Introduction of revised parametrizations of physical processes into the IFS

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Together with changes to the data assimilation system and dynamical component of the model, over the last 10 years several changes to the parametrizations of the ECMWF model have brought about improved model performance (such as the revised sub-grid scale orography and prognostic cloud schemes introduced in April 1995 - see Summer 1995 Newsletter No. 70). On the 16th of December 1997 a new set of revised parametrizations was introduced into the operational version of the IFS (as CY18R3), with changes being made to the radiation, convection and cloud parametrizations. A change was also made to the numerical treatment of vertical diffusion.

The revisions were undertaken for several reasons. Firstly to improve the physical basis of the parametrizations and their performance as measured against observations and detailed models (such as line-by-line radiation codes and fine-scale cloud resolving models for convection). Secondly the changes were aimed at correcting errors in the Top of Atmosphere (TOA) and surface energy budget, important for coupled ocean-atmosphere simulations of the model used in experimental seasonal forecasting, although some improvement in aspects of the 10-day forecast performance of the model are also seen.

In this article the changes will be briefly described and their impact upon both seasonal simulation and 10 day forecasts discussed.

Description of changes

Radiation

The treatment of the water vapour continuum in the long-wave part of the radiation code was updated to better match line-by-line computations, correcting an overestimation of clear-sky cooling in the lower troposphere and an underestimation of cooling in the upper troposphere. The short wave radiation scheme was made more flexible, being able to be used with either 2 or 4 spectral bands (operationally 2 bands are used). Short wave cloud optical properties were revised to remove excessive in cloud absorption and a temperature dependent effective radius for ice particles introduced. A treatment of cloud inhomogeneity following Tiedtke (1996) was included, the liquid water path used by the radiation scheme being multiplied by 0.7.

Convection

The Tiedtke (1989) mass flux convection scheme has been used in the operational model since 1989. It allows deep convection to form if moisture convergence into a column of the atmosphere is positive. However recent studies have indicated that a direct link between moisture convergence and convective activity may lead to poor simulation of synoptic variability in the tropics (Slingo et al., 1994). Experience also suggests that the model precipitation pattern in the tropics may be less broad (in the Intertropical Convergence Zone (ITCZ) - for example) than observed. In the revised scheme the presence of deep convection is determined by the depth of instability; if the cloud depth exceeds 200 hPa it is deemed to be deep convection, shallow convection otherwise. Also for deep convection the estimation of cloud base mass flux is changed from one using an assumption of quasi-cloud layer when convection is active, to assuming that convection acts to reduce Convective Available Potential Energy (CAPE) towards zero over a specified time-scale (Nordeng, 1994).

Cloud scheme

The prognostic cloud scheme (Tiedtke, 1993) was introduced into the operational model in 1995 (see Summer 1995 Newsletter No. 70). In that original version ice falling out of a layer is converted to snow and assumed to fall to the surface, undergoing evaporation, within a single time-step. The revised scheme has an improved mathematical treatment, allowing ice to fall from one level to the next within a cloud, although the original formulation is retained for ice falling into clear sky. This treatment was tested at the time of operational implementation of the Tiedtke cloud scheme, but the increased cloud fractions and water contents in the upper troposphere were found to cause a spurious warming in association with excessive in-cloud absorption of short-wave radiation in the radiation scheme at the time. As noted above this has now been removed through a revision of cloud optical properties.

Vertical diffusion

This is now iterated three times within a model time-step, resulting in a more accurate estimate of the surface drag coefficient. This is beneficial when the ocean wave model is running coupled to the atmospheric component of the IFS, but in the stand alone tests described here has virtually no impact.

Impact on seasonal simulations

A coupled ocean-atmosphere version of the IFS at T63 resolution is now used routinely at ECMWF as part of its seasonal forecasting activity. Of importance here is the prediction of tropical sea surface temperature (SST) anomalies, which are affected by both surface fluxes of heat and moisture, and also the surface wind stress which is related to the horizontal distribution of heating by physical processes in the atmosphere, especially convection.

The introduction of the revised parametrizations results in an improved tropical precipitation distribution, mainly as a result of the change to the convection scheme. Figure 1 shows mean surface precipitation from an ensemble of three T63 simulations (started one day apart and using observed SST) averaged over June/July/August 1987 compared with climatology (GPCP). Over India rainfall is more evenly distributed rather than being concentrated into certain locations. The intensity of the ITCZ north of the equator in the Pacific and Atlantic is reduced. Both these changes bring the simulation into better agreement with climatology. Associated with these changes is a reduction in the strength of the Hadley circulation and also trade winds over the Pacific and Atlantic.

