Cloud amounts and radiative fluxes calculated from the JMA atmospheric model

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Abstract

The Japan Meteorological Agency global atmospheric model (version JMA–GSM9603) was run for a 45-month period. Cloud amounts and radiative fluxes obtained for this particular run are examined and compared with observational and other data.

It is found that the amount of shortwave radiation reaching the surface is generally much lower than that from satellite-derived data, especially in the low latitudes of the Pacific region. This is in contrast to clear-sky conditions where the model and observational downward shortwave radiative fluxes agree well over much of the oceans. In this case, large differences are confined to parts of the continents, suggesting that some land-related factors need to be considered carefully, in addition to cloud estimation.

Cloud cover, which is diagnosed from relative humidity, is calculated by a mixture of both maximum and random overlapping. The exact dependency of the cloud amounts on the relative humidity is varied and several runs are performed until there is a suitable match between the cloud amounts from the model and from ISCCP data. Resulting radiative fluxes are then compared again.

Introduction

Radiative fluxes within the Earth's atmosphere form an important determining part in the global energy balance and affect both atmospheric and oceanic circulations. With the ultimate aim of minimizing the need for flux adjustment in atmosphere-ocean coupled models, the accuracy of the radiative fluxes from the JMA global spectral model is assessed. The computed fluxes are compared with suitable observational data. The Surface Radiation Budget (SRB) Shortwave Data Package [1], taken from the World Climate Research Program (WCRP) yields observational data for the period 1985-1988. This is used to provide a set of climatological monthly mean data consisting mainly of shortwave radiative fluxes and surface albedo. One tested algorithm within the shortwave data package is based on delta-Eddington radiative transfer equations.

In addition, NCEP/NCAR reanalysis data [2] for the period 1982-1994 are employed for longwave fluxes. The International Satellite Cloud Climatology Project (ISCCP) [3] provides cloud data with which model values may be compared. Dataset D2 utilizes an updated algorithm and includes data within three vertical ranges. Monthly means for January 1989 to December 1992 are used to calculate climatological monthly mean data. Low-, mid- and high-level clouds are defined to be for 1000–680, 680–440 and 440-50 hPa pressure ranges respectively.

JMA model

Version JMA–GSM9603 of the Japan Meteorological Agency global atmospheric model was run for a 45-month period. Output data is made available for each 5-day period. These are subsequently averaged to obtain monthly mean data.

The spectral model is set to triangular truncation at wavenumber 42 for the 45-month run. It is discretized into 30 vertical levels, up to 10hPa, using a hybrid vertical coordinate consisting of a combination of the sigma and pressure coordinate at lower and upper levels respectively. Suitable parameterization schemes are employed for the physical processes. Revisions to previous versions include the following changes to the clear-sky radiation. Within the shortwave radiation scheme, absorption by water vapour is improved and absorption by oxygen and carbon dioxide is included. For longwave radiation, the pressure dependence on the absorption spectrum of carbon dioxide and water vapour has been rectified. Introduced is a correlation parameter to specify the extent of both maximum and random overlapping of cloud layers.

An Arakawa-Schubert scheme is employed to parameterize deep cumulus convection in the atmosphere. For this particular run of the model, results of which are shown later, the cloud amount is a simple continuous quadratic function of the large-scale relative humidity [4, 5]

$$Cl = \left(\frac{R - R_C}{1 - R_C}\right)^2, \quad R > R_C$$

where Cl, R and R_C are the cloud amount, relative humidity and critical relative humidity respectively. The value of the critical relative humidity can be regarded as tunable and is set at four vertical levels: $R_{C0} = 0.85$, $R_{C1} = 0.80$, $R_{C2} = 0.65$, $R_{C3} = 0.80$ and $R_{C4} = 0.90$ at the surface, 830 hPa, 600 hPa, 300 hPa and tropopause respectively, with R_C varying linearly between the levels.

Shortwave radiation

The downward flux at the surface (see figure 1) shows that certain regions exhibit high abnormalities throughout the year. In particular, the Pacific Ocean, near low latitudes, sees the radiative flux underestimated, sometimes by more than 150Wm^{-2}. Other areas where the amount is underestimated are confined mainly to the oceans, especially in the Southern Ocean during January. There are also regions where the radiative flux is continously being overestimated, although the differences are not as serious as those in the Pacific Ocean. These regions can be found in the North Africa – Middle East – Central Asia area, Australia and the coastal areas off Peru and northern Chile. These regions are exactly where the radiative amount is high, so that the fractional error is less significant.

