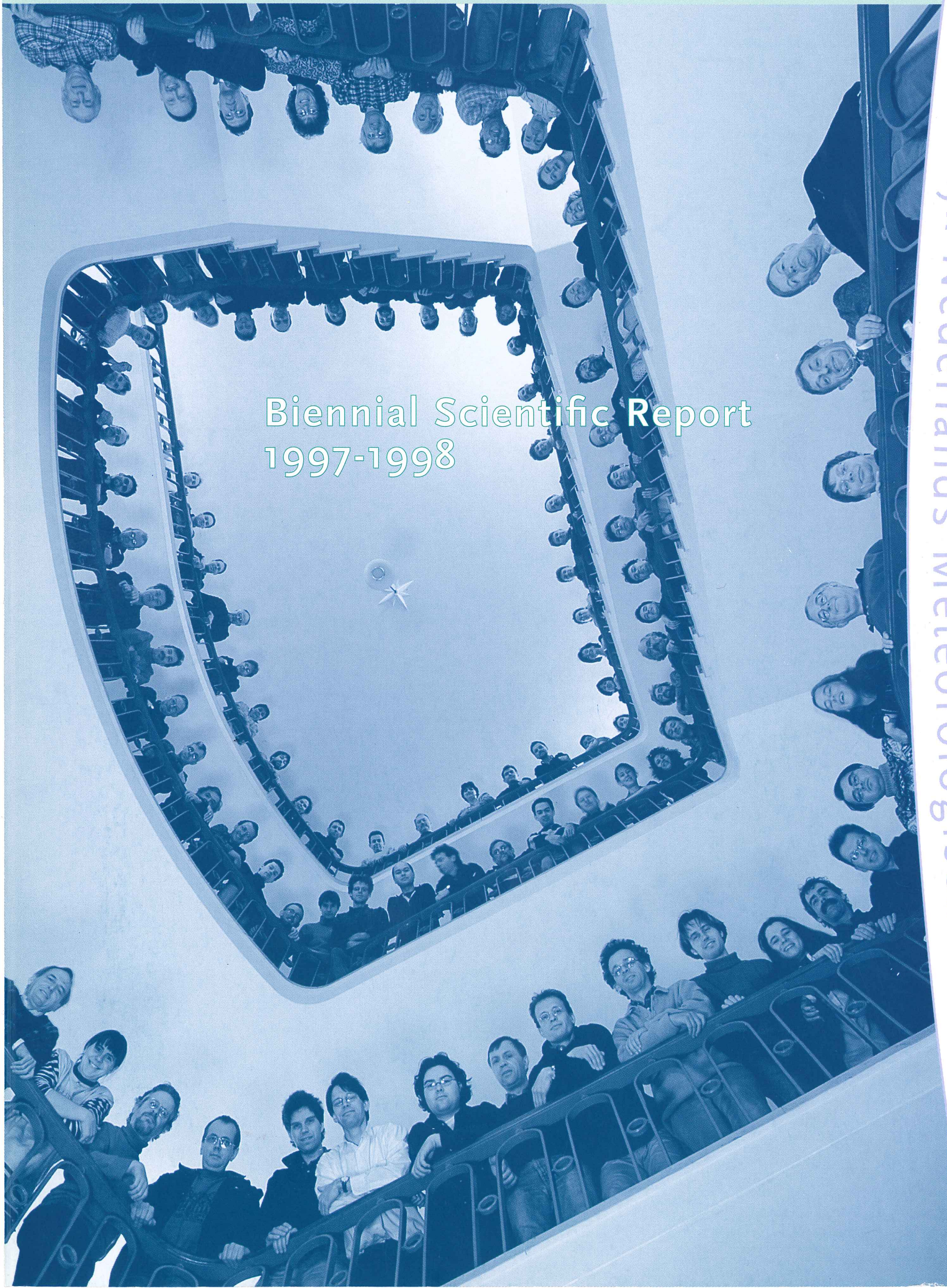
CLIMATE RESEARCH AND SEISMOLOGY DEPARTMENT

KNMI

Biennial Scientific Report 1997-1998



Koninklijk Nederlands Meteorologisch Instituut

CLIMATE RESEARCH AND SEISMOLOGY DEPARTMENT

Biennial Scientific Report 1997-1998

Contents

Preface • From 1999 the Royal Netherlands Meteorological Institute (KNMI) will concentrate entirely on its public tasks: general weather forecasts and warnings, meteorological and seismological infrastructure and research. This new role is a consequence of a Dutch governmental decision: public institutions are to abandon commercial activities. KNMI's role as a centre of knowledge on weather, climate and seismology will thus become more prominent in the future.

This Biennial Scientific Report shows that the Climate Research and Seismology Department is well prepared for this role. The research described covers a wide range of subjects, from the intricate properties of atmosphere-ocean interaction to the details of seismic wave propagation. The numerous collaborative research projects, both nationally and internationally, are evidence that the work is firmly embedded in the scientific community.

The present report, covering the years 1997 and 1998, gives a detailed impression of the Department's latest research activities.

dr. H.M. Fijnaut
Director

Introduction • This second Biennial Scientific Report offers a glimpse of the many and wide-ranging scientific and policy supporting activities of KNMI's Research Department over the past two years.

Three articles highlight very different topics that were of particular interest during the period covered by this Report.

The El Niño of 1997/1998 attracted huge media and scientific attention. El Niño - Southern Oscillation (ENSO) is an area of research with a long tradition at KNMI. It was Berlage who between the thirties and sixties made important contributions to our understanding of the Southern Oscillation. The latest results of our interest in the subject are summarised by Gerrit Burgers and Geert Jan van Oldenborgh.

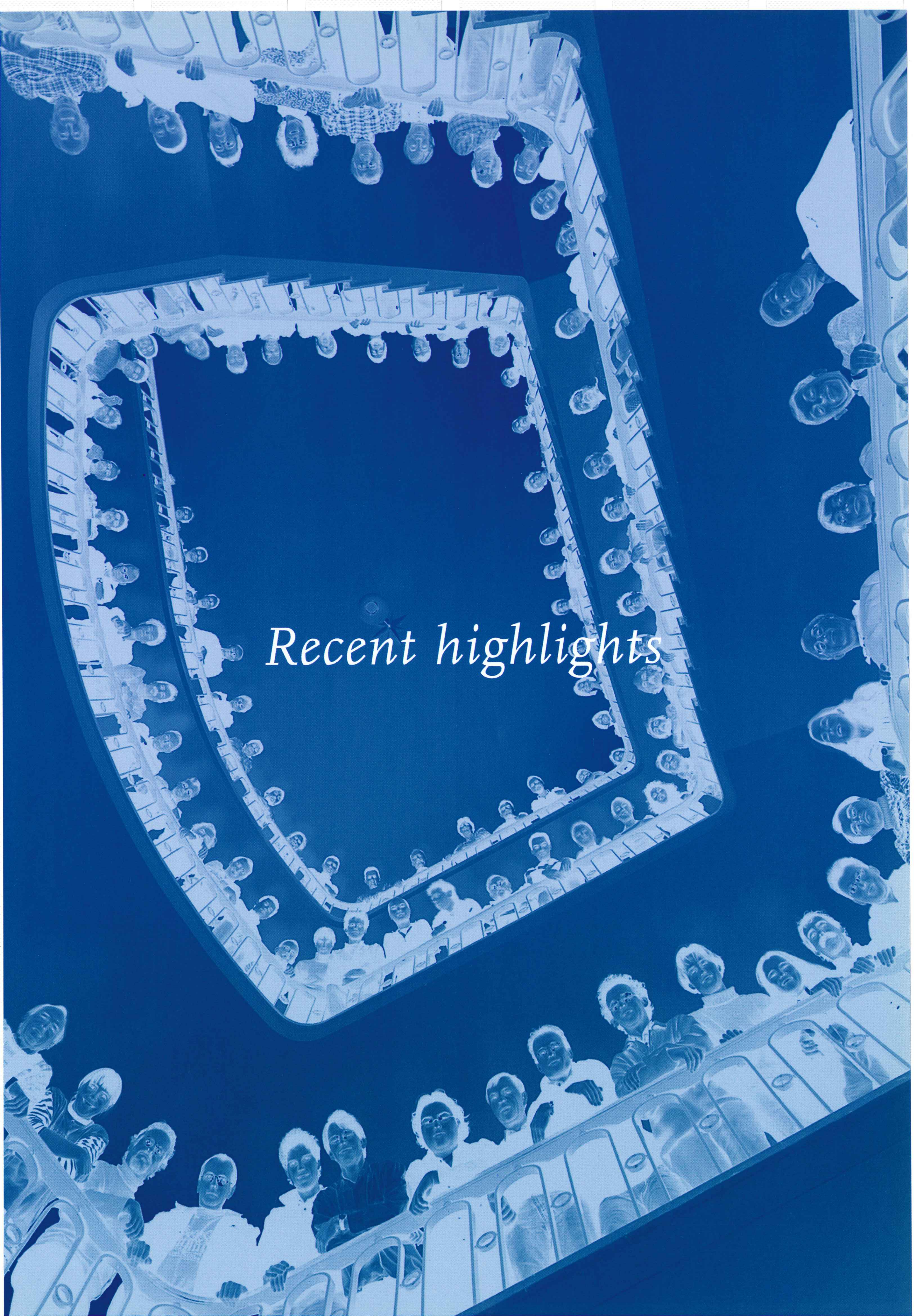
With the increase of air traffic, concern is expressed about the environmental and climate effects of aircraft emissions. Michiel van Weele and his colleagues summarise their contributions to this active area of research and to the Intergovernmental Panel on Climate Change (IPCC) Special Report on this issue.

Our Seismology Division played a leading role in supporting the negotiations that led to the conclusion of the Comprehensive Nuclear-Test-Ban Treaty (CTBT) and continues to be instrumental in implementing a detection and verification regime for that Treaty. Hein Haak, who was a member of the Netherlands Delegation, discusses the geophysical aspects of the Treaty.

The Research Department, as part of KNMI, is financed by the Ministry of Transport, Public Works and Water Management. An important aspect of our task is to give scientific advice and support to the development and implementation of the policy of the Netherlands Government. We supported the work of the Delegations that negotiated the CTBT and the Kyoto Protocol and we advise our Ministers in formulating our Government's climate policy. To carry out these tasks, the Department is first and foremost a *research* department. As such we develop and maintain close links with sister institutions at home and abroad. At home we are part of the Netherlands Centre for Climate Research (CKO), a joint effort with the Institute for Marine and Atmospheric Research (IMAU) of the University of Utrecht and with the National Institute of Public Health and the Environment (RIVM). We offer opportunities to undergraduate and graduate students to carry out their research and to write their theses, in close co-operation with our universities. Abroad we co-operate with many institutions, in particular the Max-Planck-Institutes in Hamburg and Mainz, Germany, in the framework of the International School for Co-operation on Oceanic, Atmospheric and Climate Change studies (COACh). We seek additional financial support for our work from such organisations as the Netherlands Organisation for Scientific Research NWO, the EU Framework Programmes and from specialised government sponsored research programmes. Such support is essential to guarantee an influx of young people with innovative ideas and to guard and improve the quality of our work by competitively submitting our proposals to critical reviews. This Report pays particular attention to these externally funded projects with special thanks to the funding organisations.

Finally, we look forward with confidence to a particularly exciting year, when we will move to our new premises, prepare for the Fifth EU Framework Programme and face a Review of our research by an international Review Board.

dr. A.P.M. Baede
Head Department of Climate Research and Seismology



Recent highlights

The 1997/1998 El Niño

by Gerrit Burgers and Geert Jan van Oldenborgh

The 1997/1998 El Niño: a record event. • El Niño, out of the remote vastness of the tropical Pacific Ocean, connects many seemingly unrelated events all over the world and even makes them predictable to some extent. This has captured the imagination of the public. Seldom has a meteorological phenomenon attracted so much attention as the El Niño of 1997/1998. It has not always been like this. The previous very strong El Niño was in 1982/1983. In September 1982, a group of scientists met in Princeton to discuss the El Niño phenomenon. They were unaware of the fact that one of the strongest El Niño's ever was developing. Only months later, after the peak of the El Niño, people realised something extraordinary had happened. This was completely different during the 1997/1998 El Niño. Early 1997 several of the centres that issue El Niño forecasts were observing signs that an El Niño might be imminent. During the month of May, the spectacular onset of the El Niño could be followed real-time on the Internet. By July it was clear that it would be of extraordinary strength. El Niño was a central issue at the World Meteorological Organisation (WMO) meeting in August, and forecasts for unusual and possibly catastrophic weather were issued to the public. The message came home. Television crews and journalists jumped on the subject, and soon millions of people were following the development of the 1997/1998 El Niño.

Measures of El Niño • El Niño's last for about a year, and occur irregularly with a spacing of about three to seven years. They are characterised by warmer than usual surface water along the equator in the eastern Pacific Ocean and weaker than usual trade winds in the equatorial Pacific. El Niño's cause the precipitation region around New-Guinea to shift towards the central Pacific. A convenient crude measure for the strength of the trade winds is the Southern Oscillation Index (SOI), the normalised pressure difference between Tahiti and Darwin: if the SOI is low, then there is less wind blowing from Tahiti to Darwin, and that means weaker trade winds. The NINO3 index measures the deviation from normal of the sea surface temperature in the

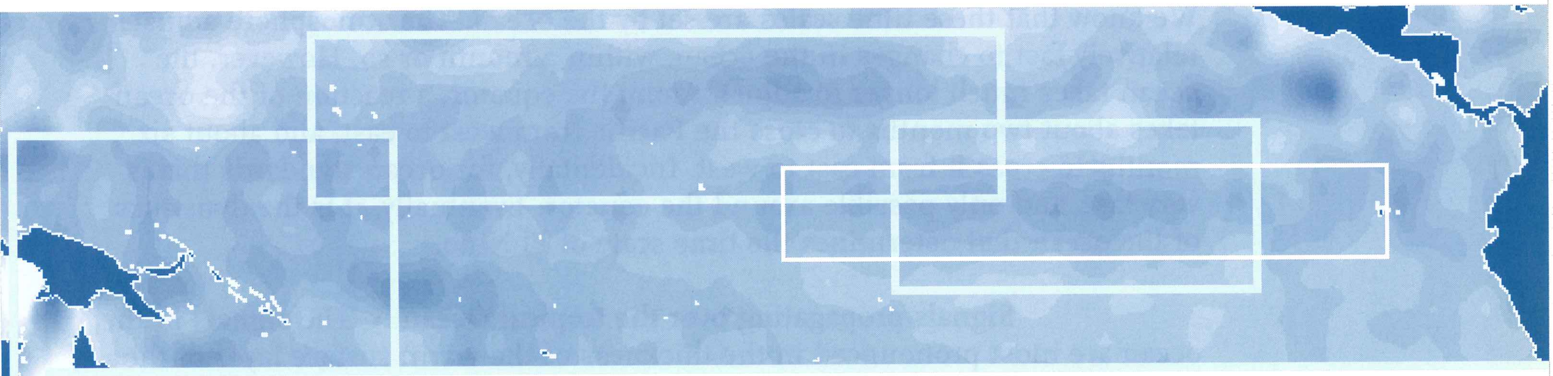
The origins of ENSO only become clear if one analyses how the atmosphere and the ocean interact

eastern Pacific. The irregular behaviour of the NINO3 index and the SOI since 1865 is shown in Figure 1. During an El Niño, the NINO3 index is high, and the SOI is low. The NINO3 index and the SOI are two indicators of the same phenomenon, El Niño - Southern Oscillation (ENSO).

Ocean-atmosphere interactions in the tropical Pacific • The origins of ENSO only become clear if one analyses how the atmosphere and the ocean interact and influence each other [1)]. Along the equator, the trade winds blow warm surface water westward in the direction of Asia, where it piles up. In the east, near South America, the water is replaced with cold water from below. This causes a temperature difference between the west (Australia and Asia) and the east (the Americas) of the Pacific. Air rises more over warm water than over cold water. Where air rises and cools as it enters higher altitudes, the water vapour in the air condenses and it rains: that is why it rains much more over the warm western Pacific near Asia than over the cold eastern Pacific near Peru and Equador. Also, the rising air in the west draws in more air, and this is partly responsible for the strength of the trade winds.

If, for one reason or another, the trade winds slacken, the water piled-up in the west will slosh back towards South-America. This heats the eastern Pacific and the temperature difference between east and west will diminish. In turn, when the difference in temperature becomes smaller, the trade winds will loose strength. In this way there is a circle of causes and effects that can reinforce each other: weaker trade winds give a smaller temperature difference, this gives weaker trade winds and so on. During the 1997/1998 El Niño, the change in sea surface temperature was extreme. In Figure 2 the sea surface temperature in the tropical Pacific of December 1997 is compared to the temperature of December 1998. At some places in the eastern Pacific, the difference was more than seven degrees Celsius.

Of course, this circular reasoning is not a complete picture. It explains why such vast deviations from normal can exist, but does not inform us about the duration of El Niño's nor about the frequency of their occurrence.



Disentangling the mechanisms

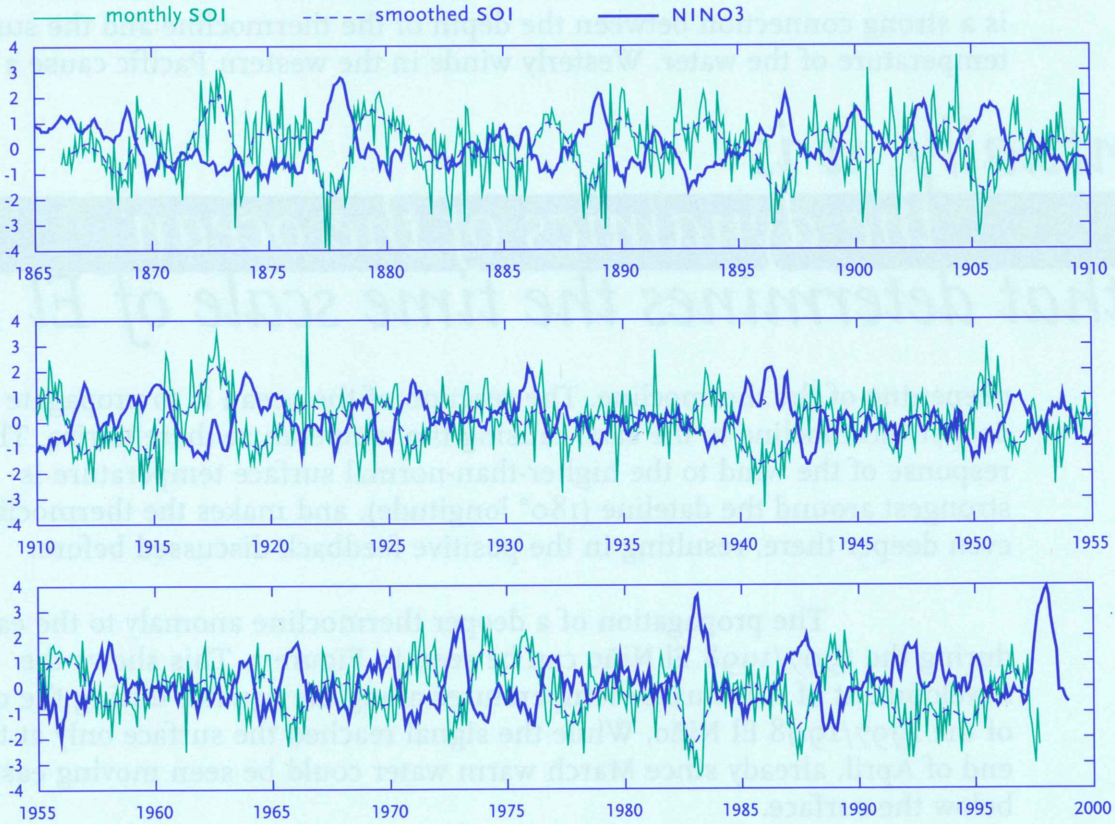


Figure 1. Two indicators of El Niño conditions, the NINO3 index and the Southern Oscillation Index (SOI), over the period 1865–1998. El Niño conditions are characterised by a high NINO3 index, and a low SOI. The NINO3 index is the deviation of the sea surface temperature with respect to normal conditions over the area 5°S–5°N, 150°W–90°W, and the SOI is the normalised sea-level pressure difference between Tahiti and Darwin. SOI made available by P.D. Jones, Climate Research Unit, University of East Anglia (UK). The NINO3 data were analysed on the basis of historical ship observations by Alexey Kaplan (Palisades, NY, USA).

The images without captions show the development of the 1997/1998 El Niño as observed by the ERS-2 (Earth Remote Sensing) satellite. They show the triggering in April 1997, the onset in June 1997, the peak in December 1997 and the following La Nina in August 1998. The white box in these images denotes the NINO3 region. Images provided by DEOS (Delft Institute for Earth-Oriented Space Research).

We know that these time scales are set by the ocean. The atmosphere adjusts relatively fast to changes in the ocean, within a month or so. However, the ocean takes much longer to adjust. Along the equator, a reaction of the ocean takes about two months to cross the Pacific from west to east, and about six months to cross it from east to west. Incidentally, for ocean standards this is very fast, and only possible around the equator. Eventually, it is the dynamics of the ocean that determines the time scale of El Niño.

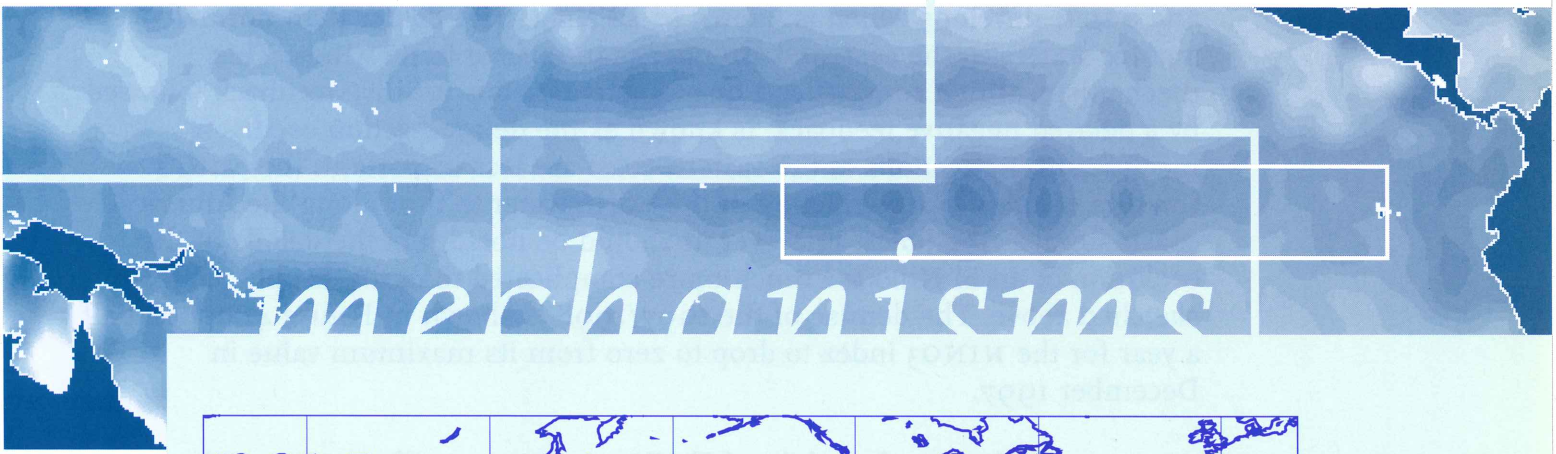
Signals propagating over the tropical Ocean • The signals in the ocean are most pronounced in the thickness of the warm surface layer of the ocean that covers the cold water of the deep ocean. As mentioned before, usually this layer is thicker and warmer in the western Pacific than in the eastern Pacific. The boundary between the warm surface layer and the deep cold water varies in depth from about 200m in the west to about 50 m in the east and is called the thermocline. In the east, where cold water surfaces, there is a strong connection between the depth of the thermocline and the surface temperature of the water. Westerly winds in the western Pacific cause a local

Eventually, it is the dynamics of the ocean that determines the time scale of El Niño

deepening of the thermocline. The reaction of the ocean is to propagate the deeper thermocline to the east, causing the temperature there to rise. The response of the wind to the higher-than-normal surface temperature is strongest around the dateline (180° longitude), and makes the thermocline even deeper there, resulting in the positive feedback discussed before.

The propagation of a deeper thermocline anomaly to the east during the 1997/1998 El Niño can be seen in Figure 3. This shows the development of sub-surface temperatures along the equator during the onset of the 1997/1998 El Niño. While the signal reached the surface only at the end of April, already since March warm water could be seen moving eastwards below the surface.

So during the onset of an El Niño, the thermocline gets deeper than normal in the east, but this also contains the germ of its own demise, because wind by itself does not heat the ocean. The warm water is drawn from areas to the north and south of the equator. The thermocline becomes shallower in those off-equatorial regions. Eventually, the shallow parts in the thermocline move back to the equator. Probably, reflections at the western coast are important in this process. Next, the shallow regions in the west travel eastward along the equator, and overcome the positive feedback of the wind anomalies. Eventually, the thermocline in the east is shallower than normal



mechanisms

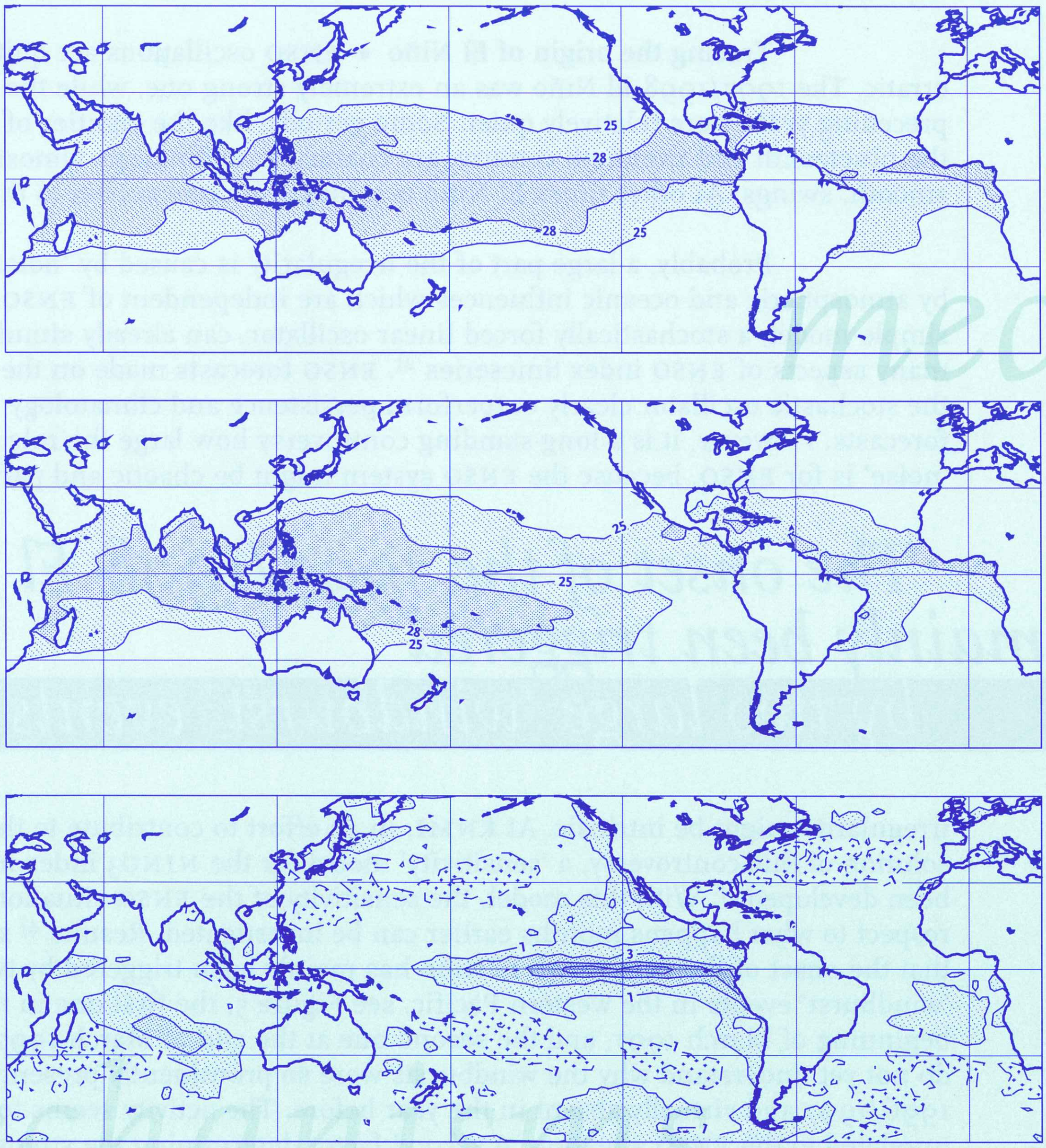


Figure 2. Areas with sea surface temperature above 25°C and 28°C in December 1997 (top), at the height of the 1997/1998 El Niño, and in December 1998 (middle), when moderate La Niña conditions prevailed. The difference in sea surface temperature shows a typical El Niño pattern (bottom) and is at some places more than 7°C (contour interval is 2°C, differences above 1°C are shaded, differences below −1°C are dotted). Sea surface temperature fields analysed by the US National Centers for Environmental Prediction (NCEP).

and a state develops which is known as La Niña, with colder than normal surface waters in the east, and stronger than normal trade winds. This mechanism, which consists of a quasi-instantaneous positive feedback followed by a delayed negative feedback, is known as the delayed-action oscillator mechanism. Reflections at the eastern coast are less important: the earth's rotation enables a large fraction of the warm water to flow along the American coasts towards the poles. However, it should be noted that the details of the evolution of an El Niño are much more complicated than the simple picture sketched above. The demise of the 1997/1998 is shown in Figure 4. It took half a year for the NINO3 index to drop to zero from its maximum value in December 1997.

Tracing the origin of El Niño • ENSO oscillations are quite erratic. The 1997/1998 El Niño was an extremely strong one, while the five preceding years were relatively quiet. Some periods, like the eighties of both the nineteenth and twentieth century, are characterised by large, almost smooth, swings. At other times El Niño is jumpy from one season to the next.

Probably, a large part of the irregularity is caused by 'noise', i.e., by atmospheric and oceanic influences which are independent of ENSO. A very simple model, a stochastically forced linear oscillator, can already simulate many aspects of ENSO index timeseries [2]. ENSO forecasts made on the basis of the stochastic oscillator clearly outperform persistence and climatology forecasts. However, it is a long-standing controversy how large the role of 'noise' is for ENSO, because the ENSO system might be chaotic and part of the

The onset of the 1997/1998 El Niño has mainly been triggered by two large 'windburst' events

irregularity might be intrinsic. At KNMI, in an effort to contribute to the solution of this controversy, a 'sensitivity' model for the NINO3 index has been developed [3]. With this model, the sensitivity of the ENSO situation with respect to what happens months earlier can be investigated. Results [4] show that the onset of the 1997/1998 El Niño has mainly been triggered by two large 'windburst' events in the western Pacific, see Figure 5, the first one in the beginning of March 1997, and the second one at the end of March 1997. We do not yet understand why the windbursts were so prominently present in 1996/1997 and virtually absent in the year before. The activity seems to be unrelated to the ENSO situation. A second factor determining the strength of last year's El Niño was the strong pile-up of warm water in the western Pacific during the preceding years. Disentangling the importance of these and other mechanisms is currently the subject of much research.

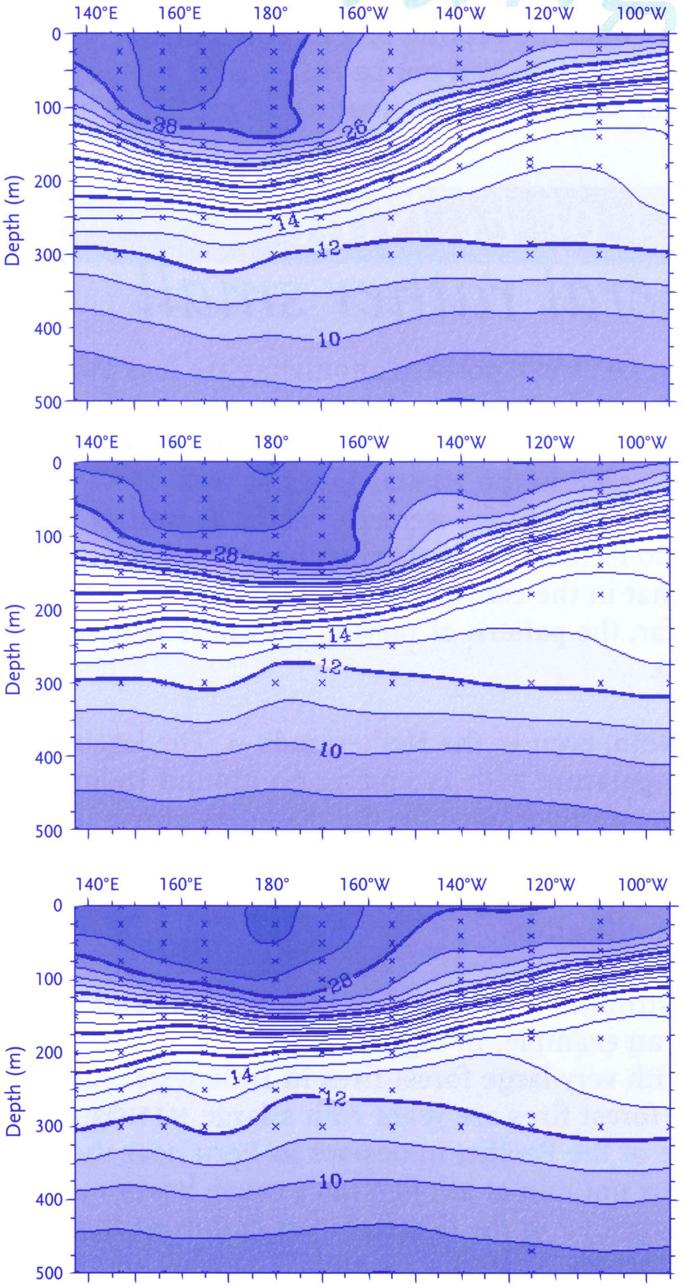


Figure 3. Sub-surface temperatures along the equator during the onset of the 1997/1998 El Niño. The plots are for March 1997 (top), April 1997 (middle) and May 1997 (bottom). A large warm sub-surface temperature signal can be seen propagating from west to east, depressing the thermocline in the east in May 1997. Sub-surface temperature fields measured by buoys of the Tropical Atmosphere Ocean (TAO) array and analysed by the US Pacific Mooring Experiment Laboratory (PMEL).

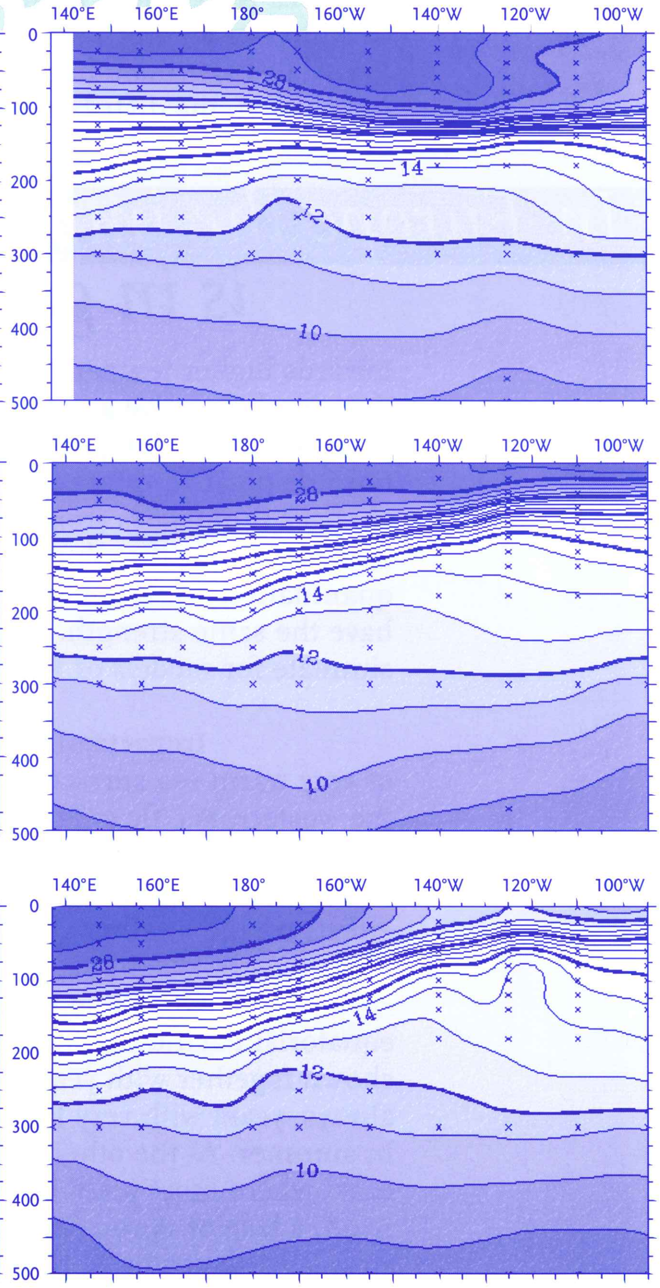


Figure 4. Sub-surface temperatures along the equator during the demise of the 1997/1998 El Niño. The plots are for December 1997 (top), March 1998 (middle) and May 1998 (bottom). It can be clearly seen that at the height of the El Niño in December 1997, already cold water was looming below the surface in the west. It took half a year before cold water reached the surface in June 1998. Sub-surface temperature fields measured by buoys of the Tropical Atmosphere Ocean (TAO) array and analysed by the US Pacific Mooring Experiment Laboratory (PMEL).

La Niña, El Niño's little sister • The opposite phase of El Niño is called La Niña. Close to the coast of South America, the surface warming of an El Niño can be much stronger than the cooling of a La Niña: that is why Peruvian fisherman discovered El Niño and not La Niña. More precisely formulated, the distribution of sea surface temperature anomalies is skewed

In Europe the impact of El Niño is in general rather small

towards higher temperatures, i.e., weak positive anomalies are less probable than weak negative anomalies, while strong positive anomalies are more probable than strong negative anomalies. To some extent, this skewness towards positive values can be seen in the NINO3 index as well. How this changes if one goes from the eastern to the western Pacific as well as the tendency of the distribution to have multiple maxima has been investigated quantitatively [5]. It appears that in the central Pacific, El Niño and La Niña can have the same strength. So far, the pattern of varying skewness is hard to simulate for models of ENSO.

Impacts of El Niño, even in the Netherlands • The large region of very warm sea surface temperature with ascending air around Indonesia and the western Pacific is of primary importance for the planetary atmospheric circulation and the redistribution over the Earth of heat from solar radiation. It is not surprising, then, that changes and shifts of this region have pronounced effects on the weather all over the globe.

Of course, the strongest effects are on countries around the equatorial Pacific Ocean. As an example, in Figure 6, the NINO3.4 index is shown together with years with very large forest fires in Indonesia. Almost always, years with very large forest fires are years with a large NINO3.4 index in summer. At the other side of the Pacific, in deserts in Peru near the Pacific coast where most years it does not rain at all, El Niño's cause heavy rain. Early 1998, a lake of 15000 km^2 appeared in the desert. Other countries that are strongly affected by El Niño include Australia, Uganda, Uruguay and the United States.

In Europe the impact of El Niño is in general rather small. A relatively large effect is that in El Niño years after 1950 there is a high probability of heavy rain in the south of the Iberian peninsula in autumn. What caused the change around 1950 is not known.

That does not mean there is no effect of El Niño at all in the Netherlands. A significant relation has been found [6] between the winter NINO3 index and the spring rainfall in the Netherlands, see Figure 7. If there is a strong El Niño in winter, it is very likely that the following spring will be

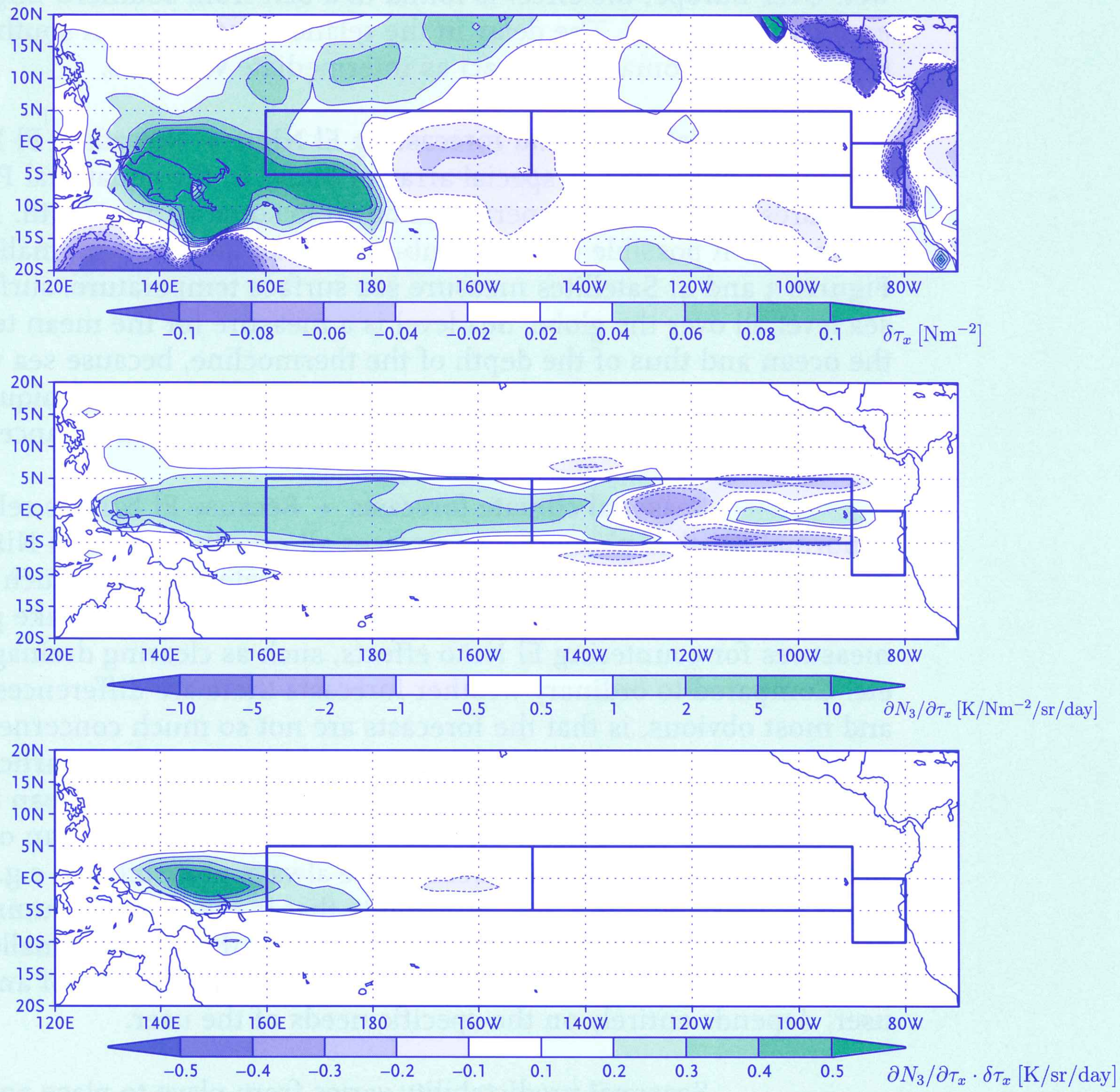
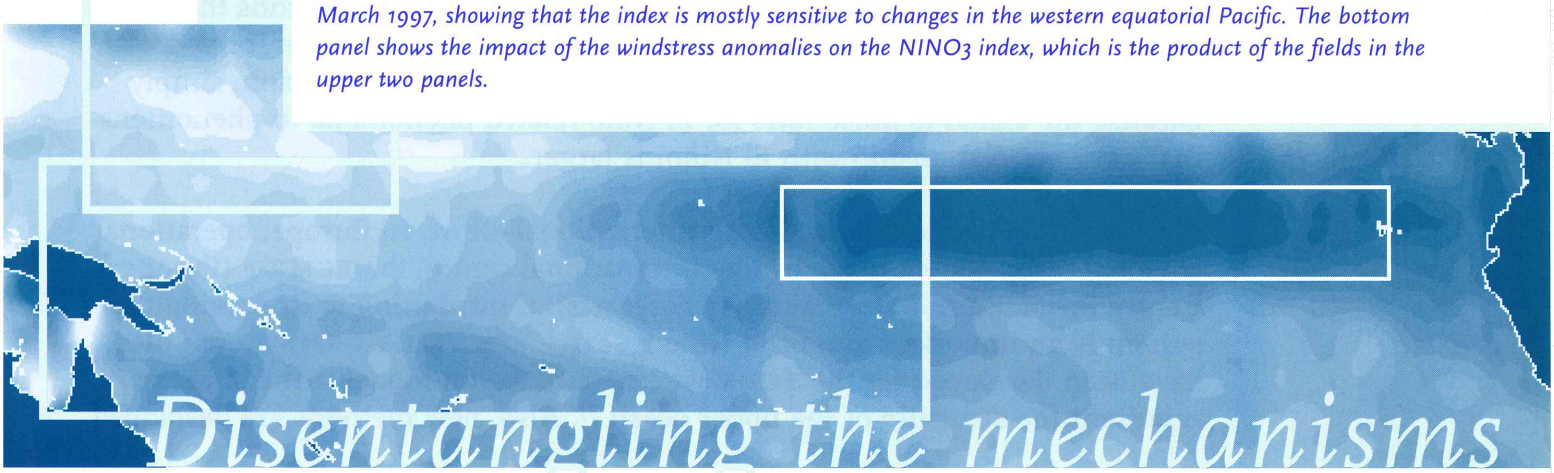


Figure 5. The effect of the March 1997 westerly windburst on the NINO3 index in early June 1998. The top panel shows the windstress anomaly field for the week centred on 11 March 1997 with a clear westerly windburst in the western Pacific. The middle panel shows the sensitivity of the June NINO3 index for windstress anomalies in March 1997, showing that the index is mostly sensitive to changes in the western equatorial Pacific. The bottom panel shows the impact of the windstress anomalies on the NINO3 index, which is the product of the fields in the upper two panels.



