Danish Climate Centre

Climate Day, 11 February 1999

Report 99-1

Ministry of Transport
Copenhagen 1999

Climate Day, 11 February 1999
Danish Climate Centre, Report 99-1

Edited by:
Jens Hesselbjerg Christensen
Anne Mette K. Jørgensen

ISSN: 1398-490-x
ISSN: 1399-1957 (Online)
ISBN: 87-7478-386-6

1999

Danish Meteorological Institute
Lyngbyvej 100
DK-2100 Copenhagen Ø
Denmark

Phone: +45 3915 7500
Fax: +45 3927 1080

Table of contents

page

Danish Climate Centre
Climate Day 1999

Preface

The purpose of the annual DMI Climate Days is to present research activities and projects and to discuss ideas, progress and plans. Exchange of information on ongoing projects and ideas for new projects may lead to formation of new consortia and development of projects and proposals to for example the European Commission's 5th Framework programme for research and technological development.

The 1999 Climate Day programme covered a broad range of topics, and we are pleased to note that about 30 researchers from the University of Copenhagen, The National Environmental Research Institute, the Risoe National Laboratory, the Max-Planck-Institute for Meteorology in Hamburg and the Danish Climate Centre of DMI participated in the Climate Day 1999.

Anne Mette K. Jørgensen
Director, Research and Development Department
Head of Danish Climate Centre

Climate Day 1999

Danish Meteorological Institute
Danish Climate Centre
11 February, the auditorium at DMI

9:15 Opening address by *Anne Mette K. Jørgensen*
9:30 Direct measurement of paleotemperatures in the Greenland ice-cap. *Klaus Mosegaard.*
10:10 How representative are recent temperature trends? *Martin Stendel.*

10:50 COFFEE

11:10 Relaxation of soil variables in a regional climate experiment. *Ole Bøssing Christensen.*
11:35 Impact of different numerical coupling techniques between surface and .atmosphere in a climate model. *Jan-Peter Schulz.*

12:10 LUNCH BREAK.

13:00 Atmospheric CO_2-fluxes in the North East Atlantic Region. *Aksel Walløe Hansen.*
13:30 High resolution climate simulations in the Arctic. Why? *Jens Hesselbjerg Christensen.*
13:55 Using tendency errors to tune the parameterization of unresolved dynamical scale interactions in atmospheric general circulation models. *Eigil Kaas, Annette Guldberg, Wilhelm May and Michel Deque.*
14:20 Using tendency errors to detect model errors in a GCM. *Shuting Yang.*
14:45 The seasonal forecast for last summer. *Henrik Feddersen.*

15:10 COFFEE

15:25 The solar signal in the global temperature record - new results on the geographical distribution. *Peter Thejll.*
15:50 A coupled ocean-ice-atmosphere oscillation with decadal time scale in the North Atlantic area. *Torben Schmith and Carsten Hansen.*

Two presentations originally scheduled for 11 February were postponed. These are:
- On the impact of the resolution on the assessment of anthropogenic climate change as simulated with a global GCM. *Wilhelm May*. (Tuesday 9 March 1999).
- Chaos, quasi-periodicity and interannual variability: Studies of a stratospheric vacillation model. *Bo Christiansen*. (Tuesday 16 March 1999.)

Direct measurements of paleotemperatures in the Greenland ice-cap

Klaus Mosegaard, University of Copenhagen

Direct, in situ measurements of temperature profiles in the boreholes of the Greenland GRIP project, at the summit of the Greenland ice cap, and the Dye 3 project, 865 km farther south, have been analysed using a Monte Carlo inversion technique. The resulting 50,000 year-long temperature history at GRIP shows the Last Glacial Maximum, the Climatic Optimum, The Medieval Warmth, the little Ice Age, and a warm period at 1930 A.D. of Amplitudes -23 K, +25 K, +1 K, -1 K, respectively. The Dye 3 temperature history is similar to GRIP, but has an amplitude 1.5 times larger, indicating higher climatic variability there. As a by-product of the study the terrestrial heat flow density at GRIP was estimated to 51.3 milliwatts per square meter.

D. Dahl-Jensen, K. Mosegaard, N. Gundestrup, G. D. Clow, S. J. Johnsen, A. W. Hansen, and N. Balling: Past temperatures directly from the GreenlandIce Sheet: Science, Oct. 9, 1998: pp. 268-271.

How representative are recent temperature trends

Martin Stendel, Danish Meteorological Institute

We examine to what degree we can expect to obtain accurate temperature trends for the last two decades near the surface, in the lower troposphere and in the lower stratosphere. Temperatures are compared from surface observations, radiosondes and from the Microwave Soundings Units (MSU), which have been corrected for orbital decay and non-linear instrument-body effects, as well as from the reanalyses of ERA and NCEP.

The estimations of global decadal temperature trends from all observing systems and reanalyses are subject to a considerable degree of uncertainty. In the data-rich regions of the Northern Hemisphere, where MSU and reanalysis data can be regarded as virtually independent, a close agreement is found between lower tropospheric temperature trends from the MSU, from radiosondes and from both reanalyses is found (not shown). In regions without sufficient conventional observations from radiosondes, temperature trends cannot reliably be estimated from reanalyses (see Fig.1). This implies that reanalyses from the pre-satellite era (i.e., prior to 1979) cannot be used to calculate multi-decadal temperature trends.

The manner by which satellite data are assimilated over data-sparse oceanic regions differs considerably between NCEP and ERA. The former employs NESDIS retrievals based on raw radiance's using algorithms that have undergone alterations over time. Thus, intersatellite biases are not specifically calculated, and the product is very sensitive to changes in the algorithms (e.g. August 1992). ERA uses only cloud cleared radiances and performs a "one-dimensional variational analysis". The results of such an analysis have to be bias-corrected. This introduces an error when the satellite, relative to which the correction is calculated is biased itself or when radiances change on a time scale longer than a couple of months, e.g. due to orbit decay. Such errors appear to have occurred with the "afternoon" satellites NOAA-9 and NOAA-11. For the reanalyses, the global trend from NCEP is probably slightly too cool, whereas that of ERA is likely too warm.

Near surface conventional observations show a temperature rise, while no such effect is visible in the near-surface temperature from the reanalyses. This is valid for ocean and land, for both data-rich and data-sparse regions. Possible mechanisms include inhomogeneities in the data coverage and measurement techniques, PBL parameterization problems in the reanalyses, real lapse rate changes during the last two decades, land-use change and urbanisation effects that may affect the surface data and a residual forcing that affects the observations, but not the reanalyses, e.g. by aerosols or stratospheric ozone destruction.

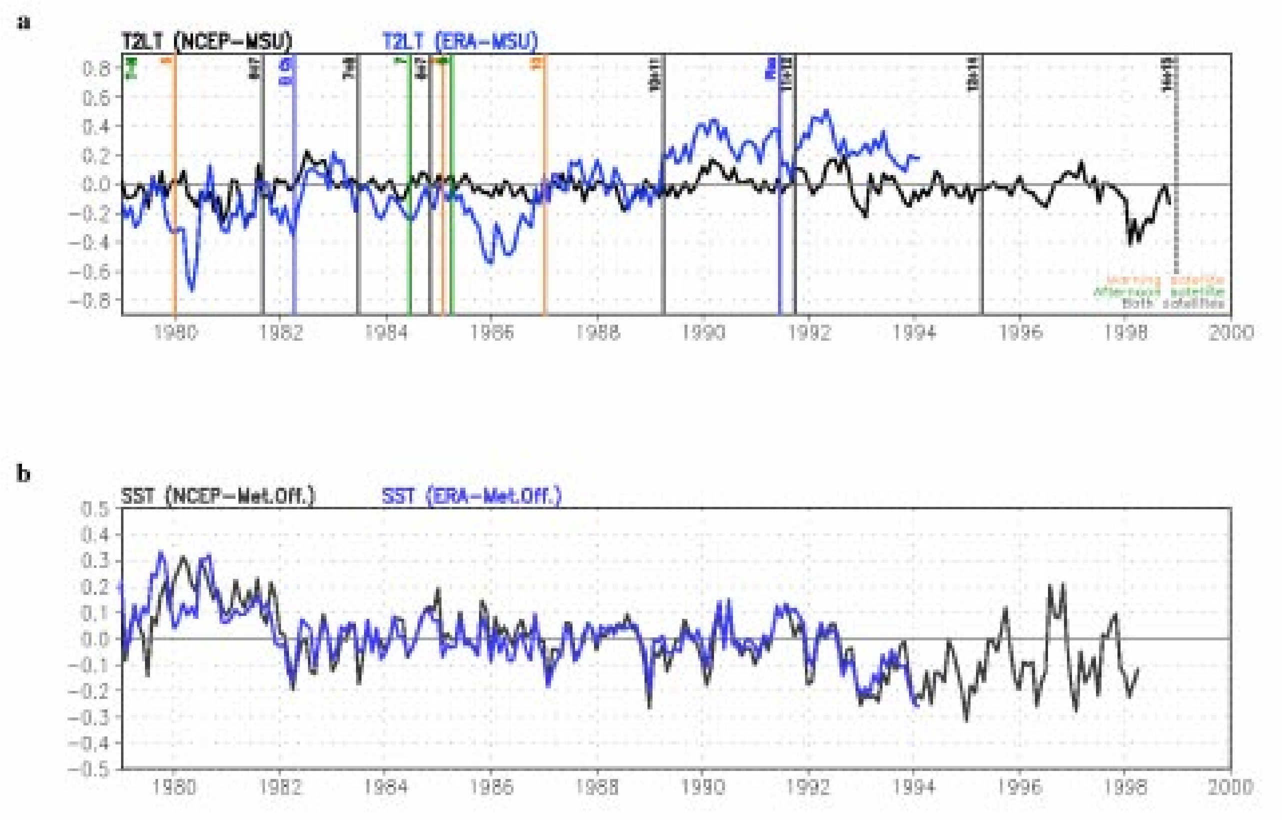


Fig.1: (a) Time series of tropical Pacific residual equivalent MSU temperature anomalies in the lower troposphere for NCEP-MSU (black curve) and ERA_MSU (blue curve). Also given (as vertical lines) are the replacement dates of polar-orbiting satellites used in the reanalyses (orange lines: only "morning" satellite, green lines: only "afternoon" satellites, grey lines: both satellites. Blue vertical lines give the dates of volcanic eruptions. (b) Time series of the difference between the global average MOHSST6 in situ SST and the optimum interpolated SST from Reynolds and Smith (1994) used for NCEP (black line) and ERA (blue line).

Relaxation of Soil Variables in a Regional Climate Model

Ole Bøssing Christensen, Danish Meteorological Institute

The initialisation of soil variables in general circulation models (GCMs) and regional climate models (RCMs) has important consequences for the energy and water balance of the atmospheric model. Initialisation of soil variables is important at an annual to a decadal time scale. Due to the one-dimensional nature of the parameterization and the diffusive equations governing heat transport in the soil, the soil variables will tend to drift towards a quasi-stationary state with a vanishing long-term energy exchange with the atmosphere.

