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A new radiation package: McRad

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A new radiation package: McRad

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A new radiation package (McRad) became operational in the ECMWF Integrated Forecast System (IFS) on 5 June 2007 (Cy32r2). It includes a new short-wave radiation scheme and a revised cloud optical properties. In addition the Monte-Carlo Independent Column Approximation (McICA) for radiation transfer is used to ensure an unbiased, though noisy, description of the radiative fields over appropriate time and space scales. This package was extensively tested in all the IFS model configurations: in high-resolution T799L91 deterministic ten-day forecasts, as part of the T399L62 Ensemble Prediction System (EPS), and in lower-resolution (T159) versions of the ECMWF model used for model development and seasonal forecasts. A new specification of the land surface albedo derived from MODIS (Moderate-resolution Imaging Spectroradiometer) observations is also part of the McRad package.

The impact of McRad on year-long simulations with a low-resolution (T159L91) version of the model and on ten-day forecasts at high resolution is illustrated in this article, with comparisons made against observations and the previous operational model configuration (Cy31r2). In long simulations, McRad has a marked effect in reducing some systematic errors in the position of tropical convection. This is due to change in the overall distribution of diabatic heating over the vertical, inducing a geographical redistribution of the centres of convection. At high resolution, with respect to simulations with the standard radiation schemes, McRad has a marked positive impact on tropical temperatures and winds, and a small but positive impact on objective scores for the geopotential.

Computing radiative fluxes

The common perception of clouds is that they are eminently variable in shape, texture, horizontal and vertical extent. However, their representation in a large-scale atmospheric model (LSAM), such as the ECMWF forecasting system, is one of the major challenges in the parametrization of physical processes.

At the grid-scale of the ECMWF model (i.e. between 25 km at T799 and 125 km at T159), domain-averaged radiative fluxes in clouds with substantial horizontal and vertical variability could in principle be determined quite accurately using the plane-parallel independent column approximation (ICA) by averaging the flux computed for each class of cloud in turn. Unfortunately, such an ICA-based method is too computationally expensive for dealing with radiation transfer in a LSAM.

Various approximations have been introduced over the years to compute domain-averaged radiative fluxes for internally variable clouds, all invoking assumptions about the nature of the horizontal variability or how cloud layers are linked in the vertical. Regardless of what assumptions are made about these unresolved structures, estimates of radiative heating should theoretically become increasingly unbiased at increasingly large spatial and temporal scales. However, this is generally not the case, and climate simulations have been shown to be very sensitive to seemingly small, but systematic, alterations to cloud optical properties.

Recently, *Barker et al.* (2003) and *Pincus et al.* (2003) introduced a new method for computing broadband radiative fluxes in LSAMs yielding unbiased radiative fluxes with respect to ICA over an ensemble average of one-dimensional radiation transfer simulations. It is referred to as the Monte-Carlo Independent Column Approximation (McICA). The most attractive features of McICA are two-fold.

- McICA extricates the description of the sub-grid scale cloud structure from the radiative transfer algorithm through a cloud generator. This provides the cloud parameters for the radiation schemes by sampling the cloud information randomly from the cloud fraction and water profiles provided by the LSAM.
- The radiative fluxes from McICA, unbiased with respect to ICA, are consistent with assumptions made about the unresolved structure in other parts of the model. In practice, this sub-grid scale cloud structure is related either to the overlapping of the cloud layers in the vertical and/or to the horizontal variability of the cloud characteristics.

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Whether in the vertical or the horizontal, the cloud characteristics referred to above correspond to input parameters in a traditional radiation transfer scheme. These are the distribution of condensed water in various phases and the distribution of the particle effective dimension; together with the distribution of intervening gases these input parameters should define the radiation exchange on the vertical within a grid of the LSAM. As with ICA, McICA does not account for true three-dimensional transfer effects, but those can generally be neglected.

The rest of this article will cover the following topics.

- The impact of the new land surface albedo.
- The McICA approach, with some details about the cloud generator and the long-wave and short-wave radiation schemes that use the cloud information.
- The impact of using a radiation grid different from the one used for the dynamics and other physical calculations.
- Comparisons of forecasts from the extended experimental suite that ran parallel to the operational suite from December 2006 to April 2007.
- Results obtained with McRad in annual simulations with the T159L91 version of the model.

A summary and some perspectives are given at the end of the article.

A climatology of land surface albedo derived from MODIS observations

A new climatology of land surface albedo has been introduced into the IFS to be used as boundary conditions in short-wave flux computations. The albedo has been derived from more recent and more spatially detailed satellite observations than the previously operational land surface albedo derived from ERBE (Earth Radiation Budget Experiment) observations. In addition this MODIS albedo will be consistent with the MODIS-derived surface reflectances that will be used when computing synthetic MODIS radiances for aerosol analysis as part of the GEMS Aerosol Project (a project aimed at providing operational aerosol products). This new climatology was derived from the 2001–2004 datasets produced at Boston University (*Schaaf et al.,* 2002) by processing the MODIS observations at 1 km spatial resolution over 16-day periods. The wide-band albedo, given for direct and diffuse radiation in both the UV-visible and near-infrared parts of the short-wave spectrum, replaces the monthly mean spectrally flat albedo previously derived from ERBE observations.

Figure 1 presents the UV-visible (0.3–0.7 μm) and near-infrared (0.7–5.0 μm) components of the short-wave albedo for April derived from MODIS, showing the large difference between these two components over most surfaces. The higher near-infrared values over vegetated areas increase the cloud-surface interactions. Figure 2 compares the previous operational spectrally flat (0.3–5.0 μm) land surface albedo derived from ERBE observations with the equivalent surface albedo obtained from the ratio of the upward and downward short-wave fluxes with the new albedo. The impact on objective scores in ten-day forecasts at T799L91 from the change in surface albedo is marginal.

