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Simulation of the earth's radiation budget with the 11-layer general circulation model

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Summary

This article examines the components of the earth's radiation budget as simulated by the first integration of the Meteorological Office 11-layer atmospheric general circulation model through a complete annual cycle. Comparisons with two independent satellite data sets are used to assess the quality of the simulation and also to highlight disagreements between the satellite data themselves. The model employed cloud amounts and heights taken from climatological data, thus providing a useful reference against which results from subsequent integrations with model-predicted cloudiness may be compared.

1. Introduction

1.1 *The earth's radiation budget*

It is well known that the ultimate energy source which drives the general circulations of the earth's atmosphere and oceans is the absorption and emission of electromagnetic radiation (Gill 1982, Houghton 1984). Short-wave radiation from the sun at wavelengths between about 0.2 and 5 μm is absorbed mainly at the surface, but also to a lesser degree by clouds and by minor atmospheric constituents such as water vapour, ozone and carbon dioxide. About 30% of the incident radiation is reflected back to space by clouds, the surface, and by Rayleigh scattering from the atmosphere itself. The largest contribution to the reflected flux comes from clouds, because of their high reflectivity and extensive coverage (on average about half the globe is covered by clouds at any instant). By reducing the short-wave radiation available for absorption, clouds act so as to cool the earth–atmosphere system. This is often referred to as the 'albedo effect'. The contribution from the surface is generally smaller than that from clouds, but is enhanced considerably over snow- and ice-covered surfaces.

The earth's radiation budget is balanced by the emission of long-wave (heat) radiation back to space, at wavelengths between about 4 and 100 μm. The important difference compared with the short-wave spectral region is that the atmosphere is a strong absorber, and hence also a strong emitter, of long-wave radiation in a series of spectral bands. This is because the minor constituents have many vibrational and rotational energy transitions which may be excited by radiation at these wavelengths. The absorption by water vapour is especially important, because it is considerable across the entire long-wave spectrum apart from the 8–13 μm region, which is commonly known as the 'atmospheric window'. Water droplets are even more efficient absorbers at all wavelengths beyond about 2 μm, so that most clouds absorb essentially all the long-wave radiation incident on them and emit radiation similar to that of a black body at the temperature of the cloud boundary. The absorption by the minor constituents and by clouds has a profound influence on the earth's climate through the so-called 'greenhouse effect'. The net long-wave cooling of the surface is reduced considerably by the downward long-wave flux from the atmosphere. The long-wave energy radiated back to space is also reduced because the radiation from the surface is absorbed and replaced by that from higher, and hence colder, levels. The system is, therefore, much warmer than if the clouds and the atmosphere were transparent to long-wave radiation.

1.2 *Representation of clouds in numerical models*

It will be clear from the above that numerical models of the atmospheric general circulation need to include schemes for calculating both the short-wave and long-wave radiative fluxes, not only within the atmosphere but also at the surface. There are many problems associated with the design of radiation schemes, for example in the choice of spectral resolution and the treatment of the minor constituents. However, the fundamental problem is in the representation of clouds, because of their significant effect on the fluxes. In most synoptic situations the cloud field has a complex structure, with different cloud types at several levels and of various horizontal and vertical extents. The radiation scheme must be designed so that it can cope with such a configuration, within the constraints of the limited vertical and horizontal resolution of the model. The effect of clouds must be modelled carefully in both spectral regions, because the net radiative effect of clouds on climate is a subtle balance between their contributions to the albedo and greenhouse effects. This means that care must be taken firstly to use realistic cloud amounts at each model level and secondly to choose radiative properties which are appropriate for each cloud type.

There are two distinct approaches to determining the cloud amounts to be used in an integration. Firstly, one can attempt to predict the cloud amounts explicitly for each grid point at each level from the other model variables. Unfortunately, there is no general theory of cloud formation which can be used to guide the modeller in this area. It is therefore common practice to use simple parametrizations based on the concept that the cloud amount in a model layer must be related in some general way to a parameter such as the mean relative humidity, which can be calculated easily from the model variables (Slingo 1980). The coefficients of such a parametrization may then be tuned so that the mean cloudiness produced by the model agrees with climatological estimates. This approach allows the model to reproduce some of the complex feedbacks associated with changes in cloud cover, but there is of course no guarantee that these feedbacks will be properly represented. It is quite possible that the increased degrees of freedom in a model with interactive cloud will lead to less realistic simulations than for a more highly constrained model. In the second approach, cloud amounts are therefore fixed at climatological values throughout an integration, which for many applications is an acceptable compromise. Unfortunately, reliable information on the vertical distribution of cloudiness is at present available only as zonal averages. Many integrations have therefore been performed with fixed cloud amounts which are a function of latitude and height only.

Whatever approach is chosen for the cloud amounts, it is also necessary to decide how to model the cloud optical properties, i.e. the long-wave emissivity and the short-wave reflectivity (albedo), transmissivity and absorptivity. For most water clouds the emissivity is essentially unity but this is not the case for cirrus, for which it is a strong function of the ice crystal content. Observational and theoretical studies have also shown that the short-wave properties are strong functions of microphysical parameters such as the number and size distribution of the water drops and macrophysical parameters such as the cloud thickness and shape. Detailed radiation schemes are now available which can predict the optical properties from these parameters. Good agreement has been obtained between the fluxes from such schemes and aircraft measurements (e.g. Stephens *et al.* 1978, Slingo *et al.* 1982). Such schemes can, in principle, be used directly in a model and many interesting developments are taking place in this area. However, it is impossible to predict all the required input parameters from the model variables, so that most have to be prescribed. The alternative approach used until recently in most models is to prescribe the optical properties themselves for each cloud type at the values most commonly observed. This allows a less elaborate but faster radiation scheme to be used.

1.3 *Model verification*

With so many approximations, it is important to verify that the radiation scheme used in a numerical model is producing realistic fluxes within an integration. It is difficult to make global comparisons for the surface fluxes because of the sporadic distribution of surface radiation stations. However, satellite measurements of the earth's radiation budget afford an excellent opportunity to compare the model fluxes at the top of the atmosphere with observations at similar resolution, obtained over several years. In this article, radiation budget quantities from the first annual-cycle integration of the Meteorological Office 11-layer atmospheric general circulation model (GCM) are compared with two independent satellite data sets. The 11-layer model is under development in the Dynamical Climatology Branch as part of an integrated model for studying climate, which will also include an ocean GCM and a sea-ice model.

2. The 11-layer model

2.1 *Background and basic structure*

Numerical modelling of the atmospheric general circulation in the Dynamical Climatology Branch began with the development of the 5-layer model (Corby *et al.* 1972, Corby *et al.* 1977) which was integrated on the Science Research Council's 'Atlas' computer and subsequently on the Meteorological Office's IBM 360/195 computer (Hinds 1981). This model has been used in several studies, notably of the atmospheric response to sea surface temperature anomalies (Rowntree 1976), of the effect of soil moisture anomalies on the summer circulation (Rowntree and Bolton 1983), of the factors which control the earth's radiation budget (J. M. Slingo 1982) and of the effect of increases in carbon dioxide concentrations on climate (Mitchell 1983). In many respects the 11-layer model is very similar, with the obvious difference of enhanced vertical resolution. The model is a primitive equation global GCM with 11 unevenly spaced layers and sigma (pressure divided by its surface value) as the vertical coordinate (Fig. 1). The horizontal grid in the version used here is 2° in latitude, with the number of points in each row progressively reduced towards the poles, so as to maintain a roughly uniform resolution of about 220 km. A leap-frog integration scheme with time smoothing and non-linear horizontal diffusion is employed. A limited-area version of this model was used in the GARP Atlantic Tropical Experiment (Lyne *et al.* 1976) and for experiments with a cloud parametrization scheme (Slingo 1980). Global integrations on the 360/195 were mostly of 50 days duration with fixed external forcing conditions for either January or July.

Physical processes are modelled in four subroutines, which deal with boundary-layer and surface exchanges, convection, large-scale precipitation and finally radiation and clouds. The boundary layer is assumed to occupy the lowest three model layers in all conditions, and transfers of heat, moisture and momentum between the layers are modelled by an eddy diffusivity approach (Carson 1982a, b). A more

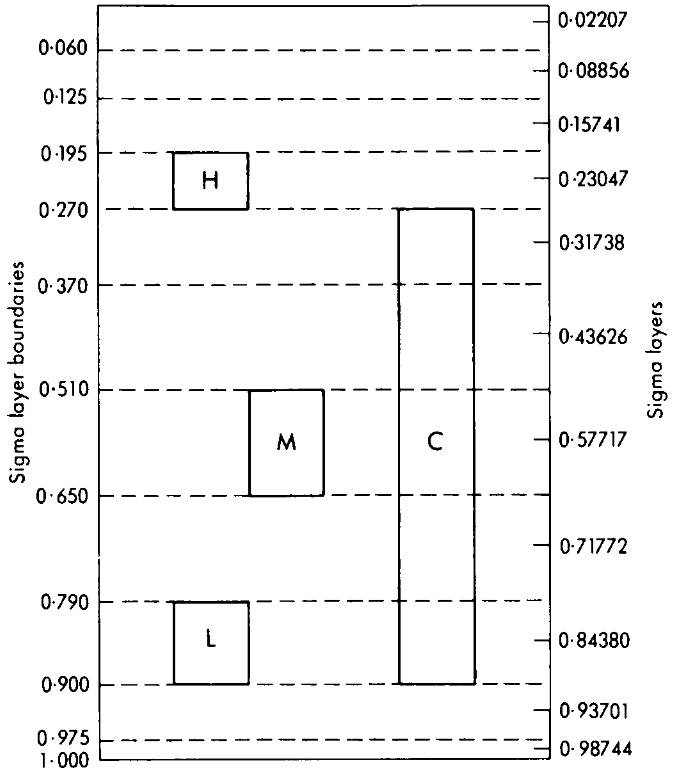

Figure 1. Vertical resolution of the 11-layer model and a possible configuration of the high (H), medium (M) and low (L) layer clouds and a convective tower (C).