Disentangling the mechanisms

wet. Over Europe, the effect is found in a belt from southern England eastwards into Asia. The delay in the relation suggests that south-east Asian temperature anomalies may act as intermediate variables.

Following and forecasting El Niño • Nowadays El Niño is monitored quite well. A special array of buoys in the equatorial Pacific measures winds, and temperatures down to some 300 m depth. It is this array that makes it possible to follow sub-surface temperature anomalies as shown in Figures 3 and 4. Satellites measure sea surface temperature, surface winds and sea level all over the globe. Sea level is a measure for the mean temperature of the ocean and thus of the depth of the thermocline, because sea water expands when heated - in which case the sea level rises. Current techniques and models are able to predict El Niño about six to twelve months in advance.

Seasonal climate forecasts • Because El Niño is related to abnormal weather phenomena in places all over the world, El Niño research has opened up the possibility of seasonal climate forecasts. Such forecasts can be used in deciding what crops to grow and whether to take preventive measures for countering El Niño effects, such as clearing drainage systems, etc. Compared to ordinary weather forecasts there are differences. The first, and most obvious, is that the forecasts are not so much concerned with specific weather events such as storms and heat waves at a particular day, but with general characteristics of a month or season, such as mean temperature, precipitation or cloudiness. The second is that, even more than ordinary weather forecasts, seasonal forecasts are always probabilistic, e.g., a forecast could be that 'there is a 75% probability that it will be a wet summer' or 'the probability that a hurricane will hit that area is three times smaller than usual'. It should be kept in mind that whether such information is of any value to a user, depends entirely on the specific needs of the user.

Seasonal predictability varies from place to place and from time to time. Obviously, seasonal climate forecasts are more skillful in the tropics where the effects of El Niño are more pronounced than in mid-latitudes. The skill also depends on the season. El Niño behaves in such a way that it is much more easy to predict what January will look like from July conditions than to predict what July will look like from January conditions. Moreover, once a strong El Niño has set in, it is relatively easy to forecast its evolution, simply because the signal to noise ratio (of El Niño related phenomena to phenomena that have no relationship with El Niño) is larger.

El Niño research is an international effort. In Europe, operational seasonal forecasts are made by one international centre, the ECMWF (European Centre for Medium-Range Weather Forecasts). Contributing to improving this system is an important aim of El Niño research at KNMI. At KNMI, modules have been developed for the ECMWF ocean circulation model that can better represent the structure of the upper ocean [7]. Also, new methods are developed

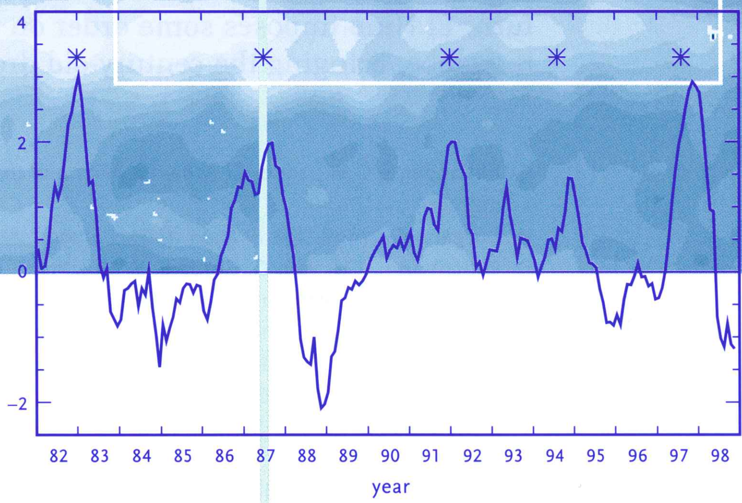


Figure 6. Forest fires in Indonesia and El Niño are strongly related. The line is an indicator for El Niño, in this case the NINO3.4 index (sea surface temperature anomaly over 5°S–5°N, 170°W–120°W). The asterisks indicate years with severe forest fires in Indonesia.

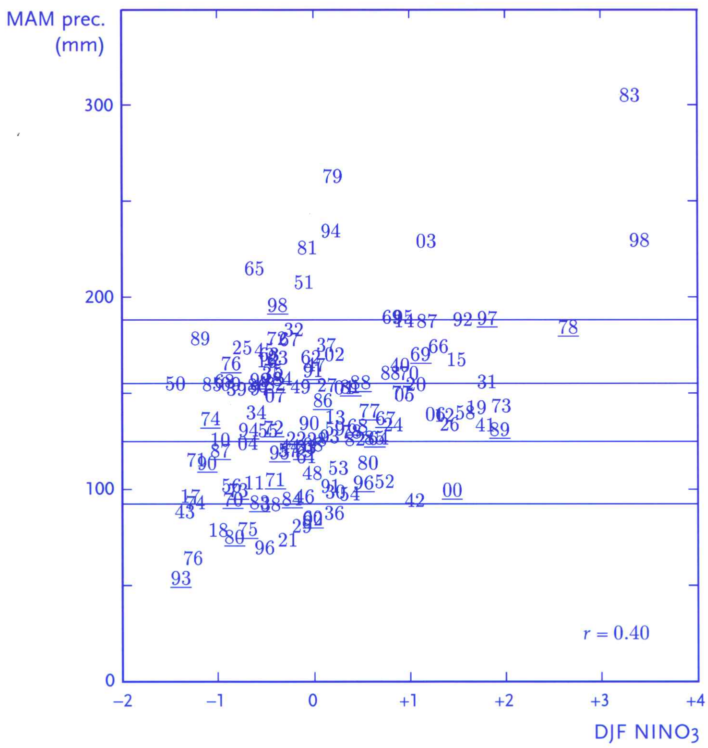


Figure 7. Scatter plot of spring precipitation in the Netherlands against the value of the NINO3 index (sea surface temperature anomaly over 5°S–5°N, 150°W–90°W) in the preceding winter, over the period 1857–1998. Underscored numbers refer to the 19th century, the horizontal lines denote the 10%, 33%, 67% and 90% percentiles of spring precipitation. The correlation between the variables is 0.40.

that aim at optimally incorporating the information from observations in the forecast model, and at giving an estimate of the uncertainty in the forecast.

Thanks to the collaborative effort in observations, theory and modelling of El Niño, useful forecasts can now be made of this capricious phenomenon. In turn, El Nino imposes some order on the chaotic weather over large parts of the globe, bringing the century-old dream of seasonal forecasts closer to reality.

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2) Burgers, G., 1998. *The El Niño stochastic oscillator*. Clim. Dyn., to be published.

3) Oldenborgh, G.J. van, G. Burgers, S. Venzke, C. Eckert and R. Giering, 1997. *Tracking down the delayed ENSO oscillator with an adjoint OGCM*. Mon. Wea. Rev., to be published.

4) Oldenborgh, G.J. van, 1998. *What caused the 1997-1998 El Niño?* Submitted to Geophys. Res. Lett.

5) Burgers, G., and D.B. Stephenson, 1998. *The 'normality' of El Niño*. Accepted by Geophys. Res. Lett.

6) Oldenborgh, G.J. van, G. Burgers and A. Klein Tank, 1999. *On the El Niño teleconnection to spring precipitation in Europe*. Submitted to Int. J. Climatol.

7) Eijk, M. van, 1998. *The implementation of two mixed-layer schemes in the HOPE ocean general circulation model*. KNMI Technical Report TR-**214**.

Measuring and modelling the effects of aviation on the atmosphere

by Michiel van Weele, Dominik Brunner, Hennie Kelder, Ernst Meijer, Veerle Pultau, Peter van Velthoven, Wiel Wauben

Introduction • The use of aircraft in transporting people and goods is an important part of today's economy. But what is the environmental impact of all those airplanes, flying ceaselessly through the atmosphere? This contribution to the 'Recent highlights' aims to give a short overview of our present knowledge of the effects of aviation on the atmosphere and also of the work that has recently been done in this field in the Atmospheric Composition Research Division at KNMI.

Even though most aircraft fly in so-called 'flight corridors', the effects of their emissions on atmospheric composition and chemistry propagate far beyond these regions and may even affect climate. The CO_2 emitted by aircraft contributes 2–3% to the total anthropogenic CO_2 emissions. Studies with global chemistry transport models show that aircraft emissions of nitrogen oxides NO_x (= $NO + NO_2$) in the North Atlantic Flight Corridor (NAFC) change the concentrations of long-lived greenhouse gases such as ozone and methane throughout the Northern Hemisphere.

When the aircraft emissions are injected in the stratosphere, they may affect the ozone concentrations in the ozone layer. Paul Crutzen [1)] explained in the early seventies that 'an artificial increase of nitrogen oxides in the stratosphere ... may lead to observable changes in the atmospheric ozone level'. Some years later these results became significant in the discussion on the effects of a fleet of supersonic aircraft flying in the stratosphere.

Aircraft NO_x emissions account for only about 2–3% of the total anthropogenic NO_x emissions. However, aircraft emissions have a larger impact than surface emissions due to the longer residence time of the emitted species at high altitudes. Furthermore, it is known that climate is especially sensitive to changes in atmospheric composition near the tropopause, which unfortunately coincides with the main cruise altitudes at mid-latitudes (8–13 km).

A potentially large climate effect of air traffic is the formation of contrails. Contrails are ice clouds (cirrus) that form in the wake of an aircraft. It is suspected that persistent contrails may initiate the formation of longer-lived cirrus cloud fields. Even a small increase in the frequency of occurrence of cirrus clouds would exert a large climate forcing.

A potentially large climate effect of air traffic is the formation of contrails

The CO_2 emissions, the effects of NO_x emissions on the abundance of other greenhouse gases by chemical transformations, and the effects of water vapour exhaust via cloud formation may result in climate changes by air traffic. Due to the fast growth of air traffic around the globe (currently about 3–4% increase of fuel use per year), it is anticipated that the magnitude of these climate effects will increase rapidly during the next century.

Research on aircraft effects in the Atmospheric Composition Research Division is focused on:

1 Participation in (inter-)national measurement campaigns.
2 Study of aircraft effects on chemistry and climate by model simulations.

Measurement campaigns • Meteorological and scientific support is given to experimental campaigns that investigate the effects of air traffic on atmospheric composition and chemistry. Trajectory calculations are made during the campaigns to optimise flight planning and, at a later stage, to help the interpretation of the observations. At KNMI the measurements are compared with calculations with a global chemistry-transport model, named TM3 (Transport Model, version 3). Highlights of recent campaigns are briefly summarised below and include the POLINAT-2 campaign (Pollution and Aircraft Emissions in the North Atlantic Flight Corridor), the NOXAR project (Nitrogen Oxides and Ozone along Air Routes), and the EULINOX project (European Lightning Nitrogen Oxides project). In the Netherlands aircraft measurements were also performed within the AIRFORCE project (Aircraft Influences and Radiative Forcing from Emissions) in co-operation with IMAU (Institute for Marine and Atmospheric Research Utrecht) and RIVM (National Institute of Public Health and the Environment).

What is the environmental impact?

The POLINAT-2 experiment • In September and October 1997 a measurement campaign took place in the North Atlantic Flight Corridor in the framework of the European POLINAT-2 project. A wide variety of cases was investigated. In cyclones over the ocean and in anti-cyclones, aircraft emissions are accumulated at flight altitudes and in some cases the aircraft emissions contribute up to 80% to the NO_x concentrations (Figure 1). In cyclones over land, the surface NO_x emissions can be lifted up to cruise altitudes. In these cases the surface contribution to the NO_x concentrations can be as large as the aircraft contribution (both about 40%). Flights from Ireland to the Canary Islands indicated a large-scale north-south gradient in NO_x concentrations with high concentrations in the north due to air traffic. The measurements also indicated that lightning is an important NO_x source in the south.

In some cases the aircraft emissions contribute up to 80% to the NO_x concentrations

The impact of these NO_x perturbations on the ozone levels can only be estimated by model calculations. The ozone perturbations are much smaller than the natural variability of the ozone concentrations at flight altitudes. Therefore, it is very difficult to validate the calculated effects on ozone with measurements. The calculations show that aircraft emissions contribute for about 4–8% to the ozone concentrations in the tropopause region, whereas surface and lightning emissions explain approximately 10–15% each. The remaining ozone is transported downward from the stratosphere.

The NOXAR experiment • In the NOXAR project it was intended to establish a representative data set of NO_x and ozone measurements in the upper troposphere and lower stratosphere over large parts of the Northern Hemisphere. The project was mainly carried out by Dominik Brunner, who did his PhD at the time at ETH (Swiss Federal Institute of Technology) in Zürich, Switzerland. An automated measurement system was in operation between May 1995 and May 1996 on a Swissair B-747 airliner between Zürich and destinations in the USA and the Far East. The upper tropospheric NO_x distribution was found to be strongly influenced by large-scale plumes extending about 100 to 1300 kilometres along the flight track [3)]. The plumes were frequently observed downwind of thunderstorms and frontal systems and are most probably caused by upward transport of polluted air from the continental boundary layer or NO_x production by lightning strokes, or both. The large-scale plumes contrast with small-scale peaks that were detected on nearly every flight. The latter are most likely caused by the sampling of exhaust plumes from other aircraft in the flight corridor.

What is the environmental impact?

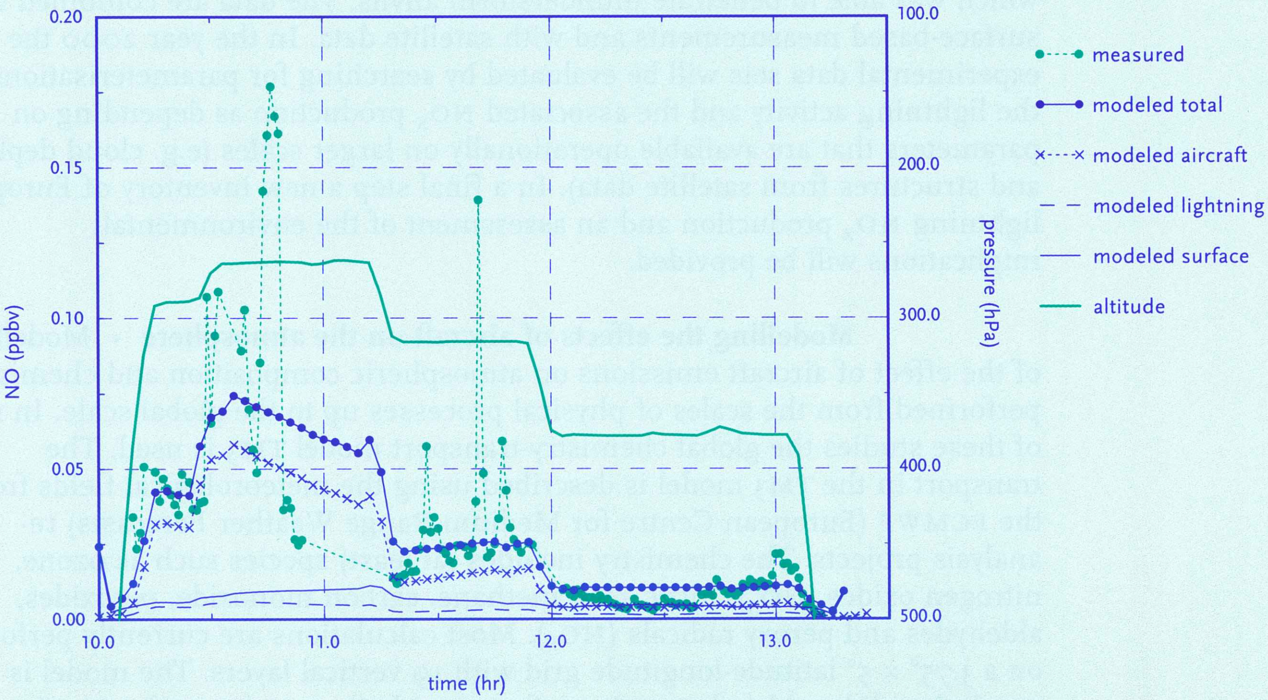
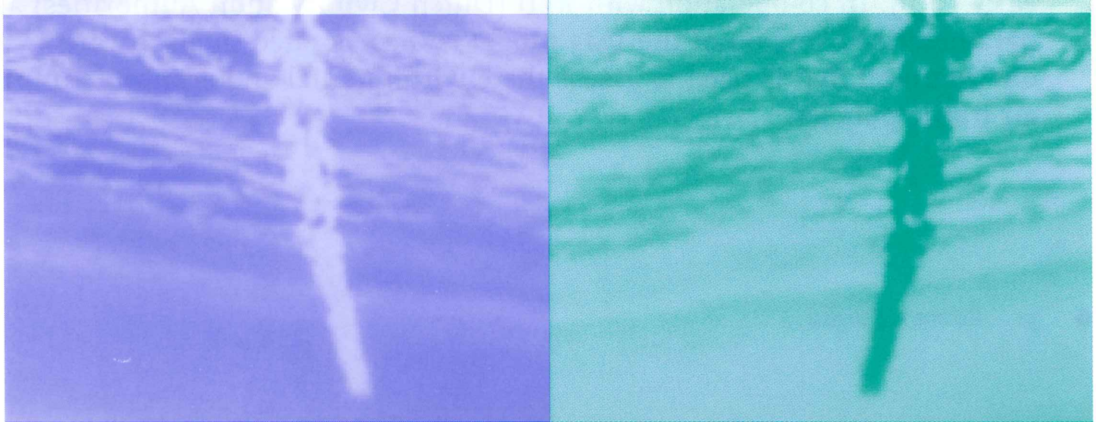


Figure 1. NO measurements in a stagnant anti-cyclone (west of Ireland in the NAFC on 23 October 1997). The highest flight level reveals the effect of 5 days of accumulated aircraft emissions without significant influence of other NO_X sources. The lowest level is below the flight corridor. The measurements compare well with TM3 model simulations. The partitioning between the source categories was modelled by using a new labelling technique in the TM3 global chemistry-transport model [2)]. NO concentration (parts per billion by volume) is indicated on the left y-axis. Flight altitude (pressure level) is indicated on the right y-axis.



The EULINOX experiment • The amount of NO_X produced by lightning is very uncertain. However, it is generally believed that it may, globally, exceed the current NO_X production by aircraft by a factor of 10. Better understanding of the lightning NO_X production is therefore necessary for studying the effect of aircraft on the atmosphere. For this reason the EULINOX experiment was started. During a field campaign in the summer of 1998 measurements were performed over central Europe with a FALCON aircraft

The amount of NO_X produced by lightning may exceed the current NO_X production by aircraft

which was able to penetrate thunderstorm anvils. The data are combined with surface-based measurements and with satellite data. In the year 2000 the experimental data sets will be evaluated by searching for parameterisations of the lightning activity and the associated NO_X production as depending on parameters that are available operationally on larger scales (e.g. cloud depth and structures from satellite data). In a final step a new inventory of European lightning NO_X production and an assessment of the environmental implications will be provided.

Modelling the effects of aircraft on the atmosphere • Modelling of the effect of aircraft emissions on atmospheric composition and chemistry is performed from the scales of physical processes up to the global scale. In most of these studies the global chemistry-transport model TM3 is used. The transport in the TM3 model is described using the meteorological fields from the ECMWF (European Centre for Medium-Range Weather Forecasts) re-analysis projects. The chemistry includes (at least) species such as ozone, nitrogen oxides (NO_X), nitric acid, methane, carbon monoxide, peroxides, aldehydes and peroxy radicals (HO_X). Most calculations are currently performed on a $3.75° \times 5°$ latitude-longitude grid with 19 vertical layers. The model is regularly validated by observations, for example in experimental campaigns as described above. The model is maintained in close co-operation with IMAU.

The TM3 model played a role in the recent IPCC (Intergovernmental Panel on Climate Change) assessment of the effects of air traffic. Scenario calculations for 1992, 2015 and 2050 are presented in the IPCC Special Report 'Aviation and the Global Atmosphere' 4) which appears early 1999. In co-operation with RLD (Dutch Civil Aviation Authorities) a parameterised version of the TM3 model is incorporated in a software environment that is used to assess the environmental and economic impacts of air traffic policies.

environmental

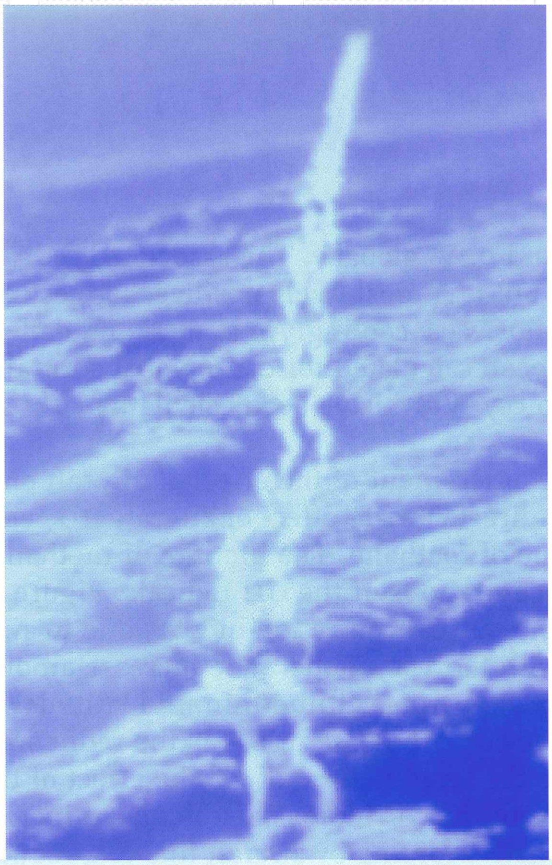
Ozone formation • The chemical mechanism of ozone formation due to aircraft NO_x emissions is similar to the ozone formation in the polluted boundary layer due to surface NO_x emissions ('smog formation'). The nitrogen oxides catalyse the oxidation of CO and hydrocarbons in the atmosphere and positive feedbacks in the chemistry enhance the ozone production. Because the background levels of NO_x at flight altitude are very low, aircraft NO_x emissions have considerable impact. Current aircraft emissions enhance the NO_x concentrations in the flight corridors by several tens of percent, and the ozone concentrations by a few percent. Increases in ozone concentrations at flight altitudes of more than 10% (relative to background levels) are calculated for the beginning of the 21-th century (Figure 2). The scenario calculations for 2015 and 2050 indicate that ozone production increases in good approximation linearly with the increasing aircraft NO_x emissions.

In a process study on the chemistry in the wake of an aircraft it has been found that incomplete mixing of the nitrogen oxides hampers ozone production. The nitrogen oxides are rapidly transformed into reservoir species such as nitric acid. A parameterisation of the plume processes for global chemistry models has been developed which includes a chemical reactive Gaussian plume model. The parameterisation has been tested in the TM3 model. The study showed that neglect of the mixing processes in the plume leads to an overestimation of the ozone production by about 20%.

Climate effects • Calculation of the possible climate effects of aircraft emissions is a relatively new research field and present results are still rather uncertain. Most important climate forcings are probably CO_2 emissions, ozone formation, contrail formation, and water vapour exhaust in the stratosphere. Further, it has recently been hypothesised that the aircraft NO_x emissions may significantly reduce the lifetime of methane, which is also an important greenhouse gas.

The estimated ozone increase due to current air traffic causes a global mean radiative forcing of 0.02 Wm^{-2}, which is about 1% of the total forcing due to the increase in greenhouse gases since pre-industrial times and is comparable with the forcing by the aircraft CO_2 emissions. A side effect of changes in the (total) ozone amount is a change in the damaging ultraviolet (UV) radiation that is incident at the Earth's surface. An increase in total ozone of 1 DU (Dobson unit) due to aircraft NO_x emissions would decrease the incident damaging UV radiation by about one percent.

Water vapour that is emitted in the dry stratosphere has a very long residence time and may enhance the prevalence of polar stratospheric clouds, which play an important role in the stratospheric ozone depletion at high latitudes. The direct radiative forcing by the water vapour increase is quite uncertain, but may be substantial. In the troposphere contrails may form. Contrails are an artificial form of cirrus clouds that can often not be distinguished from natural cirrus clouds. Average contrail cover is estimated to



impact?

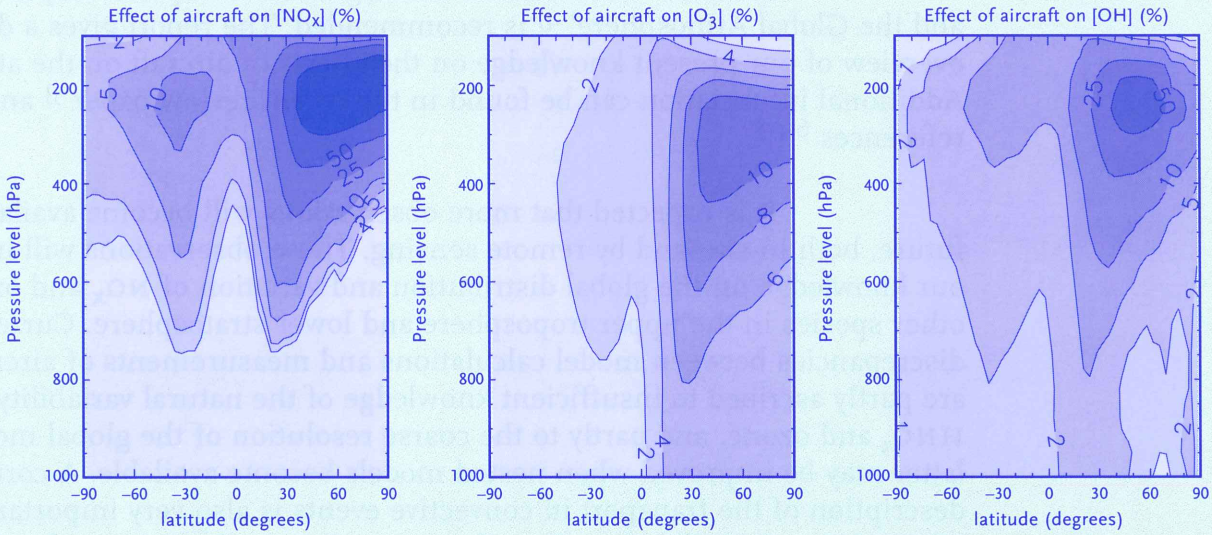


Figure 2. The effect of aircraft on the monthly mean concentrations of NO_X, O_3, and OH (in %) as a function of latitude and height for July, based on the IPCC emission scenarios for 2015. In 2015 it is estimated that the aircraft emissions are about 150% of the 1992 emissions. The figures show the difference between two model calculations: one calculation with aircraft emissions and one calculation without aircraft emissions. Contour levels for O_3 are 2, 4, 6, 8 and 10%, contour levels for NOX and OH are 1, 2, 5, 10, 25, 50 and 100%.

impact?

be 0.5% over Europe and 0.1% globally. The associated radiative forcing is again quite uncertain, but it is most likely positive, suggesting that longwave heating prevails over shortwave cooling. An annual and daily mean forcing of about 0.02 Wm^{-2} has been calculated for 0.1% global contrail cover. Regionally, maximum values up to 0.7 Wm^{-2} have been calculated.

The IPCC assessment of the effect of aircraft emissions has led to the hypothesis of an indirect climate effect of aircraft NO_X emissions by a reduction of the lifetime of methane. The lifetime of methane is largely determined by the concentrations of the OH radicals. Figure 2 shows the modelled increase in the OH concentration in 2015 due to aircraft NO_X emissions calculated with the TM3 model. The increase amounts globally to about 2–3% and is largest at cruise altitudes in mid-latitudes. A possible explanation for the large-scale increase in OH is the reduction of CO in the flight corridors. Due to the long lifetime of CO the effect of the reduction in CO is also observed outside of the corridors. The calculated increase in OH implies that there may be a negative forcing by aircraft due to a reduction in methane which is of the same order as the positive forcing by the increase in ozone.

Outlook • For further reading the IPCC Special Report 'Aviation and the Global Atmosphere' [4] is recommended. The report gives a detailed overview of our present knowledge on the effects of aircraft on the atmosphere. Additional information can be found in the recent review paper [5] and the references [6-11].

It is expected that more observations will become available in the future, both in-situ and by remote sensing. These observations will improve our knowledge on the global distribution and variation of NO_X and ozone and other species in the upper troposphere and lower stratosphere. Current discrepancies between model calculations and measurements of aircraft effects are partly ascribed to insufficient knowledge of the natural variability of NO_X, HNO_3 and ozone, and partly to the coarse resolution of the global models. The latter may be improved when nested models become available. A correct description of the transport in convective events is also very important. The EULINOX project aims to reduce the uncertainty in the NO_X production by lightning. The estimation of climate forcing by aircraft is still very uncertain. Given the fast growth in air traffic it is anticipated that research on the effects of aircraft emissions on atmospheric composition, chemistry and climate will intensify in the coming years.

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Geophysical aspects of the Comprehensive Nuclear-Test-Ban Treaty

by Hein Haak

Introduction • In New York on 24 September 1996 President Clinton was the first head of state to sign the Comprehensive Nuclear-Test-Ban Treaty (CTBT) on behalf of the United States of America. This signature was a milestone in a period of just over 50 years since the first nuclear test in July 1945, called Trinity, and the subsequent development and testing of nuclear weapons. In this 50-year period over 2000 nuclear tests have been conducted.

The signature of the US was followed by many nations and one year later 147 states had signed of which 7 already ratified the Treaty. The Treaty was opened for signature after the adoption on 10 September 1996 by the United Nations General Assembly (UNGA) of resolution 50/245 with 158 in favour, 3 opposed (India, Bhutan and Libya) and 5 abstentions.

The adoption of UNGA resolution 50/245 closed a period of intense multilateral negotiations. The Netherlands Ambassador to the Conference on Disarmament (CD), Jaap Ramaker, chaired the last part of these negotiations in Geneva. He chaired the Ad Hoc Committee on a Nuclear Test Ban, the forum in the CD where the actual negotiations took place since 1993. The negotiations were forced to an end by the Draft Chairman's Treaty Text in order to meet the internationally accepted deadline of September 1996 and the fact that, although consensus reached its peak, no real consensus could be achieved. As became gradually clear, India objected formally to the draft treaty text because it wanted a strong connection with nuclear disarmament and not just a ban on nuclear test explosions.

In that period I was part of the Netherlands negotiating team as a technical adviser and therefore had the pleasure of working in an exciting time in Ramaker's excellent team on a crucial issue in disarmament. Before, I participated for almost 10 years in the Group of Scientific Experts (GSE), a group of scientists and diplomats that focused on the verification of a nuclear test ban with seismological means.

With the signature of the Treaty the preparatory work could start in order to be ready for the Entry Into Force (EIF) of the Treaty. This work is well under way now and it is carried out by the Provisional Technical Secretariat (PTS) of the Preparatory Commission (PrepCom) for the Comprehensive Nuclear-Test-Ban Treaty Organisation in Vienna. The key element of the Treaty is the verification regime that will monitor the atmosphere, the oceans and the solid earth to ensure that the Treaty is not violated. A world-wide network of sensors encompassing four techniques enable participating states to detect, locate and identify nuclear explosions at very low thresholds: lower than 1 kiloton (kt).

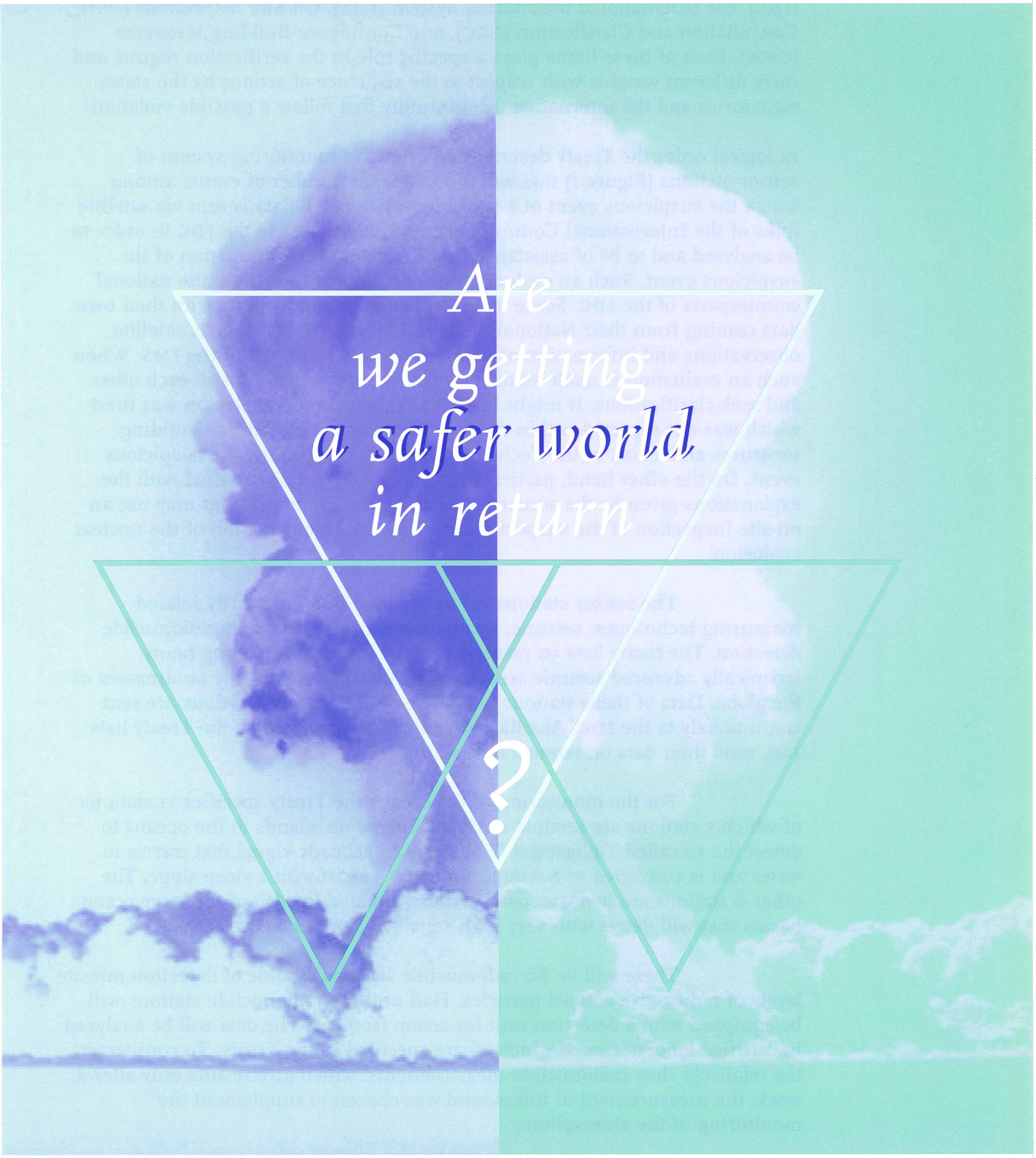
When the Treaty will actually enter into force is unknown since it depends on the ratification of a specific group of states that are member of the Conference of Disarmament and that operate nuclear reactors. Among these states are of course the five established nuclear powers and permanent

The CTBT strongly influenced seismology in terms of funding and research

members of the Security Council (P5) as well as Israel, the two Koreas but also India and Pakistan. Iran is on the list but Iraq is not. The extensive technical work to be done has somehow to be finished in a flexible time schedule. This constitutes a challenge in planning and organisation.

The CTBT strongly influenced seismology in the world both in terms of funding and of research. In this sense, it was also a subject of interest at KNMI for a period of over 20 years. In the near future the Seismology Division will host the National Data Centre (NDC) in the context of the CTBT and will continue to advise the Ministry of Foreign Affairs. Currently, research is carried out in CTBT context both in seismology and infrasound. The subject of the CTBT is not purely scientific but is intertwined with politics, yet, after many years of experimentation, an enormous infrastructure is built up to verify the Treaty. All this finds its significance in the aspiration for a safer world.

Verification of the CTBT • The verification regime of the CTBT can be subdivided into five interrelated items: the International Data Centre


Are
we getting
a safer world
in return
?

(IDC), the International Monitoring System (IMS), On-Site Inspections (OSI), Consultation and Clarification (C&C), and Confidence-Building Measures (CBM). Each of these items plays a specific role in the verification regime and carry different weights with respect to the sequence of actions by the states signatories and the international community that follow a possible violation.

In logical order the Treaty describes an extensive monitoring system of sensor stations (Figure 1) that will detect a large number of events among which the suspicious event of a possible violation. All data is sent via satellite links of the International Communication System (ICS) to the IDC in order to be analysed and to be of assistance to the states in their evaluation of the suspicious event. Such an evaluation can be done at the NDCs, the national counterparts of the IDC. Some states will supplement the data with their own data coming from their National Technical Means (NTM) such as satellite observations and information of national networks not part of the IMS. When such an evaluation is made states may feel it necessary to consult each other and seek clarifications. It might be that a large chemical explosion was fired which was not reported within the framework of the confidence building measures and a visit of the Technical Secretariat will clarify the suspicious event. On the other hand, participating states may not be satisfied with the explanations given by the accused state or by the Secretariat and may use an on-site inspection of the suspect area to find final confirmation of the nuclear explosion.

The sensor stations are subdivided into four partly related measuring techniques: seismic, hydroacoustic, infrasonic and radionuclide detection. The treaty lists 50 primary seismic stations, including many technically advanced seismic arrays, evenly distributed over the landmasses of the globe. Data of these stations with state-of-the art specifications are sent continuously to the IDC. Auxiliary seismic stations, of which the Treaty lists 120, send their data on request of the IDC.

For the monitoring of the oceans the Treaty specifies 11 stations of which 5 stations are seismic stations situated on islands in the oceans to detect the so-called T-phases. A T-phase is an acoustic signal that travels in water and is converted to a seismic signal at a coast with a steep slope. The other 6 stations are hydroacoustic stations situated in each of the large ocean basins that will detect with very high sensitivity any explosive activity.

There will be 80 radionuclide stations capable of detection minute levels of radioactive aerosol particles. Half of these radionuclide stations will be equipped with a detection unit for xenon isotopes. The data will be analysed in certified laboratories of which 16 are specified in the Treaty. To counteract the relatively slow radionuclide measurements, which give results only after a week, the measurement of infrasound was chosen to supplement the monitoring of the atmosphere.

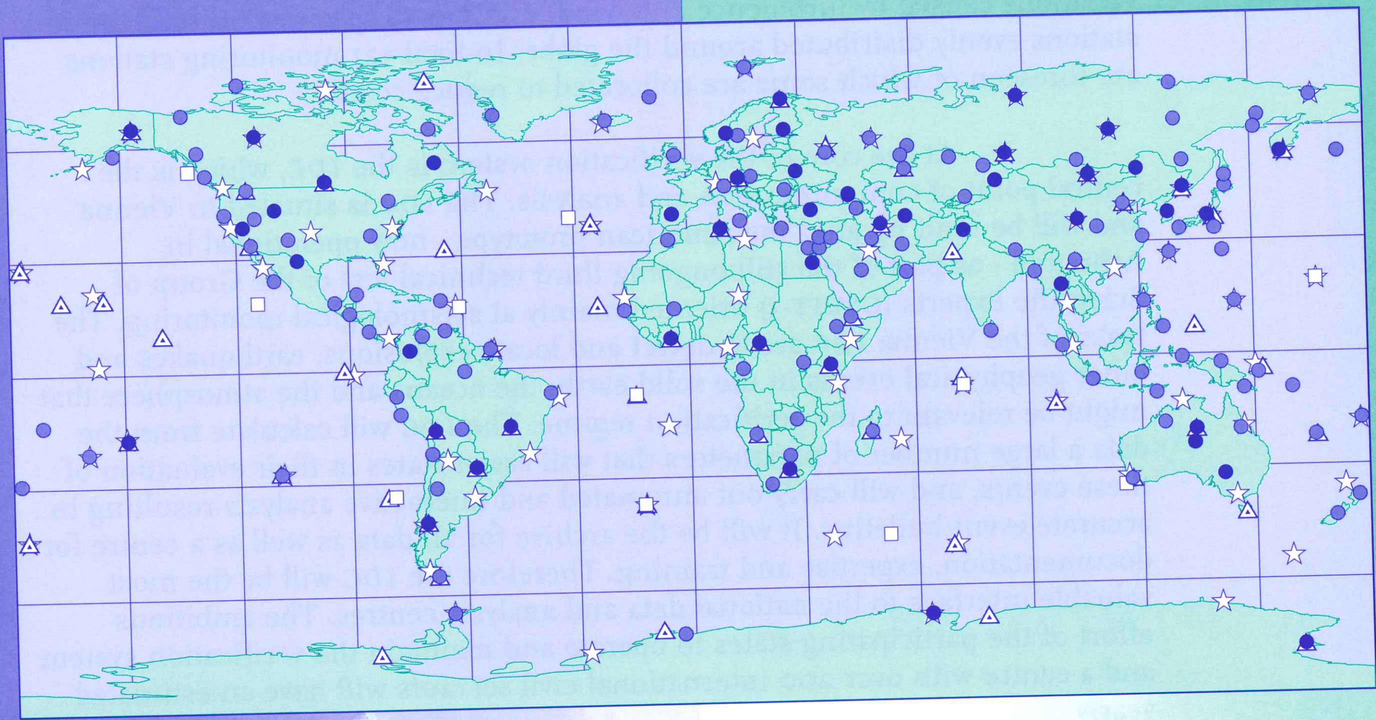


Figure 1. CTBT International Monitoring System.

- Primary seismic stations
- Auxiliary seismic stations
- Hydroacoustic stations
- Infrasound stations
- Radionuclide stations

Are we getting a safer world in return?

Infrasound is low frequency sound (< 20 Hz) that travels with very little attenuation through the atmosphere. It is produced after large explosions in air and it is to be detected against a background of pressure variations caused by turbulence and wind. The Treaty specifies 60 infrasound stations evenly distributed around the globe. In total 321 monitoring stations are foreseen of which some are collocated to reduce costs.

At the core of the verification system is the IDC, which is the central point of communication and analysis. The IDC is situated in Vienna and will be built up after the American prototype - now operational in Arlington - as part of the still ongoing third technical test of the Group of Scientific Experts (GSETT-3) oriented mainly at seismological monitoring. The tasks of the Vienna IDC are to detect and locate explosions, earthquakes and other geophysical events in the solid earth, the oceans and the atmosphere that might be relevant to the verification regime. The IDC will calculate from the data a large number of parameters that will assist states in their evaluation of these events, and will carry out automated and interactive analysis resulting in accurate event bulletins. It will be the archive for all data as well as a centre for documentation, expertise and training. Therefore the IDC will be the most valuable interface to the national data and analysis centres. The ambitious effort of the participating states to operate and maintain the verification system and a centre with over 200 international civil servants will have an estimated yearly budget of 85 million US$.

A major part of the Treaty is devoted to the unlikely event of an on-site inspection. The reason for the detailed treatment of OSI is its intrusiveness. The recent events surrounding the inspection of Iraq by the United Nations Special Commission on Iraq (UNSCOM) are a living example. The goal of an OSI is to find the 'smoking gun', i.e., the remains of a nuclear explosion. In order to be assured that the evidence is still in place, time is of the essence. The violator may, for example, remove all the equipment needed to execute a nuclear explosion, or the low level seismicity connected to a large explosion in the underground may have died out because of its short time scale.

So, these counteracting forces challenge the OSI-regime: intrusiveness versus timing. Specifically, the inspection area is estimated to be as large as 1000 square kilometres, which is the accuracy of an epicentre determination with the seismic network of the IMS. The applied geophysical methods will gradually step up in intrusiveness as the OSI progresses. It will start with passive seismic monitoring and the use of photo and video. Later, ground samples will be analysed and, finally, drilling can be applied to find whatever is left of the presumed explosion.

