Danish Meteorological Institute
Ministry of Transport

Danish Climate Centre Report 04-05

The DKCM Atmospheric Model

The Atmospheric Component of the Danish Climate Model

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Copenhagen 2005

Colophon

Serial title:
Danish Climate Centre Report 04-05

Title:
The DKCM Atmospheric Model

Subtitle:
The Atmospheric component of the Danish Climate Model

Author(s):
Shuting Yang / DMI

Other contributors:

Responsible institution:
Danish Meteorological Institute

Language:
English

Keywords:
Climate model, global, dynamical core, IFS, ECHAM5, physical parameterisation, systematic errors

Url:
www.dmi.dk/dmi/dkc04-05

ISSN:
1399-1957

Version:
31-12-2004

Website:
www.dmi.dk

Content:

Abstract

This report describes the atmospheric component of the new Danish Climate Model (DKCM). The model is based on the IFS dynamical core developed at ECMWF and Météo-France and on the ECHAM5 physical parameterization. The model is characterized by the efficiency advantage of IFS and may perform extended simulations efficiently even at high resolution. In this report the performance of the current version of DKCM is examined. Three 31-year simulations have been carried out using DKCM and ARPEGE at resolution of T63 linear, reduced Gaussian grid and 31 vertical layers (T63l L31), and ECHAM5 at T42 L31, all forced by climatological boundary conditions. The climatologies of these simulations are compared and verified using the re-analysis data of ERA40. While the systematic errors are generally comparable in all three models, indications of improvement have been seen with DKCM.

It is a problem, though, that the global amount of precipitation in DKCM appears somewhat too high. This is probably related to a non-closed hydrological cycle in the model, and will be the subject of the future work.

Resumé

Denne rapport beskriver den atmosfæriske komponent af den nye danske klimamodel (DKCM). Modellen er baseret på den dynamiske kerne fra IFS (Integrated Forecasting System), som er udviklet ved ECMWF (European Centre for Medium-range Weather Forecasts) og Météo France og på den fysiske parameterisering i ECHAM5. Modellen er karakteriseret ved effektiviteten i IFS, og der kan gennemføres lange simuleringer selv med meget detaljeret opløsning. I denne rapport undersøges kvaliteten af den aktuelle version af DKCM. Tre 31-års simuleringer er blevet gennemført: 1) DKCM og 2) ARPEGE/IFS med horisontal opløsning på T63 og lineært, reduceret Gaussisk gitter samt 31 vertikale niveauer. 3) ECHAM5 med horisontal opløsning på T42 og de samme 31 vertikale niveauer. Alle tre simuleringer er gennemført med klimatologiske nedre grænsebetingelser (SST og havis). Klimatologien i disse simuleringer sammenlignes og verificeres ved hjælp af ERA40 re-analysedata. Det vises, at der er nogle indikationer af forbedringer i DKCM, mens de systematiske fej i de tre modeller generelt er sammenlignelige.

Det er et problem, at den globale mængde af nedbør i DKCM synes at være noget for stor. Dette er sandsynligvis relateret til et ikke-lukket hydrologisk kredsløb, og det vil være genstand for fremtidige undersøgelser.

1. Introduction

In the recent decade global climate models (GCMs) have become one of the most important tools in climate studies. GCMs are widely used to understand the interaction of various components of the climate system (i.e., atmosphere, ocean, sea ice and land surface, *etc*.), to quantify the internal variability of the climate system, as well as to estimate the climate sensitivity to changes in the forcings such as those of solar irradiance and anthropogenic forcing of greenhouse gases and aerosol concentrations. These studies usually require extended integrations of the coupled GCMs for time periods ranging from several decades to hundreds of years. As computational resources are always limited, compromises have to be made between the length of simulations and the resolutions of the GCM when designing such type of studies.

On the other hand, the choice of the resolution in the GCMs is also an important issue in climate studies. There have been many studies on the resolution dependence of the large-scale aspects of simulated climate (Boyle, 1993; Deque *et al*., 1994; Willianson *et al*., 1995; Stendel and Roeckner, 1998; *etc*.). Recent studies showed that, when the vertical and horizontal resolution were chosen consistently, the systematic errors of GCMs decreased monotonously with increasing horizontal resolution (Pope *et al*., 2001, Pope and Stratton, 2002, Roeckner *et al*., 2004), in accordance with the work by Linzen and Fox-Rabinowits (1989) based on quasi-geostrophic theory. It has also been demonstrated that certain regional climate phenomena are better captured at higher horizontal resolution. This includes the Indian and East Asian summer monsoon (Sperber *et al*., 1994; May, 2004) and the Somali jet (Stephenson *et al*., 1998). High vertical resolution is of crucial importance for capturing processes in tropics like Quasi-Biennial Oscillation and the Madden-Julian Oscillation (Giorgetta *et al*., 2002; Inness *et al*., 2001).

In the recent years there have also been increasing needs for the climate research community to provide regional climate informations for both present-day climate and future climate scenario. In order to meet these requirements, atmospheric GCMs with rather high resolutions (i.e., about 100 km or less) are often employed either to produce time-slice simulations or to provide boundary conditions for dynamical downscaling with regional climate models.

For GCMs, numerous techniques aiming at an improved computational efficiency have been developed. One widely used scheme is to employ the semi-lagrangian, semi-implicit method to calculate the advection terms (Robert, 1981, 1982). The semi-lagrangian method advects all historical variables by calculating the values through an interpolation at the position of the particle at the previous time step, rather than by an extrapolation with the local gradient as is the case with Eulerian advection. This method is not constrained by the restriction of CFL criterion as for the Eulerian advection scheme for numerical stability, and can thus allow longer time step than for Eulerian advection. The method has been successfully applied to many atmospheric models with both grid-point representation (Staniforth and Temperton, 1986, McDonald and Haugen, 1992, 1993; *etc*.) and spectral representation (Côté and Staniforth, 1988; Ritchie, 1991; Willianson and Olson, 1994; *etc*.). For application to spectral models, the disappearance of the quadratic advection terms from the equations further removes the constraint of the Gaussian grid to avoid spectral blocking. Thus one can use the so-called linear, reduced grids in the model (Hortal and Simmons, 1991; Courtier and Naughton, 1994), which further increases the efficiency. Déqué (1999) compared the tendency errors in the ARPEGE/IFS model with use of Eulerian versus semi-Lagrangian scheme on linear, reduced Gaussian grid, and concluded that the latter was superior over the former.

Based on the above considerations, a new climate model, the atmospheric component of the Danish Climate Model, DKCM, has been constructed for applications in climate simulations at relatively high resolution. The goal is to combine the efficiency advantage of the semi-Lagrangian, semi-implicit scheme as featured in the Integrated Forecasting System (IFS) and the ECHAM physical parameterization package that is designed for climate simulation. Section 2 and 3 of this report gives a brief description of the DKCM model components and the numerical experiments. The results are discussed in section 4. Some concluding remarks are presented in section 5.

2. Model description

The DKCM's atmospheric component is constructed by combining the dynamical core of ARPEGE/IFS (Déqué *et al*. 1994) with the physical parameterization package of ECHAM5 (Roeckner *et al*. 2003).

