CLIMATE RESEARCH AND SEISMOLOGY DEPARTMENT

Biennial Scientific Report
2001–2002

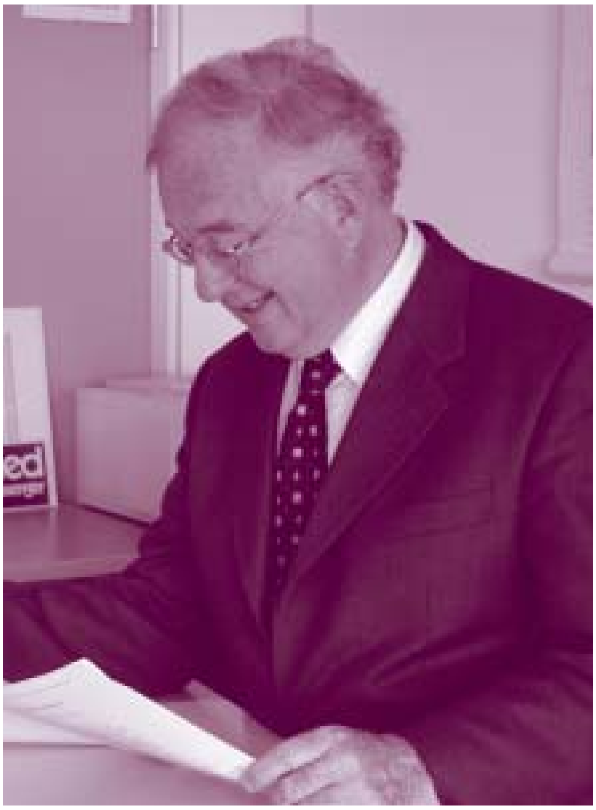
Contents

Preface • In 2001 the Intergovernmental Panel on Climate Change (IPCC) published its Third Assessment Report (TAR). It was concluded that "There is new and stronger evidence that most of the warming observed over the last 50 years is attributed to human activities". Moreover "Confidence in the ability of models to project future climate has increased". With these significant conclusions climate change continues to be an important issue on the scientific and political agenda.

Per September 2001 Prof. Gerbrand Komen became Head of KNMI's Climate Research and Seismology Department, succeeding Dr. Fons Baede, who retired. By continuating its own research and by participating in various national and international networks and programmes, the Department continued to contribute to further understanding of the global climate system.

It is with great pleasure that I present this fourth Biennial Scientific Report of the Department.

Prof. Dr. Joost de Jong
Director KNMI

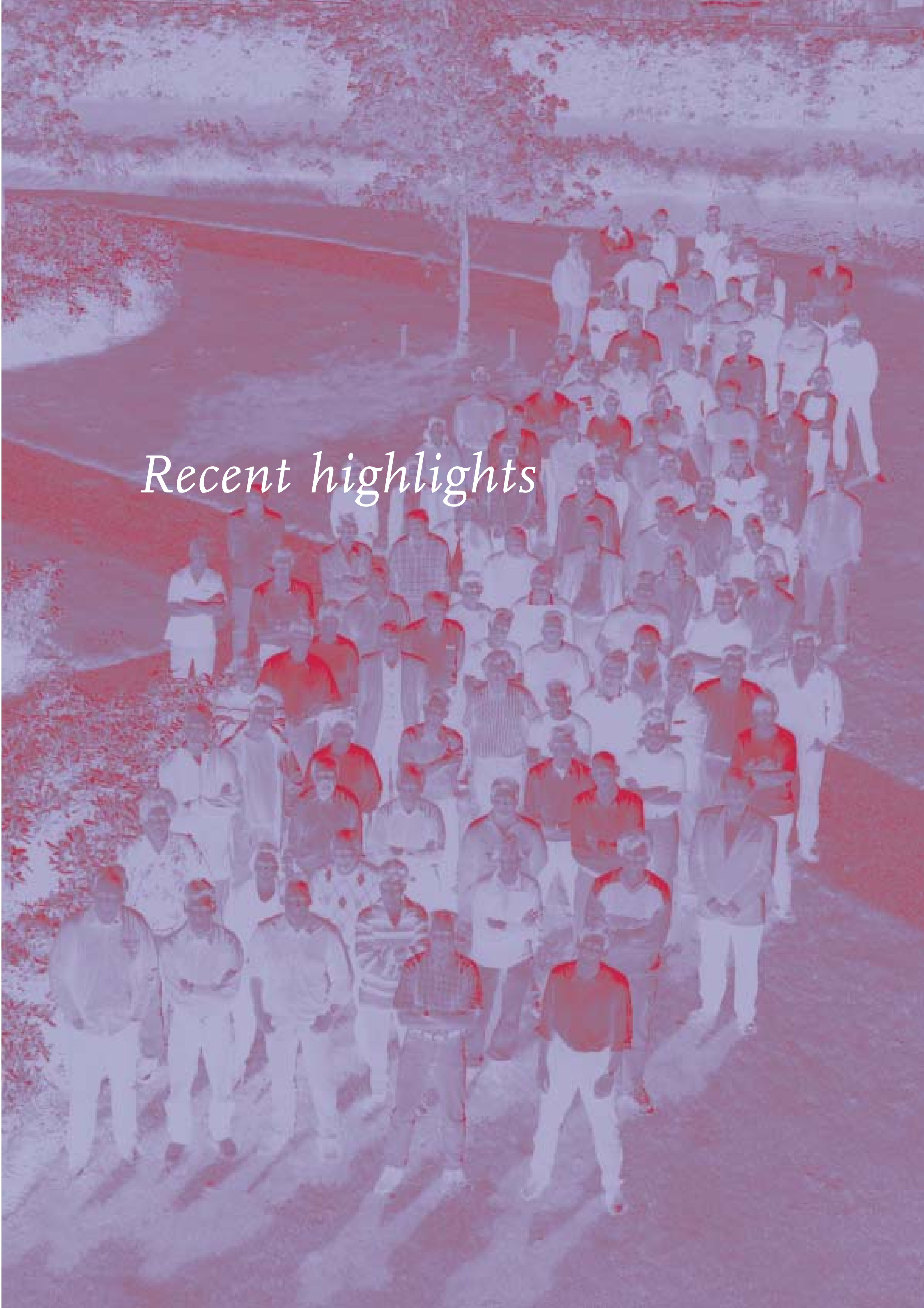


Foreword • KNMI has a long tradition in research of the atmosphere, the ocean and the solid earth. With the establishment of a separate Climate Research and Seismology Department in 1995 KNMI has focused most of its research on the issue of climate change. The climate research strategy developed over the years. The current programme is based on three criteria, namely 1) *the questions that KNMI receives from society;* 2) *the current scientific challenges in climate research*; and 3) *particular expertise available at KNMI*. The result is a programme centred around three broad themes, namely monitoring, understanding and prediction of climate variability and change. Work is carried out in a five specialised divisions, in close collaboration with other KNMI departments, and many national and international research institutes. To increase the coherence of the research programme a number of interdivisional projects was started in 2002. One of these will coordinate activities related to Monitoring of the Atmospheric Composition from Satellites, another is concerned with Patterns of Climate Variability, and a third deals with Regional Climate Prediction. At the end of 2002 these projects were in different stages of start-up.

The Seismology Division has both an operational and a research task. Operationally, it is responsible for the monitoring of seismic events. Its research programme focuses on seismic risk for both natural and induced events. In addition it has a programme on atmospheric infrasound and activities related to the implementation of the Comprehensive Nuclear-Test-Ban Treaty.

This fourth Biennial Report follows the format of earlier reports: three Recent Highlights are followed by Progress Reports of the different Divisions. We hope this gives a good and concise overview of our achievements.

Prof. Dr. Gerbrand Komen
Head of Climate Research and Seismology Department


Recent highlights

On the role of cirrus clouds in climate

by Dave Donovan

Introduction

Ice-containing clouds are globally distributed, they occur at all latitudes and in all seasons. Cirrus clouds, consisting predominantly of ice crystals, cover more than 20 % of the globe and play an important role in the Earth's radiation budget [1]. On one hand the presence of cirrus clouds can cause increased warming via trapping of infrared radiation (IR) emitted by the Earth's surface. Cirrus clouds also cause cooling because they reflect solar radiation (visible and ultraviolet light) back into space. Whether a given cirrus cloud has a net warming or cooling effect depends on its optical thickness, altitude (temperature) and microphysical properties. For high (and therefore cold) optically thin cirrus the warming effect is dominating. Cirrus clouds are not well treated in climate and forecasting models because of many uncertainties concerning their properties and the complex interactions between radiation, microphysics and dynamics in those clouds affecting their development and evolution [2]. Furthermore, General Circulation Model (GCM) simulations of the atmosphere are very sensitive to the assumptions about cloud ice [3]. Consequently, for reliable simulations of present and future climate, an accurate representation and understanding of ice cloud properties is essential. In order to realise this goal, systematic detailed measurements of ice cloud parameters are required.

Effective particle sizes in cirrus clouds

The sizes of cloud particles may lie between 5 and 50 microns. Of particular importance in determining ice cloud radiative properties is the effective radius (R_{eff}) of its constituent cloud particles. R_{eff} is one measure of the 'average-size' of these particles and determines the relationship between the total ice crystal mass and optical depth of the cloud. It also plays a large role in determining the appropriate phase function and degree of IR absorption (single-scattering albedo). For spherical cloud particles R_{eff} may be defined in terms of the radii of the cloud particles. For non-spherical ice particles the situation is more complex. However, we may usefully define R_{eff} in terms of the total mass and projected area of the ice crystals.

Lidar and Radar remote sensing • Over the past number of years, a new powerful method for estimating ice cloud radiative properties from combined lidar and radar data, including their particle effective radius, has been developed and tested at KNMI [4,5]. Lidar (Light Detection And Ranging) systems are similar in principle to Radar (Radio Detection and Ranging) systems and are often referred to as laser-radar systems. Both types of instruments transmit a pulse of electromagnetic energy and then detect the amount of energy that is scattered back to the receiver as a function of time. Since the speed of the signal is known, the time corresponding to a detected signal can be converted to range from the instrument and thus range-resolved profile measurements can be obtained. The key difference between lidars and radars is that radars operate at microwave frequencies and employ an antenna to transmit and receive signals while lidars operate at visible or IR frequencies and employ lasers and telescopes. Because of the difference in wavelength between lidar and radar the returns from cirrus clouds are not identical but are strongly dependent on the size of the particles. Loosely speaking, cloud radars tend to be most sensitive to the 'large' particles while lidars are relatively more sensitive to the 'small' particles. Thus, combined lidar and radar data give information on the particle size distribution and may be used to estimate R_{eff} in cirrus clouds.

Effective size parameterisation

To describe the effect of clouds on radiation a parameterisation of ice cloud particle effective radius is needed. Previous parameterisations are based largely upon observations made in-situ using aircraft mounted instrumentation. In-situ approaches have the advantage of being able to more-or-less directly measure the particle size distribution. However, it is difficult to obtain large in-situ data sets. Remote sensing methods, though less direct, give much better coverage in space and time. Lidars and radars sample entire cloud profiles instantaneously and may operate continuously for long periods of time. Thus, a more representative data set may be more easily obtained.

Data analysis • In order to investigate the morphology of ice cloud effective particle size the lidar/radar procedure has been applied to 7 months of continuous data from the United States Government Atmospheric Radiation Measurement's (ARM) Southern Great Planes (SGP) site situated in Oklahoma in the US [6].The lidar/radar procedure uses the ratio of the radar reflectivity profile along with the lidar derived extinction profile to measure the lidar/radar effective radius (R'_{eff}) of the ice particles along with the effective ice water content (IWC'). R'_{eff} is the lidar/radar effective radius and is similar in concept to R_{eff}. However, while R_{eff} is most useful in determining the scattering and absorption properties of the cloud particles in the visible and IR, R'_{eff} is most directly related to the relationship between the particles visible and microwave (radar) scattering properties. IWC' is related to IWC in a similar fashion and may be physically thought of as the amount of ice that would be present corresponding to a given radar signal if the cloud in question were composed of a number of solid ice spheres of uniform size. Both R_{eff} and IWC can be estimated from R'_{eff} and IWC' if assumptions concerning the modal nature of the particle size distribution along with the ice crystal habits present (i.e. plates, hex-columns, complex crystals) are made.

An example is shown in *Figure 1*. The data were acquired using the ARM Micro-Pulse Lidar operating at 532 nm and the ARM 35 GHz cloud

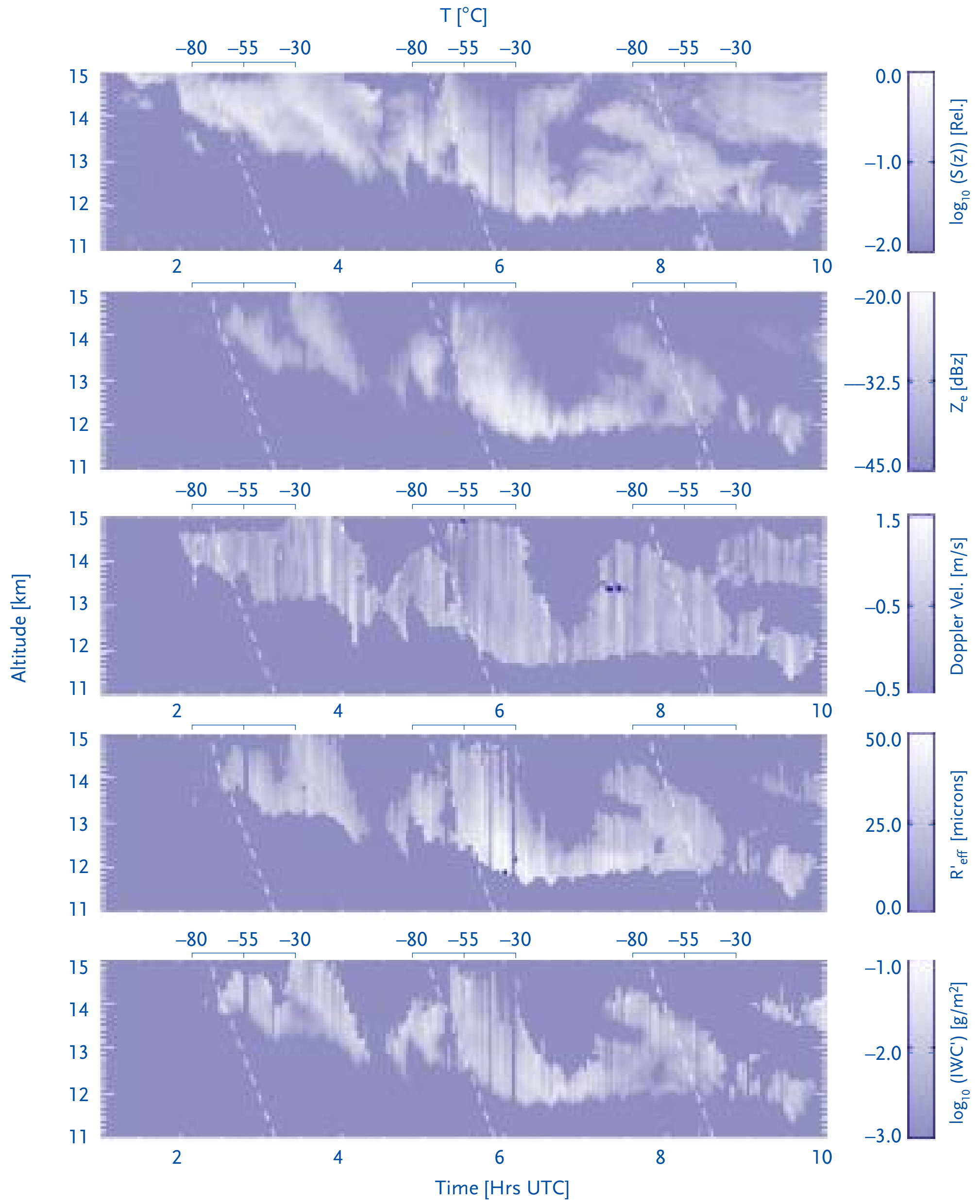


Figure 1. Lidar signal (top), Radar reflectivity (Ze), Doppler velocity and derived lidar/radar effective particle size (R'_{eff}) and effective Ice Water Content (IWC').

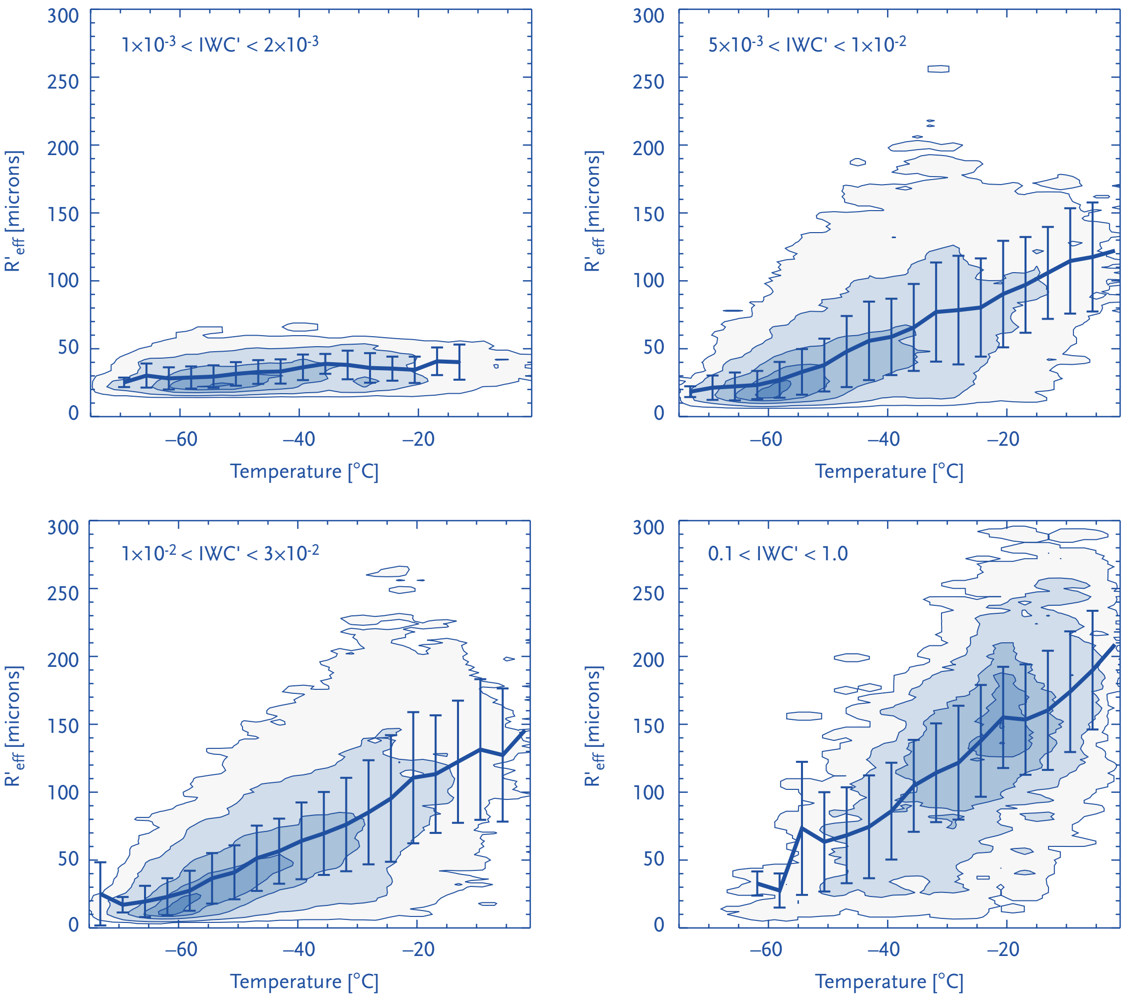


Figure 2. Lidar/radar effective particle size as a function of temperature for four different ranges of IWC'. The darkest contours contain 10% of the observations, followed by 30, 60, 90 and 99% of the observations within the specified IWC' ranges.

radar (for detailed instrument descriptions consult *http://www.arm.gov*). The data show the results of 10 hrs. of continuous measurements. The measured lidar signal, radar reflectivity, and radar Doppler velocity along with the derived R'_{eff} and IWC' are shown. Since the radar Doppler velocity of falling ice particles also depends in part on both R'_{eff} and R_{eff} radar Doppler velocity data may be used to aid the process of estimating R_{eff} and IWC from R'_{eff} and IWC'.

Results • The results of the data analysis applied to all the data is shown in *Figure 2*. Here R'_{eff} is presented as a function of temperature for four different IWC' ranges. The data show that at low values of IWC' the mean particle size does not strongly depend on temperature while at higher IWC' values the particle sizes become strongly correlated with temperature.
The exact physical reasons for this behaviour is, at present, not know but may be related in part to differences in formation and life-cycle mechanisms that dominate in different temperature regimes.

At higher IWC' values the particle sizes become strongly correlated with temperature

From aircraft in-situ measurements it is known that, in general, cirrus particle size distributions are multi-modal and may be described in terms of a small particle mode together with a large particle mode. The average R'_{eff} and radar Doppler velocity data were fitted to a model based on a bi-modal size distribution whose parameters were functions of the cloud IWC and temperature. The results were then used to build a general size distribution parameterisation whose parameters depend both on IWC and ambient cloud temperature. The predictions for the variation of the mean maximum ice crystal length for the large particle mode alone (D_l) may be compared directly to the results of previous in-situ based observations.

In *Figure 3*, our results for the predicted variation of D_l with temperature are compared with those from various sources. Our results depend on both IWC and temperature while the in-situ results shown here only take into account the variation with temperature. It can be seen that, for any given specific constant value of IWC, our results (thin pink lines) do not follow the exponential relationships that were noticed in previous studies. In particular

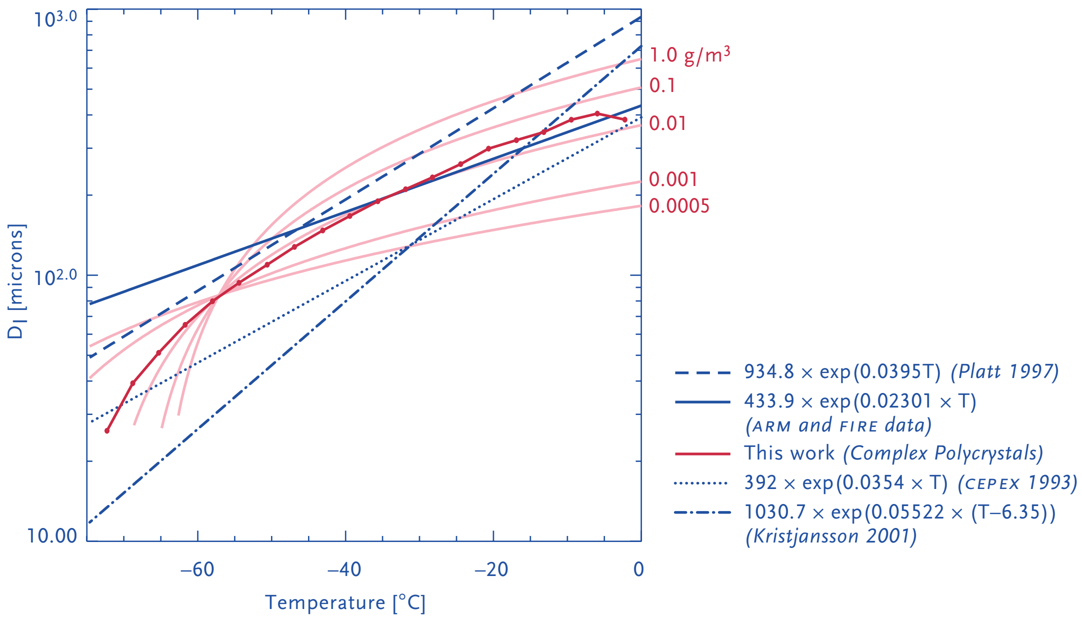


Figure 3. Thin pink lines: Predicted variation of D_l with temperature as predicted for various values of IWC (0.0005, 0.001, 0.01, 0.1, and 1.0 g/m³ from lowest to highest values at high values of temperature). Red line with dots: Predicted value of D_l at observed values of IWC corresponding to each temperature.

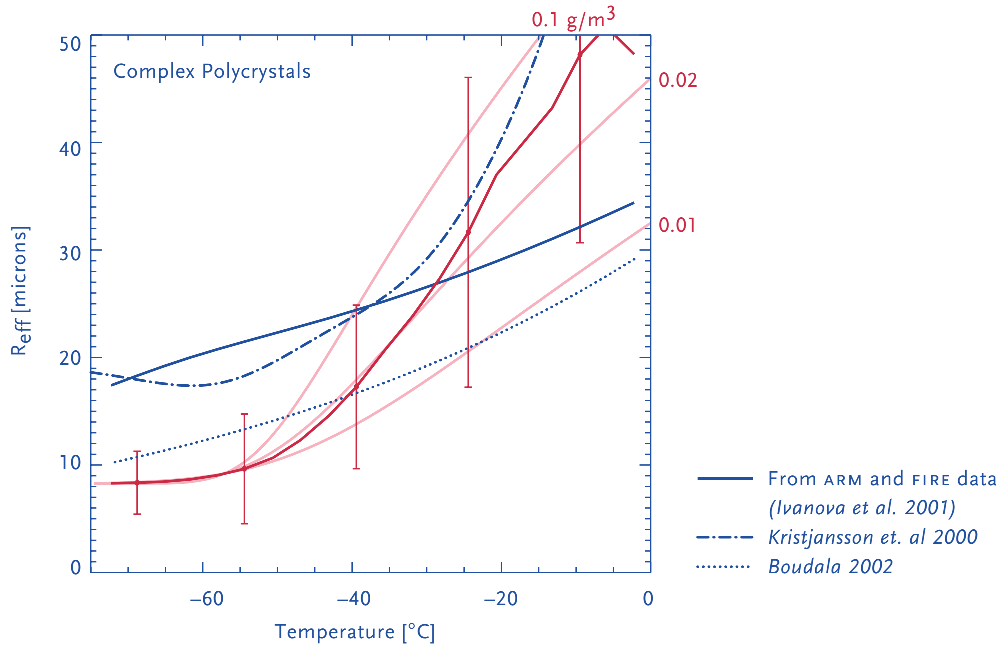


Figure 4. Average effective radius as a function of temperature derived from the ARM data set compared with three other published parameterisations, which only depend on temperature. The thin pink lines show the results or our parameterisation at three specific values of IWC while the red line shows the composite result taking into account the observed behaviour of the IWC-vs-Temperature present in the analysed data set.

for temperatures lower than –40°C the lines show a distinct curvature with slopes changing from large to small with increasing temperature. When averaged over IWC (solid line marked with + symbols) the same curvature is evident, although it appears that for larger temperatures (> –40°C) the average is (quasi-) exponential. These results depart from previous studies by demonstrating that IWC variations are an important factor determining the average effective particle sizes. Parameterisations based on simple exponential fits that do not account for variations in IWC are thus oversimplifications of reality.

In *Figure 4*, the average ice cloud effective radius as a function of temperature inferred from the ARM data is shown along with three other earlier published effective particle radius parameterisations based on in-situ data. By considering Figure 3 and 4, it can be seen that, in general, our results are within the range of previously published parameterisations. Further, our results indicate that the large differences sometimes present between the results of previous in-situ measurement based studies may be, in part, due to differences in the IWC values of the clouds that were sampled.

Conclusions

The results of this work have been used to formulate parameterisations of cirrus cloud effective particle radii and other relevant quantities that are suitable for inclusion in atmospheric models. This work strongly argues that in formulating ice-crystal size parameterisation both IWC and temperature should be taken independently into account. This is not a new idea, however, most current formulations are a function of temperature alone. This is due more to the limitations of current ice cloud schemes within GCMs rather than an accurate reflection of the character of the distributions found in nature. The final impact on accounting for cirrus radiative effects in atmospheric models of parameterising the particle size distribution in terms of both temperature and IWC as opposed to temperature alone is likely a fruitful area of further work.

The KNMI lidar/radar procedure is being applied to the analysis of various data sets including data acquired at Cabauw as part of the Cabauw Experimental Site for Atmospheric Research (CESAR) initiative. Work similar in nature to that described here is also being used to prepare for upcoming space-based missions that will be built around cloud lidars and radars. In particular, KNMI is actively involved in preparing for the CloudSat/Calypso (NASA) mission and is conducting research in support of the proposed ESA/NASDA Earth Clouds and Radiation Explorer (EarthCare) mission. These missions will combine the novel profile information available from lidars and radars with traditional passive cloud remote sensing instrument data on a global scale.

1) Arking, A, 1991. *The radiative effects of clouds and their impact on climate*. Bull. Am. Meteorol. Soc., **72**, 795–813.

2) Quante, M. and D.O'C Starr, 2002. *Dynamical processes in cirrus clouds: A review of observational Results*. In: Cirrus, Oxford University Press, New York, 346–374.

3) Jakob, C., 2002. *Ice clouds in numerical weather prediction models: progress, problems, and prospects*. In: Cirrus, Oxford University Press, New York, 327–345.

4) Donovan, D.P. and A.C.A.P. van Lammeren, 2001. *Cloud effective particle size and water content profile retrievals using combined lidar and radar observations, Part 1: Theory and examples*. J. Geophys. Res, **106**, 27,425–27, 448.

5) Donovan, D.P., A.C.A.P. van Lammeren, R.J. Hogan, H.W.J. Russchenberg, A. Apituley, P. Francis, J. Testud, J. Pelon, M. Quante and J. Goddard, 2001. *Cloud effective particle size and water content profile retrievals using combined lidar and radar observations, Part 2: Comparison with IR radiometer and in situ measurements of ice clouds*. J. Geophys. Res, **106**, 27,449–27,464.

6) Donovan, D.P. and A.C.A.P. Van Lammeren, 2002. *First ice cloud effective particle size parameterization based on combined lidar and radar data*. Geophys. Res. Lett., **29**, 10.1029/2001GL013731.

Pathways in the ocean

Pathways in the

by Sybren Drijfhout

Introduction

The properties of water masses in the ocean are set by air-sea interactions at the surface and convective overturning. As direct transfer of heat and salt to the deep ocean is not possible, to first-order approximation these properties do not change when in the interior ocean water masses are advected. The pathways followed by the water masses connect different regions of air-sea interaction in the world ocean. They are not confined to single ocean basins, but may extend over very long distances before the water is re-injected into the surface mixed layer. Through the connecting pathways in the ocean, air-sea interaction in one region can affect climate in another region. Analysing the oceanic pathways gives insight in the transports that play a critical role in the climate system and determine the stability of the present climate.

A complication is that water-mass properties do slowly change in the interior, because water-masses are mixed by small-scale processes. Still, one may trace water-mass parcels, but the properties of, for instance, North Atlantic Deep Water (NADW) gradually change while it is advected southward. The mixing rate of the water-mass is determined by two-dimensional turbulent advection and does not depend on the details of small-scale diffusion.

The thermohaline circulation (THC) is the large-scale circulation of the ocean driven by fluxes of heat and freshwater at the surface. The THC affects climate at decade-to-century timescales. The conveyor-belt hypothesis [1)] provides a useful concept for this circulation. Surface water cools and sinks in the northern North Atlantic, becomes NADW, and spreads southward into the deep ocean. It is replaced by warm surface water from the south that makes the European climate relatively warm. At various locations, upwelling connects the deep flow of NADW to a return flow of warm surface water, which closes the conveyor-belt *(Figure 1)*. Due to the lack of measured data, the structure of the conveyor-belt cannot be determined directly from observations, but it can be investigated in a comprehensive ocean general circulation model (OGCM) by

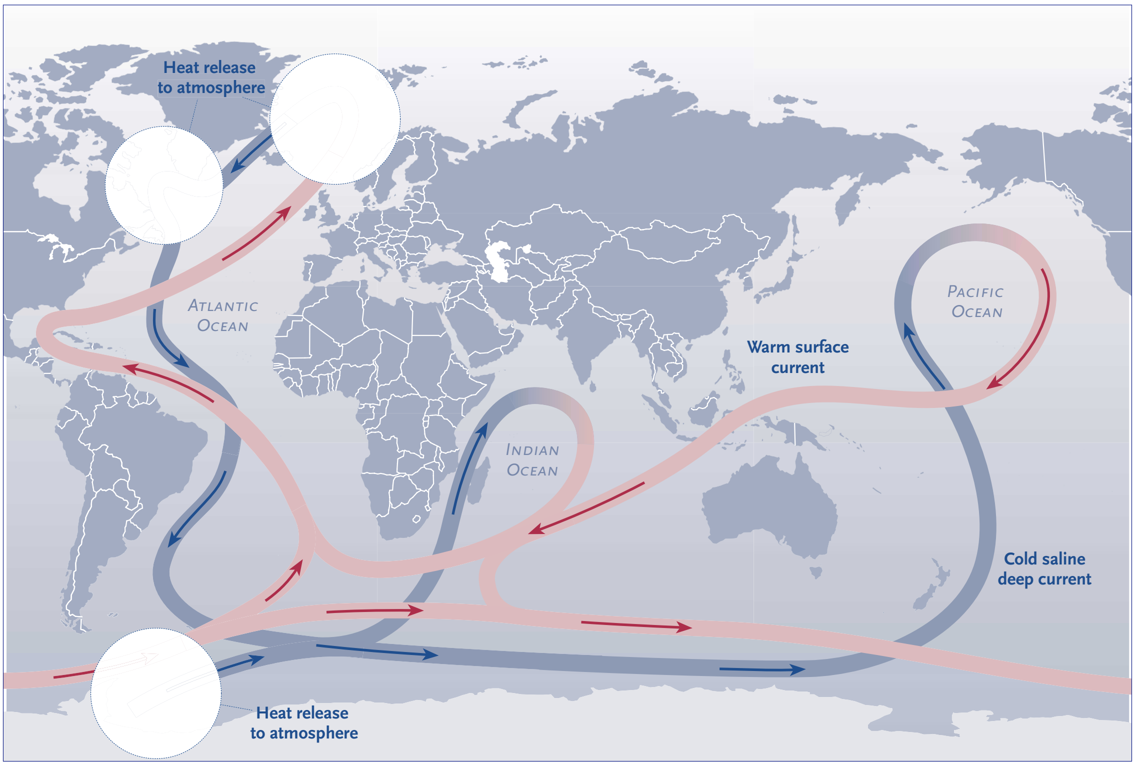


Figure 1. Schematic illustration of the conveyor-belt of the large-scale thermohaline circulation (THC). This picture, which was published a few years ago, shows the cold route from Drake Passage and the warm route from Indonesia for the surface flow into the South Atlantic, but not the Tasman leakage route south of Australia discovered by KNMI and its partners in the TRACMASS project. Source: IPCC Synthesis Report 2001.

tracking water parcels. In this highlight, we explore the pathways of the water-masses that constitute the return flow for the sinking NADW. A new, additional route is suggested by these calculations. By tracing the surface origin of the water-masses that are transported along this route, we determine where air-sea interactions set the properties of the water that flows to NADW formation sites. In another application of the parcel tracking method, we investigate the surface origin of the water-masses that constitute the Equatorial Undercurrent (EUC) in the Atlantic and the associated sub-tropical cells, which are wind-driven features of the ocean.

Method

Trajectories • In fluid mechanics, 'fluid particles' are infinitesimal small compared to the dimensions of the system under consideration, but large compared to distances between molecules. In an analytical description, every point has a unique velocity at a given time, so one can change from Eulerian to Lagrangian variables, and trajectories are well defined. In a discrete description, this is less straightforward, but it is still possible to define trajectories. Following a water parcel along a trajectory, its properties like temperature and chemical composition may change. Trajectories that start close to each other within a grid box often diverge substantially after some time. Trajectories calculated from model output depend on the grid size and the way sub-grid processes are parameterised in the model, just as the underlying model velocities do. Here our goal is to resolve the relevant two-dimensional turbulence. To this end, trajectories of parcels are calculated from the output of an eddy-permitting ocean general circulation model.

Implementation • Until recently, studies that employ parcel tracking were often qualitative [2]. This highlight presents results from the European project TRACMASS (Tracing the water-masses of the Atlantic and Mediterranean) in which two innovations were combined regarding parcel tracking in numerical model data. The first innovation was to set the number of the parcels that are released proportional to the mass transport across the initial section [3], each trajectory carrying the same mass transport. The second innovation was to use an analytical solution instead of a numerical procedure for solving the differential equations from which a trajectory is calculated [4]. This gave rise to a fast and efficient algorithm and enabled the calculation of millions of trajectories [5]. The resolution of the individual trajectories is implied by the resolution of the ocean model. How well the flow of the transport distribution is resolved also depends on the number of parcels.

We report on Lagrangian calculations based on the last 3 year from a longer run of the OCCAM global, eddy-permitting ocean model [6]. OCCAM has 36 z-levels in the vertical and a uniform horizontal resolution of ¼° by ¼°. Since in OCCAM the Boussinesq approximation is made and volume rather than mass is conserved, each trajectory carried the same volume transport. Resolving the full time dependence that is contained within all archived data is impossible because of computational limitations. For this reason, seasonally averaged fields were used for the trajectory calculations. Advecting parcels with time-averaged Eulerian velocity fields of the OCCAM model, however, leads to serious biases [7]. Biases are much smaller in isopycnal (equal density) coordinates, because motion in the ocean tends to follow isopycnal rather than horizontal surfaces. Isopycnal transports are the product of a velocity and a layer thickness. We calculated the mean isopycnal transports for each season from archived 5-day mean OCCAM velocity fields interpolated on isopycnal coordinates. Next, the transports were converted back to velocities in z-coordinates using the averaged layer thicknesses. These velocities have been used for the trajectory calculations.

Results

Tasman leakage • The technical innovations discussed above greatly improved the efficiency and accuracy of trajectory calculations. This led to new scientific results. One example is the discovery of a new, additional route for the ocean conveyor-belt. Over the last years, studies have focussed on the question which of two routes for the return flow of the THC into the South Atlantic is more important. The cold route commences at Drake Passage. Part of the cold water from Drake Passage is heated before it crosses the equator. In the warm route, water goes through the Indonesian Throughflow between the Indonesian isles from the Pacific into the Indian Ocean, and next into the Atlantic Ocean by intermittent heat and salt advection by Agulhas rings. The dominance of one route above the other has immediate consequences for climate and climate stability. If the cold route dominates, the conveyor-belt is susceptible to atmospheric forcing in the Southern Hemisphere. If the warm route dominates, the conveyor-belt depends on the intermittent shedding of Agulhas eddies south of Cape Town.

The tracking technique described above provides an accurate picture of all pathways that go into the return flow of the conveyor-belt. To this end, the trajectories of parcels that belong to the northward flowing branch of the THC at a section across the equatorial Atlantic are computed backwards in time. Each trajectory is stopped when it reaches one of the four borders of the Indo-Atlantic basin, the Drake and Indonesian passages, a section linking Australia to Antarctica, and the equatorial Atlantic.

We obtain both classical paths: the cold and warm route. However, the routes are much intertwined. Nearly all the water of the cold route recirculates in the Indian Ocean before it returns to the Atlantic *(Figure 2)*. Examining individual trajectories (not shown) makes clear that both the water from the warm route and the water from the cold route recirculates. As a consequence, not only the warm route, but also the cold route is influenced by the shedding of Agulhas eddies. At the Atlantic equator, their water-masses are completely mixed and have become indistinguishable. The striking new feature that appears is a pathway linking the westward flowing Tasman Current to the northward flow across the equatorial Atlantic, with Agulhas leakage being crucial (Figure 2). This 'Tasman leakage' contributes about 20% of the upper branch of the THC. KNMI and two of its TRACMASS partners have found the new Tasman route in three ocean models. The magnitude and characteristics are similar in the three models, and are supported by a new analysis of the WOCE observational database [8)].

Next, we trace the origin of the water coming from the Tasman outflow. Starting at the border along the line that links Australia to Antarctica, trajectories from all parcels constituting the Tasman leakage are computed further backwards until they hit the surface mixed layer. In this way the surface origin of all parcels that represent the Tasman outflow is determined. We find that they essentially originate from the Subantarctic zone as Subantarctic Mode Water (SAMW), see *Figure 3*. These waters are then transported within the Antarctic Circumpolar Current, where they are partially modified to Antarctic

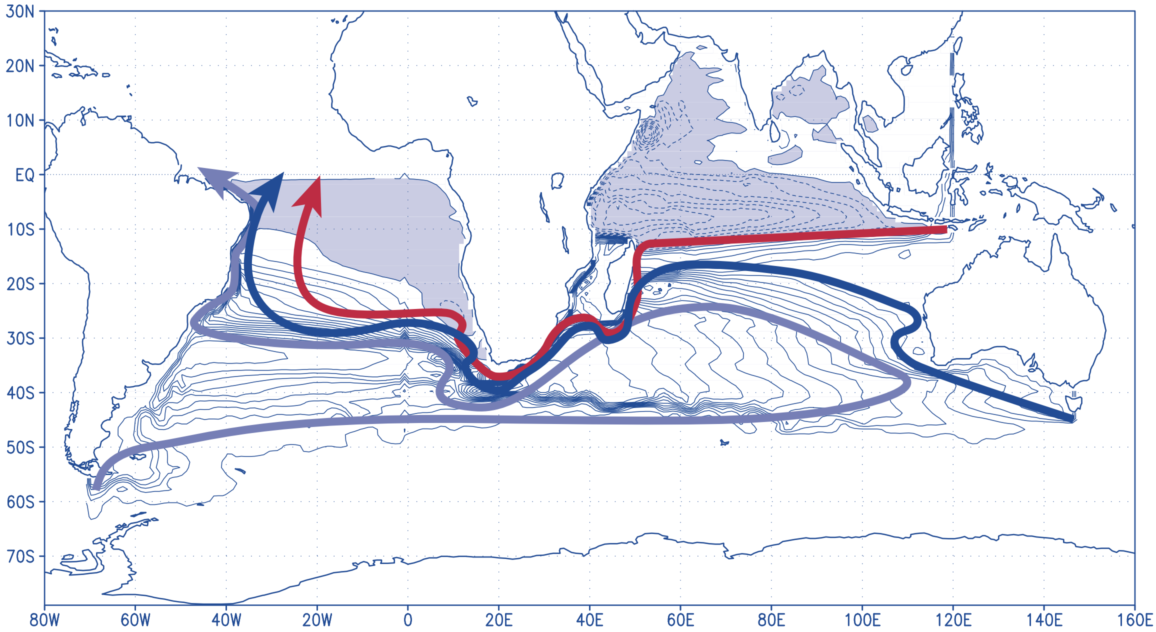


Figure 2. Lagrangian horizontal streamfunction of the vertically-integrated transport of the upper branch of the THC between Indo-Atlantic and the Atlantic equator. The contour interval is 10^6 m^3s^{-1}. Water coming from Tasmania is depicted with a dark blue arrow, from Drake Passage with a light blue arrow, and from the Indonesian Throughflow with a red arrow.

