Progress Report for the Special Project SPDKDETE
For the period 1 July 2002-30 June 2003

DETECTION OF CHANGING RADIATIVE FORCING OVER THE RECENT DECADES (DETECT)

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1. OBJECTIVES OF THE SPECIAL PROJECT

1.1. ABSTRACT

A main objective of the EC-project DETECT[1] is for the recent four decades to evaluate the observed (re-analyzed) total energy budgets, for different parts (sub volumes) of the Earth climate system, as a function of time and to try to explain the observed long term temporal variations of temperature from model estimates of the different types of forcing of the Earth's climate system. A comparison of the observed and model computed total forcing will facilitate consideration of processes not included in the IFS and give conservative estimates of errors in the model determined forcing used in the explanation of the temperature variations. In the present special project we do the computational heavy computations involved in assimilations of ERA40 data at ECMWF.

1.2. THE MAIN OBJECTIVE OF THE EC PROJECT
In the present project we introduce a new approach to the problem of detection of climate change in the past and attribution of the causes of the detected changes. Up till now efforts on quantitative attribution of causes, e.g. [1], have been based in particular on the so-called fingerprint method proposed originally by Hasselmann [2]. In this method a certain climate model is run repeatedly in long climate simulations, each time with a different forcing. One could for instance produce one simulation with increasing greenhouse gas forcing, one with an additional increasing aerosol forcing, and one with an additional prescribed variation of solar irradiance. From such simulations, and an additional so-called control simulation with constant forcing, the deviations from the control run caused by each of the forcing types are determined. These patterns of deviation are then called fingerprints for their respective type of forcing. The fingerprints, together with estimates from the control run of the model's "natural" internal variability, are then used statistically in some "best fit" way to attribute causes to the changes that has been observed in the past. A serious objection against the fingerprint method is that it relies heavily on the reliability of the fingerprints. They are based

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[1] European Commission, Contract No. EVK2-CT-1999-00048. Original project period 1 July 2000 to 30 June 2003, extended to end 31 December 2003. Partners: DMI (Coordinating institution), Max Planck Institute for Meteorology (MPIM), Germany, and Tel Aviv University, Israel.
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on long, low resolution climate model simulations, which have systematic errors, for instance too strong sensitivity to the different types of forcing, that causes errors in the fingerprints. A sign of the existence of such errors is the fact that the fingerprints deviates substantially from one model to another one.

A similar critic may be put forward for attribution experiments, as the well known Hadley Centre experiment ([3] and [4]), in which three different ensembles of long simulations covering the period 1850-2000 with a certain climate model are made with different types of forcing included. In one ensemble only volcanic and solar irradiance forcing was included. In another ensemble only volcanic and solar irradiance forcing was included, and in the third one both the natural forcing (volcanic and solar irradiance) and the anthropogenic forcing (volcanic and solar irradiance) were included. The experiment ([3] and [4]) showed that the ensemble including all four types of forcing gave the best fit of the simulated global mean (near surface) temperature to the observed one. As a reasonably good fit was obtained the simulations indicated that the types of forcing, which were included in the experiment, explained the observed variations and that they were included in the model in a correct way. Again, because of possible systematic model errors, in particular a wrong sensitivity to forcing, we cannot be sure that these conclusions are correct. If, for instance, the model used has too large sensitivity to the increasing greenhouse gas forcing, then a not included, i.e. a yet unknown type of forcing, which have also increased since the pre-industrial time may have contributed to the observed global warming. Of course, also other kinds of compensation of systematic errors may occur in long model simulations.

In the attribution method introduced here we are also using model formulations to estimate the effects of the different kinds of forcing, however, by basing these estimates on initial tendency calculations from observed (re-analysed) data we avoid a harmful influence of systematic model errors, which will develop during a model integration. Furthermore, we plan to use a much higher resolution than has been used in previous attribution experiments and should therefore get more accurate estimates of the forcing effects from individual types of forcing. Lastly, but not of least importance, by a comparison of the observed and the estimated effects of the total forcing (comparing the observed and the estimated temperature changes) we can determine the error of the estimated total forcing effects. This will facilitate consideration of additional forcing processes, which are not included in the climate model and give conservative estimates of errors in the model determined effects of forcing to be used in the explanation of the temperature variations.