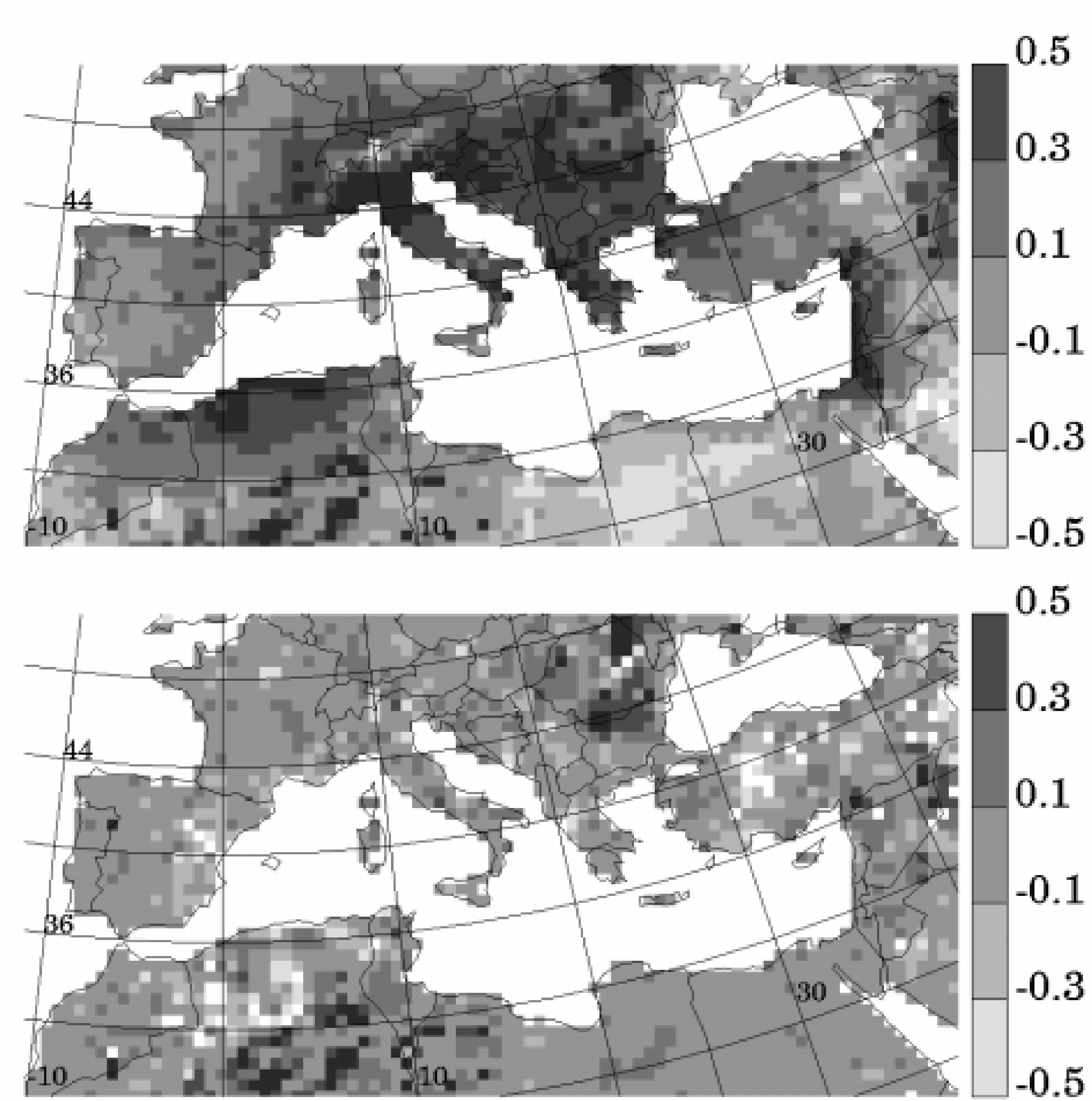
It is a difficult and computationally expensive task to make very long spin-up runs of a model in order to avoid sensitivity of the result to the initial values of soil temperature and water content. Here we have set up an experiment where the effects of transients can be examined without the simultaneous variation due to natural interannual variability. The soil temperature turns out to have a physically meaningful equilibrium value that can be accessed by a spin-up run of a limited number of years and a subsequent extrapolation of these results. Thus on these grounds, it may be possible to develop a method for the initialisation of fields with a multi-year relaxation time like the soil temperature.

We have performed a sequence of one-year simulations (iterations) with the RCM HIRHAM4 with boundary conditions relating to one particular year. At the beginning of each iteration, the initial atmospheric state is reinserted, but the soil variables are allowed to evolve throughout the experiment.

We use reanalysis fields from the European Centre for Medium Range Weather Forecasts (ECMWF) from 1982 as boundary conditions.

The model atmosphere is reset to values corresponding to the beginning of 1982 at the start of each iteration, but the soil variables are allowed to evolve. The integration area comprises Central and Southern Europe, the Mediterranean Sea, and a large part of Northern Africa. With a horizontal resolution of 0.5 degrees or about 55 km in a rotated latitude-longitude system, there are 102x61 integration points. The time step applied is 5 minutes.

While ignoring the variability of the soil variables due to the interannual climate variability, the present approach allows an extrapolation of soil temperature and moisture towards a stable state, which is in balance during the particular year of the experiment.
Here we will investigate monthly average values for July as a function of the iteration number (year) for total soil temperature and for soil water content. We have performed fits to an exponential function $T_k = A + B\exp(-ck)$. Several sets of fits have been done based on a varying choice of which iterations to use. In the following we will compare two different choices: In the first we use 3 out of the first 4 iterations, ignoring the very first iteration in order to allow for short transients to decay, and the last 6 of all 7 iterations, respectively. A comparison of results of these fits for soil temperature is found in the figure. Here the white colour signifies areas where the exponential fit is not a good approximation, i.e., areas with so small relaxation times or amplitudes that the fitting procedure is too uncertain. In the case of only 3 points being used for the fit, the following algorithm is applied: A decaying exponential function can be drawn through the 3 points provided that $0 < (T_4-T_3)/(T_3-T_2) < 1$. Otherwise we substitute the last point T_4 for A and an out-of-range value for c. When there are more than 3 points we perform an iterative gradient-expansion minimisation. For w there is a maximum water holding capacity w^{max}. In the case $A^w > w^{max}$ we set $A^w = w^{max}$ and do a two-parameter fit of B and c to the data set.



Soil temperature annual average (C): Upper panel: Difference between iteration 4 and the asymptote based on all iterations (2-7). Lower panel: Difference between asymptotes based on points 2-4 and 2-7.

A comparison of the two figure panels shows that the exponential fit is good over most of the integration area. After 7 iterations the temperature is within 0.1 degrees of the asymptote over most of the area (not shown). The asymptote estimated with the first 4 iterations does not differ significantly from the best estimate available. In contrast, the actual temperature after 4 iterations is much farther away from the asymptote (fig), consistent with the order of magnitude of the relaxation time being a few years. Typical deviations are 0.5 degrees. Corresponding differences in surface fluxes can be estimated to up to several W/m^2. The corresponding comparison for soil water (not shown) does not show significant differences between the quality of the estimated asymptote and the actual final value, both based on 4 points.

It can be concluded that the asymptotic soil temperature can be calculated by extrapolation after just four iterations of the model, resulting in an estimate much closer to equilibrium than the actual value after four years. Soil water is much more noisy and reaches approximate equilibrium after a few iterations.

The present experiment constitutes a method to distinguish between the transient behaviour of slowly varying fields and the interannual variability. The asymptotic state is independent of the initial soil state before the first iteration and is therefore a property only of the model and of the forcing through the integration period. For instance, this way of obtaining a "canonical" soil state may have been applied for model inter-comparisons, as the arbitrary influence from initial transients has been removed.

Impact of different numerical coupling techniques between surface and atmosphere in climate model

Jan-Peter Schulz, Danish Meteorological Institute

The continental surfaces represent an important component of the Earth's climate system. Meteorological models for climate simulations or numerical weather prediction therefore require a realistic description of the land surface processes. Various land surface schemes have been developed that utilise very different parameterizations of these physical processes and lead to differences in the model simulations. In addition, the numerical coupling between land surface and atmosphere in the models can have a significant impact on the results. In this study, the sensitivity of the simulated land surface energy and moisture budget to a)the numerical coupling technique between land surface and atmosphere and b) to the effect of choosing different parameterizations of the land surface processes is investigated.

Three versions of the ECHAM4 climate model are compared. The standard ECHAM4 climate model utilises a semi-implicit coupling technique between land surface and atmosphere in a way in which energy at the land surface-atmosphere interface is not conserved. This is a major deficiency. Two new model versions were developed: ECHAM4/IMPL and ECHAM4/SECHIBA. They incorporate an implicit coupling technique which conserves energy. ECHAM4 and ECHAM4/IMPL are identical with respect to all physical parameterizations they apply; the only difference is the coupling. In ECHAM4/SECHIBA the ECHAM land surface scheme was replaced by SECHIBA. The intercomparsion of one-dimensional versions of these three models shows that the energy residual term in ECHAM4, which is part of the semi-implicit coupling and represents an error in the surface/atmosphere energy balance, is not negligibly small (cf. Fig. 1). Rather, it is of the order of the physical fluxes and therefore serves as an artificial (numerical) sink or source of energy at the surface, significantly altering the surface energy balance. Biases of more than 1300 W m^{-2} are found due to the coupling technique. These are avoided in ECHAM4/IMPL, which results in a more pronounced diurnal cycle of surface temperature and generally higher temperature maxima during a warming phase.

The three model versions are also tested against observations. This is done in off-line mode, using observational data from Cabauw (The Netherlands) as atmospheric forcing for the land surface

schemes. A 1-year simulation was performed with the three models, using the same initialisation and equivalent surface parameter values. The results show that the coupling technique has an important impact on the simulated surface energy cycle, favouring the more realistic implicit coupling technique when compared to the observations.
In particular, due to the coupling, the turbulent heat fluxes in ECHAM4 tend to be underestimated, their rise in the morning and decrease in the afternoon are delayed. This is illustrated by Fig. 2, taking the simulated sensible heat flux in a 5-day period in September as an example. Due to the improved coupling the turbulent heat fluxes of the implicit models are in better agreement with the Cabauw observations, especially regarding the phases of their diurnal cycles.
Differences between ECHAM4/IMPL and ECHAM4/SECHIBA are mainly visible for the simulated surface temperature which gets closer to the observed radiative temperature for the latter model. Furthermore, the diurnal amplitude of the ground heat flux is increased in ECHAM4/SECHIBA which is in agreement with the observations.

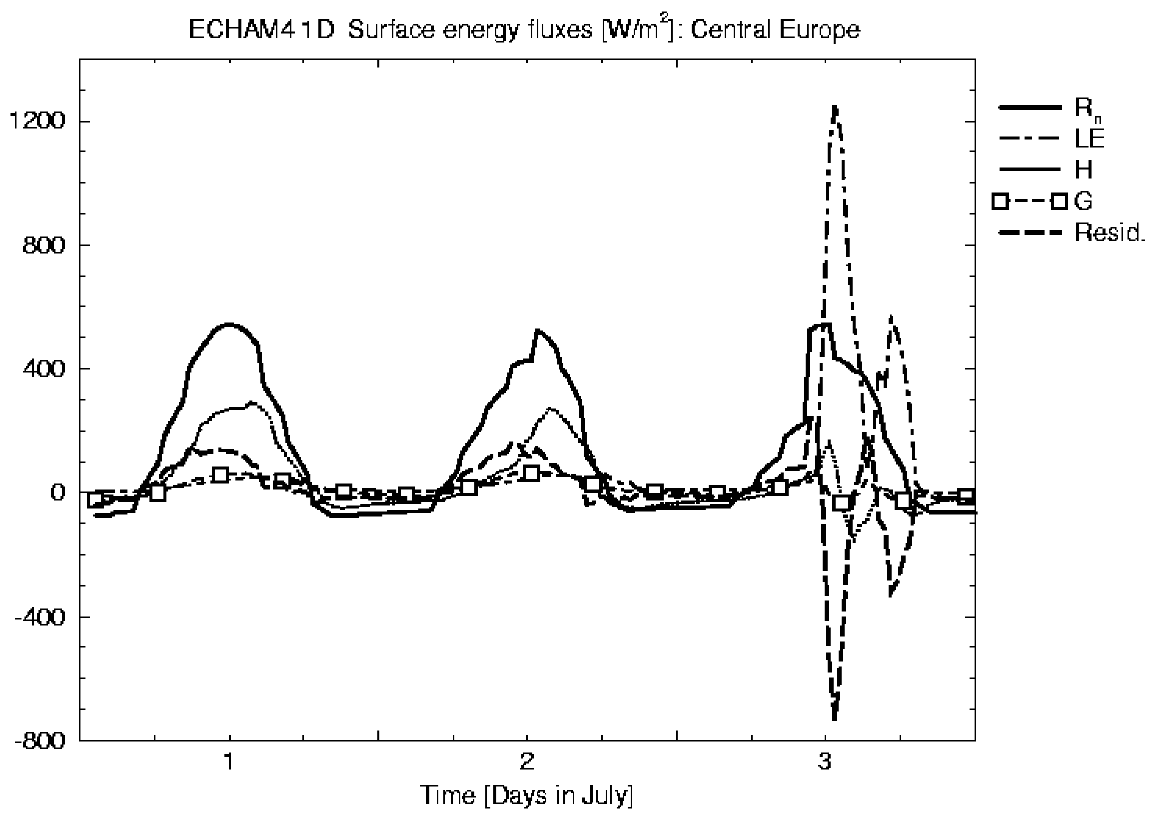


Fig. 1: Diurnal cycles of total net radiation (R_n), latent heat flux (LE), sensible heat flux (H), ground heat flux (G) and the surface energy residual term as simulated by ECHAM4 1D from 1 to 3 July at a site in central Europe. Note that the residual is not small, which was assumed, but of the order of the physical fluxes or even much higher, leading to significantly erroneous flux simulations (e. g. on 3 July).