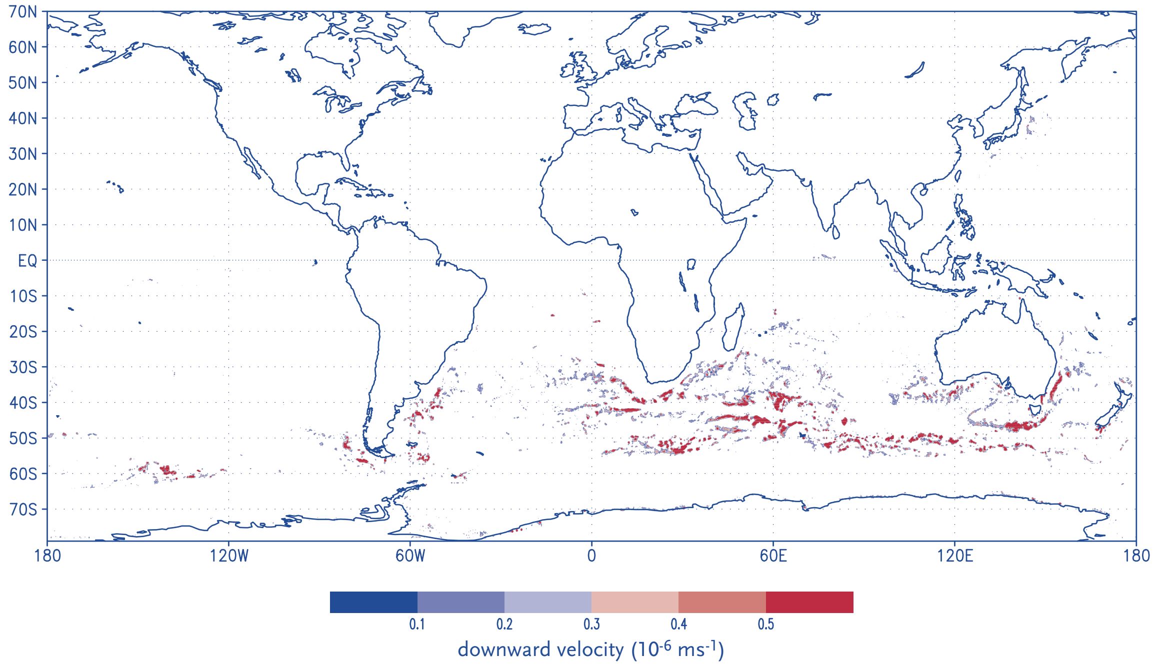


Figure 3. Downward velocity (10^{-6} ms^{-1}) through the base of the surface mixed layer of water that eventually ends in the Tasman leakage. The integral over the field equals the total Tasman leakage of 3.2 10^6 m^3s^{-1}. The field was obtained by backtracking 3 10^5 Tasman leakage particles.

Intermediate Water (AAIW). Eventually they loop back westwards and connect with the Tasman Current.

South of Australia, Tasman water has characteristics in between those of the cold and warm route, except for salinity, which is the highest for the three routes. Note that in all three cases the salinity is very low and the waters are fresh. The water from the Tasman outflow, the Indonesian Throughflow, and most of the water from Drake Passage comes together near Cape Agulhas. The water in the cold and warm routes flows mainly near the surface and is strongly influenced by atmospheric forcing. It is subject to strong evaporation and the water from the cold route is strongly heated as well. The Tasman waters flow deeper and are much less exposed to air-sea interaction. It is the only route for which most of the water never reaches the mixed layer. It thus becomes the most dense, cold and fresh of the three.

Sources of the EUC • At the Atlantic equator the warm return flow in the conveyor-belt is concentrated along the western boundary in the North Brazil Current (NBC). At 5°N, most of the NBC curves back into the eastward flowing EUC, while the remaining part of the NBC continues northward along the west coast. The main branch of the conveyor-belt follows the EUC. This is a strong current, about 100 m below the sea surface, which is connected with westward flowing surface currents to its north and south. The conveyor-belt follows the northern route and connects to the Gulf Stream in the Caribbean. The NBC and EUC transport more water than is contained in the conveyor-belt. Apart from the large-scale overturning associated with the conveyor-belt, there exist more shallow and regionally confined wind-driven overturning cells. Wind-driven divergent flow forces upwelling all along the equator. The poleward surface flow outside the western boundary currents and the equatorward subsurface flow to the upwelling region form subtropical cells. In the South Atlantic, there is a complicated interplay between the conveyor-belt and the subtropical cell.

The water that recirculates in the subtropical cells subducts some 20 degrees off the equator. In the South Atlantic, the subsurface equatorward flow reinforces the conveyor-belt. In the North Atlantic the subtropical cell opposes the conveyor-belt, and is almost absent. The subduction sites where the poleward surface flow is connected to the subsurface equatorward flow are the off-equatorial regions where air-sea interaction determines the properties of the EUC, as mixing in the interior of the ocean is small. These are also the regions where extratropical air-sea interaction influences tropical climate variability. We traced the sources of the Atlantic EUC by computing trajectories backward in time until they hit the surface mixed layer [9)]. *Figure 4* shows that the subtropical South Atlantic is indeed the main source for the EUC. The subducted water-masses follow a pathway that is mainly within the NBC. Less than a tenth of the transport in the EUC has a Northern Hemisphere origin. The subduction region that ventilates the EUC from the north is found along the North Equatorial Current. Thereafter, parcels follow an interior pathway

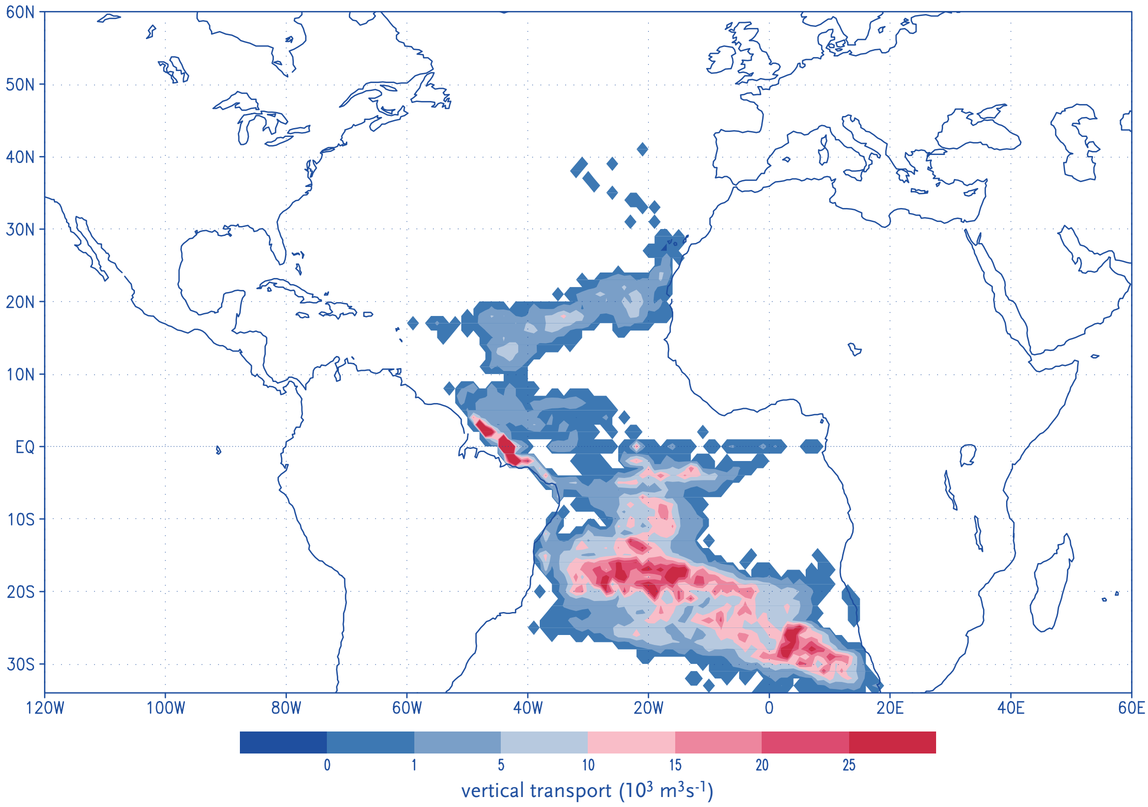


Figure 4. Subduction sites of particles that are sources of the Equatorial Undercurrent at 20°W as derived from backtracking particles.

The subtropical South Atlantic is the main source for the Equatorial Undercurrent

towards the equator. In the tropical and subtropical North Atlantic the flow along the west coast in the upper 1000 m is northward, away from the equator.

The wind-driven subtropical cells and the THC in the South Atlantic are closely connected. A large part of the conveyor-belt follows the EUC, and the subduction region for the EUC is almost completely within the South Atlantic. This implies that in the South Atlantic the poleward surface flow of the subtropical cell and the equatorward warm surface flow of the conveyor-belt meet in a zone of confluence in the subtropics where they subduct and flow equatorward in the NBC. While most of the water from the cold and warm route of the THC enters the South Atlantic near the surface, the Tasman leakage part remains deeper and probably does not enter the EUC.

Conclusions

We can describe and quantify the spread and transformation of water masses with a parcel tracking method. A new, additional route was found for the surface return flow of the conveyor-belt that originates south of Australia. Water-masses of the cold route from Drake Passage and the warm route from Indonesia thoroughly mix before entering the Atlantic Ocean. Pathways that connect remote sites of air-sea interaction were calculated, in particular in the subtropics and the tropical Atlantic. The EUC in the Atlantic Ocean mainly originates from the south because the meridional overturning cells associated with the EUC are strongly affected by the THC.

1) Broeckner, W., 1991. *The great ocean conveyor*. Oceanography, **4**, 79–89.

2) Drijfhout, S.S., E. Maier-Reimer and U. Mikolajewicz, 1996. *Tracing the conveyor-belt in the Hamburg large-scale geostrophic ocean general circulation model*. J. Geophys. Res., **101**, 22563–22575.

3) Döös, K., 1995. Interocean exchange of water masses. J. Geophys. Res., **100**, 13499–13514.

4) Blanke, B. and S. Raynaud, 1997. *Kinematics of the Pacific Equatorial Undercurrent: an Eulerian and Lagrangian approach from GCM results*. J. Phys. Oceanogr., **27**, 138–1053.

5) Vries, P. de and K. Döös, 2001. *Calculating Lagrangian trajectories using time-dependent velocity fields.* J. Atmos. Oceanic. Tech. **18**, 1092–1101.

6) Webb, D.J., A.C. Coward, B.A. de Cuevas and C.S. Gwilliam, 1997. *A multiprocessor ocean general circulation model using message passing.* J. Atmos. Oceanic Techn., **14**, 175–183.

7) Drijfhout, S.S., P. de Vries, K. Döös and A.C. Coward, 2003. *Impact of eddy-induced transport on the Lagrangian structure of the upper branch of the thermohaline circulation.* J. Phys. Oceanogr., in press.

8) Speich, S., B. Blanke, P. de Vries, K. Döös, S.S. Drijfhout, A. Ganachaud and R. Marsh, 2002. *Tasman leakage: a new route in the global ocean conveyor-belt.* Geophys. Res. Lett., **29**, 10.1029/2001GL014586.

9) Hazeleger, W., P. de Vries and Y. Friocourt, 2003. *Sources of the Equatorial Undercurrent in the Atlantic in a high-resolution ocean model.* J. Phys. Oceanogr., **33**, 677–693.

Monitoring of tropical processes relevant to climate change

Monitoring of

*by Pieter Valks, Paul Fortuin, Gé Verver, Ronald van der A,
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The importance of the tropics for the global climate

The tropics play an important role in the climate of the Earth. Many chemical, dynamical, and physical processes specific to the tropical atmosphere have impact on the distribution of greenhouse gases and aerosols on a global scale. Moreover, the composition of the tropical atmosphere has undergone dramatic changes in the last decades, due to increasing emissions related to human activity, e.g. biomass burning, industry and traffic, as well as to changed land use. This affected the concentrations of constituents such as ozone and water vapour that play an important role in the tropical troposphere and stratosphere, and are key variables of the global climate system.

Ozone and water vapour are important greenhouse gases that absorb long-wave terrestrial radiation in the upper troposphere and lower stratosphere (UTLS). The photolysis of ozone by the intense UV radiation and high humidity in the tropics causes the formation of the hydroxyl radical (OH). OH largely determines the oxidising capacity of the atmosphere, thus limiting the residence time of many atmospheric pollutants.

Excessive amounts of ozone near the surface are toxic to ecosystems, animals and men. The large emissions of ozone precursors such as NO_x, CO and hydrocarbons in the tropics have impact on the tropospheric ozone concentration on a global scale [1)]. Especially the NO_x production by lightning, the emissions by large scale biomass burning, and the natural emissions of hydrocarbons are very large but still rather uncertain emission sources.

Ozone in the stratosphere, on the other hand, protects the biosphere from harmful solar ultraviolet (UV) radiation. Again, the tropics play an important role, because stratospheric ozone is primarily produced there and is then transported to the extra-tropics by the Brewer-Dobson circulation.

Water vapour and pollutants play a key role in stratospheric ozone chemistry through the formation of HO_x radicals and polar stratospheric clouds (PSCs), and in the radiative balance of the stratosphere. The input of these constituents into the stratosphere is to a large extent determined by the dynamical and physical processes in the tropical upper troposphere and lower stratosphere. A global upward trend of stratospheric water vapour of 1% per year in the last decades has been derived from observations and is not yet understood. Other challenging tropical research topics are the influence of the Inter Tropical Convergence Zone (ITCZ) and equatorial waves on the structure of the UTLS and the distribution of trace gases, as well as the coupling between convective clouds, aerosols, radiation and dynamics. Recent KNMI contributions to research on the tropical atmosphere are presented in the next paragraphs.

Monitoring of the tropical atmosphere

Progress in tropical atmospheric research is hampered by the poor spatial coverage of the global surface observation networks in the tropics. One of the initiatives to improve the coverage was the start of an observational programme in Paramaribo, Surinam, in co-operation between KNMI and the Meteorological Service Surinam. This station is strategically located in the middle of the latitudinal migration range of the ITCZ (which travels over Surinam twice a year), so that from a meteorological point of view the southern as well as the northern hemisphere is observed, depending on the season. Since September 1999 temperature, wind, humidity and ozone profiles are observed by performing weekly balloon soundings. Since April 1999 continuous total ozone columns and ozone profiles (using the so-called Umkehr method) have been observed with a Brewer MKIII spectrometer. The observations are very valuable for studies of tropical processes, such as stratosphere-troposphere exchange, ozone formation and regional transport circulations [2)]. At Paramaribo station, also observations of the spectral UV radiation are made. These data have been used to improve algorithms for worldwide UV-index forecasting and for validation of satellite data [3)].

Observations from space are important in order to understand how ozone is transported over large distances

Although Paramaribo station and other new initiatives, such as the Southern Hemisphere Additional Ozone Sounding programme (SHADOZ) fill an important gap in the global monitoring network, the information they provide on spatial variations in the tropics is limited. Observations from space platforms play an increasingly important role in monitoring the large-scale temporal and spatial variability of the tropical atmospheric composition. Satellites enable the measurement of the distribution of ozone and its precursors over large areas. This is important in order to understand how ozone, that is formed over regions where large amounts of ozone precursors are emitted, is transported over large distances, thus affecting regions far away from the source. The GOME instrument, aboard the European Space Agency's ERS-2 satellite, is the first of a new generation of remote sensing instruments providing improved observations of ozone and other important species such as NO_2, SO_2, HCHO and water vapour in the tropical troposphere and stratosphere. GOME obtains information about these species by measuring the Sun's ultraviolet and visible radiation backscattered by the Earth's atmosphere and surface.

KNMI plays an important and internationally acknowledged role in the preparation, retrieval, processing, validation and use of the GOME instrument and it's successors SCIAMACHY, GOME-2 and OMI. Of great importance for the study of the tropical atmosphere is the ESA research project TEMIS (Tropospheric Emission Monitoring Internet Service), lead by KNMI. TEMIS is executed by six European institutes and will produce and deliver global tropospheric concentrations of ozone, NO_2, CO, CH_4, water vapour and aerosols, using GOME, SCIAMACHY and AATSR observations.

Tropospheric ozone columns • The retrieval of tropical tropospheric ozone columns (TTOCs) from GOME data and the interpretation of the observed variability in the TTOC is one of the innovative KNMI activities within TEMIS. The TTOCs are determined with the so-called convective-cloud-differential (CCD) method, by subtracting the ozone column in the stratosphere from the total ozone column [4)]. This method uses GOME ozone measurements over highly reflecting, high-altitude clouds to obtain an above-cloud ozone column. In certain regions, such as the tropical western Pacific, these high-reflectivity clouds are mostly associated with strong convection and cloud tops reaching the upper troposphere. The GOME instrument is able to determine the cloud fraction and cloud top pressure (altitude) with the Fast Retrieval Scheme for Clouds from the Oxygen A-band (FRESCO). The tropospheric ozone columns (below the 200 hPa level) are derived at cloud-free pixels by subtracting the above-cloud ozone column from the GOME total ozone column. This assumes that the ozone column above the 200 hPa level is independent of longitude, which has good validity in the tropics.

With the GOME-CCD method, monthly-averaged tropospheric ozone columns have been calculated for the tropics from July 1995 to present *(http://www.temis.nl/)*. *Figure 1* shows the tropical tropospheric ozone column for October 2001. The month October is at the end of biomass burning season, when large-scale fires occur over Southern Africa and South-America. Clearly visible are the high tropospheric ozone columns over the Atlantic Ocean, with values of 40–45 Dobson Units (DU). This phenomenon can be attributed to a complex interaction of biomass burning, NO_x emissions by lightning and large-

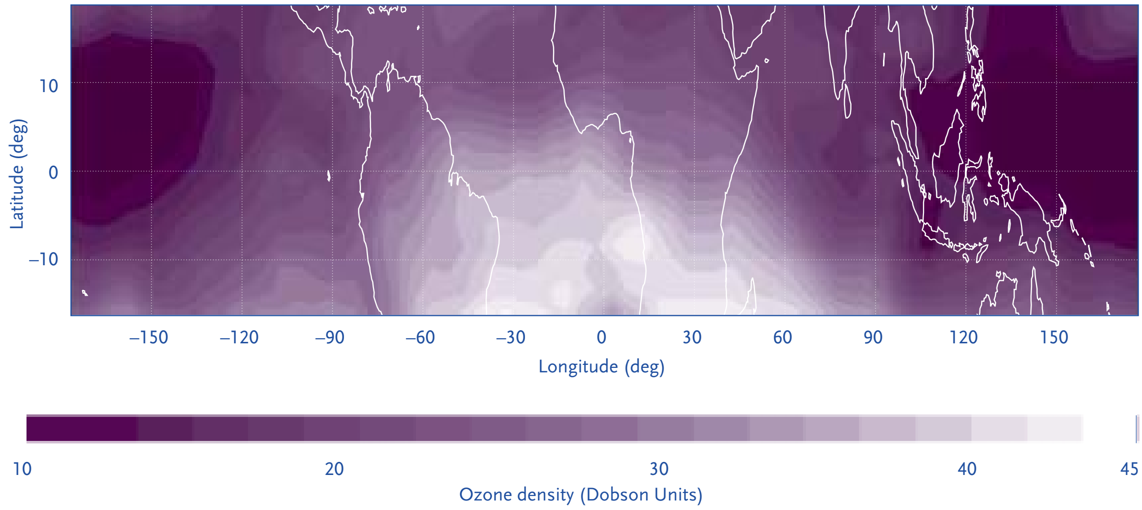


Figure 1. Tropical tropospheric ozone column (below 200 hPa) for October 2001 derived from GOME observations. The high tropospheric ozone values of 40–45 Dobson Units over the Atlantic Ocean are clearly visible.

scale transport. The GOME-CCD method provides valuable information to untangle these intriguing processes.

The accuracy of the GOME-CCD method has been assessed by comparing the derived tropospheric ozone columns with ozone sonde measurements. *Figure 2a* shows the comparison for the Brazilian station Natal. There is good agreement between the GOME tropospheric ozone values and the sonde measurements. Clearly visible is the strong yearly increase in tropospheric ozone during the biomass-burning season, starting in July and ending in October. *Figure 2b* shows the comparison for our own station, Paramaribo, which is very close to the equator. Here, the influence of biomass burning is smaller, and the seasonal variation in the tropospheric ozone column can be explained by the migration of the ITCZ over Paramaribo, twice a year, between Dec–Feb and Apr–Aug [5]. In the wet seasons, the tropospheric ozone columns are fairly low, due to convective uplift of humid and ozone-poor air. The increase in the tropospheric ozone values during the long dry season (Aug–Dec) under the influence of subsidence is found in both the GOME ozone values and the sonde measurements.

Ozone profiles • Satellite observations from GOME, and recently SCIAMACHY, offer the possibility to obtain height-resolved information about the ozone concentrations in the stratosphere as well as in the troposphere. At KNMI, an ozone profile retrieval algorithm has been developed, based on the widely used optimal estimation method, combined with on-line radiative transfer (RT) modelling. The RT model used is a fast version of the accurate Linearized Discrete Ordinate Radiative Transfer (LIDORT) model [6]. To simulate the polarisation of light in the atmosphere, a polarisation correction algorithm has been included in the RT model. In addition, the ozone profile

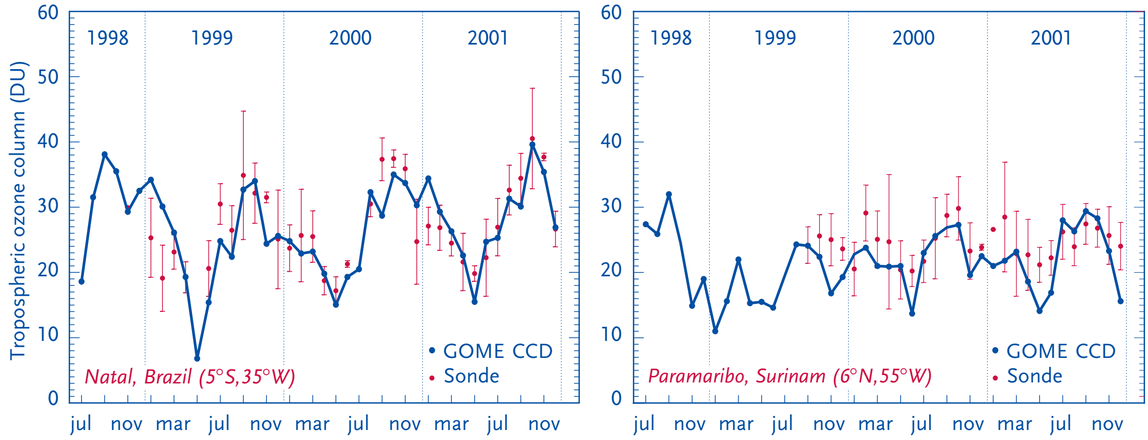


Figure 2. Tropospheric ozone columns for Natal (a) and Paramaribo (b) for the period July 1998 – Dec 2001. The red dots denote the integrated ozonesonde measurements with 1σ error bars (if there was only one sonde measurements in a particular month, the error bar is omitted). The blue dots denote the TTOCs derived with the GOME-CCD method.

retrieval uses the FRESCO cloud algorithm to accurately model the atmospheric scene, taking the ozone below the cloud into account.

The accuracy of the tropical ozone profiles retrieved from GOME and SCIAMACHY measurements depends strongly on the quality of the calibration of the measured UV spectrum. Research at KNMI has led to an important improvement of the calibration of the GOME-UV spectrum with respect to instrument degradation effects, radiometric in-flight calibration, wavelength calibration, and polarisation correction. Especially, the radiometric correction of the instrument degradation has led to improved retrievals of stratospheric ozone profiles in the tropics [7)].

Research at KNMI has led to an important improvement of the calibration of the GOME-UV spectrum

The ozone profiles, retrieved from GOME with this improved method, have been validated using collocated ozone sonde and lidar measurements at several ground stations around the world. Especially the inter-comparisons at the tropical ground station Paramaribo proved to be very important for validation. If any systematic deviations in the retrieved ozone profiles exists, they are usually clearly revealed in comparisons with tropical observations because of the relatively small variability in tropical stratospheric ozone. The GOME profiles have been compared to ozone sonde measurements at Paramaribo for the period of October 1999 till July 2000. With the improved

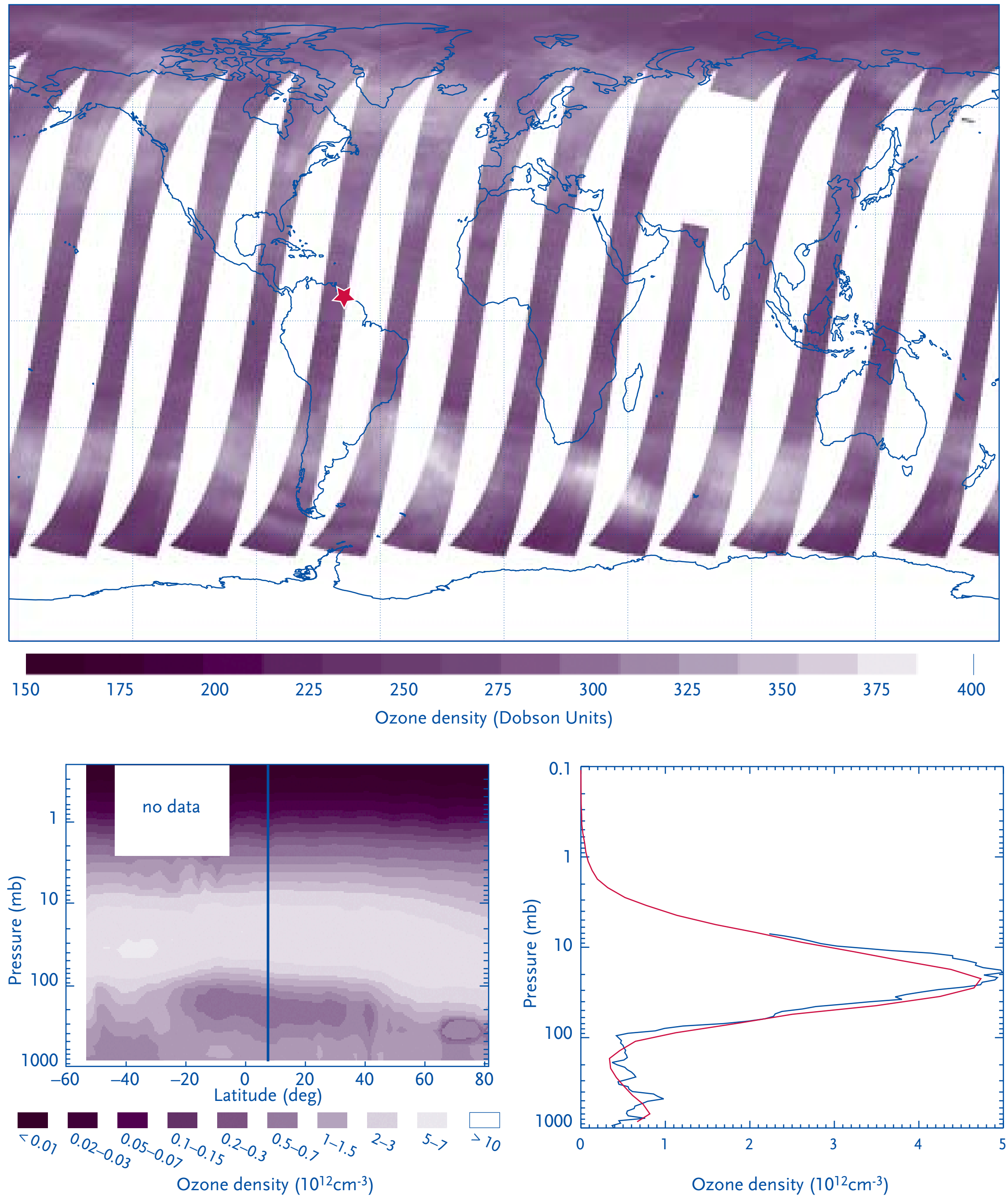


Figure 3. The large map shows the total ozone values measured by GOME on 12 August 2000. The lower left figure shows the height-resolved ozone distribution along the GOME orbit passing over Paramaribo station. At the location of Paramaribo, the ozone profile in the lower-right figure has been retrieved by KNMI from the GOME observation (red line). For comparison, the Paramaribo ozone sonde measurement from 16 August 2000 is plotted as well (blue line).

retrieval algorithm, the derived ozone profiles in Paramaribo follow the sonde profiles very well *(Figure 3)*.

Greenhouse gas precursors • Column values of some important greenhouse gas precursors, such as NO_2, HCHO, CO and the greenhouse gas CH_4, can also be obtained from satellite observations. NO_2 and HCHO, as catalysts of ozone production, are key species in tropospheric chemistry. The GOME instrument has demonstrated a fascinating ability to observe NO_2 and HCHO in the tropical boundary layer. At KNMI, a combined retrieval and assimilation approach has been developed to derive tropospheric NO_2 fields with GOME *(Figure 4)*. For the TEMIS project, the measured NO_2 data from GOME are assimilated in the TM3 tropospheric chemistry-transport model. The model provides estimates of the stratospheric contribution to the total NO_2 column, and accounts for total column changes due to variations in the surface pressure. From this, tropospheric mixing ratio fields of NO_2 are derived.

The combination of satellite measurements with chemistry transport models through data-assimilation techniques will strongly improve our knowledge of the composition and processes in the tropical atmosphere. This knowledge is a prerequisite for our understanding of the global climate system.

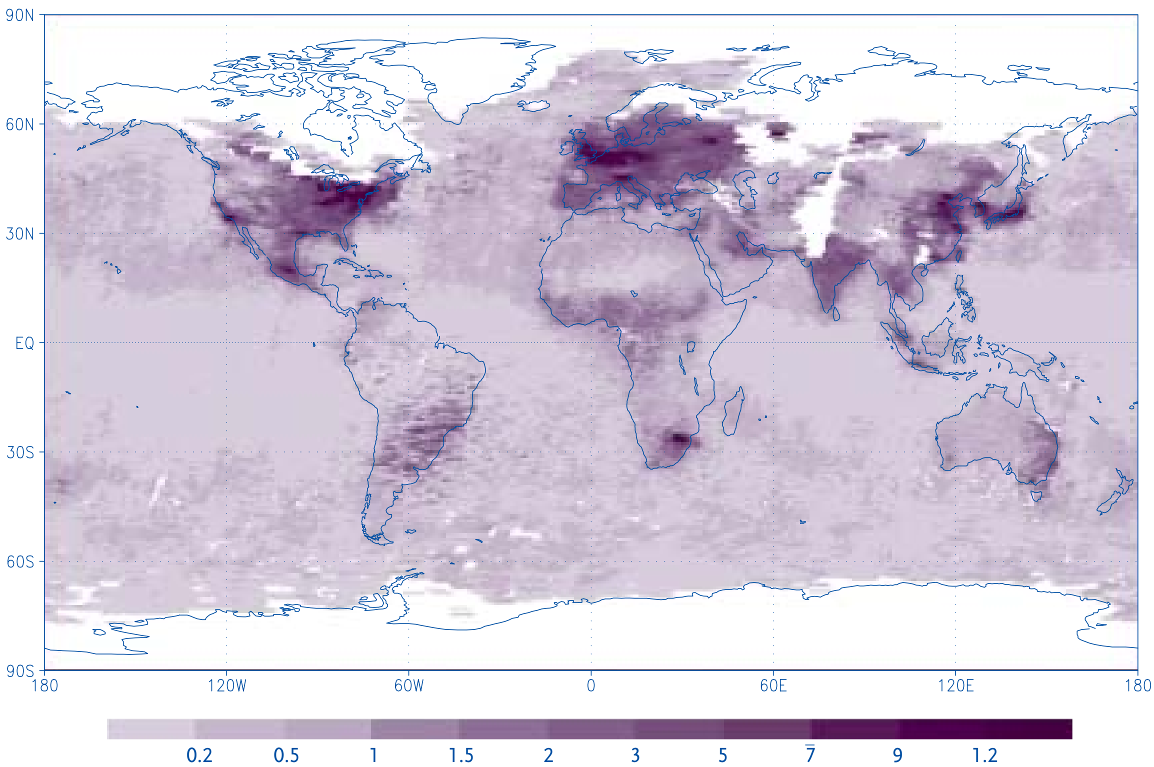


Figure 4. Tropospheric NO_2 column for March 1997 based on GOME observations and three-dimensional model calculations. Clearly visible are the industrialised regions and the enhanced NO_2 concentrations above tropical Africa due to biomass burning emissions. The scale is in 10^{15} molecules per cm^2.

Tropical dynamics

Atmospheric dynamics and transport behave different in the tropics than at higher latitudes due to the very low to complete absence of the Coriolis force, a pseudo-force due the rotational effect of the Earth, that increases with latitude. This gives rise to several dynamical features that are unique to the tropics, e.g. equatorial waves, the stratospheric QBO (quasi-biennial oscillation), and the (more) frequent occurrence of inertial instability. The latter feature happens when the local vorticity exceeds the Coriolis frequency, and has been subject of recent research at KNMI.

Sonde observations of temperature, wind, humidity and ozone at Paramaribo point out that a large domain in the upper troposphere over Surinam becomes inertially unstable in the period Jan–Apr. This domain is a layer with a depth of several kilometres centred around 12 km, stretching from the Equator toward the subtropics. It is associated with the proximity of the subtropical jet to the equator during the South American Monsoon [2]. The inertial instability causes a northward acceleration of air in the upper troposphere, hereby evidently enhancing the circulation within the well-known Hadley cell by providing a pole ward acceleration of the upper branch of the cell. Also, during this period a meridional sub-cell is apparent directly above the Hadley cell and below the tropopause *(Figure 5)*. This is most likely a manifestation of symmetric inertial instability flow as its features coincide closely with what is predicted from linear stability analyses. If the enhancing effect of moisture on inertial instability is also taken into account, large parts of

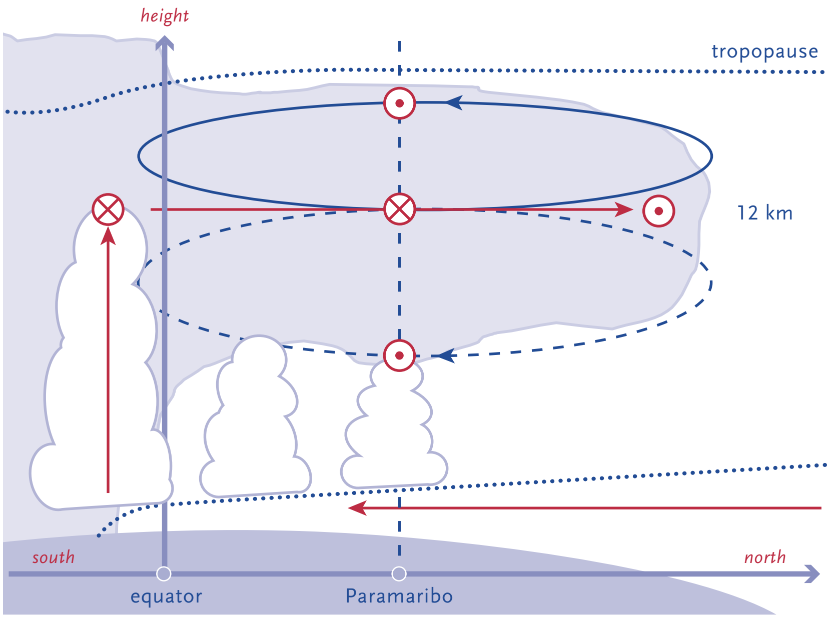


Figure 5. Schematic view of the ITCZ and the induced meridional circulation cells resulting from negative potential vorticity (blue shaded) in the upper troposphere during the South American Monsoon. The red circles indicate zonal wind (westerly/easterly with dot/cross).

the lower humid troposphere become inertially unstable as well during this period, possibly causing a southward acceleration of the trade winds, which again enhances the Hadley cell circulation. The measurements at Paramaribo suggest that inertial instability plays a more important role on tracer transport in the tropics than generally assumed so far.

1) Thompson, A.M., J.C. Witte, R.D. Hudson, H. Guo, J.R. Herman and M. Fujiwara, 2001. *Tropical tropospheric ozone and biomass burning.* Science, **291**, 2128–2132.

2) Fortuin, J.P.F., H.M. Kelder, M. Sigmond, R. Oemraw and C.R. Becker, 2003. *Inertial instability flow in the troposphere over Surinam during the South American Monsoon.* Geophys. Res. Lett., in press.

3) Allaart M.A.F., M. van Weele, J.P.F. Fortuin and H.M. Kelder, 2002. *UV-index as a function of solar zenith angle and total ozone.* submitted to Meteorol. Applications.

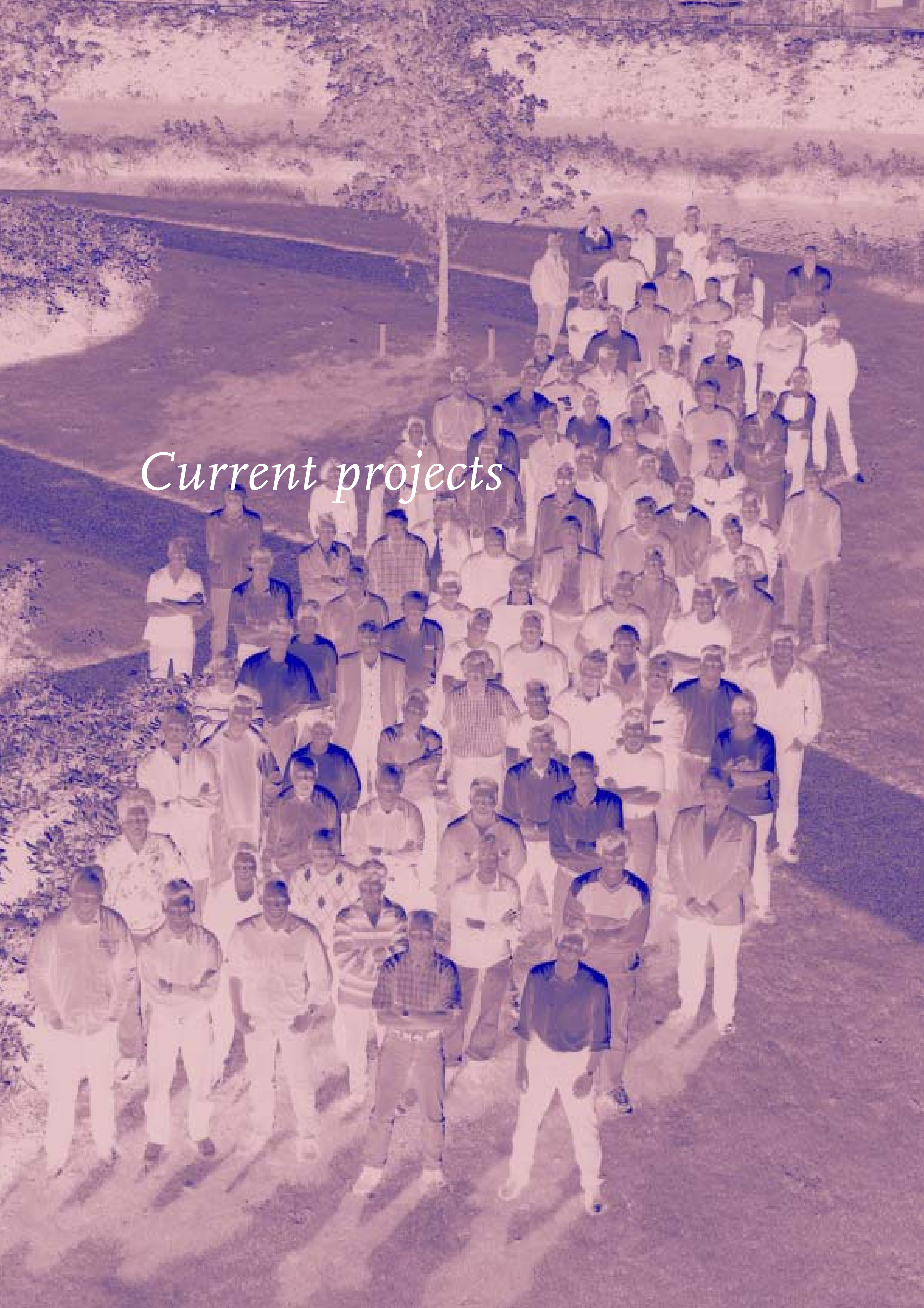
4) Valks P.J.M., R.B.A. Koelemeijer, M. van Weele, P. van Velthoven, J.P.F. Fortuin and H. Kelder, 2003. *Variability in tropical tropospheric ozone: analysis with GOME observations and a global model.* J. Geophys. Res., **108**, 10.1029/2002JD002894.

5) Peters, W., J.P.F. Fortuin, H. Kelder, C.R. Becker, P.J. Crutzen, A.M. Thompson and J. Lelieveld, 2003. *Tropospheric ozone over a tropical Atlantic station in the northern hemisphere: Paramaribo, Surinam (6N, 55W).* Tellus B, in press.

6) Oss, R. van and R.J.D. Spurr, 2002. *Fast and accurate 4 and 6-stream linearised discrete ordinate radiative transfer models for ozone profile remote sensing retrieval.* J. Quant. Spectros. Rad. Transf., **75**, 177–220.

7) A, R. J. van der, R.F. van Oss, A.J.M. Piters, J.P.F. Fortuin, Y.J. Meijer and H.M. Kelder, 2002. *Ozone profile retrieval from recalibrated Global Ozone Monitoring Experiment data.* J. Geophys. Res., **107**, 10.1029/2001JD000696.

Current projects



Climate Variability Research

Climate Variability

Research within this Division focuses on large-scale atmospheric dynamics and related physics, and on the coupled atmosphere/ocean system. Specific research objectives are: the study of variability patterns and their underlying mechanisms, understanding climate change both in the recent geological past and as a result of anthropogenic forcing, and the study of the climate system's predictability. Work includes the development of a global so-called Intermediate Complexity Model.

Climate variability and predictibility

Decadal variability and predictability

Climate variations in the North-Atlantic/Arctic area have been studied in an ensemble of integrations with the ECBILT-CLIO model, forced by greenhouse-gas emission scenario's for the period 1960–2100. In general the system warms. However, a sudden cooling occurs locally in the Greenland-Iceland-Norwegian (GIN) Sea. This is due to a high-latitude freshening of the ocean surface, an increased stability of the water column and a subsequent breakdown of oceanic convection *(Figure 1)*. Natural climate variability limits the predictability of the timing of this sudden change. The same ensemble of integrations was used to analyse the change in the probability density function (PDF) of daily temperatures and precipitation in the Northern Hemisphere. In a warming climate the whole PDF shifts to warmer temperatures, thereby increasing the probability of extreme warm events. In addition, for many gridpoints the shape of the PDF changes in such a way that the probability of extreme warm events is enhanced. In collaboration with Dr. Hugues Goosse (University of Louvain-La-Neuve), the physical processes that lead to natural variations in the total amount of Arctic sea-ice in a long simulation of ECBilt-CLIO have been identified. These variations occur with a dominant period of about 20 years. A crucial process is the oceanic convection in the GIN Sea. Occasionally, the amplitude of these spontaneous variations is large enough to completely shut down convection. This leads to cold events of decadal or sometimes century long duration.

