's to pure conceptual models, has been submitted for review (first author: Dr. Martin Claussen, Potsdam Institute for Climate Impact Research, Germany). We recently joined an initiative of Prof. Klaus Fraedrich of the University of Hamburg to develop a European community climate model of intermediate complexity. This model will be embedded in a standard model environment, including pre- and postprocessing software, debugging tools and graphical packages. The model core will have a modular structure, which will make it relatively easy to exchange different physical parameterisation routines. Below we will describe the versions presently available (ECBILT1 and ECBILT2) and new developments. Frozen versions of ECBILT can be obtained through the CKO model support website.

ECBILT1

This original configuration of ECBILT consists of an atmospheric quasi-geostrophic model (T21, three levels) with a diagnostically computed correction for the ageostrophic terms. It contains parameterisations for the diabatic physical processes and a bucket land model. ECBILT1 is coupled to a flat-bottom ocean model and a thermodynamic sea-ice model, both developed in the Predictability Division. This version is described in a Tellus (1998) paper. It has been updated so that orbital variations in the solar radiation can be taken into account.

ECBILT2

In collaboration with the RIVM (National Institute of Public Health and the Environment) as well as the Divisions of Atmospheric Research and Climate Analysis a new radiation and cloud scheme has been developed. The radiation scheme is a linearisation of the radiation scheme of ECHAM4 (Hamburg version 4 of the ECMWF model).

The cloud scheme is based on a simple parameterisation of cloud cover by prognostic model variables like relative humidity and vertical velocity. The radiation scheme now includes the possibility of studying the effects of variations in the concentration of trace gases like CO_2. ECBILT2 is coupled to the MOM3 (Modular Ocean Model) of GFDL (Geophysical Fluid Dynamics Laboratory), Princeton, USA. There also exists a version with the CLIO model (Coupled Large-Scale Ice Ocean model) of the University of Louvain-La-Neuve, Belgium. CLIO contains an ocean component as well as a thermodynamic/dynamic sea-ice component. We plan to extend ECBILT2/CLIO with a land-ice component, in collaboration with University of Utrecht. This will bring the study of the initiation and termination of glaciations within reach.

ECBILT3
New developments, which have started but are not yet completed, include:

1. Development of a boundary-layer scheme.
In collaboration with Wageningen University, the Atmospheric Research Division and the RIVM a new boundary-layer scheme is developed. It will simulate the daily variation in the boundary-layer height and surface fluxes. To this end a daily cycle in solar irradiation will be included. The new boundary-layer scheme will be tested off line with Cabauw data and simulations with a 1-D version of RACMO (Regional Atmospheric Climate Model). This project is partly funded by NOP.

2. Development of a vegetation module.
As part of a PhD project in collaboration with the RIVM a vegetation module is being developed to study climate-vegetation feedbacks.

3. Replacement of the quasi-geostrophic adiabatic code of ECBILT by a primitive equation code, which has been developed by the University of Hamburg.

Predictability and natural variability of climate

Haarsma, Selten, Schaeffer, Van Reenen, Wang, Opsteegh

Decadal variability in the midlatitudes has been investigated with ECBILT1. We have focused on decadal variability in the North Atlantic and in the Southern ocean. In those regions the dominant patterns of covariability between sea surface temperature and 800 hPa geopotential height and their preferred time scales show good qualitative agreement with observations. The physical mechanisms of the simulated decadal variability have been investigated with a number of idealised experiments in which various feedback processes have been switched on and off. This analysis revealed that the midlatitude decadal variability is strongly associated with subsurface oceanic modes. These modes are generated by dominant, internal modes of the atmospheric circulation. The ocean sets the time scale. The feedback from the ocean to the atmosphere is not crucial for either the structure or the time scale of these decadal modes. This feedback, however, enhances the intensity of the decadal variability. The generation of the dominant time scale in the subsurface oceanic mode is different for the North Atlantic decadal mode and the Antarctic Circumpolar Wave (ACW). For the ACW the preferred time scale appears to be generated by the advective resonance mechanism. In this mechanism the ocean temperature can be approximated by a passive tracer, which is advected by an ocean with a fixed velocity. The preferred time scale is set by the advection velocity of the ocean and the horizontal scale of the atmospheric mode. For the decadal variability in the North Atlantic the dynamical response of the ocean circulation to temperature anomalies and related anomalous salt advection appears to be crucial for the generation of the decadal time scale. Two papers on this subject have been published in the Journal of Climate. A PhD project has started to investigate the role of the salt anomalies and the possible interaction between the Pacific and the Atlantic more in detail. This will be done with ECBILT2/MOM3.

With ECBILT1 we have investigated the effect of variable solar forcing on climate variability. For realistic amplitudes solar forcing dominates over internal variability in global mean surface air temperature beyond decadal time scales. On the regional scale the internal variability dominates on all time scales. Evidence is found for interaction between climate variations on different time scales. The simulated decadal variability in the North Atlantic appears to be sensitive to small low frequency fluctuations in the solar irradiance. A

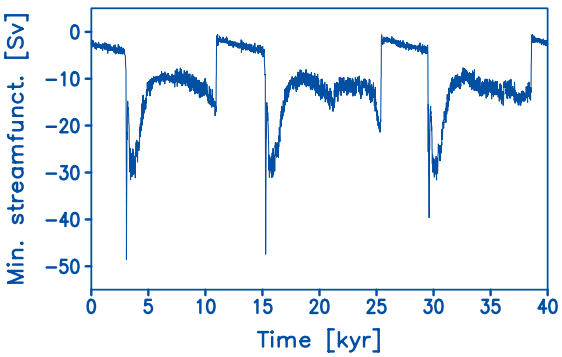

Figure 3. Extrema of the stream function of the meridional overturning (Sv) in the Southern ocean during a 40,000 years integration with ECBILT1.

paper has been published in Geophysical Research Letters. The time scale interaction has been discussed in a contribution to a book on solar variability and climate edited by Friis-Christensen.

With ECBILT1 a 40,000 year integration has been performed to study internal low-frequency behaviour. The model displays quasi-periodical behaviour on a time scale of about 10,000 years, characterised by rapid switches between two quasi-equilibrium solutions on decadal time scale (Figure 3). The mechanism is similar to the deep-decoupling oscillations observed in ocean models with mixed boundary conditions. The effect of sea-ice on the heat and freshwater fluxes appears to be crucial to generate this type of oscillation in a coupled atmosphere/ocean/sea-ice model. This experiment suggests the possibility of rapid transitions in the climate system. A paper will shortly appear in Climate Dynamics.

In collaboration with Dr. Hugues Goose of the University of Louvain-La-Neuve decadal variability over the Arctic ocean has been investigated with ECBILT2/CLIO. A decadal oscillation in the Arctic ocean with a period of about 18 year is simulated. The geographical pattern and time scale are supported by the available observational evidence. A paper describing this oscillation will appear in Annals of Glaciology. Further analysis of the driving physical mechanism is underway.

With ECBILT2/CLIO, an ensemble of integrations has been performed for future concentrations of trace gases in the atmosphere up to the year 2100. The response of surface air temperature to the increasing concentrations of green house gases qualitatively resembles the results of similar runs performed with more comprehensive climate models. The simulated increase of surface air temperature falls in the lower range of published estimates. The thermohaline circulation decreases, the sea-ice cover in the Greenland-Iceland-Norwegian sea increases. The ensemble of integrations is being analysed to estimate changes in the occurrence of extreme events due to the change in the mean climate. A paper on this subject is in preparation.

Since regional climates tend to be influenced by a few dominant circulation structures, insight in the response of the statistics of these structures to changes in the forcing is crucial in understanding and predicting regional climate changes. The sensitivity of the statistics of the dominant extra-tropical circulation structures to changes in the diabetic heating is being studied in a quasi-geostrophic atmospheric model (the dynamical part of ECBILT1) in collaboration with Dr. Grant Branstator of NCAR (National Center for Atmospheric Research). The responses turn out to be highly non-linear. A dynamical interpretation of these sensitivities is underway.

Reconstruction and modelling of past climate

Weber, Van der Schrier, Tuenter

The palaeo research of the Predictability Division aims at developing a methodology for combining dynamical knowledge, based on the analysis of model simulations, and proxy data. This is done in close co-operation with climatologists, glaciologists, geologists and palaeo-ecologists. Research themes are the low-frequency variability of the present climate and the sensitivity of the climate system to changes in the external forcing or in the boundary conditions. Both themes are highly relevant for detection and modelling of anthropogenic climate change. They are fully consistent with CLIVAR, PAGES (Past Global Changes) and the CLIVAR/PAGES intersection.

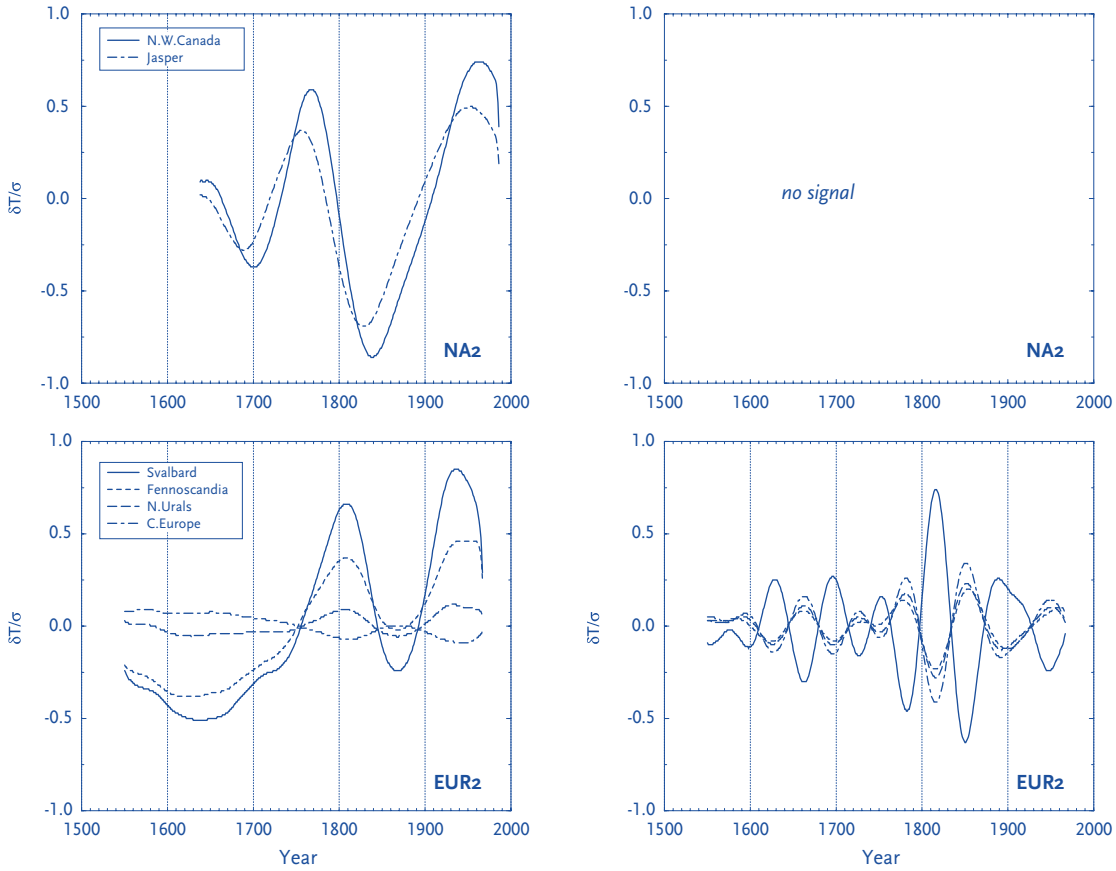

Figure 4. Low-frequency modes of temperature variability identified by MSSA in the reconstructed summer-season records of temperature for Europe (EUR2) and north-western North America (NA2). The specific locations are indicated in the legend. Shown are the normalised anomalies, with the centennial mode in the left-hand panels and the multi-decadal mode in the right-hand panels. The multi-decadal mode is absent for NA2, as it only occurs in regions bordering the North Atlantic.

The project 'Patterns of low-frequency climate variability: a model-palaeodata comparison' ended in 2000. This was a collaboration between the Predictability Division, the Climate Analysis Division and Prof. Henry Hooghiemstra (Hugo de Vries Laboratory, University of Amsterdam). Focus of this NOP-funded project was on natural climate variability on interdecadal to centennial timescales. As a data base European early-instrumental timeseries and a proxy-based network covering North America and Europe were used. The latter incorporates high-quality climate reconstructions based on various palaeo proxies.

A combination of statistical techniques was applied, including principal component analysis and multivariate singular spectrum analysis (MSSA). On timescales longer than 50 years two statistically significant modes of temperature variability were identified, one on multidecadal and one on centennial timescales. Figure 4 gives the results for the summer data. The first mode is oscillatory, with a timescale in the narrow range 60-80 years. The spatial pattern of this mode implies coherent oscillations over Europe and over north-eastern North America, with maximum amplitudes in Europe; over north-western North America this mode is absent. Its geographic shape suggests a connection to the North Atlantic Oscillation. A relation with solar forcing could not be detected. The second mode, which dominates low-frequency variability at high latitudes, describes temperature variations in a wide interval of timescales. The temporal pattern of this mode shows a multiple-phase 'Little Ice Age' and a prolonged 'Medieval Warm Period'. The interpretation of this mode is difficult, given its rather variable large-scale pattern and the uncertainty associated with centennial timescales in the proxy data. It was shown earlier that low-frequency variability patterns in early-instrumental temperature records are season-dependent. Due to a lack of seasonally resolved proxy data it is difficult to address this issue in a rigorous manner for the presently identified low-

frequency modes. In Europe, where long seasonal proxy series are available, both modes seem to be season-specific. A publication has appeared in Journal of Geophysical Research.

A simulation with ECBILT1 of a thousand years, using present-day boundary conditions, was analysed with respect to patterns of variability in surface air temperature. Although the model fails to reproduce periodicity's identified in the proxy data, some encouraging similarity was found between spatial patterns of variability in the empirical and simulated summer data. A paper on the model analysis and model-data comparison is in preparation.

An international workshop on combining modelling and palaeodata in the analysis of low-frequency climate variability was co-organised with Dr. H. von Storch (GKSS Research Centre, Geesthacht, Germany), bringing together about 30 scientists from Europe and the US. A short report on the workshop theme appeared in the American Geophysical Union Newsletter, Eos.

Research on this theme continues with another NOP-funded project 'Sea level and climate variability on multi-decadal to centennial timescales'. This is a joint project of the Predictability Division and Oceanographic Research Division with Dr. Orson van de Plassche (Faculty of Earth Sciences, Free University Amsterdam). This two-year project started in 1999. The KNMI contribution to this project is to establish, from ECBILT1 output, relations between coherent spatial patterns of North Atlantic sea level variability and prominent modes of the atmospheric circulation and other atmospheric parameters in the North Atlantic. A procedure to compute sea level diagnostically from ECBILT1 was set up. A 1500-year long sea-level record for the North American East Coast, as reconstructed by Van de Plassche on the basis of salt marsh data, will be used in the model-data comparison. Hypotheses regarding the relation between sea level at the North American East Coast and climate in NW Europe, which have been formulated on the basis of reconstructed sea level and various other climate proxies, will be validated within the context of the model experiments.

The separation of solar-induced climate variations from other sources of climatic variability is a fundamental problem in the Earth sciences. By using concepts from dynamical systems theory, a technique has been devised which has the potential to distinguish explicitly between internally generated and externally forced climate variability. This technique was applied to a long early-instrumental temperature record. A publication in Geophysical Research Letters is in press.

The mid-Holocene Optimum has been defined by the international Palaeo Modelling and Intercomparison Project (PMIP) as a key period for assessing the sensitivity of climate models to past changes in external forcing and boundary conditions. The climatic response as simulated by ECBILT1 for the mid-Holocene Optimum was found to be comparable to results of state-of-the-art GCM's. A transient simulation of 10,000 year for the Holocene was recently completed. A short paper on the impact of the imposed orbital forcing on the ultra-low frequency behaviour of ECBILT1 will appear in Global and Planetary Change. A more detailed analysis of the simulated climate change and climatic variability during the Holocene is in preparation. An off-line glacier model was used to estimate the Holocene evolution of a small number of maritime and continental glaciers. The glacier model generates synthetic glacier length records, which can be validated against known constraints for the Holocene epoch. A paper (co-author Prof. Hans Oerlemans, IMAU, University of Utrecht) is in preparation.

A PhD study on 'Modelling of astronomically forced variations in (circum)-Mediterranean climate' started at the end of 1999. This is a joint project with Dr. Frits Hilgen (Faculty of Earth Sciences, University of Utrecht). Mediterranean sedimentary records bear a clear signal of both the obliquity and precession cycle in the astronomical forcing, although the local forcing due to obliquity is very small compared to that due to precession. The aim of this study is to explain the 'observed' climatic response, which is found to be robust over the last 5 Million years. Results of time-slice experiments with ECBILT1 show both a precession and an obliquity signal in the African monsoon and in the winter precipitation in southern Europe. The large-scale dynamical model response will be analysed in more detail in 2001.

On geological timescales the Earth's climate may be stabilised by the close coupling between climate and the biota. This is demonstrated mathematically by the Daisyworld model of Watson and Lovelock (1983). It is a highly idealised zero-dimensional Earth System model, based on albedo regulation due to vegetation changes. The steady state solution exhibits homeostasis over a large range of solar luminosities. A detailed analysis of Daisyworld

was carried out in order to determine to which extent this model is relevant for the real Earth System. It was shown that the basic assumptions of the Daisymodel imply local temperatures, which are independent of incoming solar radiation. The property of fixed local temperatures and the associated heat transport mechanism do not seem to have parallels in the real climate. At the same time, this property is crucial for the homeostatic behaviour of Daisyworld. A paper will appear in Climatic Change. An invited lecture on this work was given at the second Chapman Conference on the Gaia hypothesis in Valencia, Spain, in June 2000.

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Weber, S.L. and H. von Storch, 1999. *Future Challenges: Simulating Climatic Millennial Timescales and Combining Palaeoclimatic Evidence and GCM-based Dynamical Knowledge (workshop report)*. EOS Transactions, **80**, 380.

2000 Capel, H.W. and R.A. Pasmanter, 2000. *Evolution of the vorticity-area density during the formation of coherent structures in two-dimensional flows*. Physics of Fluids, **12**, 2514-2521.

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1999 Hersbach, J.P.Th., R. Mureau, J.D. Opsteegh, 1999. *An EPS for the short and early medium range*. In: Proceedings of the Workshop on predictability, ECMWF, Reading, United Kingdom, October 1997, 349-363.

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Weber, S.L. and M.V. Shabalova, 2000. *Patterns of low-frequency climate variability: a model-palaeodata comparison*. NOP Report **410 200 056**.

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1999 Haarsma, R.J., F.M. Selten, J.D. Opsteegh, Q. Liu and A. Kattenberg, 1999. *North Atlantic decadal climate variability in a coupled atmosphere ocean sea-ice*

model of moderate complexity. In: Beyond El Nino: Decadal and interdecadal climate variability (A. Navarra, Ed.), Springer Verlag, 277-301.

2000 Haarsma, R.J., S.S. Drijfhout, J.D. Opsteegh and F.M. Selten, 2000. *The impact of solar forcing on the variability in a coupled model*. In: Solar variability and climate, (E. Friis-Christensen et al., Eds.) Space Science Series of ISSI, Kluwer Academic Publishers.

Schrier, G. van der, 2000. *Aspects of the Thermohaline Circulation in a simple model*. PhD-Thesis, University of Utrecht, The Netherlands.

Number of international presentations: 1999: 17, 2000: 35.

Externally funded projects: national 5, international 1.

Education, organisation of workshops:
Several lectures have been organised for the forecasters to inform them about probabilistic forecasting. A presentation on objective verification of ensemble forecasting systems was given at the ECMWF seminar in September 1999 (Opsteegh and Hersbach, 2000). Similar lectures were given in a workshop on predictability for weather forecasters, which was organised three times in 2000 at KNMI.

D. Crommelin and M. Schaeffer were lecturers at the Buys Ballot symposium at Rolduc Abbey, Kerkrade, October 2000.
R. Haarsma was lecturer at the Symposium Weather and Climate, Technical University of Twente, Enschede, April 1999.
J.P.Th. Hersbach was lecturer at ABACUS, Mathematical Symposium Mathematics and the future, Technical University of Twente, Enschede, May 1999.
J.P.Th. Hersbach was lecturer at the Netherlands Union for Business and Weather Expectations (NVBW), Utrecht, September 1999.
J.D. Opsteegh is part-time professor of Dynamical Meteorology at the University of Utrecht.
R.A. Pasmanter was lecturer at the Eindhoven Student Union, April 2000.
A. Timmermann organised a CKO (Netherlands Centre for Climate Research) meeting, KNMI, De Bilt, February 1999 and May 2000.
A. Timmermann organised an international workshop on Dynamical System Concepts in Climate Dynamics, KNMI, De Bilt, April 2000.
W.T.M. Verkleij was lecturer at the course Synoptic Meteorology at KNMI, De Bilt, June 2000.
S.L. Weber co-organised with Prof. H. von Storch, GKSS Research Centre, Geesthacht, Germany, an international workshop on Climate variability on multi-decadal to millenial timescales, March 1999, KNMI, De Bilt.
S.L. Weber co-organised with F. Jansen, NIOZ, Texel, a CKO (Netherlands Centre for Climate Research) meeting, KNMI, De Bilt, June 1999.
S.L. Weber organised a mini-symposium for the Dutch Society for Professional

Meteorologists (NVBM) on Polar areas and the history of climate, KNMI, De Bilt, November 2000.

Other activities:
J.D. Opsteegh, member of the Climate Committee, Royal Netherlands Academy of Arts and Sciences (KNAW).
J.D. Opsteegh, member of the Board for Earth and Climate, KNAW.
J.D. Opsteegh, member of the Policy Advisory Committee - Earth Sciences (BAC-A), Earth and Life Sciences (ALW).
J.D. Opsteegh, member of the programme committee of the Centre for Climate Change and the Biosphere (CCB) of the Agricultural University of Wageningen.
J.D. Opsteegh, member of the programme committee of the Netherlands Earth Scientific Congres V.
J.D. Opsteegh, member of the programme committee of the Climate Conference 2001, Netherlands Centre for Climate Research (CKO).
J.D. Opsteegh, member of the Scientific Advisory Committee, ECMWF.
A. Timmermann, contributing author to IPCC Third Assessment Report, chapter 7, Physical Climate Processes and Feedbacks, section 7.6.4: El Niño – Southern Oscillation, authors: K. Trenberth, T. Palmer, A. Timmermann, M. Cane, R. Mugara.
S.L. Weber, member of the review committee of ALW.

Oceanographic Research

General • The Oceanographic Research Division studies the role of the ocean and air-sea interaction in climate variability and climate change. The general objective is to contribute to the understanding of natural climate variability, the prediction of climate and the assessment of anthropogenic climate change. Efforts focus on understanding natural climate variability and its causes. Research in the division is structured in two themes: 'Air-sea interaction and climate' and 'Ocean modelling and climate'.

The division has continued experimental work at the Research Platform Meetpost Noordwijk (MPN). Results from previous campaigns were analysed, while preparations for new experiments were being made. The analysis concerned turbulent fluxes of momentum, latent and sensible heat as well as CO_2 fluxes. Among the preparations for new experiments the development of a wave following platform and its instrumentation played a central role.

An effort was made to link results of the experimental micro-meteorological work to larger-scale studies. This was done in collaboration with the European Centre for Medium-range Weather Forecasts (ECMWF) as part of its Re-analysis projects and in the framework of a National Research Programme on global air pollution and climate change (NOP) project. From our expertise we also contributed actively to the joint World Climate Research Programme/Scientific Committee on Oceanographic Research (WCRP/SCOR) Working Group on Air-Sea Fluxes. An important source of information about past global air-sea fluxes is the Comprehensive Ocean Atmosphere Data Set (COADS) database, which is partly based on observations of Dutch Voluntary Observing Ships. In the framework of the KNMI programme Historical Climate (HISKLIM) we made efforts to assess the quality of these data and to make them better available.

With support from the Netherlands Organisation for Scientific Research (NWO) in the framework of its Dutch contribution to the Climate Variability and Predictability Research (CLIVARNET) programme we collaborated with the Netherlands Institute for Sea Research (NIOZ), the Institute for Marine and Atmospheric Research Utrecht (IMAU) and the University of Capetown in the Mixing of Agulhas Rings Experiment (MARE), which can be seen as a direct contribution of the Netherlands to the international Climate Variability and Predictability Research (CLIVAR) programme. Another international project (jointly with the Southampton Oceanography Centre and others) studied particle trajectories in the thermohaline circulation in a high-resolution ocean model.

We continued the study of tropical ocean variability, in particular also the variability related to El Niño, in a two-prong approach aimed at better predictions and at better understanding of the underlying physics.

We continued our close collaboration with the National Institute of Public Health and the Environment (RIVM) and the University of Utrecht in the framework of the Netherlands Centre for Climate Research (CKO) and the Co-operation on Oceanic, Atmospheric and Climate Change studies (COACh). The Head of Division accepted a part-time professorship in Climate Dynamics at the Faculty of Physics and Astronomy of the University of Utrecht. Several PhDs were granted for research carried out under guidance of division staff members, and several new PhD projects were approved. Staff members lectured at national and international schools. Two staff members made extended research visits abroad (Scripps and Lamont Doherty.)

Research is the main activity of the division, but in addition a considerable amount of energy is put into informing policy makers and the general public about climate issues. The division played a major role in the writing of a Fact Sheet on climate and climate change, which was distributed widely in the Netherlands. Staff members also made contributions to the review of the Third Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) Working Group I.

We kept close contact with a number of international programmes such as CLIVAR, World Ocean Circulation Experiment (WOCE), Global Ocean Observing System (GOOS) and International Geosphere Biosphere Programme (IGBP). On a European level we contributed to the implementation of the EUROCLIVAR recommendations for Climate Variability and Predictability research in Europe. On a national level we represented CLIVAR in several committees (NWO, Royal Netherlands Academy of Arts and Sciences (KNAW)).

Mathematical physics

Van Duin

At the sea surface various waveforms may be observed. Among the periodic waves, the so-called Stokes wave proves to be unstable to perturbations with long wavelengths. Ultimately, this instability may lead to disintegration of the wave. Among the periodic waves, there also exists a class of weakly non-linear cnoidal waves. In the case of shallow water waves, these satisfy the Korteweg-de Vries equation and are known to be stable in general. However, when the water is deep with respect to the wavelength, the results are quite different. In contrast with the previous case, unstable wave perturbations then exist if certain conditions are satisfied. The properties of these waves have been studied. Earlier work on the effect of non-uniformity of modulated wave packets on the mechanism of Benjamin-Feir instability was published in the Journal of Fluid Mechanics.

The physics of air-sea exchange

Jacobs, Oost, Van Oort, Wallbrink, Worrell, Komen

The physical description of the microscale aspects of air-sea interaction remains the focus of our group. The research programme has an important experimental component in which we measure the exchange of momentum, heat, water vapour and CO_2 near the water surface, as well as the flux-related environmental parameters. The experimental work is performed at MPN, owned and operated by Rijkswaterstaat (Directorate-General of Public Works and Water Management). Experimental work at sea requires special strategies and instruments designed to withstand the exacting environment close to the water surface.

The Air-Sea GAs exchange / MAGE project (ASGAMAGE)

In the preceding period, the EU-supported project ASGAMAGE, for which KNMI was project co-ordinator, has been formally finished. However, analysis of the extensive data set from the ASGAMAGE field experiments is still continuing.

The main aim of the ASGAMAGE project, as far as the KNMI contribution was concerned, was the intercomparison of the values for the transport coefficient k_w for the exchange of CO_2 between the oceans and the atmosphere, found with various techniques. Until 1996, results from those techniques showed order-of-magnitude discrepancies. Improved confidence in k_w and insight in its measurement is important for our understanding of the global carbon budget.

The ASGAMAGE experiments bridged a significant part of the existing gap. The results from eddy correlation measurements, carried out by KNMI, and those from the differential tracer method, performed by colleagues from the Plymouth Marine Laboratory (PML) and the University of Newcastle upon Tyne (UNT), UK, the method that so far has yielded most values cited in the literature, are comparable to within a factor of 2-3 now. However, because the gap is still too large, the research into the remaining differences by means of data analysis and model studies has been continued, in co-operation with the Risø National Laboratory (Denmark), the PML (UK) and the UNT (UK). This study suggested that much of the remaining differences and the scatter in the eddy correlation data could be explained in terms of the assumptions made in the various measurement techniques and the degree to which these assumptions are fulfilled in practice. The earlier suggestion that near-surface vertical gradients may be an important error-source in the differential tracer method has been further explored. There are indications, especially from model studies, that this may indeed have been at least partly the cause of the discrepancies. Additional analyses showed that the eddy correlation method is more likely to be affected by instationarity and inhomogenity of the CO_2 concentration field in water and air, which may cause a lot of scatter in the data.

An analysis of the transport coefficients for heat and moisture, C_H and C_E, has been completed. C_H and C_E are both key variables in the coupling between atmosphere and sea. The analysis of the ASGAMAGE data uncovered a so far unknown dependence of these coefficients on wind speed and atmospheric stability. The results raise some doubt as to the validity of the almost universally applied Monin-Obukhov surface layer similarity theory over the sea.

The ASGAMAGE database also provided the opportunity to further analyse the transport of momentum as influenced by the wave field. An important result from Humidity Exchange over Sea (HEXOS), an earlier, well-known international experiment conducted at MPN, was confirmed. A pronounced correlation between inverse wave-age and the Charnock parameter could be established using the ASGAMAGE data. Once again, at a given wind speed the momentum fluxes were found to be much higher near MPN than over the open ocean, but it could be shown that the North Sea data are fully consistent with open ocean results by taking wave-age differences into account. The limited depth at MPN (18m) appeared to have no effect on the momentum flux data from ASGAMAGE, and must therefore be ruled out as a factor of importance to the air-sea momentum fluxes.

The wave follower

The construction of the wave-follower continued to be the main item for the technical activities within the group. The instrument has now successfully

been tested in the wave flume facility in De Voorst, owned by Delft Hydraulics, and in the North Sea, at MPN. The tests have confirmed the potential of the wave follower to enable micrometeorological observations within the wave boundary-layer. During the latest test, wind observations were made well within that layer, at about 50 and 150 cm above the sea surface, in the presence of waves with heights up to 2 m. Momentum flux measurements were made with miniature versions of the pressure anemometer during this test. These instruments were developed with the special purpose to mount them on the wave follower and to observe the wind field in the wave boundary-layer, i.e. at distances down to 20 cm above the water surface. The special mechanical provisions at MPN functioned very well, and the software programme that has been developed to control the wave follower operation was also applied with success. Special provisions that were introduced to safeguard the functional use of the instrument under adverse conditions performed well. See also the highlight in this report.

Global air-sea fluxes and ocean waves

Sterl, Bonekamp, Komen, Caires, Wallbrink

Work on global air-sea fluxes has been centred around ECMWF's Re-Analysis projects ERA15 and ERA40, and around the comparison of different flux products.

A NOP supported project aiming at the validation of the ERA15 air-sea fluxes has been finished. Two major results from this project obtained during the reporting period concern the development of an adjoint ocean model and an assessment of surface drag parameterisations. The adjoint model is used to assimilate hydrographic observations into the ocean model and from that to adjust the surface forcing of the ocean. The work on drag para-meterisations also contributed to the preparation of ERA40, which started production in July 2000. KNMI is involved in this new re-analysis and will assess its ocean wave results.

Assimilation of ocean observations

A 4DVAR data assimilation scheme developed as part of the El Niño research (see below) was used to study the possible adjustment of air-sea fluxes with the help of upper ocean observations. Identical-twin experiments and an experiment with real observation show that adjusting wind stress with the 4DVAR scheme is an effective way to correct errors in the upper ocean analysis and in the wind stress over the tropical ocean.