The ARPEGE/IFS is a spectral model originally developed for weather forecast by Meteo-France and the European Centre for Medium-range Weather Forecasts (ECMWF) (Courtier *et al*. 1991). Since its first establishment in early 90's, the model system has been continuously developed to adopt the most recent research results (see for example Simmons and Hollingsworth, 2002 and Andersson *et al*. 2003). Over the years the ARPEGE/IFS model system has been operated for performing data assimilation (Thépaut and Courtier, 1991; Rabier and Courtier, 1992), producing deterministic weather forecasts and ensemble prediction of monthly to seasonal time scales (Buizza et al. 1993), as well as for generation of the re-analyses of ERA15 (Gibson *et al*., 1997) and ERA40 (Simmons and Gibson, 2000) at ECMWF. The model is also extended to a climate version for the purpose of climate application (Déqué *et al*. 1994, Déqué and Piedelievre, 1995 and Déqué *et al*. 1998). Comprehensive documentations of the recent model versions of the ARPEGE/IFS can be found on the ECMWF's public website (http://www.ECMWF.int). The characteristics of the ARPEGE/IFS dynamical core may be summarized as the following:

- Hydrostatic shallow-atmosphere approximation;
- Spectral horizontal representation of the major prognostic variables, i.e., vorticity, divergence, temperature and the logarithm of surface pressure. Water vapor may be chosen as either spectral or grid-point;
- Linear reduced Gaussian grid;
- Pressure-based hybrid vertical coordinate;
- Two-time-level Semi-Lagrangian semi-implicit time integration scheme.

ECHAM5 is the fifth-generation atmospheric general circulation model developed at the Max-Planck Institute for Meteorology (MPIM). It is the most recent version in a series of ECHAM models that evolved originally from an early version of the ECMWF operational forecast model prior to IFS (Simmons et al. 1989) and a comprehensive parameterization package developed at Hamburg. The ECHAM model is designed for climate experiments and ECHAM5 has implemented many new developments in physical parameterizations (Roeckner *et al*., 1996, 2003). Comparing to ECHAM4, the changes made in ECHAM5 are namely:

- New formulations: advection scheme positive definite variables, longwave radiation code, cloud cover parameterization, separate treatment of cloud water and cloud ice, cloud microphysics and sub-grid scale orographic effects;
- Major changes: land surface processes and land surface dataset;
- Minor changes: shortwave radiation, vertical diffusion, cumulus convection and orbit calculation.

A comprehensive model description of ECHAM5 is given by Roeckner *et al*., 2003.

The current version of DKCM consists of the dynamical core of climate version 3 of the ARPEGE/IFS (hereafter, ARPEGEv3) and the physical parameterization package of a newly released version of ECHAM5 (i.e., ECHAM5.1). Table 1 lists briefly the characteristics of the dynamical core in different models. The main differences between DKCM and ECHAM5 resulting from adaptation of the ARPEGE/IFS dynamical can be summarized as:

- DKCM uses a linear reduced Gaussian grid, whereas ECHAM5 uses a regular Gaussian grid. For a given spectral truncation N, a linear Gaussian grid requires ML≥2N+1 grid numbers along longitudes and NL≥ (2N+1)/2 latitudes, in contrast with ML≥3N+1 and NL≥ (3N+1)/2 for a regular Gaussian grid. For a given spectral truncation the use of reduced Gaussian grid, that is designed to remain approximately constant for the local east-west grid length on each latitude row, reduces the number of grid points even further in comparison with a regular Gaussian grid;
- DKCM uses a semi-Lagrangian advection scheme for all model prognostic variables, whereas ECHAM5 uses an Eulerian scheme combined with a flux-form semi-Lagrangian scheme (Lin and Rood, 1996) for positive definite variables (i.e., water vapor, cloud liquid and ice water, as well as possible chemical substances);
- DKCM uses a semi-implicit two-time-level differential scheme, whereas ECHAM5 uses a semi-implicit leap-frog scheme of three time levels with a weak time filter to inhibited the growth of spurious computational modes.

These differences make DKCM a very efficient model compared to ECHAM5.

Table1*. Characteristics of model dynamical cores for DKCM, ARPEGE/IFS and ECHAM5. The DKCM has identical dynamical core as ARPEGE/IFS.*

	DKCM - ARPEGE/IFS	**ECHAM5**
Prognostic Variables (spectral):	ζ, D, T, ln(Ps), q	ζ, D, T, ln(Ps)
(Grid-point):	q_{liq}, q_{ice}	q, q_{liq}, q_{ice}
Grid System	Linear, reduced Gaussian grid	Regular Gaussian grid
Vertical Coordinate	Hybrid	Hybrid
Advection Scheme	Semi-Lagrangian	Eulerian + Lin&Rood
Time Scheme	Semi-implicit, two-time-level	Semi-implicit, Leap-frog with time filter (three-time-level)

So far, the ECHAM5 physical parameterization package has not been especially adapted to the new dynamical core in DKCM. Thus all parameters in the physical package in DKCM are kept to their values for the corresponding model resolution in ECHAM5.

3. Experiments

To evaluate the performance of the DKCM, three 31-year simulations were performed using climatological monthly sea surface temperatures (SSTs). The first simulation used the current version of DKCM at a resolution of triangular truncation of wave number 63 with linear, reduced Gaussian grid horizontal presentation (T63*l*) and 31 vertical layers (L31). The T63*l* grid has 64 nearly equidistant latitudes. Along latitude parallels it has 128 grid points near the equator that gradually reduces to 20 points near the poles, giving an approximately uniform horizontal resolution with total number of 6232 grid points. The L31 model levels are identical to those in the ERA-15 model with the top level placed at 10 h Pa. The other two simulations use the original models of DKCM, i.e., ARPEGE climate version 3 also at T63*l* L31 and ECHAM5.1 at T42 L31 on a regular Gaussian grid.

We have chosen a horizontal resolution of T42 for the ECHAM5.1 simulation, because the quadratic T42 grid has the same number of points along longitude parallels and near the equator as the T63*l* grid. In other words, the T42 regular grid gives about the same resolution at lower latitudes as the T63*l* grid. However, the T42 regular grid has the same number of grid points along all latitude parallels, which makes a total number of 8192 grid points in horizontal. As a consequence of the different grid representations, DKCM and ARPEGEv3 can use a much longer time step than ECHAM5 at a specific resolution. In our experiments, both ARPEGE and DKCM at T63*l* L31 resolution can run stably at a time-step of 1800 sec., compared to 1200 sec. for ECHAM5 at T42 L31. The advantage of using a longer time-step, a linear reduced grid and the two-time-level semi-implicit semi-Lagrangian scheme makes DKCM a much more efficient model than ECHAM5. Table 2 compares the benchmark runs of DKCM, ARPEGEv3 and ECHAM5. In order to compare the efficiency of the models, we also listed ECHAM5 run at the same spectral resolution of T63 as the other two models on the fourth column in parentheses. It is apparent that, although ECHAM5 physics seems more sophisticated than its ARPEGE counterpart, it is its dynamical core that makes it an inefficient model in comparison to ARPEGE. Indeed, use of the ECHAM5 physics package in DKCM slows down the ARPEGE model about the 25%, while use of the ARPEGEv3 dynamical core in DKCM speeds up ECHAM5 more than 3 times at the same spectral resolution of T63.

Table2*. Model parameters and performances for DKCM, ARPEGE (v3) and ECHAM5. Listed in the table are model resolution, number of gridpoints, length of time-step and CPU time for one year integration on a single NEC SX6 processor.*

	DKCM	**ARPEGEv3**	**ECHAM5**
Resolution	T63*l* L31 (T42 equivalent at equator)	T63*l* L31	T42 L31 (T63 L31)
Number of gridpoints	6232	6232	8192 (18432)
Time-step (min.)	30	30	20 (12)
CPU (hours)	5.6	4.5	9.6 (23.7)

We have chosen to use the ‘old’ cloud cover scheme in the ECHAM5 physics in both DKCM and ECHAM5 simulation. In contrast to the new prognostic scheme that uses a statistical model with a probability density function of total cloud water to calculate fractional cloudiness (Tompkin, 2002), the old scheme calculates the cloudiness diagnostically from the standard relative humidity as formulated in Lohmann and Roeckner (1996). ECHAM5 Experiments with the two schemes do not show significant differences in the model climatology (Roeckner, personal communication).

