

# **Project On Tendency Evaluations using New Techniques to Improve Atmospheric Long-term Simulations (POTENTIALS)**

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## **ABSTRACT**

The project identifies and minimises the tendency - or forcing - errors in four different atmospheric general circulation models (GCMs). In this way new model versions are obtained which are improved relative to the basic versions, in the sense that the total forcing errors are reduced without introducing compensations between multiple errors. The improved models are developed and tested with special attention to simulation of regional climate over Europe and to seasonal prediction. The four models are two state of the art atmospheric climate models and two simpler GCMs.

## **INTRODUCTION**

The long term mean flow simulated in General Circulation Models (GCMs) of the atmosphere exhibits certain systematic errors compared to climatology. These are errors in the position and strength of the quasi-stationary high and low pressure systems and in the phase and amplitudes of the corresponding quasi-stationary upper air waves. Such errors seriously affect simulations of regional climate. As an example many models show a too zonal flow, particularly in winter, over the Central and Southern Europe which results in most of Western Europe being simulated too warm and too wet in this season compared to climatology. Another well known systematic error in many GCMs is a too cold lower stratosphere over the polar regions. These long term mean errors are due to errors in the tendencies of the prognostic variables computed from the model equations, or in other words they are due to forcing errors. Mainly because of the efficient energy dispersion of the atmosphere and feedback's, the spatial distributions of long term mean forcing errors and long term mean errors in the prognostic variables themselves are generally quite different. Thus, for instance, the forcing errors that cause errors in the flow over Europe may be situated far away from Europe, e.g. in the tropics. This implies that it is almost impossible to use the systematic errors in the prognostic variables to deduce where the forcing errors are located in the global atmosphere and to deduce their nature.

POTENTIALS<sup>1</sup> identifies the tendency or forcing errors in four GCMs by using the ECMWF Re-analysis (ERA) data. The GCMs used are two state of art atmospheric general circulation models, one primitive equation model with only 5 levels and a 3 level quasi-geostrophic (QG) model. The space-time information of the forcing errors is then used as a guide to reduce the model's forcing errors by making changes in the physical parameterisation schemes and/or by parameterising the forcing errors empirically. The ultimate goals of the project are to improve the simulation of regional aspects of climate in climate models and to improve the capability for producing seasonal forecast. A detailed workplan can be found on the project web page<sup>1</sup>. Here a brief description of the work and some preliminary results are given.

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<sup>1</sup> Project On Tendency Evaluations using New Techniques to Improve Atmospheric Long-term Simulations. An overview over the project and its progress can be found on the web address <http://gate.dmi.dk/pub/projects/POTENTIALS/>.

