Institute for Marine and Atmospheric research Utrecht

IMAU

Utrecht University

BIENNIAL REPORT
2003/2004

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1. Introduction

Climate is on the agenda. Future global warming has been identified as a major threat for mankind, and the public as well as most politicians are convinced that anthropogenic forcing of the climate system has driven temperatures up to levels where glaciers retreat, the area covered by sea ice shrinks, and droughts and floods occur more frequently. More and more countries develop a climate policy and embark on the Arch of Kyoto.
However, are the pillars thick enough? Does our fundamental knowledge of the climate system increase significantly in time, or are we just recasting and rephrasing the major findings? Does it make sense to perform thousands of impact studies based on a handful of results from climate models that still have many shortcomings?
There is good evidence (also from the palaeoclimate record) that higher levels of atmospheric carbon dioxide will lead to a higher global temperature. Filling in the details is much more difficult, however. Perhaps a larger warming at high northern latitudes can be predicted with some certainty, but it is doubtful if climate science is at a point where reliable *regional* projections of climate change can be made.
There is a growing awareness that climate policy needs a better fundament. With its teaching and research programmes the Institute for Marine and Atmospheric Research, Utrecht University (IMAU), wants to make a contribution to this fundament. Based on sound physical principles a variety of processes in the atmosphere, ocean, coastal zone and cryosphere is studied. Meteorology and physical oceanography are the basic disciplines, but in many research projects the connection with chemistry, biology, geology and geophysics is naturally established.

The IMAU is a university research institute based in the Faculty (now ‘Department’) of Physics and Astronomy, with a substantial contribution from the Faculty of Geosciences. The research programme is organized into five themes: Ice and Climate, Ocean Circulation and Climate, Atmospheric Physics and Chemistry, Atmospheric Dynamics and Boundary Layer Meteorology, and Physical Geography and Oceanography of the Coastal Zone. As can be seen in the list of projects (Section 7), a great deal of the research is externally funded. The number of faculty positions and the budget of the IMAU is not large, and external support is essential to maintain a high-quality research programme.
In 2003-2004, a number of 172 articles were published in international journals with a review system. International cooperation is evident from the publication record: 70 of the 172 publications are with authors from outside the Netherlands! Part of these articles form the backbone of the 15 dissertations that were produced in the reporting period (Section 6).
In 2003 the Utrecht Centre for Geosciences (UCG) was established to support thematic collaboration across the full spectrum of Earth Sciences research and education on the Utrecht campus. The IMAU is participating in one of the UCG research themes, namely, climate variability and geodynamics. The work focuses on the evolution of the Antarctic ice

sheet during the Cenozoic and the role of changing ocean circulation in palaeoclimates. No doubt in the next biennial report there will be more about this work.
The IMAU plays an important role in national networks. It participates in the Centre for Climate Research (CKO) and the Netherlands Centre for Coastal Research (NCK). The IMAU is leading the Buys Ballot Research School for the Study of Fundamental Processes in the Climate System, a joint school with the Department of Meteorology and Air Quality of Wageningen University. Among the associated members of this school are the Royal Netherlands Meteorological Institute, the Royal Netherlands Institute for Sea Research, and the Space Research Organization Netherlands.
The IMAU has been active in organizing international summer schools (listed in Section 4). We are happy that we were able to attract excellent teachers and top scientists to give Ph.D. students the best possible start. These schools have also provided Ph.D. students and junior scientists with highly valuable networks across Europe and abroad. We hope that the activity of organizing summer schools can be continued for a long time.

Over the past fifteen years, the IMAU has made significant contributions to international assessments on climate change (lead authors and contributing authors for IPCC). A recent activity has been participation in ACIA (Arctic Climate Impact Assessment). We will continue to make our knowledge available to policy makers in the best possible way.

Our research work depends strongly on financial support from outside the university. We are grateful for the substantial support received from NWO (Netherlands Organisation for Scientific Research), SRON (Space Research Organisation Netherlands), FOM (Foundation for Fundamental Research on Matter), and RIKZ (National Institute for Coastal and Marine Management). In addition a large number of projects was supported by the European Union.

In spite of the difficult times and budget cuts it is facing, Utrecht University has also been generous. IMAU has been given the possibility to attract talented scientists, and the institute will certainly find a secure position in the newly established ‘Faculteit Bètawetenschappen’ (Science Federation). Our ambition is to make a truly outstanding contribution to the science of Utrecht University.

Finally a few words about this report. The primary goal is to provide insight into the scientific output of the IMAU. Full lists of publications and dissertations can be found in Sections 5 and 6. However, the descriptions of the research themes are merely meant to give a flavour of the work. Much more can be found in the publications. Please do not hesitate to contact staff members for reprints and additional information.

J. Oerlemans
Director

2. Faculty

Professors:

W.P.M. de Ruijter
H.A. Dijkstra (until 1-1-04)
P. Hoekstra
J. Oerlemans

Professors (part-time):

J.D. Opsteegh (0.2) (0.4 from 1-9-04)
J.T.F. Zimmerman (0.4)

External Professors (part-time/financed by):

G.J. Komen (0.2) / Stichting Waterloopkundig Laboratorium
J. Dronkers (0.2) / RIKZ (until 1-11-03)
L.C. van Rijn (0.2) / WL-Delft Hydraulics

Associate Professors

B.G. Ruessink (from 1-12-03)
H.E. de Swart
M.R. van den Broeke (from 1–7-2004)
H. van Dop

Assistant Professors

B.T. Grasmeijer
A. Kroon
G.J. Roelofs
L.A. te Raa (from 1-7-04)
C.H. Tijm-Reijmer (from 1-8-03)
A.J. van Delden
J.H. van den Berg (p.m.)
P.J. van Leeuwen
R.S.W. van de Wal

Supporting Staff

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M.J.A. Bolder
W. Boot
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P.J. Jonker
M. van Maarsseveen
H. Markies
M. Portanger
C. Roosendaal

H. Snellen
T. Tiemissen
C. van der Veen

Secretaries

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E. Berger (until 1-5-2004)
I. Esser
A.C. van den Berg (from 1-10-2004)
Y. Wouda

Co-manager

E.I. de Koning

3. Research Themes

Ice and Climate

faculty: J. Oerlemans
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R.S.W. van de Wal
C.H. Tijm-Reijmer

Ocean Circulation and Climate

faculty: W.P.M. de Ruijter
H.A. Dijkstra
G.J. Komen
J.T.F. Zimmerman
P.J. van Leeuwen
L.A. te Raa

Atmospheric Physics and Chemistry

faculty: P.J. Builtjes
G.J. Roelofs

Atmospheric Dynamics and Boundary Layer Meteorology

faculty: J.D. Opsteegh
A.J. van Delden
H. van Dop

Physical Geography and Oceanography of the Coastal Zone

faculty: H.E. de Swart
J. Dronkers
B.T. Grasmeijer
P. Hoekstra
A. Kroon
B.G. Ruessink
J.H. van den Berg
L.C. van Rijn

3.1 Ice and Climate

The Ice and Climate research group at IMAU studies various aspects of the cryosphere with focus on the interaction between climate and land ice masses (valley glaciers, ice caps and continental ice sheets). The tools that are used for this work are theoretical and numerical models as well as data from satellites and field experiments. Examples of theoretical models are simple conceptual models of ice sheets that can be run for millions of years to study, for instance, inception of the Antarctic ice sheet 35 million years ago and its influence on the proxy temperature record from deep sea sediment cores. More sophisticated 3-dimensional numerical models of ice sheets have been used to study the evolution of continental ice sheets during the last million years, and how this can help us in the interpretation of marine temperature proxies as well as to study the interaction of ice sheets with the Earth's lithosphere. Remote sensing is potentially a very powerful tool to study glacier mass balance variations, but needs validation from in-situ measurements. Experimental data have been gathered on various locations and dealing with different topics. The directional dependence of surface reflection, in order to be able to derive broadband albedo and melt from satellite images, was measured over an Alpine snowfield. A monochromatic model of snow albedo is used to help interpreting these data. In Iceland, a start was made of photographic monitoring of a calving glacier front, to support models of calving glaciers. Operation of automatic weather stations on the Morteratschglacier in Switzerland, on Hardangerjøkulen and on Storbreen in Norway has been continued. Furthermore, we have continued our mass balance measurements on the west-Greenland ice sheet, with 14 years now the longest mass balance record in Greenland. In support of these observations, three new automatic weather stations and a turbulence station were installed here in August 2003. To help the interpretation of ice core records from Antarctica, an isotope-trajectory model was constructed and applied to snow-isotope profiles to see what signals are really stored in the snow. For this, data of the four IMAU Antarctic automatic weather stations are of great help. Operation of these stations has been secured until 2012 with an earmarked fund of the government.

Some Antarctic highlights

In 2003/04, an important subject of research was the Antarctic ice sheet: its climate and mass balance as well as the role of the ice sheet as a climate archive. In a paper in Nature with three IMAU staff members as co-authors, the European Project for Ice Coring In Antarctica (EPICA) published the preliminary results of an ice core from Dome C, with a temperature reconstruction dating back to 800,000 years, almost twice as long as the previous record from Vostok. But there was more in terms of scientific discoveries of the Antarctic ice sheet. The most comprehensive record of trace gases comes from polar firn. Firn is a porous medium and offers the possibility to extract large amounts of air, enough to analyse all exotic gases, while in ice cores the amount of enclosed air is limited. Of course, the depth limit for firn air analyses is the pore close-off level. At this depth the age of the air is determined by temperature, accumulation rate, wind speed and pressure. Until now the oldest air retrieved from firn is about 100 years, sampled at South Pole. A model has been developed that calculates the age of firn and the width of the age spectrum for the entire

Antarctic continent. Output of the regional atmospheric model in combination with parameterisations for snow density and tortuosity allowed the calculation of pore-close off depth and firn air age, with ages up to 150 years found in interior Antarctica (Figure 1).