In July 2002, a workshop was organised at KNMI for users of the ECBILT-CLIO coupled climate model. There were participants from the University of Louvain-La-Neuve, the Institut für Meereskunde in Kiel, the Free University of Amsterdam, the RIVM and AWI in Bremerhaven. The aim was to found a users community and to define a new standard version, ECBilt-CLIO3. This version was released in October 2002. The major change with respect to the previous version involves the modular structure, which enables an easy exchange of different sub-systems. Various versions of the model are available from the CKO model support website. The Climate Variability Research Division participates in the informal network for Earth System Models of Intermediate Complexity (EMICs) chaired by PIK, Potsdam. The EMICs network initiates model intercomparison studies and organises regular meetings. We participated in the land surface model intercomparison, which was the subject of the 2002

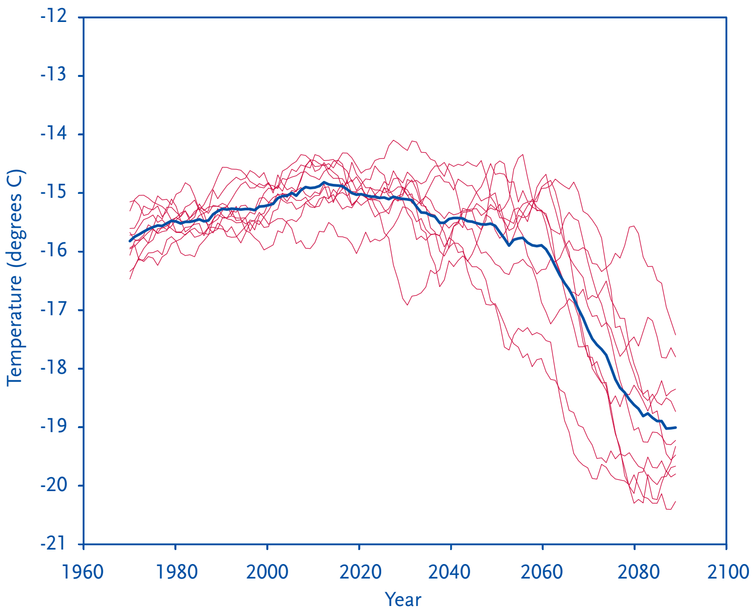


Figure 1. Time series of the winter mean surface air temperature over the Greenland-Iceland-Norway sea region for an ensemble of 10 integrations with ECBILT-CLIO for an IPCC scenario for Greenhouse-gas (GHG) emissions. The thick solid line is the ensemble average. After an initial warming, a sudden cooling is observed which is accompanied by a southward extension of the winter sea-ice cover. The timing of this event is very uncertain and crucially depends on the rate of GHG concentration increases.

EMICs workshop held as a side-event at the EGS in Nice.

In order to study climate variations involving tropical dynamics, we introduced an existing primitive-equation model of intermediate complexity, SPEEDY, into the EMIC structure at KNMI in 2002. Speedy, which was developed by Franco Molteni, is a spectral model with simplified parameterisations of physical processes. It is currently used at T31 resolution and deploys 7 levels in the vertical. In the EMIC structure SPEEDY is coupled to land surface, ocean mixed layer and sea-ice modules, thereby replacing the original prescribed surface boundary conditions and closing the hydrological cycle. Together with the Oceanographic Research Division the regional ocean model MICOM was embedded in the EMIC and coupled to SPEEDY. At present the coupled system is being tuned. In co-oporation with the University of São Paulo, Brazil, a project for studying South Atlantic decadal variability has been started using a hierarchy of atmosphere-ocean models. The hierarchy is defined by increasingly sophisticated mixed-layer ocean models coupled to SPEEDY up to the full SPEEDY/MICOM configuration.

In collaboration with the University of Wageningen a pilot study was completed using the Lorenz 63 model. A method was developed to find parameter perturbations that most effectively change the probability that the system resides in one of two regimes. The method is based on the sensitivity of short integrations to parameter perturbations and is potentially applicable to complex atmospheric models.

Cyclic Markov chains have been developed and used in order to study the predictability of ENSO. In particular, a way of partitioning the phase space has been introduced that leads, among other things, to the identification for each month of the ENSO states with the highest (or the worst) predictability properties. It also allows for a quantification of the well-known spring barrier in ENSO predictability and establishes a clear connection with unstable periodic orbits in ENSO dynamics. These ideas have also been used in an analysis of daily NCEP data to track non-diffusive dynamics in the observed large-scale atmospheric flow.

Low-frequency variability and paleoclimates

The two-year project 'Sea level and climate variability on multi-decadal to centennial timescales', funded by NRP, ended in 2001. This was a joint project between KNMI and the Faculty of Earth Sciences of the Free University of Amsterdam (Dr. Orson van de Plassche). The latter has reconstructed sea level (SL) variations, based on foraminefera in salt marsh deposits, along the northeastern seaboard of North America. The aim of the KNMI contribution to this project was to establish the mechanism underlying low-frequency SL variations, using ECBilt simulations. A number of 1000-yr simulations were made, using constant solar forcing (the control run) as well as estimates of historic variations in solar activity. In the control run variations in the ThermoHaline Circulation (THC) are related to random sea surface salinity anomalies, which are in turn advected to the deep ocean by the overturning circulation. In the solar-forced runs, THC variations are paced by sea surface temperature anomalies, which result from irradiance variations. In both simulations low-frequency (steric) SL variations were found to be dominated by deep-ocean salinity anomalies rather than temperature anomalies. These salinity anomalies propagate with the lower branch of the THC, the Deep Western Boundary Current, from the northern Atlantic to the Gulf Stream area. A comparison between the simulated and reconstructed SL curves seems to confirm the proposed mechanism of low-frequency SL variability in the Gulf Stream area.

An international workshop on 'Reconstructing Late-Holocene Climate' was co-organised (with Dr. M. Mann of the University of Virginia, Dr. H. von Storch of the GKSS Research Centre and Dr. H. Wanner of the University of Bern). The workshop took place in April 2001 in Charlotteville (Virginia, USA), with about 50 scientists attending. A report appeared in Eos, the newsletter of the American Geophysical Union.

The Climate Variability Research Division participates in the international Paleo Modelling Intercomparison Project (PMIP). The mid-Holocene Optimum and the Last Glacial Maximum (LGM) were chosen by PMIP as key periods for testing the sensitivity of climate models to past changes in the external forcing and boundary conditions. ECBIlt-CLIO experiments for the LGM were started recently. The aim is to disentangle the role of the different forcings and feedbacks within the system in shaping the climatic response. A transient Holocene simulation with orbital forcing showed that the temporal response to the forcing is basically linear. Spatial response patterns in ECBilt are similar to those found earlier in PMIP in more comprehensive GCMs. An intercomparison of mid-Holocene response patterns in coupled atmosphere-ocean simulations will appear shortly (first author Dr. P. Braconnot). We have built upon this research to analyse the separate response of the Northern Hemisphere summer monsoon to the obliquity and the precession cycle in the astronomical forcing. This is a joint project with Drs. Frits Hilgen and Lucas Lourens (Faculty of Earth Sciences, University of Utrecht), who identified such signals in Mediterranean sedimentary records extending over the last 5 Million years. Model simulations show that both heating of the Asian landmass at midlatitudes (precession and obliquity) and local insolation forcing (precession) contribute to the 'observed' climatic response.

The role of solar forcing versus internal climate variability was further examined in a 10,000 yr ECBilt simulation. This is a collaboration with Dr. T. Crowley (Duke University, USA), who prepared an estimate of irradiance variations throughout the Holocene based on 14C data. Focus of the analysis is on variability on multi-decadal and longer timescales. We find that the climatic sensitivity to the solar forcing increases in the coupled system for longer timescales. As a result temperature variability at centennial timescales is clearly linked to solar forcing, even at the local scale. The temperature response induces a weak but statistically significant signal in the large-scale monsoon circulation, which seems to be consistent with recent proxy data. The correlation between the THC and solar forcing peaks at a preferred range of timescales (150–300 yr), indicating that the forcing excites an oceanic mode of variability *(Figure 2)*.

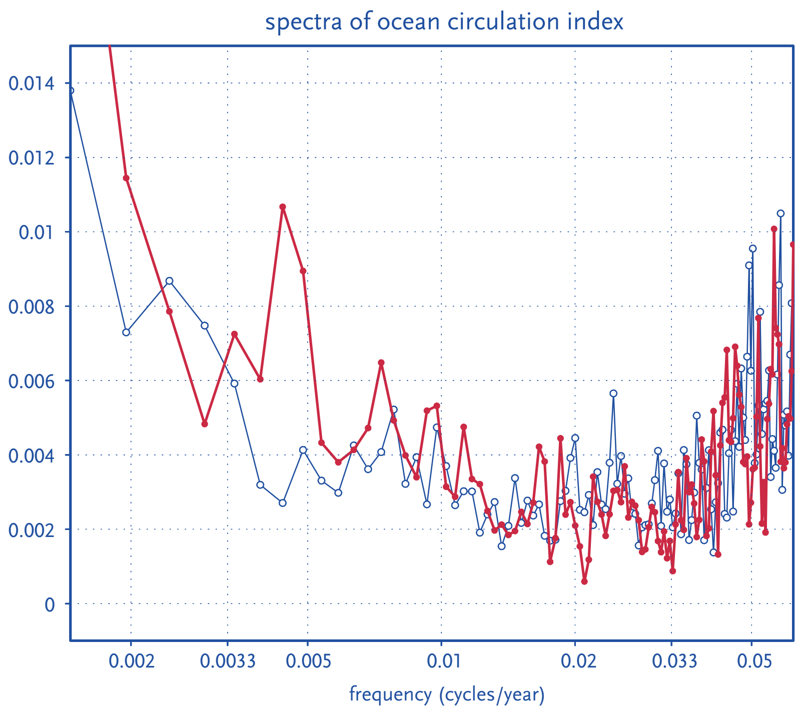


Figure 2. Variance spectrum of the strength of the oceanic overturning circulation (in Sv^2) with (closed circles) and without (open circles) solar forcing, as simulated in two 10,000 yr experiments with the ECBilt model. Variations in incoming solar radiation excite an internal mode of variability in the north Atlantic ocean with a timescale of about 200 yr (0.005 cycles/yr), which is absent in the control simulation.

Dynamics of weather and climate

Transitions between dominant circulation patterns in the atmosphere, so-called regimes, were studied in collaboration with the Mathematical Institute of the University of Utrecht. Transitions between the two regimes of a barotropic model were found to take place in a specific manner, which can be described mathematically as so-called heteroclinic connections, or remains of heteroclinic connections *(Figure 3)*. These heteroclinic connections between the two equilibriums were shown to be produced by a fold-Hopf bifurcation. This corresponds physically to topographic and barotropic instabilities present in the model. In a statistical analysis of observed 500 hPa geopotential height fields, evidence was found for preferred transition routes between the different weather regimes. This empirical result seems to confirm the barotropic model study pointing to a heteroclinic cycle.

Regime transitions in a fairly realistic baroclinic model were studied in collaboration with Dr. Grant Branstator (National Center for Atmospheric Research, Boulder, USA). These were shown to be related to an Unstable Periodic Orbit (UPO) of about 20 days, which finds its observational counterpart in the Branstator-Kushnir wave. It is hypothesized that the UPO is a remnant of a heteroclinic connection. We performed additional climate simulations with this model with perturbed diabatic heating rates. This revealed a climate response, which was not just a simple shift of the PDF in the direction of the forcing perturbation, but a change in the shape of the PDF. This indicates that understanding the dynamical behaviour of regimes and their transitions is important for determining any climatic change.

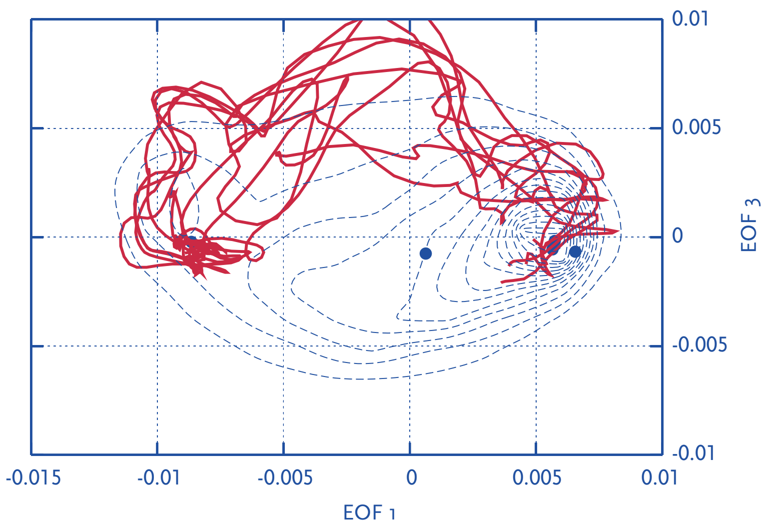


Figure 3. The joint probability distribution of the amplitudes of two dominant circulation patterns of a barotropic model (dashed contours). Two local maxima, referred to as regimes, are visible. The thick solid lines correspond to five 100-day integrations during which a transition from the left to the right regime takes place. They reveal a preferred transition route that corresponds to the remains of a so-called heteroclinic connection between the steady states (thick dots) of the two regimes.

The dynamics of low-order coupled atmosphere-ocean climate models has been the subject of a PhD research project. In these models two widely different timescales appear: a long timescale associated with the ocean and a short timescale associated with the atmosphere. The model is set up in such a manner that the atmosphere drives the ocean, but the ocean is only weakly feeding back on the atmosphere. The central research question was: to what extent is the ocean slaved to the atmosphere or plays an active role in generating the slow timescale into the atmospheric spectrum. Prominent atmospheric intermittent behaviour is observed in these models. This behaviour occurs near a point in parameter space at which the stability of periodic motion is lost. The ocean repeatedly pushes the fast sub-system (the atmosphere) through a sequence of bifurcations, causing intermittent behaviour on the timescale of the ocean. Thus the ocean plays an active role in the dynamics of the coupled system, in spite of the fact that its direct effect on the atmosphere is very weak.

A low order model of the atmospheric circulation, formulated in the dominant Empirical Orthogonal Functions (EOFs) of a realistic GCM, has been developed. The model is based on the primitive equations. It includes the seasonal cycle. The unresolved spatial scales are represented by a statistical linear closure, which has been derived by minimising the tendency errors (measured with respect to the tendencies of the original GCM). Short-term weather predictions become increasingly better by incorporating more EOFs in the low order model. However the first and second order climate statistics of the GCM are already faithfully reproduced with only 30 degrees of freedom in the low order model. Also its regime behaviour is very similar to the original GCM. There is still a problem in reproducing the effects of SST anomalies. It is not unlikely that this problem must be attributed to the employed closure scheme. A solution could be to employ physically based parameterisations rather than statistical ones.

Salmon's Hamiltonian approach to balanced flow was applied to a simplified atmospheric model, consisting of a single hydrostatic layer of dry air with constant potential temperature. The equations governing the system resemble very much the shallow-water equations and can be seen as a prototype of the more general primitive equations. It was shown how a global geostrophic approximation of this model can be constructed that behaves realistically on the whole sphere and respects all the conservation laws of the underlying (parent) model. The geostrophic velocity field of the model is a simplification of linear balance, based on the smallness of the horizontal divergence. Salmon's Hamiltonian technique gives an expression of an ageostrophic correction velocity that restores the original conservation laws of the system.

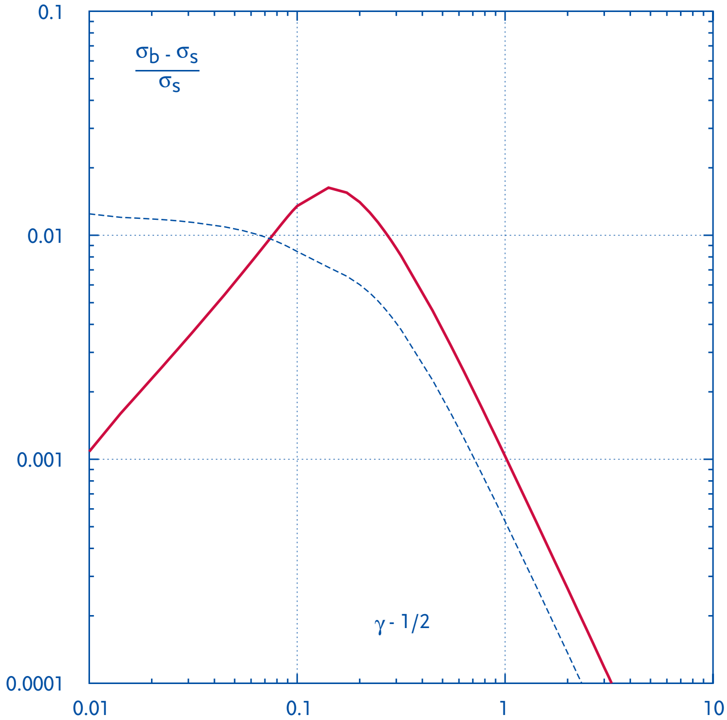


Figure 4. Relative difference between the approximated and the original frequencies of a Rossby wave with zonal wave number 1 and meridional wavenumber 5, plotted as a function of the inverse square root of Lamb's parameter. The solid line refers to the model without inclusion of the ageostrophic velocity. The figure shows that inclusion of the ageostrophic velocity leads to an improvement if Lamb's parameter is smaller than about 100.

The merits of the Hamiltonian approach to geostrophic flow has been investigated further by studying linear Rossby waves. For the original (parent) system the frequencies of these waves can be calculated by solving an appropriate eigenvalue problem, using well-known procedures. These frequencies can also be calculated for the geostrophic model, with and without inclusion of the ageostrophic velocity *(Figure 4)*. The numerical calculations are not very time-consuming and make it possible to compare the performance of the geostrophic model for a wide range of Lamb's parameter, the most important parameter of the model. Two important points have emerged from this study: First, it has become clear that our choice of basic geostrophic balance – simplified linear balance based on the smallness of the horizontal divergence – performs very well on its own when the variation of the Coriolis parameter is properly dealt with. Second, it was noticed that the ageostrophic velocity leads to an improvement of the description of linear waves only if Lamb's parameter is smaller than a threshold value. For values of Lamb's parameter larger than this threshold value the performance deteriorates.

Publications are listed by Division. A paper with authors from different Divisions will be listed more than once in this Report.

Scientific publications in reviewed journals

2001

Drijfhout, S.S., A. Kattenberg, R.J. Haarsma and F.M. Selten, 2001. *The role of the ocean in midlatitude, interannual to decadal timescale climate variability of a coupled model.* J. Climate, **14**, 3617–3630.

Goosse, H., F.M. Selten, R.J. Haarsma and J.D. Opsteegh, 2001. *Decadal variability in high northern latitudes as simulated by an intermediate complexity climate model.* Ann. Glaciology, **33**, 525–532.

Haarsma, R.J., J.D. Opsteegh, F.M. Selten and X. Wang, 2001. *Rapid transitions and ultra-low frequency behaviour in a 40 kyr integration with a coupled climate model of intermediate complexity.* Climate Dyn., **17**, 559–570.

Mann, M.E., R.S. Bradley, K. Briffa, J. Cole, M.K. Hughes, J.M. Jones, J.T. Overpeck, H. von Storch, H. Wanner, S.L. Weber and M. Widmann, 2001. *Reconstructing the Climate of the Late Holocene,* EOS, **82**, 553.

Schrier, G. van der and G.J.M. Versteegh, 2001. *Internally and externally forced climate variability: A dynamical systems approach using the Central England Temperature record.* Geophys. Res. Lett., **28**, 759.

Timmermann, A., H. Voss and R.A. Pasmanter, 2001. *Empirical dynamical system modelling of ENSO using nonlinear inverse techniques.* J. Phys. Oceanogr., **31**, 1579–1598.

Veen, L. van, J.D. Opsteegh and F. Verhulst, 2001. *The dynamics of a low order coupled ocean-atmosphere model.* Tellus, **53A**, 616–628.

Verkleij, W.T.M., 2001. *Salmon's Hamiltonian approach to balanced flow applied to a one layer isentropic model of the atmosphere.* Quart. J. Roy. Meteor. Soc., **127**, 579–600.

Weber, S.L., 2001. *On Homeostasis in Daisyworld.* Climatic Change, **48**, 465–485.

Weber, S.L., 2001. *The impact of orbital forcing on the climate of an intermediate-complexity coupled model.* Glob. Plan. Change, **30**, 7–12.

2002

Claussen, M., L.A. Mysak, A.J. Weaver, M. Crucifix, T. Fichefet, M.-F. Loutre, S.L. Weber, J. Alcamo, V.A. Alexeev, A. Berger, R. Calov, A. Ganopolski, H. Goosse, G. Lohman, F. Lunkeit, I.I. Mokhov, V. Petoukhov, P. Stone and Zh. Wang, 2002. *Earth system models of intermediate complexity: closing the gap in the spectrum of climate system models.* Climate Dyn., **18**, 579–586.

Crommelin, D.T., 2002. *Homoclinic dynamics: a scenario for atmospheric ultra-low-frequency variability.* J. Atmos. Sci., **59**, 1533–1549.

Goosse, J., H. Renssen, F.M. Selten, R.J. Haarsma and J.D. Opsteegh, 2002. *Potential causes of abrubt climate events: A numerical study with a three-dimensional climate model.* Geophys. Res. Lett., **29**, 1860, doi: 10.1029/2002.

Goosse, H., F.M. Selten, R.J. Haarsma and J.D. Opsteegh, 2002. *A mechanism of decadal variability of the sea-ice volume in the Northern Hemisphere.* Climate Dyn., **19**, 61–83.

Schaeffer, M., F.M. Selten, H. Goosse and J.D. Opsteegh, 2002. *Intrinsic limits to predictability of abrupt regional climate change in IPCC SRES scenarios.* Geophys. Res. Lett., **29**, 1767, doi: 10.1029/2002.

Schrier, G. van der, S.L. Weber and S.S. Drijfhout, 2002. *Sea level changes in the North Atlantic by solar forcing and internal variability.* Climate Dyn., **19**, 435–447.

Other scientific publications and reports

2001

Brink, H.W. van den, F.M. Selten, D.F. Doortmont, J.D. Opsteegh and G.P. Können, 2001. *Climate projections for Europe: GCM intercomparisons and analysis of the predictability in practical and theoretical sense.* NOP report No. 40 200 079.

Haarsma, R.J. and F.M. Selten, 2001. *Mechanisms of extra-tropical decadal variability.* CLIVAR Exchanges, **6**, 8–11.

Opsteegh, J.D., 2001. *Licht op de atmosfeer.* Oration, University of Utrecht.

Opsteegh, J.D., F.M. Selten, R.J. Haarsma, 2001. *Climate variability on decadal timescales.* NOP final report, No. 410 200 060.

Pasmanter, R.A. and Xue-Li Wang, 2001. *Trying a metric on atmospheric flows.* Proc. IUTAM Symp. Geometry and Statistics of Turbulence, Hayama, Japan, 1–5 November 1999, Kambe, Nakano and Miyauchi (Eds.), Kluwer.

Schrier, G. van der, 2001. *Gejaagd door de wind?* Meteorologica, **2**, 16–20.

Vosbeek, P.W.C., W.T.M. Verkleij and A.R. Moene, 2001. *Manually adjusting a numerical weather analysis in terms of potential vorticity using three-dimensional variational data-assimilation.* BCRS final report No. NSP-2, 01-01, project 1.1/AP-10, Weather analysis and forecasting.

Wang, X. and R.J. Haarsma, 2001. *Vectorization of the ECBilt model.* KNMI Technical Report TR-233.

Weber, S.L., 2001. *Reconstructing Late Holocene Climate.* Change, **58**, 8–10.

Weber, S.L., R. Guicherit, H.W. van den Brink, R. van Dorland, H. Dijkstra, W. Greuell, G.J. Komen, G. Können, P.-J. van Leeuwen, O. van de Plassche, J.D. Opsteegh, W.P.M. de Ruijter, F.M. Selten, A. van Ulden and J. Vandenberghe, 2001. *Climate Variability.* In: Berdowski, Guicherit and Heij (Eds.), The Climate System, Balkema Publ., Lisse, 135–173.

2002

Beersma, J.J., R. van Dorland and J.D. Opsteegh, 2002. *Short wave radiation and cloud parameterisations for intermediate complexity models.* KNMI Scientific Report WR 2002–02.

Veen, L. van, 2002. *Time scale interaction in low-order climate models.* PhD-Thesis, University of Utrecht.

Number of national presentations

2001: 12
2002: 18

Number of international presentations

2001: 18
2002: 24

Education and organisation of workshops

2001

Opsteegh, J.D., Climate Congress, Utrecht, the Netherlands, member Programme committee.

Opsteegh, J.D., professor of Dynamical Meteorology at the University of Utrecht.

Weber, S.L., Workshop Reconstructing Late Holocene Climate, Charlottesville, USA, 7–20 april, co-convenor (with M. Mann, H. von Storch and H. Wanner).

2002

Opsteegh, J.D., professor of Dynamical Meteorology at the University of Utrecht.

Weber, S.L., Nederlands Aardwetenschappelijk Congres VI, member Programme committee.

Weber, S.L., F.M. Selten and G. van der Schrier, Int. ECBilt/Clio users workshop, KNMI, De Bilt, the Netherlands, 8–9 July, organisers.

Committees

Opsteegh, J.D., BAC/ALW, member.

Opsteegh, J.D., Climate committee KNAW, member.

Opsteegh, J.D., Committee and board RAK (Raad voor de aarde en klimaat KNAW), member.

Opsteegh, J.D., Program committee CCB, member.

Opsteegh, J.D., Promotor L. van Veen, University of Utrecht.

Opsteegh, J.D., SAC (Scientific Advisory Committee ECMWF), member.

Selten, F.M., PhD Committee E. van der Avoird, University of Utrecht, member.

Verkleij, W.T.M., PhD Committee L. van Veen,University of Utrecht, member.

Weber, S.L. Beleids Advies Commissie ALW, member.

Weber, S.L. International Review committee, Wuppertal Institut für Klima, Umwelt und Energie, member.

Oceanographic Research

Oceanographic

Air-sea interaction

The air-sea interaction group has an experimental programme for measuring the exchange of momentum, heat, water vapour and tracers across the air-sea interface. The experimental work is performed at MPN, a platform 9 km off the coast of the Netherlands, owned and operated by Rijkwaterstaat (Directorate-General of Public Works and Water Management).

Analysis of ASGAMAGE measurements

The analysis of the ASGAMAGE measurement campaign, for which KNMI was project coordinator, has been continued through 2001–2002. In particular, more work was done on reconciling the apparent differences in measurements of CO_2 fluxes by the eddy correlation method and the differential tracer method. The result of the analysis is that the discrepancies are much smaller than they seemed first, because direct tracer methods may underestimate the exchange by up to 30%, due to near-surface vertical concentration gradients, and because horizontal and temporal heterogeneities in the aqueous CO_2 concentration may account for a scatter of around 50% in the eddy correlation measurements.

In addition, new data on the relationship between wave age and wind stress have been analysed. It was found that the ASGAMAGE results are consistent with open ocean observations of how the sea-surface roughness depends on the wave age.

Wave follower

During the previous years, a wave-following instrument has been developed and tested in laboratory experiments. The instruments allows for measurements in the wave-boundary layer at a constant height above the moving surface. The lowest sensor level is about 50 cm above the waves. The instrument can operate in significant wave heights up to several meters. The wave-follower programme has been successfully completed in the fall of 2001 with a field test. This test at MPN and its subsequent analysis demonstrated that scientific measurements of the wave-boundary layer can be made with the wave-follower close to the moving surface.

Continuous flux measurements

Previously, the analysis of ASGAMAGE data showed an unexpected dependence of the heat and moisture fluxes on wind speed and atmospheric stability. However, for drawing unambiguous and clear conclusions, more data are needed. Also, ASGAMAGE yielded only limited data on momentum exchange in high-wind conditions. For this reason a continuous flux-monitoring platform has been developed. A set-up for the measuring instruments, suitable for long periods of unattended service, was developed and tested in the fall of 2001 at MPN. The instruments have also been calibrated in wind tunnels.
In 2002, a new, sturdier boom was designed, constructed and installed that can sustain the load of the instrument unit during long, continuous measurement periods. The flux measuring instruments were installed at the end of 2002 and a measurement period of one year was started.

Global air-sea fluxes and ocean waves

Waves
ECMWF currently performs the ERA40 reanalysis project. It aims at reconstructing the conditions of the atmosphere and the ocean surface (including waves) by passing all available observations through the centre's assimilation and forecast system. As a validation partner, KNMI is responsible for assessing the quality of ERA40's ocean wave product. Monthly-mean wave heights from ERA40 were found in good agreement with those obtained from independent satellite-based altimeter measurements. However, the ERA40 system is found to underestimate high waves, especially high wave-height peaks, and to overestimate low waves. A thorough investigation into the quality of ERA40 winds which involved the simultaneous consideration of winds from different sources revealed a slight underestimation of high wind speeds in ERA40, but not large enough to explain the observed wave height differences. The method of simultaneously considering estimates from different sources also allows estimating random errors in either estimate. It was found that both for wind and for waves the random errors in ERA40 are somewhat higher than those for data from buoys or satellite altimeters. Comparing the ERA40 wave heights with those from other modelling initiatives revealed significant differences, both due to different wind products and to different models being used. The ERA40 wave heights are found to be slightly better than those of the other modelling efforts considered.

Fluxes
Ocean and atmosphere are coupled by fluxes of heat, freshwater, and momentum across their common interface. Understanding these fluxes is therefore vital for the understanding of climate variability. The fluxes modify sea surface temperature (SST), either directly (heat fluxes) or indirectly (wind-driven currents and turbulence). The relative importance of the processes that change SST varies regionally and is different for the annual cycle than it is for anomalies. Feedbacks between SST and the atmospheric circulation will make that coupled ocean-atmosphere variability is sometimes driven by the atmosphere and sometimes by the ocean. Coupled climate models should reproduce these relations and the relative importance of different forcing terms. To establish a reference for evaluating the results of coupled models, these relations have been determined and tested using data from ERA40, the NCEP/NCAR reanalysis and in-situ observations in the south Atlantic Ocean. While results from these different sources show a reasonable degree of similarity, they partly differ from published results of coupled models, indicating shortcomings in the models' representation of air-sea interaction.

Interpretation and recovery of historic marine observations
The KNMI historical marine database 1854 – 1938 is one of the biggest marine databases in the world. More then 6 million oceanographic and meteorological ship observations were collected but the accompanying metadata is often missing. Using the metadata that still is available we have cleared up some uncertainties about the application of the gravity correction to the ship's air pressure. As a result, the Dutch data was incorporated (2001) into the COADS 2° x 2° monthly summaries, expanding the temporal and spatial density of this international database significantly. Furthermore, unknown meteorological symbolic codes used during the period 1826 – 1865 have been decoded, and a description and interpretation has been given of the wind force expressions used by sailors during the 18th and 19th century. In addition, a proper interpretation was given of the Japanese air pressure observations, which were written down in a very peculiar way at Decima, Japan during the years 1820 – 1825.

Mathematical physics of ocean waves
The propagation of obliquely incident, weakly nonlinear, surface waves in shallow water has been studied in a regime where depth variations occur on a scale that is large compared to the wave length, but small with respect to the scale on which the wave evolves. Conditions have been established for fission of solitary waves incident on a region of a different depth. A principal result is that these conditions differ from the case of a normal incident wave.

Ocean Circulation

Fundamental aspects of the ocean circulation are studied as well as ocean variability and its relation to atmospheric variability. Sensitivity studies and process studies were performed with idealized models, and results from an eddy permitting global ocean model were analysed to describe and understand features of the large-scale circulation.

Large scale upper branch of the conveyor

The upper branch of the global conveyor-belt was studied in a run of the global eddy-permitting ocean circulation model OCCAM within the EU-funded programme TRACMASS with a Lagrangian methodology. We have traced water parcels along streamlines with a trajectory algorithm that interpolates between time-dependent velocity fields. A particular highlight was the discovery in OCCAM of a new route connecting the Pacific Ocean to the North Atlantic via a route south of Australia. This 'Tasmanian Leakage' also emerges in the analysis of two other ocean models by our partners in the Tracmass project. In the entire global basin eddy-induced transports reduce diapycnal (equal density) flows into the interior; the circulation in wind driven gyres is enhanced and dispersion into the interior is counteracted. Below the mixed layer, divergences of eddy mass fluxes compensate the divergence of the mean flow. In the surface layer, the eddy-induced transport reduces the Ekman transport by a factor of about one half.

Equatorial undercurrents and subtropical cells

Using the developed Lagrangian methodology, the sources and sinks of the Equatorial Undercurrent (EUC) in the Atlantic and in the Pacific were investigated in OCCAM. We collaborated with the Lamont-Doherty Earth Observatory of Columbia University (LDEO) in studying the Pacific EUC. Most of the EUC is ventilated from the southern hemisphere. Waters enter the EUC predominantly via a direct route along the western boundary currents. In the Atlantic, about two thirds of the EUC at 20° W takes part in the global Meridional Overturning Cell and leaves the Atlantic basin. The remainder recirculates in the Subtropical Cell. Mean transports in the smaller intense tropical cells are compensated by eddy motion.

In another study with LDEO, it was established that advection of temperature anomalies towards the tropics by subtropical cells is not likely to generate decadal variability in the tropics. This work was extended to studying variations in ocean heat transport in the tropical Pacific.
The contributions of subtropical cells and the horizontal flow tend to compensate, but that of Indonesian Throughflow and the indirect effect of changes in heat loss in mid-latitudes break down the compensation.

MARE

KNMI co-operates with the University of Utrecht, the Royal Netherlands Institute for Sea Research (NIOZ), and the University of Cape Town in the Mixing of Agulhas Rings Experiment (MARE). A contribution was made to the hydrographic description of the Ring 'Astrid'. Simulations with the isopycnic model MICOM showed that the initial, fast sea surface height decay of 'Astrid', that is typical for Agulhas Rings, is associated with water-mass exchange due to secondary circulations that arise from the mixed barotropic/baroclinic instability of the ring.

The splitting process of baroclinically unstable rings was examined by studying the angular momentum budget of the evolving ring. This study revealed that under certain conditions, anticyclonic rings can split without an external source of angular momentum.

With the Lagrangian trajectory technique, we calculated the pathways in OCCAM into the south Atlantic. In the model, nearly all the water that crosses the Atlantic equator northward is drawn from the Indian Ocean. However, inverse model studies point to a route through the Drake Passage from the Pacific Ocean. Analysing pseudo observations drawn from OCCAM data by the box models of inverse model studies, we found that the apparent contradiction arises because box models cannot discriminate between the two routes if they do not resolve the opposing west and eastward flows at 20° E.

The impact of Agulhas leakage on the thermohaline circulation (THC) was investigated in the Large Scale Geostrophic model. It was demonstrated that this impact is significant and the connection between a south Atlantic density anomaly and changed convection in the north Atlantic was explained in terms of a propagating Kelvin wave.

The role of air-sea interaction in the south Atlantic and the mechanisms of coupled variability have been investigated using NCEP/NCAR reanalysis data. This did not show a detectable systematic feedback of the ocean onto the atmospheric circulation. Hindcasts with MICOM are used to further investigate the role of the ocean in the generation of anomalies. Additional experiments are under way with the SPEEDY model, a simple AGCM (T30, 7 layers) of the International Centre for Theoretical Physics (ICTP) in Trieste.
In this work, we co-operate with the Variability

Research Division at KNMI and the University of São Paulo.

Process studies

For coarse resolution ocean models used for climate simulations, the parameterisation of subgrid scale mesoscale eddies remains a pertinent issue. Current work reveals that in a coarse resolution model of a double gyre flow the layer thickness balance and the momentum balance differ from those in eddy-resolving models, even when the eddy-induced bolus transports and Reynolds transports are specified. This implies that there are eddy-induced changes in the Montgomery potential that need to be parameterised as well.

The impact of winds and vertical diffusivity on the basin-scale overturning cell was investigated in an idealized configuration. This work has been done in co-operation with COLA, MIT and SOC. Localized winds drive a local overturning cell and a global-scale overturning cell, even in the absence of diapycnal diffusion. The partition between the two is a non-linear function of the wind strength and other parameters.

Another example of interaction of wind driven currents and the THC is the cross-over point of the Gulf Stream and Deep Western Boundary Current (DWBC). The interaction of Gulf Stream and DWBC introduces interannual to decadal variability. With a continuation method a stability analysis has been performed of a QG model. The DWBC stabilizes high frequencies and Hopf bifurcations at lower frequencies are introduced.

Miscellaneous

The role of the ocean in decadal climate variability has been investigated comparing several 1000 yr climate atmospheric modes simulations with varying ocean dynamics. The atmospheric modes are unchanged by the presence of the ocean, but the ocean reddens atmospheric spectra. Coupling to a dynamical active ocean may give rise to preferred modes of covariability with preferred timescales. Subsurface oscillations are associated with a forced pattern from the atmosphere and an advective pattern associated with ocean dynamics. The subsurface oscillation may feed back on SST and the atmosphere by convection and upwelling.

Finally, a project Patterns of Climate Change has been started, together with other groups at KNMI (especially the Variability Research Division). We investigate interactions between the tropics and extratropics, and their relationship to natural climate variability and anthropogenic climate change. To this end, we started with ICTP the development of a flexible coupled model consisting of the SPEEDY atmospheric model and the MICOM ocean model.

El Niño and seasonal forecasts

El Niño Southern Oscillation (ENSO) research at KNMI focuses on three themes. The theory of ENSO mechanisms is studied for gaining a better understanding of the causes and predictability of El Niño. Secondly, data-assimilation research is carried out to improve methods for estimating the ocean state from the combination of model physics and satellite and buoy observations. Finally, seasonal forecasting studies aim at establishing where and when the seasonal forecasts that are based on our knowledge of the mechanisms of El Niño and the state of the ocean have skill, in theory and in practice.

Mechanisms

A review of the fluid dynamics of El Niño variability was written by authors of KNMI and the University of Utrecht.
A conceptual model for El Niño is an oscillator that is close to instability due to a positive feedback loop, and is subject to noise. Temperature anomalies in the eastern equatorial Pacific change the trade winds in the central equatorial Pacific. Changes in the wind cause thermocline depth anomalies that propagate eastward and amplify the original temperature anomaly. In addition, changes in the wind strength in the central Pacific cause temperature changes in the same area, due to advection, upwelling and evaporation. These temperature anomalies in turn affect the wind in the central and western Pacific. Inclusion of this alternate feedback loop in a simple ENSO model markedly improved its performance, both in reconstructing past ENSO variability and in forecasts. Collaboration with the University of Hawaii has been set up for further elucidating the role of the western and central Pacific in ENSO.

Data-assimilation

In the relatively simple OI and 3D-VAR data-assimilation schemes currently used in operational centres such as the ECMWF and NCEP, correcting the thermal structure near the equator often deteriorates the currents significantly. The wrong currents in the model lead to an incorrect distribution of heat and salt, which then has to be corrected again. An investigation of the cause of these errors in a simple ocean model revealed that the lack of geostrophic balance is to blame. This problem has long been addressed in atmospheric data-assimilation, but was thought to be unimportant in the ocean. In collaboration with ECMWF, LODYC and the University of Utrecht, it was established that requiring geostrophically balanced updates near the equator greatly reduces the negative impact on the currents in a simple ocean model. The scheme has been extended to multi-layer models and is now being used at the ECMWF, where it has a positive impact on the skill of El Niño forecasts.

The possibility of making salinity corrections by combining altimeter sea level data and in-situ temperature data as well as the impact of salinity corrections has been explored in a collaboration of the Technical University of Delft, KNMI and the University of Utrecht.

Research has also continued in the use of more advanced data-assimilation schemes. The 4DVAR data-assimilation scheme in the HOPE ocean model has been extended to use sea level anomalies from satellite altimetry data. Changes in the wind, heat and precipitation forcings are used to push the model towards the observations. Idealized experiments show that changes in the wind forcing give the largest contribution to sea level adjustments in the (sub)tropics, and changes in the heat flux in the extratropics. Research on another advanced data assimilation scheme, the Ensemble Kalman Filter, has started in the context of the EU-funded programme ENACT. The Ensemble Kalman Filter will be implemented in the MPI-OM1 ocean model.

Seasonal forecasts

ENSO fluctuations influence the mean weather in large parts of the world and therefore form the basis of much of the skill of seasonal forecasts. Seasonal forecasts can be based on observed statistical relationships over the last century. An example is the strong connection between rainfall in the Dutch Caribbean and ENSO that was investigated in collaboration with the Meteorological Service of the Netherlands Antilles and forms the basis of their seasonal forecasts. Another approach is to use computer models of the ocean and atmosphere. ECMWF has used its models to produce seasonal forecasts since 1997. In collaboration with ECMWF, the skill of these forecasts and the hindcasts for 1987–1997 in predicting El Niño and worldwide temperature and precipitation has been compared to that of statistical models based on past observations. The ECMWF model was seen to perform better in El Niño predictions through the spring barrier. It also gave better seasonal forecasts in almost all areas and seasons of known ENSO teleconnections.

Publications are listed by Division. A paper with authors from different Divisions will be listed more than once in this Report.

Scientific publications in reviewed journals

2001

Bonekamp, H., G.J. van Oldenborgh and G. Burgers, 2001. *Variational assimilation of TAO and XBT data in the HOPE OGCM, adjusting the surface fluxes in the Tropical Ocean.* J. Geophys. Res., **106**, 16,693–16,709.

Drijfhout, S.S. and W. Hazeleger, 2001. *Eddy mixing of potential vorticity versus thickness in an isopycnic ocean model.* J. Phys. Oceanogr., **31**, 481–505.

Drijfhout, S.S., A. Kattenberg, R.J. Haarsma and F.M. Selten, 2001. *The role of the ocean in midlatitude, interannual-to-decadal-timescale climate variability of a coupled model.* J. Climate, **14**, 3617–3630.

Hazeleger, W., R. Seager, M. Visbeck, N. Naik and R. Rodgers, 2001. *On the impact of the midlatitude storm track on the upper Pacific.* J. Phys. Oceanogr., **31**, 616–636.

Hazeleger, W., M. Visbeck, M. Cane, A. Karspeck and N. Naik, 2001. *Decadal upper ocean temperature variability in the tropical Pacific.* J. Phys. Oceanogr., **106**, 8971–8988.

Hazeleger, W., P. de Vries and G.J. van Oldenborgh, 2001. *Do tropical cells ventilate the Indo-Pacific equatorial thermocline?* Geophys. Res. Lett., **28**, 1763–1766.

Hersbach, J. and P.A.E.M. Janssen, 2001. *Reply to: Ccomments on improvement of the short-fetch behavior in the Wave Ocean Model (WAM).* J. Atmos. Oceanic Technol., **18**, 716–721.

Katsman, C.A., S.S. Drijfhout and H.A. Dijkstra, 2001. *The interaction of a Deep Western Boundary Current and wind-driven gyres as a cause for low-frequency internal variability.* J. Phys. Oceanogr., **31**, 2321–2339.

Oost, W.A., G.J. Komen, C.M.J. Jacobs, C. van Oort and H. Bonekamp, 2001. *Indications for a wave dependent Charnock parameter from measurements during ASGAMAGE.* Geophys. Res. Lett., **28**, 2795–2797.

Seager, R., Y. Kushnir, N. Naik, J. Miller, P. Chang and W. Hazeleger, 2001. *Looking for the role of the ocean in tropical Atlantic decadal climate variability.* J. Climate, **14**, 638–655.

Sterl, A., 2001. *On the impact of gap-filling on variability patterns of reconstructed oceanic surface fields.* Geophys. Res. Lett., **28**, 2473–2476.

Vries, P. de and K. Döös, 2001. *Calculating Lagrangian trajectories using time-dependent velocity fields.* J. Atmos. Oceanic Technol., **18**, 1092–1101.

2002

Bonekamp, H., G.J. Komen, A. Sterl, P.A.E.M. Janssen, P.K. Taylor and M.J. Yelland, 2002. *Statistical comparisons of observed and ECMWF modelled open ocean surface drag.* J. Phys. Oceanogr., **32**, 1010–1027.