A seasonal climatology (DJF, MAM, JJA and SON) was constructed from the last 30 year period of the 31-year simulation and compared with the respective ERA-40 dataset. In the following section only results for boreal winter (DJF) and summer (JJA) are presented.

4. Results

4.1 Zonal means

Latitude-height cross sections of the zonal mean temperatures of the three models and their errors with respect to the ERA40 are shown in Fig. 1 for DJF and Fig. 2 for JJA. The most notable features in all three models are overall cold bias in upper troposphere and lower stratosphere in the summer hemisphere. These summer cold biases are seen strongest in ECHAM5 with minima of about -14 K in both DJF and JJA, and weakest in ARPEGEv3 with minima of about -12 in DJF and -8 in JJA. The summer cold bias in DKCM is very similar to that in ECHAM5 but slightly weaker in JJA. In the winter hemisphere, a cold bias in upper troposphere and lower stratosphere prevails again in ECHAM5 with minima of below -7 K in DJF and below -9 K in JJA. This winter cold bias is not significant in ARPEGE. Instead, a warm bias in high latitudes is seen in the stratosphere and upper troposphere. The bias pattern in winter hemisphere in DKCM is similar to that in ECHAM5, but the magnitudes in DKCM are reduced about 2 K.

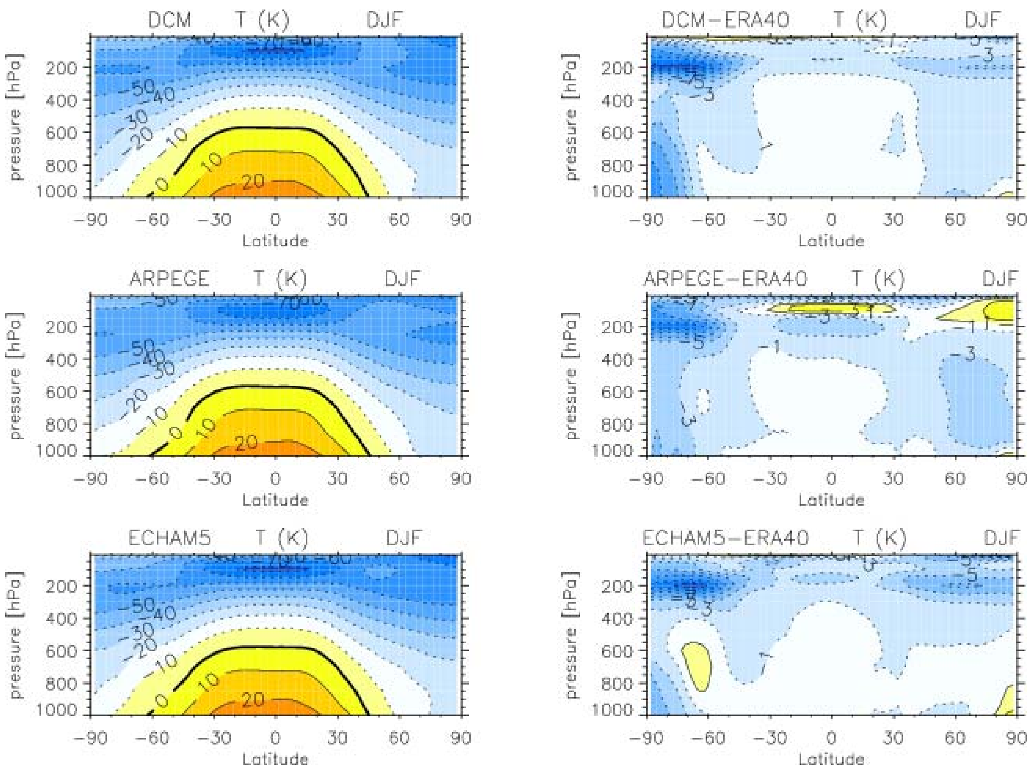

__Fig. 1__ Latitude-height distributions of zonal mean temperatures (left) and their systematic errors with respect to ERA40 (right) for boreal winter (DJF) for DKCM (top), ARPEGE (middle) and ECHAM5 (bottom), respectively. Contour intervals are 10 K for the full fields (left) and 2 K for the error fields (right). Positive bias are shaded with warm colours while negative with cold colours.

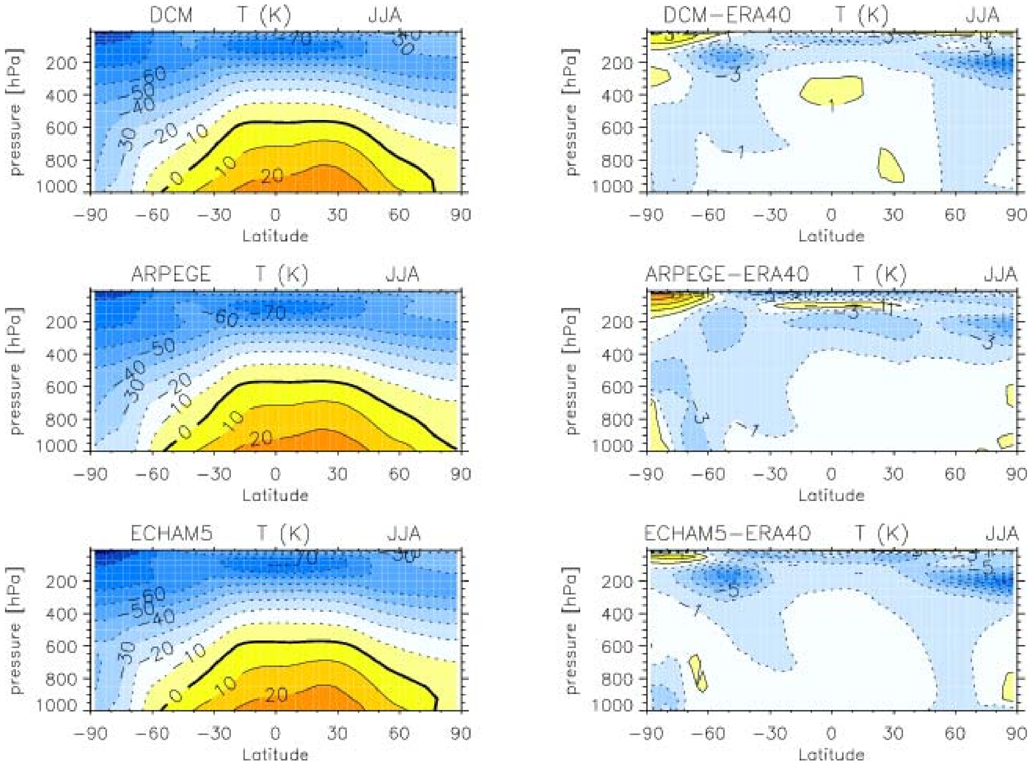

__Fig. 2.__ As Fig. 1 but for boreal summer (JJA).

Fig. 3 shows the cross section of the climatological zonal mean zonal winds and their systematic errors with respect to ERA40 in DJF. In the troposphere the error patterns are similar in all three models, in particular in mid- and high latitudes. One of the dominating features is an equatorward shift of the summer tropospheric westerlies in the southern hemisphere. This shift is most pronounced in ECHAM5 and least significant in DKCM. There is also indication of strengthening of the NH winter westerlies in ARPEGE, which are not significant in DKCM and ECHAM5. Generally speaking DKCM has least bias in troposphere compared to the other two models, in particular in equatorial area where the upper tropospheric westerlies are seen too strong in both ARPEGE and ECHAM5. Above 100 h Pa all models have positive bias in mid- and high latitudes, indicating too strong westerlies there. In the tropics, DKCM and ARPEGE demonstrate strong negative bias in the upper most layers meaning a too strong easterly stratospheric jet, whereas ECHAM5 has strong positive bias there meaning a too weak easterly stratospheric jet there.