The knowledge of actually executing an OSI is in an emerging state. During the negotiations and even in the preparatory phase the OSI-regime was hotly debated; states like Israel, US, RF and China obviously fear the intrusive character of an OSI. Israel is especially cautious; their horror scenario is to be falsely accused of a nuclear test explosion after which an OSI will disclose their national secrets, including nuclear capabilities, thereby favouring their neighbour states.

Geophysical backgrounds • The four monitoring techniques form the first hardware link in the chain of the verification system. The link between the explosion (or other geophysical source) and the detector is governed by the geophysical characteristics of the source and the medium. These will be different in the three environments of interest: atmosphere, hydrosphere and tectonosphere, i.e., the solid earth.

Atmospheric tests • A nuclear explosion in the atmosphere can be detected by a large number of techniques, all connected with the physics of the source itself. Examples are detection of sound waves, radio nuclides, electro-magnetic pulse, optical flash, and even disturbance of the ionosphere. The Expert Groups during the negotiations in Geneva chose the detection of radioactive deposits in the form of small dust particles and noble gases as well as the detection of infrasound.

High volume samplers will detect the radioactive debris. These devices force a large volume of air through filter paper and will collect aerosol particulates distributed over large distances by wind. The collection phase can last for a few days after which the filters are renewed and the old filters are analysed in specialised laboratories using gamma ray spectroscopy. In this process the fingerprint of radionuclide composition is determined. Under very

A nuclear explosion can be detected by techniques, connected with the physics of the source

wet circumstances the particulates could be washed out by rain and therefore destroy the detection capability of the network. This was the main reason for deciding that also noble gas detectors should be deployed. The noble gas detector absorbs mainly xenon isotopes on a finely divided active-charcoal bed at low temperature. After the collection phase the gases are very carefully extracted at higher temperatures and analysed. The noble gas technique could in principle also be of use in detection of underground nuclear explosions, as some radionuclides may leak to the surface after the event.

The detection of radionuclides is the only technique in the IMS with the possibility of positive identification of a nuclear explosion and is therefore indispensable. The serious drawback of the technique is the rather long time scale of the transport mechanism through the atmosphere and the long time the analysis needs before proper statistics is reached. Another drawback is the poor location accuracy that can be achieved by back-tracking the atmospheric transport path.

To counteract these difficulties the monitoring of the atmosphere is supplemented by another technique: the detection of infrasonic waves. An infrasound detector is used to detect the sound wave coming from the initial shock wave of the explosive source. The shock wave itself, just after the explosion, is a very steep high frequency and non-linear pressure change. At some distance however, after dissipative processes in the atmosphere have absorbed the high frequencies, a low frequency signal remains, which can travel over thousands of kilometres without noticeable attenuation. The atmosphere acts as a gigantic waveguide in which the signal is trapped in one of the two low-velocity layers situated in the lower stratosphere and the lower thermosphere.

The signal is detected by a small four-element array of very low frequency microphones or microbarographs. In order to minimise the effects of pressure variations by turbulent wind each of the elements of the array is equipped with a noise reducer, i.e, a device that integrates the pressure variations over a large area of over 50x50 square metres without affecting the coherent low-frequency sound wave (Figure 2). In total 60 infrasound arrays are foreseen in the IMS and they should provide a timely and accurate location

The atmosphere acts as a gigantic waveguide

of an atmospheric event. Other sources of infrasound may produce false alarms such as mining explosions, meteors, bolides (exploding fireball meteors) and sonic booms caused by military airplanes. Other signals may hinder the detection of infrasonic waves such as the long wavetrains caused by interference of oceanic water waves and infrasound generated by mountains as a result of strong winds.

At the time of the negotiations very few research groups around the world were active in this field of physics. Quite by accident the Seismology Division of KNMI had active knowledge of infrasound detection because of the concern among the Dutch public to distinguish vibrations caused by infrasound due to military airplanes from vibrations caused by earthquakes. This problem mainly occurred in the northern part of the Netherlands where unexpected earthquakes were felt due to the extraction of natural gas in the underground. Internationally, most of the infrasound research was terminated before 1980 when it became clear that no quick solution was expected in the field of arms control. Currently, research at KNMI still focuses on CTBT-issues

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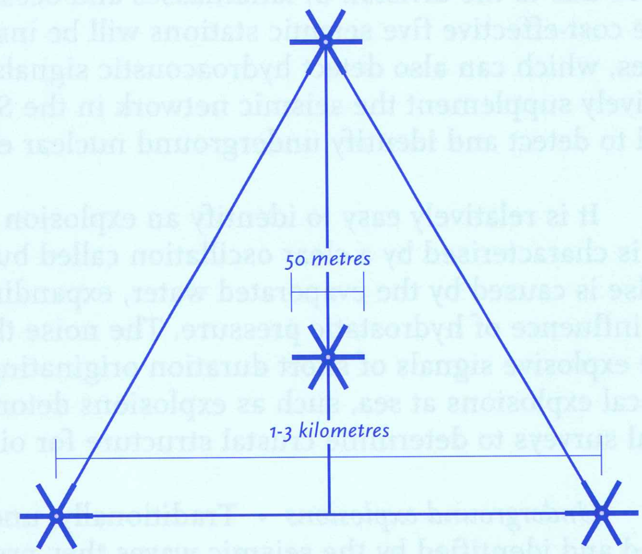


Figure 2. Layout of a typical infrasound array.

and the detection of sonic booms in order to assist the Royal Dutch Airforce with noise abatement.

Underwater nuclear explosions • Due to the very favourable transport properties in the large ocean basins the detection of explosions in the oceans is very effective. The sound velocity minimum in the oceans, along which the sound waves are trapped, is called the SOFAR channel (Sound Fixing And Ranging). The velocity minimum is caused by two competing effects in temperature and in pressure. Just under the surface mixed layer at 50 to 150 metres depth lies the seasonal thermocline layer in which the temperature and therefore the sound speed decreases with depth. Below the main thermocline and extending to the seafloor lies the deep isothermal layer with an almost constant temperature of 4°C. Here the sound speed increases again because of the increasing pressure.

The SOFAR channel is thus located between the thermocline and the isothermal layer at an average depth of just over 1 kilometre. The SOFAR channel effectively limits the geometrical spreading of underwater sound to two dimensions, resulting in an extremely low attenuation of sound waves in the oceans. Explosions of only a few kilograms of chemical explosives can be detected over thousands of kilometres. Experiments have demonstrated this extraordinary fact. Many states make use of it to detect and locate submarines. Therefore, during the negotiations, a number of states adhered to the view that a sensitive hydroacoustic network poses a threat to their national marine security. The fact that only six hydroacoustic installations are to be built ensured these states that no real national security issue was at stake. Of these six installations two are donated by the US as former missile impact location systems (MILS).

The hydroacoustic network of course focuses on the Southern Hemisphere due to the division of landmasses and oceans over the globe. In order to be cost-effective five seismic stations will be installed on islands with steep slopes, which can also detect hydroacoustic signals. These stations will also effectively supplement the seismic network in the Southern Hemisphere designated to detect and identify underground nuclear explosions.

It is relatively easy to identify an explosion under water because the signal is characterised by a clear oscillation called bubble-pulse. The bubble-pulse is caused by the evaporated water, expanding and contracting, under the influence of hydrostatic pressure. The noise that might influence the system are explosive signals of short duration originating from earthquakes and chemical explosions at sea, such as explosions detonated during geophysical surveys to determine crustal structure for oil and gas exploration.

Underground explosions • Traditionally, underground explosions are detected and identified by the seismic waves they produce. The solid earth provides a good medium for long-range seismic wave propagation. The numerous earthquakes that occur around the globe form the noise in this part of the detection system. Even the number of 20 per day of relatively modest earthquakes with a magnitude of 4 is large. It is expected that the seismic network of the IMS will have a detection and location capability of magnitude 3.5 for most parts of the world.

This task of characterising so many seismic events can be accomplished only by a high degree of automatic signal processing. Especially in the first five years the auxiliary stations will provide additional data for a more accurate location. Later, when the network is calibrated, the influence of

Characterising so many seismic events can be accomplished only by a high degree of automatic signal processing

these stations will diminish. Calibration is the accurate determination of travel times beyond the traditional spherical velocity model of the earth that are normally used in seismological studies. The aim is to locate a seismic event within an area of 1000 square kilometres in order to allow an OSI to be effective.

In the past, a great deal of effort has been invested in the detection, location and identification of underground nuclear explosions. This gave the assurance that a CTBT could indeed be verified. At the same time this research supported and stimulated seismology enormously. Seismology will benefit from the homogeneous world-wide network of 50 + 120 stations that are built up at this stage.

A preview of the verification system • Although the basic ideas of the verification system have been developed during the period that nuclear testing was common, little experience is still available on a randomly located nuclear test. Most of the nuclear tests were conducted at a small number of test sites around the world: Nevada, Semipalatinsk, Novaya Zemlya, Lop Nor and Mururoa. In this respect the test by India and Pakistan may contribute positively. This fact, together with the announcement of both states that they will abstain from further testing in the future, is perhaps the good news connected to the nuclear events in May 1998. The bad news is of course that both states are reacting to a long-lived conflict between them with nuclear threats.

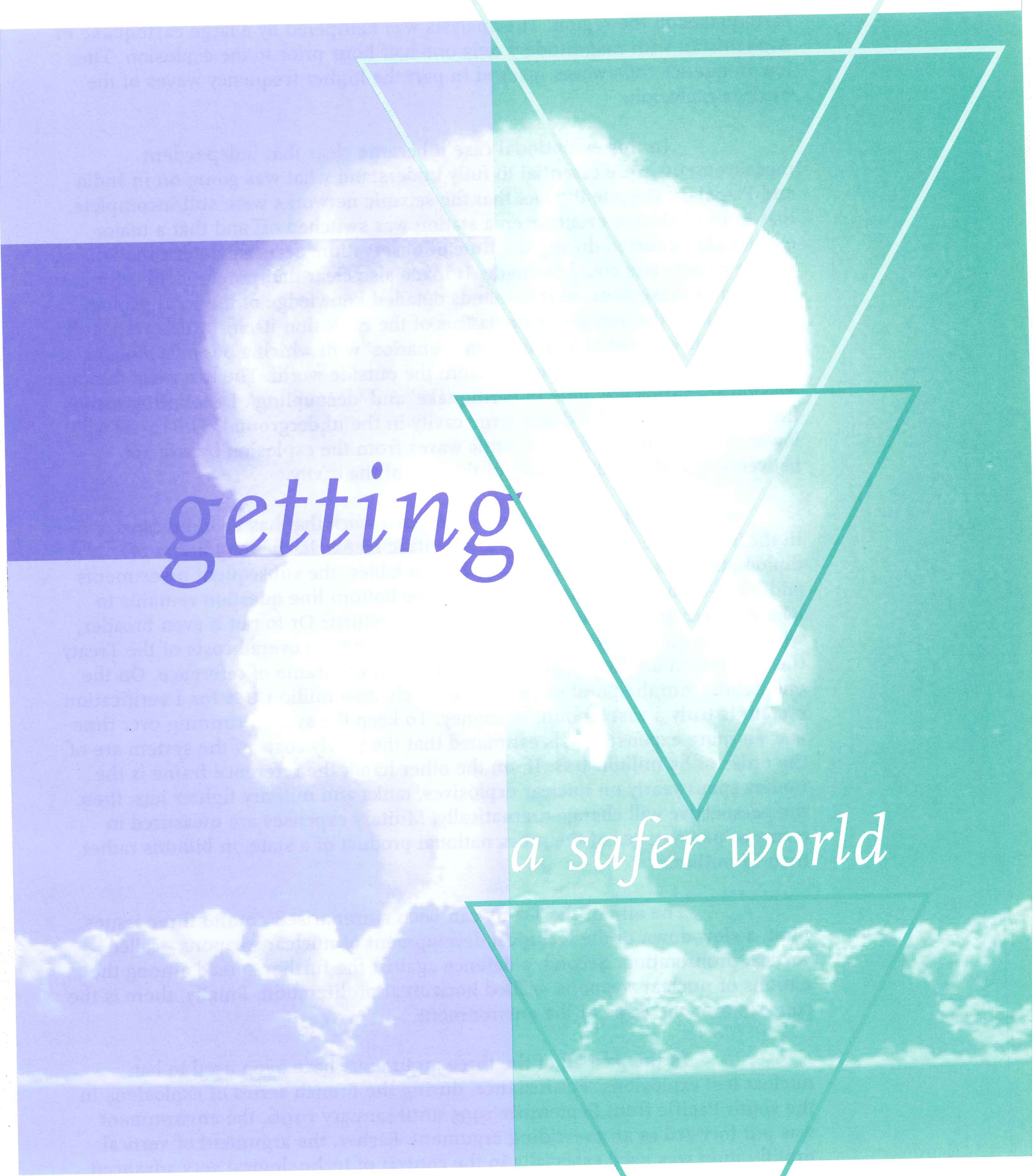
The tests on 11 May 1998 were conducted in the Rajasthan desert in the north-west of India. The argument used by the Indian government was the military 'adventurism' of Pakistan. The claim of the Indian government was that they had conducted three nuclear tests simultaneously at the Pokharan test site. Simultaneous testing has the advantage that one explosion cannot destroy nearby boreholes and that it obscures independent yield estimates by outside observers. The Indians claimed that the three explosions had yields of 43, 12 and less than 1 kt. The largest of the explosions was claimed to be thermonuclear. Two days later, on 13 May, India claims two other explosions of subkiloton size 0.6 and 0.2 kt . These explosions were probably detonated in a sand dune.

The very first explosion by India on 18 May 1974 had a yield of 8 kt, probably also at the Pokharan test site. Independent seismological evidence from the prototype IDC in Arlington indicate that the explosions on 11 May 1998 had a probable yield between 10 and 15 kt, far less than the Indian government claims. As to the possibility of a multiple source, researchers found no evidence. The signal had a striking similarity with the test of 1974. With respect to the explosions on 13 May 1998 no positive signal was recorded by seismologists world-wide. The IRIS - IDA (Incorporated Research Institutions for Seismology - International Deployment of Accelerometers) seismic station NIL located at Nilore in Pakistan recorded the shot on 11 May with a very good signal to noise ratio. The station is located 240 km north of the Indian test site. From the fact that the same station showed no signal at all of the second shot it can be concluded that the second explosions were no larger than 100-150 ton, given that they were fired in very porous and dry material: in a sand dune.

Independent yield estimates are important in order to judge the claims made by the Indian government with regard to their technological advancement. In this respect it should be noted that an explosion of 10-15 kt is probably not a thermonuclear shot. With respect to claims for subkiloton explosions these very low-level nuclear tests require a technical advanced state of development. The determination of the location of the explosions is a good test of the accuracy with which one has to deal in the case of an OSI. In all cases where signals were received the epicentre determination lived up to the expectations, although the network was still incomplete.

The Pakistan test followed soon after the Indian tests and showed that Pakistan had several nuclear devices ready. On 28 May 1998 the PIDC (Prototype International Data Centre) in Arlington as well as the USGS (United States Geological Survey) detected the Pakistani nuclear tests with their routine analysis of the data. Pakistan announced that the total yield of the tests was 40-45 kt, while the largest of the explosion was 30-35 kt; the other explosions were low yield and of tactical nature. Independent determination by seismologists of the yield of the explosion indicated a lower value of 9-12 kt. The Pakistani seismic station NIL was not operational during the testing period. On 30 May another test was announced. Independent yield estimates indicated 4-6 kt. The location of the second set was 100 km south-west from the first. This was determined by an accurate technique called Joint Hypocentre Determination (JHD) which makes use of data from previously recorded

getting a safer world



earthquakes in the region. The analysis was hampered by a large earthquake in Afghanistan with magnitude 7 only one half hour prior to the explosion. The low frequency coda waves masked in part the higher frequency waves of the nuclear explosion.

In this exceptional case it became clear that independent measurements were essential to fully understand what was going on in India and Pakistan. Despite the fact that the seismic networks were still incomplete, that in the Pakistan events even a station was switched off and that a major earthquake occurred during the time of observation, accurate determinations of source parameters could be made. It made also clear that proper yield estimates are hard to make because it demands detailed knowledge of the local geology and details of the actual circumstances of the explosion itself. In this respect it is still worthwhile studying 'evasion scenarios' with which a possible violator of the Treaty can hide the explosion from the outside world. The two most famous evasion scenarios are 'hide in earthquake' and 'decoupling'. Decoupling means that the explosion is fired in a large cavity in the underground. The cavity will lower the amplitudes of the seismic waves from the explosion by a factor between 10 and 100 depending of the size of the cavity.

Conclusion • After all the hard work that has been invested in the Treaty, the millions spent in scientific research, the long hours of diplomats and scientists at the negotiation tables, the subsequent investments and build-up of the verification system, the bottom line question remains to be answered: are we getting a safer world in return? Or to put it even broader, what are we gaining from the Treaty? Concerning the overall costs of the Treaty the conclusion on the budget level depends on the frame of reference. On the one hand, from the point of view of research, 200 million US$ for a verification system is truly a vast amount of money. To keep the system running over time is even more expensive; it is estimated that the yearly costs of the system are of the order of 85 million US$. If, on the other hand, the reference frame is the money spent yearly on nuclear explosives, tanks and military fighter jets, then the perspective will change dramatically. Military expenses are measured in terms of percentages of the gross national product of a state, in billions rather than in millions.

The aim of the Treaty can been summarised around three issues. First, a slow-down of the technical development of nuclear weapons - called vertical proliferation. Second, a defence against the further spread among the nations of nuclear weapons - called horizontal proliferation. Finally, there is the concern over the issue of the environment.

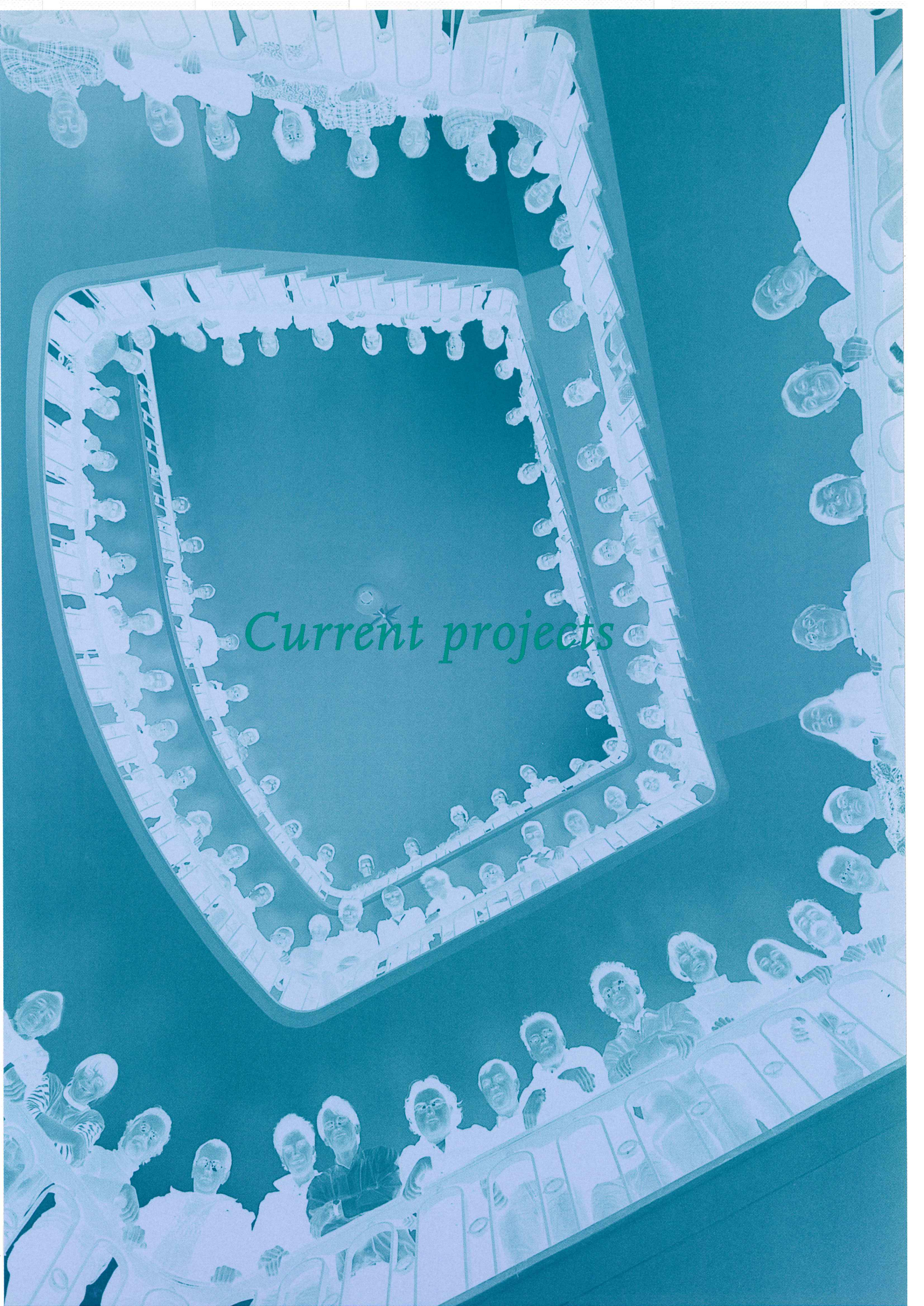
In the past all of the three arguments have been used to ban nuclear test explosions. For instance, during the French series of explosions in the south Pacific from September 1995 until January 1996, the environment was put forward as an overriding argument. Earlier, the argument of vertical proliferation was used especially in the context of technological very advanced research in the US aiming to develop a nuclear-explosion-pumped X-ray laser, enhanced electromagnetic pulse weapons, microwave weapons and even mini and micro nuclear explosives. It was a wide-spread feeling that such weapons lower the threshold for actually using them. The question that was raised by a group of third world countries immediately after such arguments became public was: Is the US not already in a position to develop such weapons on the basis of computer modelling and should this type of computer models not be

We cannot un-invent the nuclear technologies that have been used in the design of nuclear weapons

banned as well? The answer to this question is implicit in the CTBT: No, only test explosions are banned and not the further technical developments including the research to safely maintain a nuclear weapons arsenal, which is called in fatherly terms 'Stockpile Stewardship'. The argument of horizontal proliferation was heard after the Iraq and North Korean crisis. Also the India-Pakistan crisis is a recent example. Despite the Non-Proliferation Treaty a fairly large number of states have contemplated in the past the development of nuclear explosives.

We cannot un-invent the nuclear technologies that have been used in the design of nuclear weapons, nor can we stop scientific and technological advances in this area of research. At best the CTBT can slow down such developments and put forward an international norm against nuclear testing. At the same time, as a logical consequence, the CTBT and its verification regime will possibly lead a long life. In terms of spin-off the IMS will constitute the most coherent and advanced network of seismic stations the world has ever known. The other networks are also unprecedented and will lead to new geophysical research in the areas of hydroacoustics and infrasound. The network of radionuclide stations will also be an early warning system against nuclear pollution of the atmosphere. In the future, a number of these technologies will undoubtedly be set aside and be replaced by satellite monitoring technologies that are too expensive at this moment to use for CTBT monitoring. After all, a positive balance.

Current projects



Predictability Research

General • The Predictability Research Division is involved in strategic and theoretical research on the dynamical properties of the climate system. The research is concentrated on the predictability and natural variability of weather and climate. A substantial part of the Division's funding comes from external agencies.

The research can be summarised in three themes:
1 Skill prediction and ensemble forecasting.
2 Predictability and natural variability of climate.
3 Dynamics of weather and climate.

The Division has been and still is involved in international projects funded by the EU. One of these projects is DICE (Decadal and Interdecadal Climate Variability: Dynamics and Predictability Experiments) which ended in 1998. The results have been published in a book, edited by A. Navarra. A new project has started, called SINTEX (Scale Interactions Experiments). In SINTEX the interaction between various time scales of natural variability of the climate system is studied. A joint research project with the University of Louvain-la-Neuve, Belgium, was started. In this project the role of arctic sea-ice in generating climate variability on various time scales is studied. The co-operation with ECMWF (European Centre for Medium-Range Weather Forecasts) on the development of an ensemble prediction system (EPS) for the early medium range has proved to be fruitful. A targeted ensemble prediction system (TEPS) has been developed using the Centre's weather prediction model. In TEPS we concentrate on predicting the uncertainties in important but sensitive weather parameters, like rainfall and sunshine, for the western European area. Recently, the Netherlands has joined forces with Norway and Italy to further develop TEPS in close co-operation with ECMWF.

In climate modelling we co-operate with the Oceanographic Research Division. We are jointly developing a second generation climate model of intermediate complexity by coupling the LSG model (Large Scale Geostrophic model) of the MPI (Max-Planck-Institute) for Meteorology in Hamburg to the quasi-geostrophic atmospheric model that was developed in the Predictability Research Division. A joint project with the Department of Mathematics of the University of Utrecht, funded by NWO (Netherlands Organisation for Scientific Research), has produced its first results. The project is called 'A conceptual approach to climate variability' and is concerned with the fundamental properties of simple climate models. Two PhD students are involved in this project. Another project, called 'Patterns of low-frequency climate variability: a model-paleodata comparison', is a collaboration with prof.

H. Hooghiemstra (of the University of Amsterdam) who is an expert on climate reconstructions based on paleo proxy data. In this project a post-doc is involved for a period of three years. The project is an attempt to contribute to the reconstruction of climate variability on decadal to centennial time scales during the last 2000 years by interpreting existing paleo data sets. Within the context of CKO (Netherlands Centre for Climate Research) we co-operate with RIVM (National Institute of Public Health and the Environment). In this project we aim at integrating our climate model ECBILT (KNMI General Circulation Model) with IMAGE (Integrated Model for the Assessment of the Greenhouse Effect). We actively participate in the Dutch CLIVAR programme (Climate Variability and Predictability Research) called CLIVARNET. Within the context of this NWO programme a PhD student will be funded to work on the problem of explaining the observed decadal time scale variability in the North Atlantic Ocean.

Skill prediction and ensemble forecasting

Mureau, Hersbach, Oortwijn, Opsteegh

Ensemble forecasting

The skill of a weather forecast varies from day to day. Information on the skill can be retrieved from the probability density function (PDF) of the forecast errors. Ensemble prediction systems are the most straightforward tools to generate such probability density functions. In an ensemble prediction system the same forecast is repeated a large number of times (say 50 times) from perturbed initial conditions. In order to limit the size of the ensemble, perturbations are calculated that have optimal growth characteristics: so-called singular vectors. The singular vectors of which the eigenvalues are largest give the directions in phase space in which initial errors grow fastest during a predefined integration period and for a predefined area of interest. The area of interest can be the whole globe, but can also be a more limited area like Europe. Singular vectors which are computed for a limited area are called targeted singular vectors. In order to measure error growth properties a metric is needed and usually total energy is chosen for this purpose. The properties of the singular vectors do, however, depend on this choice.

In a joint project with ECMWF an ensemble prediction system has been developed for the short and early medium range (up to day 5). This system is different from the operational ensemble prediction system of ECMWF in that it makes use of targeted singular vectors for the European area. The resulting ensemble prediction system, called TEPS, has the major advantage that the full PDF of the forecast errors for Europe is generated more accurately. The system is an extension of the KNMI ensemble prediction system (KEPS) where the PDF of the forecast errors is constructed directly from the evolved singular vectors. This calculation is exact in the range where error growth is linear. The KEPS integrations were done with a 3-layer T21 quasi-geostrophic model, without parameterisations of the physical processes. However, the TEPS integrations are performed with the full ECMWF model. The singular vectors are generated with the T42 adjoint/tangent linear model, whereas an ensemble - consisting of 50 members - is integrated with the full T159 ECMWF nonlinear model.

The experiments have shown that an optimisation of the perturbations in terms of total energy results in the winter season in a modest improvement of TEPS with respect to the ECMWF EPS. However, in the autumn and spring cases that we have studied, the impact of TEPS is significantly positive. This is caused by a better performance of TEPS with respect to extreme events that have a low probability. As a result, the range of cost/loss ratios for which a user has benefit, is substantially larger for TEPS as is illustrated by Figure 1. The impact is maximal for day 2 and 3 and decreases thereafter.

A manuscript has been submitted to Monthly Weather Review. Recently it was decided that ECMWF will run TEPS in a quasi-operational mode twice a week. Several European countries have joined forces in further developing the TEPS concept.

In the foregoing we used a metric based on total energy to measure differences between atmospheric fields. However, total energy is not very appropriate to measure subtle differences in flow patterns, like the exact position of a front with its associated rain band. The main objective of TEPS is to provide the forecaster with short-term information about the uncertainty in crucial weather parameters like rain, cloudiness, timing of a cold front passage, the exact position of a storm and its associated wind field, etc. For the near future it is planned to calculate alternative perturbations by choosing a metric that ensures that the perturbations provide optimal information on the uncertainty of the weather parameters that we are interested in.

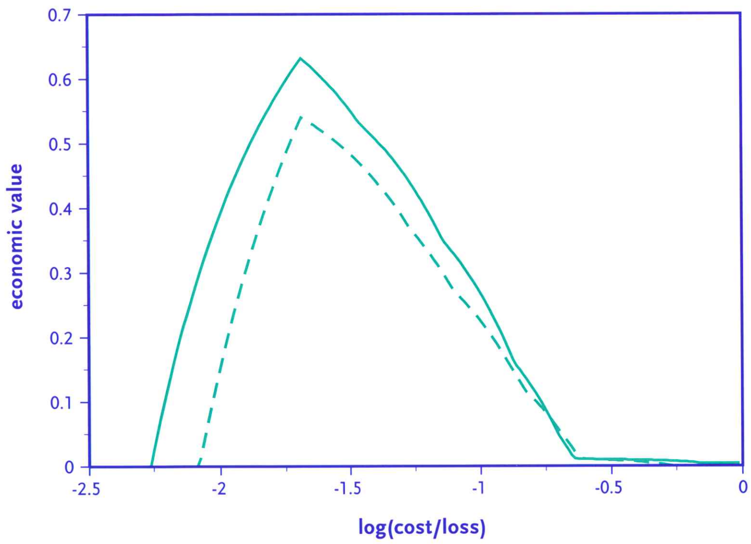


Figure 1. In case of the occurrence of a hazardous event certain people (users) will face economic loss. By taking proper precautions, this loss can usually be prevented. However, these precautions are associated with some cost. It is the objective of each user to minimise the average expenses. This can be achieved by stipulating a strategy, based on the available information, that decides when to take precautions and when to accept the risk of a loss. The economic value of the information used can be defined in such a way that it is zero in case the information is only climatological, and equal to one in case the information consists of a perfect forecast. In practice, the value is somewhere in between. The economic value strongly depends on the cost/loss ratio of the user. It appears that especially for extreme events - such as more than 10 mm precipitation in 12 hours (which occurs about once a month) - the economic value of TEPS (solid curve) is higher than that of EPS (dashed curve). In addition, the class of users who benefit from the forecast system is larger.

Several lectures have been organised for the forecasters to inform them about the status of EPS and its potential use in operational practice. It is planned to interpret the probabilistic information in terms of a categorical forecast by applying a cost/loss analysis to the predicted PDF.

Predictability of blocking

A project on the predictability of the onset of blocking (BL) and strong zonal flow (SZF) regimes has ended in March 1998 with the completion of a PhD thesis by Oortwijn entitled 'Predictability of Weather Regime Transitions'. Flows with high and low sensitivity with respect to the initial conditions for onset of BL and SZF regimes have been analysed. Experiments have been performed with a quasi-geostrophic model and its tangent and adjoint versions. The flows with a high sensitivity show an intensified jetstream to the west of a diffluent flow. The presence of this diffluence amplifies the growth of perturbations and gives them a typical dipole-like character. The flow patterns which are less sensitive are more zonal and weaker. The diffluence of the flow also results in an asymmetry between sensitivity for BL and SZF onset in the medium range. Nonlinear feedback mechanisms increase sensitivity toward BL and decrease sensitivity toward SZF.

The three-dimensional evolution of a perturbation which is optimal in triggering a transition to BL or SZF was studied as well. Barotropic and baroclinic mechanisms were distinguished by decomposing the fields in terms of vertical modes. The evolution can be divided in two phases. During the first rapid phase, the growth is strongly non-modal and baroclinic. After that, the growth is still non-modal but not as strong and almost barotropic. The two-dimensional barotropic evolution was studied using a WKB (Wentzel, Kramers and Brillouin) approximation. This approach provided insight into the terms which are important for the development of the optimal transition perturbations. Two papers on this subject have appeared in the Journal of the Atmospheric Sciences. A third one will appear soon.

Predictability and natural variability of climate

Haarsma, Weber, Selten, Wang, Crommelin, van Veen, Achatz, Timmermann, Goosse, Lenderink, Opsteegh

Modelling climate variability

The research on climate variability is centred around ECBILT, a coupled atmosphere/ocean/sea-ice model of intermediate complexity developed in the Predictability Research Division at KNMI. In the present configuration of ECBILT the atmosphere is represented by a T21 quasi-geostrophic three-level model with parameterisations for the diabatic processes. The ocean model is more or less conventional except that it has a coarse grid, a flat bottom and the wind-driven gyre circulation is assumed to be in equilibrium with the time-mean wind-forcing. The sea-ice model is a zero-layer thermodynamic model. The model is very efficient. It uses 0.2 hr CPU (Central Processing Unit) time for a one-year integration on a Silicon Graphics Power Indigo. The model is integrated without flux corrections. The simulated climate in the extratropics is reasonably realistic, with a good qualitative agreement with observations of the location of the storm tracks and the dominant patterns of variability. Due to its coarse resolution the intensity of the variability is underestimated. The model and its performance have been documented in a paper published in Tellus.

With ECBILT we have investigated the interannual to decadal variability in the North Atlantic. The dominant patterns of covariability between sea surface temperature and 800 hPa geopotential height and their preferred time scales show good qualitative agreement with the observations. The physical mechanisms of the simulated North Atlantic decadal variability have been investigated by performing many 1000 year integrations in which various feedback processes have been switched on and off. A result of such an integration can be seen in Figure 2. The picture which has emerged from these analyses is that North Atlantic decadal variability is strongly associated with a sub-surface

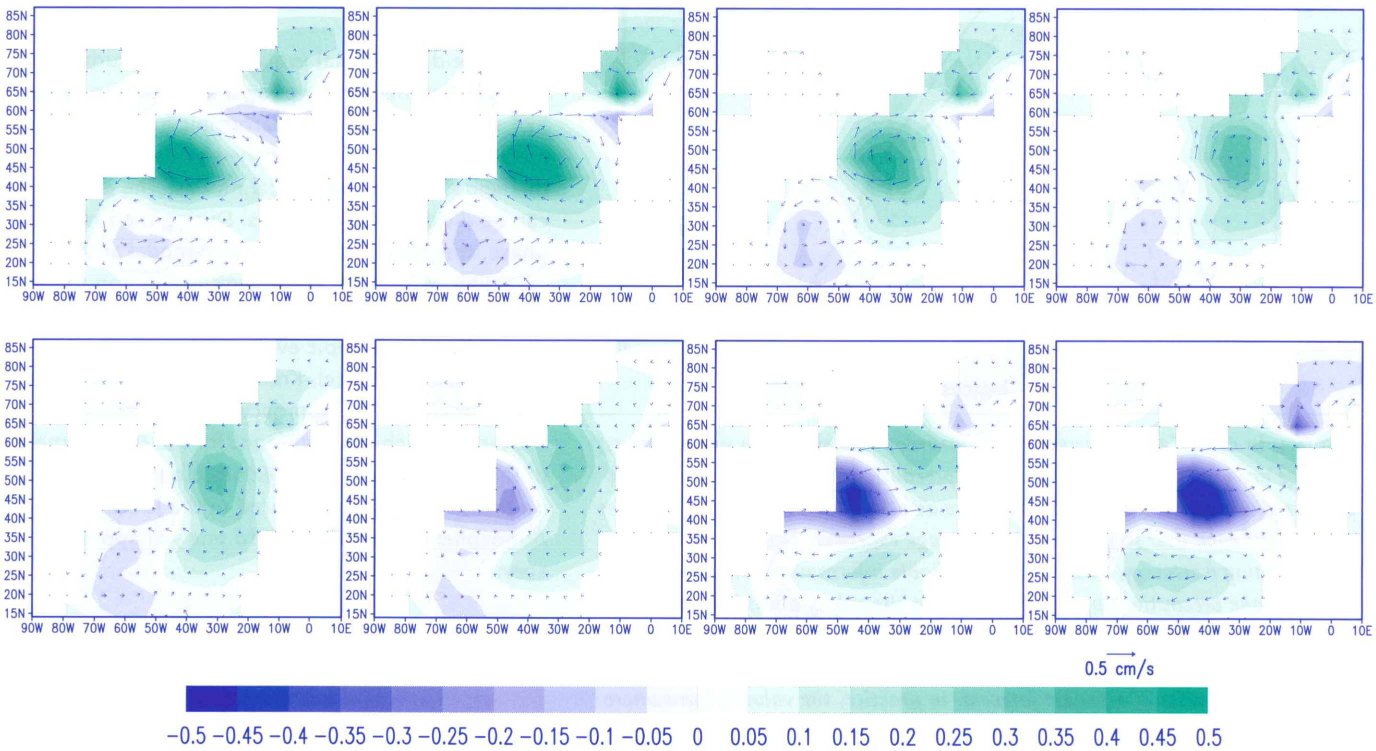


Figure 2. Time series of winter anomalies of sub-surface (80-300 m) ocean temperatures [K] filtered to optimally show the 16-18 year oscillation in the climate model ECBILT. Arrows denote the filtered anomalous ocean sub-surface currents [cm/s]. First plot corresponds to year 395 of the 1000 year model simulation. Time step between the plots is one year.

oceanic mode. This mode is generated by the dominant modes of variability in the atmosphere; its time scale is set by the ocean. Horizontal advection of salinity appears to be essential. The feedback from the ocean to the atmosphere is not crucial for either the structure or the time scale of the North Atlantic sub-surface oscillation. This feedback, however, strongly enhances the intensity of the decadal variability. A paper will soon appear in the Journal of Climate. We will continue this research in a new PhD project. The underlying mechanisms of North Atlantic decadal variability, including the role of salinity and the existence of teleconnections between Pacific and Atlantic, will be the subject of this project. With a similar strategy we have analysed the Antarctic Circumpolar Wave (ACW) which is also simulated qualitatively well by ECBILT. The basic mechanism appears to be similar to that of the North Atlantic decadal variability. The main exception is the role of salinity which appears to be of minor importance for the ACW. A paper is submitted to the Journal of Climate.

Inspired by the renewed interest in the possible effects of modulations in solar irradiance on the Earth climate we have conducted with ECBILT a series of experiments in which a variable solar irradiance is imposed for a range of frequencies and amplitudes. For realistic amplitudes solar forcing dominates over internal variability in global mean surface air temperature beyond decadal time scales. Evidence is found for interactions between climate variations with different time scales. A weak 22-yr solar (0.5 Wm^{-2}) irradiance variation excites a significant peak with a 70-yr period in the global mean surface air temperature. On the regional scale the internal variability dominates at all time scales. Patterns of internal variability and their associated variance are robust for a variable solar forcing. The temporal spectra, however, are sensitive to such forcing. A paper on these results entitled 'Solar-induced versus internal variability in a coupled climate model' will shortly appear in Geophysical Research Letters. At present we are investigating the underlying dynamics of these time scale interactions.

Due to its computational efficiency also the investigation of very long time scales lies within the range of possibilities of ECBILT. We have completed a 40000 year integration. The model displays quasi-periodical behaviour on a time scale of about 10000 years, characterised by rapid transitions between two quasi-equilibrium solutions. As such it reaffirms the experiments with ocean-only models which suggest the possibility of rapid transitions in our climate. A paper on these results is in preparation. It is planned to repeat this experiment with a second generation version of ECBILT.

The predictability of climate on decadal time scales has been investigated by performing ensemble integrations with ECBILT of 30 years from slightly perturbed initial conditions. The central questions are:

1 What are the uncertainties in a 30-year climate prediction, with the assumption that ECBILT is a perfect model of the climate system?
2 To what extent do these uncertainties depend on the initial conditions?
3 Does the existence of the decadal mode in the North Atlantic as simulated by the model lead to enhanced predictability of the climate over Western Europe?

A publication on this research is in preparation.

In collaboration with RIVM a second generation ECBILT model is being developed. This project is partly funded by NOP (National Research Programme on global air pollution and climate change). For the atmosphere this consists of a new radiation scheme and dynamic cloud scheme. The radiation scheme is a linearisation of the radiation scheme of ECHAM4 (Hamburg version (number 4) of the ECMWF model). The cloud scheme is based on simple parameterisations of cloud cover by prognostic model variables like relative humidity and vertical velocity. The radiation scheme now also includes the possibility of variations in trace gases like CO_2. At present, the new version of the atmosphere model is being tuned. The ocean model will be replaced by either the LSG model of the MPI in Hamburg or the CLIO model (Coupled Large-Scale Ice Ocean model) of the University of Louvain-La-Neuve, Belgium. The latter model is especially suitable for studying the climate at high latitudes due to its advanced sea-ice model. The new version of ECBILT will be used by RIVM for scenario studies. In order to simulate the large-scale aspects of tropical variability, the quasi-geostrophic equations will be replaced by the primitive equations.

In October 1997 Lenderink completed his PhD thesis entitled 'Physical Mechanisms of Variability of the Thermohaline Circulation'. Two papers of this thesis have already been published in the Journal of Physical Oceanography. A paper entitled 'On the mechanism of decadal oscillations in a coarse resolution ocean model' will shortly appear in Atmosphere-Ocean. In this paper a detailed analysis is made of the mechanism of decadal oscillations under mixed boundary conditions. The paper emphasises the dynamic response of the ocean circulation to changes in convective activity, especially the associated salt feedback.

A study on the sensitivity of a simplified coupled model to the oceanic vertical diffusion coefficient was concluded. The sensitivity of the coupled model was compared to the sensitivity of an ocean-only model forced by mixed boundary conditions as well as by modified boundary conditions. Differences in the response were extensively analysed in terms of the feedbacks present in the different model versions. An interesting result is that the strength of the meridional overturning circulation does not depend on the type of boundary conditions used. A publication has appeared in Climate Dynamics.

Reconstruction of past climate

The project 'Patterns of low-frequency climate variability: a model-paleodata comparison', funded by NOP, started on 1 April 1997. This is a collaboration of the Predictability Research Division and the Climate Analysis and Scenarios Subdivision with prof. H. Hooghiemstra of the Hugo de Vries Laboratory of the University of Amsterdam. Empirical knowledge of natural climate variability on time scales of decades to several hundreds of years is at present very limited. This project aims at deriving spatio-temporal patterns of variability from paleodata and comparing these to patterns derived from a 1000-year control integration of the ECBILT climate model. Mechanisms underlying the observed large-scale patterns of variability will be analysed using model simulations. As the sensitivity of different paleo indicators to temperature is season-specific, paleo data sets are typically seasonally inhomogeneous. As a first step, we examined the implications of this using early-instrumental European temperature records of 200-300 years length. We find that, at least in Europe, low-frequency variability patterns are clearly season-dependent, see Figure 3. Opposing seasonal tendencies result in a weak variability on time scales larger than 50 yr in the annual-mean data. Winter temperatures show a monotonic warming trend at almost every location, while summer temperature variations seem to exhibit a preferential time scale in the range 60-80 yr. These results stress the necessity of using seasonally homogenous datasets for reconstructing low-frequency variability patterns. A publication has appeared in Geophysical Research Letters.

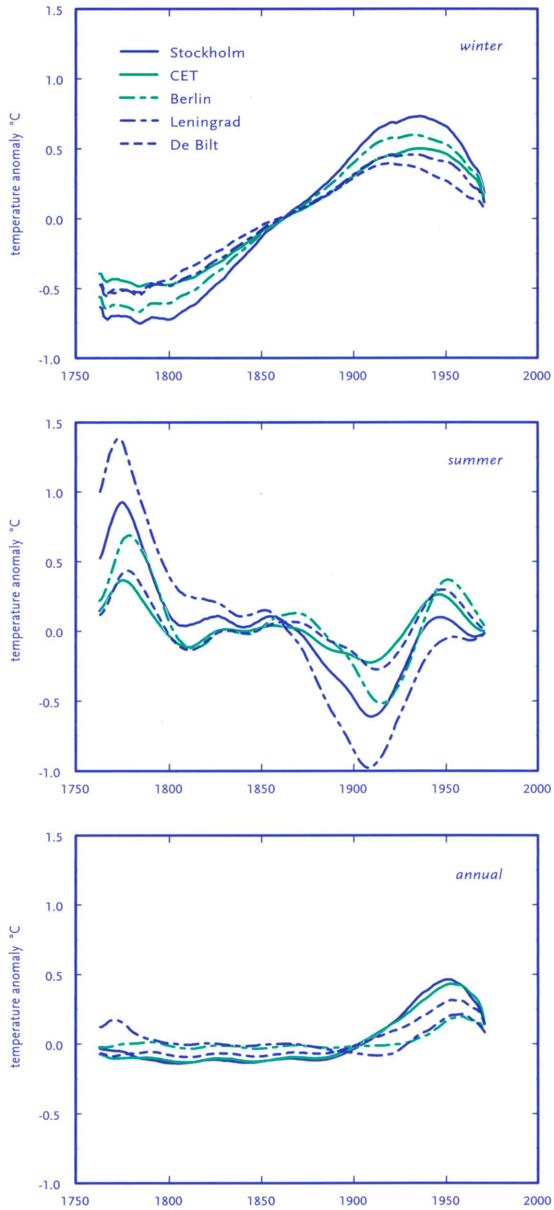


Figure 3. Low-frequency components (τ >50 yr) in 5 early-instrumental timeseries of winter, summer and annual-mean temperature, as obtained by multichannel singular spectrum analysis (MSSA) with a 50-yr window. (CET is an abbreviation of Central England Temperature.) The long-term mean is removed.