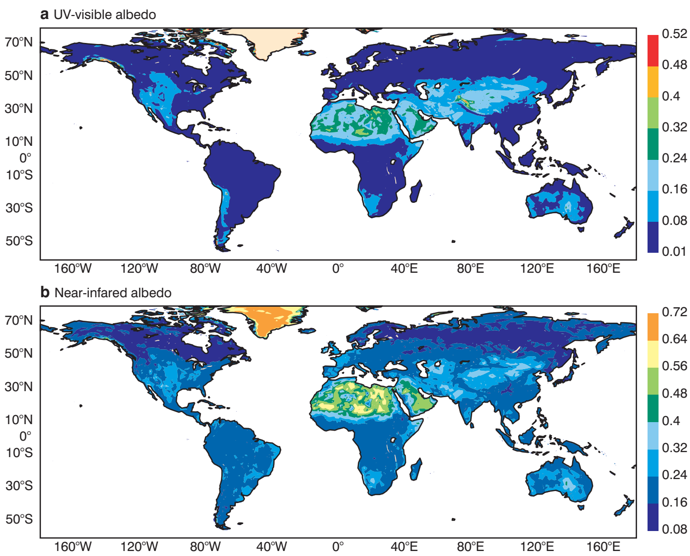

Figure 1 The land surface albedo derived from MODIS observations for April at TL799 for (a) UV-visible (0.3–0.7 *μ*m) and (b) near-infrared (0.7–5.0 *μ*m) part of the short-wave spectrum.

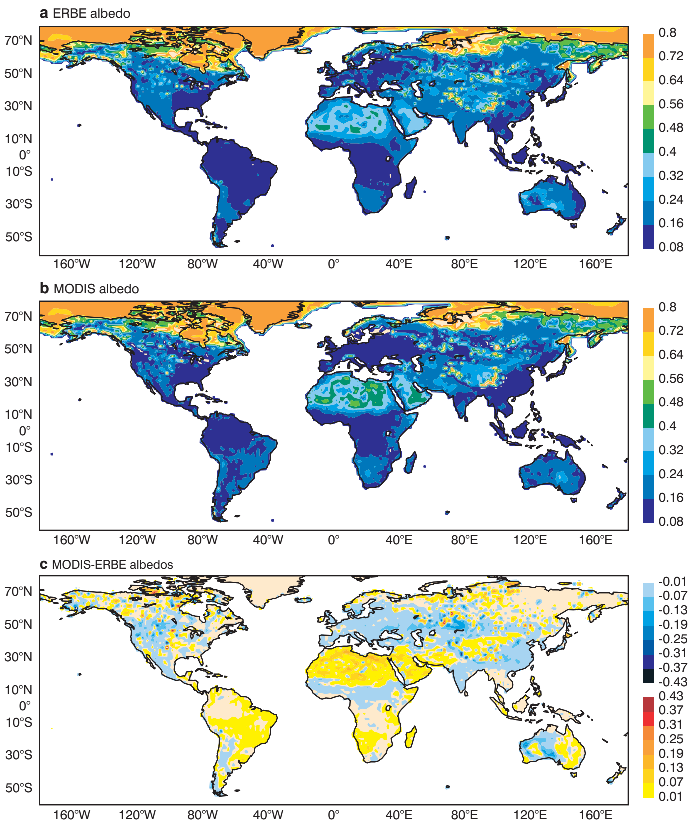

Figure 2 (a) The land surface albedo over the entire short-wave spectrum for April as seen by the model at T799 using the spectrally flat ERBE-derived albedo. (b) As (a) but using the various MODIS components to derive the albedo. (c) Difference between the MODIS and ERBE albedos.

The Monte-Carlo Independent Column Approximation

The McICA approach is an approximation to the full Independent Column Approximation (ICA). The full ICA calculation of a cloudy flux (say, at the top of the atmosphere) is a two-dimensional integral with wavelength varying in one dimension and cloud state in the other. Rather than computing the contribution of every cloud state to every wavelength interval, McICA approximates the flux by choosing a cloud state at random for each spectral interval (see Box A for more details).

McICA can in principle be used within any radiation transfer scheme provided a cloud generator is used to define how the cloud information is distributed over each spectral element in the radiation spectrum. However, to take full benefit of the McICA approach, radiation schemes with a sufficiently large number of transmission calculations are required. With the version of the ECMWF model used for this study, the long-wave radiation fluxes are computed using the Rapid Radiation Transfer Model ($RRTM_{LW}$) already in use at ECMWF since June 2000. For consistency in terms of radiative transfer solution and database of spectroscopic parameters, the short-wave radiation fluxes are now computed with $RRTM_{SW}$. The application of the McICA approach involves using a cloud generator together with slightly modified but otherwise standard radiation schemes.

The main features of the McRad radiation package are summarised in Box B. The McICA versions of $RRTM_{LW}$ and $RRTM_{SW}$ differ from the original versions in two respects.

- Avoiding any explicit reference to cloud fraction greatly simplifies the part of the algorithms devoted to the vertical integration, which now deals simply with optical thicknesses. Any cloudy calculation only involves modifying the optical parameters.
- Using McICA enables the removal of the 0.7 correction factor multiplying the cloud optical thickness, which was introduced in December 1997 into the IFS to take approximate account of the effect of cloud inhomogeneities at the sub-grid level.

As stated earlier, the McICA representation of cloud-radiation interactions requires the cloud information to be distributed by a cloud generator over the vertical with the constraint that the total cloudiness and cloud water loading for a grid-point is conserved.