general scheme in which the number of model layers within the boundary layer is allowed to vary has also been developed (e.g. Heasman 1983) and has been adapted for the Meteorological Office operational numerical weather prediction model (Gilchrist and White 1982, Dickinson and Temperton 1984). Both schemes have the same treatment of the surface with interactive soil moisture and snow depth, similar to that used in the 5-layer model (J. M. Slingo 1982). Evaporation is limited for soil moisture less than 5 cm of water and runoff occurs to prevent the soil moisture from exceeding 15 cm. The convection scheme treats both unsaturated and saturated convection as it penetrates the vertical grid of the model (Lyne and Rowntree 1976) and this has also been incorporated into the operational model. Large-scale precipitation, in the form of rain or snow, is formed whenever the relative humidity exceeds 100%.

2.2 *Treatment of radiation and clouds*

The logical structure of the radiation scheme (Walker 1977) is determined by the cloud configuration (Fig. 1). It is assumed that layer cloud may exist at any one of three levels (high, medium and low) and that convective cloud may also be present. The layer cloud is assumed to be one sigma layer in thickness, but the convective cloud may occupy more than one sigma layer. The clouds overlap randomly in the vertical, except that where layer and convective clouds are present at the same level then the overlap of the layer clouds occurs only in the clear air, after allowance has been made for the convective cloud.

In the short-wave spectral region the absorption by the minor constituents and the absorption and reflection by clouds and the surface are treated in a single spectral band. The absorptivity curves for water vapour, carbon dioxide and ozone were taken from Manabe and Möller (1961). Pressure scaling is applied only to the water vapour absorber amounts. In reality the absorptions take place in different spectral regions so that the total absorption in such a scheme is simply the sum of that from each gas. As it traverses the atmosphere the incident solar radiation splits into a maximum of five components (direct beam and diffuse beam from each cloud layer). The absorption by the minor constituents is applied to each component and also to the diffusely reflected beams, which for simplicity are assumed to pass out to space without interacting further with the other cloud layers. However, a simple treatment of the enhanced surface absorption due to multiple reflections between cloud and ground is included. For the diffuse beams the gaseous path lengths are multiplied by the usual diffusivity factor, whose value is taken to be 1.67 (Paltridge and Platt 1976). Rayleigh scattering from the air molecules is parametrized very simply by reducing the incident solar radiation by 3%. It is important to note that as a consequence this contributes about 10% to the globally averaged flux reflected back to space by the model. The cloud optical properties are prescribed for each cloud type with the values given in Table I and no account is

Table I. *Cloud short-wave properties assumed in the radiation scheme*

	Cloud type			
	High	Medium	Low	Convective
Reflectivity	0.2	0.6	0.7	0.7
Transmissivity	0.75	0.3	0.2	0.2
Absorptivity	0.05	0.1	0.1	0.1

taken of the dependence of these properties on the solar zenith angle or cloud thickness. The surface albedos are 0.06 (sea), 0.2 (land), 0.5 (snow-covered land) and 0.8 (sea-ice and land-ice; e.g. Antarctica and Greenland). A more realistic geographical distribution of the snow-free land surface albedo for the model has recently been incorporated as part of a joint project with Liverpool University.

In the long-wave region, seven spectral divisions are used to represent the complex wavelength dependence of atmospheric absorption and emission. These divisions are grouped into five distinct intervals as shown in Table II. The first interval treats both the 6.3 μm vibration/rotation band and the

Table II. *Division of the long-wave spectrum*

	Spectral interval						
	1	2	3	5	4	5	1
Wavenumber limits (cm^{-1})	0–500	500–700	700–800	800–900	900–1100	1100–1200	1200–2850
Wavelength limits (μm)	∞–20	20–14.3	14.3–12.5	12.5–11.1	11.1–9.1	9.1–8.3	8.3–3.5
Water vapour	✓	✓	✓	✓	✓	✓	✓
Carbon dioxide		✓	✓				
Water vapour continuum			✓	✓	✓	✓	
Ozone					✓		

far infra-red rotation band of water vapour. The second and third intervals deal with the overlap between water vapour and the well-known 15 μm band of carbon dioxide. The final two intervals cover the contributions in the atmospheric window from weak water vapour bands, the 9.6 μm band of ozone (which is important in the stratosphere) and the water vapour continuum. The continuum is so called because the absorption coefficient varies only slowly with wavelength, as opposed to the rapid fluctuations for band absorption (Bignell 1970). A component of the continuum absorption has been found to be dependent on the partial pressure of water vapour, which in moist profiles leads to a significant increase in the atmospheric radiative cooling near the surface. The mathematical method used to calculate the long-wave fluxes in the scheme is known as the emissivity approximation (e.g. Liou 1980). Emissivities and transmissivities for each gas in each interval at a temperature of 263 K are stored in the program as look-up tables and were calculated by applying the random-band model of Hunt and Mattingly (1976) to the spectroscopic data of McClatchey *et al.* (1973). The gaseous absorber amounts are scaled to take account of the pressure dependence of the absorption, but the temperature dependence is ignored. Clouds and the surface are assumed to absorb and emit as if they were black bodies, but the amounts of high cloud used in the long-wave calculations are halved as a simple representation of the lower emissivities which have been observed for cirrus. More recently, the long-wave part of the scheme has been revised following detailed comparisons with other schemes (Slingo and Wilderspin 1984).

2.3 *The first annual-cycle integration*

The first integration of the 11-layer model through a complete annual cycle was carried out on the Cray-1 computer at the European Centre for Medium Range Weather Forecasts, using some of the time allocated to the United Kingdom as a member state (Cunnington 1983). The integration was run for just over 500 model days, starting from an analysis for 25 July 1979 produced by the assimilation version of the model during the First GARP Global Experiment (Lyne *et al.* 1982). The sea surface temperatures, sea-ice limits and cloud amounts were prescribed and updated in the same way as for the annual-cycle integrations of the 5-layer model (J. M. Slingo 1982). The zonally averaged cloud amounts were taken from surface-based climatologies as described by Bolton (1981). Ozone concentrations were also prescribed and updated monthly. Apart from other applications, such an integration is useful in assessing runs with the cloud-prediction scheme, because with prescribed climatological cloud amounts one has a right to expect that the model should produce a realistic radiation budget, at least in the zonal mean. One can therefore hope to separate errors due to the radiation scheme and the rest of the model from those due solely to the prediction of unrealistic cloud amounts. The results presented in this article were taken from the last year of this integration.

3. Satellite data

The use of satellite measurements for studying the earth's radiation budget and the data currently available have been discussed, for example, by Stephens *et al.* (1981), J. M. Slingo (1982) and Ohring and Gruber (1983). Further information on the satellites themselves has been given by the Satellite Meteorology Branch (1982). Two independent compilations are used here:

(i) Data from the series of operational meteorological satellites launched by the US National Oceanic and Atmospheric Administration (NOAA) are described by Gruber and Winston (1978). A 45-month climatology from 1974 to 1978 has been compiled by Winston *et al.* (1979). These data have good spatial resolution (2.5° latitude), but in both the short-wave and long-wave spectral regions they are derived from measurements in narrow spectral intervals (approximately 0.5–0.7 μm and 10.5–12.5 μm respectively) and regression techniques are used to produce the broad-band fluxes. This introduces uncertainties which are especially serious in the short-wave region, as it is known that the radiative properties of clouds, land surfaces, snow and ice are all strong, and different, functions of wavelength.

(ii) Data from various research satellites, such as Nimbus 6, were collected by Stephens *et al.* (1981) and presented in diagrammatic and tabular form. The measurements are of low spatial resolution but they are for broad spectral bands.

Both these compilations are from measurements by polar-orbiting satellites and it is important to appreciate the limitations of such data. The height of a polar-orbiting satellite (roughly 1000 km) and the inclination of its orbit to the earth's equator (about 99°) are normally chosen so that the orbit precesses around the earth's axis once per year. As a result, the satellite is 'sun-synchronous' and each equator crossing takes place at the same local (solar) time. Each point near the equator is thus sampled only twice per day, typically once in daylight and once at night (giving one short-wave and two long-wave measurements), whereas at higher latitudes the increasing overlap of the areas covered by each overpass leads to more frequent sampling. Sun-synchronous satellites therefore give only limited information on the diurnal variation of the radiation budget or of cloudiness, which is especially pronounced in the tropics.