The main features of the upward flux at the surface are the areas of overestimation all year round in Central Asia, Australia and, to a lesser extent, around northern Chile. High values are computed for both North Africa and Central Asia and yet those for the former agree fairly well with SRB data. The high discrepancy for the Himalayan region, thus giving a high albedo, may be a result of different snow cover between the model and SRB and this should be investigated further in the future. Although the predicted radiative flux from the seas is comparably insignificant (about 5 to 10 Wm^{-2}), the satellite-derived value can be twice as large.

The upward shortwave flux at the top is severely overestimated above the seas, in particular the Pacific Ocean. In general, areas of overestimation correspond to those of underestimation of the downward shortwave radiation at the surface, suggesting overestimation of clouds over these areas.

In clear-sky conditions, the difference between the downward fluxes at the surface for the JMA model and for satellite-derived data has dropped to less than 10% over most of the oceans and is only greater in the Southern Ocean, during the southern summers (see figure 2). In contrast to the above results for all-sky conditions, the largest discrepancies now occur mainly over land (10-20%) with the exception of the Southern Ocean, eg Africa and South America. This suggests that some problems may lie within the treatment of surface effects or atmospheric conditions over land, eg dusts or other aerosols.

Figure 1: downward shortwave radiation at surface

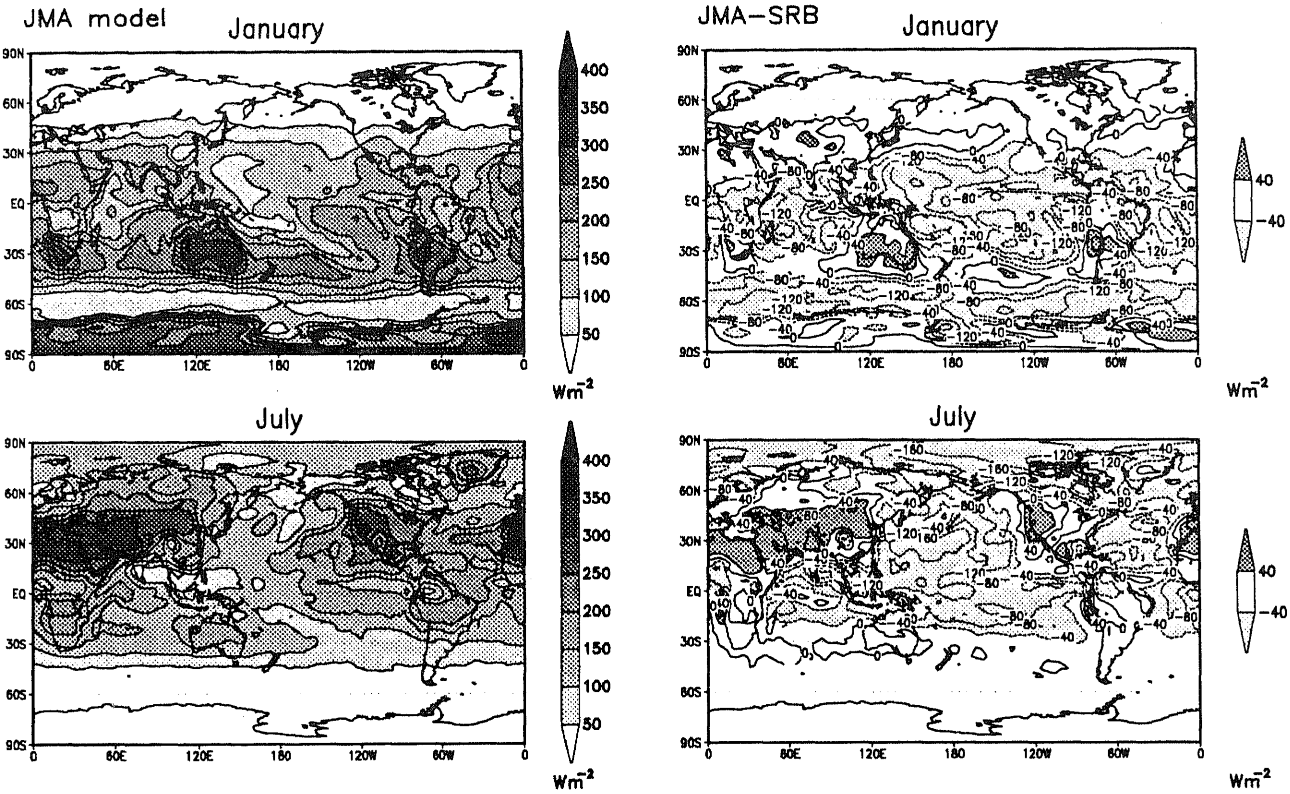
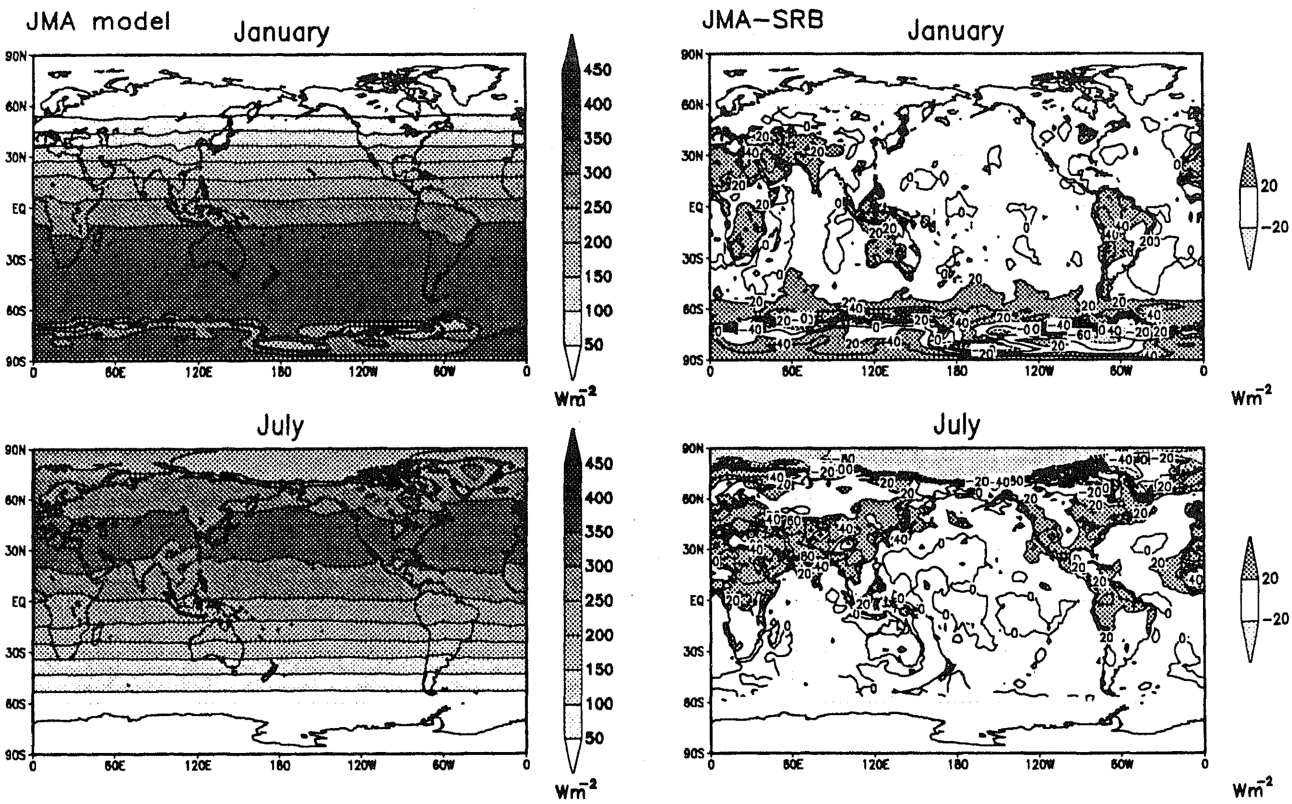


Figure 2: downward shortwave radiation at surface (clear−sky)



Longwave radiation

Both downward and upward longwave radiation on the surface show largest discrepancies with NCEP data on land. There is little variation throughout the year and the discrepancies percentage-wise are, nonetheless, fairly low, especially in the upward direction.