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The purpose of the cloud generator is, starting from a cloud profile (cloud fraction and cloud water content) provided by a traditional cloud scheme, to distribute randomly the cloud information (in terms of presence (1) or absence (0)) into each of the layers covered by the original cloud profile. This distribution is done N times (McICA with N going to infinity would be equal to ICA) with the constraint that a summation over the N profiles would recreate the original vertical distribution of partial cloudiness. In the ECMWF model, for each radiation time-step (every one hour of model time for the T799L91 forecast) and each radiation grid-point, the cloud generator is used twice: it produces two cloud distributions relevant to the long-wave and short-wave radiation schemes. We use the cloud generator of *Räisänen et al.* (2004) that can distribute vertically either the cloud cover according to a maximum-random overlap assumption or both the cloud cover and cloud water assuming a generalized overlap (*Hogan & Illingworth,* 2000). The results presented hereafter correspond to the operational McRad configuration with a generalized overlap with decorrelation lengths of 2 km for cloud cover and 1 km for cloud water, and a normalized standard deviation of 1 for the cloud condensate.

Clouds when present occupy the full horizontal extent of the layer, and the vertical distribution of such clouds (of 0 or 1 cloud cover) is defined independently for the long-wave and short-wave schemes by the cloud generator, with the constraint that the total cloudiness and cloud water loading for a grid-point is conserved when N tends to infinity.

In all comparisons discussed hereafter, the pre-McRad model (Cy31r2) uses the ECMWF six spectral interval version of the short-wave radiation code, with a slightly different set of cloud optical properties. In tests not discussed here, it was shown that replacing the operational short-wave radiation scheme by $\mathrm{RRTM_{SW}}$ alone or changing the cloud optical properties, while affecting the radiation fields, did not have much affect on the systematic errors shown by the ECMWF IFS in 13-month simulations at T159L91. Only the full McRad package with the suppression of the 0.7 inhomogeneity factor, the use of the McICA approach within $\mathrm{RRTM_{LW}}$ and $\mathrm{RRTM_{SW}}$, and the revised cloud optical properties shows the positive impact discussed below.

The McICA approach A

For the full independent column approximation (ICA), the average monochromatic radiative flux, over a domain sub-divided in N columns, in which each layer can only have a cloud fraction of 0 or 1, is

$$\langle F \rangle = \frac{1}{N} \sum_{n=1}^{N} F_n \qquad (1)$$

In sub-column n, using a radiation parametrization (plane-parallel, and considering a homogeneous cloud water distribution in all overcast layers) with a correlated k-distribution (CKD) approach to deal with absorption, the total flux F_n is

$$F_n = \sum_{k=1}^{K} c_k F_{n,k} \qquad (2)$$

Combining (1) and (2) gives

$$\langle F \rangle = \frac{1}{N} \sum_{n=1}^{N} \sum_{k=1}^{K} c_k F_{n,k} \qquad (3)$$

A radiation code explicitly integrating the double sum in (3) would be far too expensive for LSAM applications. The McICA solution to this problem is to approximate (3) as

$$\langle F \rangle_M = \sum_{k=1}^{K} F_{n_k,k} \qquad (4)$$

where $F_{n_k,k}$ is the monochromatic radiative flux for a single randomly selected sub-column nk.

From this definition, the McICA solution (4) equals the ICA solution only when all N sub-columns are identical or $N = 1$. As discussed in *Räisänen & Barker* (2004), McICA's incomplete pairing of sub-columns and spectral intervals ensures that its solution will contain random, but unbiased, errors.

Main features of the McRad radiation package B

The main features of the McRad radiation package are summarised in the table

Characteristics of the long-wave and short-wave radiation schemes in McRad. The items marked with * refer to the configuration operational with McRad.

The ECMWF version of $RRTM_{LW}$ describes the long-wave spectrum with 16 spectral intervals, corresponding to a total of K =140 g-points. In a nutshell, a g-point is a point in the space of the line intensities within a spectral interval. $RRTM_{SW}$ (*Mlawer & Clough,* 1997) describes the short-wave spectrum with 14 spectral intervals, corresponding to K = 112 g-points. For each of these g-points, an essentially monochromatic type radiation transfer is carried out using a two-stream method using an approximate provision for the long-wave scattering and using a Delta two-stream method with scattering in the short-wave. For a given g-point, a cloud when present fully occupies a model layer.

	$RRTM_{LW}$	$RRTM_{SW}$
Solution of Radiation Transfer Equation	Two-stream method	Two-stream method
Number of spectral intervals	16 (140 g-points)	14 (112 g-points)
Absorbers	H_2O, CO_2, O_3, CH_4, N_2O, CFC_{11}, CFC_{12}, aerosols	H_2O, CO_2, O_3, CH_4, N_2O, CFC_{11}, CFC_{12}, aerosols
Spectroscopic database	HITRAN, 1996	HITRAN, 1996
Absorption coefficients	From LBLRTM line-by-line model	From LBLRTM line-by-line model
Cloud handling	True cloud fraction	True cloud fraction
Cloud optical properties method	16-band spectral emissivity	14-band τ, g, ω
Data: ice clouds	Ebert & Curry, 1992 Fu et al., 1998*	Ebert & Curry, 1992 Fu, 1996*
Data: water clouds	Smith & Shi, 1992 Lindner & Li, 2000*	Fouquart, 1987 Slingo, 1989*
Cloud overlap assumption set up in cloud generator	Maximum-random or generalised*	Maximum-random or generalised*
References	Mlawer et al., 1997 Morcrette et al., 2001	Mlawer & Clough, 1997

A different radiation grid for McRad

A new interface for radiation computations was developed and implemented in October 2003. Radiation calculations are performed on a grid with a coarser resolution than the current model grid. Interpolations between model and radiation grids are performed using interfaces existing within the IFS libraries and as a result this helps reduce code maintenance. This radiation grid had been used since October 2003, with a coarsening factor of two in both latitude and longitude with respect to the rest of the model.