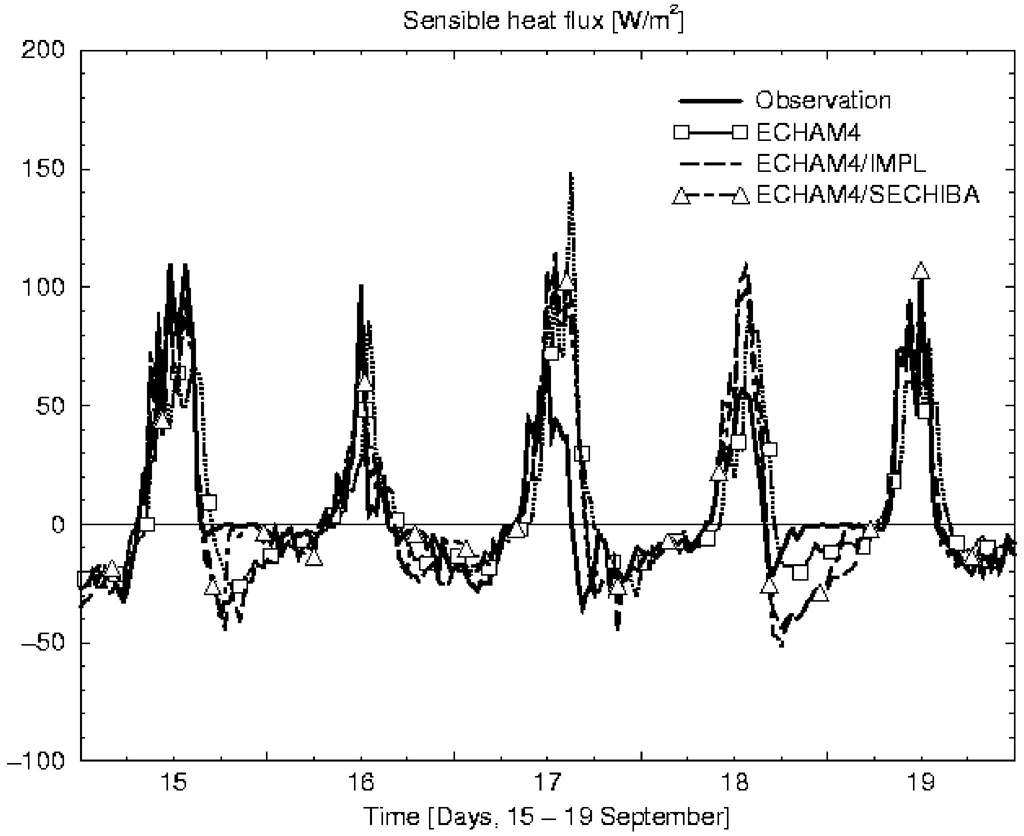


Fig. 2: Diurnal cycles of sensible heat flux as observed at Cabauw from 15 to 19 September compared to the model results of ECHAM4, ECHAM4/IMPL and ECHAM4/SECHIBA.

Atmospheric CO_2-fluxes in the North East Atlantic Region

Aksel Walløe Hansen, University of Copenhagen

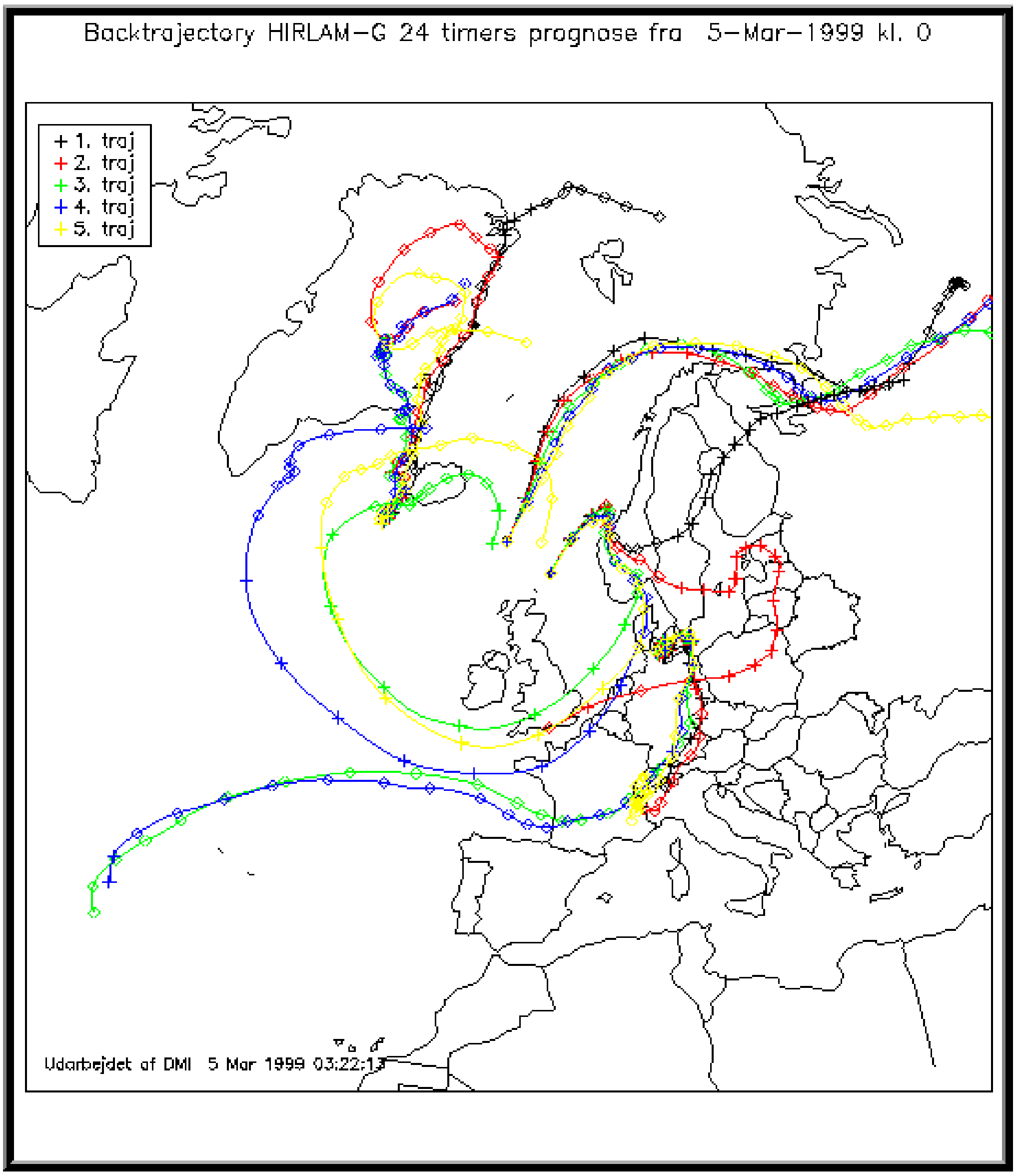
The exchange of co_2 between the atmosphere and the surface - whether it is land or sea - is an important process in the climate system and is of great interest to researchers in global climate/change studies. However, the present understanding of the exchanges is not complete. Budgets of the global carbon cycle are not balanced. An estimated emission of 7.1 GtC cannot be accounted for in inventory studies. In the ongoing discussion, several suggestions are put forward for the missing sink(s). One such study was published in Science by Fan et al. (Science October 1998). Therefore, understanding and documenting the pathways of co_2 are important tasks to the science.

Of special interest is the air-sea exchange taking place in the North East Atlantic Region (NEAR) because this region presently is believed to be a major sink of co_2 , and because model calculations show that the region is very sensitive to climate forcing. The possible magnitude of the flux of co_2 to the sea not only depends on the conditions of the surface water of the region and the flow of water masses in 3 dimensions, but also on the atmospheric mixing properties of co_2 on a regional scale. For example, one can ask the question: will a future climate change lead to air masses of different origins over NEAR as compared to present day conditions? In order to be able to answer this question one needs to be able to simulate the mixing of co_2 in the present climate over the area.

In the NEAREX-project we will attack the problem from different directions. We will combine field measurements and analyses in the laboratory with atmospheric modeling. Samples of co_2 taken at the four stations lying along a transect North West-South East from Iceland to Denmark will be analyzed for C13 and C14 isotopes. The Danish station will also provide us with co_2-concentrations. During cruises in the Norwegian Sea, ship borne measurements are taken of co_2-fluxes and concentrations. A numerical transport model driven by ECMWF data will be used to simulate the regional transport and mixing properties, i.e. "explain" the observed values.

The choice of proper episodes suitable for sampling along the transect is guided by trajectories made by DMI (HIRLAM). An example is shown here for March 5th 1999.

The figure shows the 24 hours prognosis of air parcels arriving at midnight March 6th, 1999, at stations near Copenhagen, Denmark, on Shetland Islands, Faeroe Islands and in Iceland. At each station the height of the boundary layer is calculated and the layer is divided into 6 sub layers with 5 levels separating the layers. For each level a calculation, of the trajectories leading to the 4 stations is carried out. We select events where the trajectories run from Europe over Denmark to the Faeroe Islands and to Iceland.



High resolution climate simulations in the Arctic: Why?

Jens Hesselbjerg Christensen, Danish Meteorological Institute

The largest disagreement between climate model simulations of present-day climate occurs in polar regions. The degree of disagreement between these models reflect the weakness of the current understanding of Arctic climate dynamics and the sensitive dependence of the Arctic climate to different formulations of various physical processes. Chapman and Walsh (1993) found distinct warming over northern land areas during winter and spring during the last decades. Although climate model results indicate a polar amplification of global greenhouse warming, the carbon dioxide signal would have to be distinguished from other temporal variations. This includes the forced response to variations in aerosol concentrations from volcanic, anthropogenic and biogenic sources, as well as natural variability related with the North Atlantic Oscillation (NAO). The currently available surface temperature records are not long enough to distinguish unambiguously the natural and anthropogenic influences. The observed high-latitude climate trends over the past few decades are additionally much more regional and patchy than predicted by the global models.

It has been demonstrated that certain aspects of the simulated regional climate are considerably improved with increasing model resolution, by adopting a nesting procedure in which a regional climate model is imbedded into a general circulation model (GCM), while others are not. The major improvements are found over complex terrain, where the realism of precipitation patterns and timing of snow melt gets increasingly realistic at higher resolution (Christensen *et al.,* 1998). Therefore it seems desirable to investigate the possibility of using a high resolution RCM in an Arctic region with low observational station density in order to try to simulate the hydrological cycle for present day conditions as accurate as possible. To this end the HIRHAM4 model has been applied over the Arctic part of European Russia at a horizontal resolution of 16 km. The work is part of an EU project; TUNDRA, in which the major objective is to obtain net fluxes for carbon and freshwater from an Arctic catchment under base-case and global change scenarios. Here the results from the HIRHAM simulations will be used as input to these base-case climate studies.