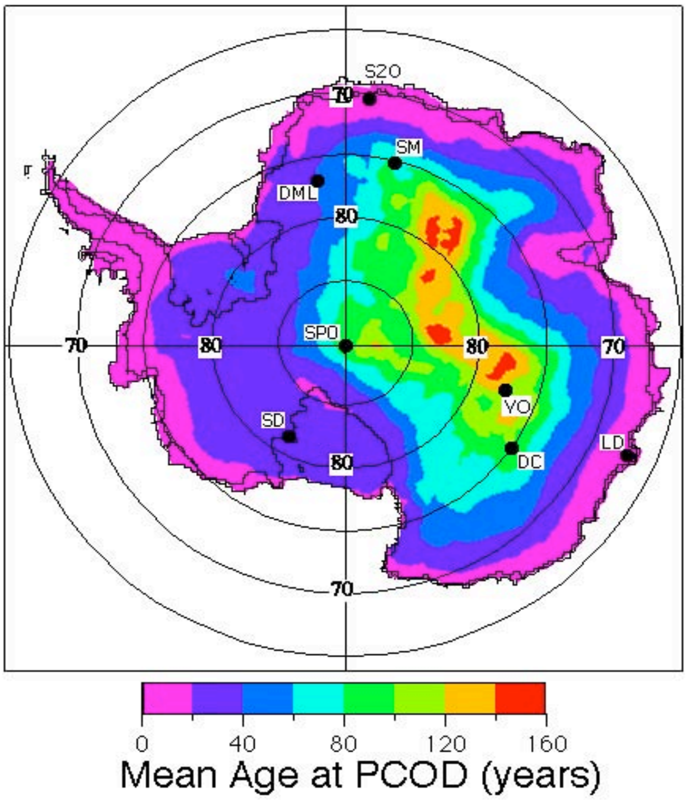

Figure 1: Distribution of the mean age at pore close-off depth (PCOD) in Antarctica. The predicted oldest air has a mean age of 156±24 years (Kaspers et al., 2004)

The impact of this work is that we can obtain a record of trace gases spanning the period from the Industrial Revolution until now once this air has been retrieved from the firn, an activity that will likely take place in the International Polar Year (2007-2009).
The firn diffusion work partly depends on the availability of reliable atmospheric data to force its upper boundary. In collaboration with KNMI, a 47-year run (1957-2004) with the regional atmospheric climate model (RACMO2/ANT) was finished in 2004, and model output was used to generate the most detailed picture of Antarctic accumulation to date (Figure 2). Apart from firn diffusion studies, these results will be used in support of studies that quantify the contribution of Antarctica to global sea level rise, as well as to drive ice sheet models at their upper boundary.
In 2003 and 2004, analysis of the EPICA-Netherlands Antarctic Boundary-Layer Experiment (ENABLE) was finalized. Figure 3 shows that the Antarctic boundary layer over the interior plateau is surprisingly dynamic, in spite of the small energy and moisture exchange. A well-developed katabatic jet characterizes the boundary layer at night, influenced by inertial oscillations at the boundary-layer top, and a shallow (100 m deep) convective layer during the day.

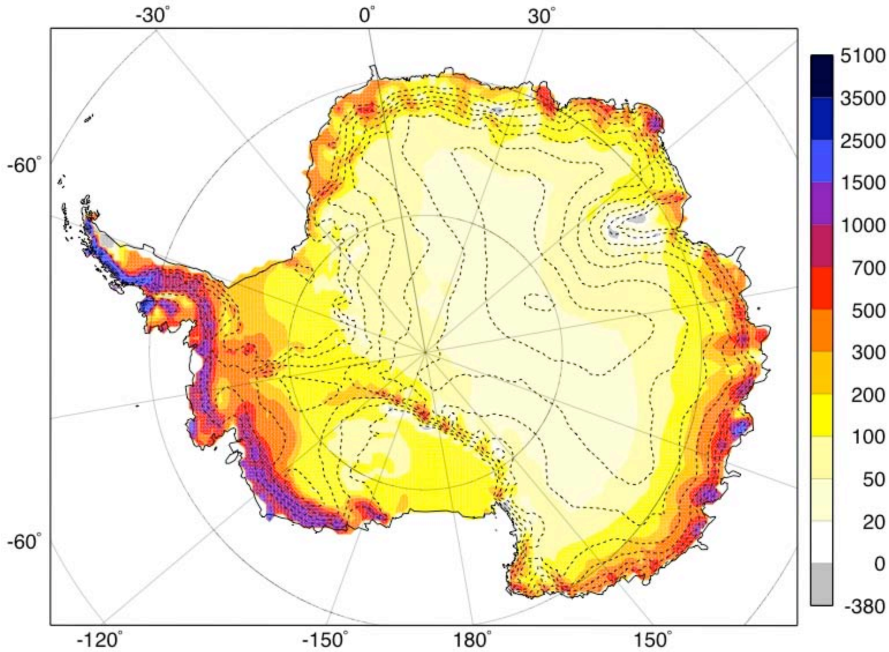

Figure 2. Calibrated surface accumulation (model output adjusted to match 1298 quality-controlled surface mass balance observations). Unit: kg m^{-2} $year^{-1}$.

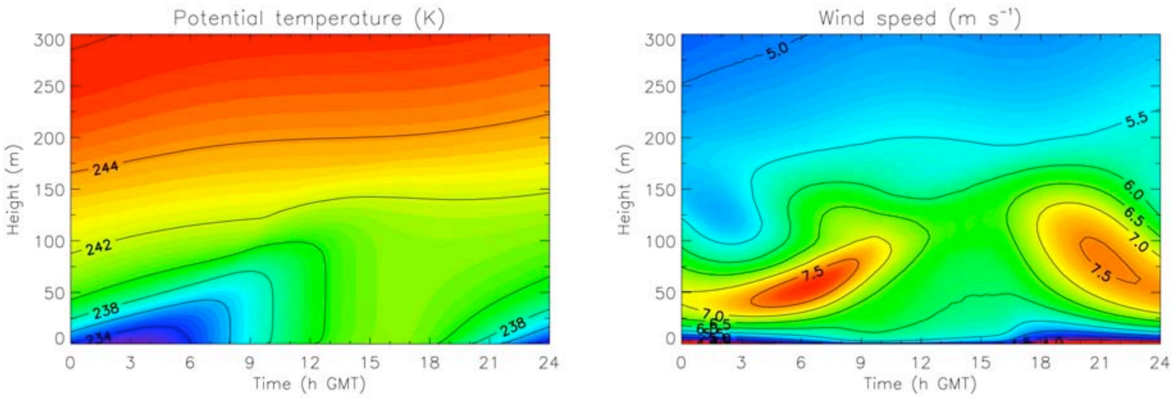

Figure 3: Daily cycle of potential temperature and wind speed in the Antarctic atmospheric boundary layer over the interior Antarctic Plateau.

Microclimate and mass balance of the Morteratschgletscher, Switzerland

In September 1995 a project was started on the Morteratschgletscher. The aim of this study is to obtain a detailed picture of the glacier's microclimate, and to quantify the processes that regulate the exchange of mass between glacier surface and atmosphere.

The Morteratschgletscher is a typical valley glacier, located in the Swiss Alps (46°24'N, 9°56'E; Figure 4). It is 7.5 km long, has an area of 17 km^2 and spans an altitudinal range of about 2000 m. The glacier front is found at an altitude of about 2000 m, which is close to the treeline. The accumulation basin is steep and rugged, whereas the ablation zone has a smaller slope with a few crevassed areas. The equilibrium-line altitude is about 3000 m. The glacier flows in northerly direction. The glacier front has retreated over a distance of about 2 km since the middle of the 19th century, as witnessed by impressive side moraines.

An automatic weather station (AWS) on the glacier snout has been operated for more than nine years now, and a unique dataset (probably the longest from the ablation zone of a glacier) has been obtained. The Morteratschgletscher appears to have a very pronounced microclimate. During more than 90% of the time the wind flows down the glacier. In summer there is a strong positive correlation between wind speed and air temperature at 3.5 m above the glacier surface. As expected, the surface albebo varies strongly, depending on the surface conditions (snow, wet snow, ice, amount of dust and morainic material). In the long-term mean, the annual average incoming solar radiation is 136.1 W m^{-2} and the mean reflected solar radiation is 71.5 W m^{-2}, so the annual albedo is about 0.53. The extraterrestrial irradiance for this site is 292 W m^{-2}, implying that altogether only about one quarter of the solar energy available at the top of the atmosphere is actually absorbed by the glacier surface. Neverheless, this amount is three times as large as the heating of the surface by the turbulent heat flux.

The data from the AWS on the snout, and from additional measuements on other parts of the glacier, have been used to construct and calibrate a mass-balance model. This model generates the spatial distribution of the specific balance from meteorological quantities measured at nearby synoptic weather station (including the high-altitude station at Corvatsch, ~3400 m a.s.l.). The spatial resolution is 25 m and shading effects are taken into account.

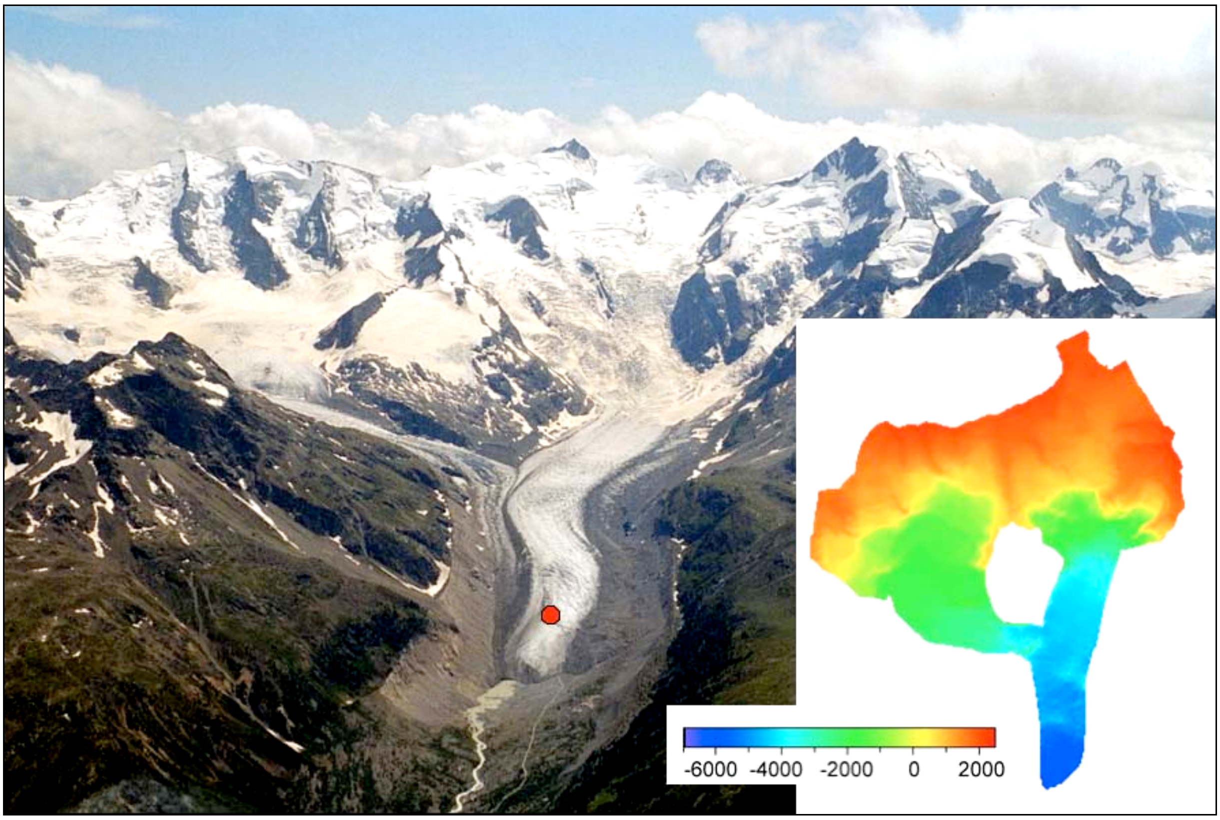

Figure 4. The specific balance of the Morteratschgletscher generated on a 25-m grid for the year 1999. Note the strong retreat of the glacier as witnessed by the large side moraines (picture on right). The elevational range is from about 2000 m (glacier snout) to 4049 m (Piz Bernina).