The implementation of the more computer-intensive McRad, through its use of $RRTM_{SW}$ with an increased number of spectral intervals, has led to the search for an optimal radiation grid for the different weather forecasting applications run at ECMWF. Depending on the model resolution, and the associated time-step and the frequency for calling the full radiation schemes, the cost of the model integration drastically increased. However, comparisons of results with the different radiation grids (from *R*399 to *R*95 for the T799L91 high-resolution model, from *R*255 to *R*31 for the T399L62 model run in the Ensemble Prediction System, from *R*159 to *R*31 for the T59L91 model used for seasonal forecasts) were systematically carried out. For the radiation grid, a best compromise was chosen (*R*319 for T799, *R*95 for T399, *R*63 for T159), which allows the maximum benefit of McRad within the time constraints for delivering the various operational products.

Results for seasonal simulations

Now consider the results from 13-month seasonal simulation at T159L91 using the previous operational model (Cy31r2) and McRad model.

McRad improves the behaviour of the model in a number of aspects: a change in the balance between long-wave and short-wave radiation heating leads to a noticeable shift in the location of the tropical cloudiness (see Figures 3 and 4). This is mainly a feature of McICA, as preliminary tests using $RRTM_{SW}$ (without the McICA approach) instead of the operational short-wave radiation code, or with a different set of cloud optical properties, changed somewhat the overall radiation budget at the top of the atmosphere, but without affecting the negative bias linked to the cloudiness over South America, Africa and the Tropical West Pacific being too small.

Table 1 shows that McRad improves markedly on the top of atmosphere (TOA) radiation biases over these areas. Differences with observations from CERES (Clouds and Earth's Radiant Energy System) are reduced with McRad, with the global annual mean bias changing from -8.1 to -3.2 $W m^{-2}$ for the outgoing long-wave radiation (OLR), from -10.0 to -5.8 $W m^{-2}$ for the absorbed short-wave radiation at the top of the atmosphere (ASW), from -9.6 to -4.0 $W m^{-2}$ for the clear-sky downward long-wave flux (LWCF), and from -5.2 to -0.2 $W m^{-2}$

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for the clear-sky downward short-wave flux (SWCF). Table 1 confirms that these improvements happen over the whole year, with a general improvement on the TOA radiative parameters also appearing in winter (December–February) and summer (June–August).

Table 1 also shows that the overall climate of the model is improved in terms of total column water vapour (TCWV), total cloud cover (TCC), total column liquid water (TCLW), and total precipitation (TP). A significant improvement is also seen in terms of temperature and specific humidity, as shown in Figure 5 by comparing the differences between the Cy31r2 seasonal simulation and ERA-40 analysis with the corresponding differences for the McRad simulation.

With McRad, the surface short-wave radiation is increased; this results in a worse agreement with the Da Silva climatology (over oceans only). However, for the ECMWF model run with an interactive ocean, the better geographical distribution of short-wave surface fluxes produced by the new radiation package has been found to be beneficial to the forecasts of ocean surface temperature.

A more extensive discussion of the impact of McRad on 13-month simulations at T159L91 with specified SSTs can be found in *Morcrette* (2006). Here we just point out the major improvements brought by McRad.