As the next step a paleo network covering the North American and European domains was studied using a combination of statistical techniques including principal component analysis and uni- and multivariate singular spectrum analysis. On time scales longer than 50 years two modes of temperature variability were identified, one on multidecadal and one on centennial time scales. The first mode is oscillatory, with a time scale in the narrow range 60-80 yr. This mode is statistically significant (against red-noise surrogates). Its geographic shape suggests a connection to the North Atlantic Oscillation (NAO); a relation with solar forcing could not be detected. The second mode (on time scales larger than 100 yr) is most pronounced at high latitudes. The interpretation of this mode is difficult as its large-scale pattern is not stationary and no single time scale is evident. Although it is not possible to assess the effect of seasonality in a rigorous manner from the present set of proxy data, it appears that both low-frequency modes of temperature variability are season-specific in Europe. On the other hand, there is no indication that low-frequency variability in North America depends on season. A publication is in preparation. In the second phase of the project these results will be compared with spatio-temporal patterns derived from model simulations.

A study has started into the applicability of ECBILT to the simulation of past climates and rapid climatic transitions. The solar radiation code was modified, so that orbital variations can be taken into account. Simulations are done in coupled mode. Both changes in mean climate as well as climate variability, with emphasis on rapid transitions, will be studied for varying orbital parameters and surface boundary conditions.

Low-order climate models

A joint research project with the Department of Mathematics of the University of Utrecht and the Institute for Atmospheric Physics at Rostock University, Germany, was started in 1997. The aim is to gain more insight into the large-scale behaviour of the atmosphere and of the coupled ocean-atmosphere system using dynamical systems theory. For this purpose simple (i.e. low-dimensional) models are needed that allow for detailed mathematical analysis. The complex, high-dimensional models that are most commonly used in atmospheric and climate research are too complex to be analysed in this way - only statistical research can be done on them. By considering low-dimensional models a certain degree of realism is lost; however, this loss will hopefully be outweighed by a gain in conceptual insight.

Within the framework of this project, three different studies are carried out. The first focuses on a five-dimensional ocean-atmosphere model, consisting of the Lorenz 84 model (describing the atmospheric component) coupled to Stommel's ocean box model. The coupled model may be simple to the point of having merely metaphorical value, it nevertheless has some very interesting features. The Lorenz model describes a simplified jetstream being disturbed by waves and allows for chaotic behaviour. The ocean model mimics the thermohaline circulation and has two equilibria: a salinity-driven and a temperature-driven circulation. The coupling is such that the atmosphere drives the ocean, but anomalies in the ocean only weakly affect the atmosphere. Global stability and bifurcations of the coupled model were studied. In the coupled model intransitivity and intermittent behaviour were found. The intermittency (alternation of regular and chaotic behaviour) was looked at in detail and explained by the use of bifurcation analysis. The presence of different time scales in the model (stemming from the ocean and the atmosphere) influences the intermittency. It appears that the length of the periods with regular behaviour in the atmosphere is associated with the intrinsic time scale of the ocean in spite of the weak coupling of the ocean to the atmosphere. This happens for many different choices of the driving parameters and seems to be a generic property of the system. Whether this still holds in more complex atmosphere/ocean models (but which are similar to the five component model with respect to (1) the vast difference in intrinsic atmosphere/ ocean time scales and (2) the strength of the coupling) remains to be seen and will be the subject of further investigation. Results obtained during the past two years have been submitted to the Journal of Nonlinear Science. A follow-up paper will be submitted to Tellus.

In the second study the development of efficient models using empirical orthogonal functions (EOF's) and empirical optimisation (i.e. an empirical closure scheme) is considered. Work being done in the past by Achatz and Branstator involved a global two-layer atmosphere model describing only nondivergent flow which - on the basis of a highly reduced number of degrees of freedom - reproduces the climate, including its variability, of a complex GCM (General Circulation Model). Building on this know-how, present work focuses on the development of an empirical coupled ocean/atmosphere model. Reduced models of varying dimensions will be extracted from data of a large coupled model. The resulting algorithms shall be used for long-time climate simulations, providing new information on the ultra-low-frequency behaviour of the climate system.

Mathematical analysis of the efficient empirical model, or rather set of models, is the third element of the project. The model that results from the aforementioned work of Achatz and Branstator is scaleable, which means that its dimension can be chosen. A whole range of models is thus obtained, with dimensions varying from 2 or 3 to 990. With as few as 30 dimensions, the model has a remarkably good performance when it comes to climate simulation. The dependence of the dynamical properties on the model truncation is investigated, using bifurcation analysis. The robustness of certain dynamical features, e.g. a very strong 30-day peak in the EOF1-power spectrum, are key issues in this investigation.

Dynamics of weather and climate

Verkley, Pasmanter, Brands, Trieling, Vosbeek

An objective metric for atmospheric states

Research was carried out on a new metric, i.e., on a new 'distance' in the phase space of fluids. By means of this metric different states of the atmosphere, whose specification involves different fields (like temperature, density, humidity and velocity), can be distinguished in a way that takes the different nature of these fields into account. The description of this metric has been published in Physica A; a pilot project to check its use for atmospheric data has resulted in a KNMI Scientific Report and, based on it, the calculation of optimal perturbations leading to baroclinic instability has been undertaken.

Other applications of ideas and techniques coming from the theory of dynamical systems are:

1 The sixteen-year North Atlantic oscillation that is observed occasionally in ECBILT runs (see Figure 2) has been stabilised by imposing an atmospheric winter pattern once every sixteen years.
2 Slow, algebraic decay of fluctuations in the global-mean temperature of ECBILT runs has been observed over time scales up to approximately two decades.
3 The Hellinger distance has been used to measure the extra information (with respect to climatology) produced by ensemble forecasting systems.
4 The techniques of chaotic mixing, first applied by Pasmanter in 1984 to the dispersion of pollutants in estuaries and shallow seas, are being used to determine the uncertainty in the trajectories of air parcels in the stratosphere.

Statistical mechanical approach to climate

Research on a statistical mechanical approach to the asymptotic behaviour of two-dimensional fluid flows resulted in a thesis by Brands (October 1998) entitled 'Coherent Structures and Statistical Mechanics in Two-Dimensional Flows' and three additional scientific publications. After a general introduction of the statistical mechanical formalism, the method has been confronted with numerical simulations and laboratory experiments. Some of the numerical simulations were performed with a spectral code for a circular flow domain of which the basic parts were developed and published by Verkley in 1997. The thesis can be considered as a critical examination of the statistical mechanical approach to idealised two-dimensional fluid flows, a theory that has potential applications in the study of the long-term behaviour of the atmosphere and the oceans. Some of the results have been published in Physics of Fluids; two more papers have been submitted for publication. As it stands now, there are a number of fundamental problems to be overcome but if these problems can be successfully addressed, then the theory offers a fresh approach to the examination of the climatic mean state and the fluctuations around it.

Contour dynamics

In January 1997 Ambaum completed his PhD thesis entitled 'Large-Scale Dynamics of the Tropopause'. The model that is studied in this thesis is a quasi-geostrophic one-layer (one-mode) isentropic model of the atmosphere. After a general introduction of the model, it is shown that the sharp transition between the low, tropospheric values of the potential vorticity and the high, stratospheric values of the potential vorticity is a natural result of the nonlinear dynamics of the system. This transition can be identified with the tropopause and it is demonstrated that breaking Rossby waves cause this transition to be so sharp. Due to the existence of the tropopause it is natural to simplify the potential vorticity structure of the model in terms of two piecewise uniform regions, separated by a single line of discontinuity. With this simplification, the quasi-geostrophic system can be formulated completely in terms of this single line (contour) of discontinuity. The resulting contour dynamics system is investigated in more detail in the thesis, with emphasis on the role of orography. A more detailed account of this work can be found in the Recent highlights section of the previous Biennial Scientific Report.

The work described above was continued in a post-doctoral research project, funded by NWO, that is called 'The predictability of two-layer contour dynamics systems'. It was investigated to which extent contour dynamics models can be used to describe actual observed synoptic developments, like cyclogenesis. If so, it makes sense to use contour dynamics to study the predictability of these developments. In predictability studies, contour dynamics has the advantage that perturbations have a clear-cut physical interpretation in terms of displacements of the contour. In line with the work reported above, first a one-layer contour dynamics model was studied. It became clear, however, that such a model is not able to simulate observed synoptic developments in a sufficiently realistic way. The work was therefore continued with a two-layer contour dynamics model, as planned originally. The contour dynamics model was derived rigorously by discretising the atmosphere in terms of isentropic layers and assuming hydrostatic and geostrophic balance. A number of technical improvements were made in the contour dynamics code, including point redistribution, contour surgery and the implementation of the CASL algorithm (Contour-Advective Semi-Lagrangian algorithm), all of which allow for a greatly enhanced speed of the calculations. It is planned to conclude the project by two publications, one on idealised baroclinic life-cycle experiments and another on the general performance of contour dynamics models in the simulation of synoptic developments.

Monitoring atmospheric analyses

A second post-doctoral project started in the summer of 1998. This project, called 'Weather Analysis and Forecasting', is funded by the BCRS (Netherlands Remote Sensing Board) and will hopefully lead to a more prominent use of water vapour satellite imagery in operational weather forecasting. The idea is to use the observed high correlation between measured radiances in the water vapour absorption band, produced each half hour by geostationary satellites like METEOSAT (Meteorological Satellite), and the potential vorticity field to check and adjust the analysis of operational weather prediction models like HIRLAM (High Resolution Limited Area Model). An example of a water vapour satellite image that points to an incomplete analysis of the atmosphere can be seen in Figure 4. A method will be developed that will enable the forecaster to manually modify the analysed potential vorticity field and study the consequences of this change in terms of the resulting forecast. A three-dimensional variational

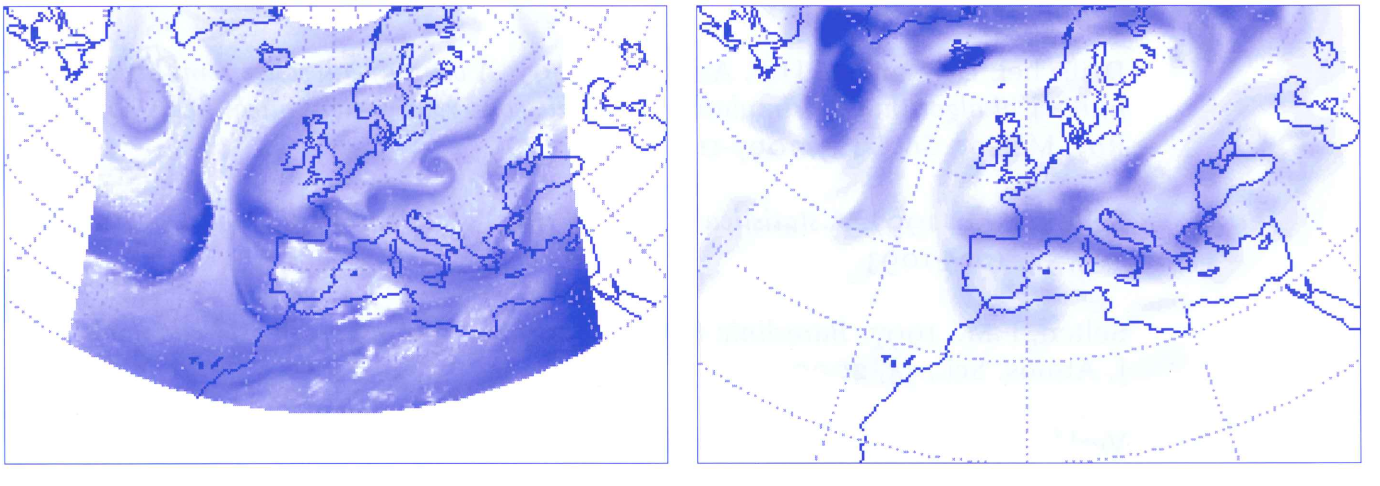


Figure 4. A water vapour satellite image (left) made by METEOSAT on 21 September 1998 at 18:00 GMT and a plot (right) of the potential vorticity for the same date and time, on the 333K isentropic surface, as analysed by the HIRLAM model. Dark shades of grey in the satellite image correspond to high radiation temperatures. In the plot of potential vorticity dark shades of grey correspond to high field values and both indicate a low height of the tropopause. Over central Europe the satellite image shows a thin band of low tropopause heights on which an instability has developed. This instability is not well represented by the model as can be seen from the potential vorticity analysis.

data assimilation scheme will be used to produce a new dynamically consistent initialisation of HIRLAM that takes into account the changes in the potential vorticity field. It is expected that the project will lead to an alternative ensemble prediction system in which the meteorologist subjectively decides - based on satellite information - of which feature of the initial state he wants to evaluate the sensitivity to small perturbations.

In December 1998 a master's thesis was completed by M. van Reenen of the Technical University of Eindhoven in which the physical mechanism of the correlation between water vapour imagery and potential vorticity was studied. A simple, basically monochromatic, radiative transfer model was developed and used to calculate the radiance fields of idealised water vapour distributions. These distributions were related in a simple way to the height of the tropopause and therewith to the potential vorticity field.

Isentropic models

The study of atmospheric models consisting of one or more isentropic layers was continued. It was shown explicitly that models of this type are physically idealised but mathematically exact solutions of the inviscid hydrostatic primitive equations. A short paper in which the vertical profile of the vertical velocity is derived for a hydrostatic isentropic layer was submitted to the Quarterly Journal of the Royal Meteorological Society. For a one-layer isentropic model a Hamiltonian approach was applied to obtain a global balanced model that respects all the conservation laws of the original system. A publication will be submitted to the same journal.

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Barkmeijer, J., 1997. *Constructing fast-growing perturbations for the nonlinear regime.* J. Atmos. Sci., **54**, 2838-2851.

Brands, H., J. Stulemeyer, R.A. Pasmanter and T.J. Schep, 1997. *A mean field prediction of the asymptotic state of decaying 2D turbulence.* Phys. Fluids, **9**, 2815-2817.

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Selten, F.M., 1997. *A statistical closure of a low-order barotropic model.* J. Atmos. Sci., **54**, 1085-1093.

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Verkley, W.T.M., 1997. *A spectral model for two-dimensional incompressible fluid flow in a circular basin.* Part II, Numerical examples. J. Comput. Phys., **136**, 115-131.

1998 Barkmeijer, J., M. van Gijzen and F. Bouttier, 1998. *Singular Vectors and estimates of the Analysis Error Covariance Metric.* Quart. J. Roy. Meteor. Soc., **124**, 1695-1713.

Brands, H., J. Stulemeyer, R.A. Pasmanter and T.J. Schep, 1998. *Response to Comment on 'A mean field prediction of the asymptotic state of decaying 2D turbulence'.* Phys. Fluids, **10**, 1238.

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Shabalova, M.V. and S.L. Weber, 1998. *Seasonality of low-frequency variability in early-instrumental European temperatures.* Geophys. Res. Lett., **25**, 3859-3862.

Weber, S.L., 1998. *Parameter sensitivity of a coupled atmosphere-ocean model.* Climate Dyn., **14**, 201-212.

Scientific and technical reports:

1997 Haarsma, R.J., F.M. Selten, J.D. Opsteegh, G. Lenderink and Q. Liu, 1997. *ECBILT, A coupled atmosphere ocean sea-ice model for climate predictability studies.* KNMI Technical Report TR-**195**.

1998 Pasmanter, R.A. and X. Wang, 1998. *Experimenting with a similarity measure for atmospheric flows.* KNMI Scientific Report WR **98-03**.

Books and/or theses:

1997 Ambaum, M.H.P., 1997. *Large-Scale Dynamics of the Tropopause.* PhD-Thesis, Technical University of Eindhoven, The Netherlands, 115pp.

Lenderink, G., 1997. *Physical Mechanisms of Variability of the Thermohaline Ocean Circulation.* PhD-Thesis, University of Utrecht, The Netherlands, 160pp.

1998 Oortwijn, J., 1998. *Predictability of Weather Regime Transitions.* PhD-Thesis, University of Wageningen, The Netherlands, 116pp.

Brands, H., 1998. *Coherent Structures and Statistical Mechanics in Two-Dimensional Flows.* PhD-Thesis, University of Amsterdam, The Netherlands, 118pp.

Haarsma, R.J., F.M. Selten, J.D. Opsteegh, Q. Liu and A. Kattenberg, 1998. *North Atlantic decadal climate variability in a coupled atmosphere ocean sea-ice model of moderate complexity*. Appeared in 'Beyond El Niño: Decadal and Interdecadal Climate Variability' (ed. A. Navarra), Springer Verlag, pp. 277-301.

Mureau, R.: Geurts H. and J. Kuiper, 'Weergaloos Nederland' (in Dutch). Contributor of text on ensemble forecasting. Kosmos-Z&K, Utrecht/Antwerpen, 1997.

Number of international presentations: 1997: 15, 1998: 14.

Externally funded projects: national 8, international 2.

Education, organisation of workshops:
A substantial contribution was made to the education of young scientists in the Netherlands. Seven students were supervised in their thesis research by staff members of the Predictability Research Division. Three master's theses and four PhD theses were completed during the period. In addition to this, several staff members contributed to the university curriculum in the field of meteorology and climate. An overview of the latter activities is given below:

R.J. Haarsma was lecturer in a course on numerical techniques in meteorology at the Agricultural University of Wageningen in 1998.
J.D. Opsteegh organised an international graduate school on 'Atmospheric Dynamics and Tracer Transport' in Boekelo, The Netherlands (28 September - 9 October 1998). The school was organised within the context of COACh (Co-operation on Oceanic, Atmospheric and Climate Change studies), which is an international co-operation of CKO and the MPIs for Meteorology in Hamburg and Mainz. *Verkley*, *Haarsma* and *Selten* lectured at this school.
J.D. Opsteegh co-organised a masterclass on 'Meteorology and Chaos' at the University of Utrecht in 1998.
F.M. Selten was lecturer in a course on 'Multivariate Data Analysis Techniques' at IMAU (Institute for Marine and Atmospheric Research Utrecht) in 1998.
R.A. Pasmanter was lecturer at a summer school on 'Fundamental Problems in Geophysical and Astrophysical Fluid Mechanics', which was held in Gignod (Val D'Aosta, Italy) from 16-20 June 1997.
R.A. Pasmanter was lecturer at a TAO (Transport in the Atmosphere and the Oceans) summer school in Börno (Sweden) from 26 July - 1 August 1998.
S.L. Weber organised an international IPCC (Intergovernmental Panel on Climate Change) workshop on rapid nonlinear climate change. The aim of the workshop was to assess the present state of knowledge of potential rapid climate change due to antropogenic effects resulting from internal nonlinearities in the climate system. The workshop was held in Noordwijkerhout, The Netherlands, from 31 March - 2 April 1998.
S.L. Weber organised a one-day workshop 'Climate Variability: models and paleodata' at KNMI on 23 October 1997.

Other activities:

J.D. Opsteegh, member of the Scientific Advisory Committee (SAC) of ECMWF.
J.D. Opsteegh, chairman of the SAC working group on the validation and evaluation of the ensemble prediction system at ECMWF.
J.D. Opsteegh, member of the Climate Committee of KNAW (Royal Netherlands Academy of Art and Sciences).
J.D. Opsteegh, member of the programme committee of the Centre for Climate Change and the Biosphere (CCB) of the Agricultural University of Wageningen.
J.D. Opsteegh, member of the advisory committee on the Earth Sciences of NWO.
R.A. Pasmanter, member of the steering committee of TAO of the European Science Foundation.
S.L.Weber, member of the programme committee of GOA (NWO - Geosciences Foundation).

Oceanographic Research

Oceanographic

General • The year 1998 was the International Year of the Ocean (IYO). IYO was an initiative of the United Nations 'in recognition of the importance of the ocean for life on earth and for sustainable development'. As if to underline this, nature provided us with the largest El Niño ever recorded, with world-wide influence on climate (see also the article by Gerrit Burgers and Geert Jan van Oldenborgh in the section Recent highlights of this Biennial Scientific Report). This triggered considerable interest, both with scientists and among the general public, not only in the Tropical Ocean but also in the variability of the Atlantic Ocean and its possible relationship with European climate.

KNMI scientists replied to the general demand for information by issuing a brochure (in Dutch) about their Sea Research, by setting up a special IYO web page and by delivering a large number of presentations and interviews.

Research was aimed primarily at natural climate variability. Using tools that had been developed in the past few years we were able to determine the origins of the large 1997/1998 El Niño. Other work was concerned with air/sea interaction and with mechanisms of Atlantic variability. An analysis of the 1996 ASGAMAGE experiment (Air Sea Gas and Aerosol Exchange Experiment) led to a better understanding of the exchange of carbon dioxide between the atmosphere and the ocean, an important issue in global change. A numerical study of the relation between solar variations and decadal climate change revealed an interesting interaction mechanism involving the ocean.

KNMI contributed to the international programming of CLIVAR (Climate Variability and Predictability Research). On a European level, through Euroclivar, research priorities were formulated. This strongly renewed the interest in ocean monitoring and in historic marine climate observations. Also, in close collaboration with NWO (Netherlands Organisation for Scientific Research), KNMI helped to formulate CLIVARNET, the Dutch contribution to CLIVAR. An ambitious plan for joint research by KNMI, IMAU (Institute for Marine and Atmospheric Research Utrecht) and NIOZ (Netherlands Institute for Sea Research) was formulated and funded.

Mathematical physics

van Duin

In the theory of the generation of surface gravity waves by wind the choice of the proper turbulence closure model is of crucial importance. For slow waves, the so-called rapid-distortion turbulence models are generally accepted. For fast waves, however, these models cease to be valid. An adapted model, describing the formation of such waves, was studied in co-operation with P.A.E.M. Janssen of ECMWF (European Centre for Medium-Range Weather Forecasts). The growth rates for fast waves, based on the latter closure model, prove to be significantly larger than those derived from previous turbulence models, and show a better agreement with measurements. For slow waves, on the other hand, the growth rates are comparable to those derived from rapid-distortion models and their derivatives.

Recent research shows that non-uniformity, characterised by slowly varying wavenumber and frequency of the primary wave, leads to modification of the development of modulated wavepackets. For an expansive wave, in which the group velocity increases in the direction of wave propagation, the Benjamin-Feir instability is quenched on a time scale determined by the degree of non-uniformity, or modulation depth. At a sufficient degree of non-uniformity, the amplitudes of the wave perturbations remain so small that the wave is stable. For a compressive wave, in which the group velocity decreases in the propagation direction, non-uniformity has a destabilising effect. The results have been submitted to a scientific journal.

The aforementioned results are based on the usual linear stability analysis. When the wavenumber and frequency of the wave vary on space and time scales that are an order of magnitude smaller than in the previous case, the stability characteristics of the wave are modified even more drastically. This study, in co-operation with H. M. Vollebregt of the Technical University of Twente, shows that the wave becomes definitely stable in the case of an expansive wave. This means that the wave becomes stable against both linear and weakly nonlinear perturbations. Apparently, the Benjamin-Feir instability is completely suppressed in this case.

Ocean wave prediction

Voorrips, Komen

In November 1998 Voorrips successfully completed his PhD thesis, entitled 'Sequential Data Assimilation Methods for Ocean Wave Models'. The first part of the thesis is concerned with the quasi-operational assimilation of spectral information, using an optimal interpolation (OI) method. The results of this study were made available to the Observations and Modelling Department, which is responsible for wave forecasting. The second part develops an assimilation method based on Kalman filtering. Kalman filtering has a sound statistical foundation and many practical applications. One of these applications is the computation of forecast errors. Another is the dynamical estimation of correlation scales. A disadvantage is the large amount of computer resources that is required. Therefore, a low-rank approximation of the Kalman filter was implemented. The method was tested in a number of idealised cases with very good results.

In addition, a number of papers appeared which were based on earlier work and earlier projects. A first set of papers described work with the adjoint of the WAM model (Wave Model). This adjoint was used to assimilate Lake George and North Sea observations. It led to an improvement of the WAM model for very short fetch, and to a new estimate of the dissipation constant. A second paper describes the effect of CO_2 doubling on the North Atlantic wave climatology. To this end a 5-year time slice climate simulation, carried out at the MPI (Max-Planck-Institute) for Meteorology in Hamburg, was analysed and the WAM model was used to derive the ocean wave response. The simulated effect of

CO_2 doubling on the wave climatology was found to be smaller than the natural decadal variability. On request of the Scientific and Technical Committee of the Global Ocean Observing System (GOOS) scientific priorities for wave and sea level monitoring and prediction were formulated.

The physics of air/sea exchange

Oost, Jacobs, Van Oort, Worrell, Wallbrink

Work in this group concentrates on a physical description of the microscale aspects of air/sea interaction.

A primary research topic was the exchange of the main greenhouse gas, CO_2, between sea and air. The activities took place in the context of the ASGAMAGE project, supported by the EU, for which KNMI is project co-ordinator. The main aim of the project, as far as the KNMI contribution is concerned, is the intercomparison of the values for the transport coefficient k_w for the exchange of CO_2 between the oceans and the atmosphere, found with various techniques. So far those results showed order-of-magnitude discrepancies and by explaining and reducing these discrepancies the uncertainty in the CO_2 flux between sea and air can be reduced. That result is important for the global knowledge of the distribution of the CO_2 sequestration over the oceans and the terrestrial biomass and its consequences for the development of the CO_2 content of the atmosphere. This work has been quite successful: results from eddy correlation measurements carried out by KNMI and those from the differential tracer method - the method that so far has yielded most values cited in the literature - are quite close together now. The remaining differences can be explained in terms of the assumptions made in the various measurement techniques and the degree to which these assumptions are fulfilled in practice. These results are based on a combination of data analysis and modelling work. Micrometeorological methods for the measurement of the transport coefficient may lead to a better description of the global distribution of the CO_2 flux: they require only a short measurement time compared with the geochemical methods used so far. Furthermore, these methods allow us to investigate more rigorously any relationship with a strongly fluctuating parameter like the wind speed than was possible so far. This, in turn, allows a better estimate of k_w when the wind speed is known, either from measurements or from a model calculation. The improved confidence in micrometeorological techniques, resulting from ASGAMAGE, may therefore be of global significance.

A serendipitous result from ASGAMAGE is a new set of values for the transport coefficients for heat and moisture, C_H and C_E. Their values were determined because they were needed for the correct interpretation of the CO_2 data but turned out to have an importance of their own when a careful analysis of the data uncovered a so far unknown structure of these coefficients as a function of wind speed and atmospheric stability. C_H and C_E are both key variables in the coupling between atmosphere and sea.

ASGAMAGE also provided another set of whitecap data. After the earlier analysis of the 1986 HEXMAX data (HEXOS - Humidity Exchange over Sea - Main Experiment), attempts were made now to devise an automated analysis method for the video images obtained. This turned out to be a tall order, due to the required discrimination between active whitecaps, and foam on the water surface from other sources (older whitecaps or algae). At the time of writing no adequate solution had been found; a literature study showed that no simple solution for this problem was available elsewhere either.

The aerodynamic roughness of the sea determines the wind stress, a key variable in air/sea interaction. The relationship of this roughness with the underlying sea surface continued to be a hot topic. Another re-analysis of the 1986 HEXMAX results indicated a relationship between the wind speed, the momentum transport from the air to the sea represented by the friction velocity u_*, and the wave spectrum, represented by c_p (the phase speed at the peak of the spectrum). The analysis further showed that the two main contenders for the relationship between the roughness of the water surface and the wave spectrum, the so-called Charnock relation and the inverse dependence on the wave-age c_p / u_*, both have their range of applicability: for young waves the data agree with the inverse wave-age dependence, for older seas the Charnock relation applies. With waves longer than 80 m no general conclusions can be derived from data that are measured at Meetpost (measuring site) Noordwijk, the site of both the HEXMAX and ASGAMAGE experiments, because under these circumstances shallow water effects significantly affect the results.

The construction of a wave-follower has been the main item of technical activities within the group. The instrument is now close to completion. Several additional elements had to be introduced to safeguard the functional use of the instrument under adverse conditions. A miniature version of the pressure anemometer is being developed for use on the wave-follower. This development is necessary due to the small distance (of the order of 10 cm) to the water surface from where the wind and flux measurements will be made. As a preparatory step for the use of the wave-follower a guest-visitor from the Ukraine, dr. V. Kudryavtsev, has prepared a survey of the differences between the predictions of the various theoretical models for wave-growth that can be studied with the wave-follower. This latter study was done in co-operation with the group of dr. V. Makin of the Observations and Modelling Department of KNMI.

Global air-sea fluxes and the upper ocean response

Sterl, Bonekamp, Komen

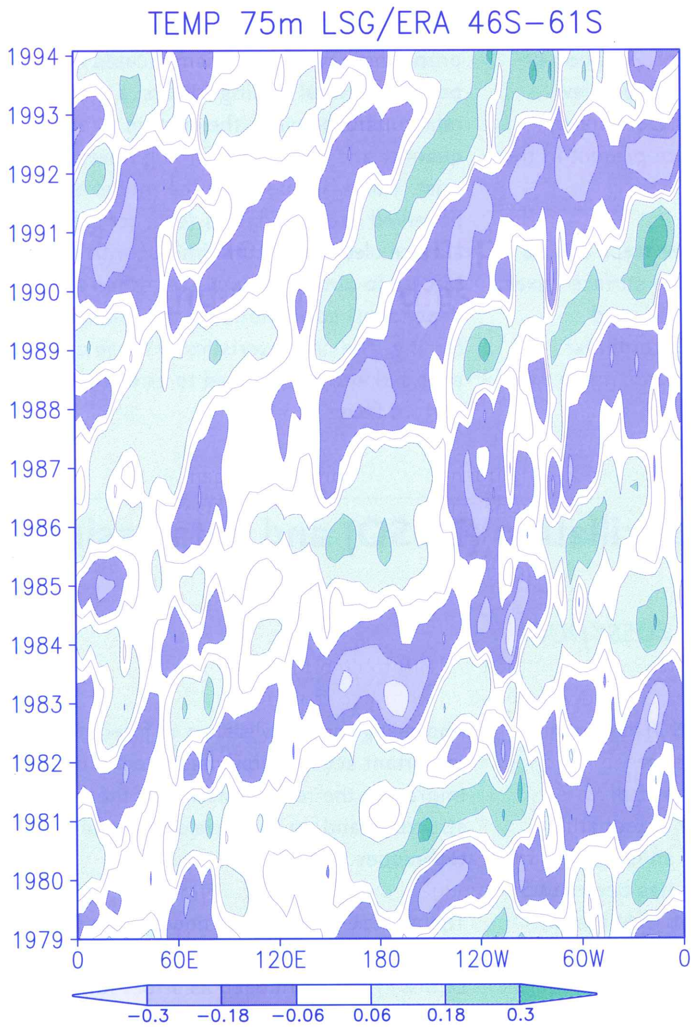

Figure 1. Time-longitude plot of temperature anomalies at a depth of 75 m. The anomalies are area averaged over 46°S–61°S and bandpass filtered (1-7 years).

The ERA project (ECMWF Re-Analysis project) has been one of the major undertakings of ECMWF during the last few years. All available meteorological data from the 15-year period January 1979 to February 1994 have been used to produce a homogeneous description of the atmosphere. Validation of this description is, however, hampered by the fact that virtually all observations have been assimilated by ERA, so that no independent observations are available to check the results. To overcome (part of) this problem we focus on the air-sea fluxes of momentum, energy and freshwater that are part of the ERA results and use them to drive an ocean and a wave model, respectively. The results of those models, like sub-surface temperature (ocean model) or wave height (wave model), are independent of observations of the same quantity, as they have not been used as input of ERA.

The work on the wave modelling part of this project has already been reported in the last Biennial Scientific Report. During the period reported here (1997-1998), that work has been finished with the publication of a paper (Sterl et al., 1998), and attention has switched to the ocean modelling part.

As a first step, the relatively simple but very robust LSG model (Large Scale Geostrophic model) has been forced with the ERA fluxes. The main objective was to investigate the mechanisms of the ACW (Antarctic Circumpolar Wave), that was first described by White and Peterson in 1996.

The major atmospheric features of the ACW are present in the ERA surface fields. The oscillation period and the propagation speed of the surface temperature and pressure anomalies are identical to those found by White and Peterson. However, surface pressure anomalies only propagate in the last part (1985-1994) of the ERA period, which is the period White and Peterson investigated, while prior to 1985 they form standing patterns. Higher amplitudes of the ACW mode are restricted to the eastern Indian Ocean and the Pacific Ocean.

When forced with ERA surface fluxes, the salinity and temperature output of the LSG ocean model contains a mode of interannual variability with ACW-like characteristics (see Figure 1): temperature and salinity anomalies, originating from roughly 70°E and 180°E and reappearing every 4 to 5 years, propagate eastward through the Southern Ocean and decay after having passed Drake Passage. This signal is also captured in the LSG output of anomalous surface elevation and oceanic convection. The oscillation period and the eastward propagation of the anomalies are sustained to a depth of a few hundred metres. Higher amplitudes and a more pronounced eastward propagation are present in the period 1985-1994.

For the generation of the mode, three steps can be distinguished: initiation by anomalous surface fluxes, amplification by anomalous convection, and advection with the ACC (Antarctic Circumpolar Current). For the initiation of the oceanic mode two forcing mechanisms can be formulated, a thermodynamic and a dynamic one, that both trigger anomalous convection. The first involves anomalous surface cooling, supported by anomalous meridional winds. In the second, Ekman pumping destabilises the stratification by bringing warm sub-surface waters to the surface. Sensitivity analyses with the LSG model are in favour of the latter, but do not exclude the first. Both mechanisms operate to a large extent in a spatial wavenumber 2-3 pattern which is determined by the first empirical orthogonal function (EOF) of the surface pressure variability. The time series of this EOF depicts no preferred time scale, which confirms the hypothesis of Weisse et al., published in 1997, who explain the oceanic ACW mode by the concept of stochastic climate models.

In the next step to assess the quality of the ERA surface fluxes the more sophisticated HOPE ocean model (Hamburg Ocean Primitive Equation model) is used. An inverse modelling approach involving the adjoint of HOPE is employed. As oceanic properties arise from a complicated interplay between several forcing factors, a simple relationship between the error in a modelled quantity and one of the forcing fluxes does not exist. The misfit between the model output and observed ocean variables (e.g., temperature and surface elevation) is minimised with respect to the forcing to obtain optimal (yet ocean model dependent) corrections for the re-analysed surface forcing. The characteristics of these corrections are analysed and should lead to error estimates of the surface fluxes.

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

Burgers, van Oldenborgh, van Eijk, Vossepoel

El Niño - Southern Oscillation (ENSO) research at KNMI is both aimed at gaining a better understanding of the phenomenon and at contributing to the improvement of seasonal forecasting systems. The adjoint of an OGCM (Ocean General Circulation Model) has been used to trace the origins of the 1997/1998 El Niño. An extremely simple ENSO model, the El Niño stochastic oscillator, was developed that is capable of simulating many aspects of ENSO behaviour. New mixed-layer schemes have been developed for the OGCM of ECMWF. Data assimilation for improving the initialisation of forecast models is an important activity; work has been done both on improving the representation of the salinity structure, and on the development of new techniques.

The adjoint of the HOPE model (the OGCM that is being used by the seasonal forecasting group of ECMWF) has been used as a tool for investigating the causes of changes in ENSO sea surface temperatures (SST) indices. This work was done in collaboration with the MPI for Meteorology in

Hamburg. In the sensitivity patterns, adjoint Kelvin and Rossby waves can be traced back in time for more than a year. Using a statistical atmosphere, and focusing on perturbations in the NINO3 region (the area 5°S–5°N, 150°W–90°W) the delayed-oscillator concept was recovered in the HOPE model.

Next, the adjoint model has been used to trace the origins of the 1997/1998 El Niño. More precisely, the question was addressed whether the ocean initial state and ocean dynamics alone account for the steep rise of El Niño. Within the analysis of the event with the ECMWF data assimilation system and the HOPE model it was found that major contributors to the rise of El Niño in the spring of 1997 were two large westerly wind events in the west Pacific. Only later, the Bjerknes positive SST-wind feedback contributed to the rise of El Niño.

It is widely accepted that the delayed-oscillator mechanism describes ENSO behaviour; it is about the simplest mechanism that ENSO can be reduced to. The stochastic oscillator is a variant of the delayed-oscillator: a stable linear oscillator, excited by weather noise. This model simulates many aspects of ENSO remarkably well, such as the autocorrelation of the NINO3 index (the deviation of the sea surface temperature with respect to normal conditions in the NINO3 region), the variability (including decadal variability) and variations in predictability. Also, the forecast skill is comparable to that of much more elaborate schemes. The stochastic oscillator can thus serve as an appropriate baseline for the skill of ENSO forecasting systems.

While the stochastic oscillator is linear, a nonlinear aspect of ENSO was studied in collaboration with David Stephenson (Toulouse): deviations of the probability density functions of the NINO indices from normal. The deviations were found to exhibit an interesting pattern going from the eastern to the western Pacific.

Two new mixed-layer modules have been developed for the HOPE model at ECMWF. One is a bulk mixed-layer scheme (BML) similar to that developed earlier by Sterl and Kattenberg, the other is a nonlocal diffusion scheme, the K-profile parameterisation (KPP) scheme as proposed by Large et al. Testing has been done in collaboration with the seasonal forecasting group at ECMWF. First results indicate a better representation of the upper thermal structure by the BML scheme, while the KPP scheme has the ability to simulate barrier layers and may be the preferred alternative for high vertical resolutions.

The salinity variability of the western Pacific has attracted much attention recently. A method for improving the analysis of the salinity in the western equatorial Pacific with altimeter observations has been developed. This work was initiated during a one-year visit of one of us to the altimetry group of Robert Cheney of NOAA (National Oceanic and Atmospheric Administration) and in collaboration with the Climate Prediction Center of NCEP (National Centers for Environmental Prediction). Presently, work is in progress to use this method in the assimilation of altimetry data in the OGCM of NCEP. For an illustration we refer to Figure 2.

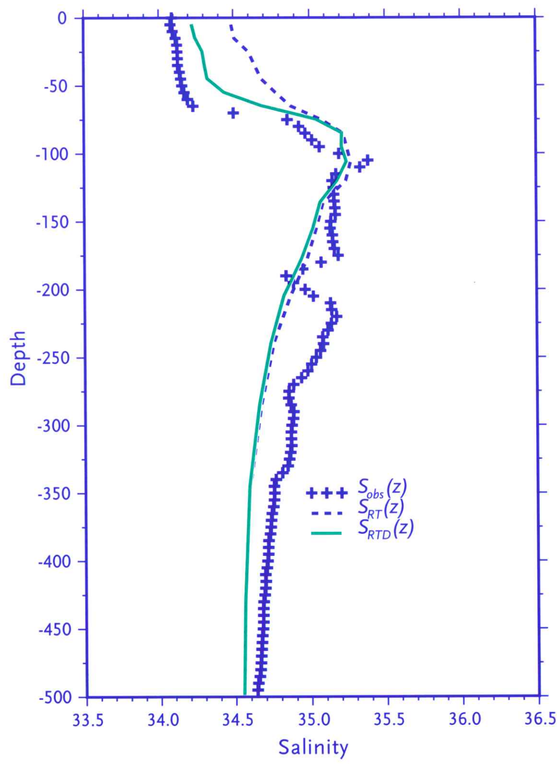

Figure 2. Model salinity compared to conductivity-temperature-depth (CTD) observations at the equator for 154°E. Crosses denote salinity observations for March 1993. The dashed line gives the monthly averaged salinity for an assimilation run in which only temperature observations have been assimilated; the solid line gives the monthly averaged salinity for an assimilation run which also includes TOPEX-POSEIDON sea level observations.

Both NCEP and ECMWF use OI methods for data assimilation. At KNMI more advanced methods are being studied in collaboration with the seasonal forecasting group at ECMWF. The first approach is a 4-D variational data assimilation scheme, which uses again the adjoint of HOPE. The ensemble Kalman filter (EKF) approach has been tested on the nonlinear Oxford intermediate ENSO model, and it has been found that it worked just as well as on a linear model. Currently, it is being investigated whether assimilation with the EKF has advantages over other methods.

Naturally, the El Niño made the years 1997 and 1998 very special for this research group. A spin-off of the services to a more general public has been a joint study with the Climatic Data Division of the Observations and Modelling Department of KNMI into the relationship of wintertime ENSO conditions with enhanced spring precipitation in parts of Europe and in particular in the Netherlands. It was found that this relationship is highly significant.

Ocean dynamics

Drijfhout, Hazeleger, Katsman, Kattenberg, Sterl

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

An isopycnic model of an idealised North Atlantic subtropical gyre, coupled to a mixed layer model, was used to study mode water formation and its variability. A snapshot of the sea surface temperature produced by this model can be seen in Figure 3. Three studies have been performed. Firstly, the role of eddies in subduction and mode water formation has been investigated. It has been found that annual mean subduction rates into mode water reach 200 m/yr south of the Gulf Stream extension. Eddy subduction rates up to 100 m/yr are found. The high frequency variability enhances the annual mean subduction by almost a factor 2. Also, a significant eddy-induced enhancement of the Ekman overturning occurs. Conclusions are drawn with respect to parameterisation of eddy subduction and the eddy-induced Ekman overturning. Secondly, the response of mode water to stochastic atmospheric forcing has been investigated. The response to stochastic wind forcing is characterised by propagating baroclinic waves with a preferred interannual time scale. Only stochastic heat flux forcing generates mode water variability of the observed amplitude. The pattern is characterised by a dipole rotating in the subtropical gyre. A preferred time scale is absent and the spectrum is red. Finally, internally generated mode water variability has been investigated with a high resolution version of the model. Two modes of low frequency have been found. Both modes consists of westward propagating anomalies. Preferred time scales are 8 and 4.5 years, respectively. The 8-yr mode is similar to the one excited by stochastic wind stress in the low-resolution and high-diffusion case. Now, this mode is associated with the instability of the mean flow. The amplitude is large enough to account for the observed variability.

With a two-layer quasi-geostrophic model of the wind-driven ocean circulation the transition to time dependence through a Hopf bifurcation associated with a mixed barotropic/baroclinic instability has been investigated. It has been shown that the nonlinear self-interaction of this unstable oscillatory mode induces a nonzero time mean response in the lower layer. The origin of this deep flow is clarified through a weakly nonlinear analysis near critical conditions. It is explained how the patterns of vorticity input, integrated over a cycle of the perturbation, induce a forcing of the second layer. At present, the same methodology is used to investigate the origin of variability in a limited domain with inflow of an idealised Gulf Stream and Deep Western Boundary Current. Emphasis is placed on variability in which the Gulf Stream and Deep Western Boundary Current appear to be coupled by nonlinear interactions. This research is performed in co-operation with IMAU.