A typical results is shown in Figure 4. The specific balance (net annual gain/loss of mass) is shown in mm water equivalent per year. For the Morteratschgletscher, which flows in a northerly direction, shading effects are important. A calculation without shading yields a 20% larger absorption of solar energy by the glacier surface. The model has been used to generate the mass budget of the glacier over a longer period of time, and also to determine basic climate sensitivities. For temperature perturbations of +1 K and -1 K, the changes in the mean balance are -0.70 and +0.65 m yr^{-1}, respectively (water equivalent). For changes in precipitation of +10% and -10%, the changes in the mean balance are 0.17 and -0.16 m yr^{-1}.
Because the parameterization of the albedo is a critical step in the constructuon of a mass balance model, a series of Landsat images were analysed. Normally the upward progression of the snowline in the course of the melt season is well reflected in the surface albedo, but there are many other factors related to the flow and evolution of the glacier which are not easy to handle (crevasse patterns, medial moraines, side moraines, dead ice, etc.).

3.2 Ocean Circulation and Climate

The general objectives within this research theme are (i) to contribute to a more detailed description of the present large-scale ocean circulation including its variability; (ii) to identify physical processes maintaining this circulation, and (iii) determine the role of the ocean circulation in the evolution of the climate system. The research effort has been divided in two main projects.
The first research project focuses on the ‘South Atlantic inter-ocean exchange and its global connection’. One of the key areas in the global ocean circulation is the inter-ocean connection between the Indian and the South Atlantic Oceans, near the southern tip of the African continent. The major western boundary current of the Indian Ocean, the Agulhas Current overshoots the African continent but retroflects back into the Indian Ocean. Occasionally large rings are shed from the retroflection into the South Atlantic Ocean, transporting large amounts of excess heat and salt. In 2003-2004 the MARE (Mixing of Agulhas Rings) and ACSEX (Agulhas Current Sources Experiment) observations have been analyzed and interpretations supported by numerical simulations, including data assimilation. Furthermore, in the LOCO project (Long-term Ocean Climate Observations) an array of six moorings have been placed in the Mozambique Channel to study the transport and variability of the upstream sources of the Agulhas.
The second research project focuses on the ‘Stability and variability of the ocean circulation’, by using elements from dynamical system theory on the large-scale ocean circulation. In particular, it studies equilibria of this circulation, and the stability of these equilibria, with applications to potential sources of (past) climate changes. Under this project the ocean circulation some twenty million years ago is simulated with a coupled ocean-atmosphere-ice model, in which interesting new circulation patterns have been found, which confirmed and enhanced interpretation of paleoceanographic data records.

Data assimilation for nonlinear dynamics

Conventional methods to combine observations and numerical models in a data-assimilation scheme are all based on linearizations at some point. For instance, the Kalman filter assumes that the circulation model is linear when confronted with observations, while variational methods like 4D-VAR need the so-called adjoint circulation model, which is linearized along a normal model trajectory. However, the more realistic the models are, the more nonlinear they become due to the inclusion of more and more nonlinear physics. Recently we proposed to use so-called sequential importance resampling, which is a truly nonlinear data-assimilation method, based on ensemble integrations The method is used on the inter-ocean exchange area south of Africa in a high-resolution ocean circulation model. By studying the probability density function from the ensemble during the integration we found that it is multimodal, showing that nonlinearities are dominant and a method like this is needed. Furthermore, it was shown that the error in the model can increase at confrontation with observations, but the entropy decreases always. The method allows us to get a much better description of the ocean circulation than conventional methods, which tend to induce all kinds of biases, hampering a proper analysis.

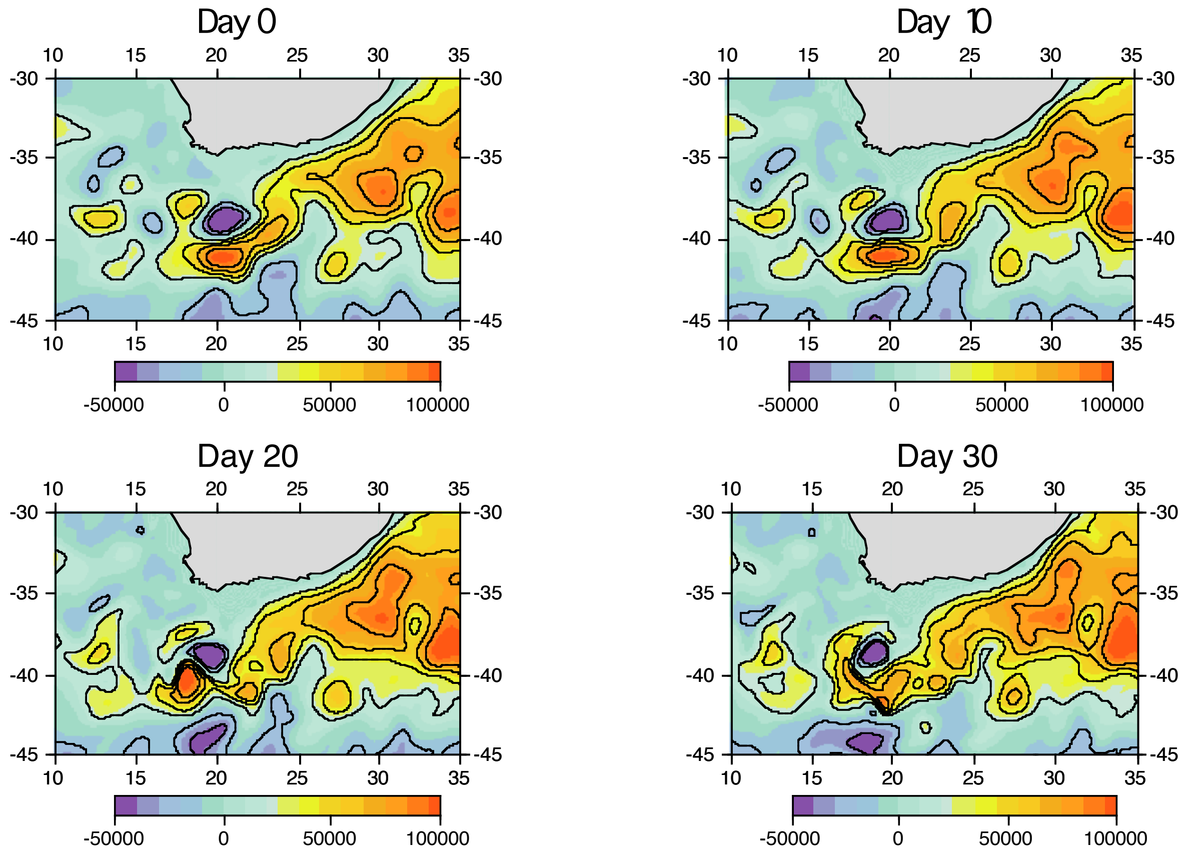

Figure 5. Ocean circulation around South Africa determined by assimilating satellite altimetry data in an ocean circulation model. The flow is along contours of the streamfunction. Note the high variability in the retroflection area, and the shedding and recapture of an Agulhas ring.

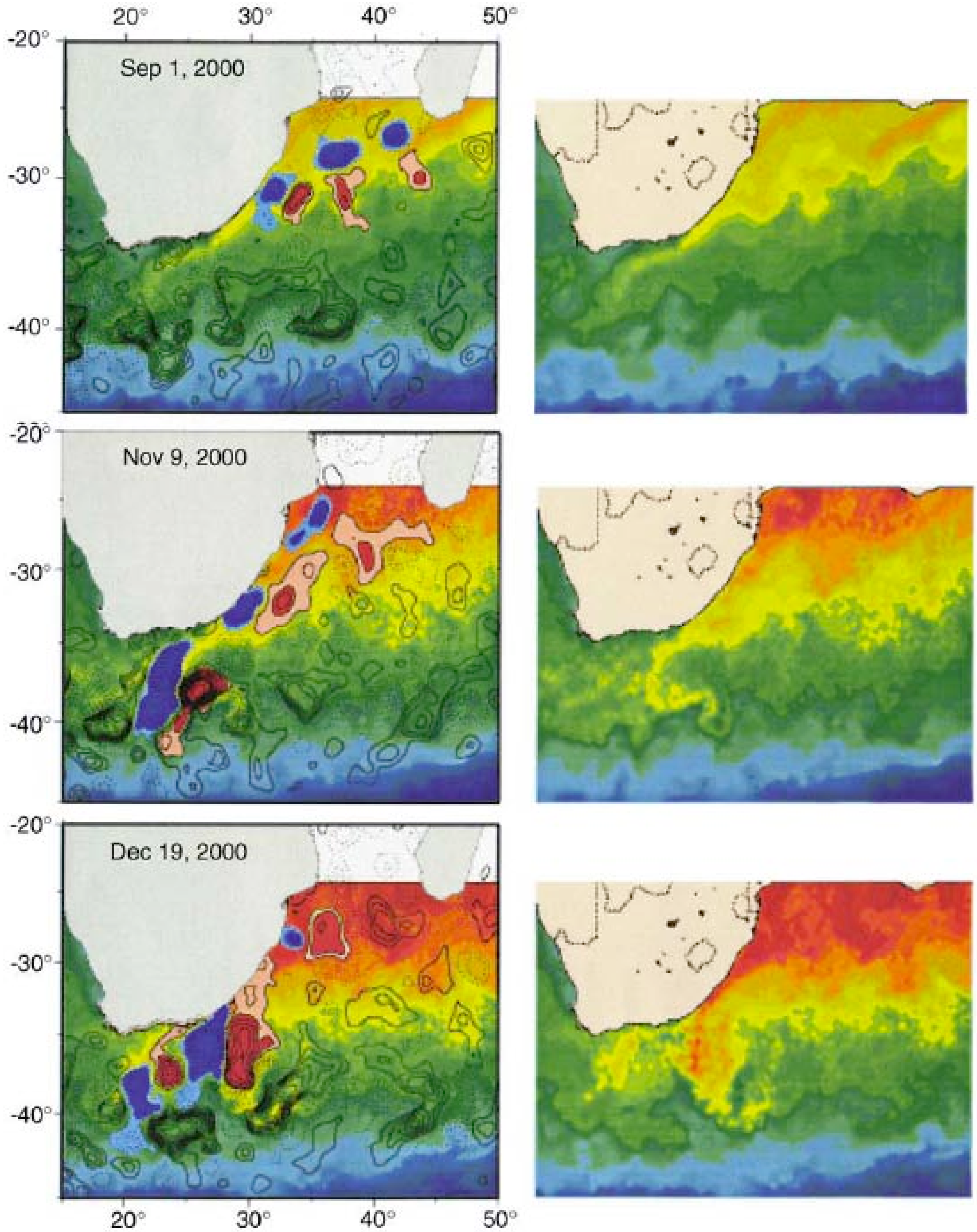

Figure 6. The 'dipole train' of 2000. The right-hand side shows SST patterns (from the Naval Res. Lab. MODAS program) at monthly intervals; on the left-hand side these patterns are overlain with SSH-anomaly contours from satellite altimetry. The dipoles have been highlighted with blue and red colors. The propagation of the dipoles into the Agulhas Current region, their interaction with the retroflection loop and the subsequent very early retroflection of the Agulhas are clearly visible in both the SST and SSH fields.