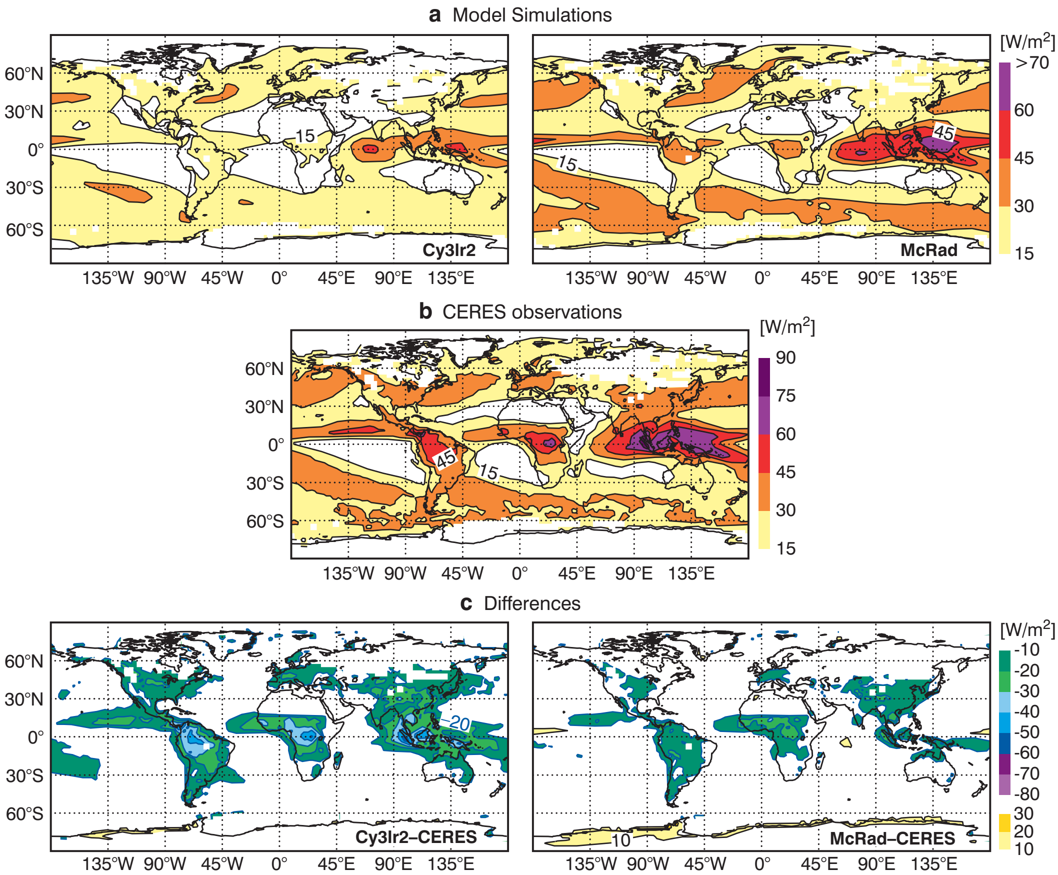

Figure 3 (a) The long-wave cloud forcing (in W m^{-2}) from the seasonal simulation using the Cy31r1 model (left) and McRad model (right). (b) Long-wave cloud forcing (in W m^{-2}) derived from CERES observations. (c) Differences in long-wave cloud forcing (in W m^{-2}) between the Cy31r1 model simulation and CERES observations (left) and between the McRad model simulation and CERES observations (right).

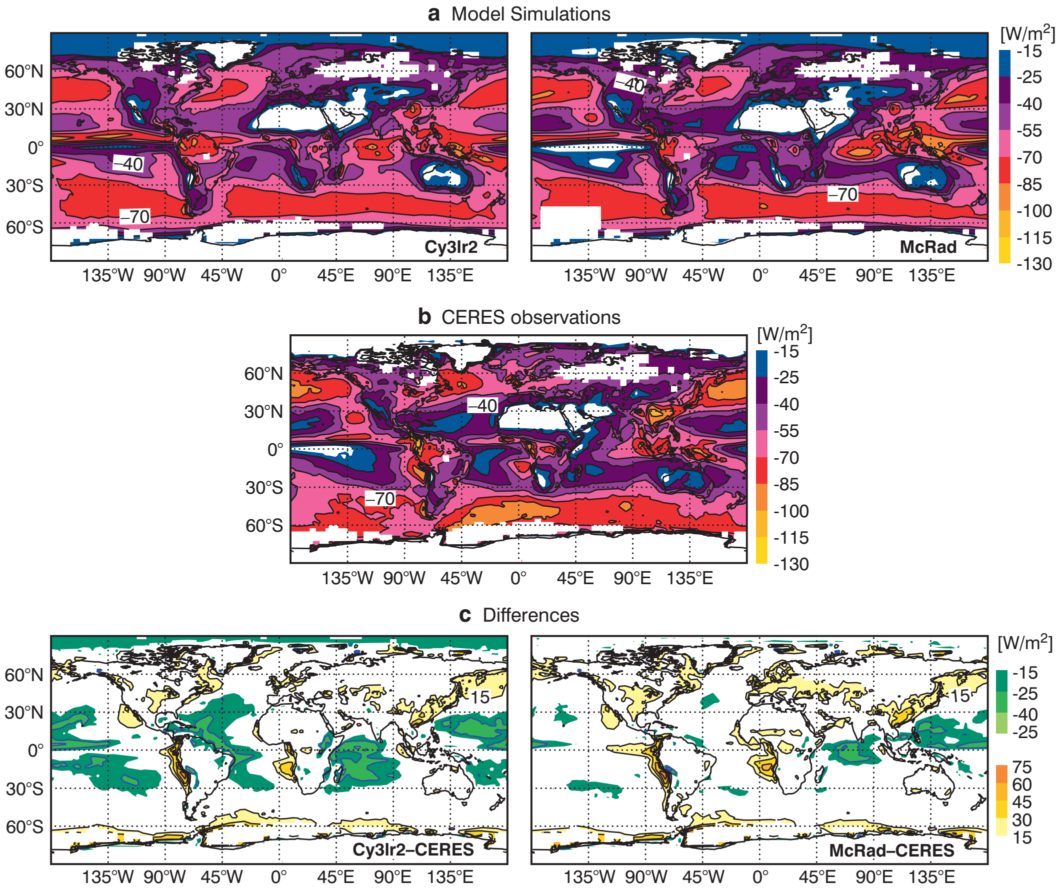

Figure 4 The short-wave cloud forcing (in W m^{-2}) from the seasonal simulation using the Cy31r1 model (left) and McRad model (right). (b) Short-wave cloud forcing (in W m^{-2}) derived from CERES observations. (c) Differences in long-wave cloud forcing (in W m^{-2}) between the Cy31r1 model simulation and CERES observations (left) and between the McRad model simulation and CERES observations (right).represent the observed frequency.

	OLR (W m−2)	ASW (W m−2)	LWCF (W m−2)	SWCF (W m−2)
Observed	−239	244	27.3	−48.7
Cy31r2–Observed	−8.1 (12.7)	10.0 (17.5)	9.6 (13.6)	−5.2 (15.4)
McRad–Observed	−3.2 (7.9)	−5.8 (14.2)	−4.0 (7.9)	−0.2 (12.9)
	TCWV (kg m−2)	**TCC** (%)	**TCLW** (g m−2)	**TP** (mm/day)
Observed	29.0	62.2	82.2	2.61
Cy31r2–Observed	−2.10 (3.65)	−6.0 (10.3)	1.67 (22.1)	0.45 (1.39)
McRad–Observed	−1.67 (3.13)	−5.3 (9.5)	0.86 (22.4)	0.40 (1.21)

Table 1 Results from 13-month simulations at T159L91 in terms of the bias and standard deviation (in parentheses) for the previous operational model (Cy31r2) and McRad model. Radiative fluxes at TOA are compared to CERES measurements for outgoing long-wave radi- ation (OLR), absorbed short-wave radiation at the top of the atmosphere (ASW), clear-sky downward long-wave flux (LWCF), and clear-sky downward short-wave flux (SWCF). Also total cloud cover (TCC) is compared ISCCP D2 data, total column water vapour (TCWV) and liquid water (TCLW) to SSM/I data, and total precipitation (TP) to GPCP data.