It is interesting to note that the first satellite to be designed primarily for radiation budget measurements (launched by the National Aeronautics and Space Administration, USA in October 1984 and called ERBS — Earth Radiation Budget Satellite) is in an asynchronous orbit to provide data at different solar times. The advanced sensors used by ERBS are also mounted on two NOAA operational satellites (NOAA F, launched in December 1984 and NOAA G, to be launched in August 1985) so that comprehensive measurements will be available throughout the duration of the Earth Radiation Budget Experiment (Barkstrom 1984).

4. Results

The components of the earth's radiation budget as modelled and observed are presented here as global and zonal averages through the annual cycle. The geographical distributions from the model will not be shown, as the use of zonally averaged clouds means that these are not directly comparable with the observed distributions. The global averages are also compared with those from a 3-year integration of the 5-layer model, which was studied by J. M. Slingo (1982) and used as a control for experiments with increased carbon dioxide concentrations and sea surface temperatures (Mitchell 1983). The results shown here are from the mean of two years of that run, the differences from the single year studied by Slingo being minimal.

4.1 *Global averages*

The annual means of the global averages from the model integrations and the satellite data sets are given in Table III. Various values for the solar constant have been assumed, that used by Stephens *et al.*

Table III. *Global annual averages of earth radiation budget quantities in model integrations and satellite data sets*

Source	Solar constant ($W m^{-2}$)	Planetary albedo (per cent)	Absorbed short-wave ($W m^{-2}$)	Outgoing long-wave ($W m^{-2}$)	Net radiation ($W m^{-2}$)
11-layer model	1395	32.2	236.3	239.1	-2.8
5-layer model	1395	33.2	233.0	239.2	-6.2
NOAA satellites	1353	31.4	232.0	244.9	-12.9
Research satellites	1376	30.0	240.8	231.9	8.9

(1981) being closest to the value of 1373 $W m^{-2}$ suggested by Neckel and Labs (1981). The annual mean incoming short-wave radiation per unit area at the top of the atmosphere may be found by simply multiplying the value of the solar constant by one quarter. Note that the modelled planetary albedos are slightly higher than the observed values. The 5-layer model albedo is higher than that for the 11-layer model, mainly because of the neglect of the additional absorption by the minor constituents of the short-wave radiation reflected back to space by clouds and the surface. The modelled values of the absorbed short-wave and outgoing long-wave radiation are similar to those observed, although the disparity between the satellite data sets is quite marked. This disparity is also evident in the values of net radiation, which is the difference between the absorbed short-wave and the outgoing long-wave radiation, and illustrates one of the difficulties in comparing the modelled and observed radiation budgets. In the model integrations the external forcing repeats exactly every year, so that variations in the inter-annual heat storage are negligible. This does not necessarily imply that the annual mean net radiation will be zero, because in integrations with fixed sea surface temperatures the oceans effectively provide an infinite store of heat which can balance any radiative deficit. It is clearly desirable that the modelled annual mean net radiation should be as close to zero as possible, although the magnitude of the deficits shown here is not serious. In the real world the net radiation may well be non-zero, but the large and contradictory values from the satellite data merely reflect the difficulty in estimating the small difference between two large fluxes, which are measured independently with absolute errors as high as 10 W m^{-2} (Stephens *et al.* 1981). This is too large to enable the absolute values of the globally averaged fluxes from the model to be checked rigorously. However, the zonally averaged fluxes show a much larger range with latitude and time of year than 10 W m^{-2}. The satellite data, therefore, do allow a reasonably accurate assessment of whether the pole to equator gradient in radiative heating is being modelled correctly, as will be seen later.

The factors which control the variation of the global means through the year (Fig. 2) have been

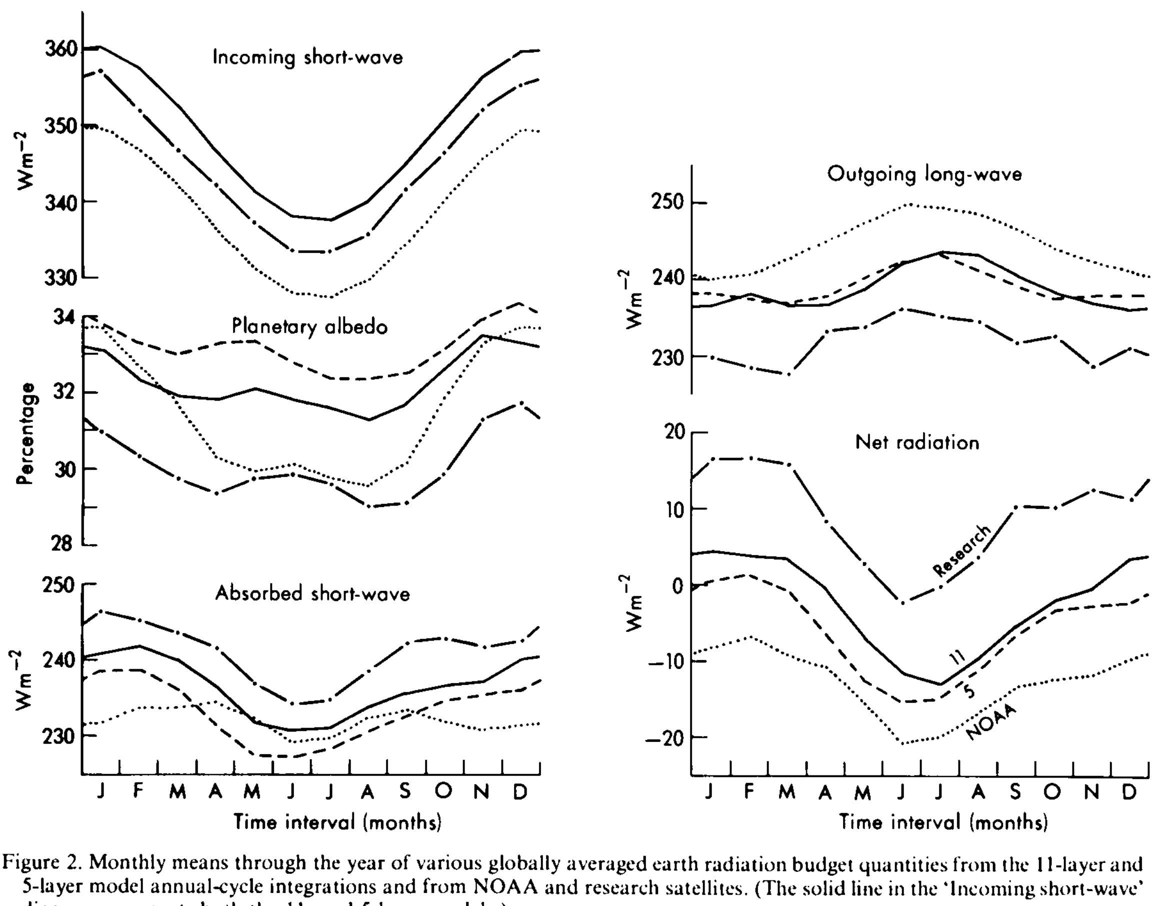

Figure 2. Monthly means through the year of various globally averaged earth radiation budget quantities from the 11-layer and 5-layer model annual-cycle integrations and from NOAA and research satellites. (The solid line in the 'Incoming short-wave' diagram represents both the 11- and 5-layer models.)

discussed by J. M. Slingo (1982) and are worth summarizing briefly. The earth's elliptical orbit produces a roughly sinusoidal variation in the incoming short-wave radiation with an amplitude of about 7%, the flux being greatest in January when the earth is closest to the sun. The planetary albedo shows a maximum at this time of year owing to the illumination of Antarctica and a weaker maximum in northern spring from the illumination of the northern hemisphere sea-ice and continental snow cover. In all but the NOAA data set the variations in the planetary albedo only partly offset those in the incoming short-wave, so that the forcing from the latter is clearly visible in the absorbed short-wave radiation. The seasonal variation in surface temperature is much greater in the northern than in the southern hemisphere due to the larger land area, so the globally averaged outgoing long-wave radiation is a maximum in northern summer, despite the fact that the incoming radiation is a minimum at this time. The outgoing long-wave is in anti-phase with the absorbed short-wave, so the net radiation shows a strong seasonal variation with a maximum in northern winter. In general the modelled changes agree well with the satellite data, apart from the systematic differences discussed earlier. However, the amplitude of the planetary albedo variations is less than in the satellite data, due to a much weaker maximum in the southern summer, which will be discussed later.

4.2 *Zonal averages*

4.2.1 *Incoming short-wave radiation*. The zonal averages are shown in the form of time–latitude diagrams of the monthly meaned data. These are a convenient way of demonstrating the response of the model to the seasonal changes in the applied forcing. On such a diagram the mean incoming short-wave radiation (Fig. 3(a)) has a characteristic pattern which follows the changing declination of the sun, shown as the dotted line. The shape of the pattern is strongly influenced by the changes in the length of day, especially at high latitudes. For example, at the solstice the permanent daylight over the summer pole leads to a larger mean value than over the tropics. The magnitude of the peak over the South Pole in December is slightly larger than that over the North Pole in June because the earth is closer to the sun. Averaged over the year, however, the two hemispheres should receive identical solar radiation totals. This is not the case in the model integrations, in which various simplifying assumptions were made (J. M. Slingo 1982). As a result, the southern hemisphere received 1.3% more radiation than the northern hemisphere through the year, although this does not affect the results shown here significantly. For a more complete discussion see A. Slingo (1982).

