CLIMATE RESEARCH AND SEIMOLOGY DEPARTMENT

KNMI

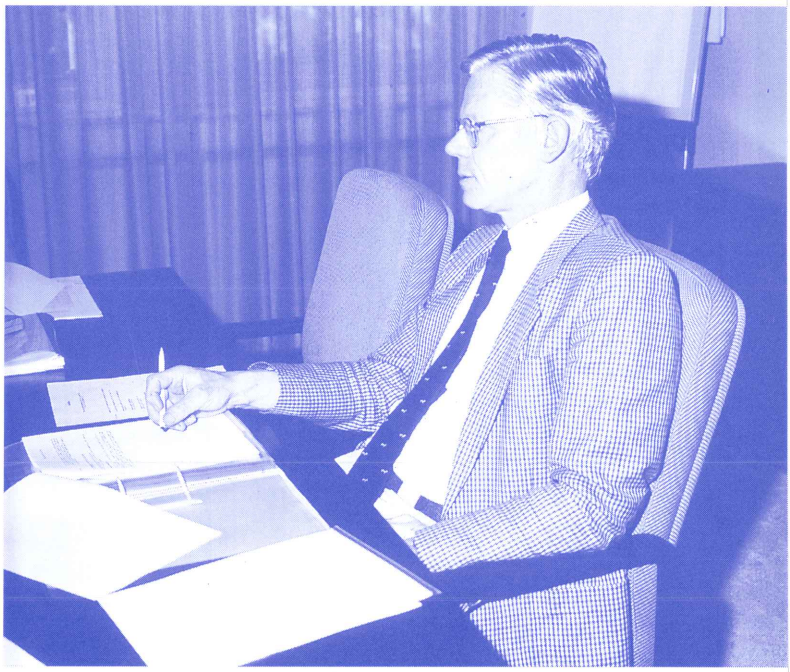
Biennual Scientific Report 1996

Koninklijk Nederlands Meteorologisch Instituut

ROYAL NETHERLANDS METEOROLOGICAL INSTITUTE

Biennual Scientific Report 1996

Contents



Preface · KNMI is by tradition a multidiciplinary institute. Our tasks include meteorological forecasting and research, observation and climatology, and climate reseach and seismology. The mix of tasks is the secret of our achievements. Science and operational forecasting are under one roof and benefit of each other. Due to the presence of the operational forecasting department, science is inclined to listen to practical problems, while the operational department benefits from the presence of science. In fact we hope and intent to contribute with our scientific efforts to the challenge of climate forecasting. Although KNMI reached in 1997 the impressive age of 143 years, its heart is still young. The achievements of the Climate Research and Seismology Department, outlined in this Biennial Report, supports this statement.

dr. H.M.Fijnaut
Director

Introduction · This is the first Biennial Scientific Report of the Royal Netherlands Meteorological Institute's (KNMI) Research Department. It aims at presenting to our colleagues world-wide a selection of our results of the past year. Since this is the first Report, an introduction to the department and its work seems appropriate.

Since KNMI's foundation in 1854, research has always been a key activity of the Institute. Meteorological, oceanographic and geophysical research have a long and outstanding history at KNMI. The present Research Department was established in 1989. Covering both climatological and seismological research, it is the offspring of this long tradition.

Climate Research · The aims of the climate research programme are to contribute to the improvement of our understanding of the climate system and its predictability and to support our Government's national and international climate policy by giving advice and information to the Government and the public on climate, its natural variability and anthropogenic change.

The climate research area is very broad, too broad to be covered by an Institute of our size. Moreover certain areas, such as the development of General Circulation Models (GCMs) and their use for climate prediction, are well covered by excellent research institutions in Europe. Based on such considerations and on existing experience, our research focuses on two themes:

- composition of the atmosphere and radiative forcing
- climate variability and change.

Within these two, still quite broad, research areas we concentrate on:
- atmospheric and oceanographic process studies, both observational and theoretical
- theoretical and observational studies of the nature and predictability of the chaotic climate system
- application of observations for monitoring, model validations and process studies
- analysis of climate and climate change.

National and international co-operation · KNMI's climate research is embedded in an extensive network of national and international co-operation. We are part of the recently established Netherlands Centre for Climate Research (CKO), a joint effort with the Intsitute for Marine and Atmospheric Research of Utrecht University and with the National Institute of Public Health and the Environment. We co-operate and are partly financed by national research programmes and maintain strong links with all national geophysical institutions.

Internationally our research is carried out in the context of programmes such as Climate Variability and Predictability (CLIVAR), Global Energy and Water Cycle Experiment (GEWEX) and Stratospheric Processes and their Role in Climate (SPARC) and in close co-operation with numerous research organizations. We take part in many joint projects of the European Framework Programme on Environment and Climate.

Recently the Minister of Education, Culture and Sciences has taken an initiative to strengthen the co-operation between the Netherlands

Centre for Climate Research and the Max Planck Institutes in Hamburg and Mainz.

Policy support · In order to maintain a close link between the outcome of climate research and the policy of the Netherlands Government, the task of supporting this policy and giving advice to government and the public is assigned to the Research Department. Our staff represents the Netherlands in IPCC and in the Subsidiary Board on Scientific and Technological Advice (SBSTA) of the Framework Convention on Climate Change and are involved in the Climate Convention negotiations.

Being an Agency of the Ministry of Transport, Public Works and Water Management we coordinate all aspects of the climate policy of this Ministry. We develop regional climate scenarios in close co-operation with those responsible for coastal defence and water management, and we study the impact of emissions from transport and aviation on climate. It is this combination of science and policy support that distinguishes KNMI's climate research from that of many other institutions.

Our Department is 'the national centre for research and information on climate and climate change'. As such in 1996 we gave secretarial and scientific support to a Parliamentary Committee on Climate Change.

Seismology · The Netherlands is not exactly a country prone to earthquakes. Nevertheless our country is prominent in the international

The Scientific Aims of KNMI's Climate Research Programme

- to further our knowledge of the climate system and its predictability;
- to contribute to national and international efforts in the area of observation, monitoring and prediction of the climate system;
- to support the Netherlands climate policy, national and international, and to give advice on climate and natural and anthropogenic climate change to government and to the public;
- to support other KNMI-activities in the area of observation, instrument and model development, and weather prediction.

Mission of KNMI's Climate Research Programme

- to act as the national research and information centre for climate, climate change and seismology at a recognized high scientific level;
- to act as the national research and information centre for climate, climate change and seismology at a recognized high scientific level.

seismological world. Traditionally the responsibility for this task lies on KNMI's shoulders and is part of the science department. Our seismology section plays a leading role in the detection of nuclear test explosions in the framework of the Test Ban Treaty and is host to the international Orfeus data centre.

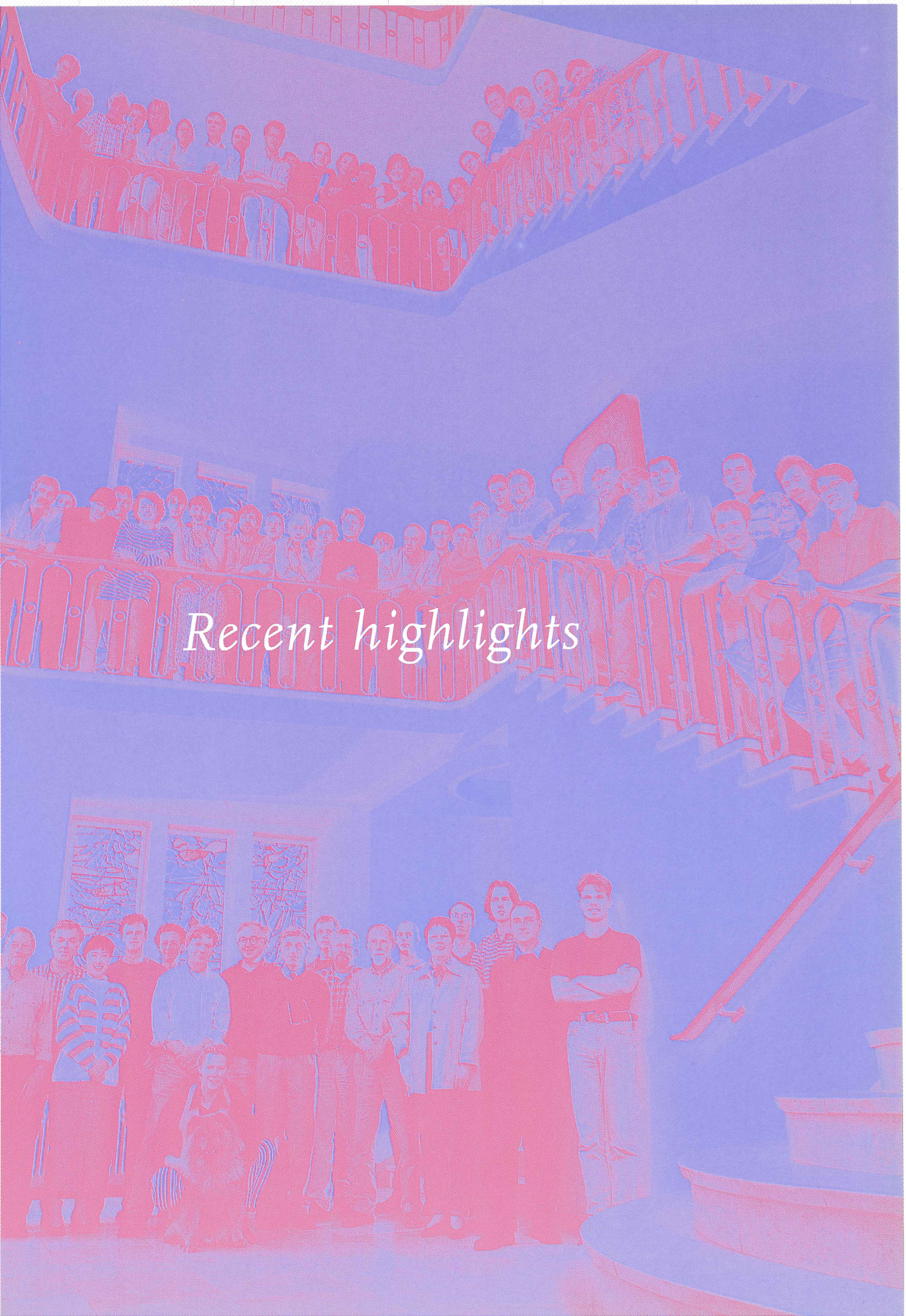
In recent years the seismicity in certain parts of the country has increased substantially, probably due to gas extraction. The seismology Division develops and installs detection networks and carries out research on this problem that causes damage to buildings and to economic activity.

This Report · In this first Biennial Report the results of our work in 1996 are summarized, ordered by project, together with a complete list of publications, KNMI Scientific and Technical Reports, books, theses and the number of international presentations. The list of publications refer to papers in standard journals only, which are the Source Journals of the Science Citation Index. We offer in-depth information on four selected topics covering the wide spectrum of activities of our department. Finally we present more detailed information on the organization, staff and funding of the Department.

I encourage you to send me your comments so that we can improve the next report. If you wish further information, don't hesitate to contact me or the scientists involved.

And finally, don't forget to visit our Web site (*http://www.knmi.nl*), which offers you an opportunity to learn more about us and to order reprints of the published papers.

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



Recent highlights

Ten years of seismic monitoring of gas reservoirs in the northern provinces of the Netherlands

by H.W. Haak

Introduction · Since 1986 the northern provinces of the Netherlands experienced a large number of weak earthquakes. Of these events, 18 were of magnitude 2.5 on the Richter Scale, the detection threshold for the region prior to 1991. The first event, at the town of Assen in December 1986, had a magnitude of 2.8 and was followed nearly one year later by a 2.5 tremor a few kilometers south near Hooghalen, also in the province of Drenthe. It was not clear what caused these earthquakes. Some newspaper reports suggested that gas production in the area could be held responsible. The Ministry of Economic Affairs decided to ask the Royal Netherlands Meteorological Institute (KNMI) to install a network of seismometers around Assen. This small network was completed by the end of 1988. At the end of 1989, a third tremor occurred, not in the province of Drenthe but in the province of Noord-Holland near the village of Purmerend some 100 kilometers away. This earthquake had a magnitude of 2.7. In 1990, the initial steps were taken towards setting up a research program, intending to clarify the cause of the earthquakes and to obtain better knowledge on the backgrounds. In June 1991 this research program was sent to the Government for approval. The study, which was committed for a fixed period of two years, commenced in October 1991. The KNMI was prepared to take on the task of project management, while a committee of experts was given the responsibility to supervise the study. This program resulted in a conclusive report to the Dutch Government in 1993.

Further research on the subject is still going on, now focusing on the effects on the earth surface of shallow earthquakes and the effects of damage of the larger events. Quite recently, in February 1997 we experienced

the largest of all the earthquakes thus far with a magnitude of 3.4 it occurred in the south of the province of Drenthe near Emmen (Roswinkel).

Scope of the problem · Earthquakes are relatively uncommon in the Netherlands. This is because the country is located in the center of a continental plate, where changes in the stress field within the bedrock are generally quite minor. The southern part of the Netherlands experiences several earthquakes every year although not every tremor is felt by the public. These earthquakes have a natural cause, being associated with faults within a

The activity occurred near gas reservoirs in production

major Graben system. Conversely, the northern part of the Netherlands is considered to be aseismic, in other words: it does not experience natural earthquakes of any significance.

However, since 1986, seismic activity has been recorded in the northern part of the Netherlands. The activity occurred either in or around gas reservoirs in production. This in turn provoked the question about the origin of these events and the degree to which gas extraction can be held responsible. Monitoring of the earthquakes with local seismometers contributed significantly to the solution of this problem.

At an early stage, the estimations of the maximum possible anticipated strength of future shocks were based on calculations with numerical models. This was due to the fact that the initially available seismic data (location, magnitude) had been calculated for a small number of earthquakes only. Later, when additional seismic data became available, various statistical methods could also be employed.

Gas production induces a redistribution of stresses within the bedrock, particularly within the gas reservoir itself and the immediate surroundings. The natural gas occurs in a layer of porous rock, the gas reservoir, as for example a sandstone. Porosity can also arise due to numerous small cracks and faults in the reservoir rock. The reservoir is sealed at the top by a type of rock impermeable to gas, such as rock salt.

The complex geological nature of the local bedrock makes it almost impossible to obtain more than an approximate value for the stress field in the northern part of the Netherlands. Thus an outline of the problem can only be effectively resolved by collaboration with various disciplines such as, geology and geomechanics.

What caused these tremors?

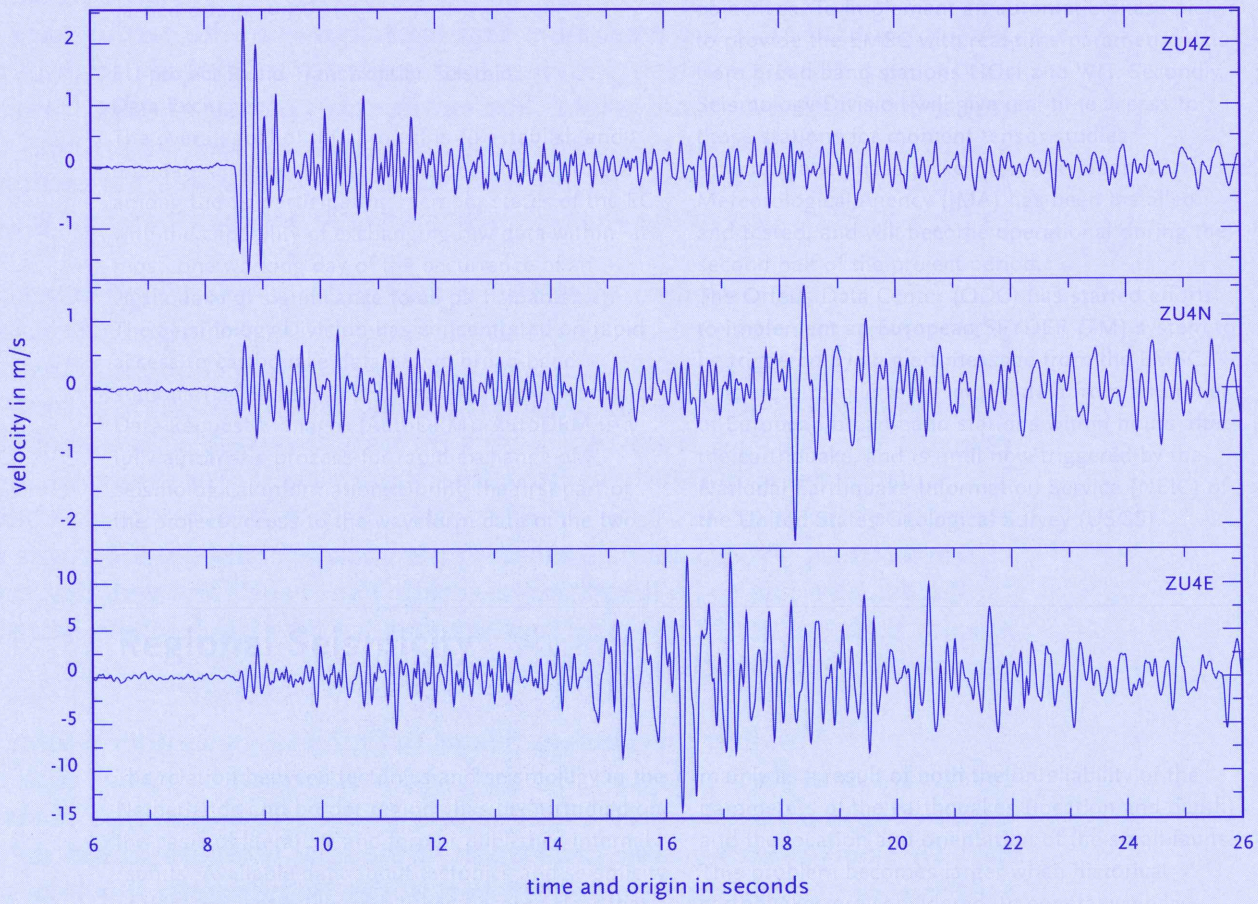


Figure 1. Recording of an earthquake of magnitude 2.3 in the northern part of the Netherlands at station Zuidlaarderveen. Ground velocity is shown for the vertical (ZU4Z), radial (ZU4N) and transverse component (ZU4E). This gas-induced earthquake took place at 17 November 1996.

Three main questions had to be answered. The first of these concerned the anticipated consequences of future earthquakes. In other words, what is the most severe tremor that can be expected to occur in a certain time window and what damage might result from it. The second question is related to the optimal recording of subsequent earthquakes, in order to arrive at an acceptable quantification of location, depth and magnitude. The third question was, what the actual accelerations were in epicentral areas.

The complete statement of the problem therefore incorporates the cause and the repercussions of the tremors as well as the prospects for making acceptable recordings of future events. These three topics are discussed separately in the following paragraphs.

Earthquakes and gas production · In a multidisciplinary study on the relationship between gas production and earthquakes as conducted by the Netherlands government it was concluded that these tremors were of 'non-tectonic origin and may therefore have been induced by gas production". This was concluded after the realization that the majority of the earthquakes exhibited a seismic pattern, location and frequency-magnitude relation that was not in line with a tectonic origin. The earthquakes of magnitudes from -0.1 to 3.4 on the Richter scale occurred at depths of 4 km or less, hence near the depth of the gas reservoirs. By contrast, the depth of the tectonic earthquakes in the southern part of the Netherlands is usually between 5 and 30 km.

The diagnosic question regarding the relationship between gas production and earthquakes was tackled, using the knowledge that existing faults often form a zone of weakness as a response to a changing stress field. The analysis was done by calculating the stress changes resulting from pressure drops in gas reservoirs, with a numerical model. This was done at the Technical University Delft and Grondmechanica Delft. For this purpose, the strength of the rock was used as input data, along with other geomechanical characteristics. These calculations are quite complex, since small shifts along fault lines also has to be taken into account. The results showed, that broadly speaking, there are three acting mechanisms for existing faults to be re-activated by gas extraction.

The first mechanism relates to faults located either within gas reservoirs or at their margins. The gas, which is located in porous rock at a depth of approximately three kilometers, is under a local pressure of about 350 bar. This makes up a sizable proportion of the total pressure within the gas reservoir of 750 bar. In the northern part of the Netherlands, this total pressure within the bedrock is almost completely due to the weight of the overlying rock. In this part of the world, the component of the stress which results from the large scale movement of the tectonic plates is quite limited. In fluids and in solids which exhibit fluidal behavior, stress is equally distributed in all directions. While shear stains cannot persist in fluids the opposite is true of solids. In general, the bedrock stresses involved act vertically rather than

horizontally. The magnitude of shear strain is partly determined by the difference between the largest and the smallest stress component. Movement along a fault plane results from the shear strain acting along that fault. The stress component perpendicular to the fault plane affects the friction which accompanies such movement.

During gas production, gas pressure in the reservoir gradually declines. This reduction in counter-pressure results in increased pressure on the reservoir rock, the total pressure exerted by the weight of the overlying rock remains the same. As a result of this increased pressure on the rock matrix, the reservoir is compressed, an effect described as compaction. Such compaction at depth results in ground subsidence at the surface. Whereas, in the central areas of large gas fields, ground subsidence is almost exactly equal to the compaction at reservoir depth, in small fields such subsidence is only a small fraction of the total compaction.

Earthquakes can arise along faults where the level of compaction on one side of the fault differs from that on the other. This is referred to as differential compaction. It may occur where the edge of a gas reservoir is

The locations and depths of the earthquakes coincide with the gas reservoirs

sealed by a fault and also at faults within the reservoir itself. Calculations based on numerical models have shown that, at least for the Eleveld gas field, this mechanism is responsible for the tremors. In this diagnostic study the Eleveld gas field was selected as test case for numerical modelling for two reasons. All the seismological information was available for this reservoir in an accurate form and the field can serve as a model for the majority of the gas fields in the northern part of the Netherlands.

In most cases, differential compaction is a very gradual process. In places where movement along faults in the bedrock is obstructed, due to the presence of conglomerate for example, large shear stresses can build up. When these shear stresses exceed a given threshold value, this barrier will be shattered, producing a sudden shift giving rise to an earthquake.

The second mechanism which can account for earthquakes in the northern part of the Netherlands applies to the situation in the immediate vicinity of a gas reservoir. Large shear stresses are generated around a gas reservoir which is in production. This can lead to relative shifts along fault planes. In a zone ranging from several dozen meters above and below gas reservoirs, the redistribution of stress along existing faults can result in an

abrupt settling. Such settling is largely dependent upon geological conditions along the fault plane. The successive rock strata in the area of the reservoir all have different compositions. These differences are critical in determining the extent of possible shifts along a fault plane. Some of the earthquakes in the Groningenveld and the area near Roswinkel may have been caused by this mechanism. An observable difference between quakes resulting from the first mechanism and the second mechanism is the location of the events. In the first case these will occur either within the gas reservoir or at its edge while in the second case the earthquakes will occur either above or below the reservoir.

Earthquakes which can be described in terms of either the first or the second mechanism are referred to as 'induced'. The amount of energy released by such tremors is directly related to gas production.

The third mechanism is applicable to faults situated further away from the gas reservoir. The majority of the gas reservoirs in the north-eastern part of the Netherlands is located underneath a thick layer of salt. The properties of rock salt, especially its fluid-like or plastic behavior, are of critical importance for the redistribution of the stresses and for the movements far beyond the immediate vicinity of the reservoir under production. Even in these remote locations such redistribution of stresses depends upon the predominant tectonic stress, and may produce sudden sliding motions along existing fault planes. The amount of energy realized by such sudden settling, which is principally determined by natural tectonic processes gives rise to a 'triggered earthquake'. This mechanism may account for the tremors which occurred around Assen and Hooghalen.

To distinguish between the various mechanisms, as far as possible, a highly accurate hypocenter determination is needed. Especially depth is a hard parameter to extract from the recorded data. Fortunately, very good 3D-exploration data exists to study in detail the geological circumstances of a number of larger earthquakes.

Consequences of the gas-induced earthquakes • The surface effects of earthquakes with a certain magnitude, are mainly determined by three factors.

First, the strength of an earthquake is dependent upon the size of the relative displacement at the focus of the earthquake. This displacement, together with the surface area of the fault segment, which moved and the elasticity of the local rock, that determines the strength of the resultant tremor. From calculations based on numerical models it can be deduced that the strength of an earthquake caused by gas production in the northern part of the Netherlands will never exceed a value of about magnitude 3.3 on the Richter scale. Statistical calculations of tremors recorded in the northern part of the Netherlands show that no earthquake caused by gas extraction will exceed a magnitude 3.4, in agreement with the former result.

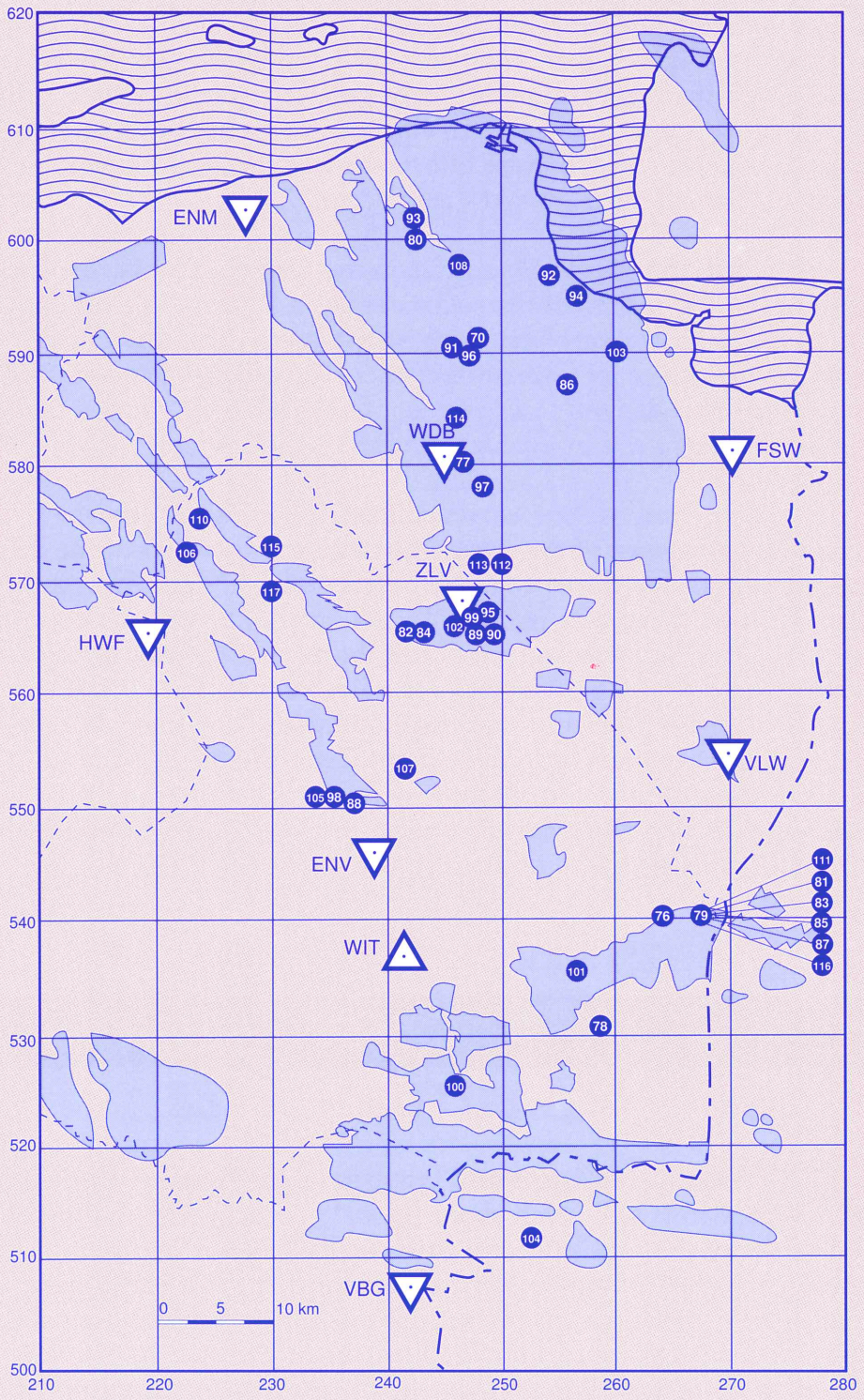


Figure 2. Earthquakes in 1996.

▽ *Borehole seismometer*
△ *Suface seismometer*
Gasfields
(12) *Earthquakes*

Code	Site	AMF-Y	AMF-X	Code	Site	AMF-Y	AMF-X
ENM	= Eenrum	602.79	227.79	VLW	= Vlagtwedde	554.84	269.90
FSW	= Finsterwolde	582.15	270.73	ENV	= Elp	545.96	238.85
WDB	= Woudbloem	580.98	245.00	WIT	= Witteveen	536.90	241.42
ZLV	= Zuidlaarderveen	568.11	246.53	VBG	= Venebrugge	507.05	241.93
HWF	= Haulerwijk	565.30	219.60				

Second, the depth of earthquakes is also significant. In all cases where it was possible to determine the depth of the hypocenter, the tremors were found to have occurred at depth of less than 4 kilometers. Given a certain magnitude, more shallow earthquakes have greater repercussions at ground level. On the other hand, the nearer an earthquake occurs to the surface, the smaller is the area over which these effects are noticeable. In general, close to the surface, only smaller earthquakes may occur.

Third, the effects depend upon the geological conditions, such as the thickness and the nature of the sediment layer, for example, under certain conditions, only slightly consolidated sediment layers can amplify the vibrations on the surface by resonance effects. The effects of the earthquakes in terms of damage also depend to a great degree on the construction methods for houses and buildings used in the area around the epicenter.

The notion of 'Intensity' is a description of the effects of earthquakes at the surface of the earth. Intensity is a measure of the degree to which people experience the earthquake or the extent of damage to buildings. Intensity is defined using a 12-point scale, denoted I-XII. Various definitions exist, in Europe the countries agreed to use the EMS (European Macroscopic Scale) from 1992 onward. Statistically, for a fixed depth there is a linear relation between magnitude and maximum intensity. The noise in this relation may be caused by variations in local geological conditions. For a given magnitude the maximum intensity may vary as much as one intensity unit. This means in turn that the same maximum intensity may be measured when the magnitude varies 0.5 units on the Richter scale.

Extension of the dataset will allow an improved analysis of gas-induced earthquakes

The estimated maximum intensity of earthquakes in the northern part of the Netherlands will reach about intensity VI. The distribution of the estimated values of the maximum magnitudes has been taken into consideration in determining the maximum intensity of an earthquake. Tremors of these intensities have repercussions for certain building structures. These consequences can be summarized by concluding that in the worst case, there is a small chance of slight damage in a limited area around the epicenter. The effects of intensity VI first became apparent in the area with an earthquake in the neighborhood of Roswinkel in the south of the province of Drenthe (Feb. 97). Above this level of intensity VI more serious structural damage to buildings is to be expected. Intensity VI corresponds to gas-induced quakes of roughly magnitude 3.5 (depth 3 km), as well as to tectonic quakes (depth 15 km) of roughly magnitude 4.5.