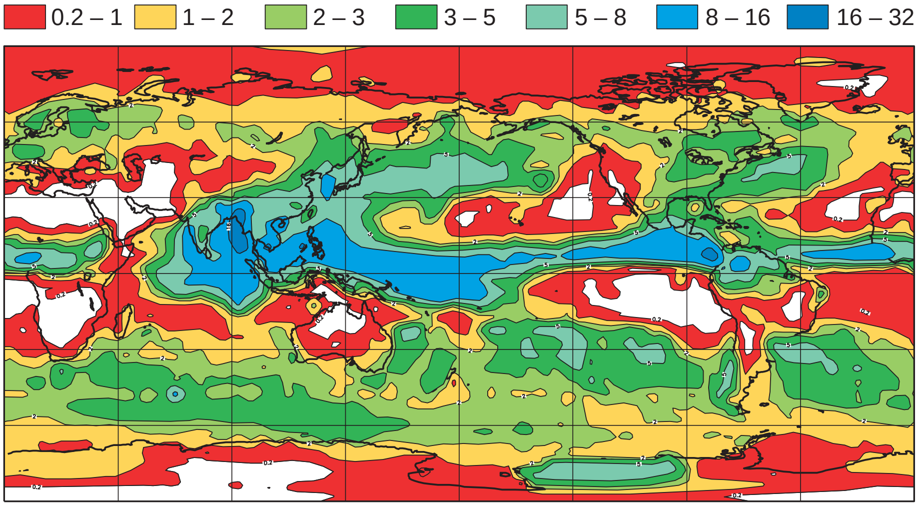
Radiative fluxes at the top the atmosphere and at the surface are improved. Figure 2 shows differences between simulated Outgoing Long-wave Radiation (OLR) and satellite measurements for June/July/August 1987. Large decreases in negative errors (implying too high an OLR in the model) are seen in the tropics, due to a combination of the revised radiation scheme plus changes to the cloud distribution and amount brought about by the convection and ice fallout changes. In mid-latitudes errors are also reduced by the revision of the long-wave radiation scheme.

The change to the ice fall out formulation causes both upper level cloud amounts and ice water content to increase. Although the ice content of the atmosphere is not well observed, previous studies (Rizzi and Jakob, 1996) have suggested that the original ice fall out formulation leads to an underestimate of the ice water amounts. Study of a well documented FIRE case (Klein and Morcrette, 1997) indicates that the increased ice water contents are in better agreement with observed amounts.

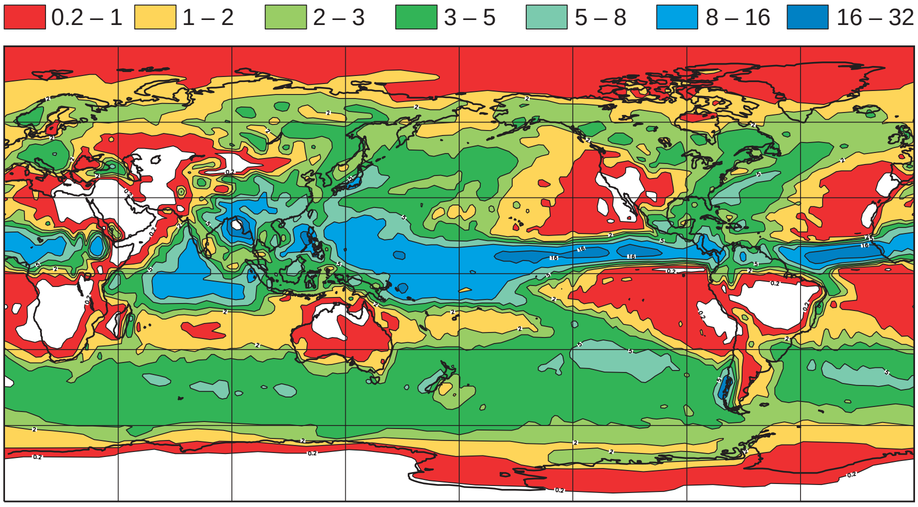
Similar changes to those described above also occur in winter 1987/88 simulations. In this season the changed distribution in heating due to convection and clouds in the tropics leads to stronger westerly flow in the upper troposphere of the central and east Pacific, in better agreement with observations. The upper level westerly flow in this region is important for tropical-extratropical interactions which in turn play a role in determining blocking over the North Atlantic and Europe.