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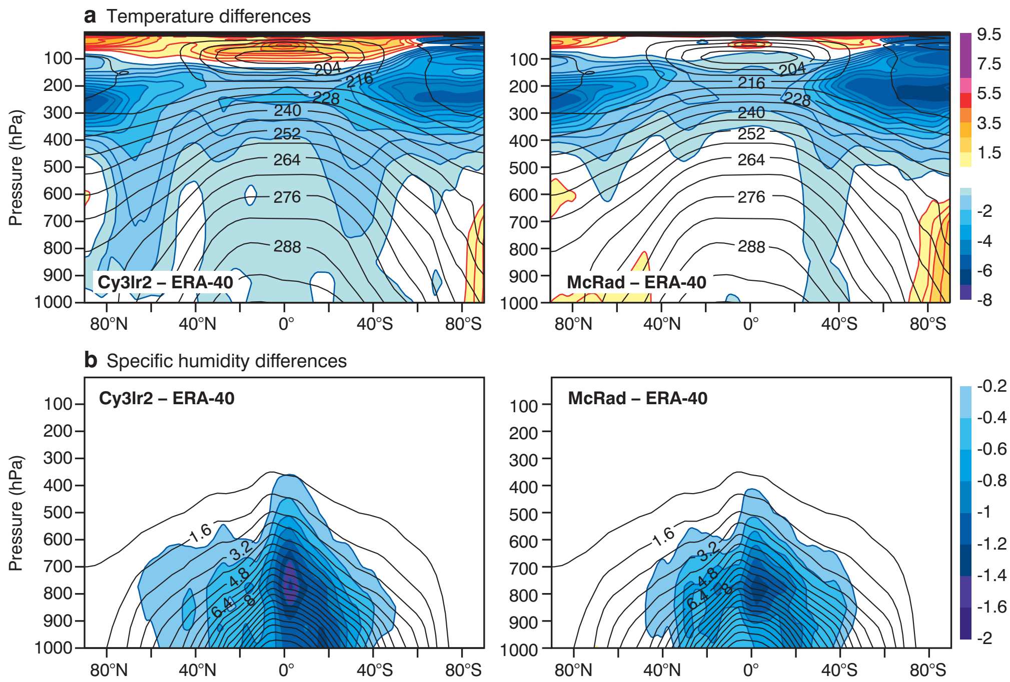

Figure 5 (a) Comparison of the difference between the Cy31r2 seasonal simulation and ERA-40 analysis (left) with the corresponding difference for the McRad simulation (right) for zonal mean temperature (K). (b) As (a) but for specific humidity (kg kg^{-1}).

Impact on high-resolution ten-day forecasts

An experimental suite, parallel to the operational suite at T799L91, was run from July 2006 to April 2007. This included McRad and some other modifications to the IFS that are unlikely to affect the response of the model beyond the first few days. Results are presented here for December 2006 to April 2007, with some more results specific to January 2007.

The main impact of McRad, compared to the previously operational radiation scheme, is to modify separately the vertical distributions of the additional long-wave and short-wave heatings induced by the presence of the clouds. This is linked to several factors: the revised cloud optical properties, particularly for ice clouds where the effective particle size is now diagnosed from temperature and the local ice water content (only temperature up to Cy31r2) contributes to more radiatively active ice clouds particularly at high latitudes. Through the McICA approach, the effect of the previous 0.7 inhomogeneity factor scaling all cloud optical thicknesses in the long-wave and short-wave parts of the spectrum is replaced by the inherent variability in cloud optical thickness provided by the cloud generator.

The change in radiative heating profiles directly impacts the position of the convective activity, as can be seen in Figure 6. This presents the change in outgoing long-wave radiation (OLR) and absorbed short-wave radiation (ASR) during the first 24 and last 24 hours of the ten-day forecasts for January 2007. In the tropical area the decrease in OLR (a negative quantity) and increase in ASR (a positive quantity) indicates more high level cloudiness over South America, Southern part of Africa and the Tropical West Pacific. The impact over Sahara is linked to the revised surface albedo.

The improvements brought by McRad can be seen in various objective scores. Figure 7 presents the variation in the RMS error of geopotential at 200, 500 and 1000 hPa for the European area computed over the period 1 December 2006 to 30 April 2007. A small but systematic improvement is seen over most of the ten days of the forecasts over Europe. The same kind of improvement is found for the northern and southern hemispheres. The improvement in the location of the major tropical cloud systems has a direct impact on the tropical scores at all heights in the troposphere, as illustrated in Figure 8 for the RMS error of the vector wind at 850 and 200 hPa.