Instrumental approach to seismic detection · The instrumental approach to the detection problem was to design a network of seismometers to monitor the region of gas-induced earthquakes. The network focuses on the detection of small earthquakes. The use of borehole seismometers proved to be essential. The surface of the earth is constantly vibrating due to traffic and to industrial activity. In this respect, even wind and weather contribute to the continuous ground noise recorded by seismometers. This ground noise reduces the observation of small seismic signals and it may even hide the smallest signals altogether. With the initial network around Assen, it has been calculated that under favorable noise conditions any earthquake occurring within the network with a magnitude of 1.7 will only just be capable of being recorded by all instruments.

Seismometers placed in boreholes perform better, since the ground noise diminishes rapidly with depth. An experiment carried out with seismometers in a borehole in Finsterwolde demonstrated a reduction in noice by almost a factor of ten. Hence, the limit of detection is improved by a full unit of magnitude. Continuous recording of borehole seismometers near Finsterwolde, showed for the first time dozens of minor tremors in the Groninger field.

After the successful experiment at Finsterwolde, a network of eleven borehole seismometers was installed in the northern part of the Netherlands. The boreholes drilled for this network are 200m deep, have no casing and contain a minimum of 4 levels of 3 component low frequency geophones.

Up to present, the total network shows a detection threshold of magnitude 1.5 at the Richter Scale, although much smaller tremors have been detected close to some stations. In total, a dataset consisting of 120 tremors has been collected for the period 1986 till January 1997 by the gradually upgraded network. This dataset forms the basis of the statistical calculations, discussed above.

During 1996 five accelerometers were placed in the region at locations that experienced multiple events in the past. Until present four events near Roswinkel were recorded by one of the accelerometer stations, showing a maximum acceleration of 0.3g for the February 1997 event at a distance of 2 km from the epicenter. Extension of the dataset will allow an improved analysis of the relation between maximum intensity and magnitude of gas-induced earthquakes in the future.

This article is partly reproduced from the 'Summary of the final report on a multidisciplinary study of the relationship between Gas production and earthquakes in the northern part of the Netherlands'. It was updated to the situation of end 1996.

A Lagrangian view on the tropopause

by M.H.P. Ambaum

Lagrangian vs. Eulerian · In studies of the dynamics of continuous media like the atmosphere or the oceans we can discern two approaches. The first approach is called *Eulerian*. Here, variables (for example, temperature) are observed at fixed points in space, while the continuum sweeps by. The second approach is called *Lagrangian*. Here, particles of the continuum are followed through space, while their qualities (like, for example, their temperatures) change.

The first approach is ideally suited for implementation on a computer. A set of variables, which is chosen at fixed points in space (possibly spectral space), is evolved according to discretisations of the underlying partial differential equations. A numerical weather prediction model is a particular implementation of such an approach. The second approach seems to be more suited for the human mind. A spatial structure may be recognized and followed through space, while its qualities change continually. The frontal theory of the Bergen School is an important instance of such a Lagrangian approach.

Nowadays it seems as if the approach of the Bergen School is somewhat overruled by the huge computer power that is available to meteorologists. But there is a lot to say in favour of the Lagrangian viewpoint compared to the Eulerian viewpoint. First of all, the Lagrangian viewpoint appeals to our natural talent - unsurpassed by modern computer power - of pattern recognition. A human will never look at a weather map as a bunch of separate numbers; he will always try to find structures in it, and the nature of the atmospheric flow is such that he usually succeeds in this. Secondly, the way

in which the flow evolves fits often well in a Lagrangian approach; most of the behaviour of the atmosphere consists of the transport of air masses along with their respective qualities like, for example, their moist content or entropy.

Why not try to link the best of both worlds; Eulerian with Lagrangian, computer power with human power? This chapter is a result of the

A human will never look at a weather map as a bunch of separate numbers

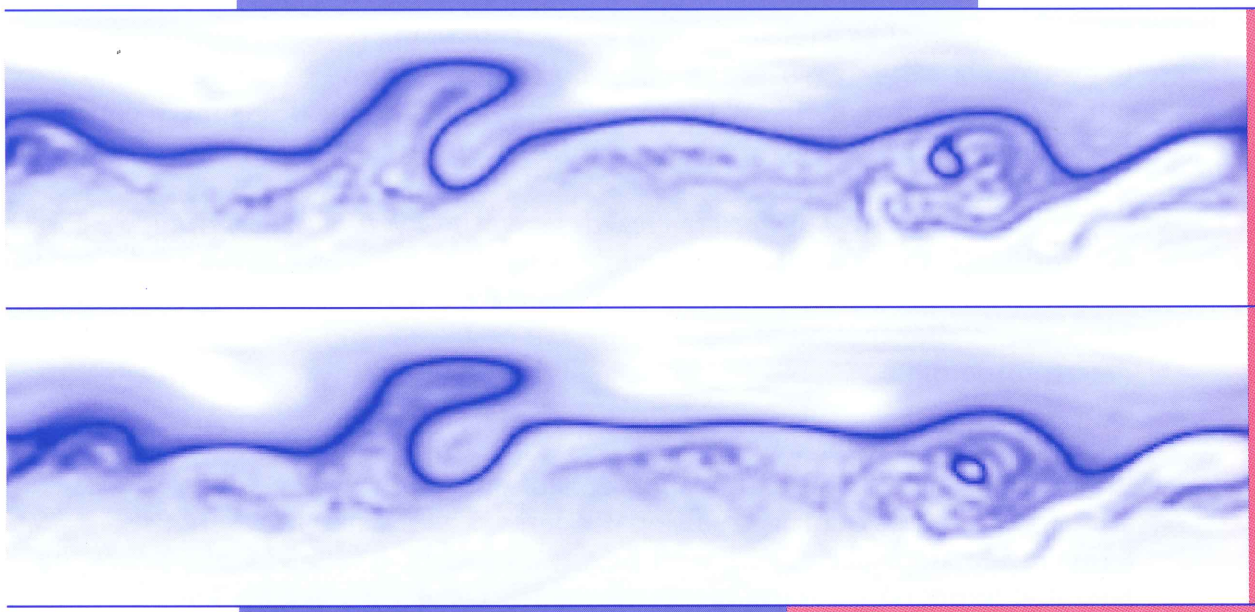
ongoing effort at the Predictability Research Division at KNMI to tackle this problem. In the next paragraph a physical framework in which the problem can be approached is introduced. Then several applications to our understanding of the tropopause are treated. The chapter concludes with an outlook to future research in this field.

A Lagrangian view on the atmosphere · In the study of the atmosphere we have some freedom of choice of coordinates and variables. For example, think of the choice between height or pressure as a vertical coordinate. If height is chosen as the vertical coordinate, pressure is a variable, and *vice versa*. There is a particular set of coordinates and variables that is ideally suited for a Lagrangian view on the atmosphere.

In this set the vertical coordinate is the potential temperature θ or, equivalently, the specific entropy. In the absence of heat-sources or sinks, so-called adiabatic conditions, the potential temperature of an air parcel does not change. This means that under adiabatic conditions an air parcel will have to move over surfaces of constant θ. In other words: if we choose θ as the vertical coordinate, all vertical velocities are the results of diabatic effects.

In our Langangian view on the atmosphere, the only variable is the potential vorticity PV. Under adiabatic conditions the PV of an air parcel does not change either. Both PV and θ are so-called *Lagrangian labels* they can be used to tag an air parcel and follow it through space.

The fact that PV is the *only* variable is a result of the so-called *invertibility principle.*[1] The principle states that *all* other meteorological variables can be deduced from the PV. It is the result of the mutual dependence of all meteorological variables through the action of balance (hydrostatic and geostrophic, or a more general balance) and the equation of state. The ultimate reduction of all dependencies leads to the definition of PV and the formulation of the invertibility principle. The invertibility principle is only valid under certain conditions. The most restricting condition is the assumed balance. As a



link worlds

result, the PV-θ viewpoint can be most successfully applied to extratropical large-scale motion.

In Figure 1 an example of the distribution of θ through the atmosphere is given. The iso-surfaces of θ, so-called *isentropic surfaces*, are largely horizontal as well as fixed in space. Due to the (almost) conservation of θ, air parcels will move over the quasi-horizontal isentropic surfaces, while (almost) conserving their PV. Our Lagrangian view on the atmosphere consists of the motion of PV-structures over isentropic surfaces.

The PV-θ system is closed: given the PV at a certain time, we can determine, by the invertibility principle, what the winds are. Given these winds, air parcels are blown over the isentropic surfaces, while conserving their PV. Thus the PV distribution at a later time can be found, and the procedure of determining the new wind field starts all over again.

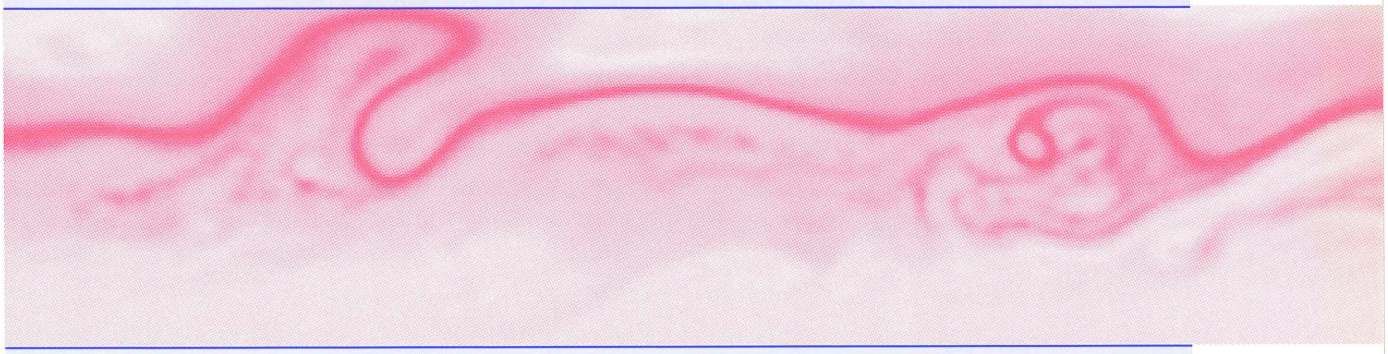
The isentropic tropopause · The tropopause, the boundig surface between troposphere and stratosphere, is of enormous importance to the atmosphere. Its position is traditionally defined as the height where the temperature stops decreasing with height. Similarly, it is the height where the potential temperature starts increasing much faster with height. The tropopause is a major factor in the chemical household of the atmosphere and it's height determines the structure of cut-off lows and blocking highs. What links all these different aspects of the tropopause?

The PV-θ view provides a unifying viewpoint

The PV-θ view provides the unifying viewpoint: the (extra-tropical) tropopause may as well be defined as an iso-surface of PV. This follows from the fact that the PV is proportional to the vertical gradient of the potential temperature, which is much larger in the stratosphere than in the troposphere. In Figure 1 it is illustrated that with this alternative definition the tropopause virtually coincides with the traditionally defined tropopause. With the PV definition the tropopause gains, besides its thermodynamic qualities (the vertical temperature structure), also a dynamic quality, due to the invertibility principle. It is the latter quality that helps us to understand the different aspects of the tropopause.

From Figure 1 it can be inferred that there are isentropic surfaces that cut the tropopause, that lie everywhere under the tropopause, or that lie everywhere above it. These three sets of isentropic surfaces define the *Middleworld*, the *Underworld*, and the *Overworld*, respectively. The Middleworld is the realm of stratosphere–troposphere exchange and the jet-stream. In the

Why not try to link the best of both worlds?



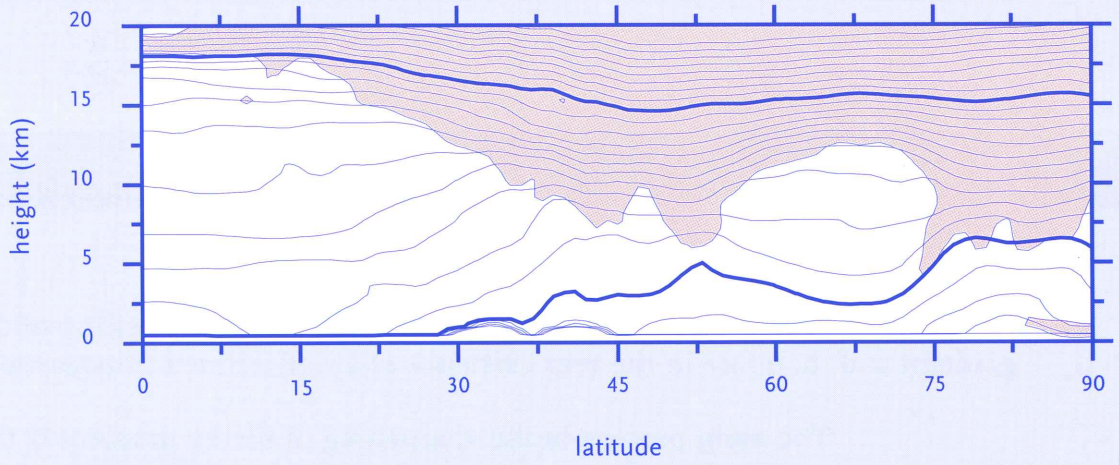


Figure 1. Potential temperature as a function of height along the Greenwich meridian at 0 UTC 15 February 1994. Isolines are plotted every 10 K. At the lower boundary between about 30° and 45° lat the highlands of Northern Africa and Spain are visible. Shaded regions correspond to PV values that are larger than 2 PVU (A potential vorticity unit, PVU, is defined as $10^{-6} m^2 s^{-1} K\ kg^{-1}$).

Note that this region also coincides with the region of large vertical gradients of potential temperature, the stratosphere. (See also figure 2). The thick isolines represent represent the boundaries between Underworld, Middleworld and Overworld.

Underworld the connection between the planetary boundary layer and the 'free' atmosphere is made. The Overworld is the realm of the ozone layer and the stratospheric circulation. In the following we will mainly concentrate on the Middleworld.

Because an isentropic surface of the Middleworld by definition cuts through the tropopause, the PV on such an isentrope will have low values, corresponding to where the surface lies in the troposphere, as well as high values, corresponding to where the surface lies in the stratosphere.

In Figure 2 a PV field on a Middleworld isentropic surface is depicted. Besides the rather fine-scale structure some important features are always present in a Middelworld PV field: the PV has high, stratospheric, values around the poles, and low, tropospheric, values around the tropical region. The transition between the two regions is remarkably sharp, and it is the signature of the tropopause in the PV-θ viewpoint - the isentropic tropopause. Its position largely coincides with that of the jet-stream.

The origin of the tropopause · One may wonder why there is an isentropic tropopause at all, that is, why the transition from high PV values to low PV values is so sharp (if this transition were not sharp, one would not identify the tropopause as a separate entity). The overall positive gradient of PV in the northward direction can be understood from the gradient in radiative forcing. This is equivalent to the traditional picture of a tropopause resulting from radiative equilibrium, but this cannot account for the observed sharpness of the isentropic tropopause. We have developed and tested the idea that the

One may wonder why there is an isentropic tropopause at all

inertial motion of the atmosphere plays a key role in the sharpening of the PV gradient and therefore in the very existence of a well-defined tropopause. [2)]

The main process in the sharpening of the PV gradient is that of vortex stripping, which, in fact, is the actual mechanism behind Reynold's Stresses associated with eddies. Essential is the (almost) conservation of PV combined with the (almost) non-divergence of isentropic winds. These two features combined lead to the conservation of area inside isolines of PV on isentropic surfaces. The mechanism of stripping can now be understood from purely geometric arguments: the polar vortex, which is forced by radiative processes, exhibits wave breaking events at its boundary. Smaller-scale events are associated with small depressions, large-scale events with cut-off lows or blocking anticyclones. These events transport the area between isolines of PV away from the boundary of the polar vortex toward the pole or equator. This

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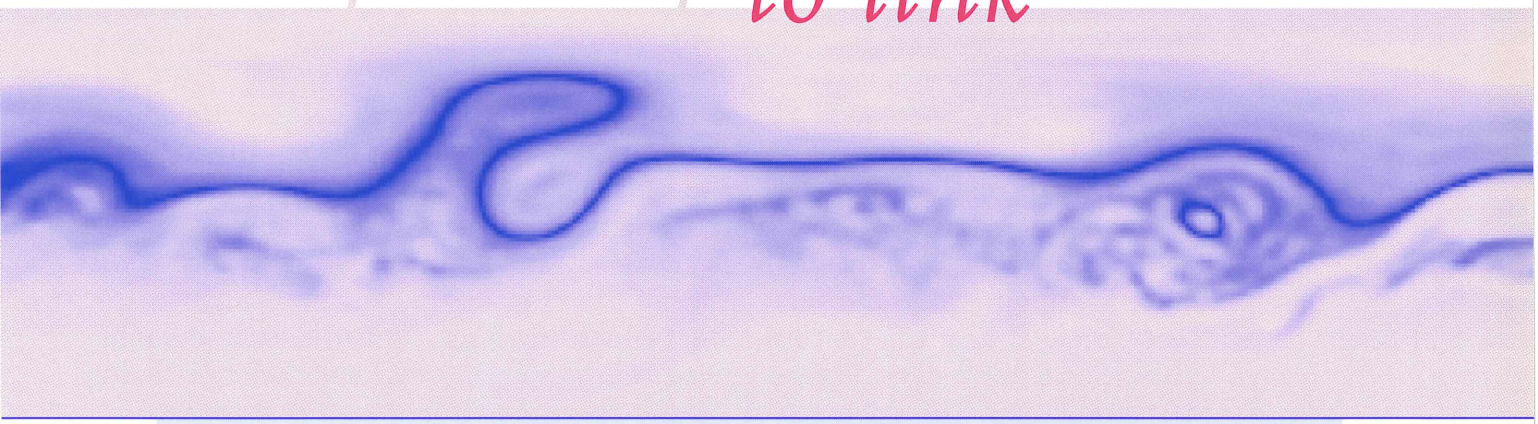

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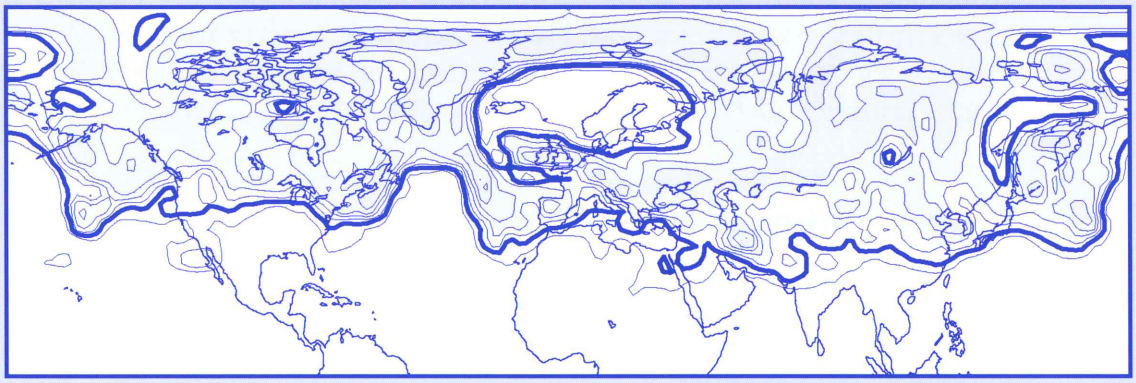


Figure 2. Potential vorticity on the 320K isentropic surface at 0 UTC 15 February 1994, in lat-lon projection for the Northern Hemisphere. Isolines are plotted every 1 PVU. Field produced by P. van Velthoven, using analysed data from the European Centre for Medium Range Weather Forecasts (ECMWF). The thick isoline corresponds to 2 PVU, and defines the isentropic tropopause.

both worlds?

means that during such an event the remaining area between the isolines at the polar vortex boundary must have diminished, so the isolines must have come closer to each other; in other words the gradient at the boundary of the polar vortex has increased. Thus a sharp tropopause has formed.

This image of a radiatively forced polar vortex, being stripped, has been illustrated in a simple one-layer model for the Middleworld. The model is similar to the early numerical weather prediction models. It is Eulerian and based on the equivalent barotropic vorticity equation, with orographic and radiative forcing. The orography is capable of inducing the required waves, that after breaking lead to the sharpening of the PV gradient. The model has been implemented as a T85 spectral model which was spun up and then integrated forward for 1000 days. Figure 3 gives an example of a PV field obtained during the simulation. The existence of a sharp isentropic tropopause is clear even though this was not forced *a priori*. This is possibly the simplest model context in which an isentropic tropopause is formed.

Thus far we have only concentrated on isentropic surfaces that spanned the whole globe, but what happens on isentropic surfaces that cut the Earth's surface? Such an isentropic surface will in fact intersect the planetary boundary layer, which has a low stratification. With this low stratification a low PV is associated. Turbulent exchange between the planetary boundary layer and the isentropic surface, which cuts it, leads to a strong PV sink for the isentropic surface. It may well be that this PV sink prevents the PV from obtaing high (that is, stratospheric) values on such isentropic surfaces. Apparently, isentropic surfaces which cut the Earth's surface generally will not cut the tropopause, so are part of the Underworld. Indeed, it has been confirmed many times by observations, that the lowest isentropic surface that cuts the tropopause, grazes the Earth's surface near the equator. Incidentally, Figure 1 is an example which shows that this is not always exactly the case.

Contour dynamics · The typical PV structure of a Middleworld isentropic surface, as observed in Figure 2, restricts its possible behaviour enormously. As we have seen, the motions in the atmosphere are mainly dominated by the advection of PV over isentropic surfaces. With the advection of the low PV air in the tropospheric part of the Middleworld isentropic surface not much can happen; it is as if you would mix white paint with white paint. The same is true for the uniformly high PV values of the stratospheric part of the isentropic surface; as if you would mix red paint with red paint. The interesting behaviour occurs at the interface of the two regions, the isentropic tropopause. Here the red paint of the stratosphere meets the white paint of the troposphere. Advection leads to the displacement of the interface (mixing at the interface is a result of the cascade of the interfacial structure to small scales.)

The Middleworld dynamics can now be reduced to the motion of the interface. The stratosphere is represented by a constant high PV, the

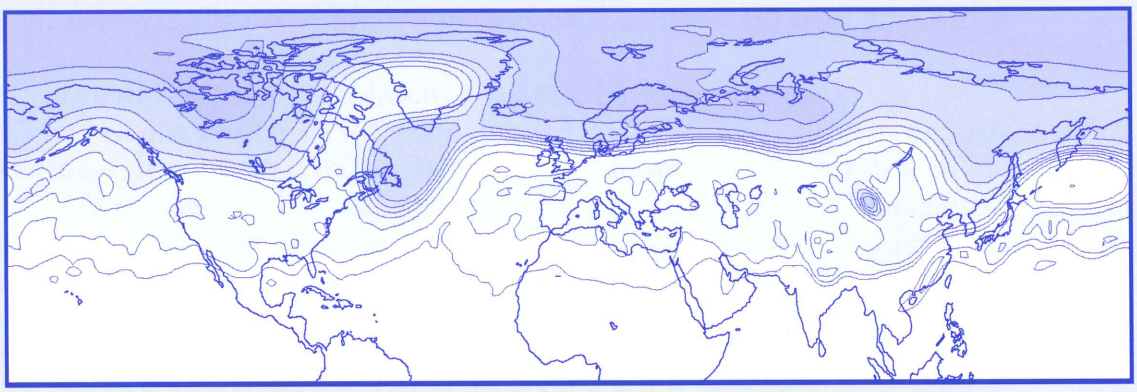


Figure 3. An example of the PV field in a one-layer simulation of the Middleworld.

troposphere with a constant low PV. The transition between the two, the isentropic tropopause, is represented by a single contour of PV. [3]

As the position of this contour fully describes the Middleworld PV structure, we can use the invertibility principle to deduce the isentropic wind field. Given this wind field we can displace the contour accordingly. It can be shown that for quasi geostrophic dynamics, the wind field can be expressed as an integral over the contour. This type of dynamics is called *contour dynamics.*

An advantage of contour dynamics is that it resolves very small structures in the PV field. These filamentary PV structures are not an artifact of the model; they have been observed directly by aircraft measurements of stratospheric chemicals and play an essential role in the process of stratosphere-troposphere exchange. Furthermore the PV field is represented in an optimal way. Eulerian models of moderate resolution cannot resolve the observed sharpness of the isentropic tropopause and the eddies needed to generate such a sharp structure (see previous section). The contour dynamics technique circumvents this problem by explicitly resolving the sharp isentropic tropopause and the small scales in its structure.

With the contour dynamics model for the isentropic tropopause many interesting features of the atmosphere have been studied and reproduced. Explicit results are resonances of orographically forced planetary waves [4], multiple equilibria, or the influence of stationary waves on the dynamics of the atmosphere. We have also found that the area inside the isentropic tropopause on the Middleworld isentropic surface is an important parameter in the model. Is this also true for the real atmosphere? A full account of these studies are described in the thesis of the author. [5]

Just to give an idea of the ensuing complexity of the contour dynamics model, we present Figure 4, where a typical evolution of the model is shown. Though the contour seems to be limiting the PV field substantially, its behaviour is as rich and as complex as that of the true isentropic tropopause.

Future work · The PV-θ view has proven its power in the study of the atmosphere and the tropopause in particular. It has also given rise to new questions about the atmosphere. Also questions concerning the climate of the atmosphere have risen. What parameters will change in our PV-θ view on changing climatic forcing? How do these changing parameters influence the behaviour of the atmosphere? What is the climatology of isentropic PV fields? What is the influence of the Underworld and the Overworld on the Middleworld dynamics? These are all questions that we have just begun to ask, and which may well prove to fundamentally change our view on the atmosphere and its climate.

In the studies done at KNMI, not only the conceptual approach to atmospheric dynamics is changing, also the modelling approach is changing.

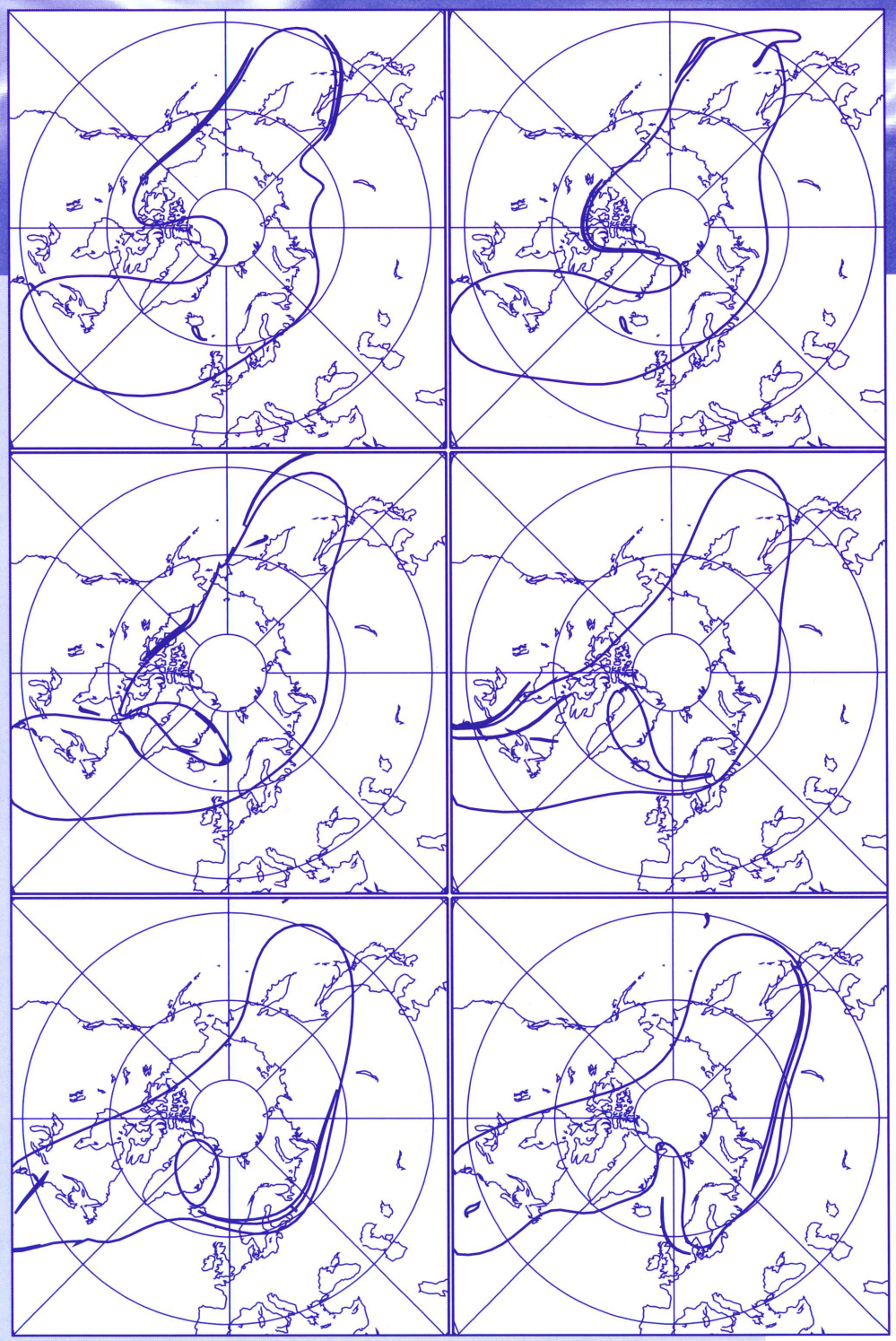


Figure 4. Example of a time evolution of the contour dynamics model of the tropopause. The contour is plotted in polar-stereographic projection for model days 106 to 111. An anticyclone intrudes into the polar vortex above Greenland and is later caught in the jet stream north of Scandinavia.

Presently, work is in progress on the further development of a new algorithm for PV dynamics, which combines the advantages of Lagrangian schemes (the advective character of contour dynamics) with those of Eulerian schemes (fast inversion techniques of spectral models.) This synthesis of techniques has already been implemented for a multi-layer quasi geostrophic model. [6]

Here an enormous leap in computational efficiency has been obtained both compared to standard Eulerian schemes as well as compared to contour dynamics. Present research is directed toward the inclusion of diabatic effects in the model and its use as a chemical transport model.

The PV-θ view has given rise to new questions about the atmosphere

And what about the synthesis of our human talent of pattern recognition with the number crunching power of modern computers? A first step is getting used to looking at PV structures in the atmosphere and trying to interpret their meaning. To this goal daily maps of isentropic PV are produced and studied at the Predictability Research Division. Already some cases have been found in which the PV approach has led to a much sharper view on certain atmospheric events. Possible implications for data assimilation are discussed. Furthermore, theory has to be developed to understand the importance of surface PV structures. The latter are strongly related to surface temperature structures. If successful, this quest will close in again on the frontal theory of the Bergen School.