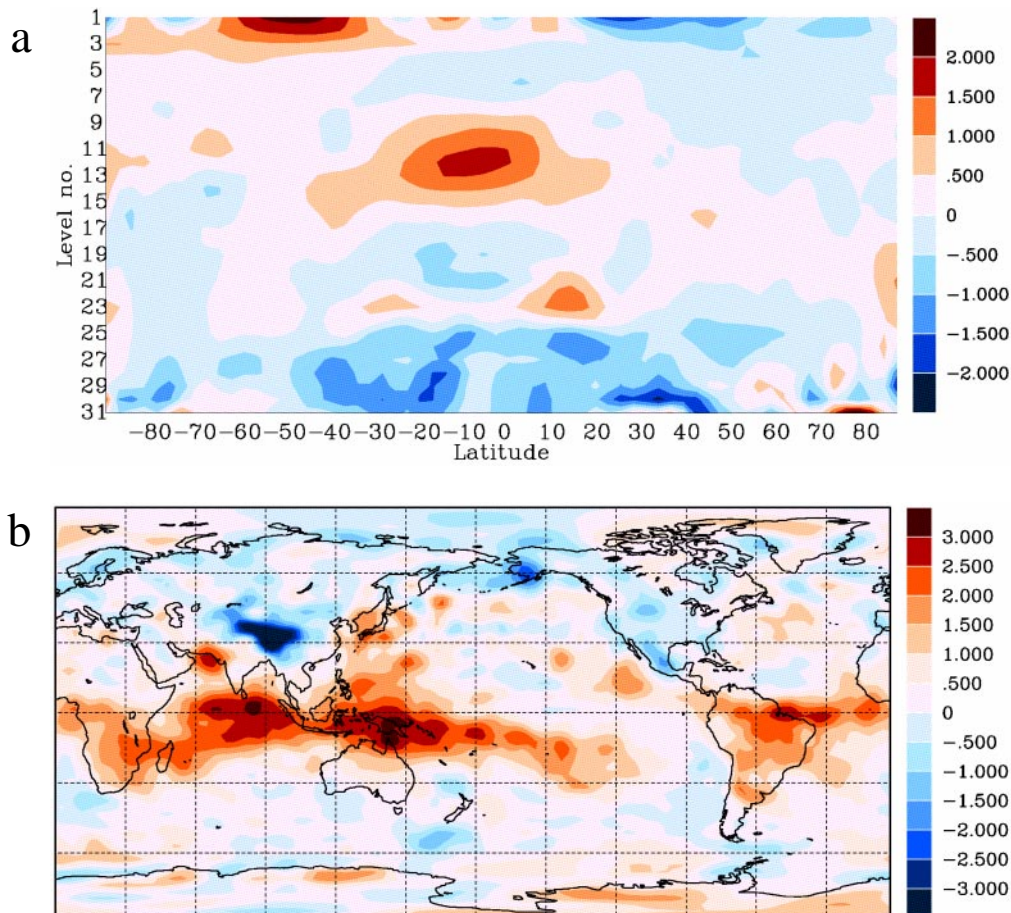


Fig. 1. Residual temperature forcing (e.g. needed additional heating) estimated via nudging of all the dynamical model variables in ARPEGE/T42/L31 (version 2) towards 6 hourly ERA data in Jan. 1985. Panel a): zonal mean plot for all 31 model levels and panel b) latitude - longitude plot for model level 12. Units: K/day.

## CONSTRUCTION OF TENDENCY ERRORS

The tendency errors may be obtained as the difference between observed tendencies and model tendencies given the instantaneous observed atmospheric state and the state of the lower boundary of the atmosphere (e.g. sea surface temperature (SST), temperature and humidity of the soil including possible snow cover etc.). Assuming no errors in observations (analyses) and exact calculation of observed tendencies, the size and time/space structure of the tendency errors reflects all the deficiencies – forcing errors – in a model. It is a main objective in POTENTIALS to develop methods that minimises problems and consequent misinterpretations due unbalanced observed data and due to spin-up of moist processes and physical parameterisation generally. These problems arises because initialised analyses must be interpolated to the actual model grid and because the physical parameterisation in the ERA assimilation model is different from that used in our models. Different approaches are tested ranging from nudging (of the slow manifold) of the dynamical variables to direct estimation of tendency errors based on re-initialised interpolated analyses.

Fig. 1a shows the zonal mean forcing errors in the temperature estimated by nudging all the dynamical model variables in ARPEGE-Climate version 2 T42/L31 model toward 6 hourly ERA data in Jan. 1985. In the lower troposphere, the forcing error is generally negative, in particular at lower latitudes, indicating that the model is over-heated. In the upper troposphere, the dominant feature is a large positive forcing error in the tropics, which indicates a cooling of the model. Above

the troposphere (level 5 and up), the forcing errors are dominated by warming up (negative error) in the winter hemisphere and cooling down (positive error) in the summer hemisphere. The prominent tropical cooling in the model may be seen clearly in Fig. 1b, which plots the geographic distribution of the forcing error for model level 12 (approximately around 280 hPa). Forcing errors as large as 1.5 K/day and higher are evident in the south Pacific ITCZ, tropical Indian Ocean and tropical Atlantic ocean, implying that additional heating is needed in these regions.