In the equatorial Pacific, a large reduction in wind stress and upper ocean temperature misfits can be achieved by assimilating hydrographic data. The main reason is that the equatorial region combines a high ocean model sensitivity to short term disturbances with a high number of observations, which are uniformly distributed. Off-equatorial regions of the Pacific lack this combination and the performance of the 4DVAR method is not that well there.

An intercomparison of wind stresses as obtained from ERA15 and from the Research Vessel Moana Wave during the Tropical Ocean Global Atmosphere - Coupled Ocean Atmosphere Response Experiment (TOGA-COARE) identified discrepancies between the two. On average, the ERA15 zonal wind stress is too weak for the first leg of the RV Moana Wave (November 11, 1992 to December 3, 1992) and too strong for the second leg (December 17, 1992 to January 11, 1993). Assimilating the upper ocean observations reduces the discrepancy between ERA15 and observed wind stress. Therefore, the wind stress estimate adjusted by the 4DVAR scheme seems to be more realistic than the original ERA15 wind stress for the considered region and period.

Drag coefficients

In preparation of ERA40 different wind stress parameterisations have been compared with wind stress measurements over the open ocean. The comparison reveals some clear differences in the mean drag coefficient or, equivalently, the mean dimensionless aerodynamical surface roughness (or Charnock parameter) for all wind speed ranges greater than 6 m/s (Figure 1). These differences are significant and need to be resolved.

In addition, three alternative wind stress para-meterisations have been compared by statistical means using the Royal Research Ship (RRS)

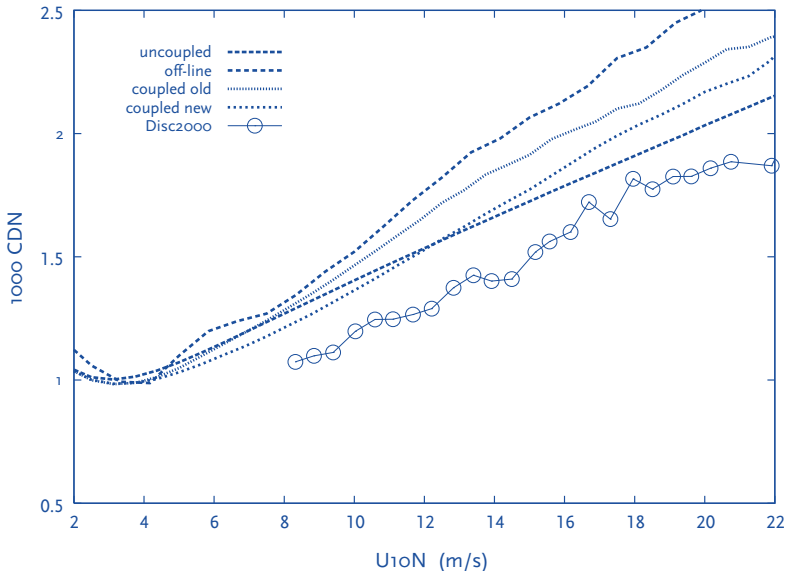

Figure 1. The mean drag coefficient CDN as a function of wind speed at 10 m. From the five curves shown, four are from different model versions and one from observations. The dashed, dashed-dotted, dotted and solid line are from ERA15 (constant Charnock parameter), an uncoupled wave model run, and two versions of a coupled atmosphere-wave model, respectively. The line with open circles is for the Discovery data as described by Taylor and Yelland.

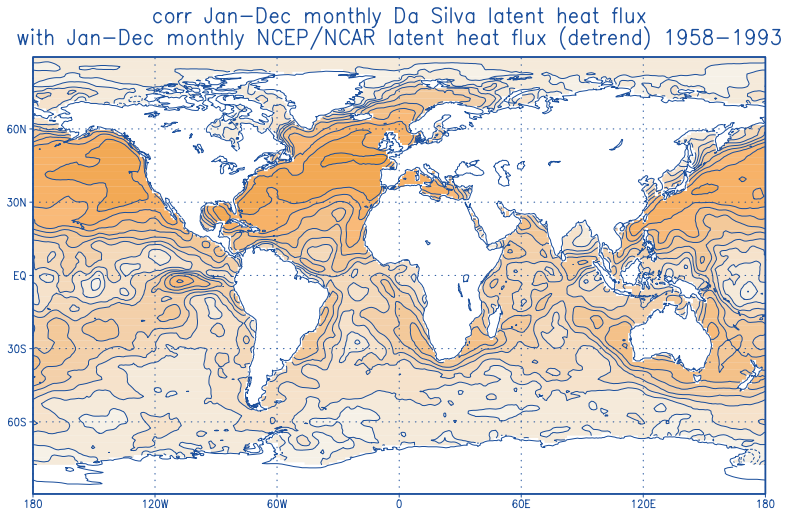

Figure 2. Correlation's between the latent heat fluxes from the NCEP re-analysis and the reconstruction of DaSilva.

Discovery wind and wind stress measurements. The parameterisations are characterised by a constant Charnock parameter, a linear dependence of the drag coefficient on the near-surface wind ($CD_{10} = a + b \bullet U_{10}$) and a wave-age dependent Charnock parameter. On the basis of the statistical tests and published estimates of the random errors an order of preference could be given. The wave age dependent parameterisation provides the best description of the observed wind stresses. A very good second is the above linear relationship. For wind speed bin averaged neutral drag coefficients this parameterisation gives at least a description as good as the wave-age dependent one, but the description of the wind stress variability is slightly poorer. By far the poorest representation of the surface drag is provided by the constant Charnock parameter case.

These results have helped in establishing details of the drag parameterisation to be used in ERA40, in which the constant drag coefficient as used in ERA15 is replaced by a sea-state dependent one.

Intercomparison of fluxes

Global fields of historical surface fluxes can be obtained by three methods, re-analysis, reconstruction, and satellite observations. In a re-analysis an atmospheric model is run and constrained by atmospheric observations. The result is a time history of the state of the atmosphere from which the surface fluxes can be deduced. In a reconstruction fluxes are calculated from in-situ measurements made from buoys and ships. These observations are subsequently inter- and extrapolated to obtain global coverage. Satellites measure some surface variables from which fluxes can be calculated with near-global coverage.

As it turns out, fluxes obtained form these three methods differ widely, not only between methods (re-analysis vs. reconstruction, say), but also within one method (e.g., reconstruction's made by different scientists). Intercomparing different flux products can teach us something about the errors inherent in each of the products as well as in the method used.

For the reconstruction's the biggest problem is the inhomogeneous coverage of observations. Especially in the Southern Hemisphere large areas are essentially data-void, making extensive extrapolation necessary to obtain global coverage. Figure 2 shows a map of the pointwise correlation of latent heat flux as obtained from the National Centers for Environmental Prediction (NCEP) Re-Analysis and the reconstruction of DaSilva. While the correlations are very high in the data-rich Northern Hemisphere, they are poor in the Southern Hemisphere. A similar comparison between the NCEP and the ERA15 reanalyses shows very high correlation's in the extratropical regions of

both hemispheres, but poor correlation's in the Tropics, indicating problems in at least one of the reanalyses in these regions.

Recovery of historic marine observations
An important source of information about past global air-sea fluxes is the COADS database, which is partly based on observations of Dutch Voluntary Observing Ships. In the framework of the KNMI HISKLIM project we made efforts to assess the quality of these data and to improve their availability. This involved recovery of lost metadata and the reconstruction of the fate of 20 000 meteorological ships journals that had disappeared in the Second World War. See also chapter Climate Analysis and Scenarios.

El Niño Southern Oscillation (ENSO) and data assimilation in ocean models

Burgers, Van Oldenborgh, Bonekamp, Vossepoel, Appeldoorn, Zelle

El Niño Southern Oscillation (ENSO) research at KNMI aims both at gaining a better understanding of the causes and effects of the phenomenon and at contributing to the improvement of seasonal forecasting systems. Software for the systematic investigation of teleconnections has been developed and a strong teleconnection between El Niño winters and spring precipitation in Europe was found and documented. An important activity is data assimilation for improving the initialisation of forecast models. A technique for combining satellite altimeter measurements with in-situ sub-surface buoy measurements has made possible improved estimates of salinity in the Equatorial Pacific. A 4D-VAR assimilation scheme has been developed for making better use of sub-surface data.

Whenever there is a big weather event, questions reach KNMI about how unusual this is and whether it is connected to El Niño and/or greenhouse warming. Because answering these questions took more and more time, a system has been developed for investigating teleconnections in a systematic way. This web-based 'climate explorer' allows one to make plots of correlation's between a large number of fields and time series from a large database. Because researchers outside KNMI showed considerable interest, it has been put on the public KNMI web: http://www.knmi.nl/onderzk/oceano/special/nino/nino.html. Now climate researchers are using it all over the world.

The climate explorer was used in establishing the El Niño teleconnection between winter El Niño events and high precipitation in Europe in a band from southern England eastward to the Ukraine. Lagged correlations suggest that south-east Asian surface temperature anomalies may act as intermediate variables. In a joint project with the Meteorological Service of the Netherlands Antilles, the seasonal predictability of the Dutch Caribbean is being documented, again using the climate explorer.

Predictability was studied in the context of the simple stochastic oscillator system. It was shown that if 'ocean data' are assimilated the gain in predictability of this system depends on details of the noise that drives the system, illustrating the need for a proper representation of small-scale processes if one wishes to assess the predictability of the ENSO system.

A method for estimating salinity in the equatorial Pacific from comparisons of satellite altimetry sea-level observations with sub-surface buoy temperature observations had been developed before. Now this method has been incorporated in a version of the NCEP model. It is a three-dimensional variational method that uses sea-level observations and sub-surface temperature observations for obtaining both temperature and salinity corrections to the model state at a given time, in contrast to the operational NCEP scheme which only corrects temperature. The scheme has been tested on real data in a four-year model run. The new scheme clearly improves the simulation of salinity variability and of displacements of the Western Pacific fresh pool. In addition, it improves the simulation of sea-level variability without degrading the temperature field.

A four-dimensional variational scheme (4D-VAR) has been developed for the Hamburg Ocean Primitive Equation (HOPE) model that is used by the seasonal forecasting group at ECMWF. The driving wind stress field has been used as a control field, guaranteeing dynamical consistency of the ocean fields. The adjoint of the HOPE model, which is necessary for the 4D-VAR method, had been developed and tested at KNMI before. In the runs made so far, sub-surface data have been assimilated. Both synthetic experiments and a run with real observations over 14 weeks have been done. The scheme is able to reduce errors in the ocean analysis which originate either from the wind-stress forcing or the initial state. First results indicate a better reconstruction of equatorial zonal currents than a standard Optimal Interpolation (OI) scheme.

Variability of the wind driven and thermohaline circulation

Donners, Drijfhout, Hazeleger, Katsman, Sterl, De Vries

Limited knowledge of the ocean and limited ability to model ocean processes still form critical issues in climate modelling. Therefore, we have carried out process studies as well as large scale modelling studies.

An isopycnic model of an idealised North Atlantic subtropical gyre, coupled to a mixed layer model and an atmospheric anomaly model, was used to study variability in Subtropical Mode Water formation. The response to deterministic (North Atlantic Oscillation (NAO)) and stochastic forcing has been investigated, as well as internally generated variability. Finally, subduction processes and the role of eddies have been studied. We have studied mechanisms for decadal variability in watermass formation and its impact on the North Atlantic subtropical gyre. Another series of process studies focuses on eddy parameterisations. The effect of eddies is to mix properties along surfaces of constant density. In coarse resolution models used in climate studies these processes are parameterised. We study mixing of thickness and potential vorticity in the same idealised isopycnic model, but now within a configuration that comprises both a subtropical and subpolar gyre and in which diabatic processes have been neglected. Although potential vorticity is a conserved quantity, while thickness is not, it appears that the mixing by eddies of thickness is better captured by a down-gradient diffusion scheme than the mixing of potential vorticity, especially when the flow becomes strong and unstable. At present, we evaluate the skill of various parameterisation schemes in a coarse resolution model with a similar configuration as the high-resolution model.

With an idealised quasi-geostrophic model mechanisms for interannual to decadal variability of the wind driven circulation have been studied. In particular we focus on the role of deep western boundary currents in selecting or enhancing decadal timescales in the wind driven gyres. To this end a continuation method is used that calculates stationary solutions as a function of a critical parameter, that is, the strength of the forcing or dissipation. Also the stability characteristics of the stationary solutions are determined in order to describe the transition to time dependence and the associated unstable oscillatory modes. In the purely wind driven configuration the flow becomes unstable to oscillatory instabilities with timescales in the order of months. Low-frequency variability occurs naturally when a deep western boundary current is present. The perturbations with intermonthly timescales stabilise when a deep western boundary current is added, and different perturbations with near-annual to decadal timescales become important. This research is performed in co-operation with IMAU.

Despite progress made in the World Ocean Circulation Experiment, there is still an enormous lack of ocean observations. Therefore, the analysis of numerical simulations is a useful approach to a better understanding of ocean circulation. This work is done with global ocean models developed elsewhere. The response of the Atlantic overturning circulation to South Atlantic sources of buoyancy, characteristic for the impact of Agulhas Rings in the South Atlantic, has been investigated within the Large Scale Geostrophic model. This work is part of a PhD-study carried out at IMAU. It appears that the Atlantic overturning circulation is sensitive to the parameterised inflow of Agulhas eddies. In co-operation with the Lamont Doherty Earth Observatory simulations with a basin-scale model of the Pacific have been analysed. The interaction

between the subtropical and tropical Pacific ocean was investigated as a possible mechanism for decadal variability in ENSO. Also, a para-meterisation of the impact of atmospheric transient eddies (the storm track) was applied to a coupled atmospheric mixed-layer Ocean Model to study the effect on sea surface temperature, heat fluxes and the thermocline in the Pacific. A further study addressed the role of the ocean in tropical Atlantic decadal variability. This work was carried out at Lamont. With the global high-resolution ocean general circulation model OCCAM (developed at the Southampton Oceanographic Centre) the meridional overturning cells in the tropics have been evaluated. In particular, the role of the eddy mass transport in the overturning circulation was studied. It appears that the eddies compensate the mean flow in the meridional plane.

The route of the North Atlantic Deep Water (NADW) and its return flow has been investigated by following Lagrangian trajectories simulated by a high resolution ocean general circulation model (OCCAM). This work is carried out in a co-operation with the Southampton Oceanography Centre, Southampton (UK), Meteorologiska Institutionen Stockholms Universitet, Stockholm (Sweden) and Laboratoire de Physique des Océans, Brest (France) in the EU-funded project 'Tracing the Water Masses of the North Atlantic and the Mediterranean (TRACMASS)'. The upwelling zones of NADW have been traced by forward integrating trajectories released in the equatorial Atlantic until NADW upwells. The same method has been applied to the NADW-return flow, now by backward integrating trajectories. Most trajectories upwell in the Southern Ocean, which implies that wind driven upwelling is more important in connecting the upper and lower branch of the conveyor belt than was previously thought. Much work has been carried out on more fundamental and methodological aspects of the trajectory method in a drifting, high-resolution z-co-ordinate global ocean model. In particular the time averaged eddy-induced transport velocity was estimated, a separate assessment was made of the impact of the seasonal cycle and of the higher frequencies, a method was developed to correct the divergent part of the velocity field for drift and spurious diapycnal mixing while securing mass conservation and finally an evaluation was carried out of the mass budget on density surfaces by transforming all diabatic processes into separate diapycnal velocities. As the net diapycnal velocity forces the overturning or thermohaline circulation correct assessment of this velocity is of highest importance. Also, we used the trajectory method to depict the pathway of the various water masses that constitute the NADW outflow and return flow on the World Ocean by calculating the horizontal streamfunction for each separate watermass.

Large climate models are very time consuming to run, and therefore less suitable to study inter-decadal variability. Therefore, KNMI has chosen to develop a fast-coupled model of intermediate complexity: ECBILT. See also chapter Predictability Research. A study has been performed to isolate the role of the ocean in inducing atmospheric variability. On interannual timescales the oceans do not affect the patterns of atmospheric variability, nor their explained variance. But the spectra change. The oceans act to redden the spectra, especially the atmospheric temperature spectra. When the atmosphere is coupled to a slab mixed layer this reddening is strongly overestimated. Ocean dynamics make the temperature spectra above sea to deviate from that of a first-order auto regressive process. No preferred timescales arise for the dominant patterns of atmospheric variability. The dominant patterns of ocean/atmosphere covariability, however, do show the existence of preferred timescales. The latter only occur when the atmosphere is coupled to a dynamically active ocean. Also, a simple isopycnic model of an idealised Atlantic together with a similar configured z-co-ordinate model (GFDL) has been used to study the role of wind driven upwelling in the Southern Ocean versus interior diapycnal mixing in connecting the upper and lower branch of the thermohaline circulation. This is a co-operation with institutes from the US and the UK. The role of wind driven upwelling can be significant, but depends on the strength of the interior mixing and the eddy return flow in the Southern Ocean. Both processes are parameterised in climate models and still largely unknown. This result strongly suggests an increased effort to better determine and parameterise eddy transports and the interior diapycnal mixing in the ocean.

In co-operation with IMAU and NIOZ and the university of Cape Town the consorted observational and modelling experiment 'Mixing of Agulhas Rings Experiment (MARE)' has been formulated. It is financed by the Netherlands' CLIVAR programme. Its main goals are to estimate the proportion of Agulhas Ring leakage that contributes to the upper branch of the Conveyor Belt and to identify the dominant mixing processes that determine that proportion. Also, we assess the impact of varying

Indian-Atlantic interocean exchanges on variability on regional scales as well as on the strength of the Atlantic overturning circulation and associated climate fluctuations over the North Atlantic sector. Two cruises have been carried out with active participation of KNMI scientists. The KNMI contribution to MARE consists of a series of modelling and observational studies. At present we have started an analysis of coupled and oceanic South Atlantic variability from both re-analysis data sets (NCEP/ECMWF) and hydrographic data (NODC). A hindcast of this variability using a South Atlantic isopycnic model (Miami isopycnic co-ordinate ocean model (MICOM)) coupled to an atmospheric anomaly model has been made. An analysis of the spreading of Indian Ocean Water in the South Atlantic model using particle-tracking techniques is done. Finally we analyse secondary circulations and watermass exchange in a model of the observed Agulhas Ring. We also contribute to the cruise-data analysis carried out at NIOZ.

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Oost, W.A., 1999. *Flux measurements at the Noordwijk platform*. In: Air-Sea Exchange: Physics, Chemistry and Dynamics, (G.L. Geernaert, Ed.), Kluwer, 197-230.

Swail, V., V. Ryabinin, G.J. Komen, M. Holt, P.K. Taylor and J. Bidlot, 1999. *Wind waves in the Global Ocean Observing System*. Proceedings Conference on OCEANOBS99, St. Raphael, France, 18-22 October 1999.

Vossepoel, F.C., 1999. *Sea-level data assimilation for estimating salinity variability in the tropical Pacific*. PhD-Thesis, Technical University of Delft.

2000 Reynolds, R.W., Richard W., D. Behringer, Ming Ji, A. Leetmaa, C. Maes, F.C. Vossepoel, Yan Xue, 2000. *Analyzing the 1993-1998 interannual variability of NCEP model stimulations: the contribution of TOPEX/Poseidon observations*. In: Satellites, Oceanography and Society, (David Halpern, Ed.), Elsevier, 299-308.

Number of international presentations: 1999: 35, 2000: 18.

Externally funded projects: national 5, international 5.

Educational, organisation of workshops:
G. Burgers was lecturer at the Vening Meinesz Research School of Geodynamics at the Technical University of Delft, 13 January 1999. Modelling the dynamics of El Niño.
S.S. Drijfhout organised a TRACMASS meeting at NIOZ, Texel, 17 - 20 May 2000.
S.S. Drijfhout guided a student from France. Report: The Conveyor Belt the OCCAM model; tracing watermasses by a Lagrangian methodology, 15 June - 15 September 2000.
W. Hazeleger organised a CKO (Netherlands Centre for Climate Research) meeting on Subtropics - Tropical interaction in the Pacific at KNMI, 11 January 2000.
W. Hazeleger, G.J. Komen, C. Severijns and P. de Vries participated in the Buys Ballot Symposium , Rolduc Abbey, Kerkrade, 27 October 2000.
G.J. Komen was lecturer at the Vening Meinesz Research School of Geodynamics at the Technical University of Delft, 13 January 1999. Climate variability and climate changes.
G.J. Komen was lecturer at the Centro de Investigación Científica y

Educación Superior de Ensenada (CICESE), Ensenade, Mexico, 22-28 August 2000.
G.J. Komen organised a Clivar meeting at KNAW, Amsterdam, 16 March 2000.
G.J. Komen is professor at the University of Utrecht, Faculty of Physics and Astronomy.

Other activities:
J. Donners and S.S. Drijfhout went on the Mare-II cruise, 18 July - 9 August 2000.
S.S. Drijfhout prepared and supervised the Mare-I cruise, 21 February - 18 March 2000.
G.J. Komen, G. Burgers and G.J. van Oldenborgh, 1999, contributed to the preparation of a KNMI/NOP Fact sheet on Climate and Climate Change.
G.J. Komen, member of the Netherlands IGBP/WCRP Committee, Royal Netherlands Academy of Arts and Sciences.
G.J. Komen, member of the Netherlands SCOR Committee, Royal Netherlands Academy of Arts and Sciences.
G.J. Komen, chairman of the Program Board CKO.
G.J. Komen, member of the Scientific Board of SRON.
G.J. Komen, chairman of the Clivarnet.
G.J. Komen, associate editor, Journal of Physical Oceanography.
G.J. Komen, member of the Advisory Board of the National Geographic Magazine for the Netherlands and Belgium.
G.J. Komen, member of the Advisory Committee Marine Facilities, NWO.
A. Sterl, member of the JSC/SCOR Working group Air-Sea Fluxes.

Atmospheric Composition Research

Introduction • The division investigates the atmospheric composition and the coupling between changes in atmospheric composition and the climate system. The objective of this research is to contribute to the understanding of the natural variability in the atmospheric composition and the anthropogenically induced changes.
The research strategy is to study the atmospheric composition along three lines:
- Observations
- Global three-dimensional modelling
- Process studies

The different research activities are described in more detail below. The main activities of the division are focussed on research. However, considerable effort is put in advising and informing governmental services and the general public on results of our research, e.g. concerning effects of aircraft emissions. Contributions to the Intergovernmental Panel for Climate Change (IPCC) Special Report on ' Aviation and the global atmosphere' and the participation in the chemical model intercomparisons of IPCC 2001 should also be mentioned.

One of the large programmes of the division is the scientific lead of the Dutch-Finnish Ozone Monitoring Instrument OMI that will fly on the NASA EOS AURA Mission. The Principal Investigator and the Dutch part of the science team has been staffed and embedded in the division.

An important development on observation side was the installation of an ozone observation station in Surinam in close co-operation with the Surinam Meteorological Service. Processes in the tropical regions are important for the global climate and the global atmospheric composition. The participation in Indoex (Indian Ocean Experiment) and this Surinam station emphasize our involvement in this promising field. An overview of the Surinam station is given in the section Recent Highlights.

The preparation of the validation of SCIAMACHY observations (the Scanning and Imaging Absorption Spectrometer for Atmospheric Cartography on board of the European Space Agency Envisat Satellite) under KNMI responsibility is a huge challenge. The funding, infrastructure and formation of teams in the different participating countries is now well organised.

Near real time availability of ozone data from the Global Ozone Monitoring Experiment (GOME) instrument on board of the European Space

Agency's (ESA) European Remote Sensing Satellite-2 (ERS-2) has been set up for the scientific community and broad public. Due to the near real time access KNMI was one of the first to detect the mini-ozone hole above Europe end of November 1999.

The work in the division is structured in three working groups:
- modelling of the atmospheric composition
- observations of the atmospheric composition
- the OMI programme

Co-operation between the three working groups is significant in the domains of chemical data assimilation, development and validation of retrieval algorithms and validation of models and reflects the synergy between the work programmes of the groups.

Modelling the atmospheric composition

Introduction

The objective of this working group is to study natural and anthropogenic changes in the atmospheric composition and their influence on climate. To simulate atmospheric chemistry and transport the group uses the Chemistry-Transport Model Version 3, TM3, and the Chemistry Climate Model of the Max Planck Institute, ECHAM. TM3 is mainly used for long-term simulations, whereas ECHAM is used for process and case studies, as it is computationally more expensive. Both models are developed further in co-operation with IMAU (Institute for Marine and Atmospheric Research Utrecht) and the German Max Planck Institutes for Chemistry and Meteorology in the framework of the Netherlands Centre for Climate Research (CKO) and the international research school COACh.

Meteorological (re-)analyses made with the weather forecast model of the European Centre for Medium Range Weather Forecast (ECMWF) are used to drive TM3 and to study trends in atmospheric transport. For process studies and model evaluation extensive use is made of instrumented aircraft measurements and satellite measurements. A promising technique to combine observations and models is chemical data assimilation, which is being developed in co-operation with the Observations working group. The TM3 model is also used for simulations for climate (e.g. IPCC) and ozone assessments (WMO and United Nations Environmental Programme, UNEP).

Understanding the tropospheric cycles of greenhouse gases and their pre-cursors

Brunner, Meijer, Olivié, Van Velthoven, Verver, Van Weele

Nitrogen oxides in the troposphere act as a catalyst that promotes the formation of ozone. The concentration of nitrogen oxides has strongly increased in recent decades due to increased fossil fuel burning by traffic and industry at the surface and by aircraft emissions in the free troposphere. Nitrogen oxides are also produced during lightning discharges. Both aircraft emissions and production

by lightning occur in the upper troposphere where the produced ozone is especially effective as a greenhouse gas. Since global air traffic grows with a rate of 5-6 % per year the possible effect of aviation on climate has been the topic of many recent studies and a special IPCC report 'Aviation and the Global Atmosphere' (1999), to which we have contributed. While the magnitude of air traffic and surface emissions is rather well known, the production by lightning is only known to within an order of magnitude and its geographical distribution is also very uncertain. The bulk of the production by lightning is generally assumed to take place in the tropics. This means that nitrogen oxides emitted by aircraft are found mostly in northern mid-latitudes and nitrogen oxides produced by lightning mostly remain in other regions of the troposphere. If the production of nitrogen oxides by lightning at mid-latitudes is significant, a reconsideration of the estimated impact of aircraft emissions on ozone may be necessary. Using observations made during the European Lightning Nitrogen Oxides Experiment (EULINOX) the TM3 model simulations of nitrogen oxides have been evaluated and improved. The simulated distribution of lightning strikes has been compared to both ground-based and satellite lightning observations. It was found that the amount of lightning at mid-latitudes was underestimated, and the model description has been updated according to these findings. It has hitherto not been possible to calibrate the total global production by lightning with observations. With regard to aircraft emissions an important remaining question is how large the induced changes are in cloud cover and what their impact is on climate.

The surface and boundary-layer are important for the composition of the troposphere as a whole since they include the primary sources and sinks of many trace gases. It has been shown previously that for specific, simple cases the conventional approach to estimate turbulent transport and chemical transformations in terms of only mean concentrations can be significantly wrong due to the interaction of turbulent mixing and chemistry. These interactions were now studied for a comprehensive state-of-the-art chemistry scheme as used in current global and regional chemistry/transport models. In the more realistic cases considered, we found no significant effect on the mean concentrations of stable species. However, it was demonstrated that the turbulent flux itself as well as the concentrations of fast reacting radical species may be significantly wrong in the traditional approach.

The effect of stratospheric ozone depletion on the net ozone production in the troposphere was studied with a one-dimensional model. It was found that the tropospheric response is different in different chemical regimes, but that the global effect would be a decrease of tropospheric ozone production.

Finally, it should be mentioned that in preparation for IPCC 2001 we participated in an atmospheric transport and chemistry model intercomparison (OxComp). With the TM3 model simulations were performed for 2000 and 2001 based upon the IPCC emission scenarios. The results are documented in chapter 4 and 5 of the Third Assessment Report.

Aerosols: the Indian Ocean Experiment

Scheele, Siegmund, Verver, Zachariasse, Van Velthoven

The effect of atmospheric aerosols on climate is large but its exact magnitude is still highly uncertain. Therefore in recent years a number of experiments has been organised focussing on the climate forcing of aerosols (e.g. the second Aerosol Characterisation Experiment, ACE-2). One of the most extensive measurement campaigns, the Indian Ocean Experiment (INDOEX), took place in February and March 1999. It was a joint project organised by Indian, American, and several European research institutes. The primary goal of the experiment was to study the effect on climate of natural and anthropogenic aerosols over the Indian Ocean. The area and season of the experiment were chosen because emissions from India are large and steadily growing and because during to the north-east winter monsoon there is persistent outflow of pollutants from India over the Indian Ocean. Polluted Northern and clean Southern hemispheric air converge near the equator causing sharp gradients in aerosol concentrations and aerosol radiative forcing, making this an excellent environment for a measurement campaign.

The contribution of KNMI focussed on transport processes. Apart from meteorological support during the experiment, we performed post-campaign meteorological analyses in order to interpret the observations. Secondly, studies were made of the vertical distribution of ozone as observed by ozone soundings. The general picture that emerges from these studies is that the mid-latitude stratosphere feeds ozone into the tropical middle and upper troposphere from both the Northern and Southern Hemispheric sides. This process affects the ozone distribution in almost the entire north-south cross section of the Indian Ocean sampled during the 1999 measurements. Another finding was that upper-tropospheric interhemispheric transport occurs in certain preferred channels. Pollution from the Indian continent that has been transported in such a channel was sampled by the Netherlands research aircraft during INDOEX. The chemical consequences of these interhemispheric transport channels need to be further investigated.

Atmospheric tracer transport and dynamics

Cuijpers, Ollers, Meloen, Scheele, Siegmund, Sigmond, Van Velthoven, Zachariasse

The distribution of greenhouse gases in the atmosphere is to a large extent determined by transport by the general circulation. For instance, the seasonal variation of ozone in the troposphere is strongly affected by transport of ozone from the stratosphere to the troposphere. Due to the large internal variability of the atmosphere it is difficult to detect atmospheric circulation changes that may be due to enhanced concentrations of greenhouse gases. Therefore it is important to have consistent long-term (re-)analyses of the meteorological state of the atmosphere, like the 15-year re-analysis performed recently by ECMWF. A diagnostic study found no statistically significant trend in the strength of the stratospheric circulation during this 15-year period (1979-1993). Since 15 years is still a short time scale from the point of view of climate change analysis, we will perform a similar study using the forthcoming 40-year re-analysis by ECMWF. The 15-year re-analysis has further been used to study the relation between vertical wind and temperature variations in the tropical lower stratosphere.

The tropopause and the polar vortex edge with their strong gradients in potential vorticity are barriers for the transport of atmospheric constituents from one atmospheric compartment to another. This is the reason that the ozone hole is so well-isolated. New tools for the evaluation of transport across such atmospheric transport barriers were developed. A new Lagrangian technique to calculate the air mass flux across the dynamical tropopause was developed. It is applied in a case study of tropopause folding along the Southern Hemisphere subtropical jet. This folding was observed during the EU TRACAS experiment (TRAnsport of Chemical species Across the Subtropical tropopause). A trajectory model inter-comparison gave further confidence in the algorithm applied in this KNMI trajectory model. Three independently developed trajectory codes showed relative differences of only about 3-5 % for 2-day forward calculations. A study was performed to the use ECMWF ensemble forecasts to estimate the uncertainty in predicted trajectories due to errors in the meteorological input data.

A study using water vapour observations made in the lower stratosphere has shown that the transport of tropospheric air into the mid-latitude lowermost stratosphere is important up to about 5 km above the tropopause. This has implications for the assessment of the effects of human-made pollutants.

Observations of the atmospheric composition

Introduction

The task of the working group observations is to make, validate, improve, and interpret observations of the atmospheric composition using remote sensing techniques from satellites in combination with surface-based measurements. The present and future satellite instruments involved are GOME (launched in 1995), Sciamachy (to be launched in 2001), OMI (to be launched in 2003) and GOME-2 and successors (GOME-2 to be launched in 2005). In order to fulfil this task the activities can be grouped as follows:

- development of satellite retrieval algorithms,
- validation of satellite data,
- assimilation of satellite data,
- interpretation of ground-based and satellite observations,
- preparation of atmospheric chemistry missions, and
- monitoring of the atmospheric composition.