Despite progress made in the World Ocean Circulation Experiment (WOCE), there is still an enormous lack of ocean observations. Therefore, the analysis of numerical simulations is a useful approach to a better understanding of the ocean circulation. This work is done with global ocean

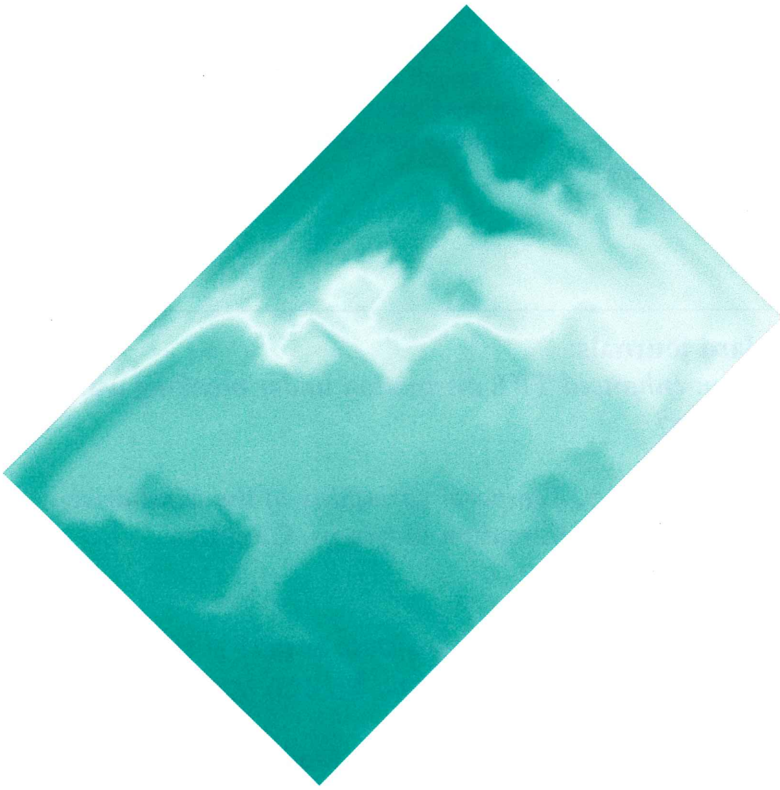

Figure 3. Sea surface temperature in a high-resolution isopycnic model of the Gulf Stream region.

models developed elsewhere. The response to noise-forcing - derived from an AMIP-run (Atmospheric Model Intercomparison Project) with ECHAM (Hamburg version of the ECMWF model) - has been investigated within the LSG model. In this study, which was done in co-operation with the MPI for Meteorology in Hamburg and the GKSS (Geesthacht Research Centre), an analysis has been made of the variability in the model and it has been found that this variability is dominated by an ACW. It appears that this ACW is forced by wind-stress variability with a pattern resembling the Pacific South American (PSA) teleconnection. The effect of anomalous Ekman-pumping is amplified by convection in the marginally stable/unstable boundary of the South Pacific/Southern Ocean. The resulting salt/temperature anomalies are then advected by the Antarctic Circumpolar Current/southern subtropical gyres. The route of the North Atlantic Deep Water (NADW) and its return flow has been investigated by following Lagrangian trajectories simulated by OCCAM, a high-resolution ocean general circulation model. This work consists of a co-operation with SOC (Southampton Oceanography Centre) and MISU (Department of Meteorology of the University of Stockholm) in the EU-funded project TRACMASS (Tracing the Water Masses of the North Atlantic and the Mediterranean). The upwelling zones of NADW have been traced by forward integration of trajectories released in the equatorial Atlantic until NADW upwells. The same method has been applied to the NADW-return flow, now by backward integration of trajectories. Most trajectories following NADW upwell in the Southern Ocean whereas trajectories backtracing the sources of the return flow originate chiefly from the equatorial regions, especially the Pacific. These results imply that NADW-upwelling is a multi-stage process.

Large climate models are very time consuming to run, and therefore less suitable to study interdecadal variability. Therefore, KNMI has chosen not to develop its own high-resolution coupled climate model. Instead, we contribute to work on high-resolution models elsewhere. In addition, a fast coupled model ECBILT (KNMI General Circulation Model) was developed by the Predictability Research Division for the study of predictability and variability of climate. The ocean component of this system is a linear flat-bottom OGCM. A study has been performed to isolate the role of the ocean in inducing atmospheric variability. On interannual time scales the oceans do not affect the patterns of atmospheric variability, nor their explained variance. However, the spectra change. The oceans act to redden the spectra, especially the atmospheric temperature spectra. No preferred time scales arise for the dominant patterns of atmospheric variability. The dominant patterns of ocean/atmosphere covariability, however, do show the existence of preferred time scales. The latter only occur when the atmosphere is coupled to a dynamically active ocean. Also the impact of solar variability on atmospheric variability has been investigated. For realistic amplitudes, solar forcing dominates over internal variability in the global mean surface air temperature. Evidence is found for time scale interactions in the climate system. A weak 22-yr solar variation excites a significant spectral peak at the 70-yr period in global mean temperature. On the regional scale the internal variability dominates. Patterns and their explained variance are robust for a variable solar forcing. The spectra, however, are sensitive to this forcing. In many cases preferred time scales of the internal modes of the coupled system disappear.

In co-operation with IMAU and NIOZ and the universities of Oregon and Cape Town a consorted observational and modelling experiment with emphasis on a seagoing programme has been formulated and will be financed within the Netherlands CLIVAR programme. It is referred to as MARE (Mixing of Agulhas Rings Experiment). Its main goals are to estimate the proportion of Agulhas Ring leakage that contributes to the upper branch of the Conveyor Belt and identify the dominant mixing processes that determine that proportion, and to determine the impact of varying Indian-Atlantic interocean exchanges on variability on regional scales as well as on the strength of the Atlantic overturning circulation and associated climate fluctuations over the North Atlantic sector.

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Katsman C.A., H.A. Dijkstra and S.S. Drijfhout, 1998. *The rectification of wind-driven flow due to its instabilities.* J. Mar. Res., **56**, 559-587.

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Scientific and technical reports:

1997 Jacobs, C.M.J., W. Kohsiek and W.A. Oost, 1997. *Direct determination of the air sea transfer velocity of CO_2 during ASGAMAGE.* KNMI Scientific Report WR **97-06**.

Janssen, J.A.M. and H. Wallbrink, 1997. *SATVIEW: a semi-physical scatterometer algorithm.* KNMI Scientific Report WR **97-03**.

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1998 Eijk, M. van, 1998. *The implementation of two mixed-layer schemes in the HOPE ocean general circulation model.* KNMI Technical Report TR-**214**.

Jacobs, C.M.J., W. Kohsiek, W.A. Oost, C. van Oort, H. Wallbrink and E. Worrell, 1998. *KNMI analyses of ASGAMAGE data and results: status September 1997.* Report of the ASGAMAGE workshop, 22-25 September 1997 (ed. W.A. Oost), KNMI Scientific Report WR **98-02**, 20-32.

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Books and/or theses:

1998 Voorrips, A.C., 1998. *Sequential Data Assimilation Methods for Ocean Wave Models.* PhD-Thesis, Technical University of Delft, The Netherlands, 175pp.

Giorgi, F., G.A. Meehl, A. Kattenberg, H. Grassl, J.F.B. Mitchell, R.J. Stoufer, T. Tokioka, A.J. Weaver and T.M.L. Wigley, 1998. *Simulation of regional climate change with global coupled climate models and regional modelling techniques.* IPCC Special Report 'Regional Impacts of Climate Change' (eds. R.T. Watson, M.C. Zinjowera, R.A. Moss), Cambridge University Press.

Number of international presentations: 1997: 37, 1998: 22.

Externally funded projects: national 7, international: 6.

Education, organisation of workshops:
Two master's theses and one PhD thesis were completed during the period.

W. Hazeleger organised a CKO (Netherlands Centre for Climate Research) meeting on Mode Water Variability at KNMI, 23 September 1997.
C.A. Katsman organised a CKO meeting on Internal Variability of the Wind-driven Ocean Circulation at IMAU, 18 November 1997.
G.J. Komen was lecturer at a Mast advanced study course, International Marine Centre, Torregrande, Italy, 30 June - 6 July 1997.
G.J. Komen was lecturer at an ECMWF Seminar on Atmosphere-Surface Interaction, Reading, 9 September 1997.
G.J. Komen organised the following Euroclivar workshops:
1 Cloud Feedbacks and Climate Change, Bracknell, 9 - 11 April 1997.
2 Past Climate Data, Abisko, 31 August - 3 September 1997.
3 Climate Change Detection and Attribution, Bracknell, 9 - 12 March 1998.
4 The Role of the Atlantic in Climate Variability, Florence, 11 - 14 May 1998.
5 African Climate Variability, Bologna, 3 - 5 June 1998.
6 Climatic Impact of Scale Interaction for the Tropical Ocean-Atmosphere System, Paris, 14 - 16 September 1998.
7 Data Assimilation in Ocean Models, Bologna, 5 - 7 October 1998.
G.J. van Oldenborgh was a guest lecturer at the Catholic University of Nijmegen, 26 November 1997 (Computational Physics: the causes of El Niño).

Other activities:
A. Kattenberg, member of the Task Team Monitoring Systems.
G.J. Komen, member of COACh (Co-operation on Oceanic, Atmospheric and Climate Change studies), an international research school of CKO, MPI for Meteorology in Hamburg and MPI for Chemistry in Mainz.
G.J. Komen, member Joint GOOS Scientific and Technical Committee.
G.J. Komen, vice chairman of GOA (NWO - Geosciences Foundation), until January 1998.
G.J. Komen, chairman of the Dutch CLIVAR (CLIVARNET) committee.
G.J. Komen, member of the ERA-40 steering group.

G.J. Komen, Euroclivar co-ordinator.
A. Sterl, member of SCOR - WCRP (Scientific Committee on Oceanographic Research - World Climate Research Programme) working group on air-sea fluxes.
A. Sterl, member of the ERA-40 steering group.

Atmospheric Composition Research

General • The Atmospheric Composition Research Division is involved in strategic and fundamental research on changes in the composition of the Earth atmosphere and on how these changes are related to changes in the climate. The Division has put the emphasis on trace gas distributions, in particular on the dynamical and physical aspects of changes in these distributions.

The research strategy is to study the field along the following lines:
1 Observations, especially from satellites, of ozone and related quantities.
2 Global three-dimensional modelling of atmospheric composition and studies of relevant transport processes.

The progress along both lines was considerable due to the influx of good scientists and the growth in expertise of the whole group.

For example, in the observational part, developments on the retrieval of data from GOME (Global Ozone Monitoring Experiment) on board of the ERS satellite (Earth Remote Sensing satellite) made it possible to generate good quality ozone column data within three hours after passage of the satellite. This is important for the application of ozone observations in numerical weather prediction models, a domain in which our group plays an active role. A next step is the use of vertical profiles of the ozone distribution. We are now among the few groups able to generate ozone profiles from satellite spectrometer observations like GOME. This opens up the possibility of using these data for process studies and model validation.

KNMI was asked to take the scientific lead of OMI, the Dutch Ozone Monitoring Instrument, on board of the EOS-CHEM satellite (Earth Observing System - Chemistry satellite) to be launched by NASA (National Aeronautics and Space Administration). The potential of this satellite for our research field is large.

In the domain of global modelling and process studies broad progress was booked. Different aspects of stratosphere-troposphere exchange were analysed and published. For validation of global models an ozone climatology based on observations was made and published.

Assimilation of satellite data in chemistry-transport models was another exciting field in which significant progress was made and where the synergy between the observational and modelling groups could be fully exploited. At the end of 1998 the state of the art in the field of chemical data assimilation was summarised at a KNMI workshop on chemical data assimilation and published as symposium proceedings.

An important international scientific effort in the last years was the preparation of the IPCC (Intergovernmental Panel on Climate Change) Special Report on 'Aviation and the Global Atmosphere'. Different members of the group have contributed to the assessment of the effects of aircraft emissions. An overview of our understanding of the effects of aircraft emissions on the atmosphere is given in the section Recent highlights.

Observation of the atmospheric composition

Introduction

The task of this group is to observe the atmospheric composition, mainly using remote sensing techniques from satellites. The present and future satellite instruments involved are GOME, launched in 1995, SCIAMACHY (Scanning Imaging Absorption Spectrometer for Atmospheric Cartography), to be launched in 2000, OMI, to be launched in 2002, and GOME-2, to be launched in 2003. In order to fulfil this task the activities can be grouped as follows:

- Development of satellite retrieval algorithms.
- Validation of satellite data.
- Assimilation of satellite data.
- Interpretation of ground-based and satellite observations.
- Preparation of atmospheric chemistry missions.
- Monitoring the atmospheric composition.

A special project is the OMI mission, which is described separately at the end of this section. KNMI is the scientific leader of this mission.

Development of satellite retrieval algorithms

Van der A, Van Oss, Piters, Valks

The rapid retrieval of accurate ozone profiles and ozone column amounts from the GOME instrument is a field in strong development. At KNMI a new algorithm is being developed to obtain height-resolved ozone distributions from GOME UV (Ultraviolet)/VIS (Visual) spectra. The work is carried out in the project DORAS (Development of O_3 profile Retrieval Algorithm Space-borne Spectrometer), funded by the BCRS (Netherlands Remote Sensing Board). The radiation transport in the current version of the algorithm is approximated by a fast 'two-stream' method. A first validation with ozone sonde measurements shows that the approximation is reasonable, see for example Figure 1. Current research aims at simultaneous improvement of radiation transport and processing speed, for future use in near real-time (NRT) applications. The profile retrieval is also used in the EU project OASE (Ozone Application Simulator and Explorer). The main objective of OASE is to demonstrate that it is possible to process satellite data in a distributed environment, i.e., to carry out subsequent processing steps at different locations around the globe.

The group has succeeded in creating a breakthrough in rapid retrieval. Retrieval algorithms have been developed for NRT delivery of GOME total ozone columns (i.e., within 3 hours after observation). An experimental operational system has been developed and tests for the application in numerical weather prediction models have been

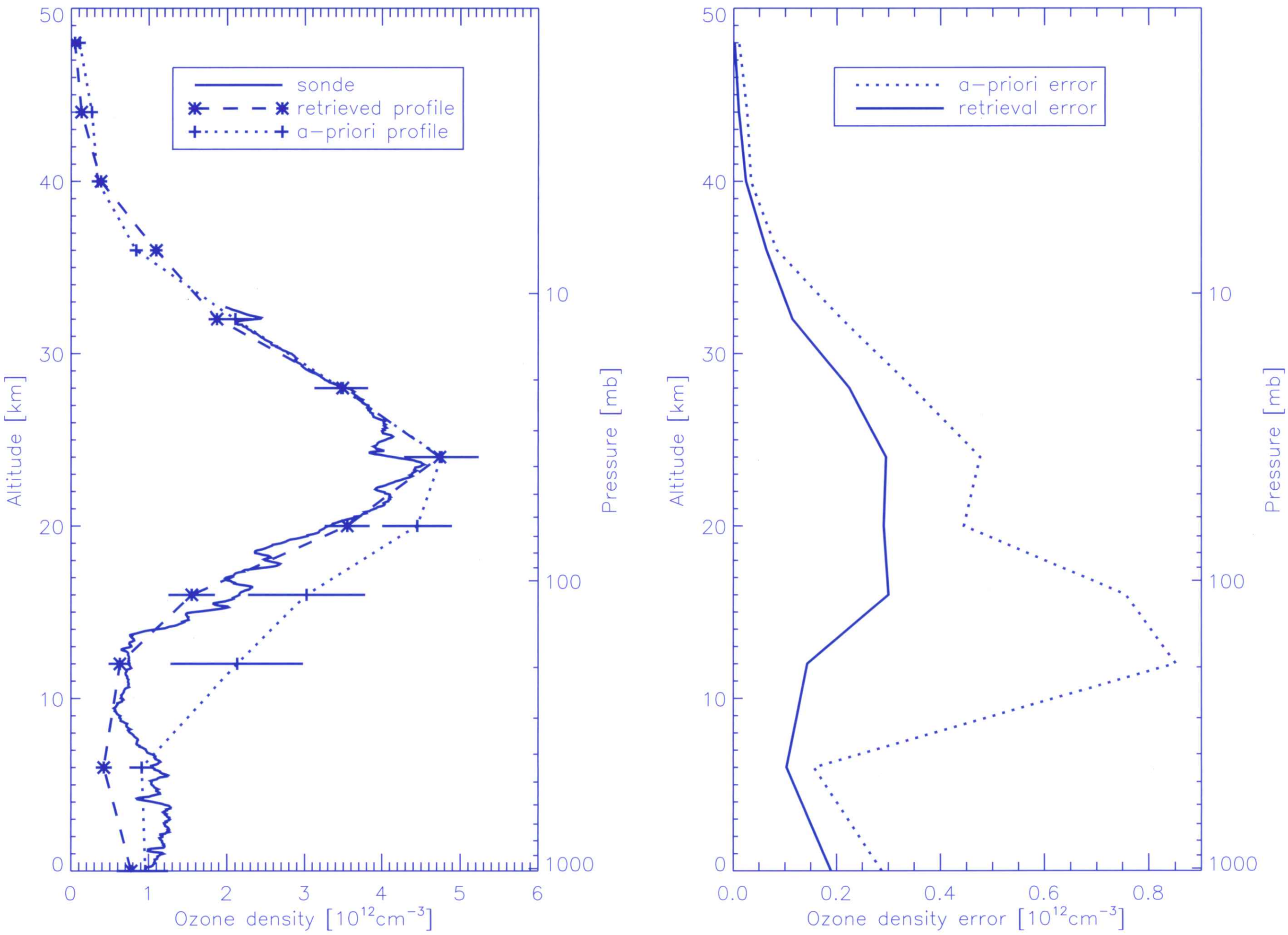

Figure 1. The left figure shows the ozone profile over De Bilt as obtained from the retrieval algorithm (asterisks, dashed line). The profile as measured by an ozone sonde launched at the same time is shown as a solid line. The dotted line through the plus signs shows the a priori profile. The errors of the a priori profile and the retrieved profile, represented by horizontal error bars, are drawn separately in the right figure. Both figures show that the retrieval clearly improves our knowledge of the ozone profile, when compared to the a priori profile, especially in the lower stratosphere.

performed in collaboration with ECMWF (European Centre for Medium-Range Weather Forecasts). The NRT ozone columns have been validated with off-line ozone columns, TOMS (Total Ozone Mapping Spectrometer) and Brewer data. The accuracy is better than 5%.

Validation of satellite data

Piters, Timmermans, Kelder

Validation of satellite data is essential to assess systematic and random errors in the data. Validation of GOME data is an international co-operation, consisting of about 100 different projects. We have participated in the validation of GOME by developing a method to derive random errors of the data using data assimilation. Also, systematic errors as a function of the viewing direction of GOME have been found. The Brewer instrument has been used for direct comparison with the GOME data.

The international validation of SCIAMACHY is being co-ordinated by our group. A validation requirements document has been produced. Preparatory studies are performed in the development of retrieval algorithms. Sensitivity studies and error assessments performed on the GOME processor algorithms give insight into the possible causes for errors in the SCIAMACHY data found during validation (Kelder et al., 1998).

Assimilation of satellite data

Eskes, Levelt, Jeuken, Timmermans

Chemical data-assimilation is an important tool for analysis, validation and retrieval. Data assimilation is therefore one of the main research areas of the group.

The EU project SODA (Studies of Ozone Distributions based on Assimilated Satellite Measurements) is concerned with the development of ozone data-assimilation methods for the use in numerical weather prediction models. For this project we have implemented a 4-D variational assimilation scheme in the 2-D Assimilation Model KNMI. This version is currently being used for the

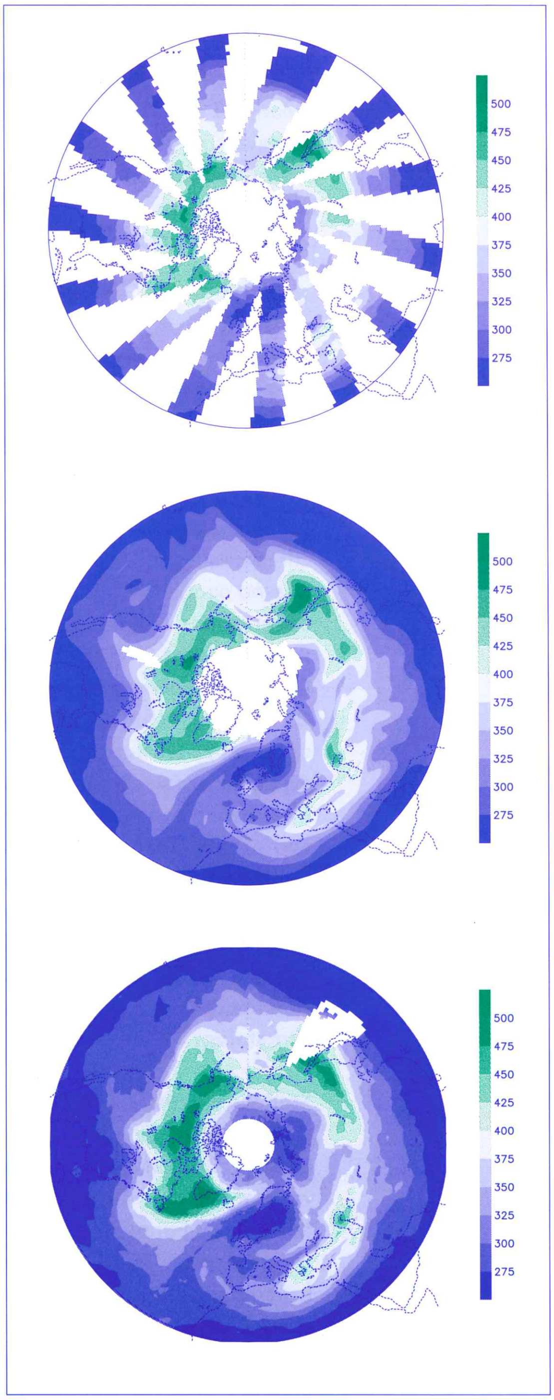

Figure 2. The figure shows GOME ozone column observations, accumulated over twenty-four hours for 9 March 1997 (top), and the corresponding assimilated ozone field (middle) at 12 GMT. The scale is Dobson units. The analysed field is calculated using the 4-D variational data assimilation scheme, and GOME total ozone values of the top figure are used as input. Due to the swath width of about 900 km, GOME has a global coverage in about 3 days. The model calculates the ozone transport on a two-dimensional (lat, lon) grid using ECMWF wind fields. The assimilation scheme also provides a realistic estimate of the space and time dependent forecast error, and the white area in the middle figure corresponds to a forecast uncertainty larger than 25 Dobson units. For comparison the accumulated ADEOS-TOMS (Advanced Earth Observing System - Total Ozone Mapping Spectrometer) total ozone field, made available by NASA, is shown in the bottom figure. TOMS has a larger swath width than GOME, and a near global coverage is obtained in one day. Although no GOME ozone values are available above Kazakhstan (60°E, 45°N), see the top figure, the analysis correctly predicts a peak in ozone at this location. Note that the time difference between the observation and the analysis at 12 GMT often leads to a slight displacement of ozone features in the assimilated field as compared to the observations. This is due to transport.

operational generation of assimilated ozone fields from NRT ozone columns. An illustration of the performance of the scheme is given in Figure 2. Furthermore, a simplified Kalman filter is implemented in the 3-D chemistry-transport model TM3, for the analysis of TOVS (TIROS - Television and Infrared Observation Satellite - Operational Vertical Sounder) and GOME ozone column data. The ECMWF weather forecast model performance, with respect to the calculation of ozone, was evaluated by comparing the model ozone calculations with ozone sonde measurements from the EASOE campaign (European Arctic Stratospheric Ozone Experiment campaign). The comparison revealed that dynamical details are described well by the model. However, the model overestimates the ozone concentration around the ozone maximum at high latitudes and underestimates the ozone concentration around the ozone maximum in the tropics.

KNMI has organised an international workshop on chemical data assimilation in De Bilt in December 1998. The contributions will be summarised in the symposium proceedings.

In co-operation with Dr. B. Khattatov from NCAR - ACD (National Center for Atmospheric Research - Atmospheric Chemistry Division), Boulder, USA, a sequential data-assimilation scheme has been implemented in the off-line global stratospheric chemistry-transport model ROSE (Research on Ozone in the Stratosphere and its Evolution). The model is driven by UKMO (United Kingdom Meteorological Office) wind fields. Ozone profiles from MLS (Microwave Limb Sounder) on board of the UARS (Upper Atmosphere Research Satellite) were used for the assimilation. The results of a two-month run were compared to TOVS total ozone measurements of the same period and showed a reasonable agreement (Levelt et al., 1998).

Interpretation of ground-based and satellite observations

Van der A, Allaart, Fortuin, Piters, Pultau, Van Weele

For the validation of atmospheric models climatologies of chemical species are needed. There was no ozone climatology available based on observations of the last decades. In the context of the EU project SINDICATE (Study of Indirect and Direct Influences on Climate Anthropogenic Trace Gas Emissions) KNMI has created an ozone climatology (Fortuin and Kelder, 1998). A zonally averaged ozone climatology has been constructed from ozone sondes and satellite data, between 1000 and 0.3 hPa, for each month of the year. It is implemented in ECHAM4 (the Hamburg version (number 4) of the ECMWF model) for a control climate run. The climatology is also used as a priori information for ozone profile retrievals from satellite data. A more extensive discussion on this climatology will be given in the modelling section.

Modelling activities in the SUVDAMA project (Scientific UV Data Management project) have concentrated on a model intercomparison of various radiative transfer codes that are used throughout Europe to calculate the surface spectral UV irradiance. On the basis of the intercomparison benchmark, results have been obtained for the surface UV irradiance in six precisely described situations. These six cases are characterised by different values of solar angle, total ozone column, aerosol loading and surface albedo. The benchmark results have an accuracy of a few percent and can be used to validate newly developed radiative transfer codes for UV irradiance. A manuscript has been submitted for publication.

Radiation measurements made at KNMI with narrow-band radiometers have been used to study the effects of (partial) cloudiness on the incident UV irradiance. A special study was devoted to situations during partially cloudy days on which the incident solar radiation can exceed the irradiance on a cloud free day.

Following a request of EUMETSAT (European Organisation for the Exploitation of Meteorological Satellites), a study has been performed in co-operation with Meteo France to find out whether it is possible to derive wind information from the ozone channels of the new generation of METEOSAT (Meteorological Satellite). A height assignment has been done with the 2-D (lat-lon) Assimilation Model KNMI, using winds at different heights. Another part of the study aimed to find a method to follow structures in the ozone layer. It has been shown that lower stratospheric wind information can be derived from structures in the ozone distribution.

Algorithms have been developed for a software tool for atmospheric data analysis. This is a project funded by ESA (European Space Agency) aiming at a better use of satellite data. With this tool it will be possible to analyse and compare different kinds of atmospheric data. In the future it will be used for the validation and interpretation of SCIAMACHY data.

Preparation of future atmospheric chemistry missions

Van der A, Van Oss, Piters, Valks and Van Weele

The Ozone Satellite Application Facility (Ozone SAF) of EUMETSAT was established in 1997. The Ozone SAF has as a main objective the preparation of GOME-2 which will fly on board of METOP (Meteorological Operational Satellite) from 2003. KNMI has the responsibility for retrieval and validation of some operational data products from METOP. We started to define and develop the off-line and near real-time retrieval algorithms for aerosol optical depths and ozone profiles. For the validation of ozone data products a plan has been defined using data-assimilation techniques.

ESA is planning an ACE mission (Atmospheric Chemistry Explorer mission) after the year 2005. Together with other European institutes we have started to formulate the user requirements for this mission, based on the current perception of the main scientific issues in atmospheric chemistry research. These include for example the evolution and the possible recovery - due to the phase out of chlorofluorocarbons (CFCs) - of the ozone layer in the new millennium and the interactions between atmospheric composition, atmospheric chemistry and climate. Emphasis will be put on sounding of the gaseous composition in the upper troposphere and lower stratosphere.

Monitoring the atmospheric composition

Allaart, Fortuin and Van Weele

The ozone density distribution over De Bilt is measured with ozone sondes. Between 50 and 100 ozone sondes are launched each year. These sondes are used for monitoring, stratosphere-troposphere exchange studies, and for international campaigns. A recent project in which we have participated is called MATCH (this is not an acronym). The objective of this project was to determine the role of fast chemical ozone depletion in the Northern Hemisphere (Rex, et al., 1997). The ozone sondes have also been used for the validation of GOME ozone profiles and the ozone lidar (light detecting and ranging) at RIVM (National Institute of Public Health and the Environment) and as input profiles for radiative transfer calculations. The distribution of ozone-sonde data to the international community, e.g. WOUDC (World Ozone and UV Data Centre), has been made operational.

The ozone column density over De Bilt is measured continuously with the Brewer instrument. The Zenith Sky measurements, used when the Sun is not visible, have been calibrated with Direct Sun measurements. The Brewer measurements have been used for validation of GOME and ozone sondes. They have also been used by RIVM to calculate UV impact on skin cancer incidence.

Measurements of UV radiation have been analysed and radiative transfer modelling studies have been performed within the European project SUVDAMA. One of the goals of this three-year project (1996-1998) is to establish a database for measured spectral UV-irradiance in Europe. The data can be used for questions on, e.g., the European UV climatology and possible trends in UV doses.

An UV-index (in Dutch: 'zonkracht') forecast system has been developed, delivered and implemented in the KNMI weather forecast system. The Brewer UV scans are used for the validation of this forecast.

One of the key issues in atmospheric research is the interaction between dynamics and chemistry in the tropics. However, there is an enormous lack of observations in the tropics. A project funded by

NWO-NIVR (Netherlands Organisation for Scientific Research - Netherlands Agency for Aerospace Programmes) has started in 1998 to carry out ozone observations in Surinam. This project is a co-operation between KNMI, IMAU (Institute for Marine and Atmospheric Research Utrecht) and MPI (Max-Planck-Institute) for Chemistry in Mainz. The observing system will include a Brewer instrument and regular launches of ozone sondes. The observations will also be used for validation of future satellite missions like SCIAMACHY and OMI.

Outlook

SCIAMACHY will be launched in 2000. The preparation of the validation and the actual validation of the data will be a major issue in the coming years. With GOME-2 and OMI following in 2002 and 2003, the development of accurate and fast retrieval algorithms, especially in relation with numerical weather prediction, will become important. An increasingly important issue will be the study of chemical data assimilation, especially for the validation of models, the validation of satellite and ground-based data, and the proper description of the evolution of the atmospheric composition. The use of data-assimilation in operational satellite retrieval will be an exciting new avenue of research.

The new ozone station in Surinam is expected to deliver a wealth of data that are important for studies in tropical dynamics, chemistry and stratosphere-troposphere exchange. These data will also be used for the validation of satellites in tropical regions.

The Ozone Monitoring Instrument (OMI)

Levelt, Noordhoek

Introduction

The Ozone Monitoring Instrument will fly on NASA's satellite EOS-CHEM, which will be launched in December 2002. The OMI-instrument will be built by the Netherlands and Finland by main contractor Fokker-Space. NIVR will provide the instrument to NASA. KNMI leads the OMI-project scientifically and provides the Lead Scientist. A special research group is formed to realise this project.

The EOS-CHEM Mission

The objectives of the EOS-CHEM mission are: (1) to monitor the ozone layer, (2) to monitor air quality and tropospheric chemistry and (3) to monitor key components that affect the climate. These mission objectives are tackled by a suite of 4 instruments, which are the MLS, the HIRDLS (High Resolution Dynamics Limb Sounder), the TES (Tropospheric Emission Spectrometer) - which is a nadir and limb sounder - and OMI.

The Instrument

OMI is a high resolution UV/VIS spectrometer with a large field-of-view (114 degrees around nadir), and is derived from GOME (ERS-2) and SCIAMACHY (ENVISAT - Environmental Satellite). OMI is important within the EOS-CHEM mission, because it will measure ozone and NO_2 in the troposphere and stratosphere with global coverage on a daily basis. It should serve as a successor of the TOMS and SBUV (Solar Backscatter Ultraviolet) spectrometer instruments. OMI is capable of measuring (ir)radiances of the Sun and Earth in the wavelength range of 270 to 500 nm, from which ozone column and profile data, data on NO_2, SO_2 and BrO as well as UVB flux, aerosols, cloud coverage and cloud top height can be derived. Data on OClO and HCHO are also possible products of OMI. The ground pixel-size of OMI will be in the order of 20 x 20 km^2, which will enable EOS-CHEM to monitor tropospheric pollution on a regional scale.

The OMI team and its tasks

KNMI will be responsible for defining the science requirements for OMI, the requirements for the consolidated level 1b product (i.e. solar irradiance and atmospheric radiance) and the requirements for calibration of the instrument. Moreover KNMI will lead the development of the (operational) retrieval-algorithms for the above-mentioned (level 2) data products of OMI, and the validation of level 1b and level 2 products. About 10 scientists will work for 10 years on this project in the Netherlands. This work will be embedded in an International Science Team consisting of Dutch, Finish and American scientists. The International Science Team will be led by the Dutch Lead Scientist or Principle Investigator (PI), together with a Finnish co-PI and an American co-PI.

Modelling atmospheric composition

Introduction

The objective is to study changes in the atmospheric composition and how these changes influence the climate. The group uses for these studies the off-line chemistry-transport model TM3, which is coupled to meteorological fields from ECMWF, and the on-line Chemistry General Circulation Model ECHAM to simulate atmospheric chemistry and transport. TM3 is mainly used for long-term simulations, while ECHAM is used for process and case studies because it is computationally more expensive. Both models are further developed in co-operation with IMAU and the MPIs for Chemistry and Meteorology in the framework of CKO (Netherlands Centre for Climate Research) and COACh (Co-operation on Oceanic, Atmospheric and Climate Change studies). Finally, for the interpretation of instrumented aircraft and other in-situ measurements a trajectory model driven by ECMWF wind input is used extensively.

Influence of transport on trace gas distribution, and trend studies

Ambaum, Brunner, Cuijpers, Fortuin, Meijer, Meloen, Scheele, Siegmund, Stockwell, Straume, Van Velthoven, Zachariasse

Transport of atmospheric constituents is strongly affected by the presence of transport barriers such as the tropopause and the polar vortex edge. The leakage of these barriers is a continuing subject of research.

For TM3, input data of the full ECMWF Re-Analysis (ERA) period of 1979-1994 have recently been completely pre-processed. These re-analysis data are also directly used to study transport processes, e.g. stratosphere-troposphere exchange. Using the ECMWF re-analysis data for 1979-1994 the temporal variation of the air mass fluxes from the stratosphere to the troposphere and vice versa has been studied. As expected, in both hemispheres the extra-tropical downward flux shows a strong seasonal variation with a maximum in winter. In addition, the analysis shows a slightly positive trend of the strength of the stratospheric circulation in the course of the re-analysis period of 1979-1994. Some aspects of the ERA temperature trends in the stratosphere can be attributed to trends in the vertical circulation.

The transport of chemical constituents between the troposphere and stratosphere was also investigated experimentally by making use of instrumented aircraft in the EU-projects STREAM (Stratosphere-Troposphere Experiment by Aircraft Measurements), see Lelieveld et al, 1997 and Schneider et al, 1998, and the POLINAT campaign (Pollution and Aircraft Emissions in the North Atlantic Flight Corridor), see Ovarlez and van Velthoven, 1997. It has long been suggested that gravity waves might induce transport between the troposphere and the stratosphere. Analysis of POLINAT aircraft measurements of the atmospheric composition has revealed evidence for non-reversible transport

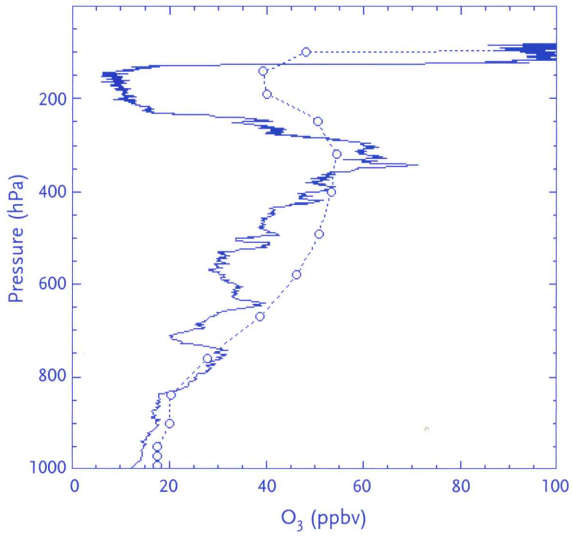

Figure 3. Results from a preparatory ship cruise for the Indian Ocean Experiment INDOEX. Observed ozone profile (solid line) and modelled ozone profile (dashed line with open circles) at 4 April 1995. Location and time of release of the sonde are respectively 55.0°E, 18.02°S and (approximately) 11.00 UTC. An ozone minimum in the upper troposphere (around 200 hPa) is clearly visible.

of ozone across the tropopause caused by interacting gravity waves.

Planetary waves modulate the total ozone distribution and the transport of ozone-depleted air from the Antarctic polar vortex into southern mid-latitudes. An elegant method to analyse the effect of planetary waves on ozone in terms of geopotential and density perturbations on isentropic surfaces was developed. Strong minima in total ozone over the inhabited regions of South-America were found to be associated to deformations of the vortex edge by large-scale planetary waves (Teitelbaum et al., 1998).

In the framework of the EU project SINDICATE a zonal and monthly mean ozone climatology over the period 1980-1991 has been constructed for use in general circulation models and chemistry transport models (Fortuin and Kelder, 1998). It is mainly based on ozone soundings from WOUDC, complemented with SBUV and SBUV-2 satellite observed ozone profiles in the upper stratosphere and with TOMS-SAGE (Total Ozone Mapping Spectrometer- Stratospheric Aerosol and Gas Experiment) tropospheric ozone residuals to improve the representativeness in the tropical belt. The historical ozone soundings have also been used to determine trends in the vertical ozone and temperature distribution. It shows that in the stratosphere ozone and temperature trends can be linked through radiative cooling.

The ozone climatology has been implemented in the ECHAM model to replace the outdated London climatology. The changes in the simulated general circulation, due to improved ozone radiative heating rates, are being assessed. The ozone climatology is now also widely used as a priori ozone distribution for the retrieval of ozone profiles from GOME.

Over the Indian Ocean the pollution of the continent can be rapidly transported upward to the middle and upper troposphere by tropical cyclones and by deep convection in the ITCZ (Intertropical Convergence Zone), as was shown in a preparatory study with the ECHAM model (see Figure 3). The seasonal and interannual variability of precursor transport into the Indian Ocean free troposphere is studied with the help of measurements on board of civil aircraft flying 12-24 times per year from Germany to Male/Colombo and back. This work is carried out in the context of the EU project CARIBIC (Civil Aircraft for Remote sensing and In-situ measurements in troposphere and lower stratosphere Based on the Instrumentation Container concept).

Data assimilation

Eskes, Jeuken, Siegmund, Van Velthoven

We have implemented an optimal interpolation scheme for the assimilation of total ozone data in the chemistry-transport Model TM3. It is found that this three-dimensional assimilation gives much more realistic results for the ozone columns than earlier two-dimensional assimilation models. Also the ozone profiles look quite realistic, which is mainly due to the good descripion of transport in the model and the fact that ozone has a rather long chemical lifetime in most of the model domain. The impact of assimilated ozone columns on the simulated ozone profiles was therefore relatively small.

In the free running climate mode the ECHAM model cannot be directly compared to instantaneous observations. Therefore also a procedure has been developed to relax it to ECMWF analysed meteorology.

Interaction between chemistry and turbulence in the boundary layer

Verver

The conventional approach in atmospheric transport/chemistry modelling is to describe turbulent transport of reactive tracers with methods similar to those applied to inert tracers, such as water vapour or sensible heat. It is also usually assumed that concentration fluctuations of reactive tracers are not correlated, and that concentration co-variances can thus be neglected. These assumptions were tested for a single irreversible bimolecular reaction using a second order closure model in Verver et al. (1997). It was shown that, depending on reaction rates, the turbulent exchange coefficient will be affected significantly by the chemical reaction. Furthermore it was found for this simple case that anti-correlated concentration fluctuations may alter effective transformation rates by more than 80%.

A slightly more realistic case was studied by Verver (1998) describing NO-NO_2-O_3-hydrocarbon chemistry that includes 3 chemical reactions. A small effect was found on vertical concentration gradients, while boundary-layer averaged concentrations remained nearly unchanged. The chemistry scheme was extended with a comprehensive set of chemical reactions that describes the oxidation of isoprene. With this set of chemical reactions, the model is able to reproduce fairly well the observed concentrations of O_3, NO_x and isoprene and its reaction products during the ABLE-2a (Amazon Boundary Layer Experiment). The turbulent flux of NO and NO_2 is altered by 30% when the covariance of concentration fluctuations as well as chemistry effects on the flux are taken into account explicitly. In that case we find a change of the mean concentrations of some short-living radicals of roughly 10%. However, the concentration profiles of the stable reaction products remain unchanged. It was concluded that neglecting covariance effects and chemistry effects on the flux is justified for the cases that are studied.

Aerosol modelling

Jeuken, Verver, Van Velthoven, Scheele

In TM3 a module containing a description of the life-cycle and budget of sulfate was included in the framework of the project MEMORA (Measurement and Modelling of the Reduction of radiation by Aerosols), funded by NOP (National Research Programme on global air pollution and climate change). The module includes emissions, gas- and liquid phase chemistry, and dry and wet deposition for sulphur dioxide, sulphate, and dimethylsulfide (DMS). The importance of long-range transport of aerosols from Europe to the sub-tropical Atlantic was demonstrated during the international ACE-2 (Aerosol Characterisation Experiment) in 1997 (Raes et al, 1997).

The simulated distributions correspond well with available surface measurements and GOME and ATSR-2 (Along Track Scanning Radiometer) satellite observations. We have also participated in a model intercomparison exercise organised by the WCRP (World Climate Research Programme) and the IGAC project (International Global Atmospheric Chemistry project).

Outlook

In February-April 1999 we will participate in the INDOEX experiment (Indian Ocean Experiment) which aims to study the budget and life-cycle of radiatively active gases and aerosols in this region. Important sources of ozone precursors in this ocean environment are the rapidly developing emissions in India as well as biomass burning on the African continent.

With TM3 multi-year simulations using the ECWMF re-analysed meteorology will be made of the past changes in the tropospheric composition. An assessment of the performance of the model simulations over the past is expected to give better insight in the uncertainties in predictions about future trends and in scenario calculations (see the section Recent highlights on aircraft emissions). Such studies will be of importance for upcoming IPCC and WMO - UNEP (World Meteorological Organisation - United Nations Environmental Programme) assessments. The TM3 model will be further validated through data assimilation and validation studies with satellite data. Special attention will further be given to the importance of NO_x-production by lightning (compared to aircraft NO_x-emissions) for the tropospheric ozone budget by simulating observations made during the EULINOX experiment (European Lightning Nitrogen Oxides experiment) in summer 1998.

The studies of the coupling between ozone chemistry, the general circulation and climate - which is a rapidly evolving research area - will be continued in the years up to 2001 through more extensive studies with the on-line ECHAM model.

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Number of international presentations: 1997: 26 1998: 47.

Externally funded projects: national 8, international 19.

Education, organisation of workshops:

H.M. Kelder is part-time professor of Atmospheric Physics at the Technical University of Eindhoven.
P. Siegmund and M.P. Scheele contributed to an international graduate school on 'Atmospheric Dynamics and Tracer Transport' in Boekelo, The Netherlands

(28 September - 9 October 1998). The school was organised within the context of COACh, which is an international co-operation of CKO and the MPIs for Meteorology in Hamburg and Mainz. They organised classroom lectures on stratosphere-troposphere exchange and the trajectory model, and laboratory exercises on the trajectory model.
H.J. Eskes and H. Kelder organised a workshop on 'Chemical Data Assimilation' at KNMI on 9 en 10 december 1998.

Other activities:
H.M. Kelder, Dutch member of the WMO - UNEP Ozone Research Managers Committee.
H.M. Kelder, member of the SCIAMACHY Science Advisory Group.
H.M. Kelder, principal user of the OMI User Advisory Group of ESA.
H.M. Kelder, member OMI Science Advisory Group.
H.M. Kelder, lead author IPCC - UNEP Special Report 'Aviation and the Global Atmosphere'.
H.M. Kelder, member AEREA (Association of European Research Establishments in Aeronautics) - NASA Organising Committee of symposium 'Aviation and the Global Atmosphere'.
P.F. Levelt, Lead Scientist of OMI.
P.F.J. van Velthoven, M. van Weele and W.M.F. Wauben, contributing authors IPCC - UNEP Special Report 'Aviation and the Global Atmosphere'.

Atmospheric Research

General • The Atmospheric Research Division investigates atmospheric energy and water budgets on local, regional and global scales. Research is focused on the transport of heat, water vapour and momentum by turbulence and clouds and on the earth radiation budget in relation to clouds, aerosols and greenhouse gases. Research includes both experimental studies and the development of local, regional and global models.

The start of 1997 marked the end of a period with intensive measurement campaigns: Cabauw, Garderen, TEBEX (Tropospheric Energy Budget Experiment) and CLARA (Clouds And Radiation experiment). The emphasis of the work shifted towards the analysis of data and the writing of publications.

The group dealing with observation and analysis of clouds and radiation experienced a growing international acknowledgement and a rapid growth in manpower due to successful applications for external funding. The cloud detection system developed for TEBEX was successful to the extent that it is now being transformed into an operational cloud observation system. This system includes cloud lidars (light detecting and ranging), ground-based infrared sensors and satellite retrievals and will replace in the future the existing synoptic observation network in the Netherlands. Co-operation with the ARM programme (Atmospheric Radiation Measurement programme) in the USA has been established, as well as co-operation with groups in Europe dealing with cloud observation research. The research group on clouds and radiation was also active in the analysis of the data of GOME (Global Ozone Monitoring Experiment) and in the preparations for the projects SCIAMACHY (Scanning Imaging Absorption Spectrometer for Atmospheric Cartography) and OMI (Ozone Monitoring Instrument).