Overall the changes in the precipitation distribution and radiative fluxes lead to an improved surface energy balance, with generally more heat going into the ocean. Initial coupled ocean atmosphere simulations indicate that the SST bias over a large part of the tropics is reduced by the revised parametrizations. Figure 3 shows the annual mean drift in SST after 6 months for an ensemble of forecasts obtained using the coupled ocean-atmosphere version of the IFS for the new and old physics. Errors have been substantially reduced in the tropical Indian, Pacific and Atlantic oceans, although warm biases have increased in the vicinity of stratocumulus sheets and in the southern hemisphere depression tracks due to remaining deficiencies in cloud amounts in these regions. Initial indications are that the ability of the revised model to predict seasonal sea surface temperature anomalies appears to be slightly increased. The changes to the climatology of the model will also impact upon the performance of the model in a 19-year simulation (1979-1997) to be carried out shortly as part of the AMIP-II project.

a) Total Precipitation (mm per day) JJA 87, GPCP



b) Total Precipitation (mm per day) JJA 87, Exp: zq3t



c) Total Precipitation (mm per day) JJA 87, Exp: zpsd

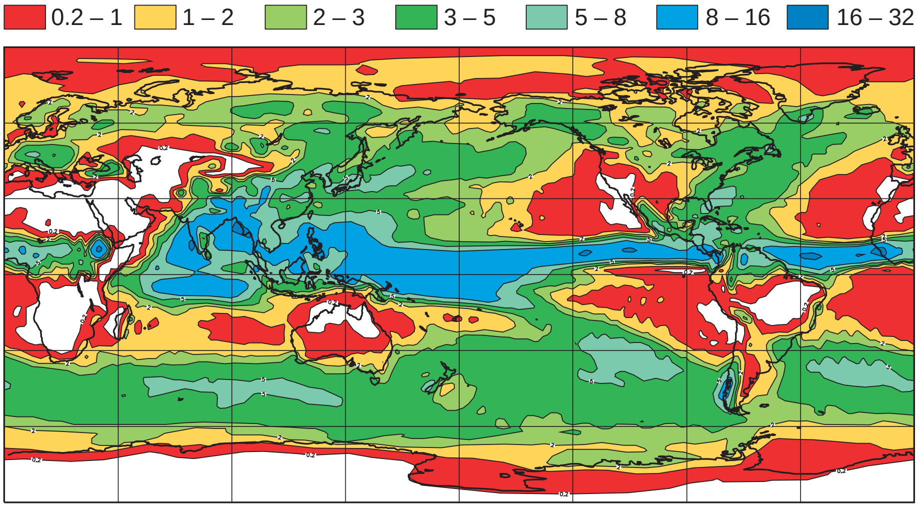
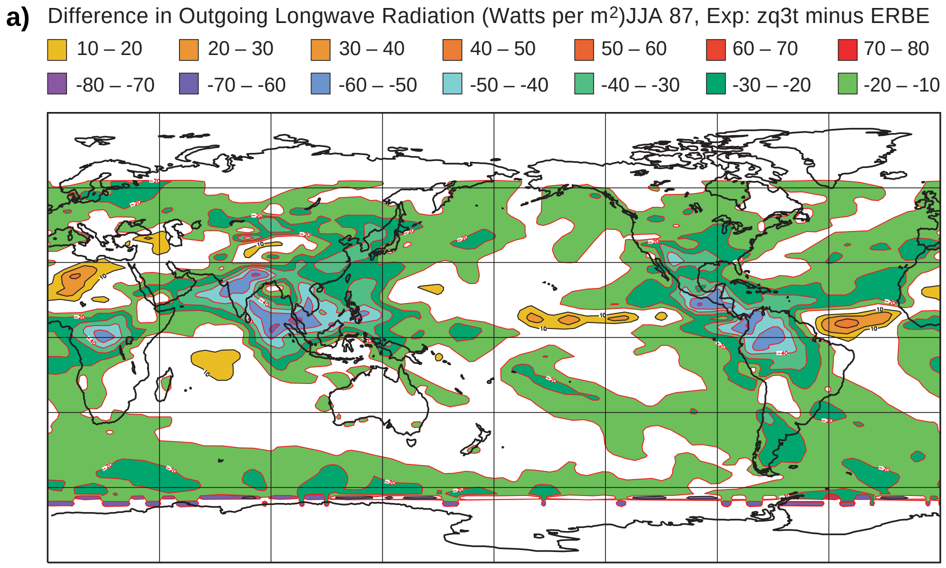


Fig.1 Comparison of (a) GPCP precipitation climatology for June/July/August 1987 with average precipitation over an ensemble of three seasonal forecasts with the IFS at T63 for the same period using (b) the control physics package and (c) the revised physics package.