4.2.2 *Albedo*. The two main factors which determine the global albedo (Fig. 3(b)) are the cloud cover and the state of the surface. The albedo is a minimum in the subtropics where the cloud amounts are smallest and there is a weak maximum near the equator from the cloud associated with the Inter-Tropical Convergence Zone (ITCZ). In the southern hemisphere the albedo increases towards about 60°S owing to the extensive cloudiness in the circumpolar depression belt. A marked jump is apparent at 60°S as the edge of the Antarctic sea-ice is reached, the variations at this latitude through the year being due to changes in the imposed sea-ice distribution, which reaches its maximum extent in the southern spring. Further south the albedo is high throughout the year because of the permanent snow and ice cover of Antarctica. In the northern hemisphere the effects of the cloud in the depression tracks and of the imposed sea-ice distribution are also important, but there is an additional contribution from the changes in the continental snow cover, which is not imposed but is predicted by the model. This is largely responsible for the significant seasonal variation in the global albedo between about 30°N and 70°N.

The behaviour of the modelled albedo is in broad agreement with that in the two satellite data sets. However, it is instructive to make the comparison more rigorous by calculating the differences between the modelled and observed albedos, which can be plotted in time–latitude form. This emphasizes the

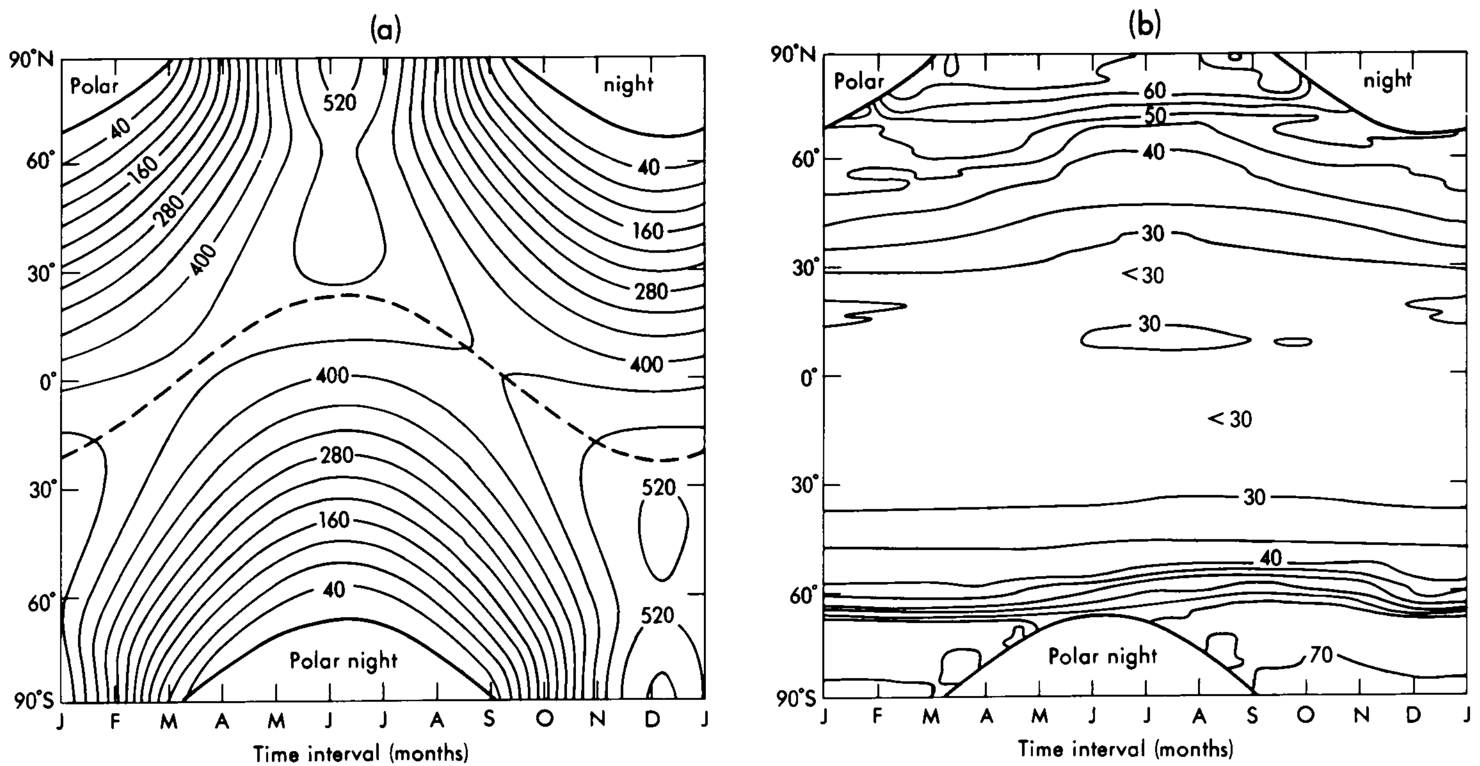

Figure 3. Time-latitude diagrams of the zonal averages of the monthly meaned (a) incoming short-wave radiation (W m^{-2}) and (b) global albedo (per cent) from the 11-layer model.

areas of disagreement between the model and the satellite data sets and also between the satellite data sets themselves. The results are shown in Fig. 4, where the clear areas indicate that the modelled albedo is higher than that from the satellites, the reverse being true in the shaded areas. Over most of these figures there is good agreement between the satellites, so that the errors in the modelled albedos are well defined. An obvious exception is the ITCZ. In the model this feature is artificially broadened because the cloud climatology is specified at 10° latitude intervals. However, the good spatial resolution of the NOAA satellites leads to a realistic representation of the narrowness of the albedo maximum, so that in Fig. 4(a) there is a thin shaded band near the equator where the modelled albedo is too low. There is some suggestion of this feature in Fig. 4(b) but it is much weaker than in the comparison with the NOAA data. Over the rest of the tropics and in the northern hemisphere in summer the albedo from the model is clearly too high, in some places by over 5%, representing a 20% overestimate of the observed value. The importance of clouds in determining the planetary albedo in these areas suggests that either the cloud albedos or the cloud amounts used in the model are too high. Certainly the albedos for low and convective cloud which are assumed (Table I) are at the upper limits of values which have been observed for such cloud.

In the southern hemisphere between about 35°S and 60°S there is a large underestimate of the global albedo, by up to about 10%. A similar underestimate was also noted in the 5-layer model integration (J. M. Slingo 1982) and was attributed to the neglect of the increase of ocean albedo with solar zenith angle. However, the magnitude of the error shown in Fig. 4 and the fact that it occurs over the southern hemisphere depression belt strongly suggests that it is caused by problems with the treatment of clouds. In the southern hemisphere the cloud climatology was taken from Sasamori *et al.* (1972), who took the total cloud cover data compiled by van Loon (1972) and with various assumptions derived a breakdown into the component cloud amounts. However, the combination of these amounts and the assumption in the model of random overlap leads to a significant underestimate of the total cloud cover compared with van Loon's original data. In more recent integrations the component amounts have therefore all been increased so that van Loon's total cloud cover amounts are reproduced. These amounts are also in good agreement with the climatology of Berlyand *et al.* (1980). The use of the revised cloud climatology leads to a marked improvement in the modelled planetary albedo in this region. It also increases the amplitude of the annual variation of the globally averaged planetary albedo to a value much closer to that observed (Fig. 2). This suggests that the marked maximum in the observed globally averaged albedo in the southern summer is caused by the illumination not only of Antarctica but also of the clouds in the circumpolar depression belt, the amounts of which are more realistic in these later integrations.

At the southern edge of the depression belt the modelled albedo is too high, most noticeably from August to November but also to a lesser degree through to March. This suggests that either the sea-ice limits are too far north or the surface albedo for sea-ice is too high. Comparison of the sea-ice distribution with the data of Lemke *et al.* (1980) showed that the sea-ice was much too extensive, owing to a logical error in creating the pentad sea surface temperature data sets. This has been corrected in more recent versions of the model. The surface albedo used (0.8) may also be too high, especially in marginal ice regions where the effect of reduced areal coverage of ice and the presence of melt-water pools would lead to a much lower areal average albedo in reality.