In order to provide the present-day model climate, a simulation using 15 years of boundary data from the European Centre for Medium Range Weather Forecasts (ECMWF) re-analyses project has been performed. For practical reasons the model has been set up for a larger region than that required by the investigation. Figure 1 depicts grossly the integration domain (small map inserted), while the major region of interest – the Usa basin - is provided for illustration along with climate records for four climate stations.

The 15 years of simulations have just been completed and the preliminary verification suggests that the general performance of the simulation is realistic in terms of mean monthly temperature and precipitation, but with some deficiencies in the simulated monthly mean daily maximum temperatures and precipitation during summer. Figure 2 compares time series of the simulated monthly mean precipitation with that observed for the 4 stations indicated in Figure 1. These deficiencies require further analysis, but are in agreement with findings of Christensen *et al.* (1998).

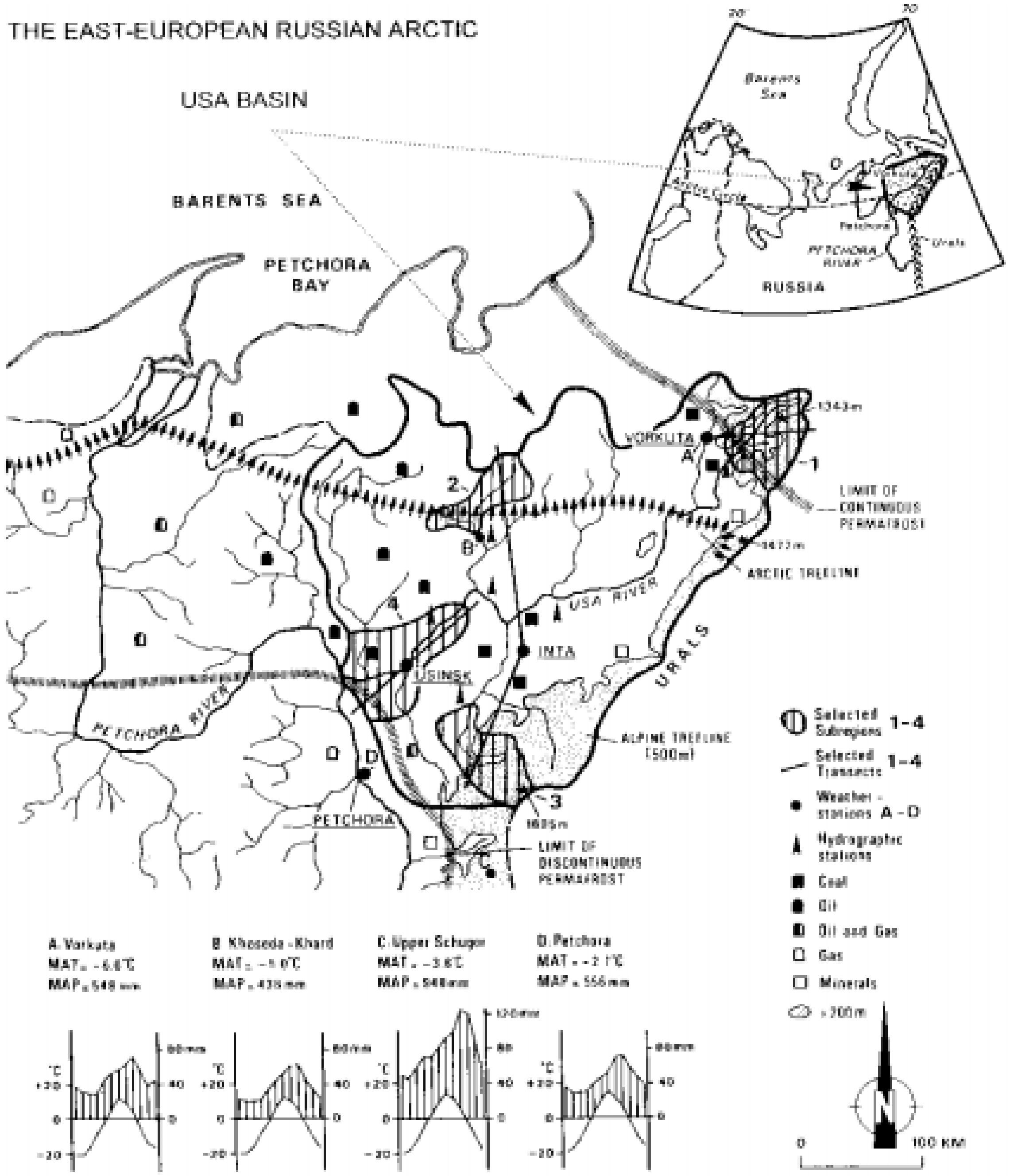


Figure 1 The Usa river basin in the East-European Russian Arctic (inserted map upper right corner). Regional climatic gradients in temperature and precipitation are displayed at the bottom.

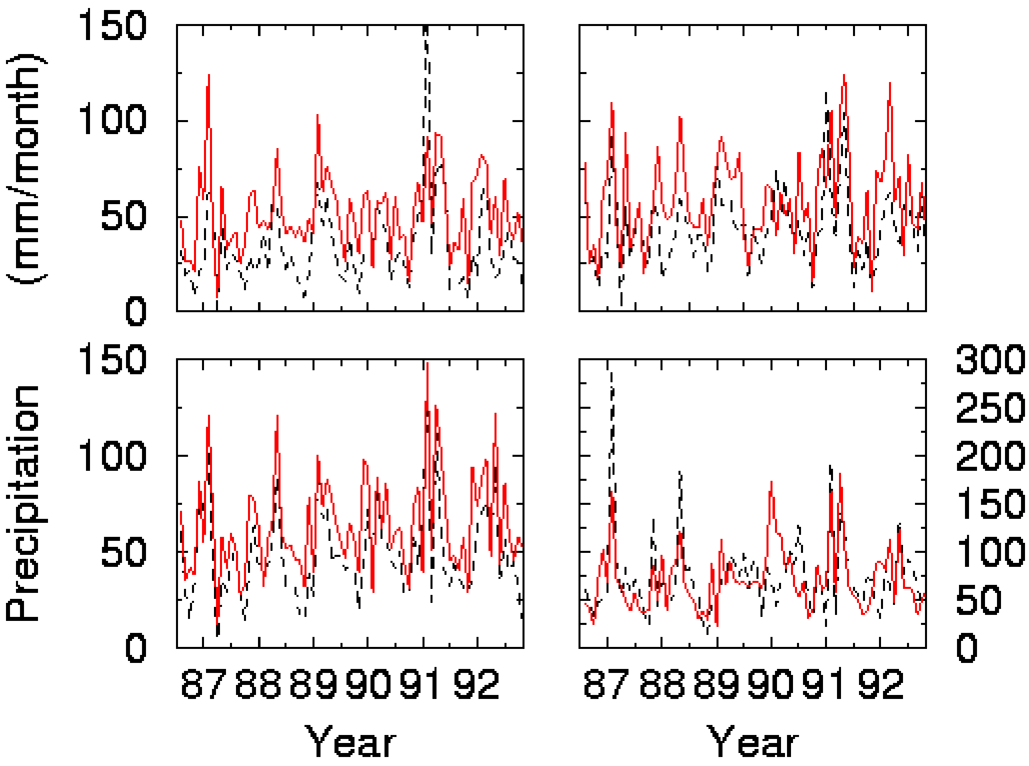


Figure 2 Time series of simulated (full line) and observed (dashed line) monthly mean precipitation from January 1987 to April 1993 for Khoseda-Khard (upper left), Vorkuta (upper right), Petchora (lower left), and Upper Schugor (lower right). Note the different vertical scaling on the latter. The station locations are shown in Figure 1.

References:

Chapman, W. L. and J. E. Walsh, Recent variations of sea ice and air temperature in high latitudes, *Bull. Amer. Meteor. Soc.*, **74**, 33-47, 1993.

Christensen, O.B., J.H. Christensen, B. Machenhauer, and M. Botzet, Very-high resolution climate Simulations over Scandinavia: Present Climate, *J. Clim.*, **11**, 3204-3229, 1998.

Using tendency errors to tune the parameterization of unresolved dynamical scale interactions in atmospheric general circulation models

Eigil Kaas, Annette Guldberg, Wilhelm May all from Danish Meteorological Institute and Michel Deque from Meteo France.

Horizontal diffusion (HD) is an approach used in atmospheric models to parameterize the effect of unresolved dynamical processes. The formulation of HD is often somewhat arbitrary, and is different from model to model. Here we demonstrate a technique that is quite general and is considered powerful in refining the formulation and tuning of HD. For a further discussion of the method and the results obtained we refer to Kaas et al. (1998).

The basic idea is to first calculate the tendency errors of the model to be improved, and then to use these to obtain a new HD which minimise the tendency errors in a broad sense.
Therefore we have performed a simple 4-dimensional assimilation - "nudging" - of the data produced by the reference model (Jeuken et al., 1996) to calculate tendency errors, *R*. In the nudging procedure our model is forced towards the reference data via a Newtonian term.

In many spectral GCMs HD is formulated on model levels as a damping of individual spectral components of a prognostic variable, $\psi_{n,m}$, and the damping coefficient varies with total wave number and vertical level. To calculate HD one must first perform the data assimilation run for a given period and monitor *R* at specified temporal frequency. During the data assimilation run our model is run without HD at all. One can next formally compare *R* and HD for each wave component. Performing a linear regression between *R* and ψ values, one can estimate the new diffusion, $\hat{h}$.
We have tested the above outlined technique both for the ARPEGE/IFS model at T21, L31 resolution and the ECHAM4 model at T30, L19 resolution. In order to avoid problems of misinterpreting tendency errors not related to HD, the reference dataset is created from a model run in which the model is in adiabatic T106 configuration driven by very low resolution relaxation towards climatology. Furthermore, the mountains are truncated at the low resolution, and standard T106 HD is used. The next step is to perform the assimilation run with exactly the same model configuration except that the prognostic variables are truncated at the low resolution and no HD is applied. The assimilation is done as "hard nudging" meaning that it follows exactly the same trajectory in phase space as the reference run.

Figure 1 shows the resulting diffusion for all vertical levels for vorticity for the ECHAM4 T30, L19 model. The empirical diffusion coefficient is weaker at the truncation limit than the one normally used in the model. It is also important to notice that for medium wave numbers the diffusion is negative. The standard model diffusion is larger than or equal to zero everywhere. But the empirical diffusion obtained here is somewhat similar to the one obtained by Koshyk and Boer (1995).

In figure 2a is shown the long term difference in mean sea level pressure (MSLP) between the last 600 days of two perpetual January simulations at T106 and T30 resolutions made with the CHAM4 model. Orography is truncated at T30 in both simulations, and the HD is the standard diffusion.

Figure 2b shows the same the long term difference in MSLP but the two runs are an ECHAM4/T30 with the new diffusion applied and an ECHAM4/T30 with the old - standard - diffusion.
It is seen that the patterns of difference in fig. 2a and 2b are quite similar particularly over the SH. Thus the retuned model behaves somewhat more like a higher resolution model version than the original model. Over the NH the variability is generally too large to obtain significant difference maps - except over Siberia where the sign in both figures is negative.

Figure 3a shows the generation of kinetic energy due to interactions with unresolved scales for ARPEGE/T21. This generation of energy was simply calculated from the kinetic energy in grid point space before and after nudging. Figure 3b shows that part of the kinetic energy generation that originates from the parameterized term $\hat{h}_n\psi_{n,m}(t)$, and this shows how well the unresolved dissipation in fig. 3a is parameterized. The amplitudes in fig. 3b are generally much smaller than in fig. 3a, except for the boundary layer where they are comparable. Furthermore, the position of the regions of energy is not well aligned with those in fig. 3a. Fig. 3b raises serious doubts that a formulation of the form used here (and in most other GCMs) can adequately parameterize the effect of unresolved scale interactions at low truncation. If in fig. 3b $\hat{h}_n$ is replaced by the original h_n the situation is even worse since this function is positive definite, and therefore the resulting energy generation is negative everywhere.