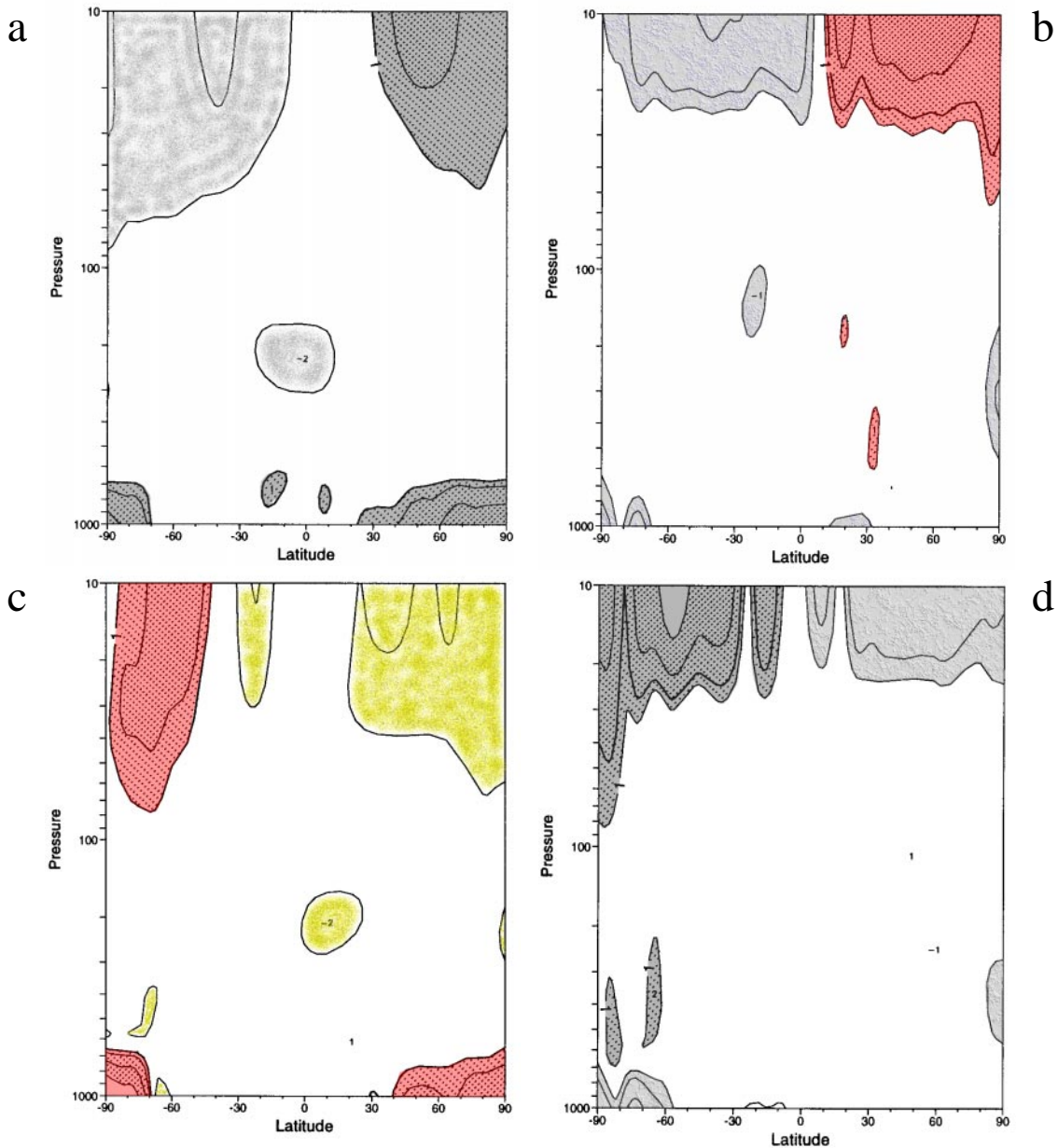


Fig. 2. Zonal mean of residual temperature (panels a and c) and zonal wind forcing (panels b and d) (sign convention opposite to that in Fig. 1) estimated via nudging of all the dynamical model variables in ARPEGE/T63/L31 (version 3 (Eulerian advection)) towards 6 hourly ERA data in DJF (panels a and b) and JJA (panels c and d) in 1979 and 1980. Units: K/day in panel a and c and m/sec/day in panel b and d.