The experimental boundary layer group completed a 10-year data base with Cabauw observations and also extensive data sets obtained in Garderen over a forest. Observational methods for carbon dioxide flux and longwave radiation were improved. Studies into the forest-atmosphere interaction were performed. The wind profiler/RASS (Radio Acoustic Sounding System) produces continuous observations of wind and temperature profiles, which are real-time available for operational applications and research.

The group played a significant role in the COST-76 project (European Co-operation in the field of Scientific and Technical research) dealing with the preparations for a European network of wind profilers. The group was also involved in other international projects, including PILPS

(Project for Intercomparison of Land surface Parameterisation Schemes) and ERA (ECMWF - European Centre for Medium-Range Weather Forecasts - Re-Analysis project).

The modelling group continued the development of the LES model (Large Eddy Simulation model) and its cloud resolving version CREAM (Cloud Resolving Atmospheric Model) in close co-operation with IMAU (Institute for Marine and Atmospheric Research Utrecht). This work was embedded in the work of the GCSS (GEWEX - Global Energy and Water Cycle Experiment - Cloud System Studies) and in an EU-supported project EUCREM (European Cloud-Resolving Modelling). These projects aim at the improvement of parameterisations of clouds in large-scale models. New parameterisations are tested against detailed experiments as well as against simulations with RACMO (Regional Atmospheric Climate Model). For this purpose RACMO is run daily in forecast mode, and these forecasts are compared with synoptic observations in the Netherlands and Western Europe to test the quality of various parameterisations. In addition, detailed checking of the results against the Cloud Detection System (CDS) with TEBEX data has been made. A closer co-operation with ECMWF and with the HIRLAM project (High Resolution Limited Area Model project) has been established, leading to a better feeding of research products into the operational forecast community.
The co-operation with the Max-Planck-Institute (MPI) for Meteorology in Hamburg with regard to the improvement of climate models was continued, in particular with regard to the parameterisations of radiative processes and the role of greenhouse gases, aerosols and clouds.

New research was started into the impact of solar activity and volcanic eruptions on the global radiation budget in relation to the influence of global circulations on global temperatures. The regional climate model RACMO was also applied to the study of the mass balance of the Antarctic ice-cap.

In 1997 a colloquium on 'Clear and Cloudy Boundary Layers' was organised under the wings of KNAW (Royal Netherlands Academy of Arts and Sciences) and in close co-operation with IMAU. Recently a book appeared containing the edited contents of this colloquium.

Preparations have been made for new experiments in the future. The Cabauw tower is being renovated. The new observation programme includes an operational part, which will be run as a synoptic/climatological station. In addition, facilities are created for experimental research which will be carried out as dedicated research projects of limited duration. The Atmospheric Research Division is actively involved in the BALTEX - BRIDGE project (Baltic Sea Experiment - Main Experiment). An experiment focused on the stable boundary layer is also in preparation.

Observational systems

Wind profiler/RASS systems

Klein Baltink, Monna

For July 1995 the Cabauw wind profiler data were analysed to derive the convective boundary layer height from the backscatter signal. The results were used to evaluate the diagnostic height derived from RACMO output. Considerable differences were found in some situations. Single Column Model (SCM) runs with modified soil moisture availability were performed to study the effect on the boundary layer height. When SCM-boundary layer height coincided with the profiler measurement the model surface heat fluxes were in good agreement with the observed TEBEX surface fluxes.

The performance of a longwave radiation instrument was improved to meet the requirements for accurate radiation balance observations. The detection limit of a CO_2/H_2O fluctuation sensor was improved.

Comparison of profiler winds with tower winds was extended with measurements from a Doppler sodar (sound detecting and ranging). Sodar and profiler showed similar behaviour, and compared to the tower an offset of 5° in the wind direction is found for both systems. Furthermore both profiler and sodar wind speed are slightly lower than the tower winds. Comparison of RASS temperature with tower measurements showed a very good agreement when some corrections for vertical wind speed and range dependent backscatter are applied to the RASS measurements.

COST-76 carried out the WINDE97 experiment (Wind Initiative for Network Demonstrations in Europe) in January and February 1997, in which KNMI participated with its wind profiler. Combining nearly all wind profilers in Europe in one observation period, in parallel with FASTEX (Fronts and Atlantic Storm Track Experiment), the feasibility of a European wind profiler network was demonstrated for the first time. Subsequently, the data are used to study the usefulness of wind profilers. In May 1997, the COST-76 Profiler Workshop was organised at Engelberg (Switzerland). With several contributions from outside Europe, this workshop was very successful. At a later stage, about 25 contributions were extended to full papers that were published in the Meteorologische Zeitschrift. After much preparatory work, worldwide allocations for wind profilers were finally realised at the World Radio Conference in November 1997.

Cloud Detection System (CDS)

Van Lammeren, Feijt, Konings

The Cloud Detection System (CDS) was installed and operated for a two-year period (1995-1996). The cloud detection system consists of a network of stations for ground-based remote sensing and a processing and archiving environment for the AVHRR (Advanced Very High Resolution Radiometer) and METEOSAT (Meteorological Satellite) measurements. The ground-based network observes the cloud fields from below. If multi-layered clouds are present, only the lowest layer is observed. The satellites observe only the cloud tops. It is expected that a combination of the ground and satellite observations will provide a more complete picture of the cloud fields.

The network stations are located in a 120x120 km^2 area in the Netherlands. Each station consists of a lidar ceilometer, a narrow-band infrared radiometer (type Heimann KT15.85A) and a pyranometer (Kipp&Zonen CG10) to measure global shortwave (SW) radiation. In the network two types of lidar ceilometers are used: Vaisala CT12K and Impulsphysik LD-WH-X5. Both systems are comparable in wavelength (911 nm), measurement range (4 km) and resolution (15 m for the Vaisala, 15 m increasing to 60 m for the Impulsphysik). Every minute the measured backscatter signals and cloud base heights are archived.

The wavelength range of the vertically pointing infrared radiometer is 9.6–11.5 µm. The opening angle of the lens is 50 mrad. The measurement range of the sky temperature is between +50 and –53°C with a typical accuracy of 1–2°C. To obtain this accuracy, the temperature of the infrared (IR) radiometer housing is stabilised at 35°C. A precipitation detector controls the cover to shield the sensor. If precipitation is detected, the cover is closed. In this way the instrument is protected against rain. The data-acquisition is incorporated in the housing. Every 10 minutes specific characteristics of the measured sky temperature distribution are collected.

Simultaneously to the installation of the ground-based instrumentation a processing environment for METEOSAT and NOAA (National Oceanic and Atmospheric Administration) - AVHRR data was set up. The METEOSAT data for North-Western Europe of all three channels was archived every half hour. The NOAA - AVHRR images, which included the Netherlands, Belgium and part of the North Sea, were also archived. The data for all spectral channels was collected. On average this included about 4 overpasses a day. Several tools are available for interpretation of the measurements such as data on the actual atmospheric conditions and radiative transfer models.

The cloud detection system is designed to retrieve the following cloud characteristics: cloud cover, cloud top temperature, cloud base height, cloud base temperature, infrared emissivity, reflectivity and optical thickness. Also the variability of these properties in time and space are characterised. In the sections 'Regional cloudiness' and 'Vertical profiles of cloud cover: observations and model predictions' the use of CDS data is described.

Water vapour observations with GPS

Klein Baltink, Derks, van Lammeren

Starting with some periods during the CLARA campaigns in 1996 the Global Positioning System (GPS) technique was applied to measure the water vapour column. Since mid 1997 the data are archived routinely. This technique uses the tropospheric delay of the GPS signals to estimate the water vapour column. A comparison was made with measurements from the microwave radiometer and radiosondes. The results from all three systems agreed within acceptable limits. From a comparison of the GPS-results with RACMO model output it was concluded that also the predicted water vapour column values (+0 – +72 hour) show a good agreement with the observations. Finally, the problems that limit the use of real-time GPS water vapour values in model assimilation have been investigated. It was found that the most pressing problem of timely availability of orbit data can be solved by applying the 'orbit relaxation method'. From a first analysis it was shown that this method provides data that are as accurate as data that are derived from the accurate - but delayed - orbits. Adapting the GPS data transport infrastructure may solve the remaining problems for real-time data use. This project was partly financed by BCRS (Netherlands Remote Sensing Board) and was executed in co-operation with several national parties. For an illustration we refer to Figure 1.

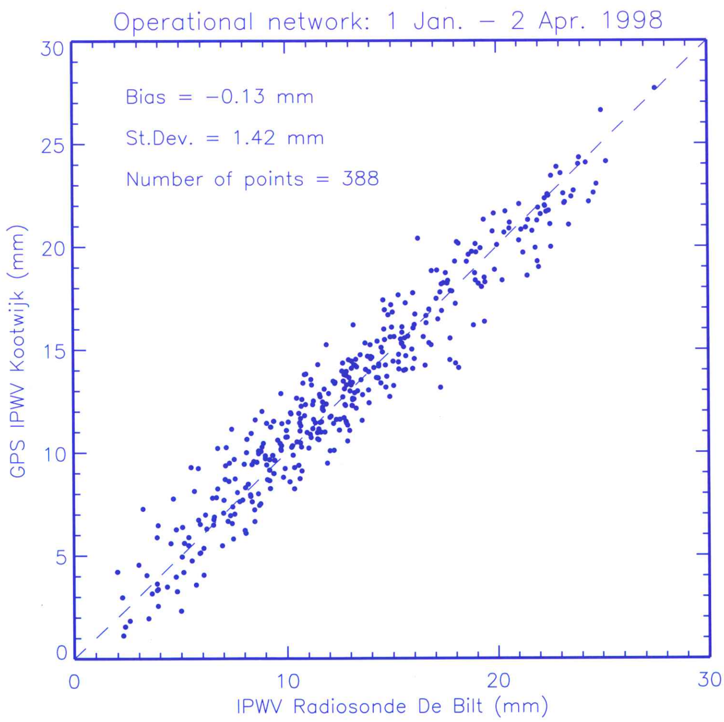


Figure 1. Comparison of Integrated Precipitable Water Vapour (IPWV) as derived from radiosonde data with GPS operational processing data for Kootwijk.

Surface fluxes over land

Bosveld, Holtslag, Kohsiek, van den Hurk

Introduction

Uncertainties in the representation of the surface energy flux over land is one of the key problems in climate modelling. The coupling with soil hydrology introduces anomalies on the time scale of seasons. Moreover, the partitioning of the energy flux into latent and sensible heat flux directly influences boundary layer moisture and cloud formation. Carbon dioxide fluxes are important for understanding changes in the global carbon cycle in relation to climate change. In all cases the upscaling of local information to the scale of a grid box in a global circulation model is of importance.

Data Analysis

After finishing the TEBEX monitoring programme at the grassland site 'Cabauw' and the forest site 'Garderen', a validated data base was constructed. A first analysis of the data at the Cabauw site showed important problems with the closure of the energy balance. In the last half year of TEBEX complementary measurements were performed to check the observations of the different components of the energy balance. Although some deviations were found they were not large enough to explain the observed imbalances. This is subject of further investigation.

Observations of water and carbon dioxide fluxes taken over the forest site are used in a study on the coupling between hydrology and assimilation of carbon dioxide in forests. This work is performed in co-operation with W. Bouten from the University of Amsterdam.

Flux measurements of momentum and sensible heat, obtained along the 200 m Cabauw meteorological tower, are used to investigate the impact of surface inhomogeneity on flux-profile relations. Exchange processes in the nocturnal boundary layer are investigated. This work is performed in co-operation with H.A.R. de Bruin from the Agricultural University of Wageningen and J. Verkaik from the Observations and Modelling Department of KNMI.

The behaviour of the surface temperature of the forest site is investigated. It is found that during day-time surface temperature can be adequately described with surface layer similarity theory. At night-time, however, convection in the interior of the forest leads to deviations from the theory. A two-layer radiation/energy balance model is developed to explain these deviations.

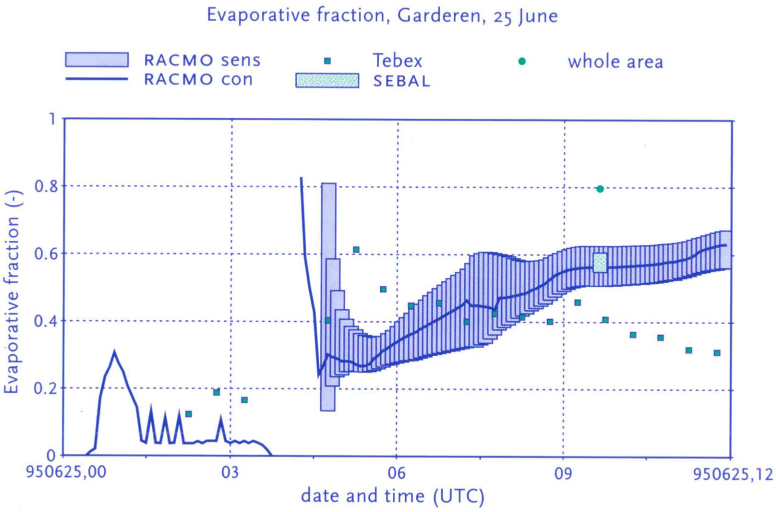


Figure 2. Evaporative fraction (evaporation divided by available energy) on 25 June 1995, between 0:00 and 12:00 UTC, for the Garderen location. Shown are TEBEX observations (dark green squares), a model simulation with RACMO using surface parameters derived from satellite images (blue solid line), the range of a set of RACMO simulations in which these surface parameters were varied (blue vertical bars), and estimates based on the satellite retrieval algorithm SEBAL for the morning of 25 June for the Garderen location only (light green vertical bar) and for the average of a large area including the Garderen site (green circle). For this particular case, RACMO and SEBAL agreed very well, but both give somewhat higher evaporation rates than shown by the TEBEX data.

Model studies

The relation between surface fluxes, soil and vegetation representation, and atmospheric boundary layer development were investigated with the CAPS scheme (Coupled Atmosphere-Plant-Soil scheme) of OSU (Oregon State University). The land surface scheme was updated with changes in the parameterisation of soil heat flux, soil hydraulic processes, soil layering and plant root density.

Model surface fluxes compared favourably with observations from Cabauw. This work is performed in co-operation with M. Ek from OSU.

Surface flux data, measured at Cabauw and Garderen on 4 days in 1995, were used as a reference for a comparison with surface flux estimations based on LANDSAT (Land Remote Sensing Satellite) images using the so-called Surface Energy Balance Algorithm for Land (SEBAL). It was shown that SEBAL overestimated evaporation considerably for the Cabauw area, owing to the small contrast in LANDSAT surface temperatures. For the Garderen site, surface temperatures show a larger variability, and evaporation measurements were fairly well described by the SEBAL algorithm (see Figure 2). This work was carried out in co-operation with B. Su from the Winand Staring Centre in Wageningen.

New experiments

KNMI participated in LITFASS (Lindenberg Inhomogeneous Terrain Fluxes between Atmosphere and Surface - a long-term Study), a field-experiment organised by the German Weather service. The aim of LITFASS is to determine surface fluxes over an inhomogeneous terrain and the atmospheric conditions aloft at a horizontal scale of 10 km×10 km. The hilly terrain is situated close to the Observatory of Lindenberg in the east of Germany. LITFASS is likely to be continued within the context of BALTEX. The KNMI contribution consisted of net radiation observations and eddy-correlation flux measurements of momentum, sensible heat, latent heat and carbon dioxide at two levels in a mast.

Boundary layer and cloud dynamics

Boundary layer structure and dynamics

Holtslag, Siebesma, van Ulden, Jonker

This project focuses on the understanding and modelling of processes in the dry boundary layer. As such we study entrainment processes, mixing in the boundary layer interior and the interaction of the boundary layer with the surface. In addition, the interaction of the boundary layer with clouds and chemistry is studied (in co-operation with the Atmospheric Composition Research Division and IMAU). Several papers were submitted and accepted for publication in international journals. One of these papers deals with the background and the formulation of non-local mixing processes in the convective boundary layer.

Two new lines of research of the convective boundary layer were opened. The first line is based on the fact that the strongest convective updrafts dominate both non-local transport and entrainment at the top of the boundary layer. Equations have been derived which describe the dynamics of these strong eddies and the resulting contribution to transport and entrainment. First results have been presented at a conference and a publication is in preparation. The second line is a search for the origins of meso-scale variability in convective boundary layers. First results indicate that meso-scale variance of scalars is produced at meso-scales and that there is a flow of variance towards smaller scales. This suggests that an inertial subrange type of behaviour is also present at the meso-scale. An article on this issue is in preparation.

Turbulence parameterisation for HIRLAM

Holtslag, Lenderink, Siebesma

In the HIRLAM project there are at least three competing approaches of the improvement of the turbulence parameterisation, in particular of the atmospheric boundary layer. To make a selection for further development within HIRLAM, a benchmark among three different turbulence formulations was organised. The findings of the benchmark were presented during a meeting at KNMI, on 23 and 24 March 1998. At the meeting three turbulence formulations were compared in a one-dimensional context for three specific cases, and three cases for the full three-dimensional model. Based on the findings, it was recommended to further develop a turbulence scheme in which mixing is formulated on the basis of a prognostic turbulent kinetic energy equation in which advection is taken into account. The work is carried out in collaboration with G. J. Cats of the Observations and Modelling Department.

Non-precipitating cumulus clouds

Siebesma, Jonker, van Ulden, van Meijgaard, Neggers

International intercomparisons of case studies with cloud resolving models were continued, both in a European context - in the EUCREM project - and in GCSS context. It appears that cloud resolving models provide good simulations of non-precipitating cumulus clouds. In the same projects single column models with parameterised clouds have been compared. Two types of parameterisations have been tested: mass flux models and models using an eddy diffusivity in combination with a statistical cloud scheme. Both approaches are in principle able to produce satisfactory simulations, provided well chosen mixing coefficients are used. Several papers have appeared on these issues and interactions with ECMWF and the HIRLAM group have been intensified. A new project has been started which focuses on the interaction between boundary layer convection and shallow cumulus clouds. Various closure approaches are being tested. A new thermodynamic diagram reveals an interesting ordering in the distribution of the properties of cloud parcels.

In the context of an international course on buoyant convection a rather comprehensive review paper on shallow cumulus convection has been written.

Dynamics and modelling of stratocumulus clouds

Holtslag, Lenderink, van Meijgaard, van Ulden

Stratocumulus clouds are very important for the global radiation budget. In climate models it is therefore important to have a good representation of these clouds. Yet, climate models have large difficulties in simulating stratocumulus clouds, and in general severely underestimate the area occupied by these clouds.

A first order mixing-condensation scheme, based on conserved variables, was developed. This scheme contains a turbulence closure based on cloud top radiative cooling and a description of entrainment based on dynamical overshoot. The scheme was tested against the ASTEX data (Atlantic Stratocumulus Transition Experiment data), with reasonable results. An article was published. A new project was started, partly financed by NWO (Netherlands Organisation for Scientific Research), aiming to improve the representation of stratocumulus clouds in numerical climate (and weather prediction) models. Data of ASTEX, June 1992, and data of LES models were used to evaluate the performance of the physical schemes used in climate models. This intercomparison between measurements, LES models and climate models has been done in the EUCREM project.

The representation of entrainment by a turbulence scheme on the basis of a prognostic turbulent kinetic energy equation has been investigated. Such a turbulent scheme is presently used in the ECHAM4 model (Hamburg version (number 4) of the ECMWF model). The research has revealed some deficiencies in the ECHAM4 version of this turbulence scheme, and a few modifications were proposed which lead to a better representation of entrainment. Much effort has also been put into the performance of turbulence schemes at a low vertical resolution, such as presently used in operational numerical climate models.

Clear and cloudy boundary layers

Holtslag

From 26-29 August 1997 an official Academy-colloquium was held at KNAW in Amsterdam, the Netherlands. The meeting was organised in co-operation with P.G. Duynkerke from IMAU. The purpose of the colloquium was to provide an overview of the advances during the last decade in the understanding and modelling of clear and cloudy boundary layers. The invited lectures were given by fifteen senior scientists active in the field and cover topics on the current understanding of theory and concepts in use for atmospheric boundary layers, surface interactions, and boundary-layer clouds and radiation. In addition, there were presentations on the application of boundary-layer knowledge for the (large-scale) modelling of air quality, and for weather forecasting and climate research. Also a presentation was given on the history, philosophy and sociology of boundary-layer modelling.

On the basis of the material presented at the meeting, a book with 15 chapters was published by the end of 1998 (Clear and Cloudy Boundary Layers, A.A.M. Holtslag and P.G. Duynkerke, editors, 1998, published by KNAW, Amsterdam, 372pp). The meeting was sponsored by KNAW, KNMI and IMAU.

Clouds, aerosols and radiative processes

Regional cloudiness

Van Lammeren, Feijt, Dlhopolsky, Konings, van Meijgaard

The representation of clouds and their impact on radiative transfer remains one of the greatest sources of uncertainty in present day climate models. To improve this representation, better parameterisations of clouds are needed. In addition, the relation between clouds and radiative transfer has to be clarified. For model improvements, dedicated measurements are needed.

As remarked earlier, the Cloud Detection System (CDS) was installed and operated for a two-year period (1995-1996). From an analysis of the data for a two month period (January-February 1995) it is shown that the synoptic cloud cover observations are reproduced by the CDS with a standard deviation of two octa for a single station and one octa for the CDS-area averaged values. The CDS data allow for the derivation of the following cloud parameters: cloud base and top heights, and temperatures, optical depth and emissivity.

The CDS data set contains a two-year time series of objective cloud observations, which are used for evaluation of cloud parameterisation schemes. The RACMO model was operated with two different cloud parameterisation schemes. The results from the two runs have been compared to the observations for the same period. This type of work has been embedded in the EU project NEW BALTIC II. Output from different European atmospheric models are being compared with the CDS observations.

The CDS concept is widely applicable. Worldwide there is a large number of potential ground-based stations which have not been fully exploited yet. KNMI has decided to apply the CDS concept in its operational network. Discussions have started to operate similar networks in a European context.

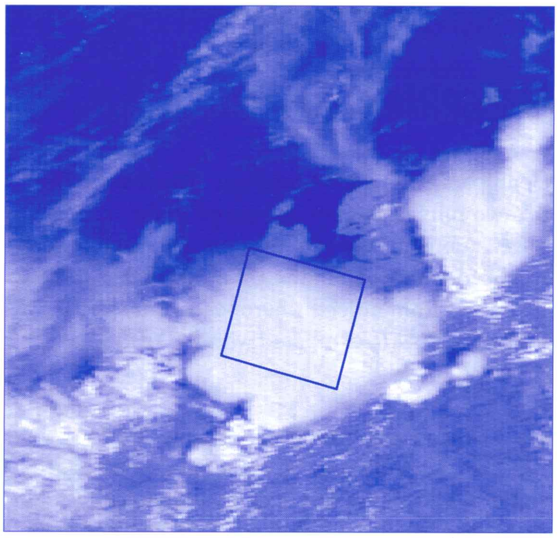
METEOSAT data has been used within the CDS concept to derive cloud parameters. Initially, the METCLOCK (METEOSAT Cloud Detection and Characterisation KNMI) scheme was developed for this purpose. In co-operation with other groups within KNMI the scheme is being developed as an operational tool for forecasters. An extensive development and validation project was started. It was concluded that the METCLOCK scheme operates well for North-Western Europe, the area for which it was developed.

The first MSG (METEOSAT Second Generation) satellite is expected to be launched in the year 2000. In order to prepare for the data analysis of this new satellite several projects have been started. The APOLLO (AVHRR Processing scheme over Clouds, Land and Ocean) scheme for AVHRR is used as a basis for the cloud characterisation for MSG. With support from BCRS the APOLLO scheme is now thoroughly validated with CDS data and improvements are being developed. Our expertise for retrieving cloud parameters from operational satellite data is used within the EUMETSAT (European Organisation for the Exploitation of Meteorological Satellites) Climate SAF (Satellite Application Facility) project. KNMI will validate retrieval algorithms with the available data sets (CDS, CLARA, Operational CDS, etc.)

Vertical profiles of cloud cover: observations and model predictions

Van Meijgaard, Konings, Feijt, Van Lammeren

Cloud cover profiles predicted with a regional atmospheric model (RACMO) are directly compared with observations analysed with the KNMI CDS. Observed profiles of cloud cover are inferred from measurements with a ground-based network of Heimann infrared radiometers and from satellite



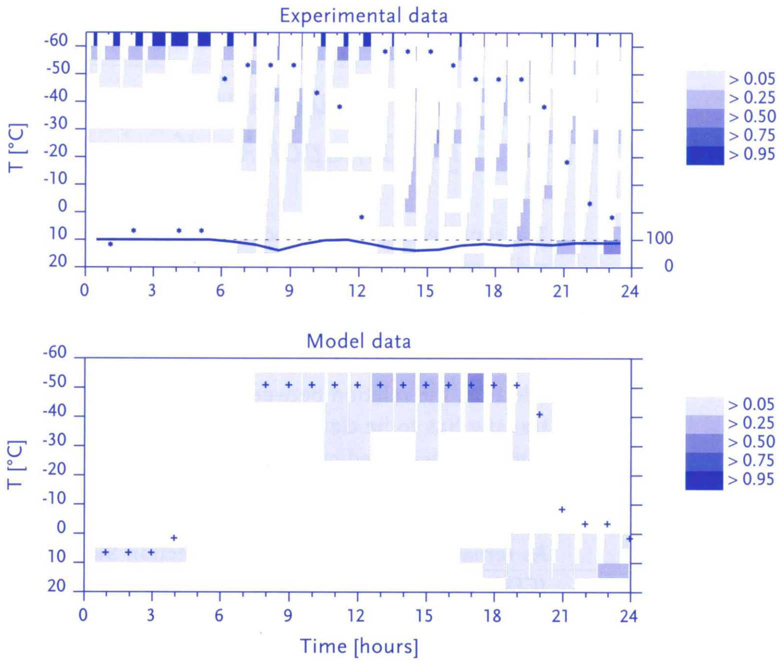


Figure 3 (left). The satellite image (AVHRR; channel 1 visible; overhead time 13:41 UTC on 8 June 1996) shows the mid- and high level clouds associated with two well-developed convective systems, the largest system covering the southern part of the Netherlands. Synop station Volkel reported 54 mm of precipitation in the hour preceding 14 UTC. The square box indicates the border of the CDS-area.

Figure 3 (right). The upper time-temperature (or time-height) diagram shows the occurrence of cloud cover as inferred from measurements taken with the CDS network of IR radiometers. The solid line indicates the relative number of times the IR radiometers were actually measuring (e.g. in the event of rainfall IR measurements are interrupted). The lower time-temperature diagram shows the corresponding model predicted cloud cover profiles obtained with the regional atmospheric model RACMO. The asterisk-symbols in the upper diagram correspond to the cloud top temperature as derived from satellite observations found in at least 5% of the pixels. Similarly, the plus-signs in the lower diagram indicate the highest model level with a cloud fraction exceeding 5%.

observations covering an area of 120×120 km^2. The corresponding model quantity is derived from the model cloud fraction profile assuming random-maximum overlap and viewing from the surface. Several case-studies, including a frontal system, a convective system and a case with low-level stratus, indicate that there is room for substantial improvement. The model generally underpredicts the observed total cloud cover. In particular, the occurrence of mid-level cloud cover is underestimated by the model.

An example of such a comparison is shown in Figure 3. It depicts a satellite image (13:41 UTC) of a deep-convective system that crossed the Netherlands on 8 June 1996. Time-temperature diagrams of observed and model predicted cloud cover profiles for that day are also shown. In the interpretation of the observed profiles it is assumed that height increases with decreasing temperature. It is furthermore assumed that clouds are opaque so that once a cloud is detected in a certain temperature layer the colder layers aloft are shielded from detection. This is expressed by the width of each box which represents the amount of time a temperature layer was accessible for detection by the IR radiometers, i.e. the amount of time that the layer was not shielded by clouds in lower layers. The degree of shading of a box indicates the relative amount of time during which clouds were actually detected in the corresponding temperature layer. In cloud free conditions the IR radiometer detects a clear-sky temperature which is indicated by the lowest temperature. For the case shown this occurs frequently during night and around noon, but for the rest of the day the sky is almost overcast. Nicely shown by the observed profiles is the presence of clouds in almost all temperature layers, in particular during the second half of the day. The model predicted cloud cover profiles are transformed from the usual model cloud fraction profiles in such a way that they simulate the observations. The result can be quite sensitive to the used assumption on cloud overlap. Most noteworthy in the model predicted cloud cover profiles is the complete absence of model clouds in the mid-level atmosphere. The model seems to capture the high cirrus in the afternoon and the low-level clouds in the evening quite reasonably.

Remote sensing of cloud parameters

Van Lammeren, Feijt, Bloemink, Boers, Donovan, De Hond, Meijer

To understand and model the radiative transport in a cloudy atmosphere, information on the cloud structure, optical properties and microphysics is indispensable. In order to obtain a complete as possible data set, four Dutch institutes joined their efforts in the CLARA project. This project is partly financed by the National Research Programme on global air pollution and climate change (NOP). After the start of the preparations for the first campaign, the total number of participating national and international institutes increased to 10. In total three experimental campaigns took place in the Netherlands in 1996. An extensive set of instrumentation was employed during the experimental campaigns including lidars, radar, infrared radiometers, microwave radiometers and radiosondes. Furthermore, in-situ aircraft measurements were carried out. With a Forward Scattering Spectrometer Probe (FSSP) the cloud droplet size distribution and the liquid water content was measured.

The CLARA data is used to develop and validate remote sensing algorithms for cloud properties both for ground-based and satellite instruments. For example, the cloud Liquid Water Path (LWP) as derived from passive satellite instruments, has been compared with the in-situ aircraft data and the ground-based microwave radiometer data. It was shown that the cloud particle size is a critical parameter in the retrieval of LWP.

One way of retrieving information on the cloud microphysical properties is by combining different remote sensing techniques. For example, the lidar/radar backscatter ratio of clouds contains information on the particle size (under certain assumptions). The CLARA data set has proven to be well suited for the development of these so-called 'sensor synergy algorithms'. Within several externally funded projects (funded by SRON (Space Research Organisation Netherlands) and ESA (European Space Agency)) algorithms are developed to explore this sensor synergy.

KNMI has participated in the international CLARE'98 campaign (Cloud Lidar and Radar Experiment 1998) in Chilbolton, Great Britain. This project focuses on the potential of sensor synergy for retrieving cloud parameters. The ERM (Earth Radiation Mission), one of the possible future ESA Earth explorer missions, aims at the retrieval of cloud and aerosol properties by combining lidar and radar observations. Results from CLARA and CLARE'98 are used to demonstrate the potential of such a mission.

The TEBEX CDS measured both cloud parameters (at 10 stations) and incoming shortwave radiation (approx. 30 stations) for a two-year period. The correlation between cloud parameters like cloud cover, cloud base height etc. and the incoming shortwave radiation was studied. It was concluded that cloud cover alone is insufficient to describe the incoming radiation at the surface.

From the radiation data the cloud optical depth has been retrieved. The influence of cloud variability on the accuracy of this retrieval was investigated thoroughly. In a simulated cloud field with 'realistic variability' the pyranometer signals were simulated using the independent pixel approximation. It was shown that the retrievals are reliable if some conditions are fulfilled (such as a sufficiently long averaging period).

Radiative transfer model developments

Stammes, van Dorland, Hess, Stam

Wide-band radiation code

Absorption and emission properties of greenhouse gases in longwave radiative transfer schemes are based on laboratory measurements of spectroscopic line parameters, such as line strength, half-widths due to pressure broadening, and the temperature dependencies of these parameters. Such data need to be parameterised in radiative transfer schemes due to the coarse spectral resolution. In 1998, the most recent compilation of spectroscopic data, the HITRAN 1996 data base (High-Resolution Transmission data base 1996), has been processed into absorption coefficients for the wide band scheme, used in the KRCM (KNMI Radiative-Convective Model).

The radiation transfer scheme in the KRCM is checked against surface radiation measurements at Cabauw under clear sky conditions, gathered during the TEBEX campaign (1995-1996). As input for the scheme, 253 atmospheric profiles of temperature and humidity from the Cabauw tower are combined with rawin sonde data at De Bilt. Total ozone data are derived from the Brewer spectrophotometer. For the investigated clear sky cases, covering a large range of atmospheric conditions, the scheme performs very well with a correlation coefficient of 0.99. The bias of only -2 Wm^{-2} and the standard deviation of 4.2 Wm^{-2} are both within the range of measurement errors.

Spectral shortwave radiation code

The spectral radiative transfer model DAK (Doubling-Adding KNMI), used for satellite retrievals, has been improved and compared with the GOMEtran model of the University of Bremen. A good agreement has been found when polarisation is neglected (DAK includes polarisation).

In the GOBELIN project (GOME Breadboard Experimental Link project), performed by SRON, KNMI and the Free University of Amsterdam, a large amount of spectral polarisation measurements of skylight have been acquired. Exciting results have been found, showing a rich spectral fine-structure in the polarisation. This fine structure is related to atmospheric absorption bands (of oxygen and water vapour) and to Raman scattering in Fraunhofer lines.

Detailed polarised radiative transfer modelling of the oxygen A-band using the DAK/GAP (Generalized Adding Programme) model has been continued. The effects of aerosols and surface reflection on the oxygen A-band have been studied systematically. Validation of the model using GOBELIN data is ongoing. Completion of the PhD thesis of D.M. Stam on this topic is expected in the course of 1999.

A new ray-tracing code has been developed for determining the optical properties of ice crystals. This code can compute the scattering matrix of so-called imperfect hexagonal crystals, which are intended to be a realistic model of cirrus cloud particles.

Spectral remote sensing of clouds and atmospheric composition

Stammes, Koelemeijer, Knap, Schutgens, Hasekamp

High spectral resolution measurements of the Earth by GOME on board the ERS-2 (Earth Remote Sensing satellite) have been analysed (see Figure 4). Two main aspects are studied: the accuracy of the polarisation-correction of radiances, and the accuracy of the GOME cloud detection technique. New releases of the GOME data processor have been tested on these aspects. A start has been made with the preparation for validation of SCIAMACHY polarisation measurements, building on experience with GOME.

Cirrus cloud properties, namely optical thickness, particle shape, and particle size, have been retrieved using the ATSR-2 (Along-Track Scanning Radiometer) measurements at two wavelengths and two viewing angles. The retrieval method will be extended to handle SCIAMACHY multispectral data.

The effects of clouds on the ozone retrieval results from GOME have been studied theoretically. Validation of the GOME cloud detection technique has shown large errors on an individual pixel basis.

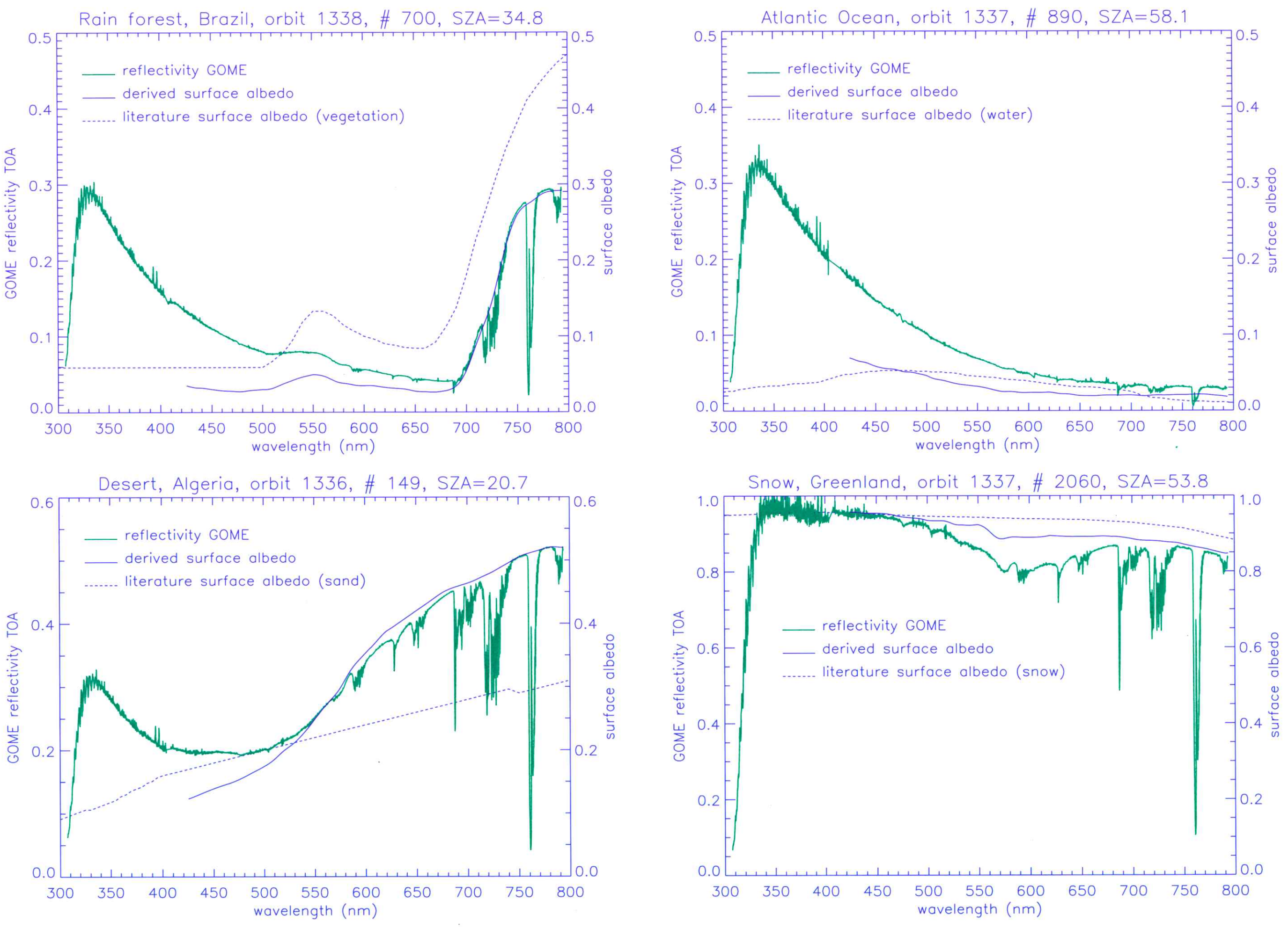


Figure 4. Spectral reflectivity at top-of-atmosphere of four cloud-free scenes as measured by GOME on 23 July 1995: rain forest, ocean, desert, and snow. From the measured spectra, the surface albedo has been derived by using the DAK radiative transfer model. For comparison, the literature surface albedo is also shown.

An improved retrieval method for cloud coverage and cloud top height using the oxygen A-band is being developed. Completion of the PhD thesis of R. Koelemeijer on this topic is expected in the course of 1999.

The scientific requirements for OMI on board the NASA (National Aeronautics and Space Administration) EOS-CHEM satellite (Earth Observing System - Chemistry satellite) have been defined (together with the Atmospheric Composition Research Division). A comprehensive plan for scientific support of OMI in the Netherlands has been made. P. Stammes has acted temporarily as the Lead Scientist of OMI.

Ground-based measurements of the aerosol optical thickness have been performed in De Bilt since mid-1997, using the Sun Photometer Ultraviolet (SPUV) instrument. This instrument measures direct sunlight at 6 wavelengths between 360 and 940 nm. An automated cloud removal technique has been developed. An aerosol particle size retrieval method has been implemented using these multispectral data.

Regional and global climate studies

Soil moisture and regional climate

Van den Hurk, van Meijgaard, Holtslag

Ongoing efforts of studying land surface processes are embedded by KNMI-participation into a number of (international) research projects.

Work on soil moisture assimilation using satellite derived estimates of surface heat fluxes is continued. After a successful demonstration study, applied to the Iberian peninsula, additional efforts have been invested in correcting RACMO soil moisture over the entire European land area during the complete growing season of 1995, using satellite information. A RACMO control run for that year showed excessive soil drying, resulting in an overestimation of near-surface temperature and an underestimation of specific humidity in summer. An optimum interpolation scheme has been designed in order to correct RACMO soil moisture as a function of forecast errors of temperature, humidity and satellite derived surface fluxes. The major focus is currently on improving the quality of the satellite retrieval algorithm.

The excessive soil drying in 1995 is also the subject of a nationally funded research project, aiming at an improved description of the hydrological cycle in regional climate and weather forecast models. The land surface parameterisation scheme in RACMO is replaced by a somewhat more sophisticated four-layer scheme. Four soil layers are included in order to cover a wide range of relevant time scales, varying from daily to seasonal cycles. Despite a very detailed soil hydrological model, this new scheme is shown to have clear deficiencies in the description of surface and deep water runoff. Modifications of the formulation of these processes in the scheme are currently being explored.

In the context of the EU-funded research project NEW BALTIC II, KNMI participates in a modelling study focusing on the energy and water cycle of the Baltic Sea area. RACMO joined in a model intercomparison study for a 3-month period in the late summer of 1995, and again appeared to compute unrealistic runoff values. On the other hand, calculated values of surface evaporation, cloud cover and rainfall seem to be very realistic. Additionally, RACMO will be used in another model intercomparison, focusing particularly on soil hydrological processes. A few model simulations will be carried out at a high horizontal and vertical resolution during an entire growing season. This work is still going on.

The surface mass balance of the Antarctic ice-cap: a study with a regional atmospheric model

Van Lipzig, van Meijgaard

The mass balance of the Antarctic ice-cap, which is the sum of precipitation, evaporation, melt, snow drift, runoff and calving, is important for global sea level. As data on the surface mass balance (accumulation) are relatively sparse, additional information at high spatial resolution may be provided by an atmospheric model. RACMO (horizontal grid spacing 55 km, 20 model layers in the vertical with a very shallow layer near the surface) is used to simulate the meteorological conditions in the Antarctic region for a period of 10 years (1980-1989). The prognostic variables at the lateral boundaries of the model domain are forced by ERA fields. Sea-ice extent and sea surface temperature are prescribed from observations. The simulated 10-year mean surface mass balance (precipitation minus evaporation) of the grounded Antarctic ice is found to be 156 mm per year, with an annual standard deviation of about 8 mm per year. The value found for the mean accumulation appears to be quite similar to estimates made on the basis of glaciological measurements. The simulated mean precipitation is 195 mm per year without a clearly discernible annual cycle. The simulated mean evaporation is 39 mm per year with a maximum in summer.

Atmospheric models are recognized to be useful tools for studying the sensitivity of the surface mass balance to climatic perturbations. A 5-year sensitivity simulation is performed for the period 1980-1984. In this simulation, (1) the temperature at the lateral relaxation zone of the model domain is raised by 2 K at constant relative humidity, (2) the sea surface temperature is raised by 2 K, and (3) the sea-ice is partially removed. As a response to these perturbations, the simulated surface mass balance of the grounded Antarctic ice increases with 47 mm per year, which is about 30% of the outcome from the control run. This value is larger than results found in studies that were based on simplified models and on statistical analyses between surface temperature and surface mass balance. Further sensitivity runs indicate that forcing applied at the sea surface level has a smaller effect on the accumulation over the continent than forcing applied throughout the entire atmosphere in the lateral relaxation zone of the model domain. In the latter case the excess water vapour is already added to the upper troposphere where transport towards the continent dominates. In the former case, however, the increase of water vapour due to a warmer ocean surface must first be taken upward by resolved or sub-grid scale motions through the boundary layer before it can be transported to the continent. This process is less effective.

Global radiation budget

Van Dorland, van Ulden

The appearance of the book 'The manic sun' by Nigel Calder received wide attention in the Netherlands. This led to the start of an assessment study on the role of variations in solar activity in climate change. Time series of global mean temperature were analysed using statistical regression techniques and a one-dimensional climate model. This climate model consists of a radiative-convective atmosphere model coupled with a ten-layer ocean model.

Anthropogenic radiative forcing was computed using histories of greenhouse gas concentrations and aerosols since 1850. As natural forcing mechanisms, the effects of large volcanic eruptions and variations in solar irradiance were included. The latter variations were modelled using observed sunspot numbers and the solar cycle length. From a comparison between model simulations and observed temperatures the following conclusions could be drawn. Anthropogenic radiative forcing is probably the major factor behind the observed long term warming trend. Solar activity variations proportional to the inverse of the solar cycle length may contribute to this trend and to interdecadal variations, although no proven mechanism exists. Variations in solar activity over the 11-year solar cycle lead to very modest temperature signals. Major volcanic eruptions are an important source for temperature variations on interannual time scales. With linear regression techniques similar results were obtained. These results were presented at a national symposium: 'Sun and climate: the influence of variations in solar activity on the earth's climate' The symposium was held in November 1997 and organised by KNMI and IVM (Institute for Environmental Studies). At this symposium 6 papers were presented on various aspects of solar variability and on possible influences on climate. These papers and the results of the panel discussion were included in the symposium report which appeared in January 1998.