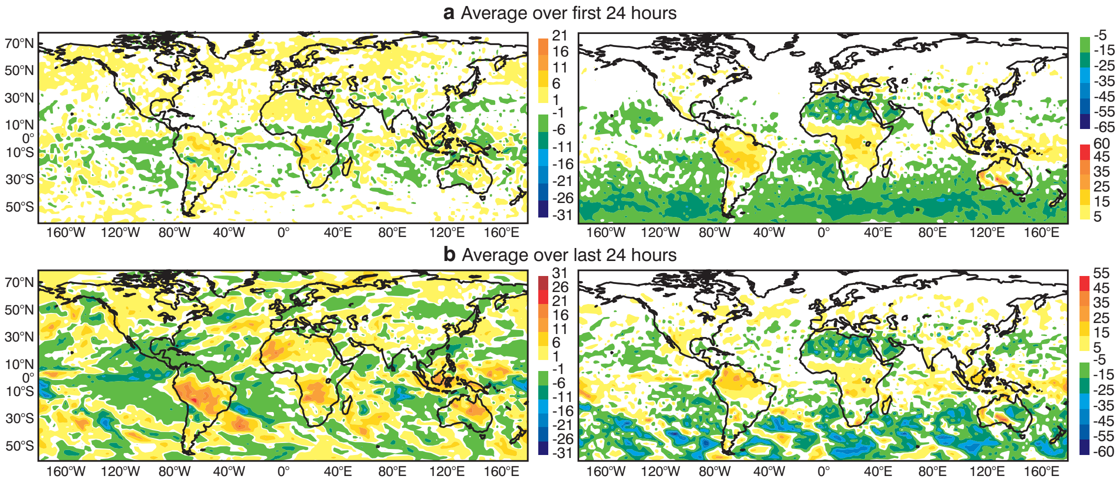

Figure 6 (a) The difference in outgoing long-wave radiation (OLW, left) and absorbed short-wave radiation (ASW, right) at the top of the atmosphere between the McRad and the Cy31r2 simulations averaged over the first 24-hour of the forecasts for the month of January 2007. (b) As (a) but for forecasts averaged over the last 24-hour of the ten-day forecasts. All quantities in W m^{-2}.

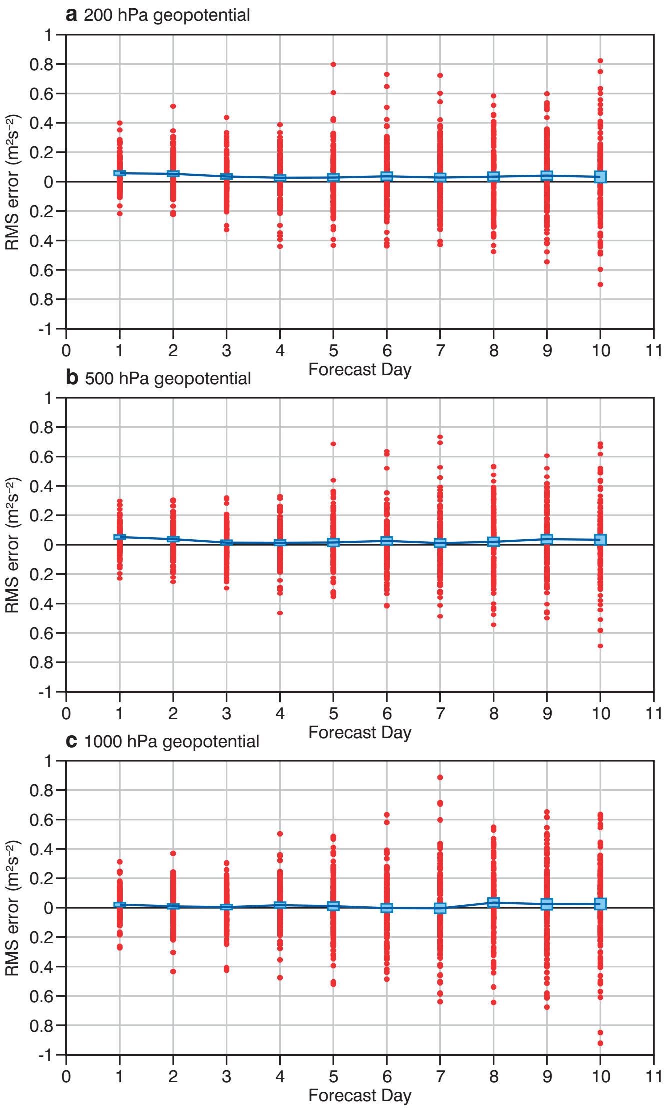

Figure 7 Variation of RMS error of the geopotential in the European area at (a) 200, (b) 500 and (c) 1000 hPa over the period 1 December 2006 to 30 April 2007.

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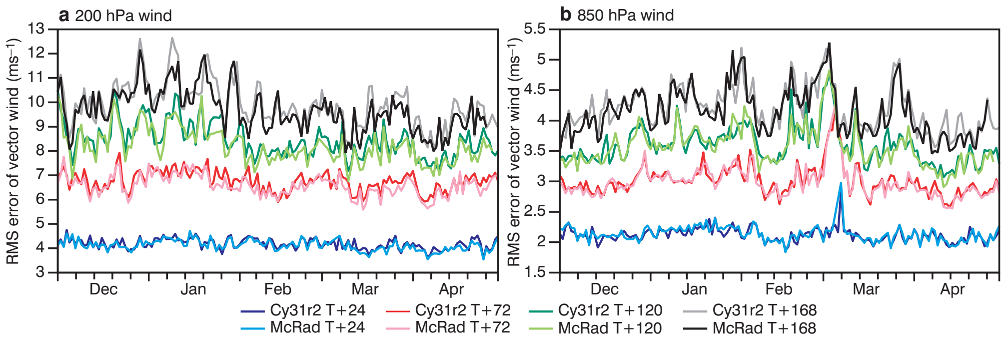

Figure 8 The time-series of the RMS error of the vector wind in the tropics (20°N–20°S) at (a) 200 and (b) 850 hPa over the period 1 December 2006 to 30 April 2007.