Ocean variability around Madagascar

During the ACSEX cruise we found that a steady Mozambique Current in the Mozambique Channel does not exist. Instead, the flow field consists of large anticyclonic eddies that move southward. These eddies are of the same size as the Agulhas rings that take care of the inter-ocean transport further south, and reach all the way to the bottom, as the figure shows. Furthermore, we encountered enormous dipoles south of Madagascar that move southwestward towards the Agulhas Current. By using satellite altimetry and infra-red imagery we were able to track them flowing southward disturbing the Agulhas Current to a large extend. South of the continent they induce the shedding of Agulhas rings, and sometimes even a so-called early retroflection. During such an event the Agulhas Current retroflects about 10 degrees further east, locking on to the Agulhas Plateau directly. When this occurs the shedding of Agulhas rings is strongly inhibited. This is indeed what we observed during the MARE project in 2000, in which no rings were shed for a period of about 9 months. These results show that the variability upstream of the Agulhas Current proper has significant influence on the interocean exchange. Presently we are investigating the connection between large-scale Indian Ocean variability, like the Indian Ocean Dipole, on the meso-scale variability around Madagascar. In this way we hope to track down the present operation of the inter-ocean exchange, and its sensitivity to various components of the overall system.

3.3 Atmospheric Physics and Chemistry

Environmental issues such as air pollution, stratospheric ozone depletion and global warming are closely linked to anthropogenic activities and a changing chemistry of the atmosphere. The Atmospheric Physics and Chemistry group at IMAU uses global three-dimensional atmospheric models to study the impact of chemical, physical and dynamical processes on the atmospheric chemical composition. The models simulate distributions of, for example, aerosols and cloud microphysical parameters, and of greenhouse gases such as carbon dioxide (CO_2), methane (CH_4) and ozone (O_3). The results can be used to assess the effect of the changing abundance of trace species on the Earth's climate. For that purpose a coupled chemistry-climate model and a chemistry-transport model are available. Additionally, more detailed box-models and 1D-models of, e.g., radiative transfer, atmospheric chemistry, or cloud microphysics are used for process oriented studies of the climate system. The model performance is evaluated by comparing simulation results with measurements made at the surface, from aircraft, or from satellite platforms. The research is carried out in collaboration with other research groups in the Netherlands (KNMI, SRON, TNO, ECN) and in Europe (e.g., the Max Planck Institutes for Chemistry (MPI-C) and for Meteorology (MPI-M) in Germany, the Joint Research Centre in Italy, and the University of Crete in Greece).

Space-based measurements of atmospheric CO_2

There is large interest in space-based monitoring of CO_2, and new satellite missions are currently being developed. The first instruments that are already in orbit, like Sciamachy, may contribute invaluable in-flight experience. IMAU and SRON jointly investigate the possibility to measure CO_2 with Sciamachy. Sciamachy was launched in 2002 aboard the European environmental research satellite ENVISAT to measure the chemical composition of the atmosphere. The observed wavelength range includes relevant CO_2 absorption lines, and the instrument precision is theoretically sufficient to resolve dominant CO_2 concentration gradients. The first Sciamachy CO_2 results displayed a realistic global pattern of CO_2 but the observed variability was much larger than expected from surface observations and atmospheric modelling. Over the Sahara, which is not a region with large CO_2 sources and sinks, hot spots of enhanced CO_2 appeared almost randomly, overestimating the total column abundance by as much as 10%. Further analysis showed that this variability correlates significantly with wind blown dust. Figure 7 shows a comparison of CO_2 derived from Sciamachy and the TOMS aerosol index, which is a measure for the atmospheric aerosol column. The sand storm activity over the Sahara maximizes in summer and subsides towards the end of the year. The same cycle appears in the retrieved CO_2. This correlation is due to multiple scattering of light on aerosol particles, which significantly enhances the average optical path length. Radiative transfer model calculations confirm that this mechanism may explain the observed CO_2 variability over the Sahara. The results of our study indicates that space-based measurements of CO_2 at near infrared wavelengths (as used in Sciamachy) will require aerosol correction. Associated errors are expected to maximize over the Sahara due to its high surface albedo but errors in other regions may be significant as well.

Aerosols influence radiative transfer in the atmosphere and, hence, climate. The atmospheric aerosol abundance has strongly increased as a result of anthropogenic activities as fossil fuel burning and biomass burning. The European project PHOENICS (Particles of Human Origin Extinguish Natural solar Irradiance in the Climate System; EVK2-CT-2001-00098; http://phoenics.chemistry.uoc.gr) is a global modelling project to study the direct climate effect of multi-component mixed tropospheric aerosol, and commenced in January 2003.

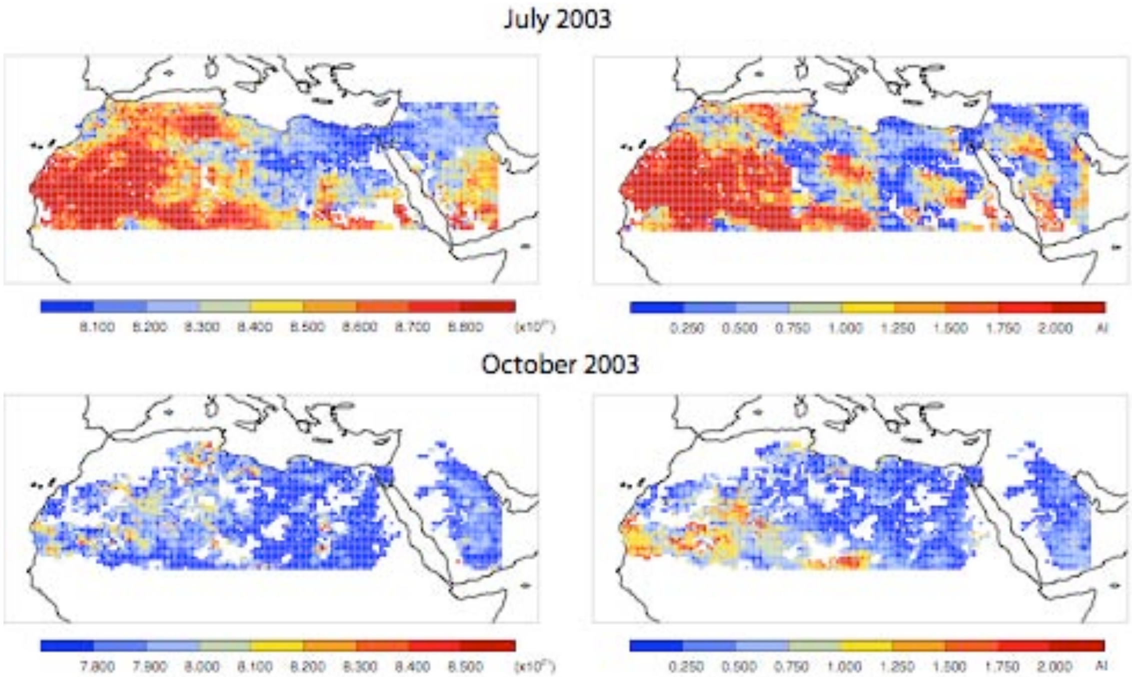

Figure 7. Comparison of Sciamachy CO_2 and TOMS aerosol index (AI) for July and October 2003.

The impact of European emissions on the European and global environment and climate, and the influence of other world regions on Europe will be assessed focusing on the role of the Mediterranean. PHOENICS combines the expertise of participants from 5 EU countries (Germany, France, The Netherlands, Greece, Italy), which covers modelling of the aerosol dynamics, the individual aerosol components, photochemistry, cloud microphysics and chemistry, equilibrium models, emissions, deposition, satellite observations and field experiments. IMAU is involved in PHOENICS with several modeling activities. One of these is the implementation of an aerosol module in the global off-line chemistry-transport model TM5. The aerosol module describes emission, transport, formation and removal processes of the sea salt, dust, black carbon (BC), particulate organic matter (POM), and inorganic aerosol. The meteorology to drive the simulated atmospheric transports is derived from ECMWF re-analyzed data. TM5 can be used in zoom-mode (1˚x1˚ horizontal resolution) over specific regions so that high resolution simulations of gas and aerosol chemistry become feasible. This makes TM5 a suitable tool to study the aerosol distribution and the associated radiative impacts over Europe.

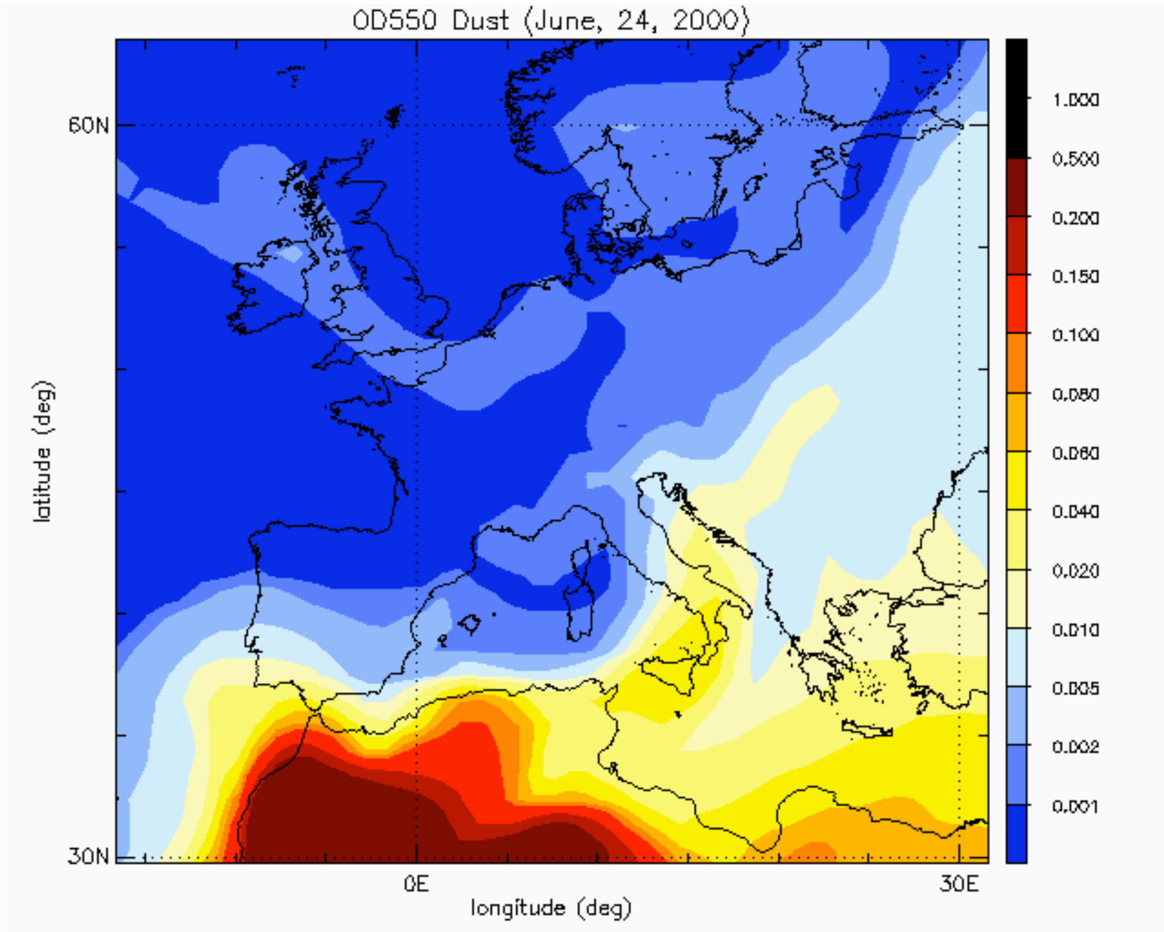

Figure 8. Optical depth of dust aerosol at 550 nm on June, 24, 2000 calculated with TM5. Strong winds over the Saharean region cause large emissions of desert dust into the atmosphere, with subsequent northward transport across the Mediterranean.