The upward longwave radiation at the top of the atmosphere show contrasting situations for all-sky and clear sky conditions. On the whole, JMA model values are lower, with the greatest differences observed in the equatorial Pacific region and northern Africa. Clear-sky values are in very good agreement. Maximum differences, although not very significant, are found over the Asian continent.

Cloud amounts

To provide a valid comparison between the calculated cloud covers and those of the ISCCP data, some alterations are made. Firstly, the original pressure ranges used for the definition of low-, mid- and high-level clouds are changed from 1000–830, 830–300 and 300– hPa to match ISCCP data, although this alone made little noticeable difference. Secondly, cloud cover for each three level is derived from the vertical clear line of sight from the level to the top of the model [6]. The clear line of sight is given by:

$$\begin{aligned} C_{a,b} &= CORR_{a,b} \cdot \min\Big(C_{a,b-1}, (1 - Cl_b)\Big) \\ &\quad + (1 - CORR_{a.b}) \cdot C_{a.b-1} \cdot (1 - Cl_b) \end{aligned}$$

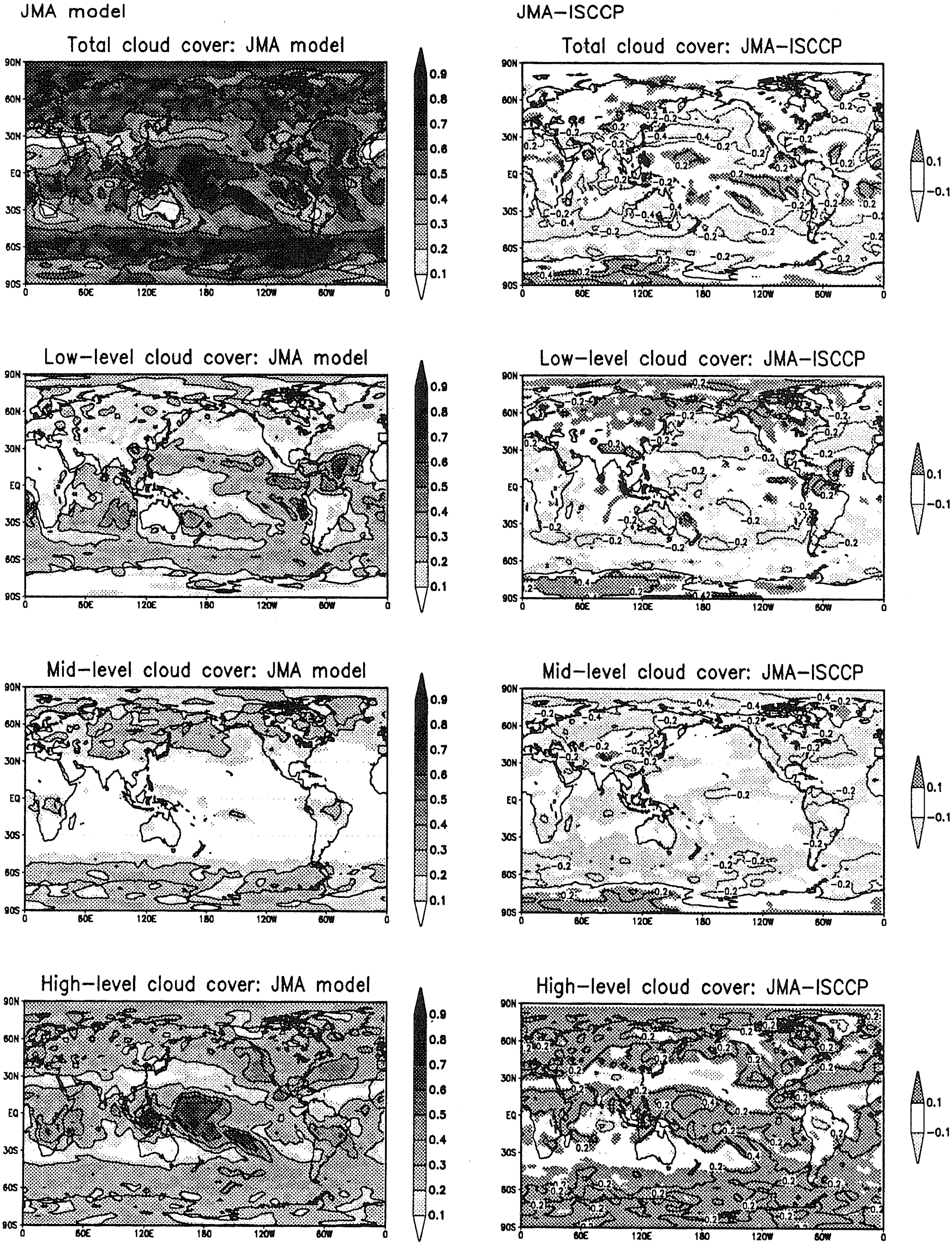
where $C_{a.b}$ is the clear line of sight from vertical level a to vertical level b and Cl_b is the cloud amount between levels b and $b+1$. The correlation variable, $CORR_{a.b}$, is used in the model to provide a weight for random and maximum cloud overlapping. Control runs where the cloud overlapping is set to either random or maximum are also performed. The total cloud amounts using maximum overlapping is very similar to that of the original control run. However, using random overlapping yields larger low-level cloud amounts, especially in the low and mid latitiudes.