Burgers, G., M.A. Balmaseta, F.C. Vossepoel, G.J. van Oldenborgh and P.J. van Leeuwen, 2002. *Balanced ocean-data assimilation near the equator.* J. Phys. Oceanogr., **32**, 2509–2519.

Dijkstra, H.A. and G. Burgers, 2002. *Fluid dynamics of El Niño variability.* Ann. Rev. Fluid Mech., **34**, 531–558.

Jacobs, C., J.F. Kjeld, P. Nightingale, R. Upstill-Goddard, S. Larsen and W. Oost, 2002. *The narrowing gap between air-sea transfer velocities determined using deliberate tracers and from eddy correlation measurements. ASGAMAGE observations and a modeling study.* J. Geophys. Res., **107**, C9, 11-1/11-26. doi: 10.1029/2001jc000983.

Martis, A., G.J. van Oldenborgh and G. Burgers, 2002. *Predicting rainfall in the Dutch Caribbean- more then El Niño?* Int. J. Climatology, **22**, 1219–1234.

Oost, W.A., G.J. Komen, C.M.J. Jacobs and C. van Oort., 2002. *New evidence for a relation between wind stress and wave age from measurements during ASGAMAGE.* Bound.-Layer Meteor., **103**, 409–438.

Schrier, van der G., S.L. Weber and S.S. Drijfhout, 2002. *Sea level changes in the North Atlantic by solar forcing and internal variability.* Climate Dyn., **19**, 435–447.

Speich, S., B. Blanke, P. de Vries, K. Döös, S.S. Drijfhout, A. Ganachaud and R. Marsh, 2002. *Tasman leakage: a new route in the global ocean conveyor belt.* Geophys. Res. Lett., **29**, 10, 55-1/55-4, doi: 10.1029/2001 GL014586.

Vossepoel, F.C., G. Burgers and P.J. van Leeuwen, 2002. *The effects of correcting salinity with altimeter measurements in an equatorial Pacific ocean model.* J. Geophys. Res., **107**, SRF 2-1/14, doi: 10.1029/2001JC000816.

Weijer, W., W. de Ruijter, S.S. Drijfhout and A. Sterl, 2002. *Response of the Atlantic overturning circulation to South Atlantic sources of buoyancy.* Glob. Plan. Change, **34**, 293–311.

Other scientific publications and reports

2001

Balbous, T. and S.S. Drijfhout, 2001. *The Conveyor Belt in the OCCAM model.* KNMI Technical Report TR-231.

Bonekamp, J.G., 2001. *On the physical air-sea fluxes for climate modeling.* PhD-Thesis, University of Utrecht.

Bonekamp, H., A. Sterl, G.J. Komen, G. Burgers, G.J. van Oldenborgh and P.A.E.M. Janssen, 2001. *An assessment of the ECMWF reanalysis (ERA) air/sea fluxes using Wave and Ocean General Circulation Models.* Final Report NOP project 951207, The Upper Ocean in Complex Realistic Climate Models, NOP No. 410 200 063.

Friocourt, Y. and S.S. Drijfhout, 2001. *Tracing water masses in the Atlantic.* KNMI Technical Report TR-237.

Haarsma, R.J., S.S. Drijfhout, J.D. Opsteegh and F.M. Selten, 2001. *The impact of solar forcing on the variability in a coupled climate model.* In: Friis-Christensen et al. (Eds.), Space Science Series of ISSI, **94**, 287–294, Kluwer.

Katsman, C.A., 2001. *Internal variability of the wind-driven ocean circulation.* PhD-Thesis, University of Utrecht.

Oldenborgh, G.J. van and G.J. Komen 2001. *Hangt het warme weer de laatste tijd in Nederland samen met het versterkte broeikaseffect?* Meteorologica, **10**, no. 3, 4–9.

Sterl, A., 2001. *Decadal variability in the South Atlantic Ocean.* CLIVAR Exchanges, **6**, 20–22.

Sterl, A., H. Bonekamp and G.J. Komen, 2001. *ERA-15 seen from the ocean.* Change, **58**, 14–16.

Sterl, A. et al., 2001. *Intercomparison and Validation of the Ocean-Atmosphere Energy Flux Fields.* In: Final Report of the joint WCRP/SCOR Working Group on Air-Sea Fluxes (SCOR Working Group 110), Geneva, Switzerland, November 2000, WCRP-112, WMO/TD-No. 1036.

Drijfhout, S.S. and P. de Vries, 2001. *Tracing the Water Masses of the North Atlantic and the Mediterranean.* Final report of the EU project TRACMASS.

Wallbrink, H. and F. Koek, 2001. *Historische Maritieme Windschalen tot 1947.* KNMI Memorandum HISKLIM 3.

Wallbrink, H. and F. Koek, 2001. *Onbekende weersymbolen in oude Extract journalen (1826–1865).* KNMI Memorandum HISKLIM 4.

2002

Caires, S., A. Sterl, J.R. Bidlot, N. Graham and V. Swail, 2002. *Climatological Assessment of Reanalysis Ocean Data.* Proc. Wave Workshop, Alberta, Canada, 21–25 October, 1–12.

Drijfhout S.S., L. de Steur and P.J. van Leeuwen, 2002. *Decay of Agulhas rings.* Proc. Hawaiian Winter Workshop, January 16–19, 2001, University of Hawaii, Manao, USA, 67–71.

Jacobs, C., P.D. Nightingale, R. Upstill-Goddard, J. Kjeld, S.E. Larsen and W. Oost, 2002. *Comparison of the deliberate tracer method and eddy covariance measurements to determine the air/sea transfer velocity of CO^2.* Proc. 4th Int. Symp. gas transfer at water surfaces, Miamy Beach, USA, 5–8 June 2000, Geophysical Monograph **127**, 225–231.

Oldenborgh, G.J. van, 2002. *De El Niño van 2002.* Meteorologica, **11**, no. 4, 27–28.

Oldenborgh, G.J. van, 2002. *Komt El Niño er weer aan?* Meteorologica, **11**, no. 1, 13–15.

Oldenborgh, G.J. van, 2002. Mei 2002: *El Niño komt er niet aan.* Meteorologica, **11**, no. 2, 28.

Oost, W.A., 2001. *ASGAMAGE: the air/sea gas-exchange/MAGE experiment.* Proc. 4th Int. Symp. gas transfer at water surfaces, Miami Beach, U.S.A., 5–8 June 2000, Geophys. Monograph **127**, 219–223.

Number of national presentations

2001: 9
2002: 17

Number of international presentations

2001: 17
2002: 16

Education and organisation of workshops

2001

Burgers, G.J.H., JASON-2 users platform, KNMI, De Bilt, the Netherlands, 22 November, organiser.
Sterl, A., JSC/SCOR Working group Air-Sea Fluxes, member.

2002

Drijfhout, S.S., EGS session OA2, Nice, France, 24 April, convenor.
Hazeleger, W., Clivar South Atlantic workshop, member Scientific Committee.
Sterl, A., JSC/SCOR Working group Air-Sea Fluxes, member.

Committees

Burgers, G.J.H., Advisory Committee Marien Facilities NWO, member.
Burgers, G.J.H., Netherlands SCOR Committee KNAW, member.
Drijfhout, S.S., Review committee ALW, member.
Jacobs, C.M.J., Users group Meetpost Noordwijk, member.
Komen, G.J., Advisory Committee Marine Facilitities NWO, member.
Komen, G.J., Journal of Physical Oceanography, associate editor.
Komen, G.J., Netherlands SCOR Committee KNAW, member.
Sterl, A., Steering Committee ERA-40, member.

Atmospheric Composition Research

Modelling and process studies

Model calculations of greenhouse gases, ozone and aerosols

The atmospheric chemistry Transport Model (TM) is used to evaluate the distributions of non-CO_2 greenhouse-gases, ozone, aerosols and pollutants, based on emission inventories. These distributions serve as input to radiative forcing calculations, such as reported in the Third Assessment Report (TAR) of IPCC. TM uses winds and other meteorological data from the ECMWF weather forecast model as input.

In the framework of the EU project TRADEOFF earlier estimates of the impact of aircraft emissions on the atmospheric composition and climate have been updated. It was shown that chemical reactions on the surfaces of ambient aerosol particles in the tropopause region can strongly reduce the amount of ozone formed due to aircraft emissions. Moreover, the consequences of various air traffic control options such as polar routes have been evaluated. The research results have been contributed to the EU Scientific Assessment (2001) and have been communicated to Dutch policy makers through the Aircraft Cruise project.

New model descriptions were developed of the production of nitrogen oxides by lightning that make use of the convective cloud parameters archived by ECMWF. It was found that, out of several possible parameters, the convective precipitation gives the highest correlation with observed lightning distribution statistics over Europe. Comparison of the chemistry-transport model simulations, using this new description, with aircraft observations made during EULINOX and SONEX showed considerable improvement in model performance.

The number of aerosol types in TM (formerly only sulphate, nitrate, ammonium-nitrate aerosols) has been extended with hydrophilic and hydrophobic organic and black carbon aerosols. In the near future also sea salt en dust aerosols will be included. In the ARIA project a scheme for the assimilation of aerosol observations has been implemented. The goal of the next phase of ARIA is to use future ENVISAT and EOS-AURA aerosol optical depth observations to derive a product that gives the 3D distribution of aerosols. This can then be used to improve estimates of the global climate forcing by aerosols. The application of TM for chemical data assimilation is described in a separate paragraph.

The coupling of the TM model to the new 40 year ECMWF reanalysis (ERA40) of the global atmosphere has started and will proceed within the new EU project RETRO. It will enable to distinguish between the effects of variations in emissions and meteorological variability on the concentrations of greenhouse gases, ozone depleting substances and other pollutants. At our request ECMWF is archiving a small set of additional parameters important for chemistry-transport modelling during the execution of ERA40. For the 1990's the convective mass fluxes were found to be roughly similar to the ones previously calculated by our group in a diagnostic way. However, the simulation of nitrogen oxides and ozone was found to be quite sensitive to the particular choice of convective mass fluxes, giving differences of up to 30 %. Hence a comprehensive comparison to observations is needed.

Several model studies have been performed in the framework of the EU project TOwards the Prediction of stratospheric OZone (TOPOZ) III. The vertical transport given by ERA40 has been evaluated by comparing simulations of the age-of-air to an independent estimate based on observations of SF_6. Furthermore, a new zoom version of TM with a horizontal resolution down to 1 by 1 degree, developed at IMAU, was applied and evaluated for the Arctic stratosphere. Simulations of the passive tracers (HF and CH_4) for the 1999–2000 Arctic winters show reasonable agreement with observations.

Coupling between the stratosphere and the troposphere

Recent research at KNMI on the coupling between the stratosphere and the troposphere has focused on two subjects: estimates of stratosphere-troposphere exchange (STE), and the coupling between the winds in the stratosphere and near the surface. Quantification of STE is essential for understanding the budgets and distributions of ozone, greenhouse-gases and pollutants in the troposphere and stratosphere. For instance, estimates of the impact of aircraft emissions on ozone depend strongly on the quality of the simulation of STE. Despite several decades of research, the uncertainty in estimates of the amount of air and tracers exchanged between the stratosphere and the troposphere is still large.

After improving the numerical description of vertical transport in the TM chemistry transport model, the annual and global mean flux of ozone into the troposphere was reduced by almost a factor of two to 500–800 Tg/year, much closer to observational estimates.

Methods for the evaluation of STE were compared for the first time as part of the EU-project STACCATO (Influence of Stratosphere Troposphere Exchange in a Changing Climate on Atmospheric Transport and Oxidation Capacity). Mass fluxes of stratospheric and tropospheric tracers through the tropopause and the 700 hPa surface were calculated with 9 different models. These included trajectory models, chemistry-transport models, and general circulation models. For a 12-day case study over Europe and the northeast Atlantic most models showed the same temporal evolution and the same geographical pattern of STE, but generally with different amplitudes. Some of the differences could be attributed to specific model characteristics.

It has recently been discovered by Baldwin and Dunkerton that sudden large circulation changes in the stratosphere may be harbingers of anomalous weather regimes in the troposphere. The propagation of wind anomalies in the stratosphere down to the tropopause is explained by interaction between the background flow and upward propagating planetary waves. The propagation further down from the tropopause to the surface is less well understood. We have investigated this by analysing low-frequency variations in 1) the meridional mass flux into the polar cap (north of 60° N), computed separately for the stratosphere and the troposphere, 2) the polar cap mean surface pressure, and 3) the meridional surface pressure gradient and zonal wind around 60° N. The analysis has been done for the 1979–1993 northern hemisphere winters, using 6-hourly ECMWF circulation data. The results show that for all winters the meridional mass flux variations in the stratosphere precede those in the troposphere by about one day. The analysed variations in the polar cap mean surface pressure, associated with variations in the meridional mass flux, determine most of the variability in the analysed meridional surface pressure gradient and the associated surface zonal wind around 60° N. This indicates that in the extra-tropical northern winter hemisphere, low-frequency variations in the meridional wind in the stratosphere almost directly induce low-frequency variations in the zonal wind in the lower troposphere.

Observations

Development and application of satellite retrievals of ozone and other trace gasses

Several data retrieval studies and data processing activities have been conducted for a number of presently operational and future satellite instruments: GOME on ERS-2 (1995 -), SCIAMACHY on ENVISAT (2002 -), and GOME-2 on the METOP series (2005 -). Retrieval constitutes the extraction of information on atmospheric variables from radiance measurements. It demands an adequate description or forward model of the effect of these variables on the radiance and a technique to invert this relation. Retrieval algorithms are often not fully developed and improvements directly lead to better data quality.

For the retrieval of ozone profiles from GOME, OMI, SCIAMACHY and GOME-2 nadir measurements, a dedicated radiative transfer model which is fast and accurate enough for operational ozone profile retrieval has been developed and implemented.

Within the project SCIARALI an accurate radiative transfer model for SCIAMACHY limb observations has been developed, that will be used in the retrieval of profiles of ozone and other trace gasses. The construction of the full limb retrieval algorithm will be completed in 2003.

Commissioned by ESA, the group started in Autumn 2002 with the development of an improved algorithm for the retrieval of ozone column density from GOME measurements. The current ESA algorithm is shown to be too inaccurate to infer decadal trends in ozone. The project is performed in close co-operation with the ozone retrieval development within the OMI group.

Retrievals using GOME spectral measurements are hampered by inaccuracies in the calibration. Improved calibration schemes were developed for the wavelength registration of the spectra, for the sun-normalized earth radiance and for correction for the degradation of GOME. The resulting new re-calibration software package GOMECAL that applies these corrections has been constructed and is distributed, including documentation, to GOME data users.

Retrieval algorithms for ozone column and profiles have been installed in the GOME Fast Delivery Service that operationally processes near-real time GOME data (within three hours after sensing). This service has been set-up within the framework of the ESA Data User Programme. The ozone data is delivered to users via the Internet (http://www.knmi.nl/gome_fd/). The ozone column data is further used to compute and publish surface UV data and assimilated ozone fields. In 2002 the project TEMIS has started extending the range of products and satellite instruments from the Service. Users of the satellite data have been more involved in the definition of the service and products.

Assimilation of atmospheric composition satellite observations in a tracer transport model

Data assimilation applied to the composition of the atmosphere is a relative new field of research in which the group has an internationally highly regarded position. Chemical data assimilation involves the combination of (satellite) observations of atmospheric gases with chemistry-transport models. In data assimilation information from the measurements and a forecast model is mixed. This produces model fields of trace gas concentrations, which are in accordance with input measurements, but whose spatial and temporal coverage is not restricted to the fixed orbits and overpass times of the satellite.

The group has established an operational assimilation system that produces daily global maps of ozone column density based on GOME observations. The data, including a five-day forecast, are published directly on the Internet (http://www.knmi.nl/gome_fd/tm3/lvl4.html). This has enabled timely warnings for ozone events such as mini ozone holes over Europe and the breaking-up of the Antarctic ozone hole in Autumn 2002 *(Figure 1)*.

The integration of retrieval and assimilation methods is an approach for the future to achieve higher-quality data. Studies have started in the field of nitrogen-dioxide column retrieval/data assimilation and radiance assimilation for ozone profiles. Data assimilation is also used to analyse the quality of both the input measurements and the model. As a validation tool for satellite observations it has proven to be an important addition to comparisons with collocated ground-measurement. Evaluation of forecast-analysis differences can detect errors related to atmospheric and viewing conditions that are difficult to discern in ground-truth comparisons.

GOME data were retrieved and assimilated within the EU projects GOA and SAMMOA. The resulting long-term data sets were delivered to the project partners, scientific users and policy makers.

Validation of atmospheric composition satellite data

The objectives of the validation activities are to develop and apply strategies for the geophysical validation of satellite measurement of atmospheric trace gasses. Validation independently establishes the precision and accuracy of data. In practice improvements in satellite products are mainly

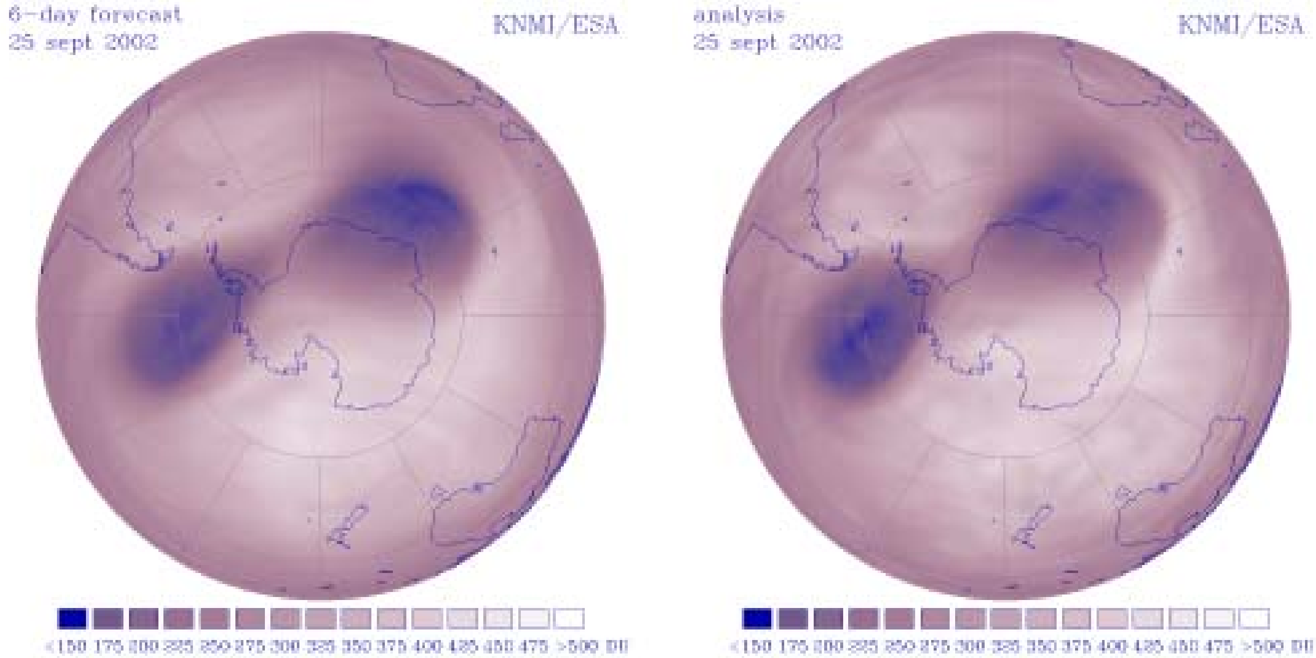


Figure 1. Breaking-up of the ozone hole in September 2002. Shown are the 6-day forecast, which was constructed and published on the 19th, (left panel) and the analysis for the 25th of September (right panel), when the ozone hole started to split. The large similarity illustrates the quality of the forecast.

driven by the outcome of data validation. The comparison to collocated observations from other instruments makes systematic errors visible that may be recognised as deficiencies in instrument calibration or retrieval algorithms.

The division leads the international effort to validate the data products of SCIAMACHY on board of ENVISAT (launched March 1st, 2002). SCIAMACHY measures trace gasses such as ozone, methane and carbon monoxide that are important for climate and atmospheric chemistry studies.

Four distinct phases of validation of SCIAMACHY data products are distinguished: the preparatory phase until launch, the commissioning phase, the main validation phase and the long-term validation phase. The main validation phase started in the second half of 2002 and will last until the end of 2003.

Preparation of future satellite missions

An early involvement in the preparation of future satellite missions gives opportunities to influence instrument design such that it optimally fulfils scientific needs.

The Satellite Application Facility on Ozone Monitoring (O3MSAF) project is a joint project of EUMETSAT and several European meteorological institutes and prepares for the operational delivery of ozone products from the GOME-2 instrument on the three METOP missions in the timeframe 2005–2020. KNMI has the responsibility to develop retrieval algorithms for the ozone profile and aerosol and leads the validation.

Coordinated by the group, scientific requirements have been established for a possible future atmospheric chemistry mission, ACE-CHEM. This study formed the basis of a proposal for an Earth Explorer Core mission delivered to ESA in 2001. Although the mission was not selected in this round of further studies and possible launch, the concept remains ‘alive’ and new possibilities for development and future launch are being studied. Also, the results of the requirements study are frequently used in preparations for other missions.

Paramaribo Station

In 1999 KNMI and the Meteorological Service of Surinam (MDS) have started an atmospheric observation programme in Paramaribo, Surinam (South America, 5.8° N, 55.2° W). Initially the observations consisted of surface ozone concentrations, weekly ozone soundings and continuous observations of UV spectra, ozone columns and (stratospheric) Umkehr profiles with a Brewer spectrophotometer. These observations are submitted on a routine basis to international networks such as NDSC, SHADOZ, WOUDC and the Envisat calibration/validation database. In 2002 a sun photometer, a solar radiation station, a total-sky imager and a MAX-DOAS spectrometer have been installed. These observations are very valuable for satellite validation and for studies of atmospheric composition and radiation in the tropics. Some results are presented in the Highlight on tropical processes in this Report.

The Ozone Monitoring Instrument

The Ozone Monitoring Instrument (OMI) will fly on NASA's EOS-AURA satellite, now scheduled for launch in January 2004. OMI is a UV/VIS, nadir viewing spectrometer that will provide near global coverage of solar backscatter radiances in one day. OMI has heritage from the TOMS, SBUV, GOME, GOMOS and SCIAMACHY, but has several technological advances. Using the wavelength range 270 to 500 nm with a 0.5 nm resolution, OMI will measure several key parameters for stratospheric and tropospheric chemistry and for climate research, including O_3 (column and profile), NO_2, SO_2, OClO, BrO, HCHO, UVB, aerosol and cloud properties (see *Figure 2*). Combining OMI data with the other Aura instruments will allow derivation of further tropospheric gases important for air quality studies and climate. OMI's high spatial resolution (13 x 24 km) will allow more frequent observations between clouds, thus giving better penetration into the troposphere than any other UV/VIS backscatter instrument flown to date.

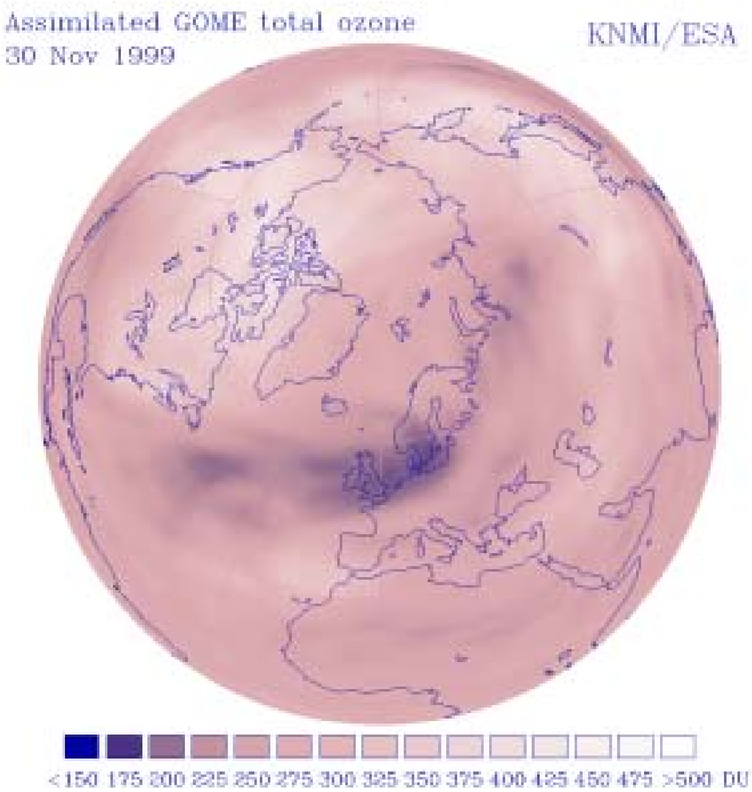


Figure 2. Mini Ozone hole above Europe on 30 November 1999, as derived from GOME measurements

The overall project management resides with the Dutch Space Agency NIVR in co-operation with FMI (Finnish Meteorological Institute) and NASA. A consortium of Dutch Space and TNO-TPD built the OMI instrument and developed the level 0 → 1b software with contributions by the Finnish industry (VTT and Finavitec).

KNMI is the Principal Investigator (PI) institute. The PI has to safeguard the overall scientific value of the mission. This is done in close co-operation with NASA GSFC and FMI scientists, represented in the international OMI science team, which is chaired by the OMI PI. Responsibilities of KNMI are to define the science, instrument and calibration requirements, to develop data products and to validate those. Moreover, KNMI will manage the Instrument Operation Team (IOT), which will perform the commanding of the OMI-instrument during the lifetime of the mission. A data processing site is also being developed, which will process part of the OMI-data and will be used to monitor instrument parameters for in-flight calibration. All data will be available via the EOSDIS NASA Goddard Space DAAC System. Preparations have been made for a KNMI Near Real Time system that produces ozone columns within 3 hours after measurement. These provide wind fields at high altitudes, which will be used for operational meteorology. Furthermore, OMI will provide Very Fast Delivery (VFD) ozone and UV products (within 30 minutes of detection) for north and middle Europe using the direct broadcast feature from Aura.

During 2001 and 2002 the KNMI OMI science team has worked on many aspects of the OMI project. Two of them, the development and review of retrieval algorithms and tests of the performance of the instrument are discussed in more detail in the next paragraphs. Another highlight occurred in November 2002 when OMI was the first instrument of the EOS-Aura payload which was delivered for spacecraft integration. Currently, KNMI is heavily involved in tests concerning the operation of the instrument.

OMI ATBD Review

For each data product developed within the NASA EOS system, the scientific foundation is described in the so-called Algorithm Theoretical Basis Documents (ATBDs). The ATBDs present a detailed picture of the instrument and the retrieval algorithms used to derive atmospheric information from the instrument's measurements. NASA reviews all ATBDs by installing an external panel of independent experts. The OMI ATBDs were written by the International OMI Science Team. The Dutch contribution is predominantly from KNMI researchers and describes the algorithms for total ozone DOAS, Ozone Profile, UV-VIS aerosol optical thickness, NO_2 total columns and cloud fraction and cloud pressure. The OMI ATBD review took place in Washington DC, USA at the 8th of February 2002. The review was chaired by Prof. Burrows from Bremen University and was very favourable, which is seen as a strong indication for the scientific validity and accuracy of the data products to be produced by OMI. Based on the review report, the OMI ATBDs were updated and posted on the NASA web site: http://eospso.gsfc.nasa.gov/eos_homepage/for_scientists/atbd/

Initial tests of the performance of OMI

In August 2002 two types of test measurements were performed with the OMI flight model. The purpose of these measurements was to test OMI under in-flight thermal-vacuum conditions, by measuring atmospheric constituents using scattered solar radiation observed at different solar elevations (zenith sky measurement) and thus to perform OMI's first real atmospheric experiment. First the overall performance of the OMI instrument was successfully checked, by measuring the absorption of radiation from a lamp with known properties by ozone and nitrogen dioxide present in a gas cell that was put in front of the instrument.

To perform the zenith sky measurement the instrument, placed on the ground, views the sky in zenith, looking at solar radiation that has travelled through the ozone layer, is partly absorbed there, and is subsequently scattered towards OMI by aerosols or molecules in the atmosphere *(Figure 3)*. The ratio of the two spectra measured at two different solar elevations matches the absorption cross section of ozone. *Figure 4* shows that the measured absorption spectrum of atmospheric ozone compares well with literature values of this spectrum. The zenith sky and absorption gas cell measurements have demonstrated that the OMI flight model is capable of measuring ozone and nitrogen dioxide from space.

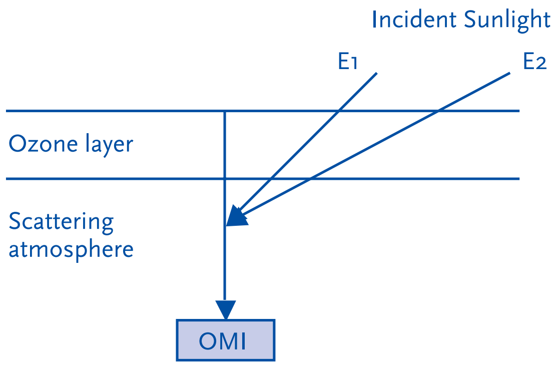


Figure 3. Principle of zenith sky measurements. At two solar elevations, E1 and E2, the path through the absorbing ozone layer differs and the ratio of these spectra will correspond to the absorption spectrum of ozone.

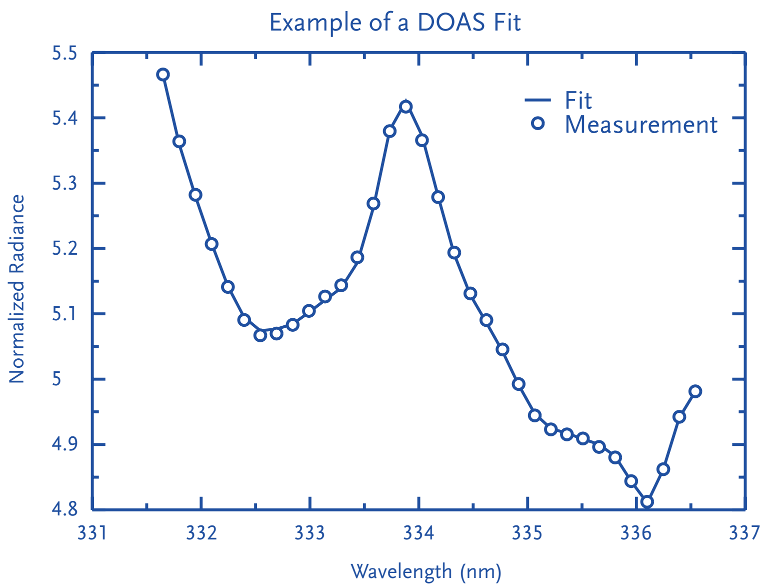


Figure 4. Example of a DOAS fit for the wavelength window used for the retrieval of ozone from a zenith sky measurement. The circles are the measurements, the line the fit, based on absorption cross-sections taken from the literature.

Publications are listed by Division. A paper with authors from different Divisions will be listed more than once in this Report.

Scientific publications in reviewed journals

2001

A, R. J. van der, 2001. *Improved ozone profile retrieval from combined nadir/limb observations of SCIAMACHY.* J. Geophys. Res., **106**, 14,583–14,594.

Andreae, M.O., P. Artaxo, H. Fischer, S.R. Freitas, J.-M. Gregoire, A. Hansel, P. Hoor, R. Kormann, R. Krejci, L. Lange, J. Lelieveld, W. Lindinger, K. Longo, W. Peters, M. de Reus, B. Scheeren, M.A.F. Silva Dias, J. Strom, P.F.J. van Velthoven and J. Williams, 2001. *Transport of biomass burning smoke to the upper troposphere by deep convection in the equatorial region.* Geophys. Res. Lett., **28**, 951–954.

Barrie, L.A., Y. Yi, W.R. Leaitch, U. Lohmann, P. Kasibhatla, G.-J. Roelofs, J. Wilson, F. McGovern, C. Benkovitz, M.A. Melières, K. Law, J. Prospero, M. Kritz, D. Bergmann, C. Bridgeman, M. Chin, J. Christensen, R. Easter, J. Feichter, C. Land, A. Jeuken, E. Kjellstrom, D. Koch and P. Rasch, 2001. *A comparison of large scale atmospheric sulphate aerosol models (COSAM): overview and highlights.* Tellus B, **53**, 615–645.

Braak, C.J., J.F. de Haan, C.V.M. van der Mee, J.W. Hovenier and L. D. Travis, 2001. *Parameterized scattering matrices for small particles in planetary atmospheres.* J. Quant. Spectros. Rad. Transf., **69**, 585–604.

Chepfer, H., P. Goloub, J. Riedi, J.F. de Haan, J.W. Hovenier and P.H. Flamant, 2001. *Ice crystal shapes in cirrus clouds derived from POLDER-1/ADEOS-1.* J. Geophys. Res., **106**, 7955–7966.

Dop, H. van, and G.H.L. Verver, 2001. *Countergradient transport revisited.* J. Atmos. Sci., **58**, 2240–2247.

Franke, K., A. Ansmann, D. Muller, D. Althausen, F. Wagner and R. Scheele, 2001. *One-year observations of particle lidar ratio over the tropical Indian Ocean with Raman lidar.* Geophys. Res. Lett., **28**, 4559–4562.

Gouw, J.A. de, C. Warneke, H.A. Scheeren, C. van der Veen, M. Bolder, M.P. Scheele, J. Williams, S. Wong, L. Lange, H. Fischer and J. Lelieveld, 2001. *Overview of the trace gas measurement on board the citation aricraft during the intensive field phase of INDOEX.* J. Geophys. Res., **106**, 28,453–28,467.

Hoogeveen, R.W.M., R.J. van der A and A.P.H. Goede, 2001. *Extended wavelenght In GaAs infrared (1.0–2.4 mm) detector arrays on SCIAMACHY for space-based spectrometry of the Earth atmosphere.* Infr. Phys. Technol., **42**, 1–16.

Jeuken, A., J.P. Veefkind, F. Dentener, S. Metzger and C. Robles Gonzalez, 2001. *Simulation of the aerosol optical depth over Europe for August 1997 and a comparison with observations.* J. Geophys. Res., **106**, 28,295–28,311.

Koelemeijer, R.B.A., P. Stammes, J.W. Hovenier and J.F. de Haan, 2001. *A fast method for retrieval of cloud parameters using oxygen A-band measurements from the Global Ozone Monitoring Experiment.* J. Geophys. Res., **106**, 3475–3490.

Lange, L., P. Hoor, G. Helas, H. Fischer, D. Brunner, B. Scheeren, J. Williams, S. Wong, K.-H. Wohlfrom, F. Arnold, J. Strom, R. Krejci, J. Lelieveld and M.O. Andreae, 2001. *Detection of lightning-produced NO in the midlatitude upper troposphere during STREAM 1998.* J. Geophys. Res., **106**, 27,777–27,785.

Lohmann, U., W.R. Leaitch, L. Barrie, K. Law, Y. Yi, D. Bergmann, C. Bridgeman, M. Chin, J. Christensen, R. Easter, J. Feichter, A. Jeuken, E. Kjellstrom, D. Koch, C. Land, P. Rasch and G.-J. Roelofs, 2001. *Vertical distributions of sulfur species simulated by large scale atmospheric models in COSAM: comparison with observations.* Tellus B, **53**, 646–672.

Meijer, E.W., P.F.J. van Velthoven, D.W. Brunner, H. Huntrieser and H. Kelder, 2001. *Improvement and evaluation of the parameterisation of nitrogen oxide production by lightning.* Phys. Chem. Earth, **26**, 557–583.

Meloen, J., P.C. Siegmund and M. Sigmond, 2001. *A Langrangian computation of Stratosphere-troposhere exchange in a tropopause folding event in the subtropical Southern Hermisphere.* Tellus, **53**, 367–378.

Müller, D., K. Franke, F. Wagner, D. Althausen, A. Ansmann, J. Heintzenberg and G.H.L. Verver, 2001. *Vertical profiling of optical and physical particle properties over the tropical Indian Ocean with six-wavelength lidar, part II: Case studies.* J. Geophys. Res., **106**, 28,577–28,595.

Muñoz, O., H. Volten, J.F. de Haan, W. Vassen and J. W. Hovenier, 2001. *Experimental determination of scattering matrices of randomly oriented fly ash and clay particles at 442 and 633 nm.* J. Geophys. Res., **106**, 22,833–22,844.

Naus, H., W. Ubachs, P.F. Levelt, O.L. Polyansky, N.F. Zobov and J. Tennyson, 2001. *Cavity-Ring-Down Spectroscopy on Water Vapor in the Range 555 – 604 nm.* J. Molec. Spec., **205**, 117–121.

Reus, M. de, R. Krejci, J. Williams, H. Fisher, R. Scheele and J. Ström, 2001. *Vertical and horizontal distributions of the aerosol number concentration and size distribution over the northern Indian Ocean.* J. Geophys. Res., **106**, 28,629–28,641.

Roelofs, G.-J., P. Kasibhatla, L. Barrie, D. Bergmann, C. Bridgeman, M. Chin, J. Christensen, R. Easter, J. Feichter, A. Jeuken, E. Kjellstrom, D. Koch, C. Land, U. Lohmann and P. Rasch, 2001. *Analysis of regional budgets of sulfur species modeled for the COSAM exercise.* Tellus B, **53**, 673–694.

Scheele, M.P. and P.C. Siegmund, 2001. *Estimating Errors in trajectory forecastst using ensemble predictions.* J. Appl. Meteor., **40**, 1223–1232.

Schulz, A., M. Rex, N.R.P. Harris, G.O. Braathen, E. Remier, R. Alfier, I. Kilbane-Dawe, S. Eckermann, M. Allaart, M. Alpers, B. Bojkov, J. Cisneros, H. Claude, E. Cuevas, J. Davies, H. De Backer, H. Dier, V. Dorkhov, H. Fas, S. Godin, B. Johnson, B. Kois, Y. Kondo, E. Kosmidis, E. Kyro, Z. Litynska, I.S. Mikkelsen, M.J. Molyneux, G. Murphy, T. Nagai, H. Nakane, F. O'Connor, C. Prondo, F.J. Schmidlin, P. Skrivankova, C. Varotsos, C. Vialle, P. Viatte, V. Yushkov, C. Zerefos and P. von der Gathen, 2001. *Arctic ozone loss in threshold conditions: Match observations in 197/1998 and 1998/1999.* J. Geophys. Res., **106**, 7495–7503.

Stohl, A., L. Haimberger, M.P. Scheele and H. Wernli, 2001. *An intercomparison of results from three trajectory models.* Meteor. Appl., **8**, 127–135.

Verver, G.H.L., D.R. Sikka, J.M. Lobert, G. Stossmeister and M. Zachariasse, 2001. *Overview of the meteorological conditions and atmospheric transport processes during INDOEX 1999.* J. Geophys. Res., **106**, 28,399–28,413.

Volten, H., O. Muñoz, E. Rol, J.F. de Haan, W. Vassen, J.W. Hovenier, K. Muinonen and T. Nousiainen, 2001. *Scattering matrices of mineral aerosol particles at 441.6 nm and 632.8 nm.* J. Geophys. Res., **106**, 17,375–17,401.

Zachariasse, M., H.G.J. Smit, P.F.J. van Velthoven and H. Kelder, 2001. *Cross-tropopause and interhemispheric transport into the green troposphere over the Idian Ocean.* J. Geophys. Res., **106**, 28,441–28,452.

2002

A, R.J. van der, R.F. van Oss, A.J.M. Piters, J.P.F. Fortuin, Y.J. Meijer and H.M. Kelder 2002. *Ozone profile retrieval from recalibrated Global Ozone Monitoring Experiment data.* J. Geophys. Res., **107**, 10.1029/2001JD000696.

Braak, C.J., J.F. de Haan, J.W. Hovenier and L.D. Travis, 2002. *Spational and temporal variations of Venus haze properties obtained from Pioneer Venus Orbiter polarimetry.* J. Geophys. Res., **107**, 5-1–5-13.

Bregman, B., Pi-H. Wang and J. Lelieveld, 2002. *Chemical ozone loss in the tropopause region on subvisible ice clouds, calculated with a chemistry-transport model.* J. Geophys. Res., **107**, 10.1029/2001JD000761.

Bregman, B., A. Segers, M. Krol, E. Meijer and P. van Vel*thoven, 2002. On the use of mass-conserving wind fields in chemistry-transport models.* Atmos. Chem. Phys. Discuss., **2**, 1765–1790.

Bremer, H., M. von Koenig, A. Kleinboehl, H.Kuellmann, K.F. Kuenzi, K.Bramstedt, J.P. Burrows, K.U. Eichmann, M. Weber and A.P.H. Goede, 2002. *Ozone depletion observed by ASUR during the Arctic Winter 1999/2000.* J. Geophys. Res., **107**, 10.1029/2001JD000546.

Brinksma, E.J., J. Ajtic, J.B. Bergwerff, G.E. Bodeker, I.S. Boyd, J.F. de Haan, W. Hogervorst, J.W. Hovenier and D.P.J. Swart, 2002. *Five years of observations of ozone profiles over Lauder, New Zealand.* J. Geophys. Res., **107**, 10.1029/2001JD000737.

Dentener, F., M. van Weele, M. Krol, S. Houweling and P. van Velthoven, 2002. *Trends and interannual variability of methane emissions derived from 1979–1993 – global CTM stimulations.* Atmos. Chem. Phys. Discuss., **2**, 249–287.

El Serafy, G., R. van der A, H. Eskes and H. Kelder, 2002. *Assimilation of 3D ozone field in global chemistry-transport models using Kalman filter.* Adv. Space Res., **30**, 2473–2478.

Eskes, H.J., P.F.J. van Velthoven and H.M. Kelder, 2002. *Global ozone forecasting based on ERS-2 GOME observations.* Atmos. Chem. Phys., **2**, 271–278.

Fischer, H., D. Brunner, G.W. Harris, P. Hoor, J. Lelieveld, D.S. McKenna, J. Rudolph, H.A. Scheeren, P. Siegmund, H. Wernli, J. Williams and S. Wong, 2002. *Synoptic tracer gradients in the upper troposphere over central Canada during the STREAM 1998 summer campaign.* J. Geophys. Res., **107**, 10.1029/2001JD000312.

Hakvoort, H., J. de Haan, R. Jordans, R. Vos, S. Peters and M. Rijkeboer, 2002. *Towards airborne remote sensing of water quality in The Netherlands – validation and error analysis.* ISPRS J. Photogramm. Remote Sensing, **57**, 171–183.

Hasekamp, O.P., J. Landgraf and R.F. van Oss, 2002. *The need of polarization modelling for ozone profile retrieval from backscattered sunlight.* J. Geophys. Res., **107**, 10.1029/2002JD002387.

Huntrieser, H., Ch. Feigl, H. Schlager, F. Schroder, C.H. Gerbig, P. van Velthoven, F. Flatoy, C. Thery, A. Petzold, H. Holler and U. Schumann, 2002. *Contribution of lightning –produced NOx to the European and global NOx budget: Results and estimates from airborne EULINOX measurements.* J. Geophys. Res., **107**, 10.1029/2000JD000209.

Joeckel, P., C.A.M. Brenninkmeijer, M.G. Lawrence, A.B.M. Jeuken and P.F.J. van Velthoven, 2002. *Evaluation of stratosphere-troposphere exchange and the hydroxyl radical distribution in 3-dimensional global atmospheric models using observations of cosmogenic 14CO.* J. Geophys. Res., **107**, D20, 446, 10.1029/2001JD001324.