A special project is the OMI mission, of which KNMI has the scientific lead. A separate OMI working group was formed in the last two years. Therefore, the OMI project is described in a separate section.

Development of satellite retrieval algorithms

Van der A, Van Geffen, Van Gent, Van Oss, Piters, Valks

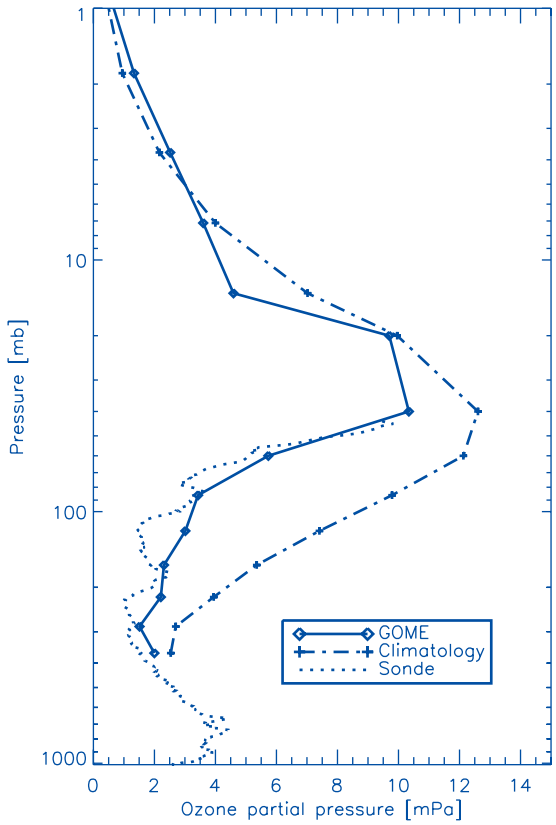
The main difference between satellite remote sensing observations of atmospheric composition and in-situ measurements is the additional need for complex, but accurate and validated retrieval algorithms that convert the radiation measurements of the satellite instrument into atmospheric and geophysical parameters. The development and validation of such algorithms is a non-trivial task and requires extensive scientific study.

Within the GOFAP project (GOME Fast delivery and value-Added Products) an operational system has been developed and put into use for near-real time (NRT) delivery (i.e. within 3 hours after observation) of GOME total ozone columns and stratospheric ozone profiles (http://www.knmi.nl/gome_fd/). The NRT ozone columns and profiles are distributed via the Netherlands Sciamachy Data Centre (Neonet, http://www.neonet.knmi.nl). The products have been validated through an extended pole-to-pole comparison with ground-based ozone data from NDSC stations. In order to deliver high-quality products several corrections of the reflectivity data have been implemented. Among these are an improved wavelength calibration algorithm based on a high-resolution solar spectrum, an instrument polarisation correction algorithm, and a correction for interference signals of the Peltier cooler.

Furthermore, improved correction algorithms have been developed for the radiometric calibration mismatch and for the degradation of the measured reflectivity's of GOME.

Even better profiles can be expected from a newly developed algorithm (within the BCRS project DORAS (Development of an Ozone profile Retrieval Algorithm for ozone profiles from atmospheric Spectra)) to obtain height-resolved ozone distributions from GOME UV-VIS spectra. A tailor-made radiation transport model has been especially developed for the algorithm. It uses a fast 'four-stream' analytic method that includes the simultaneous calculation of the Jacobian derivatives needed for the retrieval.

In preparation for the Sciamachy mission, the project Sciamachy Radiative Transfer model development for Limb viewing (SCIARALI) aims at the development of an accurate radiative transfer model for limb observations that is fast enough to perform on an operational basis. During the first few months of the SCIARALI project, promising existing radiative transfer schemes have been selected that could be adopted in the development of a fast and accurate radiative transfer model for limb view.



Ozone profiles from GOME overpasses have been validated with observations at De Bilt (Netherlands) and Paramaribo (Surinam), representative for urban-mid-latitude and rural-tropical situations. Validation is performed by comparison with ozone sonde measurements (figure 1) and collocated satellite measurements from the Halogen Occultation Experiment (HALOE).

Figure 1. Ozone profiles above De Bilt on December 1, 1999. The solid line/diamonds: profile retrieved from GOME data. Dotted line: ozone sonde at De Bilt. Dashed line/plusses: climatology of Fortuin and Kelder (1998).

Validation of satellite data

Eskes, Kelder, Meijer, Piters, Timmermans, Valks

KNMI chairs the international validation of the German/Dutch/Belgium Sciamachy instrument on board of Envisat. The Sciamachy validation group (SCIAVALIG) is a sub-group of the Sciamachy Science Advisory Group (SSAG). The main objective of Sciamachy is to measure profiles and vertical columns of atmospheric trace gases. Envisat will be launched in summer 2001.

The validation group has issued two documents that describe the validation activities: The Sciamachy Validation Requirements Document and the Validation Handbook. A living validation website (http://www.knmi.nl/sciamachy-validation) was set-up where up to date information can be exchanged and discussed, and which will play a central role in the validation. Apart from co-ordination, Sciamachy validation activities at KNMI include (participation in) the validation of the following Sciamachy products: ozone columns and profiles, surface UV radiation, H_2O, temperature and pressure.

The ozone validation efforts within SCIAVALIG will be supported by data assimilation. The preparations in 1999 and 2000 consisted of the development of operational assimilation software and a friendly internet interface to the data produced, to be used by the validation teams.

Assimilation of satellite data

Eskes, ElSerafy, Kelder, Van Velthoven

In chemical data assimilation, observations of the atmospheric gases made by satellite instruments are combined with chemistry-transport models. Data assimilation is used to generate synoptic maps from the incomplete sequential data sets provided by the satellites. It provides information on the quality of the data and the performance of the model.

The EU project Studies of Ozone Distributions based on Assimilated satellite measurements, SODA, has been successfully completed in 1999. The aim of the project was the development of ozone data assimilation for numerical weather prediction models and chemistry-transport models. One important focus of SODA was the inclusion of ozone in the ECMWF model.

A database of assimilated GOME ozone fields has been created from November 1999 to the present, using the TM3-DAM (TM3 Data Assimilation Model) model. The new 60-layer ECMWF analyses and forecasts drive this model, which has a fast parameterised description of the stratospheric chemistry. The assimilation work was done in the BCRS project Sciamachy and the EU project Gome Data Interpretation, Validation and Application, GODIVA.

Work has started on the assimilation of retrieved ozone profiles from the GOME instrument in the transport model TM3, using the Kalman filter technique. The full Kalman filter proved to be very efficient in accurately describing the vertical distribution of ozone in the stratosphere and higher troposphere. A simplified version of the Kalman filter has been developed for the near-real time delivery of assimilated ozone profiles. This version is in the validation phase.

The retrieval of concentrations of trace gases with strongly varying vertical profiles from UV-visible satellite spectrometers like GOME is very sensitive to a-priori assumptions about the vertical distribution of the trace gas. Therefore, a combined retrieval-assimilation approach is developed for NO_2.

The EU DARE (Data Assimilation in Readiness for Envisat) project has explored the use of Envisat data, and has co-ordinated interactions between European groups working on Chemical Data Assimilation. The EU Spring-to-Autumn Measurements and Modelling of Ozone and Active species (SAMMOA) project studies the ozone decline in northern mid latitudes in the winter-spring period. The assimilation of ozone profiles is used to quantify the evolution of the vertical distribution of ozone. Data assimilation will be used in the validation phase of GOME-2 (Ozone SAF (Satellite Application Facility)) and Sciamachy.

Interpretation of ground-based and satellite observations

Allaart, Fortuin, Van Weele

A region of extremely low ozone passed over north-west Europe during November 30 and December 1, 1999 (figure 2). Total ozone in this so-called 'mini-hole' was measured with the Brewer Spectrophotometer at KNMI. This was the first time that accurate ozone values were measured in a mini-hole. The mini-hole has also been observed with the GOME satellite instrument. On December 1, an ozone-sonde was launched to measure the ozone profile in the hole. The results have been published in 'Geophysical Research Letters'.

The observations at Paramaribo station Research on Atmospheric Dynamics and Chemistry in Surinam (RADCHIS project) are being interpreted in various fields of atmospheric science (cf. highlights of this report). The observations consist of total ozone columns, ozone ('Umkehr') profiles and UV measurements from a Brewer instrument and of ozone soundings (The German word 'Umkehr' refers to a technique through which an ozone profile can be derived from zenith-sky irradiation measurements when the sun is skimming the

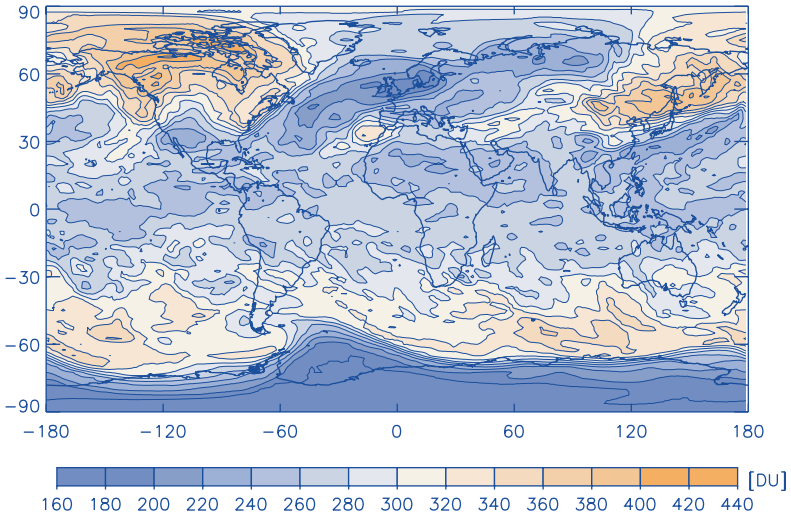


Figure 2. The global distribution of ozone based on assimilated Gome observations for November 30, 1999. Apart from the large ozone hole at the South Pole, typical nowadays for this time of the year, the figure shows very low ozone values above Western Europe and the Atlantic. With column values well below 200 DU these are the lowest ozone values observed in this region since the start of the observations in 1979.

horizon). The Umkehr profiles are appended to the sonde profiles above the burst level. On average, the correction factor obtained in this way was well within the WMO quality criterion.

A first analysis has been made of the spectral UV (Ultra-Violet) measurements. It is observed that the UV surface irradiance is fairly constant over the year, with a maximum measured UV Index ('Zonkracht') of about 18. The UV Index is a linear internationally agreed measure for the UV irradiance at the Earth surface, reaching values up to 8 in The Netherlands.

Within the SUVDAMA (Scientific Ultraviolet Data Management) project benchmark data for spectral UV surface irradiance were established. The benchmarks have an accuracy of a few percent and are now available to validate radiative transfer codes for spectral UV surface irradiance. In the follow-on project European Database for Ultraviolet radiation Climatology and Evaluation (EDUCE) the UV data will be used to address questions e.g., on European UV climatology and possible trends in UV doses.

The narrow-band radiometers measurements made in De Bilt in the period 1995-1996 have been used to study the effects of (partial) cloudiness on the incident UV irradiance. It was found that on partial-cloudy days the incident UV radiation regularly exceeds the irradiance on a cloud free day for prolonged time periods, while sunshine duration is found to be a better measure for the incident UV radiation than cloud cover.

Preparation of future atmospheric chemistry missions

Van der A, Kelder, Van Oss, Valks, Van Velthoven, Van Weele

The ozone satellite application facility (Ozone-SAF) project has been established by EUMETSAT in 1997. The Ozone-SAF project prepares for ozone and other trace gas retrievals for the Meteorological Operational satellites (METOP) and MSG satellites. For GOME-2 on board METOP-1, 2 and 3 the section has the responsibility for the retrieval of the ozone profile and aerosol operational data products, and for the validation of the total ozone product. For the total ozone validation data-assimilation techniques will be used.

ESA is planning an Atmospheric Chemistry Explorer (ACE) mission for the post-Envisat period. Under the co-ordination of our group scientific requirements have been established, based on the current perception of the main scientific issues in atmospheric chemistry research. It has been proposed that the mission objective of ACE should be 'to investigate atmospheric composition, its evolution under anthropogenic impact and its interaction with climate'. Emphasis will be put on sounding of the gaseous composition in the upper troposphere and lower stratosphere.
In autumn 2000 the ACE proposal was selected by ESA as a candidate core mission. In the coming year a 'Report for Assessment' will be written in preparation of the mission selection by ESA, scheduled for autumn 2001. If successful, the ACE mission is not likely to be launched before 2008.

The experience with GOME and Sciamachy has been used to assist the newly formed OMI working group in setting up the instrument requirements and retrieval algorithms for OMI.

Monitoring the atmospheric composition

Van der A, Allaart, Eskes, Fortuin, Piters, Valks

Chemically active gases such as ozone and methane play an important role in the Earth's climate system. Human-induced increases in the atmospheric concentrations of these gases have been identified and are shown to be a cause of detected changes in the global climate. Monitoring the distribution of the climate gases and their evolution is an essential task in climate research. Only remote sensing observations of atmospheric trace gas concentrations provide the global extend, spatial resolution and daily coverage that is required. The sequence of GOME, Sciamachy, OMI, GOME-2 and successor satellite instruments guarantee a long, uninterrupted and homogeneous time series of measurements.

Currently GOME ozone measurements are generated and archived by the division within the framework of ESA's Data Users Program (GOFAP project). These activities will be carried through in 2001. Furthermore, under the lead of our division an EU project has been defined which is specifically devoted to establish a coherent data set from the currently available five years of GOME observations.

Under the RADCHIS project, a Brewer MKIII spectrophotometer was installed on the premises of the Meteorological Service in Surinam (cf. article in highlights of this report). This happened in March 1999, and the Brewer has since been performing continuous total ozone and UV observations - along with ('Umkehr') profile observations during dusk and dawn. To this observation programme was added a balloon sonde station in September 1999. Since then sondes measuring profiles of ozone, temperature, humidity, and wind velocity plus direction are released weekly.

The ozone density distribution is measured with ozone sondes over De Bilt since 1992. These sondes are used for monitoring, the study of stratosphere-troposphere exchange, event studies, for international campaigns, and for validation of satellite data. In each winter we participated in the 'MATCH' campaign. The objective of these campaigns was to determine the role of fast chemical ozone depletion near the Polar Vortex. The ozone-sonde data are submitted to the European database at the Norwegian Institute for Air Research (NILU) and the WOUDC (World Ozone and UV Data Centre). Both Paramaribo and De Bilt have been accepted as NDSC stations for ozone soundings.

The ozone column density over De Bilt is measured continuously with the Brewer Spectrophotometer. Brewer ozone measurements are used for verification of ozone-sonde results, and the validation of satellite retrieval systems. The data are submitted to the World Ozone Mapping Centre in Greece and to the World Ozone and UV Data Centre (WOUDC). The data are also sent to RIVM (National Institute of Public Health and the Environment) to calculate UV impact on skin cancer incidence. The Brewer ultraviolet radiation spectra are being used to validate radiative transfer models.

Within the European Union project SUVDAMA a database for measured spectral UV surface irradiance in Europe has been developed. The Brewer spectral UV measurements from De Bilt for the period 1994-1997 were submitted into the database. The database will be extended in the follow-on project EDUCE (European Database for Ultraviolet radiation Climatology and Evaluation).

The OMI programme

Levelt, Van den Oord, Van Dijk, Acarreta Rodriguez, Boersma, Brinksma, Decae, Dobber, Dirksen, De Haan, Noordhoek, Veefkind, Voors

Introduction

Since 1998 KNMI is involved in the OMI programme. Centrepiece of this programme is the Ozone Monitoring Instrument (OMI) that will fly on the NASA AURA Mission that will be launched in 2003. A consortium of Fokker Space and the Institute for Applied Physics of the Netherlands Organisation for Applied Scientific Research (TNO-TPD) builds the instrument with contributions by the Finnish industry (VTT and Finavitec). For the management of the project NIVR (Netherlands Agency for Aerospace Programmes) and FMI (Finnish Meteorological Institute) have established a Project Office.

KNMI is the Principal Investigator (PI) institute. The PI is responsible for: defining the science requirements for OMI, managing the science team, safeguarding the performance aspects of the instrument, instrument calibration, algorithm development, data validation, the quality of the OMI data products, managing the Instrument Operations Team and instrument operations over the lifetime of the mission. Based on these responsibilities, three elements can be distinguished in the programme: the OMI Science Team, guidance of the industrial process, and the OMI Groundsegment. These elements are discussed below.

OMI on EOS-AURA

The OMI instrument will fly on the AURA mission that is part of the NASA Earth Observing System (EOS). Apart from OMI, the AURA payload consists of three other instruments: HIRDLS (High Resolution Dynamics Limb Sounder), MLS (Microwave Limb Sounder) and TES (Tropospheric Emission Spectrometer). The Earth Observing System will consist of three major scientific satellites (TERRA, AQUA and AURA) and a number of smaller satellites. The scientific objectives of the AURA mission are to study: 1) the ozone layer, 2) air quality and tropospheric chemistry and 3) climate change. OMI will contribute to these studies by providing information about ozone (columns and profiles), NO_2, aerosols, clouds, SO_2, BrO, HCHO, OClO and surface UV irradiance.

The OMI instrument will observe the wavelength range 270-500 nm. The instrument has various innovative features: a polarisation scrambler, a frametransfer CCD (Charge Coupled Device) and an extremely wide swath (114°). OMI will be launched into a sun-synchronous polar orbit and will provide daily global coverage with typical groundpixel sizes in the range 13×24 km² and 13×48 km². This implies that OMI will generate about 4,5 million spectra each day, divided over three channels.

The OMI science team

Over the past two years the OMI Science Team (OST) has been established. The core team consists of 33 scientists located at KNMI (9), FMI (4) and the US (20). Next to the core team there are several tens of scientists involved in the OMI programme as collaborators, co-investigators and associated scientists. The activities of the OST reside ultimately under the responsibility of the PI but are co-ordinated through the OMI Science Advisory Board (OSAB) consisting of the Dutch PI and the US and Finnish co-PI's. The US part of the OST is managed on a daily basis by the US Team Leader. On a working level the OST has been split into five Working Groups for algorithms, calibration, validation, data systems and operations. Apart from the calibration working group, these working groups are copied on AURA mission level. On mission level there is also an Education & Public Outreach working group. The current baseline is to review the Algorithm Theoretical Basis Documents for the OMI data products in the September 2001 timeframe.

Guidance of the industrial process

The industrial consortium will deliver three components of the OMI system: the instrument, the Level 0-1b processing (data processing from raw instrument data to Earth radiance and solar irradiance spectra) software and the command and telemetry database. In the light of the very tight schedule of the OMI programme, (the instrument delivery to NASA will be in March 2002), the major

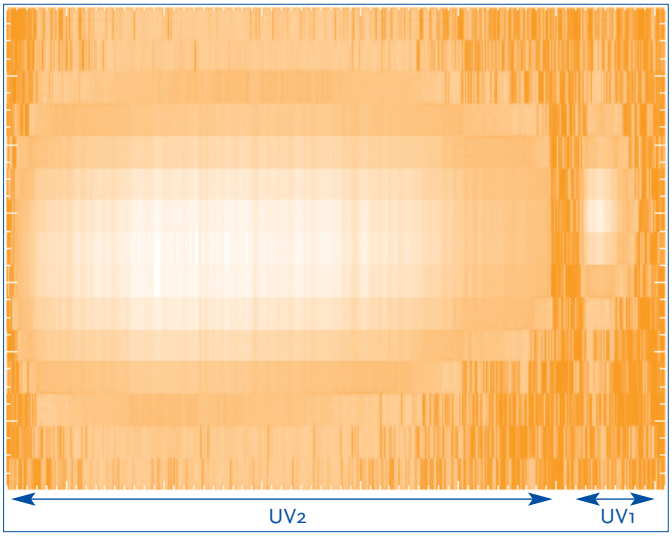


Figure 3. Zenith sky image obtained with the OMI Development Model. On the left the UV2 subchannel and on the right the UV1 subchannel. Clearly visible are the Fraunhofer lines and the ozone absorption lines. The UV1 signal is truncated because of the atmospheric cut-off.

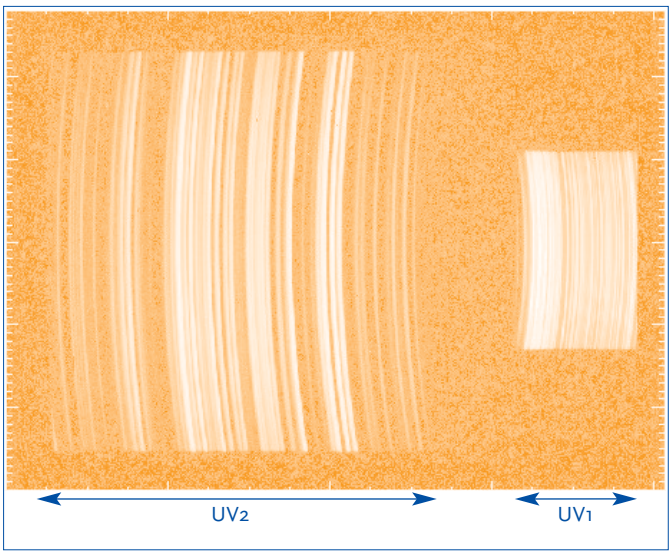


Figure 4. A spectral line source observed with the OMI Development Model. The horizontal direction gives the intensity as a function of wavelength. The vertical axis corresponds to the 260 km wide east-west swath as observed in orbit. The left side shows the UV2 sub channel (310 - 370 nm, left to right) and on the right side the UV1 sub channel (310 - 270 nm, left to right).

effort of KNMI has been to participate in industry-related activities. This includes participation in reviews of the hardware both on units and on system level as well as in various reviews related to the software development. On numerous occasions KNMI has advised the NIVR/FMI Project Office about performance issues.

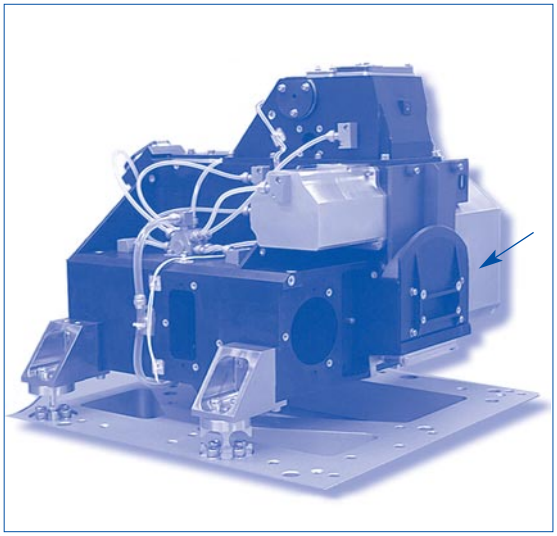


Figure 5. Optical Bench of the OMI instrument. The telescope entry is at the right hand side. Apart from the optical bench the instrument consists of two other small boxes, the Electronic Unit and the interface Adapter Module. The plastic tubes provide nitrogen flushing.

A milestone in the OMI programme was the test programme of the OMI Development Model in 2000 (see Figures 3-5). KNMI led an international team of experts that has been doing tests at the OMI facilities at TPD over a period of several weeks. The results of this programme indicate that the design of OMI is sound and that various performance aspects require further attention. After the Development Model the OMI Flight Model will be built. This Flight Model will be fully assembled in June 2001 after which an intense period of instrument characterisation and calibration will follow including measurements by the principal investigator.

The OMI groundsegment

Next to the OMI instrument in orbit, the OMI system also contains an OMI groundsegment. The groundsystem contains elements related to instrument operations and to data processing.

For instrument operations there will be a Flight Operations Team at Goddard Space Flight Center (GSFC) and an Instrument Operations Team at KNMI. The Instrument Operations Team will perform the actual commanding of the OMI instrument on a daily basis under supervision of the PI. The team will also be responsible for health checking of the instrument. To co-ordinate and plan

all the operational aspects between NASA flight operations personnel and the PI-team a small Instrument Planning Group (three persons) has been established. The team at KNMI will use an Instrument Support Terminal to interact with the Flight Operations Team and the instrument.

For dataprocessing the OMI system will have the following elements: a Science Investigator Processing System (SIPS) at GSFC where the Level 0-1b processing (data processing from raw instrument data to Earth radiance and solar irradiance spectra) will take place and the Level 1b-2 processing (data processing from Earth radiance and solar irradiance spectra to the vertical column amounts or vertical profile of the dataproducts) of various joint US/NL dataproducts. At GSFC KNMI will have a small processing system for delivery of Near Real Time ozone column and profile. Near-Real Time dataproducts have to be available for end-users within three hours after observation. At KNMI there will be a Science Computing Facility for Level 1b-2 processing (data processing form Earth radiance and solar irradiance spectra to the vertical column amounts or vertical profile of the data products) of KNMI specific dataproducts. Finally, in Finland (Sodankyla) there will be a Science Computing Facility to produce regional ozone columns and profiles, and surface UV fluxes based on direct broadcast by the AURA spacecraft.

During the past biennium the KNMI team has been working on establishing all these operational elements of the OMI system. This work will continue till launch but in 2002 the system should have reached a large degree of maturity in order to be able to support the various end-to-end system tests after OMI will have been integrated on the spacecraft.

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P.F. Levelt et al. (contributors in alfabetical order: R. van der A, P.K. Bhartia, F. Boersma, E. Brinksma, J. Carpay, K. Chance, J. de Haan, E. Hilsenrath, I. Isaksen, H. Kelder, G.W. Leppelmeier, P.F. Levelt, A. Mälkki, R.D. McPeters, R. Noordhoek, G.H.J. van den Oord, R. van Oss, A. Piters, R. Snel, P. Stammes, P. Valks, J.P. Veefkind, P. van Velthoven, R. Voors, M. van Weele), 2000. *Science Requirements Document for OMI-EOS*. RS-OMIE-KNMI-001, Version 2 of 7 December 2000. ISBN 90-369-2187-2, KNMI publication: **193**.

Veefkind, J.P., 1999. *Aerosol Satellite Remote Sensing*. PhD-Thesis, University of Utrecht, The Netherlands.

Verver, G.H.L., 1999. *Interactions of Chemistry and Turbulence in the Atmospheric Boundary-layer*. PhD-Thesis, University of Utrecht, The Netherlands.

2000 ElSerafy, G.Y., 2000. *Data Assimilation in Particle models for Ground water Contamination*. PhD-Thesis, Technical Universtity of Delft, The Netherlands.

Jeuken, A.B.M., 2000. *Evaluation of chemistry and climate models using measurements and data assimilation*. PhD-Thesis, Technical University of Eindhoven, The Netherlands.

Number of international presentations: 1999: 47, 2000: 50.

Externally funded projects: national: 17, international: 21.

Education, organisation of workshops:
H.M. Kelder is part-time professor of Atmospheric Physics at the Technical University of Eindhoven.

Other activities:
H.M. Kelder, Dutch member of the WMO – UNEP Ozone Research Managers Comittee.
H.M. Kelder, member of the SCIAMACHY Science Advisory Group.
H.M. Kelder, principal user of the OMI User Advisory Group of ESA.
H.M. Kelder, member OMI Science Advisory Group.
H.M. Kelder, lead author IPCC – UNEP Special Report 'Aviation and the Global Atmosphere'.
P.F. Levelt, Lead Scientist OMI

Atmospheric Research Division

General • The Atmospheric Research Division investigates the role of energy and water cycles in the climate system. This research field is closely related to that of GEWEX (Global Energy and Water cycle Experiment) of the World Climate Research Programme (WCRP). Activities include the development of monitoring systems, dedicated field campaigns and the development and application of models. The division runs the Cabauw Observatory. In these activities, about 36 people were directly involved, half of them were externally funded. In addition, the division received technical support from within KNMI.

Specific research themes were:
- Observation and analysis of land-surface and boundary-layer processes
- Observation and analysis of clouds, aerosols and radiation
- Physical parameterisations for weather and climate models
- Regional and global climate studies

With respect to land-surface and boundary-layer processes experimental in-situ data from Cabauw (grassland) and Garderen (forest) were analysed and reported on. Remote sensing data obtained with Windprofilers, a Radio-Acoustic Sounding System, various Scintillometers and GPS-data were also analysed and reported on. These activities included co-operations with several Universities, with the DWD (German Meteorological Office) in Lindenberg and with the US National Center for Atmospheric Research (NCAR). The division was also active in COST 76 and COST 720.

In the past two years the instrumental infrastructure at the Cabauw site and its 200m tower were renovated and a new monitoring programme was started. New Remote Sensing systems were installed. Formal co-operation agreements are being made, both nationally (the CESAR Consortium) and in the context of international projects like BALTEX (the Baltic Sea Experiment, which is part of GEWEX).

In addition to these ground-based observation activities, the division is active in many satellite missions like Meteosat, NOAA AVHRR and GOME. Activities focus on the development of algorithms for cloud retrievals (e.g. KLAROS and FRESCO, for details see below) and related products such as aerosols and short-wave albedo. The division has developed significant expertise in Sensor Synergy (combining data from different sources). An increasing flow of publications based on past observation programmes (TEBEX, CLARA, CARL, for details see below) is appearing in the literature, indicating that the division is becoming mature in this field of research.

Using the experience gained with these programmes, the division also contributed to the preparations for future missions like SCIAMACHY, OMI, MSG (Climate Monitoring SAF), ERM, CloudSat and Picasso.

The division operates a fairly extensive model suite, including very detailed models for clouds and radiation, a simple energy balance climate model and a state of the art regional atmospheric climate model (RACMO). RACMO can be run both in a nested forecast mode and in a climate mode. RACMO is used both for validation of parameterisations against observations and for regional climate studies, such as the mass balance of the Antarctic ice sheet.

The division is very active in GCSS (GEWEX Cloud System Studies). In this project cloud resolving models and field campaigns are used to develop and test cloud parameterisations.

The division co-operates with the HIRLAM consortium and with ECMWF and MPI-Hamburg. In particular the division develops and tests physical parameterisations for these models. In exchange these models are made available for diagnostic climate studies. For example the MPI model is being used for the analysis of the impact of natural and anthropogenic radiative forcings on climate. The ECMWF model (and RACMO) has been used in soil-moisture and run-off studies and in cloud parameterisation studies.

Cabauw observatory and observational systems

Tower observations

Bosveld

In the beginning of 1997 a long term profile and surface flux measurement programme came to an end. A detailed homogeneous data set was gathered over a period of 11 year, data that found their way in the literature and in the operational weather service of KNMI. Instruments had become old, data logging and data transmission had become old-fashioned and the mast itself had to be renovated. A consultance of Cabauw data users revealed that there was still an important need for a new measurement programme at Cabauw. Important users are the operational weather service of KNMI, other national institutes like the National Institute of Public Health and the Environment (RIVM), the Netherlands Energy Research Foundation (ECN) and the Climate Research Department of KNMI itself. It was decided to renovate the tower and the instrumentation, using standard synoptical instruments for the measurements of profiles of wind, temperature and humidity. This would result in a slightly lower accuracy of the measurements compared to the previous observational programme. However, an advantage would be the lower cost of maintenance of the instruments and a reduced effort for data validation. During 1998 and 1999 test measurements were performed at the 80 m level of the mast to judge the performance of the operational instruments in the tower. On the basis of this tests the final observational program was defined. It consists of the measurement of profiles of wind speed, wind direction, temperature and dewpoint temperature at the levels 200, 140, 80, 40, 20, 10 m. Additionally at the 1.5 m level only temperature and dewpoint temperatures are observed. Also measured are precipitation amount, surface pressure, in- and out going short wave

radiation and in- and outgoing long wave radiation. Cloud base height and cloud base temperature are measured and a cloud video is operated. Software has been developed for automating the data handling, transmission and archiving. In May 2000 this programme became operational. Observations of the past few days can be found on the KNMI Internet site: http://www.knmi.nl click to ▸ research ▸ atmospheric research ▸ Cabauw-operational measurement programme.