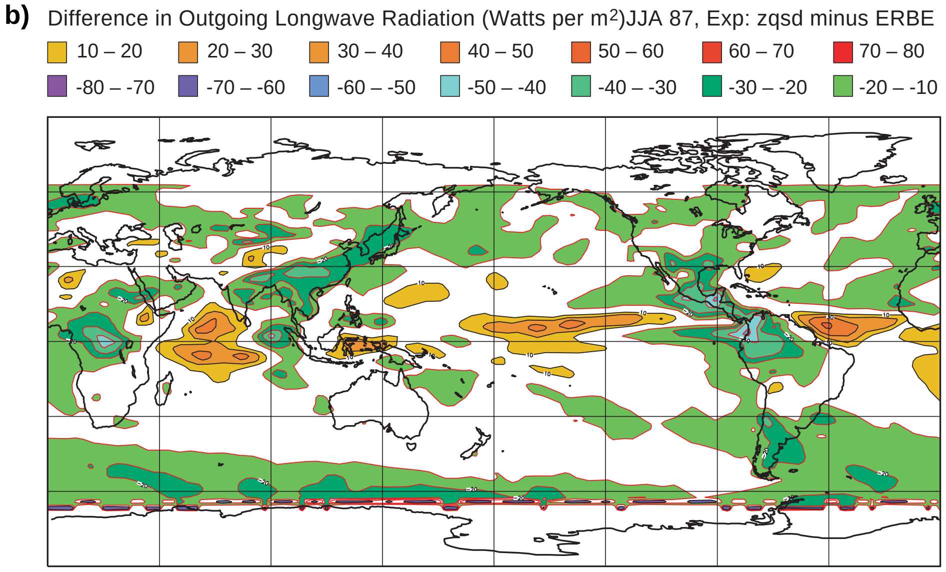
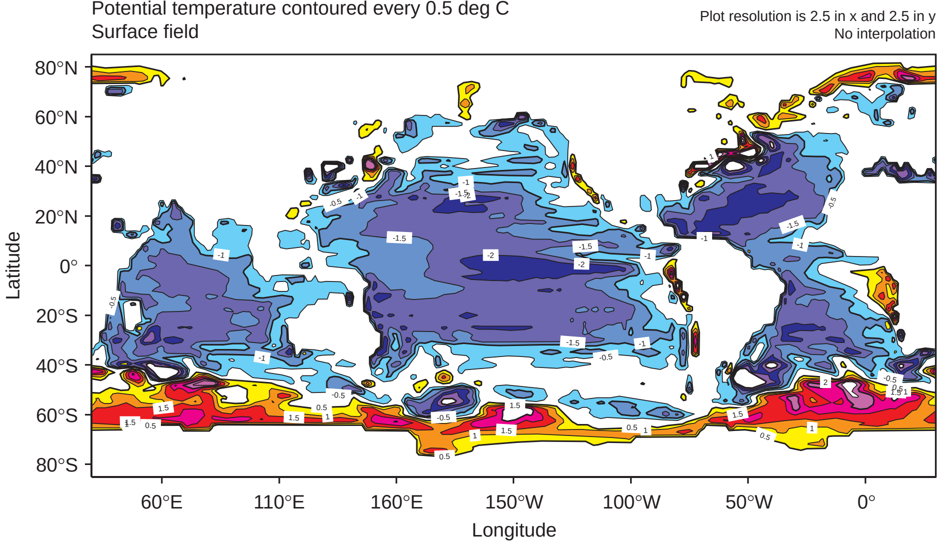


Fig. 2 Difference between simulated Top of Atmosphere Outgoing Long-wave Radiation (OLR) from ERBE data for June/July/August 1987 averaged over an ensemble of three seasonal forecasts with the IFS at T63 using (a) the control physics package and (b) the revised physics package.