TM5 participates in the PHOENICS-activity AEROCOM (Global aerosol model intercomparison), that aims to study measurement data (from satellite, ground measurements and field experiments) and model results from different angles in order to make better use of existing measurements and improve aerosol models (http://nansen.ipsl.jussieu.fr/AEROCOM/aerocomhome.html). Figure 8 shows the optical depth of desert dust as simulated by TM5. The main source for dust over Europe and the Mediterranean is the Sahara desert. Saharean dust is transported from its sources over land and sea to regions like Europe, the Middle East and even across the Atlantic Ocean. This transport is effected by storm-like events, when desert aerosol may form a plume that spans the North-South extent of the Mediterranean and extends more than 1000 km from the source.

3.4 Atmospheric Dynamics and Boundary Layer Meteorology

Adjustment to heating, potential vorticity and cyclogenesis

The adjustment of the atmosphere to internal heating is relevant to the understanding of cyclogenesis due to latent heat release (tropical cyclones and polar lows) or due to radiative cooling (polar stratospheric vortex). Some interesting questions concerning this problem remain to be investigated and answered. These questions can best be stated after introducing the following thought experiment. Imagine that a brief, localized pulse of heating is applied to some region within the atmosphere. Isentropes are depressed locally and associated with this, mass is transferred across isentropes so that potential vorticity values are increased below, and decreased above, the location of maximum heating. The subsequent evolution, involves frictionless, adiabatic adjustment towards thermal wind balance. Inertial gravity waves and acoustic waves are radiated to infinity and mass and potential vorticity substance (PVS) are redistributed along isentropic surfaces until the balanced state is reached with cyclonic vorticity below and anticyclonic vorticity above the level of maximum heating.

The following questions now arise. To what extent does the heating induce a vertically symmetric dipole in the potential vorticity (i.e. a positive/negative anomaly below/above the level of maximum heating)? There are indications that the induced potential vorticity dipole frequently exhibits a marked vertical asymmetry. Does this vertical asymmetry depend on the timescale of the heating, the heating intensity or other parameters? Can the direct effect of heating or cooling on the potential vorticity budget (i.e. the mass flux across isentropes) indeed be viewed independent of the adiabatic adjustment process, even when the heating is applied relatively slowly and gently, i.e. on the same time scale as the time needed for adjustment? What is role of waves excited by the heating? Are the fluxes of mass and of PVS from or to the surrounding (non-heated) region during the adjustment process small or large? What part of the surrounding region (above, below or beside the heated region) is affected by this exchange of mass and PVS? Will this adiabatic exchange of mass and PVS

significantly alter the potential vorticity anomaly induced by the heating? How exactly is PVS redistributed *within* the heated region during the adjustment?
These questions have been investigated with a numerical isentropic coordinate model. The solutions of this model demonstrate that a vertically symmetric heat source in the troposphere usually induces a vertically asymmetric dipole anomaly in the potential vorticity, with an intense, tall and thin positive (cyclonic) anomaly below a less intense, flat and broad negative (anticyclonic) anomaly. The emergence of this asymmetry is associated with the vertical gradient of the potential vorticity, which is an important factor in the local potential vorticity budget, even when this gradient is zero initially. The degree of vertical asymmetry of the response to heating depends on the “thickness” (in K) of the heated layer relative to the total heat added. The adjusted balanced state shows little sensitivity to the heating intensity (i.e. the timescale within which the heat is added), in spite of the existence of large amplitude waves when the heating is applied very abruptly relative to the adiabatic adjustment time scale. The surrounding (non-heated) region shows little permanent change due to the process of adjustment as far as potential vorticity substance and mass is concerned and only functions as a transmitter of acoustic waves and inertial gravity waves. The balanced state is sensitive to variations in the horizontal scale of the heat source. The response to heating within a potential vorticity stratified region (for example: in the stratosphere) is quite subtle. For example, it is shown that a heat source in the stratosphere induces a predominantly anticyclonic wind anomaly as is obeserved in the summer over the pole (Figure 9).

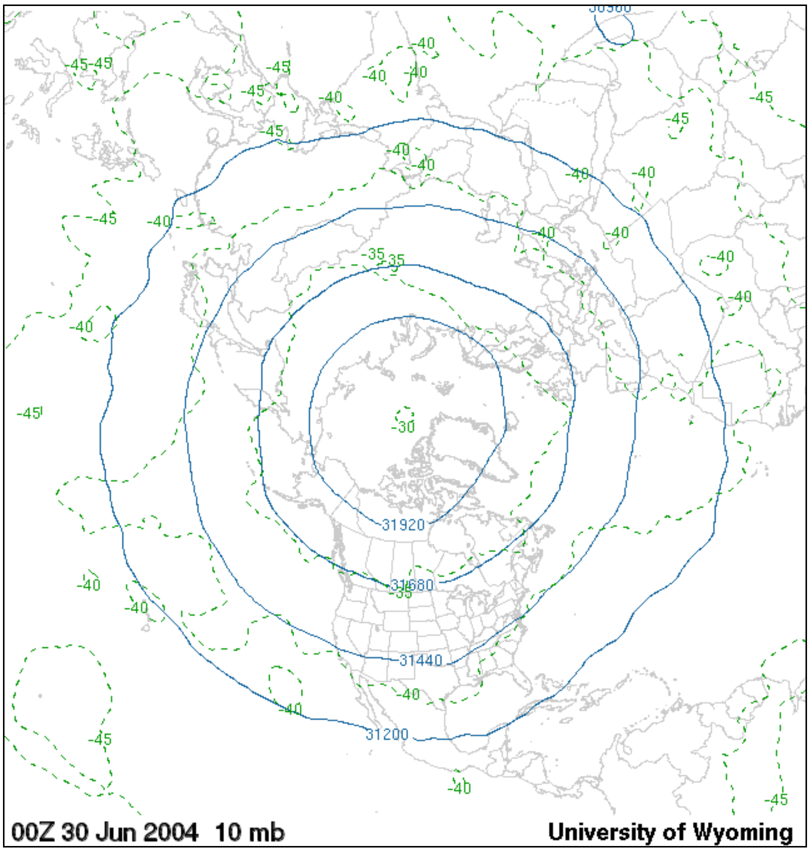

Figure 9. Isopleths of the geopotential height (solid, blue), labeled in m, and isopleths of the temperature (dashed, green), labeled in °C, at 10 hPa over the North Pole on June 30, 2004 (00 UTC).

Explosive cyclogenesis in the atmosphere

For more than a century, it is known that transient interactions between perturbations may temporarily lead to significant disturbance growth (the Orr-mechanism). Brian Farrell was the first to realize that this transient growth mechanism is important for incipient intensification of atmospheric disturbances, called cyclogenesis. If the initial disturbance is configured properly, finite-time growth rates will in general be several times larger than growth rates obtained from standard normal mode instability theory. It is for this reason that researchers started to compute the so-called optimal perturbations or singular vectors. The optimal perturbation constitutes that initial perturbation of unit amplitude that most rapidly amplifies (according to some norm) for a given time interval. Nowadays, optimal perturbations are computed to indicate the regions on a weather map which are sensitive to error-growth. Besides, they are also widely used to construct ensembles of weather forecasting.

One of the potential difficulties (hence interesting parts) of singular vector dynamics is that the singular vector changes its structure during the time-evolution. Using a physically intuitive approach (called the potential vorticity (PV) perspective) we have analyzed the dynamics of singular vectors for several prototype quasi geostrophic models for mid-latitude cyclogenesis. The rationale behind the use of these simple models is that they allow one to reveal the physical mechanisms which cause the singular vector growth.

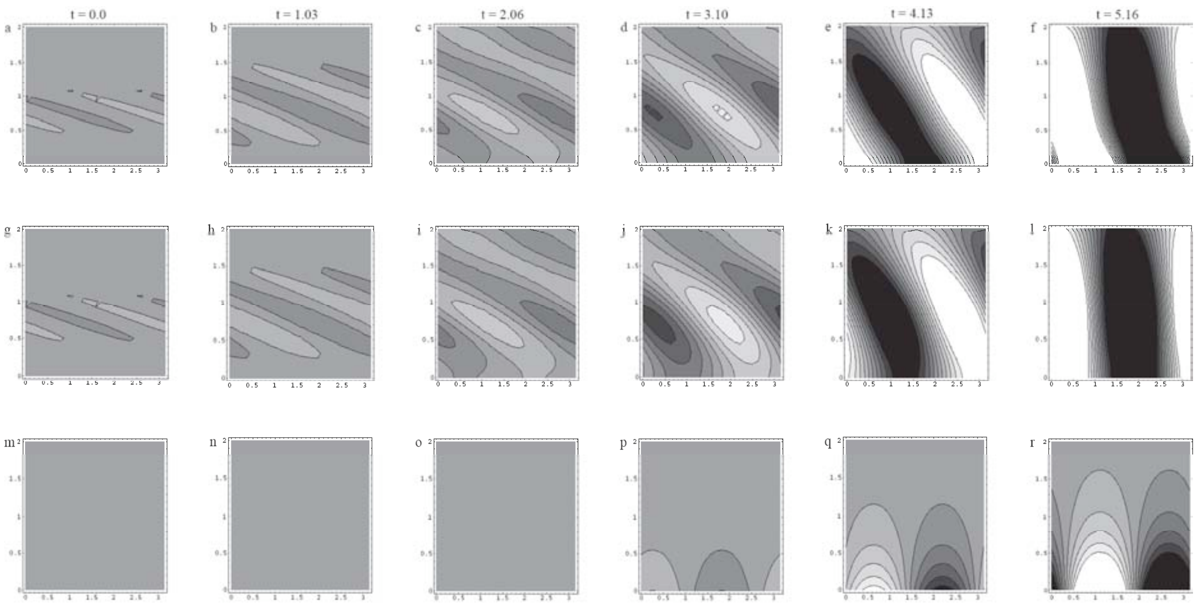

Figure 10. Zonal to height contour plot of the evolution of the SV stream function optimizing kinetic energy after 48 hrs (t=5.16 in non-dimensional units). The wave number is chosen to be fixed. Panels a-f show the evolution of the complete stream function, panels g-l show the contribution from the interior PV, and panels m-r show the contribution from the boundary PT. Both at the surface and the interior, PV unshielding is most important initially. When the stream function reaches the surface (roughly after one day t=3.10), a surface PT wave is excited very rapidly (due to the resonance with the PV). At optimization time, the largest contribution at the surface is from this resonantly excited PT wave.