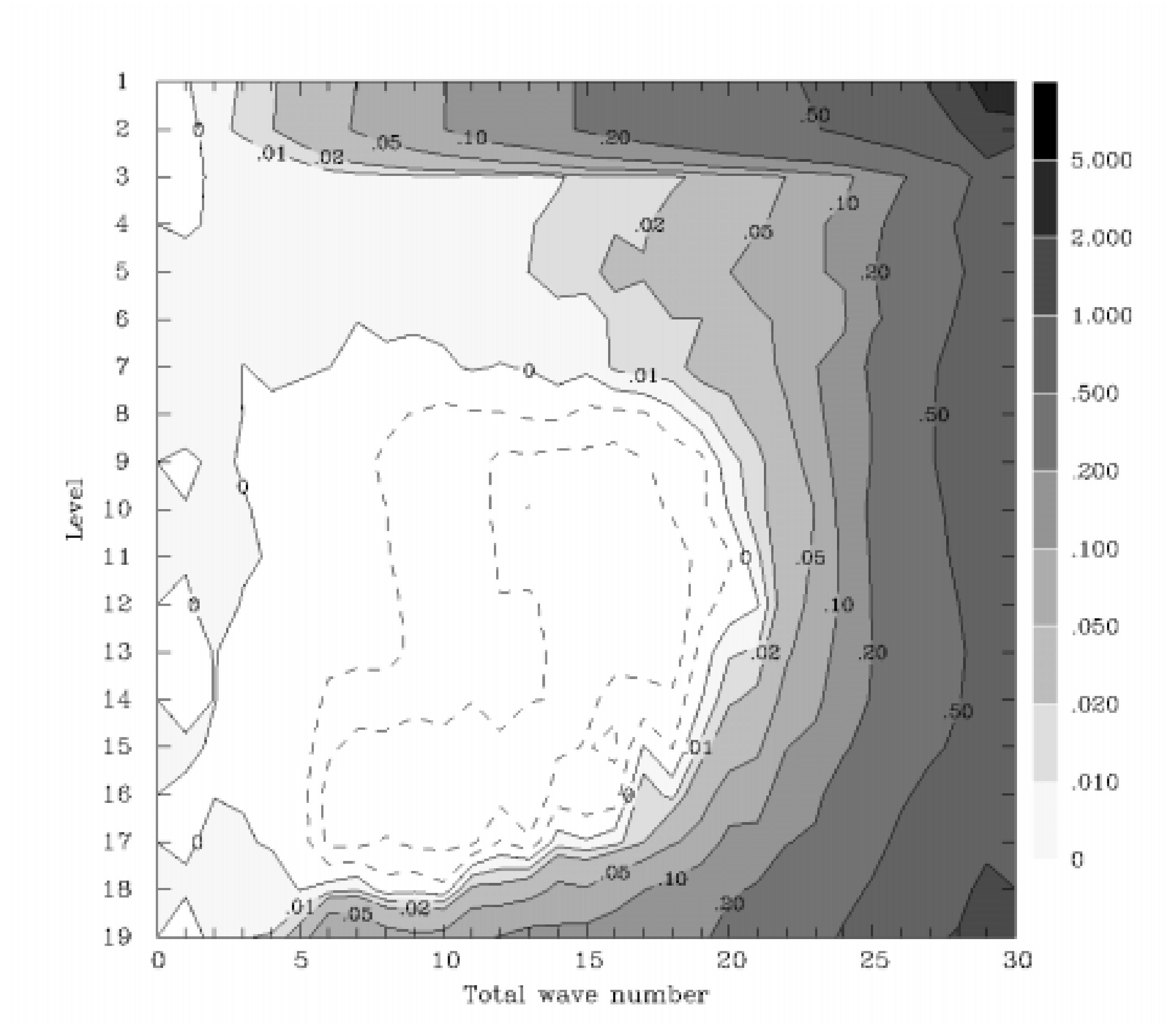


Fig.1: Empirical damping coefficient for vorticity in the ECHAM4 T30, L19 version, The unit is days^{-1}

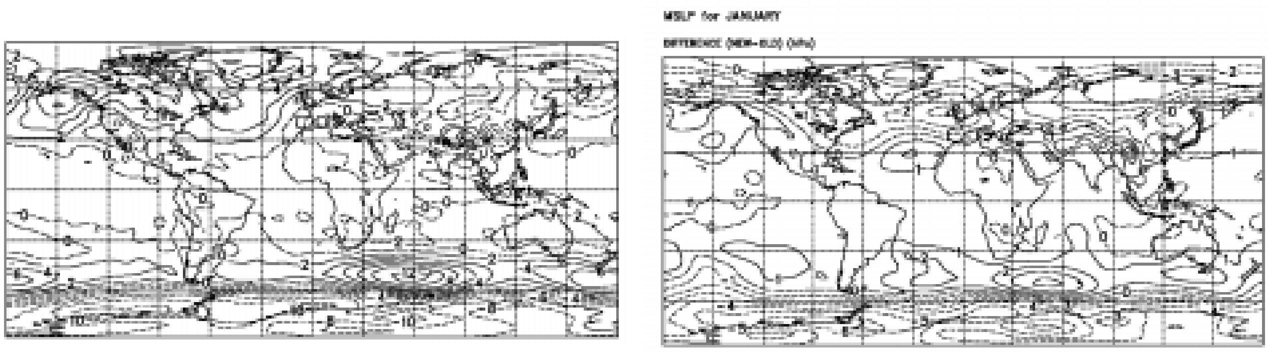


Fig 2.Long term difference in MSLP between the last 600 days of two perpetual January simulations with ECHAM4. a) The two runs are at T106 and T30 resolution respectively. b) The two runs are at T30 resolution but with new and old formulation of HD respectively.

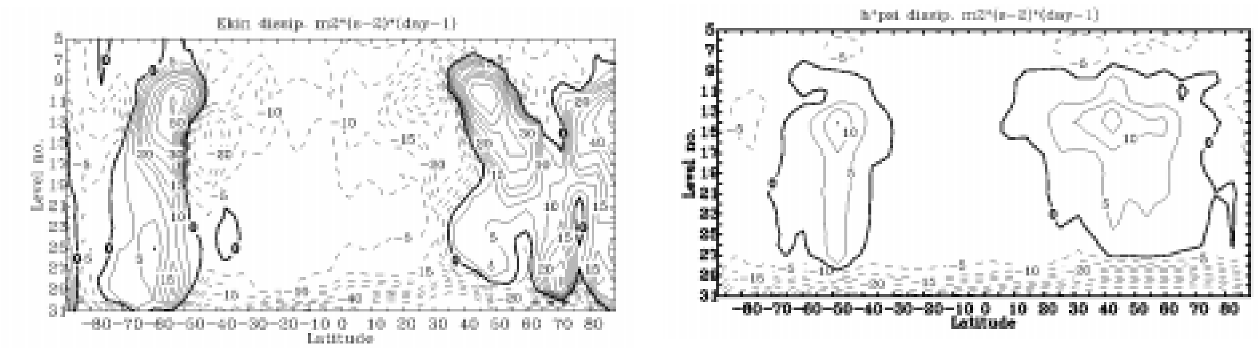


Fig 3.Zonal and temporal mean of energy dissipation a) exact b) parameterized part

References

Jeuken, A.B.M., P.C. Sigmund, L.C. Heijboer, J. Feichter and L. Bengtsson, 1996 : On the potential of assimilating meteorological analyses in a global climate model for the purpose of model validation. *Geophys. Res., 101,* D12, 16939-16950.

Kaas, E., A. Guldberg and W. May, 1998 :
Using tendency errors to tune the parameterization of unresolved dynamical scale interactions in atmospheric general circulation models, *Tellus,* Submitted.

Koshyk, J.N. and J. Boer, 1995 : Parameterization of dynamical subgrid-scale processes in a spectral GCM, *J. Atmos. Sci., 52,* 965-976.

Using tendency errors to detect model errors in a GCM

Shuting Yang, Danish Meteorological Institute

Certain systematic errors excist in the long term mean circulation simulated in General Circulation Models (GCMs) as compared to the observed climatology. Such systematic errors are due to errors in the model forcing, namely, in tendencies of the prognostic variables computed from the model equations. However, due to the nonlinearity of the atmospheric system such as energy dispersion and feedback processes, the patterns of the forcing errors in the model and those of the long term mean systematic errors in the prognostic variables are generally quite different. The goal of this study is to identify the forcing errors in the ARPEGE GCM, and to understand their possible causes. In this study, a simple four dimensional data assimilation technique (i.e., nudging) is used to determine the forcing errors for the model's dynamical variables for the period of May 1986 to August 1987. To identify the sources of the forcing errors, the budgets of model equations are calculated during the model integration. In particular, the contribution from individual terms are extracted. The possible connection between forcing errors and individual physical process (given by each term) is then evaluated.

As shown in Fig. 1, the zonal mean forcing errors in the temperature for DJF 86-87 in the lower troposphere are generally negative, in particular at lower latitudes, indicating that the model is over-heated. In the upper troposphere, the forcing errors are dominated by strong positive values in the tropics which indicate a cooling of the model. Above the troposphere, warming up (negative errors) in the winter hemisphere and cooling down (positive errors) in the southern hemisphere are evident. The strong cooling in the tropical upper troposphere seems to be related to the tropical conversion zones and moves slightly towards the summer hemisphere as the season changes, while forcing errors in the upper hemisphere demonstrate strong seasonal cycle and change signs from winter to summer.

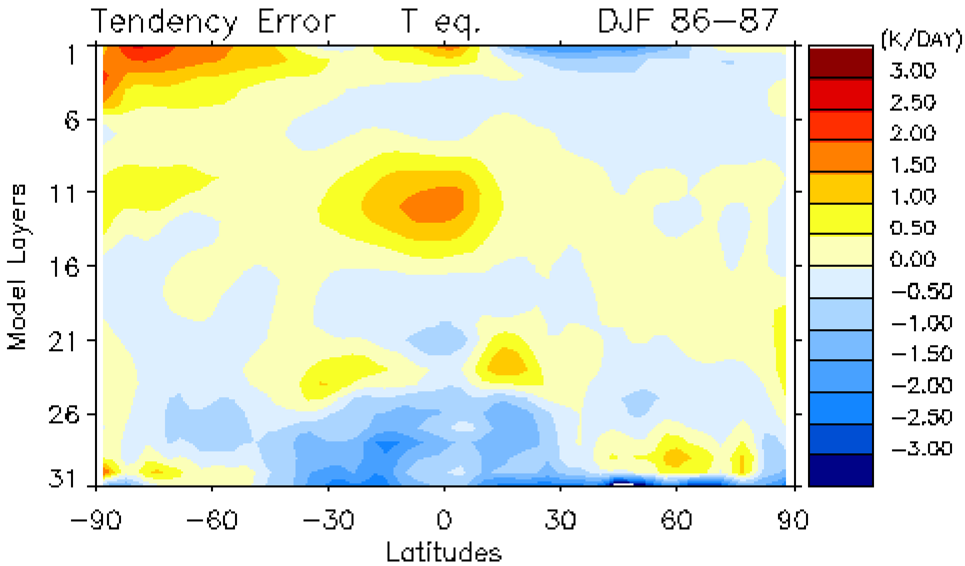


Fig. 1 Zonal mean temperature forcing errors estimated by nudging all the dynamical model variables in the model towards 6 hourly ERA data in DJF 1986-1987. Positive (negative) values in the plot indicate the additional heating (cooling) needed in the model.