In 1998 the work was continued with an analysis of the joint contributions of volcanic forcing and ENSO (El Niño - Southern Oscillation). Preliminary results indicate that these factors may be more important than variations in solar activity both on interannual time scales and on interdecadal time scales.

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Books and/or theses:

1998 Holtslag, A.A.M. and P.G. Duynkerke, editors, 1998. Proceedings KNAW-symposium 'Clear and Cloudy Boundary Layers', Amsterdam (ISBN 90-6984-235-1), 372pp.

Dorland, R. van: Harvey, D., 'Global warming: the hard science'. Contributor of ozone and sulfate aerosol fields from van Dorland et al. (1997). To appear in 1999.

Number of international presentations: 1997: 50, 1998: 43.

Externally funded projects: national 14, international 7.

Education, organisation of workshops:

A.A.M. Holtslag is part-time professor (20 % position) at the University of Utrecht. Gives a course on 'Atmospheric modelling and forecasting' and guidance to MSc and PhD students.

R. van Dorland, G. Lenderink and E. van Meijgaard contributed to an international graduate school on 'Atmospheric Dynamics and Tracer Transport' in Boekelo, The Netherlands (28 September - 9 October 1998). The school was organised within the context of COACh (Co-operation on Oceanic, Atmospheric

and Climate Change studies), which is an international co-operation of CKO (Netherlands Centre for Climate Research) and the MPIs for Meteorology in Hamburg and Mainz.
A.A.M. Holtslag co-organised the colloquium on 'Clear and Cloudy Boundary Layers' at KNAW, Amsterdam, August 1997.
A.A.M. Holtslag and G. Lenderink organised meetings on boundary layers and clouds in the context of CKO, April/December 1997-1998.
W. Kohsiek provided a course 'Meteorology for Hydrologists' at IHE (International Institute for Infrastructural, Hydraulic and Environmental Engineering), Delft, 1997.
A.C.A.P. van Lammeren organised the 7th joint Scientific and Technical Committee Meeting of GCOS (Global Climate Observing System), Eindhoven, September 1997.
A.C.A.P. van Lammeren organized a Public Information Symposium on GCOS, Eindhoven, September 1997.
W.A.A. Monna co-organised a COST-76 Profiler Workshop, Engelberg, Switzerland, May 1997.
A.P. Siebesma organised the 4th GCSS Boundary Layer Clouds Workshop 'An intercomparison of cloud resolving models and 1D-column models of shallow cumulus convection based on BOMEX (Barbados Oceanographic and Meteorological Experiment)', Seattle, USA, July 1997.
A.P. Siebesma lectured at the NATO Advanced Study Institute on 'Buoyant Convection in Geophysical Flows', Germany, March 1997.
A.P. van Ulden organised the second EUCREM Workshop, De Bilt, May 1997.
A.P. van Ulden co-organised the symposium 'Sun and climate: the influence of variations in solar activity on the earth's climate', Den Haag, November 1997.

Other activities:
A.A.M. Holtslag, chairman review committee on research proposals, submitted to GOA (NWO - Geosciences Foundation).
A.A.M. Holtslag, chairman of the programme board of CKO.
H. Klein Baltink, member Working Group II Science and Technology of COST-76.
A.C.A.P. van Lammeren, member of the ESA ERM Advisory Group.
A.C.A.P. van Lammeren, member of the User Consultancy Committee on Atmospheric Radar Research of STW (NWO - Technology Foundation).
A.C.A.P. van Lammeren, co-ordinator 'Radiation and remote sensing of clouds' of CKO.
W.A.A. Monna, chairman of COST-76.
P. Stammes, member of the GOME Science Advisory Group.
P. Stammes, member of the SCIAMACHY Science Advisory Group.
P. Stammes, member of the OMI Science Team.
P. Stammes, temporary Lead Scientist of OMI.
A.P. van Ulden, member of the programme committee of NOP, chairman programme group I.

Climate Analysis and Scenarios

General • The central themes of research are:

1 Analysis and diagnosis of climate variability in instrumental records, proxy records and in models.
2 The production of climate scenarios for impact studies, in particular by means of statistical downscaling.
3 Data rescue and reconstruction of historical climate series.

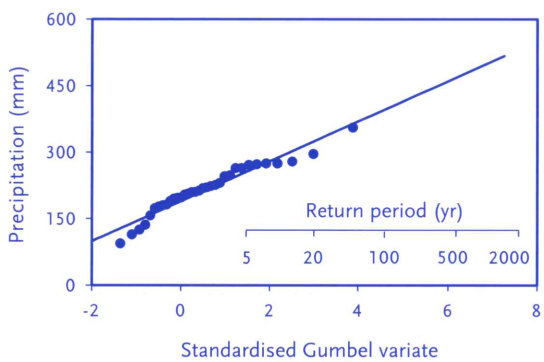
The climate scenarios have been made in close co-operation with the users from the impact community. The focus is mainly on temperature and precipitation and on hydrological applications. The Subdivision provides climate information to specialists, to the Government and to the general public.

Stochastic rainfall generator

Buishand, Brandsma, Beersma

A main activity in the last two years is the development of a weather generator for daily precipitation and temperature in the Rhine basin using nearest-neighbour resampling. The aim of the project is to get a better insight into extreme river discharges. Precipitation is the main variable but temperature is also needed in order to account for the effects of snowmelt and frozen soils on large river discharges. For the time being, the generator is developed for the current climate.

The method has been tested for the German part of the basin. It showed a good reproduction of



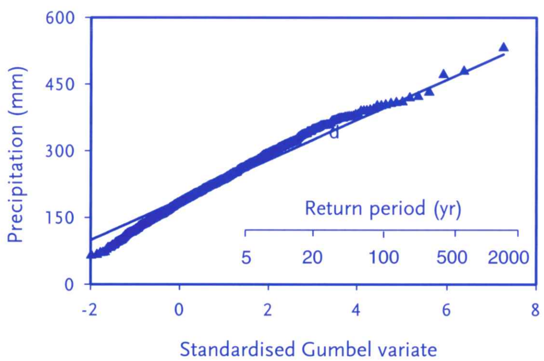


Figure 1. Maxima of 10-day precipitation amounts in the winter half-year (October-March) for Freudenstadt (Germany) in ascending order. The dots (upper figure) refer to the observed data for the period 1961-1995; the triangles (lower figure) to a 1000-year multi-site simulation by means of nearest-neighbour resampling. Through a transformation of the horizontal axis the points should be scattered about a straight line if the 10-day maxima follow a Gumbel distribution (a popular distribution for extreme-value data). The straight lines are the same in both figures and are obtained from a fit to the observed data. The return period denotes the mean number of years between two exceedances of the 10-day precipitation amounts.

autocorrelation properties and of the probability distributions of multi-day precipitation amounts. In a 1000-year simulation, multi-day precipitation amounts were generated that exceed the maxima in the observational series (see Figure 1). The spatial and temporal patterns of these simulated super-events were found to be different from those of historical extreme events. A first paper reporting on the project was published in Hydrology and Earth System Sciences.

The project is part of a larger study to reduce the uncertainties in the design of water levels for flood protection. The project is commissioned by the National Institute for Inland Water Management and Waste Water Treatment (RIZA), part of the Ministry of Transport, Public Works and Water Management (V&W). RIZA aims at coupling the weather generator to a hydrological model for the Rhine basin which is currently developed. It has been decided to extend the co-operation in the next years. In the future, projects concerning the Meuse basin and extensions to climate change will be incorporated in the project.

Downscaling

Buishand, Helmyr, Brandsma, Beersma, Können

To assess the impacts of climate change on the hydrology of Europe, precipitation scenarios are needed on a much finer spatial and temporal scale than those available from General Circulation Models (GCMs). Research has been undertaken to explore the potentials of downscaling. For this purpose, daily amounts of precipitation in a number of European river catchments were related to near-surface temperature and atmospheric circulation variables. For coastal regions, sea surface temperature was also included. This work was done in the framework of the EU project POPSICLE (Production of Precipitation Scenarios for Impact Assessments of Climate Change in Europe). In 1997 the KNMI contribution to that project led to the publication of a paper in the Journal of Hydrology and another paper in the International Journal of Climatology.

WRINCLE (Water Resources: the Influence of Climate Change in Europe) is the follow-up project of POPSICLE and started in 1998. The project aims at the production of a digital atlas of European precipitation, river discharge and water resource impacts. The KNMI responsibility to WRINCLE is to improve the meteorological basis of statistical downscaling techniques for climate change.

Initiated by questions from the Government, the effect of a changing Atlantic oceanic circulation on the temperature climate in the Netherlands is estimated. The estimate is based on a simple scenario that assumes unchanged atmospheric circulation and systematic oceanic cooling. The results were obtained by lowering the observed daily temperatures in the De Bilt series by a fixed value in case of advection from the sea. This leads to a preferential cooling of warm days in winter and of cold days in the other seasons and hence to a decrease of the daily standard deviation in winter and an increase in the other seasons. A paper on this research (with A. Klein Tank, Observations and Modelling Department) appeared in Climatic Change.

In 1998, the EU ECLAT-2 (European Climate Change Project - Concerted Action Initiative) started with KNMI as a partner. The project aims at the co-ordinated provision of scientific and technical advice for applying climate data in European climate change projects and at exchange of knowledge through workshops covering various aspects of the subject.

Applied statistical research

Buishand, Beersma

The impacts of changes of the variability of climate are considered to be at least as important as changes in the mean. Traditional statistical tests are not designed for testing differences in variances of spatially correlated data. A method has been developed in which spatially correlated data can be combined into a single test-statistic. The method is suitable to compare the variances in observed and simulated climates. The test is most powerful when the sign of the difference is the same throughout the grid. The second paper on the subject, dealing with the application to monthly data, has been accepted by the Journal of Climate.

(Paleo) climate variability

Shabalova, Beersma, Können

Most activities within this theme are carried out in close co-operation with the Predictability Research Division. In the framework of this co-operation, short-wave radiation and cloud schemes for the ECBILT model (KNMI General Circulation Model) have been developed. The short-wave radiation scheme, as well as a long-wave radiation scheme that was simultaneously developed by M. Schaeffer of RIVM (National Institute of Public Health and the Environment), are derived on the basis of the KNMI radiative convective model due to R. van Dorland (Atmospheric Research Division). The new schemes allow for radiation-cloud interactions in ECBILT and hence for enhanced temporal variability. These schemes, that also allow for climate change experiments with the model, will be incorporated in the next generation of ECBILT.

Commissioned in 1997 by the Dutch National Research Programme on global air pollution and climate change (NOP), a project is carried out to analyse multidecadal climate variability in (proxy) data and in models. Multidecadal, season-specific temperature variability modes have been detected in the data. A first paper on the seasonality of low frequency variability appeared in Geophysical Research Letters (co-author S. Weber, Predictability Research Division); a second paper is currently in preparation.

As part of the EU project SINTEX (Scale Interactions Experiments), and in co-operation with the Predictability Research Division, coupled models are compared with respect to the characteristic time scales and with respect to atmosphere-ocean interactions associated with the North Atlantic Oscillation (NAO). This work started in the course of 1998.

The EU project WASA (Waves and Storms in the North Atlantic) ended in 1997. In the framework of this project one of us, in collaboration with four other members of the WASA group, analysed the Atlantic storm activity in a high-resolution climate change experiment. In case of a doubled CO_2 concentration, a weak increase in storminess is apparent in the Bay of Biscay and the North Sea. There is a slight decrease in storminess over the ocean north of 55°N, but is was concluded that these projected changes fall well within the limits of observed variability in the past. These results appeared in a 1997 paper in Tellus; the summarising paper on the results of the WASA project was published in 1998 in the Bulletin of the American Meteorological Society.

A model/paleo comparison of precipitation on large spatial scales has been carried out. High-resolution model simulations of precipitation in equilibrium climates of enhanced CO_2 were confronted with paleo precipitation data from Russian reconstructions of warm epochs. Distinct model/paleo differences, that can be attributed to slow feedbacks, were identified. A paper on this research (co-authored by I. I. Borzenkova, State Hydrological Institute, St. Petersburg, Russia) has been accepted by Climatic Change. The issue of the reliability of the Russian paleo reconstruction has been addressed separately in a paper published in Climatic Change.

Data rescue

Können, Kaltofen

A joint project with P. Jones of the University of East Anglia, United Kingdom, and R. Allan of CSIRO (Commonwealth Scientific and Industrial Research Organisation) in Australia to recover early 19th century meteorological observation series from Indonesia and Tahiti ended for the time being with a publication in the Journal of Climate of an extended Southern Oscillation Index (SOI) time series back to 1841 (based on pressure readings) and to 1829 (based on rainfall). Attempts are still going on to find missing pressure data to fill the 4-year gap in the pressure-based SOI. Co-operation with the Indonesian Meteorological Service is still in progress. For an illustration we refer to Figure 2.

A project on the recovery of pre-1875 Japanese instrumental data started in 1998. It concerns data taken by the Dutch on the island of Dejima (Nagasaki). These data overlap with the long documentary series from the Edo era and hence bear potential for calibration. Dejima data covering 1845-1858 and 1871-1882 have been found in the Dutch archives, while data from 1820-1830 were discovered during an on-spot search in the Nagasaki archives. This project is carried out in co-operation with T. Mikami, Metropolitan University of Tokyo.

A project has been formulated to systematically digitize and homogenize data in the KNMI archive of Dutch sources.

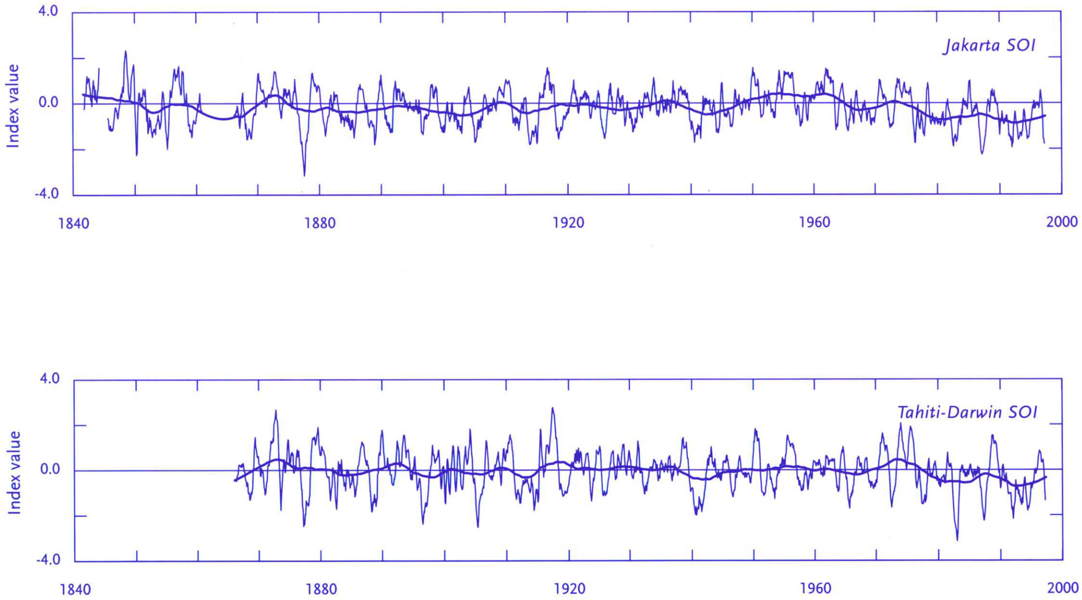


Figure 2. Southern Oscillation Index (SOI). Above: single-station SOI based on Jakarta pressures 1866-1997 with its extension back to 1841. Below: the official Tahiti-Darwin SOI time series, which starts in 1866. A 5-month running mean is applied. The thick lines represent a 10-year smoother.

Fourth Governmental Bill on Water Management

Können, Fransen

Two documents were published for the Ministry of Transport, Public Works and Water Management in which the effects of climate change on hydrology are quantified. The reports are used by the Ministry in formulating the long-term policy on flood protection and water management. The climate scenario presented in the documents is based on the UKHI model (United Kingdom High resolution model) and relies on statistical downscaling techniques in the estimations of exceedance frequencies. The uncertainties in the results are extensively discussed. This work was done in co-operation with R. Mureau of the Predictability Research Division.

Antarctic field expedition

Können

During the 1997-1998 austral summer, G. Können participated in a NSF (National Science Foundation) sponsored two-month Antarctic field campaign at US Amundsen-Scott South Pole Station to collect data in order to establish the relation between the shape, intensity distribution and polarization of ice crystal halos on the one hand and the shape and sizes of the ice crystals on the other hand. This work is meant to provide a firmer basis to passive remote sensing by means of halo scattering. The project resulted in three papers in a special issue of Applied Optics; a fourth paper on the theory has been accepted by the same journal. As a result of this work, contacts have been established with the NASA-ESA (National Aeronautics and Space Administration - European Space Agency) Huygens Science Team to play a role in the interpretation of halos in the pictures to be taken by the Huygens Probe during its decent on the Saturn satellite Titan in 2004.

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Buishand, T.A. and T. Brandsma, 1997. *Comparison of circulation classification schemes for predicting temperature and precipitation in the Netherlands.* Int. J. Climatol., **17**, 875-889.

Klein Tank, A.M.G. and G.P. Können, 1997. *Simple temperature scenario for a Gulf-stream induced climate change.* Climatic Change, **37**, 505-512.

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1997 Brandsma , T. and T.A. Buishand, 1997. *Rainfall generator for the Rhine basin; single-site generation of weather variables by nearest-neighbour resampling.* KNMI-publication **186-1**

Können, G.P., W. Fransen en R. Mureau, 1997. *Meteorologie ten behoeve van de Vierde Nota Waterhuishouding.* Projectteam NW4, RWS (in Dutch).

Können, G.P. (contributor), 1997. *Klimaatverandering en bodemdaling; gevolgen voor de waterhuishouding van Nederland.* Projectteam NW4, RWS (in Dutch).

Number of international presentations: 1997: 5, 1998: 6.

Externally funded projects: national 3, international 5.

Other activities:
T.A. Buishand, member of the Editorial Board of Stochastic Hydrology and Hydraulics.

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

Seismology

General • Seismology at KNMI flourished in the years 1997 - 1998. The acquisition of externally financed new research projects was emphasised, as was the modernisation of the seismological infrastructure.

In the period 1997 - 1998 several earthquakes occurred again in the northern parts of the Netherlands, more specifically near the village of Roswinkel in the province of Drenthe. These series of earthquakes are highly similar and are the strongest observed so far in connection with the extraction of natural gas from the Dutch sub-surface. The deployment of a small group of accelerometers showed that the amount of shaking was enough to cause substantial damage. Part of our research is directed to the estimation of ground movements and their possible risk to Dutch society. In this respect the good news is that the magnitude of the gas-induced earthquakes will be limited, according to a recent study that took into account all the induced seismicity recorded thus far. The bad news is that local amplification contributes to ground movements that may lead to moderate damage under specific circumstances.

The newly initiated projects were centred around paleoseismicity, tilt and infrasound. Paleoseismicity is the study of strong earthquakes in pre-historic times. A new EU-project focuses on the seismicity along the Roer Valley Graben. The measurement of tilt, conducted in co-operation with the Ministry of Economic Affairs (EZ), has the aim to follow slow movement in the deep sub-surface. The detection of infrasonic waves with a new infrasonic array near Deelen, and the research in this area, are conducted both in the context of the CTBT (Comprehensive Nuclear-Test-Ban Treaty) and to assist the Royal Netherlands Airforce (Klu) in their noise abatement of military airplanes.

The operational task of the Seismology Division accounts for half of the activities in the group, due the always-present need to provide an accurate daily analysis of the incoming data. This data is received from both the national networks directed to seismicity in the northern and southern provinces of the Netherlands and from stations directed to global seismology. The modernisation of the data acquisition system in De Bilt will ensure an up-to-date operation in the future. In the coming years the program will be extended by an upgrade of the station electronics to broad-band 24 bit sampling. A new three-component broad-band station near Winterswijk will be operational in the first half of 1999 to replace the existing single-component short-period station. The introduction of a Geo-Information System (GIS) will ensure a modern approach to the handling of the data. In particular, it will make it possible to combine the archive of earthquakes in the Netherlands with topographical and geological information.

Observations

Recent developments in the digital seismograph network

Haak, Dost, Sleeman, Houtgast, Jansen

In 1997 two stand-alone stations (1 broad-band, 1 short-period) were installed in Brabant (Herkenbosch, Ospel) in collaboration with the Royal Observatory of Belgium. A third, broad-band, station was installed by KNMI in 1998 in Oploo. These stations enhance the geographical coverage of seismic stations in the southern part of the Netherlands and improves the monitoring of seismic activity in the Roer Valley Graben as well as of global seismic activity. Station Oploo is equipped with a state-of-the-art, 24 bit, Quanterra datalogger, which enables seismologists to have direct access to the waveform data for scientific purposes.

In 1998 the data acquisition system of the three-component broad-band stations HGN (Heimansgroeve) and WIT (Witteveen) was modernised. Two SUN Ultra workstations were purchased to collect the data in real-time, sampled at 40 and 20 Hz respectively. A client/server software package was developed, written in the Java language, to manage and monitor the continuous data streams. A third SUN Ultra workstation was purchased to modernise and accelerate seismic data analysis and research. All preparations for a modernisation of the station WTS (Winterswijk) were finalised in 1998. Early 1999 this station will be operational.

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

Haak, Dost, Sleeman, Houtgast, Looman, van Gend, Meester, van Bodegraven, Jansen

Monitoring induced seismicity continued in the northern part of the Netherlands using a network of borehole seismometers. In 1997 a total of 44 events were located. Local magnitudes (M_L) vary between −0.8 and 3.4. Although a reduced number of 23 events were recorded in the same region in 1998, local magnitudes vary between 0.4 and 3.3. The total number of stronger events ($M_L \geq 2.0$) remains stable: 4 in 1997 versus 6 in 1998.

The onset of a series of events near Roswinkel (eastern part of Drenthe) in 1996 continued in 1997 and 1998. A total of 23 events of magnitude between 0.8 and 3.4 was detected. The largest event generated a maximum intensity of VI on the European Macroseismic Scale (EMS) in the epicentral region. Using correlation techniques a precise relative location of these events could be calculated. Analysis of acceleration data from a small network of 3 accelerometers installed in the source region enabled an absolute location. Correlation with the local geology shows that all events occur at the top of an anticlinal structure that covers a shallow gasfield. Due to its shallow depth (2 km), the magnitude 3.4 event is felt in the epicentral area and produced a measured peak horizontal acceleration of 0.3 g at a high frequency of 10 Hz.

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

Monitoring natural seismicity

Haak, Dost, van Eck, Sleeman, Houtgast, Looman, van Gend, Meester, van Bodegraven, Jansen

In the south-eastern part of the Netherlands earthquakes are related to the tectonic regime of the Lower Rhine Embayment, mainly in the Roer Valley Graben. In the period under review four weak and not-felt earthquakes occurred in this region, namely near Linne/Roermond ($M_L = 2.6$), Echt ($M_L = 1.9$) and two near Heerlen ($M_L = 1.9$ and $M_L = 1.0$) successively.

Two tectonic earthquakes occurred in this period in the centre of the Netherlands near Beverwijk (magnitude 2.0, depth 14 km) and Apeldoorn (magnitude 2.2, depth 5 km). The relation with local or regional geology is not clear yet.

Accelerometers

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

During 1997 and 1998 the network of stand-alone strong-motion accelerographs has been extended in the northern part of the Netherlands. At the end of 1998 11 accelerometers were operational. All but one sensor are located in concrete buildings and fixed to the foundation. One site is equipped with two sensors, one fixed to the building and one installed in the soil at shallow depth next to the building, in order to monitor so-called 'difference in site-effects'. During 1997 and 1998 10 earthquakes were recorded in three accelerometer stations near Roswinkel.

Tilt observations in Noord-Holland using shallow borehole tiltmeters

Haak, Sleeman, Looman, van Gend, Meester, Jansen

In 1997 two tiltmeters were installed in the region around a peak-gas installation in Alkmaar, at a depth of 5 meters. The objectives of this experiment are (1) to investigate the usefulness of tilt measurements in the Netherlands for the monitoring of volume changes within a (gas)reservoir at depth, and (2) to quantify the limitations of this type of observations around a gasfield. The experiment indicates that pressure variations of at least 6 bar within one week within the gasfield result in tilt variations that may exceed the tilt noise level. However, these variations did not occur during the period of the experiment. Secondly, site conditions and installation of the tiltmeters are critical elements for this type of observations.

EU-project Rapid Warning System Earthquakes

Haak, Dost, Sleeman, Looman, van Gend, Meester

The project 'A rapid warning system for earthquakes in the European-Mediterranean region' lasted from May 1996 until August 1998 and was supported by the EU. The objective of this project is to improve the reliability, accuracy and rapidity of the system in use at the EMSC (European-Mediterranean Seismological Centre) for locating potentially destructive earthquakes with magnitude 5 and above. The contribution of the Seismology Division comprises (1) the automatic transfer of seismic phase onset-times of broad-band stations HGN and WIT to the EMSC, and (2) the development of a system to collect automatically waveform data from a number of European broad-band stations through the ORFEUS (Observations and Research Facilities for European Seismology) Data Center (ODC).

The Seismology Division developed a new and unique scenario to exchange phase onset-times to the EMSC. Once a significant earthquake has been detected by a co-operating seismic network within the EMSC, a request for P-phase onset-times is generated and sent electronically to KNMI. On arrival of this request an automatic process estimates the onset-times of these phases at HGN and WIT, and returns these high-accuracy estimates electronically to the EMSC. This scenario is fully automatic and performs in near real-time.

As part of this project the ODC extended its global, near real-time data collection system (SPYDER®) to serve as a regional system as well, where the magnitude threshold is set to a lower value (from 5.5 to 5.0) and more regional stations are involved. This regional system, called Euro-SPYDER, is triggered by locations from the EMSC for any earthquake in the European-Mediterranean region with magnitude above 5.0. The development of Euro-SPYDER is a major advance in the rapid exchange of seismological waveform data in Europe. It is an important result of the joint expertise at ORFEUS and EMSC.

Nuclear explosions

Haak, Sleeman, Looman, van Gend, Meester, van Bodegraven

Traditionally, as part of the observational task, the Seismology Division takes care of the detection and identification of nuclear explosions. The data is exchanged with International Data Centres (IDC) through a procedure that is completely automated by software in worldwide use which is named Auto Data Request Manager (AutoDRM).

On 16 August 1997 a number of seismic stations of the International Monitoring System (IMS) detected an event in the Novaya Zemlya region, which was initially considered to be a possible Russian underground nuclear explosion. After detailed studies and comprehensive analyses of the available seismic data, seismologists finally came to the conclusion that the event in question was, in fact, a magnitude 3.5 seismic event occurring in the Kara Sea at about 130 kilometres from the Russian test site. The KNMI seismograph station HGN recorded only weak signals from this event.

In May 1998 India conducted its first nuclear tests in 24 years, followed by Pakistan conducting its first tests ever. These tests were the first nuclear detonations since the CTBT opened for signature in September 1996 (both countries are non-signatories of the CTBT).

On 11 May 1998 India carried out three underground nuclear explosions, followed by two more tests on 13 May. Testing took place at the Pokhran test site near the Pakistani border. According to the Indian authorities the 11 May devices yielded 12, 43 and 0.2 kiloton (kt), respectively, and were detonated simultaneously in two deep holes about 1 km apart. The seismic signals that were recorded on 11 May correspond to a magnitude 4.7 event, indicating an equivalent explosive yield of approximately 12 kt. The two 13 May devices were reported to have had sub-kiloton yields in the range of 0.2 to 0.6 kt and to have been detonated simultaneously as well.

In response to the Indian tests Pakistan announced six nuclear tests, five on 28 May and one on 30 May 1998. The tests were conducted in the Chagai Hills region, close to the Iranian border. One of the five devices tested on 28 May was reported to be in the 30 to 35 kt range, with the other four having small yields, totalling the five yields at 40 to 45 kt. The five devices were detonated simultaneously. The 30 May test should yield 15 to 18 kt. Seismic stations recorded signals with magnitude 4.6 for the 28 May event and with a magnitude 4.3 for the event on 30 May. These magnitudes, however, would indicate equivalent explosive yields of about 10 and 5 kt, respectively. As with India, the seismically estimated yields are significantly lower than what has been announced.

This general conclusion is in full agreement with the size of the signals recorded at the KNMI seismograph station HGN, being close to the detection threshold for this station at these particular distances (i.e. about 10 kt). The 11 May Indian test as well as the Pakistani test of 28 May have been detected by HGN.

Infrasound

Haak, Evers, Looman, Jansen

The Seismology Division uses infrasound measurements primarily in order to distinguish between seismic and acoustic events. Within CTBT context infrasound measurements are also used to detect possible atmospheric nuclear tests. These tests can be detected with similar instrumentation; it is only needed to extend the passband to lower frequencies. Most signals detected with two electret arrays in the Netherlands (in Witteveen and De Bilt) originate from (military) supersonic flights. The Royal Netherlands Airforce is interested in these detections and in derived maximum pressure values in order to evaluate damage claims resulting from sonic booms. For this purpose a third array was developed and installed at Deelen airforce base.

Research

Regional seismicity

Haak, de Crook, Dost, van Eck, Houtgast

The rapidly increasing data set concerning the northern part of the Netherlands enabled the calculation of attenuation curves for the region, resulting in an increased accuracy of the local magnitudes. The acceleration data for events at very short distance (Roswinkel) provide an independent data set that was used to test the validity of the attenuation functions. A good fit was observed, giving confidence in the basic assumptions.

Waveform similarities at a station for clusters of events enable the use of relative location methods to improve the location accuracy. Attention was focused on the Roswinkel area, where a diffuse pattern of locations became focused after application of the method, enabling the connection to local geology. The data set is being searched for other sub-regions where the method can be applied.

The acceleration data at short distances also allow the application of sophisticated methods to retrieve source mechanism information. Using relative amplitudes of direct P and S arrivals in a grid-search provides us with much better constraints on possible double couple mechanisms than the constraints obtained by onset polarity methods. Again, this was applied to the Roswinkel events.

All seismicity data, induced as well as natural, is made available in digital form and imported in GIS. This not only allows an easy access to and maintenance of the data base, but also allows a correlation with other digital data sets, like geological faults, geomorphological information, gravity data, etc. In the south-eastern part of the Netherlands the correlation between seismicity and deep geological structure leads to the distinction between active and non-active faults. This is an important addition to the more general seismic hazards maps.

Modelling of the seismic source

van Eck

During 1998 a start was made to model the seismic source due to induced stresses in the crust using Boundary Element Methods.

Local site effects

Haak, de Crook, van Eck

Reports of local damage outside the average intensity IV-V contours of events near Roswinkel led to an investigation of the influence of shallow soil deposits on the amplification of earthquake signals. As a pilot study, the borehole seismic station ZLV (Zuidlaarderveen) was equipped with a three-component sensor at the surface. This station is the only one with a 25 m sensor separation and indicates that most of the amplification takes place in the uppermost 25 m. Comparison of measured amplification (from local events) with theoretical values, based on a one-dimensional geomechanical model of the uppermost 25 m, shows a good agreement up to a signal frequency of 15 Hz. Most important model data are layer thickness, shear velocity and damping. Site investigations are carried out to determine accurate soil parameters. Shear wave velocities are measured by a seismic cone penetration test and damping factors are estimated from shear wave signals generated with a seismic vibrator. The shallow structure in the vicinity of the borehole also influences the results. Therefore, representative soil profiles are selected to calculate the variation in amplification. This study is performed in co-operation with NITG-TNO (Netherlands Institute for Applied Geoscience - Netherlands Organisation for Applied Scientific Research).

Seismic hazard analysis

Haak, de Crook, Dost

The revision of the magnitudes and the extension of the seismicity data base required a revision of the existing hazard estimates for the northern part of the Netherlands. In addition, a strong event of magnitude 3.4 occurred near Roswinkel, which reached the previously estimated maximum magnitude for the region. Updated estimates are a maximum magnitude of 3.8, while maximum intensity remains at VI-VII. Results of the analysis were published.

On request, information on seismic hazards was provided to the national industry and authorities for national and international projects on the design and safety of constructions.

Improvement of automatic analysis of seismic waveform data using wavelets

Dost, van Eck, Sleeman

The increase of the number of seismometers as well as the evolution in real-time data exchange in Europe require enhancement of automatic analysis of seismic data. The Seismology Division implemented a high-accuracy automatic P-phase picker at stations HGN and WIT. This work was extended in co-operation with the Centre for Mathematics and Computer Science in Amsterdam to estimate the S-phase onset time automatically. A new method was developed based on wavelet analysis and traditional polarisation analysis.

Infrasound

Haak, Evers

A research project with the Royal Netherlands Airforce was initiated in 1998 with the purpose to develop a robust infrasound sensor and an automated procedure to detect sonic events. In the sensor development noise reducers play a large role. Because the most important source of noise is small-scale wind turbulence, the noise reducers are designed as spatial filters. Aspect of this research are also studied by other Divisions within KNMI and brings synergy between the Seismology Division and the Research Divisions oriented at meteorology.

A demonstration of the sensor as a part of an infrasonic array is planned early 1999 in Deelen. After this period the Deelen infrasonic array will remain operational to assist the Royal Netherlands Airforce in their noise abatement.

EU-project PALEOSIS

Dost, Evers

Seismic hazard estimates in the Netherlands and neighbouring countries are based on the analysis of historical seismicity in the region. However, this implies that earthquakes occurring at a recurrence time exceeding the historical period may not be included. These paleo-earthquakes are characterised by a large magnitude and are therefore a potential danger. The objectives of the EU project PALEOSIS (Evaluation of the potential for large earthquakes in regions of present day low seismic activity in Europe) are to identify paleo-earthquakes along active faults in regions of present day low seismic activity in Europe and to evaluate their impact in seismic hazard analysis.

One of the target areas is the seismic active Roer Valley Graben, where a recent experiment shows evidence for the occurrence of large earthquakes (magnitudes larger than 6.4) at a return rate of 3-5 kyears. The experiment was carried out by the Royal Observatory of Brussels along the Feldbiss fault, which is the southern boundary fault of the Graben. In the current project the Peelrand fault, the northern boundary fault of the Graben, is the research target for the Dutch partners (NITG-TNO and KNMI). During 1998 a site selection was carried out for the construction of a trench along the target fault, which will be realized in 1999.

EU-project ASPELEA

Haak, Dost, van Eck, Dineva

The project ASPELEA (Assessment of Seismic Potential in European Large Earthquake Areas) is a project in which scientists from Albania, Bulgaria, Greece, Italy, Netherlands, Romania and Russia participate. The Seismology Division of KNMI participates in co-operation with the University of Utrecht in studying probabilistic seismic hazard assessment (PSHA) methodologies and sensitivity analysis. Preliminary PSHA and sensitivity analysis have been performed for two test areas: the Gulf of Corinth in Greece (master's thesis of M. van der Meijde, 1998) and the Kresna region in Bulgaria. The results showed that a considerably better analysis can be obtained by improving the existing seismotectonic models. Consequently, the Seismology Division has attracted Dr. S. Dineva from the Bulgarian Academy of Sciences to relocate earthquakes and perform tomograpic inversion with the aim to improve the seismotectonic model for the Kresna region. This work is done with T. van Eck and in co-operation with W. Spakman (University of Utrecht) and members of the ASPELEA project

Global Seismic Hazard Assessment Program

Haak, de Crook, Dost

The aim of the Global Seismic Hazard Assessment Program (GSHAP) is to co-ordinate the effort to produce a set of global maps related to seismic hazards. KNMI contributed data for the compilation of maps for North-Western Europe concerning seismicity, distribution of seismic source regions, hazard intensity and acceleration at an average return rate of 475 years. These maps will be published in a final joint publication in 1999.

ORFEUS

Dost, van Eck, Sleeman, Evers

Observatories and Research Facilities for European Seismology (ORFEUS) pursued during 1997 and 1998 its original goal (1986) to co-ordinate and promote broad-band seismology in the European-Mediterranean area. Although the ORFEUS Data Center (ODC) with its waveform archive remains its core activity, ORFEUS co-ordination and promotion activities have presently attained a significant status within the global scientific seismological community. In 1998 two new Corporate Founders joined, bringing the total at 13. At the same time 5 new institute participants have been recruited, bringing the total at 50.

Four working groups (Station siting, Technical assistance, Mobile equipment and seismological software), the ORFEUS Executive Committee and its four half-time staff members (at KNMI) have been the main driving force behind a successful web site (http://orfeus.knmi.nl) and different international activities. For example, the ORFEUS Seismological Software Library (SSL) is presently the global source for shared software within seismology. Two ORFEUS work meetings (at the 1997 IUGG (International Union of Geodesy and Geophysics) Assembly in Tessaloniki, Greece and at the 1998 ESC (European Seismological Commission) Assembly in Tel Aviv, Israel) initiated basic discussions about waveform data availability to the seismological scientific community. The ORFEUS workshop (1998 in Prague, Czech Republic) was a successful exchange of knowledge within seismometry between the major experienced scientists and scientists new in this field.

ORFEUS Data Center (ODC)

Dost, van Eck, Sleeman, Evers

An exponential growth of the number of high quality broad-band seismograph stations within the European-Mediterranean area since 1994 is having a major impact on the ODC operations. Its data archive is rapidly growing and innovative procedures for data quality checks, data exchange and on-line availability have been developed, often in co-operation with IRIS (Incorporate Research Institutes in Seismology) in the USA. At the end of 1998 the ODC offers 11 Gbyte quality controlled data on 19 CD-ROM volumes, on-line access to 'rapid' global SPYDER® waveform data (16 Gbyte), quality controlled European-Mediterranean ODC-volumes (also 16 Gbyte) and near real-time waveform data (278 Mbyte for 1998; all at ftp://orfeus.knmi.nl and http://orfeus.knmi.nl). An example of the station distribution for an event catalogued by SPYDER® is given in the Figure.

The ODC is active internationally in promoting a unified data exchange format and free and rapid exchange of seismological waveform data, among others within the Federation of Digital Seismograph Networks (FDSN). Within Europe the ODC is a major driving force behind improving waveform data exchange. Research activities associated with the ODC are related to the use of large data volumes (Curtis et al., 1998).

ORFEUS produced 13 CD-ROMs with quality controlled event waveform data from European-Mediterranean broad-band seismograph stations for May 1990 until December 1992.

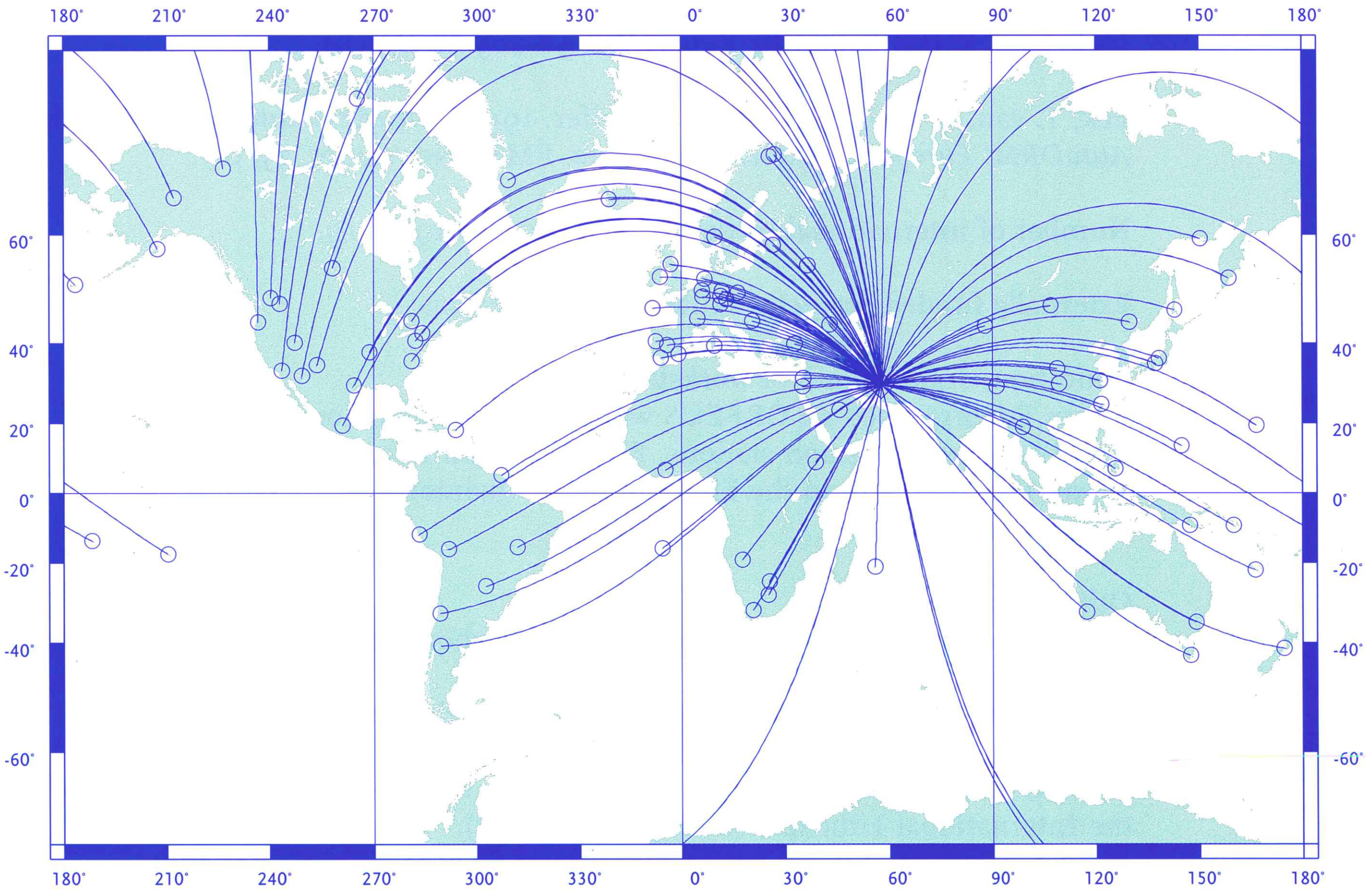

Figure. Example of station distribution of a Spyder event in Iran (14 March 1998, 19:40 GMT, magnitude 6.9). Data are on-line available within a few hours after the origin time.

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Kebede, F and T. van Eck, 1997. *Probabilistic seismic hazard assessment for the Horn of Africa based on seismotectonic regionalisation.* Tectonophysics, **270**, 221-237.

Snieder, R. and T. van Eck, 1997. *Earthquake prediction, a political problem?* Geologische Rundschau, **86**, 446-463.

1998 Curtis, A., J. Trampert, R. Snieder and B. Dost, 1998. *Eurasian fundamental mode surface wave phase velocities and their relationship with tectonic structures.* J. Geophys. Res., **103** (BII), 26,919-26,947.

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1997 Dost, B. and H.W. Haak, 1997. *Macroseismische waarnemingen Roswinkel 19/2/97.* KNMI Technical Report TR-**199**, 1-6 (in Dutch).

1998 Crook, Th. de, H.W. Haak and B. Dost, 1998. *Seismisch risico in Noord-Nederland.* KNMI Scientific Report WR **98-205** (in Dutch).

Eck, T. van, R. Sleeman and U. Kradolfer, 1998. *Waveform data access through AutoDRM: European-Mediterranean Area.* EMSC Newsletter, **13**, 6-7.

Number of international presentations: 1997: 9, 1998: 19.

Externally funded projects: national 2, international 5.

Education, organisation of workshops:
T. van Eck organised an ORFEUS workshop on installation and operation of broad-band seismograph stations, Prague, Tsjech Rep.
T. van Eck co-organised the First European Quanterra Users Group meeting, Prague, Tsjech Rep.

Other activities:
Th. de Crook, member of the Commission 'Earthquakes' of NNI (Netherlands Standardization Institute).
B. Dost, secretary Sub-commission on Data Acquisition Theory and Interpretation of ESC.
B. Dost, member Co-ordinating Committee on Data Exchange and Centres of the International Lithosphere Programme (ILP).
B. Dost, member of users group Wavelets of STW (NWO (Netherlands Organisation for Scientific Research) - Technology Foundation).
B. Dost, manager ORFEUS Data Centre.
B. Dost, representative ORFEUS in the FDSN.