The so-called invertibility principle for balanced flow tells us that the complete instant flow can be obtained from the distribution of interior PV and potential temperature (PT) at the boundaries. This implies that we can use interior PV and boundary PT as building blocks to create any initial disturbance, especially the singular vector. When time increases the interior PV and the boundary PT interact (via the mean flow) and due to the non-normality of the underlying dynamical operator (which is characteristic for shear-flow problems) the singular vector amplifies. For the unbounded Eady model (comprising a linear shear flow in thermal wind balance with a north-south PT gradient) it is found that the most important role in the surface development is played by a resonance between interior PV and the PT at the surface (see Figure 10), although initially so-called PV unshielding is most important (PV unshielding is the tower-formation of an initially up-shear tilted PV distribution by the mean wind shear).

Radiative transfer in shallow cumulus cloud fields

Atmospheric radiation plays a major role in green-house studies. Virtually all energy on earth originates from solar radiation which is scattered, reflected and partially absorbed at the surface and in the atmosphere (primarily by clouds and aerosols). This energy flux is balanced by the upwelling infrared radiation from the earth's surface and the atmosphere. Small disturbances of this balance (e.g., enhanced absorption of infrared radiation by increasing concentrations of green-house gases, or enhanced reflection of solar radiation by increasing aerosol concentrations) are major topics in climate studies. Clouds are major actors in this process and their role is complex since their abundance and optical properties are influenced by climate parameters (aerosol content, evaporation, temperature). The earth albedo is greatly determined by the mean cloud cover, which reflects 20% of the solar radiation, corresponding with approximately 250 W m^{-2}.

We have designed and made a device, Diram (directional radiance distribution measurement device), which not only measures reflection and transmission of solar radiation through clouds, but which also determines the radiance distribution. The construction contains 42 sensors, consisting of a collimation system and a detector, which are mounted in two domes (21 in each) which were mounted on the Meteo France Merlin-IV research aircraft. Radiation data was collected during a number of flights in the framework of the Baltex Bridge-2 campaign at Cabauw (The Netherlands) in May 2003. The Diram instrument provided radiances during in-situ observations of cumulus and (broken) stratocumulus clouds and detected anisotropic effects in solar radiation scattered by clouds which are due to different cloud geometries and which are related to microphysical cloud properties (Figure 11). Microphysical cloud properties were obtained from the Gerber PVM100A optical sensor aboard the aircraft. Liquid water content and particle surface area were also logged. Data has been collected from a total of 10 days in different weather conditions (clear sky, broken cumulus, stratocumulus and multilayered cloud). A clear sky test of the Diram indicated that the device was able to reproduce the Rayleigh scattering pattern. During flights in stratocumulus fields strongly anisotropic patterns were observed. In thin clouds a strong preference for forward scattering is observed in the transmitted radiation field. For thicker clouds the pattern becomes more isotropic, with a slightly brighter centre relative to the limb direction. Actinic flux appears to be a radiation parameter which is particularly sensitive to microphysical cloud properties.

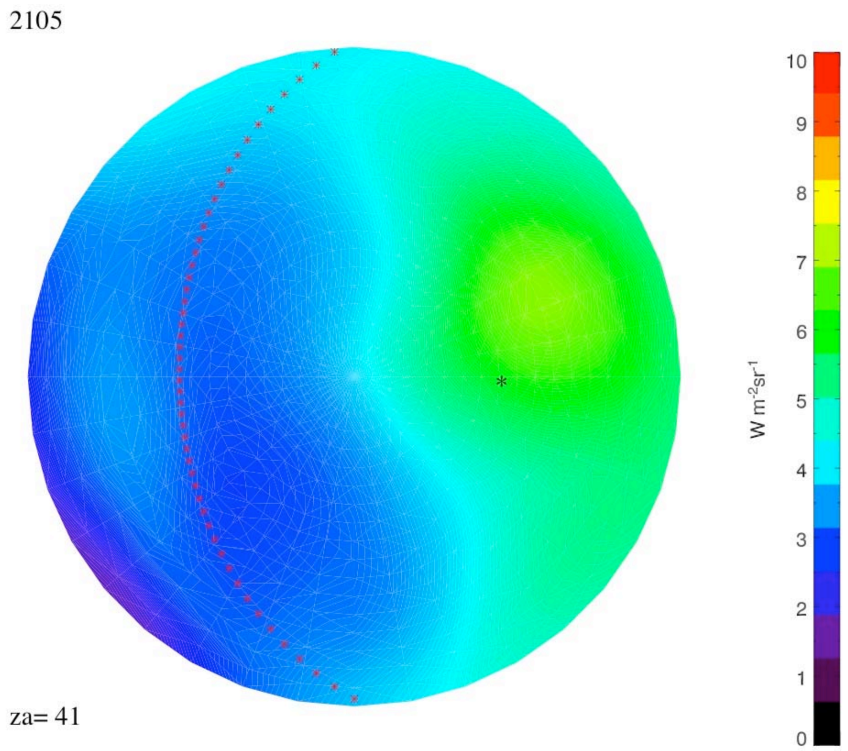

Figure 11. Below cloud irradiance in the UV-A band as a function of zenith and azimuth angle. The solar position is indicated by the asterisk. The maximum irradiance at the solar position (the solar zenith angle is 41°) is a measure for the dominant forward scattering by the (thin) cloud.

Large eddy simulation of katabatic flows

In alpine areas, the heating and cooling of air, in combination with sloping terrain, generate convective valley winds and down slope flows over melting glaciers and ice sheets (katabatic winds), which determine the water supply in lower regions, e.g., relevant for hydro power control and irrigation. In the past, many analytical and computational studies of these flows have left some questions, the first mostly because of the necessary simplifications and the latter because of their lack of resolution of the flow structure and the orography in the domain. This situation has vastly improved and we are now able to perform computations of fairly detailed structures of density driven flows a in complex environment. Supported by recent and planned field and laboratory experiments in idealized topography, these studies provide a better description and understanding of mesoscale weather phenomena in complex terrain.

Present day computers allow the numerical simulation of slope flows by means of a Large Eddy Simulation (LES) model of the Navier-Stokes equations. LES has proven to be a powerful tool in atmospheric boundary layer (ABL) studies and is able to faithfully reproduce

the (thermo) dynamic structure of the ABL. A version of the IMAU LES model was adapted to simulate up-slope flow over tilted terrain, where the acceleration of gravity has a non-zero component in the direction parallel to the ground surface. This required the reformulation of the model equations in a tilted frame of reference. As a first step, it was successfully applied for steady up-slope (anabatic) flow along an 'infinitely long' hill (Figure 12).
The next step will be the application to glacier wind or katabatic flow. It is more complicated, since these flows are stably stratified and the LES model has difficulty in maintaining its turbulence in these conditions. A finer grid and an adapted sub-grid-scale parameterization have proven to be successful in horizontal flow and awaits application in slope flow.
At IMAU glacier winds have been thoroughly observed and a wealth of data can be used in LES model validation.

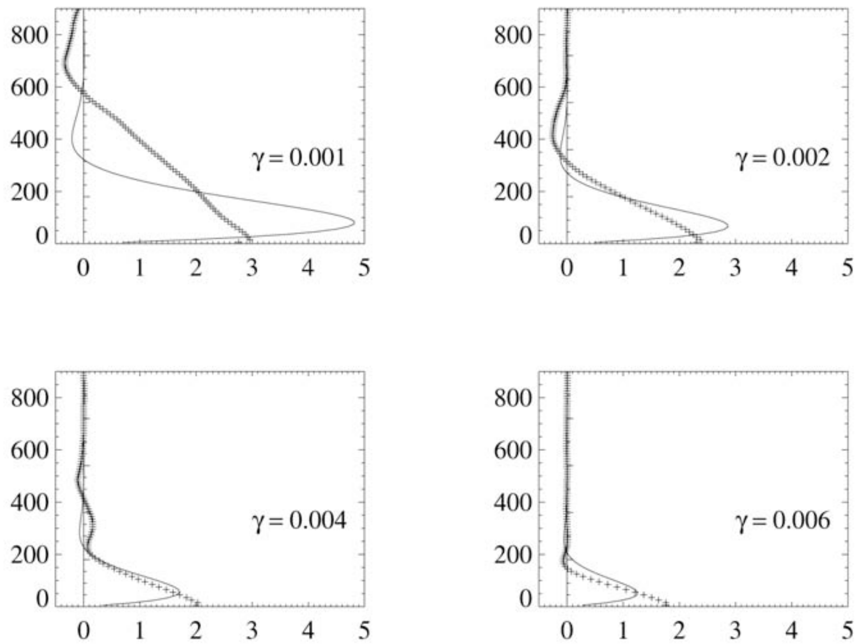

Figure 12. Up-slope wind velocity (horizontal axis; m/s) as a function of height (vertical axis; m) for four different values of the ambient stratification (γ in K m^{-1}). The thick curves show the results of the LES model. The thin curves are analytical solutions.

3.5 Physical Geography and Oceanography of the Coastal Zone

Sedimentary coastal systems are highly dynamic morphodynamic systems that show strong interactions and mutual feedbacks between the water motion (driven by wind, waves and tides as well as density gradients), the associated sediment transport and the resulting morphological change. The main aim of the coastal research group at the IMAU is to increase the fundamental understanding of the hydrodynamic and morphologic behaviour of sedimentary coastal environments, including shallow shelf seas and shoreface. The integrated research approach is based on a combination of research methodologies that are highly complementary and comprise the collection and analysis of new field data, the development and analysis of both process-oriented numerical models as well as idealised mathematical models and, more recently, the implementation and application of Data-Model Integration (DMI) techniques.

Apart from aspects of global change, such as changing hydro-meteorological conditions (e.g. wind- and wave climates), sea level change and variations in sediment supply, coastal environments are increasingly subject to human interventions due to the development of constructions and the extraction of natural resources (sand, oil, gas etc.).

During the period 2003-2004 research efforts were aiming at the understanding of estuarine and deltaic systems and the (morphologic) development of beaches, surfzones and offshore located large-scale sandbanks such as shoreface-connected ridges, located in the transition zone from shoreface to shelf. Estuarine and deltaic studies were performed in Dutch coastal waters and the far East (Vietnam and Indonesia). In the Netherlands studies started on the modelling of the dynamics of estuarine turbidity maxima, partly in combination with field measurements on suspended sediment distribution in the Ems-Dollard estuary. The Red River delta programme in Vietnam was completed (thesis Van Maren, 2004). This study demonstrates and explains the cyclic growth pattern of this river delta due to the interaction of both river outflow patterns and wave-driven sediment transport processes.