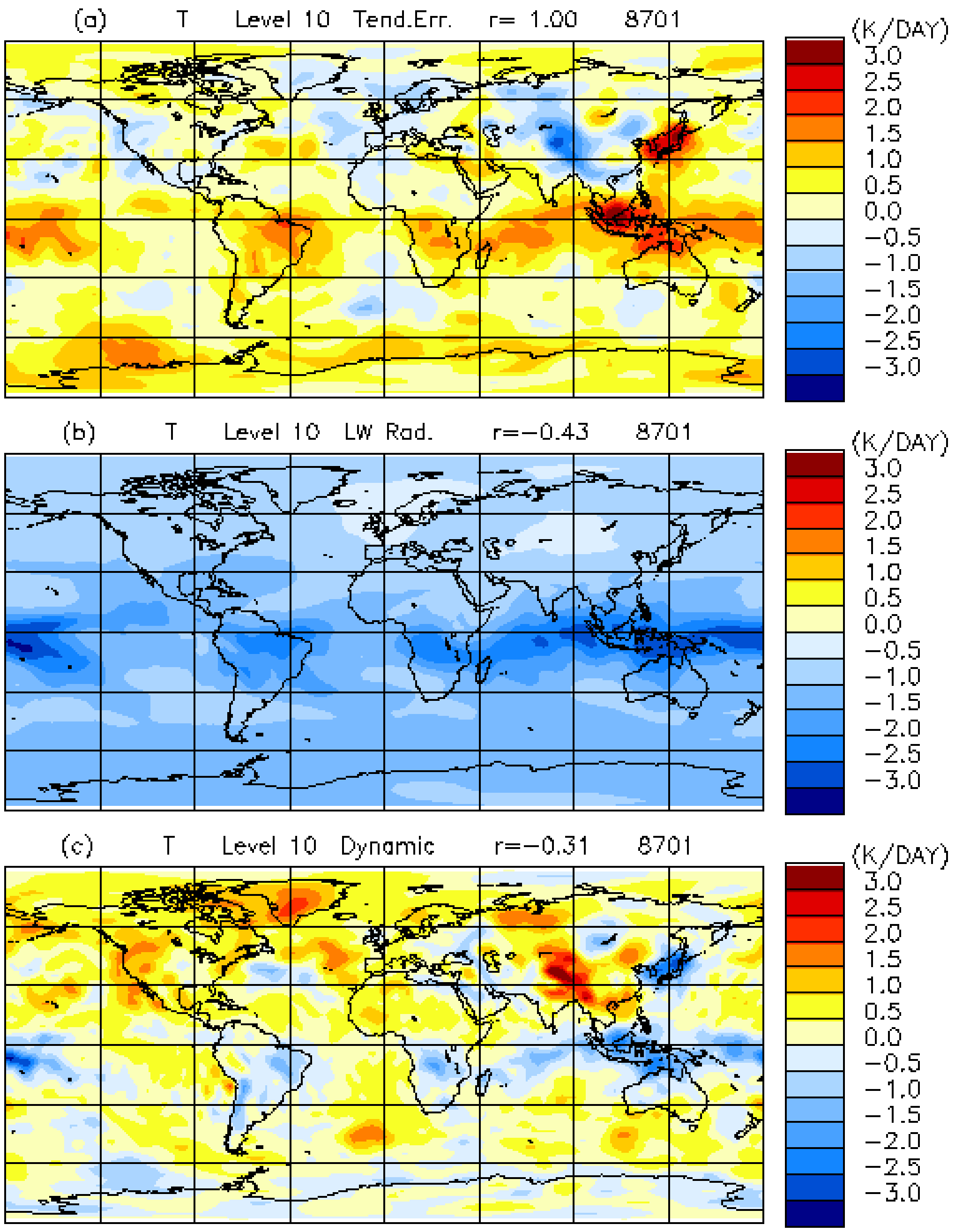


Fig. 2. (a) Geographic distribution of the temperature forcing errors for model level 10 and the averaged tendencies due to (b) longwave radiative fluxes and (c) dynamical processes. The signs on (b) and (c) are opposite to (a), so that a negative (positive) correlation between (b), (c) and (a) indicates the former acts to enhance (reduce) the forcing error.

Fig. 2a shows the geographic distribution of the temperature forcing errors for January 1987 at model level 10 (approximately around 200 hPa), in which the prominent tropical cooling is highly significant. Forcing errors in the south Pacific ITCZ, tropical Indian Ocean and the Amazon basin are as large as 1.5 K/day and bigger. These errors in tropics may be largely related to the deficiencies in parameterizations of processes associated with longwave radiation. As shown in Fig. 2b, the amplitudes and patterns of the tendencies due to longwave radiative fluxes are very similar to that shown in Fig.2a in the tropics. Note that the opposite signs in Fig. 2b to that in Fig. 2a indicate that this term acts to enhance the forcing errors. In fact, the averaged daily pattern correlation of this term and the forcing errors for January 1987 is as strong as -.43, indicating that this term may be the main source of tropical forcing errors at this level. Another significant contribution to forcing errors at this level is the term associated with the dynamical processes, which, as shown in Fig. 2c, seems to be responsible for the errors at the mid- and high latitudes and has an averaged daily pattern correlation of -.31. Contributions from other terms to the forcing errors tend to be very small at this level. Studies of the budget of the model equations, including examination of the relationship between amplitudes and patterns of tendencies from different physical processes and that of the forcing errors, reveal that the model errors at different altitudes are caused from different physical processes. While the main sources of the forcing errors in the upper troposphere seem to lie in parameterizations of processes related to longwave radiation, the errors in the lower troposphere are largely caused by the parameterization of vertical diffusion in the model. Furthermore, the erroneous warming in the winter hemisphere and cooling in the summer hemisphere in the upper atmosphere may be associated with errors in resolving the model dynamics.

The seasonal forecast for last summer

Henrik Feddersen, Danish Meteorological Institute

Since the beginning of March 1998, DMI and The Danish Climate Centre have issued seasonal temperature forecasts for Denmark (and later also for south-west Greenland) at approximately one-monthly intervals. Seasonal forecasts are fundamentally different from short- and medium-range weather forecasts in the sense that seasonal predictability is believed to be closely related to forcing from the lower boundary of the atmosphere, most notably from sea surface temperature, whereas short- and medium-range predictability depend strongly on the actual state of the atmosphere at the initial time of the forecast. At longer lead-times, predictability is lost due to the chaotic nature of the atmosphere. However, the forcing from the relatively slowly varying lower-boundary fields such as sea surface temperature, sea ice extent, snow cover and soil moisture, modulates the chaotic variability of the atmosphere, i.e. for seasonal mean fields the atmospheric variability can be divided into a potentially predictable (“signal”') part and an unpredictable (“noise'”) part.

Based on a set of atmospheric model simulations forced by observed sea surface temperatures over a 15-year period, calculations of potential predictability (``signal-to-noise ratio'') and predictability relative to observed seasonal mean temperature suggest that forecasts of summer mean temperatures in Europe, including Denmark, should be moderately skilful, i.e. better than random forecasts.

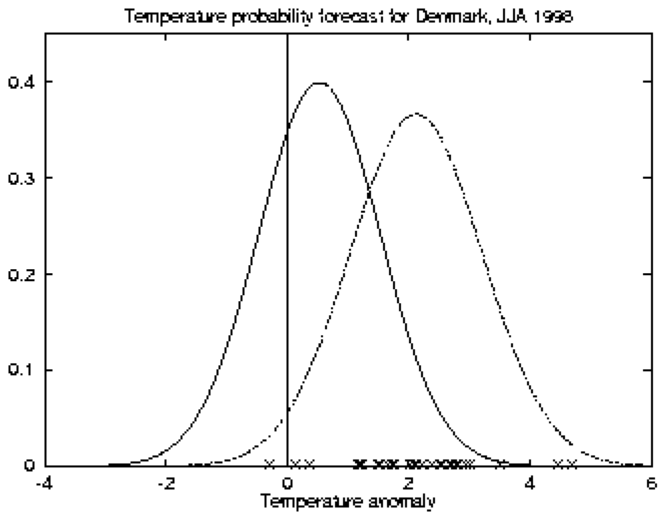
A real seasonal forecast requires also a forecast of sea surface temperature (and preferably all other parts of the atmospheric lower boundary). The first results from ECMWF's coupled ocean-atmosphere model (summer 1997, winter and spring 1998) showed remarkably good agreement between predicted and observed surface air temperature in Europe, possibly, in part, due to the record-breaking El Niño in the tropical Pacific. Thus the first seasonal forecast issued by DMI and The Danish Climate Centre, based on the model prediction from ECMWF, predicted a high probability (~80%) for above average mean temperature in Denmark in the March-May season. The corresponding observed mean temperature did in fact come out 1.3°C above the 1961-90 average.

Seasonal forecasts are uncertain, particularly in north-western Europe. The signal-to-noise ratio is relatively low so the preferred way to present seasonal forecasts is in terms of probabilities. The forecast issued for the mean temperature in Denmark in the summer season (June-August) 1998 gave 70% probability for a temperature above the June-August average (and hence 30% probability for a below-average temperature).

With an observed mean temperature 0.7°C below the 1961-90 June-August average, the summer forecast was by many (not least the media) seen as a wrong forecast. But it is impossible to validate a single binary (only two categories: above and below average) probability forecast (unless, of course, the probabilities are 0 and 100%). However, the binary probability forecast is based on an ensemble of predictions from the ECMWF coupled ocean-atmosphere model, and as this ensemble forecast contains more information, a first order validation is possible if the ensemble is large enough. The validation would simply be whether the ensemble encompasses the observation with some specified confidence, e.g. 95%.

The figure below shows model temperature anomaly forecasts for Denmark from the 30 individual ensemble members for the 1998 summer forecast (marked with crosses) and a probability density function which fits the ensemble members (dashed line). An anomaly of -0.7°C or less, as observed, would be predicted with very little probability and therefore it is likely that the model probability forecast is wrong.

However, we were aware of model deficiencies before the summer forecast was issued, and therefore the issued 70/30% forecast was based on the corrected forecast probability density shown with a solid line. With reference to that forecast an anomaly of -0.7°C is certainly within the 95% confidence limit.



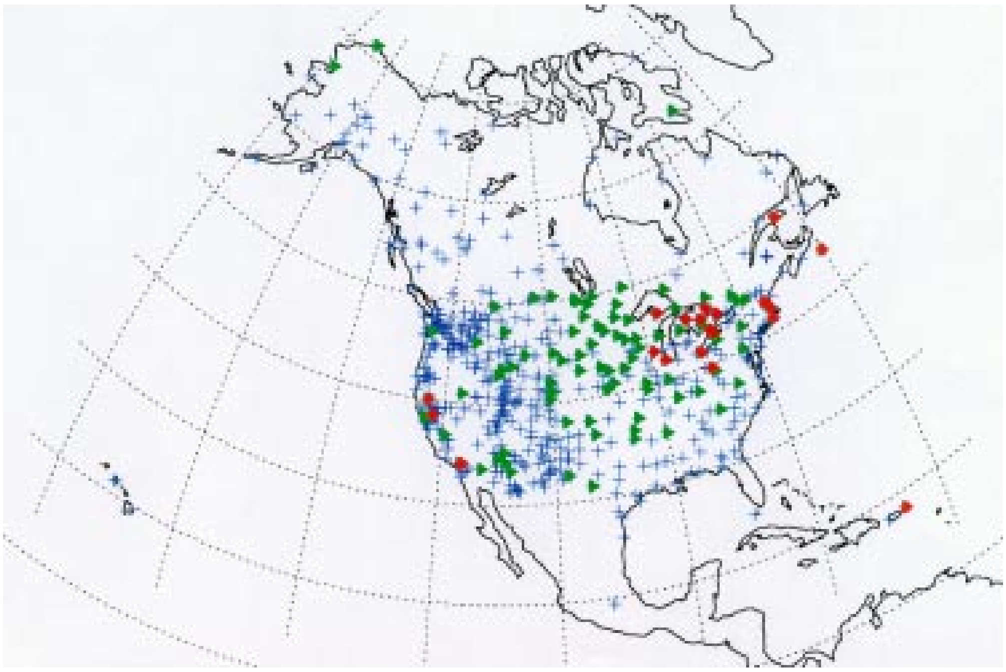
The geographical distribution of the 10-11 year signal in terrestrial temperatures

Peter Thejll, Danish Meteorological Institute

It has been know for some decades that there is a clear 10-11 year “signal” in the observed temperatures at most places on the globe, but especially in North America. The “signal” can be seen as peak in power spectra and is usually interpreted as some sort of climatic response to a periodic influence from the Sun - typically the “Sunspot period”, although usually no physical mechanism is specified for how varying numbers of Sunspots might cause temperature variations on Earth. I have studied this signal in further detail in order to see if it is possible to extract more insight from the geographic distribution of the stations on Earth with the strongest signal.