a) HOPE gcm: Expt zpd7 – Annual mean drift after 6 months
Potential temperature contoured every 0.5 deg C
Surface field



b) HOPE gcm: Expt zrp7 – Annual mean drift after 6 months
Potential temperature contoured every 0.5 deg C
Surface field

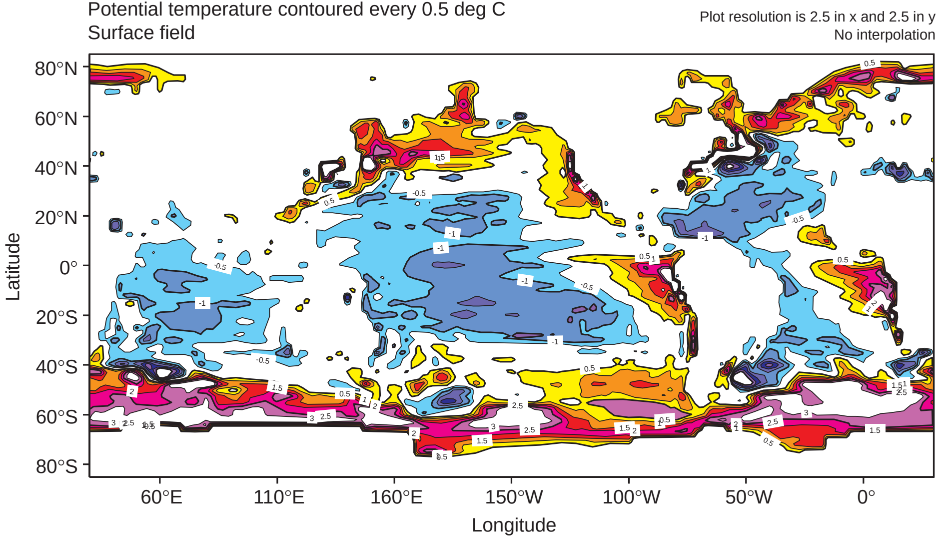


Fig. 3 Drift of sea surface temperature (as compared to observations) for the last month of a six month forecast at T63 with the coupled ocean-atmosphere version of the IFS, averaged over an ensemble of 24 forecasts (starting from the 1st January, 1st April, 1st July and 1st October for years 1991 to 1996) using (a) the control physics package and (b) the revised physics package.