Over Antarctica there are significant differences between the albedos from the two satellite data sets, the NOAA satellites giving much higher values (80–90% as opposed to 70–80%). At about 70% the model values appear to be too low. Over the northern high latitudes the patterns in the difference plots are similar, but the feature at 70°N in April/May is much more marked in the comparison with the NOAA data. Both data sets suggest that over the North Pole in June the modelled albedo at 65% is about 10% too low. This is not due to the state of the surface, as the Arctic is assumed to be covered in sea-ice throughout the year. It has been found that the cloud amounts used over the Arctic at this time of year

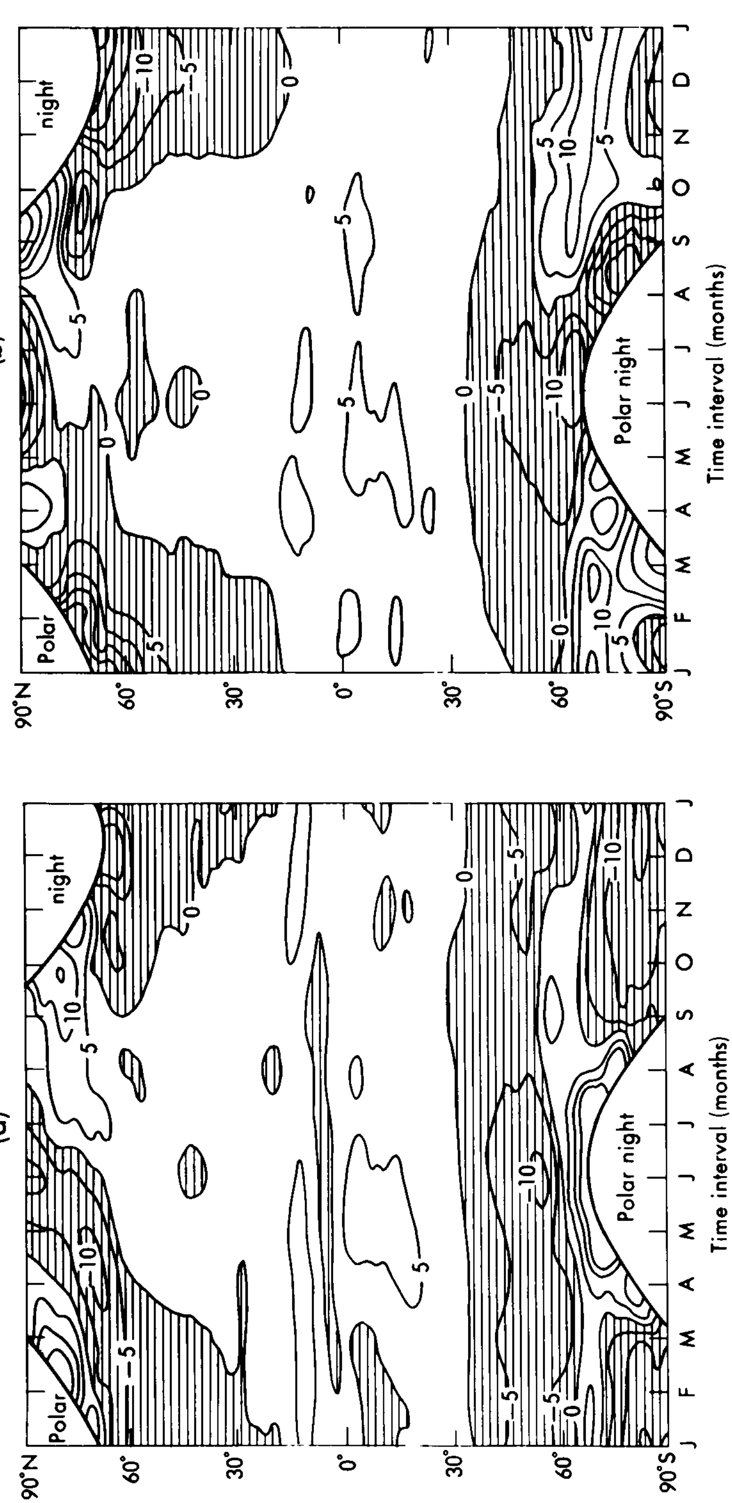

Figure 4. Time-latitude diagrams of the differences (per cent) between the global albedo from the model and from (a) the NOAA and (b) the research satellites.

are too low. Low-cloud amounts were 41%, whereas Huschke (1969) gives values of about 70% for the central Arctic. However, increasing the low-cloud amounts produces virtually no change in the planetary albedo, because of enhanced absorption from the increased multiple reflections between cloud and surface. Reducing the low-cloud absorptivity, which at 10% is probably too high to represent Arctic stratus, would remove the insensitivity to the cloud amounts. Detailed aircraft measurements of the radiative properties of cloud layers in the Arctic (e.g. Herman and Curry 1984) are thus most useful in helping to resolve these uncertainties.

Disagreements between the observed and modelled planetary albedos cannot be due entirely to errors in the model. An overestimate by the NOAA satellites of the planetary albedo at high latitudes has been known about for some time (e.g. Ohring and Gruber 1983). It is often attributed to the fact that the NOAA sensors work in the 0.5–0.7 μm band where the albedos of snow and ice are much higher than at longer wavelengths (Shine *et al.* 1984). Nevertheless, there are also large disagreements between data sets from broad-band measurements. For example, Jacobowitz *et al.* (1979) show results from the first 18 months of the Nimbus 6 Earth Radiation Budget Experiment. Albedos over Antarctica were in the range 70–75% and over the Arctic were 65–70%, which is closer to the model values than the satellite data used here. Stephens *et al.* (1981) include the same Nimbus 6 data, but as processed by Campbell and Vonder Haar (1980). In this data set the planetary albedo exceeds 80% over both poles. It is clearly difficult to make definitive statements about the modelled albedos at high latitudes when there are such wide variations in the measurements.

4.2.3 *Reflected and absorbed short-wave radiation*. The importance of the polar regions in influencing the globally averaged planetary albedo is emphasized by Fig. 5(a), which shows the reflected short-wave energy from the model. At the solstices there are large peaks over the summer pole due to the constant illumination of the ice and snow. In northern winter the maximum in the globally averaged albedo (Fig. 2) is clearly not due to the northern hemisphere cloud and snow cover, as suggested by Ohring and Gruber (1983) but to the illumination of Antarctica (J. M. Slingo 1982) and its surrounding sea-ice and cloudiness. The entire northern hemisphere contributes only about one quarter of the total reflected short-wave radiation in December, despite the underestimate of the southern hemisphere cloud amounts discussed earlier.

The high albedo of the polar regions in summer significantly reduces the amount of absorbed short-wave energy compared with lower latitudes. The positions of the maxima in the time–latitude diagram of absorbed short-wave radiation (Fig. 5(b)) are thus much closer to the equator than for the incoming radiation, the pattern showing strong symmetry about the latitude corresponding to the sun's declination. Comparison with Fig. 3(b) shows that the seasonal changes in the planetary albedo produce relatively minor variations in the shape of the diagram. Time–latitude diagrams of the differences between the modelled and observed reflected and absorbed short-wave radiation are not shown as these are of the same basic shape as Fig. 4.

4.2.4 *Outgoing long-wave radiation*. The model successfully reproduces the main features of the variations in the outgoing long-wave radiation (Fig. 6(a)). The high cloudiness of the ITCZ leads to a weak minimum in outgoing long-wave radiation over the equator and there are maxima in the subtropics associated with relatively clear skies. The strong latitudinal gradient in tropospheric and surface temperatures leads to a corresponding drop in the long-wave flux towards the polar regions, the lowest values of about 100 W m^{-2} being found over the central Antarctic plateau in the southern winter. Apart from over Antarctica itself, the seasonal variation in outgoing long-wave radiation is small in the southern hemisphere owing to the moderating influence on temperatures of the extensive oceans. In

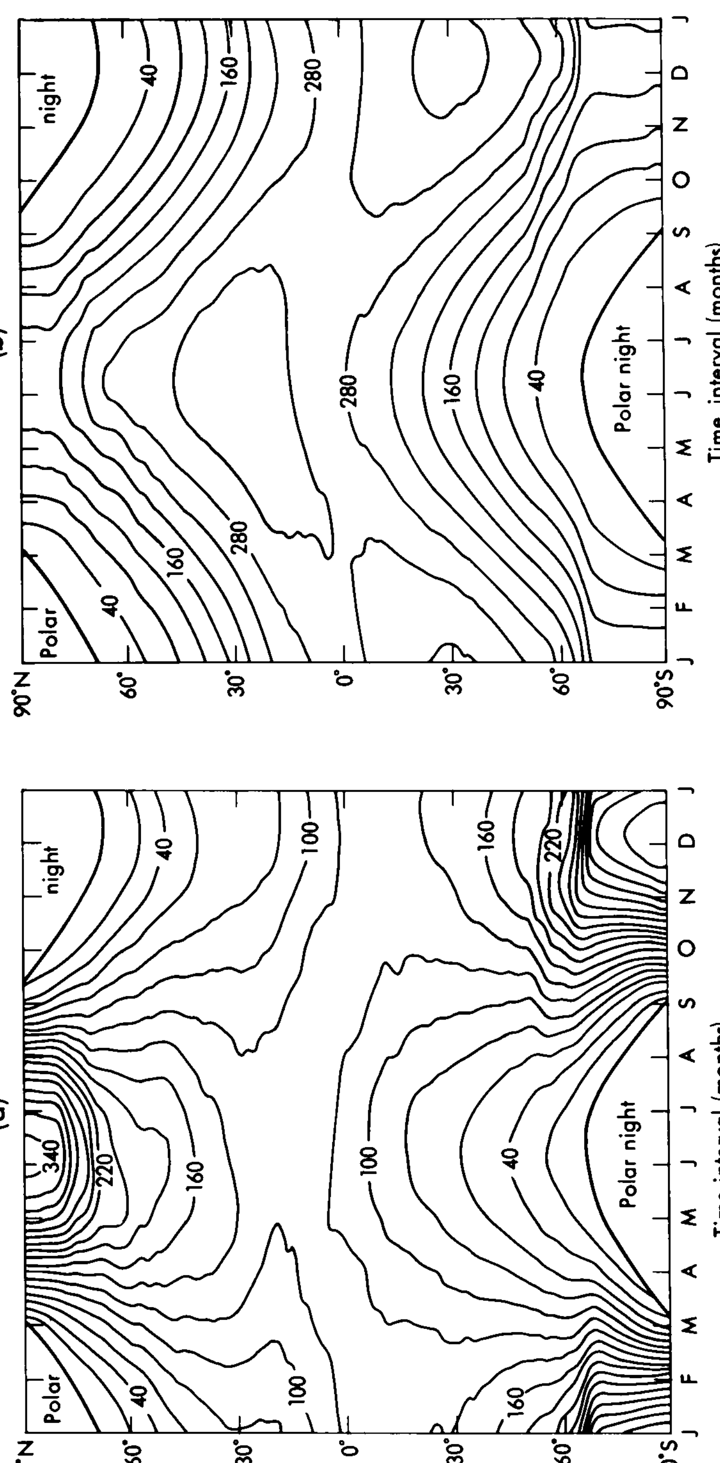

Figure 5. Time-latitude diagrams of the (a) reflected short-wave radiation (W m^{-2}) and (b) absorbed short-wave radiation (W m^{-2}) from the model.