By simply plotting the locations of stations with the signal on a map, it is possible to recognize the previously published result that in North America most of the stations with a signal are in the north-east part of the USA, whereas most of the stations with suitable temperature data are in fact in the west, thus indicating a special factor having to do with location on the continent.

Further inspection of the location of the stations with the strongest signal reveals that they are likely to be close to large bodies of water, and this is a new finding potentially offering new insight into the physical mechanism.



The figure shows with coloured symbols the location of various stations blue crosses are all stations with suitable data (i.e. at least 50 years of data with no more than 5% missing data) - green triangles are stations with a clear 10-11 year signal - and red diamonds are the stations with the strongest 10-11 year signal chosen in order of decreasing strength of the signal until one station was no longer near a coast.
Notice the nearness of all stations, except the one at McConnelsville Ohio, to large bodies of water - either ocean shores or the Great Lakes.
The probability of this distribution of stations arising by chance is very small. Using a Monte Carlo approach I picked the same number (22) of stations at random from the total number of stations in the USA (386) and considered the 2-dimensional KS test statistic and its probability. Repeating this many times, I built the Null-hypothesis distribution of 2-d KS probabilities, and from this I can see that the chance probability of the observed distribution of near-water stations with periods in the 10-11 year band is very small indeed - on the order of 10^{-4} or 10^{-5}.
The finding of this highly significant link between stations with the 10-11 year “solar” signal and nearness to large bodies of water will now be investigated closely.

A coupled ocean-ice-atmosphere oscillation with decadal time scale in the North Atlantic area.

Torben Schmith and Carsten Hansen , Danish Meteorological Institute

The dominant mode of atmospheric variability in the North Atlantic region is the North Atlantic Oscillation (NAO). This mode can be understood as variations in position and strength of the East American through, which is an important part of the quasi-stationary wave system in the upper-air westerlies on the Northern Hemisphere. At the surface, the NAO is a pressure pattern with centres of action near Iceland and the Azores, and the NAO index is defined as the winter mean of the pressure difference between these two points (e.g. Hurrell, 1997).

The quasi-stationary waves and the NAO can be understood as constructive interference of stochastically exited long Rossby waves, which are partly phase-locked to orography and land/sea contrasts. However, one problem remains: the aforementioned picture will imply a continuos spectrum of the NAO-index, in opposition to the observed, namely enhanced power below 3 years and between 6 and 10 years. Therefore, some kind of memory must be present in the system. It is straightforward to think of the ocean as a candidate for supplying that memory.

In the present work variations of sea ice cover in the marginal seas of the North Atlantic: Barents Sea, Greenland Sea and Labrador Sea are a key process. These variations represent a thermal forcing of the atmosphere by preventing the turbulent heat fluxes directed from the ocean to the atmosphere.

A concurrent analysis of sea ice extent (Walsh, 1979+updates) and atmospheric variables from the NCEP/NCAR reanalysis data set (Kalnay et al., 1996) during the period 1958-1995 has been carried out. Four important areas of sea ice variation are identified, namely: Barents Sea, Greenland Sea, Labrador Sea and Grand Banks/New Foundland and annual (Jan-Mar) sea ice indices are constructed for each area. From the variation of these indices propagation is indicated of sea ice anomalies from Barents Sea to Grand Banks in 4-5 years time.

The turbulent heat fluxes from ocean to atmosphere have large inter-annual variability in the same areas as the sea ice, in particular in the Labrador Sea. This is interesting because GCM studies (Lopez et al., 1998) show a large impact of sea ice extent in the Labrador Sea on the atmospheric circulation.

Composite maps of the MSL pressure show that variations in Labrador Sea ice extent are connected with a NAO-like pattern in the MSL flow, while there is no similar connection for Greenland Sea ice extent and MSL flow. This lead us to propose a coupled oscillation with 8-10 year period whose main elements are as follows: propagation of sea-ice anomaly from Barents Sea to Labrador Sea, forcing of positive/negative NAO pattern in the atmosphere through thermal forcing, enhanced heat transport to the Barents Sea, both in the ocean and in the atmosphere. After two loops the whole cycle is run through. The mechanism is described in more detail in Schmith et al. (1998).

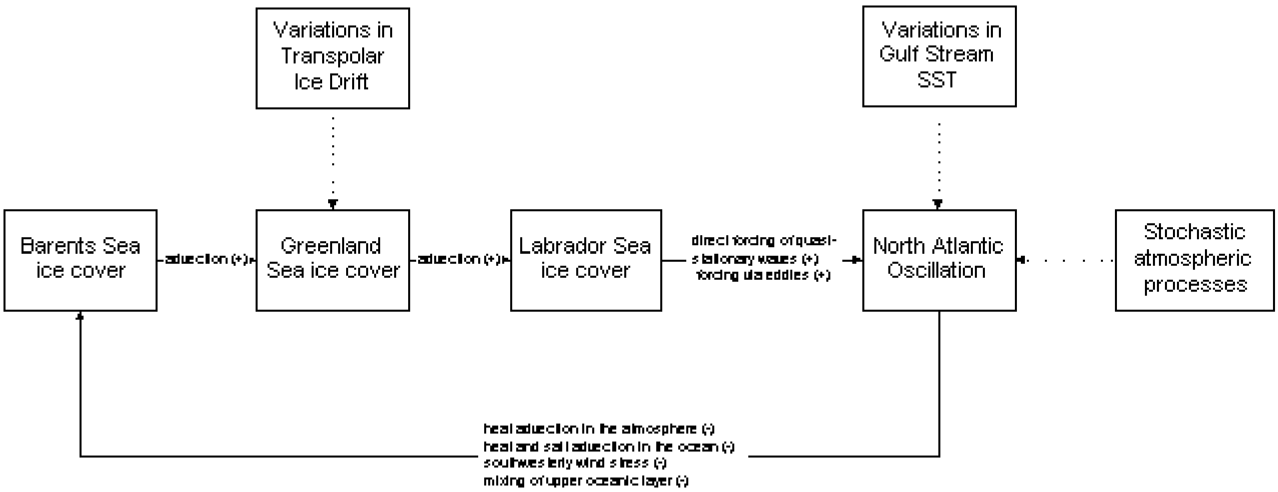


Figure: Diagram showing the proposed mechanism for a climate cycle in the North Atlantic.

References:

Hurrell, J.W., & Loon, H. 1997: Decadal variations in climate associated with the North Atlantic Oscillation. *Climatic change*, 36, 301-326.

Kalnay, E., Kanamitsu, M., Kistler, R., Collins, W., Deaven, D., Gandin, L., Iredell, M., Saha, S., White, G., Woollen, J., Zhu, Y., Chelliah, M., Ebisuzaki, W., Higgins, W., Janowiak, J., Mo, K.C., Ropelewski, C., Wang, J., Leetmaa, A., Reynolds, R., Jenne, R. & Joseph, D. 1996: The NMC/NCAR 40-year reanalysis project. *Bull. Am. Met. Soc.*, 77, 437-471.
Lopez, P., T. Schmith and E. Kaas, 1998: Sensitivity of the northern hemisphere circulation to North Atlantic SSTs in the Arpège climate AGCM. *Clim. Dyn.*, in review.
Schmith, T., P. Frich and C. Hansen, 1998: Variations in sea ice extent in the North Atlantic-Arctic region and connection with atmospheric circulation. *Polar. Res.*, in review.
Walsh, J.E. & Johnson, C.M. 1979: An analysis of Arctic sea ice fluctuations, 1953-1977. *J. Phys. Oceanogr., 9, 580-591.*

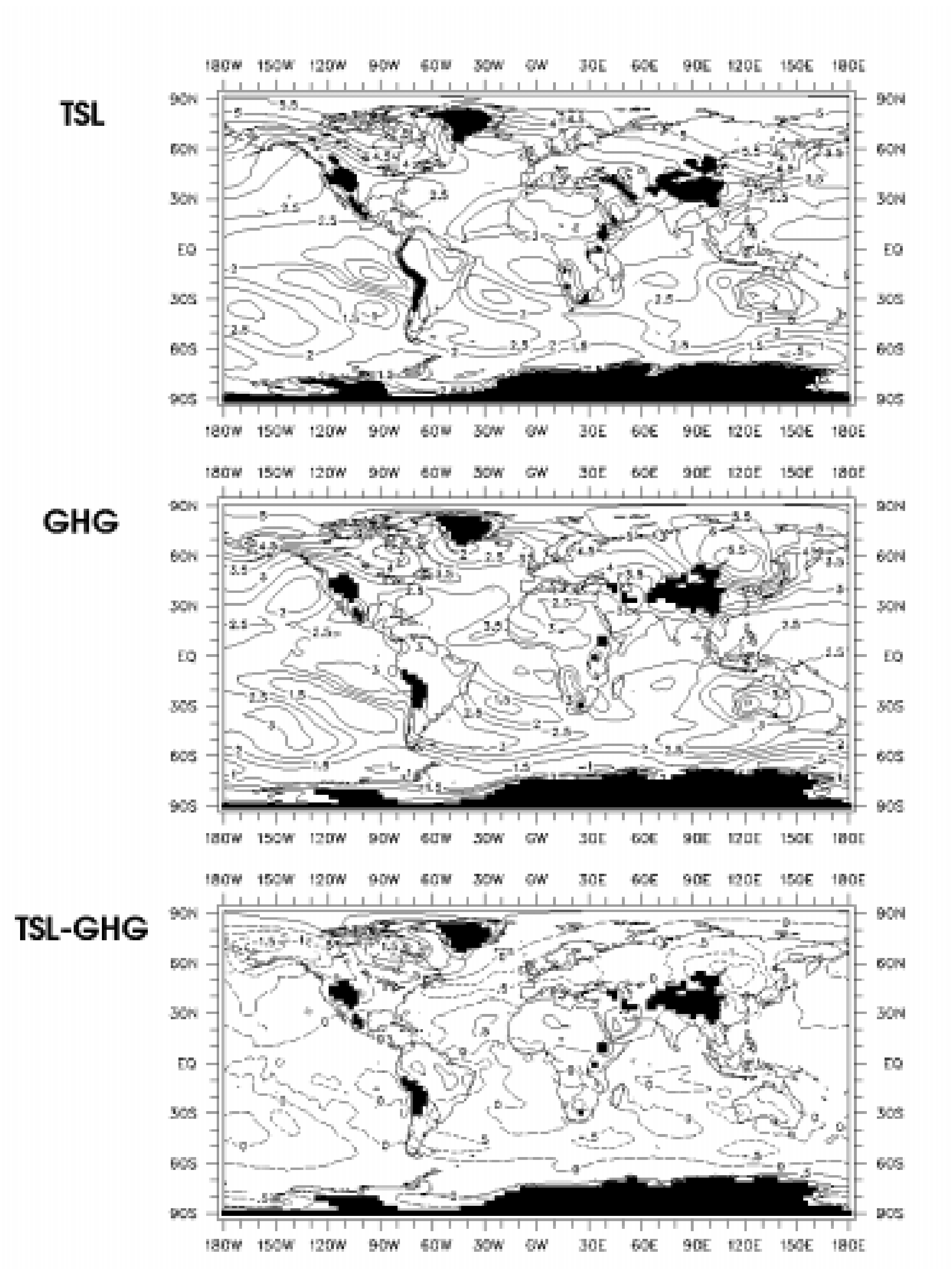
On the impact of the resolution on the assessment of anthropogenic climate change as simulated with a global GCM

Wilhelm May, Danish Meteorological Institute

By comparing results from two climate change experiments employing the same atmospheric GCM at different horizontal resolution we investigate to which extent the change in climate inferred from these simulations depends on the different characteristics of the GCM, i.e. the horizontal resolution. The study is based on a time-slice experiment, which has been performed with the ECHAM4 atmospheric GCM at a horizontal resolution of T106 and a climate change experiment, which has been performed at the Max-Planck-Institute for Meteorology in Hamburg with the ECHAM4/OPYC coupled model at a horizontal resolution of T42 (Roeckner et al. 1998). In the time-slice experiment the atmosphere has been forced by monthly mean values of the sea-surface temperatures, the sea-ice extent and the sea-ice thickness originating from the aforementioned climate change simulation. In both experiments the concentrations of the important greenhouse gases have been prescribed according to observations (until 1990) and the IPPC scenario IS92a. The first time-slice (1970-1999) represents the present-day climate and the second one (2060-2089) the climate at a time, when the concentration of CO_2 in the atmosphere has doubled.