The forcing errors are of course model-dependent. In addition, different techniques used in calculating the forcing errors may give different structures of the forcing errors. Fig. 2 illustrates zonal mean forcing errors in temperature and zonal wind estimated using the same technique as Fig. 1 (with slightly different nudging coefficients) but for ARPEGE-Climate version 3 T63/L31 and for

two seasons (DJF for upper panels and JJA for lower panels) averaged for 1979 and 1980. Note that Fig. 2 has opposite signs of Fig 1, so that a negative/positive value in Fig. 2a (Fig. 2b) indicates a cooling/heating (enhanced easterly/westerly) in comparison with the observed tendencies. Also notice that the vertical co-ordinate in Fig. 2 differs from that in Fig. 1a. Despite the difference between the two model versions and the model resolutions, the overall patterns of Fig. 2a, c demonstrate striking similarity to that in Fig. 1a, in the sense that the model is over-heated in the lower troposphere and with too much cooling in the tropical upper troposphere, as well as heating (cooling) in the upper atmosphere in winter (summer). These similarities indicate that the method used here is stable and the patterns identified are robust for the ARPEGE model.

## **RE-TUNING/IMPROVEMENT OF PHYSICAL PARAMETERIZATION**

In the POTENTIALS the forcing errors are used both to improve the physical parameterisation and as an empirical type of flux correction. As an example of the former, tendency errors in low to medium resolution adiabatic versions of ARPEGE and ECHAM4 relative to high resolution adiabatic versions have been successfully used to tune the damping parameters in the horizontal diffusion (Kaas et al., 1998). Horizontal diffusion is used in GCMs to parameterise the effects of un-resolved dynamical scale interactions. When the re-tuned parameterisation is used it is seen (not shown) that the systematic errors are reduced in the medium resolution model versions - particularly over the southern hemisphere.

## **EMPIRICAL PARAMETERIZATION OF FORCING ERRORS**

The objective of this part of the work is to test to what extent the model errors can be parameterised empirically as functions of the prognostic model variables and of the lower boundary condition, and to apply such parameterisation to the model as (small) correction terms to the prognostic equations. In this way a mostly dynamical but also somehow statistical model will be built which should result in smaller systematic errors than is seen without the parameterisation. Such a model should be very well suited for extended range forecasts. The latter are considered to be only marginally dependent on the initial state of the atmosphere, but are very dependent on the local interaction with the lower boundary of the atmosphere and the atmospheric dispersion properties.

The most simple way of parameterising the forcing errors is to use the long term ensemble of forcing error for a given season as a constant correction to the model. This method has been tested on the ARPEGE-Climate version 2 and the results are summarised in the next section.

On the other hand, the forcing error is time dependent. Thus it is also necessary to consider a parameterisation for the temporal anomalies of forcing error. In the latter aspect, the analogue method is a simple and straightforward but probably powerful approach for this application. In the project, weighted analogues of the instantaneous large-scale flow will be sought for within the longest available data bases where an average residual can be calculated by approximating the first-order moment of the conditional distribution  $P(R/X)$ . Here,  $R$  represents the forcing error and  $X$  is generally a truncated atmospheric-oceanic state vector containing for instance the current leading EOF coefficients, a limited number of spectral expansion coefficients or empirical normal modes. Second-order moments may also be considered by looking at the covariance structure of this conditional distribution. A GCM with analogue type empirical parameterisation of the temporal varying component of  $R$  may, however, for some operational applications be connected with practical file-handling and storage problems. The application of these techniques has been tested for the QG model.