Wind profiler/RASS systems

Klein Baltink, Monna

It has been investigated whether the assimilation of observations from a mesoscale network of profiler instruments could improve the mesoscale wind forecast for the Netherlands. To this end profiler data from Cabauw were assimilated in the HIRLAM model with increased spatial resolution (5 km grid size). The results indicate that a mesoscale network of six profiling stations in the Netherlands could provide sufficient wind data for a mesoscale analysis. To assess the feasibility of a new VHF boundary-layer wind profiler for use in this future mesoscale network, a profiler intercomparison experiment was set-up (CaPRIX: Cabauw PRofiler Intercomparison eXperiment). The results show that the VHF profiler underestimates the wind speed by 8% compared to the UHF profiler. The systems differ in the measuring method applied, the VHF uses a spaced antenna techniques whereas the UHF is a Doppler Beam Swinging system. The cause of the underestimation will be analysed, first results indicate that the so-called apparent velocity from the spaced antenna technique is closer to the UHF measured wind speed than the estimated true velocity.

Backscatter data from the profiler and Cabauw tower data at 200 m level and surface data are used to derive the timing of the morning transition of the nocturnal boundary-layer to the convective daytime boundary-layer. Onset times of turbulence at the 200 m level derived from profiler and tower compared reasonably well. Therefore, the method to derive the onset time using only profiler backscatter data seems feasible.

A multiple peak detection algorithm has been implemented for off-line analysis of spectral profiler /RASS data. The first results show some improvement in conditions with intermittent rainfall. Further development of the algorithm is planned.

Analysis of the wind direction of profiler and the new tower observational programme show no significant bias. This seems to indicate that the previous measured 5 degree bias between profiler and tower wind direction could have been due to some bias in the tower data.

COST-76, a programme supported by the European Commission (Co-operation on Science and Technology), concluded its activities with a Final Workshop which was combined with the MST9 Workshop (Mesosphere Stratosphere Troposphere) in Toulouse in March 2000. The evaluation of the COST-76 activities, as carried out by the Technical Committee Meteorology of COST, led to satisfactory conclusions. The final draft of the COST-76 Final Report was nearly finished by the end of 2000. The CWINDE (COST Wind Initiative for a Network Demonstration in Europe) based network of European wind profilers, with the network hub facilities provided by the UK Met Office, continued its operations also after the end of the action. In order to organise the transition of this network towards a fully operational European wind profiler network a proposal was made to bring these activities under the umbrella of the European Network of National Meteorological Services EUMETNET. No final decisions were made yet by the end of 2000. The European Commission accepted a proposal for a new COST action on the integration of ground-based remote sensing techniques (COST-720), and this action started in October 2000.

National and international co-operation at Cabauw

Bosveld, Van Lammeren

In the course of 2000 the initiative was taken to develop a co-operation of several national atmospheric research groups around the observational facility in Cabauw. At this moment ten research groups from various research institutes and universities are exploring the possibilities for such a co-operation. It is planned that CESAR (Cabauw Experimental Site for Atmospheric Research) will start in the autumn of 2001. The partners will transfer their instrumentation to Cabauw. Data will be archived in a central database. The synergy between the different instruments will be fully exploited by this new co-operation.

Long term monitoring of atmospheric profiles and surface fluxes continues to be of importance for model evaluation and the testing of satellite based observations and their related retrieval algorithms. Plans are being developed to have a network of such locations over Europe with different vegetation types and climate. The aim of such a network would be to standardise measurements, data formats and time gap-filling procedures and to formulate procedures to obtain atmospheric profiles and flux measurements representative on a regional scale.

Scintillometry

Kohsiek

Scintillometry makes use of the interaction between a laser beam over a horizontal path in the atmosphere and the variations of the refractive index due to temperature and moisture variations. Path length ranges from a few 100 m to 10 km. Scintillation as a tool for inferring the area-averaged heat flux was studied experimentally and theoretically in co-operation with the University of Wageningen. Topics studied were: the effect of absorption by water vapour on the performance of a scintillometer, path limitation due to saturation of scintillation, application over inhomogeneous terrain, application in the stable boundary-layer, evaporation measurement by the use of a combination of a near-infrared and a microwave scintillometer. Part of this work was done in co-operation with the New Zealand institute Hort&Research. Several publications found their way in the literature and more are in preparation. A 0.3 m aperture scintillometer was constructed and functioned during August-September 2000 over the 9.8 km path between the Cabauw tower and the TV tower at IJsselstein. A scintillometer with spatially filtered apertures was built. In such a device a vertical grating is put in front of the transmitter and the receiver. With this technique the sensitivity for atmospheric turbulent structures that fit the size of the gratings is greatly increased. From the shape of the scintillation spectrum, the crosswind speed and the inner scale of turbulence, and thereby the friction velocity, may then be inferred. The instrument needs further testing, and algorithms for on-line analysis of the spectrum need to be developed.

Water vapour observations with GPS

Klein Baltink

The presence of water vapour along the atmospheric transmission path between satellites of the Global Positioning System and a receiver at the Earth surface gives rise to small delays in the transmission times. This phenomenon is utilised to obtain reliable and accurate high temporal resolution measurements of the atmospheric water vapour column. Semi-operational processing of the data retrieved from the earlier installed AGRS.NL network is continued and data are presented on the

Internet with typical delay of one day. Orbit relaxation, a method to increase the accuracy of the water vapour estimates, has been applied to a one-month data set using the less accurate predicted orbits instead of the high accurate final orbits. The results show that the water vapour estimates derived with the predicted orbits are as accurate as those retrieved with the final orbits. Furthermore the orbit relaxation method yielded about 10% more valid data. Therefore, operational near-real time calculation of accurate water vapour estimates must be feasible. Further actions to establish an operational European real-time network are co-ordinated in the COST716 project.

Landsurface processes

Surface fluxes over forest

Bosveld

The interaction between transpiration and evaporation of a partially wet forest canopy was studied. A combination of microwave attenuation measurements, sapflow measurements and micro-meteorological measurements at the Douglas Fir forest research site Speulderbos in the Netherlands, enabled the discrimination between these two processes. An extension of the Penman-Monteith equation was proposed that explains the observed evaporation and transpiration flux and their interaction in relation to external conditions and vegetation characteristics. This work is performed in close co-operation with Dr. W. Bouten from the University of Amsterdam. More information can be found in one of the highlights of this report.

Energy balance

Kohsiek, Bosveld

Closure of the surface energy balance is a fundamental problem in experimental micro-meteorology. At many micrometeorological sites, including Cabauw, an excess of net radiation is observed when compared to the sum of the surface heatfluxes, i.e. soil heat flux, turbulent sensible heat flux and turbulent latent heat flux. At some locations, for example the forest location Speulder-bos, a good closure is found. In co-operation with Dr. Panin of the Moscow Institute of Water Problems the energy budget in Cabauw was investigated. To this end the 1996 measurements of the Tropo-spheric Energy Budget Experiment (TEBEX) were analysed. A relation was sought between the energy deficit and the characteristics of the surrounding terrain at a scale of several km. A fair indication of the existence of such relation was found. The analysis is still in progress.

KNMI and the University of Wageningen participated in an international field experiment that was especially designed to study the concept and evaluate the measuring methods of the energy balance. This Energy Balance Experiment (EBEX), was held in July-August 2000 over a highly evaporating cotton field in the San Joaquin Valley in California, USA. Other participants were from Germany, Switzerland, Portugal, Italy, Hungary, and several groups from the USA participated with a main input from the National Centre for Atmospheric Research (NCAR). The KNMI contribution consisted of turbulent flux instrumentation and a net radiometer. Preliminary results show that the sensible heat flux as well as the ground heat flux are much smaller than the latent heat and that the sum of these three components is significantly smaller then the observed net radiation. Further analysis into the energy balance closure is now underway. In 2001 a workshop is organised for a first evaluation of the results.

Surface fluxes over complex terrain

Kohsiek, Bosveld

Numerical atmospheric models represent surface fluxes as area averages over grid cells with sizes ranging from 500 km to 10 km depending on the purpose of the model. Satellite based retrieval schemes for surface fluxes give fluxes representative for pixels of typically 1 km extend. Many terrestrial landscapes show large subgrid variations. For the evaluation of atmospheric models and retrieval schemes observations of surface fluxes are needed that are representative for their grid sizes. However, ground-based flux measurements have a typical footprint of a few hectares.

LITFASS (Lindenberg Inhomogeneous Terrain - Fluxes between Atmosphere and Surface: a Long-term Study) of the Deutscher Wetter Dienst is designed to study this scale aggregation problem for surface fluxes. KNMI contributed to an intensive field campaign at Lindenberg in 1998. Sensible and latent heat fluxes were measured at 10 and 30m height on a 99m meteorological tower. These observations have been combined with measurements at other levels in and near the tower with the purpose to investigate the height dependency of the fluxes An analysis of the energy balance showed that at the LITFASS grassland site also the energy balance was not closed by about 20%. When comparing measuring techniques for sensible heat flux, representative for different spatial scales over the inhomogeneous LITFASS area it was found that typical large scale techniques like scintillometry, atmospheric energy budget, high tower measurements and airborn measurements, showed a consistent behaviour, whereas a weighted average of in-situ surface flux measurements over the different vegetation types gave much lower sensible heatflux values.

Dry boundary-layer: turbulence parameterisations

Siebesma, Lenderink, Jonker, Van Ulden

This project focuses on the understanding of the vertical turbulent mixing in the dry boundary-layer and its parameterisation in large-scale models for weather forecasting and climate prediction. For the convective boundary-layer a new parameterisation has been developed. This parameterisation is based on evidence suggested by Large-Eddy-Simulation (LES) that strong convective updrafts dominate both non-local transport and entrainment at the top of the boundary-layer. These convective updrafts are described by an advective mass flux approach whereas the remaining small-scale turbulence is described by a diffusive approach. Equations for these strong updrafts have been derived and evaluated with results from LES. This parameterisation is implemented in the ECMWF model and currently being tested in close collaboration with the ECMWF. These tests show that the simple combination of mass flux and diffusion can realistically describe the transport of heat, moisture and momentum in the dry convective boundary-layer. The main advantage of this approach is that it naturally opens the way to a scheme for a cumulus topped boundary-layer by allowing the strong updrafts to condensate. No switching to a cumulus convection scheme is then needed anymore.

A new parameterisation of turbulent mixing has been developed for HIRLAM. This new parameterisation mainly consists of a new mixing length formulation to be used in a 1.5 order turbulence closure (TKE-l closure). This mixing length formulation is an alternative for the standard lifting parcel method employed in the reference version of HIRLAM (the CBR-scheme). Motivation for the development was the production of excessive wind mixing in neutral conditions by the reference version. The new scheme has been tested against Cabauw tower measurements. Results show considerable improvement for the winds at all levels in the boundary-layer, as well as much better predictions of the wind shear. Experiments with the new scheme at FMI show a considerable reduction in mean sea level pressure biases. Results have

been presented at a HIRLAM workshop held in December 2000. This work is done in collaboration with Wim de Rooy of the Observations and Modelling Department.

Non-precipitating cumulus clouds: dynamics and geometry

Neggers, Jonker, Siebesma

Nowadays, Large-Eddy-Simulation models provide a powerful numerical laboratory generating three-dimensional fields of cloud and turbulence parameters that are now widely used as testbeds for conceptual models of cloud dynamics. No effort has been made however to do a critical test (or even to formulate one) for the geometrical properties of these numerically produced synthetic clouds. Fortunately, Nature does provide an excellent and critical test, as one of the most striking examples of statistical selfsimilarity is the fractal scaling of cloud boundaries. Area-perimeter analyses of the geometry of satellite- and radar-determined cloud and rain patterns indirectly suggest a fractal scaling of cloud surfaces with a fractal dimension D_f=7/3.

In Figure 1 we show a snapshot of a typical cloud field generated by a LES model after a simulation time of 4 hours. In analogy with the aforementioned area-perimeter analyses, a volume-surface analysis for this cumulus field has been performed by measuring the surface area A and the volume V of each cloud. A linear size of each cloud is then defined as $L \equiv V^{1/3}$. For smooth shapes (balls, cubes etc.) the surface area should scale as $A \sim L^{Ds}$ with a surface dimension of D_s=2. Figure 2 shows a scatter plot of A versus L of all the clouds in logarithmic co-ordinates. This demonstrates that synthetic cloud surfaces show a strong and significant non-Euclidean scaling behaviour indicating a surface dimension close to $D_s \cong 7/3$. A heuristic proof of this fractal scaling behaviour answering the question: 'Why are clouds fractal?' has been published.

As this analysis is showing that LES models are capable of reproducing the proper geometries, we used these models as well to diagnose which cloud size determines the cloud cover. A priori it is not easy to predict the dominating cloud size: large clouds obviously have a large influence on the mentioned quantities, but they form a minority in the total ensemble. Conversely, the smallest clouds have a small effect per cloud, but their number is very large. For fair weather cumulus it seems that there is indeed a dominant cloud size of a few hundred meters that determines the cloud cover to a large extent.

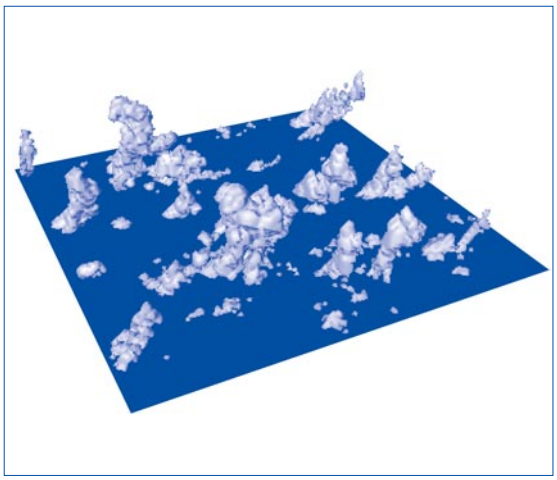


Figure 1. Snapshot of a three-dimensional cloud field generated by the LES model.

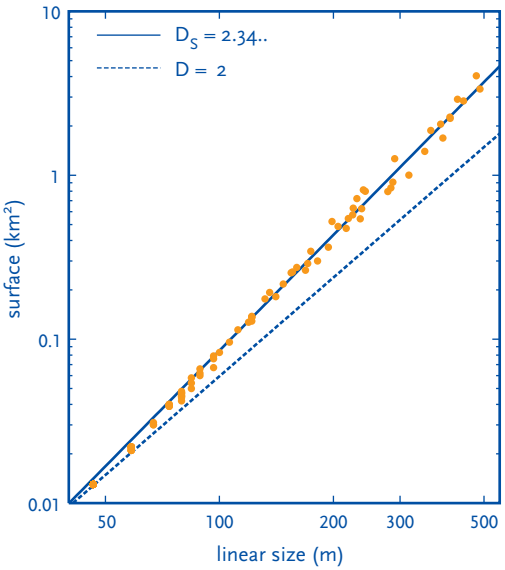


Figure 2. Log-log plot of the surface area A versus its linear size L of all clouds displayed in Fig. 1 along with a linear fit and a line corresponding to the Euclidean case D_s= 2.

Concerning cumulus dynamics, a new stochastic method for cumulus convection is formulated, which consists of an ensemble of small, rising parcels. LES results are used to parameterise the lateral mixing of such a parcel. A relaxation timescale for this mixing process is defined, and is sampled in LES clouds. It appears to be approximately independent of cloud depth. This result implies a dynamical feedback in the lateral mixing rate. All parcels in the ensemble have slightly different initial thermodynamic properties, so when subjected to this dynamic relation, it leads to an ensemble of differing mixing rates. Therefore, in contrast with many previous stochastic models, the only randomness of the present model resides in the distributions of the initial conditions in the ensemble. The stochastic parcel model is evaluated with LES fields. The characteristics of the buoyant part of the clouds are reproduced: i.e. the decreasing fractional cloud cover and increasing liquid water content with height, the vertical dynamics and mass flux, the conserved properties and the marginally buoyant state. The model also reproduces the variability in temperature, moisture, and vertical velocity for the cloud core of an ensemble of shallow cumuli, as inferred from LES results.

Non-precipitating cumulus clouds: parameterisations

Lenderink, Siebesma, Neggers

A simple statistical cloud scheme suitable for cumulus clouds has been developed. Statistical cloud schemes derive cloud parameters from the (idealised) distributions of temperature and moisture. Up-to-now, statistical cloud schemes have been used frequently in combination with turbulent diffusion schemes, and estimates of the moments of the distributions (e.g. variance, skewness) are computed in the diffusion scheme. This approach has been proved to be very successful for stratocumulus clouds, but seems to fail for cumulus clouds. In our scheme, a statistical cloud scheme has been combined with a mass flux scheme. A simple estimate of the variance is computed from a simple budget equation for the variance using mass-flux-scaling arguments. Results with this scheme for a case study of the diurnal cycle of cumulus clouds over land were presented in a GCSS (GEWEX Cloud System Studies) WG-1 (Working Group) workshop in Boulder (January 2000). This case is based on measurements at the ARM (Atmospheric Radiation Measurement program) Southern Great Plains site in June 1997. The results showed a reasonably good correspondence with the LES results, and very good performance compared to other state-of-the-art models.

As project leader, KNMI has selected the GCSS WG-1 ARM case for an intercomparison in the EUROCS-project (EUROpean project on Cloud Systems in climate models) in which nearly all-main European centres for weather forecasting and climate prediction are participating. The main goal of the EUROCS project is to improve the cloud and turbulence parameterisations used in large-scale atmospheric models. Typical problems of these parameterisations are: too large values of layer cloud fraction and cloud liquid water, unrealistic representation of the diurnal cycle, and abundant numerical noise. A case has been formulated with special emphasis on diagnostics, highlighting these deficiencies and their causes.

Mesoscale fluctuations, or: is there a spectral gap in the boundary-layer?

Jonker

Energy spectra of turbulent variables inferred from recent detailed aircraft measurements of the convective boundary-layer are found to contain significant contributions on the mesoscale (1 to 100km). Moreover, the range of horizontal scales in the energy spectra is not constrained by a length

scale in the order of the boundary-layer depth. No indication of the once so widely accepted 'spectral gap' that supposedly divides 2D and 3D turbulence has been observed. Inspired by these intriguing observations 'very' Large Eddy Simulations of the convective boundary-layer have been analysed. The results show that the energy spectra of passive scalars indeed develop mesoscale fluctuations under certain conditions. The energy turns out to flow from the large scales to the smaller scales. Implications for mesoscale modelling, parameterisations of GCM's are currently being studied. The results of this work are published, and as a next step watertank experiments have been conducted to study these phenomena. This work has been done in collaboration with Hans Cuijpers, presently posted at the Atmospheric Composition division at funding from CKO.

Clouds, aerosols and radiative processes

Spectral radiative transfer modelling

Stammes, Schutgens, Knap, Koelemeijer

The spectral short-wave radiative transfer model DAK (Doubling-Adding KNMI) has been extended with the optical properties of realistic ice crystals, in order to simulate reflection by cirrus clouds. Furthermore, several UV/visible trace gas absorption spectra have been added. The model is now used intensively for sensitivity studies and retrieval of cloud properties from satellite instruments like GOME (Global Ozone Monitoring Experiment), SCIAMACHY, Meteosat, MSG (Meteosat Second Generation), and AVHRR, and for the development of various retrieval algorithms for OMI (Ozone Monitoring Instrument) products like ozone, NO_2, aerosols, and clouds.

The DAK model has been compared in the UV/visible range to the much-used MODTRAN (version 4.1) model. A difference of a few percent has been found, which is yet unexplained.

The unique feature of the DAK model is its polarisation capability. In the past years we have developed, on the basis of DAK calculations, a parameterisation of the polarisation in the UV as a function of geometry and ozone column. This parameterisation will help to correct GOME and SCIAMACHY radiances for the polarisation sensitivity of the instrument.

The study of the spectral distribution of the polarisation of the Earth's atmosphere was the topic of the Ph. D. thesis of D. M. Stam, which was defended in September 2000 at the Vrije Universiteit of Amsterdam.

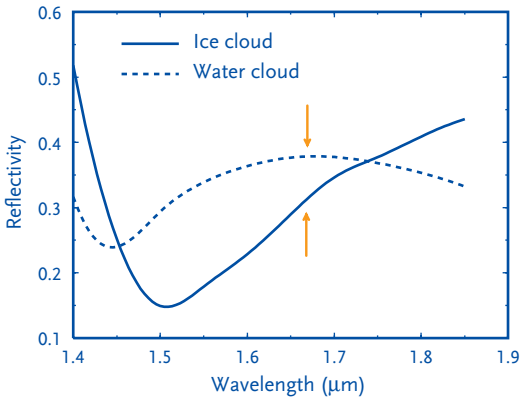
Spectral remote sensing of clouds and atmospheric composition

Stammes, Acarreta, Koelemeijer, Knap, Schutgens

New space-borne spectrometers like GOME, SCIAMACHY, and OMI require the development of new cloud retrieval methods. We are focussing on three spectral areas for cloud retrieval:

1 the oxygen A-band at 761 nm for cloud top pressure retrieval (see chapter on recent highlights),
2 the 1.6 micron absorption band of liquid water and ice for retrieval of cloud thermodynamic phase, and
3 the use of the O_2-O_2 absorption band at 477 nm for cloud pressure retrieval.

The oxygen A-band method has been validated, and is in use for the GOME fast delivery processor at KNMI. The 1.6 micron method has been demonstrated to work using AVIRIS airborne data of



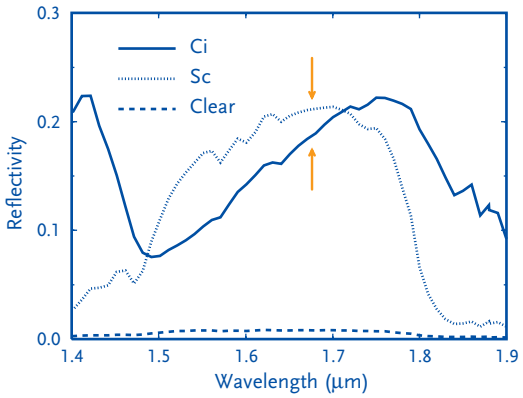


Figure 3. Spectra of ice and water clouds around 1.6 micron. Left: Calculations with the DAK model. Right: measurements with AVIRIS. The arrow indicates the wavelength within the atmospheric window (1.55 - 1.75 µm) where the spectral slope difference is largest between water and ice clouds.

stratocumulus and cirrus clouds, (see Figure 3) and will be applied in the near future to SCIAMACHY data. The O_2-O_2 method is still in a developmental stage, but looks promising.

In UV/visible satellite spectrometry the Differential Optical Absorption Spectroscopy (DOAS) method is an important technique for retrieving trace gas column densities, e.g. of ozone and NO_2. In the DOAS method the air mass factor plays an important role, because it represents the scattering processes in the atmosphere. We have derived a new formula for the air mass factor.

We contributed to the validation of the new version of the GOME data processor regarding polarisation measurements and cloud retrievals.

We contributed to the development of the Netherlands SCIAMACHY data center and its user interface. The data center, which is run by the observations and modelling department of KNMI, now contains the entire GOME database 1995-2000. This is an important source of data for research in the Atmospheric Research and Atmospheric Composition divisions.

Ground-based aerosol monitoring

Stammes, Henzing, Carolus, Rauw

Ground based measurements of the aerosol optical thickness (AOT) with a six-channel sunphotometer (SPUV, Yes, Inc.) have been performed in De Bilt since mid-1997. End of 1999 the sunphotometer has been moved from the backyard-terrain to the top of building B, and new software for data acquisition has been installed. The data can now be viewed via Intranet. Based on four years of data, a first climatology of aerosol optical thickness in De Bilt has been made. It appears that the average AOT at 500 nm is 0.22 (see Figure 4). The Angstrom exponent is 1.4.

In 2000, the CLOSAER project has started. This project studies the effect of aerosols on the closure between measurements and model calculations of clear-sky irradiances. An investigation of the quality

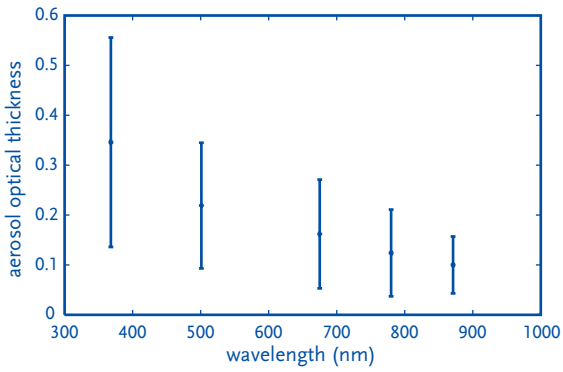


Figure 4. Aerosol optical thickness at 5 wavelengths from sunphotometry in De Bilt for the period 1997-2000. The average and standard deviation are plotted.

of the operational short-wave irradiance measurements in De Bilt was performed. First comparisons were done between the measured direct and diffuse irradiances and the modelled irradiances, using the MODTRAN4 model.

Remote sensing of cloud properties

Van Lammeren, Bloemink, Donovan, Mebold, Meijer

The present generation of cloud observations provides insufficient information on important cloud properties such as cloud structure, optical properties and microphysics. Information can be obtained by combining different remote sensing techniques. For this research we used lidar, radar, infrared radiometer and microwave radiometer observations. Data from the Cloud Detection System (CDS), CLARA'96 (Clouds And Radiation experiment), CLARE'98 (Cloud Lidar And Radar Experiment) and CARL (Cloud Analysis from ground-based and airborne Radar and Lidar) campaigns and from the Atmospheric Radiation Measurement sites (ARM) were used. KNMI participated in the international CARL'99 campaign in Palaiseau and the CARL2000 campaign in Brest. These campaigns focus on the potential of sensor synergy for retrieving cloud parameters.

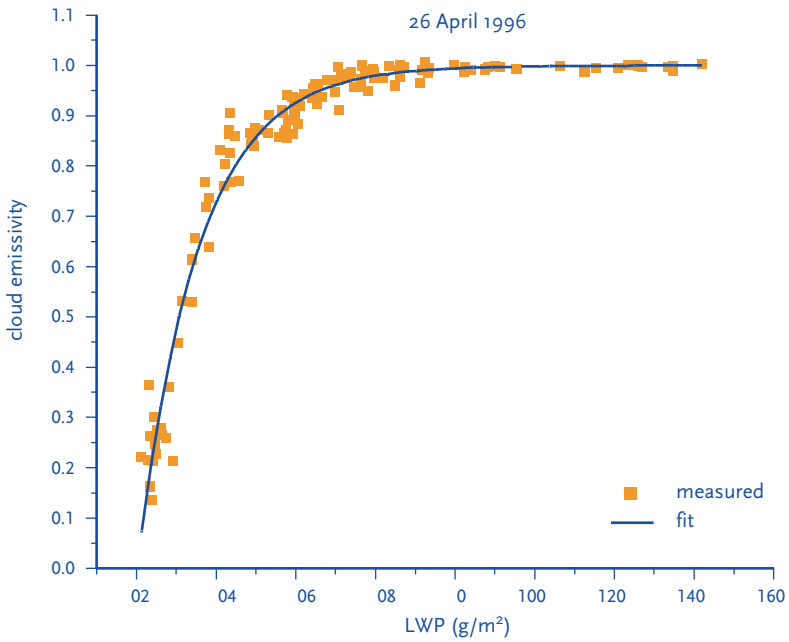


Figure 5. Derived cloud emissivity versus measured Liquid Water Path (LWP) for 26 April 1996. The fitted line agreed very well with the theoretically derived relationship.

Within several externally funded projects (SRON, ESA) algorithms are developed to explore this sensor synergy in more detail. Different algorithms have been developed and validated for the following cloud properties:
- Cloud base and top
- Cloud emissivity
- Particle size and Ice Water Content (IWC)
- Cloud optical thickness

Lidar and radar: cloud base and top

The return signal of the radar is proportional to the 6^{th} moment of the particle radius, whereas the lidar return signal is proportional to the 2^{nd} moment. This makes a lidar more sensitive to smaller particles, compared to the radar. Since smaller cloud particles tend to be present near the cloud base and larger ones near the cloud top, lidar is better suited for determining cloud base height and radar for cloud top height. Another argument for using the radar for cloud top height is that lidar signals are easily extinct by liquid water clouds, whereas radar signals are largely unaffected. Statistics were performed on the results using selected CLARA '96 cases (60 hours of data). It was found that cloud bases determined for radar and lidar differ considerably and that, in order to detect radiatively significant clouds, one active instrument, be it a radar or a lidar, does not suffice.

Lidar, infrared- and microwave radiometer: emissivity

In order to derive the infrared (IR) emissivity, first the cloud base is determined, using lidar observations. Next, the temperature at this cloud base altitude is found using radiosonde data. Combining this temperature with the temperature measured by the IR radiometer results in the emissivity in the IR window of the radiometer. A basic assumption in the retrieval algorithm is that there is only a single cloud layer present, but effects of multiple layers can in some cases be incorporated. The emissivity was compared with cloud liquid water measurements using the microwave radiometer, and a clear correlation between the two was found (see Figure 5, showing IR emissivity vs. Liquid Water Path for 4

hours of data on April 26th, 1996). A theoretical relationship was derived, which agreed very well with the observations.

Lidar and radar: particle size and ice water content
The particle size retrieval algorithm is also based on the different responses to particle size by the lidar and radar (see also the highlight on Cloud Observations). It simultaneously inverts the radar and lidar return signals to take into account the lidar extinction and multiple scattering. In the retrieval, a gamma-type particle size distribution is assumed. When translating the results for ice crystals to particle dimensions or ice water content, crystal properties also need to be assumed. The algorithm gives good results in particle size retrievals when compared to in-situ aircraft measurements, although it is difficult to compare point measurements (from the ground) with measurements taken along a flight track. IR emissivities calculated from the retrieved particle sizes agree very well with the observations.

Space born lidar and radar
The Earth Radiation Mission (ERM), one of the possible future ESA Earth Explorer Missions aims at the retrieval of cloud and aerosol properties by combining lidar and radar observations. Results from our studies were used in the ERM assessment report and in the presentation on ERM during 'The Four Candidate Earth Explorer Core Missions Consultative Workshop' in Granada, 12 - 14 October 1999. Despite a positive evaluation from the ESA's Earth Science Advisory Committee (ESAC), ERM was not selected as an Earth explorer core mission. At this moment the concept of ERM is further developed in a joint ESA-NASDA mission called EarthCARE (Earth Clouds Aerosol Radiation Explorer). The EarthCARE mission has recently been selected for a pre-phase A study.

CloudSat will fly the first cloud radar in space and will be launched in 2003. Intensive collaborations have now been established with the CloudSat science team. CloudSat will fly in formation with the PICASSO/CENA mission, which carries a lidar. KNMI has been asked to take the lead in the development of lidar/radar synergy algorithms for CloudSat and PICASSO/CENA.

Analysis of observations from the Cloud Detection System (CDS)

Van Lammeren, Feijt, Mebold, Tunc

In 1995 and 1996 KNMI operated the Cloud Detection System (CDS). This two-year data set has been analysed within several projects.

In the context of generating automatic cloud synoptic codes the project SCA (Synergetic Cloud Algorithm) was started. The project objective is to optimise and validate an algorithm which can be used for generating synoptic cloud reports based on data from a Lidar-ceilometer, an infrared-radiometer and Meteosat. The CDS database is used for optimising and developing the algorithms. It has to be realised that some of the instruments in the operational network are different from the instruments used within the CDS. For example, the lidar ceilometer, which will be used in the new network, has better specifications (detection range is increased to 16 km).

The first research task was to investigate the performance of each single instrument to detect the total cloud cover for single cloud layers. In the next phase of the project the cloud base height and cloud cover per layer were derived for multi-layer situations. The final algorithm treats the observations from the different instruments in a consistent way. The same assumptions on cloud overlap and on combining layers are used for all three instruments. The results show that by combining the observations from the different instruments a better agreement with the synop from the observer is obtained. At this moment the final algorithm is further optimised. The project will end in spring 2001.