Kleinboehl, A., H. Bremer, M. von Koenig, H. Kuellmann, K.F. Kuenzi, A.P.H. Goede, E.V. Browell, W.B. Grant, G.C. Toon, T. Blumenstock, B. Galle, B.M. Sinnhuber and S. Davies, 2002. *Vortex wide Denitrification of the Arctic Polar Stratosphere in Winter 1999/2000 determined by Remote Observations.* J. Geophys. Res., **107**, 10.1029/2001JD001042.

Koelemeijer, R.B.A., P. Stammes, J.W. Hovenier and J.F. de Haan, 2002. *Global distribution of effective cloud fraction and cloud top pressure derived from oxygen A band spectra measured by the Global Ozone Monitoring, Experiment: Comparison to ISCCP data.* J. Geophys. Res., **107**, 10.1029/2001JD000840.

Koenig, M. von, H. Bremer, A. Kleinboehl, H. Kuellmann, K.F. Kuenzi, A.P.H. Goede, E.V. Browell, W.B. Grant, J. Burris, T. McGee and L. Twigg, 2002. *Using gas-phase nitric acid as an indicator of PSC composition.* J. Geophys. Res., **107**, 10.1029/2001JD001041.

Lelieveld, J., P. Siegmund et al., 2002. *Global air pollution crossroads over the Mediterranean.* Science, **298**, 794–799.

Muñoz, O., H. Volten, J.F. de Haan, W. Vassen, J.W. Hovenier and L.D. Travis, 2002. *Experimental determination of the phase function and degree of linear polarization of El Chichón and Pinatubo volcanic ashes.* J. Geophys. Res., **107**, 10.1029/2001JD000983.

Noel., S., H. Bovensmann, M.W. Wuttke, J.P. Burrows, M. Gottwald, E. Krieg, A.P.H. Goede and C. Muller, 2002. *Nadir, Limb and Occultation Measurements with SCIAMACHY*. Adv. Space Res., **29**, 1819–1824.

Oberlander, E.A., C.A.M. Brenninkmeijer, P.J. Crutzen, N.F. Elansky, G.S. Golitsyn, I.G. Granberg, D.H. Scharffe, R. Hofmann, I.B. Belikov, H.G. Paretzke and P.F.J. van Velthoven, 2002. *Trace Gas Measurements Along the Trans-Siberian Railroad and River Ob, the Troica 5 Expedition.* J. Geophys. Res., **107**, 10.1029/2001JD000953.

Öllers, M.C., P.F.J. van Velthoven, H. Kelder and L. Kamp, 2002. *A study of the leakage of the Antarctic polar vortex in late austral winter and spring using isentropic and 3-D trajectories.* J. Geophys. Res., **107**, 10.1029/2001JD001363.

Oss, R. van and R.J.D. Spurr, 2002. *Fast and accurate 4 and 6-stream linearised discrete ordinate radiative transfer models for ozone profile remote sensing retrieval.* J. Quant. Spectros. Rad. Transf., **75**, 177–220.

Papaspiropoulos, G., B.G. Martinsson, A. Zahn, C.A.M. Brenninkmeijer, M. Hermann, J. Heintzenberg, H. Fischer and P.F.J. van Velthoven, 2002. *Aerosol elemental concentrations in the tropopause region from intercontinental flights with the Civil Aircraft for Regular Investigation of the Atmosphere Based on an Instrument Container (CARIBIC) platform.* J. Geophys. Res., **107**, 10.1029/2002JD002344.

Pitari, G., E. Manchini and A. Bregman, 2002. *Climate forcing of subsonic aviation: Indirect role of sulphate particles via heterogeneous chemistry.* Geophys. Res. Lett., **4**, 29,22,2057 10.1029/2002 GL 015705.

Reijmer, C.H., M.R. van den Broeke and M.P. Scheele, 2002. *Air parcel trajectories and snowfall related to five deep drilling locations on Antarctica, based on the ERA –15 data set.* J. Climate, **15**, 1957–1968.

Rogers, H., H. Teyssedre, G. Pitari, V. Grewe, P. van Velthoven and J. Sundet, 2002. *Model Intercomparison of the Transport of Aircraft-like Emissions from Sub- and Supersonic Aircraft*. Meteor. Z., **11**, 151–159.

Zahn, A., C.A.M. Brenninkmeijer, W.A.H. Asman, P.J. Crutzen, G. Heinrich, H. Fischer, J.W.M. Cuijpers and P.F.J. van Velthoven, 2002. *Budgets of O3 and CO in the upper troposphere: CARIBIC passenger aircraft results 1997–2001.* J. Geophys. Res., **107**, 10.1029/2001 JD001529.

Other scientific publications and reports

2001

A, R.J. van der, 2001. *Recalibration of GOME spectra for the purpose of ozone profile retrieval.* KNMI Technical Report TR-236.

A, R.J. van der, M. van Weele, M.A.F. Allaart and J.P.F Fortuin, 2001. *Satellite and site measurements of ozone and UV at De Bilt (52N) and Paramaribo (6N), Validation of GOME ozone profiles, Current problems in atmospheric radiation.* Proc. Int. Radiation Symp., St. Petersburg, Russia, 24–29 July 2000, 148–150.

Boersma, K.F and E.J. Brinksma, 2001. *Vertical NO_2 column densities from the Ozone Monitoring Instrument: (1) slant colmn density retrieval.* Proc. Workshop Nitrogen Oxides in Lower Stratosphere and Upper Troposphere, Heidelberg, Germany, 19–22 March, 2–4.

Braathen, G.-O., F. Goutail, H. Flentje, F. Stroh, M. Chipperfield, P. von der Gathen, G. Vaughan, K. Kuenzi, E. Kyroe, B. Knudsen, C. Brogniez, K.H. Fricke, G. Hochschild, A. Goede, K. Pfeilsticker, C. Camy-Peyret, M. Pirre, U. Raffalski, T. Peter and N. Kämpfer. *Improved understanding of stratospheric ozone loss by measurements and modelling.* THESEO-EuroSOLVE Final Report, EC 5FP EESD-ENV-99-1, contract EVK2-CT-1999-00047.

Brink, H.M. ten, A. Hensen, A. Khlystov, R. van Dorland, A. Jeuken, P. van Velthoven, J. Lelieveld, A. van den Berg, D.P.J. Swart, J.B. Bergwerff and A. Apituley, 2001. *Aerosol: Cycle and Influence on the Radiation Balance.* NOP-final report.

Brinksma, E.J., 2001. *Lidar investigations of the middle atmosphere.* PhD-Thesis, Free University of Amsterdam.

Brinksma E.J. and K.F. Boersma, 2001. *NO_2 column densities from the Ozone Monitoring Instrument: (2) sensitivity of the Airmass Factors to Clouds.* Proc. Workshop Nitrogen Oxides in Lower Stratosphere and Upper Troposphere, Heidelberg, Germany, 19–22 March, 6–7.

Brinksma, E.J. and K.F. Boersma, 2001. *Validation of NO_2 Column densities Measured by the Ozone Monitoring Instrument (OMI).* Proc. NDSC Symposium, Arachon, France, 24–27 September, 152.

Craig, C., K. Stone, N. Livesey, S. Friedman, S. Lewicki, D. Ilg, P. Veefkind and P. Leonard, 2001. *Version 1.1, HDF-EOS Aura File Format Guidelines.*

Eskes, H., P. van Velthoven, P. Valks, M. Allaart, A. Piters and H. Kelder, 2001. *GOME ozone data assimilation and validation of SCIAMACHY ozone observations.* Proc. Pre-launch Workshop Atmospheric Chemistry Validation Envisat (ACVE), Noordwijk, the Netherlands, 16–18 May (CD-ROM).

Eskes, H.J., G.Y. El Serafy and H.M. Kelder, 2001. *Sciamachy Data Assimilation.* Final report BCRS Project 4.1/AP-09.

Froidevaux L., A. Douglass, D. Kinnison, E. Brinksma, D. Rider, K. Boersma, P.F. Levelt et al., 2001. *EOS-Aura Validation Plan, version 1.0.* NASA Report.

Froidevaux, L., R. Beer, D.M. Rider, S.P. Sander, J.W. Waters, J.J. Barnett, J.C. Gille, B. Johnson, D. Kinnison, S.T. Massie, K.F. Boersma, E.J. Brinksma, P. Levelt, G.W. Leppelmeier, P.K. Bhartia, A.R. Douglass, E. Hilsenrath, R. McPeters and M.R. Schoeberl, 2001. *The Aura Mission: Measurements, Validation Plan, and Synergies with NDSC.* Proc. NDSC Symp., Arachon, France, 24–27 September, 157.

Goede, A.P.H. and H. Nett, 2001. *Calibration, Radiative transfer and Data Assimilation.* Session Chair Report Atmosphere, ERS-ENVISAT Symp. Looking down to Earth in the New Millennium, Gothenburg, Sweden, 16–20 October 2000, ESA Publication SP-461, 2.

Goede, A.P.H., C.P. Tanzi, M. van den Broek, F. Wittrock, J.P. Burrows, K. Bramstedt, M. Weber, K.-U. Eichmann, A. Richter, D. Perner, P.S. Monks, G.K. Corlett, B. Arlander, G.H. Hansen, K.K. Toernkvist, B.-A.K. Hoiskar, U. Platt, T. Wagner, K. Pfeilsticker, P. Taalas, L. Koskinen, H. Kelder, G. El Serafy and H. Eskes, 2001. *GODIVAERS - GOME Data Interpretation, Validation and Application.* ERS-ENVISAT Symp. Looking down to Earth in the New Millennium, Gothenburg, Sweden, 16–20 October 2000, ESA Publication SP-461, 124.

Huntrieser, H., Ch. Feigl. H. Schlager, F. Schroder, Ch. Gerbig, P. van Velthoven, F. Flatoy, C. Thery, A. Petzold, H. Holler and U. Schumann, 2001. *Airborne measurements of Nox, tracer species and small particles during the European Lightning Nitrogen Oxides Experiment.* DLR Institut fuer Physik der Atmosphaere, Report No. 146.

Kelder, H., A. Piters, H. Eskes and R. Timmermans, 2001. *Sciamachy, the long-term validation plans.* Proc. ACVE workshop, ESTEC, Noordwijk, the Netherlands, 16–18 May, Paper 5-3 (CD-ROM).

Kelder, H., P.F.J. van Velthoven and P. Siegmund, 2001. *Stratosphere-troposphere exchange.* Proc. EC advanced study course ASTAIRE, Atmospheric Effects of Aircraft Emission in Upper troposphere and Lower Stratosphere, Bergen, Norway, 22–31 August 1999, Air pollution research report 77, European Commission, 100–115.

Kelder, H., M. van Weele, H. Eskes and A. Piters, 2001. *SCIAMACHY: Een Nederlands-Duits-Belgische bijdrage aan het ozon- en klimaatonderzoek.* Remote Sensing & Geo-informatie, **3**, BCRS, Delft, the Netherlands.

Kelder, H.M., H.J. Eskes, G.Y. El Serafy, I. Isaksen, M. Gauss, C.S. Zerefos, D. Balis, U. Platt, M. Wenig, T. Wagner, G.H. Hansen and C. Zehner, 2001. *The GOA project.* Proc. SAF Training Workshop on Ozone Monitoring, Halkidiki, Greece, 21–23 May, EUM P 32, 68.

Laan, E., D. de Winter, J. de Vries, P. Levelt, G.H.J. van den Oord, A Maelkki, G. Leppelmeier and E. Hilsenrath, 2001. *Towards the use of the Ozone Monitoring Instrument (OMI).* Proc. SPIE Int. Symp. Remote Sensing, Toulouse, France, 17–21 Sept.

Levelt, P. and R.F. van Oss, 2001. *The Ozone Monitoring Instrument.* Proc. SAF Training Workshop on Ozone Monitoring, Halkidiki, Greece, 21–23 May, EUM P 32, 203–217.

Meijer, E.W., 2001. *Modelling of the impact of subsonic aviation on the composition of the atmosphere.* PhD-Thesis, Technical University of Eindhoven.

Muller, C. and H. Kelder, 2001. *Antartic ozone observations from Base Roi Baudouin: 1965–1967.* The Belgica Expedition Centennial, 223–228.

Oss, R.F. van, 2001. *Development of an ozone profile retrieval algorithm for GOME and GOME-2.* Proc. SAF Training Workshop on Ozone Monitoring, Halkidiki, Greece, 21–23 May, EUM P 32, 154.

Oss, R.F. van, J. Landgraf, O. Hasekamp, A. Goede and H. Kelder, 2001. *Development of an off-line retrieval algorithm for ozone profiles form atmospheric spectra.* Final Report BCRS project DORAS, USP-2 report 01-19, June 2001.

Plate, M. te, F. Draaisma, J. de Vries and B. van den Oord, 2001. *Ozone Monitoring Instrument: system description and test results.* Proc. 52nd Int. Astronautical Congress (IAF-2001), Toulouse, France, 1–5 Oct.

Platt, U., J.P. Burrows, P. Borell, M. Dameris, A.P.H. Goede, H. Kelder, P.S. Monks, A. Richter, H.G.J. Smit and T. Wagner, 2001. *TROPOSAT – The Use and Usability of Satellite Data for tropospheric research.* ERS-ENVISAT Symp. Looking down to Earth in the New Millennium, Gothenburg, Sweden, 16–20 October 2000, ESA Publication SP-461, 184.

Roemer, M., P. Zandveld, M. van Weele, P. van Velthoven and G. Velders, 2001. *Monitoring Emissions of Greenhouse Gases using SCIAMACHY.* BCRS project 4.1/AP-08, Status report Milestone 2, TNO report-MEP-R2001/298.

Roemer, M., P. Zandveld, P.J.F. van Velthoven, M. van Weele and G. Velders, 2001. *Monitoring Emissions of Greenhouse Gases using Sciamachy (MEGGY).* Status Report Milestone 2, BCRS report 01-42, USP-2.

Roemer, M., P. Zandveld, P.J.F. van Velthoven, M. van Weele and G. Velders, 2001. *Monitoring Emissions of Greenhouse Gases using Sciamachy (MEGGY0).* Status Report Milestone 1, BCRS report 00-36, USP-2.

Schoeberl, M.R., A.R. Douglass, E.Hilsenrath, M. Luce, J. Loiacono, J. Barnett, R. Beer, J. Waters, J. Gille, P.F. Levelt and P. DeCola, 2001. *The EOS Aura Mission.* Proc. Int. Geoscience Remote Sensing Symp. (IGARSS), Sydney, Australia, 9–13 July.

Straume, A.G., I. Aben, H. Eskes, J. Gille, M. Krol, H. Schrijver and M. van Weele, 2001. *Validation of Sciamachy CO and CH4 data products.* Proc. ACVE, ESTEC, Noordwijk, the Netherlands, 16–18 May, Paper 4-5 (CD-ROM).

Weele, M. van, 2001. *Climate Change: The Scientific Basis, IPCC Third Assessment Report.* Contributing author Chapters 4 and 5.

Weele, M. van, 2001. *ESA, The five candidate Earth Explorer Core Missions, Report for Assessment, ACECHEM, Atmospheric Composition Explorer for Chemistry-Climate Interaction.* Contributing author, User Consultation Meeting Granada.

Weele, M. van, O. Boucher, C. Clerbaux, M. Gauss, D. Hauglustaine, I.S.A. Isaksen, H. Kelder and P.J.F. van Velthoven, 2001. *Part II, Definition of Mission objectives and Quantittative requirements.* In: Kerridge et al. (Eds.), Final Report on Definition of Observational Requirements for Support of Future Earth Explorer Atmospheric Chemistry Mission (ACE), ESA contract No.: 1-3379/98/NL/GD, ESA Report.

Weele, M. van, R.J. van der A, M.A.F. Allaart and J.P.F. Fortuin, 2001. *Satellite and site measurements of ozone and UV at De Bilt (52N) and Paramaribo (6N), II, 2001, Relating ozone profiles with surface UV radiation.* Proc. Int. Radiation Symposium 2000, St Petersburg, Russia, 24–29 July 24–29 2001.

Winter, de D., E. Laan, B. van den Oord, A.C. Kelly, J.C. Rivera, J. Carpay and A. Malkki, 2001. *The International Ozone Monitoring Instrument (OMI).* Proc. 52nd Int. Astronautical Congress (IAF-2001), Toulouse, France, 1–5 Oct.

2002

Badosa, J. and M. van Weele, 2002. *The effect of aerosols on UV Index.* KNMI Scientific Report WR 2002-07.

Boersma, K.F., E.J. Brinksma, E. Bucsela and J. Gleason, 2002. *Three Good Reasons to Eagerly Await OMI NO_2 column Measurements.* Proc. 8th European Symp. Physical-Chemical Behaviour Atmospheric

Pollutants, Torino, Italy, 7–20 September, J. Hjorth, F. Raes and G. Angeleletti (Eds.), CD-ROM, AP128.
Bregman, A., A. Segers, M. Krol, E. Meijer and P.J.F. van Velthoven, 2002. *3-D Model evaluation in the tropopause region and lower stratosphere.* Proc. Sixth European Symp. Stratospheric Ozone, Goteborg, Sweden, 2–6 September.
Eskes, H.J. and H.M. Kelder, 2002. *NO_2 and ozone observations from space and the prospect for chemical forecasting.* Proc. Int. Conf. Modelling, Monitoring, Management of Air Pollution, Segovia, Spain, 1–3 July, 451–462.
Havskov-Sorensen, J., I. Jacobsen, V. Lindfors, T. Lindkvist and P. van Velthoven: *Feasibility study of a system for ozone forecasts for Europe operated by NMS co-operation.* Report to the Working Group Environment of EUMETNET, DMI, Copenhagen, Danmark, 22 August.
Kelder, H.M., H.J. Eskes, F. Boersma, I. Isaksen, M. Gauss, C.S. Zerefos, D. Balis, U. Platt, M. Wenig, T. Wagner, G.H. Hansen, O.F. Vik and C. Zehner, 2002. *The GOA project.* Proc. Sixth European Symp. Stratospheric Ozone, Goteborg, Sweden, 2–6 September.
Kleinboehl, A., H. Bremer, M. von Koenig, H. Kuellmann, K.F. Kuenzi and A.P.H. Goede, 2002. *Investigation of Stratospheric Trace Gases using the Airborne Submillimeter Radiometer ASUR.* Proc. Deutsche Physikalischen Geselschaft, Fruehjahrstagung, Leipzig, Germany, 13 March.
Meirink, J.F., 2002. *The role of wind waves and sea spray in air-sea interaction.* PhD-Thesis, Technical University of Delft.
Meloen, J., 2002. *Simulations and Diagnosis of Stratosphere-Troposphere Exchange.* PhD-Thesis, Technical University of Eindhoven.
Pulles, J.W., G. Baarse, A. van Velzen, C. Kloditz, P. Kouwenhoven, R.Hancox, D. Edmonson, S. Lowe, S. Woodhouse, J. Middel, H.B.G. ten Have, T.D. de Witte, P.H.H. Brok, P.F.J. van Velthoven, W.M.F. Wauben, E.W. Meijer and H. Kelder, 2002. *Aviation Emissions and Evaluation of Reduction Options.* AERO Main report, Directorate General for Civil Aviation, Ministry of Transport, Public Works and Watermanagement, The Hague, the Netherlands.
Runhke, R., A. Bregman, M. Chipperfield and F. Lefevre, 2002. *Intercomparison of Photolysis rates Calculated by 3-D CTMs.* Proc. Sixth European Symp. Stratospheric Ozone, Goteborg, Sweden, 2–6 September.
Segers, A., 2002. *Data assimilation in atmospheric chemistry models using Kalman filtering.* PhD-Thesis, Technical University of Delft.
Sigmond, M., P. Siegmund and H. Kelder, 2002. *Analysis of the coupling between the stratospheric meridional wind and the surface level zonal wind during 1979–93 NH winters.* Proc. EGS XXVII General Assembly, Nice, France, 21–26 April (CD-ROM).
Straume, A.G., E. Manzini and P. Siegmund, 2002. *Sensitivity of the MAECHAM4 model to imposed ozone distributions.* KNMI Internal Report IR 2002-01.
Verver, G.H.L., J.S. Henzing, G. De Leeuw, C. Robles-Gonzalez and P.F.J. van Velthoven, 2002. *Aerosol Retrieval and Assimilation (ARIA), NUSP-2 02-09.* KNMI Publication 200.
Vries, J. de, G.H.J. van den Oord, E. Hilsenrath, M.B. te Plate, P.F. Levelt and R. Dirksen, 2002. *Ozone Monitoring Instrument.* Proc. SPIE, Imaging Spectrometry VII, San Diego, USA, July, Michael R. Descour and Sylvia S. Chen (Eds.) 4480, 315–325.
Weele, M van, 2002. *WMO-UNEP ozone assessment.* Contributing author Chapter 5.
Zachariasse, M., 2002. *The impact of Atmospheric Transport on the Tropical Tropospheric Composition.* PhD-Thesis, Technical University of Eindhoven.

Number of national presentations

2001: 24
2002: 27

Number of international presentations

2001: 30
2002: 56

Education and organisation of workshops

2001

Kelder, H.M., professor of Atmospheric Physics, Technical University of Eindhoven.

2002

Kelder, H.M., professor of Atmospheric Physics, Technical University of Eindhoven.

Committees

Brinksma, E.J., OMI Validation Working Group, chairman.
Claas, J., OMI Operations Working Group, chairman.
Dobber, M.R., OMI Calibration Working Group, chairman.
Goede, A.P.H., BESC Begeleidingscommissie Sciamachy (NIVR), member.
Goede, A.P.H., GeoTROPE, (ESA), co-investigator.
Goede, A.P.H., GOME Science Advisory Group (ESA/EUMETSAT), member.
Goede, A.P.H., ROAT Remote sensing Onderzoek ATmosfeer (BCRS), member.
Goede, A.P.H., SCIAMACHY Science Advisory Group, chair calibration (NIVR).
Goede, A.P.H., SCIAMACHY, co-principal investigator (NIVR).
Goede, A.P.H., TROPOSAT Steering Group (EuroTRAC), member.
Haan, J.F. de, Dutch OMI Algorithm Working Group, chairman.
Kelder, H.M., EGS session Chemical data assimilation, co-convenor.
Kelder, H.M., EU Project Vintersol, Coregroup, member.
Kelder, H.M., IGACO, member.
Kelder, H.M., International Ozone Committee, member.
Kelder, H.M., PhD Committee E. Brinksma, member.
Kelder, H.M., PhD Committee C. Ethé, rapporteur.
Kelder, H.M., PhD Committee G. Koch, co-examiner.
Kelder, H.M., PhD Committee R. Koelemeier, member.
Kelder, H.M., PhD Committee M. Marchand, rapporteur.
Kelder, H.M., PhD Committee E. Meijer, member.
Kelder, H.M., PhD Committee J. Meloen, 1st promotor.
Kelder, H.M., PhD Committee W. Peters, member.
Kelder, H.M., PhD Committee A. Segers, member.
Kelder, H.M., PhD Committee R.J. Spurr, promotor.
Kelder, H.M., PhD Committee A. Staay, member.
Kelder, H.M., PhD Committee O. Tuinder, member.
Kelder, H.M., PhD Committee M. Zachariasse, 1st promotor.
Kelder, H.M., Review Committee University of Graz, Austria, member.
Kelder, H.M., SCIAMACHY Validation and Interpretation Group, chairman.
Kelder, H.M., SSAG, member.
Kelder, H.M., TROPOSAT Steering group, member.
Levelt, P.F., Dutch OMI Science Team, chairman.
Levelt, P.F., EOS Investigators Working Group (IWG), member.
Levelt, P.F., International OMI Science Team, chairman.
Levelt, P.F., OMI Science Advisory Board (OSAB), chairman.
Levelt, P.F., OMI Science Coordination Team (OSCT), chairman.
Levelt, P.F., OMI, principal investigator.
Piters, A.J.M., SCIAMACHY Validation and Interpretation Group, project manager.
Siegmund, P.C., PhD Committee J. Meloen, co-promotor.
Timmermans, R., SCIAMACHY Validation and Interpretation Group, scientific secretary.
Veefkind, J.P., Dutch OMI Algorithm Working Group, chairman.
Veefkind, J.P., OMI Algorithm Working Group, chairman.
Veefkind, J.P., OMI Datasystems Working Group, co-chairman.
Velthoven, P.F.J. van, EGS session Aircraft Emissions, co-convener.
Velthoven, P.F.J. van, Eumetnet Theme-group Ozone forecasting feasibility study.
Velthoven, P.F.J. van, PhD Committee M. Zachariasse, co-promotor..

Atmospheric Research

The research of the Division focuses on land-atmosphere interaction, on observations of clouds and aerosols, and on modelling of the hydrological cycle and of the link between radiation and climate.

The atmospheric column at Cabauw

Detailed, high quality and long-term ground-based observations of clouds, aerosols, radiation, atmospheric composition, boundary-layer and land surface contribute to the evaluation and development of atmospheric models, satellite retrieval schemes and to climate monitoring programmes.

National consortium 'CESAR'

On the 23rd of May 2002, deputies of eight national atmospheric-research groups from three universities (Delft, Eindhoven, Wageningen) and five research institutes (ECN, ESA-ESTEC, KNMI, RIVM), signed a memorandum of understanding in order to start collaboration within the framework of CESAR: Cabauw Experimental Site for Atmospheric Research. This national observatory accommodates numerous remote sensing and in-situ instruments brought together by the various institutes for research on the themes of land-atmosphere interaction, of clouds, aerosols and radiation, and of atmospheric composition.

Land surface – atmosphere interaction

An issue of great interest is how well point measurements at Cabauw represent the local area, and how well closure of the atmosphere landsurface exchange budgets of relevant constituents (heat, moisture, carbon dioxide) can be obtained. These issues were studied using point measurements at Cabauw (tower: carbon dioxide, moisture, temperature; wind profiler: wind speed and direction), path-averaged measurements of fluxes (10 km, by a novel scintillometer remote sensing device), and airplane and satellite observations.

Airplane based sensible heat flux observations were made along the 10 km path of the scintillometer during the 2002 summer campaign of RECAB. In this limited set of observations good agreement was obtained between the two techniques provided that proper corrections were made for flux divergences in the convective boundary-layer. Satellite based sensible heat flux estimates on a 1 km resolution for one instant were also used to compare with the scintillometer observations. Also here good agreement was obtained. The satellite retrieved fluxes showed moderate variations along the scintillometer path, except for the village of Lopik, which takes less than 10 % of the path, where sensible heat flux was considerably higher. Local point sensible heat flux observations at Cabauw compared quite well with the scintillometer observations. This is not surprising given the reasonable homogeneous terrain around Cabauw. The scintillometer work is done in close co-operation with the University of Wageningen.

The satellite based observations show that variations in surface temperature on the 1 km scale are moderate over the agricultural areas around

Cabauw. Analyses of airplane based surface temperature observations during the 2001 BBC campaign on a much finer resolution showed that important variations are present at smaller horizontal length scales of 10 to 100 m. This kind of findings might help explain the imbalance found in the surface energy budget at Cabauw.

Contributions have been made to the analysis of the energy budget experiment EBEX-2000 in California (USA). A comparison between net-radiometer measurements revealed significant differences between different types instruments. In addition, contributions have been made to the analysis of the inhomogeneous surface flux experiment LITFASS-1998 conducted over the inhomogeneous terrain around the Lindenberg observatory of DWD (Germany).

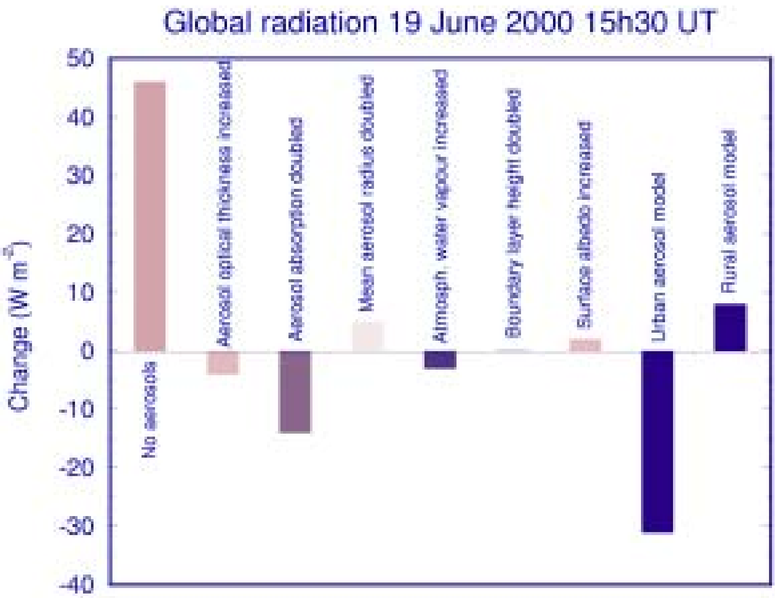


Figure 1. Sensitivity of the global irradiance at the surface to several aerosol and other parameters. Case study for 19 June 2000, 15:30 UT, in De Bilt.

Clouds and radiation

The construction of a climatology of macro-physical cloud-properties over Cabauw (FP5-CLOUDNET) is underway involving the set-up of a user-friendly data set. Novel synergetic techniques for ground-based remote sensing of clouds are being developed, such as the synergetic use of radar and lidar measurements to detect cirrus clouds described in the Highlight of Dr. Donovan elsewhere in this Report. An intensive observation campaign supported by aircraft measurements was conducted at Cabauw in August and September 2001. The results are presented below in the paragraph Connecting observations with models.

Aerosols and radiation

For the first time, the effect of aerosols on the shortwave radiation budget at the surface in the Netherlands was measured and modelled in a joint project involving ECN, RIVM and KNMI (project CLOSAER). Calculations indicate that on a typical sunny day in De Bilt, aerosols increase the reflection of solar radiation at the top of the atmosphere by 10 %, whereas the global irradiance at the surface is reduced by 8 %, as compared to the situation without aerosols.
Climatological aerosol models do not sufficiently explain the observed surface irradiance.
Figure 1 shows for the 19th June 2000 the sensitivity of irradiance to changes in the aerosol structure.

One of the outcomes of the CLOSAER project was that more accurate irradiance measurements are needed to explain differences between observations and results from radiative model transfer calculations. Therefore, a new radiation measurement set-up has been designed for Cabauw, to fulfil the Baseline Surface Radiation Network (BSRN) requirements of standardised high accuracy radiation observations. Construction of a BSRN-type site is underway with anticipated completion in 2003.

New techniques for the retrieval of clouds and aerosols from remote sensing instruments

A large externally funded programme is conducted in the Atmospheric Research Division to improve the retrieval of clouds and aerosols from active and passive ground-based and satellite-based remote sensors.

Climate monitoring from space

KNMI participates in the EUMETSAT Satellite Application Facility on Climate Monitoring (CM-SAF) that aims at providing the climate research community with a consistent data set on cloud parameters, radiation components, vertically integrated humidity fields and surface properties.

In 2001–2002 significant progress was made in the retrieval and validation methods, using data from the EU-co-funded CLIWA-NET project. AVHRR and ATSR were used as a prototype for SEVIRI, the passive imager onboard of the recently launched MSG. In *Figure 2* an example is given of the relation between the reflectivity at 0.6 and 1.6 micron as a function of the cloud particle type, as calculated from Radiative Transfer Modelling.

The graph shows this relation for 7 types of cloud particles, so for various optical depths. The lines indicate the reflectivity for clouds of constant cloud particle type. Size and characteristic (water or ice) are given in the figure. The lines are clearly separated, which implies that these parameters can be used for identification of cloud particle types.

When a cloud is identified as consisting of water droplets, the liquid water path (LWP) can be calculated, using a relationship that links the cloud optical depth, LWP and the cloud droplet effective radius (proportional to the particle size). So, the cloud particle type classification also improves the LWP retrievals.

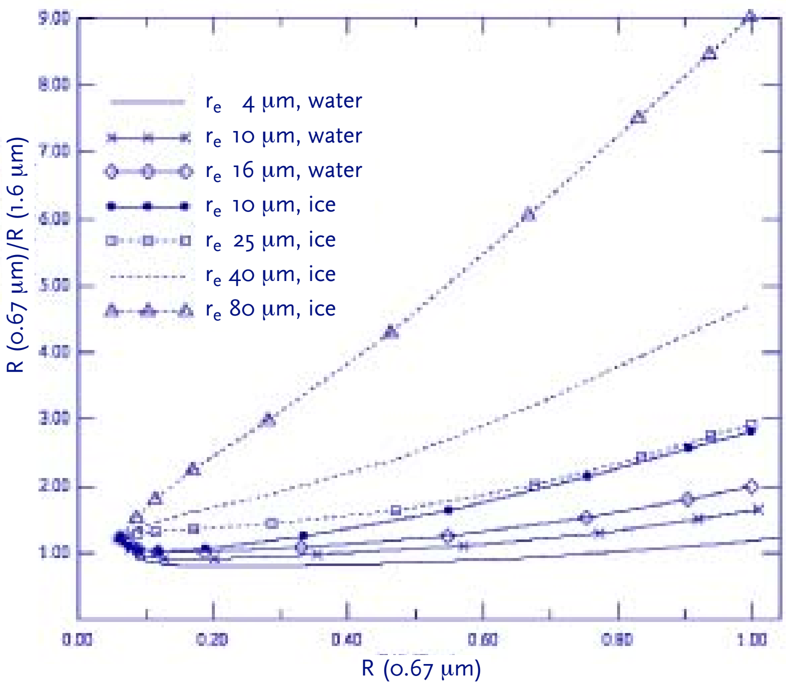


Figure 2. Reflectivity measured at 0.6 micron versus the ratio of reflectivity at 0.6 and 1.6 micron for various cloud types.

The values of LWP thus retrieved were compared to 4 month of ground-based microwave radiometer measurements over Europe during the CLIWANET-project and two month of dedicated measurements from the CESAR-site. This enabled a first statistical analysis of the quality of this AVHRR LWP retrieval. With this new technique, the accuracy of the retrievals is higher than anticipated at the start of the CM-SAF.

The EarthCARE SIMULATOR software package

In recent years, synergetic cloud observations from the ground have been very successful in obtaining microphysical details. Different sensors observe the same cloud, while yielding complementary information. The proposed ESA/NASDA mission EarthCARE aims at synergetic cloud observations from space, retrieving cloud properties with global coverage. EarthCARE features a Doppler radar, a lidar, a VIS/IR imager as well as a Fourier transform spectrometer and broadband radiometers.

KNMI has the responsibility for the development of the EarthCARE SIMULATOR software package that will assess the quality of the scientific products from EarthCARE. The SIMULATOR is capable of modelling EarthCARE observations, using a physical treatment of cloud physics, radiative transport and instrument sampling and noise characteristics. The package will also contain several off-the-shelf cloud retrieval algorithms so that a complete end-to-end test becomes possible.

UV, Clouds and Aerosols using GOME and SCIAMACHY instruments

SCIAMACHY was launched on board Envisat on 1 March 2002. In *Figure 3* a first reflectance spectrum of SCIAMACHY over a Sahara scene is depicted, showing the very high-resolution capability of this instrument. For the new satellite spectrometers GOME, SCIAMACHY and OMI new cloud retrieval methods are developed that focus on three spectral areas: 1) the oxygen A-band at 761 nm for cloud top pressure (altitude) retrieval (the FRESCO method), 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 effect of clouds on GOME ozone retrieval, and on the O_2 A-band cloud detection technique have been analysed with the FRESCO method, which is currently the best method available for cloud pressure retrieval from GOME. It is also used for operational GOME and SCIAMACHY data processing at KNMI.

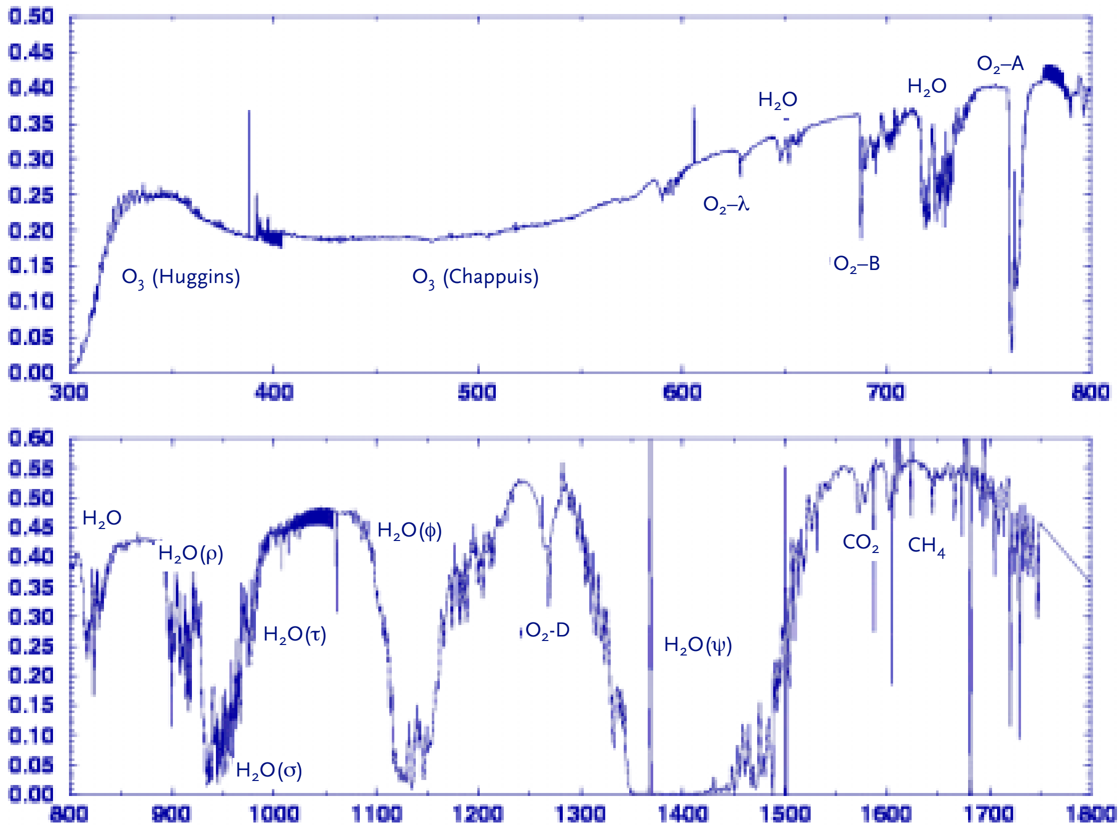


Figure 3. Reflectance spectrum at top of atmosphere of a Sahara scene as measured by SCIAMACHY. The atmospheric gas absorption lines are indicated.

UV absorbing aerosols, like desert dust and biomass burning particles, can be detected with GOME and SCIAMACHY. The advantage over the method using shortwave visible data is that the UV method is also sensitive over land. From the GOME reflectance data of the period 1995–2000, a spectral surface albedo database has been created, which assists the retrievals of other constituents from GOME and SCIAMACHY.

Development and evaluation of cloud and turbulence parameterisations in atmospheric models

This line of research aims to improve the representation of the hydrological cycle in numerical weather prediction and climate models with an emphasis on cloud related processes.

Improving the physics
By using Large Eddy Simulation (LES) results a power law scaling at the small cloud scale sizes with a scale-break for the larger clouds has been found in agreement with observed populations. These findings suggest a universal functional form for the cloud size distribution. A new conceptual model for lateral mixing between cumulus clouds and their environment was developed that explains observed thermodynamic properties of cumulus clouds.

Improving parameterisations
A new turbulence parameterisation scheme was developed based on a prognostic equation for turbulence kinetic energy combined with a diagnostic length scale depending on the atmospheric stability. The length scale formulation combines local and non-local stability

characteristics in a new way. It is in particular suited for cloudy boundary-layers and combines well with a statistical approach for the cloud scheme. It has been tested successfully for cases with stratocumulus and cumulus clouds in single column model intercomparison studies. The scheme is part of the latest reference version of the high-resolution limited area model HIRLAM.
A new sub-cloud module to be used in cloud convection schemes has been developed. It consists of an entraining parcel model which is a function of near surface properties. It predicts the existence of cumulus convection (the so called trigger function), cloud base height, cloud base temperature and vertical velocity at cloud base. Implementation of this sub-cloud model in the ECMWF model has reduced the warm temperature bias near the tropopause. These developments have been part of the EU-funded EUROCS (European Cloud Systems Studies) project.

Connecting observations with models: the CLIWA-Net / Baltex-Bridge Cloud Campaigns (BBC)

An important goal of the EU funded BALTEX Cloud Liquid Water Network project (CLIWA-Net) was the evaluation of model predicted cloud parameters with a focus on liquid water path (LWP) and integrated water vapour (IWV). It brings together the observational and modelling branches in the Atmospheric Sciences Department. Within CLIWA-Net ground-based continuous cloud remote sensing measurements were conducted in a regional-scale network with 12 stations in the BALTEX modelling domain campaigns CNNI (Aug/Sep 2000) and CNNII (Apr/May 2001), and in a local-scale network in the Netherlands centred on the Cabauw facility (BBC: Aug/Sep 2001). During BBC (which also was operated in the German 4D-CLOUDS framework), Cabauw served as central site for cloud observations using cloud radars, lidar ceilometers, microwave and infrared radiometers, radiation measurements and standard meteorological observations. Three aircraft equipped with various instruments provided in-situ measurements of cloud properties and radiative fluxes.

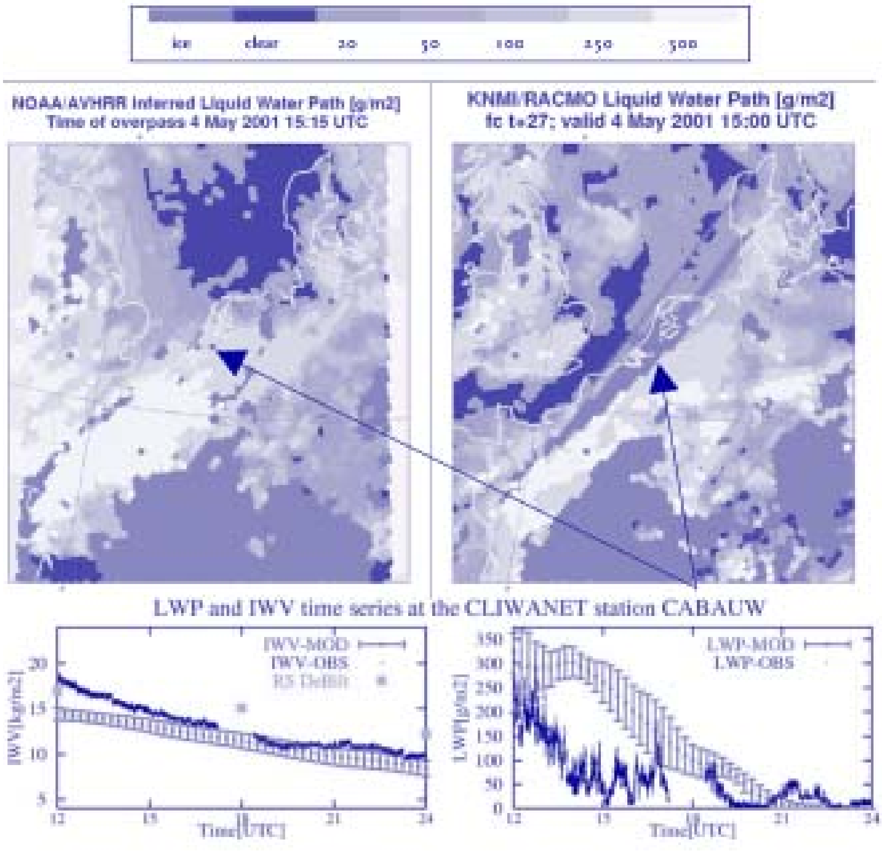


Figure 4. Upper left panel shows satellite inferred LWP projected from a nominal 1 km resolution on the 18 km model grid mesh. Upper right panel shows the corresponding model prediction. Ice is flagged at a cloud top temperature of –13°C. Lower panels show time series of IWV and LWP at Cabauw during overpass.