1) An overview on PV dynamics and many references can be found in: Hoskins, B. J., M. E. McIntyre, and A. W. Robertson, 1985. *On the use and significance of isentropic potential vorticity maps.* Quart. J. Roy. Meteor. Soc., **III**, 877 - 946.

2) Ambaum, M.H.P., 1997. *Isentropic formation of the tropopause.* J. Atmos. Sci., **54**, 555 - 568.

3) Verkley, W.T.M., 1994. *Tropopause dynamics and planetary waves.* J. Atmos. Sci., **51**, 509 - 529.

4) Ambaum, M.H.P., and W. T. M. Verkley, 1995. *Orography in a contour dynamics model of large-scale atmospheric flow.* J. Atmos.Sci., **52**, 2643 - 2662.

5) Ambaum, M.H.P., 1997. *Large-scale dynamics of the tropopause.* Ph.D. thesis, Eindhoven University of Technology, ISBN 90-386-0249-9, 128 pp.

6) Dritschel, D. G., and M. H. P. Ambaum, 1997. *A contour-advective semi-Lagrangian numerical algorithm for simulating fine-scale conservative dynamical fields.* Quart. J. Roy. Meteor. Soc., **123**, 1097 - 1130.

Tropospheric Energy Budget Experiment (TEBEX)

by A.C.A.P. van Lammeren, W.A.A. Monna and A.P. van Ulden

Introduction · The tropospheric energy budget is determined both by radiative transfer of energy and by transfer of energy and water due to air motions and precipitation. These transport processes are highly variable in time and space, mainly due to the presence of clouds, to variability in landsurface properties and to small scale turbulence and convection.

In numerical weather and climate models these small scale processes are represented by area averaged vertical fluxes, which are parameterised in terms of large scale variables. Large scale energy budgets are then described by the vertical divergence of these vertical fluxes, and by the advection by the large scale flow.

For an adequate diagnosis of the tropospheric energy budget, data are needed both on the large scale flow properties and on small scale processes. Such data are scarce. Available global data sets suffer from a lack of detail, whereas experimental data with sufficient datail are generally only available for specific sites and short observation periods.

Aims of TEBEX · In the design of the Tropospheric Energy Budget EXperiment (TEBEX) a compromise was sought between space and time resolution and space and time coverage, thus filling a gap between global and local data sets. In this respect TEBEX resembles the regional scale experiments of GEBEX, be it with a more pronounced focus on the smaller mesoscale. TEBEX comprises 10 observation sites in an area of about 100 x 100 km^2 in the Netherlands (Figure 1) and a state of the art retrieval system for meteorological satellite data.

Specific goals of TEBEX are:

- To provide 2 years of observations of cloud characteristics, profiles of mean atmospheric parameters and surface fluxes.
- To validate satellite retrieval methods for cloud characteristics.
- To develop and test a prototype of an automatic cloud observation system.
- To validate and improve physical parameterizations of clouds, cloud-radiation interaction and energy fluxes for global climate models.
- To validate and improve regional weather and climate models.

Observations · The observations of TEBEX started in the autumn of 1994 and were concluded on the last day of 1996. The experiment was conducted by KNMI in co-operation with the Royal Air Force, the National Institute of Public Health and the Environment (RIVM), the Agricultural University Wageningen (AUW) and the University of Amsterdam (UA). The experiment was supported by the National Research Program for Global Air Polution and Climate. In view of future operational applicability - e.g. in GCOS - it was decided to employ in TEBEX primarily commercially available instrumentation.

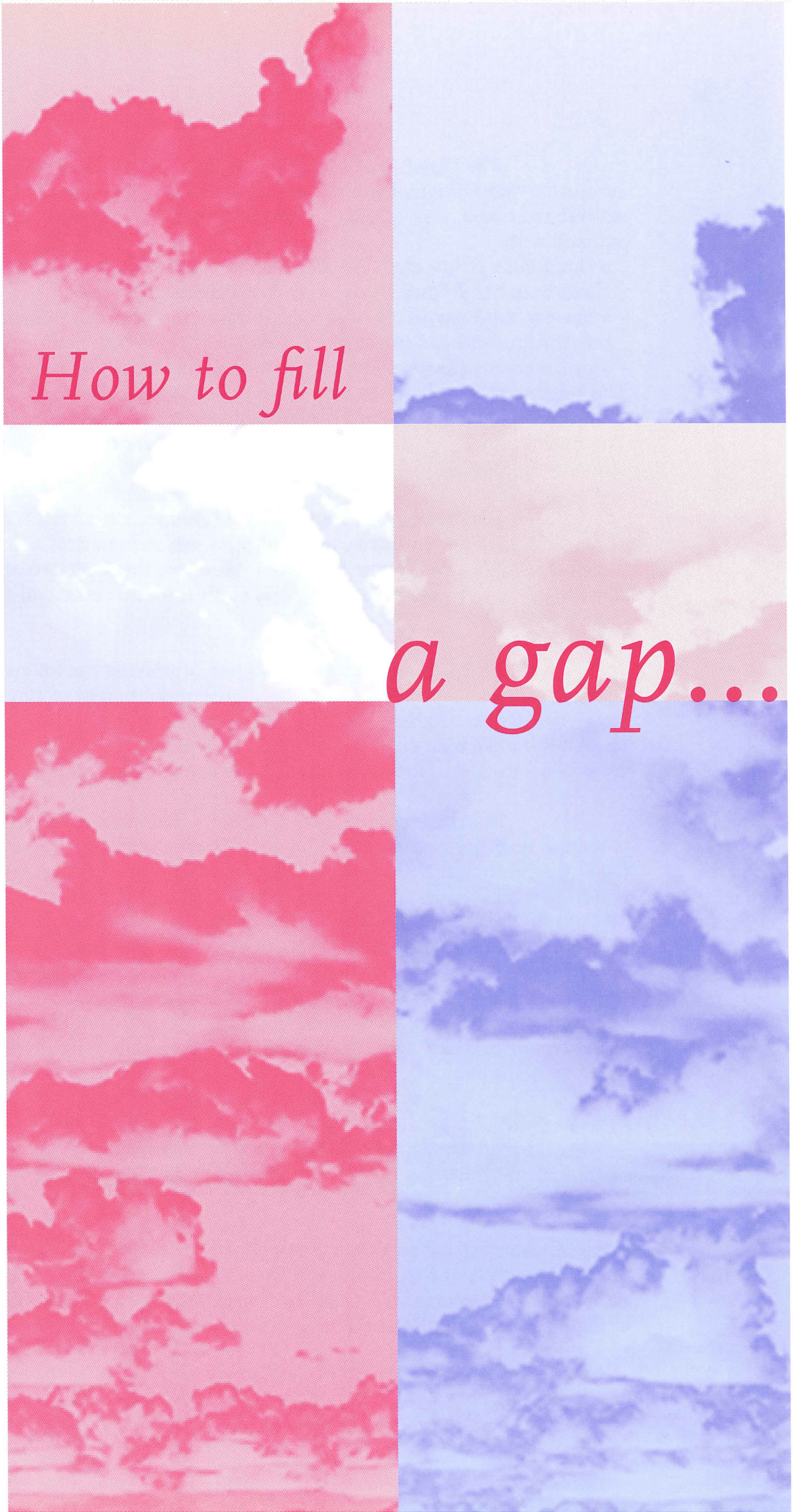
The TEBEX observations include:

- A ground based cloud observing network.
- Cloud observations from satellites.
- A main observing site at Cabauw with a 200 m meteorological mast.
- A secondary observing site in a forest near Garderen equiped with a 36 m mast.
- Operational weather observations from synoptic stations in the TEBEX area.

An overview of the TEBEX instrumentation is given in Table 1.

Table 1. Overview of the TEBEX instrumentation

Instrument	Location	Remarks
Cloud lidar	Network	Wavelength 911 nm, max. range 4 km
	Cabauw	Wavelength 911 nm, max. range 7 km
IR-radiometer	Network	Spectral range 9.6 - 11.5 µm
Pyranometer	Network	Spectral range 0.3 - 4 µm
Meteorological tower	Cabauw	Vertical profiles of temperature, humidity, wind and visibility up to 200 m
	Garderen	Vertical profiles of temperature, humidity and wind up to 36 m
Windprofiler / RASS	Cabauw	1290 Mhz profiler
Sonic and IFM	Cabauw Garderen	Measurement of turbulent fluxes of heat, moisture, CO_2 and momentum
Shortwave and longwave radiometres	Cabauw Garderen	Measurement of the components of the radiation budget (shortwave and longwave) and netto radiation
Heat flux plates	Cabauw	Measurement of the ground heat flux
Pressure sensors	Cabauw	Measurement of the water table depth
Thermometer needles	Cabauw	Measurement of the soil temperatures at different depths
NOAA / AVHRR	Netherlands	5 spectral channels; 2-4 times a day
Meteosat	N-W Europe	3 spectral channels; every half hour


How to fill
a gap...

The Cloud Detection System (CDS) · The Cloud Detection System comprises observations from the ground and from satellites. The ground bases *network* consisted of 10 stations in the Netherlands (Figure 1). Each station was equiped with:

- a cloud lidar ceilometer (Vaisala) measuring overhead presence of clouds, cloud base height and some other cloud characteristics.
- a narrow band narrow field of view infrared radiometer (Heimann) measuring overhead presence of clouds and cloud base temperature.
- a pyranometer (Kipp) measuring incoming shortwave radiation.

The satellite system handles data from NOAA-AVHRR and from Meteosat. *NOAA* data are analysed using a modified version of the APOLLO scheme.[1] This scheme provides the following data: cloud cover fraction, cloud top temperature and reflectivity optical depth.

For *Meteosat* a cloud retrieval scheme called MetClock [2] was developed in house. In this scheme output from a numerical weather forecast model is used for optimizing threshold values for the detection of clouds. This scheme yields the following data: cloud cover fraction and cloud top temperature.

The data sources are combined to provide the following local characteristics: cloud cover, cloud size distribution, height of cloud base, temperature of cloud base and cloud top, reflectivity and optical thickness. In addition ensemble characteristics are determined for the whole observation area: cloud fraction, cloud structure and effective optical depth.

The main observing site Cabauw · The main observing site Cabauw is located near the center of the cloud observation network (Figure 1), in a very flat agricultural area.[3] Observations include profiles of temperature, humidity, wind and visibility. In addition profiles of wind and virtual temperature were measured with a Wind Profiler - RASS system up to heights of several kilometers. An acoustic sounder was used for the detection of inversion layers up to 500 m.

Extensive observations of the components of the surface energy budget were performed on a field close to the mast. Turbulent fluxes of heat, water vapour and CO_2 were measured with a sonic anemometer and an

Data sources are combined to provide local characteristics

infrared water vapour sensor at a height of 5 m. The soil heat flux was measured with heat flux plates. The incoming and outgoing shortwave radiation was measured with standard instruments. Moreover the components of the longwave radiation and the surface radiation temperature were

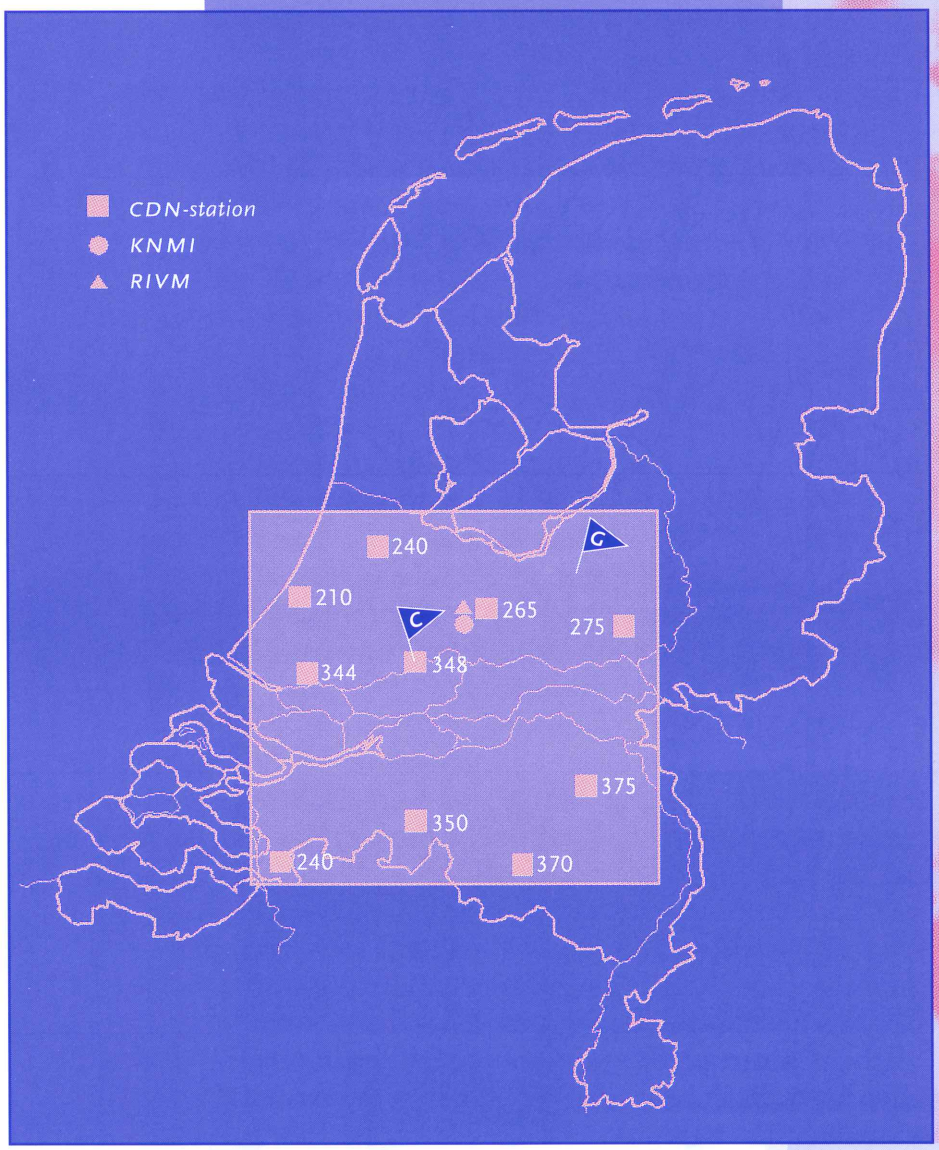


Figure 1. Cloud Detection Network (CDN)
C: Main observing site Cabauw, G: Observing site Garderen

a gap...

measured. Finally the soil temperature profile, the precipitation and the water table depth were monitored.

In 1996 additional measurements were implemented. Some were intended to be used for the verification of the quality of the original program. Moreover, the program was extended with measurements by the AUW of profiles of turbulence characteristics along the mast with K-vanes, and with measurements of the water temperature in ditches.

As an addition to the standard instruments of the CDS ground station at Cabauw a video-camera for time-lapse images of the sky was installed.

The observing site Garderen · The observing site near Garderen was located in a Douglas fir stand of 2.5 ha on sandy soil. The average tree height was 22 m. The stand is surrounded by stands of other tree species. On a 36 m mast vertical profiles of temperature, humidity, CO_2 and wind were measured at several levels within the canopy and above the tree tops. The turbulent fluxes of heat, water vapour and the components of the radiation were measured above the tree tops with similar instruments as at Cabauw. Soil moisture and precipitation were also monitored.

Synoptic weather observations · The weather observations of the eight synoptic stations situated in the TEBEX area were archived. The data from the four radiosondes that are launched daily on a routine basis at De Bilt were added to the database.

Data analysis tools · The TEBEX analysis tools include:

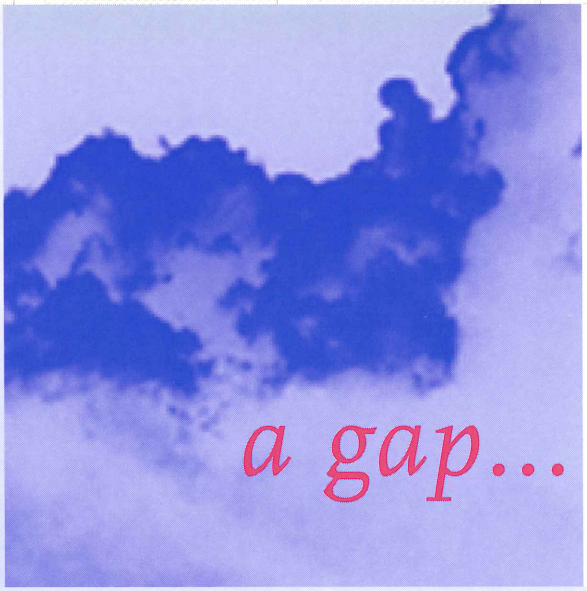
- Two regional models with a horizontal resolution of 50 km:
  - The HIRLAM operational weather forecast model;
  - RACMO, a Regional Atmospheric Climate Model which has the dynamics of HIRLAM and the physical parameterizations of the MPI-Hamburg global climate model (ACHAM).
- A Large Eddy Simulation Model for the analysis of boundary layer processes and non-precipitating clouds.
- Various dedicated radiation codes for the analysis of radiative transfer and for the interpretation of remote sensing data.

Prelimenary results of TEBEX · As examples of the first results of TEBEX preliminary case studies on cloud characteristics and on the energy balance are presented below.

Cloud size distribution · The lidar ceilometers provided continuous measurements of the overhead presence of clouds. With the advection speed of the clouds, the cloud size distribution can then be estimated.

An example, giving the distribution for a period of nine hours, is shown in Figure 2. The measurements were taken at Cabauw during a day with Cumulus clouds. The vertical axis represents the fraction of time that a cloud

How to fill a gap...



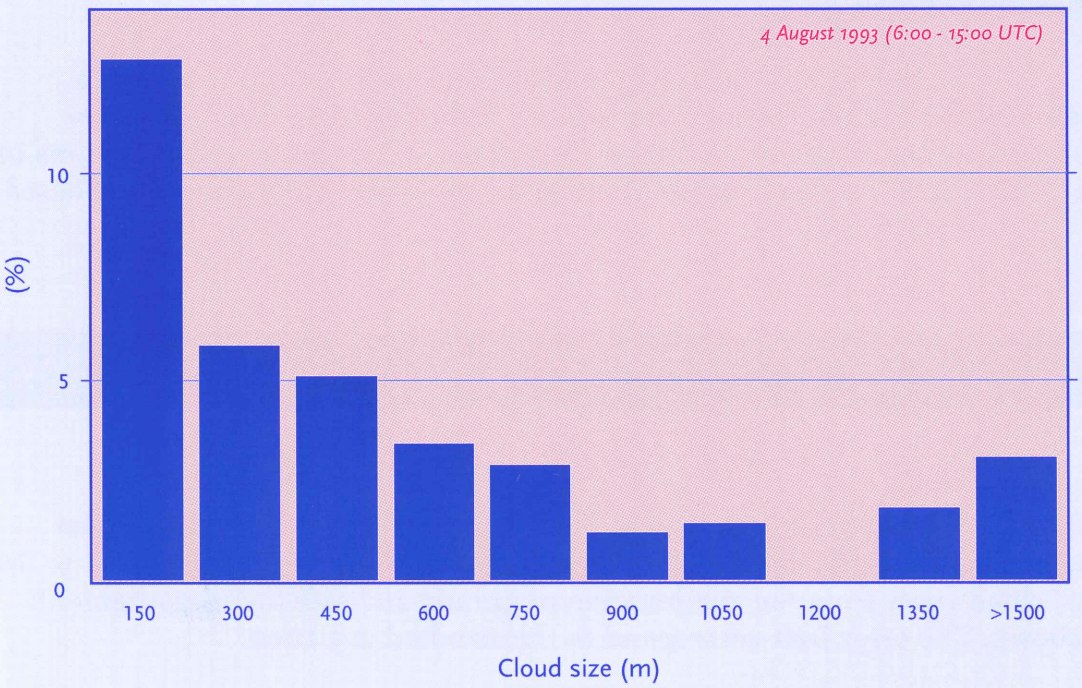
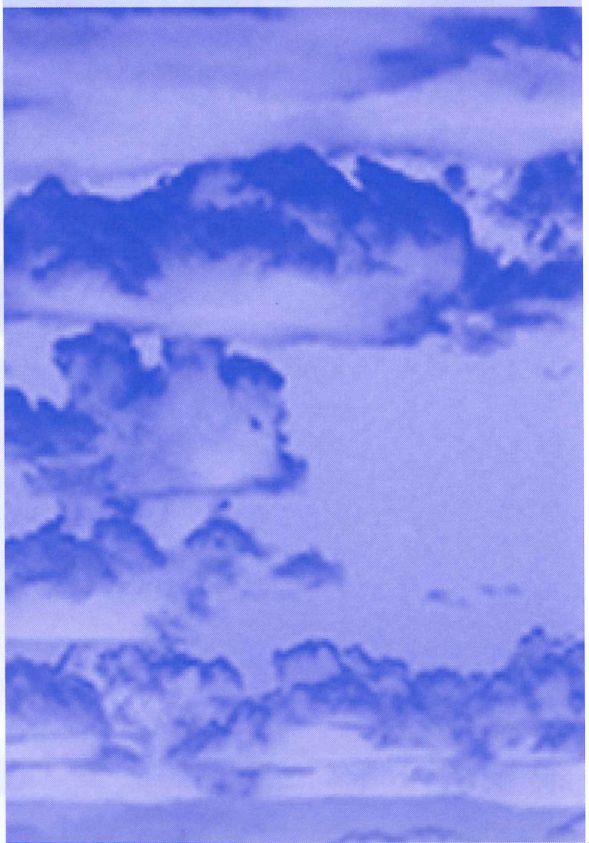


Figure 2. Horizontal cloud size distribution as measured at Cabauw with cloud lidar.



of a particular size is observed. The time averaged cloud cover for this time period is 37%.

Area averaged cloud cover · One of the primary products of the CDS is the area averaged cloud cover. Satellite retrieval algorithms have difficulties with the detection of broken clouds and optical thin clouds. Ground based measurements of high (semi-transparant) clouds are also difficult. Moreover, in the case of more than one cloud layer, only one layer is observed from the satellite or ground. So, integration of ground based and satellite observations is expected to improve the results. This is illustrated in the following example.

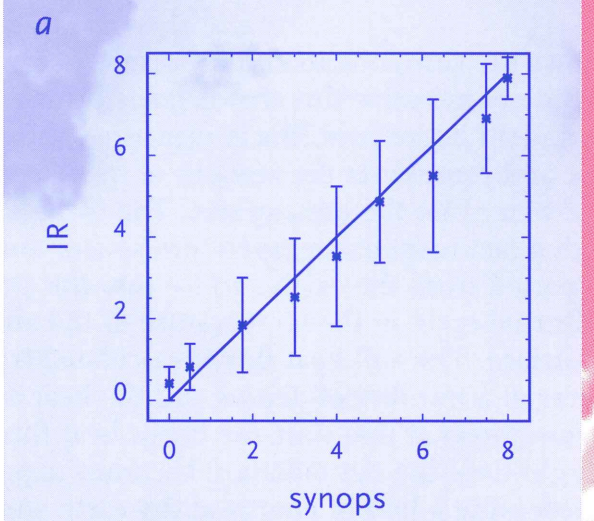
In Figure 3 the averaged total cloud cover for the TEBEX area, derived with the CDS, is shown for January/February 1995. The results are compared to the visual cloud cover observations at the eight weather stations in the TEBEX area. In Figure 3a the cloud cover as derived from the ground based

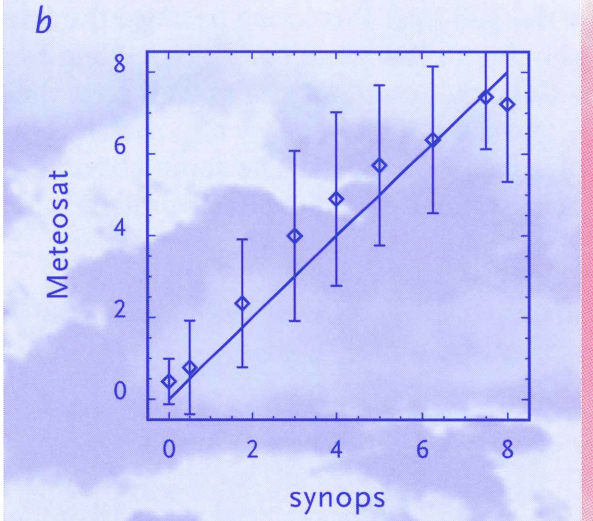
Integration of ground based and satellite observations improves results

infrared radiometers only is shown. The cloud cover derived from Meteosat imagery only with the MetClock scheme is shown in Figure 3b. In Figure 3c the total cloud cover from the combination of ground and satellite measurements is shown. The error bars correspond to the standard deviation.

The advantage of combining ground and satellite observations is clear. The standard deviation for the area averaged cloud cover decreases to about 1 octa when ground and satellite observations are combined. Also the average values agree very well to the synoptical observations.

Surface Energy budget · Figure 4 shows the components of the surface radiation budget at the earth surface for a cloudless day, the 18th of August 1996, at the Cabauw grassland site. Short wave downward and short wave upward radiation are measured with pyranometers. Longwave downward and long wave upward radiation are measured with pyrgeometers. Appropriate corrections are performed for temperature differences between domes and house. Fluxes toward the earth surface are positive, fluxes away from the surface are counted negative. It is observed that approximately 20% of the incoming solar radiation is reflected by the surface. The thermal longwave radiation emitted by the earth surface is larger than the corresponding radiation received by the earth surface from the atmosphere. The net radiation is calculated from the four observed radiation components. This represents the radiation energy that is lost at the earth surface.





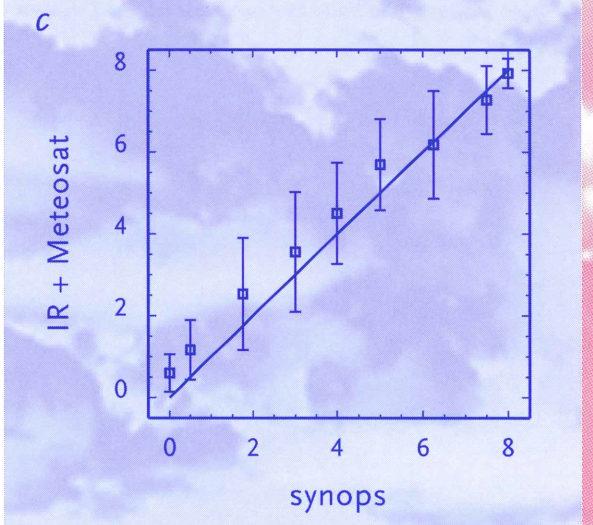


Figure 3. The averaged total cloud cover for the TEBEX *area as measured by Infrared Radiometers (IR), Meteosat and MetClock (Meteosat) and visual observations from 8 weather stations (Synops). The error bars indicate the standard deviation.*

How to fill a gap...

Figure 5 shows the components of the surface energy budget. The net radiation represents the net radiative flux that is transformed into heat at the earth surface. The turbulent latent heat flux is measured with a fast response humidity sensor and represents the amount of heat used at the earth surface for evaporation of water into the atmosphere. The turbulent sensible heat flux is measured with a fast response temperature sensor and represents the amount of heat transported from the earth surface into the atmosphere. This flux gives rise to a diurnal cycle in the temperature of the atmospheric layers close to the earth surface. The soil heat flux is calculated from the rate of change of soil temperatures at a number of depths and the heat capacity of the soil. Due to the dry soil conditions at that time the latent heat flux is lower than normal for this site. At night time the net radiation becomes negative due to clear sky conditions, representing a loss of energy at the earth surface. This energy loss is supplied by the soil heat flux alone because the latent and sensible heat fluxes vanishe due to low wind conditions. Long time series of this measurements at the Cabauw grassland site as well as at the forest site Garderen will provide the lower boundary energy and moisture flux conditions for studies of clouds in atmospheric models. The same observations will be used to validate landsurface schemes of atmospheric models.

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2) Veen, S.H. van der and A.J. Feijt. *Cloud characterization for short range cloud prediction model.* In: Proceedings of the Meteosat Data User's Meeting. Vienna, September 1996, 257 - 264. Darmstadt, Eumetsat.

3) Van Ulden, A.P., and J. Wieringa, 1996. *Atmospheric boundary layer research at Cabauw.* Boundary-Layer Meteorology, **78**, 39 - 69.