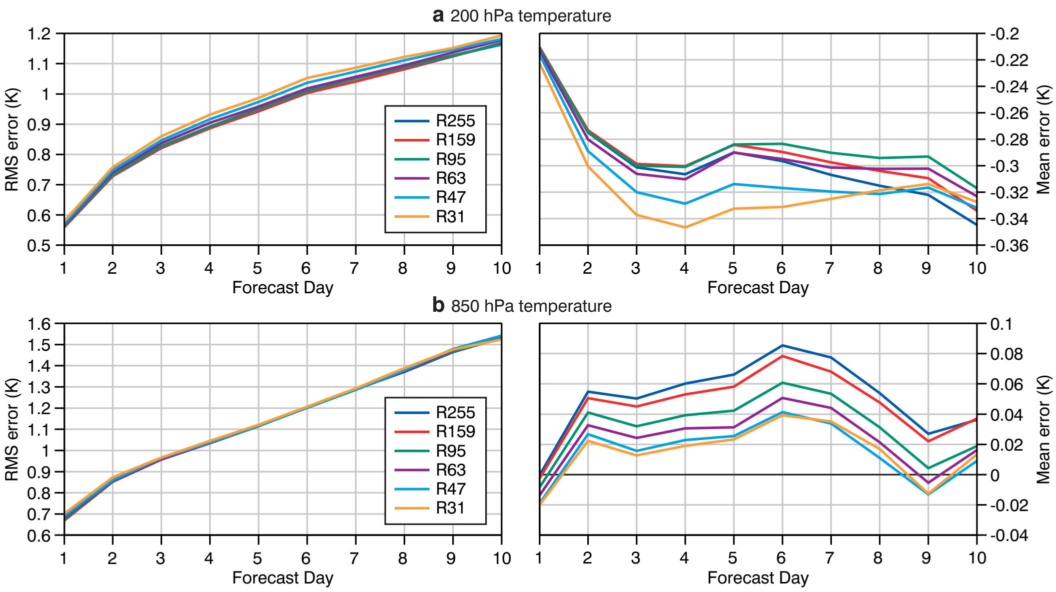

Figure 9 (a) RMS error (left) and mean error (right) of the temperature at 200 hPa for McRad ten-day forecasts at T399L62, started every 96 hours from 12 December 2006 to 12 May 2007, and using the six different radiation grids from *R*255 to *R*31. (b) As (a) but for 850 hPa temperature.

Impact on medium resolution ten-day forecasts used in the Ensemble Prediction System

For ECMWF's Ensemble Prediction System (EPS), the model uncertainties deriving from parametrized physical processes are simulated by applying a random number between 0.5 and 1.5 to the sum of the physical tendencies within a 10°×10° box over three hours. The scaled physical tendencies are then passed to the thermodynamic equation to be solved. Therefore, introducing a more approximate treatment of the radiation tendencies (as through the use of a more reduced radiation grid) is not likely to deteriorate the quality of the EPS forecasts.

In ten-day forecasts with McRad running the T399L62 model with various resolutions for the radiation grid, the impact on the objective scores was small. For example, Figure 9 presents the RMS error of the temperature at 850 and 200 hPa (the most sensitive parameter) in the tropics for sets of 93 forecasts starting every fourth day spanning a year from 2 February 2006 to 5 February 2007. For these sets of forecasts with the resolution of the radiation grid being reduced from *R*255 to *R*31, the impact on the geopotential is small and does not appear before day 6 of the forecasts. Similarly small is the impact on the RMS error of temperature at 850 and 200 hPa. Only the mean error in temperature at 850 hPa for all areas (northern and southern hemispheres, and tropical area) and the mean error in temperature at 200 hPa in the tropics show a distinct signal. However, the difference between *R*255 and *R*31 (i.e. a radiation grid coarsening from [0.70°]2 to [5.625°]2) is at most 0.06 K. In the tropics, where these differences in temperature between the various radiation grids are the most marked, the impact on the wind is very small. So after further testing of the EPS in pre-operational mode, it was found that reducing somewhat the radiation grid allows for a decreased cost of the EPS without affecting its overall quality. Therefore, from 5 June 2007, the EPS including McRad is being run at T399L62 *R*95 for 10 days, then at T255L62 *R*63 up to 15 days.

Summary and outlook

The new radiation package McRad presented in this article was made operational with model cycle Cy32r2 on 5 June 2007. It includes a new short-wave radiation scheme, revised cloud optical properties, the MODIS-derived land surface albedo and the McICA approach to radiation transfer in cloudy atmospheres. In addition there can be a more extensive use of a flexible radiation grid; the grid can be made coarser when the highest accuracy of the radiative heating rates is not essential for the application, as with the EPS.

McICA is the most important change as it simplifies the radiation transfer schemes by suppressing all references to partial cloud cover, the subsequent separate calculations for clear-sky and cloudy parts of the layers, and the inherent complexity of the vertical integration accounting for the overlapping of these clear and cloudy quantitites (reflectances/transmittances or fluxes). The cloud generator used here (*Räisänen et al.,* 2004) being independent from the radiation transfer can now handle any overlap situation, and is used here with a definition of the overlap of cloud layers through decorrelation lengths (*Hogan & Illingworth,* 2000).

The impact of McRad was studied in seasonal simulations, and ten-day forecasts, and it was shown to benefit the representation of most parameters at both short and longer time-scales, relative to the previous operational version.

McRad allows the same overlap assumption to be used for radiation transfer and precipitation/evaporation processes, a problem previously solved either only approximately or through additional calculations. In the future, it will help connect the radiation transfer calculations with cloud information derived from cloud schemes based on a probability distribution function or from observations of the vertical profiles of the condensed water as made available from CALIPSO-type measurements.

Further Reading

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