The cross section of the zonal mean zonal winds and their systematic errors in JJA are shown in Fig. 4. As for DJF the JJA error patterns are alike in all three models and generally small in the lower and middle troposphere. The most pronounced biases are seen above 200 hPa in south of 30°S, indicating weakening and equatorward shifts of the stratospheric westerly jet.

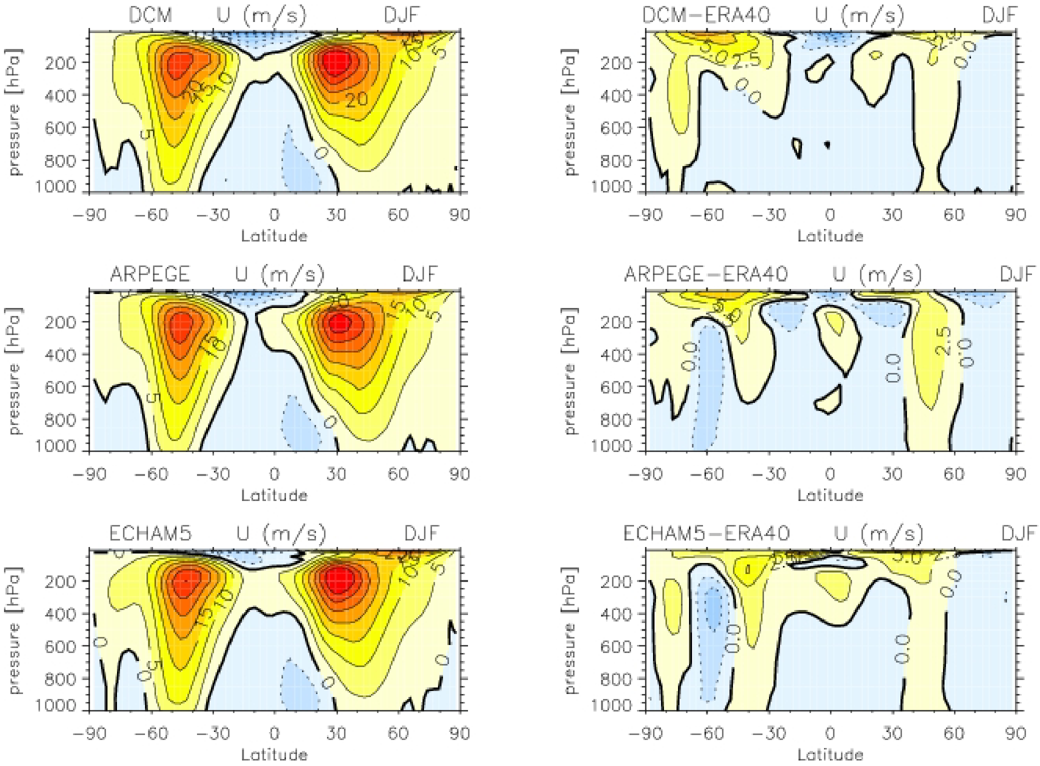

Fig. 3. *Latitude-height distributions of zonal mean zonal winds (left) and their systematic errors with respect to ERA40 (right) for boreal winter (DJF) for DKCM (top), ARPEGE (middle) and ECHAM5 (bottom), respectively. Contour intervals are 5 m/sec for the full fields and 2.5 m/sec for the error fields. Positive bias are shaded with warm colours and negative with cold colours.*

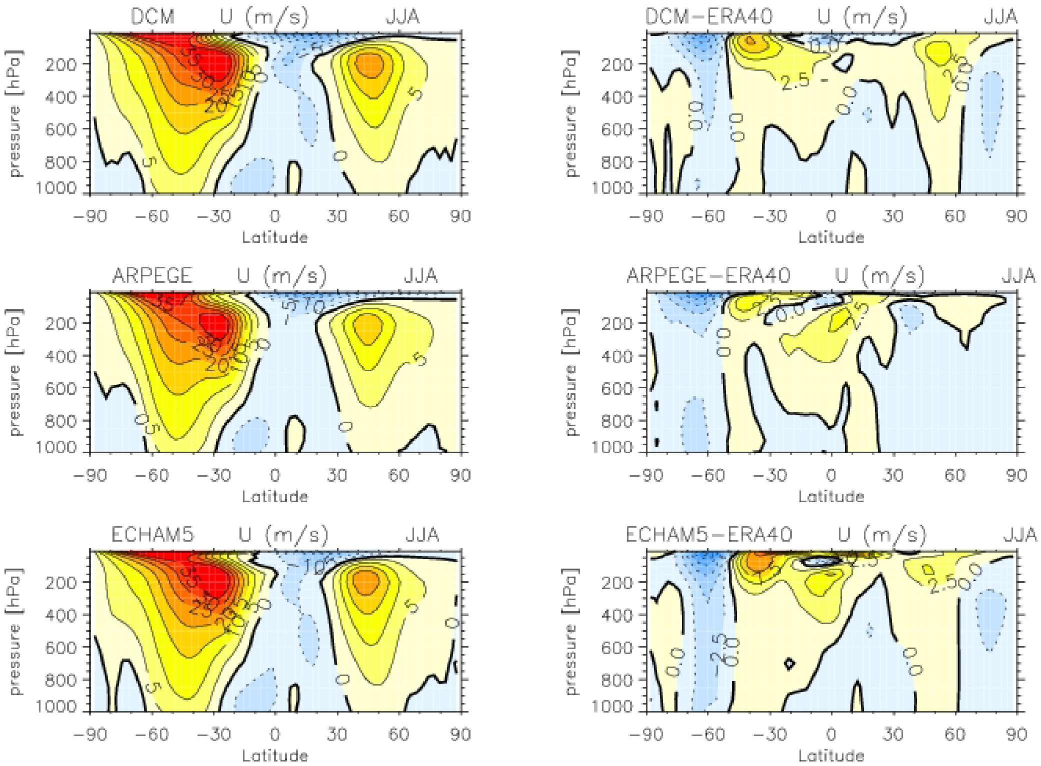

Fig. 4. *As Fig. 3 but for boreal summer (JJA).*

4.2 Geographic distributions

The zonal mean latitude-height cross sections give some idea of the vertical distribution of the general circulation of the models. In this section we will examine the geographic distribution of the model circulations. The climatological mean sea level pressure (contour lines) and their errors with respect to that of the ERA40 are shown in Fig. 5 for DJF and in Fig. 6 for JJA. In DJF (Fig. 5) the core of the Aleutian low is positioned too far west in all three models. The Icelandic low, on the other hand, is captured differently for different models. Its core and position is best represented in ECHAM5, whereas it is slightly underestimated in DKCM and overestimated in ARPEGE. The subtropical anticyclones are captured realistically in all three models, except for the anticyclone over East Atlantic/South Europe/North Africa in the ECHAM5 simulation which seems to be overestimated. Boer et al (1992) had documented that a common weakness GCMs is the poor simulation of the Antarctic circumpolar lows. This is also seen in all three simulations with too high mean sea level pressure over Antarctic, in particular in ARPEGE.