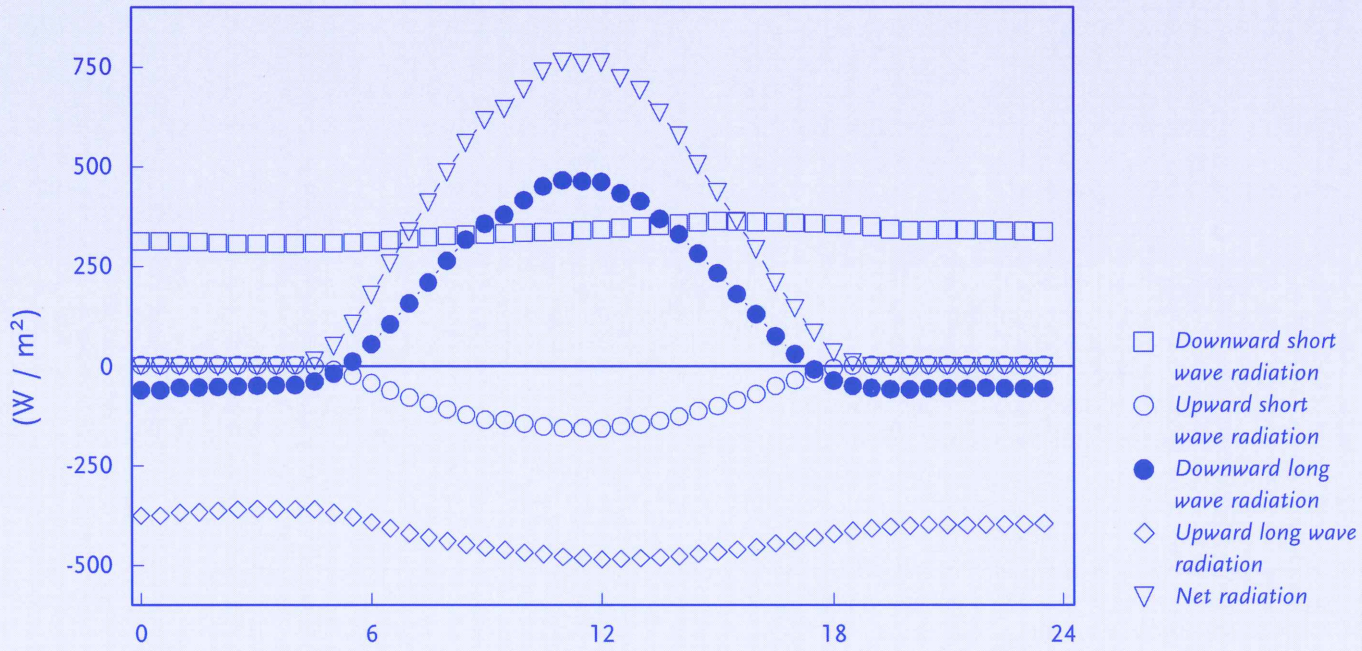

Figure 4. Surface radiation budget for a cloudless day

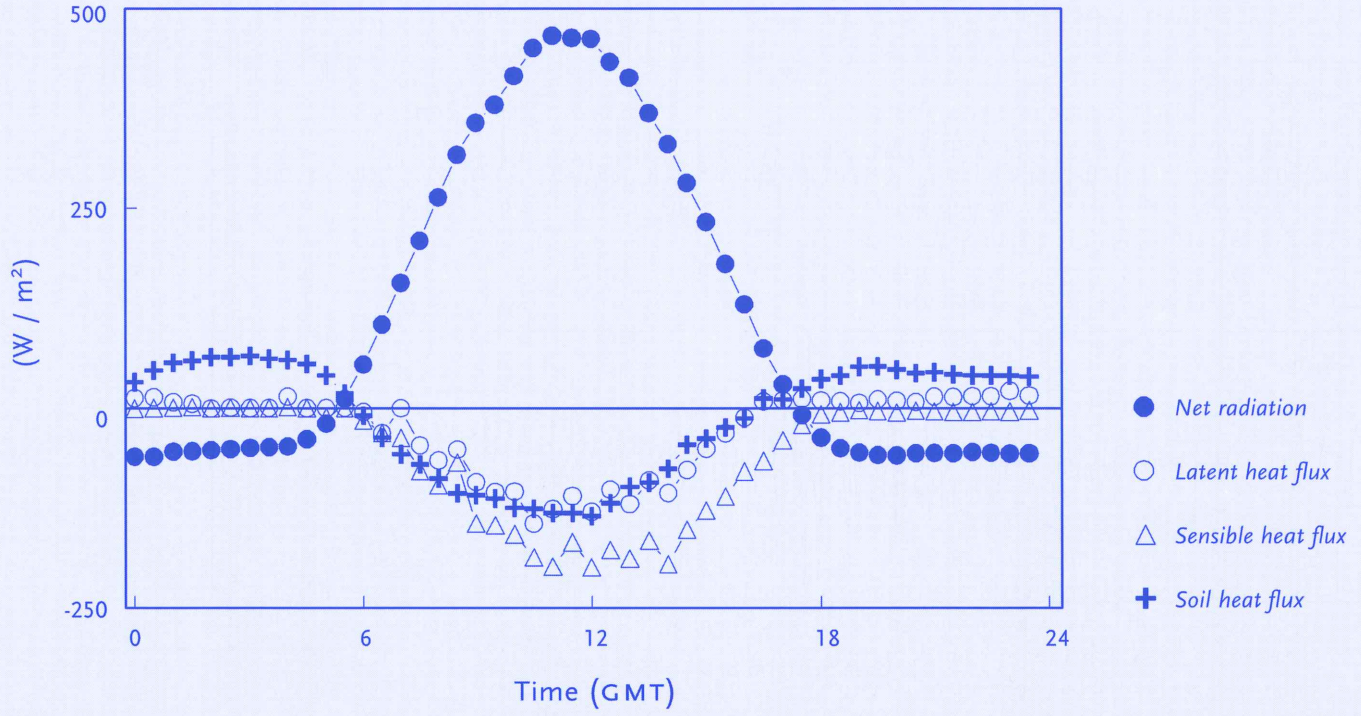

Figure 5. Surface energy budget for a cloudless day (Cabauw, 18 August 1996)

Current projects

Predictability Research Division

General · The Predictability Division of the Department of Climate and Seismology 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.

The research of the section can be summarized in three themes.

1 Skill prediction and ensemble forecasting
2 Predictability and natural variability of climate
3 Dynamics of weather and climate

International co-operation · The division is involved in several international projects funded by the European Community. The first one is called DICE. It will finish in 1997. Two new projects have been initiated, SINTEX and MILLENNIA II. In both projects the intention is to study aspects of the natural variability of climate on decadal to centennial time scales. We will concentrate on the variability that is associated with the North-Atlantic ocean. A new joint project with ECMWF was started. We will develop an ensemble prediction system (EPS) for the short and early medium range using the Centers model. We will concentrate on predicting the uncertainties in important but quite sensitive weather parameters, like rainfall and sunshine, for the Western-European area.

National co-operation · Co-operation with the Oceanographic Division of the research department has intensified. We will jointly develop a new climate model by coupling the Large Scale Geostrophic (LSG) model of MPI to the Quasi-Geostrophic atmospheric model that was developed in the Predictability Research Division. This model is the next generation of our current climate model ECBILT). A joint project on fundamental properties of simple climate models with the mathematical department of Utrecht University, funded by the Netherlands Organization for Scientific Research (NWO), was started. Two PhD students are involved in this project which is called 'A conceptual approach to climate variability'. Another project called 'Patterns of low-frequency climate variability: a model-paleodata comparison' is a collaboration with prof. H. Hooghiemstra (University of Amsterdam), who is an expert on climate reconstructions based on paleo proxy data. In this project a Postdoc is involved for a period of three years. The project is an attempt to contribute to the reconstruction of climate variability on decadal time scales during the last 2000 years by interpreting existing paleo data sets. National co-operation within the context of the Centre for Climate Research (CKO) has been marginal, although some promising new initiatives have been taken. We are presently developing a Dutch CLVAR progamme in co-operation with the meteorological and oceanographical department (IMAU) of Utrecht University.

Skill prediction and ensemble forecasting

Mureau, Hersbach, Oortwijn, Opsteegh

The KNMI ensemble prediction system gives alternative scenarios for upper air flow regimes (Fig. 1). These scenarios are generated through a Singular Vector calculation with a three layer T42 Quasi-Geostrophic model, and its adjoint version. The Singular Vectors represent fastest growing perturbations in a given time interval and their eigenvalues correspond to their respective growth rates, both of which provide the necessary ingredients to calculate the probabilities of alternative scenarios of flow patterns. The system focuses on the European area and is optimized for a forecast period of 2-4 days. All calculations are done under the linear assumption, the system should therefore be described as linear, short range, probabilistic forecasting system. The system has shown very promising skill, in the sense that the verification frequency of the alternative scenarios show good agreement with the predicted probability. However the inherent inability of the model to provide information on synoptic parameters is considered a major shortcoming. In 1996 the section has started experimenting with a more advanced model. Firstly, the same calculations as described above were repeated with a 19-level T42 Primitive Equation model (the ECMWF T42 IFS). This was done in order to derive the necessary synoptic information, lacking in the older system. It was demonstrated that the forecast error could be reproduced almost entirely by the

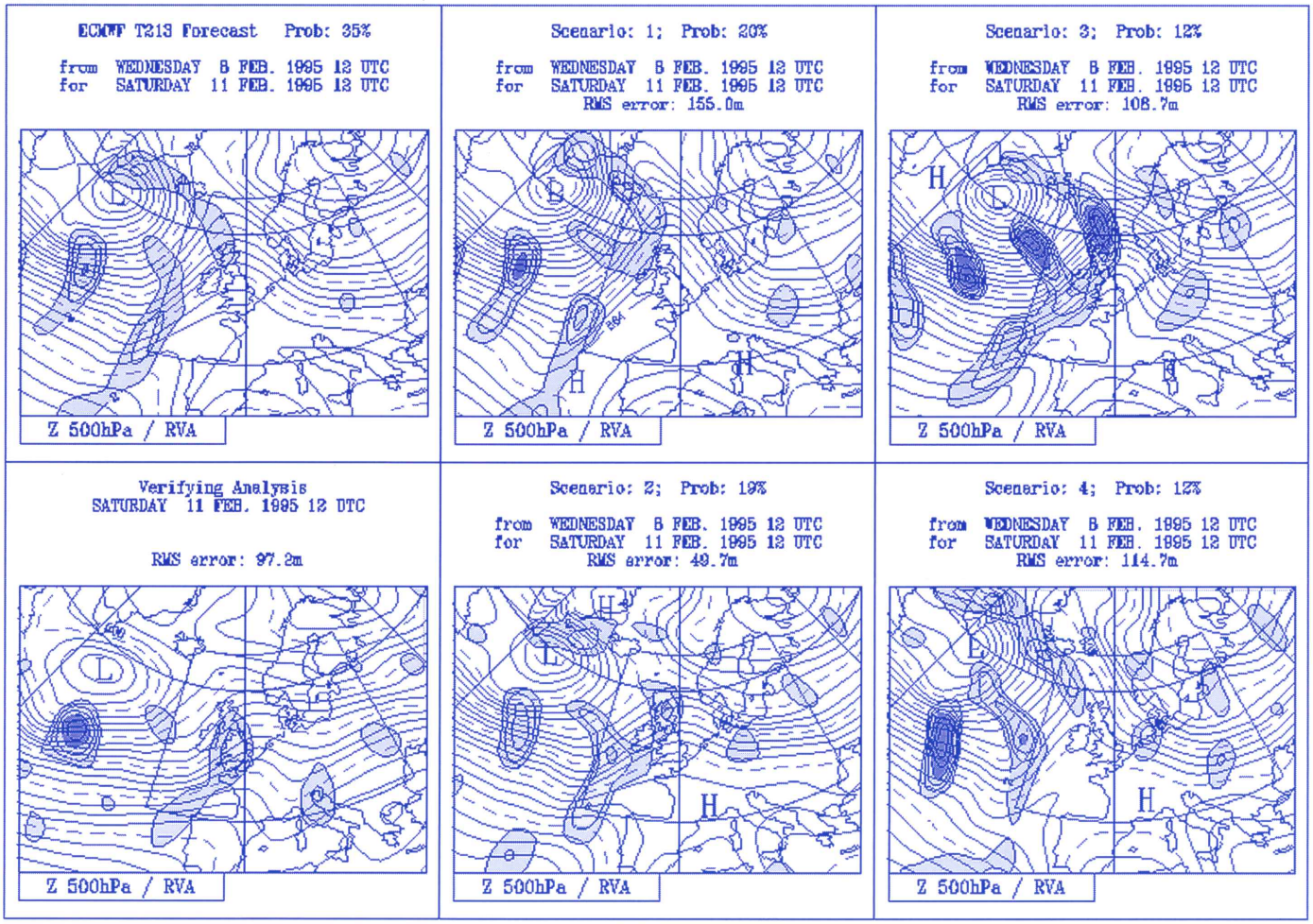

Figure 1. An example of skill prediction. Top left: the operational T+72 ECMWF 500hPA forcast. Bottom left: the verifying analysis (11 February 1997). Next 4 panels: 4 alternative scenarios. Each forecast is assigned with a probability. The probability that the operational forecast is correct is 35%. The forecast with 19% probability turned out to be closest to the truth.

first 10 Regional Singular Vectors, confirming the results of the Quasi-Geostrophic system. Secondly, a major experiment has started to create a fully non-linear ensemble prediction system for the short and early medium range. The perturbations for such a system, will be constructed from the same Regional Singular Vectors as mentioned above, i.e. optimized for the day 3 range and for Europe, but will be superimposed on the analysis and integrated non-linearly with the T159 L31 ECMWF model, out to 3 days. Emphasis will, in this project, be given to the estimation of phase errors of frontal systems. This project is in close co-operation with ECMWF.

Research on the predictability of the onset of blocking and strong zonal flow regimes was continued. The sensitivity in the initial conditions is calculated by perturbing the reference flow with perturbations which optimally trigger the onset of a blocking or strong zonal flow regime after a prescribed forecast time. For forecast times larger than 3 days an iterative technique is used to take into account nonlinear growth of the perturbations. It turns out that flows with a high sensitivity show an intensified jetstream to the west of a diffluent flow and an enhanced ridge upstream of the intensified jetstream. Flow patterns of low sensitive periods are found to be more zonal and weaker.

We started a study on the interactions between Rossby wave packets and non-zonal mean flows. Using the WKB approximation, dispersion relations and propagation and transport equations for Rossby wave packets are derived. Ray tracing is applied to calculate the evolution of the zonal and meridional wavenumbers of such a wave packet. The main goal of this study will be to obtain more insight into the effects of the eddies on such a mean flow, which should result in a better understanding of the mechanisms which are involved in the onset, maintenance and decay of blocking regimes.

We introduced the use of skill predictions to the the operational forcasters. Several lectures have been given, and several discussion meetings have been held with the main forecasters. The medium range ensemble forecasting system (EPS) will be made operational at KNMI in the course of 1997. The assistance to the forecasters will be continued in the coming year, particularly as the short range EPS will become available, perhaps as soon as the end of 1997. This new system will again require a great deal of rethinking about the practive of operational forecasting, because now probabilistic forecasting techniques become available for the short range.

Predictability and natural variability of climate

Haarsma, Weber, Selten, Lenderink, Wang, Pasmanter, Opsteegh

Decadal climate variability was studied within the context of a coupled atmosphere/ocean/sea-ice model of moderate complexity (ECBILT). The atmospheric model is a T21 Quasi-Geostrophic three level model with parameterizations for the diabatic physical processes. The ocean is more or less conventional except that it has a coarse grid, a flat bottom and the winddriven gyre circulation is assumed to be in equilibrium with the time mean windforcing. The sea-ice model is a zero-layer thermodynamic model. The model is very efficient. It uses 0.2 hr CPU time for a one year integration on a Silicon Graphics Power Indigo. The climate of the individual models and their variability is reasonably realistic, although significant discrepancies occur with the observed climate. A thousand year integration in coupled mode was performed without applying flux corrections. The variability properties of the coupled model in the Atlantic European area were analysed. Both the EOFs for the atmosphere and the ocean show good qualitative agreement with observed variability patterns in the extratropics. The connection was explored between the atmosphere and ocean by performing a singular value decomposition of sea-surface temperature (SST) anomalies and 800 hPa geopotential height anomalies. The second mode shows a peak in the spectrum at a timescale of about 18 years. The time scale of this mode is set by the ocean but the physical mechanisms that are operating are not yet identified. Additional experiments show that it is essential for the spectral peak to appear that the atmosphere is allowed to respond to the SST anomalies, in spite of the fact that the atmospheric response to SST anomalies is quite small. A decadal mode of variability at a time scale of about 18 years has also been identified in the North-Pacific. It evolves in phase with the Atlantic mode. This may be an indication that the dynamical response over the North-Atlantic is influenced by events in the

North-Pacific. The mechanisms for this coupling are not yet understood. A technical report (TR 195) will be published in 1997, describing the details of ECBILT.

The behaviour of the atmospheric component of ECBILT has been extensively studied. Experiments were done to investigate the sensitivity of the model climate to parameter changes. The model climate response to tropical SST anomalies was also investigated.

Interannual variations in the blocking activity of the ECBILT model were studied. A sensitivity study of the model simulated blocking activity to changes in the external forcing and to various model parameters was done. The Rossby deformation radius at the upper and lower levels appear to have a big impact on blocking.

A study on the parameter sensitivity of the equilibrium state of a coupled atmospheric EBM-ocean model was concluded. Emphasis was on the oceanic vertical diffusion coefficient, a closure parameter which is very sensitive in uncoupled ocean models. The coupled model contains three feedback processes which are not represented in ocean-only models: the (negative) feedbacks of oceanic temperature and atmospheric meridional heat transport and the (positive) feedback of atmospheric meridional moisture transport. Ocean-only models, which are forced by so-called mixed Boundary Conditions (BCs), only contain the (positive) feedback of oceanic salinity. The inclusion of these feedbacks results in a temperature and salinity response to the vertical diffusion coefficient which is stronger in the coupled model than in the ocean-only model. On the other hand, the response in oceanic processes like the meridional heat transport, deep-water formation at high latitudes, etc., is much weaker. Ocean-only sensitivity experiments were also performed with modified BCs, which parameterise the feedback processes present in the coupled model. It was found that an ocean-only model, forced by modified BCs, shows a similar response as the coupled model in large-scale features of oceanic surface fields. However, the sensitivity of the deep ocean temperature is only partly captured. This is due to local differences in the surface response as well as to shifts in the pattern of deep-water formation.

A study on the mechanism of climate drift within the context of a coupled atmosphere-ocean box model was continued. It was examined how a strongly stabilizing mechanism, related to biological processes, affects climate drift.

The variability of the thermohaline circulation in an ocean-only model has been studied. A decadal oscillation known from the literature has been extensively analyzed. The oscillation is characterized by large fluctuations in convective activity, air/sea heat flux, and meridional overturning rate and heat transport on an interdecadal time scale. The results indicate that the oscillation depends crucially on the existence of a large horizontal salinity gradient near the convective area, which enables an advective feedback. Because the surface salinity in the North Atlantic ocean indeed shows a large gradient near Greenland, the mechanism analyzed could be of relevance for the observed ocean circulation. Furthermore, the oscillation is only moderately dependent on the surface heat forcing, which indicates that the oscillation could also occur in coupled atmoshere-ocean models. The mechanism has been conceptualized further in a simple box model. The results have been written down as two chapters of a PhD thesis, and have been submitted for publication to scientific journals.

Dynamics of weather and climate

Verkley, Pasmanter, Ambaum, Brands, Trieling

Work was continued on the use of potential vorticity as a central concept in analysing the dynamics of the atmosphere. Part of the effort consisted of making the potential vorticity fields, which are calculated on the basis of ECMWF predictions. It was investigated to which extent the calculation of potential vorticity depends on the method of approximating vertical derivatives.
Research was continued on atmospheric models that consist of one or more layers of constant potential temperature (isentropic layers). A model that received particular attention is a two-layer model of which the lower layer ends in a temperature front. The model is meant to provide a dynamical basis for the conceptual models of the Bergen School.
A theoretical study on the role of boundary conditions in isentropic Quasi-Geostrophic theory

has been performed. It is shown that the way in which the lower boundary condition is included is of essential influence on the behaviour of the model. A previously developed contour dynamics model for the tropopause has been examined further in its behaviour. The area inside the tropopause on an isentropic surface serves as a bifurcation parameter. It can be used to predict the average amplitude of planetary waves in the model. An analogous study has been performed for analysed data from the ECMWF archive. It is shown that here the area is also an important parameter, but its relation to the amplitude of planetary waves is not as clear-cut as in the contour dynamics model.
A thesis, titled 'Large-Scale Dynamics of the Tropopause', has been written.

During a visit to the Department of Applied Mathematics and Theoretical Physics of the Cambridge University, England, an article was completed on a new numerical technique, the CASL algorithm, which is a combination of a standard Eulerian model with a modern Lagrangian model. The CASL algorithm improves on both computational cost and resolution by factors compared to other models.

An application of the intrinsic, thermodynamically based metric found last year has been developed. It deals with the problem of transient instabilities in compressible flows, a situation that arises often in the atmosphere. In this way, it is possible to find, e.g. optimal perturbations and the instant of maximal perturbation in compressible flows which are only transiently unstable. The same metric has been applied to the analysis of atmospheric data. It was found that the metric gives valuable results in areas far from the jet (probably the boundary layer is also excluded). Some possible ways of extending this approach to systems far from thermal equilibrium (like the jet and the boundary layer) are under study.

A numerical spectral model was developed of two-dimensional incompressible fluid flow on a circular domain. The model applied in the context of statistical mechanical description of two-dimensional fluid flow.

A critical comparison between the predictions of the statistical mechanical theory of coherent structures in 2D incompressible flows and this high-resolution, long-time numerical simulation has been performed. It was found that the theory gives excellent predictions if the initial vorticity field satisfies some criteria.
Research was done in the field of high Reynolds number two dimensional decaying turbulence. Several theories were studied based on statistical mechanics that describe the long term behavior of high Reynolds number two dimensional decaying turbulence. In particular, the differences between the predictions of Point Vortex Models and Vortex Patch Models were studied for the long term equilibrium structure such flows evolve to.
A numerical code was developed that calculates the mean field prediction of the Vortex Patch model for a particular initial vorticity field.
Work was done on a pseudo-spectral numerical code that simulates the two dimensional dynamics on a disc. This code is now almost operational, and will be used to further study the predictive power and range of applicability (both in initial and boundary conditions) of the statistical theories.

A variational method has been developed in order to extract from a long series of data the 'most predictable mode', i.e. the dynamical variable with the longest memory or strongest autocorrelation. A way of quantifying predictability in noisy dynamical systems was developed. A modification of this method is now being studied which would improve its short-term performance.

Articles, published in standard journals:

Lenderink, G., and R.J. Haarsma, 1996. *Modeling Convective Transitions in the Presence of Sea-Ice.* J. Phys. Oceanogr., **26**, 1448-1467.

Pasmanter, R.A., 1996. *Stochastic selfsimilar branching and turbulence.* Physica A., **228**, 273-295.

Scientific and technical reports:
Opsteegh, J.D. Chapter 2 of the KNMI Climate Report: *De toestand van het klimaat in Nederland 1996* [The State of the Climate in the Netherlands in 1996] (in Dutch).

Number of international presentations: 23.

Externally funded projects: national 1, international 1

Other activities:
J.D. Opsteegh, member of the Scientific advisory committee of the ECMWF.
J.D. Opsteegh, chairman of SAC working group on the validation and evaluation of the ensemble prediction system (EPS) at ECMWF.
R.A. Pasmanter, member of the Steering Committee of TAO (Transport in the atmosphere and the oceans) of the European Science Foundation (Strasbourg, 28-29 May, 1996).

Oceanographic Research Division

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

(Burgers, Van Eijk, Van Oldenborgh, Vossepoel)

Much of the observed interannual climate variability originates in the Pacific Ocean (ENSO). To contribute to efforts aimed at understanding and predicting this signal we have investigated the problem of initialization of tropical ocean models. We have also studied the representation of upper ocean mixing in models that are being used for ENSO prediction.

Two ocean mixed-layer models, a bulk mixed-layer and a non-local diffusion model, have been evaluated with respect to the behaviour in idealised test cases and with data from the BOMEX experiment. A 1.5 layer shallow water reduced gravity model was developed. The model is fast, about 30s CPU on a workstation per model year, and the correlation with the observed $NINO_3$ index exceeds 0.8. The purpose of the model is to test new data assimilation methods. A new analysis scheme for the Ensemble Kalman Filter was proposed and a note submitted, with P.J. van Leeuwen (IMAU) and G. Evensen (Bergen). A visit to the group of D. Anderson (University of Oxford and ECMWF) has resulted in an attempt to apply the Ensemble Kalman Filter to the Oxford intermediate ENSO model. A method based on simulated annealing has been developed for assimilating satellite radar altimeter measurements and temperature measurements in the oceanic component of the Cane-Zebiak model. The construction of the adjoint of the HOPE (Hamburg Primitive Equation Ocean Model) OGCM (Ocean Global Circulation Model) has been completed and tests have been performed running the model forward and the adjoint backward for periods up to one month. The tangent forward model has been constructed as well. This work forms part of a larger effort on data assimilation in ocean models with M. Fischer, M. Latif and Chr. Eckert from MPI Hamburg.

Global air/sea fluxes and the upper ocean in complex realistic climate models

Komen, Bonekamp, Sterl, Wallbrink

Coupled atmosphere ocean models - used for the study of climate - tend to drift away from the observed mean state because they have an incorrect representation of air/sea fluxes. Therefore, knowledge of global air/sea fluxes is of key importance in climate research. The aim of this project is to use the air-sea fluxes from the ECMWF Re-Analysis (ERA) to force both an ocean wave model and an ocean circulation model. The wave part of the project focuses on momentum fluxes; the ocean part also uses latent and sensible heat fluxes. A comparison of model results with observations gives an idea of the quality of the ERA fluxes. In 1996 research concentrated on the wave part of the project, which was nearly completed. Work on the ocean part has started in the fall and consisted mainly of preparations for the numerical experiments to be made .

In the wave part of the project the WAM wave model has been run for the fifteen years of ERA (1979-1993) on a global 1.5° x 1.5° grid. Comparison with satellite-measured wave heights obtained form P. Challenor and D. Cotton (Southampton Oceanographic Centre, SOC) show that the modelled wave heights are in reasonable agreement

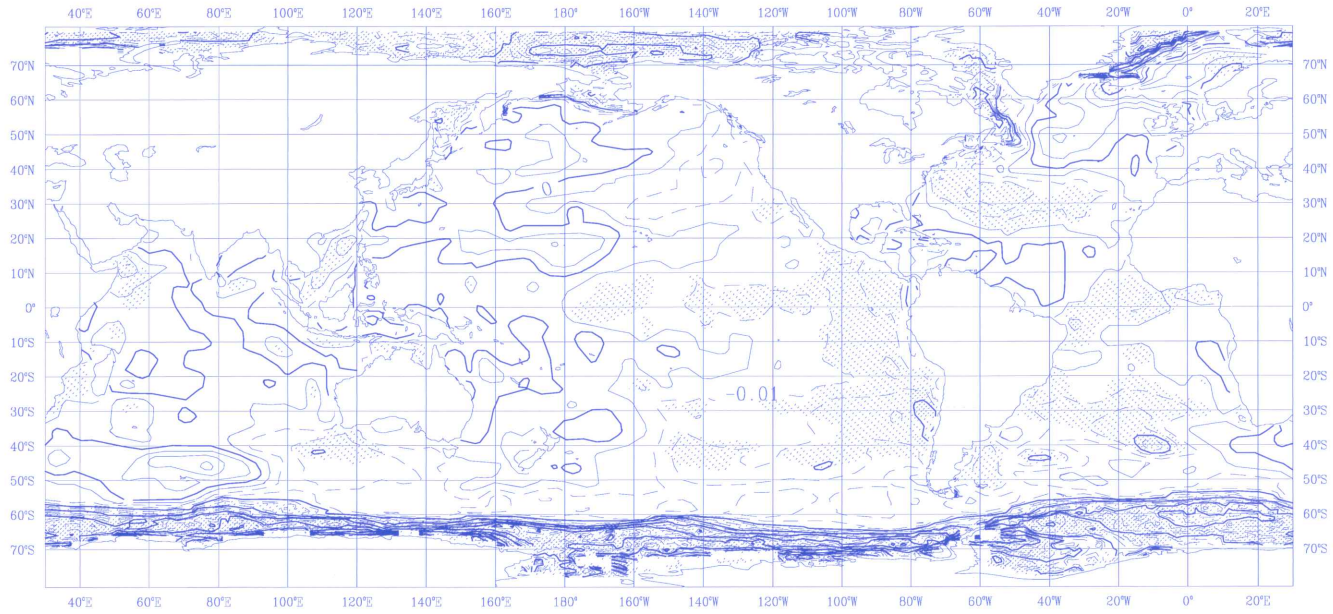

Figure 1. Linear trend of anual-mean significant wave height (m/y) over the ERA period. In the shaded areas, these trends are significant at the 95% level according to Student's t-test. Contour interval is 0.05 m/decade. Negative isolines are dashed

with the observed ones, albeit generally underestimating them. This is, however, in accordance with the general behaviour of WAM (P. Janssen ECMWF). Thus the wave hindcast suggests that the ERA winds are well representing the real wind field.

Besides being useful as a verification of the ERA winds, the hindcast data also form a 15 year climatology of global waves. This climatology has been investigated to detect trends in wave height (Fig. 1). The largest trends in wave height occur in the North Atlantic with up to 12 cm/y in January and south of Africa with up to 8 cm/y in July. They are, however, only marginally significant and exhibit a large month-to-month variability, so that on a seasonal basis the trends are significant only in small parts of the ocean. Concluding, the wave climate has not changed significantly during the ERA period.

Ocean dynamics

Drijfhout, Hazeleger, Katsman, Kattenberg, Sterl, Wolting

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.

A coupled isopycnic OGCM/mixed layer module/atmospheric anomaly model was used to investigate the coupling between ocean and atmosphere on the eddy-scale. It has been found that on the eddy-scale the coupling is much stronger than the average value, i.e. 120 versus 20 W/km^2. With this coupling strength eddies affect the integrated heat budget of the ocean, and current parameterizations are inappropriate.

An isopycnic model of an idealised North Atlantic subtropical gyre, coupled to a mixed layer model, was used to study the response of mode water formation to typical atmospheric forcing anomalies. Emphasis was placed on possible mechanisms for generating the observed interannual to decadal variability in mode water. It has been found that variability in mode water of the observed amplitude can be generated by the model if cold-air outbreaks are included and the ocean is preconditioned by a former series of cold winters. The preconditioning is explained by a storage mechanism of the ocean.

Finally, a two-layer quasi-geostrophic and isopycnic model has been used to construct the bifurcation

tree for the wind-driven ocean circulation (Fig. 2). Both time-integrations and a continuation method have been applied. Emphasis has been placed on a description of the first mode of instability (Hopf-bifurcation) and the rectification of the mean flow due to self-interactions of the unstable mode. It has been found that the character of the first unstable mode changes from intra-annual to interannual when reducing the Coriolis parameter and the upper-layer depth (research jointly with IMAU) .

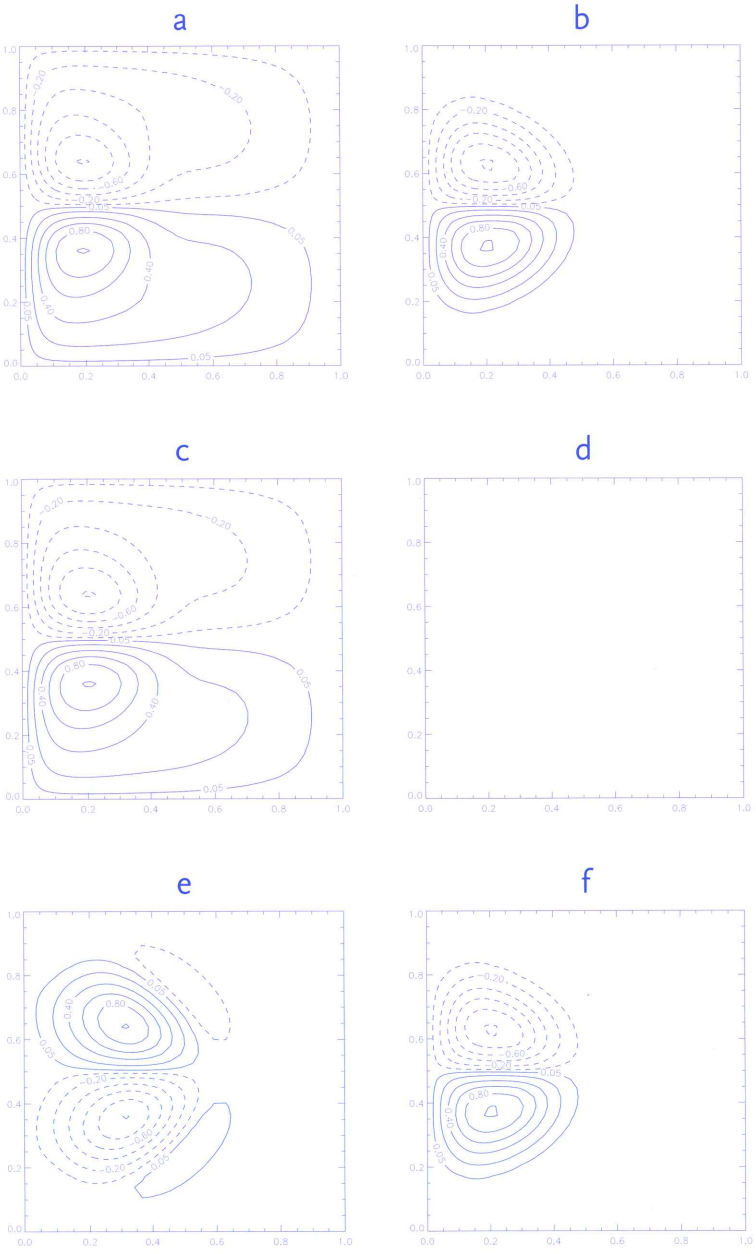

Figure 2. Period-averaged streamfunction during the limit cycle in the (a) upper and (b) lower layer; streamfunction of the unstable steady state in the (c) upper and (d) lower layer (nb: no flow in d); difference between the averaged flow and the unstable steady state in the (e) upper and (f) lower layer (all contourplots scaled with ψ_{max}).