Figure 3 shows cloud amounts for the month of January. High-level clouds are generally overestimated, especially in the tropics. This results in an overestimation in the total cloud amount over the central Pacific region. High-level cloud amount in ISCCP data is mostly less than 0.25. On the other hand, mid- and low-level cloud cover, as calculated by the model, is too low, and results in the underestimation of total cloud amount over most areas, except the Pacific Ocean.

Changes to cloud amounts

The model is re-run using different cloud amounts and the subsequent radiative fluxes are compared. One case uses the following values for the critical relative humidities: $R_{C0} = 0.85$,$R_{C1} = 0.70$, $R_{C2} = 0.60$, $R_{C3} = 0.90$ and $R_{C4} = 0.98$. High-level clouds are still overestimated, but have been reduced by about 0.1. Despite lowering the value of R_C in the middle levels, cloud amounts remain largely unchanged. It was possible to vary low-level clouds, but no particular value gave an overall satisfactory result. Low-level cloud amounts over the northern Pacific Ocean, Australia and the southern areas of Africa and South America always remained extremely low. The amount of shortwave radiation reaching the surface in these areas remain overestimated, but a slightly better agreement is observed over other areas. Further changes in R_C resulted in unusually high amounts in low-level clouds over the central Atlantic Ocean. The upward shortwave radiation at the top shows some improvement, for example, over the Pacific Ocean.

Figure 3: cloud cover (January)



Cloud amounts were also calculated by choosing suitable values for R_C and the tuning parameter, B, such that

$$Cl = B\left(R - R_C\right)^2, \quad R > R_C,$$

In a previous version of the model, R_C and B were set to the values (0.45, 1.6), (0.35, 0.6), (0.3, 0.3) and (0.15, 0.7) within the four vertical levels, from the lower to the upper. The resulting cloud amounts for low- and mid-levels were even lower. With other values, it was possible to obtain a better distribution across the vertical levels. However, the horizontal distribution still posed some problems and shortwave radiative fluxes did not improve significantly. For example, low-level cloud amounts remained too low over Australia and the northern Pacific Ocean.

Summary

The control run for version JMA–GSM9603 of the JMA model yields an unusually large amount of high-level clouds, in particular, over the central Pacific Ocean. Shortwave radiation reaching the surface of the ocean is consequently decreased, whilst the upward flux is overestimated. Apart from this region, the zonal mean shortwave received at the surface compares well. Over some areas, eg Australia, the downward shortwave radiation remains too high and can only be corrected by increasing overlying low-level clouds which cannot be achieved easily. Differences in the shortwave radiation and surface albedo also point to possible problems with snow cover. Radiative fluxes within clear-sky conditions generally fit well with satellite-derived data, except over land which suggests that there may be some problems with atmospheric conditions over land, eg aerosols.

References

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