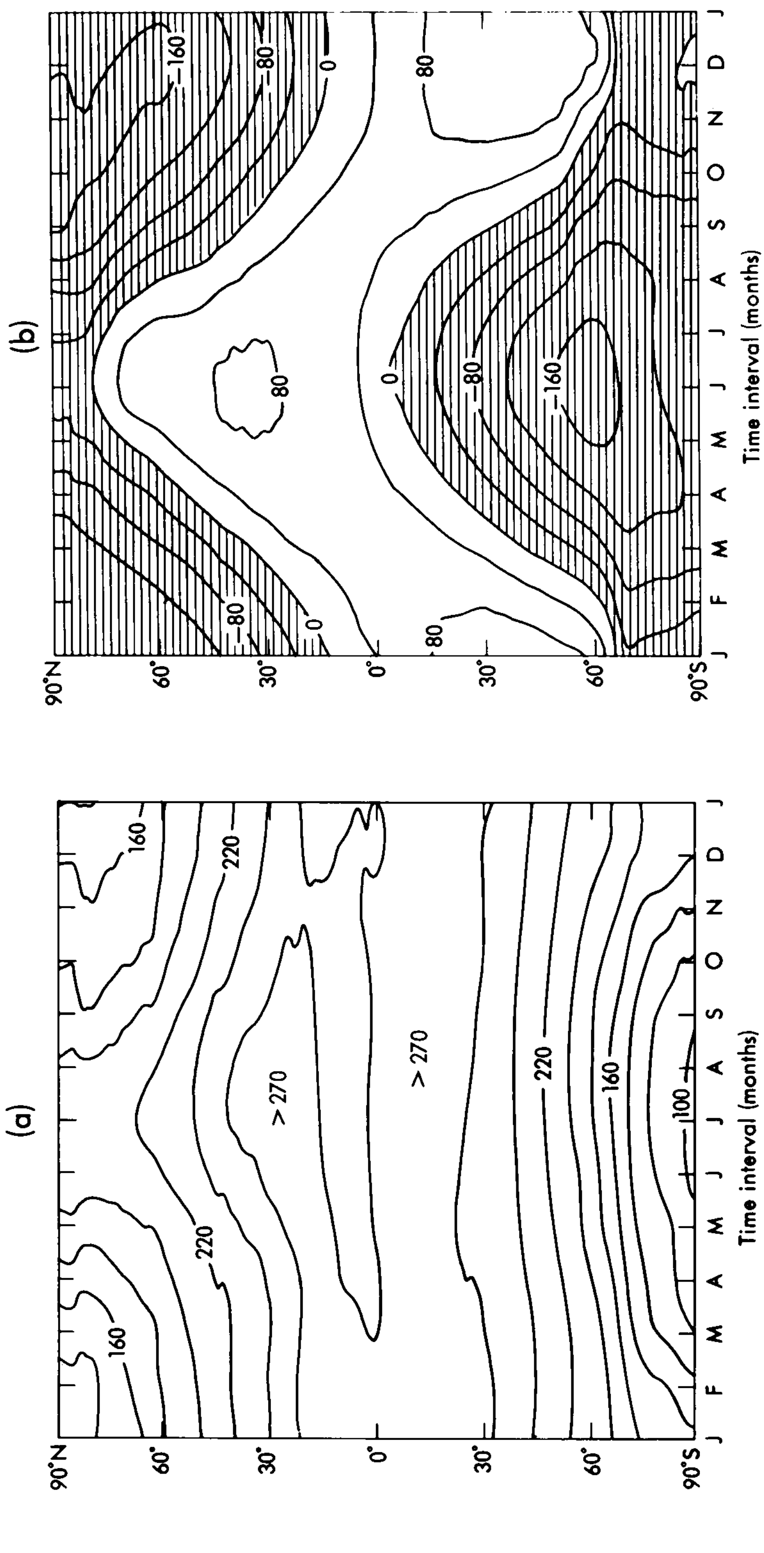

Figure 6. Time–latitude diagrams of the (a) outgoing long-wave radiation (W m^{-2}) and (b) net radiation (W m^{-2}) from the model.

contrast, the land masses of the northern hemisphere produce a much stronger variation between about 30°N and 70°N. Over the Arctic the seasonal variation is similar to that over Antarctica, although values are generally about 40 W m^{-2} higher.

Comparison with the satellite values (Fig. 7) shows that the minimum in outgoing long-wave radiation over the ITCZ is too weak in the model. This could be due to the artificial broadening of the ITCZ by the cloud climatology, as mentioned earlier. It may also be that the very simple treatment of the reduced emissivity of high cloud compared with lower (and hence optically thicker) cloud, namely the halving of the amounts in the long-wave part of the radiation scheme, is too crude. This is an area of the model where a sounder physical basis for the parametrization is under consideration. Over the rest of the tropics and the high latitudes there are substantial areas of disagreement between the satellite data sets over the sign of any model error, reflecting the large differences in the global averages shown in Fig. 2. NOAA have recently revised their algorithms for deriving the outgoing long-wave radiation, leading to a better agreement with other data (Gruber and Krueger 1984). Nevertheless, the general impression is that the modelled values are too low towards the polar regions. This is probably due to the tendency for the model to be too cold in these areas compared with climatological data (Cunnington 1983). Northward of about 70°N, for example, tropospheric temperatures are 5–10 °C lower than in the data of Newell *et al.* (1972). The reason for the cooling has not yet been isolated and is the subject of current research.

4.2.5 *Net radiation*. The balance between the heating of the system by the absorption of short-wave radiation and the cooling from the emission of long-wave radiation to space is shown in the time–latitude diagram of net radiation (Fig. 6(b)). Areas of positive net radiation, indicating a net warming by radiative processes, are shown unshaded. Over most of the globe the seasonal changes in outgoing long-wave radiation are much smaller than those in the short-wave absorption, so the latter dominates the shape of the net radiation diagram and the latitude of the maximum follows the sun's declination. It is interesting that the large seasonal variation in southern mid-latitudes is almost entirely due to the changes in the illumination (i.e. Fig. 3(a)), as the changes in the albedo (Fig. 3(b)) and the outgoing long-wave radiation (Fig. 6(a)) are much weaker. In the polar regions the signal from the outgoing long-wave radiation is more important and of course during polar night is the only term in the net radiation.

In calculating the differences between the modelled and observed net radiation (Fig. 8) two corrections were made to remove the systematic biases between the data sets which are evident in Fig. 2. The satellite values of absorbed short-wave radiation were first corrected for the different values assumed for the solar constant. The differences between the modelled and observed net radiation were then adjusted by a single value at each point to ensure that the global annual mean was zero. Following these corrections, the two comparisons are in good agreement in most areas. Both satellite data sets indicate that the latitudinal gradient of system radiative heating is too weak in the model integration. In the tropics, the net radiation is about 20 W m^{-2} too low. This is a result of the overestimates of both the planetary albedo and the outgoing long-wave radiation, due to the assumed cloud radiative properties and the cloud climatology, as discussed earlier. In the polar regions the net radiation is generally too high and the apparent albedo underestimate in certain regions leads to large differences, e.g. about 100 W m^{-2} compared with the NOAA data over the South Pole in December.