In the framework of the East Kalimantan programme, pilot projects were carried out in the Mahakam and Berau delta of East Borneo (Indonesia) to analyse the scientific potential of these regions for a new interdisciplinary and bilateral Indonesian-Dutch coastal zone research project for the period 2005-2009. The pilot projects focused on estuarine dynamics in relation to the longshore and offshore dispersion of suspended matter in the form of large river plumes.

In the Netherlands the project on Outer deltas of tidal inlets (2001-2005) continued (see description below).

In the Dutch nearshore zone the ARGUS video research programme and the study of nearshore sandbar dynamics received a new important impulse by the NWO-VIDI grant for Ruessink for a project on Data-Model Integration techniques in relation to the development and dynamics of nearshore sandbars. The behaviour of nearshore sandbars in the surfzone of the barrier island of Terschelling and in response to both natural and man-made conditions - the implementation of a shoreface nourishment - were studied by Grunnet (thesis 2004). The use of video-remote sensing techniques for both scientific and coastal zone management purposes of beaches and surfzones was also part of the EU-COASTVIEW project. Partners from the United Kingdom, Denmark and the Netherlands joined forces in a common field campaign at the coastal research site at Egmond aan Zee, the Netherlands. Also, IMAU staff members carried out model work on shoreline sand waves, in joint collaboration with Prof. A. Falqués (UPC Barcelona), who spent 6 months of his sabbatical at the IMAU (January-July 2004).

Sediment transport processes on the shoreface in relation to both short term as well as long term morphological developments were analysed in the EU project SANDPIT (see below). In addition, the study on shoreface-connected ridges resulted in a thesis of Walgreen (2003) in which she analysed and discussed the non-linear evolution of and sediment sorting over shoreface-connected ridges. Meanwhile, a new project started that focuses on the effect of waves and vertical sorting on the dynamics of these ridges.

Outer deltas of tidal inlets

An important and successful initiative within the outer deltas programma was the development of an idealised morphodynamic model that simulates the interaction between waves, tides and the sandy bottom in the area seaward of a tidal inlet. The forcing of the water motion is due to prescribed cross-shore tidal currents over the inlet and offshore wave conditions. The model was used to investigate whether ebb-tidal deltas can be modelled as morphodynamic equilibria (no evolving bathymetry), as was suggested by earlier work using time integrations with a complex numerical model. Thus, the idealised model calculates steady state solutions as a function of parameters (e.g., the maximum tidal velocity amplitude in the inlet). Indeed, it was found that this model predicts flow and bottom patterns that have similar characteristics as those of observed ebb-tidal deltas (Figure 13). In the centre of the tidal inlet an ebb-dominated channel is present that branches further offshore into two flood-dominated channels. At the end of the ebb-dominated channel a large shoal is present. The modelled patterns are found for a wide range of parameter settings. By varying the tidal forcing conditions a linear relation between the volume of sand stored in the delta and the tidal prism (amount of water transported through the inlet during one tidal period) was found, which agrees well with field data.

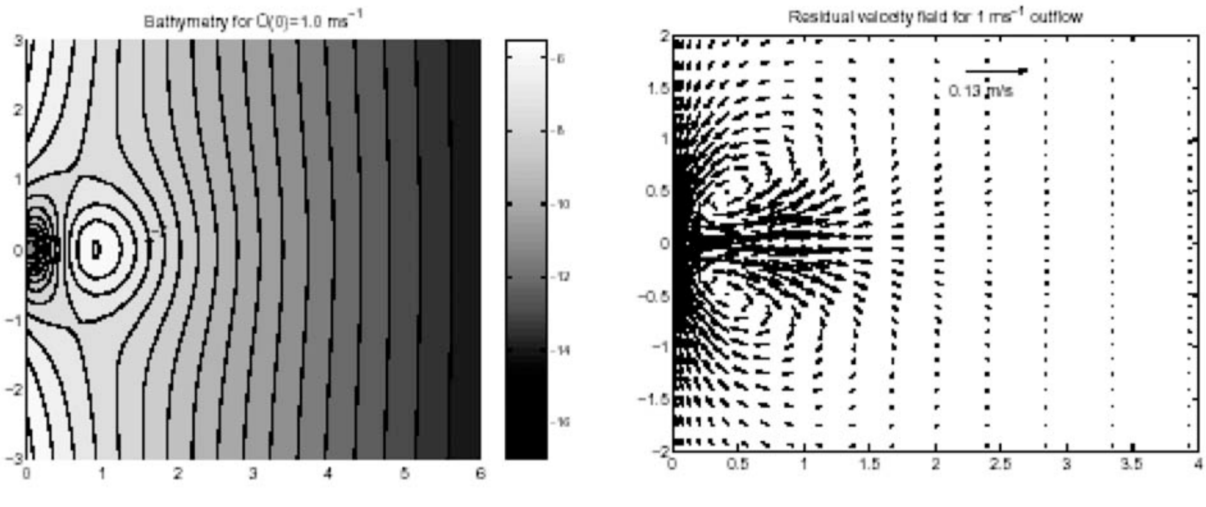

Figure 13. Left: bathymetry calculated with the idealised model. The coast is on the left, the inlet is centered at the origin and has a width of 2 km. Maximum tidal current amplitude is 1 m/s. Right: corresponding residual current pattern, showing the presence of two residual circulation cells.

Sand Transport Processes on the Shoreface: the EU-SANDPIT project

The large-scale mining (and dumping) of sand will be one of the most important marine environmental problems of the coming decades. Massive sand mining from the middle and lower shoreface will be required in the future in many regions of the world to nourish beaches and coastal dunes and to compensate for natural losses of sediment, e.g. in relation to sea

level rise. Furthermore, the large-scale reclamation of coastal areas and development of (coastal) infrastructure will also require huge amounts of sand as building material. However, large-scale sand mining may have far-reaching effects on the hydrodynamic and sediment transport processes in the nearshore and offshore coastal waters and the morphological development of shoreface and adjacent coastal zone. The EU SANDPIT project was initiated with the main objective to develop reliable prediction techniques to better understand, simulate and predict the morphological behaviour of large-scale sand mining areas and the surrounding coastal zone. Therefore, part of the SANDPIT project was dedicated to the execution of detailed field measurements and laboratory experiments to improve the existing knowledge on sediment transport processes and conditions, to develop and test more reliable sediment transport models and to generate an extensive database for model calibration and validation.
In the years 2003 and 2004 field measurements were performed in the Noordwijk transect on the Dutch shoreface, approximately in water depths between 12 and 25 m. Detailed measurements of sediment transport were carried out during concentrated campaigns in both spring and autumn, using sophisticated and state-of-the-art instrumented tripods, including the HSM tripod (see Figure 14). In addition, a year-long monitoring programme was executed to continuously measure wind, waves and tides (incl, tidal currents). This part of the programme was aiming at the establishment of hydro-meteorological conditions and probability-density functions for sediment transport measurements and net annual sediment transport computations.

Figure 14. Deployment of HSM tripod (HSM = Hydrodynamics, Sediment transport and micro-Morphology of the seabed) in the Noordwijk transect during the SANDPIT project.

The detailed sediment transport studies have significantly increased our knowledge on sediment transport processes on the shoreface in general and for the Noordwijk transect in particular. Net sand transport on the Dutch shoreface (along the Holland coast) appears to be in a northward direction. The net transport in the flood direction can be explained by a small tidal flow asymmetry with flood currents being somewhat larger than ebb currents and the effect of residual flows. A combination of wind-, density- and low-frequency tidal effects may result in residual flows up to 0.2 – 0.3 m/s in a northward direction. Based on an extensive series of combinations of predictors for both suspended load and bedload transport rates, the present estimates indicate a net annual total transport of about 1.5-6.5 m^3/m/year. Remarkably, these figures for the net total transport rates are at least a factor 5 smaller than those previously estimated by Van Rijn (1995) for the Noordwijk transect in water depths of about 8 to 20 m. A major reason for this discrepancy in results probably is the schematisation of the flow field. The present computations were based on the observed flow field whereas the past estimates used a modelled flow field in which the flood and ebb currents were overestimated in comparison to the present observations and, secondly, the flood and ebb flow were assumed to be of equal duration.

Net transport rates on the shoreface are determined by both bedload and suspended load transport; a comparison of suspended load measurements and model calculations is illustrated in Figure 15. However, the predicted relative magnitude of these transport modes very much depends on the type of bedload predictor. Conservative estimates based on local measurements and predictors suggest that gross bedload transport is only about 10 % of of the gross suspended load transport. According to the Bailard energetics approach though the gross bedload and suspended load transports are about equally important.

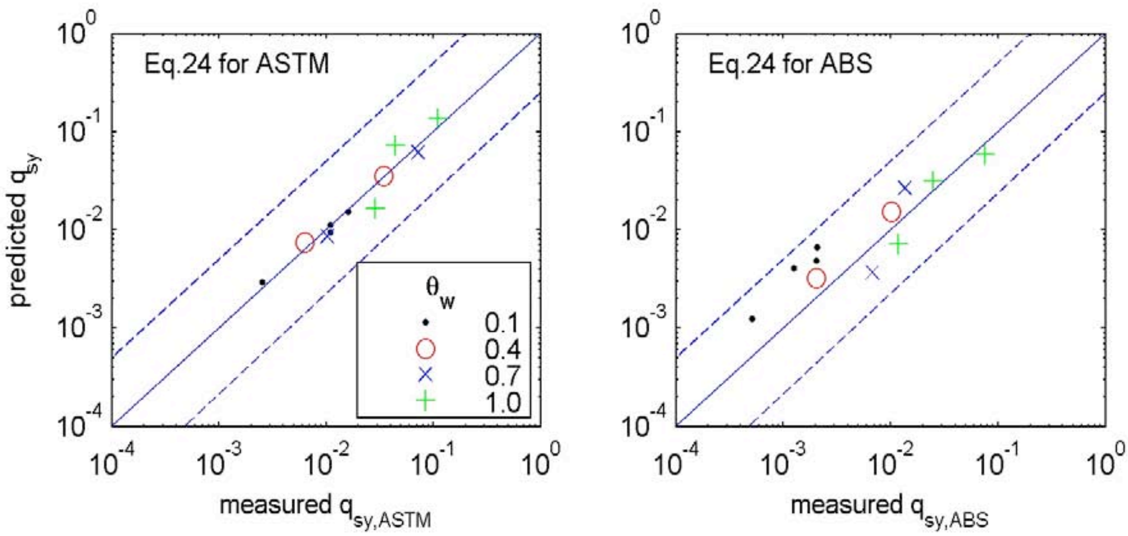

Figure 15. Measured and predicted sand transport rates on the shoreface of Noordwijk aan Zee (North Sea) for clustered data, representing different wave regimes. Measurements were carried out by acoustic devices (ASTM = Acoustic Sand Transport Meter; ABS = Acoustic Back Scatter sensor).