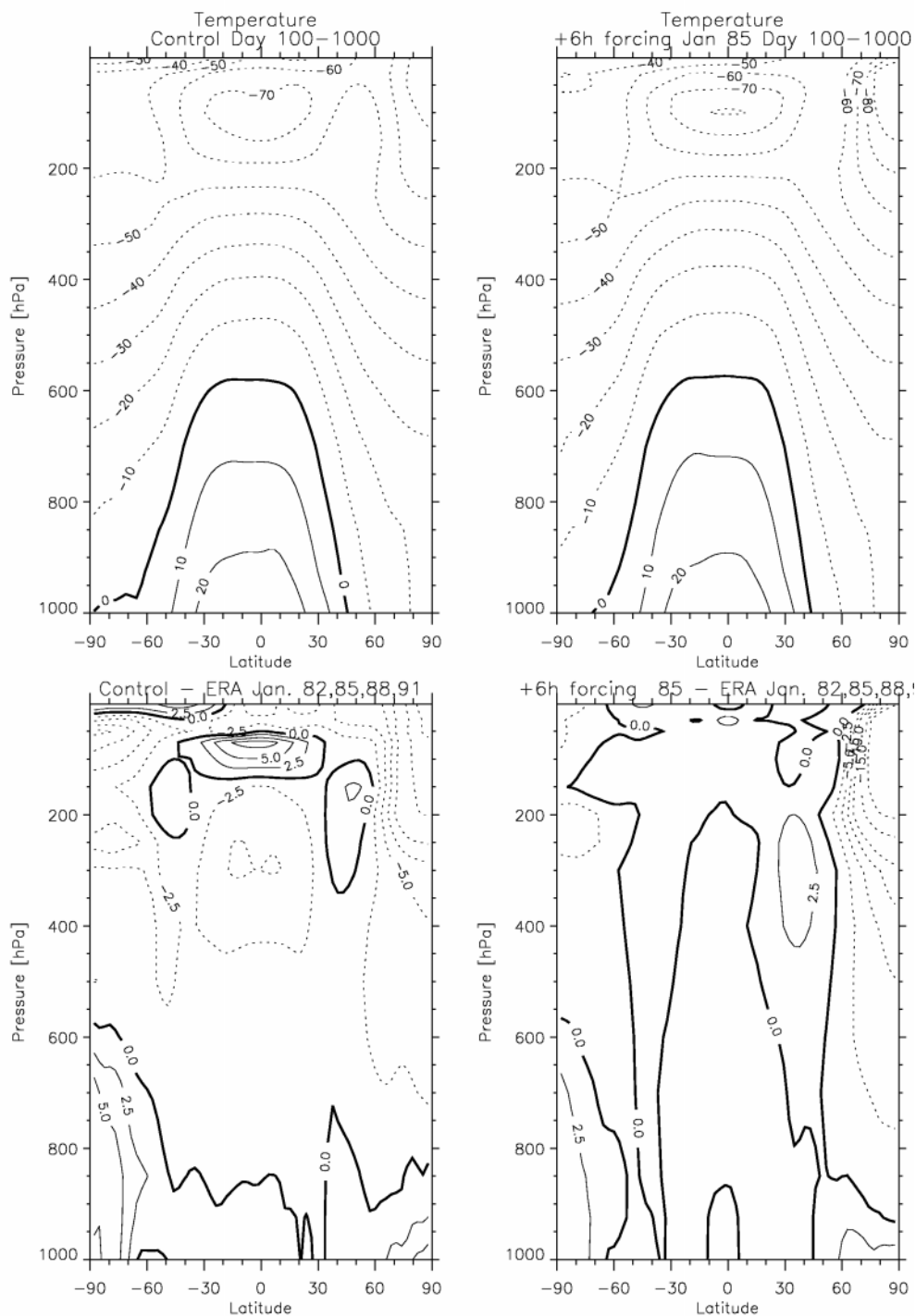


Fig. 3. Long term zonal mean temperature in two perpetual January simulations with (right column) and without (left column) constant additional dynamical forcing (flux correction). Upper panels show full temperature fields in °C for simulated days 100-1000 and lower panels the systematic error in °C relative to ERA-data in Januarys 1982, 85, 88 and 91, with negative contour stippled.