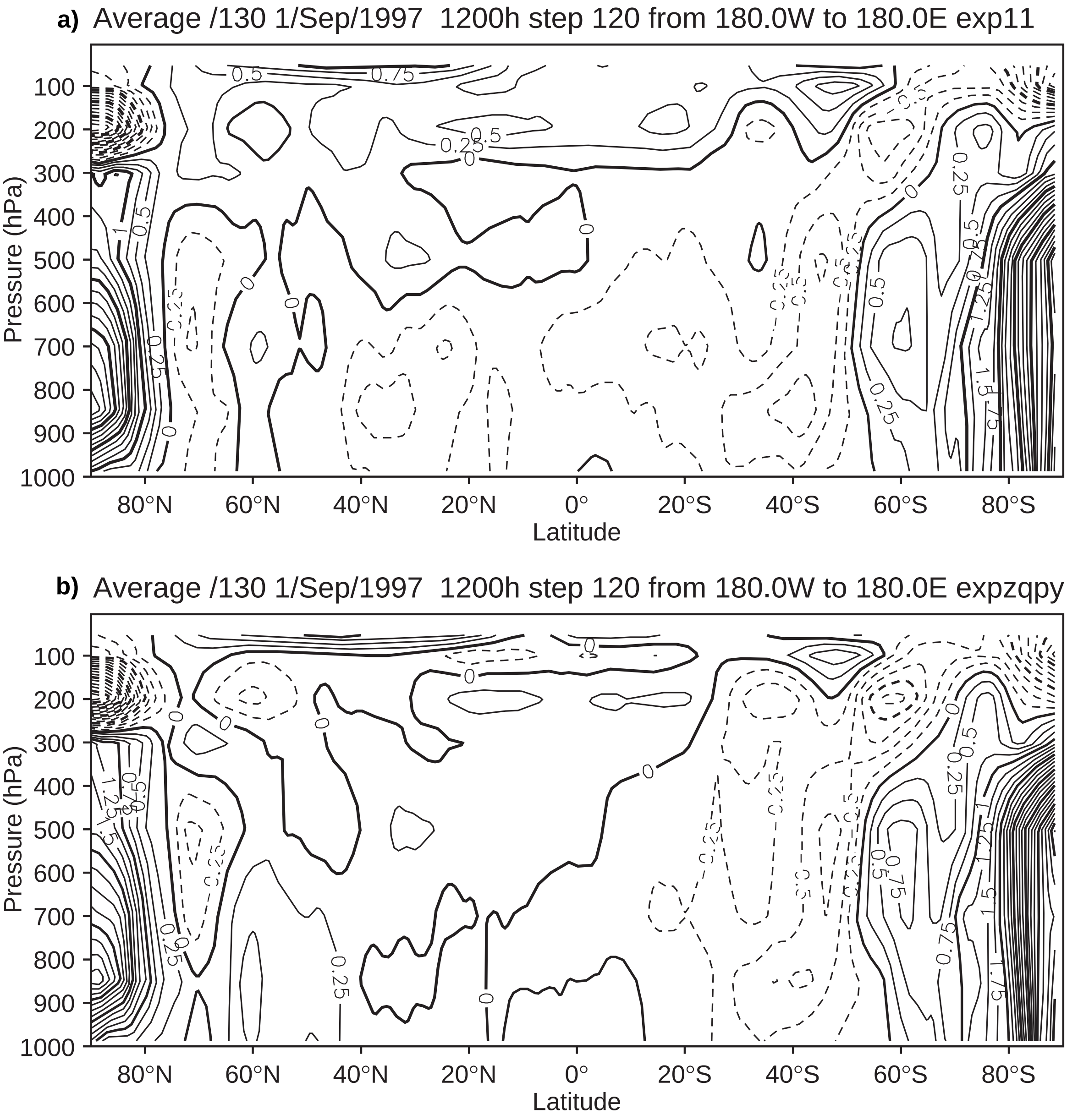


Fig. 4 Zonal mean temperature error at day 5 from a series of 15 forecasts for September 1997 using (a) the control physics package and (b) the revised physics package.

Impact on 10-day forecasts

Several series of experiments were carried out during testing of the package of parametrization changes to assess their impact on data assimilation and 10-day forecast skill. In 4D-Var experiments the impact of the package is neutral, although during pre-operational testing in December there was a small improvement in skill in both northern and southern hemisphere scores.

As in the seasonal simulations, the change to convection has an impact upon the distribution of precipitation in 7213 forecasts. The ITCZ in the Pacific and Atlantic does not intensify as much over the first 5 days of a forecast than with the operational scheme, giving better agreement with observed estimates. Also looking at precipitation amounts from individual forecasts it is noticeable that the new scheme gives smoother rainfall patterns in both the tropics and mid latitude oceans.

The changes have a non-negligible impact upon the temperature bias of the model. Figure 4 shows zonal mean temperature differences between 5-day forecasts and analysis for a series of 15 forecasts in September 1997 carried out using an experimental version of the 4D-Var assimilation system (introduced into operations in early December 1997). 'Me new parametrizations substantially reduces the cold bias of the control forecasts, especially in the lower troposphere of the tropics and sub-tropics. bias is mainly due to the revised long-wave radiation scheme. In the upper troposphere the warm bias at 200 hPa in the tropics is removed, while in the mid-latitudes the cold bias in the upper troposphere is increased.

As mentioned previously, although the new radiation scheme is a better fit to detailed radiation calculations, it cools the upper troposphere more that the previous operational code. Alone it produces more substantial increases in the cold bias of the model in the upper troposphere which are detrimental to forecast skill. Only by combining the revisions to the radiation scheme with the ice fallout and convection changes, which tend to increase upper level cloud cover and warm these regions is acceptable forecast skill maintained. This illustrates an important point when developing new parametrizations. Although a revised parametrization may provide a better physical representation of a process, comparing well with observations and detailed models, improved model performance is not guaranteed. Deficiencies in other parts of the models parametrization package may contribute to a worsening of performance, and interactions between different components of the models parametrization need to be taken into account.

Summary

A revised set of physical parametrizations for the IFS has been described. Although the direct impact upon mediumrange forecasts is small, there is a large impact upon the ability of the model to accurately capture many aspects of the tropical climate on seasonal timescales. The improved distribution of heating and TOA and surface energy budgets is of benefit to coupled ocean-atmosphere modelling at ECMWF and hence to forecasting on seasonal time-scales.

David Gregory, Jean-Jacques Morcrette, Christian Jakob and Anton Beljaars, Physical Aspects Section

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