4. Summer schools

Hydro- and morphodynamics of coastal seas
29 June - 12 July 2003
organized by IMAU and NCK
convenors: H.E. de Swart and A. Falqués
venue: Renesse, The Netherlands
28 Ph.D. students and postdocs
teaching staff: *J.A. Battjes, P. Blondeaux, D. Calvete, N. Dodd, A. Falqués, K. Horsborough, A. Kroon, M. Losada, D. Eppel, D.A. Huntley, G. Parker, D. Prandle, H.M. Schuttelaars,H.E. de Swart, H.J. de Vriend, J. Winterwerp, J.T.F. Zimmerman*

Glaciers and ice sheets in the climate system
9 - 20 September 2003
organized and sponsored by IMAU; co-sponsored by the Autonomic Province of Alto Adige
convenor: J. Oerlemans
venue: Karthaus, Italy
36 Ph.D. students and junior scientists
teaching staff: *A. Fowler, J.W. Greuell, H. Gudmunddson, A. Jenkins, G. Kaser, K. Lambeck, R. Mulvaney, J. Oerlemans, T. Payne, D. Pollard, C.H. Tijm-Reijmer, B. Stauffer, R.S.W. van de Wal*

Ocean and climate
21 September - 1 October 2003
organized and sponsored by IMAU, KNMI and KNIOZ
convenors: H.A. Dijkstra and W.P.M. de Ruijter
venue: Les Diablerets, Switzerland
24 Ph.D. students and postdocs
teaching staff: *D. Marshall, W. Dewar, A.C. de Verdiere, M. Spall, H. Bryden, E. Chassignet H.A. Dijkstra, H. van Aken, S. Drijfhout, N. Weber, P.-J. van Leeuwen*

5. Publications

Reviewed scientific publications

	2003	2004	Total
Only IMAU author(s)	34	23	57
First author IMAU + foreign author(s)	21	23	44
First author foreign + IMAU	25	13	38
First author IMAU + other Dutch	5	6	11
First author Dutch + IMAU	14	10	24
Total	99	75	174

2003

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6. Dissertations

Crommelin, D. - January, 17 2003
Nonlinear dynamics of atmospheric regime transitions
Promotores: prof.dr.ir. J.D. Opsteegh, prof.dr. F. Verhulst

Hoitink, A.J.F. - May 2, 2003
Physics of coral reef systems in a shallow tidal embayment
Promotores: prof.dr. P. Hoekstra, prof.dr. J.H.J. Terwindt

Te Raa, L.A. - May 21, 2003
Internal variability of the thermohaline ocean circulation
Promotores: prof.dr.ir. H.A. Dijkstra , prof.dr. W.P.M. de Ruijter

Robles Gonzalez, C. - June 11, 2003
Retrieval of aerosol properties using ATSR-2 observations and their interpretation
Promotores: prof.dr.ir. P.J.H. Builtjes, prof.dr. G. de Leeuw

Nauw, J.J. - September 3, 2003
Low-frequency variability of the wind-driven ocean circulation
Promotores: prof.dr.ir. H.A. Dijkstra, prof. dr. W.P.M. de Ruijter

Scheeren, H.A. - September 15, 2003
Reactive hydro-and chlorocarbons in the troposphere and lower stratosphere
Promotor: prof.dr. J. Lelieveld
Co-promotor: dr. G.-J. Roelofs

Walgreen, M. - October 27, 2003
Dynamics of sand ridges in coastal seas: the effect of storms, tides and grain sorting
Promotor: prof.dr. J. Dronkers
Co-promotor: dr. H.E. de Swart

Klok, E.J. - December 3, 2003
The response of glaciers to climate change
Promotor: prof.dr. J. Oerlemans

Schaap, M. - December 8, 2003
On the importance of aerosol nitrate in Europe
Promotor: prof.dr.ir. P.J.H. Builtjes
Co-promotores: Dr. H.M. ten Brink (ECN, Petten), dr. F.J. Dentener (JRC, Ispra, Italië)

Van Maren, D.S. - September 17, 2004
Morphodynamics of a cyclic prograding delta: the Red River, Vietnam
Promotor: prof.dr. P. Hoekstra
Co-promotor: dr. B.G. Ruessink

Kaspers, K.A. - October 4, 2004
Chemical and physical analyses of firn and firn air
Promotor : prof.dr. J. Oerlemans
Co-promotor : dr. R.S.W. van de Wal

Klein Tank, A.M.G. - October 4, 2004
Changing temperature and precipitation extremes in Europe's climate
Promotor : prof.dr. G.J. Komen
Co-promotor : dr. G.P. Können (KNMI)

Van den Broek, M.M.P. - October 4, 2004
The Arctic winter stratosphere, simulated with a 3-D chemistry transport model
Promotor : prof.dr. J. Lelieveld
Co-promotor : dr.ir. A. Bregman (KNMI)

Volkov, D. - November 18, 2004
Monitoring the variability of sea level and surface circulation
Promotor : prof.dr. W.P.M. de Ruijter
Co-promotor : dr. H.M. van Aken (NIOZ)

Grunnet, N.M. - December 9, 2004
Morphodynamics of a shoreface nourishment in a barred nearshore zone
Promotor: prof.dr. P. Hoekstra
Co-promotor: dr. B.G. Ruessink

7. Projects 2003/04

Project title	Funding	Project leader
Mixing of Agulhas Rings Experiment (MARE) (Clivarnet)	NWO/ALW	De Ruijter
Propagation of equatorial climate variability of the Southwest Indian Ocean	NWO/ALW	De Ruijter
Retroflection and ring formation of ocean currents	NWO/ALW	De Ruijter
Outer delta dynamics: process analysis of water motion, sediment transport and morphological variability	NWO/ALW	De Swart, Kroon
Netherlands participation in the Nordic Svalbard ice core drilling project 2003/2004	NWO/ALW (NAP)	Van de Wal
Climatic interpretation of glacier records by inverse modelling (Clivarnet)	NWO/ALW	Oerlemans
European Project on Ice coring in Antarctica (EPICA-NL-2)	NWO/ALW	Van den Broeke
Long-term high resolution of the climate and mass balance of the Antarctic ice sheet	NWO/ALW	Van den Broeke
Netherlands Participation in the Greenland Climate Network (GC-NET)	NWO/ALW (NAP)	Van den Broeke
A request for long-term baseline funding of 5 Automatic Weather Stations in Antarctica	NWO/ALW (NAAP)	Van den Broeke
Generation of mesoscale fluctuations in convective atmospheric boundary layers	NWO/ALW	Van Dop
Large-scale morphodynamics of shelf seas	NWO/ALW	Dronkers
Ice and Climate-programme (SPINOZA)	NWO	Oerlemans
Reconstruction of the time-mean absolute velocity field of the ocean circulation	NWO/STW	Dijkstra
Airborne measurements of radiances in cloudy conditions	NWO/STW	Van Dop

Delta morphodynamics – Red River Delta Vietnam	NWO-WOTRO	Hoekstra
East Kalimantan Project	KNAW-WOTRO-INDONESIA	Hoekstra/Hoitink
Rapid changes in complex flows	NWO/E	Dijkstra
Parallelisation of a large eddy simulation code density currents	NWO/NCF	Van Dop
The evolution of oceanic rings and cyclonic recirculation cells	NWO/ FOM/v Stim.	De Ruijter
Turbulent mixing across a stably stratified interface: the effect of evaporative cooling	NWO/ FOM/v Stim.	Van Dop
Nonlinear dynamics of shoreface-connected sand-ridges, the role of grain sorting, waves and three-dimensional transport processes	FOM	De Swart/Zimmerman
Framework programme Space Research System Earth	SRON	De Ruijter
Framework programme Space Research System Earth	SRON	Roelofs
Occurrence and modelling of the 1.7 year oscillation in stratospheric ozone	SRON	Roelofs/ Alkemade
Monte Carlo radiative transfer in spherical geometry applied to the satellite measurements from SCIAMACHY	SRON	Roelofs/Krol
Observing the thermohaline ocean circulation from the Pacific to the Indian Ocean via the Indonesian Passages	COACh	De Ruijter
Dynamics and stability of tidal inlet – Outer delta systems	COACh	Hoekstra/De Swart
Meteorology and mass balance of the Greenland ice sheet: a proposal for two COACh-funded automatic weather stations	COACh	Van den Broeke
Aircraft observations of solar radiation, turbulence and chemistry in shallow-cumulus clouds	COACh	Van Dop
Sandpit	EU	Hoekstra
Human interaction with large scale morphological evolution (HUMOR)	EU	Kroon/De Swart
CoastView	EU	Kroon
Space born measurements of Arctic glaciers and implications for sea-level (SPICE)	EU	Oerlemans

European Project on Ice Coring in Antarctica (EPICA) III	EU	Van den Broeke
European project on cloud systems in climate models (EUROCS)	EU	Van Dop
Tropospheric ozone and precursors – trends, budgets and policy (TROTREP)	EU	Roelofs
Mineral dust and tropospheric chemistry (MINATROC)	EU	Roelofs
Particles of human origin extinguish natural solar irradiance in the climate system (PHOENICS)	EU	Roelofs
Marine Environment and Security for the European Area (MERSEA)	EU	Van Leeuwen
Intercomparison of wave data based on ADCP's and conventional Wave buoys	RWS-RIKZ	Hoitink/Ruessink/Hoekstra
Assessment of the concentration field of climate relevant aerosol species over Europe by data analysis and modelling	ECN	Builtjes
Nonlinear dynamics of shoreface-connected sand ridges	CLS	De Swart
Dynamics of nearshore oblique sand bars: data analysis and modelling	IMAU/UU/EU	De Swart/Kroon
Dynamics and transport in the stratosphere	Faculteit Natuur- en Sterrenkunde/UU	Roelofs
Cyclogenesis and non-model wave growth	Faculteit Natuur- en Sterrenkunde/UU	Opsteegh/Van Delden
Modelling of estuarine turbidity maxima	Faculteit Natuur- en Sterrenkunde/UU	De Swart
Large eddy simulation of katabatic Flows	Faculteit Natuur- en Sterrenkunde/UU	Van Dop
Antarctic climate studies	IMAU/UU	Van den Broeke
Changes in the global ocean circulation over the last 65 Ma	IMAU/UU	Dijkstra/Van de Wal
Inception of the Antarctic ice sheet	UCG/UU	Van de Wal
The temporal and spatial dynamics of shoreline sandwaves	UCG/UU	Ruessink

Ph.D. students:	status on January 1, 2001:	25
	status on January 1, 2002:	24
	status on January 1, 2003:	24
	status on January 1, 2004:	21
	status on January 1, 2005	20

Postdocs:	status on January 1, 2001:	25
	status on January 1, 2002:	17
	status on January 1, 2003:	18
	status on January 1, 2004:	18
	status on January 1, 2005	13

8. Management team

Director

Prof.dr.ir. H.A. Dijkstra (until 1-10-2003)

Prof.dr. J. Oerlemans (from 1-10-2003)

Members of the Governing Board

Prof.dr. J. Oerlemans

Prof.dr. W.P.M. de Ruijter (until 1-9-2003)

Dr. H.E. de Swart

Prof.dr. P. Hoekstra

Prof.dr.ir. J.D. Opsteegh (from 1-9-2004)

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Dr. P.J. van Leeuwen (from 1-9-2003)

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