1.3. SET-UP OF THE DETECTION/ATTRIBUTION EXPERIMENT

A main objective of the present project is to estimate and try to explain long term variations in the temperature, for different parts (sub volumes) of the Earth climate system, over the recent four decades. For the different sub volumes of the atmosphere we consider variations in the total energy E consisting of the internal energy I, the potential energy P, and the kinetic energy K. In a quasi hydrostatic atmosphere, as that of the Earth's, the potential and internal energy combines to the total potential energy P + I, the main part of which is proportional to the temperature T. For a unit mass of air this part is the enthalpy e = Cp T, where Cp is the specific heat capacity of air at constant pressure. We are mainly interested in this part of the total energy, as we are interested in explaining observed temperature changes. Also, the different kinds of forcing we consider act directly only on the enthalpy and not on the other kinds of energy. However, we must monitor also the other parts of the total energy in order to estimate to what extend enthalpy is converted to these other forms of energy. As the atmosphere exchange heat energy with the land surface and the oceans we also monitor the model computed energy fluxes at the surface of the Earth. These fluxes act as forcing on the atmosphere. The boundary conditions over the ocean, in particular the sea surface temperature and the ice coverage, is taken from the re-analysis, whereas over land the fluxes constitute the forcing terms in the surface/sub soil model tendency equations for internal energy of the vegetation and sub soil layers of the AGCM.

Originally, it was planed to use a new climate model version, called IFSHAM, which has been developed at DMI in corporation with MPIM in Hamburg. It combines the very efficient dynamical core of the ECMWF Integrated Forecast System, IFS (i.e. the latest ARPEGE climate version) with the newest physical parameterization package (version 5) of the German climate model ECHAM. It was expected to include a new parameterization package of aerosol physics and chemistry in this model. Different circumstances have, however, lead to a change of that plan. We have decided, instead of the IFSHAM, to use an ECMWF IFS model version similar to the one used in the ERA-40 assimilations. Firstly, it turned out that an implementation of the new parameterization package of aerosol physics and chemistry in IFSHAM could not be ready to be used in our experiment. So, although the IFS model includes only a very simple, constant in time parameterization of aerosol physics and chemistry it is even better in this respect than IFSHAM. Another advantage is that we can insert the surface and subsoil variables in the IFS model without any modifications. Secondly, our experiments had to be run at the new IBM computer at ECMWF, in order to avoid the transfer of a huge amount of ERA-40 data to DMI, and we could foresee a difficult, time consuming migration of the IFSHAM to the IBM computer if that model should have been used.

The relevant measure of the IFS model computed forcing we will calculate is the magnitude of the forcing term in the tendency equation for the enthalpy. This term may be split up into the contributions from different kinds of modeled processes. We call long term mean values of such a forcing a systematic initial tendency, SIT^{m}, when contributions from all modeled processes are included. When only the contribution from a certain process is included, we call it SIT_{q}^{m}, where the index q refers to that specific process. We compute also observed long term trends SIT^{ERA} and define systematic initial tendency errors SITE= SIT^{m} - SIT^{ERA} .

The data input to the tendency calculations are

- the new ECMWF high resolution (TL159,L60) global reanalysis ERA-40, for the period 1957 to 2001,

and

- For the same period “observed” solar irradiances and greenhouse gas concentrations.

The forcing components SITq to be calculated separately are those due to

- The standard concentration of aerosols
- Varying concentrations of well mixed greenhouse gases and ozone (ERA-40 analyses)
- Varying concentrations of water vapor (specific humidity) and cloud cover

as well as

- Also the forcing effects due to anomalies in solar irradiance and surface albedo (snow/ice coverage) will be estimated.