Despite progress made in the World Ocean Circulation Experiment, there is still an enormous lack of ocean observations. Therefore, the analysis of numerical simulations is a useful approach to a better understanding of ocean circulation. This work is done with ocean models developed at MPI-Hamburg. A study in which the conveyor was traced in the Large Scale Geostrophic Model (LSG) and an analysis of the variability of the Hamburg Primitive Equation Ocean (HOPE) model was followed by a new study in which the response to noise-forcing - derived from an AMIP-run with ECHAM - has been investigated within LSG. In this study, which was done in co-operation with MPI and GKSS, an analysis has been made of the variability in the model and it has been found that this variability is dominated by an Antarctic Circumpolar Wave. It appears that the ACW is forced by wind-stress variability with a pattern resembling the 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 then are advected by the ACC/southern subtropical gyres.

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 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. To assess the climatology of this model, a detailed comparison of its mean state has been made with that of the Hamburg LSG-model. This showed that both models reproduce the gross features of integrated ocean circulation, i.e., the Conveyor Belt, Antarctic Bottom Water and Intermediate Water. However, in details ECBILT-OGCM performs significantly worse than the comparably inexpensive LSG-model. It suffers from a too high diapycnal diffusion and too large intermediate water mass formation. These problems seem for a large part associated with anomalous circulations related to the flat bottom (joint research with the Predictability Division of KNMI). As a result of this study it was decided that we will introduce LSG in ECBILT.

The physics of air/sea exchange

Oost, H. Janssen, Jacobs, P. Janssen, Mastenbroek, Van Oort, Worrell, Wallbrink

Work in this group concentrates on a physical description of the microscale aspects of air/sea interaction. Much work concerns the study of momentum and moisture fluxes, but recently the exchange of gases, like CO_2, between sea and air is getting more and more attention. CO_2 exchange is of immediate interest for climate change studies, due to the importance of CO_2 as a greenhouse gas, the large surface area of the oceans and the fact that the oceans are the main known sink for CO_2. The transport coefficients describing the air/sea exchange of CO_2 form a direct input in the biogeochemical models used to forecast the future development of the CO_2 content of the atmosphere.

Whitecaps play a central role in A/S interactions. Observations made during the 1986 HEXMAX (Humidity Exchange over Sea Main Experiment) resulted in a number of publications. In one paper whitecapping coverage was related to other parameters. Another paper emphasized the role of droplets in air/sea transfer and the substantiated and rapid rise of the evaporation coefficient at wind speeds above 15 m/s.

The aerodynamic roughness of the sea continued to be a hot topic. The roughness determines the wind stress which is a key variable in air/sea interactions. There are indications that the stress does not only depend on the wind speed but also on the sea state. A statistical analysis of the HEXOS data confirmed that the dimensionless roughness is not a constant for high wind speeds (> 17 m/s); it also showed that the effect of waves on the stress can not be accounted for in terms of wave age. The effect may be explained in terms of a parameter involving the wave height, which can be interpreted as the orbital velocity of the dominant sea wave. Earlier it had been noted already that the HEXOS data by itself do not prove a wave age dependence. The observational indication for such a dependence, which can be understood in terms of spectral wave evolution, is based on a joint analysis of different experiments. The effect of waves on the exchange of sensible heat was also studied (research jointly with V. Makin, Observations and Modelling Department - KNMI).

The main activities were concerned with the ASGAMAGE project. KNMI's objective here, is to measure gas fluxes from a platform at sea and to derive parameterizations. There is still a large uncertainty in the coefficients that characterise the exchange of CO_2 and other trace gases between sea and air, especially its wind dependence but also very little is known about the relationships with e.g. wave geometry, whitecap coverage and bubble flux spectra. One of the factors contributing to the uncertainty is the discrepancy in the transport coefficients found with the so called eddy correlation method, which provides a direct measurement of the CO_2 transports compared with the conventionally used indirect methods. KNMI is one of a very few institutes capable of applying the eddy correlation method for gases over sea. The two experimental phases of the project took place in the period 6 May to 6 June and from 7 October to 8 November, at 'Meetpost Noordwijk'. Both phases have been quite successful. In total 14 Institutes from 7 countries participated. The UK participation in the second phase consisted not only of a party on board the platform, but also of a fortnight's activity of RRS 'Challenger'. The preliminary results of the KNMI contribution to the first measurement period are meanwhile available and indicate a better correspondence between eddy correlation and conventional measurements than ever before. The transport coefficients found with the eddy correlation method are still higher than the conventional values, but the remaining differences can largely be attributed to differences in the time scales contributing to the outcome in both types of methods and the non-linearity of the transport coefficients as a function of the wind speed.

In a multi-year effort a wave-follower is being constructed which will enable us to make observations very close to the sea surface. The large amount of time taken up by the ASGAMAGE project led to very slow progress of the wave-follower project until November. However, some (external) activities did continue in that period, so that the design and the construction of several parts was completed. In December construction activities were resumed energetically and it is expected that the instrument will be completed in the first half of 1997 and that the full instrument can be tested under operational circumstances (i.e. at sea) in the fall of that year. As a corollary to the construction of the wave-follower some parts for a small and light weight version of the pressure anemometer,

intended for use on the wave-follower have been designed and constructed .

There have been no new technical developments. Previous developments turned out to be quite adequate for the execution of the ASGAMAGE project. They will serve again in future activities. Progress was made with the technical description of the data collection system.

Remote sensing and air-sea interaction

Komen, H. Janssen, P. Janssen, Oost, Wallbrink

Satellites can infer wind speeds over the ocean with the help of radar scatterometers. This is of great importance for a determination of global wind fields over the ocean. Scatterometers measure the radar backscatter from the ocean surface. Operationally, an empirical algorithm is used for the determination of winds from observed backscatter. At KNMI, in the past few years, a so-called 'physical algorithm' has been developed, i.e. an algorithm containing separate blocks for the relation wind speed - surface stress, surface stress - short wave spectrum and short wave spectrum - backscatter, respectively. This work, done in collaboration with Delft Hydraulics, Delft Technical University (TUD) and TNO-FEL, was completed. The resulting algorithm (Viers) has been tested, and promising wind fields were obtained (Fig. 3). However, this success was somewhat overshadowed by the detection of a misfit in backscatter space. To overcome this problem a follow-up project (SatView) was carried out. Adjustment of the directional distribution of the short waves and a major revision of the numerous sensitive parameterizations led to a significant improvement of the algorithm. Both Viers and SatView are physical algorithms producing winds that are of comparable quality to those obtained with CMOD4, the empirical algorithm in operational use. It is hoped that the physical approach will lead to a superior algorithm as knowledge of basic processes advances.

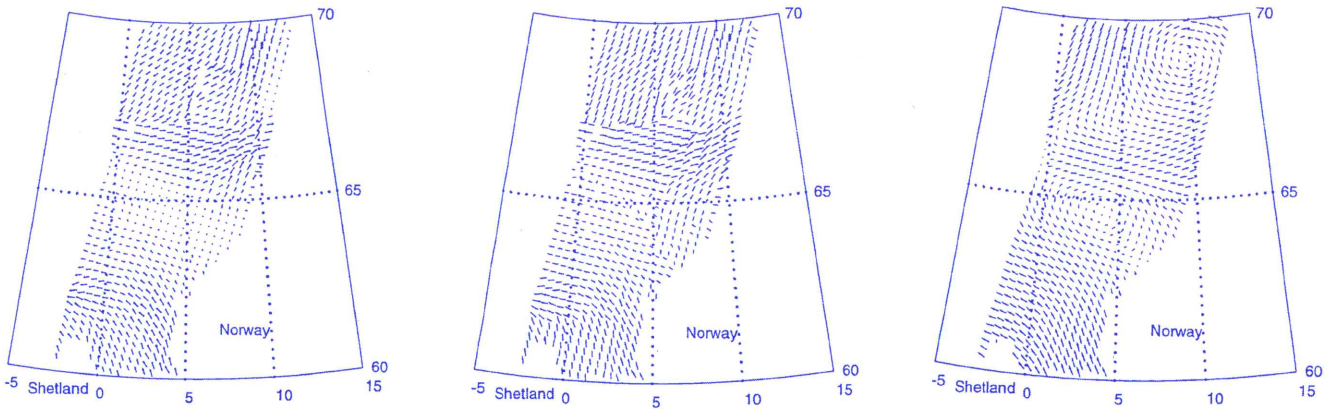

Figure 3. The VIERS algorithm was subjected to a comparison with both a Norwegian meteorological model (METEO) and CMOD4, using data from the 1991 ESA CalVal campaign in the Norwegian Sea. The resulting winds on 6 November 1991 are imaged in this figure. Wind speed is coded in the plots by the length of arrows, while the direction of the arrows indicates the flow direction. The first image shows the VIERS retrieved windfield, the second the corresponding CMOD4 result and the third the METEO windfields. In all images a large front is visible. There is a striking correspondence between the VIERS and CMOD4 results, which both show a clear discrepance with the METEO winds. In the METEO windfield the front is nog as pronounced and the position is approximately 200 km north of the front as observed by ERS-1.

Wind generated waves and ocean wave prediction

Komen, Burgers, Van Duin, Hersbach, Mastenbroek, Rider, Voorrips

Traditional interest in ocean waves stems from practical issues regarding wave forecasting and wave climatology. More recently, interest has shifted to the role of waves in air/sea interaction and climate and to a possible anthropogenic change of ocean wave climatology.

A number of basic studies was carried out concerning the mechanism of wave growth. An analytical study on the generation of nonlinear water waves by wind has been published in J. Fluid Mech. A paper commenting the work of Belcher and Hunt (1993), based on the use of a truncated rapid-distortion turbulence model, has been published in the same journal. The results obtained differ significantly from the Belcher-Hunt results, although the models are physically similar. For fast water waves, rapid-distortion models cease to be valid. The effect of an adapted turbulence model, describing the formation of such waves, is studied in co-operation with P. Janssen (ECMWF). The wave growth rates based on this model are significantly larger than those derived from previous models describing turbulence effects. For slow waves, on the other hand, the results for the wave growth rate are comparable with those derived from rapid-distortion models. The effect of turbulent closure on wave growth was also studied with a numerical model. A second order Reynolds stress, in which advection is explicitly modelled, gave results that are consistent with rapid distortion ideas. The results compared favourable in general with measurements in wave tanks. It was found in this study that the wave growth depends sensitively on the distribution of roughness along the wave. Therefore, the model was extended to include the three-way interaction between long waves, short waves and the wind. There was also progress in our understanding of dissipation. On the basis of results of Terray et al. and Drennan et al. simple parameterizations have been proposed for the surface wave-enhanced turbulent kinetic energy dissipation in the upper ocean.

In two other studies the problem of data assimilation in ocean modelling was addressed. Central to these studies was the WAM model, a third generation ocean wave model, described in the monograph *Dynamics and Modelling of Ocean Waves* (which was reprinted in 1996). In order to further optimise the model in an objective way and also to study sensitivities, the 2-D adjoint of the WAM model was constructed with the help of an Adjoint Model Compiler. During this construction a number of shortcomings of the model became apparent, which however could be remedied. With the adjoint three cases were studied: (i) fetch limited growth (idealised) (ii) realistic wind sea growth (with the Lake George data kindly provided by I. Young); and (iii) a severe North Sea storm. These studies gave insight in the problem of how to choose control variables and a cost function. It also resulted in a fine tuning of model parameters. Another study aimed at the real time use of wave observations for wave forecasting. To this end a new scheme (OIP) for the assimilation of spectral wave data was developed. This scheme was tested against conventional observations and against satellite data. The results indicate that assimilation has a positive impact both on the analysis and on the forecast. The effect on the forecast is largest in specific situations such as swell-from-the-north. It was found that in the North Sea the impact of the SAR observations was generally small compared to the impact from conventional 2-dimensional buoy observations. To go beyond OI the development of an efficient suboptimal Kalman filter was started. This new approach is expected to remove some of the deficiencies of the OI scheme, while keeping the computational costs limited by making a suitable approximation of the forecast error covariances.

Two climate related studies were completed. The first quantified the effect of a sea state dependence of the wind stress on the climatology of the ECMWF model. A definite impact was found, both on the atmospheric and on the wave climate. In a second study data from high resolution numerical simulations were analysed to study the effect of greenhouse warming on the atmospheric and wave climatology in the North Atlantic region. Changes were found, but generally these changes are smaller then those due to natural variations.

Komen

General climate change issues

To coordinate climate research world wide the World Meteorological Organisation has launched Clivar (Climate Variability), a new research programme, with an envisaged duration of 15 years. Clivar is part of the World Climate Research Programme. Objective of Clivar is the understanding and - if possible - prediction of climate variations, both natural and anthropogenic, on timescales from months to centuries. To help implement Clivar in Europe a Euroclivar committee has been set up under KNMI chairmanship. This Euroclivar committee met twice. At these meetings an outline of a European Clivar implementation plan was formulated and plans for a number of workshops were made.

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Kattenberg, A. Chapter 2 of the KNMI Climate Report: *De toestand van het klimaat in Nederland 1996* [The State of the Climate in the Netherlands in 1996] (in Dutch).

Number of international presentations: 20.

Externally funded projects: national 1, international 5.

Other activities:

A. Kattenberg, chairman of the board of European Climate Computer Network (ECCN), Joint Coordination Committee.
G.J. Komen, member IPCC Working Group 1 on Scientific Assessment.
G.J. Komen, member Joint GOOS Scientific and Technical Committee.
G.J. Komen, Eurclivar coordinator.
G.J. Komen, member of the board of GOA, the Geosciences Foundation of NWO.
G.J. Komen, member of the board of 'Nederlandse SCOR Commissie'.
G.J. Komen, member of the board of 'Contactgroep Aardgericht Ruimteonderzoek' of NWO.
W.A. Oost, member International Geosphere-Biosphere Programme (IGBP) Project 2, Focus 1, International Global Atmospheric Chemistry Programme.
W.A. Oost, member Marine Aerosol and Gas Exchange (MAGE).

Atmospheric Composition Research Division

The field of research is focussed on changes in the composition of the earth atmosphere and its relation with climate changes. The group has put the accent on the dynamical and physical aspects of the changes in trace gas distributions. The research strategy is to study the field along three different paths

1 Observations especially from satellites of ozone and related quantities.
2 Global three-dimensional modelling from atmospheric composition and climate.
3 Studies of a few relevant transport processes in the boundary layer and between the stratosphere and troposphere.

1. Observations

Reconstruction of global ozone fields by assimilation of total ozone satellite data in an atmospheric model

Levelt, Piters, Eskes and Allaart

A two-dimensional model for advection and data assimilation of total-ozone data has been developed. The Assimilation Model KNMI (AMK) is a global model describing the transport of the column amounts of ozone, by a wind field at a single pressure level, assuming that total ozone behaves as a passive tracer. In this study, ozone column amounts measured by the TIROS Operatinal Vertical Sounder (TOVS) instrument on the National Oceanic and Atmospheric Administration (NOAA) polar satellites and wind fields from the Meteorological Archive and Retrieval System (MARS) archives at ECMWF have been used. By means of the AMK, the incomplete space-time distribution of the TOVS measurements is filled in and global total-ozone maps at any given time can be obtained. The choice of wind field to be used for transporting column amounts of ozone is extensively discussed. It is shown that the 200-hPa wind field is the optimal single-pressure-level wind field for advecting total ozone. Assimilated ozone fields are the basic information for research on atmospheric chemistry and dynamics, but are also important for the validation of ozone measurements.

2. Modelling

Validation of a climate model by nudging technique

Jeuken, Siegmund

A simple four-dimensional assimilation technique, called Newtonian relaxation, has been applied to the ECHAM climate model, to enable comparison of model output with observations for short periods of time. The prognostic model variables vorticity, divergence, temperature and surface pressure have

been relaxed towards ECMWF global meteorological analyses. The use of the method for validation of model physics or chemistry, requires a good agreement of the model simulated mass and wind field with observations. In addition the model physics should not be disturbed too strongly by the relaxation forcing itself. Both aspects have been investigated. Good agreement for the prognostic variables was found for most simulations in the extra-tropics. Parameterized variables, like precipitation and evaporation, have been compared with ECMWF forecasts and observations. Agreement for these variables is smaller than for the prognostic variables. Nevertheless, considerable improvement is obtained relative to a control run without assimilation. Differences between tropics and extra-tropics are smaller for the parameterized than for the prognostic variables. Results also show that precipitation and evaporation are affected by a continuous spin-up which is introduced by the relaxation. In addition we found that with increasing relaxation forcing the vertical exchange of tracers by turbulent boundary layer mixing and, in a lesser extent, by convection, is reduced.

Effects of aviation on the atmosphere

Wauben, Van Velthoven, Meijer

The effects of aircraft emissions on the atmospheric composition were investigated by airborne measurement campaigns performed in the framework of the Dutch AIRFORCE project and the European Community POLINAT and STREAM projects. Since several relevant components are measured simultaneously during these campaings, the abundance of certain chemical components

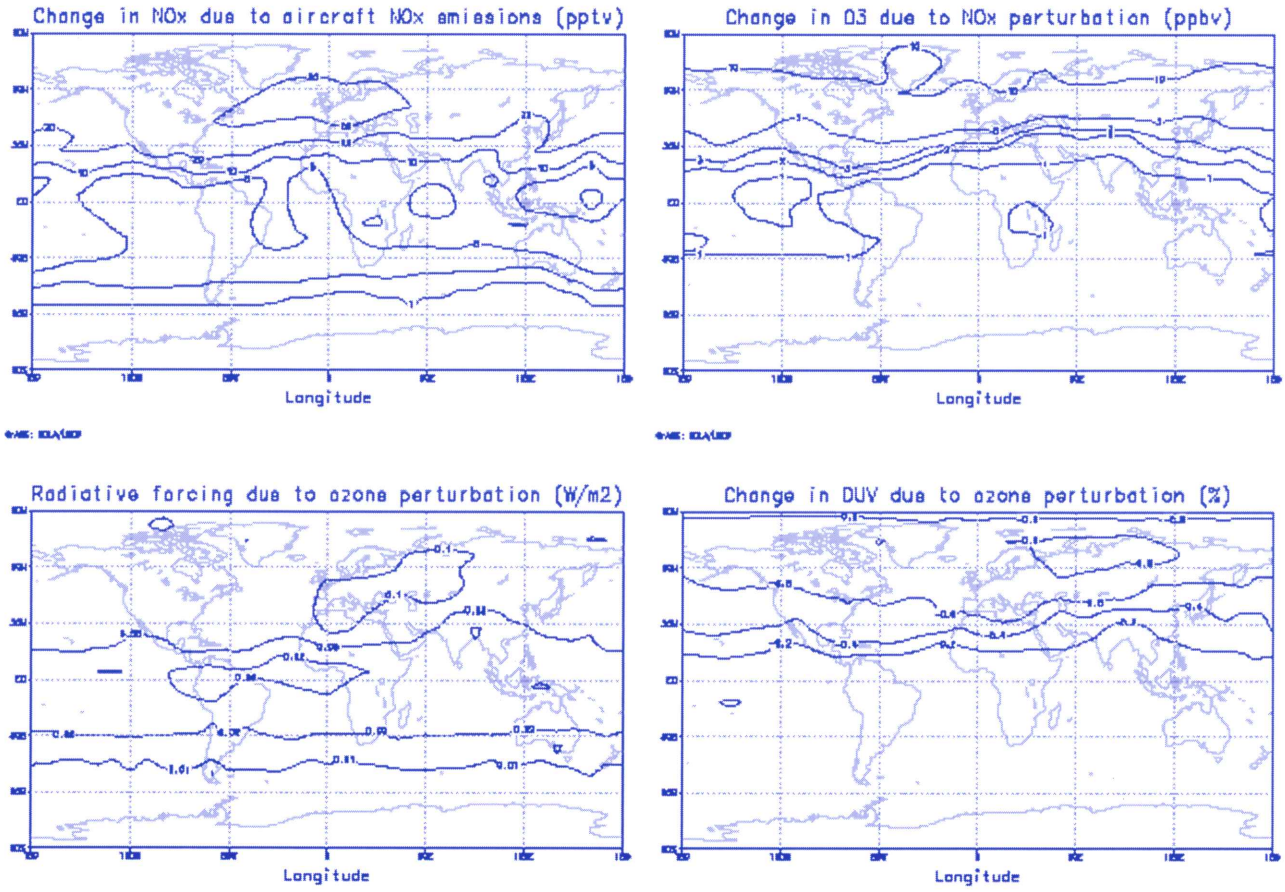

Figure 1. Change in NO_x concentration at 200 hPa due to aircraft emissions, the resulting change in ozone concentration at 200 hPa, and the consequent changes in radiative forcing and damaging ultraviolet radiation (DUV) at the surface. Values for July.

gives information on the history of the air parcel. In accordance with back-trajectories, the observations showed events of upward transport from the polluted boundary layer and accumulation of pollutants within a stagnant anti-cyclone. It was also found that the analysed meteorological fields show good agreement with the airborne observations of temperature, wind and water vapour.

The airborne measurements have been used to validate the atmospheric composition calculated with the Chemistry Transport Model of the KNMI (CTMK). For long-lived tracers such as ozone the agreement between model results and observations is rather good. The calculated ozone distributions generally are close to the observations. The calculated distribution of nitrogen oxides and their reservoir species show larger discrepancies (Fig. 1) which probably result from gaps in our knowledge of the chemistry near cruise altitudes, and in the presence of aircraft plumes. It was found that the signal of aircraft emissions of nitrogen oxides could be measured during the accumulation of pollutants in the presence of a stagnant anti-cyclone. This was corroborated by the numerical simulations with CTMK.

The global distribution of the ozone perturbations caused by aircraft emissions of nitrogen oxides has been assessed with CTMK within the framework of the Dutch AERO project and the European Community AERONOX project. A maximum ozone perturbation of about 8% occurs during summer in the northern polar region at aircraft cruise altitudes. This perturbation has subsequently been used to calculate the change in the net downward radiation at the tropopause, as an indicator for climate change. It was found that ozone changes near the tropopause, and particularly in the tropics give the largest changes in the radiative forcing. The net change is maximally about 0.14 W/m^2 in the Mediteranean during summer. The resulting change in the level of damaging ultraviolet radiation at the surface due to the ozone perturbation has been determined for clear-sky situations by using an empirical relation between damaging ultraviolet radiation, total ozone and the solar elevation. A maximum decrease in damaging ultraviolet radiation of about 1% occurred over Siberia.

The effect of plume chemical processes on the global distribution of the ozone perturbation caused by aviation has been investigated. Incorporation of the processes occurring in a plume leads to a typical reduction of 15-55% of the amount of NO_x introduced on a global grid in the North Atlantic Flight Corridor, and consequently leads to a 15-25% reduction of the ozone perturbation by aviation which contributes maximally about 8% to the ozone concentrations during summer.

Validation of the Chemical Transport Model KNMI (CTMK)

Wauben, Van Velthoven

Comparison of models such as CTMK with observations are required in order to assure the quality of the impact studies. For that purpose, the ozone distributions calculated by CTMK were compared with a climatology of ozone sonde observations and with instantaneous total ozone column values derived from satellite observations. This comparison showed that CTMK results are in reasonably good qualitative agreement with the observations. Some minor model deficiencies have been indicated and need to be addressed in the future. These are (1) the seasonality of the ozone concentrations near the surface and (2) the overestimation of ozone concentrations near the tropopause at midlatitudes. Both differences could be the result of shortcomings of the chemistry module, i.e the neglect of non-methane hydrocarbons near the surface and the absence of stratospheric gas-phase chemistry. The day-to-day variability in the total ozone column values observed by satellite is rather well reproduced by the model calculations. This variability is generated by the rapid changes in the ozone concentrations near the tropopause due to transport.

Fortuin

The coupling between ozone and temperature

Long-term trends in concurrent ozone and temperature measurements in the stratosphere, using a linear multiple regression analysis were examined. It is then attempted to explain the derived temperature trends, either in terms of radiative adjustment to the corresponding ozone trends (plus change in other greenhouse gases), or in terms of a shift in the vertical advection regime. The analysis is performed for a specific case, Hohenpeissenberg station, and a general case, 8 Northern Hemisphere stations averaged; over a warm (April-September) and cold (October-March) half year. For Hohenpeissenberg over the period 1983-1993, it is found that the dynamical explanation fits the observed cooling in the lower stratosphere much better than the radiative explanation (cf. Fig. 2). This dynamical explanation corresponds with an average rise in tropopause height of around 1 km over the last decade. It is important to note that such an upward shift of the tropopause would also explain the observed ozone trend at these pressure levels (200-70 hPa), instead of the standard assumption of chemical ozone depletion. For the 8 Northern Hemisphere stations combined (4 in Canada, 3 in Japan and 1 in the USA), the radiative explanation for the observed lower stratospheric cooling in the warm cycle is now more reasonable, but again the dynamical option can not be ruled out.

We also investigated the correlation and linear relation between the ozone and temperature residuals of the regression analysis. For the 8

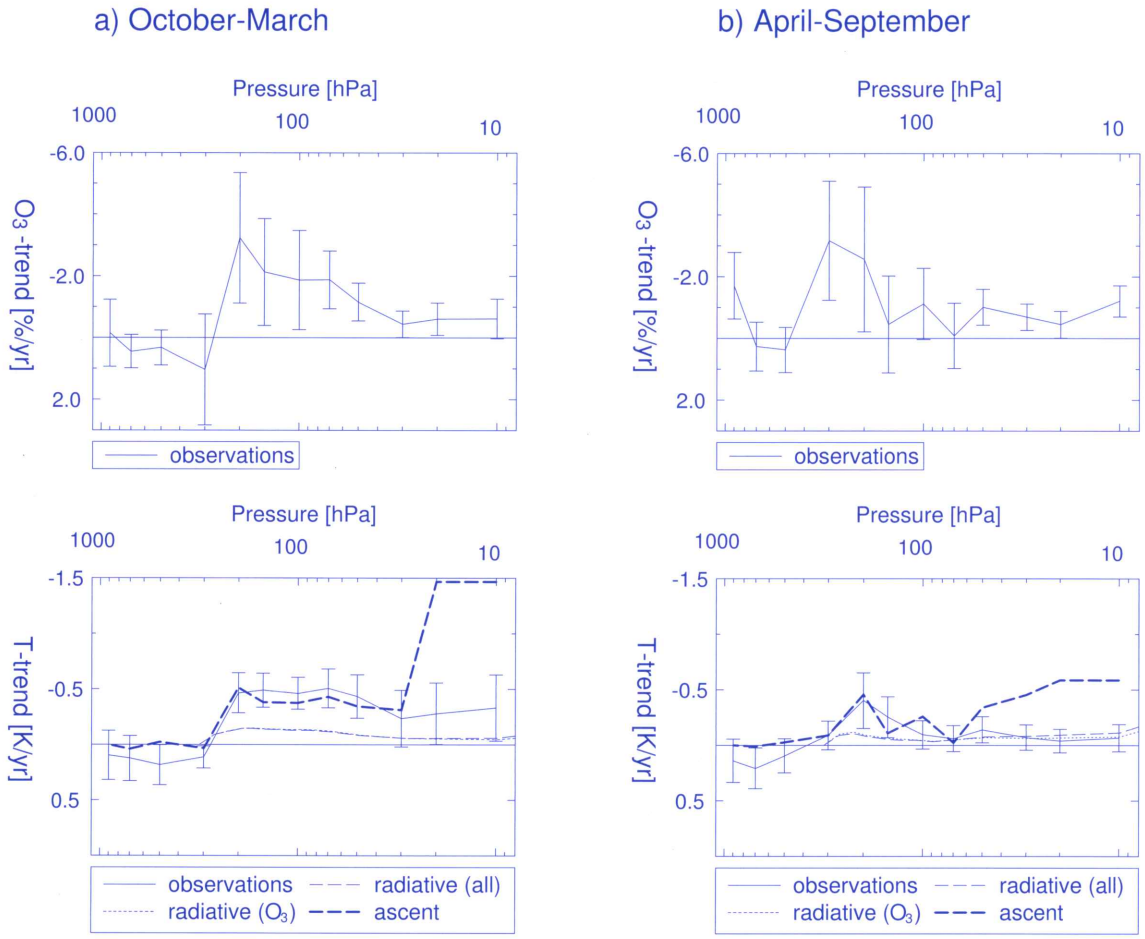

Figure 2. Ozone and temperature trends over the cold (a) and warm (b) half year, for Hohenpeissenberg station over the period 1983-1993. Also shown are estimated temperature trends according to a dynamical and radiative approach (see text).

stations averaged, the corresponding correlation and sensitivity curves over the warm and cold cycle are shown in Fig. 3. From these curves a slightly positive correlation and sensitivity between ozone and temperature at the Earth's surface are evident, with an insignificant relation further upward in the troposphere. Near the tropopause there is a sudden increase, the sensitivity reaching a local maximum of around 0.05 K for each percentage ozone increase. For the cold half year, the positive sensitivity and correlation continues further upward in the stratosphere, whereas for the warm cycle the relation becomes negative above 20 hPa - most likely due to the well known temperature dependence of the kinetic rate coefficients for ozone formation and destruction. Also shown along with the sensitivity curves of Fig. 3 is the radiative sensitivity of temperature to changes in ozone, as determined with a radiative transfer model (RTM). This curve was calculated by increasing the ozone concentration in a model layer by 10%, and calculating the corresponding heating in the same layer under the assumption of fixed dynamical heating. This procedure was repeated for every stratospheric model layer. The resulting (dashed) curve indicates to which extent the sensitivity of temperature to ozone is due to radiation. For the cold half year, there is a clear correspondence for the entire stratospheric region considered, whereas the agreement in the warm half year is confined to the lower stratosphere.