### SIMULATIONS INCLUDING EMPIRICAL PARAMETERIZATION OF FORCING

Climate simulations using models with the empirical parameterisation of forcing error incorporated as discussed above have been performed and compared with the ‘unforced mode’ of the original model. Fig. 3 shows results from such an experiment done with the ARPEGE-Climate version 2

T42/L31 model in a perpetual January mode. The left column of Fig. 3 shows the time average of simulated days 100-1000 of the zonal mean temperature from the ‘unforced’ (control) run and its difference from an average of four Januarys (1982, 1985, 1988 and 1991) of the ERA data. The latter simply gives the systematic error of the model. It may be seen that the model is too warm in the lower atmosphere in particular in the polar regions. Above the planetary boundary layer the model is too cold, except at the top level at southern mid- and high latitudes and around the tropopause at mid and low latitudes where warm biases are seen. The cold bias is particularly pronounced in the northern stratospheric polar night, which is probably because the model is run in perpetual January mode, giving rise to a (physically realistic) slow radiative cooling which after 50-100 days of simulation settles at a lower value than the observations in January. It is of interest to point out that the systematic errors shown here demonstrate rather different pattern from the forcing error of this model as discussed in the previous section and shown in Fig. 1. The right column of Fig. 3 shows similar plots but from the ‘forced’ run in which the mean forcing error for all the dynamical variables is re-injected into the model as a constant correction (the forcing error for temperature is shown in Fig. 1 at model levels). It is evident that the systematic error is greatly reduced almost everywhere, except in the stratospheric polar night, which may be because the slow radiative cooling is too weak in the model leading to much too low temperature after many days of perpetual January simulation. It is, however, yet to be investigated in simulations including annual cycle if this argument is correct.

To investigate the impact of the time varying components of forcing errors, a flow-dependent empirical parameterisation of the forcing error as discussed in the above section is tested in the QG model. For this model the forcing errors were obtained via a variational approach using a set of analyses covering many years. The flow dependence was introduced in a very simple manner by searching for analogues in the Euro-Atlantic sector in the NH in the historical record, i.e. for historical weather maps which were similar to actual model flow. Then the (global field of) residual forcing for this particular date was used as forcing. The comparisons of the model long-term simulation without and with the parameterisation is summarised in Fig. 4. Also plotted on the top panel of Fig. 4 is the winter time (DJF) streamfunction over Northern hemisphere extra-tropics obtained from a 10 year average of the ERA data of 1983-1993 (Fig. 4a) and the observed storm tracks estimated as standard deviation of 10 day high-pass filtered streamfunction in the corresponding period (fig. 4b). Fig. 4c and d show the systematic error and the storm tracks in a very long simulation using the original QG model (i.e., control run). Large positive errors are seen over northern Atlantic, western and eastern North Pacific as well as the subtropical region in Asia, while negative errors are evident over Russian and in the subtropical area over north Atlantic and north America. There are also large biases in the simulated storm tracks in the control run. In particular, storm tracks over north Atlantic are not reproduced. However, the systematic errors are largely reduced when the flow-dependent forcing is introduced in the model, in particular over north Atlantic (Fig. 4e), but also elsewhere. Furthermore, and maybe of greater interest, the simulated storm tracks over north Atlantic is improved considerably (Fig. 4f).