5. Discussion

The comparisons presented in this article demonstrate the importance of satellite earth radiation budget measurements in validating the radiation and cloud schemes employed in climate models. The

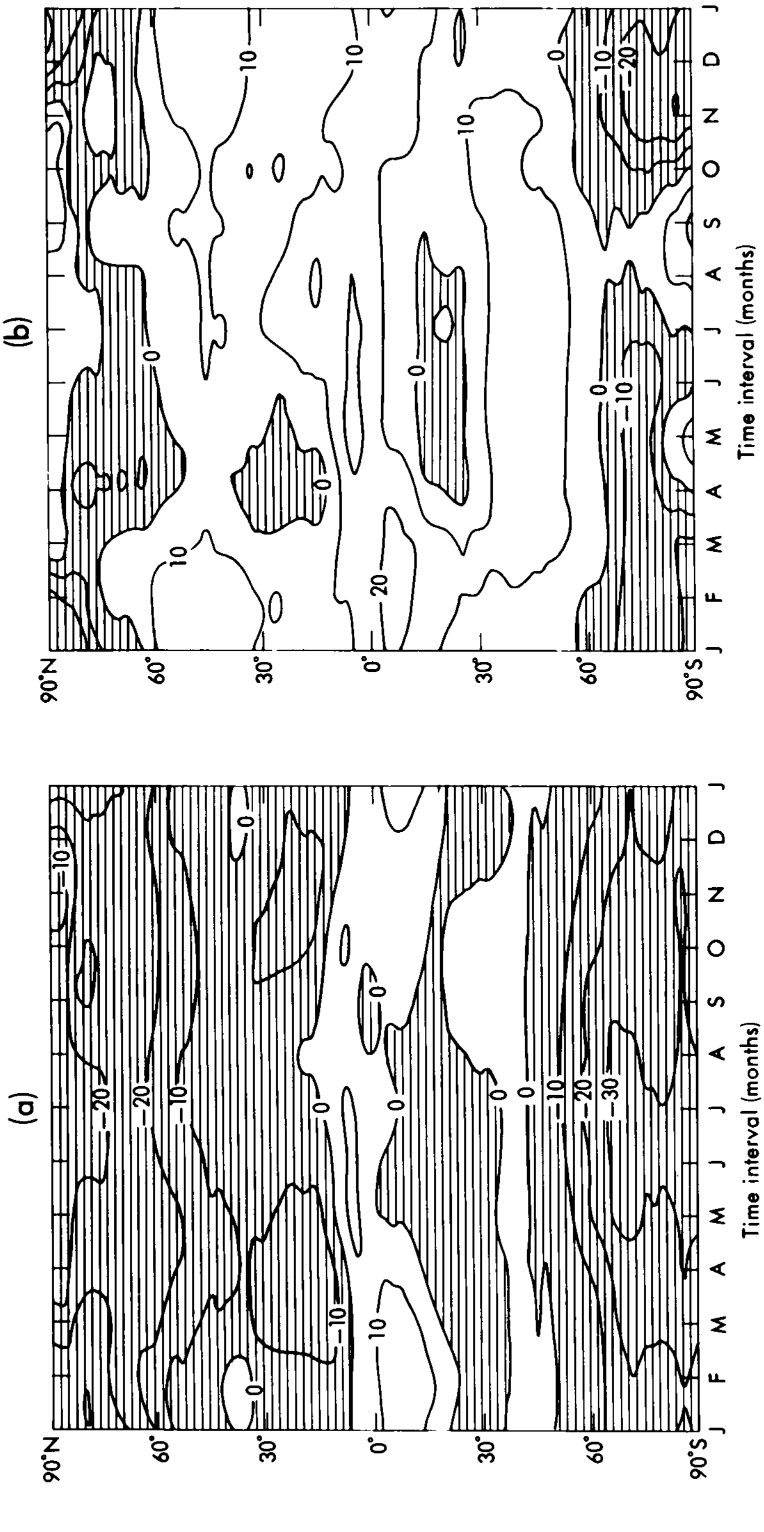

Figure 7. Time–latitude diagrams of the differences (W m^{-2}) between the outgoing long-wave radiation from the model and from (a) the NOAA and (b) the research satellites.

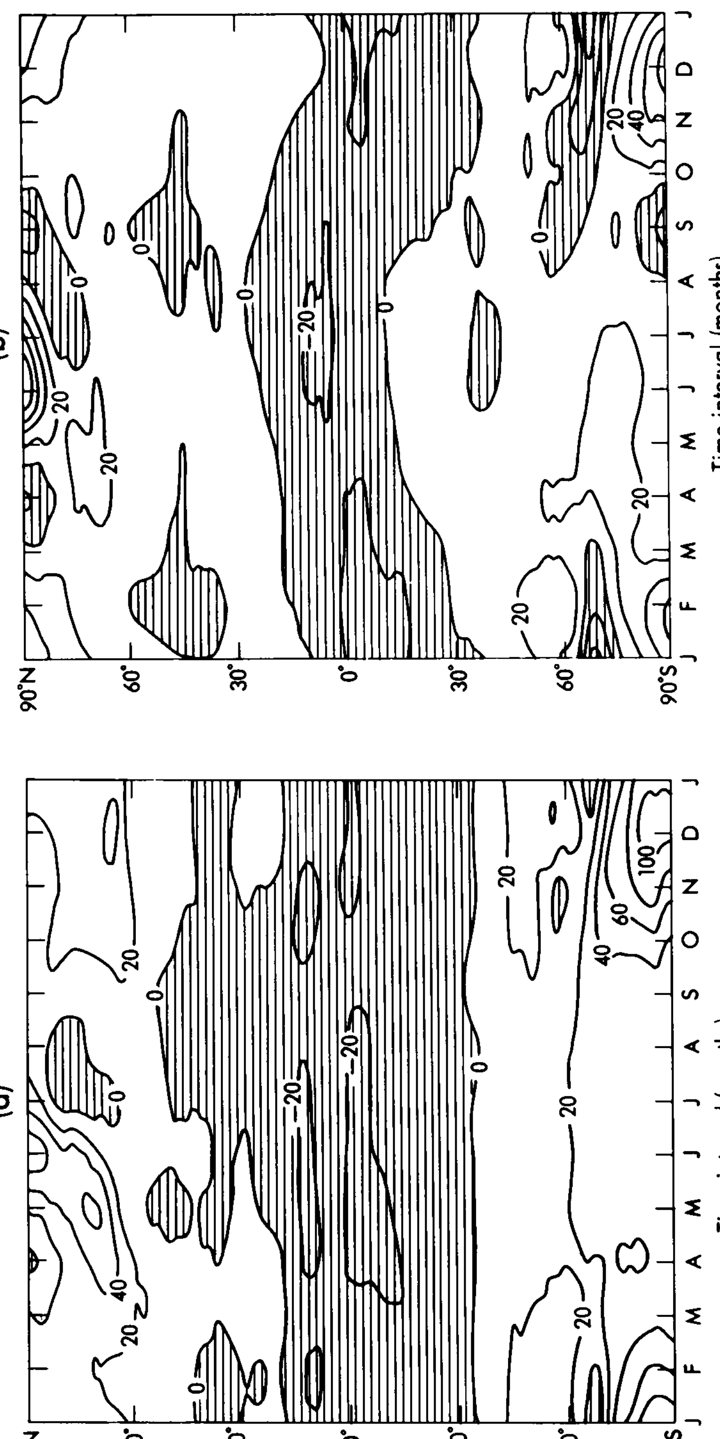

Figure 8. Time–latitude diagrams of the differences (W m^{-2}) between the net radiation from the model and from (a) the NOAA and (b) the research satellites. The differences have been corrected to remove biases from the data sets, as described in the text.

main features of the seasonal variations in the radiation budget have been reproduced in the first annual-cycle integration of the 11-layer GCM. The use of two independent satellite data sets has allowed the model's deficiencies to be determined with some confidence. However, it has also emphasized the significant disagreements between those data sets. Some of the model's deficiencies may be attributed simply to errors in its formulation, such as the excessive areas of sea-ice around Antarctica, which stand out in the albedo comparisons. Several others have been shown to be due to the cloud climatology and cloud radiative properties which were assumed. Relatively small adjustments to either of these would remove many of the more obvious errors and for some applications such 'tuning' would be perfectly acceptable. However, the use of fixed zonally averaged cloud amounts deprives the model of the ability to represent some important feedback mechanisms which should operate when a perturbation is applied.

The development of a method for predicting realistic cloud distributions in long integrations of the model therefore has a high priority in current research. Several experiments have been made with versions of the cloud prediction scheme proposed by Slingo (1980). Forecast experiments with this scheme show that it can represent quite well the major synoptic features in the global cloud distribution; but in longer integrations the cloud amounts become unrealistic because of interactions with model systematic errors (Slingo 1983). Useful progress has been made in understanding and rectifying some of these errors. Satellite observations of the earth's radiation budget will continue to play an important part in model development, but the model itself should provide an ideal tool for studying interesting features in the observations, such as inter-annual variations caused by anomalies in the cloud cover or surface state. This symbiotic relationship between climate models and satellite data should provide much stimulating research in the next few years.

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Notes and news

100 years ago

The Minutes of the Proceedings of the Meteorological Council used to carry regular monthly reports of the work of the Office which then had between 30 and 40 staff.

That for May 1885, submitted on 3 June 1885, is as follows:

MARINE ROOM.

Examined 19 new logs. June 3, 1885.

North Atlantic Weather Charts.

Making additions to isobars for November and December 1882.

Preparing weather areas and generalized winds for December 1882, and for part of January 1883.

Drawing of air and sea isotherms for May completed.

Making 'tracings' of all data for June also drawing air and sea isotherms.

Testing glass pens for use with eidographs.

Various work in connexion with land isobars, isotherms, and winds.

The female clerks steaming June charts, plotting the observations for July and August, assisting in the copying of land isobars, isotherms and winds, and preparing 'tracings' of data. Three members of the staff practising the working of the eidographs.

General.

Indexing data in ocean 10-degree squares, and obtaining amount and distribution of data in the Office to the end of 1884.