In JJA (Fig. 6) the too high pressure over Antarctic is again seen in both DKCM and ARPEGE, but much less pronounced in ECHAM5. The pressures in the arctic area are also too high in all three models. The positive biases are most pronounced in ARPEGE. Outside the polar areas, DKCM gives an overall somewhat smaller bias compared to both ARPEGE and ECHAM5. It is evident that ARPEGE underestimates the low pressure regime over south-east North America and west North Atlantic sector, while ECHAM5 poorly estimates the southern hemispheric westerlies.

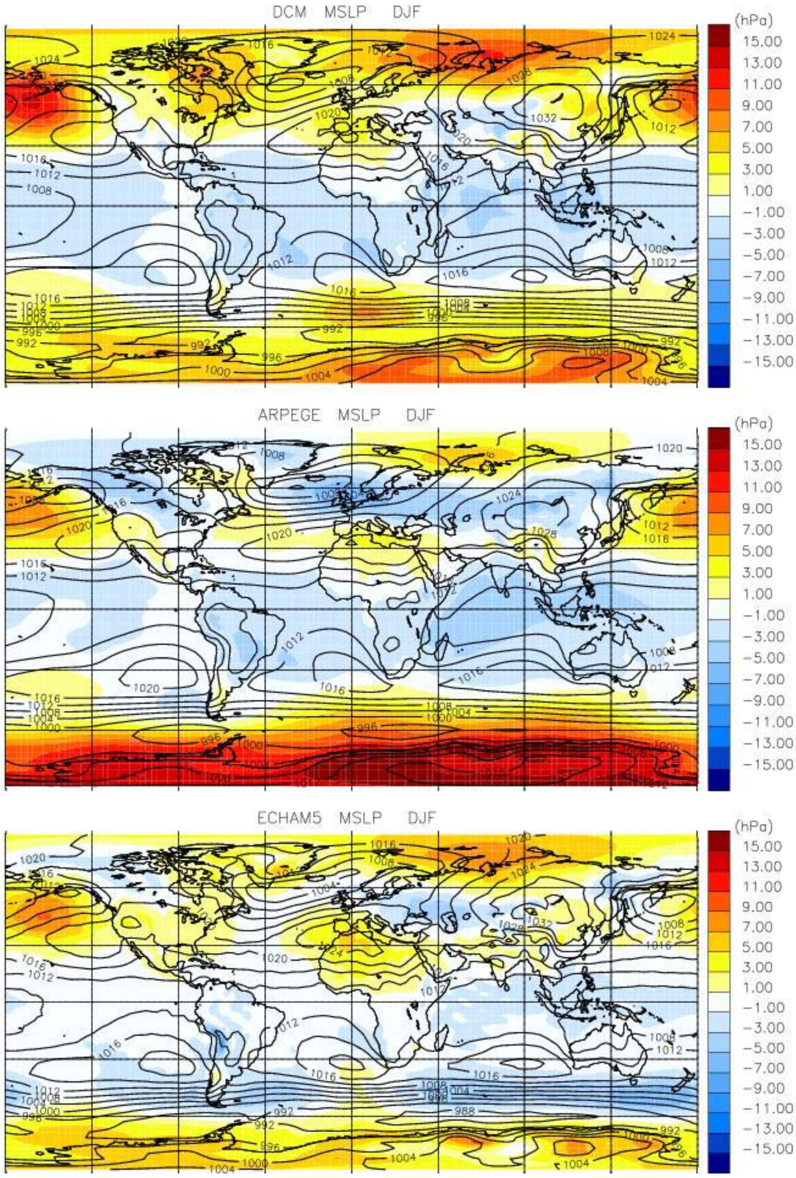

Fig. 5 *Seasonal mean mean-sea-level pressure (contour lines) and its differences between the model and the ERA40 (color shading) for boreal winter (DJF) for DKCM (top), ARPEGE (middle) and ECHAM5 (bottom), respectively. Unit: h Pa.*

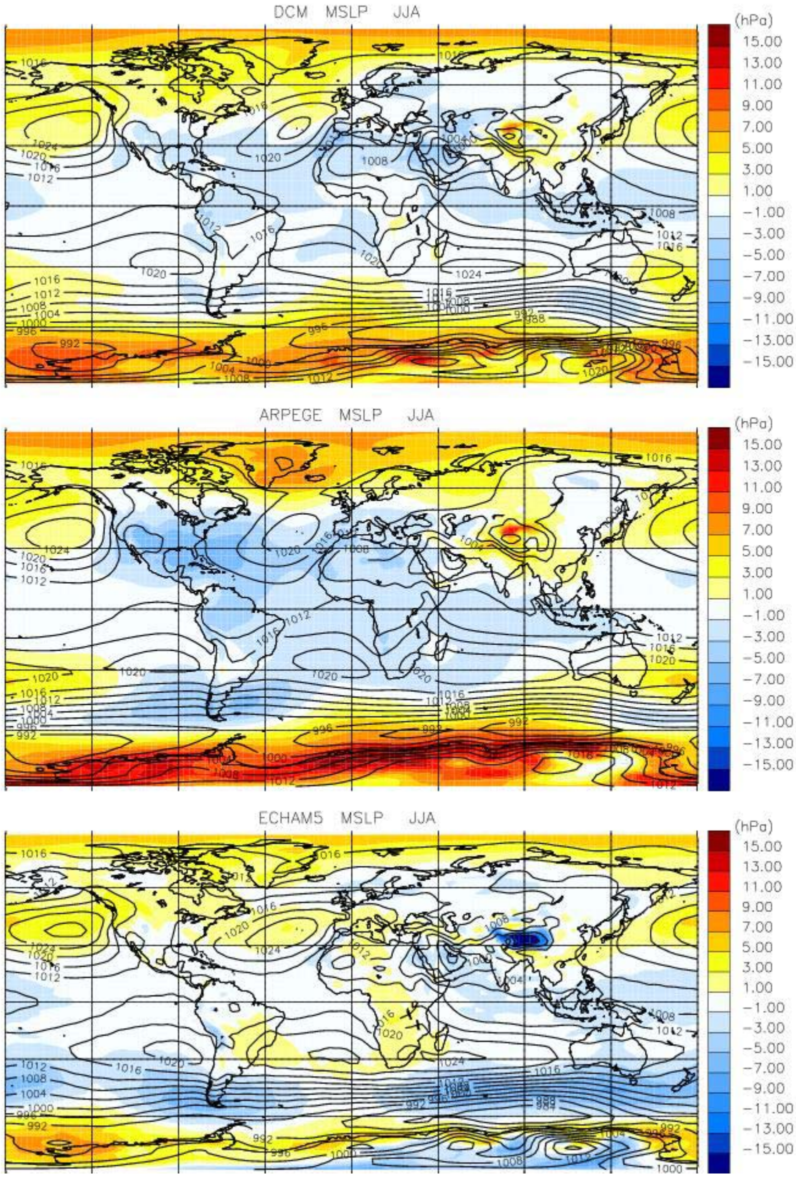

Fig. 6. *As Fig. 5 but for boreal summer (JJA).*

To further investigate the model performance, the winter time (DJF) 500 h Pa geopotential heights (contour lines) in the northern hemisphere and their systematic errors with respect to ERA40 (color shading) for the three models are shown on the left panel in Fig. 7. Also shown in Fig. 7 are the eddy components of the systematic errors, i.e., with the zonal means are removed from the systematic errors (right panel). It can be seen that, besides that ARPEGE has larger bias on the zonal component, all three models have similar bias patterns in stationary eddy components, meaning positive anomalies over north Pacific, Russia and Canada that extended to Greenland in contrast to negative anomalies dominating west parts of the continents. In other words, the 500 h Pa stationary waves are too weak in all three models in comparison with that of ERA40. Of all the three models, DKCM seems to have the largest bias over the Pacific- North American sector and smallest bias over the Eastern Atlantic-European sector. It is evident that a particular model may show somewhat larger systematic error at a particularly location. In other words, the systematic errors are comparable in all three models. We note that, due to nonlinearities systematic errors of the type discussed here may be somewhat different and smaller in model runs with boundary conditions varying as observed.