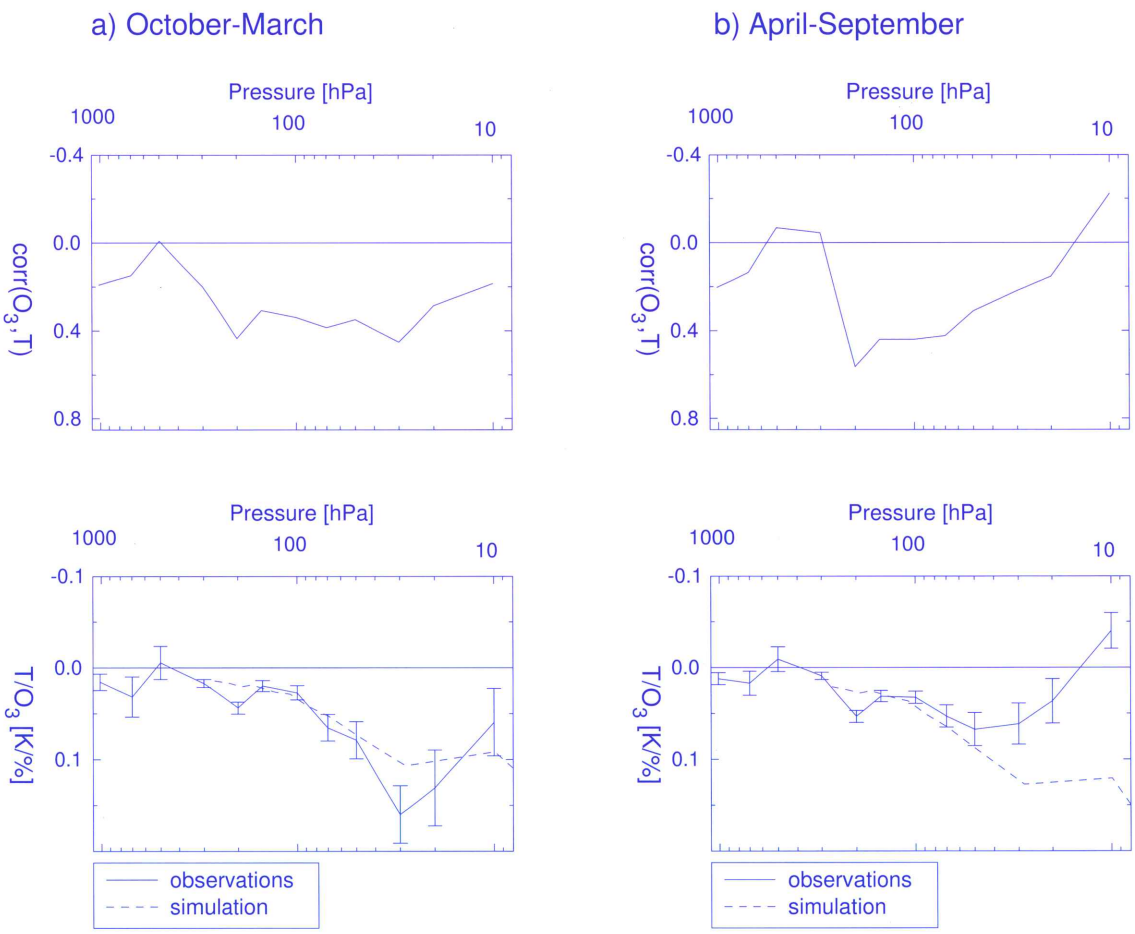

Figure 3. The average (for 8 ozonesonde stations) correlation and linear relation between the ozone and temperature residuals, for a cold (a) and warm (b) cycle. Also shown (dashed line) is a RTM-simulation of the sensitivity of temperature to ozone changes.

Global ozone climatology for model validation

Fortuin

A first attempt to construct an ozone climatology based entirely on observations was presented by Fortuin and Langematz in 1994. For the troposphere and lower stratosphere (surface-30hPa), the climatology used data from 33 ozonesonde stations scattered around the world. However, this early climatology has the disadvantage of being inhomogeneous in time. An updated version of this climatology is now under construction, consisting of an ozonesonde climatology (1000-0.3 hPa, 12 layers), matched with satellite SBUV and SBUV/2 observation (10-0.3 hPa), all over the target period 1980-1991. The integrated zonal monthly mean climatology is made consistent with a TOMS (version 7) total ozone climatology over the same period. An accompanying standard deviation climatology gives an indication of the interannual natural variability of the new mean climatology.

Simulation of the climate response to changes in ozone concentrations

Bintanja, Fortuin

The climate response due to changes in the radiative fluxes caused by prescribed changes in stratospheric as well as tropospheric ozone was investigated. With a simplified climate model, basically consisting of an energy balance atmospheric model coupled to an advection-diffusion ocean model. Latitudinal and seasonal variations in zonal mean surface air temperature and the lower (12-22 km) and higher (22-100 km) stratospheric temperatures are simulated. The quasi-equilibrium response to a uniform 50% reduction in the lower stratospheric ozone was found to result in a global average cooling of 3.5°C in the lower stratosphere with maximum values in the tropics, and of 0.46°C at the surface with maximum cooling in the polar winter. The latter is largely due to the albedo-temperature feedback, mainly through increases in sea ice. Due to differences in the meridional gradient in tropospheric radiative forcing, the albedo-temperature feedback is consistently stronger in case of tropospheric and lower stratospheric ozone perturbations than in case of, for instance, CO_2-perturbations. Our conclusion from these quasi-equilibrium experiment is that concepts like global radiative forcing and global climate sensitivity have little meaning in quantifying climate change. The transient model responses to various ozone trend scenarios were also investigated. They indicate that the net effect of tropospheric ozone increases and stratospheric ozone depletions is a slight global average cooling (-0.001 to -0.003 K yr^{-1}), which offsets by approximately 10% the projected surface warming due to increases in the other greenhouse gases.

3. Processtudies

Transport through the Antarctic vortex boundary

Wauben, Bintanja, Van Velthoven

The amount of transport of air through the Antarctic vortex boundary is subject to discussions. Some consider the vortex as a so-called 'containment vessel', with only little transport through the vortex boundary; others are in favour of a flowing processor with an amount of transport

through the vortex boundary corresponding to several times the vortex mass during the period of August through September.
With our three-dimensional tracer transport model we have calculated the transport through the vortex boundary (Fig. 4). The model results indicate that in late winter and spring a quasi-horizontal cross-vortex boundary transport of about 0.24% per day of the total tracer amount takes place while 0.83% per day descends into the troposphere. This implies that roughly 65% of the vortex is flushed out during the August through October period. The results of our calculation support the 'containment vessel' hypothesis of McIntyre with a higher amount of leackage then he found on purely theoretical grounds.

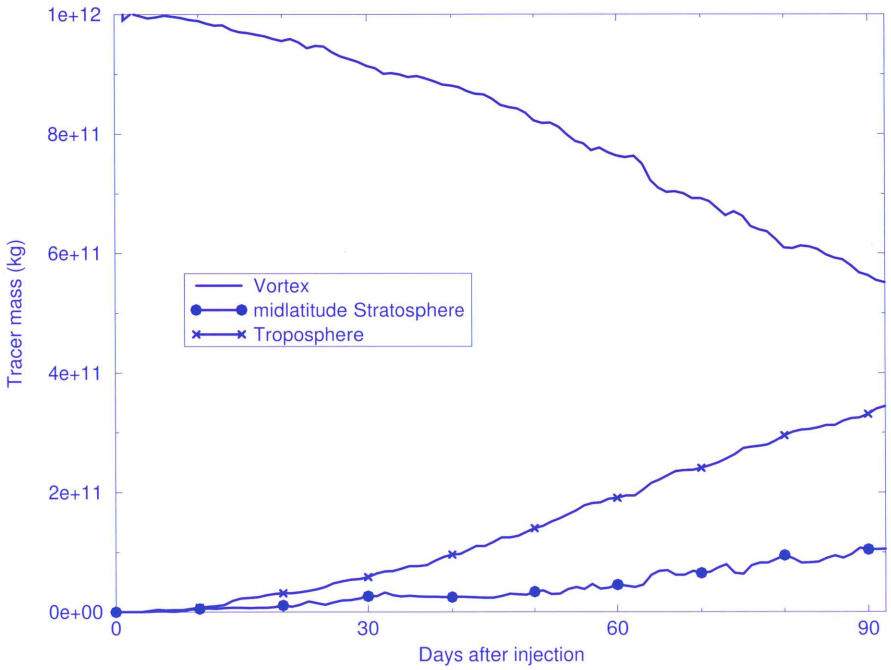

Figure 4. Redistibution of mass among the Antarctic vortex, the mid-latitude stratosphere and the troposphere, of a tracer released inside the vortex.

Stratosphere - troposhere exchange estimation with the Chemistry Transport Model KNMI (CTMK)

Van Velthoven

The vertical transport between the stratosphere and the troposphere was studied by evaluating a matrix that gives the amount of air that is transferred between the different model layers of a 3-dimensional off-line transport model coupled to ECMWF analyses. The latitudinal structure of vertical exchange reflects the Hadley circulation with upward transport in the tropics and with downward transport at mid-latitudes. Maxima in downward transport occur near the subtropical and polar jet streams. Its seasonal cycle and the asymmetry between the two hemispheres are at least qualitatively represented by the model. However, it is found that the evaluated total amount of air transferred from the stratosphere to the troposphere per month is sensitive to the chosen horizontal model resolution. Refinement of this resolution from 8°x10° to 4°x5° leads to almost a doubling of the computed downward transport. Also, the vertical transport is found to depend strongly on changes in the parameterization schemes of the ECMWF model. Internal consistence of the meteorological input data is a prerequisite for performing multi-year simulations with off-line Chemistry-Transport Models.

Cross-tropopause transport in the extratropical Northern winter hemisphere, diagnosed from high-resolution ECMWF data

Siegmund, Van Velthoven

A detailed analysis of the upward and downward mass fluxes of air across the tropopause was made. The tropopause was defined as the potential vorticity=3.5 PVU-surface for the extratropical Northern Hemisphere. High spatial and temporal resolution (0.5° latitude and longitude, 31 levels, 3-hourly) ECMWF-circulation data for January 1994 was used in this study.

The diagnosed net cross-tropopause transport is -0.35 x 10^{17} kg for January 1994 (downward) for the area north of 28°N. This net transport is smaller than that across the 2.5- and 1.5 PVU-surfaces (see Fig. 5), and larger than the 'downward control'-result. This indicates that the net downward transport across the tropopause is a combination of transport from the upper stratosphere to the troposphere and transport from the lower stratosphere to the troposphere. The latter transport indicates the existence of a circulation in which air is transported from the subtropical upper

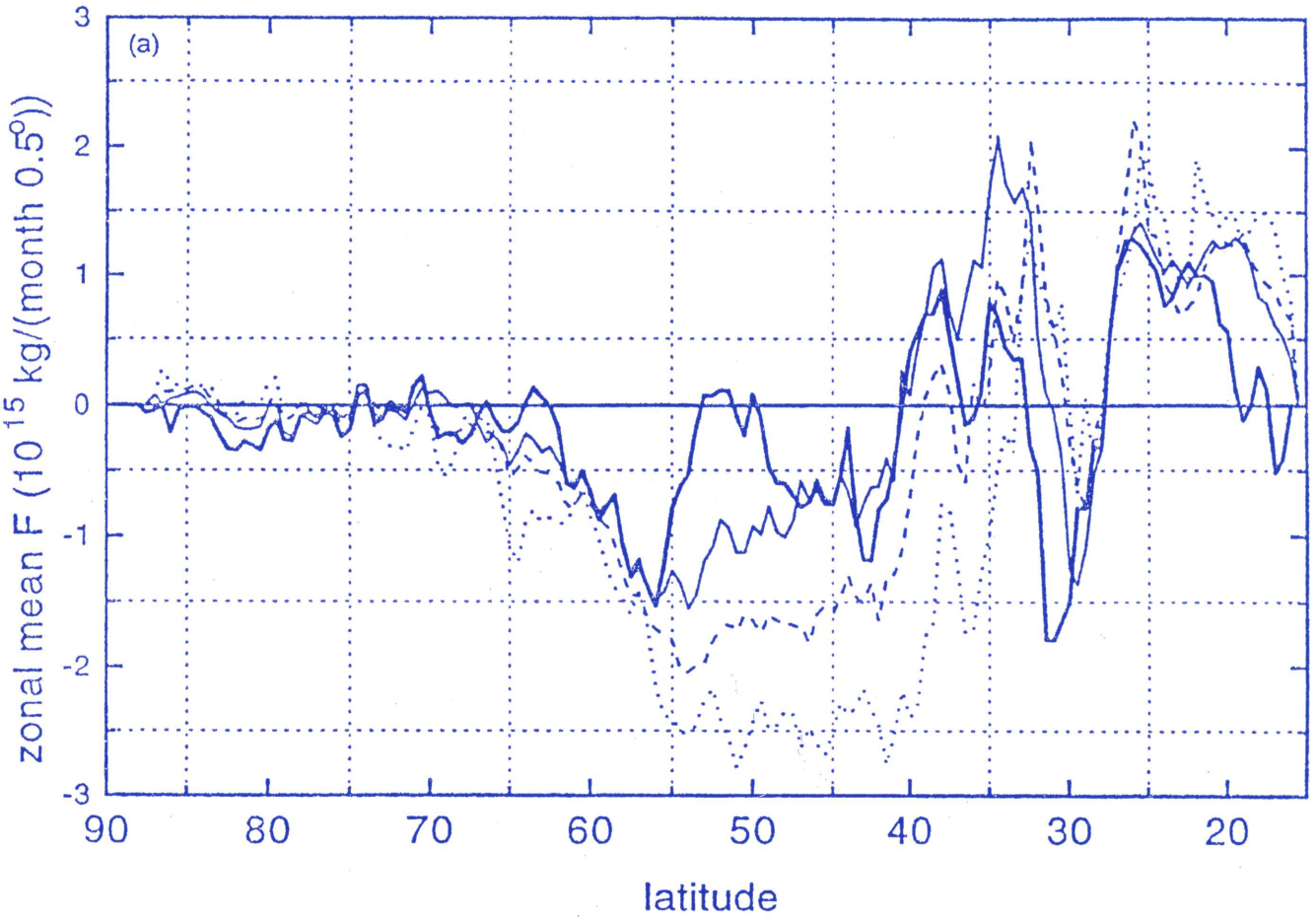

Figure 5. Zonal January 1994 mean mass flux across the 3.5 PVU-defined tropopause (thick solid curve); zonal and 1-14 January 1994 mean mass flux across the PV-defined tropopause at levels of 1.5 PVU (dotted), 2.5 PVU (dashed) and 3.5 PVU (thin solid curve); the results are computed from 0.5° resolution data and refer to the Northern Hemisphere. Units are 10^{15} kg per month per 0.5° latitude interval. Positive values indicate upward fluxes, negative values indicate downward fluxes.

troposphere to the upper troposphere at middle and higher latitudes via the lower stratosphere without ever reaching the upper stratosphere.
The diagnosed local and instantaneous cross-tropopause fluxes are, on average, about 40 times as large as their area- and time-mean value of -0.35×10^{17} kg (or -0.01×10^{-2} kgm^{-2}s^{-1}). This confirms the existence of a relatively large bidirectional exchange in the extratropics between the lower stratosphere and the troposphere.

Stratosphere-troposphere experiment by aircraft measurements

Siegmund, Van Velthoven

In 1996 the Atmospheric Composition Division provided meteorological and scientific support to the EU Stratosphere-Troposphere Experiment by Aircraft Measurements (STREAM) campaign in May/June near Shannon (Ireland). The main scientific objective was to improve the understanding of the processes that control stratosphere-troposphere exchange, notably cross-tropopause transport of air associated with synoptic disturbances and fronts.
In more detail, the meteorological and scientific support consists of: 1) meteorological guidance of the flights (implying: provision and interpretation of forecasts of standard and special meteorological fields (such as potential vorticity) and of forecasted back-trajectories), 2) post-campaign meteorological analysis, and 3) research on stratosphere-troposphere exchange.
For the precise planning of the flight, particularly the vertical cross sections of the potential vorticity were deemed very useful. From the STREAM-measurements it can be concluded that the location of the large gradients were forecasted with high accuracy. The measured ozone concentrations, for example, showed strong increases or decreases in those regions were the forecasted potential vorticity changed from tropospheric to stratospheric values or vice versa.

Boundary-layer processes

Verver

Modelling the chemical composition of the atmosphere involves the calculation of transport, mixing as well as chemical tranformations. Only when gases are mixed at the molecular scale chemical reaction between two molecules may occur. A measure of the importance of tuburlent mixing in controling the effective reaction rate is the Damkohler number (Da), the ratio of the chemical reaction rate and the turbulent mixing rate. When $Da \gg 1$ the chemical transformation rate is limited by the mixing process; when $Da \ll 1$ it is limited by the reactivity of the species involved. The effects of this interaction for Da-1 is studied in the Convective Boundary Layer (CBL) using a one-dimensional second order closure model, that includes chemical effects on the turbulent fluxes and on the (co-) variances of concentration fluctuations. Mixing timescales in the middle of a CBL is typically 1000 seconds.

The model is verified for inert species using observations of humidity and temperature. The results show that transport processes are represented well in the model. Numerical experiments are performed with two chemical reactive tracers that diffuse in opposite directions (top-down and bottom-up) as well as two tracers that are released from the surface. In the first case the negative correlation inhibits the mean transformation rate between 30% and 75% in the middle of the CBL, depending on Da. In the second case chemistry itself tends to generate a negative correlation of concentration fluctuations, while turbulence contributes to a positive correlation. For this case the effective transformation rate is either increased or decreased due to the covariance of concentrations.

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Wauben, W.M.F, 1996. *A new algorithm for total ozone retrieval from direct sun measurements with a filter instrument.* KNMI Scientific Report, WR **96-01**.

Piters, A.J.M, 1996. *OMI-Ozone Monitoring Instrument for Metop.* ESA Report WPP-**123**.

Number of international presentations: 32.

Externally funded projects: national 11, international 13.

Other activities:
H. Kelder, Dutch member of the WMO/UNEP Ozone Research Managers Committee.
H. Kelder, member of the SCIAMACHY Science Advisory Group.
H. Kelder, principal user of the Ozone Monitoring Instrument User Advisory Group of ESA.

Atmospheric Research Division

Surface energy balance over land

Bosveld, Holtslag, Ek, Van den Hurk, Kohsiek

Uncertainties in the representation of the surface energy over land is one of the key problems in climate modelling. The coupling with soil hydrology introduces anomalies on the time scales of seasons. Moreover the partitioning of energy into latent and sensible heatflux directly influences boundary layer moisture and cloud formation. In all cases the upscaling of local information to the scale of a grid box in a global circulation model is of importance.

Measurements of the energy balance and related quantities as the components of the radiation budget, CO_2-flux and vertical profiles of wind, temperature and moisture were continued at two locations, the Cabauw grassland site, representative for large parts of the west of the Netherlands, and at the Garderen forest site (TEBEX, Cabauw monitoring programme).

The reliability of net radiation instruments was investigated. The best instruments were found to marginally meet the requirements needed within the climate programme. Also the behaviour of a longwave radiation instrument was investigated. The sensitivity of a CO_2 fluctuation sensor was improved to meet the requirements for measuring fluxes over sea.

One year of Cabauw data were used in the Project for Intercomparison of Landsurface Schemes (PILPS). The same data were used to validate the boundary layer and surface representation in the ECMWF Re-analysis (ERA). The relation between fluxes and profiles was investigated in the roughness layer of a forest.

The relation between surface fluxes, soil and vegetation representation and atmospheric boundary layer development were investigated with the OSU CAPS model by improving the description of water movement in the soil and by a more sophisticated treatment of vegetation respons on atmospheric conditions. A new physically based formulation of the transfer coefficients between land surface and atmosphere was developed allowing for different roughness lengths for momentum and heat.

Boundary-layer structure and dynamics

Holtslag, Vogelezang, Siebesma, Petersen, Van Ulden

This project focusses on the formulation and evaluation of boundary-layer processes in large scale models. As such we studied the formulation of the boundary-layer height, the representation of boundary-layer fluxes, and the interaction of boundary-layer transports with chemistry and clouds (see below). In addition the representation of the boundary layer in the ECMWF model is evaluated with Cabauw tower and wind profiler data.

Bulk formulations for the boundary layer height are evaluated with field data at Cabauw, and with results of a Large Eddy Simulation (LES) model and a fine scale turbulence closure model. An updated formulation is introduced, which combines the effects of shear in the outer region of the boundary layer with surface friction. The updated formulation has a better performance for neutral boundary layers with upper level stratification. We show that for stable conditions, the updated formulation performs better than estimates on basis of surface friction alone. Overall the updated formulation improves model performance, when embedded in a non-local diffusion approach. The updated

formulation has also been evaluated to provide useful estimates of boundary-layer depth for air pollution studies within the COST-710 project.

To improve the flux formulation in convective boundary layers, we performed a number of Large-Eddy Simulations for different types of boundary layers (in co-operation with Hans Cuijpers (IMAU)). Useful approximations for the transport and buoyancy terms in the flux budgets are achieved by using a generalized convective scaling. This directly provides an expression for scalar and buoyancy fluxes which combines downgradient and non-local effects on the fluxes. The non-local effects are due to vertical velocity variance and the integrated flux over the boundary layer. This result is compared with an alternative expression in which the non-local flux is related to the skewness of the vertical velocity field and the scalar flux gradient. Overall it appears that the nonlocal flux is mostly related to the vertical velocity variance and the integrated flux and not so much to the skewness. The final result is a simple expression for scalar and buoyancy fluxes, that can be used in mesoscale and global models.

In addition we studied the usefulness of updraught-downdraught structures in the parameterization of scalar transport (temperature, humidity, and chemically reactive species) in the convective boundary layer. This work is done in collaboration with A.C. Petersen (IMAU). The boundary-layer structures are included in mass-flux schemes, which are applicable for an arbitrary source-sink distribution. Also the co-variance of two scalars is easily modelled, which is an important quantity for modelling segregation effects in atmospheric chemistry.

Cabauw data have also been used in the ECMWF re-analysis project (ERA). Analysed profiles of wind, temperature and humidity have been compared with observations along the Cabauw mast. Especially in conditions with low level inversions, modelled profiles deviate significantly from the observations. This is probably due to deficiencies in the model representation of vertical mixing.

The structure and dynamics of non-precipitating clouds

Van Ulden, Siebesma, Holtslag, Van Meijgaard, Jonker, Bechtold

This project aims at the improvement of parameterizations for cloud cover, cloud liquid water and cloud optical depth in weather and climate models. To this end characteristic observed cases are analysed and simulated with a Cloud Resolving Model (CREAM). From these analyses dominant processes are identified and improved parameterizations are developed. These parameterizations are then tested in a single column model and in a Regional Climate Model (RACMO; described below). This work is done in international collaboration (EU project EUCREM and GEWEX cloud system studies GCSS). Several approaches have been tested.

One approach is based on the Tiedtke mass-flux scheme and applicable to shallow cumulus. It appears that such a scheme has a satisfactory performance, provided suitable entrainment coefficients are used.

Another approach uses a parameterization for the sub-grid distribution of total moisture in combination with a non-local eddy diffusivity to describe cloud mixing. This approach works satisfactory also, provided a suitable profile for the eddy diffusivity is used.
A third approach aims at the derivation of fundamental prognostic equations for cloud fractions and cloud liquid water. It has been attempted to merge the mass flux approach and the moisture distribution approach. Preliminary results have been presented at the GEWEX conference in Washington DC.

In addition to these studies the structure of cloud fields has been studied. A sophisticated wavelet analysis system has been developed and applied to observed cloud fields and to cloud fields produced by the cloud resolving model. Publications are in preparation.

Interaction of surface fluxes with shallow cumulus convection over sea

Holtslag, Siebesma, Van Ulden, Vogelezang

In this study we explore the performance of five alternative model formulations in use in Europe for climate research and weather forecasting. The study is sponsered by the EC. For one location in the tropics, we compare the model results and their impact on the surface fluxes. To this end, we selected data from the 'Barbados Oceanic and Meteorological EXperiment (BOMEX). These data are also utilized to perform a 'Large-Eddy Simulation' (LES) with realistic forcings. The latter study produced tendencies of turbulence and cloud processes in response to the prescribed forcings by radiation, and horizontal and vertical advection.

Using the same forcings as for the LES model, we compare the outputs of the five models for one column. Thus for each of the selected models, the active physical modules are the surface flux scheme, the boundary layer diffusion scheme and the cloud convection scheme. The outputs of the various schemes provide insight in the actual variation of the surface fluxes in controlled conditions. To reduce the dynamical feedbacks even futher, we also keep the wind field constant in time for all of the models.

It is found that the five different models, even with the same forcings and initial conditions, do show quite different behaviour. This is particularly true for the structure of mean profiles in the cumulus layer, and for the magnitude of the surface fluxes for sensible and latent heat.

Comparing the outputs for the surface fluxes of the different model runs, shows a range for the sensible and latent heat fluxes of about 20 and 65 W/m^2, respectively! This provides an uncertainty of about 80 W/m^2 in the enthalpy flux forcing the ocean for this particular case.

After experimenting with the different model codes, it appears that the range of calculated fluxes is not so much related to the flux formulations themselves (as originally was thought). In fact the range of flux values arises mostly due to the different interactions of the surface fluxes with the respective convection schemes. All the original formulations of the convection schemes provide too much activity for the BOMEX case (in comparison with the LES output and observations).
This confirms conclusions obtained previously by Siebesma and Holtslag (J. Atmos. Sci., **53**, 2354-2364, 1996). After adjustments are made in the formulations of the different convection schemes, four of the five model codes have a surface enthalpy flux within 6 W/m^2 (the fifth model code shows even after adjustment still too much activity).

A major conclusion of this work is that an inadequate representation of shallow convection in atmospheric models may lead to serious drift problems in coupled atmosphere-ocean modelling studies.

RACMO (Regional Atmospheric Climate Model)

Van Meijgaard

In recent years a Regional Atmospheric Climate Model (RACMO) is developed on the basis of the physics package of the ECHAM general circulation model. RACMO integrates the model representations of the various diabatic processes such as boundary layer mixing, convection, clouds and precipitation, radiation, and surface processes. RACMO primarily serves as an instrument to evaluate the performance of existing or new physical parameterizations on a regional scale, and to study their mutual interactions. In its customary setup the model employs a 0.5 degree horizontal spacing and 19 levels in the vertical. ECMWF-analyses are used to drive the model at the lateral boundaries.

In 1996 RACMO is used in three distinct applications.

a. Precipitation forecasts

Van Meijgaard

RACMO is used to evaluate the ability of the model physics to generate realistic amounts of precipitation during the flooding episodes of the Meuse in December 1993 and January 1995. The model is run in verification mode. In such a mode the model is initialized only once from an analysis. For the remainder of the run the model state is only directed by observations at the lateral boundaries.

The precipitation time series for the Meuse catchment area, generated by model runs with a range of over a month are found to have negligible bias. The correlation between modelled and observed 24-hour amounts is in the order of 0.8. For the shorter-term periods with intense precipitation just prior to the floodings, the simulation with the regional model underestimated the observed amounts in the Belgian Ardennes by 10 to 15 percent.

In both events the general circulation over Western Europe was dominated by an intense and persistent cyclonic zonal flow. It can be concluded that RACMO is capable of simulating the huge amounts of precipitation which are typically observed in wintertime in relation to this type of circulation.

b. Soil Moisture Assimilation

Van den Hurk, Van Meijgaard, Holtslag

In the framework of research funded by the Dutch Remote Sensing Committee the Atmospheric Research Division continued efforts involving assimilation of remotely sensed land surface energy balance indicators into a RACMO, in order to control prognostic soil moisture evolutions in the model.

As a test case, a simple assimilation procedure was designed and applied to a seven-day summer period for the Iberian peninsula. During that period in July 1994, METEOSAT and NOAA data at three days were processed into maps of land surface evaporative fraction (evaporation divided by available energy). Using these images, predictions of evaporative fraction with RACMO were forced to match the remotely sensed quantities by updating soil moisture content in RACMO.

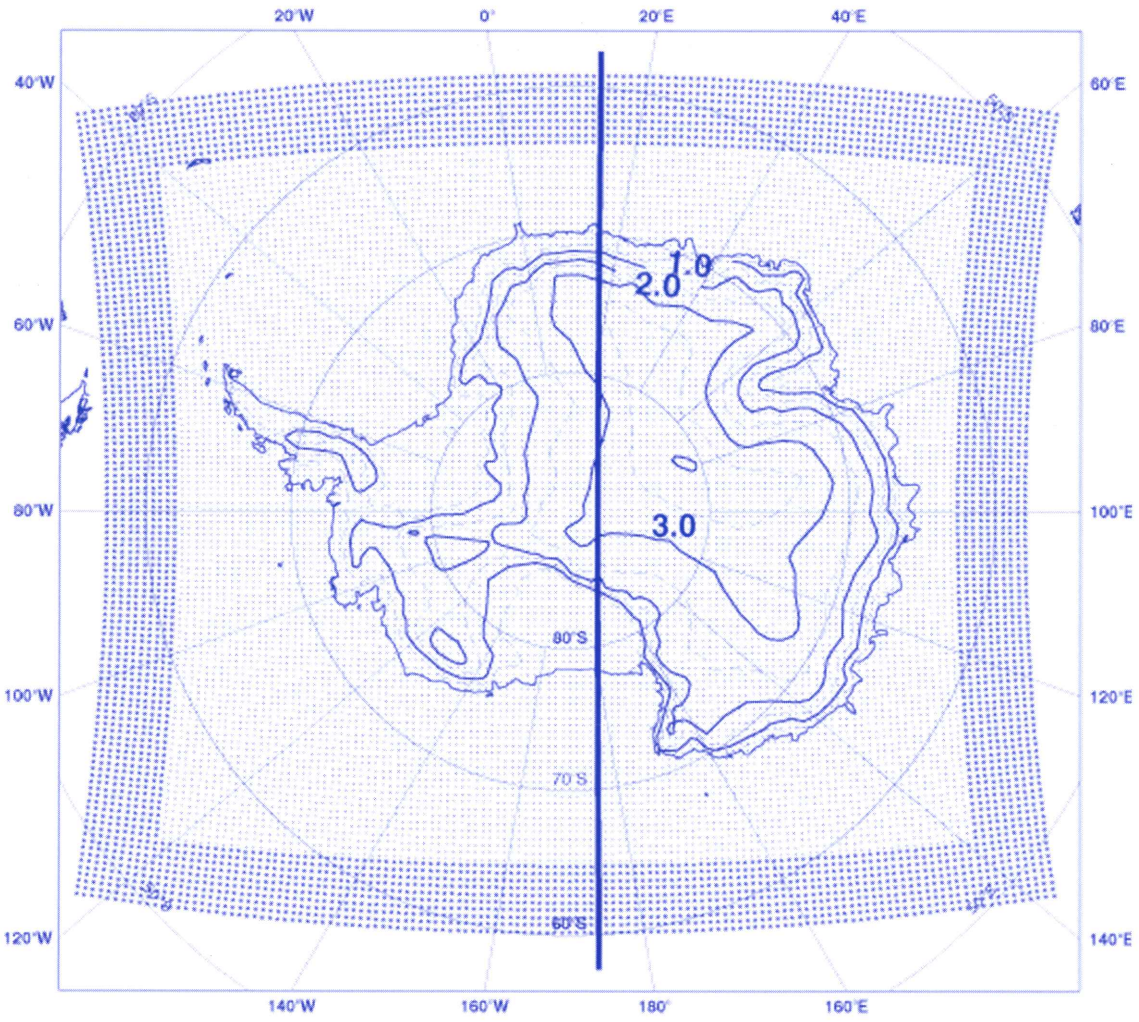
Two parallel runs - one with soil moisture update and one without - showed a clear improvement of biases of 2m temperature and specific humidity when soil moisture was updated. The excessive drying as predicted by RACMO without soil moisture update was avoided by nudging soil moisture using satellite data.

c. Climate of Antarctica

Van Lipzig, Van Meijgaard

As the surface mass balance of the Antarctic continent is determined by the atmospheric circulation, an atmospheric model may provide detailed information on its evolution in present and future climates. However, the capability of 'state of the art' atmospheric models to simulate the present-day climate of Antarctica is not well established, partly due to the lack of comprehensive field campaigns on the continent.