Within the TEBEX Cloud Detection System (CDS) cloud parameters (at ten stations) and incoming short-wave radiation (approx. 30 stations) was measured for a two-year period. From the radiation data the cloud optical depth has been retrieved. These optical depths are compared to the optical depths derived from NOAA/AVHRR data. The

validity of the retrieval algorithms is being investigated. Presently the data are used to evaluate the output from the RACMO model.

BALTEX Cloud Liquid Water Network: CLIWA-Net

Van Lammeren, Bloemink, Feijt, Jolivet, Mathieu, Van Meijgaard

In March 2000 the EU project: 'BALTEX Cloud Liquid Water Network: CLIWA-Net' started. The CLIWA-NET project establishes a prototype of a European cloud observing system by co-ordinating the use of existing, ground-based passive microwave radiometers and profiling instruments (radars and lidars). In total 12 stations within the BALTEX modelling area will contribute to this network. The network was operated during August/September 2000 and will again be operating in the period April/May 2001). The ground-based remote sensing instruments feed high quality cloud information, with high temporal but poor spatial resolution, into the calibration of satellite-based estimates of cloud water content with high spatial resolution (NOAA/AVHRR, AMSU, Meteosat). New procedures are being developed to fully exploit this synergy.

The combination of vertical profiles of cloud water and temperature information enables an accurate detection of super cooled water layers. These layers are responsible for in-flight icing, which is considered to be one of the major hazards in today's aviation.

The retrieved CLIWA-NET data sets are used for an objective evaluation of the performance of state-of-the-art cloud parameterisation schemes. The focus is on liquid water path (LWP) and on vertical structure of cloud amount and cloud water. Three lines of research are pursued:
- evaluation of cloud related output from several European atmospheric models (ECMWF, HIRLAM, DWD-LM and RACMO)
- investigation of the sensitivity of model cloud parameters to the employed horizontal grid spacing in the meso-scale range (1-10 km)
- to develop/improve/test cloud parameterisations and underlying assumptions.

The first results of the evaluation of the models are already available.

In summary the CLIWA-NET objectives are:
- Implementation of a prototype of a European Cloud Observation Network. This network might also serve as an operational validation system for current and future satellite cloud missions (e.g. MSG, METOP, ENVISAT, CLOUDS)
- Development of an adequate observing system for the detection of icing conditions for aircraft
- Objective evaluation and improvement of state-of-the-art cloud parameterisations for weather forecast and climate prediction models, with a focus on integrated cloud liquid water and vertical structure of clouds.
- Design of a 'low cost' microwave radiometer in co-operation with industry.

The end users organised in the 'CLIWA-NET user's advisory group' provide suggestions on the social-economic aspects of the project. A User's Requirement Document has been written based on their input.

A microwave radiometer calibration campaign will be organised as part of the BALTEX BRIDGE Cloud campaign (BBC) at the Cabauw site in the Netherlands (August/September 2001). After the calibration campaign the microwave radiometers are distributed over a regional network (100x100 km^2). At the central facility in Cabauw an extensive set of advanced remote sensing instruments will be operated (radars, lidars, microwave radiometers, radiometers etc.). Several aircraft will provide in-situ measurements for validation of ground-based and space borne remote sensing observations. The preparations for this large-scale campaign have already started.

More information and an overview of the first results of the CLIWA-NET project can be found at our web site: www.knmi.nl/samenw/cliwa-net.

Cloud analysis using meteorological satellites

Feijt, Dlhopolsky, Jolivet, Mebold, Roebeling

KLAROS, is the KNMI cloud analysis environment for AVHRR data. The cloud analysis is done in two steps: cloud detection using thresholding techniques and retrieval of cloud parameters from the cloud areas. The cloud field products are: cloud cover fraction, cloud top temperature, optical thickness, infrared emissivity and liquid water path. KLAROS is used in the CLIWANET project to obtain estimates of liquid water path fields.

Recently, an interactive interface was added to KLAROS written in IDL (Interactive Data Language). This enables visual inspection of the images, selection of interesting areas and statistical analysis of cloud properties. Thresholds and surface properties can be set using sliders and enables detailed, pixel by pixel, analysis of cloud field properties.

The results from the cloud parameter retrievals were validated with radar, lidar and microwave radiometer time series for a number of cases from the Clouds and Radiation Intensive Observational campaigns (CLARA).

The use of surface temperatures from a Numerical Weather Prediction model enables automated runs for KLAROS for the two-year data set of the Tropospheric Energy Budget Experiment, TEBEX. This enables the statistical analysis of liquid water path as derived from AVHRR and ground based microwave radiometer.

An algorithm was developed to obtain a size range estimate of water droplets from a combination of 0.6 and 1.6micron reflectivity's. Sensitivity studies were performed using two radiative transfer codes, DAK and SHDOM. This sensor combination will be important for the retrieval of liquid water path with the SEVERI, the imager onboard of the Meteosat Second Generation, which will be launched January 2002.

Climate SAF (CM-SAF)

Feijt, Roebeling, Jolivet, Dlhopolsky

Data derived from satellite measurements are an important component in the climate observing system. Satellite data provide a high spatial coverage compared to conventional surface networks and especially fill gaps in areas with sparse conventional observations. They also provide information, which cannot be measured from the ground, like the outgoing radiation at the top of the atmosphere.

EUMETSAT is developing the Satellite Application Facility on Climate Monitoring (CM-SAF) with the objective to generate and archive data sets for climate studies on the basis of NOAA-AVHRR and MSG data. These data sets will be produced on continuous basis for applications in support of climate studies.

The CM-SAF project focuses on three areas:
1 the generation of regional (Europe) cloud and radiation parameters,
2 the generation of global datasets of sea surface temperature and sea ice cover,
3 the statistical quality evaluation of vertical profiles of temperature and humidity.

The role of KNMI is to develop and validate the CM-SAF cloud parameter products. KNMI has built up an extensive set of cloud property data, obtained during the measurement campaigns of the CLARA, CDS and CLIWANET projects. These data together with synoptic data, are used to validate the CM-SAF cloud parameter products i.e.: fractional cloud cover, cloud type, cloud top temperature, cloud top height, cloud phase (water / ice), cloud optical thickness and cloud liquid water path. Based on the validation results KNMI will improve the cloud parameter modules of the CM-SAF algorithm. The validation environment is being set up.

In addition, KNMI is responsible for the development the Cloud Optical Thickness (COT)

and the Cloud Water Path (CWP) products. The method proposed to retrieve COT and CWP is being developed in conjunction with the CLIWA-NET project. This method uses visible (0.6 micron) and near infrared (1.6 micron) channel data, which will be collected by the next generation meteorological satellites (MSG, METOP and NOAA-16). The underlying principle of this method is that the reflection of clouds of the 0.6 micron channel is primarily a function of the cloud optical thickness, whereas the reflection at 1.6 micron is primarily a function of cloud particle size. A radiative transfer model is used to simulate the behaviour of 0.6 and 1.6 micron reflectivity as a function of optical thickness and droplet effective radius. A first version of COT and CWP retrieval algorithm has been developed. This algorithm has been tested satisfactorily.

Regional and global climate studies

Land surface modelling at local and regional scales

Van den Hurk, van Meijgaard, IJpelaar

Several international research projects addressed the evaluation and further development of land surface parameterisation models.

Many components in the land surface parameterisation scheme of the European Centre for Medium-range Weather Forecasts (ECMWF) have been revised, prior to starting the 40-year ECMWF Re-Analysis (ERA40) cycle. Guided by comments from researchers in the area of land surface modelling, the land surface package has undergone a major change. The effects of this operation were evaluated using observations from over half a dozen dedicated field experiments. The comparison study included short vegetation and forest sites, boreal and tropical forests, and agricultural land in Western Europe and the Sahel. A pronounced improvement in evaporation is shown in Figure 6, where simulations with the old and new ECMWF land surface scheme are compared to observations collected in the context of the BOREAS experiment in the boreal forests in Canada. In the revised scheme, the snow pack is positioned under the forest canopy rather than on top of it, giving rise to a systematic reduction in snow evaporation in winter and spring. The impacts on Northern hemisphere precipitation were clearly shown from global simulations carried out at ECMWF.

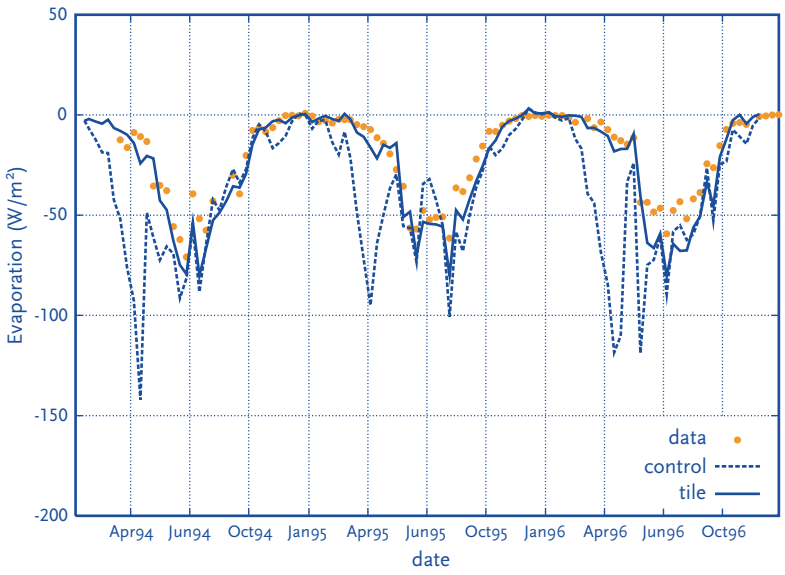


Figure 6. Observed and simulated surface evaporation (10-day averages, negative numbers denoting upward fluxes) over a three-year period 1994-1996 for a Boreal forest area in Canada. Observations were made in the context of the BOREAS experiment. Shown are simulations with two land surface models. The model labelled 'control' represents the former operational ECMWF land surface model of Viterbo and Beljaars (1995), whereas 'tiles' represents the new version developed in the context of the 40 year ECMWF Re-analysis cycle (Van den Hurk et al, 2000).

In a number of regional model experiments, soil hydrological components in the ECMWF land surface scheme were addressed. The runoff parameterisation was evaluated in the context of the EU-funded project NewBaltic II. Simulations with RACMO were carried out for the Baltic Sea area for the growing season in 1995. Using results from a detailed hydrological model for the Baltic Sea area, it was clearly found that model runs in which surface runoff is also simulated when the soil is not yet completely saturated show far more realistic

behaviour than the ECMWF treatment, in which soil saturation is conditional to generating surface runoff. In particular, fast runoff response to intense precipitation or snowmelt events was not well simulated in the ECMWF model. The study has given guidance to further improvements to the ECMWF land surface scheme.

Another evaluated aspect of the ECMWF land surface scheme is the treatment of the soil physics. Up to now, characteristics of soil physics are assumed uniform over the globe. In a suite of RACMO simulations, this assumption was evaluated by comparing a control simulation to a land surface model version in which broad classes of soil types were discerned. In particular the strong percolation capacity of sandy soils appeared to give rise to shifts in the partitioning of precipitation over evaporation and runoff, with a small but beneficial effect on the near surface relative humidity simulated by the model. More substantial effects of changes in the treatment of the soil can be expected for sandy semi-arid areas. Studies with surface-soil models driven by prescribed atmospheric forcings indicated that the seasonal evolution of surface evaporation in the Sahelian area is strongly dependent on the values of the soil hydraulic properties.

Soil moisture assimilation using satellite observations

Van den Hurk

Work on the use of satellite based land surface observations in Numerical Weather Prediction (NWP) has been addressed in two separate studies, funded by the Netherlands Remote Sensing Board (BCRS) and the European Space Agency (ESA).

One set of case studies aimed at adjusting soil moisture in RACMO using surface temperature observations from METEOSAT. The surface-heating rate was calculated from a series of surface temperature observations collected between sunrise and local noon. In general, heating rates are well correlated to the surface wetness: lower heating rates are associated with areas where evaporation is high. RACMO evaporation rates were changed by altering the soil moisture content in the layer, tuning the simulated heating rates to the observations.

The relative humidity calculated from simulations including the optimised soil moisture content were compared to observations and to model runs without this soil moisture adjustment. For the northern part of Western Europe, the effect of using the METEOSAT data was small but beneficial in terms of near surface relative humidity predictions. Larger impacts are expected in the Mediterranean areas, where soil moisture and evaporation are stronger coupled. The method is being explored further for operational implementation.

Another study with satellite derived surface temperatures was funded by ESA in the context of a new land observation mission in the Earth Explorer programme. In this study, the possible benefits of directional surface temperature measurements, a feature of the possible future satellite, were explored. Under certain assumptions simultaneous temperature observations of one site but inferred from different viewing angles can be transferred into a distinct temperature for both vegetation and the underground. Accurate knowledge of these temperatures is of importance to NWP and climate models for determining the thermal exchange properties of a vegetated surface. Multi-angular surface temperature data from the ATSR-2 satellite were analysed for two different European sites: a predominantly grass covered area in the Netherlands and direct surroundings, and a sparsely vegetated area in the south-eastern part of Spain. It appeared that the properties expressing the thermal exchange processes for these two areas were clearly different and in accordance to expectations based on field measurements and theory. Multi-angular temperature measurements can, once interpreted in terms of vegetation and soil temperatures, provide a valuable datasource for improving surface energy balance and surface temperature calculations in NWP and climate models.

Impacts of cloud and turbulence parameterisations on structures of integrated water vapour

Lenderink, Van Meijgaard

New parameterisations for turbulent transports and cloud parameters have been tested in high-resolution (horizontal resolution 18 km) predictions with RACMO for the Baltic Sea catchment area. The new parameterisation treats the interaction between the turbulence and the cloud physics in a physically more consistent way than the standard ECHAM4 physics package of RACMO. Predictions of three cyclones (Kerstin, Monica, and Liane) during the PIDCAP period in 1995 have been made. The new physics package produces more pronounced structures in atmospheric integrated water vapour (IWV) with well-developed bands of dry and moist air curving into the centre of the cyclone. An intercomparison of the model output of IWV with timeseries of GPS based measurements has been made for many stations in Sweden and Finland. By comparing the performances of the time series predictions for the various GPS stations it could be unambiguously demonstrated that the passages of these bands were much better captured with the new physics package. Also the consistency between two consecutive model forecasts appears to be much larger with the new physics package.

Vertical distribution of cloud amount: observations and model predictions

Van Meijgaard, Feijt, Van Lammeren

Ongoing work on the vertical distribution of cloud amount has been focusing on analysing observations of cloud base parameters with ground-base measurements from infrared radiometer and lidar ceilometer and cloud top temperature from satellite observations (Meteosat and NOAA/AVHRR overpasses) in order to quantify the vertical cloud extent on the scale of the Cloud Detection System (CDS) domain (100x100 km^2). The main findings for an arbitrarily taken 10-day sample in Aug/Sep 1995, which can be characterised as quite variable and in general quite cloudy, are i) the distribution of cloud base temperature inferred from the infrared radiometer suggests higher cloud bases (after transforming temperature into height by use of the radiosonde profile) than the directly measured cloud base height distribution inferred from the lidar. This suggests that a part of the low-level water clouds is optically thin. ii) for a subset of low-level water clouds selected to be optically thick the infrared inferred cloud base height seems to be lower than the corresponding lidar height for unexplained reasons. iii) the satellite inferred cloud top temperature is often higher than the infrared radiometer cloud base temperature, indicating that a lot of high- and midlevel clouds are optically thin, iv) on scales varying from 1 to 20 km the satellite inferred cloud top temperature profiles, averaged over the CDS-domain, are identical, indicating that the characteristics of brokenness of cloud systems is not changing on these scales.

In the context of the EU-funded research project NEW BALTIC II, a comparison study of model predicted cloud parameters from three regional models, i.e. SMHI-HIRLAM, and KNMI-RACMO, and GKSS-REMO, with observations inferred from TEBEX-CDS has been co-ordinated by KNMI. The main result is that all models predict a too high cloud amount at low altitudes below 900 hPa, which is then compensated by an underestimation of cloud amount around 800 hPa. This is likely to be related with a tendency exposed by all models to underestimate the planetary boundary-layer height. All models overpredict the high-level cloud amount albeit it is difficult to quantify to what extent due to the frequent presence of optically thin clouds. Whereas reasonably alike in cloud parameters, the models differ considerably in radiative fluxes. One model links a well matching incoming solar radiation to a radiatively transparent atmosphere over a too cool surface, another model

underpredicts incoming solar radiation at the surface due to a too strong cloud feedback to radiation, the last model represents all surface radiative fluxes quite well.

The surface mass balance of the Antarctic ice sheet: a model study with RACMO

Van Lipzig, Van Meijgaard

The mass balance of the Antarctic ice sheet, which is controlled by the net moisture input at the surface (surface mass balance) minus the ice flow off the continent to the ice shelves, is important for global sea level. The atmospheric model RACMO (Δ=55 km) is used to study the temporal and spatial variations in the surface mass balance by performing an integration for the 14-year period 1980-1993. The prognostic variables at the lateral boundaries of the model domain are relaxed towards ERA (ECMWF Re-Analyses) fields. Sea-ice extent and sea surface temperature are prescribed from observations.

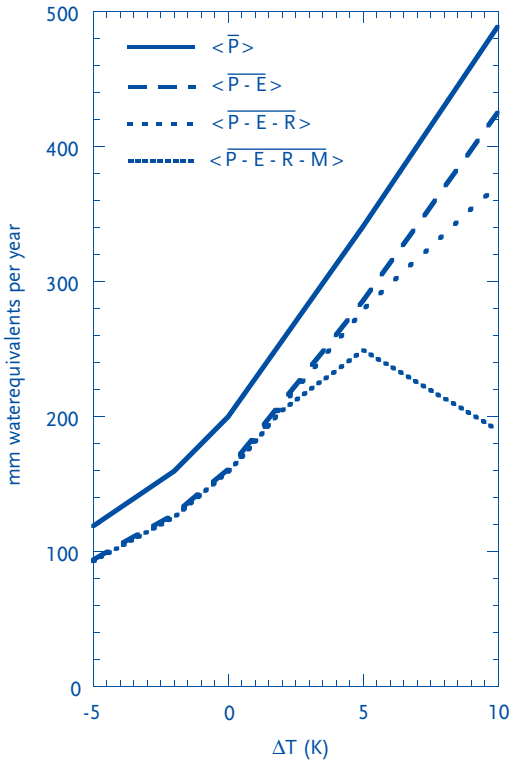


Figure 7. Two-year mean precipitation <$\overline{P}$>, precipitation minus sublimation <$\overline{P\text{-}E}$>, precipitation minus sublimation minus rain <$\overline{P\text{-}E\text{-}R}$>, precipitation minus sublimation minus rain minus melt <$\overline{P\text{-}E\text{-}R\text{-}M}$> averaged over the entire ice sheet as a function of the temperature forcing ΔT.

Atmospheric models are recognised to be useful tools for studying the sensitivity of the Antarctic mass balance to climatic variations. On the century timescale, the response of the ice dynamics to variations in temperature and precipitation can be neglected; the relation between mass balance and temperature is then controlled by the relation between surface mass balance and temperature. Two-year sensitivity integrations are performed for the period 1980-1981. In these integration's, i), the temperature at the lateral relaxation zone of the model domain is raised by ΔT at constant relative humidity, ii), the sea surface temperature is raised by ΔT, and iii), the sea-ice extent is changed as a function of ΔT. Integration's are performed for ΔT = -5, -2, 0, 2, 5 and 10 K.

The two-year mean precipitation minus sublimation averaged over the entire ice sheet <$\overline{P - E}$> increases with the temperature forcing (see Figure 7). For ΔT = 2 K, <$\overline{P - E}$> increases with 47 mm water-equivalents per year, which is 30% of the control value. Melt and rain become important at ΔT = 5K. The melt and rain water either freezes internally or runs off. The total mass balance of the ice sheet is not affected by a change in melt or rain that freezes at some depth. Only the fraction that runs off is important. A refreezing model is needed to calculate this fraction. However, we can use the sensitivity runs to study the extreme case that all liquid water runs off. At ΔT = 10K, 56% of the <$\overline{P - E}$> leaves the ice sheet as liquid water. The temperature sensitivity of the surface mass balance becomes negative. However, even in the assumption of complete run-off, the surface mass balance for ΔT = 10K is still larger that in the control run. Evidently, only at very large temperature forcings the increase in melt would exceed the increase in snowfall.

Natural and anthropogenic causes of global mean temperature change

Van Dorland, Van Ulden

Global mean temperatures show a broad spectrum of variability, ranging from quasi-biennial oscillations to a long-term warming trend over the past century. Attribution of observed temperature variations to specific causes requires specifications of both the response due to the radiative forcings and the dynamic state of the climate system. Important sources of radiative forcings are major volcanic eruptions, variations in solar activity and anthropogenic emissions of greenhouse gases and aerosols. The transient surface-temperature response to these forcings is determined by the equilibrium climate sensitivity and by the delay and attenuation of the response due to the thermal inertia of the oceans. The delay and attenuation can be determined with a one-dimensional coupled atmosphere-ocean climate model.

A prominent example of variations in the dynamic state of the climate system is the El Niño-Southern Oscillation (ENSO). ENSO has a broad spectrum of variability with most of its variance on interannual to decadal time-scales. The state of ENSO is well documented by observations of surface air pressure over the Pacific. Interdecadal variations in all radiative forcings are uncertain except for the well-mixed greenhouse gases. For the net anthropogenic forcing, which is increasing in time (implying a major contribution on the long time-scales), uncertainties are mainly due to the aerosol forcing. Also, the solar forcing on the timescale of several decades is not well known. In contrast, fast variations on interannual to decadal time-scales are much more certain, especially over the last 50 years. Therefore a regression has been made between the natural causes of climate change and the observed temperature using a 2-20 year bandpass filter. An estimate of the total response of the natural factors has been made by using the same regression coefficients for the slow signals and extended for the whole period from 1880 onwards. The last step was to subtract these natural variations from the observed temperature record. It appears that the residual temperature shows a warming trend, which increases exponentially in time and can be explained by a plausible anthropogenic forcing (Figure 8). The analysis suggests that human activities may be responsible for a warming of about 0.6 K, which mainly occurred in the last 50 years. These results have been documented in the 1999 NRP-report and presented at the SOLSPA conference at Tenerife in September 2000.

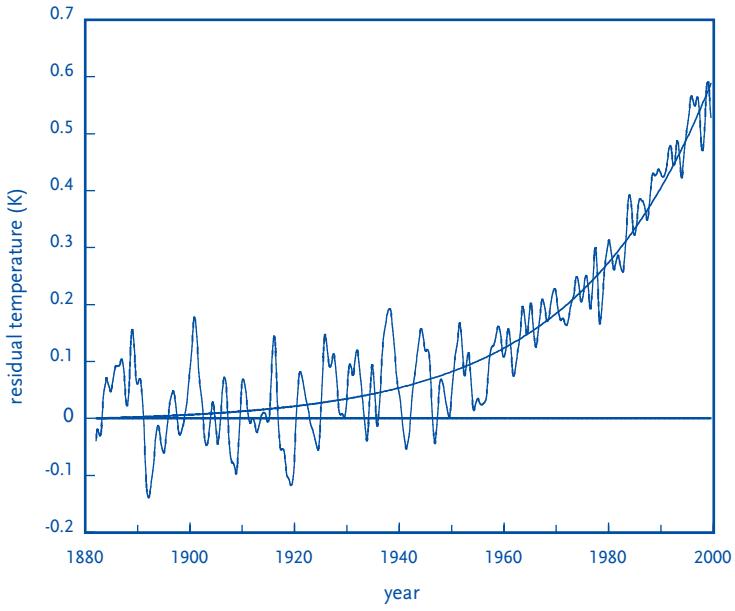


Figure 8. Residual temperature (1y running mean). Oscillating line: $\Delta T_{VinKap} - \Delta T_{Natural}$; smooth line: computed response to an exponential radiative forcing with an e-folding time of 25y (corresponding to an annual increase of about 4%). The magnitude of this forcing is about 1.1 Wm^{-2} in 1990. This estimate falls within the range of net anthropogenic forcings given in IPCC (1995).

Climate response due to changes in UV radiation of the active sun

Van Dorland, Tourpali

The extent to which solar activity is a factor in climatic change is still a matter of debate. In this study the response of ozone and tropopause pressure to solar UV radiation changes in combination to variations of the solar constant resulting from the 11 - year solar cycle is investigated using the global three-dimensional dynamic-chemical model MA-ECHAM4/CHEM. The general circulation model (MA-ECHAM4), an extended upward version of ECHAM4 with the top at 0.01 hPa, has been interactively coupled to the tropospheric and stratospheric chemistry module CHEM. The coupled model employs interactive photochemistry and includes heterogeneous reactions on Polar Stratosheric Clouds (PSC's) and sulphate aerosols. Our model has a high resolution in the vertical and is fully interactive, i.e. changes in chemistry have a feedback into the dynamics trough their influence on radiation.

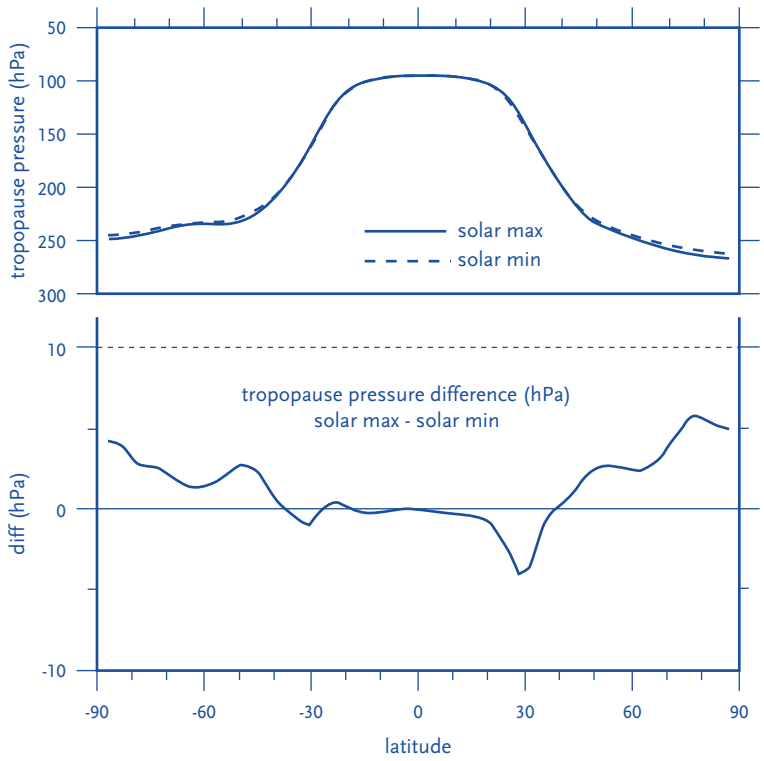


Figure 9. Average annual tropopause pressure in years with solar maximum and solar minimum activity. The lower panel shows the pressure difference.

Our experiment aims at investigating the effects of enhanced solar UV radiation on climate. For this purpose, 2 separate runs of the model are being performed, lasting for 20 model years. The first model run represents conditions prevailing at the state of maximum solar activity during the sun's 11-year cycle, with enhanced solar irradiance mainly at the UV intervals, while the second run represents minimum solar activity conditions. The basic state of the model, an 'average' state of the 11-year solar cycle, is a simulation of the present-day atmosphere, representing a time-slice for 1990, with carbon dioxide concentration set to 353 ppmv and chemical boundary conditions for 1990. The Sea Surface Temperature is fixed in the model, representing a 1974 -1994 climatology. The runs are performed from re-start files from a 60-year model run. The solar fluxes in both perturbation runs were adjusted in the model's spectral intervals according to the difference between the solar minimum and solar maximum spectral solar flux changes.

A preliminary analysis of the first 6 years of simulation shows a consistent effect of enhanced UV radiation on the ozone distribution accompanied by changes in tropopause height in the vicinity of 30 N, indicative of a stretching of the northern hemisphere Hadley cell (Figure 9). Our preliminary results are in accordance with findings reported by other researchers in the UK and USA. Our results have been presented at the SPARC (Stratospheric Processes And their Role in Climate) meeting in Argentina in November 2000.

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Dorland, R. van., 1999. *Radiation and Climate. From Radiative Transfer Modelling to Global Temperature Response.* PhD-Thesis, University of Utrecht, the Netherlands.

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2000 Feijt. A.J., 2000. *Quantitative Cloud Analysis using Meteorological Satellites.* PhD-Thesis, University of Wageningen, the Netherlands.

Number of international presentations: 1999: 48, 2000: 47.

Externally funded projects: national: 14, international: 10.

Education, organisation of workshops:
A.J. Feijt co-organised (scientific program committee) the symposium 'Remote sensing of cloud parameters: retrieval and validation', Delft, the Netherlands, October 1999.
A.A.M. Holtslag is part-time professor (20% position) at the University of Utrecht.
B.J.J.M. van den Hurk convened and co-organised the workshop 'Towards advanced assimilation of satellite based land observations', De Bilt, the Netherlands, October 2000.
A.C.A.P. van Lammeren co-organised (scientific program committee) the symposium 'Remote sensing of cloud parameters: retrieval and validation', Delft, the Netherlands, October 1999.
W.A.A. Monna convened session 'Ground-based remote sensing of wind, temperature and humidity in the troposphere and lower stratosphere', EGS Assembly, The Hague, the Netherlands, April 1999.
W.A.A. Monna convened session 'Ground-based remote sensing of wind, temperature and humidity in the troposphere and lower stratosphere', EGS Assembly, Nice, France, April 2000.
W.A.A. Monna co-organised the 9th International Workshop on Technical and Scientific Aspects of MST Radar combined with the COST-76 Final Profiler Workshop, Toulouse, France, March 2000.

Other activities:
A.A.M. Holtslag, chairman review committee on research proposals, submitted to GOA (NWO-Geosciences Foundation)
A.A.M. Holtslag, chairman of the programme board of CKO.
A.C.A.P. van Lammeren, member of the ESA Earth Radiation Mission Advisory Group (ERMAG).

A.C.A.P. van Lammeren, member of the ESA Science Preparatory Group for the Earth CARE-mission.
A.C.A.P. van Lammeren, member of the ESA/NASDA Joint Science Preparatory Group for the Earth CARE-mission.
A.C.A.P. van Lammeren, member of the CloudSat Science team (NASA).
A.C.A.P. van Lammeren, member of the BALTEX/BRIDGE management team.
A.C.A.P. van Lammeren, co-ordinator 'Radiation and remote sensing of clouds' of CKO.
A.C.A.P. van Lammeren, member of the User Consultancy Committee on Atmopheric Radar Research of STW (NWO – Technology Foundation).
W.A.A. Monna, chairman Cost 76.
W.A.A. Monna, member Dutch delegation World Radiocommunication Conference WRC2000, Istanbul, Turkey, May 2000.
W.A.A. Monna, member WMO/CBS Steering Group Radio Frequency Coordination.
W.A.A . Monna, member Netherlands Contactgroup ITU-Policy Matters (NCGI).
P. Stammes, member of the GOME Science Advisory Group (ESA).
P. Stammes, member of the SCIAMACHY Science Advisory Group (NIVR/DLR).
P. Stammes, member of the OMI Science Team (NIVR/FMI/NASA).
P. Stammes, member of the Atmospheric Chemistry Science Advisory Group (ESA).
P. Stammes, member of the EGOM Atmospheric Panel (ESA).
P. Stammes, chairman Netherlands SCIAMACHY Data Centre Users Group.
P. Stammes, chairman of the Netherlands Earth Observation (NEONET) Users Group.
P. Stammes, member of the Netherlands Earth Observation (NEONET) Steering Group.
P. Stammes, chaiman of the Study group 'Radiation in the Atmosphere'.
A.P. van Ulden, member of the Steering Group Climate Monitoring SAF.
A.P. van Ulden, member of the Scientific Steering Group BALTEX.
A.P. van Ulden, member of the Programme Committee NOP, chairman programme group I.
A.P. van Ulden, member of the programme board CKO (representative KNMI).
A.P. van Ulden, member of the Focal Point Working Group I IPCC.