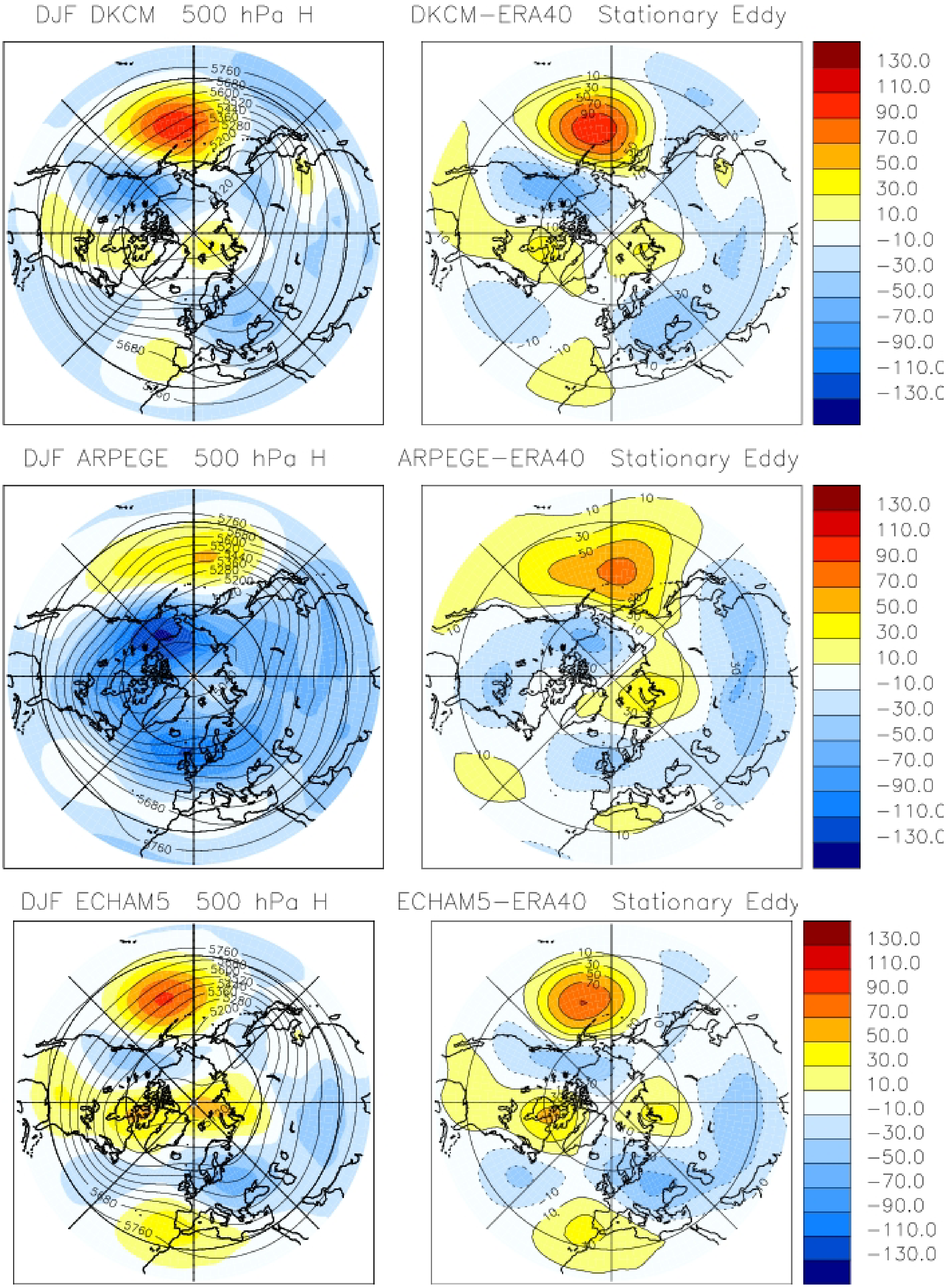

***Fig.** 7 Left panel: Seasonal mean 500 h Pa geopotential heights in the Northern Hemisphere (contour lines) and their systematic errors with respect to ERA40 (color shading) for boreal winter (DJF) for DKCM (top), ARPEGE (middle) and ECHAM5 (bottom), respectively. Right panel: The eddy part of the corresponding systematic errors of 500 h Pa geopotential height. Unit: gpm.*

4.3 Variability

It is important for a climate model to reproduce not only a good climatology (mean state) but also reasonably good temporal variability, especially the low-frequency variability from intra-seasonal to interannual time scales. Fig. 8 illustrates the DJF standard deviation of the monthly mean 500 hPa geopotential height in Northern Hemisphere for the three models as well as for the ERA40 re-analyses, respectively. It is evident that all three models underestimate the variability over North Atlantic, in particular over Iceland-Nordic Sea sector. Over the North Pacific region the core of the maximum variability is displaced somewhat too far north in all three models, but the respective magnitudes are reasonably well captured in DKCM and ECHAM5, while they are underestimated considerably in ARPEGE. It is worth pointing out that, large amount of low frequency variability in the atmosphere are associated with interactions with phenomena such as El Niño in the varying lower boundary conditions. The underestimation of the variability in the models may partly be explained by the fact that the models are forced with unchanged boundary conditions.