In the austral summer of '92-'93, extensive measurements of the boundary-layer structure and the surface energy fluxes, were carried out by the IMAU at the Swedish research station SVEA, Dronning Maud Land. A two-week period of this summer is simulated with RACMO. A horizontal grid of 55 km (Fig. 1) is required to resolve the topography and the katabatic winds in sufficient detail. 122*130 grid points are used to cover the continent and part of the circumpolar sea ice. ▶



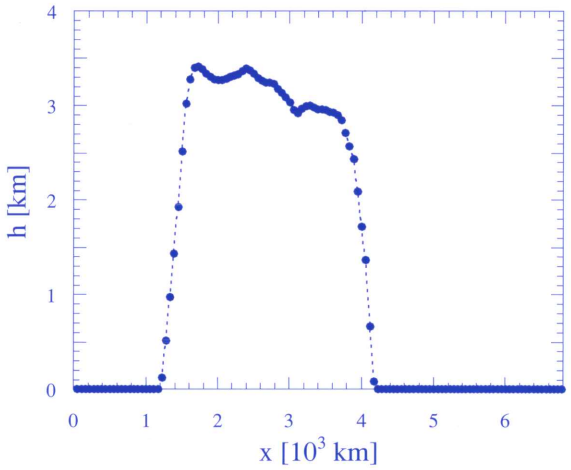


Figure 1. Top: RACMO grid. A horizontal resolution of 55 km is required to represent the Antarctic topography in sufficient detail. The surface geopotential height (km) is indicated by contour lines. Below: Model orography along the cross section, through the model domain, as indicated by the bold line in the top Figure. Dots refer to model grid points.

An important finding is that the RACMO temperature profiles in the boundary layer correspond reasonably well to the observed profiles. On the other hand, the model significantly overestimates the oberved water vapour content in the boundary layer. There is a sharp contrast between the RACMO temperature profiles and the re-analyzed profiles of the ECMWF model. Near the surface the latter profiles are far too stable.

Radiative transfer and atmospheric composition

Stammes, Van Dorland, Hess, Koelemeijer, Stam

In 1996, the optical parameters of 11 aerosol components of the Global Aerosol Data Set (GADS) have been incorporated into the ECHAM (MPI, Hamburg) broad band radiation code, to calculate the anthropogenic influence on climate due to sulfate and soot aerosols.
Furthermore, a start has been made with the parameterization of photolysis rates in the ECHAM shortwave radiation code in co-operation with MPI (Mainz).
It is expected that chemical modelling will improve if actinic fluxes can be computed on-line in the climate model.

The modelling of atmospheric radiative transfer in the shortwave range with special emphasis on the spectral dependence of radiance and polarisation in absorption bands, has been pursued. First results have been obtained on the effect of aerosol on radiance and polarisation in the oxygen A-band at 760 nm. The GOBELIN experiment at Space Research Organization Netherlands (SRON) has started in May. Measurements of spectral radiance and polarisation of skylight, to be performed in the GOBELIN framework in 1997, will be used to validate the DAK radiation model and help interpretation of Global Ozone Monitoring Experiment (GOME) data.

Work has started on the modelling of optical properties of ice crystals,which is relevant for e.g. interpretation of cirrus cloud observations.
The aim is to have a ray-tracing code by mid-1997 which can calculate the scattering and absorption properties of ice crystals with various shapes, in such a way that multiple scattering calculations needed for cirrus clouds can easily be performed.

This year the international GOME validation campaign, which lasted from mid-1995 to mid-1996, has been concluded.
We have contributed to the validation of GOME level 1 data (radiance, polarisation) and level 2 data (clouds). GOME data were compared to radiation model calculations and cloud observations from the ground (Cabauw) and from other satellites (Meteosat).
The potential of the PMD data of GOME for scene identification and cloud detection has been demonstrated. Furthermore, new information on the spectral surface albedo has been derived from GOME data. Work on calibration intercomparison between GOME and ATSR-2 has shown good agreement.
Spectral studies of clouds using GOME data have been started. It has been shown that vegetation shines through clouds in the near-infrared.
Preparatory work for the successors of GOME, Scanning Imaging Absorption Spectrometer for Atmospheric Cartography (SCIAMACHY) (1999) and Ozone Monitoring Instrumtent (OMI) (2001), has been an ongoing activity.

Regional cloudiness and water vapour (TEBEX, CLARA, GPS)

Van Lammeren, Feijt, Konings, Klein Baltink, Derks, Van Meijgaard

The representation of clouds and of their impact on radiative transfer remains one of the greatest sources of uncertainty in present day climate models. To improve this representation, better parameterizations of clouds are needed. In addition, the relation between clouds and radiative transfer has to be clarified. For model improvements, dedicated measurements are needed. In the Netherlands, KNMI has established a Cloud Detection System (CDS) which focusses on the observation of macro properties of clouds and radiation, spatial and temporal variability of clouds, but which also provides some information on microphysics. This network operated continuously for a period of more than two years (data collection was stopped on 31 December 1996). In the CDS remote sensing measurements from 10 ground stations are archived. At each station a lidar, infrared radiometer, pyranometer and a precipitation detector is installed. Satellite measurements from Meteosat and NOAA/AVHRR are also archived. ►

The CDS data for the first two months of 1995 have been analysed. The first parameter on which we concentrated was total cloud cover. The main conclusions are:
- The integration of ground and satellite measurements improves the quality of the total cloud cover measurements. The combined result is significantly better than the total cloud cover derived from the ground based or satellite measurements alone.
- The CDS-data gives a reliable area-averaged total cloud cover (2σ is little more than one octa) if compared with the traditional synops. The total cloud cover per station is less accurate (2σ is two octa).

A start has been made with the validation of RACMO results with TEBEX-CDS and CLARA (Clouds and Radiation) data. For a one week period of 24 - 30 January 1995 the measured total cloud cover was in reasonable agreement with the RACMO-results. In RACMO different parameterization schemes were used. The differences between the different schemes were significant. The CDS-data will help to validate the different schemes.

In 1995 the CLARA-project started. This project is partly financed by the Netherlands Research Program on Air Pollution and Climate Change (NOP). In this project four institutes planned three experimental campaigns on clouds and radiation. In the start-up phase of the project the number of participating institutes increased to a total of nine. A full set of ground based remote sensing instruments (lidars, radar, microwave radiometer, GPS-receiver, Infrared-radiometer, visual and Infrared video) was combined with satellite measurements (Meteosat, ATSR, AVHRR and GOME), in situ aircraft data (FSSP to measure dropplet spectra) and traditional meteorological observations (radiosondes, surface temperature and humidity). In 1996 three campaigns (spring, summer and autumn) took place. Data was collected for about 8 weeks in total. Over fourty hours of aircraft measurements were taken. The information from the field campaigns is used to improve routine remote sensing retrieval methods (for ground-based and satellite remote sensing) and will also serve to test detailed models for clouds and radiative transfer.

During the CLARA campaigns the GPS (Global Positioning System) technique was applied to measure the water vapour column. This technique uses the tropospheric delay of the GPS signals to estimate the water vapour column. The first results are promising. An initial intercomparison was made with measurements from the microwave radiometer and radiosondes. The results from all three systems agreed within acceptable limits. Another intercomparison between the GPS-results and RACMO predicted water vapour column values (+6 - +30 hour) also showed a good agreement. This project was partly financed by the Dutch Board for Remote Sensing (BCRS).

TEBEX windprofiler/RASS/COST76

Klein Baltink, Monna

In the framework of TEBEX measurements of wind and temperature with the windprofiler/RASS were continued (Figs. 2,3). Some minor adjustments to the system set-up were implemented amongst

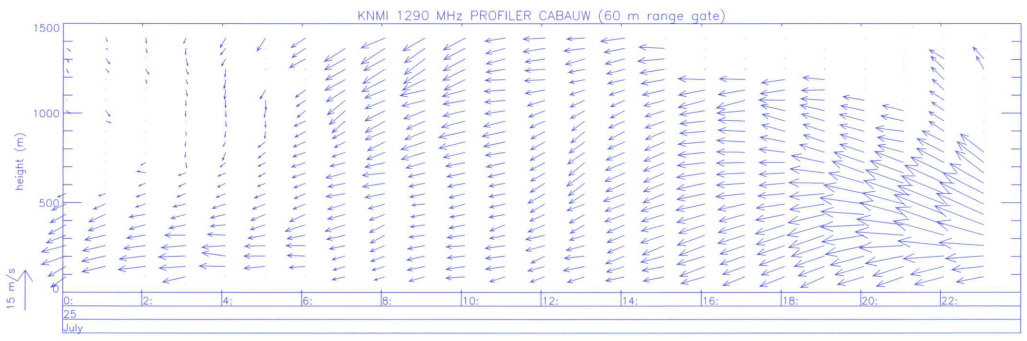


Figure 2. Example of 1290 Mhz profiler wind data low mode for 25th July 1995. After 20:00 h a nocturnal jet is clearly visible in the wind data.

which the time synchronisation of profiler and a collocated ceilometer. This is an essential condition for performing 'conditional sampling' of vertical velocity variances in (boundary layer) clouds to be executed in the analysis of TEBEX dataset.

In close co-operation with DWD-Lindenberg a new method for processing of heatflux measurements was assessed with positive results. Data from dedicated RASS measurements at the TEBEX observing site Cabauw were used for this assessment. Intercomparison of profiler/RASS, tower and radiosonde measurements was continued. In general good agreement is found but preprocessing and quality control still need more research to improve data quality.

COST76 initiated the demonstration project CWINDE 97 for a real time European network of windprofilers. A real time BUFR encoding and transmission on the GTS was implemented for this project.

Regional and global radiation budget

Van Dorland, Feijt, Van Lammeren

Atmospheric radiative transfer is an important process in the climate system. Changes in atmospheric compostion, such as anthropogenic increases of greenhouse gases and aerosol burden, affect the radiation balance and in turn influence a variety of physical as well as chemical processes. In this respect, changes (feedbacks) of the hydrological cycle are considered to be quite relevant. Therefore, better knowlegde of the interaction between radiation and clouds by measurements may result in the improvement of the physical parameterizations in climate models.

Within the framework of SINDICATE-II the radiative forcing due to anthropogenic increases of tropospheric ozone and sulfate aerosols has been evaluated using the broad band radiative transfer model of the KRCM (KNMI Radiative-Convective Model), which is compatible with the ECHAM Climate Model (MPI, Hamburg). The monthly averaged global concentration fields of the investigated constituents and their precursors have been computed with the MOGUNTIA transport/chemistry model (IMAU, Utrecht) for the pre-industrial (1850) case, the contemporary atmosphere (1990) and for the future (2050).

The TEBEX Cloud Detection System (CDS) was designed to measure cloud parameters and radiation. For a period of two years, global radiation data for over 30 stations in a 200x300 km area was collected and archived. A first analysis of the data showed the large variability of global radiation over distances of less then 50km. Qualitative comparisons have been made with reflectivity measurements from satellites (Meteosat and NOAA/AVHRR).

For the TEBEX region the area averaged global radiation data was correlated with the area averaged total cloud cover. Examples of strong correlation but also of anti-correlation were found. This illustrates the ambiguous relation between total cloud cover and global radiation.
Other cloud parameters have to be included in order to clarify this relation.

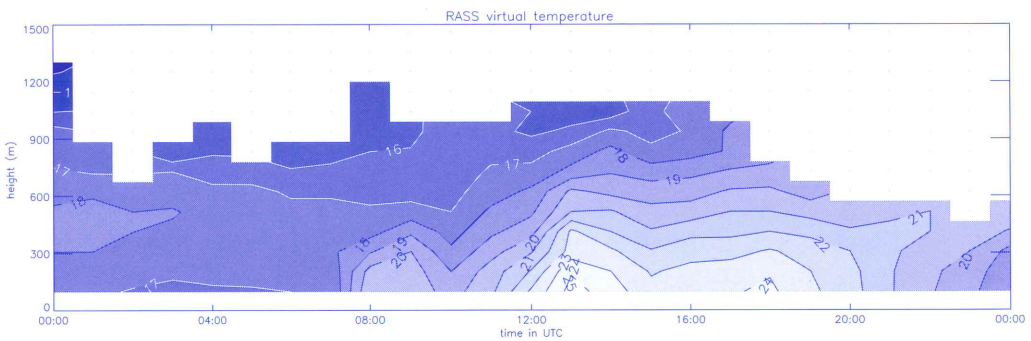


Figure 3. RASS temperature data (100 m. gate) for 25th July 1995, contours at 1°C intervals.

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Ayotte, K.W., P.P. Sullivan. A. Andren, S.C. Doney, A.A.M. Holtslag, W.G. Large, J.C. McWilliams, C.-H. Moeng, M. Otte, J.J. Tribbia and J.C. Wijngaard, 1996. *An evaluation of neutral and convective planetary boundary layer parameterizations relative to Large Eddy simulations.* Boundary-Layer Meteorol., **79**, 131-175.

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Christensen, J.H., O.B. Christensen, P. Lopez, E. van Meijgaard, and M. Botzet, 1996. *The HIRHAM4 Regional Atmospheric Climate Model.* DMI Scientific Report 91-4, DMI, Copenhagen.

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Number of international presentations: 47.

Externally funded projects: national 5, international 3.

Books and/or theses:
Hurk, B.J.J.M. van den, 1996. *Sparse canopy parameterization for meteorological models*; PhD-thesis Wageningen Agricultural University, Wageningen, The Netherlands, 271 pp.

Other activities:
A.A.M. Holtslag, associate-editor Journal of Geophysical Research, Section Atmosphere.
A.A.M. Holtslag, chairman review committee on research proposals, submitted to Netherlands Organisation for Research/Geosciences, Oceanography and Atmospheres (NWO/GOA).
A.A.M. Holtslag, member of the programme board Netherlands Centre for Climate Research (CKO).
A.A.M. Holtslag, member of the Advisory Committee: International collaboration in fundamental climate and atmospheric chemistry research (Crutzen committee, July 1996).
H. Klein Baltink, member working group II Science and Technology of COST-76.
W.A.A. Monna, chairman of COST-76.
P. Stammes, member of the GOME Science Advisory Group of ESA.
P. Stammes, member SCIAMACHY Science Advisory Group of DARA/NIVR.

Climate Analysis and Scenarios Subdivision

Within this theme the research is focussed on climate variability in instrumental records and in proxy records and on the production of climate scenarios by means of statistical downscaling. The climate scenarios were made in close co-operation with the users from the impact community. The focus is mainly on temperature and precipitation. There is a heavy statistical component in the activities. The subdivision provides climate information to specialists, to the government and to the general public.

Climate Report

Können, Fransen, Beersma, Brandsma, Buishand

In the framework of the latter, a report (in Dutch) has been compiled 'The state of the climate in the Netherlands, 1996'. In this report, time series of meteorological elements are presented for the Netherlands and analysed for trends. The fluctuations are put in the perspective of the climate changes for the next century. A possible realisation of the Netherlands climate, based on downscaling is presented. This report was presented to the Minister of Transport, Public Works and Water Management on 5 June 1996. Co-authors outside the group were H. Wessels, J. Opsteegh, A. Kattenberg and E. Bouws.

Fourth Governmental Bill on Water Management

Können, Fransen

A document was prepared for the Ministry of Transport, Public Works and Water Management in which potential changes in climate for the next century are quantified. The outcomes are used by the Ministry for formulating in 1997 a long-term policy about dike reconstruction and water management. The climate scenario presented in this background document is an extended version of the one formulated in the Climate Report. Co-author of this document outside the group is R. Mureau.

Weather generator for precipitation

Buishand, Brandsma

This year, activity started to design a statistical weather generator for precipitation and temperature in the the Rhine basin. This project is part of a larger study to reduce the uncertainties about the design water levels for the planning of river dikes. The project is commissioned by the Institute for Inland Water Management and Waste Water Treatment (RIZA), part of the Ministry of Transport, Public Works and Water Management. The aim of the project is to get a better insight in extreme river discharges.

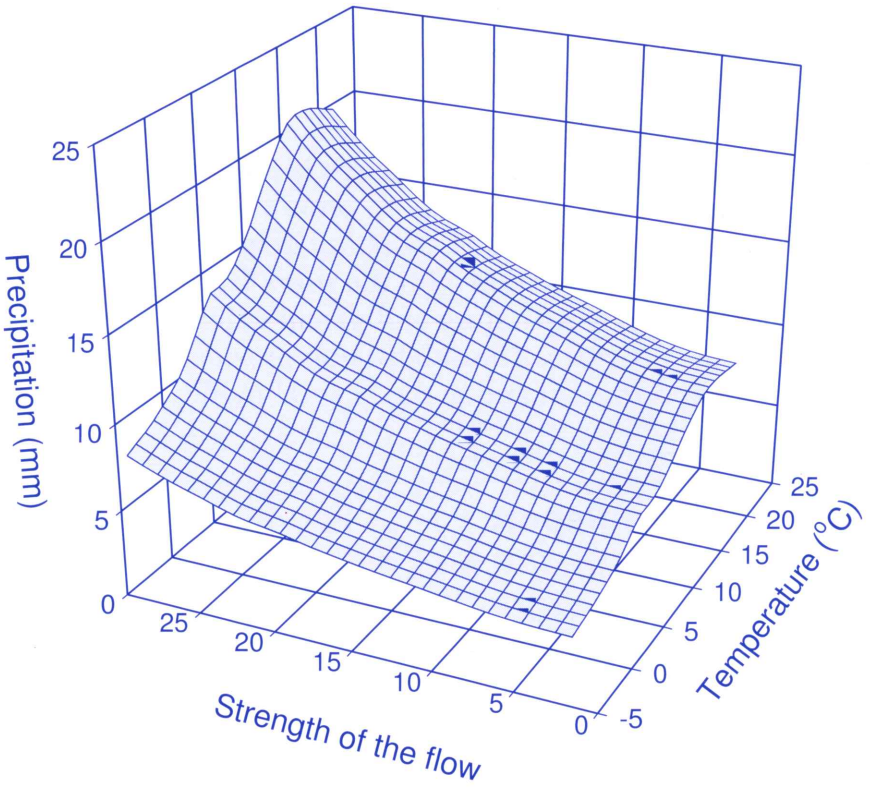


Figure 1. Relationship between mean precipitation on wet days, temperature and strength of the atmospheric flow at Bern (Switzerland) for the period 1901-1993 for flow directions between Southwest and Northwest. Flow units are geostrophic and expressed as hPa per 10° latitude at 45° N.

Downscaling

Buishand, Brandsma, Beersma, Fransen

Commissioned by the Dutch National Research Program on Global Air Pollution and Climate Change (NOP) an assessment has been made about techniques for producing regional climate scenarios for impact studies (in co-operation with A. Klein Tank). The assesment includes a strength and weakness analysis in methodological and practical sense. Special attention has been given to statistical downscaling techniques. There is an increasing international interest in this approach (IPCC, Eclat). J. Beersma has been invited to serve in the steering committee of the EU Eclat project, that aims at development of climate scenarios on European level.

In the framework of the EU-project Popsicle, daily sums of precipitation in a number of European river catchments were related to temperature and atmospheric circulation.

The temperture is found to be an important explanatory variable for making climate scenarios for a future warmer world (Fig. 1).

Statistical Research

Buishand, Beersma

A method has been developed for testing differences in variance between climate time series. T. Buishand has been invited to participate in the Editorial Board of the new journal Extremes.

(Paleo) climate variability

Shabalova, Können

A study has been performed to compare temperature/precipitation relations in paleodata and in CO_2 equilibrium runs. A project has been formulated to analyse interdecadal climate variability in models and (proxy) data.

El Niño, data base building

Können, Kaltofen

Time series are indispensible for climate research. Several precipitation series over the Netherlands have been digitized. In the framework of the study of climate variability, a successful attempt has been undertaken to recover early 19th century meteorological observation series from Indonesia and Tahiti. The data enable an extension by 25% of the existing Tahiti-Darwin Southern Oscillation Index time series (joint project with P. Jones, UEA (UK) and R. Allen, CSIRO (Australia)).

Articles, published in standard journals:

Buishand, T.A., and A.M.G. Klein Tank, 1996. *Regression model for generating time series of daily precipitation amounts for climate change impact studies.* J. Stoch. Hydrol. and Hydraul., **10**, 87-106.

Buishand, T.A., and J.J. Beersma, 1996. *Statistical tests for comparison of temporal variability in observed and simulated climates.* J. Climate, **9**, 2538-2550.

Scientific and technical reports:

Rider, K.M., G.J. Komen, and J.J. Beersma, 1996. *Simulations of the response of the ocean waves in the North Atlantic and North Sea to CO_2 doubling in the Atmosphere.* KNMI Scientific Report WR **96-05**.

Brandsma, T., and T.A. Buishand, 1996. *KNMI contribution to the European project Popsicle.* KNMI Technical Report TR-**194**.

Buishand, T.A., and T. Brandsma, 1996. *Rainfall generator for the Rhine catchment: a feasibility study.* KNMI Technical Report TR-**183**.

Können, G.P. KNMI Climate Report: *De toestand van het klimaat in Nederland 1996* [The State of the Climate in the Netherlands in 1996] (in Dutch); editor and contributer.

Fransen, W. KNMI Climate Report: *De toestand van het klimaat in Nederland 1996* [The State of the Climate in the Netherlands in 1996] (in Dutch); co-editor.

Beersma, J.J. Contributor to Chapter 1 of the KNMI Climate Report: *De toestand van het klimaat in Nederland 1996* [The State of the Climate in the Netherlands in 1996] (in Dutch).

Brandsma, T. Contributor to Chapter 1 of, and constructive figures in the KNMI Climate Report: *De toestand van het klimaat in Nederland 1996* [The State of the Climate in the Netherlands in 1996] (in Dutch).

Buishand, T.A. Contributor to Chapter 1 of the KNMI Climate Report: *De toestand van het klimaat in Nederland 1996* [The State of the Climate in the Netherlands in 1996] (in Dutch).

Number of international presentations: 2.

Externally funded projects: national 5, international 1.

Books

Buishand, T.A. contributing author of Chapter 6 of Houghton, J.F., G. Meira, B.A. Callander, N. Harris, A. Kattenberg, and K. Maskell (eds.), 1996. *Climate Change, 1995: IPCC WGI Assessment Report.* Cambridge UP.

Können, G.P. contributing author of Chapter 6 of Houghton, J.F., G. Meira, B.A. Callander, N. Harris, A. Kattenberg, and K. Maskell (eds.), 1996. *Climate Change, 1995: IPCC WGI Assessment Report.* Cambridge UP.

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 Commission for Climatology (CCl) of the WMO.

Climate Research and Society

Staff Unit Coordination Climate Policy (CCP)

A staff unit Coordination Climate Policy of KNMI is charged with representing the Ministry of Transport, Public Works and Water Management in the national and international climate discussions. It serves as a 'look-out' in scanning relevant external climate related developments and initiates and resumes actitivities and other responses if necessary, by the sectors within the Ministry. The unit is not responsible for the actual policy on climate related aspects of the Ministry, such as road transport, aviation, shipping and coastal protection.

The unit also serves as an interface between science and scientists on the one hand and policy and policy makers on the other hand.

IPCC

Interest in climate change issues in society continued to be large.

The Head of the Department of Climate Research and Seismology, A. Baede, is principal delegate for the Netherlands to the plenary meetings of IPCC. In this capacity he chairs the meetings of the national IPCC coordination group, which convenes several times each year in order to coordinate activities and exchange information on all IPCC related matters.

The Head of the Division Oceanographic Research, G. Komen, is the Netherlands focal point for IPCC Working Group I. A. Kattenberg contributed to the IPCC Working Group I Report as editor and as convening lead author of Chapter 6. T. Buishand and G. Können served as contributing authors to Chapter 6 of this report. Many others from the Department of Climate Research and Seismology were involved in the review of the IPCC Working Group I Report.

Framework Convention on Climate Change (FCCC)

The CCP-unit represents the Ministry to all bodies of the FCCC: Conference of the Parties (CoP), Subsidiairy Body on Implementation (SBI), Subsidiairy Body on Scientific and Technological Advice (SBSTA), Ad-hoc Group on the Berlin Mandate (AGBM) and Ad-hoc Group on article 13 (AG13).
In SBSTA the Head of the CCP-unit has been appointed head of the Dutch delegation, and therefore acted as a central point in the national preparation. The SBSTA is meant to give the CoP scientific and technological advice. However, SBSTA was confronted with a variety of political topics as well. For instance, a lot of attention was given to the balanced representation of experts of developing and industrialised countries in work for the SBSTA, also to ensure capacity building during the process.
As a delegate from the Royal Netherlands Meteorological institute, the Head of CCP paid special attention to the consideration by the SBSTA of the IPCC Second Assessment Report. The SBSTA recommended this Report to the CoP as the most comprehensive and authoritative assessment available.
As a representative of the Ministry of Transport, the CCP-unit took care of issues involving aviation and marine transport. Under the FCCC, there is no agreement yet on how to allocate the emissions related to these sectors to particular countries, because of the international character of these

sectors. The CCP-unit prepared a document on this issue to facilitate the national discussions between ministries on this topic. This lead to a Dutch position, which than formed the basis for the EU position. The CCP-unit was requested by the secretariat of the FCCC to assist in the preparation of a document on the issue of international civil aviation and marine transport. This resulted in a fortnights outplacement of one of the staff of the unit, and strengthened the informal contacts with the secretariat.

The expertise within CCP was recognized by the secretarial of FCCC, which led to an urgent appeal by the secretariat to assist in the preparation of the SBSTA-document on this issue. Following this request a two weeks stay in Geneva of one of the policy advisors of CCP has been granted to assist the secretariat. An additional positive effect of this stay are the excellent informal contacts with the officials of the secretariat.

NOP

The Netherlands Research Program on Air Pollution and Climate Change (NOP) is a policy orientated scientific research program. KNMI is involved on several levels in the preparation of the research program and in the actual execution of research projects. The Director of KNMI acts as vice-chairman of the Steering Board, whereas the Head of CCP is vice-chairman of the Program Board. In that capacity the latter acted as interim chairman during the summer of 1996, after which the newly appointed chairman took over. Several KNMI staff members are involved in Programming Groups of NOP.

Public Relations

The Ministries for the Environment and for Foreign Affairs were invited at KNMI to have discussions and lectures on climate change. The main purpose was to strengthen the position of KNMI in the inter-ministerial working field and its position as an independent source of scientific information on atmospheric issues.
Additionally the Directorate for Development Co-operation of the Ministry for Foreign Affairs was invited.

Parliamentary inquiry Commission on Climatic Change

In December 1995 the decision was made by the government to organize a parliamentary hearing on climate change, its causes, impacts and response strategies.
For this, the Temporary Commission on Climatic Change was established with parliamentarian E. Middelkoop as chairman.

The Commission requested the KNMI for technical scientific assistance. Consequently Head of the Atmospheric Research Division A.P. van Ulden was appointed as advisor and KNMI employee W. Fransen as executive secretary.

The Commission organized private and public hearings, for which about fourty persons were invited. Topics were the science of climate, impacts, socio-economic effects and response strategies. Scientists as well as representatives from non-governmental organizations were invited for the hearing. The KNMI representatives among them were A. Baede, A. Kattenberg, G. Komen en A. van Ulden. They informed the Commission about the scientific side of the problem, both in closed sessions and in public hearings. ▶

The whole process of the parliamentary inquiry took about 10 months. The Commission acknowledged in the final report the significance of the climate issue and the need to act on basis of the precautionary principle. The Commission considered the enquiry and the direct hearing of representatives of (physical) sciences a successful and productive approach.

Articles, published in standard journals:

Books or/and thesis:
Baede, A.P.M., P.A. Schenck, J.E. Hinte, A. van Leusink, W. Spakman, H. Speelman, P.J.G. Teunissen, A.J. de Gier, P.K. Teeuw, and P. Vellinga, 1996. *Eindrapport van de Verkenningscommissie Aardwetenschappen: Ruimte voor Aardwetenschappen, Toekomstverkenning aardwetenschappelijk onderzoek*, VCA.

Number of international presentations: 2.

Other activities:
A.P.M. Baede. Member of GCOS Panel on Atmospheric Observation.
A.P.M. Baede. Member of WMO/CBS Working Group on Observation.
A.P.M. Baede. Expert member of COPEC Programming Committee, Framework programme Environment and Climate.
A.P.M. Baede. Netherlands representative for IPCC.
A.P.M. Baede. Representative of the Ministry of Transport, Public Works and Water Management in the NOP Steering Committee.
A.P.M. Baede. Chairman of the board of Space Research Organization Netherlands (SRON).
A.P.M. Baede. Chairman of the SRON/GO Programming Committee Users support.
A.P.M. Baede. Member of the IGBP Committee of the Royal Netherlands Academy of Arts and Sciences.
P.J.W. de Wildt. Member Dutch delegation Climate negotiations.
P.J.W. de Wildt. Netherlands representative SBSTA/FCCC.

Seismology Division

In general · 1996 was a memorable year for world wide seismology. After over 20 years of discussion and negotiations finally a Comprehensive Test Ban Treaty (CTBT) was signed. This treaty strongly has influenced seismology in the world. The verification of the treaty involves the establishment of a world wide geophysical network of stations distributed among four techniques; seismic, hydroacoustic, infrasonic and the measurement of radio nuclides. This constitutes the core of the International Monitoring System. The Monitoring System will be highly beneficial to the seismic community.