Case study for 4 May 2001

CLIWA-Net involves the compilation of spatial distributions of LWP from satellite observations (see paragraph Climate monitoring from space above). For this purpose, an automated cloud detection and cloud property scheme was developed at KNMI, referred to as KLAROS. In order to optimise the result, the AVHRR based LWP values are compared with and, when required, recalibrated by the LWP time series inferred from ground-based measurements. This procedure improves the quality of the derived LWP field. The satellite LWP fields can then be used to evaluate model predicted LWP fields. A qualitative example taken from CNNII is depicted in *Figure 4,* showing that the modelled and observed large-scale features of the LWP- fields are reasonably well in agreement, but that the small-scale structures are less adequately represented.

BBC (Aug, Sep 2001)

We compared distributions of Liquid Water Path (LWP) and Integrated Water Vapour (IWV) from the RACMO prediction with those inferred from MRAD (Microwave Radiometer) measurements made during BBC *(Figure 5)*. The observations are 10-minute averages collected in a set of histograms. The model is operated in forecast-mode and forced by ECMWF analyses. The model results are derived from 12–36 hour forecasts. Microwave Radiometers do not operate reliably when it is raining. Therefore, the data are separated into a class showing all events (including precipitation) and classes without precipitation. The class of liquid water clouds is probably best represented by the blue bars. The model provides good estimates for the mean values, but overpredicts the amount of liquid water clouds.

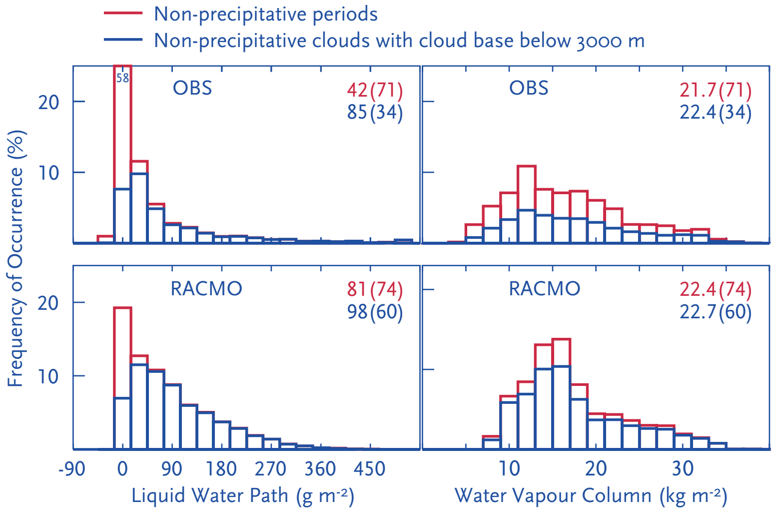


Figure 5. Frequency histograms of LWP and IWV inferred from Microwave Radiometer (MRAD) measurements and compiled from model predictions during the BBC-campaign (Aug/Sep 2001). The numbers in each panel indicate the average value of LWP (g m^{-2}) or IWV (kg m^{-2}), and (between hyphens) the occurrence (%) of the specified event relative to the total number of measurements

CLIWANET / BBC projects conclusions

In the full evaluation of the cloud parameter data sets two NWP models and two regional climate models were involved. The major finding is that three models produce reasonably accurate predictions of the statistics of the temporal distributions of LWP, irrespective of the site; one model substantially underestimates LWP. All models underpredict the observed frequency of clear skies and overpredict the occurrence of precipitation. Integrated Water Vapour (IWV) is much better predicted than LWP, in particular the longer-term structures in IWV associated with synoptic-scale transitions are very well captured by the models. The model ability to adequately represent observed LWP time series is limited, even for models operated in NWP-mode. In particular, LWP corresponding to stratocumulus or shallow convection can be entirely missed or, in reverse, strongly overpredicted.

Modelling the regional climate

The regional climate is being modelled using KNMI's in house developed regional climate model RACMO.

Northwest-Europe

In the Regional Climate modelling project RegioKlim regional downscaling of global climate change is investigated. The project aims at providing information on climate change on a regional scale. An important goal of RegioKlim is to predict changes in extreme weather events, such as storm surges and heavy precipitation.

The downscaling tool of choice in RegioKlim is the regional atmospheric model RACMO. RACMO provides information on a scale of 50 km by using a high-resolution limited area model, forced at its lateral boundaries with data from coarse resolution global climate models.

A climate run of RACMO forced by ERA15 reanalysis data (hereafter, ERA 15 run) has been completed. Its purpose was the evaluation of the quality of the model forced by realistic boundaries. The model temperature is about 2 K too warm in summer, while precipitation amounts are 30 % too low. This summer warming is most pronounced in central Europe with a temperature bias of 4 to 8 K. Associated effects are a strong weakening of the hydrological cycle, a strong drying of the soil layer, a strong reduction in the cloud cover, and consequently an overestimation of the short wave radiation penetrating to the surface. An investigation to overcome these problems is currently underway.

Antarctica

The so-called δ-signal measured in ice cores can be used as a proxy to reconstruct past temperature fluctuations. The δ-signal contains information about the temperature at the time when and the place where snow is accumulated. Hence, the δ-signal inferred from ice cores does not reflect the time-mean temperature at the surface – which we are interested in – but a time averaged temperature restricted to periods with snow fall valid for the atmospheric level where snow is formed. To investigate the relation between the weighted temperature associated with the d-signal and the mean surface temperature, a 14-year model integration (1980–1993) has been carried out with a version of RACMO carrying the ECHAM4 physics package. On an inter-annual time scale variations in the seasonality of snowfall complicate the derivation of a clear relation between fluctuations in the surface temperature and fluctuations in the proxy related temperature. Results from 5-year model integrations obtained with a +2 K temperature forcing show that the increase in the proxy temperature is 18% larger than the increase in the surface temperature.

Data assimilation studies

The European Land Data Assimilation Project ELDAS aims to improve soil moisture estimates on European scale by data assimilation techniques. For this, new data assimilation schemes have been designed and tested in a single-column set-up. They show superior characteristics compared to currently operational schemes. A demonstration database of precipitation and surface radiation, covering Europe in 2000, has been prepared. From these datasets the first soil moisture fields will be available during 2003.

Modelling the global climate

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

The extent to which solar activity is a factor in climatic change is a matter of debate. The atmospheric response to the variations to the 11-year solar sunspot cycle is studied using an interactive 3-D coupled chemistry/general-circulation model. The stratosphere-troposphere system shows significant response to a realistic, i.e. observed, solar cycle enhancement of total solar irradiance, causing additional heating, and increased ultra-violet radiation, resulting in ozone production. This response consists of increases in stratospheric ozone and temperature, giving rise to changes in the zonal wind from the stratosphere into the troposphere. Our radiative forcing results show that the 11-year solar cycle effect on global mean temperature is negligible with a clear lack of an 11-year cycle in global mean temperature. However, simulated responses of sea level pressure do suggest that regional effects are significant, e.g. by affecting the North Atlantic Oscillation.

The high temperature projections for 2100: a comparison between IPCC's Second and Third Assessment Reports (SAR and TAR) values

The causes of the difference in the high end of the projected temperature change in 2100 relative to 1990 between the IPCC SAR (DT=3.5 K) and TAR (DT=5.8 K) have been investigated. The relative change of the high temperature projection is more than twice the change in radiative forcing from SAR to TAR. About 40% of the temperature difference of 2.3 K can be attributed to the change in aerosol burden and about 18% of the difference is caused by the change in greenhouse gas concentrations from the IS92e (SAR) to the A1FI (TAR) scenario. A change in reference (1990) radiative forcing results in a contribution of about 13%. So 71% of the total difference is assigned to scenario changes. The remaining, about 29%, is found to be due to model changes. This includes a higher climate sensitivity as a result of a lowered radiative forcing due to CO_2 increases, a smaller heat uptake by the oceans as well as changes in the model's biogeochemistry, resulting in a different carbon cycle and therefore in changes in methane and tropospheric ozone concentrations.

Publications are listed by Division. A paper with authors from different Divisions will be listed more than once in this Report.

Scientific publications in reviewed journals

2001

Angevine W.M., H. Klein Baltink and F.C. Bosveld, 2001. *Observations of the Morning Transition of the Convective Boundary Layer.* Bound.-Layer Meteor., **101**, 209–227.

Betts, A.K., P. Viterbo, A. Beljaars and B.J.J.M van den Hurk, 2001. *Impact of Boreas on the ECMWF forecast model.* J. Geophys. Res., **106**, D24, 33593–33604.

Bosveld F.C. and W. Bouten, 2001. *Evaluation of transpiration models with observations over a Douglas fir forest.* Agric. Forest Met., **108**, 247–264.

Bosveld F.C. and W. Bouten, 2001. *The impact of finite sampling time on eddy-covariance flux estimates.* Agric. Forest Met., **109**, 39–45.

Dekker S.C., W. Bouten and F.C. Bosveld, 2001. *On the information content of forest transpiration measurements for identifying canopy conductance model parameters.* Hydrol. Proc., **15**, 2821–2832.

Donovan, D.P. and A.C.A.P. van Lammeren, 2001. *Cloud effective particle size water content profile retrievals using combined lidar and radar observations. Part I: Theory and simulations.* J. Geophys. Res., **106**, No. 27,425–27,448.

Donovan, D.P., A.C.A.P. van Lammeren and R.J. Hogan, 2001. *Cloud effective particle size water content profile retrievals using combined lidar and radar observations. Part II: Comparison with IR radiometer and in-situ measurements of ice clouds.* J. Geophys. Res. **106**, D21, 27,449–27,464.

Feijt, A. and P. de Valk, 2001. *The use of NWP surface temperatures in cloud detection from satellite.* Int. J. Remote Sens., **13**, 2571–2584.

Grody, N., J. Zhao, R. Ferraro, F. Weng and R. Boers, 2001. *Determination of precipitable water and cloud liquid water path over oceans from the NOAA 15 advanced microwave sounding unit.* J. Geophys. Res., **106**, D3, 2943–2953.

Hanssen R.F., A.J. Feijt and R. Klees, 2001. *Comparison of Precipitable Water Vapor Observations by Spaceborne Radar Interferometry and Meteosat 6.7 mm Radiometry.* J. Atmos. Oceanic Technol., **18**, 756–764.

Hurk, B.J.J.M. van den, 2001. *Energy balance based surface flux estimation from satellite data, and its application for surface moisture assimilation.* Meteor. Atmos. Phys., **76**, 43–52.

Jacob, D., B.J.J.M. van den Hurk, et al., 2001. *A comprehensive model intercomparison study investigating the water budget during the BALTEX-PIDCAP period.* Meteor. Atmos. Phys., **77**, 19–44.

Kalma, J.D., S.W. Franks and B.J.J.M. van den Hurk, 2001. *On the representation of landsurface fluxes for atmospheric modelling.* Meteor. Atmos. Phys., **76**, 53–67.

Koelemeijer, R.B.A., P. Stammes, J.F. de Haan and J.W. Hovenier, 2001. *A fast method for retrieval of cloud parameters using oxygen A-band measurements from the Global Ozone Monitoring Experiment.* J. Geophys. Res., **106**, D4, 3475–3490.

Lenderink, G. and E. van Meijgaard, 2001. *Impacts of cloud and turbulence schemes on integrated water vapor: comparison between model predictions and GPS measurements.* Meteor. Atmos. Phys., **77**, 131–144.

Meijgaard, E. van, U. Andrae and B. Rockel, 2001. *Comparison of model predicted cloud parameters and surface radiative fluxes with observations on the 100 km scale.* Meteor. Atmos. Phys. **77**, 109–130.

Raschke, E. et al. (incl. F.C. Bosveld and A.C.A.P. van Lammeren), 2001. *The Baltic Sea Experiment (BALTEX): A European Contribution to the Investigation of the Energy and Water Cycle over a Large Drainage Basin.* Bull. Amer. Meteor. Soc., **82**, 2389–2413.

Stevens, B., A.S. Ackerman, B.A. Albrecht, A.R. Brown, A. Chlond, J. Cuxart, P.G. Duynkerke, D.C. Lewellen, M.K. MacVean, R.A.J. Neggers, E. Sanchez, A.P. Siebsema and D.E. Stevens, 2001. *Simulations of trade-wind cumuli under a strong inversion.* J. Atmos. Sci., **58**, 1870–1891.

2002

Baedi, R., R. Boers and H. Russchenberg, 2002. *Detection of boundary layer water clouds by spaceborne cloud radar.* J. Atmos. Oceanic Technol., **19**, 1915–1927.

Broeke, M.R. van den, N. van Lipzig, E. van Meijgaard and J. Oerlemans, 2002. *Momentum budget of the East-Antarctic atmospheric boundary layer: results of a regional climate model.* J. Atmos. Sci., **59**, 3117–3129.

Brown, A.R., R.T. Cederwall, A. Chlond, P.G. Duynkerke, J-C. Golaz, J. Khairoutdinov, M. Khairoutdinov, D.C. Lewellen, A.P. Lock, M.K. Macvean, C-H. Moeng, R.A.J. Neggers, A.P. Siebesma and B. Stevens, 2002. *Large-eddy simulation of the diurnal cycle of shallow cumulus convection over land.* Quart. J. Roy. Meteor. Soc., **128**, 1075–1094.

Crewell, S., M. Drusch, E. van Meijgaard and A. van Lammeren, 2002. *Cloud observations and modeling within the European BALTEX Cloud Liquid Water Network.* Boreal Env. Res., **7**, 235–245.

Donovan, D.P. and A.C.A.P. van Lammeren, 2002. *First ice-cloud effective particle size parameterization based on combined lidar and radar data.* Geophys. Res. Lett., **29**, 6.1–6.4.

Feijt, A.J., D. Jolivet and E. van Meijgaard, 2002. *Retrieval of the spatial distribution of liquid water path from combined ground based and satellite observations for atmospheric model evaluation.* Boreal Env. Res., **7**, 265–271.

Gustafsson, D., E. Lewan, B.J.J.M. van den Hurk, P. Viterbo, A. Grelle, A. Lindroth, E. Cienciala, M. Mölder, S. Halldin and L.C. Lundin, 2003. *Boreol-forest surface parameterisation in the ECMWF model – ID test with NOPEX longterm data.* J. Appl. Meteor., **42**, 95–112.

Hurk, B.J.J.M. van den, P. Graham and P. Viterbo, 2002. *Comparison of land surface hydrology in regional climate simulations of the Baltic Sea Catchment.* J. Hydrol., **255**, 169–193.

Hurk, B.J.J.M. van den, L. Jia, C. Jacobs, M. Menenti and J-L. Li, 2001. *Assimilation of land surface temperature data from ATSR in an NWP environment – a case study.* Int. J. Remote Sens., **23**, 5191–5208.

Klein Baltink, H., H. van der Marel and A. van der Hoeven, 2002. *Integrated Water Vapour Estimates from a Regional GPS-network.* J. Geophys. Res., **107**, D3, 3/1–3/8.

Knap, W.H., P. Stammes and R.B.A. Koelemeijer, 2002. *Cloud thermodynamic phase determination from near-infrared spectra of reflected sunlight.* J. Atmos. Sci., **59**, 83–96.

Koelemeijer, R.B.A., P. Stammes, J.W. Hovenier and J.F. de Haan, 2002. *Global distributions of effective cloud fraction and cloud top pressure from oxygen A-band spectra measured by the Global Ozone Monitoring Experiment: comparison to ISCCP data.* J. Geophys. Res., **107**, AAC5-1–AAC 5-9.

Kohsiek, W., W.M.L. Meijninger, A.F. Moene, B.G. Heusinkveld, O.K. Hartogensis, W.C.A.M. Hillen and H.A.R. de Bruin, 2002. *An extra large aperture scintillometer for long range application.* Bound.-Layer Meteorol., **105**, 119–127.

Lipzig, N.P.M. van, E. van Meijgaard and J. Oerlemans, 2002. *Temperature sensitivity of the Antarctic surface mass balance in a regional atmospheric climate model.* J. Climate, **15**, 2758–2774.

Lipzig, N.P.M. van, E. van Meijgaard and J. Oerlemans, 2002. *The spatial and temporal variability of the surface mass balance in Antarctica: results from a regional climate model.* Int. J. Climatology, **22**, 1197–1217.

Neggers, R.A.J., A.P. Siebesma and H.J.J. Jonker, 2002. *A stochastic parcel model for shallow cumulus convection.* J. Atmos. Sci., **59**, 1655–1668.

Reijmer, C.H., M.R. van den Broeke and M.P. Scheele, 2002. *Air parcel trajectories and snowfall related to five deep drilling locations on Antarctica, based on the ERA-15 data set.* J. Climate, **15**, 1957–1968.

Ronda, R.J., B.J.J.M. van den Hurk and A.A.M. Holtslag, 2002. *Spatial Heterogeneity of the soil moisture content and its impact on surface flux densities and near-surface meteorology.* J. Hydrometeor., **3**, 556–570.

Schutgens, N.A.J. and P. Stammes, 2002. *Parameterisation of Earth's polarisation spectrum in the ultra-violet.* J. Quant. Spectros. Rad. Transf., **75**, 239–255.

Other reviewed scientific publications

2001

Bloemink, H.I., D.P. Donovan and A.C.A.P. van Lammeren, 2001. *Sensor Synergy for the Earth Radiation Mission.* Final Report SRON project EO-026.

Bloemink, H.I., D.P. Donovan and A.C.A.P. van Lammeren, 2001. *Sensor Synergy for the Earth Radiation Mission.* KNMI Report.

Bloemink, H. and A.C.A.P. van Lammeren, 2001. *Retrieval of cloud properties using sensor synergy algorithms.* Proc. IAMAS, Innsbruck, Austria, 10–18 July, 147.

Bloemink, H.I., A.C.A.P. van Lammeren, A.J. Feijt and S. Jongen, 2001. *Sensor Synergy for Cloud Observation; Theory and Observation (for Liquid Water Clouds).* In: Remote Sensing of Clouds and the Atmosphere V., Proc. SPIE Vol. 4168, J.E. Russel, K. Schaefer and O. Lado-Bordowsky, (Eds.), 1–10.

Brink, H.M. ten, A. Hensen, A. Khlystov, R. van Dorland, A. Jeuken, P. van Velthoven, J. Lelieveld, A. van den Berg, D.P.J. Swart, J.B. Bergwerff and A. Apituley, 2001. *Aerosol: cycle and influence on the radiation balance.* NRP-report 410 200 064.

Brink, H.M. ten, G.P. Kos, A. Even, J.S. Henzing, W.H. Knap, P. Stammes, D.P.J. Swart, A. Apituley and J.B. Bergwerff, 2001. *The effect of aerosol on closure of the regional shortwave radiation balance, CLOSAER.* Dutch National Research Programme on Global Air Pollution and Climate Change (NRP), Report no. 410 200 087.

Crewell, S., M. Drusch, U. Löhnert and A.C.A.P. van Lammeren, 2001. *Wolkenwassergehalt im BALTEX-Modellgebiet.* Proc. Deutsch-Österreichisch-Sweizerische Meteorologentagung, Wien, Österreich, 18–21 September.

Crewell, S., M. Drusch, U. Löhnert, C. Simmer and A.C.A.P. van Lammeren, 2001. *Cloud Observations from the Ground-Based CLIWA-NET Network I (CNNI) during BRIDGE EOP I.* Proc. Third Study Conf. BALTEX, Åland, Finland, 2–6 July, 43–44.

Dlhopolsky, R. and A. Feijt, 2001. *Cloud products retrieval for MSG.* Final Report BCRS.

Donovan, D. and AC.A.P. van Lammeren, 2001. *Combined lidar radar particle size retrievals.* Proc. IAMAS, Innsbruck, Austria, 10–18 July, 146.

Donovan D.P. and A.C.A.P van Lammeren et al., 2001. *Combined Lidar and Radar Cloud remote sensing.* Proc. 20th Int. Laser Radar Conf., 10–14 July, Vichy, France, 239–242.

Feijt, A.J., 2001. *Quantitative Cloud Analysis using Meteorological Satellites.* Remote Sensing and Geo-Informatie.

Heijnen S.H., H. Klein Baltink, W.F. van der Zwan and H.W.J. Russchenberg, 2001. *3-D Wind Measurements with the S-band Atmospheric Profiler TARA.* Proc. 30st Int. Conf. Radar Meteorology, AMS, München, Germany, 19–25 July.

Henzing, J. S. and W.H. Knap, 2001. *Uncertainty in pyranometer and pyrheliometer measurements at KNMI in De Bilt.* KNMI Technical Report TR-235.

Hurk, B.J.J.M. van den, A.J. Dolman, A.A.M. Holtslag, R. Hutjes, F. van de Kassteele, R. Ronda and R. Ijpelaar, 2001. *The land component in the climate system.* In: J. Berdowski, R. Guicherit and B. Heij (Eds), The Climate System, Balkema Publ., Lisse, the Netherlands, 79–104.

Illingworth, A., A.C.A.P. van Lammeren and J.P. Baptista, 2001. *EarthCARE: a proposed ESA/NASDA mission to provide vertical profiles of clouds and aerosol characteristics.* Proc. IAMAS, Innsbruck, Austria, 10–18 July, 151.

Knap, W.H., P. Stammes and R.B.A. Koelemeijer, 2001. *Cloud-phase determination using near-infrared AVIRIS measurements.* In: W. L. Smith and Yu. M. Timofeyev (Eds.), IRS 2000: Current Problems in Atmospheric Radiation, A. Deepak Publishing, Hampton, (Va), USA, 941–944.

Koelemeijer, R., 2001. *Influence of clouds on ozone measurements obtained by satellite spectrometry.* PhD-Thesis, Vrije Universiteit Amsterdam, ISBN 90-646-4518-3.

Kohsiek, W., E.W. Meijer, P.J.B. Versteeg, O.K. Hartogensis and H.A.R. de Bruin, 2001. *EBEX-2000: the KNMI/WAU contribution.* KNMI Technical Report TR-240.

Lammeren, A.C.A.P. van, 2001. *Ground-based observations at Cabauw, The Netherlands.* Proc. IAMAS 2001, Innsbruck, Austria, 10–18 July.

Lammeren, A.C.A.P. van, (contributor) 2001. *The five candidate Earth Explorer Core Missions: EarthCARE – Earth Clouds, Aerosols and Radiation Explorer.* ESA Reports for Assessment SP-1257 (1).

Lammeren, A.C.A.P. van, S. Crewell, A. Macke, A. Feijt and E. van Meijgaard, 2001. *BALTEX BRIDGE Cloud liquid Water Network: CLIWA-NET.* Kick-Off Workshop Report.

Lammeren, A.C.A.P. van, S. Crewell, A. Macke, A. Feijt and E. van Meijgaard, 2001. *BALTEX BRIDGE Cloud liquid Water Network: CLIWA-NET.* First Annual Interim Report, April 2001.

Lammeren, A.C.A.P. van, D. Donovan, A.J. Feijt, R. Koelemeijer and P. Stammes, 2001. *New ways of observing clouds: a tour along satellite based and ground based remote sensing techniques.* Biennial Scientific Report 1999–2000, Climate Research and Seismology Department, KNMI, De Bilt, the Netherlands.

Lammeren, A.C.A.P. van et al., 2001. *Clouds and radiation: intensive observational campaigns in the Netherlands (CLARA).* Global Change. Dutch National Research Programme on Global Air Pollution and Climate Change. NOP Final Report 410 200 057.

Lammeren, A.C.A.P. van et al., 2001. *The role of clouds, aerosols and radiation in our climate system. Clouds and Radiation Project (CLARA) contributes to the puzzle.* Research and Policy Newsletter on Global Change from the Netherlands, Change, **59**.

Lenderink G., E. Sanchez and J. Cuxart, 2001. *Status of work on turbulence modeling in the CBR scheme: instability with high u*.* Hirlam Newsletter, **38**, 70–73.

Lipzig, N.P.M. van, 2001. *Variaties in neerslag op het Antarctische continent: een studie met een atmosfeermodel.* Circumpolar Journal, **16**, 7–9.

Lipzig, N.P.M. van and M.R. van den Broeke, 2001. *The relation between the atmospheric boundary layer and poleward atmospheric moisture transport in Antarctica in a regional atmospheric climate model.* Proc. Climate Conf., Utrecht, the Netherlands, 20–24 August, 35.

Lipzig, N.P.M. van, E. van Meijgaard and J. Oerlemans, 2001. *Variations in precipitation on the Antarctic continent: a study with a regional atmospheric model.* Proc. IAMAS, Innsbruck, Austria, 10–18 July, 27.

Mebold, H., A.C.A.P. van Lammeren and A.J. Feijt, 2001. *Comparison of pyranometer and satellite derived cloud optical depths.* Proc. IAMAS, Innsbruck, Austria, July 10–18, 145.

Meijgaard, E. van, 2001. *ECMWF physics in HIRLAM.* Hirlam Newsletter, **38**, 137–143.

Meijgaard, E. van, U. Andrae and B. Rockel, 2001. *Model predicted cloud amount and cloud vertical structure compared with ground-based observations from the KNMI Cloud Detection System.* Proc. Third Study Conf. BALTEX, Mariehamn, Åland, Finland, 2–6 July, 243–244.

Meijgaard, E. van and A. Mathieu, 2001. *Analysis of model predicted liquid water path using observations from CLIWA-Net.* Proc. Third Study Conf. BALTEX, Mariehamn, Åland, Finland, 2–6 July, 241–242.

Meijgaard, E. van, A. Mathieu, A.J. Feijt and A.C.A.P. van Lammeren, 2001. *First result from the BALTEX BRIDGE Cloud Liquid Water Network Project.* Proc. Fourth Int. Conf. GEWEX, Paris , France, 10–14 September, 26.

Meijgaard, E. van, C.J. Stubenrauch and N.P.N. van Lipzig. *Evaluation of model predicted cloud parameters around Antarctica using satellite observations.* Proc. Fourth Int. Conf. GEWEX, Paris, France, 10–14 September, 26.

Reijmer, C.H., 2001. *Antarctic Meteorology. A study with Automatic Weather Stations.* PhD-Thesis, University of Utrecht, ISBN 90-393-2802-1.

Roebeling, R.A., D. Jolivet, R. Dlhopolsky and A. Feijt, 2001. *Determination of Cloud Optical Thickness and Cloud Liquid Water path using multi-spectral NOAA-AVHRR or MSG data.* Proc. CM-SAF Training Workshop 2000, Dresden, Germany, 20–22 November, 28–35.

Stammes, P., 2001. *Spectral radiance modelling in the UV-Visible range.* In: W.L. Smith and Y.M. Timofeyev (Eds.), IRS 2000: Current problems in Atmospheric Radiation., A. Deepak Publ., Hampton (VA), USA, 385–388.

Tourpali, K., R. van Dorland and C.J.E. Schuurmans, 2001. *Research on a mechanism by which enhanced UV-radiation of the active sun affects weather and climate.* NRP-report 410 200 077.

Ulden, A.P. van and R. van Dorland, 2001. *An assessment of the influence of variations in solar activity and of major volcanic eruptions on climate.* In: Berdowski, Guicherit and Heij (Eds.), The Climate System, Balkema Publ., Lisse, the Netherlands, 150–153.

Vila-Guerau de Arellano J., O.S. Vellinga, A.A.M. Holtslag, F.C. Bosveld and H. Klein Baltink, 2001. *Observational evaluation of PBL parameterizations modelled by MM5.* Proc. 11th PSU/NCAR Mesoscale Model Users' Workshop, Boulder (Co), USA, 25–27 June, 102–104.

Weber, S.L., R. Guicherit, H.W. van den Brink, R. van Dorland, H. Dijkstra, W. Greuell, G.J. Komen, G. Können, P.-J. van Leeuwen, O. van de Plassche, J.D. Opsteegh, W.P.M. de Ruijter, F.M. Selten, A.P. van Ulden and J. vandenBerghe, 2001. *Climate variability.* In: Berdowski, Guicherit and Heij (Eds.), The Climate System, Balkema Publl., Lisse, the Netherlands, 135–173.

2002

Beersma, J.J., R. van Dorland and J.D. Opsteegh, 2002. *Shortwave radiation and cloud parameterizations for intermediate complexity models.* KNMI Scientific Report WR 2002–02.

Deneke, H.M., 2002. *Influence of clouds on the solar radiation budget.* KNMI Scientific Report WR 2002–09, also PhD-Thesis.

Donovan, D. P., 2002. *Ice Cloud effective particle size parameterization based on combined lidar and radar data.* Proc. AMS Conf. Clouds Radiation, Ogden, Utah, USA, 3–7 June, J1.2.

Donovan, D.P., J.P.V. Poiars Baptista, H. Barker, J-P. Blanchet, M. Quante, N. Schutgens and J. Testud, 2002. *Lidar Synergetic remote sensing from space: Simulation of the EarthCARE Mission.* Proc. 21nd Int. Laser Radar Conf., Quebec, Canada, 8–12 July, L. R. Bissonnette, G. Roy and G. Vall'ee (Eds.), 751–754.

Graaf, M. de, 2002. *Sensitivity study of the residue method for the detection of aerosols from space-borne sensors.* KNMI Scientific Report WR 2002–03.

Heijnen, S., H. Klein Baltink, H.W.J. Russchenberg, H. Verlinde and W.F. van der Zwan, 2002. *Boundary Layer Measurements with a 3 GHz FWCW Atmospheric Profiler.* Proc.15th Symp. Boundary Layers Turbulence, AMS, Wageningen, the Netherlands, 15–19 July, 386–389.

Heijnen, S., H. Klein Baltink, W.F. van der Zwan and H.W.J. Russchenberg, 2002. *Polarimetric cloud studies at 3.3.* GHz. Proc. 2nd Europ. Conf. Radar Meteorol., Delft, the Netherlands, 18–22 November, 117–121.

Hurk, B.J.J.M. van den, 2002. *European LDAS Established.* Gewex Newsletter, **12**, 9.
Hurk, B.J.J.M. van den, P. Houser and J. Polcher, 2002. *Glass Workshop sets new experimental strategy on testing land-atmosphere interactions.* Gewex Newsletter, **12**, 11–12.
Hurk, B.J.J.M. van den, Z. Su, W. Verhoef, G. Roerink and L. Jia, 2002. *ENVISAT Land Surface Processes Phase 2 – End report.* KNMI Scientific Report WR 2002-06.
Hurk, B.J.J.M. van den and H. The, 2002. *Assimilation of satellite derived surface heating rates in a Numerical Weather Prediction model.* KNMI Scientific Report WR 2002-04.
Kohsiek, W., 2002. *Long range scintillometry.* Proc. 15th Symp. Boundary Layers and Turbulence, AMS, Wageningen, the Netherlands, 15–19 July, 125–128.
Lenderink, G., 2002. *An integral mixing length scale formulation for a TKE-l turbulence closure in atmospheric models.* Proc. 15th Symp. Boundary Layer and Turbulence, AMS, Wageningen, the Netherlands, 15–19 July, 628–631.
Lenderink, G., 2002. *Recent and future developments in turbulence modeling in Hirlam.* Hirlam Newsletter, **41**, 55–61.
Meijgaard, E. van, September 2002. *Projectie van de Elbe-zomerneerslag op de Rijn en Maas: onderzoek naar aanleiding van de recente overstromingen in Midden-Europa.* KNMI Publication 198.
Neggers, R., 2002. *Shallow Cumulus Convection.* PhD-Thesis, University of Wageningen.
Skaropoulos, N.C., S. Heijnen, H. Klein Baltink, J. Verlinde, W. v.d. Zwan and H. Russchenberg, 2002. *Model calculations and measurements of radar reflections from the melting layer of precipitation at 3 and at 35 GHz.* URSI Commission F, Open symposium propagation and remote sensing, Garmish-Partenkirchen, Germany, 12–15 February (CD-ROM).
Skaropoulos, N.C., S. Heijnen, H. Klein Baltink, J. Verlinde, W. v.d. Zwan and H. Russchenberg, 2002. *Simulations and measurements of radar reflections from the melting layer of precipitation at mm-wavelengths.* Proc. 11th Conf. Atmos. Radiation, AMS, Ogden, Utah, USA, 3–7 June, J.P. 1.22.
Tijm S., B. Wichers Schreurs and H. Klein Baltink, 2002. *Visie Bovenluchtwaarnemingen Nederland.* KNMI Technical Report 248.
Tilstra, L.G., M. de Graaf and P. Stammes, *First verification of SCIAMACHY's polarisation measurements.* Proc. Envisat Calibration Review, ESA Special Publication SP-520 (CD-ROM).

Number of national presentations

2001: 47
2002: 28

Number of international presentations

2001: 61
2002: 75

Education and organisation of workshops

Dorland, R. van, ANW lerarendag, Utrecht, the Netherlands, 25 November 2002, co-organiser.
Hurk, B.J.J.M. van den, EGS session Data assimilation in hydrology, April 2002, co-convenor.
Hurk, B.J.J.M. van den, GLASS workshop Land-Atmosphere Interaction, April 2002, convenor.
Hurk, B.J.J.M. van den, WorkshopSMOS/ELDAS, 11 December 2002, organiser.
Lammeren, A.C.A.P. van, Session 11.1 Ground-based Remote Sensing, IAMAS 2001, Innsbruck, Austria, 10–18 July, convenor and chair.
Siebesma, A.P., EUROCS-Workshop, Utrecht/De Bilt, the Netherlands, 8–10 April 2002, organiser.
Stammes, P., Workshop Atmosferic aerosol, De Bilt, the Netherlands, 6 March 2001, co-organiser, convenor.

Committees

Acarreta, J.R., OMI Algorithm Working Group (NIVR/FMI/NASA), member.
Acarreta, J.R., OMI Science Team (NIVR/FMI/NASA), member.
Acarreta, J.R., SCIA-CIRRUS (SRON/KNMI), member.
Boers, R., Clouds working group of the Baseline Surface Radiation Network science panel, member.
Boers, R., Cloudsat Science Team, member.
Boers, R., ESF Scientific User Committee EUFAR, chairman.
Boers, R., Externe beoordelingscommissie Milieuonderzoek, member.

Boers, R., Global Aerosol Climatology Project, project investigator.
Boers, R., ICES-KIS Module 3, coordinator.
Boers, R., IPCC TAR, Chapter 5, Aerosols, their direct and indirect effects, contributing author.
Boers, R., Programme Board NVKO, member.
Bosveld, F.C., CESAR, member Executive Committee.
Bosveld, F.C., PhD Committee M. van der Molen, Free University of Amsterdam, member.
Donovan, D.P., Cloudsat Science Team, member.
Donovan, D.P., Joint ESA/NASDA mission advisory group for the EarthCARE earth explorer mission Proposal, member.
Dorland, R. van, Commissie Lerarendag ANW, member.
Dorland, R. van, IPCC TAR, Radiative forcing of climate change, contributing author.
Dorland, R. van, Zenit, editor meteorology.
Feijt, A.J., PhD Committee R. Dankers, University of Utrecht, member.
Lammeren, A.C.A.P. van, BALTEX/BRIDGE management team, member.
Lammeren, A.C.A.P. van, CloudSat Science team (NASA), member.
Lammeren, A.C.A.P. van, ESA Science Preparatory Group for the Earth CARE-mission, member.
Lammeren, A.C.A.P. van, ESA/NASDA Joint Science Preparatory Group for the Earth CARE-mission, member.
Lammeren, A.C.A.P. van, Gebruikerscommissie atmosfeer radaronderzoek van de Stichting Technische Wetenschappen (STW), member.
Siebesma, A.P., BBC2 aircraft measurement campaign, co-ordinator.
Siebesma, A.P., PhD Committee R. Neggers, Universiteit of Wageningen, co-promotor.
Stammes, P., Atmospheric Chemistry Science Preparation Group (ESA), member.
Stammes, P., GOME Science Advisory Group (ESA), member.
Stammes, P., Klankbord commissie Lichtverstrooiingsexperiment, AMOLF, member.
Stammes, P., Nederlands SCIAMACHY Data Centrum Gebruikersgroep, chairman.
Stammes, P., NEONET Gebruikersgroep, chairman.
Stammes, P., NEONET Stuurgroep, member.
Stammes, P., OMI Science Team (NIVR/FMI/NASA), member.
Stammes, P., PhD Committee O.N.E. Tuinder, University of Utrecht, member.
Stammes, P., SCIAMACHY Science Advisory Group (NIVR/DLR), member.
Stammes, P., Studiekring Straling in de Atmosfeer, chairman.
Ulden, A.P. van, National Focal Point Working Group I, IPCC, member.
Ulden, A.P. van, NOP Programma commissie, member.
Ulden, A.P. van, Programma Raad CKO, member.
Ulden, A.P. van, Scientific Steering Group BALTEX, member.
Ulden, A.P. van, Steering Group Climate Monitoring SAF, member.

Climate Analysis

Climate Analysis

Climate Analysis and Scenarios

The aim of this activity is the analysis and diagnosis of the climate on the basis of empirical studies and the formulation of climate scenarios suitable for impact studies in the Netherlands. The emphasis is on extreme events. In this context, the study of the probability distribution of extremes for present-day conditions is a research topic in its own right, as design heights of e.g. dykes are based on extreme events with average return periods of thousand years or more. Institutions that are responsible for the safety of live and property are strongly interested in the extremes that correspond to these long return periods. Primary interest is directed towards the values in the present climate, but even these are only poorly known. Advanced statistical studies are required to derive these values from the observational and model data. An additional concern in safety policy is the change in extremes as induced by the greenhouse effect. To address the latter question, climate scenarios are developed, mostly relying on statistical downscaling methods – hence on empirical relations between different weather elements. These climate scenarios include changes in the mean as well as estimates of changes in extremes of a number of impact-relevant parameters. In the framework of the preparation of the Governmental Bill on Water Management 21st Century (WB21) the KNMI climate scenarios for impact studies in the Netherlands have been updated in co-operation with RIZA (The Dutch governmental institute responsible for protection against river flooding). Although the original scenarios were primary developed for water-related problems, the current KNMI climate scenarios serve also as a standard for the broader scientific community in the Netherlands studying climate impact. After the publication of the IPCC Third Assessment Report (TAR), a KNMI brochure was published on Weather and Water in the 21st Century, outlining the main IPCC results and presenting the updated Dutch scenarios to policymakers, stakeholders and the general public.

Stochastic rainfall generators and contribution to the National Drought study

The development of stochastic weather generators for the Rhine and Meuse basins takes place in close co-operation with RIZA. Sequences of daily precipitation and temperature have been generated at multiple locations in the Rhine basin using nearest-neighbour resampling. Several 1000-year simulations were handed to RIZA, WL/Delft Hydraulics and the German Governmental Institute BfG for further research with hydrological models. The first results from the coupling of the generator with a hydrological model for the Rhine indicate realistic values of the simulated discharge peaks. For the Ourthe basin (the largest sub basin of the river Meuse) a weather generator for sub-daily precipitation and temperature was completed.
A paper on the use of nearest-neighbour resampling for generating sub-daily weather variables was accepted by the Journal of Hydrology. For the Rhine basin, a version of the weather generator is available that simulates precipitation and temperature conditional on the atmospheric circulation. This conditional simulation approach offers prospects for applications to a changed climate.
In the framework of the National Drought study, nearest-neighbour resampling has been used to

generate 10-day values of precipitation, potential evapotranspiration and the river Rhine discharge in the Netherlands. The probability of rainfall deficits in the Netherlands as well as the joint probability of a rainfall deficit and low river flows are of interest here. The return period of the notoriously dry 1976 summer is 75 years in terms of rainfall deficit alone, but 190 years if besides the rainfall deficit the flow of the river Rhine is also taken into account.

Downscaling

The research on downscaling is presently concentrated in the EU project SWURVE, of which RIZA is an end-user. Statistical relationships for daily and monthly precipitation have been compared for three sites in the river Rhine basin. In the daily models the increase in the amount of precipitation due to a systematic increase in specific humidity was about twice as large as in the monthly models. The low sensitivity of the monthly models was found to be a result of bias due to averaging of predictors over wet and dry days.

From integrations of the Hadley Centre regional climate model HadRM2, climate change scenarios for the end of the 21st century were derived to determine the change in the flow regime of the river Rhine, using the hydrological model RhineFlow. The RhineFlow simulations show a large increase in the mean discharge in winter and a large decrease in summer *(Figure 1)*. These changes in the mean discharge are accompanied by more extreme flood peaks and an increased frequency of low flows. The change in the occurrence of floods does not only depend on the changes in the mean precipitation and temperature but also on the changes in their variability. The work is being continued with recent integrations of the HadRM3 regional climate model. In 2002 two papers on the SWURVE project were submitted to international journals.

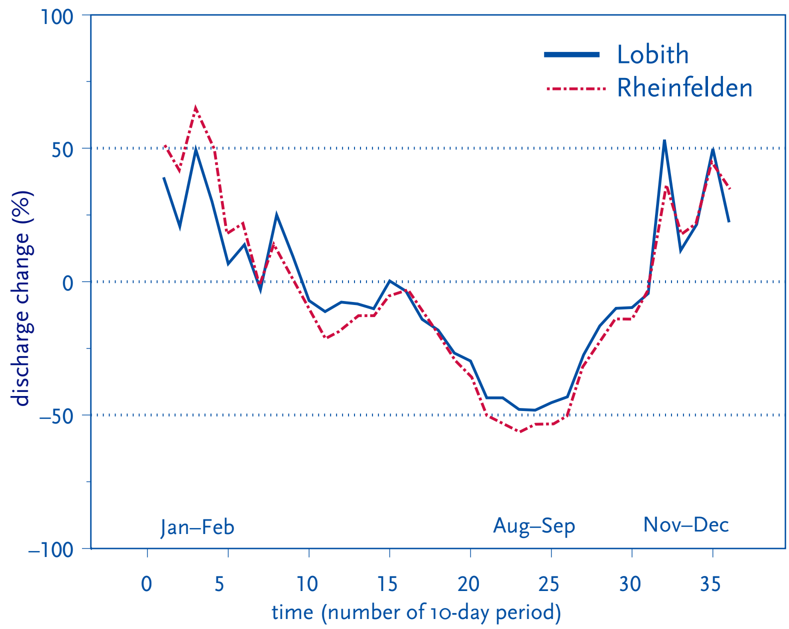


Figure 1. Relative changes in the river Rhine discharge at Rheinfelden (Switzerland) and Lobith (the Netherlands) for the 2080s based on the HadRM2 regional climate model and the hydrological model RhineFlow.

Extreme wind and surges, and explosive cyclogenesis

Financed by RIKZ (The Dutch governmental institute responsible for coastal protection) research is ongoing on the extreme statistics of gales and surges for return periods up to 100 centuries (being the safety standard of the sea dykes). The methodology consists of analysing very long time series as generated by the intermediate complexity climate model ECBilt. Within this model context, indications are found for the existence of two regimes in the extreme wind and surge statistics, the second regime becoming dominant for return periods larger than 100 yr. A paper on this topic is accepted by the Journal of Coastal Research. The follow-up research is directed to the cyclogenesis leading to extreme violent gales.