B. Dost, chairman Working Group (WG) on Data Exchange of the FDSN.
B. Dost, chairman ESC WG on Data centres and data exchange.
T. van Eck, secretary-general of ORFEUS.
T. van Eck, secretary Working Group 1 on station siting ORFEUS.
T. van Eck, secretary Working Group 2 for technical assistance ORFEUS.
T. van Eck, secretary Working Group 3 for mobile equipment ORFEUS.
T. van Eck, secretary Working Group 4 on Seismological software ORFEUS.
T. van Eck, member Working Group 4 on Seismological software of FDSN.
H.W. Haak, member Committee 'International' of the Earth Sciences Council of KNAW (Royal Netherlands Academy of Arts and Sciences).
H.W. Haak, member WG B of the CTBT.
H.W. Haak, member International Association of Seismology and Physics of the Earth's Interior (IASPEI).
H.W. Haak, member ORFEUS Board of Directors.
G. Houtgast, member Sub-commission 'Ground Movement and Sea Level Rise' of the Netherlands Commission for Geodetics.
G. Houtgast, member ESC Sub-commission WG on Historical Earthquake Data.
G. Houtgast, member ESC Sub-commission WG on Macroseismology.
R. Sleeman, Dutch representative of the EMSC.
R. Sleeman, titular member of the ESC.

National and international policy related activities

General • The Head of Research, members of the Staff Unit 'Co-ordination Climate Policy' and various other staff members of the Research Department represent the Netherlands, the Ministry of Transport, Public Works and Water Management (V&W) and KNMI in national and international climate related organisations and negotiations. Moreover the Staff Unit co-ordinates the formulation and implementation of climate related activities and policies of the Ministry. The Unit also serves as an interface between science and scientists on the one hand and policy makers on the other.

Intergovernmental Panel on Climate Change (IPCC)

The Head of Research, dr. Baede, is the Netherlands principal delegate to the Intergovernmental Panel on Climate Change. In this capacity he chairs the meetings of the national IPCC Co-ordination Group, which meets several times a year in order to co-ordinate IPCC related activities, to exchange information on all IPCC related matters and to prepare the Plenary and Working Group Meetings. The Head of the Division of Atmospheric Research, dr. van Ulden, is the Netherlands Focal Point for IPCC Working Group I.

The IPCC Plenary met twice in 1997 and 1998 to reorganise IPCC in preparation of the Third Assessment Report (TAR), to re-elect its Bureau and to initiate the TAR process. The most important success of the Netherlands delegation was the election of dr. Metz as co-chair of Working Group III and, as such, as a member of the IPCC Bureau. The Netherlands Delegation contributed actively to the preparation of the Third Assessment Report, resulting in the election of thirteen Dutch Lead Authors of the Report, among whom dr. Baede.

From 31 March - 2 April 1998 the Research Department organised a successful IPCC Workshop on rapid nonlinear climate change in Noordwijkerhout, the Netherlands. This meeting received considerable attention from the press.

Framework Convention on Climate Change (FCCC)

The Staff Unit represents the Ministry in all bodies of the FCCC: the Conference of the Parties (CoP), the Subsidiary Body on Implementation (SBI), the Subsidiary Body on Scientific and Technological Advice (SBSTA) and in various Ad-hoc Groups, the most important of which was the Ad-hoc Group on the Berlin Mandate (AGBM), which negotiated the Kyoto protocol concluded during the Third CoP in Kyoto from 1-10 December 1997. An action plan on the implementation of the Kyoto Protocol was developed during the Fourth CoP in Buenos Aires from 2-13 november 1998.

The Head of the Staff Unit is head of the Dutch Delegation to SBSTA, to provide the link with climate science. The Staff Unit co-ordinates the Ministry's position on climate policy, represents the Ministry in the interministerial negotiations, and in the EU prepatory meetings before participating in the above mentioned international negotiations. In these capacities, it has taken part in the international negotiations for the reduction targets under the Kyoto Protocol, and in de EU negotiations to share the burden of the EU reduction target among the Member States, as well as in the current interministerial negotiations on the implementation of the Dutch reduction target.

To support the implementation of the Kyoto Protocol and its reduction targets, the Staff Unit also provided input to the negotiation processes on other issues like policies and measures, and the so-called flexiblility or Kyoto mechanisms (e.g. emissions trade).

Global Climate Observing System (GCOS)

Both the research and the policy community are very much aware of the importance of observing and monitoring the global climate system. These communities have expressed concern about the decline of and large gaps in existing operational observing systems. The Global Climate Observing System, GCOS, has been established by several international organisations, among whom WMO (World Meteorological Organisation) and IOC (Intergovernmental Oceanographic Commission), to develop a dedicated world-wide observing system needed to meet the scientific and operational requirements for monitoring the climate system, detecting climate change and predicting climate variations and change. The first priority of GCOS is to define and develop an Initial Observing System (IOS), building to the extent possible on already existing systems such as the World Weather Watch of WMO and the climate related part of the Global Ocean Observing System (GOOS).

At an international level, the Research Department is involved in various GCOS activities. The Head of Research is a member of the GCOS Panel on Atmospheric Observations and has played a leading role in defining a GCOS Baseline Upper-air Network and a GCOS Surface Network. The Panel met twice to define the atmospheric component of GCOS and to prepare a Work Plan for the establishment of an atmospheric IOS. Until early 1998 dr. Komen, Head of the Ocanographic Research Division, was member of the Joint Scientific and Technical Committee of the Global Ocean Observing System (J-GOOS).

Nationally, the Ministry of Education, Culture and Science (OC&W) initiated a study to define a plan and seek financial support for strengthening the Netherlands contribution to monitoring the Climate System and Global Change. Dr. Kattenberg was a member of the Task Force that carried out the first phase of this study. Dr. Baede represented KNMI in the Steering Group. One of the recommendations of the study was the establishment of national Focal Points for the various components of GCOS. KNMI was invited to assume the role of Focal Point for the atmospheric and oceanographic components. In December 1998 the Director consented with this proposal and nominated dr. Baede as Focal Point. Moreover a second phase of the study was started, which should result in concrete proposals for a stronger Netherlands contribution to the world-wide monitoring effort.

National Research Programme on global air pollution and climate change (NOP)

The National Research Programme on global air pollution and climate change is a policy-oriented scientific research programme, financed by the Ministry of Housing, Spatial Planning and the Environment (VROM). KNMI is involved at several levels in formulating and steering the programme and in carrying out research projects. The Director of KNMI is vice-chairman and the Head of Research is a member of the Steering Board. Until September 1998 the Head of the Staff Unit 'Co-ordination Climate Policy' was vice-chairman of the Programme Board and several staff members are involved in Programming Groups. The Programme has been very successful in bringing together scientists from various disciplines and creating a platform that serves as a basis and a source of scientific information for the formulation and implementation of the Netherlands climate policy, as well as in improving the quality and quantity of the Netherlands contribution to the international scientific effort. The current programme will finish in 2002. In 1998 the first steps were taken to define a follow-up to the present programme.

Public information

An important task of the Research Department is to provide reliable information on the climate issue to the Government and the general public. To this end the Department produces special publications, maintains excellent relations with the Dutch press and organises or contributes to special meetings. The Department publishes a regular Newsletter to inform the Ministry of Transport, Public Works and Water Management and other governmental organisations on recent policy developments, and a collection of scientific and climate policy related press clippings (Knipselkrant) to inform a broad community and the press about recent scientific developments. Several staff members appeared on national television, were interviewed by the press, or contributed to public information meetings. In November 1997 the Research Department organised a successful meeting for policy makers (among whom Members of Parliament), the press and a wide public about the then hotly debated topic of the influence of solar variability on the climate. The following list contains a number of selected presentations by dr. Baede on several issues related to climate and climate change.

13 June 1997	*Sun and Climate Change*, Dutch Association for Clean Air, Utrecht.
20 January 1998	*The Kyoto Protocol: an Introduction*, Workshop on Kyoto, organised by NOP, Den Haag.
22 April 1998	*Global Climate Models*, Annual Meeting of the Netherlands Physical Society, Delft.
19 June 1998	*Kyoto and the Global Climate*, Annual Meeting of the Section for Clean Air of the Dutch Association of Environmental Professionals, Utrecht.
11 September 1998	*The IPCC Third Assessment Report*, Workshop organised by VROM, Bilthoven.
9 October 1998	*Causes and Consequences of the Greenhouse Effect*, Symposium organised by VROM, Den Haag.
17 November 1998	*Climate Predictability*, Symposium on Climate Research organised by the National Institute of Public Health and the Environment (RIVM), Bilthoven.

Scientific and technical Reports

1997 Baede, A.P.M., 1997. *A review of the design of the GCOS Surface Network*, WMO, (in co-operation with the WMO Secretariat).

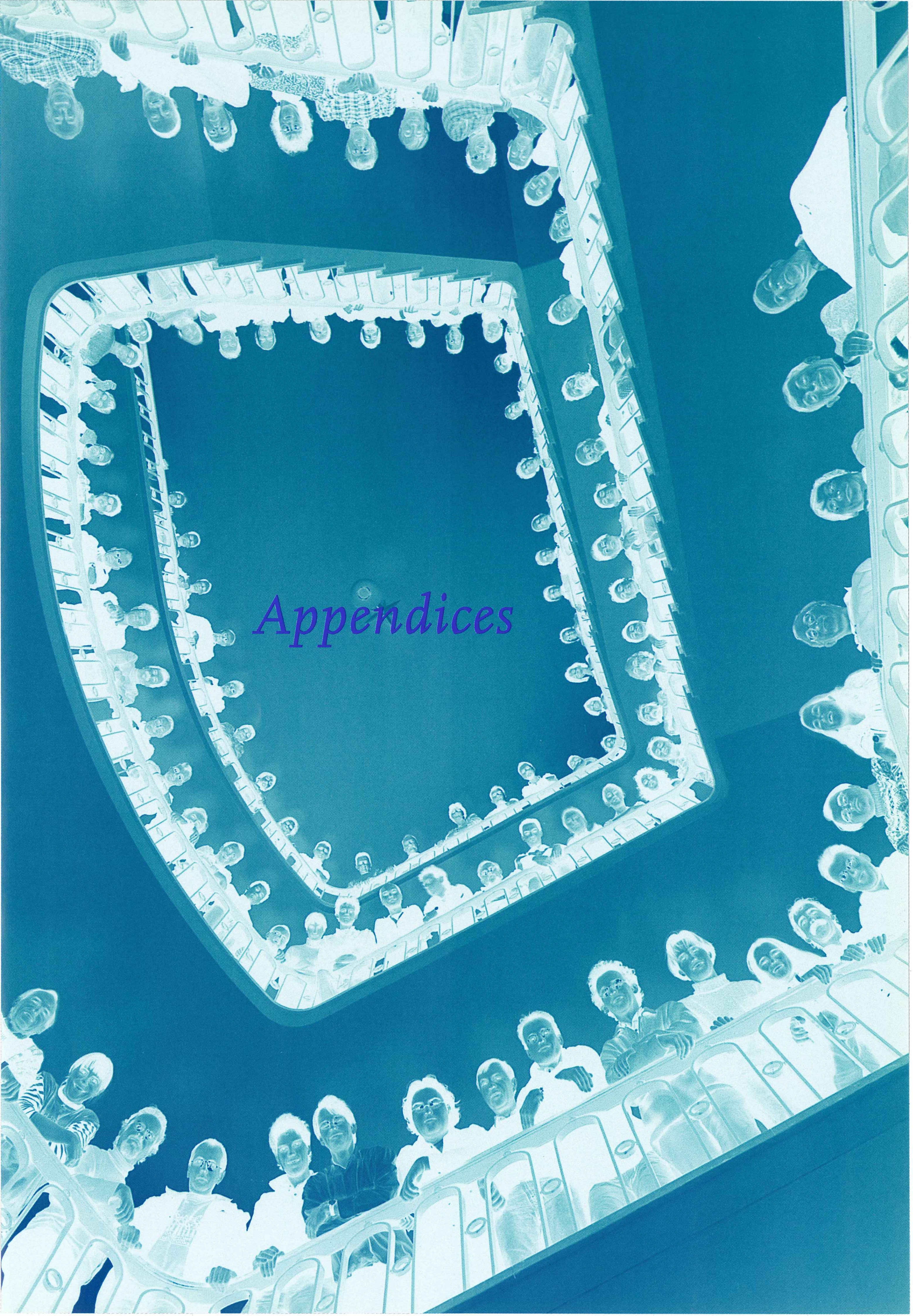
1998 Baede, A.P.M., 1998. *Sun and Climate, Summary and Conclusions*, in KNMI Symposium Report 'Sun and climate: the influence of variations in solar activity on the Earth's climate', February 1998.

Number of international presentations: 1998: 1.

Other activities:

A.P.M. Baede, member GCOS Panel on Atmospheric Observations.
A.P.M. Baede, member of WMO - CBS (Commission on Basic Systems) Working Group on Observations.
A.P.M. Baede, expert member of COPEC (Permanent Committee on Environment and Climate), Programming Committee of the 4th EU Framework Programme on Environment and Climate.
A.P.M. Baede, Netherlands Representative in IPCC.
A.P.M. Baede, representative of V&W in the Steering Group of NOP.

A.P.M. Baede, chairman of the Board of SRON (Netherlands Space Research Organisation).
A.P.M. Baede, chairman of the SRON Programming Committee on Earth Observation User Support.
A.P.M. Baede, member of the Council on Earth Sciences of KNAW (Royal Netherlands Academy of Arts and Sciences).
P.J.W. de Wildt, member (until September 1998) of the Netherlands Delegation to the Climate Negotiations.
P.J.W. de Wildt, Netherlands Representative (until September 1998) in FCCC - SBSTA.
P.J.W. de Wildt, vice-chairman of the Programme Board of NOP.
M.I. Oosterman, member (from September 1998) of the Netherlands Delegation to the Climate Negotiations.
M.I. Oosterman, Netherlands Representative (from September 1998) in FCCC - SBSTA.



Appendices

Appendices

Externally funded projects

Predictability Research

	Project title	Begin - end	Participants *	Funded by
National	A conceptual approach to climate variability	1997 - 2001	Opsteegh, *van Veen*, *Crommelin*	NWO
	Climate variability on decadal time scale	1995 - 2000	Opsteegh, Haarsma, Weber, *Selten*	NOP
	Natural variability in a coupled ocean-atmosphere model	1993 - 1997	Haarsma, Opsteegh, *Lenderink*	NOP
	Patterns of low-frequency climate variability: a model paleodata comparison	1997 - 2000	Weber, Können (Clim An), *Shabalova* (Clim An)	NOP
	The predictability of two-layer contour dynamics systems	1996 - 1998	Verkley, *Trieling*	NWO
	Predictability of weather regimes	1993 - 1997	Barkmeijer, *Oortwijn*	NWO
	Two-dimensional geophysical flows and statistical mechanics	1994 - 1998	Pasmanter, *Brands*	NWO
	Weather Analysis and Forecasting ('Appl Mod' is a Division of the Observations and Modelling Department.)	1998 - 2000	Verkley, Moene (Appl Mod), *Vosbeek*	BCRS
International	DICE - Decadal and Interdecadal Climate Variability: Dynamics and Predictability Experiments	1994 - 1998	Opsteegh, Haarsma, *Selten*	EU
	SINTEX - Scale Interactions Experiments	1998 - 2001	Opsteegh, Haarsma, Beersma (Clim An), *Timmermann*	EU

Oceanographic Research

	Project title	Begin - end	Participants	Funded by
National	Assimilation of satellite sea level observations into a seasonal climate forecast model	1996 - 1998	Komen, *Zambresky*, *van Oldenborgh*	NWO
	Data assimilation for the estimation of salinity in the western Pacific	1995 - 1999	Burgers, *Vossepoel*	SRON
	Data assimilation in the wave model NEDWAM	1995 - 1998	Komen, Makin, *Voorrips*	NWO
	On the dependence of tropical circulation on mixing processes in the ocean	1994 - 1998	Burgers, *van Eijk*	NWO
	Mechanisms for decadal variability in the formation of mode water	1994 - 1999	Drijfhout, *Hazeleger*	NWO
	Natural variability of the wind-driven ocean circulation	1996 - 2000	Drijfhout, *Katsman*	NWO
	The upper ocean in complex realistic climate models	1995 - 1999	Komen, *Bonekamp*	NOP
International	ASGAMAGE - Air Sea Gas and Aerosol Exchange Experiment	1996 - 1999	Oost, Jacobs	EU
	AUTOFLUX - An Autonomous system for monitoring air-sea Fluxes using the inertial dissipation method and ship mounted instrumentation	1998 - 2001	Kohsiek (Atm Res), Oost, van Oort, Worrell	EU
	Euroclivar - A Concerted Action for the co-ordination of CLIVAR-related research in Europe	1996 - 1999	Komen, *van Beers*	EU
	Intercomparison of the World Ocean wind and wave climatology from in-situ, voluntary observing, satellite and model data	1997 -2000	Sterl	INTAS
	TRACMASS - Tracing the Water Masses of the North Atlantic and the Mediterranean	1998 - 2001	Drijfhout	EU
	WASA - Waves and Storms in the North-Atlantic	1994 - 1997	Komen, Beersma (Clim An)	EU

Atmospheric Composition Research

	Project title	Begin - end	Participants	Funded by
National	DORAS - Development of O_3 profile Retrieval Algorithm Space-borne Spectrometer	1998 - 2000	Kelder, Van Velthoven, *Van Oss*	BCRS
	INDOEX - Indian Ocean Experiment	1996 - 2000	Kelder, *Stockwell*, *Zachariasse*, Van Velthoven	NWO
	MEMORA - Measurement and Modelling of the Reduction of radiation by Aerosols	1995 - 1999	Van Dorland (Atm Res), Van Velthoven, Scheele, *Jeuken*	NOP
	NEONET - Netherlands Earth Observation Network; application: SCIAMACHY Data Centre	1997 - 2000	Piters, Stammes (Atm Res), *Koelemeijer* (Atm Res), *Valks*	BCRS, SRON
	OMI - Ozone Monitoring Instrument	1998 - 2008	*Levelt*, *Noordhoek*	EZ, V&W
	RADCHIS - Research on Atmospheric Dynamics and Chemistry in Surinam	1998 - 2002	Kelder, *Fortuin*	NWO
	SCIAMACHY Validation Scientific Support	1997 - 2001	*Piters*, Kelder	SRON
	SCIAVALIG - SCIAMACHY Validation and Interpretation Group	1997 - 2005	Piters, Kelder, *Timmermans*	NIVR
International	ACE - Atmospheric Chemistry Explorer	1998 - 2000	Kelder, Van Velthoven, *Van Weele*	ESA

AEROCHEM - Modelling of the impact on ozone and other chemical compounds in the atmosphere from airplane emissions	1998 - 2000	Van Velthoven, *Pultau*	EU, University of Oslo
ATOP - Atmospheric and Optical data Preprocessing reference chain	1997 - 1999	Kelder, *Piters*	ESA
AVION - Study of airplane emissions	1997 - 1999	Van Velthoven, *Van Weele, Pultau*	RLD
CARIBIC - Civil Aircraft for Remote Sensing and In-situ measurements in troposphere and lower stratosphere Based on the Instrumentation Container concept	1996 - 1999	Van Velthoven, *Cuijpers*	EU
DARE - Data Assimilation in Readiness for ENVISAT	1997 - 1999	Kelder, Eskes	EU
EULINOX - European Lightning Nitrogen Oxides Experiment	1998 - 1999	Van Velthoven, *Meijer*	EU
EUROCONTROL - Study of climate effects of contrails caused by aircraft emissions	1998 - 1998	Kelder, Van Velthoven, *Pultau*	EURO-CONTROL
FALCON - Pollution from aviation	1996 - 1997	Kelder, Van Velthoven	DLR
GODIVA - GOME Data Interpretation, Validation and Application	1998 - 2000	Eskes	EU
GOFAP - GOME Ozone Fast delivery and value-Added Products	1997 - 2000	Piters, Kelder, Scheele	ESA
OASE - Ozone Application Similator and Explorer	1996 - 1999	Kelder, Allaart, *Van der A*	EU
Ozone SAF - Satellite Application Facility for ozone data	1997 - 2002	Kelder, *Valks*, Van Oss, Van der A	EUMET-SAT
POLINAT - Pollution from Aircraft Emissions in the North Atlantic Flight Corridor	1995 - 1999	Kelder, *Meijer*, Van Velthoven	EU
SINDICATE III - Study of Indirect and Direct Influences on Climate of Anthropogenic Trace Gas Emissions	1998 - 1999	Kelder, Van Velthoven, Siegmund, Van Dorland (Atm Res), Scheele, Verver, *Fortuin, Straume*	EU
SODA - Studies of Ozone Distributions based on Assimilated Satellite Measurements	1996 - 1999	Kelder, Allaart, *Levelt, Eskes*	EU
STREAM III - Stratosphere-Troposphere Experiment by Aircraft Measurements	1998 - 2000	Van Velthoven, Siegmund, *Ambaum, Brunner*	EU
SUVDAMA - Scientific UV Data Management	1996 - 1998	Kelder, *Van Weele*	EU
TRACAS - Transport of Chemical species through the Subtropical tropopause	1997 - 1999	Siegmund, *Meloen*	EU

Atmospheric Research

	Project title	***Begin - end***	***Participants***	***Funded by***
National	Analysis and modelling of boundary layer clouds during ASTEX	1997 - 2000	Holtslag, *Lenderink*	NWO
	Antarctic mass balance modelling	1994 - 2002	Van Meijgaard, *van Lipzig*	NWO
	CARIS - Cloud Absorption Retrieval from the near IR-channels of SCIAMACHY	1998 - 2001	Stammes, *Knap*	SRON
	CLARA - Clouds And Radiation; Intensive experimental study of clouds and radiation in the Netherlands	1995 - 1999	Van Lammeren, Feijt, *Konings*	NOP

	Clouds products retrieval for MSG	1997 - 2000	Feijt, *Dlhopolsky*	BCRS
	Detection and characterisation of clouds using satellite observations	1994 - 1998	Stammes, *Koelemeijer*	SRON
	EOS Measurements of surface energy and water balance	1996 - 1998	Holtslag, *van den Hurk*	BCRS
	GOME and SCIAMACHY radiation study	1994 - 1998	Stammes, *Stam*	SRON
	GPS Water Vapour Meteorology	1996 - 1998	Klein Baltink, van Lammeren, *Derks*	BCRS
	Representation of the seasonal hydrological cycle in climate and weather prediction models in West Europe	1997 - 2001	Holtslag, *van den Hurk*	NOP
	SCIAPOL - SCIAMACHY Polarisation-correction and validation	1998 - 2001	Stammes, *Schutgens*	SRON
	Sensor Synergy Study for the ERM	1998 - 2001	Van Lammeren, *Bloemink*	SRON
	Shallow cumulus convection and its interaction with the atmospheric boundary layer	1998 - 2002	Siebesma, Jonker, Holtslag, *Neggers*	NWO
	Sunspot; Possible influence of variation in s olar activity on the global climate	1997 - 1999	Van Ulden, van Dorland	NOP
International	Analysis of ERM Synergy by use of CLARA observations	1998 - 1999	Van Lammeren, *Donovan*	ESA
	AUTOFLUX - An Autonomous system for monitoring air-sea Fluxes using the inertial dissipation method and ship mounted instrumentation	1998 - 2001	Kohsiek, Oost (Ocea Res), van Oort (Ocea Res), Worrell (Ocea Res)	EU
	CLARE'98 - Cloud Lidar and Radar Experiment 1998	1998 - 1999	Van Lammeren	ESA
	EUCREM - European Cloud-Resolving Modelling	1996 - 1998	Van Ulden, *Jonker*	EU
	NEW BALTIC II Energy and water cycle of the Baltic Sea catchment	1998 - 2000	Holtslag, van Meijgaard, *van den Hurk*	EU
	Quantification of the Synergetic aspects of the ERM	1998 - 1999	Van Lammeren, *Donovan*	ESA
	Validation Surface Scheme	1998 - 1999	Holtslag, *van den Hurk*	ECMWF

Climate Analysis and Scenarios

	Project title	***Begin - end***	***Participants***	***Funded by***
National	Paleoclimatic research	1995 - 1997	Können, *Shabalova*	V&W
	Patterns of low-frequency climate variability: a model paleodata comparison	1997 - 2000	Weber (Pred Res), Können, *Shabalova*	NOP
	Weather Generator for the Rhine basin	1997 - 2000	Buishand, Beersma, *Brandsma*	RIZA
International	ECLAT-2 - European Climate Change Project - Concerted Action Initiative	1998 - 2001	Beersma	EU
	POPSICLE - Production of Precipitation Scenarios for Impact Assessments of Climate Change in Europe	1994 - 1997	Buishand, *Brandsma*	EU
	SINTEX - Scale Interactions Experiments (Opsteegh, Haarsma and *Timmermann* from Pred Res)	1997 -2000	Opsteegh, Haarsma, Beersma, *Timmermann*	EU
	WASA - Waves and Storms in the North-Atlantic	1994 - 1997	Komen (Ocea Res), Beersma	EU
	WRINCLE - Water Resources: the Influence of Climate Change in Europe	1998 - 2000	Buishand, *Helmyr*	EU

Seismology

	Project title	Begin - end	Participants	Funded by
National	Sonic Boom	1998 - 1999	Haak, *Evers*	Klu
	Pilot experiment tiltmeters	1996 - 1998	Haak, *Sleeman*	EZ
International	PALEOSIS - Identification of paleoseismic events in low seismicity areas	1998 - 2000	Dost, *Evers*	EU
	ASPELEA - Assessment of Seismic Potential in European Large Earthquake Areas	1997 - 2000	Van Eck, *Dineva, Van der Meijde*	EU
	Rapid transfrontier seismic data exchange network	1994 - 1997	De Crook, *Sleeman*	EU
	A Rapid warning system for earthquakes in the European-Mediterranean region	1996 - 1998	Haak, *Sleeman*, Dost	EU
	PILOTO - Regional earthquake monitoring and hazard assessment	1996 - 1998	Dost, *Sleeman*	EU

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

Theses *

1997 Ambaum, M.H.P., 23 January 1997. *Large-Scale Dynamics of the Tropopause.* Technical University of Eindhoven, 115pp, Supervisors: prof. G.J.F. van Heijst, prof. J.T.F. Zimmerman, Co-supervisor: dr. W.T.M. Verkley.

Lenderink, G., 20 October 1997. *Physical Mechanisms of Variability of the Thermohaline Ocean Circulation.* University of Utrecht, 160pp, Supervisor: prof. W.P.M. de Ruijter, Co-supervisor: dr. R.J. Haarsma.

1998 Oortwijn, J., 25 March 1998. *Predictability of Weather Regime Transitions.* University of Wageningen, 116pp, Supervisor: prof. J. Grasman, Co-supervisor: dr. J. Barkmeijer.

Brands, H., 20 October 1998. *Coherent Structures and Statistical Mechanics in Two-Dimensional Flows.* University of Amsterdam, 118pp, Supervisor: prof. H.W. Capel, Co-supervisor: dr. R.A. Pasmanter.

Voorrips, A.C., 23 November 1998. *Sequential Data Assimilation Methods for Ocean Wave Models.* Technical University of Delft, 175pp, Supervisor: prof. A.W. Heemink, Co-supervisor: dr. G.J. Komen.

* The theses listed here are the result of work carried out in the Department of Climate Research and Seismology.

Acronyms

ABLE - Amazon Boundary Layer Experiment
ACC - Antarctic Circumpolar Current
ACE - Atmospheric Chemistry Explorer
ACE - Aerosol Characterisation Experiment
ACW - Antarctic Circumpolar Wave
ADEOS - Advanced Earth Observing System
AEREA - Association of European Research Establishments in Aeronautics
AIRFORCE - Aircraft Influences and Radiative Forcing from Emissions
AMIP - Atmospheric Model Intercomparison Project
APOLLO - AVHRR Processing scheme over Clouds, Land and Ocean
ARM - Atmospheric Radiation Measurement programme
ASGAMAGE - Air Sea Gas and Aerosol Exchange Experiment
ASPELEA - Assessment of Seismic Potential in European Large Earthquake Areas
ASTEX - Atlantic Stratocumulus Transition Experiment
ATSR - Along-Track Scanning Radiometer
AVHRR - Advanced Very High Resolution Radiometer

BALTEX - Baltic Sea Experiment
BCRS - Netherlands Remote Sensing Board
BOMEX - Barbados Oceanographic and Meteorological Experiment
BRIDGE - BALTEX Main Experiment

CARIBIC - Civil Aircraft for Remote sensing and In-situ measurements in troposphere and lower stratosphere Based on the Instrumentation Container concept
CBS - Commission on Basic Systems
CCB - Centre for Climate Change and the Biosphere (Agricultural University of Wageningen)
CCL - Commission for Climatology
CCM - Climate Community Model
CDS - Cloud Detection System
CFC - chlorofluorocarbon
CKO - Netherlands Centre for Climate Research
CLARA - Clouds And Radiation experiment
CLARE'98 - Cloud Lidar and Radar Experiment 1998
CLIO - Coupled Large-Scale Ice Ocean model
CLIVAR - Climate Variability and Predictability Research
CLIVARNET - Dutch contribution to CLIVAR
CNES - National Centre of Space Studies (France)
COACh - Co-operation on Oceanic, Atmospheric and Climate Change studies
COST - European Co-operation in the field of Scientific and Technical research
COPEC - Permanent Committee on Environment and Climate
CREAM - Cloud Resolving Atmospheric Model
CSIRO - Commonwealth Scientific and Industrial Research Organisation

CTBT - Comprehensive Nuclear-Test-Ban Treaty
CTD - conductivity-temperature-depth

DEOS - Delft Institute for Earth-Oriented Space Research
DICE - Decadal and Interdecadal Climate Variability: Dynamics and Predictability Experiments
DLR - German National Aerospace Research Centre
DMS - dimethylsulfide
DORAS - Development of O_3 profile Retrieval Algorithm Space-borne Spectrometer
DRM - Data Request Manager
DU - Dobson unit

EASOE - European Arctic Stratospheric Ozone Experiment
ECBILT - KNMI General Circulation Model
ECHAM - Hamburg version of the ECMWF model
ECHAM4 - Hamburg version (number 4) of the ECMWF model
ECLAT - European Climate Change Project - Concerted Action Initiative
ECMWF - European Centre for Medium-Range Weather Forecasts
EMS - European Macroseismic Scale
EMSC - European-Mediterranean Seismological Centre
ENSO - El Niño - Southern Oscillation
ENVISAT - Environmental Satellite
EOS - Earth Observing System
EOS-CHEM - Earth Observing System - Chemistry
ERA - ECMWF Re-Analysis
ERM - Earth Radiation Mission
ERS - Earth Remote Sensing
ESA - European Space Agency
ESC - European Seismological Commission
ETH - Swiss Federal Institute of Technology
EU - European Union
EUCREM - European Cloud-Resolving Modelling
EULINOX - European Lightning Nitrogen Oxides experiment
EUMETSAT - European Organisation for the Exploitation of Meteorological Satellites
Euroclivar - European implementation of CLIVAR
EUROCONTROL - European Air Traffic Control Organisation
EZ - Ministry of Economic Affairs

FASTEX - Fronts and Atlantic Storm Track Experiment
FDSN - Federation of Digital Seismograph Networks
FMI - Finnish Meteorological Institute
FSSP - Forward Scattering Spectrometer Probe

GCM - General Circulation Model
GCOS - Global Climate Observing System

GCSS - GEWEX Cloud System Studies
GEWEX - Global Energy and Water Cycle Experiment
GIS - Geo-Information System
GKSS - Geesthacht Research Centre
GOA - NWO-Geosciences Foundation
GOBELIN - GOME Breadboard Experimental Link
GOME - Global Ozone Monitoring Experiment
GOOS - Global Ocean Observing System
GPS - Global Positioning System
GSHAP - Global Seismic Hazard Assessment Program

HEXMAX - HEXOS Main Experiment
HEXOS - Humidity Exchange over Sea
HGN - KNMI seismograph station Heimansgroeve
HIRDLS - High Resolution Dynamics Limb Sounder
HIRLAM - High Resolution Limited Area Model
HITRAN 1996 - High Resolution Transmission data base 1996
HOPE - Hamburg Ocean Primitive Equation model

IASPEI - International Association of Seismology and Physics of the Earth's Interior
ICS - International Communication System
IDA - International Deployment of Accelerometers
IDC - International Data Centre
IGAC - International Global Atmospheric Chemistry
IHE - International Institute for Infrastructural, Hydraulic and Environmental Engineering
ILP - International Lithosphere Programme
IMAGE - Integrated Model for the Assessment of the Greenhouse Effect
IMAU - Institute for Marine and Atmospheric Research Utrecht
IMS - International Monitoring System
INDOEX - Indian Ocean Experiment
INTAS - International Association for the Promotion of Co-operation with Scientists from the New Independent States of the Former Soviet Union
IOC - Intergovernmental Oceanographic Commission
IOS - Initial Observing System (of GCOS)
IPCC - Intergovernmental Panel on Climate Change
IPWV - Integrated Precipitable Water Vapour
IRIS - Incorporate Research Institutes in Seismology
ITCZ - Intertropical Convergence Zone
IUGG - International Union of Geodesy and Geophysics
IVM - Institute for Environmental Studies
IYO - International Year of the Ocean

J-GOOS - Joint Scientific and Technical Committee of GOOS
JHD - Joint Hypocentre Determination

Klu - Royal Netherlands Airforce
KNAW - Royal Netherlands Academy of Arts and Sciences
KNMI - Royal Netherlands Meteorological Institute
KRCM - KNMI Radiative-Convective Model

LANDSAT - Land Remote Sensing Satellite
LES - Large Eddy Simulation
lidar - light detecting and ranging (laser radar)
LITFASS - Lindenberg Inhomogeneous Terrain Fluxes between Atmosphere and Surface - a long-term Study
LSG - Large Scale Geostrophic model
LWP - Liquid Water Path

MARE - Mixing of Agulhas Rings Experiment
MEMORA - Measurement and Modelling of the Reduction of radiation by Aerosols
METCLOCK - METEOSAT Cloud Detection and Characterisation KNMI
METEOSAT - Meteorological Satellite
METOP - Meteorological Operational Satellite
MISU - Department of Meteorology of the University of Stockholm
MLS - Microwave Limb Sounder
MPI - Max-Planck-Institute
MSG - METEOSAT Second Generation

NADW - North Atlantic Deep Water
NAFC - North Atlantic Flight Corridor
NAO - North Atlantic Oscillation
NASA - National Aeronautics and Space Administration
NCAR-ACD - National Center for Atmospheric Research - Atmospheric Chemistry Division
NCEP - National Centers for Environmental Prediction
NDC - National Data Centre
NIOZ - Netherlands Institute for Sea Research
NITG - Netherlands Institute for Applied Geoscience
NIVR - Netherlands Agency for Aerospace Programmes
NNI - Netherlands Standardization Institute
NOAA - National Oceanic and Atmospheric Administration
NOP - National Research Programme on global air pollution and climate change
NOXAR - Nitrogen Oxides and Ozone along Air Routes
NSF - National Science Foundation
NWO - Netherlands Organisation for Scientific Research
NASE - Ozone Application Simulator and Explorer

OASE - Ozone Application Simulator and Explorer
OC&W - Ministry of Education, Culture and Science
OCCAM - A high-resolution ocean general circulation model
ODC - ORFEUS Data Centre

OGCM - Ocean General Circulation Model
OMI - Ozone Monitoring Instrument
ORFEUS - Observations and Research Facilities for European Seismology
OSU - Oregon State University

PALEOSIS - Evaluation of the potential for large earthquakes in regions of present day low seismic activity in Europe
PIDC - Prototype International Date Centre
PILOTO - Regional earthquake monitoring and hazard assessment
PILPS - Project for Intercomparison of Land surface Parameterisation Schemes
PMEL - Pacific Mooring Experiment Laboratory
POLINAT - Pollution from Aircraft Emissions in the North Atlantic Flight Corridor
POPSICLE - Production of Precipitation Scenarios for Impact Assessments of Climate Change in Europe
PSA - Pacific South American
PSHA - Probabilistic Seismic Hazard Assessment

RACMO - Regional Atmospheric Climate Model
RASS - Radio Acoustic Sounding System
RIVM - National Institute of Public Health and the Environment
RIZA - National Institute for Inland Water Management and Waste Water Treatment
RLD - Dutch Civil Aviation Authorities
ROSE - Research on Ozone in the Stratosphere and its Evolution

SAC - Scientific Advisory Committee
SAF - Satellite Application Facility
SAGE - Stratospheric Aerosol and Gas Experiment
SBUV - Solar Backscatter Ultraviolet spectrometer
SCIAMACHY - Scanning Imaging Absorption Spectrometer for Atmospheric Cartography
SCIAPOL - SCIAMACHY Polarisation-correction and validation
SCOR - Scientific Committee on Oceanographic Research
SINDICATE - Study of Indirect and Direct Influences on Climate of Anthropogenic Trace Gas Emissions
SINTEX - Scale Interactions Experiments
SOC - Southampton Oceanography Centre
SODA - Studies of Ozone Distributions based on Assimilated Satellite Measurements
sodar - sound detecting and ranging
SOFAR - Sound Fixing and Ranging
SOI - Southern Oscillation Index
SPUV - Sun Photometer Ultraviolet
SPYDER - The name for a system to collect and exchange waveform data from globally distributed broad-band seismic stations
SRON - Space Research Organisation Netherlands

SSL - Seismological Software Library
STREAM - Stratosphere-Troposphere Experiment by Aircraft Measurements
STW - NWO-Technology Foundation
SUVDAMA - Scientific UV Data Management

TAO - Tropical Atmosphere Ocean
TAO - Transport in the Atmosphere and the Oceans
TEBEX - Tropospheric Energy Budget Experiment
TES - Tropospheric Emission Spectrometer
TIROS - Television and Infrared Observation Satellite
TM3 - Transport Model, version 3
TNO - Netherlands Organisation for Applied Scientific Research
TOMS - Total Ozone Mapping Spectrometer
TOPEX-POSEIDON - Ocean Topography Experiment - Poseidon (NASA-CNES Altimetric Mission)
TOVS - TIROS Operational Vertical Sounder
TRACMASS - Tracing the Water Masses of the North Atlantic and the Mediterranean

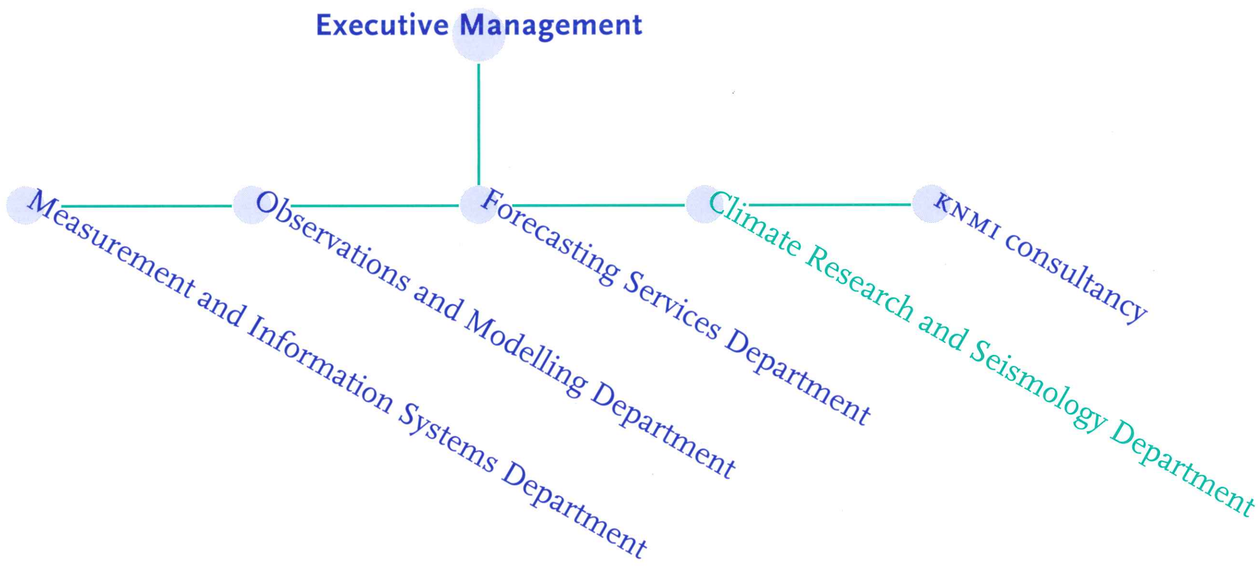
UARS - Upper Atmosphere Research Satellite
UKHI - United Kingdom High Resolution
UKMO - United Kingdom Meteorological Office
UNEP - United Nations Environmental Programme
USGS - United States Geological Survey

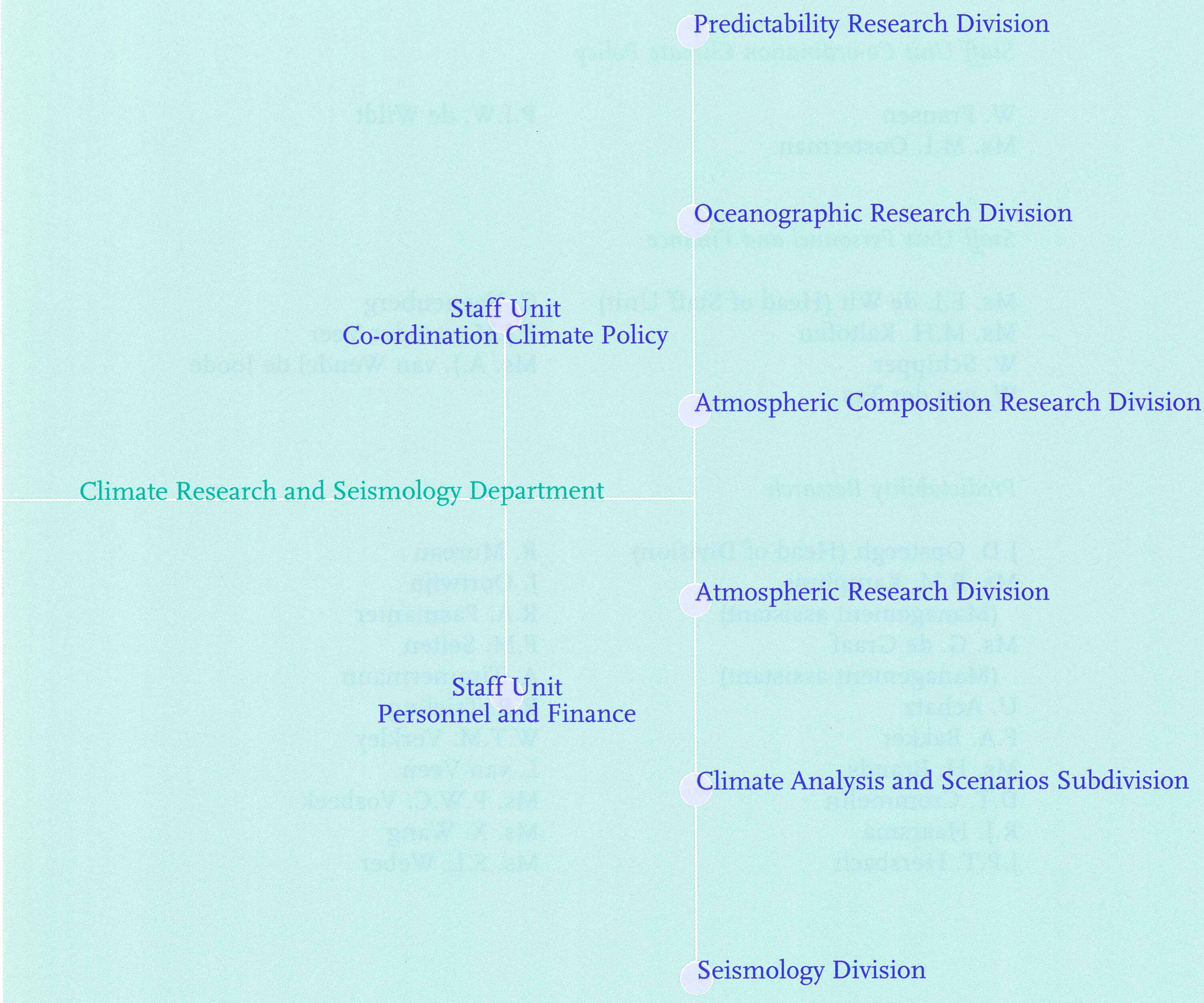
V&W - Ministry of Transport, Public Works and Water Management
VROM - Ministry of Housing, Spatial Planning and the Environment

WAM - Wave Model
WASA - Waves and Storms in the North Atlantic
WCRP - World Climate Research Programme
WINDE - Wind Initiative for Network Demonstrations in Europe
WIT - KNMI seismograph station Witteveen
WMO - World Meteorological Organisation
WOCE - World Ocean Circulation Experiment
WOUDC - World Ozone and UV Data Centre
WRINCLE - Water Resources: the Influence of Climate Change in Europe
WTS - KNMI seismograph station Winterswijk

ZLV - KNMI borehole seismic station Zuidlaarderveen

Organisational scheme

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Atmospheric Composition Research Division
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Staff Unit Personnel and Finance
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Design
Studio KNMI, Birgit van Diemen

Production
Johan Bremer

Photography
Raoul Somers

Lithography and print
Meerpaal Offset BV, Tiel

Paper
Inner pages: Reviva Mega 100 g/m^2
Cover: Reviva Mega 250 g/m^2

Reviva Mega: 50% recycled and 50% completely chloride-free paper.