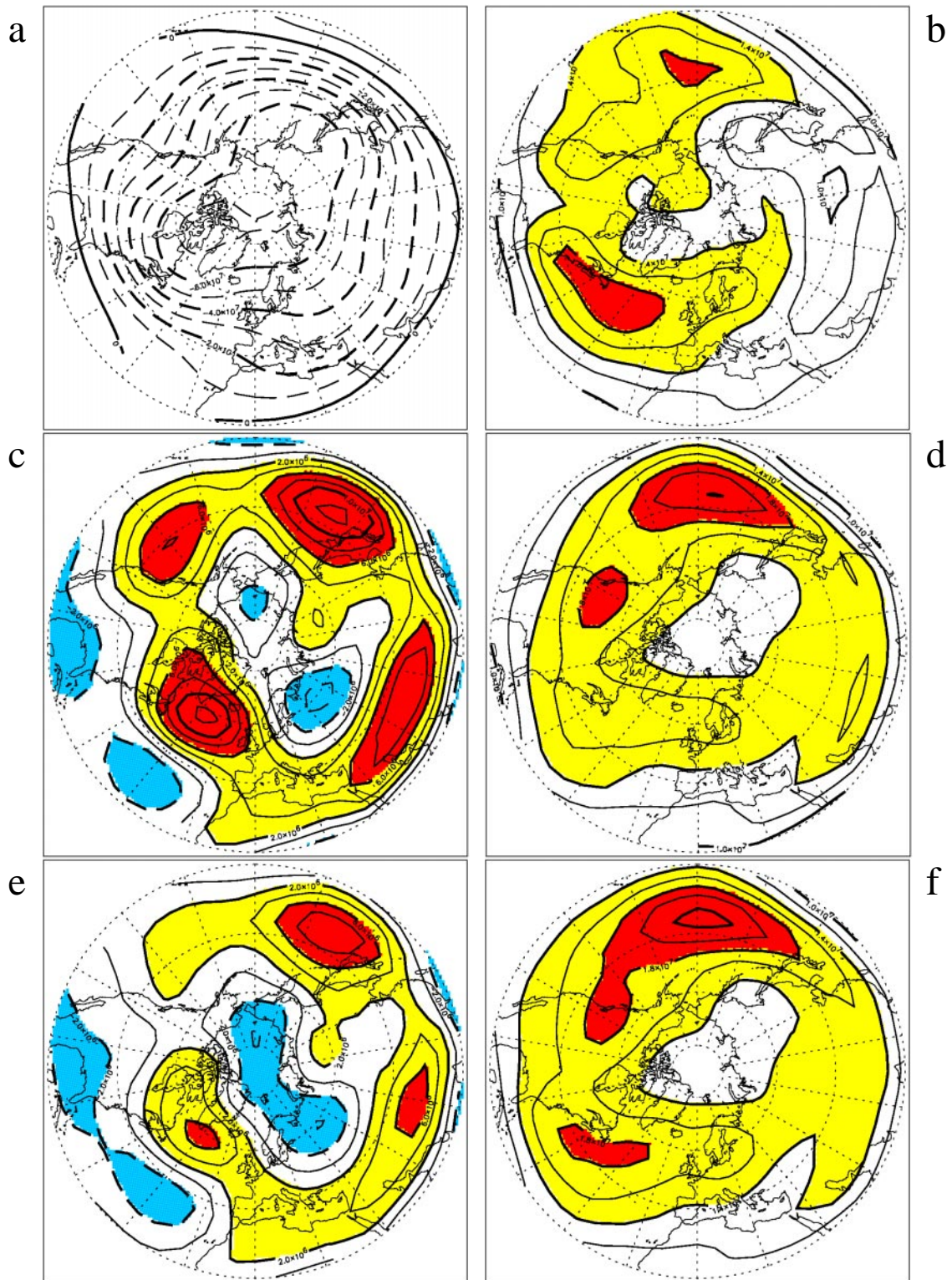


Fig. 4. Panel a): long term mean streamfunction in winter (DJF) over the Northern hemisphere extra-tropics obtained from ECMWF analyses 1983-1993. Panel b): observed storm tracks estimated as standard deviation of 10 day high pass filtered analysed streamfunction. Panel c): long term mean error of streamfunction relative to panel a) in a control simulation with the 3 level QG model. Panel d): storm tracks in the control simulation relative to panel b). Panel e) and panel f): as panel c) and d), but for the model version with flow dependent empirical forcing. Contour interval  $1.0 \times 10^7 \text{ m}^2/\text{sec}$  in panel a), and  $2.0 \times 10^6 \text{ m}^2/\text{sec}$  in the remaining panels.

## SEASONAL PREDICTION

A major task, on which work has only started recently, is to study to what extent seasonal predictability can be enhanced when running atmospheric models with full flux-correction which can depend on season or on the actual atmospheric state and/or on the state of the lower boundary (e.g. SSTs/sea ice). One may anticipate that at least some improvement can be obtained relative to the standard versions of the models since presumably the systematic errors are reduced and therefore the energy dispersion characteristics of the models are more realistic.

## ACKNOWLEDGEMENTS

This research was supported by the "Environment and Climate Programme" under contract number ENV4-CT97-0498.

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