Elbe case study

In August 2002, heavy precipitation in Central Europe caused widespread flooding in the Elbe catchment. On request of the Ministry of Transport and Water Management, it was calculated how high the Rhine and Meuse discharges would have been if the Elbe precipitation had occurred in the Rhine or Meuse catchments instead. The report had to be completed within 6 weeks after the Elbe event took place. The study was performed in co-operation with the KNMI Department Observation and Models and with RIZA and WL/Delft Hydraulics. It was concluded that the discharges of this virtual case would have resulted in a third place in the row of observed high Rhine discharges of the 20th century. For the Meuse, it reached to a fourth place. In terms of summer situations, the calculated discharges of Rhine and Meuse exceed all historical observations.

Climate Reconstruction

Databases form the fundament of empirical studies. Within KNMI a large-scale programme HISKLIM started to digitise and homogenise series available on hard copy with the highest possible temporal and spatial resolution. The activities have three branches: land data, ocean data and data from abroad but available from Dutch sources. Sub activities are data homogenisation and database building.

Land data and series homogenisation
Within the HISKLIM programme, an effort is undertaken to digitise the 1700–1950 hourly Amsterdam series; the digitisation of the 19^{th} century KNMI yearbook data is in progress. A unique series, though only of 2-year length, of pressure readings in the late 17th century has also been digitised. The first release of a homogenised De Bilt series appeared by the end of 2002. A study on the empirical determination of the advected heat island effect (with H.R.A. Wessels from the Department of Observation and Models as co-author) revealed in the temperature series of De Bilt a clear signal of heat advected from near-by towns *(Figure 2)*. A paper on this effect was accepted in early 2003 by the International Journal of Climatology. The ECA (European Climate Assessment) database of daily European data, as coordinated within the Department of Observation and Models (A.M.G. Klein Tank and J.B. Wijngaard), was installed in 2002. Co-operation with these two ECA coordinators about the interpretation of the data resulted in a joint paper about the ECA database that was published in 2002; a paper on the homogeneity of the ECA data was accepted by the International Journal of Climatology. A long-lasting joint effort to assess the quality of the long (800-present) so-called Low Country Temperature series resulted in a paper that is now accepted by Climate Change.

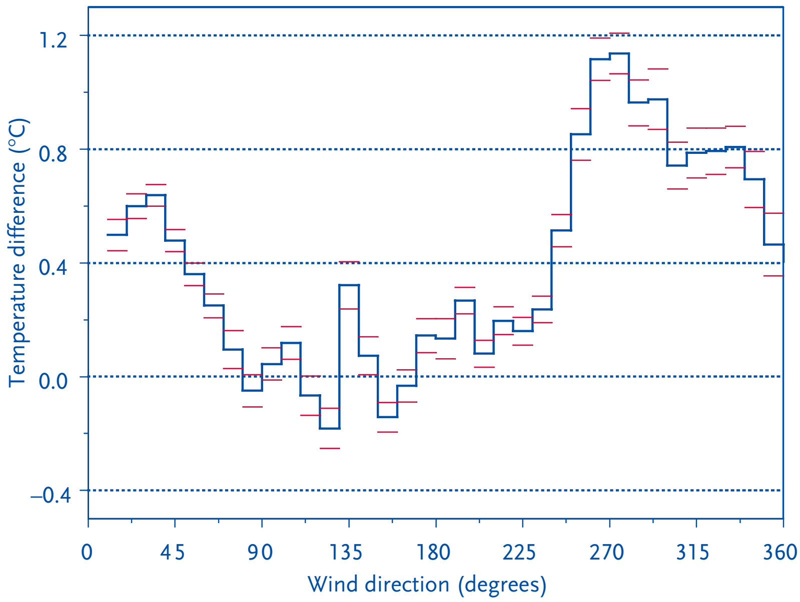


Figure 2. Dependence of the hourly temperature difference De Bilt minus Soesterberg on wind direction. The figure refers to night time hours with cloud cover ≤ 5/8 in summer for the period 1993–2000. The dashes give standard errors for each 10° wind direction class. The peaks at 30° and 270° reflect the advection of urban heat from the towns De Bilt and Utrecht, respectively, towards the measuring site at De Bilt.

Ocean data
The EU project CLIWOC, aiming to digitise and analyse marine observations from the period 1750–1850, completed its first two years. As the project has a clear interdisciplinary component, the Dutch (KNMI) contribution is carried out in close co-operation with NIWI, a scientific institute for historians. The European partners are from Spain and the UK, each of them digitising their own logbooks. Together with the US Maury collection and French logs that are brought in via the Spanish partner, the ship logs from the EU countries participating in CLIWOC comprises virtually all observations from the world's oceans of that period. By early 2003 it was estimated that the final CLIWOC database will consist of 300,000 observations, evenly distributed over the partners. The main coverage is in the Atlantic and Indian Oceans. After completion of CLIWOC, all available Spanish data, 50% of the Dutch data, and 7% of the UK data of the period considered will be digitised.

The evaluation of the 1854–1938 Dutch pressure data in the COADS database is completed and resulted in the incorporation of 6 million Dutch pressure records in the 2001 release of the COADS database, extending the amount of data of that period by more than 25%. A paper on this topic (first author: H. Wallbrink, KNMI Oceanographic Research Division) was accepted early 2003 by the International Journal of Climatology.

Rescue of data from the colonial era
A paper on the recovery of pre-1875 Japanese instrumental data taken by the Dutch is published in early 2003 in the Journal of Climate. It was co-authored by two Dutch, one English and three Japanese scientists. In the wake of that project,

additional 19th century instrumental series were discovered, some of them being taken by Japanese observers. Unexpectedly, these series date back to the early 19th century, in which period no instrumental observations besides those from the Dutch factory Dejima were believed to exist. The data are currently analysed in co-operation with our Japanese partners T. Mikami and M. Zaiki of the Metropolitan University of Tokyo, and T. Tsukahara of the University of Kobe.
In co-operation with the Indonesian Meteorological Institute, hourly pressure values of Jakarta for 1945–2000 are obtained, supplementing the 1866–1944 Jakarta hourly series from NCAR. This series may enable calibration of the extension of the Quasi-Biennial Oscillation series 1866–1950. These two rescue projects are carried out in co-operation with P.D. Jones, University of East Anglia, UK.

Publications are listed by Division. A paper with authors from different Divisions will be listed more than once in this Report.

Scientific publications in reviewed journals

2001

Buishand, T.A. and T. Brandsma, 2001. *Multi-site simulation of daily precipitation and temperature in the Rhine basin by nearest-neighbor resampling.* Water Resour. Res., **37,** 2761–2776.

Datsenko, N.M., M.V. Shabalova and D.M. Sonechkin, 2001. *Seasonality of multidecadal and centennial variability in European temperature: the wavelet approach.* J. Geophys. Res., **106,** 12449–12460.

2002

Beckmann, B.R. and T.A. Buishand, 2002. *Downscaling relationships for precipitation for the Netherlands and North Germany.* Int. J. Climatology, **22,** 15–32.

Klein Tank, A.M.G., J. B. Wijngaard, G.P. Können et al., 2002. *Daily surface air temperature and precipitation dataset 1901–1999 for the Europe on Climate Assesment (ECA).* Int. J. Climatology, **22,** 1441–1453.

Other scientific publications and reports

2001

Asselt, M.B.A. van, H. Middelkoop, S.A. van 't Klooster, W.P.A. van Deursen, M. Haasnoot, J.C.J. Kwadijk, H. Buiteveld, G.P. Können, J. Rotmans, N. van Gemert and P. Valkering, 2001. *Integrated water management strategies for the Rhine and Meuse basins in a changing environment.* Final report NRP project 958273, NRP report 410200081.

Asselt, M.B.A. van, H. Middelkoop, S.A. van 't Klooster, W.P.A. van Deursen, M. Haasnoot, J.C.J. Kwadijk, H. Buiteveld, G.P. Können, J. Rotmans, N. van Gemert and P. Valkering, 2001. *Integrated water management strategies for the Rhine and Meuse basins in a changing environment.* IRMA-SPRONGE project3/nl/1/164/99, 15 183 0.

Beckmann, B.R. and T.A. Buishand, 2001. *Downscaling relationships for precipitation for several European sites.* KNMI Technical Report TR-230.

Beersma, J.J., B.J.J.M. van den Hurk and G.P. Können, 2001. *Weer en water in de 21e eeuw,* KNMI Brochure.

Brink, H.W. van den, F.M. Selten, D.F. Doortmont, J.D. Opsteegh and G.P. Können, 2001. *Climate projections for Europe.* Final report NRP project 951269, NRP report 410200079.

Jong, J. de, G.P. Können and A. Kattenberg, 2001. *Climate Changes in the Rhine Basin.* Watershed Conference, Tokyo, July 2001. Also published as KNMI Brochure.

Wójcik, R. and T.A. Buishand, 2001. *Rainfall generator for the Meuse basin: Simulation of 6-hourly rainfall and temperature for the Ourthe catchment.* KNMI Publication 196-1.

2002

Beersma, J.J., 2002. *Rainfall generator for the Rhine Basin; Description of 1000-year simulations.* KNMI Publication 186-V.

Beersma, J.J. and T.A. Buishand, 2002. *Droog, droger, droogst. Bijdrage van het KNMI aan de eerste fase van de Droogtestudie Nederland.* KNMI Publication 199-I.

Beersma, J.J., T.A. Buishand and R. Wójcik, 2001. *Rainfall generator for the Rhine basin: multi-site simulation of daily weather variables by nearest-neighbour resampling.* In: Generation of hydrometeorological reference

conditions for the Assessment of flood hazard in large river basin, P. Krahe and D. Herpertz (Eds.), 69–77, CHR-Report no. I-20, Lelystad.
Beersma, J.J., R. van Dorland and J.D. Opsteegh, 2002. *Shortwave radiation and cloud parameterizations for intermediate complexity models.* KNMI Scientific Report WR 2002–02.
Brandsma, T., 2002. *Contamination of the long-term temperature series of De Bilt (The Netherlands) by urban heat advection.* Proc. Fourth Symp. Urban Environment, AMS, Norfolk, (Va), USA, 20–24 May, 45–46.
Langemheem, W. van de, J.R.A. Onvlee, G.P. Können and J. Schellekens (Eds.), 2002. *Projectie van de Elbe-zomerneerslag op de Rijn en Maas, Onderzoek naar aanleiding van de recente overstromingen in Midden-Europa.* RIZA rapport 2002 042, KNMI Publication 198, WL rapport Q 3352, ISBN 903695472x.
Zaiki, M., T. Tsukahara, T. Mikami and G.P. Können, 2002. Instrumental *Meteorological Records at Dejima, Nagasaki in the 19th Century.* Geographical Review of Japan, 75, 901–912 (in Japanese).

Number of national presentations

2001: 9
2002: 6

Number of international presentations

2001: 12
2002: 4

Committees

Beersma, J.J., Steering committee EU-project ECLAT-2, 2001, member.
Buishand, T.A., Extremes, member editorial board.
Können, G.P., Commision for climatology, principal delegate for the Netherlands.

Seismology

Sysmology

Seismology is the basic science concerning earth movements and is connected to the solid ground under our feet that can be shaky from time to time. The years 2001 and 2002 showed again that the earth has not given up its movements. The earthquake of magnitude 4.9 near Alsdorf on 22 July 2002 in Germany just across the border with the Netherlands is a recent example. The two years 2001 and 2002 were productive in many ways, building on the investments both in knowledge and equipment in previous years. Especially the work related to infrasound has drawn much attention internationally.

Observations

Monitoring natural seismicity
In the southeastern 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 17 earthquakes took place within the political borders of the Netherlands, i.e. 8 in 2001 and 9 in 2002. Of these earthquakes 8 occurred near Roermond, which shows that this region is still active after the large event of magnitude 5.8 in 1992.

The large swarm of earthquakes near Voerendaal that already started in December 2000 continued in 2001 and 2002. Near Voerendaal, 132 earthquakes occurred in 2001 and 4 in 2002. The magnitude varies between –0.1 and 3.9. There were 6 events with magnitude 3.0 or higher. The strongest event, with magnitude 3.9, occurred on June 23, 2001.

On July 22, 2002, a large earthquake with magnitude 4.9 occurred near Alsdorf, just across the border in Germany. In the first 6 hours after the event 13 after-shocks were recorded with a maximum magnitude of 2.5. Just after the event a questionnaire was put on the KNMI Internet site where people could report whether they felt the earthquake or not. In one week we received almost 4000 reactions, from which we could conclude that the earthquake was felt in the whole country. The maximum intensity for this earthquake was VII and damage to buildings was reported.

Also 7 earthquakes occurred in 2000 and 2001 in the North Sea, with magnitudes varying between 1.3 and 4.5. It is not clear if these events are natural or induced. An example of an interesting and large event is the one near the Ekofisk gas field on May 7, 2001, with a magnitude of 4.5. In any case it is clear that the North Sea has a low level of seismic activity, also on the continental margin of the Netherlands.

Monitoring gas production related earthquakes in Groningen, Drenthe and Noord-Holland
In 2001 21 earthquakes have been recorded and located. Magnitudes vary between -0.2 and 3.5. Of special interest were two events near Alkmaar in September 2001, with magnitude 3.5, the largest induced event ever recorded in the Netherlands, and magnitude 3.2. These two events follow two previous events in the region in 1994, and could be attributed to one fault within the Bergermeer

gas field. In addition to these events, one event occurred for the first time at the edge of the Bergen gas field. These Alkmaar events caused damage in the region. The statistics of the Alkmaar events is not in line with the general rule concerning the distribution of magnitudes. After these events 3 accelerometers were installed in the region by the end of 2002 to be prepared for future events.

NAM conducted a down-hole micro-earthquake survey in the Roswinkel area with a set of sensors at reservoir level (2000 m depth) for a period of two weeks. About 40 events were recorded at magnitudes between –6 and –2. Accurate locations coincided with results from KNMI locations for the larger events and confirmed a depth of 2 km.

In 2002 25 events have been recorded and located, with magnitudes ranging from 0.0 to 2.2. The Roswinkel area remained active, as well as the Annerveen area. NAM also carried out a down-hole micro-earthquake experiment in close co-operation with KNMI, with respect to the Annerveen gas field. Although only 10 events were recorded, this experiment did generate additional information of use in the interpretation of the larger events.

Development of the seismometer network

In June 2001 a Quanterra Q4120 6-channel datalogger and a Streckeisen STS-2 broadband seismic sensor were installed at seismic station Heimansgroeve (HGN). In 2002 two Applied Geomechanics tiltmeters and a Lacoste-Romberg gravimeter were installed and connected to the same datalogger. The analog outputs of these seismic and geophysical sensors are digitised by the Quanterra datalogger and transmitted in real-time to KNMI over Internet. In January 2002 a calibration board was installed in the datalogger to calibrate the STS-2 seismic sensor at regular intervals. In early 2003 the STS-2 will be replaced by the Streckeisen STS-1 very broadband seismic sensor, which is operational at HGN since 1993.

Two Quanterra Q730 datalogger systems were configured in 2002 to deploy two new seismic broadband stations. One system will be installed at station Winterswijk B (WTSB) in early 2003 to modernise the acquisition system and to make WTSB a contributing station in the VEBSN. Two Quanterra Q330 dataloggers were purchased in 2001, which will be deployed in the southern part of the Netherlands as mobile seismic stations together with Streckeisen STS-2 broadband sensors.

In 2002 a real-time application was developed under Real-Time Linux to send data over Internet to an analog recording system (drum recorder). Even today such an analog system is desirable for real-time visualisation purposes and for monitoring of seismic activity and data quality.

Accelerometers

During the last 5 years a successful programme was carried out to install accelerometers in epicentral areas where earthquakes are to be expected within a relatively short timeframe. Accelerometers are quite useful in the determination of the level of shaking in areas where damage to buildings could occur both due natural and induced events.

Following the start of the earthquake swarm near Voerendaal in December 2000, four accelerometers were deployed in Voerendaal during 2001 and the first half of 2002. This local network recorded 40 earthquakes over 2001 and 2002. The recordings of the largest earthquake, at 23 June 2001 with magnitude 3.9, showed an acceleration of about 1.8 m/s^2.

During 2001 and 2002 4 new accelerometers were purchased, bringing the total number to 20. This number of stations requires remote access of the instruments, both for maintenance purposes and for retrieval of the data. Therefore the accelerometer stations were successively equipped with GSM dial-up modems during 2001 and 2002. In 2002 3 accelerometers were installed nearby Alkmaar, after the two larger earthquakes in the region.

Instrument testing

Towards the end of 2002 Shell asked KNMI to contribute to a test of different seismic sensors in the frequency range of 1–10 Hz. The site of station HGN was used to conduct this experiment, where in addition to the broad-band sensors (STS-1 and STS-2) also a series of analog and digital micro machined electro-mechanical system (MEMS) sensors were tested, as well as an array of 4.5 Hz geophones at the surface and a high sensitivity geophone in the vault. These MEMS-sensors are ultra small solid-state devices that can detect mechanical vibrations and are used, for example, as trigger devices in automobile airbags. The instruments recorded continuously for one week and at the end a 16 tons Vibrator truck was arranged to allow for an active source. The experiment is evaluated early 2003 and a report will be prepared.

Research

Regional seismicity

In order to have a fast and efficient access to historical earthquake data in the region a Geographical Information System (GIS) was further expanded. Apart from seismicity data (phases, locations), the GIS system was extended with information on (active) faults and gas fields. For some regions also subsidence data were added and data from micro earthquake surveys at reservoir levels (NAM). This system is also used for the reanalysis of old events.

During 2001 and 2002 an earthquake swarm occurred near Voerendaal. This swarm started in December 2000 and included a series of events of magnitude up to 3.9 (June 23, 2001). A study started on all aspects of this swarm, including the statistics and b-value, the source mechanism and accurate locations using correlation techniques. First results show a normal faulting mechanism, in accordance with the regional pattern. Locations show a migration of locations along the fault, which changes from a SE-NW direction to an E-W direction near Voerendaal.

In order to improve locations, an effort was undertaken to improve the 1D crustal model in the Roer Valley Rift System together with colleagues from Germany and Belgium. Within this co-operation KNMI focused on the calculation of 'receiver functions' for the broadband station HGN and the short period stations available (Valkenburg (VKB), Rolduc (RDC) and Schinveld (SCHN)). First results show significant variations in crustal structure within a small distance (10–20km) from station HGN. The influence of dipping layers is visible and is subject of further research.

Research into induced events in the northern part of the Netherlands focused on the two events near Alkmaar and the continued activity near Roswinkel. The events near Alkmaar showed continued activity along the same fault compared to the previous events in 1994. The mechanism for this event showed a reactivation of an existing normal fault, but its movement is reversed, in line with the fact that gas is extracted from the upper block. In the case of Roswinkel, results from micro earthquake monitoring operated by the NAM showed seismicity in line with the locations from the shallow boreholes. This confirmed the accuracy of the relative locations for the larger events determined by KNMI.

Local site effects

The effects of the shaking during an earthquake can be enhanced or diminished due to local circumstances such as the composition of the shallow subsurface. Shallow is in most cases the first 25–50 meters. These shallow surface effects are known as site effects in seismology and play an important role in the determination of seismic hazard. In previous years, detailed velocity models were made at two locations equipped with borehole stations. From these data the site effects could be calculated. Now, a more engineering type of approach is under study to produce eventually maps on which the site effects are plotted. This is foreseen to be done by the analysis of shallow borehole data and by the measurement of S-wave velocity structure with small arrays.

Seismic hazard analysis

International developments towards a more sophisticated society and a more intricate infrastructure are also relevant in the Netherlands. The consequence is a larger vulnerability towards different natural risks, like earthquake related risks, and this has been recognised by national law enforcing institutes. For example, the new Dutch exploration law that will enter into force January 1, 2003, requires an extensive mining plan, including, specifically, an (induced) earthquake risk assessment. Therefore, a project was initiated to reassess seismic hazard in the Netherlands and its immediate surroundings. This reassessment involves a probabilistic characterisation of the ground acceleration and ground velocity to be expected in the Netherlands due to tectonic and induced seismicity. In a number of cases a deterministic approach will be followed. This work is coordinated with among others the NITG. Within an informal discussion group, 'Technisch Platform Aardbevingen' (TPA), KNMI discusses research initiatives in a broader forum with other research institutes and larger exploration companies.

Furthermore, the Seismology Division has been requested to perform international expert reviews on seismic hazard studies for, among others, Shell Global Solutions and specific hazard studies for governmental organisations, like the Ministry of Foreign Affairs and the Ministry of Public Transport and Water Management. The latter study was an assessment of the risk to river dikes in the case of a severe loading by high water levels. A report was published in December 2002.

Modelling of seismic sources

Earthquake processes show chaotic behaviour and are therefore difficult to describe deterministically. Still, good observations close to the rupture area are an important prerequisite to understand these processes better. In the Netherlands, we have no realistic options to study tectonic earthquakes at the depths they occur (around 12–17 km). However, induced seismicity occurs at much shallower depths near the gas reservoirs to be exploited. The Division has set up a co-operation with both the NAM and Shell Research to study micro earthquakes jointly with KNMI borehole sensors and sensors deployed at depths corresponding to the occurrence of induced earthquakes. While the NAM and Shell Research are interested in micro earthquakes for reservoir characterisation, KNMI is interested in these measurements to model the recorded micro earthquakes. Within this co-operation the Division has also given a three days seminar on seismology, specifically related to source processes. In parallel the Division maintains a capability to perform numerical modelling using Boundary Element Methodologies.

Attenuation of seismic waves

Attenuation is an important factor for the calculation of seismic hazard. The attenuation of seismic waves in the southern part of the Netherlands (Limburg) was determined. 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 show up in seismograms as the tail of a primary (P) or secondary (S) arrival 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 these countries. The results show a significant difference in Q between small (< 25 km) epicentral distances and larger ones. Moreover, intrinsic absorption dominates over scattering. Given these and other observations we deduce that the lower crust and the upper mantle have a significant effect on the seismic coda. Better modelling is needed.

Comprehensive Nuclear-Test-Ban Treaty (CTBT)

The activities in the context of the Comprehensive Nuclear-Test-Ban Treaty (CTBT) concentrated mainly on advisory work for the Ministry of Foreign Affairs and on the monitoring aspects of infrasound. The contribution in the area of the infrasound monitoring technique is focussed on source characterisation and array processing. Both are fundamental in the operation of the International Monitoring System (IMS) to verify the Treaty. This work is highly visible and resulted in a workshop organised in the Netherlands in November 2002. The work on the Netherlands National Data Centre (NDC) was not much advanced in the light of the political situation. However, Canada and the Netherlands will be the open and free accessible data centres for infrasound. In the beginning of 2003 the Netherlands National Data Centre is formally installed at the request of the Ministry of Foreign Affairs.

Infrasound

Infrasound is inaudible low frequency sound with air pressure fluctuations in the range from 0.005 to 40 Hz. The Seismology Division measures infrasound to distinguish between earthquakes signals and signals from atmospheric sources. Infrasound from a sonic boom, for example, can cause similar vibrations in houses as those associated with an earthquake. Furthermore, infrasound measurement is one of the verification techniques of the CTBT. Research is carried out to scientifically support the CTBT with the unique network of sensors in the Netherlands.

Arrays are operated in De Bilt (DBN) and Deelen (DIA). DBN consist of six in-house developed microbarometers laid out over an area of 70 x 70 meters, for DIA 16 microbarometers are used in an area of 1500 x 1500 meters. A third array in Witteveen is currently being upgraded.

The volcanic explosions of Mount Etna in Italy were recorded in the Netherlands during the summer of 2001. Also several bolides were detected and localized from the North Sea to South Germany. Bolides generate infrasound because they penetrate the Earth’s atmosphere at super-sonic speeds and sometimes thermally explode at the end of their trajectory. A bolide of 26 kT TNT equivalent was detected over the Mediterranean Sea. Infrasound from the Concorde and military fighter jets are measured on a daily basis.

EC-project MEREDIAN

The Mediterranean-European Rapid Earthquake Data Information and Archiving Network (MEREDIAN) is an EC-project within the 5th framework programme under 'Support for Research Infrastructure' and is coordinated by the Seismology Division. Goal of this project is to make earthquake waveform data, primarily from European high-quality seismograph stations, rapidly and effectively available for basic research and studies on earthquake effects mitigation. Ten European national seismological observatories are presently participating in this project, i.e. in Austria, France, Germany, Greece, Italy, Netherlands, Norway, Slovenia, Spain and Switzerland. Late 2002 the project has been extended to include eight EC candidate countries: Bulgaria, Czech Republic, Estonia, Hungary, Malta, Poland, Romania and Slovak Republic.

The ORFEUS Data Centre facilities are being significantly upgraded within the MEREDIAN project. The Virtual European Broadband Seismograph Network (VEBSN), i.e. real time data arriving centrally at the ODC from all over Europe and its vicinity, is being realised. New data products, for example rapid event locations and arrival picks, are becoming available. The other consortium members make similar investments at their national observatories.

EC-project EMICES

European-Mediterranean Infrastructure Coordination for Earthquake Seismology (EMICES) is an EC-project under the 5th framework programme under 'Accompanying Measures' and is coordinated by the Seismology Division of KNMI. The goal of this project is to support the MEREDIAN project with the organisation of three workshops; 'Real-time data exchange in Europe', Barcelona, Spain, October 23–25, 2002; 'Distributed, Object Oriented Computing for Seismology', Athens, Greece, 2003 and 'Seismic hazard and data exchange within the Mediterranean', Nicosia, Cyprus, 2003/4. Participants in this project are the EMSC (European-Mediterranean Seismological Centre), Institut d'Estudis Catalan, Barcelona, Spain, University of Athens, Greece and the Geological Survey of Cyprus.

ORFEUS and the Orfeus Data Centre

Observatories and Research Facilities for European Seismology (ORFEUS) maintained and strengthened its position in the coordination and promotion of broadband seismology in the European-Mediterranean region. During the reporting period 11 corporate founders provided the main funding. The number of paying participants went from 53 in 2001 to 62 in 2002. The data centre has been upgraded with, among others, a new data storage (RAID) system accommodating nearly one terabyte of data and reorganised to meet the requirements of the networking and security specialists at KNMI.

ORFEUS co-ordinating activities have been numerous and can be followed on our web pages http://orfeus.knmi.nl, which are kept up-to-date on a daily basis. The Seismological Software Library, maintained by ORFEUS, is presently a well-established global reference for public seismological software (see also the AGU International Handbook of Earthquake and Engineering Seismology, Part A, 2002). July 3–5, 2001 a meeting of European Seismologists in De Bilt was organised to discuss long-term strategies for a European Research Infrastructure in seismology. July 6–10, 2001 a meeting of major European and US data centres was held in De Bilt to coordinate their activities. From November 18–22, 2002 there was an ORFEUS workshop 'Installation and operation of seismic broadband stations' in Istanbul. During 2001 and 2002 4 issues of the ORFEUS Electronic Newsletter have been published on our web pages. Both ORFEUS and the EMSC have started coordinating their European activities during 2002.

Publications are listed by Division. A paper with authors from different Divisions will be listed more than once in this Report.

Scientific publications in reviewed journals

2001

Demanet, D., L.G. Evers, H. Teerlynck, B. Dost, and D. Jongmans, 2001. *Geophysical investigations along the Peel boundary fault (The Netherlands) for a paleoseismological survey.* Geol. Mijnb., **80** (3-4), 119–127.

Dirkzwager, J.B., J.D. van Wees, S.A.P.L. Cloetingh, M.C. Geluk, B. Dost and F. Beekman, 2001. *Geo-mechanical and rheological modelling of upper crustal faults and their near surface expression in the Netherlands.* Glob. Plan. Change, **27**, 67–88.

Evers, L.G., H.E. de Bree, H.W. Haak and A.A. Koers, 2001. *The Deelen Infrasound Array for recording somic booms and events of CTBT interest.* J. Low Freq. Noise, **19**, 123–133.

Evers, L.G. and H.W. Haak, 2001. *Listening to sounds from an exploding meteor and oceanic waves.* Geophys. Res. Lett., **28**, 41–44.

Gussinklo, H.J., H.W. Haak, R.C.H. Quadvlieg, P.M.F.M. Schutjens and L. Vogelaar, 2001. *Subsidence, Tremors and Society.* Geol. Mijnb., **80** (1), 121–135.

Thurber, C., C. Trabant, F. Hasliner and R. Hartog, 2001. *Nuclear explosion locations at Balapan, Kazakhstan, nuclear test site: the effects of high-precision arrival times and three-dimensional structure.* Phys. Earth Plan. Int., **123**, 283–301.

2002

Berg, M. van den, K. Vanneste, B. Dost, A. Lokhorst, M. van Eijk and K. Verbeek, 2002. *Paleoseismic investigations along the Peel boundary fault: geological setting, site selection and trenching results.* Geol. Mijnb., **81**, 39–60.

Dahlman, O., J. Mackby, S. Mykkeltveit and H. Haak, 2002. *Cheaters Beware.* Bull. Atomic Scientists, **58**, 28–35.

Dineva, S., T. Batllo, D. Mihaylov and T. van Eck, 2002. *Source parameters of four strong earthquakes in Bulgaria and Portugal at the beginning of the 20th century.* J. Seism., **6**, 99–123.

Trabant, C., C. Thurber and W. Leitz, 2002. *Ground truth seismic events and location capability at Degelen mountain Kazakhstan.* Phys. Earth Plan. Int., **131**, 155–171.

Other scientific publications and reports

2001

Dost, B., 2001. *Seismiciteit van de Roerdal Slenk en omgeving.* Bijdrage aan: Toelichting bij kaartbladen XIII en XIV; Breda-Valkenswaard en Oss-Roermond. Uitgave NITG-TNO Geologische Atlas van de Diepe Ondergrond van Nederland, 100–102.

Evers, L.G. and H.W. Haak, 2001. *An optimal infrasound array at Apatity (Russian Federation).* KNMI Technical Report TR-195.

Haak, H.W., B. Dost, and F.H. Goutbeek, 2001. *Seismische analyse van de aardbevingen bij Alkmaar op 9 en 10 September en Bergen aan Zee op 10 oktober 2001.* KNMI Technical Report TR-239.

Haak, H.W., L.G. Evers and M.E. Petit, 2001. *The Deelen Infrasound Array for recording sonic booms and events of CTBT interest.* Proc. Ninth Annual Int. Symp. Long-Range Sound Propagation, The Hague, the Netherlands, 14–15 Sept. 2000, 221–228.

Oonincx, P., R. Sleeman and T. van Eck, 2001. *An application of the DWT in Seismic Data Analysis.* In: A. Petrosian and F. Meyers (Eds), Wavelets in Signal and Image Analysis, Kluwer.

2002

Dost, B. and H.W. Haak, 2002, *A comprehensive description of the KNMI seismological instrumentation.* KNMI Technical Report TR-245.

Eck, T. van, 2002. *MEREDIAN: an infrastructure for rapid exchange of earthquake waveform data in Europe.* Proc. EU-MEDIN Workshop on Natural and Technolocal Hazards, Brussels, Belgium, 15–17 November 2000, K. Fabbri and M. Yeroyanni (Eds.), European Commission, 56–59.

Eck, T. van, B. Dost, C. Trabant, R. Sleeman and F.H. Goutbeek, 2002. *Developments at ORFEUS and its Data Center.* ORFEUS Electronic Newsletter, **4**, 13.

Eck, T. van et al., 2002. *Towards a Virtual European Broadband Seismograph Network.* ORFEUS Electronic Newsletter, **4**, 5.

Evers, L.G., 2002. *De doorbroken stilte rondom meteoren.* Meteoor, **58**, 2.

Haak, H.W. and L.G. Evers, 2002. *Infrasound as a tool for CTBT verification.* VERTIC Yearbook, 207–221.

Lee, H.K., Kanamori, H., Jennings, P.C. and C. Kisslinger (Eds.), T. van Eck (coordinator), 2002. *International Handbook of Earthquake and Engineering Seismology, Part A.* Academic Press.

Sleeman, R. and T. van Eck, 2002. *Single station real-time P and S-phase pickers for seismic observatories. Methods and applications of signal processing in seismic network operations.* Lecture Notes in Earth Sciences, **98**, 173–189.

Number of national presentations

2001: 9
2002: 11

Number of international presentations

2001: 13
2002: 28

Education and organisation of workshops

2001

Eck, T. van, Datacenter coordination meeting, KNMI, De Bilt, the Netherlands, 6–10 October, organiser.
Eck, T. van, Second MEREDIAN meeting INGV, Rome, Italy, 1–2 October, organiser.
Eck, T. van, B. Dost and F.H Goutbeek, Strategy meeting on data exchange for European Seismology, KNMI, De Bilt, the Netherlands, 3–5 July, organisers.
Eck, T. van, First MEREDIAN Meeting, KNMI, De Bilt, the Netherlands, 1–2 February, organiser.

2002

Eck, T. van, Orfeus workshop Installation and operation of broadband seismic stations, Istanbul, Turkey, 18–20 November, organiser.
Eck, T. van, B. Dost, Th. de Crook and F.H. Goutbeek, 3-day Course for employees of NAM and Shell Research Lab., Introduction to seismology, De Bilt, the Netherlands, 27 February–1 March, organisers.
Eck, T. van and F.H. Goutbeek, EMICES workshop Real-time data exchange in Europe, Barcelona, Spain, 23–25 October, organisers.
Eck, T. van and F.H. Goutbeek, Third MEREDIAN meeting, Barcelona, Spain, 20–21 October, organisers.
Evers, L.G., Infrasound Technology Workshop, De Bilt, the Netherlands, 28–31 October, organiser.

Committees

Crook, Th. de, Commissie Aardbevingen van het Nederlands Normalisatie Instituut, member.
Dost, B., ESC WG Data centres and data exchange, chairman.
Dost, B., Federation of Digital broad-band Seismograph Networks (FDSN), member Executive Committee.
Dost, B., Orfeus Data Centre, director.
Dost, B., Subcommission Bodembeweging en Zeespiegelvariatie of the Nederlandse Commissie voor Geodesie, member.
Dost, B., User panel of Seismological Research Emphasizing Array Technologies (SRESAT) project, member.
Dost, B., Working Group on Data Exchange of the FDSN, chairman.
Eck, T. van, EC fifth framework proposals, evaluator.
Eck, T. van, EC-project EMICES (EVRI-2001-00030), coordinator.
Eck, T. van, EC-project MEREDIAN (EVRI-2000-40007), coordinator.
Eck, T. van, FDSN Working group 3, Seismological software, member.
Eck, T. van, Observatories and Research Facilities for European Seismology (ORFEUS), secretary-general.
Eck, T. van, ORFEUS Working group 1, Station siting, secretary.
Eck, T. van, ORFEUS Working group 2, Technical assistance, secretary.
Eck, T. van, ORFEUS Working group 3, Mobile equipment, secretary.
Eck, T. van, ORFEUS Working group 4, Seismological software, secretary.
Eck, T. van, Technisch Platform Aardbevingen, member.
Haak, H.W., beoordelingscommissie ALW-1, Diepe Ondergrond, member.
Haak, H.W., International Association of Seismology and Physics of the Earth's Interior (IASPEI), member.
Haak, H.W., ORFEUS Board of Directors, member.
Haak, H.W., Technische Commissie Bodembeweging (Tcbb), member.
Haak, H.W., WG B of the CTBT, member.
Sleeman, R., European Seismological Commission (ESC), titular member.
Sleeman, R., European-Mediterranean Seismological Centre (EMSC), Dutch representative.
Sleeman, R., ORFEUS Working group 4, Seismological software, member.

Policy related and other Staff activities

Climate change is subject of both national and international political debate and draws much attention of the general public. The Climate-Policy Support Unit of the Department is involved in this by advising the national policymakers, by acting as national focal point for IPCC and GCOS, and through various outreach activities.

Framework Convention on Climate Change (FCCC)
The Climate-Policy Support Unit provides scientific support to the Netherlands Delegations to the bodies of the FCCC. In 2001 the Unit participated in the negotiations on GCOS-matters during CoP7 in Marrakech, and coordinated the detailed national GCOS-report that is part of the third Netherlands' National Communication on Climate Change Policies, published by the Ministry of Spatial Planning, Housing and the Environment.

Intergovernmental Panel on Climate Change (IPCC)
The Head of the Department is the Netherlands' Principal Delegate to the IPCC. Dr. A.P. van Ulden is the Netherlands' focal point for IPCC Working Group I. The publication of IPCC's Third Assessment Report (TAR) (early 2001, three volumes) was a milestone. TAR provides the scientific basis for climate policymaking until 2007. The Unit coordinated the national government review of all three volumes and represented the Netherlands in the acceptance of the Working Group I report (the Scientific Basis) in Shanghai. Subsequently many activities were undertaken (interviews, articles, symposia, brochures) so as to communicate the TAR's content to both the general public and professionals (e.g. politicians, civil servants, water management, journalists, representatives on Non-Governmental Organisations (NGOs)). These activities included two symposia for experts in water management, a symposium for media meteorologists and a symposium for policymakers, journalists and NGOs. A very successful abstract of the TAR was prepared for water professionals.

Climate monitoring and the Global Climate Observing System (GCOS)
In order to understand the mechanisms behind climate change long-term datasets of many parameters of the global climate system are essential. In addition to weather related parameters, data are needed of the atmospheric composition, oceans, land surface and vegetation, snow and ice, and of the biomass. This is a worldwide activity covering a variety of disciplines, where coordination is essential. Addressing the Netherlands' society, an informative website with various links was created on the organisation and methods of climate monitoring (Http://www.knmi.nl, onderzoek, monitoren van klimaatveranderingen; in Dutch). To further stimulate the co-operation between Institutions of various disciplines that contribute to climate monitoring a National Climate Monitoring Platform was initiated in co-operation with NWO/ALW. A first meeting, bringing together Alterra, ECN, NIOZ, NIVR, RIKZ, RIVM, RIZA, SRON and TUD is foreseen for early 2003. At a SBSTA/GCOS meeting in Offenbach (Germany) in 2002 contributions were made to discussions on the further development of GCOS, on ways to reverse the decline of global monitoring networks, on plans for a Regional GCOS Workshop in Eastern Europe, and on enhancing the co-operation between national GCOS focal points in Europe.

Netherlands Centre for Climate Research (CKO)
The CKO is a collaboration between RIVM, IMAU

and KNMI. It aims at achieving a coherent climate research programme by tuning the individual programmes and by undertaking joint activities. The Unit acts as CKO secretariat. CKO-activities include science projects, meetings, model support and the promotion of free exchange of scientific data. In 2002 an annual report was written for 2001. The CKO has been evaluated in 2001. The main conclusion was that CKO achieves its goals satisfactory within the limits set by the budget.

Public information

An important task of KNMI is to provide reliable information on the climate issue to the Netherlands' society. KNMI researchers frequently appear in the media. The Unit coordinates these activities. In 2002 a KNMI Communication Plan on Climate and Climate Change was developed. We aim at getting across our message concerning 1) physical aspects of the climate system, 2) the scientific basis of climate policy, 3) climate monitoring, 4) specific aspects of climate change in the Netherlands and 5) the way KNMI scientists contribute to all of this. To this end a wide range of activities were undertaken.

Publications are listed by Division. A paper with authors from different Divisions will be listed more than once in this Report.

Scientific publications and reports

2001

Baede, A.P.M. (Ed.), 2001. *Appendix 1: Glossary.* In: Climate Change 2001: The Scientific Basis, IPCC Third Assessment Report, J.T. Houghton et al. (Eds.), Cambridge University Press, 787–798.

Baede, A.P.M., E. Ahlonsou, Y. Ding and D. Schimel, 2001. *The Climate System: an Overview.* In: Climate Change 2001: The Scientific Basis, IPCC Third Assessment Report, J.T. Houghton et al. (Eds.), Cambridge University Press, 85–98.

IGBP/WCRP Committee (including G.J. Komen), 2001. *Global change research in The Netherlands.* Dutch research within the framework of the IGBP and the WCRP. A. de Gier and L. Groen, KNAW (Eds.).

Komen, G.J., 2001. *Lente in de broeikas.* Oration, University of Utrecht.

Monna, W.A.A. (Ed.), 2001. *KNMI Climate Research and Seismology Department Biennial Scientific Report 1999–2000.* KNMI, De Bilt, the Netherlands.

Monna, W.A.A. and J. Verbeek, 2001. *Global Climate Observing System, Detailed Netherlands national report on global climate observation systems.* In: Third Netherlands' national communication on climate change policies, Ministry of Housing, Spatial Planning and the Environment, The Hague, the Netherlands.

Verbeek, J., 2001. *Samenvatting klimaatrapport voor het Nederlandse waterbeheer.* Het Waterschap, December 2001.

2002

Baede, A.P.M. and R. Guicherit, 2002. *Short-lived atmospheric species and their impact on climate.* ArenA, **8**, 41–43.

Ham, J. van, A.P.M. Baede, R. Guicherit and J.G.F.M. Williams-Jacobse (Eds.), 2002. *Non-CO_2 Greenhouse Gases: scientific understanding, control options and policy aspects.* Millpress- Rotterdam, ISBN: 90 77017 70 4.

Komen, G.J., 2002. *Forecasting wind-driven ocean waves.* In: Ocean Forecasting, Conceptual Basis and Applications, N. Pinardi and J. Wood (Eds.), Springer, 267–280.

Solas Scientific Steering Committee (including Komen, G.J.), 2002. *Surface Ocean-Lower Atmosphere Study (SOLAS).* Science Plan.

Verbeek, J., 2002. *Jaarverslag Centrum voor Klimaatonderzoek 2001.*

Number of national presentations

2001: 16

2002: 15

Number of international presentations

2001: 2

2002: 2

Interviews and contacts with media

2001: 128

2002: 101

Advice, collective effort of the whole Department

At numerous occasions specific advice was given on climate and seismology related issues.

Education and organisation of workshops

2001

Baede, A.P.M., Open Science Conference, Session on Science and the Policy Process: IPCC and beyond, Amsterdam, the Netherlands, 10–13 July, convenor.

Komen, G.J., Climate modelling in Europe (COACh/PRISM Summer school), Les Diablerets, Switzerland, 25–29 June, organiser.

Komen, G.J., professor of Climate Dynamics, University of Utrecht.

Komen, G.J., Watersymposium RIKZ and WL, Den Haag, the Netherlands, 25 September, organiser.

Verbeek, J., 2001, National Symposium IPCC's Third Assessment Report, Amsterdam, organiser

2002

Komen, G.J., professor of Climate Dynamics, University of Utrecht.

Komen, G.J. and J. Verbeek, Symposium Weer en Water in de 21ste eeuw: Omgaan met scenario's, Den Haag, the Netherlands, 21 November, organisers.

Monna, W.A.A., Workshop on COST Action 720, Integrated ground-based remote sensing stations for atmospheric profiling, L'Aquila, Italy, 18–21 June, co-organiser.

Verbeek, J., Klimaatpanel NOVEM Vijfde Energy Awardsdag, Nijmegen, the Netherlands, 9 December, organiser, chairman.

Verbeek, J., Landelijk Seminar Klimaatverandering voor Beroepsmeteorologen, De Bilt, the Netherlands, 17 December, organiser, chairman.

Verbeek, J., Wetenschapsdag KNMI, De Bilt, the Netherlands, 20 Oktober, organiser.

Verbeek, J., Workshop Een strategie voor het IPCC, Utrecht, the Netherlands, 23 May, organiser.

Verbeek, J., Workshop Klimaatportaal NOVEM Vijfde Energy Awardsdag, Nijmegen, 9 December, organiser and chairman.