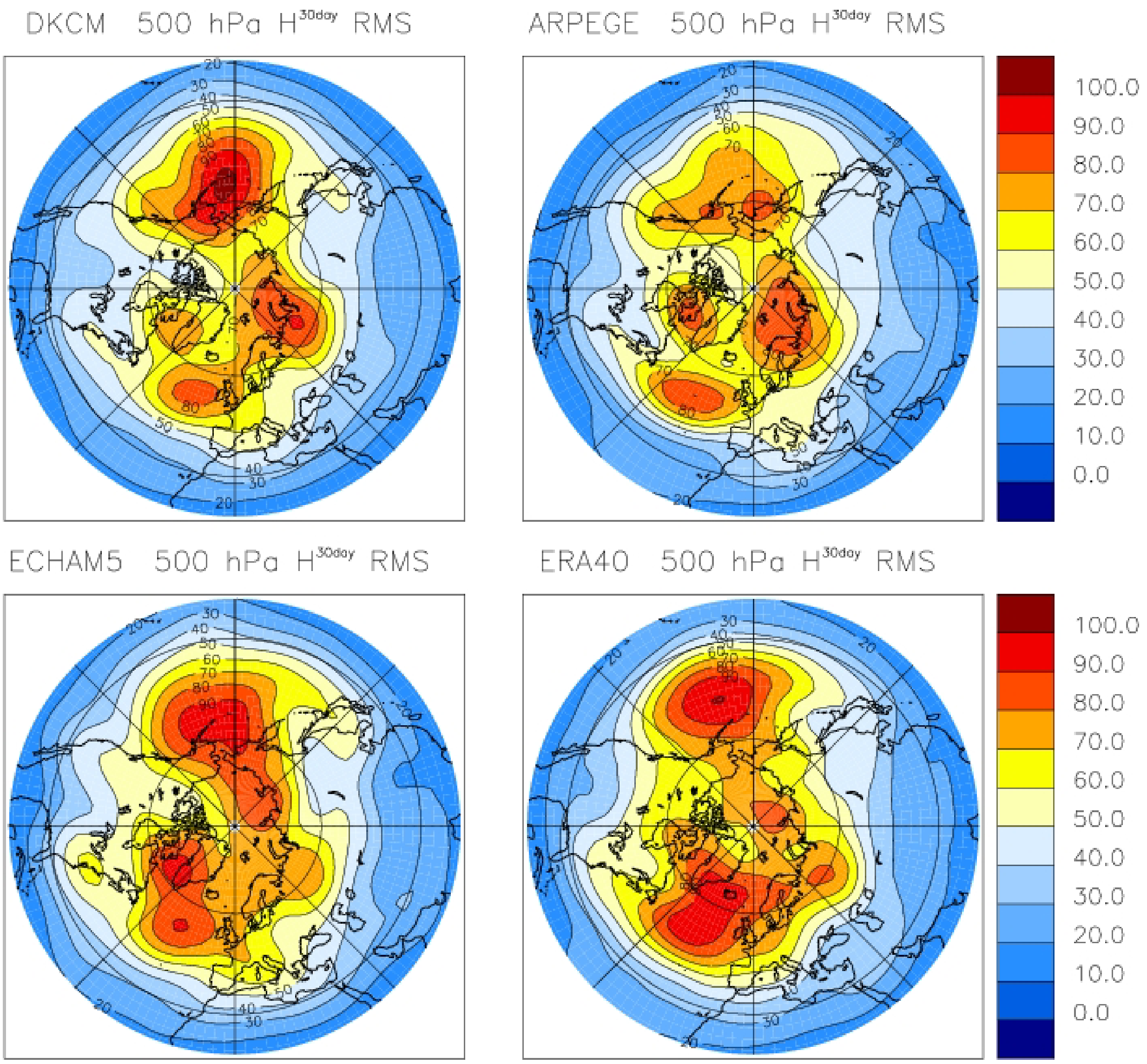

Fig. 8 *Standard deviations of the monthly mean geopotential height at 500 h Pa for boreal winter (DJF) for DKCM (upper left panel), ARPEGE (upper rightpanel), ECHAM5 (lower left panel) and the ERA40 re-analyses (lower right panel), respectively. Unit: gpm.*

4.4 Precipitation

The distributions of the model simulated precipitation are compared with the Xie and Arkin's data set (Xie and Arkin, 1997) and shown in Fig. 9 for DJF and in Fig. 10 for JJA. An overall impression from both Fig. 9 and Fig. 10 is that the models overestimate the observed precipitation, in particular in equatorial zones for DJF and in southern midlatitudes for both DJF and JJA. Indeed, the global annual averaged precipitation is 3.28, 3.06 and 3.11 mm day^{-1} for DKCM, ARPEGE and ECHAM5 respectively, compared to 3.05 mm day^{-1} from the Xie and Arkin's data. However, the precipitation patterns given by the models are seen broadly realistic. In DJF the most questionable rainfall is perhaps seen in the Sahara area and in south Asia in the ARPEGE run (see Fig. 9, second panel from the top), where precipitations of more than 5 mm are found, while in reality it is the dry season in these area. In both DKCM and ECHAM5 the precipitation over North Atlantic is too broad and extended too much into Europe (see Fig. 9, top and second lowest panels). In JJA the local structures of the Indian monsoon are perhaps best provided by DKCM (*i.e.*, Fig. 10, top panel), where there are clear separations in the precipitation maxima between east and west coast of India, and off-coast of the western Indonesia, as shown in observation (Fig. 10, bottom panel). Some signatures of these separations can also be recognized in the ECHAM5 simulations, but are completely missing in the ARPEGE run.

As mentioned above, the DKCM seriously overestimates precipitation, in particular in the tropics. Globally speaking the exaggerated precipitation in DKCM is not balanced by the evaporation. The global mean precipitation exceeds the global mean evaporation by about 8%, resulting in non-closed hydrological cycle in DKCM. One possible cause for the imbalance may be due to the semi-Lagrangian advection scheme applied to humidity and cloud water. It is known that semi-Lagrangian advection schemes are non-conservative. This may result in unrealistic mass accumulation. Furthermore, the humidity in DKCM is represented as spectral harmonic and transformed to grid-point space for physical parameterization, as in the ARPEGE. Since spectral transform may result in negative values, the positive definite humidity is no longer guaranteed everywhere on the grid-point space, and unrealistic high cloud liquid water may occur at where humidity becomes negative. In ARPEGE the negative humidity values are corrected in each layer by introducing an artificial evaporation from the layer below (Déqué *et al*., 1994). This kind of correction is not yet implemented in DKCM.

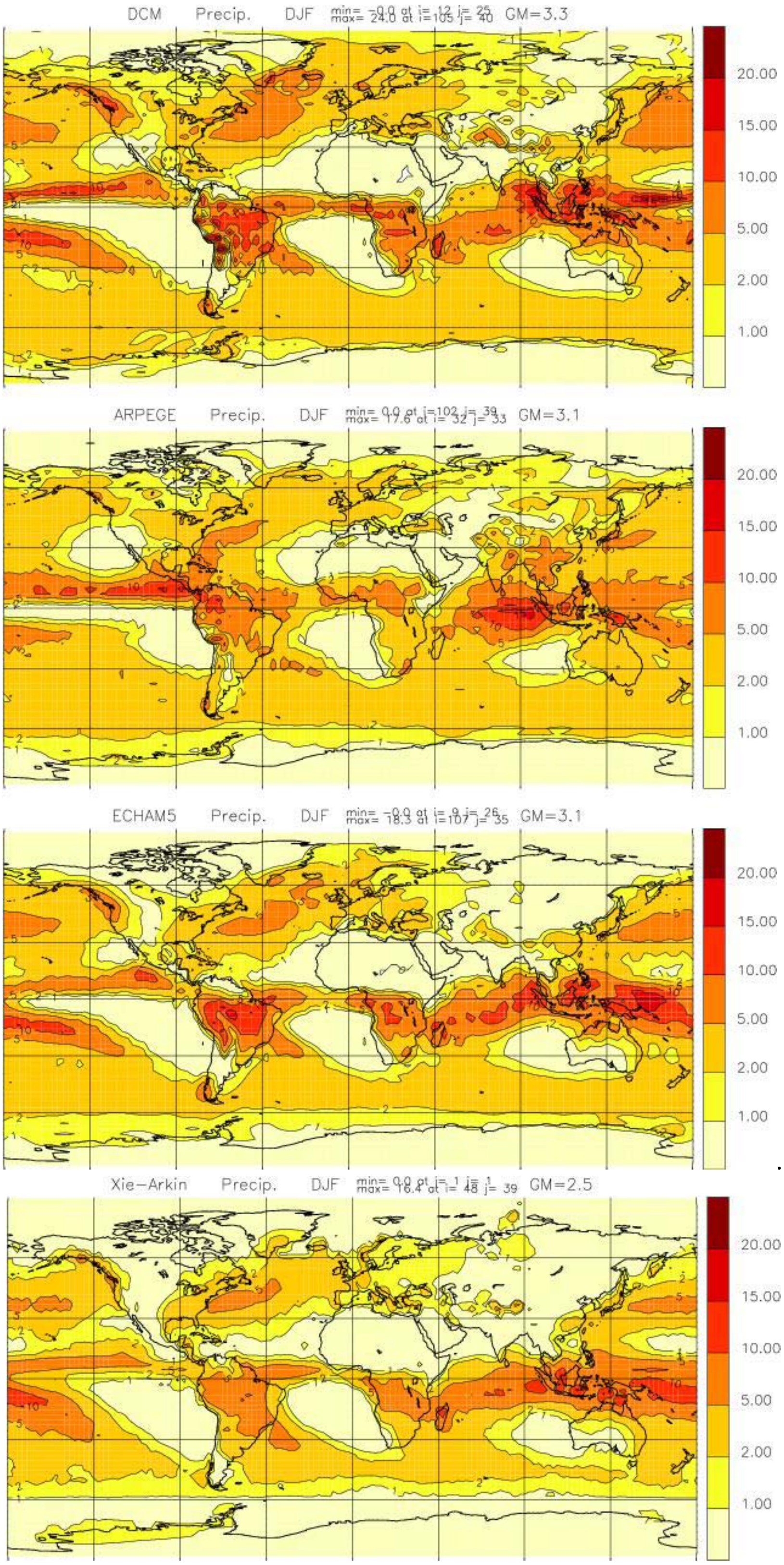

Fig. 9 *Seasonal mean precipitation for boreal winter (DJF) for the three models as well as for the Xie and Arkin data set, respectively. From top to bottom: DKCM, ARPEGE, ECHAM5 and the Xie and Arkin data set. Unit: mm/day.*