Climate Analysis

The central theme of the Climate Analysis Division is the analysis and diagnosis of the climate and its variability on the basis of observations and models. The objective of this research is to contribute to the understanding of natural variability and to use this knowledge in the formulation of climate change scenarios for impact studies using downscaling techniques. The research can be summarised in two themes:

1. Climate analysis and scenarios
2. Climate reconstruction and palaeoclimate

There has been an increasing involvement in European co-operation via projects funded by the European Union (EU). In 1999-2000, there were two successful proposals that supplemented the two ongoing EU projects. Nationally, the closest co-operation is with Institutes responsible for water management. The co-operation has become structural and is now established by an official long-term co-operation agreement with RIZA (National Institute for Inland Water Management and Waste Water Treatment) on March 3, 1999. A short-duration NRP (National Research Programme on Global Air Pollution and Climate Change) project on climate scenarios was also granted. Within the Climate Research Department of KNMI, there is close co-operation with the Predictability Research Division.

An important event in the past two years was the formal start of the data rescue programme on Historical Climate (HISKLIM). This long-term programme aims at digitalisation, homogenisation, and analysis of climate data from Dutch sources. The activities involve co-operation with all Departments of KNMI. The approval of the HISKLIM programme gave an important boost to the Climate Analysis Division's research theme 2.

The Division is responsible for compiling the triennial Climate Report 'The state of the climate in the Netherlands'. In 1999 the third report of the series was published. This time the themes consisted of climate diagnosis and climate variability. Co-authors outside the Division were H. Wessels, A. Klein Tank, J. D. Opsteegh, G. J. van Oldenborgh, G. Burgers and A. Baede. On September 29, 1999 the Climate Report was presented to Mrs J.M. de Vries, Deputy Minister of Transport, Public works, and Water Management.

The third workshop of the EU Concerted Action on Climate Change ECLAT was organised under responsibility of the Division. It took place in Lage Vuursche 10-12 May 2000. The topic was Climate Scenarios for water-related and coastal impacts.

In the framework of the Commemoration of 400 Years Relations between Japan and the Netherlands, an International Public Symposium on the Recovered 19th-Century Meteorological Observations of Deshima was organised in Nagasaki, Japan on October 8, 2000. Results of the data recovery were presented by Japanese, English and Dutch speakers in the presence of Mrs T. Netelenbos, Minister of Transport, Public works, and Water Management.

Stochastic rainfall generator

Buishand, Beersma, Wójcik

The activities on the development of a weather generator for daily precipitation and temperature were continued. The ultimate aim of the project is to get a better insight in extreme river discharges. There is direct co-operation with the Institute for Inland Water Management and Waste Water Treatment (RIZA), part of the Ministry of Transport, Public Works and Water Management. This institute is responsible for protection against river flooding.

The first version of the weather generator for the Rhine basin has been completed and will be delivered to RIZA for further testing with the hydrological model. Three KNMI Reports about the generator were published. A follow-up paper of the 1998 article in Hydrology and Earth System Sciences was submitted to Water Resources Research. The potential of the method is recognised by RIZA and a long-term co-operation agreement has been signed. Work continues with the development of a weather generator for subdaily precipitation for the Meuse basin. Like the current generator for the Rhine, it applies nearest-neighbour resampling and, for the time being, the generator is developed for the current climate. For the Meuse, a subdaily time resolution is desirable. This implies that the development of the generator for the Meuse basin, rather than being just an extension of the earlier method, is a project in its own right.

Downscaling

Buishand, Beckmann, Beersma

The activities on downscaling are related to water resources. The long-term aim is to develop methods that can produce precipitation scenarios on the spatial and temporal scale required. Work on this subject took place in the framework of the EU project Water Resources: the Influence of Climate Change in Europe (WRINCLE). This project ended in December 2000. Daily rainfall for stations in the Netherlands, Northern Germany, Austria, Switzerland and Spain has been analysed. The precipitation amounts per wet day and the probability for wet days were linked to circulation variables and to a measure of the absolute (precipitation amount) or relative (probability of precipitation) humidity. No seasonal separation was made in deriving the (non-linear) regression. Despite of this, it turned out that the model was capable of simulating the annual cycles in the probability and amount of precipitation well (see Figure 1). The change in the seasonal mean precipitation amounts for the future climate were calculated by perturbing the predictor variables with the changes in their means between the periods 1968-1997 and 2070-2099 in a simulation with the Hamburg version of the ECMWF model (ECHAM4), a coupled atmosphere-ocean Global Circulation Model (GCM). For most sites these estimated changes are comparable with those in the direct

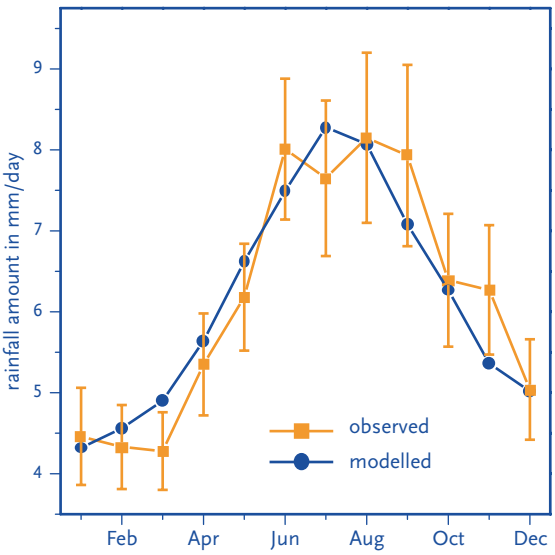

Figure 1. Observed and simulated seasonal cycle of the mean wet-day rainfall amount at Bern (Switzerland) for the period 1968 - 1997. The simulation was obtained by linking the amounts per wet day to circulation variables and to a measure of the absolute humidity. From the daily time series of the predictors, the simulated rain amounts were obtained. No seasonal separation was made in deriving the (non-linear) regression. The error bars indicate twice the standard error of the observed mean wet-day rainfall amounts.

climate-model output. These encouraging results make it likely that on a long run meaningful weather generators for changing climate can be developed.

A successful project proposal was submitted to the successor of the EU projects POPSICLE (Production of Precipitation Scenarios for Impact Assessment of Climate Change in Europe) and WRINCLE, as the EU project SWURVE (Sustainable Water: Uncertainty, Risk and Vulnerability in Europe) was granted. This lifts the projects to the level of a long-tem activity. SWURVE has basically the same partners as its predecessors and started in December 2000.

The Division contributed actively to the EU ECLAT-2 Concerted Action. The project aims at the co-ordinated provision of scientific and technical advice to European climate change projects and at the exchange of knowledge through workshops covering various aspects of the subject. The (water-related) ECLAT Workshop 3 was organised in May 2000 in the Netherlands.

Surges, wind and weather in a changing climate

Van den Brink, Doortmont, Können

A 1.5-year project was commissioned in 1999 by the Dutch National Research Programme on Global Air Pollution and Climate Change (NRP) to analyse regional signals in GCM models. The project started in December 1999. Temperature and precipitation output of four models is evaluated on a global scale, European scale, and for a grid point representative for the Netherlands. It was found that for all models the response of the temperature to greenhouse warming is about the same in the three areas. The signal/noise ratio of regional greenhouse signals is investigated.

A second line in this project is the exploration of extreme value statistics for wind and surge. The scientific question is: what is the information content of a series with a typical lengths of one century in determining an event with a 10000-year mean recurrence time (determining the heights of the sea dikes). The study is done in an ECBILT (KNMI intermediate-complexity climate model) context, augmented with observed series. The analysis is performed for the current climate as well as for the mid-21th century climate. The project is carried out in co-operation with the Predictability Research Division.

Applied statistical research

Buishand, Beersma

A relatively simple and powerful statistical test based on jackknive resampling has been developed to test for equality of variances in observed and simulated climates. In contrast to the classical variance test (F-test), the new test can be used to compare variances in spatially correlated data. An article describing the method with an application to monthly GCM data appeared in the Journal of Climate.

The prospects of resampling have been demonstrated with a simple stochastic model for daily precipitation. This theoretical exercise also provided insight into the required length of the simulation runs.

(Palaeo) climate variability

Shabalova, Beersma, Können

The activities in this subtheme are carried out in close co-operation with the Predictability Research Division. A joint project to analyse multidecadal climate variability in (proxy) data and models, commissioned by the Dutch National Research Programme on Global Air Pollution and Climate Change (NRP), came to an end in 2000. So far, two papers on patterns of variability have been published (co-authored by S. Weber, Predictability Research Division). A third paper is in preparation.

As part of this project, the information content of the recently released long temperature series of the Low Countries was evaluated. This series runs from 800 to present and is reconstructed by J. Buisman in co-operation with A. van Engelen of the Observations and Modelling Department of KNMI from documentary sources. A paper about this is submitted to Climate Change.

In 1999, a second paper was published on model/data comparison of the climate of remote warm epochs. The paper discusses large spatial scale precipitation. It was co-authored by I. I. Borzenkova, State Hydrological Institute, St. Petersburg, Russia, who was the author of the precipitation and temperature reconstruction's. This publication concluded the Division's research on remote equilibrium climates.

The co-operation with the Predictability Research Division on the development of ECBILT model continued. A new version of the model, that allows for climate change experiments was released. The Climate Analysis Division developed short-wave radiation and cloud schemes for the new version. A hindcast study with E. de Bruijn of the Observations and Modelling Department of KNMI on rainfall in Ireland by hurricane Charley was published in the Journal of Hydrology.

Data rescue and reconstruction of historical climate series (HISKLIM)

Brandsma, Können

A KNMI programme on Historical Climate (HISKLIM) has been formulated to systematically digitise and homogenise data in KNMI archives from Dutch sources. The project extends over several years and involves all departments of KNMI. It started in 2000. It aims at direct electronic access to all data from KNMI, revisiting Dutch data in international data-bases, and the release of long

and homogenised time series. The primary target is on data from Dutch sources, taken on land or over sea.

The first result is the incorporation of 6 million Dutch pressure records in the Comprehensive Ocean Atmosphere Dataset (COADS) marine database. The problems with the gravity correction were solved in close co-operation with the Climate Data Center (CDC) of the National Oceanic and Atmospheric Administration (NOAA) and the Hadley Centre. The new release of COADS (January 2001) contains the Dutch data. This is a big improvement, as the Dutch data make up 90% of the pre-1900 COADS data.

A project called CLIWOC (Climate of the World's Oceans) was commissioned by the EU to digitise and analyse marine observations 1750-1850. The project is a co-operation between UK, Spain, Argentina and the Netherlands and started in December 2000. When completed, it will extend the COADS database (1850-present) back in time. The Dutch contributions to CLIWOC are digitising and analysing the Dutch data (including data of Dutch East Indian Company ships) and setting up the database.

Rescue of data from the colonial era

Können

The results of a project on the recovery of pre-1875 Japanese instrumental data were presented in an International Public Symposium on the Recovered 19th-Century Meteorological Observations of Deshima, Nagasaki. The symposium took place a few meters from the former island Deshima, where the observations were taken. It concerns an extension backwards in time of the Japanese series by Deshima data covering 1820-1830, 1845-1858 and 1871-1882, which have been found in Dutch archives (see Figure 2). Recently discovered Osaka data 1828-1832 taken by a Japanese scientist were also presented. This project is carried out in co-operation with T. Mikami and M. Zaiki, Metropolitan University of Tokyo, and T. Tsukahara, University of Kobe. A paper on the subject is in preparation.

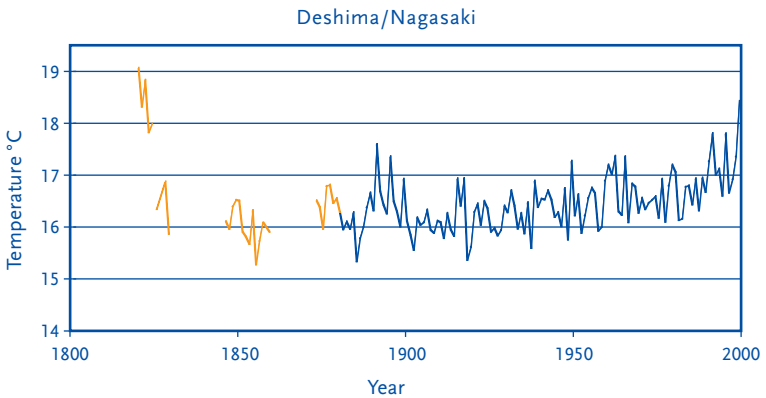

Figure 2. Temperature series of Nagasaki (Japan). The blue line, starting in 1878, is taken by Nagasaki Observatory. There are no official observations prior to this period in Japan. The orange line is the extension of the Nagasaki series on basis of the observations taken by the Dutch in Deshima. Deshima was only a few hundred meters from the later-established Nagasaki Observatory. The first few years of the series exhibit a still unexplained bias.

Hourly pressure values of Jakarta for 1945-1980 are recovered and digitised, supplementing the 1866-1944 Jakarta hourly series from the National Center for Atmospheric Research (NCAR). This series enables calibration of the extension of the Quasi-Biennial Oscillation series 1866-1950 on basis of the semidiurnal cycle in the Jakarta pressure. The project is carried out in co-operation with P. Jones, University of East Anglia UK, and the Indonesian Meteorological Institute.

Water management act 2100 (WB21)

Können

In co-operation with RIZA and WL Delft Hydraulics, a report is made about the possible changes in climate for the Commission for Water Management in the 21st Century (WB21). It presents climate scenarios for 2050 and 2100. The scenarios are basically the same as those for the 4th Governmental Act on Water Management (1997). The Report was a background document to the advice of the Commission to the Minister.

Titan atmosphere

Können

In the framework of a co-operation with the European Space Agency (ESA) on the upcoming descent of the NASA (National Aeronautics and Space Administration)-ESA Huygens probe in the Titan atmosphere, the relation between symmetry in halo displays and the symmetry of halo-generating crystals was studied. The aim of this work is to be prepared for the interpretation of halos if they appear at a certain stage of the descent, which will take place in 2004.

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2000 Beersma, J.J., M. Agnew, D. Viner, and M. Hulme (Eds.), 2000. *Climate Scenarios for Water-Related and Coastal Impacts*. Report ECLAT-2 Workshop **3**, May 2000, Lage Vuursche, the Netherlands. CRU, Norwich, UK.

Number of international presentations: 1999: 7, 2000: 7.

Externally funded projects: national 5, international 5.

Education, organisation of workshops:
J.J Beersma organised the Eclat EW-3 workshop in Lage Vuursche, the Netherlands, May 2000.
G.P. Können co-organised the International Public Symposium on the Recovered 19th-Century Meteorological Observations of Dejima, in Commemoration of 400 Years Relations between Japan and the Netherlands, in Nagasaki, Japan, October 2000.
T. Brandsma organised a meeting with IHE PhD-students, KNMI, De Bilt, the Netherlands, April 2000.

Other activities:
J.J. Beersma, Member of the steering committee of EU-project ECLAT-2.*T.A. Buishand*, Member of the Editorial Board of Extremes.
G.P. Können, Member of the Commission for Climatology (CCL) of the World Meteorological Organisation (WMO).

Seismology

General • Seismology is a fascinating science even when applied to a relative aseismic region of the world like the Netherlands. The years 1999-2000 were productive for the Seismology Division at KNMI and saw the initiation of a new EC financed project aiming at establishing a Mediterranean-European Rapid Earthquake Data Information and Archiving Network (MEREDIAN) of which ORFEUS (Observatories and Research Facilities for European Seismology) is co-ordinator. The modernisation of the seismological infrastructure was continued and is beginning to bear fruit with interesting results in seismology and infrasound.

In general the activities of the Seismology Division range from observations and data collection to analysis of data leading to applied research in the field of seismology. During the last few years the connection between observations and research have become stronger due to the deployment of more specialised problem oriented and up-to-date seismic and infrasound equipment. The division also disseminates the results to the press and the media. Another way to reach the general public is the use of Internet for public education. The popularity of this medium for up-to-date information and background material in seismology is growing fast. The number of web pages more than doubled in the past biennium.

The renovated villa, the new building of the Seismology Division.

In the past period earthquakes continued to shake the northern parts of the Netherlands, more specifically near the village of Roswinkel. These series of earthquakes show strong similarity in their waveforms and are the strongest ones observed so far in connection with the extraction of natural gas. The five accelerometers showed not only that the amount of shaking was enough to cause again substantial damage, but also that the shallow source mechanism probably involved thrust faulting. In a multidisciplinary workshop on induced earthquakes, organised by KNMI and attended by all institutes involved, it became clear that the question of attribution of the induced events is solved. The remaining important questions are the 'how and why' of the induced quakes: the geophysical aspects of the problem.

The EC project on palaeoseismicity in the Netherlands was concluded with a series of publications. Palaeoseismicity is the study of strong earthquakes in pre-historic times. It became clear that palaeoseismic events can be recognised in the field, which is a major achievement, but that more research is needed to quantify the results in terms of long return period seismic risk of large earthquakes.

The detection of infrasonic waves with a new infrasonic array near Deelen, and the research in this subject are conducted both in the context of the Comprehensive Nuclear-Test-Ban Treaty (CTBT) and to assist the Royal Netherlands Airforce (Klu) in their noise abatement of military aeroplanes. The observation of infrasound from a large meteorite explosion (1.5 kt) over Northern Germany and the subsequent analysis resulted in a publication that attracted a great deal of national and international attention. The size of this explosion is relevant in a CTBT context.

The operational task of the Seismology Division constitutes half the workload within the division. The modernisation of the data acquisition system in De Bilt will ensure an up-to-date operation in the years to come. The programme also upgrades the station electronics to broadband 24-bit sampling. A new three component broadband station near Winterswijk (WTSB, Figure 1) became operational and has noise characteristics comparable to that of the station in Limburg (HGN). Given the noise conditions in the Netherlands WTSB is an excellent station. The operation of a Geo-Information System (GIS) ensures a

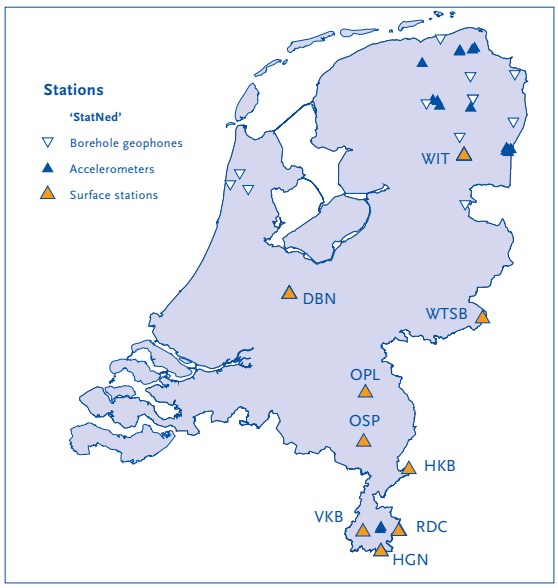


Figure 1. Overview of KNMI operated seismic stations in the Netherlands

modern approach to the handling of the data and combines an archive function of earthquakes in the Netherlands with topographical and geological information. More and more data are now available in this system, recent digital data as well as old data. Data on Dutch earthquakes are even going back as far as 1910 with scanned analogue records.

A major event for the Seismology Division was the move to a new building. The renovated villa on a fourteenth century foundation will house the group to their full satisfaction for a long future to come.

Observations

Monitoring gas-related earthquakes in Groningen, Drenthe and Noord-Holland

Haak, Dost, Sleeman, Looman, Van Gend, Meester, Van Bodegraven, Jansen

Monitoring induced seismicity continued in the northern part of the Netherlands using a network of borehole seismometers. In 1999 a total of 31 events were recorded and located. Local magnitudes (M_L) vary between 0.2 and 2.8. In 2000 a total of 25 events occurred with $0.3 \leq M_L \leq 3.2$. The total number of stronger events ($M_L \geq 2.0$) remains stable: 2 in 1999 versus 5 in 2000. The installation of accelerometers near locations where events were felt in the past was continued in 1999. Two stations were installed near 't Zandt and one near Annen.

A special case is a series of events near Roswinkel (eastern part of Drenthe) starting in 1996 and continuing in 1999 and 2000. A total of 9 events of magnitude between 1.1 and 3.2 were detected. The largest event generated a maximum intensity of V on the European Macroseismic Scale (EMS) in the epicentral region. Using correlation techniques a precise relative location of these events could be calculated. Analysis of acceleration data from a small network of 3 accelerometers installed in the source region enabled an absolute location. Early 2000 one additional accelerometer was placed in the centre of the Roswinkel network, allowing an improved absolute location.

In the province Noord-Holland no gas-related earthquakes were detected in this time period. In this area mainly explosions at sea were recorded.

Monitoring natural seismicity

Haak, Dost, Van Eck, Sleeman, Houtgast, Looman, Van Gend, Meester, Van Bodegraven, Jansen, Goutbeek

In the south-eastern part of the Netherlands earthquakes are related to the tectonic regime of the Lower Rhine Embayment, mainly in the Roer Valley Graben. In the period under review a number of 14 earthquakes took place in this region, i.e. 5 in 1999 and 9 in 2000 respectively. The strongest event, a M_L 3.4 earthquake near Uden on 11 September 1999 was felt with Intensity 4.5.

At the end of 2000 a swarm of small earthquakes was observed near Voerendaal initiated by two felt shocks on December 20 of magnitudes M_L 2.3 and 2.5 respectively. These were followed the same month by another five events of magnitudes varying from M_L 0.4 to 1.7. The series of shocks near Voerendaal continued in January 2001.

Recent developments in the digital seismograph network

Haak, Dost, Sleeman, Evers, Jansen

During 1999 a new seismic station was constructed near Winterswijk in order to modernise station WTS. Early 2000 (February 21) the station started to produce data. The new site (WTSB) is located on top of an outcrop of 'Muschelkalk' and has on average a 10-20 db lower noise level compared to the old station site. During 6 months the station did operate in an experimental mode and was fully integrated in the analysis system in the summer of 2000.

In Chaam, near Breda, KNMI could use an unused geophone vertical seismic profiling (VSP) string of Shell Research for earthquake monitoring. This string contains a total of 48 levels of 3 component geophones down to a depth of 150 m. The string was tested in the field and preparations were made to construct a more permanent observation point. The station is expected to become operational in 2001.

The network of broadband seismometers (HGN, WTSB, WIT (Witteveen)) is equipped with (very) broadband seismic sensors, as to monitor local, regional and global seismicity in real-time. These sensors require high-resolution digitizers, which are capable to resolve the full seismic spectrum and dynamic range provided by a (very) broadband seismic sensor. During 2000, preparations were made for implementing such a data logger in this network, which concerned infrastructure, communication, data acquisition software and acquisition monitoring tools (Java). At the end of 2000 a QUANTERRA Q4120 data logger successfully replaced the data acquisition system at station WIT. Stations HGN and WTSB will be upgraded with such a data logger in 2001. This system has a dynamic range of more than 145 dB, produces simultaneously different sample rate streams, has local data storage and communicates over Internet (TCP/IP). In this way, a reliable, permanently monitored data acquisition system is implemented and integrated in the KNMI network, which meets today's state-of-the-art in real-time global earthquake monitoring. It is expected that the data availability (98.7 % for HGN over 2000) will further increase.

Accelerometers

Haak, Dost, Sleeman, Looman, Van Gend, Meester, Jansen

The installation of accelerometers in the southern part of the Netherlands was given high priority when an earthquake swarm started near Voerendaal in December 2000. Although only two earthquakes happened with magnitudes of 2.3 and 2.5, many people reported both events to be felt in only a small area (a few km^2). This implies a shallow source. It was expected that activity continued over a period of one to two months. This was based on the appearance of a similar series of 8 small earthquakes near Voerendaal in 1985/86. After installation of an accelerometer one aftershock of magnitude 1.7 was recorded. Early January 2001 one more accelerometer station was installed in Voerendaal.

The network of stand-alone strong motion accelerographs in the northern part of the Netherlands is proved, stable and low-maintenance network to monitor the seismicity in this part of the country. During 1999 and 2000 three more accelerograph systems were installed: two near 't Zandt, and one near Roswinkel. The number of earthquakes (10) recorded by these instruments during 1999 and 2000, resulting in 24 earthquake, recordings reflects the importance of the network.

Tilt observations in Noord-Holland using shallow borehole tiltmeters

Haak, Sleeman, Looman, Van Gend, Meester, Jansen

During 1999 and 2000 two tiltmeters continued the measurement of tilt around a peak-gas installation in Alkmaar. The background of this measurement is the question whether tiltmeasurements are sensitive enough to detect surface effects of fast gas extraction. Theory indicates that pressure variations within the gasfield of at least 6 bar within one week result in tilt variations that may exceed the tilt noise level. However, such variations did not occur during the period of the experiment. As a spin-off analysis of the data during 1999 revealed a large effect of ocean tides on the coastal area in terms of tilt. The observed tide (M_2) in the tiltmeasurements is a factor 3 larger than the modelled earthtide. The difference is interpreted as an effect of ocean loading on the coast due to ocean tides.

Comprehensive Nuclear-Test-Ban Treaty (CTBT)

Haak, Sleeman, Looman, Van Gend, Meester, Van Bodegraven

Traditionally, as part of the observational task, the seismology division includes the detection and identification of nuclear explosions and advisory work for the Ministry of Foreign Affairs. In the period 1999-2000 no nuclear test explosions were conducted. The five nuclear powers and India and Pakistan stayed by their self proclaimed moratoria. Data are exchanged with the International Data Centre (IDC) in Vienna through a procedure that is completely automated by software in world-wide use which is named Auto Data Request Manager (AutoDRM). Also secure Internet connections are applied successfully. In the past few years the International Monitoring System (IMS) to verify the Comprehensive Nuclear-Test-Ban Treaty was built up at a steady pace by the treaty organisation in Vienna. So a growing data set is available at the IDC. Towards the end of 2000 preparations were made to install the Netherlands National Data Centre, the counterpart of the IDC, to receive and analyse seismic and infrasound data.

Research

Regional seismicity

Haak, De Crook, Dost, Van Eck, Houtgast, Goutbeek

A considerable effort has been made to further develop a Geo-Information System (GIS) for regional seismicity. This system allows the input of phase readings and an interactive determination of locations. More than 1000 events in the Netherlands, western Germany and Belgium, of natural or induced nature, have been included in the database at the end of 2000. This dataset is basic to the research, since it allows e.g. all data to be used in studies involving highly accurate hypocenter determinations, using a Joint Hypocenter Determination (JHD) for the region. This study started in 2000 and is first focused on natural seismicity in the southern part of the Netherlands.

In the northern part of the Netherlands the GIS system was used to investigate the details of the origin of the Roswinkel events. From a study of the source mechanism of the Roswinkel events a shallow dipping overthrust mechanism was inferred that did not fit an earlier interpretation by geologists of a steeply dipping normal fault. A reinterpretation of the geology, based on the KNMI inferred mechanism, resulted in the summer of 2000 in the observation of a shallow dipping overthrust plane at 1.7-2.0 km depth that fits the seismological data and is the most likely cause of the series of events. For the more general northern region a search was made for waveforms from events that have a similar location and show a high correlation. The result for Groningen was a poor correlation, implying that a situation like Roswinkel is not likely in a larger gasfield.

In the southern part of the Netherlands an earthquake swarm started in December 2000 near Voerendaal. This swarm shows comparable behaviour to a swarm in 1985/86 and therefore a study was initiated on the causes of these events.

Modelling of the seismic source

Van Eck, Van Bodegraven, Meester

Earthquake processes due to stresses in the crust are being modelled using Boundary Element Methods (BEM) for situations that are comparable to those for induced seismic events in the gas fields in the Northern part of the Netherlands. The goal is to obtain understanding of the underlying mechanisms and complementing the observational studies.

Analogue modelling of mining induced seismic sources was mainly done through sandbox experiments.

Attenuation of seismic waves

Van Eck, Goutbeek, Dost

The attenuation of seismic waves in the southern part of the Netherlands (Limburg) was determined. Attenuation is an important factor for the calculation of seismic hazard. Attenuation can be represented by a quality factor Q, which stands for the damping of an oscillation in general, but here more specifically for the damping of seismic waves. One way to determine this quality factor is the use of coda waves. Coda waves are the tail of seismograms having an envelope whose amplitude gradually decreases with time. They are composed of a superposition of waves scattered by heterogeneities in the Earth. From the coda envelope the quality factor can be calculated. We used local earthquakes from the southern part of the Netherlands and from Belgium and Germany, recorded at permanent and temporary digital seismograph stations in the Netherlands, Belgium and Germany. The results show an increasing quality factor with increasing epicentral distance and they compare very well with two other attenuation measurements.

Local site effects

Haak, De Crook, Van Eck

The aim of this study is to investigate the influence of shallow soil deposits on the amplification of S-waves in the northern provinces of the Netherlands, near the gas-fields. On the records of the borehole stations with a geophone near the surface, amplification effects in the upper soils are often clearly observed, especially in the upper 25 m. Normally, a one-dimensional modelling of the

earthquake response provides a good approximation for regular soil deposits. Two pilot studies were carried out to test this method, one in ZLV (Zuidlaarderveen) and one in FSW (Finsterwolde). Here, site geotechnical investigations are performed to determine accurate soil parameters, layer thickness, density, shear wave velocity and damping. Comparison of the measured amplification function from local earthquakes in the upper layers with the theoretical amplification function, based on a one-dimensional geomechanical method shows a high degree of agreement up to 20 Hz.

Seismic hazard analysis

Haak, de Crook, Dost

Information on seismic hazard was given on request (about 25 times) to the national industry and authorities, for national en international projects on the design and safety of constructions.

Improvement of automatic analysis of seismic waveform data using wavelets

Dost, Van Eck, Sleeman

The evolution of seismic monitoring systems towards real-time ('live') seismic data collection over Internet opens new perspectives in automatic analysis of seismic waveform data. Automatic detection of seismic energy and the identification of phases are crucial in any automatic, real-time alert system. Automatic locations are mostly based on P-phase onset times, whereas S-phase onset times are crucial for accurate depth estimates. A wavelet-based technique to automatically estimate S-phase onset times at a single 3-component broadband station was developed in co-operation with the Centre for Mathematics and Computer Science (CWI) in Amsterdam. The technique automatically reveals the distance range of the earthquake (local, regional or global) in an efficient way, and is developed to be implemented in a real-time seismic data collection system.

Infrasound

Haak, Evers, Looman, Jansen

The Seismology Division operates three infrasound arrays, of which two small six-element arrays are in De Bilt and Witteveen, where electret microphones are used as sensors. During 1999 the Deelen Infrasound Array (DIA) has been installed and its capabilities have been demonstrated in 2000 to the Royal Netherlands Airforce who supported the so-called 'sonic boom' project. The sixteen in-house developed microbarometers, the array configuration and wind noise reduction were major topics of research and development. Combining the recordings from DIA with infrasound data from De Bilt and Witteveen leads to accurate source detection and identification of e.g. sonic booms, exploding meteors and microbaroms. Microbaroms are almost continuous noise signals with periods near 6 seconds that are generated by interfering ocean waves. The recordings not only contain information on the source but also on the atmosphere through which the infrasonic energy travelled. Together with University of Utrecht a master thesis was carried out with the aim to

improve understanding of acoustic wave propagation through the atmosphere. This research will be continued in an interdisciplinary approach, because of its dependence on seismological and meteorological knowledge. This unique combination has already been proved useful in supporting the investigations related to the disastrous S.E. Fireworks' explosions in Enschede on 13 May 2000 by an accurate timing of the events. Interdisciplinary research on an exploding meteor proved to be of CTBT interest, since the energy of the meteor was within the range of nuclear explosions.

EC-project PALEOSIS

Dost, Evers

The PALEOSIS project stands for evaluation of the potential for large earthquakes in regions of present day low seismic activity in Europe. In this project the occurrence of palaeo-earthquakes is evaluated. Palaeo-earthquakes are large magnitude earthquakes with a recurrence exceeding the historical period used in hazard evaluation. Therefore, knowledge of palaeo-earthquakes is important for hazard estimates of the Netherlands and its surroundings.