Committees

Baede, A.P.M., Bestuur COACh, member.

Baede, A.P.M., Bestuur Sectie Lucht, Vereniging voor Milieukundigen VVM, member.

Baede, A.P.M., Bestuur Stichting Ruimte Onderzoek Nederland (SRON), chairman.

Baede, A.P.M., Externe Beoordelingscommissie Milieuonderzoek (ECN), member.

Baede, A.P.M., GCOS Atmospheric Observations Panel, member.

Baede, A.P.M., Interdepartementale Begeleidingsgroep OMI (BOMI), KNMI representative.

Baede, A.P.M., Interdepartementale Coördinatiegroep IPCC, chairman.

Baede, A.P.M., Intergovernmental Panel on Climate Change (IPCC), Netherlands representative.

Baede, A.P.M., Platform Ruimtevaart NIVR, member.

Baede, A.P.M., Raad voor de Raad voor Aarde en Klimaat (RAK) van de KNAW, member.

Baede, A.P.M., Steering Group Ozone SAF EUMETSAT, member.

Baede, A.P.M., Stuurgroep Nationaal Onderzoeksprogramma Klimaatverandering (NOP), member.

Baede, A.P.M., WMO Commission on Atmospheric Sciences, member.

Komen, G.J., Advisory Board National Geographic Magazine Netherlands and Belgium, member.

Komen, G.J., Bestuur COACh, member.

Komen, G.J., CKO Programme Board, chairman.

Komen, G.J., European Network for Earth System Modelling (ENES), co-coordinator.

Komen, G.J., IGBP/SOLAS, member Scientific Steering Group.

Komen, G.J., Intergovernmental Panel on Climate Change (IPCC), Netherlands representative.

Komen, G.J., Journal of Physical Oceanography, associate editor.

Komen, G.J., KNAW IGBP/WCRP committee, member, vice chairman.

Komen, G.J., Nederlands Vervolgprogramma Klimaat Onderzoek (NVKO), co-chairman programme board.

Komen, G.J., NWO/ALW CLIVARNET committee, chairman.
Komen, G.J., Scientific Board SRON, member.
Monna, W.A.A., COST-720, chairman.
Monna, W.A.A., Netherlands Delegation CoP7, member.
Monna, W.A.A., GCOS, Netherlands national focal point.
Monna, W.A.A., Guest Editor EGS Physics and Chemistry of the Earth, 26, 3, B (Special Issue).
Monna, W.A.A., Guest Editor Meteorologische Zeitschrift, 10, 6 (Special Issue).
Monna, W.A.A., National Preperation Commitee World Radiocommunication Conference 2003, member.
Monna, W.A.A., VROM/TKP, member.
Monna, W.A.A., WMO/CBS Steering Group on Radio Frequency Co-ordination, member.

Model support

KNMI is participating 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 coordination and co-operation between the national institutes involved in the field of climate research. Climate models are important tools in this research but they are difficult to use and maintain for individual researchers or groups because of their complexity. Therefore, a CKO model support group was established in April 1999.

The group ports the models to and tests them on the computing platforms that are used in the CKO and makes them available to scientists in the form of 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, such as visualisation tools, 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.

Six models are currently supported: the global atmosphere model ECHAM4, the regional atmosphere model RACMO, the chemistry-transport model TM, the global ocean model OPA 8.1, the regional ocean model MICOM 2.7 and the coupled atmosphere-ocean model ECBILT.

There is a close cooperation with the European PRISM project. In PRISM a European model infrastructure for earth-system modelling is developed. Apart from contributing earth subsystem models KNMI contributes to developing diagnostic and visualisation tools for the PRISM model, and to the demonstration runs.

Results

Work in the model support group consisted of the following activities:

First, maintenance of the CKO web site (http://www.knmi.nl/onderzk/CKO) that provides information about and easy access to the supported models and data analysis tools. This site also provides links to important external web sites with climate data and analysis tools.
Second, the maintenance, porting and testing of the supported models on all computing platforms used in the CKO. Linux and SUN Solaris were added as supported computing platforms. In 2002 the support was extended with two models: the regional atmospheric climate model RACMO and the chemistry-transport model TM.

Third, maintaining a standard software infrastructure for the analysis of climate and model data consisting of a standard data format and related software libraries and (visualisation) tools. An easy-to-use coupler for coupled model experiments and an editor for NetCDF files were developed.

Description of models

ECHAM4
The global atmospheric climate model ECHAM4 is available at several horizontal resolutions and with different vertical levels. The model runs on single processor computers and parallel computers, in free running mode as well as in nudged mode. For the latter a database with ECMWF analyses is available. The model is used to do simulations of up to about 30 years as well as case studies for specific periods of weeks to a few months.

RACMO
The regional atmospheric climate model RACMO can be run both in a weather forecast mode and in a climate mode. RACMO is used both for validation of parameterisations against observations and for regional climate studies. Adjustments to the model have been made to improve the roughness length calculations. Software was developed to create a dataset that will be used for relaxation of model variables at the lateral boundaries.

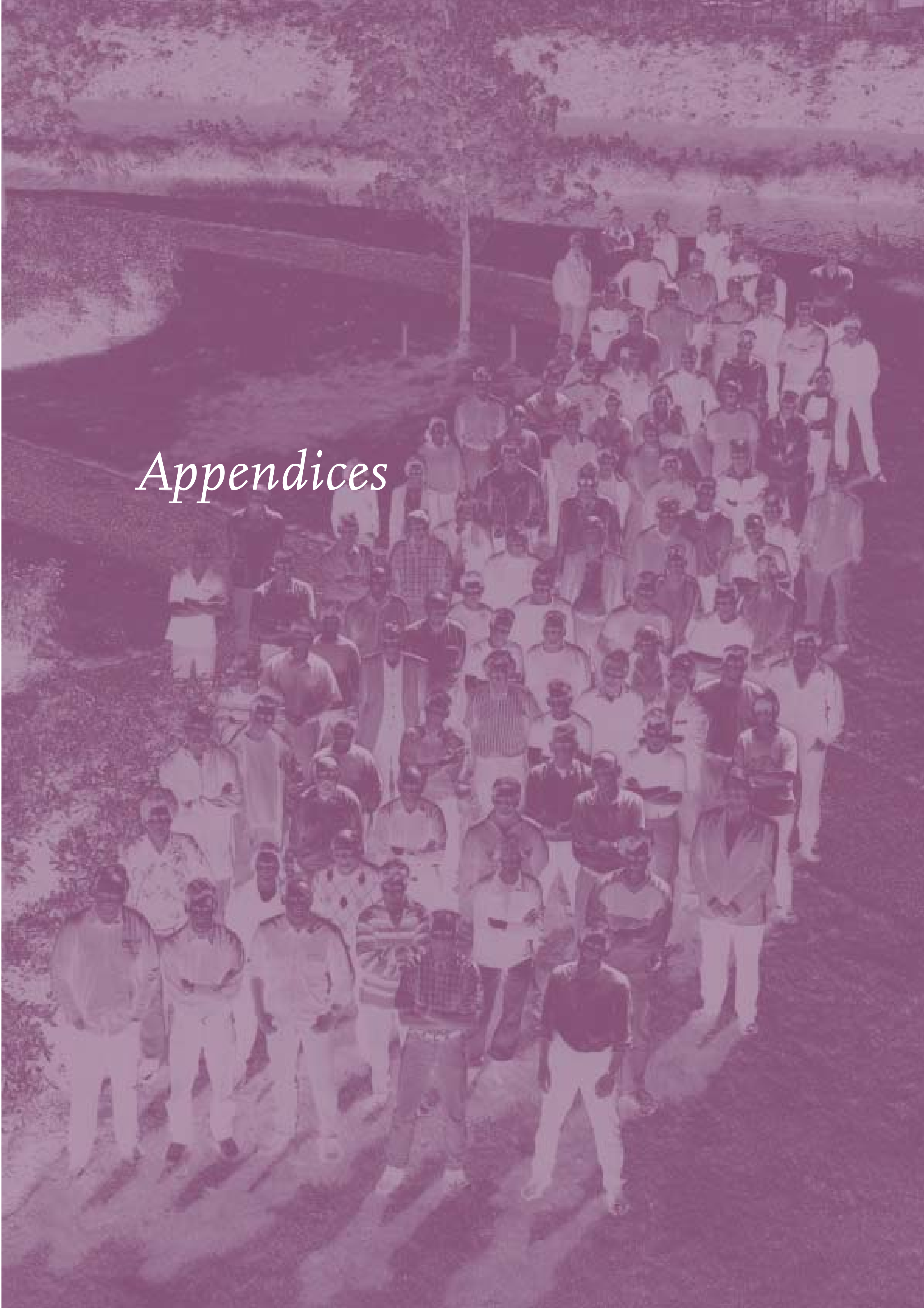
TM
The chemistry-transport model TM is used for long-term simulations of up to about 40 years as well as process studies. The model is developed further in co-operation with IMAU, JRC (Joint Research Centre) and others. Meteorological (re-)analysis data is required to drive the model. Presently a database with global data is constructed using both the 40 year reanalysis (ERA40) and operational data of ECMWF.

OPA
OPA (Océan PArallélisé) is an Ocean General Circulation Model (OGCM) that 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 either a resolution of about four or two degrees in longitude and latitude and 31 layers. The OPA model was ported to the new computing platforms Linux and SUN Solaris.

MICOM
The Miami Isopycnic Coordinate Ocean Model (MICOM) is a regional isopycnic ocean model that aims at simulating thermodynamically and mechanically driven flows in realistic basins. Version 2.7 of this model with CKO specific extensions is available for single processor and vector processor computers. Functionality has been added to perform hindcast runs, to couple to atmospheric models and for process studies.

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. The version 3 of the ECBILT model coupled to the CLIO global ocean model was made available.

Appendices



Appendices

Externally funded projects

Variability Research

National / International	Project Title	Begin–End	Participants	Funded by
National	ECBILT - Image-Defining Interactions and Feedbacks between Land Cover and Climate to Apply in an Integrated Assesment Model	1999–2002	Schaeffer	RIVM
National	LANDGEBRUIK - Interactions between land use, atmospheric concentration of greenhouse gases and climate in Western Europe and their consequences for post-Kyoto options	1999–2003	Haarsma, *Ronda*, Selten, *De Vries*, Weber	NOP
National	SEALEVEL CLIMATE VAR. - Ocean-climate varibility and sea level in the North Atlantic region since AD 0	1999–2001	Drijfhout, *Schrier*, Weber	NOP
International	SINTEX - Scale Interactions Experiments	1998–2001	Haarsma, *Timmermann*	EU

Oceanographic Research

National / International	Project Title	Begin–End	Participants	Funded by
National	ENSO-FORECASTING - The impact of variational assimilation of altimetry data on ocean analysis and ENSO forecasting	2000–2003	*Appeldoorn*, Burgers, Van Oldenborgh	SRON
National	ENSO-PACIFIC - Analysis of ENSO-related variability in the equatorial Pacific in the 90's	2000–2004	Burgers, Van Oldenborgh, *Zelle*	NWO
National	MARE - Mixing of Agulhas Rings Experiment	2000–2004	*Donners*, Drijfhout	NWO
International	A new generation ocean wave statistics and wave based sea-air interaction	2002–2005	Sterl	INTAS
International	ENACT - Enhanced Ocean Data Assimilation and Climate Prediction	2002–2004	Burgers, *Leeuwenburgh*, Van Oldenborgh	EU
International	ERA-40 - A Forty-Year European Re-Analysis of the Global Atmosphere	2000–2003	Burgers, *Caires*, Komen, Sterl	EU
International	TRACMASS - Tracing the Water Masses of the North Atlantic and the Mediterranean	1998–2001	Drijfhout, *De Vries*	EU

Staff members with names in italics are financed (wholly or partly) by the funding organisation. The abbreviation of a Division between parentheses refers to the Divion in which the Staff member is usually employed. The full names of the funding organisations can be found in the list of acronyms.

Atmospheric Composition Research

National / International	Project Title	Begin–End	Participants	Funded by
National	AIRCRAFT CRUISE - Summary of Impacts of Aviation Emissions on the Environment	2001–2002	*Henzing*, Van Velthoven	NLR
National	ALW OZONE CLIMATE - Modelling of Interactions between climate change and stratospheric ozone depletion	2002–2003	*Bregman*, Van Velthoven	NWO
National	ARIA-Phase I - Aerosol Retrieval and Assimilation	2001–2002	*Henzing*, Van Velthoven, Verver	NIVR
National	DROP - Data Assimilation of Radiances for Ozone Profile Estimation	2001–2003	*Eskes, Van Oss, Van Soest*	SRON
National	MEGGY - Monitoring Emissions of Greenhouse Gases using SCIAMACHY	1999–2001	Van Velthoven, *Van Weele*	BCRS
National	NOX - Improving model simulations of tropospheric nitrogen oxides and ozone	2001–2005	Kelder, *Olivié*, Van Velthoven	NWO
National	NRT-studie"OMI follow on 2002" - Ozone Monitoring Instument follow on 2002	2002–2003	Kelder, Levelt, *Veefkind, Goede*	NIVR/Dutch Space
National	OMI - Ozone Monitoring Instrument	1998–2008	*Acarreta, Boersma, Brinksma, Claas, Van Dijk, Dirksen, Dobber, Duurland (Financ. Dept.), Van Geffen, De Haan*, Kelder, Levelt, *Noordhoek*, Van den Oord, *Van Oss, Rivas*, Som De Cerff (Obs. & Mod. Dept.), *Veefkind*, Van de Vegte (Obs. & Mod. Dept.), *Ten Voorde, Voors*	EZ/V&W
National	OMI grondsegment - Ozone Monitoring Instument grondsegment	2002–2008	*Claas, Dirksen, Dobber*, Levelt, Van den Oord, Som De Cerff (Obs. & Mod. Dept.), *Veefkind*, Van de Vegte (Obs. & Mod. Dept.)	EZ/V&W
National	RADCHIS - Research on Atmospheric Dynamics and Chemistry in Surinam	1998–2002	Allaart, *Fortuin*	NWO
National	SASCIA - Studies of Assimilated Sciamachy data	2001–2004	*Segers*, Van Velthoven	SRON
National	SCIA-CO-PI - SCIAMACHY Science Plan - Support SCIA CO-PI	2002–2003	*Goede*	SRON
National	SCIADA-2 - SCIAMACHY Data Assimilation 2	2001–2002	*Eskes, Meirink*, Van Velthoven	NIVR
National	SCIAMACHY Validation Meteorological Products	2000–2003	*Piters, Timmermans*	NIVR
National	SCIAMACHY Validation Ozone Columns and Profiles	2002–2004	*Brinksma, Piters*	NIVR
National	SCIAMACHY Validation Ozone Models	1999–2004	*Eskes, Meirink, Piters*	NIVR
National	SCIAMACHY Validation Scientific Support	2000–2005	*Piters, Timmermans*	NIVR
National	SCIAMACHY Validation UV Products	2000–2002	*Piters, Van Weele*	NIVR
National	SCIARALI - Sciamachy Retrieval	2000–2001	*Van Gent, Van Oss*	SRON
National	SCIARALI-PHASE II - Development of a radiative transfer model for SCIAMACHY limb measurements-Phase II	2001–2003	*Van Gent, Van Oss*	SRON
National	SCIAVALIS - Sciamachy Interpretation and Validation Support	1997–2001	*Piters*	SRON
International	CARIBIC 3 - Civil Aircraft for Regular Investigation of the Atmosphere Base on an Instrument Container	2002–2005	*Henzing, Meijer*, Van Velthoven	EU
International	Development of algorithms for retrieval of Gome total ozone column	2002–2003	*Van Oss, Valks*	ESA
International	EDUCE - European database for Ultraviolet Radiation Climatology and Evaluation	2000–2003	*Van Weele*	EU
International	ENVISAT Atmospheric Toolbox	2002–2003	*Van der A, Van Geffen, Van Oss*	ESA
International	GOA - GOME Assimilated and Validated Ozone and Nitrogen Dioxide Fields for Scientific Users and for Model Validation	2001–2003	*Boersma, El-Serafy, Eskes*, Kelder, *Meirink, Segers*	EU
International	GOFAP - Development of GOME Ozone Fast Delivery and Value Added Products	1997–2001	*Van der A, Van Geffen, Valks*	ESA
International	OZONSAF - Satellite Application Facility for ozone data	1997–2002	*Van Oss, Valks*	EUMETSAT
International	PRISM - Programme for Integrated Earth System Modelling	2001–2004	Burgers (Ocea. Res), *Cuijpers*, Kelder, Komen (Ocea. Res), *De Martino, Severijns (Ocea. Res)*, Siegmund, Van Velthoven	EU
International	SAMMOA - Spring-to-Autumn Measurements and Modelling of Ozone and Active species	2000–2002	*Van der A, El-Serafy*	EU
International	SCAVEX - Schneefernerhaus Aerosol and Reactive Nitrogen Experiment	2001–2003	*Henzing, Meloen, Meijer*, Van Velthoven	DLR

Atmospheric Composition Research

National / International	Project Title	Begin–End	Participants	Funded by
International	STACCATO - Influence of Stratosphere-Troposphere Exchange in a Changing Climate on Atmospheric Transport and Oxidation Capacity	2000–2002	*Meloen*, Siegmund, Van Velthoven	EU
International	TEMIS 1 - Tropospheric Emission Monitoring Internet Service	2001–2002	*Van der A, Valks*	ESA
International	TEMIS 2 - Tropospheric Emission Monitoring Internet Service	2002–2004	*Van der A, Van Geffen*	ESA
International	TRADEOFF - Aircraft emissions: contribution of different climate components to changes in radiative forcing-trade-off to reduce atmospheric impact	2000–2003	Kelder, *Meijer*, Van Velthoven	EU

Atmospheric Research

National / International	Project Title	Begin–End	Participants	Funded by
National	CARIS - Cloud Absorption Retrieval from the near IR-channels of SCIAMACHY	1998–2001	*Knap*, Stammes	SRON
National	CLOSAER - The effects of aerosol on closure of the regional short-wave radiation balance	1999–2001	*Henzing, Knap*, Stammes	NOP
National	Customizing and improving MSG cloud products	2001–2001	Feijt, *Jolivet, Roebeling*	BCRS
National	Database of ECMWF Analysis world grid in application ready format	2002–2003	*Van den Hurk*	ESA
National	ENVISAT Land Surface Processes Phase 2	2001–2002	*Van den Hurk*	NIVR
National	ERM-SYNERGY - Sensor Synergy Study for the Earth Radiation Mission	1998–2001	*Bloemink*, Van Lammeren	SRON
National	PICASSO-CENA - Sensor Synergy Algorithms for CloudSat and PICASSO-CENA	2002–2005	*Donovan, van Zadelhoff*	SRON
National	Representation of the seasonal Hydrological Cycle in Climate and weather prediction Models in West Europe	1997–2001	*Van den Hurk*, Van Meijgaard	NOP
National	SCIA-CIRRUS - Retrieval of ice and water cloud properties from SCIAMACHY's near-IR channels	2001–2004	*Acarreta, Knap*, Stammes	SRON
National	SCIAMACHY Core Validation of Radiances and Clouds	1999–2004	*Koelemeijer*, Stammes	NIVR
National	SCIAPOL - SCIAMACHY Polarisation-correction and validation	1998–2001	*Schutgens*, Stammes	SRON
National	SCIA-POLARISATION - Validation and interpretation of SCIAMACHY's polarisation measurements	2001–2004	Stammes, *Tilstra*	SRON
National	ZON & KLIMAAT - Research on a michanism by which enhanced UV-radiation of the active sun affects weather and climate	1999–2001	Van Dorland, *Tourpali*	NOP
International	AUTOFLUX - An Autonomous system for monitoring air-sea Fluxes using the inertial dissipation method and ship mounted instrumentation	1998–2001	Koshiek	EU
International	CLARA AND ERM - Development of multi-sensor cloud remote sensing techniques in support of upcoming and proposed satellite missions	1998–2003	Boers, *Donovan*, Van Lammeren, *Schutgens*, Van Ulden	ESA
International	CLIWA-NET - BALTEX 2000-Cloud Liquid Water Network	2000–2003	*Bloemink, Deneke, Dlhopolsky*, Feijt, Hovius, *Jolivet*, Van Lammeren, *Mathieu*, Van Meijgaard, *Roebeling*	EU
International	CLOUD-NET - Development of European Pilot Network of Situations for Observing Cloud Profiles	2001–2005	*Deneke, Donovan*, Klein-Baltink, Van Lammeren	EU
International	CM-SAF - Satellite Application Facility on Climate Monitoring	1999–2003	*Dlhopolsky*, Feijt, *Roebeling*	EUMETSAT
International	CONCEPTS...IMAGER - Concepts for Future Visible and Infrared Imager	2001–2002	*Dlhopolsky*, Feijt	ASTRIUM
International	DAASCEES/SPECTRA - Data Assimilation and Scaling for the Earth Explorer Core Candidate Mission SPECTRA	2001–2002	*Van den Hurk*	ESA
International	ELDAS - Development of a European Land Data Assimilation System to predict	2001–2004	Bosveld, Feijt, *Van den Hurk*, Van Meijgaard	EU
International	EUROCS - European Project on Cloud Systems in Climate Models	2000–2003	*Lenderink*, Van Meijgaard, *Neggers*, Siebesma, Van Ulden	EU
International	RAMV - Study on Representative heights for Atmospheric Motion Vectors.	2001–2002	*Dlhopolsky*, Feijt, *Jolivet,*	EUMETSAT
International	SMOS - Soil Moisture Retrieval by a Future Space-borne Earth Observation Mission	2000–2003	*Van den Hurk*	ESA
International	Validation of SCIAMACHY aerosol data products	2001–2003	*De Graaf*, Stammes	NIVR

Climate Analysis

National / International	Project Title	Begin–End	Participants	Funded by
National	Development rainfall generator Meuse basin	1999–2002	Beersma, Buishand, *Wójcik*	RIZA
National	Development rainfall generator Rhine/Meuse	2002–2002	Beersma, Buishand, *Leander*	RIZA
National	GCM-COMPARISON - Climate projections for Europe; GCM intercomparisons and analysis of the predictability in practical and theoretical sense	2000–2001	*Van den Brink, Doortmont,* Können	NOP
National	IRMA-SPONGE - Integrated water management strategies for the Rhine and Meuse basins in a changing environment	1999–2001	Können	NOP
National	WATEROPZETTEN - The reliability of extreme surge levels, estimated from observational records of order hundred years	2001–2004	*Van den Brink,* Können, Opsteegh	RIKZ
International	CLIWOC - Climatological database for the world's oceans 1750-1850	2000–2003	*Barnhoorn, Boekhorst,* F. Koek (Obs. & Mod. Dept.), *M. Koek,* Können, *Verlinde*	EU
International	ECLAT-2 - European Climate Change Project - Concerted Action Initiative	1998–2001	Beersma	EU
International	SWURVE - Sustainable Water Uncertainty, Risk and Vulnerability in Europe	2000–2003	Buishand, *Shabalova*	EU

Seismology

National / International	Project Title	Begin–End	Participants	Funded by
National	Invloed aardschokken op overstromingsrisico	2002–2002	Van Eck	WL DELFT
National	Pilot experiment tiltmeters	1996–2001	Haak	EZ
National	REVIEW VOOR SHELL - Seismic Hazard Independent Review	2001–2002	Crook, Van Eck	SHELL
National	Sonic Boom Detection Technique	1998–2002	Evers, Haak, Jansen	KLU
National	Workshop Seismology for the Nam	2002–2002	*Calje,* Crook, Van Eck, *Goutbeek*	NAM
International	EARTHQUAKEMON. - Pilot project for regional monitoring and seismic hazard assesment	1995–2001	Dost, *Petit*	EU
International	EMICES - European-Mediterranean Infrastructure Coordination for Earthquake Seismology	2002–2004	Van Eck, *Goutbeek*	EU
International	MEREDIAN - Mediterranean-European Rapid Earthquake Data Information and Archiving Network	2000–2003	Dost, Van Eck, *Goutbeek,* Sleeman, *Trabant*	EU
International	SHIVTA-PSAR - Shivta-Rogem Microseismicity Analysis	2001–2001	Van Eck	IEC
International	To advice the European Commission as an independent expert in evaluating project proposals in the framework of the programme Energy, Environment and Sustainable Development	2001–2001	Van Eck	EU

Model Support

National / International	Project Title	Begin–End	Participants	Funded by
National	Model Support	1999–2003	*Cuijpers (Atmos. Comp. Res),* *Severijns (Ocea. Res),* Van Velthoven (Atmos. Comp. Res)	OC&W

Acronyms

3DVAR	Three Dimensional Variational assimilation scheme
4D-CLOUDS	Four Dimensional clouds
4DVAR	Four Dimensional Variational assimilation scheme
A1FI	Highest IPCC scenario, Third Assessment Report
AAIW	Antarctic Intermediate Water
AATSR	Advanced Along Track Scanning Radiometer
ACE-CHEM	Atmospheric Composition Explorer Mission for Chemistry-climate interactions
AGCM	Atmospheric General Circulation Model
AGU	American Geophysical Union
ARIA	Aerosol Retrieval and Assimilation (BCRS)
ARM	Atmospheric Radiation Measurement
ASGAMAGE	Air Sea GAs exchange / MAGE project
ATBD	Algorithm Theoretical Basis Documents
ATSR	Along Track Scanning Radiometer
AVHRR	Advanced Very High Resolution Radiometer
AWI	Alfred-Wegener Institut
BALTEX	BALtic Sea EXperiment
BBC	BALTEX-BRIDGE Cloud Campaigns
BCRS	Netherlands Remote Sensing Board
BfG	Bundesanstalt für Gewässerkunde, Germany
Bsik	Besluit subsidies investeringen kennisinfrastructuur
BSRN	Baseline Surface Radiation Network
CCD	Convective-Cloud-Differential method
CESAR	Cabauw Experimental Site for Atmospheric Research
CKO	Netherlands Centre for Climate Research
CLIO	Coupled Large-Scale Ice Ocean Model
CLIWA-NET	Cloud Liquid Water Network project
CLIWOC	CLImatological database for the World's OCeans 1750-1850, EU project
CLOSAER	The effect of aerosol on closure of the regional short-wave radiation balance
CM-SAF	Satellite Application Facility on Climate Monitoring
CNNI	CLIWA-NET Network I (August/September 2000)
CNNII	CLIWA-NET Network II (April/May 2001)
CO_2	Carbon dioxide
COADS	Comprehensive Ocean Atmosphere Data Set
COLA	Center for Ocean Land Atmosphere Studies
CoP	Conference of the Parties (of the FCCC)
CTBT	Comprehensive Nuclear-Test-Ban Treaty
DAAC	Distributed Active Archive Center
DBN	KNMI seismic station De Bilt
DIA	Deelen Infrasound Array
DOAS	Differential Optical Absorption Spectroscopy
DWBC	Deep Western Boundary Current
DWD	German Meteorological Office
EarthCARE	Earth Clouds Aerosol Radiation Explorer
EBEX-2000	Energy Budget Experiment 2000
EC	European Community
ECA	European Climate Assessment, ECSN project
ECBILT	KNMI General Circulation Model
ECHAM4	Hamburg version (number 4) of the ECMWF model
ECMWF	European Centre for Medium-range Weather Forecasts
ECN	Netherlands Energy Research Foundation
ECSN	European Climate Support Network
EGS	European Geophysical Society

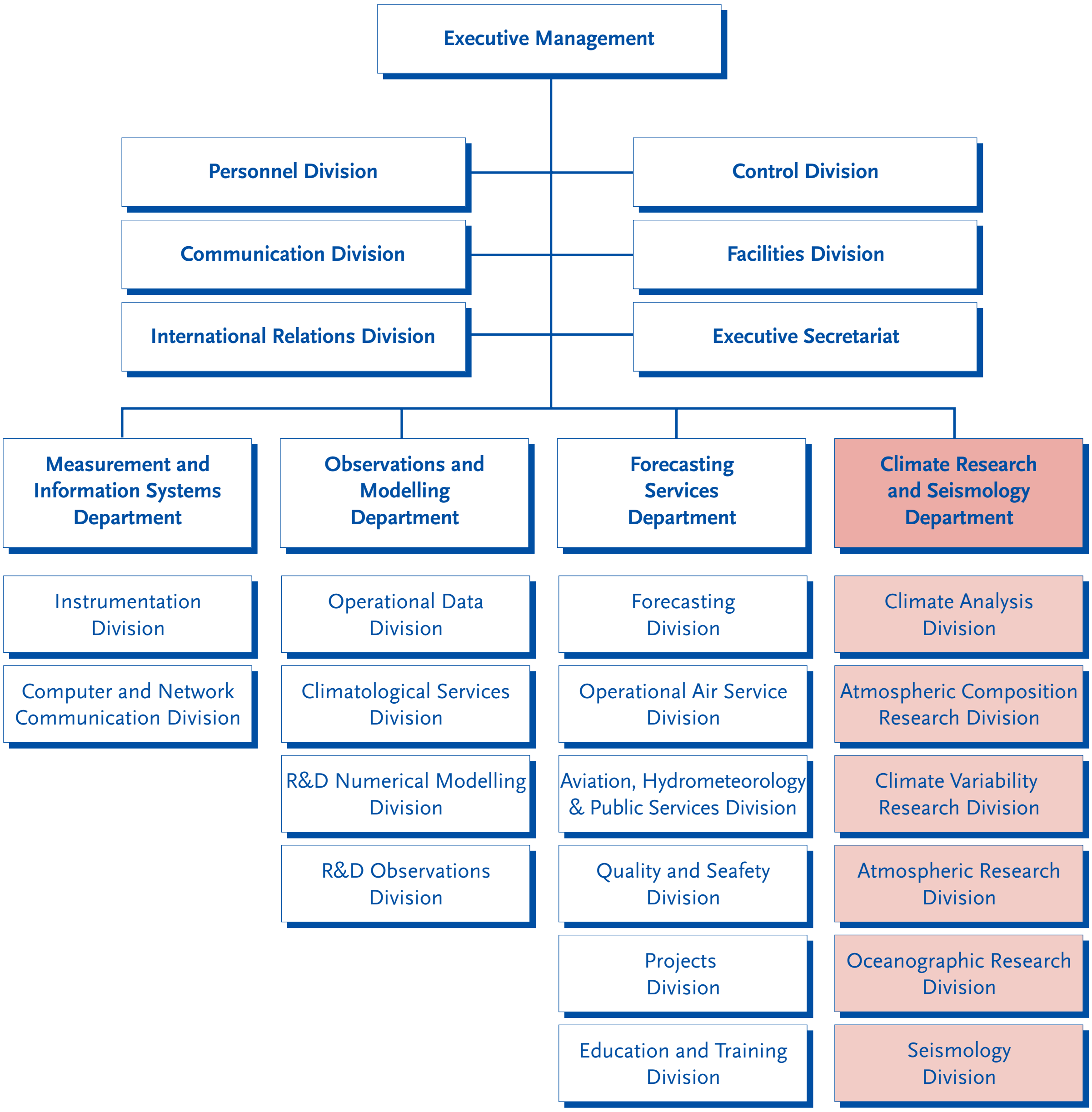
ELDAS	European Land Data Assimilation System
EMICES	European-Mediterranean Infrastructure Coordination for Earthquake Seismology
EMICs	Earth system Models of Intermediate Complexity
EMSC	European-Mediterranean Seismological Centre
ENACT	ENhanced ocean data Assimilation and Climate predicTion
ENSO	El Niño Southern Oscillation
ENVISAT	ENVIronmental SATellite (ESA)
EOF	Empirical Orthogonal Function
EOS	Earth Observing System
EOS Aura	Earth Observing Satellites Aura Mission
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)
ERS-2	European Remote Sensing Satellite - 2 (ESA)
ESA	European Space Agency
ESTEC	European Space Research & Technology Centre
EU	European Union
EUC	Equatorial UnderCurrent
EULINOX	European Lightning NOx Experiment (EU)
EUMETSAT	Satellite Application Facility on Climate Monitoring (CM-SAF)
EUROCS	European Cloud Systems Studies
FCCC	Framework Programme on Climate Change (of the United Nations)
FMI	Finnish Meteorological Institute
FP5-CLOUDNET	EU Framework Programme 5, European network of stations for observing cloud profiles.
FRESCO	Fast Retrieval Scheme for Clouds from the Oxygen A-band
GCM	General Circulation Model
GCOS	Global Climate Observing System
GIN sea	Greenland-Iceland-Norwegian sea
GIS	Geographic-Information System
GKSS	Research Center Geesthacht, Germany
GOA	GOME assimilated and validated ozone and NO2 fields for scientific users and model validation (EU)
GOME	Global Ozone Monitoring Experiment
GOMECAL	GOME Calibration program
GOMOS	Global Ozone Monitoring by Occultation of Stars
GSFC	Goddard Space Flight Center
HadCM3	Hadley Centre Model
HGN	KNMI seismic station Heimansgroeve
HIRLAM	High Resolution Limited Area Model
HISKLIM	Historical Climate, KNMI programme on data rescue, digitising and series homogenisation
HOPE	Hamburg Ocean Primitive Equation model
hPa	hectopascal, or 100 Newton per square meter
ICTP	the Abdus Salam International Centre for Theoretical Physics
ICW	IceWater Content
IMAU	Institute for Marine and Atmospheric research Utrecht
IMS	International Monitoring System
IPCC	Intergovernmental Panel on Climate Change
IS92e	Highest IPCC scenario, Second Assessment Report
ITCZ	InterTropical Convergence Zone
IWV	Integrated Water Vapour
JRC	Joint Research Centre in Ispra, Italy
KLAROS	KNMI Local Implementation of Apollo Retrievals in an Operational System
KNMI	Koninklijk Nederlands Meteorologisch Instituut/Royal Netherlands Meteorological Institute
LDEO	Lamont Doherty Earth Observatory of the Columbia University, USA
LES	Large Eddy Simulation

LGM	Last Glacial Maximum
LIDORT	Linearised Discrete Ordinate Radiative Transfer
LITFASS-1998	Lindenberg Inhomogeneous Terrain Fluxes between Atmosphere and Surface: a long term study
LODYC	Laboratoire d'Océanographie Dynamic et de Climatologie
LWP	Liquid Water Path
MA-ECHAM	Middle-Atmosphere version of ECHAM4
MAGE	MArine Aerosol and Gas Exchange
MARE	Mixing of Agulhas Rings Experiment
MDS	Meteorological Service of Surinam
MEMS	Micro Machined Electromechanical System
MEREDIAN	Mediterranean-European Rapid Earthquake Data Information and Archiving Network
METOP	Meteorological Operational Satellite (EUMETSAT)
MICOM	Miami Isopycnic Coordinate Ocean Model
MIT	Massachusetts Institute Technology, USA
MPN	Research Platform Meetpost Noordwijk, the Netherlands
MRADs	Microwave Radiometer
MSG	METEOSAT Second Generation
NADW	North Atlantic Deep Water
NAM	Nederlandse Aardolie Maatschappij
NASA	National Aeronautics and Space Administration
NASDA	National Space Development Agency of Japan
NBC	North Brazil Current
NCAR	National Center for Atmospheric Research, Boulder Co, USA
NCEP	National Centers for Environmental Prediction
NDC	National Data Centre
NDSC	Network for the Detection of Stratospheric Change
NEC	North Equatorial Current
NGO	Non Governmental Organisation
NH	Northern Hemisphere
NIOZ	Netherlands Institute for Sea Research
NITG	Nederlands Instituut voor Toegepaste Geowetenschappen
NIVR	Netherlands Agency for Aerospace Programmes
NIWI	Netherlands Institute for Scientific Information
NRP	National Research Programme on global air pollution and climate change
NRT	Near Real Time
NSF-USA	National Science Foundation, USA
NWO	Netherlands Organisation for Scientific Research
NWO/ALW	Netherlands Organisation for Scientific Research/Earth and Life Sciences
NWP	Numerical Weather Prediction
O_3-MSAF	Satellite Application Facility on Ozone Monitoring
OCCAM	Ocean Circulation and Climate Advanced Modelling Project
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
ORFEUS	Observatories and Research Facilities for EUropean Seismology
PDF	Probability Density Function
PI	Principal Investigator
PIK	Potsdam Institut für Klimafolgenforschung, Germany
PMIP	Paleo Modelling and Intercomparison Project
PRISM	Program for Integrated Earth System Modelling
QBO	Quasi-Biennal Oscillation
QG	Quasi Geostrophic

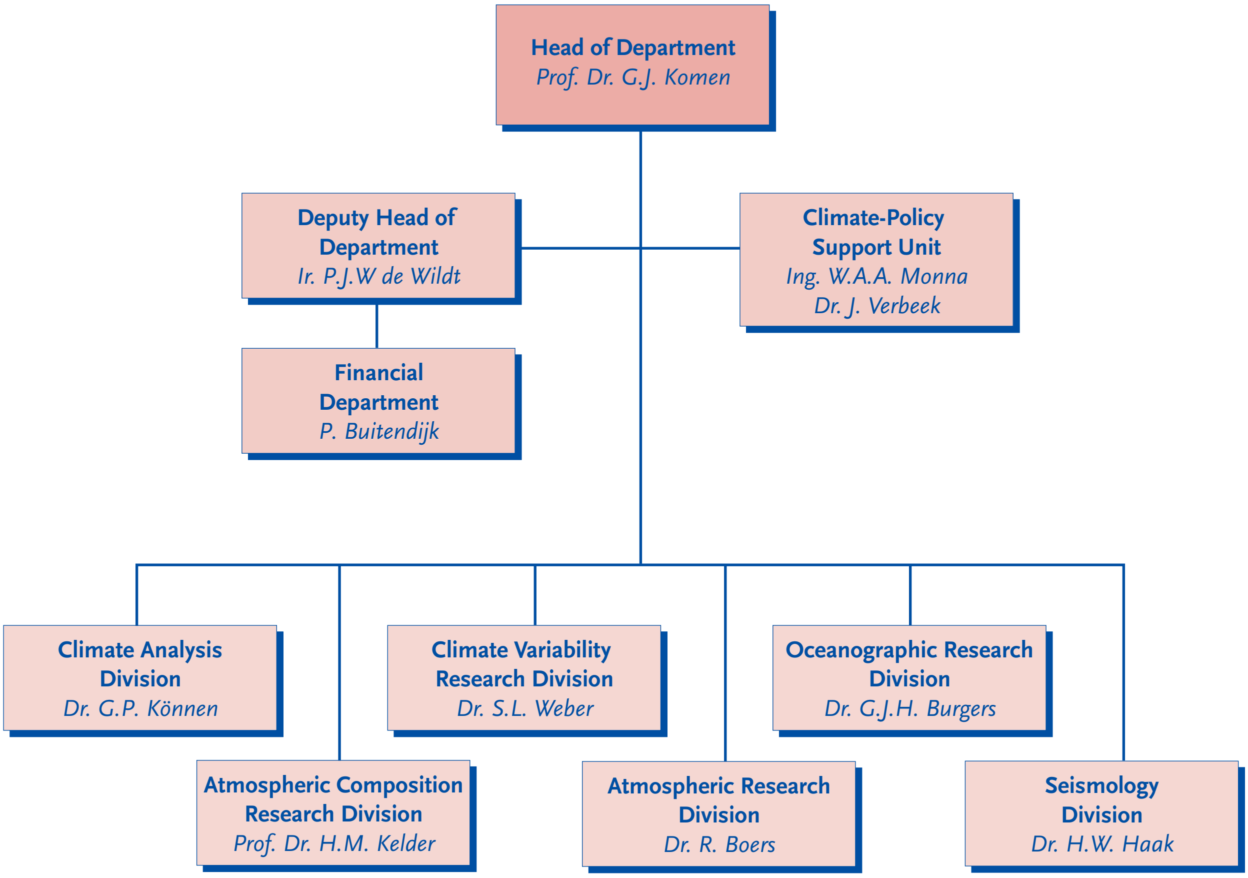
RACMO	Regional Atmospheric Climate Model
RADCHIS	Research on Atmospheric Dynamics and Chemistry in Suriname (NWO)
RAID	Redundant Array of Inexpensive Disks
RDC	KNMI seismic station Rolduc
RECAB	Regional assessment and modelling of the carbon balance in Europe
Reff	effective radius
RegioKlim	Regional Climate Modelling Project
RETRO	Re-analysis of Trends in atmospheric composition (EU)
RIKZ	Institute for Coastal and Marine Management, the Netherlands
RIVM	National Institute of Public Health and the Environment, the Netherlands
RIZA	Netherlands Institute for Inland Water Management and Waste Water Treatment, The Netherlands
RT	Radiative Transfer
SAMMOA	Spring-to-Autumn Measurements and Modelling of Ozone and Active species (EU)
SAMW	Subantarctic Mode Water
SAR	Second Assessment Report
SBSTA	Subsidiary Body for Scientific and Technological Advice (to CoP)
SBUV	Solar Backscatter UltraViolet instrument
SCHN K	NMI seismic station Schinveld
SCIAMACHY	Scanning Imaging Absorption Spectrometer for Atmospheric Cartography
SCIARALI	Radiative model for SCIAMACHY
SeiSComP	Seismological Communication Processor
SEVIRI	Spinning Enhanced Visible and Infrared Imager
SGP	Southern Great Planes
SH	Southern Hemisphere
SHADOZ	Southern Hemisphere ADditional OZonesondes
SOC	Southampton Oceanography Centre
SONEX	Subsonic Ozone and Nitrogen EXperiment (NASA)
SPEEDY	Simplified Parametrization, primitivE Equation DYnamics
SRES	Special Report on Emissions Scenarios
SRON	Space Research Organisation Netherlands
SST	Sea Surface Temperature
STACCATO	influence of Stratosphere Troposphere exchange in A Changing Climate on Atmospheric TransporT and Oxidation capacity (EU)
STE	Stratosphere-Troposphere Exchange
Sv	Sverdrup, or 10^6 m^3 s^{-1}
SWURVE	Sustainable Water: Uncertainties, Risk and Vulnerability in Europe, EU project
TAR	Third Assessment Report (IPCC)
TEMIS	Tropospheric Emission Monitoring Internet Service
Tg	teragram, or 10^9 kg
THC	ThermoHaline Circulation
TM	Chemistry-Transport Model
TNT	Tri-Nitro-Toluene
TOMS	Total Ozone Mapping Spectrometer
TOPOZ	TOwards the Prediction of stratospheric Ozone (EU)
TPA	Technisch Platform Aardbevingen
TRACMASS	Tracing the Water Masses of the North Atlantic and Mediterranean
TRADEOFF	Aircraft emissions: Contribution of different climate components to changes in radiative forcing - Tradeoff to reduce atmospheric impact (EU)
TTOC	Tropical Tropospheric Ozone Column
TUD	Technical University of Delft, the Netherlands
UNEP	United Nations Environmental Programme
UPO	Unstable Periodic Orbit
US	United States of America
USA	United States of America

UTLS	Upper Troposphere and Lower Stratosphere
UV	UltraViolet radiation
VEBSN	Virtual European Broadband Seismograph Network
VFD	Very Fast Delivery
VIS	Visible radiation
VIS/IR	Visible/Infrared
VKB	KNMI seismic station Valkenburg
WB21	Governmental Bill on Water Management 21st century
WIT	KNMI seismic station Witteveen
WMO	World Meteorological Organisation
WOCE	World Ocean Circulation Experiment
WOUDC	World Ozone and Ultraviolet Data Center
WTSB	KNMI-seismic station Winterswijk-B
WUR	Wageningen University and Research Centre

Organisational chart
KNMI
June 2003



Organisational chart
Climate Research and Seismology Department
June 2003



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