Again in 1996 the seismicity in the northern part of the Netherlands was higher than that of the southerly provinces. The South is known for its natural earthquakes, the North for its gas-induced events. The research within the Seismology Division is directed to both situations. Monitoring and studies of amplification of earthquake signals is conducted for the gas-induced events and a study of the relations between the geology of the Netherlands and earthquakes focus more directly on the natural events.

Also in 1996 a number of international projects such as the Global Seismic Hazard Assessment Programme (GSHAP) and the CEC-project 'Pilot project for regional earthquake monitoring an seismic hazard assessment' made sure that the Seismology division is active as part of the international seismic community.

Seismological Observations

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

Monitoring gas-related earthquakes in Groningen and Drenthe

Since summer 1995 a new network of 8 borehole seismometers is operational in the Netherlands, which resulted in better accuracy in epicentres and a lower threshold of detection of earthquakes. During 1996 a total of 41 earthquakes was recorded in the region. Magnitudes (M_L) vary between -0.2 and 2.7. A remarkable series of events occurred near the village of Roswinkel (South-East Drenthe). During February/March 5 events occurred (magnitude 1.3-2.6) and the activity continued in December 1996/January 1997 with another 3 events (magnitude 1.6-2.7). The depth of these events is shallow (1.5-2.5 km). Other felt events are also concentrated in Drenthe (Nieuw Roden, M_L = 2.1; Wachtum, M_L = 2.3).

During 1996 five accelerometers were installed in the Netherlands. Sites were selected where multiple events occurred in recent years. The first unit was installed near Roswinkel. At this site two events were recorded, providing for the first time measured peak accelerations in the epicentral area. Also, these recordings are used in the

determination of an accurate location of the events. Since the new network produced a high data volume the first year, a revision of the magnitude determination was made. The larger magnitude events ($M_L > 2.2$) did not change significantly, but the lower magnitudes scaled down.

Monitoring gas-related earthquakes in the province Noord-Holland

In Noord-Holland, around the city of Alkmaar, a network of 3 borehole seismometers is operational since 1995. During 1996 no events were recorded in Noord-Holland. However, there are frequently signals from off-shore explosions. These explosions are always verified detonations of old explosives from second world war.
Since in the region around Alkmaar a peak-gas installation became operational, an experiment with tiltmeters was planned. This experiment will be carried out in 1997.

EU-project Rapid Transfrontier Seismic Data Exchange

The overall goal of this project is to establish and maintain a network of seismological institutions among the 10 participating member states of the EC with the capability of exchanging raw data within, at most, one working day of the occurrence of an earthquake of significance to all participants.
The Seismology Division has concentrated on rapid access to earthquake data of two broad-band stations (HGN and WIT) by installing an Automatic Data Request Manager (AutoDRM). AutoDRM is a fully automatic process for rapid exchange of seismological information. During the first part of the project access to the waveform data of the two stations has been established. In 1996 the functionality has been extended to include parameter data from three stations (HGN, WIT and WTS). The parameter data include detections (the result of the detection process which runs on the waveform data) and arrivals (detections associated with a seismic source).
Other participants were advised on the implementation of AutoDRM. During a work-visit to the Dublin Institute of Advanced Studies (DIAS) a AutoDRM was installed to create rapid access to seismic stations from the Irish seismic network.

EU-project Rapid Warning System Earthquakes

This project intends to develop and upgrade the system in use at the European Mediterranean Seismological Centre (EMSC) for locating rapidly potentially destructive earthquakes. The Seismology Division is participating in this project with two objectives: To implement an automatic phase-picker to provide the EMSC with real-time parametric data from broad-band stations HGN and WIT. Secondly, Seismology Division will give real-time access to those stations for moment tensor studies.
An automatic phase-picker from the Japanese Meteorological Agency (JMA) has been installed and tested, and will become operational during the second half of the project period.
The Orfeus Data Center (ODC) has started efforts to implement an European SPYDER (TM) system to be triggered by an alert message from the EMSC. This system collects waveform data from a number of European broad-band stations within hours after the earthquake, and is until now triggered by the National Earthquake Information Service (NEIC) of the United States Geological Survey (USGS).

Regional Seismicity

Houtgast, Dost, Sleeman, Haak

The relation between tectonics and seismology in the Netherlands and border regions has been studied on the basis of literature and former published internal reports. Available data about tectonics and seismicity of this area were collected. It has become clear that the strongest earthquakes in the south-eastern part of the Netherlands are related to the most important faults such as the Peel Boundary Fault and the Feldbiss Fault. The fault plane solutions of these earthquakes are in good agreement with the position of these faults. In the case of weak earthquakes it has become more difficult to determine this relation, mainly as a result of both the unreliability of the parameters of the earthquakes (location and depth) and the location and orientation of the small faults. This problem becomes larger when historical earthquakes are considered. In general we have found a reasonable correlation between seismicity and tectonics.

The Basic Information System Seismology is an information system for the Seismology Division which contains data regarding seismicity and tectonics of countries and regions which are

situated in the most important seismic areas of the world. These data serve as easy accessible background information in the case of important earthquakes and at the same time a source for advising.

With regard to historical data information have been exchanged occasionally within the ESC Working Groups 'Historical Earthquake Data' and 'Macroseismology'.

Hazard and risk assessment

De Crook, Haak, Dost

Accelerometers

At the end of 1996 four stand-alone strong motion accelerographs have been installed in the northern part of the Netherlands for measuring ground accelerations during earthquakes. Therefore sites were selected with the highest frequency of earthquake occurrence. Another 3 will be installed in the beginning of 1997. Two earthquakes were recorded in December 1996 nearby Roswinkel with maximum horizontal accelerations around 10 and 140 cm/sec^2 and magnitudes 1.6 and 2.7.

Global Seismic Hazard Assessment Program

The Global Seismic Hazard Assessment Program (GSHAP-project) is a contribution of the International Lithosphere Program (ILP) to the International Decade for Natural Disaster Reduction (IDNDR) of the United Nations (UN), coordinated by the Istituto Nazionale di Geofisica (ING) in Rome. The project started in 1992 and will be finished in 1997. There are nine regional centres selected. The GeoForschungsZentrum at Potsdam is the regional centre for north and central Europe. The main activity of GSHAP is to assess regional seismic hazard maps.
The results for Central and North-West Europe will be published in a joint publication

Regionalisation

Initially Gutenberg & Richter subdivided the earth surface into 50 seismic regions. Later Flinn & Engdahl suggested a computer orientated regionalisation scheme of 728 regions. As even this concept seems to be too coarse for modern research the IASPEI Working Group on Regionalisation was founded with the aim to subdivide the existing regions into local seismogeographical regions, called level three regions.
The new regionalisation for the Netherlands, mainly based on seismicity and tectonics, was discussed with the adjacent countries for the borderline areas. There is now an agreement with United Kingdom and Germany. The regionalisation for Belgium is not yet finished. Each country in Europe will publish his new regionalisation in a joint publication coordinated by G. Leydecker (BGR Hannover).

Amplification of earthquake signals

In the northern part of the Netherlands three-component seismometers are installed on several levels in 11 boreholes to monitor the earthquakes, which are observed since 1986 and probably caused by gas extraction. On the seismograms of the stations with seismometers on the surface, Finsterwolde (FSW) and Zuidlaarderveen (ZLV), amplification effects are clearly observed. These amplification effects of local sedimentary layers are important in terms of seismic hazard and will be investigated in co-operation with the Geological Survey in several sites to identify the areas of higher hazard.
The theoretical amplification of the upper layers is calculated based on the wave propagation equation for vertically propagating S-waves. The model is one-dimensional and consists of horizontal layers. Each layer is homogeneous and isotropic, and is characterized by the parameters thickness, density, shear modulus or velocity of the S-wave and damping factor. The layers are known from the soil profile and the parameters can be estimated from geotechnical and seismic data. The model is tested in FSW in the upper 75 m and in ZLV in the upper 200 m.
In FSW three-component geophones are installed on five levels in a borehole of 300 m. The parameters of the upper 75 m are based on the soil profile and geotechnical data. Only the average velocity of the S-wave and the damping of the upper 75 m can be determined from seismograms of earthquakes. The results of the model do not fit well with the observations. An introduction of lower S-wave velocities in the upper 10 m improves the results.

In ZLV three-component geophones are installed on nine levels in a borehole of 200 m. The amplification, calculated with the computerprogram SHAKE, below 10 Hz of a rough model with layers of 25 m agree very well with the observed amplification. The average density of each layer is determined from the soil profile and geotechnical data. The velocity of the S-wave and the damping of the layers is calculated from seismograms. Moreover, a S-wave sonic log from 20 to 200 m is available. For frequencies above 10 Hz a detailed model of the upper 25 m is needed. However, the parameters can not be determined sufficiently accurate from the soil profile and known geotechnical data. More accurate geotechnical parameters are needed. A proposal was submitted to the Ministry of Economic Affairs for the measurements of accurate parameters to really fit theory and observations.

Comprehensive Test Ban Treaty

Haak, Sleeman, Van Bodegraven, De Wilde

During 1996 much time and effort was invested to advise on a technical level the Ministry of Foreign Affairs, more specifically the Netherlands Ambassador and his co-workers in Geneva. During the negotiations the Netherlands chaired the negotiating body of the Conference of Disarmament.
After over 20 years of discussion and negotiations finally the world has a Comprehensive Test Ban Treaty (CTBT). This treaty strongly influenced seismology in the world, technically and scientifically. The verification of the treaty involves a world wide geophysical network of stations distributed among four techniques; seismic, hydroacoustic, infrasonic and the measurement of radio nuclides. This constitutes the core of the International Monitoring System. With respect to seismology 75 primary stations and 120 secondary stations will monitor explosions in the world down to one kiloton of TNT and with an equivalent of magnitude 3.5 on the Richter Scale. All data will be sent to the International Data Centre in Vienna where it will be analyzed and filed. Participating states to the treaty will, if so requested, receive all data and all numerical results of the analysis such as location, depth and magnitude. A majority of the data will be available within 24 hours of a dataday. Besides the use of the networks for the pure purpose of monitoring there will be extensive use for scientific goals. Already now in the experimental phase our analysts use the data on a daily basis.

Nuclear explosions in 1996

In 1996 three nuclear explosions were carried out. One of them was conducted by France, the other two were conducted by China. All three nuclear explosions have been detected and identified by at least one of the KNMI seismograph stations.
On 27 January 1996 France conducted his final underground nuclear test, that was carried out at the Fangataufa Atoll test site. It was the last test of a series of six, announced by France to be essential before signing a Nuclear Test Ban Treaty. The previous five tests in this series were carried out in 1995. Shortly after the 27 January 1996 test President Chirac announced in a television address that this was 'the definitive end of France's nuclear tests'.
China conducted two underground nuclear tests in 1996, on June 8 and on July 29 respectively. Both tests were carried out at the Lop-Nor test site in the southern part of the Xinjiang Province. After the second test the Chinese authorities declared that this would be the final test and that an indefinite moratorium was now in force.

Nuclear Explosions 1996

Date (UT)	Expl. time hr:mn:sec	Georgr. Coord. Lat.°	Georgr. Coord. Long.°	Magnitude	Yield (KT)	Test site	Remarks
960127	21:29:57.7	22.236 S	138.815 W	5.3	15-30	Fangataufa	1,2
960608	02:55:57.9	41.657 N	88.690 E	5.9	50-90	Lop Nor	1,2,3
960729	01:48:57.8	41.824 N	88.420 E	4.9	< 10	Lop Nor	1

Data supplied by neic/usgs unless otherwise indicated. Yield data are estimates from various sources. Remarks:
1 = recorded at KNMI-seismographstation Heimansgroeve, coordinates 50.764N - 5.932E
2 = recorded at KNMI-seismographstation Winterswijk, coordinates 51.996N - 6.810E
3 = recorded at KNMI-seismographstation Witteveen, coordinates 52.814N - 6.670E


Herald INTERNATIONAL Tribune
PUBLISHED WITH THE NEW YORK TIMES AND THE WASHINGTON POST
An appeal to delegates at the Comprehensive Test Ban Treaty talks.
First nuclear test explosion: 16 July 1945.
2045 nuclear explosions since then...
LAST nuclear test explosion...?
The answer is in your hands.
GREENPEACE

Infrasound

The Seismology Division investigates infrasound events in order to distinguish seismic and sonic events. Measurement of infrasound is carried out with two electret microphone arrays located at De Bilt and Witteveen (each array consists of six microphones). Horizontal slowness and direction of the passing wave are determined by cross-correlation calculations. Two direction measurements make it possible to carry out cross-bearing and to determine the source location of infrasound events.
Theoretical and experimental study of sonic booms and unexplained sonic events in the Netherlands, by order of the Government after questions in Parliament about the so called 'Friese Knal' (Frysian Bang) (19-8-1992), have resulted in the following. Measurements and modelling have shown that the impact of sonic booms induced by military supersonic flight above the North Sea varies from unobservable to observable far inland, dependent on meteorological situation. Refraction of soundwaves by the temperature/wind profile and low atmospheric absorption is responsible for this propagation characteristic of infrasound.
Agreements between KNMI and Royal Netherlands Air Force are made about exchange of data, information to the public and the installation of a third infrasound array at Deelen.
In 1996 infrasound research was conducted in relation to the CTBT. Investigations focus on detection of infrasound waves in the frequency band 0.01 Hz - 20 Hz. This range is typical for small nuclear explosions. The main problem of infrasound detection is the reduction of noise due to turbulent wind. Recent experiments with a microbarograph coupled with a large (40 m diameter) noise reducer system consisting of a star-configuration of porous hoses are hopeful. This research is reported in the KNMI Scientific Report 96-06.
Further research of array configurations and noise reducers, with respect to frequency band, resolution and signal-to-noise ratio, is proposed in a STW project.

Orfeus Data Center

Dost, Sleeman

The ORFEUS Data Center (ODC) focused in 1996 on the on-line access of its database. This database contains digital broad-band seismological data from seismic stations in the European-Mediterranean region. Early 1996 2.2Gb of data was made available on a fileserver, accessible through WWW and ftp (http://orfeus.knmi.nl). At the end of 1996 this database expanded to 5 Gb and continues to grow rapidly. Development of software and procedures to access the data resulted in the availability of an event search capability and an automatic Data Request Manager (autoDRM) accessible through the WWW pages or through E-mail.
The original ORFEUS goals, as defined in its Science Plan (1986) are not only confined to its Data Center. In 1996 three working groups were formed and coordinated from the ODC. In addition a workshop was organized in De Bilt. The ORFEUS board of directors decided to finance 0.5 position of a secretary-general to organize these activities. The secretary-general started its position in 1997.
In 1996 2 CD-ROMs (volume 5 and 6) were produced containing digital waveform data.

EU-project Regional Earthquake Monitoring

The main objectives of the CEC project 'Pilot project for regional earthquake monitoring and seismic hazard assessment' are to improve the monitoring of seismicity and to implement seismological data-exchange techniques in South-America. The Seismology Division is participating in this project with the main objective to initiate a seismological data exchange system in this area.
A report of recommendations and activities to be initiated concerning the earthquake monitoring part of the project has been produced, based on visits of R. Sleeman to the data centers of the South-American participants.

Articles, published in standard journals:
Crook. Th. De, 1996. *A seismic zoning map conforming to Eurocode 8, and practical earthquake parameter relations for the Netherlands.*
Geol. Mijnbouw, **75**, 11-18.

Scientific and technical reports:
Haak, H.W., 1996. *Tiltmeting, een alternatief voor waterpassing.* KNMI Technical Report TR-**192**.

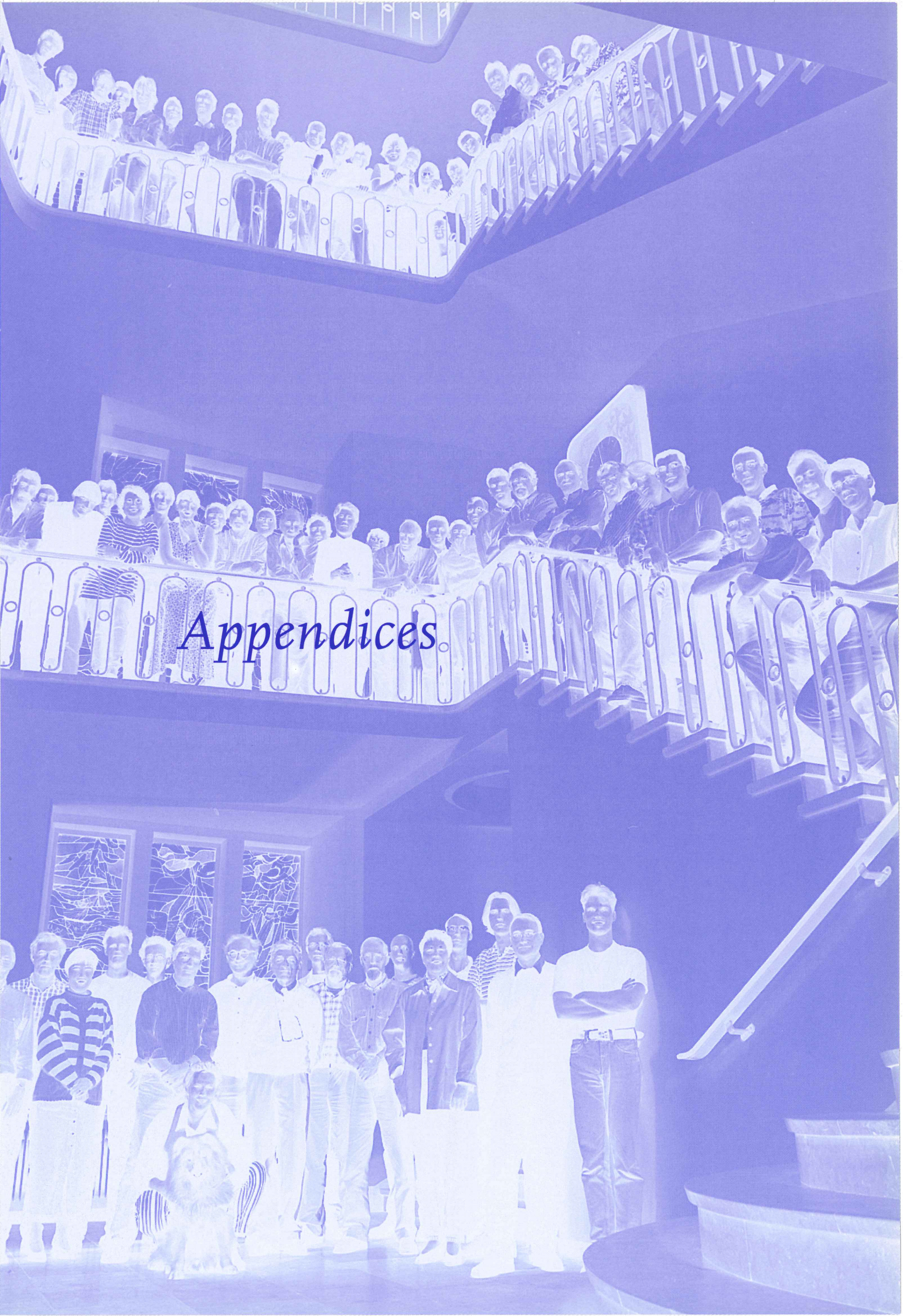
Haak, H.W., 1996. *An acoustical array for subsonic signals.* KNMI Scientific Report WR **96-03**.

Haak, H.W., and G.J. de Wilde, 1996. *Microbarograph Systems for the infrasonic detection of nuclear explosions.* KNMI Scientific Report WR **96-06**.

Number of international presentations: 8.

Other activities:
Th. de Crook, secretary of the European Seismological Commission (ESC) Subcommission: Engineering Seismology.
B. Dost, secretary of the ESC Subcommission: Data Acquisition Theory and Interpretation.
B. Dost, member of the Coordinating Committee Data Exchange and Centres of the International Litosphere Program (ILP):
B. Dost, director of the Data Center Observatories and Research Facilities for European Seismology (ORFEUS).
B. Dost, representative of ORFEUS and chairman of the Working Group on Data Exchange: Federation of Digital broad-band Seismograph Networks (FDSN).
H.W. Haak, member Working Group Seismology. Geosciences, Oceanography and Atmospheres (GOA).
H.W. Haak, Dutch delegate of the Conference on Disarmament, Ad hoc Group of Scientific Experts to Consider International Co-operative Measures to Detect and Identify Seismic Events.
H.W. Haak, Dutch delegate of International Association of Seismology and Physics of the Earth's Interior (IASPEI) of the Internation Union of Geodesy and Geophysics (IUGG).
H.W. Haak, member of the board of directors of ORFEUS.

Production Orfeus CD-ROMS, volume 5 en 6.



Appendices

Appendices

Acronyms

AMK - Assimilation Model KNMI
APOLLO - AVHRR Processing scheme Over cLouds, Land and Oceans
ASGAMAGE - Air Sea Gas and Aerosol Exchange Experiment
ATSR - Along-Track Scanning Radiometer
AUW - Agricultural University Wageningen
AVHRR - Advanced Very High Resolution Radiometer

BCRS - Dutch Board for Remote Sensing
BOMEX - Barbados Oceanic and Meteorological Experiment

CDS - Cloud Detection System KNMI
CKO - Netherlands Centre for Climate Research
CLARA - Clouds and Radiation project
CLIVAR - Climate Variability and Predictability project
COST-76 - European CO-operation in the field of Scientific and Technical Research
CTMK - Chemistry Transport Model KNMI

DAK - Doubling-Adding short wave radiation transfer model KNMI
DIAS - Dublin Institute of Advanced Studies
DICE - Decadal and Interdecadal Climate Variability: Dynamics and Predictability Experiments

ECBILT - KNMI General Circulation Model
ECHAM - ECMWF-HAMBURG The Hamburg Version of the ECMWF Model
ECMWF - European Centre for Medium Range Weather Forecasts
EMSC - European Mediterranean Seismological Centre
ENSO - El Nino - Southern Oscillation
EPS - Ensemble Prediction System
ERA - ECMWF Re-Analysis

FCCC - Framework Convention on Climate Change

GADS - Global Aerosol Data Set
GCM - General Circulation Model
GCOS - Global Climate Observing System
GEWEX - Global Energy and Water Cycle Experiment
GOME - Global Ozone Monitoring Experiment
GPS - Global Positioning System
GSHAP - Global Seismic Hazard Assessment Programme
GTS - Global Telecommunication System

HEXMAX - Humidity exchange over sea main experiment
HEXOS - Humidity exchange over sea
HIRLAM - High Resolution Limited Area Model
HOPE - Hamburg Primitive Equation Ocean Model

IDNDR - International Decade for Natural Disaster Reduction
ILP - International Lithosphere Program
IMAU - Institute for Marine and Atmospheric Research Utrecht
IPCC - Intergovernmental Panel on Climate Change

KNMI - Royal Netherlands Meteorological Institute
KRCM - KNMI Radiative Convective Model

LES - Large Eddy Simulation
LHF - Latent Heat Flux
LSG - Large Scale Geostrophic Model

MARS - Meteorological Archive and Retrieval System of ECMWF
MetClock - METEOSAT Cloud detection and characterization KNMI
MPI - Max Planck Institute

NEIC - National Earthquake Information Service
NOAA - National Oceanic and Atmospheric Administration
NOP - Netherlands Research Program on Air Pollution and Climate Change
NWO - Netherlands Organization for Scientific Research
NWP - Numerical Weather Prediction

ODC - Orfeus Data Centre
OGCM - Ocean Global Circulation Model
OMI - Ozone Monitoring Instrument
Orfeus - Observartories and Research Facilities for European Seismology

POLINAT - Pollution from Aircraft Emissions in the North-Atlantic Flight Corridor
PVU - Potential Vorticity Unit

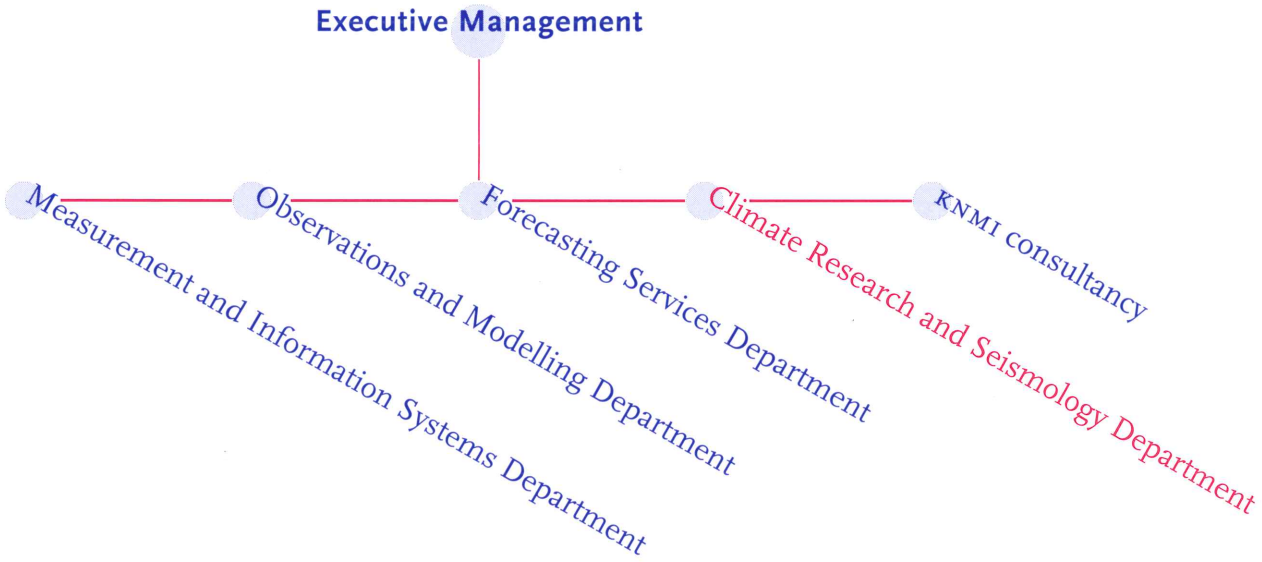
RACMO - Regional Atmospheric Climate Model
RASS - Radio Acoustic Soundig System
RIVM - National Institute of Public Health and the Environment
RIZA - National Institute for Inland Water Management and Wast Water Treatment

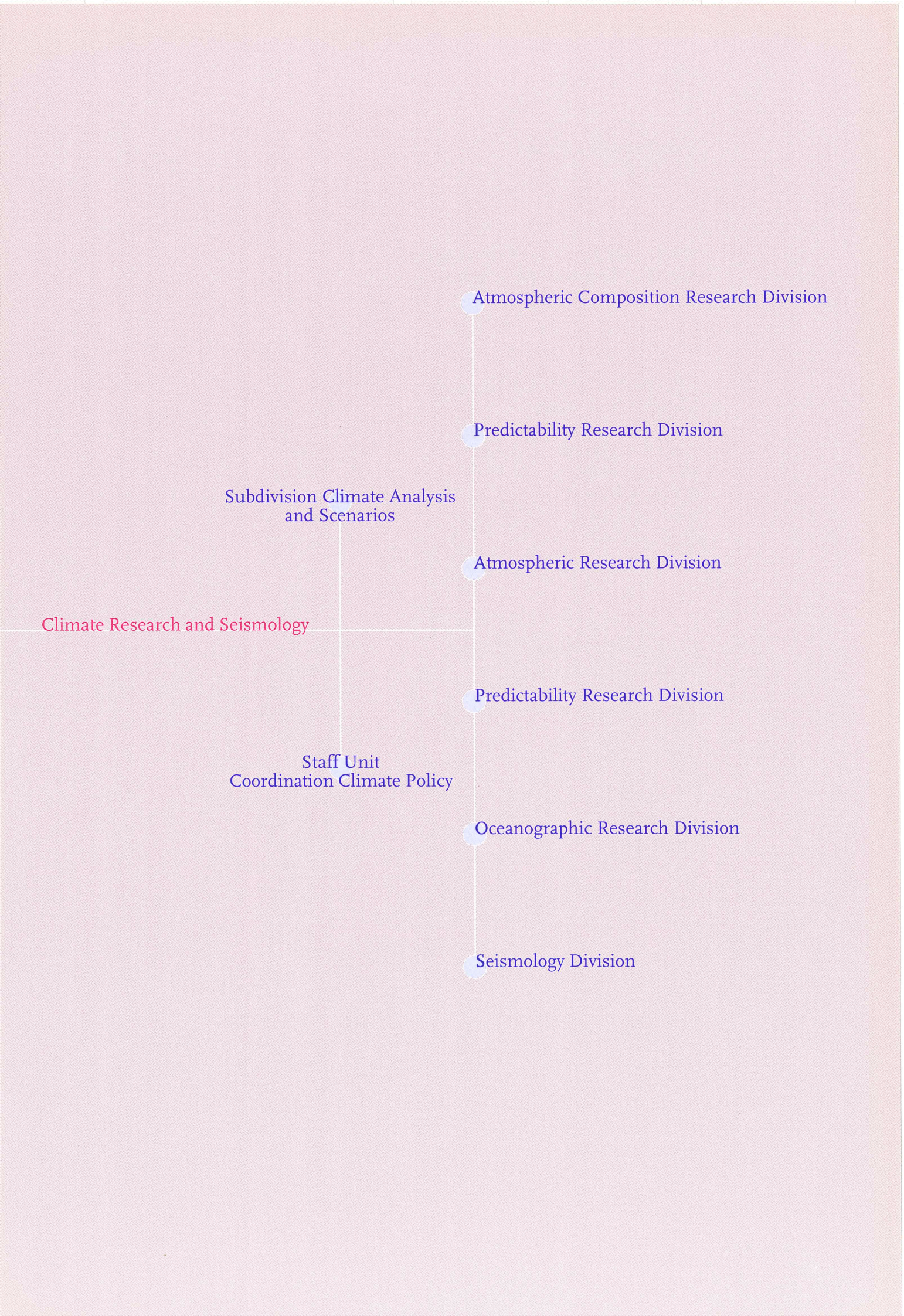
SBI - Subsidiairy Body on Implementation
SBSTA - Sibsidiairy Body on Scientific and Technological Advice
SCIAMACHY - Scanning Imaging Absorption Spectrometer for Atmospheric Cartography
SPARC - Stratospheric Processes and their Role in Climate
SRON - Space Research Organization Netherlands
STREAM - Stratosphere-Troposphere Experiment by Aircraft Measurements

TEBEX - Troposphere Energy Budget Experiment
TIROS - Television and InfraRed Observation Satellite
TOMS - Total Ozone Mapping Spectrometer
TOVS - TIROS Operational Vertical Sounder
TUD - Delft Technical University

UA - University of Amsterdam
USGS - United States Geological Survey

Organization scheme

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