Natural seismicity in the Netherlands is mainly restricted to the Roer Valley Graben in the Southern part of the Netherlands. The Peel boundary fault borders the graben to the North and is expected to have shown activity during the Quaternary. Near the village of Neer (Limburg) a site at the Peel boundary fault for palaeo-seismological research was identified through an extensive geophysical campaign (ground penetrating radar measurements, electrical tomography and seismic reflection/refraction surveys). Trenching across the Peel boundary fault enabled a detailed geological interpretation of the sediment structures on both sides of the fault. Considerable displacements were found, indicating the occurrence of palaeo-earthquakes. Only rough estimates of occurrence time (10 to 20 kyears ago) and magnitude (6-6.5) could be obtained due to the uncertainties in this study. Knowledge of the lateral extension of the observed phenomena (i.e. displacements) could confirm the preliminary results.

EC-project ASPELEA

Haak, Dost, Van Eck, Dineva

The ASPELEA (Assessment of Seismic Potential in European Large Earthquake Areas) project lasted from October 1997 till June 2000. Scientists from Albania, Bulgaria, Greece, Italy, Netherlands, Romania and Russia participated in different approaches to seismic hazard assessment. The Seismological Division of KNMI in co-operation with the University of Utrecht studied Probabilistic Seismic Hazard Assessment (PSHA) methodologies, sensitivity analysis and re-assessment of earthquake magnitudes. Preliminary PSHA and sensitivity analysis performed for two test areas, the Gulf of Corinth in Greece and the Kresna region in Bulgaria, showed that improved seismotectonic models are crucial. Consequently, magnitude re-evaluations of large earthquakes, tomography inversions and stress tensor inversions have been made with the aim to improve the seismotectonic model for the Kresna region. The results are presently being summarised in scientific papers.

EC-Project MEREDIAN

Van Eck, Dost, Sleeman, Evers, Goutbeek

The last five years we have seen an exponential increase of the number of digital broadband seismograph stations in Europe and the Mediterranean area. Observing the rapid developments in communication technologies and substantial improvements in hard- and software we realised that the Orfeus Data Centre (ODC) operations need a significant upgrading in the next few years. Therefore, we applied and received funding for a 'Support for Research Infrastructure' EC-project MEREDIAN. The project started November 1, 2000, involves 10 European countries, most of them national seismograph networks, and is co-ordinated by the Seismology Division of KNMI.

MEREDIAN, an acronym for Mediterranean-European Rapid Earthquake Data Information and Archiving Network, aims at three major improvements with respect to earthquake waveform data exchange and storage in Europe and the Mediterranean area. Firstly, fast exchange (real-time) of data through Internet and satellite communication. Secondly, secure data archival and efficient access to these archives for the research community. Thirdly, develop software enabling effective viewing, searching and mining of earthquake waveform data.

ORFEUS

Dost, Van Eck, Sleeman, Evers, Goutbeek

Observatories and Research Facilities for EUropean Seismology (ORFEUS) continued its development in 1999 and 2000. Its aim is to co-ordinate and promote broadband seismology in the European-Mediterranean area. ORFEUS and its core activity, the Orfeus Data Centre (ODC), maintained their significant position within the global scientific seismological community. An important step forward has been the EC funding of a 'Support for Research Infrastructure' project named MEREDIAN, co-ordinated by the Seismology Division. This project started November 2000 and is aimed at improving the seismological data exchange in Europe. During 1999 and 2000 new institute participants have been recruited, bringing the total presently at 52.

Four working groups (Station siting, Technical assistance, Mobile equipment and Seismological Software), the ORFEUS Executive Committee and its five half-time staff members (at KNMI) have been the main driving force behind a successful web site (http://orfeus.knmi.nl) and many different international activities. The ORFEUS Seismological Software Library (SSL) remains the global source for shared software within seismology. Two ORFEUS workshops have been organised, one co-ordinating Java and CORBA (Common Object Request Broker Architecture) developments in seismology, spring 2000 in Nice, France, and one on seismometry, autumn 2000 in Rome, Italy. This last workshop was partly funded by United Nations Educational, Scientific and Cultural Organisation (UNESCO). Work meetings and many presentations at conferences and workshops have been given to further improve and broaden the ORFEUS activities.

ORFEUS Data Centre (ODC)

Dost, Van Eck, Sleeman, Evers, Goutbeek

The growing number of broadband seismograph stations within the European-Mediterranean area is having a major impact on the ODC operations.

With a rapidly growing archive, new innovative procedures for data quality checks, data exchange and on-line availability needed to be developed.

Presently, the ODC is focussing its activities on data archive and exchange improvements and pursuing a distributed European archive of earthquake waveform data. These developments are internationally co-ordinated, among others, within the Federation of Digital Seismograph Networks (FDSN). At the end of 2000 the ODC offers 24 Gbyte quality controlled data on 37 CD-ROM volumes, on-line (ftp://orfeus.knmi.nl and http://orfeus.knmi.nl) access to 'rapid' global SPYDER (waveform collection and exchange system) waveform data (20 Gbyte), all quality controlled European-Mediterranean ODC-volumes (34 Gbyte) and Near Real Time waveform SEED (Standard for the Exchange of Earthquake Data) data (6 Gbyte).

Articles, published in standard journals:

1999 Eck, T. van and B. Dost, 1999. *Orfeus, a European initiative in broad-band seismology; status and future plans*. Phys. Earth Plan. Int., **113**, 45-55.

Sleeman, R. and T. van Eck, 1999. *Robust automatic P-phase picking: An on-line implementation in the analysis of broad-band seismogram recordings*. Phys. Earth Plan. Int., **113**, 265-275.

2000 Sleeman, R., H.W. Haak, M.S. Bos and J.J.A. van Gend, 2000. *Tidal tilt observations in the Netherlands using shallow borehole tiltmeters*. Phys. Chem. Earth, Part A, **25**, 4, 415-420.

Reports and conference proceedings:

1999 Eck, T. van (Ed.), 1999. *Orfeus Electronic Newsletter*, **1**, no. 1, 2, 3.

Eck, T. van, B. Dost, R. Sleeman and L. Evers, 1999. *Orfeus and its European-Mediterranean Waveform Data Center*. In: Proceedings Third Int. Conf. Seismology and Earthquake Engineering, May 1999, Teheran, Iran, **I**, 165-173.

Haak, H.W. and B. Dost, 1999. *Aardbevingen in Noord Nederland in 1998*. KNMI Technical Report TR-**189**.

2000 Dost, B. and L.G. Evers, 2000. *Site selection and interpretation of trenching results along the Peel boundary fault*. In: Workshop Proceedings (PALEOSIS), Han-sur-Lesse, Belgium, 53-56.

Evers, L.G. and H.W. Haak, 2000. *The Deelen Infrasound Aray: on the detection and identification of infrasound*. KNMI Technical Report TR-**225**.

Evers, L.G., H.E. de Bree, H.W. Haak and A.A. Koers, 2000. *The Deelen Infrasound Array for recording sonic booms and events of CTBT interest*. In: Proceedings of the 9th Intern. Meeting on Low Frequency Noise and Vibration, Aalborg, Danmark, 39-46.

Evers, L.G. and H.W. Haak, 2000. *Explosies bij S.E. Fireworks – Enschede, 13 mei 2000*. KNMI Technical Report TR-**227**.

Haak, H.W. and C. Meester, 2000. *Seismisch netwerk Noord-Nederland*. KNMI Technical Report TR-**190**.

Number of national presentations: 1999: 13, 2000: 15.

Number of international presentations: 1999: 25, 2000: 22.

Externally funded projects: national 2, international 3.

Education, organization of workshops:
T. van Eck, organised the ORFEUS workshop on the use of Java in seismological applications, May 2000, Nice, France.
T. van Eck, organised the ORFEUS workshop on the installation and operation of seismic broadband stations, November 2000, Rome, Italy.
H.W. Haak, organised the TCBB workshop on gas-related earthquakes in the northern part of the Netherlands, November 2000, De Bilt, the Netherlands.

Other activities:
Th. de Crook, member Commissie Aardbevingen van het Nederlands Normalisatie Instituut.
B. Dost, member Coordinating Committee: Data Exchange and Centres (ILP).
B. Dost, member Gebruikerscie. STW Wavelets.
B. Dost, manager Orfeus Data Centre.
B. Dost, representative Orfeus in the Federation of Digital broad-band Seismograph Networks (FDSN).
B. Dost, chairman Working Group on Data Exchange of FDSN.
B. Dost, chairman ESC WG: Data centres and data exchange.
B. Dost, member Subcommission Bodembeweging en Zeespiegelvariatie van de Nederlandse Commissie voor Geodesie.
T. van Eck, secretary-general Observatories and Research Facilities for European Seismology (ORFEUS).
T. van Eck, Co-ordinator EC-project MEREDIAN (EVRI-2000-40007)
T. van Eck, secretary Working group 1 on station siting ORFEUS.
T. van Eck, secretary Working group 2 for technical assistance ORFEUS.
T. van Eck, secretary Working group 3 for mobile equipment ORFEUS.
T. van Eck, secretary Working group 4 Seismological software ORFEUS.
T. van Eck, member Working group 3 Seismological software Federation of Digital broad-band Seismograph Networks (FDSN).
H.W. Haak, member Commissie Internationaal ARA.
H.W. Haak, member WG B of the CTBT.
H.W. Haak, member International Association of Seismology and Physics of the Earth's Interior (IASPEI).
H.W. Haak, member Orfeus Board of Directors.
H.W. Haak, member TCBB Technische Commissie Bodembeweging.
H.W. Haak, member Beoordelingscommissie ALW-1; Diepe Ondergrond.
G. Houtgast, member Subcommission Bodembeweging en Zeespiegelvariatie van de Nederlandse Commissie voor Geodesie (until July 1, 1999).

G. Houtgast, member ESC Subcommission WG on Historical Earthquake Data (until September 1, 1999).
G. Houtgast, member ESC Subcommission WG on Macroseismology (until September 1, 1999).
R. Sleeman, titular member of the European Seismological Comission (ESC).
R. Sleeman, Dutch representative of the European-Mediterranean Seismological Centre (EMSC).

National and international policy related activities

Introduction • With the increasing awareness during the 1980s of a human influence on the Earth system, human induced climate change became an issue on the national and international political agenda. This led in 1992 to the adoption and ratification of the Framework Convention on Climate Change (FCCC) followed in 1997 by the adoption of the Kyoto Protocol. The international assessment of the scientific understanding of the climate system and natural and human induced climate change is the task of the Intergovernmental Panel on Climate Change (IPCC), established in 1988.

The Climate-Policy Support Unit of the Department lends scientific support to the development and implementation of the climate policy of the Dutch Government, both domestically and internationally. Initially KNMI represented the Ministry of V&W in the Dutch Delegation to the Bodies of the Climate Convention and participated in the actual policy making process. However, realising that scientific integrity is essential and that KNMI, as an independent advisor, should remain beyond any suspicion of being an active participant in the actual policy making and implementation process, the task of this Unit was redefined as recommended by the 1999 Review Board, and concentrated on providing solely scientific support to the Government. In accordance with this task, the Unit also supports the Netherlands representatives to the various bodies of IPCC.

It is essential that the Dutch society is well informed and understands the risks of human induced climate change and its consequences. The Department is in an excellent position to provide such information. It is the task of the Unit to organise informative meetings, to publish reports for the public at large, and to inform and assist the media, in close co-operation with KNMI's Public Relations Office.

Framework Convention on Climate Change (FCCC)

The Climate-Policy Support Unit provides scientific support to the Netherlands Delegations to the Bodies of the FCCC. A special event was the Sixth Conference of the Parties (CoP6), held in The Hague in November 2000 The conference chairman, the Netherlands' Minister of Housing, Spatial Planning and Environment, visited KNMI to be informed about the latest scientific insights in climate change. The Minister and Vice Minister of V&W were informed as well. KNMI contributed substantially to the special national scientific symposium that preceded CoP6. At this symposium scientific information was presented that formed the basis for the Netherlands' position at CoP6.

Intergovernmental Panel on Climate Change (IPCC)

The Head of the Department is the Netherlands' Principal Delegate to the Intergovernmental Panel on Climate Change (IPCC). He chairs the meetings of the national IPCC Co-ordination Group, which meets several times a year in order to co-ordinate IPCC related activities, to exchange information on IPCC related matters and to prepare the Plenary and Working Group Meetings. Dr. A.P. van Ulden, Head of the Atmospheric Research Division, is the Netherlands Focal Point for IPCC Working Group I (The Scientific Basis).

In this biennium, the IPCC Plenary met twice, in 1999 and 2000. The 1999 meeting mainly concerned the acceptance of the Summary for Policy Makers of the Special Report on Aviation, the formulation of the policy relevant scientific questions underlying the Third Assessment Synthesis Report and the planning of various IPCC reports in progress (Land Use, Land Use Change and Forestry, Emissions Scenario's, Technology Transfer and Third Assessment Report). Several KNMI scientists contributed prominently as author to the Special Report on Aviation, which was presented to the international aviation industry and policymakers as well as to the press at a symposium organised by KNMI and NLR (National Aerospace Laboratory) in Amsterdam in 1999. The Minister of V&W addressed this symposium. The 2000 meeting of the IPCC Plenary was largely dominated by the approval and acceptance of the Special Report on Land Use, Land Use Change and Forestry. In the course of 1999-2000 the Third Assessment Report (TAR) was written and reviewed, with contributions from thirteen Dutch Lead-Authors. The Review process was co-ordinated by the Unit. The TAR will be published in 2001.

Public information

Next to supporting the Government, an important task of KNMI and the Research Department is to provide reliable information on the climate issue to the Netherlands' society. To this end the Department produces special publications, maintains active relations with the Dutch press and media and organises or contributes to special meetings. Staff members frequently appear on national television. The Sixth Conference of the Parties in The Hague enhanced these activities. Here we mention also KNMI's highly praised fact sheet on climate and climate change, especially written for schools and for people with a general interest in climate and climate change.

Other activities:

A.P.M. Baede, member GCOS (Global Climate Observing System) Panel on Atmospheric Observations.
A.P.M. Baede, member of the CBS (Commission on Basic Systems) Working Group on Observations of the World Meteorological Organisation (WMO).
A.P.M. Baede, Netherlands Representative to IPCC.
A.P.M. Baede, representative of V&W in the Steering Group of the National Research Programme on global air pollution and climate change (NOP).
A.P.M. Baede, chairman of the Board of SRON (Netherlands Space Research Organisation).
A.P.M. Baede, chairman of the SRON Programming Committee on Earth Observation User Support.
A.P.M. Baede, member of the Council on Earth Sciences of the Royal Netherlands Academy of Arts and Sciences (KNAW).

M.I. Oosterman, Netherlands Representative (until November 1999) in FCCC – SBSTA (Subsidiary Body for Scientific and Technological Advise).
J. Verbeek, Netherlands Representative (from November 1999) in FCCC – SBSTA.
J. Verbeek, member of the informal group of National GCOS Focal Points.
J. Verbeek, Secretary of the Netherlands' Centre for Climate Research (CKO).

Model Support

Model Support

Cuijpers, Severijns

Introduction • KNMI participates in the Netherlands Centre for Climate Research (CKO) together with imau (Institute for Marine and Atmospheric Research Utrecht) and RIVM (National Institute of Public Health and the Environment). The primary aim of CKO is to improve co-ordination and co-operation among the participants in the field of climate research. Climate models are important tools in this research but, because of their complexity, they are difficult to use and maintain. Therefore, there was a need for support of models within CKO. A support group was established in April 1999.

The group ports the models to and tests them on the computing platforms that are used in CKO and makes them available to the scientists as a baseline version. In addition, the group improves the usability and user-friendliness of the models. This is done in several manners: by defining and maintaining a common software infrastructure for analysing climate and model data, by making improvements and extensions to the models that are relevant for the scientific community, and by guaranteeing continuity in knowledge about the models and their use.

Four models are currently supported: the global atmosphere model ECHAM4, the global ocean model OPA 8.1, the regional ocean model MICOM 2.7 and the coupled atmosphere-ocean model ECBILT.

Results • Work in the model support group consisted of the following activities.

- creation and maintenance of the CKO web site (http://www.knmi.nl/onderzk/CKO). The main purpose of this site is to provide easy access to the supported models and data analysis tools. Next to this, the site contains information about the models and provides links to important web sites with climate data and analysis tools.

- the porting and testing of the four supported models on all computing platforms used in the CKO. The installation of these models has been simplified and installation instructions for each of them are given on the web site.

- creation of a standard software infrastructure for the analysis of climate and model data. To improve the interoperability of models and tools, a standard data format was selected. The models were adapted to accept their input and create their output in this format. A software library was developed to simplify this task. This library is available at the CKO web site for people who want to

adapt models not supported by the model support group. To complete the common software infrastructure for analysing climate and model data, a number of analysis tools accepting the data format were selected. These include HIPHOP, a graphical user interface (GUI) based IDL programme, programme Ferret, a climate data analysis tool with a command-line and GUI, and OpenDX, a high-end scientific data visualisation tool.

The result of these activities is that the use of the supported models has been greatly simplified, enabling scientists to focus on the scientific problems they are studying.

This work was funded by the Ministry of Education, Culture ans Science in the framework of the Co-operation on Oceanic and Atmospheric Change Studies (COACh).

ECHAM4

The global atmospheric climate model ECHAM4 is available at several horizontal resolutions (T21, T30 and T42) with 19 vertical levels (with a model top at 10 hPa, about 30 km height) and at T30 with 39 levels. The latter version is known as MA-ECHAM, the middle-atmosphere ECHAM4 with its top at 0.01 hPa, corresponding to a height of about 80 km. The model runs on single processor computers as well as parallel computers. A database with ECMWF analyses is available to nudge ECHAM4.

An extensive tropospheric chemistry scheme, developed at IMAU, can be coupled to ECHAM4. The model is used to do multiyear simulations as well as case studies for specific periods of weeks to a few months. Software to extract specific data from the ECHAM4 output is available too.

OPA

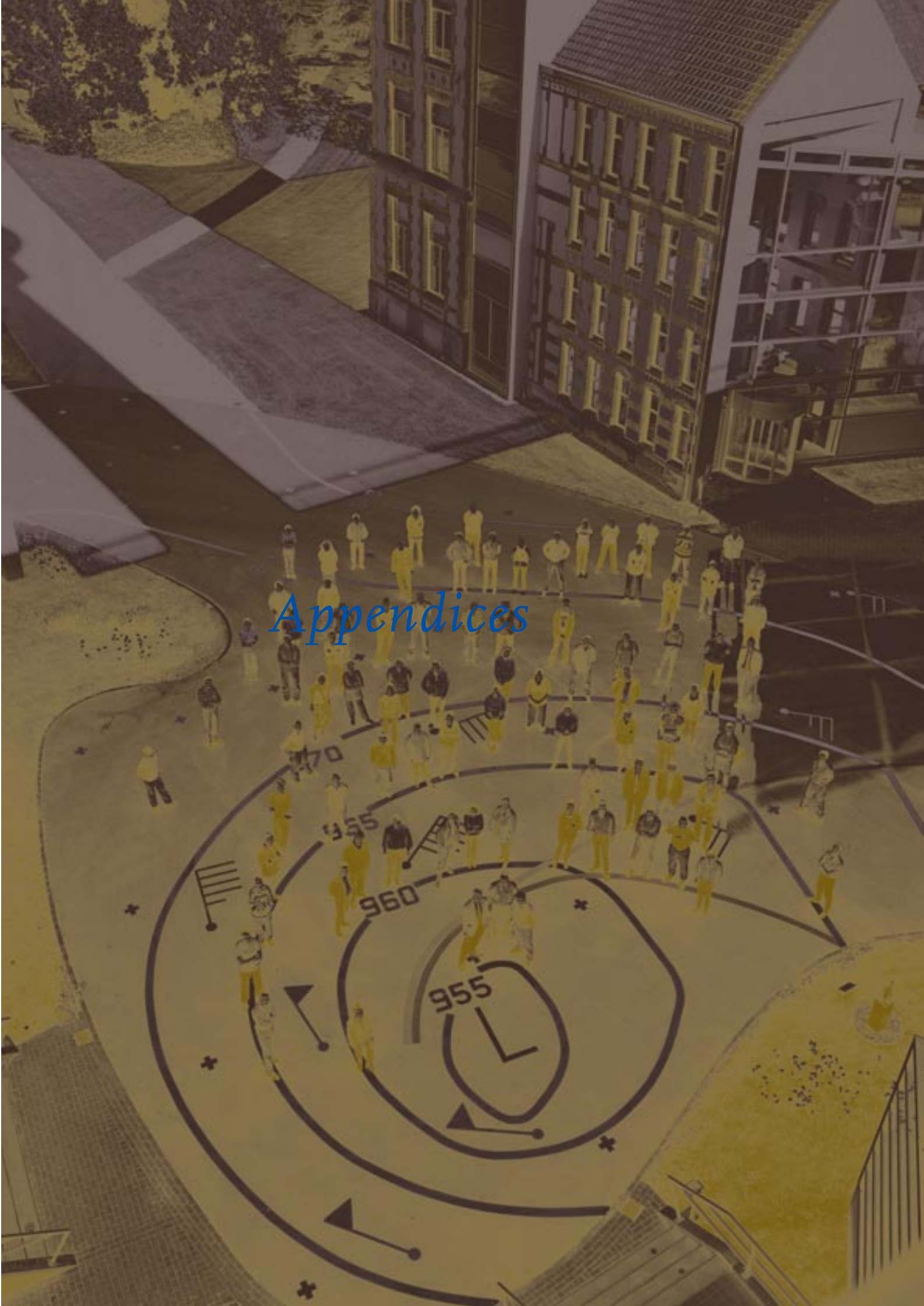
OPA (Océan PArallélisé) is an Ocean General Circulation Model (OGCM) which has been developed at the Laboratoire d'Océanographie DYnamic et de Climatologie (LODYC) to study large-scale ocean circulation and its interaction with the atmosphere and sea-ice. The model uses a grid with a resolution of either about four or two degrees in longitude and latitude and 31 layers. A version of the OPA model was made available that can run on single processor, multiprocessor and vector processor computers. A set of scripts to plot and analyse the model output was developed and added to the package.

MICOM

The Miami Isopycnic Coordinate Ocean Model (MICOM) is a regional isopycnic ocean model that aims at simulating thermodynamically and mechanically driven flow in realistic basins. Version 2.7 of this model was made available for single processor and vector processor computers with a global climatology data set from which input data for any part of the Earth's oceans can be created in an automated manner. The input and output facilities of the model were improved. The possibility to nudge to a prescribed state at the northern, southern, and sea surface boundaries was added to the model.

ECBILT

ECBILT is a spectral T21 global three level quasi-geostrophic atmosphere model with simple parameterisations for the diabatic processes. It can be coupled to an ocean model to study ocean-atmosphere dynamics on time scales of the order of thousand years. Two versions of the ECBILT model were made available: one for single processor computers and one for the Fujitsu vector computer at ECMWF.



Appendices

Appendices

The web site

Van Oldenborgh

Over the last few years the KNMI web site (www.knmi.nl) has grown into an important communication channel, also for Climate Research and Seismology. In fact, as the World-Wide Web was conceived at a science laboratory (CERN), it is ideally suited to the needs of the research groups at KNMI: large amounts of information can be made available to a wide audience using simple tools.

Audience • The target audience of the Climate Research and Seismology Department part of KNMI web site can be roughly divided into three groups with very different requirements. First there is the need to reach fellow scientists, to share the results of research undertaken at KNMI, show our publications and related (multimedia) material and make data sets available. Often scientists also post and discuss preliminary results within an international collaboration using the project or private home pages on the KNMI web site. The language of these web pages is invariably English and the amount of material quite large. They attract a relatively small number of highly interested visitors, who may transfer large amounts of data.

A second group that frequently searches the web site for information consists of pupils and students at all levels, from elementary school to university, looking for information for projects and papers. Other

interested members of the public also expect KNMI to provide accessible and authoritative information about climate and seismology. For these target groups we try to provide well-organised web pages in the Dutch language at a popular-science level, hyperlinked to the more advanced material discussed above. Colourful graphics are often highly appreciated.

Finally, certain topics suddenly have news value to a much wider audience. Examples are earthquakes, the ozone hole, climate change reports (IPCC), El Niño. In close collaboration with the public relations department a web page giving background information and links to the general information is then put on the research web site in conjunction with a news item on the front page.

Site layout • The departmental web pages can be reached via the KNMI home page, which prominently features 'Research'. This then forks into Applied Research, Climate Research, Policy Advice and Seismology. At the lower levels the divisions run parallel with the organisational structure: each division is responsible for presenting its own research. Some divisions have even delegated this further to individual projects. This scheme implies that the web site is maintained by a large number of web masters, each motivated to present her or his research to as wide an audience as possible and enabled by the simplicity of the web to do so. There is a policy that each page must be signed by its author, so that she/he can be contacted if questions arise about the content.

A downside of the distributed maintenance system is that the pages are made by design amateurs who normally stress content over form. Another problem is that key elements like the publication area (indices, abstract and content) and contact information are also decentralised. There are plans to improve upon this situation.

The site consists of approximately 2500 HTML pages (of which about 1000 have been automatically generated) and 100 postscript and PDF files. It is illustrated by 7500 images (many also automatically generated from measurements) and 10 movies. There are also about 100 CGI scripts, consisting of the publication search engine, a discussion board and one web application.

Visitor statistics • The web site of the Department serves about 100 000 pages per month, 3% of the total number transmitted by the KNMI web server (which has the weather forecast). In kilobytes the fraction is much higher, about one-quarter. The vast majority of visitors do not enter via the 'front door', but immediately access one of the informative pages deeper down in the hierarchy. The most popular section is seismology, which is responsible for 30-40% of the hits, 99% of which are the Dutch popular pages. (Note that these statistics exclude the traffic from the European seismology data exchange project ORFEUS, which operates its own server.) The number of visitors

fluctuates strongly with the number of earthquakes. Atmospheric Composition Research generates a lot of traffic on international collaborative projects (e.g., Sciamachy). Apart from that, the most-viewed pages are the publication areas of the different divisions. Another popular destination for visitors is the Climate Explorer, a web application that allows access to monthly historical climate data and allows for quick exploration of correlations among these data.

Future plans • The web site of the Climate Research and Seismology Department seems to fulfil its purposes quite well: to a large extent the main target groups seem to be served with the information they want. The navigation possibilities of the site can be improved. The main weak point is the scattered and sometimes incomplete publication service. Plans are being made to centralise this at the KNMI Library. An investigation is also being made into the possibility to separate form and content to improve upon the visual design while leaving the content under the responsibility of the authors.

Externally funded projects

Predictability Research

	Project title	Begin - end	Participants	Funded by
National	Climate variability on decadal time scale	1995 - 2000	Opsteegh, Haarsma, Weber, *Selten*	NOP
	Patterns of low-frequency climate variability: a model paleodata comparison	1997 - 2000	Weber, Können (Clim An), *Shabalova* (Clim An)	NOP
	Weather Analysis and Forecasting ('Appl Mod' is a Division of the Observations and Modelling Department.)	1998 - 2000	Verkley, Moene (Appl Mod), *Vosbeek*	BCRS
	ECBILT image-Defining Interactions and Feedbacks between Land Cover and Climate to Apply in an Integrated Assesment Model	1999 - 2002	Schaeffer	RIVM
	SEA LEVEL CLIMATE VAR.- Ocean-climate varibility and sea level in the North Atlantic region since AD 0	1999 - 2001	Van der Schrier, Weber, Drijfhout	NOP
	LANDGEBRUIK - Interactions between land use, atmospheric concentration of greenhouse gases and climate in Western Europe and their consequences for post-Kyoto options	1999 - 2001	Opsteegh, Weber, Haarsma, Selten	NOP
International	SINTEX - Scale Interactions Experiments	1998 - 2001	Opsteegh, Haarsma, Beersma (Clim An), *Timmermann*	EU

Oceanographic Research

	Project title	Begin - end	Participants	Funded by
National	Data assimilation for the estimation of salinity in the western Pacific	1995 - 1999	Burgers, *Vossepoel*	SRON
	Mechanisms for decadal variability in the formation of mode water	1994 - 1999	Drijfhout, *Hazeleger*	NWO
	Natural variability of the wind-driven ocean circulation	1996 - 2000	Drijfhout, *Katsman*	NWO
	The upper ocean in complex realistic climate models	1995 - 1999	Komen, *Bonekamp*	NOP
	Modelondersteuning CKO	1999 - 2001	Komen, Kelder, Severijns, Cuijpers	UvU-COACH
International	ASGAMAGE - Air Sea Gas and Aerosol Exchange Experiment	1996 - 1999	Oost, Jacobs	EU
	AUTOFLUX - An Autonomous system for monitoring air-sea Fluxes using the inertial dissipation method and ship mounted instrumentation	1998 - 2001	Kohsiek (Atm Res), Oost, van Oort, Worrell	EU
	Euroclivar - A Concerted Action for the co-ordination of CLIVAR-related research in Europe	1996 - 1999	Komen, *van Beers*	EU
	Intercomparison of the World Ocean wind and wave climatology from in-situ, voluntary observing, satellite and model data	1997 - 2000	Sterl	INTAS
	TRACMASS - Tracing the Water Masses of the North Atlantic and the Mediterranean	1998 - 2001	Drijfhout	EU

* The participants whose names are printed in italics are financed (wholly of partly) by the funding organisation. If a participant is a member of another Division than the Division associated with the table, the abbreviation of the participant's Division is given between parentheses. The full names of the funding organisations can be found in the list of acronyms.