According to the figure included both climate change experiments reveal a general warming due to the increase of the concentrations of the important greenhouse gases in the lower troposphere (i.e., 850 hPa) in the boreal winter season (December to February). In both cases the warming is strongest at high latitudes, and it is stronger on the Northern than on the Southern Hemisphere. Moreover, the warming is stronger over the continents than over the oceans. In the northern parts of Eurasia and North America, for instance, the warming (approximately 6° C) is twice as strong as over the extratropical North Atlantic and the extratropical North Pacific (about 3° C).
It is also in the extratropical part of the Northern Hemisphere, that we find the most pronounced differences between the climate changed inferred from the two climate change experiments.
There is a stronger warming in the climate change simulation with ECHAM4/OPYC over the entire area except for north-western Canada and Siberia. The strongest differences exceed 1.5° C, which is about 25% of the magnitude of the climate change signal obtained from the two experiments, and they occur over central Asia and Alaska. These differences in the climate change signal can mainly be attributed to differences in the simulation of the present-day climate in the two climate change experiments, whereas the differences in the simulation of the future climate are considerably smaller.
This indicates that the horizontal resolution has a different impact on the simulation of the future than on the present-day climate with different large-scale flow patterns and, hence, on the climate change signal inferred from simulations at different horizontal resolutions.

References:
Roeckner, E., L. Bengtsson, J. Feichter, J. Lelieveld, and H. Rodhe, 1998: Transient climate change simulations with a coupled atmosphere-ocean GCM including the tropospheric sulfur cycle. MPI-Report No. 266, 48 pp.



Difference of the boreal winter mean temperature in 850 hPa between the future and the present-day climate for the time-slice experiment (“TSL”) and the climate change experiment (GHG) and the difference between these differences (“TSL-GHG”). Units are [°C], the contour interval is 0.5°C. Terrain above 1500m is blanked out.

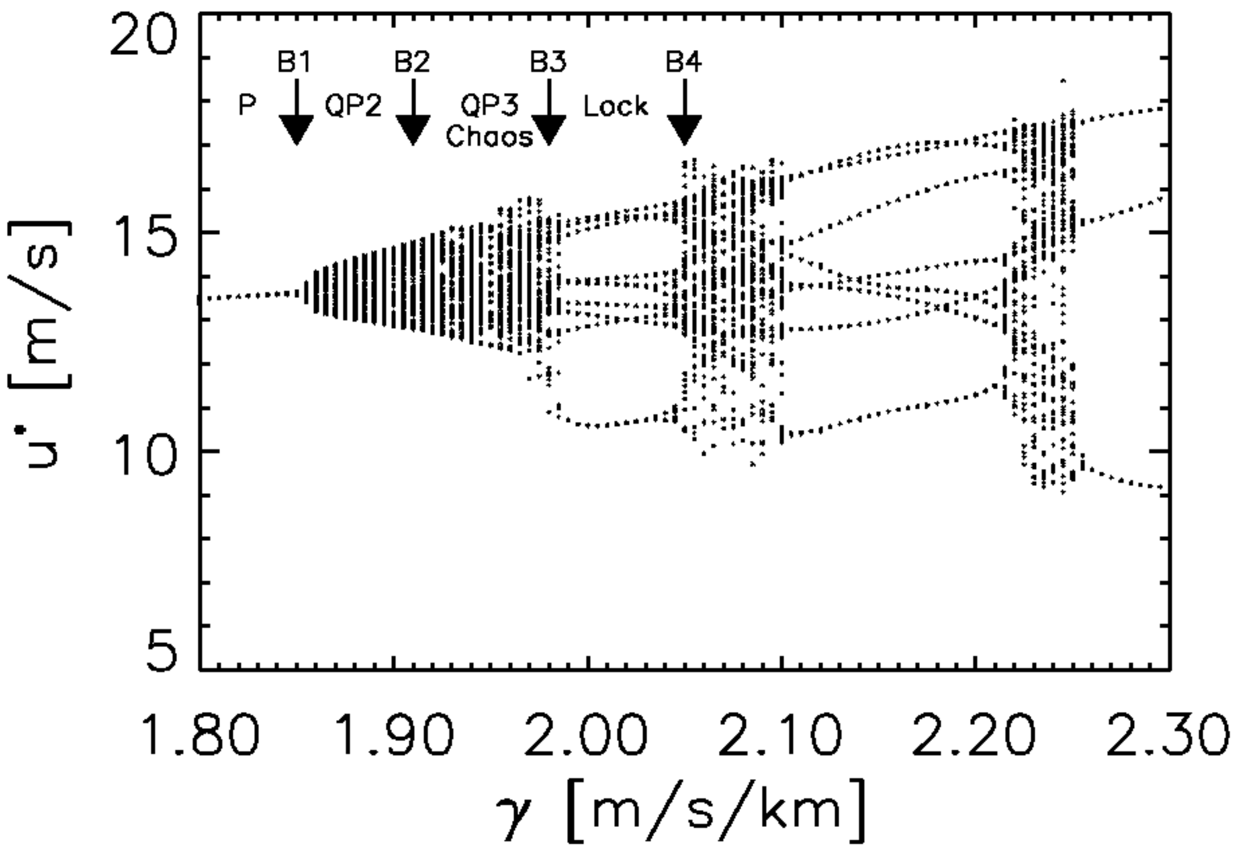
Chaos, quasi-periodicity and interannual variability: Studies of a stratospheric vacillation model

Bo Christiansen, Danish Meteorological Institute

Sudden stratospheric warmings are among the most spectacular events in the stratosphere. Although the first observations of this phenomenon go almost fifty years back and the first successful theoretical insight goes almost 30 years back, a thorough understanding of its mechanism is still lacking. Together with the equatorial quasi-biennial oscillation the stratospheric sudden warmings provide a unique opportunity to study the non-linear dynamics in general, and the wave-mean interactions of the large scale flow in particular.

The idea pursued in this paper is that the variability is created internally in the extra-tropical stratosphere. Studies with a one dimensional model formulated by Holton and Mass (1976) have shown the existence of a Hopf bifurcation when the system is forced from below with a time independent forcing. When the strength of the forcing exceeds a critical threshold a stable steady state looses stability, and a periodic vacillating state emerges. Recently, a similar transition has been reported in a general circulation model run in perpetual January mode (Christiansen B., 1999) and in a primitive equation model of the middle atmosphere. The vacillations strongly resemble stratospheric warmings and result from wave-mean flow interactions.

The Holton-Mass is a quasi-geostrophic, β-plane model truncated to include only one zonal wave number and one meridional mode. The model includes two independent variables, time and height, and three vertical fields of dependent variables; the zonal mean state and the amplitude and phase of the eddies.



Bifurcation diagram obtained with the Holton-Mass model. When the vertical slope of the γ of the radiative equilibrium profile is varied, several different types of solutions are obtained. P: periodic solutions, QP2: quasi-periodic solutions with two basic frequencies, QP3: quasi-periodic solutions with three basic frequencies, Chaos: chaotic solutions identified by a positive Luapunov exponent, LOCK: frequency locked solution.

In addition to the previously described steady and periodic vacillating states we observe both quasi-periodic and chaotic states. The figure shows the types of solutions which exist when the vertical slope γ of the radiative equilibrium profile is varied. In particular, the maxima u^* (obtained from 4000 days long simulations) of the zonal wind 20 km above the tropopause is plotted for each value of γ. The arrows denoted B1, B2, B3, and B4 mark the bifurcation points. Quasi-periodic states with both two and three frequencies are found. Regions with quasi-periodic and chaotic states are separated by regions of periodic, frequency locked states.
The two frequency quasi-periodic state is reached through a secondary Hopf bifurcation from the periodic state. A third Hopf bifurcation introduces a third frequency after which chaotic states are found.

When the system is forced with a periodic annual cycle, strong interannual variability may develop as a consequence of the long time scales introduced to the system by the secondary Hopf bifurcations.

The dramatic variability in the northern hemispheric stratosphere has previously been attributed to interannual variability in one or more of the stratospheric boundary conditions. The results presented here suggest that the extra-tropical interannual stratospheric variability to some extent can be explained by internal stratospheric dynamics. In this context we note that Pierce and Fairlie (1993) found observational evidence for preferred flow regimes in the northern hemisphere winter similar to the regimes found in the Holton-Mass model for an intermediate range of forcings. A similar result was obtained by Pawson and Kubitz (1996). These authors also noted a missing relation between the interannual variability and the possible forcing mechanisms such as the QBO or tropospheric variability. This strongly supports the suggestion that much of the interannual variability in the northern hemisphere stratosphere is internally driven. However, recent work by Kinnersley (1998) emphasises the importance of tropospheric variability by reproducing the observed interannual variability in a stratospheric model forced with observed waves on the tropopause.
Thus, a full understanding of the variability probably requires inclusion of both internal chaotic dynamics and transient wave forcing from the troposphere.

References:
Christiansen B.,
Stratospheric vacillations in a general circulation model, to appear in *J. Atmos. Sci.*, 1999.

Holton, J. R., and C. Mass, 1976:
Stratospheric vacillation cycles, *J. Atmos. Sci., 33*, 2218-2225.

Kinnersley, J. S., 1998:
Interannual variability of stratospheric zonal wind forced by the northern lower-stratospheric large-scale waves,
J. Atmos. Sci., 55, 2270-2283.

Pawson, S., and T. Kubitz, 1996:
Climatology of planetary waves in the northern stratosphere,
J. Geophys. Res., 101, 16987-16986.

Pierce, R. B., and T. D. A. Fairlie, 1993:
Observational evidence of preferred flow regimes in the northern hemisphere winter stratosphere, *J. Atmos. Sci, 50*, 1936-1949.

The Danish Climate Centre

The Danish Climate Centre was established at the Danish Meteorological Institute in 1998. The main objective is to project climate into the 21st century for studies of impacts of climate change on various sectors and ecosystems in Denmark, Greenland and the Faroes.

The Climate Centre activities include development of new and improved methods for satellite based climate monitoring, studies of climate processes (including sun-climate relations, greenhouse effect, the role of ozone, and air/sea/sea-ice interactions), development of global and regional climate models, seasonal prediction, and preparation of global and regional climate scenarios for impact studies.

The Danish Climate Centre is organised with a secretariat in the Research and Development Department, and it is co-ordinated by the Director of the Department. It has activities also in the Weather Service Department and the Observation Department, and it is supported by the Data Processing Department.

The Danish Climate Centre has established the Danish Climate Forum for researchers in climate and climate related issues and for others having an interest in the Danish Climate Centre activities. The Centre issues a quarterly newsletter KlimaNyt (in Danish).

DMI has been doing climate monitoring and research since its foundation in 1872, and establishment of the Danish Climate Centre has strengthened both the climate research at DMI and the national and international research collaboration.

Previous reports from the Danish Climate Centre:

Dansk Klimaforum 29.-30. april 1998. (Opening of Danish Climate Centre and abstracts and reports from Danish Climate Forum workshop). *Climate Centre Report 98-1* (in Danish).