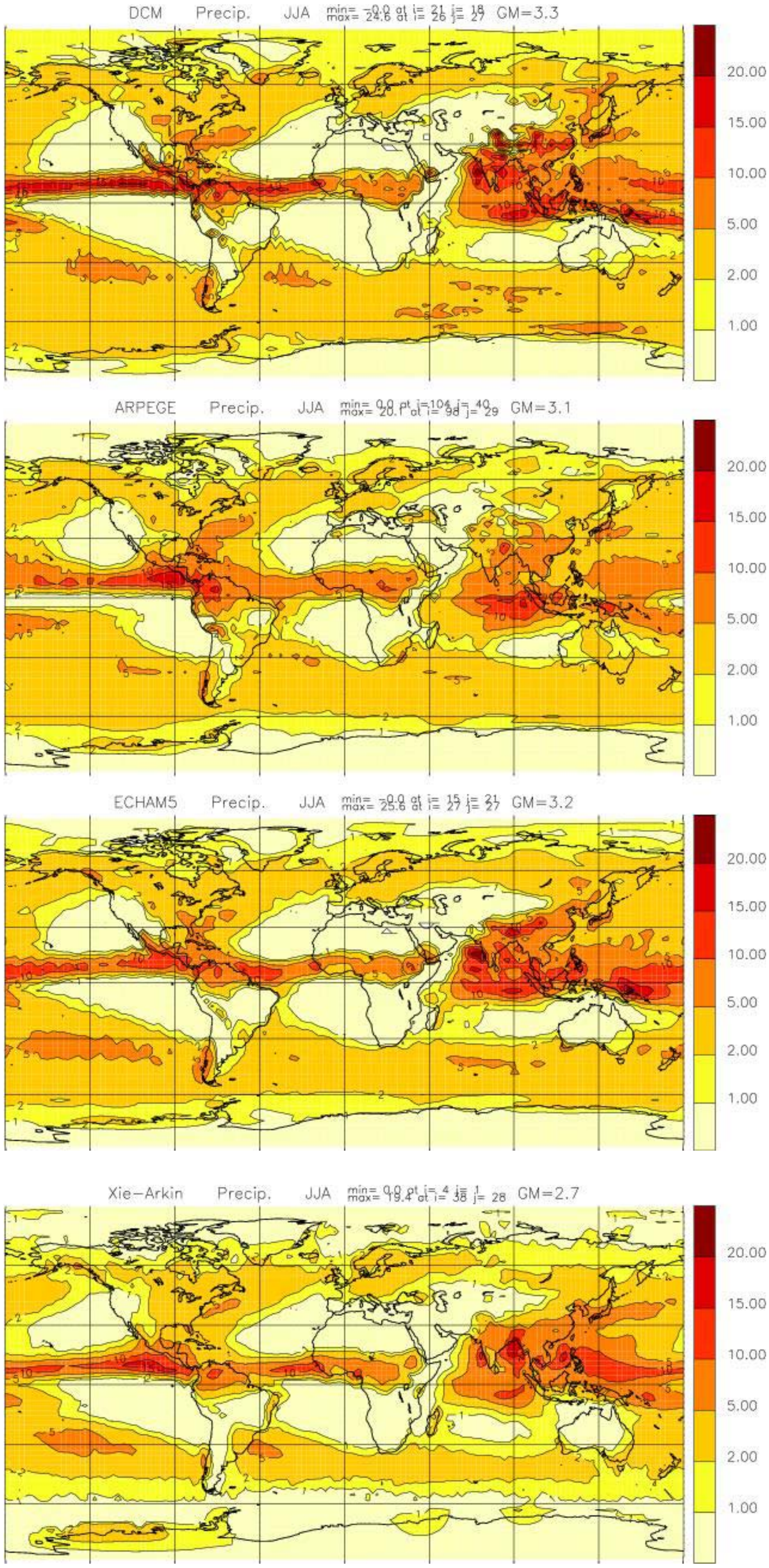

***Fig. 10** As Fig. 9 but for boreal summer (JJA).*

5. Summary

In this report the atmospheric component of the Danish Climate Model (DKCM) has been presented. The model is constructed using the ARPEGE/IFS dynamical core and the ECHAM5 physical parameterization. The DKCM runs very efficiently compared to an Eulerian model such as ECHAM5. Typically, the DKCM runs about 3 to 4 times faster than ECHAM5 for the same spectral resolution. Thus the model may be employed for extended simulations even at high horizontal resolution.

Experiments forced with climatological boundary conditions show that DKCM simulates the climatology and variability reasonably well. Generally speaking, the systematic errors seen in DKCM are comparable with those in ARPEGE and ECHAM5. DKCM gives a apparent cold bias at upper troposphere and lower stratosphere (Fig. 1), a too high mean-sea-level pressure at high latitudes (Fig. 5 and 6) and too weak stationary eddies at the Eastern Pacific/North America sector at 500 hPa (Fig. 7). Similar errors with comparable magnitudes can also, more or less, be identified in runs with ARPEGE and/or ECHAM5.

It is also found that DKCM generally overestimates precipitation, in particular in tropics (Fig. 9 and 10). Furthermore, the global mean precipitation exceeds the global mean evaporation by about 8%, thus the hydrological cycle is not closed. These errors may be caused by the non-conserving advection scheme applied to humidity, and need to be further investigated.

Simulations using DKCM at a high resolution of T159 has also demonstrated encouraging results. It is planed to use the high resolution T159 L31 DKCM to produce a set of time-slice simulations for the present-day and the future climate scenarios in studies of climate change.

Recently, a new climate version of ARPEGE has been released. This version includes many important developments in the ARPEGE/IFS dynamics such as use of pseudo-spectral vertical representation which reduces vertical noise and gives more accurate pressure-gradient. The DKCM atmospheric model is undergoing an upgrading using this new climate version of ARPEGE/IFS and the newest version of ECHAM5. The complete system of DKCM will then consist of the above upgraded atmospheric model coupled to a global version of the MICOM ocean model (Bleck *et al*., 1992) using the OASIS coupler (Terray *et al*., 1998). At DMI, a new, mass conserving advection scheme using the Cell Integrated Semi-Lagrangian scheme originated by Nair and Machenhauer (2002) is under development. It is hoped that such a mass-conserved advection scheme will be introduced into the dynamical core in the DKCM in the future.

Acknowledgement

The author is greatly grateful to Michel Déqué at the Météo-France, Toulouse, and Erich Roeckner at the Max-Planck Institute for Meteorology, Hamburg, for providing the original models of ARPEGE and ECHAM5 and for their technical assistance, support and many useful scientific discussions during the course of this work. Great appreciations are to Eigil Kaas at DMI for his inspiration and support throughout the work. Many thanks go to Bennert Machehauer at DMI for many valuable discussions and suggestions. The development of the DKCM has been supported by the EU project DETECT and by the Danish Climate Center.

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