Atmospheric Composition Research

	Project title	*Begin - end*	*Participants*	*Funded by*
National	DORAS - Development of O_3 profile Retrieval Algorithm Space-borne Spectrometer	1998 - 2000	Kelder, Van Velthoven, *Van Oss*	BCRS
	INDOEX - Indian Ocean Experiment	1996 - 2000	Kelder, *Stockwell*, *Zachariasse*, Van Velthoven	NWO
	NEONET - Netherlands Earth Observation Network; application: SCIAMACHY Data Centre	1997 - 2000	Piters, Stammes (Atm Res), *Koelemeijer* (Atm Res), *Valks*	BCRS, SRON
	OMI - Ozone Monitoring Instrument	1998 - 2008	*Levelt*, *Noordhoek*	EZ, V&W
	RADCHIS - Research on Atmospheric Dynamics and Chemistry in Surinam	1998 - 2002	Kelder, *Fortuin*	NWO
	Sciavalig validatie	1997 - 1999	Piters, Kelder, Timmermans	NIVR
	AERO-Aviation Emissions and Evaluation of Reduction Options	1998 - 2000	Meijer, Van Weele, Van Velthoven, Kelder	RLD
	Sciamachy Data Assimilatie	1999 - 2000	Eskes, El-Serafy	BCRS
	MEGGY-Monitoring Emissions of Greenhouse Gases using SciamachY	1999 - 2001	Van Velthoven, Van Weele	BCRS
	SCIAMACHY Validation Scientific Support	2000 - 2005	Piters, Timmermans, Van der Teems	NIVR
	SCIAMACHY Validation Meteorological Products	2000 - 2003	Piters, Timmermans	NIVR
	SCIAMACHY Validation Ozone Models		Piters, Eskes	NIVR
	STROPDAS-Satellite Remote Sensing for Ozone Prediction with Data Assimilation	1999 - 2000	Van Oss, Van Velthoven, Van Geffen	BCRS
	SASCIA-Studies of Assimilated Sciamachy data	1999 - 2003	Van Velthoven, Segers	SRON
	SCIARALI-Sciamachy Retrieval	2000 - 2001	Van Gent, Van Oss	SRON
	SCIAMACHY Validation UV Products	2000 - 2002	Piters, Van Weele	NIVR
	UFA1, 2Upper Troposheric Aerosol Formation	1999 - 2000	Van Velthoven, Meloen	
International	ACE - Atmospheric Chemistry Explorer	1998 - 2000	Kelder, Van Velthoven, *Van Weele*	ESA
	AEROCHEM - Modelling of the impact on ozone and other chemical compounds in the atmosphere from airplane emissions	1998 - 2000	Van Velthoven, *Pultau*	EU, University of Oslo
	ATOP - Atmospheric and Optical data Preprocessing reference chain	1997 - 1999	Kelder, *Piters*	ESA
	AVION - Study of airplane emissions	1997 - 1999	Van Velthoven, *Van Weele, Pultau*	RLD
	CARIBIC - Civil Aircraft for Remote Sensing and In-situ measurements in troposphere and lower stratosphere Based on the Instrumentation Container concept	1996 - 1999	Van Velthoven, *Cuijpers*	EU
	DARE - Data Assimilation in Readiness for ENVISAT	1997 - 1999	Kelder, Eskes	EU
	EULINOX - European Lightning Nitrogen Oxides Experiment	1998 - 1999	Van Velthoven, *Meijer*	EU
	GODIVA - GOME Data Interpretation, Validation and Application	1998 - 2000	Eskes, El Serafy	EU
	GOFAP - GOME Ozone Fast delivery and value-Added Products	1997 - 2000	Piters, Kelder, Scheele, Van der A, van Geffen, Valks	ESA
	OASE - Ozone Application Similator and Explorer	1996 - 1999	Kelder, Allaart, *Van der A*	EU

Ozone SAF - Satellite Application Facility for ozone data	1997 - 2002	Kelder, *Valks*, Van Oss, Van der A	EUMET-SAT
POLINAT - Pollution from Aircraft Emissions in the North Atlantic Flight Corridor	1995 - 1999	Kelder, *Meijer*, Van Velthoven	EU
SINDICATE III - Study of Indirect and Direct Influences on Climate of Anthropogenic Trace Gas Emissions	1998 - 1999	Kelder, Van Velthoven, Siegmund, Van Dorland (Atm Res), Scheele, Verver, *Fortuin, Straume*	EU
SODA - Studies of Ozone Distributions based on Assimilated Satellite Measurements	1996 - 1999	Kelder, Allaart, *Levelt, Eskes*	EU
STREAM III - Stratosphere-Troposphere Experiment by Aircraft Measurements	1998 - 2000	Van Velthoven, Siegmund, *Ambaum, Brunner*	EU
SUVDAMA - Scientific UV Data Management	1996 - 1999	Kelder, *Van Weele*	EU
TRACAS - Transport of Chemical species through the Subtropical tropopause	1997 - 1999	Siegmund, *Meloen*	EU

Atmospheric Research

	Project title	*Begin - end*	*Participants*	*Funded by*
National	Analysis and modelling of boundary layer clouds during ASTEX	1997 - 2000	Holtslag, *Lenderink*	NWO
	Antarctic mass balance modelling	1994 - 2002	Van Meijgaard, *van Lipzig*	NWO
	CARIS - Cloud Absorption Retrieval from the near IR-channels of SCIAMACHY	1998 - 2001	Stammes, *Knap*	SRON
	CLARA - Clouds And Radiation; Intensive experimental study of clouds and radiation in the Netherlands	1995 - 1999	Van Lammeren, Feijt, *Konings*	NOP
	Clouds products retrieval for MSG	1997 - 2000	Feijt, *Dlhopolsky*	BCRS
	Representation of the seasonal hydrological cycle in climate and weather prediction models in West Europe	1997 - 2001	Holtslag, *van den Hurk*	NOP
	SCIAPOL - SCIAMACHY Polarisation-correction and validation	1998 - 2001	Stammes, *Schutgens*	SRON
	Sensor Synergy Study for the ERM	1998 - 2001	Van Lammeren, *Bloemink*	SRON
	Shallow cumulus convection and its interaction with the atmospheric boundary layer	1998 - 2002	Siebesma, Jonker, Holtslag, *Neggers*	NWO
	Sunspot; Possible influence of variation in solar activity on the global climate	1997 - 1999	Van Ulden, van Dorland	NOP
	CM-SAF-Satellite Application Facility on Climate Monitoring	1999 - 2003	Feijt, Roebeling	EUMETSAT
	SCIAMACHY core validation	1999 - 2002	Stammes, Koelemeijer	NIVR
	CLOSAER-The effects of aerosol on closure of the regional short-wave radiation balance	1999 - 2001	Stammes, Knap, Henzing	NOP
	ZON & KLIMAAT	1999 - 2001	Van Dorland	NOP
International	Analysis of ERM Synergy by use of CLARA observations	1998 - 1999	Van Lammeren, *Donovan*	ESA
	AUTOFLUX - An Autonomous system for monitoring air-sea Fluxes using the inertial dissipation method and ship mounted instrumentation	1998 - 2001	Kohsiek, Oost (Ocea Res), van Oort (Ocea Res), Worrell (Ocea Res)	EU
	CLARE'98 - Cloud Lidar and Radar Experiment 1998	1998 - 1999	Van Lammeren	ESA
	NEW BALTIC II Energy and water cycle of the Baltic Sea catchment	1998 - 2000	Holtslag, van Meijgaard, *van den Hurk*	EU

Quantification of the Synergetic aspects of the ERM	1998 - 1999	Van Lammeren, *Donovan*	ESA
Validation Surface Scheme	1998 - 1999	Holtslag, *van den Hurk*	ECMWF
ERM-Imager	1999 - 2000	Beysens, Feijt, Jolivet, Van Lammeren, Mebold	ESA
CLIWA-NET-BALTEX Cloud Liquid Water Network: CLIWA-NET	2000 - 2003	Van Lammeren, Jolivet, Bloemink	EU
GOME-Delta validation	1999 - 1999	Stammes, Schutgens	ESA
EUROCS-European Project on Cloud Systems in Climate Models	2000 - 2003	Siebesma, Lenderink	EU

Climate Analysis and Scenarios

	Project title	***Begin - end***	***Participants***	***Funded by***
National	Patterns of low-frequency climate variability: a model paleodata comparison	1997 - 2000	Weber (Pred Res), Können, *Shabalova*	NOP
	Weather Generator for the Rhine basin	1997 - 2000	Buishand, Beersma, *Brandsma*	RIZA
	Neerslaggenerator Maasgebied	2000 - 2002	Wócjik, Buishand, Beersma	RIZA
	GCM Comparison-Climate projections for Europe: GCM intercomparisons and analysis of the predictability in practical and theoretical sense	2000 - 2001	Van den Brink, Doortmont, Opsteegh, Können	NOP
	IRMA-SPONGE- Integrated water management strategies for the Rhine and Meuse basins in a changing environment	1999 - 2001	Können	NOP
International	ECLAT-2 - European Climate Change Project - Concerted Action Initiative	1998 - 2001	Beersma	EU
	SINTEX - Scale Interactions Experiments (Opsteegh, Haarsma and *Timmermann* from Pred Res)	1997 -2000	Opsteegh, Haarsma, Beersma, *Timmermann*	EU
	WRINCLE - Water Resources: the Influence of Climate Change in Europe	1998 - 2000	Buishand, *Helmyr,* Beckman	EU
	SWURVE	2000 - 2003	Buishand, Shabalova	EU
	CLIWOC	2000 - 2003	Koek, Können	EU

Seismology

	Project title	***Begin - end***	***Participants***	***Funded by***
National	Sonic Boom	1998 - 2001	Haak, *Evers*	Klu
	Pilot experiment tiltmeters	1996 - 2001	Haak, *Sleeman*	EZ
International	PALEOSIS - Identification of paleoseismic events in low seismicity areas	1998 - 2000	Dost, *Evers*	EU
	ASPELEA - Assessment of Seismic Potential in European Large Earthquake Areas	1997 - 2000	Van Eck, *Dineva, Van der Meijde*	EU
	MEREDIAN-Mediterranean-European Rapid Earthquake Data Information and Archiving Network	2000 - 2003	Van Eck, Dost, Sleeman, Evers, Goutbeek	EU

Model Support

Project title	***Begin - end***	***Participants***	***Funded by***
Model support	1999 - 2001	*Cuijpers* (Atmos. Comp. Res) *Severijns* (Ocea. Res)	OCW

PhD-Theses

1999 Hazeleger, W., 1 February 1999. *Variability in Mode Water Formation on the Decadal Time Scale*. University of Utrecht, the Netherlands.

Lipzig, N.P.M. van, 6 October 1999. *The surface mass balance of the Antarctic ice sheet: a study with a regional atmospheric model*. PhD-Thesis, University of Utrecht, the Netherlands.

Veefkind, J.P., 11 October 1999. *Aerosol Satellite Remote Sensing*. PhD-Thesis, University of Utrecht, the Netherlands.

Bosveld, F.C., 3 November 1999. *Exchange processes between a Douglas fir forest and the atmosphere*. PhD-Thesis, University of Wageningen, the Netherlands.

Dorland, R. van, 15 November 1999. *Radiation and Climate. From Radiative Transfer Modelling to Global Temperature Response*. PhD-Thesis, University of Utrecht, the Netherlands.

Vossepoel, F.C., 16 November 1999. *Sea-level data assimilation for estimating salinity variability in the tropical Pacific*. Technical University of Delft, the Netherlands.

Verver, G.H.L., 29 November 1999. *Interactions of Chemistry and Turbulence in the Atmospheric Boundary-layer*. PhD-Thesis, University of Utrecht, the Netherlands.

2000 Jeuken, A.B.M., 10 May 2000. *Evaluation of chemistry and climate models using measurements and data assimilation*. PhD-Thesis, Technical University of Eindhoven, the Netherlands.

Schrier, G. van der, 12 October 2000. *Aspects of the Thermohaline Circulation in a simple model*. University of Utrecht, the Netherlands.

ElSerafy, G.Y., 31 October 2000, *'Data Assimilation in Particle models for Ground water Contamination'*. PhD-Thesis, Technical Universtity of Delft, the Netherlands.

Feijt. A.J., 29 November 2000. *Quantitative Cloud Analysis using Meteorological Satellites*. PhD-Thesis, University of Wageningen, the Netherlands.

Acronyms

3DVAR - Three-Dimensional Variational Data-Assimilation system
4DVAR - Four Dimensional Variational Data-Assimilation system

ACE - Aerosol Characterisation Experiment
ACE - Atmospheric Chemistry Explorer
ACIFORN - Acidification research on Douglas fir Forests in the Netherlands
ACW - Antarctic Circumpolar Wave
AGRS - Active GPS Reference System
ALW - Earth and Life Sciences section of NWO
AMSU - Advanced Microwave Sounding Unit
AOT - Aerosol Optical Thickness
ARM - Atmospheric Radiation Measurement program
ASGAMAGE - Air-Sea GAs exchange / MAGE project
ASPELEA - Assessment of Seismic Potential in European Large Earthquake Areas
ATSR - Along Track Scanning Radiometer
AutoDRM - Auto Data Request Manager
AVHRR - Advanced Very High Resolution Radiometer
AVIRIS - Airborne Visible and Infrared Imaging Spectrometer

BALTEX - Baltic Sea Experiment
BBC - BALTEX Bridge Cloud Campaign
BCRS - Netherlands Remote Sensing Board
BEM - Boundary Element Methods
BOREAS - Boreal Ecosystems Atmosphere Study
BP - Before Present

CAPRIX - Cabauw Profiler Intercomparison Experiment
CARL - Cloud Analysis from ground-based and airborne Radar and Lidar
CBS - Commission on Basic Systems
CCD - Charge Coupled Device
CCL - Commission for Climatology
CDC - Climate Data Centre
CDS - Cloud Detection System
CESAR - Cabauw Experimental Site for Atmospheric Research
CKO - Centre for Climate Research
CLARA'96 - Clouds and Radiation experiment in the Netherlands
CLARE - Cloud Lidar And Radar Experiment
CLIO - Coupled Large-Scale Ice Ocean Model
CLIVAR - Climate Variability and Predictability Research
CLIVARNET - Dutch contribution to CLIVAR
CLIWA-NET - BALTEX Cloud Liquid Water Network: CLIWA-NET
CLIWOC - Climate of the World's Oceans

CLOSAER - The effects of aerosol on closure of the regional short-wave radiation balance
CloudSat - Spaceborn Cloud Radar
CM-SAF - Satellite Application Facility on Climate Monitoring
COACh - Co-operation on Oceanic, Atmospheric and climate Change studies
COADS - Comprehensive Ocean Atmosphere Data Set
COP6 - Sixth Conference of the Parties of the UNFCCC (The Hague, November 2000 and Bonn, July 2001)
CORBA - Common Object Request Broker Architecture
COST - European Co-operation in the field of Scientific and Technical Research
COT - Cloud Optical Thickness
CRU - Climate Research Unit
CTBT - Comprehensive Test Ban Treaty
CWI - Centre for Mathematics and Computer Science
CWINDE - COST Wind Initiative for a Network Demonstration in Europe
CWP - Cloud Water Path

DAK - Doubling - Adding KNMI
DARE - Data Assimilation in Readiness for Envisat
DIA - Deelen Infrasound Array
DOAS - Differential Optical Absorption Spectroscopy
DORAS - Development of an Ozone profile Retrieval Algorithm from atmospheric Spectra
DU - Dobson Unit
DUV - damaging UV
DWD - German Meteorological Office

EarthCARE - Earth Clouds Aerosol Radiation Explorer
EC - European Commission
ECBILT - KNMI Intermediate-complexity Climate Model
ECBILT IMAGE - Defining Interactions and Feedbacks between Land Cover and Climate to Apply in an Integrated Assessment Model
ECC - Electrochemical cell
ECHAM4 - Hamburg version (number 4) of the ECMWF model
ECLAT - EU concerted action on Climate Change
ECMWF - European Centre for Medium-Range Weather Forecasts
ECN - Netherlands Energy Research Foundation
EDUCE - European Database for Ultraviolet radiation Climatology and Evaluation
EGS - European Geophysical Society
EMIC - Earth System Model of Intermediate Complexity
EMS - European Macroseismic Scale
ENSO - El Niño Southern Oscillation
EOF - Empirical Orthogonal Function
EOS - Earth Observing System
EPS - Ensemble Prediction System

ERA - ECMWF Re-Analysis
ERA15 - 15 year ECMWF Re-Analysis (covering the period 1997-1993, finished in 1996)
ERA40 - 40 year ECMWF Re-Analysis (covering the period 1958-2001, started in 2000)
ERM - Earth Radiation Mission
ERMAG - ESA Earth Radiation Mission Advisory Group
ERS - Earth Remote Sensing
ESA - European Space Agency
ESAC - Earth Science Advisory Committee
ET - Electrical Tomography
EU - European Union
EULINOCS - European Lightning Nitrogen Oxides Experiment
EUMETNET - European Network of National Meteorological Services
EUMETSAT - European Organisation for the Exploitation of Meteorological Satellites
EUROCS - European project On Cloud Systems in climate models

FCCC - Framework Convention on Climate Change (of the United Nations)
FDSN - Federation of Digital Seismograph Networks
FMI - Finnish Meteorological Institute
FRESCO - Fast Retrieval Scheme for Clouds from the Oxygen A-band
FSW - KNMI-seismographstation Finsterwolde

GAW - Global Atmospheric Watch
GCM - General Circulation Model
GCOS - Global Climate Observing System
GCSS - Gewex Cloud System Studies
GEWEX - Global Energy and Water Cycle Experiment
GFDL - Geophysical Fluid Dynamics Laboratory
GIS - Geographic-Information System
GKSS - Research Center Geesthacht
GODIVA - GOME Data Interpolation Validation and Application
GOFAP - GOME Fast Delivery and Value-added Products
GOME - Global Ozone Monitoring Experiment
GOOS - Global Ocean Observing System
GPR - Ground Penetrating Radar
GPS - Global Positioning System
GSFC - Goddard Space Flight Center
GUI - Graphical User Interface

HALOE - Halogen Occultation Experiment
HEXOS - Humidity Exchange over Sea
HGN - KNMI-seismographstation Heimansgroeve
HIRDLS - High Resolution Dynamics Limb Sounder
HIRLAM - High Resolution Limited Area Model

HISKLIM - Historical Climate
HOPE - Hamburg Ocean Primitive Equation model

IDC - International Data Centre
IDL - Interactive Data Language
IGBP - International Geosphere Biosphere Programme
IHE - International Institute for Infrastructural, Hydraulic and Environmental Engineering
IMAU - Institute for Marine and Atmospheric Research Utrecht
IMS - International Monitoring System
INDOEX - Indian Ocean Experiment
IPCC - Intergovernmental Panel on Climate Change
IR - Infra Red
IRMA-SPONGE - Integrated water management strategies for the Rhine and Meuse basins in a changing environment
ISCCP - International Satellite Cloud Climatology Project
ITCZ - Inter-Tropical Convergence Zone
IWC - Ice Water Content
IWV - Integrated Water Vapour

JHD - Joint Hypocenter Determination

KLAROS - KNMI Local implementation of Apollo Retrievals in an Operational System
Klu - Royal Netherlands Airforce
KNAW - Royal Netherlands Academy of Arts and Sciences
KNMI - Royal Netherlands Meteorological Institute

LES - Large Eddy Simulation
LIDAR - LIght Detection And Ranging
LITFASS - Lindenberg Inhomogeneous Terrain Fluxes between Atmosphere and Surface: a long term study
LODYC - Laboratoire d'Océanographie Dynamic et de Climatologie
LUT - Look-up tables
LWP - Liquid Water Path
LWS - Liquid Water Sensor

MA-ECHAM - Middle-atmosphere version of ECHAM 4
MA-ECHAM 4/CHEM - Middle Atmosphere European Centre – Hamburg Climate Model with Interactive Chemistry
MARE - Mixing of Agulhas Rings Experiment
M_b - Body-wave Magnitude
MDS - Meteorological Service of Suriname
MEREDIAN - Mediterranean-European Rapid Earthquake Data Information and Archiving Network
MetClock - METEOSAT Cloud Detection and Characterisation KNMI

MICOM - Miami Isopycnic Co-ordinate Ocean Model
M_L - Local Magnitude
MLS - Microwave Limb Sounder
MODTRAN - Moderate Resolution Transmission Radiative Transfer Model
MOM - Modular Ocean Model
MPI Hamburg - Max Planck Institute for Meteorology, Hamburg
MPI-Mainz - Max Planck Institute for Chemistry in Mainz
MPN - Research Platform Meetpost Noordwijk
M_s - Surface-wave Magnitude
MSG - METEOSAT Second Generation
MSSA - Multivariate Singular Spectrum Analysis
MST - Mesosphere Stratosphere Troposphere
M_w - Moment Magnitude

NADW - North Atlantic Deep Water
NAO - North Atlantic Oscillation
NASA - National Aeronautic and Space Administration
NASDA - National Space Development Agency of Japan
NCAR - National Centre for Atmospheric Research
NCEP - National Centers for Environmental Prediction
NDSC- Network for Detection of Stratospheric Change
NILU - Norwegian Institute for Air Research
NIOZ - Netherlands Institute for Sea Research
NITG-TNO - Netherlands Institute of Applied Geosciences-TNO
NIVR - Netherlands Institute for Aviation and Space Research
NLR - National Aerospace Laboratory
NOAA - National Oceanic and Atmospheric Administration
NODC - National Oceanographic Data Committee
NOP - National Research Programme on global air pollution and climate change
NRP - National Research Programme on Global Air Pollution and Climate Change
NRT - Near Real Time
NWO - Netherlands Organisation for Scientific Research
NWP - Numerical Weather Prediction

OASE - Ozone Application Simulator Explorer
OCCAM - high resolution ocean general circulation model
OCW - Ministry of Education, Culture and Science
ODC - ORFEUS Data Centre
OGCM - Ocean General Circulation Model
OI - Optimum Interpolation
OMI - Ozone Monitoring Instrument
OPA - Océan Paralléllisé, an ocean general circulation model developed at LODYC
ORB - Observatoire Royal de Belgique

ORFEUS - Observatories and Research Facilities for EUropean Seismology
OSAB - OMI Science Advisory Board
OST - OMI Science Team
OxComp - Reactive Oxygen Comparison

PA - Pressure Anemometer
PAGES - Past Global Changes
PALEOSIS - European project on Palaeoseismology
PBF - Peel Boundary Fault
PDF - Probability Distribution Function
PE - Primitive Equations
PI - Principal Investigator
Picasso - Spaceborn Cloud/Aerosol Lidar
PIDCAP - Pilot Study of Intense Data Collection and Analysis of Precipitation
PMIP - Palaeo Modelling and Intercomparison Project
PML - Plymouth Marine Laboratory
POPSICLE - Production of Precipitation Scenarios for Impact Assessment of Climate Change in Europe
PSC - Polar Stratospheric Clouds
PSHA - Probabilistic Seismic Hazard Assessment
PV - Potential Vorticity

QBO - Quasi-Biennial Oscillation

RACMO - Regional Atmospheric Climate Model
RADCHIS - Research on Atmospheric Dynamics and Chemistry in Surinam
RASS - Radio Acoustic Sounding System
RIVM - National Institute for Public Health and the Environment
RIZA - Institute for Inland Water Management and Waste Water Treatment
RLD - Dutch Civil Aviation Authorities
RRS - Royal Research Ship
RVG - Roer Valley Graben

SAF - Satellite Application Facility
SAMMOA - Spring to Autumn Measurements and Modelling of Ozone and Active species
SASCIA - Studies of Assimilated Schiamachy data
SBSTA - Subsidiary Body for Scientific and Technological Advice
SCA - Synergetic Cloud Algorithm
SCIAMACHY - Scanning Imaging Absorption Spectrometer for Atmospheric Cartography
SCIARALI - Development of a radiative transfer model for Schiamachy limb measurements
Sciavalig - SCIAMACHY Validation and Interpretation Group
SCOR - Scientific Committee on Oceanographic Research
SEED - Standard for the Exchange of Earthquake Data

SEVIRI - Spinning Enhanced Visible and Infrared Imiger
SHADOZ - Southern Hemisphere Additional Ozonesondes
SHDOM - Spherical Harmonics Discrete Ordinate Method
SINTEX - Scale Interactions Experiments
SIPS - Science Investigator Processing System
SMI - Swedish Meteorological Office
SODA - Studies of Ozone Distributions based on Assimilated satellite measurements
SOLSPA - Solar and Space Weather Euroconference
SPARC - Stratospheric Processes And their Role in Climate
SPYDER - Stands for a system to collect and exchange waveform data from globally distributed broadband seismic stations
SRON - Space Research Organisation Netherlands
SSAG - SCIAMACHY Science Advisory Group
SSL - Seismological Software Library
STACCATO - Influence of Stratosphere Exchange in a Changing Climate on Atmospheric Transport and Oxidation Capacity
STROPDAS - Satellite Remote Sensing for Ozone Prediction with Data Assimilation
SUVDAMA - Scientific Ultraviolet Data Management
SWURVE - Sustainable Water: Uncertainty, Risk and Vulnerability in Europe
SZA - Solar Zenith Angle

TAR - Third Assessment Report
TEBEX - Tropospheric Energy Budget Experiment
TEPS - Targeted Ensemble Prediction System
TES - Tropospheric Emission Spectrometer
TNO - Netherlands Organisation for Applied Scientific Research
TOGA-COARE - Tropical Ocean Global Atmosphere - Coupled Ocean Atmosphere Response Experiment
TOMS-EP - Total Ozone Mapping Spectrometer instrument on board the Earth Probe Satellite
TPD - Institute for Applied Physics of TNO
TRACAS - Transport of Chemical Species Across the Subtropical Tropopause
TRACMASS - Tracing the Water Masses of the North Atlantic and the Mediterranean
TRADEOFF - Aircraft emissions: contribution of different climate components to changes in radiative forcing
TSR - Along Track Scanning Radiometer

UFA - Upper Tropospheric Formation of Aerosol
UK - United Kingdom
ULFV - Ultra-Low Frequency Variability
UNEP - United Nations Environmental Programme
UNESCO - United Nations Educational, Scientific and Cultural Organisation
UNT - University of Newcastle uponTyne

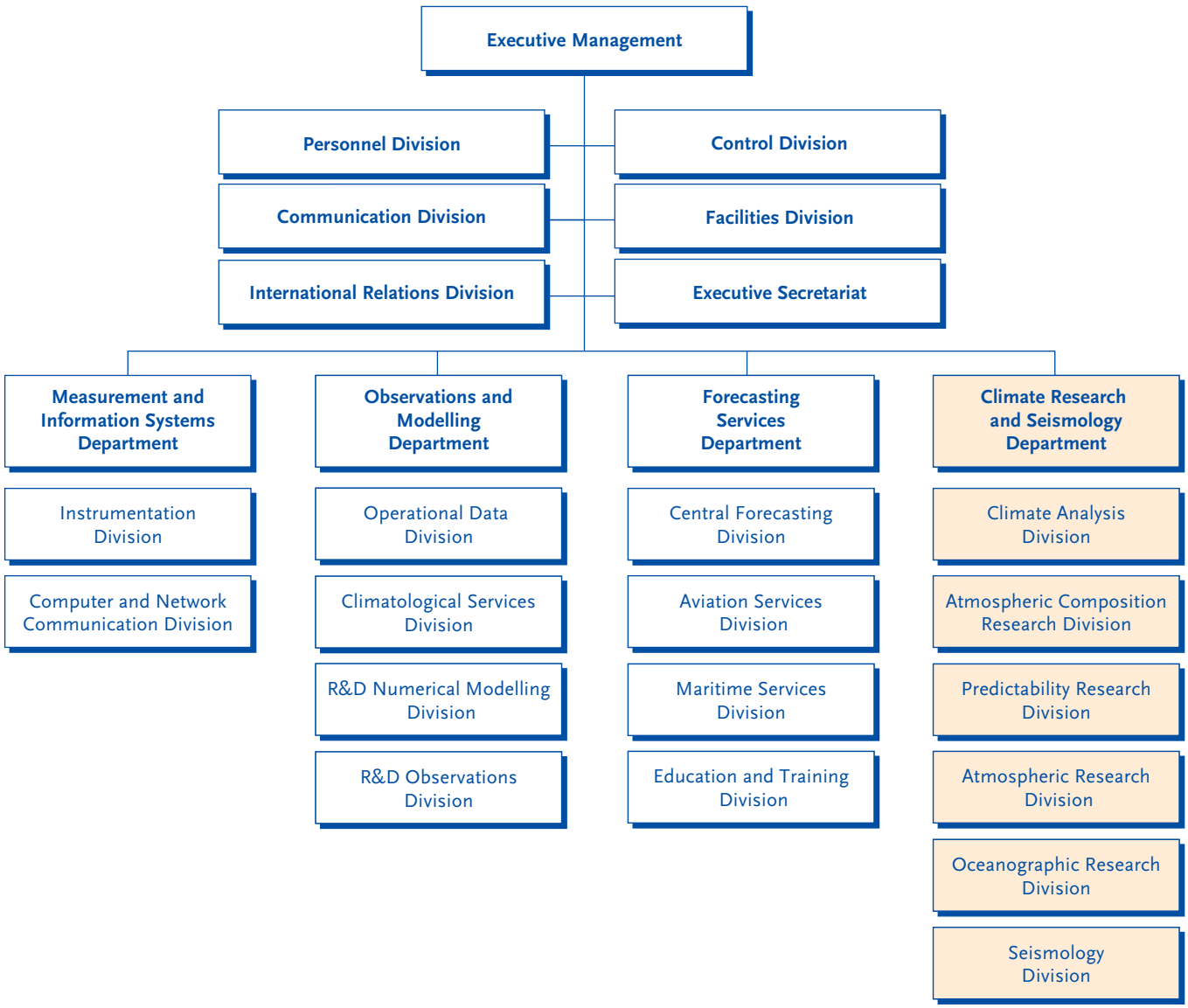
USA - United States of America
UV - Ultra Violet
UvU - University of Utrecht

VCP - Voluntary Co-operation Programme
VSP - Vertical Seismic Profiling
V&W - Ministry of Transport, Public Works and Water Management

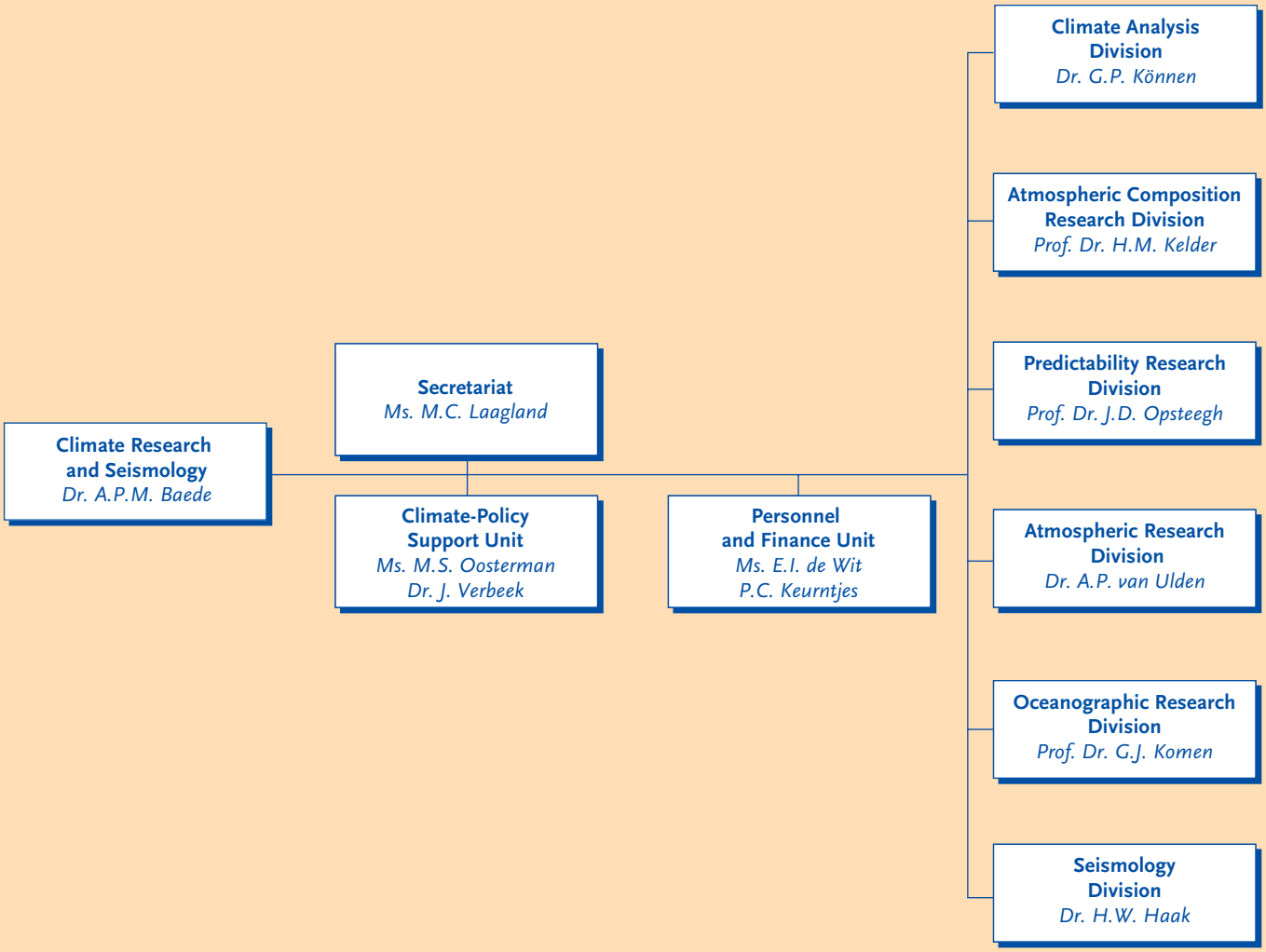
WBL - Wave Boundary-layer
WCRP - World Climate Research Programme
WF - Wave Follower
WIT - KNMI-seismographstation Witteveen
WMO - World Meteorological Organisation
WOCE - World Ocean Circulation Experiment
WOUDC - World Ozone and UV Data Centre
WRINCLE - Water Resources: the Influence of Climate Change in Europe
WTS - KNMI-seismographstation Winterswijk
WTSB - KNMI-seismographstation Winterswijk-B

ZLV - borehole seismic station Zuidlaarderveen

Organisational scheme
KNMI as from May 2001



Organisational scheme
Climate Research and Seismology Department



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