In addition to these radiative forcing components we compute contributions due to the following three processes:

- All phase changes of water (condensation – evaporation in connection with convective and large scale cloud formation/dissolution)
- Dynamic processes (horizontal advection, vertical advection, the "αω" energy conversion term, and the semi-implicit correction term, and the kinetic to internal energy conversion term)
- Turbulent vertical and horizontal diffusion and gravity wave drag.

The different parts (sub volumes) of the Earth climate system, which will be analyzed separately, remains to be defined in detail. Roughly speaking we will use a horizontal division in high, medium and low latitude bands together with a separation in land and ocean covered areas and a vertical division in the boundary layer, two to three tropospheric layers, and two to three stratospheric layers. The sub volumes will be chosen so that specific areas of interest for desert dust episodes, major volcanic eruptions, and the ozone depletion are covered and can be studied separately. In time we will generally use a basic resolution of monthly averages, which will facilitate also stratification in the four seasons. In order to isolate systematic variations we will compute also long period (e.g. five year) running mean values.

2. THE SPECIAL PROJECT WORK DURING THE PRESENT PERIOD

In 2002 we finalized some experiment to find the optimal method to be used in the assimilation of ERA-40 data in an AGCM. In these experiments we used the ECMWF 15-years reanalyzes, available in a T106, L31 resolution to estimate systematic initial model tendency errors in an ECHAM with resolution T42, L19. In order to be assimilated in ECHAM the reanalyzes had to be truncated to the model resolution and to be interpolated in time to the 15 minutes time steps of the model. The truncation and possibly also model differences creates imbalances which tends to give large spurious tendencies that may obscure the real slow manifold tendency errors we are interested in. Furthermore, the cubic interpolation in time from just four daily analyzes smooth out the real daily cycle with adverse effects on the model physics, e.g. on the local release of convection. In order to alleviate the first problem we introduced a so called slow normal mode insertion (SNMI) technique where only the ECHAM slow normal modes with frequencies larger than 24 hours were assimilated, whereas all faster modes were free during the assimilation and thus adjust to a balance with the forced slow modes. In order to alleviate the second problem we introduced a nudging coefficient that were decreasing from 1 (corresponding to full insertion of the slow modes) at an analysis time to zero in a time window and then were increasing again to 1 at the next analysis time. Thus, during the time window all normal modes were free and thus the model takes over the interpolation between the analysis times in a more physically correct way. Due to relatively poor ERA-15 humidity analyzes and differences in the land surface/soil schemes of the models the specific humidity and surface/soil variables were not assimilated. The idea was that ECHAM should create its own model consistent moisture and surface/soil fields. The SNMI assimilations fulfilled our expectations: they were noise free and had a realistic diurnal cycle, however, twin experiments where a free ECHAM run was assumed to be the truth showed that the SNMI failed to reproduce imposed error in parameterization schemes sufficiently correct. So did a simple nudging scheme, whereas full insertion of all normal modes gave the best reproduction. We explain these results by adjustment of the free prognostic variables toward a balance with the forced variables.

As a consequence of these experiments we have decided to avoid noise by inserting all prognostic variables from the new initialized ERA-40 reanalyzes in the full T159, L60 resolution into the same IFS model version (see above) that was used to produce the reanalyzes. We furthermore avoid adjustment and effects of an unrealistic daily cycle by using only zonal averaged tendencies from the available four daily reanalyzes.

Naturally, the consequence of the change of model was that we had to use some time to get used to the IFS model and to build in the required diagnostics, which we had almost finished in the ECHAM and the IFSHAM. As an example of this diagnostic is shown in the attached Figure global averages of contributions from different radiative processes to the temperature tendencies at a specific (randomly selected) date. In the figure RL X=0 stands for the linear contribution from a constituent X. As expected the nonlinear contribution (black diamond) is seen to be small.

We plan to start our productive ERA40 assimilations in IFS in August 2003, when the diagnostics is ready.

References

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Copenhagen, July 31, 2003

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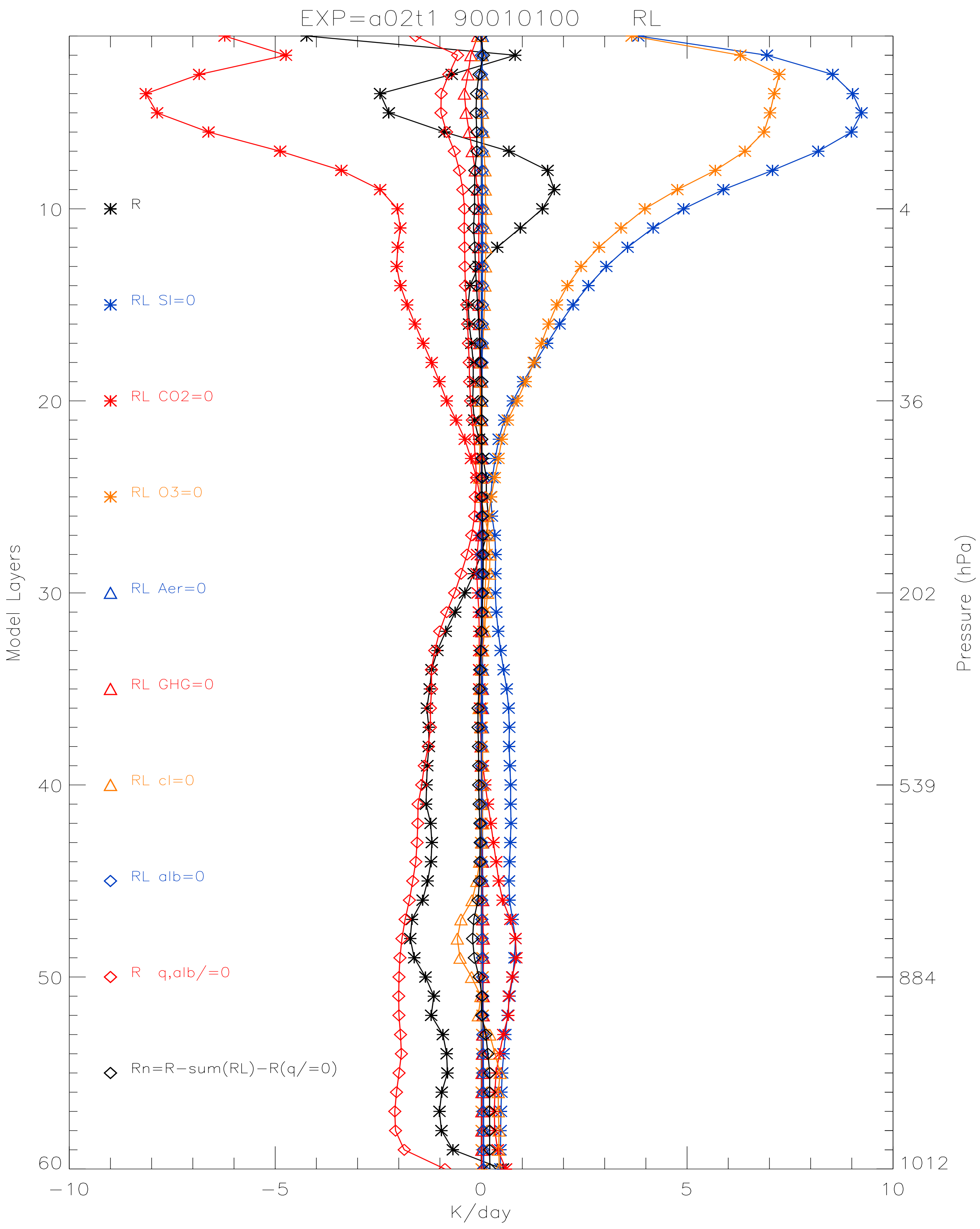

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