(Signed) CHAS. HARDING.

The Marine Superintendent.

Forwarded for the information of the Council.

(Signed) HENRY TOYNBEE,
Marine Superintendent.

TELEGRAPHIC (FOREST AND STORM WARNING) BRANCH.

Monthly Weather Reports. — 1885, *February.* — Expected from printer daily (complete). 1885, *March.* — In printer's hands. 1885, *April.*—Half done. There has been some little delay with these just lately on account of holidays, and sickness of various clerks.

Checking Daily Forecasts. — Complete up to date.

Checking Storm Warnings, 1884. — Completed.

Weekly Weather Report.

1884, Appendix II. — Sheets 3 and 4 of proof have been received, corrected, and returned for press, and the printer has been requested to deliver remainder of proof at once.

1885. — All numbers have appeared promptly.

Comparing the Records of Mr. Galton's ('trigger') Anemometer, with Estimations of Wind Force on board the Newarp Light Vessel. — Computations all finished. Inquiry is now being made as to method of observing, &c., as the results appear somewhat peculiar.

(Signed) FREDC. GASTER.
3/6/85.

PANTAGRAPH ROOM.

June 1, 1885.

Quarterly Weather Report, Part IV., 1877. — Chart plate XVI. partly drawn.

Observatory Returns. — The Hourly Readings for May 1883 sent to printer. Proof read and revised to end of March, and Part 1. signed for press.

The calculation of vapour tension values, and of daily, five-daily, and monthly means for May completed.

Harmonic Analyser. — A correction for non-periodicity has been applied to the coefficients for the 12 years 1871–1882. The examination of the readings of the machine (Minutes, April 29, 1885) is now in hand. Several plates of curves have been drawn with General Strachey's instrument.

Krakatoa Air Waves. — My own time has been chiefly occupied in discussing, under the Chairman's instructions, the observations relating to these phenomena; Mr. Thompson has also been partly engaged on diagrams for the work.

Miscellaneous. — Bunhill Row sunshine cards for the first three months of the year tabulated for the Royal Meteorological Society.

Some assistance has been given to the Examination Room by myself and others during the month.

R. H. Scott, Esq., F.R.S. (Signed) R. H. CURTIS.

Reported — That the cash accounts for the six months ended the 31st March 1885 had been audited this day by the Chairman and Professor Darwin, and would be sent forthwith to the Treasury for the Audit Office. The receipts for the six months, exclusive of a balance of 1,123*l*. 2*s*. 11*d*. on the 1st October 1884, amounted to 9,199*l*. 12*s*. 6*d*. The payments amounted to 8,579*l*. 10*s*. 7*d*., leaving a balance of 1,743*l*. 4*s*. 10*d*. in hand and at the Bank on 1st April 1885.

[There followed a list of cheques drawn during the month.]

Submitted at the same meeting was a report on the forecasts for May 1885, district by district (11 in all), classified by the letters a to d, where a stood for 'complete success', b 'partial (i.e. more than half) success', c 'partial failure', and d 'total failure'. There was also a summary table as follows:

SUMMARY

3.30 P.M.	Percentages.			Percentage of Success a + b.	8.30 P.M.	Percentages.			Percentage of Success a + b.
	Wind.	Weather.	Average Forecast.			Wind.	Weather.	Average Forecast.	
BRITISH ISLES a	51	69	60	86	BRITISH ISLES a	52	64	58	88
,, ,, b	33	19	26		,, ,, b	33	26	30	
,, ,, c	12	6	9		,, ,, c	12	5	8	
,, ,, d	4	6	5		,, ,, d	3	5	4	

These figures seem to compare very favourably with those for the present day!

Weather information in the Shetland Isles

One of the problems in providing accurate weather forecasts for oil industry operations in and out of the bleak, remote oil terminal at Sullom Voe in the Shetland Isles has been the shortage of accurate and detailed weather observations from the local area. Five years ago the Meteorological Office put an automatic weather station on Muckle Holm, an island in Yell Sound, to provide information from this vital channel for large tankers entering Sullom Voe. Last year the gap in observations from the direction of the prevailing south-westerly winds was filled, thanks not only to the latest in automatic weather stations but also the co-operation of two crofters, Mr and Mrs Holbourn on the island of Foula.

This small, remote but inhabited island 40 miles west of Lerwick and about the same distance south-west of Sullom Voe is a key site for meteorological observations. The nearest land to the west is the southern tip of Greenland, 1500 miles away. An automatic weather station on Foula was installed last June by the Meteorological Office with the co-operation of the Shetland Islands Council. It is battery powered and has a 20-foot lattice mast on which the meteorological instruments and a VHF aerial are mounted. It became fully operational on 1 August and now every hour measurements of wind speed and direction, barometric pressure, relative humidity and air temperature are sent out automatically to Shurton Hill near Lerwick and then by microwave link through Bressay to Sella Ness. If measurements are needed between times the station can be interrogated by telephone by any meteorological office which has the right equipment.

Automatic weather stations like the one on Foula cannot yet provide adequate information about clouds, visibility or other weather phenomena — however, Mr and Mrs Holbourn have agreed to be local meteorological observers. Every 3 hours during the day they send reports to Lerwick Observatory to complete the picture of the weather on Foula; their reports include details of the cloud over the island, its amount, height and type, also visibility, whether it is raining or snowing and so on. Mr and Mrs Holbourn require great dedication to fit weather observing duties into their busy and demanding life on a croft, but they know that their reports are a vital link in the chain that provides essential meteorological information and forecasts.

Reviews

Land surface processes in atmospheric general circulation models, edited by P. S. Eagleson. 180 mm × 250 mm, pp. ix + 560, *illus*. Cambridge University Press, 1982. Price £30.00.

This is a large book with 14 main contributions prepared specially for the World Meteorological Organization/International Council of Scientific Unions Joint Scientific Committee Study Conference held at Greenbelt, Maryland in January 1981. The conference was carefully planned to help bridge a gap in communication between general circulation modellers, wishing to represent the large-scale effects of the micro-scale land surface processes (i.e. 'parametrize' them), and hydrologists and soil scientists with an understanding of these smaller scales. The book's structure reflects these different scales, the first three sections, constituting nearly two-thirds of the book, covering (I) general circulation models, (II) microphysical processes of momentum, heat and water transfers and (III) mesoscale parametrizations of those transfer processes. Most of the rest of the book is entitled 'Land surface global data sets' with a final one-chapter section on remote sensing.

J. Smagorinsky introduces the first section with an instructive and readable discussion of climate models and the need for parametrization of small-scale processes. This is followed by S. Manabe's more detailed description of the structure of atmosphere and coupled (atmosphere–ocean) general circulation models (GCMs) with good illustrations of the simulations they give. D J. Carson provides an admirably comprehensive review of the treatment of land surface processes in 13 different models, with detailed discussions of the theory behind the parametrizations. What should have been the final contribution on the sensitivity of the models to albedo and soil moisture by Y. Mintz was regrettably not available in time.

The section describing microphysical processes contains three chapters on the vertical fluxes of heat and moisture for a bare soil surface (W. H. Brutsaert), a vegetated surface (L. J. Fritschen) and snow and ice (M. Kuhn). Brutsaert provides a thorough exposition of the mathematical treatments of the flow of water in soil and of surface evaporation. Heat transfer is dealt with similarly, with a discussion of methods of determining the soil heat flux. Both this and Kuhn's briefer chapter on snow and ice make a real attempt to provide a practical basis for parametrization. Fritschen's topic is much more complex so he presents a model for its solution together with an extensive collection of estimates of evaporation for various crops etc. which occupy half this long chapter. It is difficult to see that they are very useful except as references to the original papers. It would have been more helpful and appropriate here to introduce important concepts such as stomatal and root resistances; the reader will find a more useful discussion of the topic in R. E. Dickinson (1984). (Modelling evapotranspiration for three-dimensional global climate models. Climate processes and climate sensitivity. *Geophys Monogr*, **29**, 58–72.) In this volume, Perrier's chapter in the 'data sets' section is more informative while Fritschen's evaporation data might have been better placed in that section.

The third section on mesoscale parametrizations focuses on hydrology. J. C. I. Dooge points out that hydrologists have mainly emphasized flood hydrology and ground-water systems, with least progress where climate modellers need help — the accounting and transfer of soil moisture. The heterogeneity at field scale, evident in studies reviewed here, explains much of the pessimism of hydrologists about the GCM parametrization problem. P. S. Eagleson provides a systematic introduction to mesoscale hydrology, reviewing the state of art of parametrization for each of the main terms (evapotranspiration, runoff etc.).

In the fourth section on global data sets, M. J. Gardiner provides a history of soil classification and mapping with some informative (though globally incomplete) maps of soil types. The latest series of maps go part of the way towards providing the data on soil moisture capacity and permeability and albedo needed for climate models. A. Perrier contributes a useful review of vegetation types and the dependence on them of albedo, roughness length and, especially, stomatal resistance including the large seasonal variations of some crops. V. M. Kotliakov and A. N. Krenke briefly review available data on snow and ice. A valuable collection of data on surface solar albedo and long-wave emissivity is provided by K. Ya Kondratyev, V. D. Korzov, V. V. Mukhenberg and L. N. Dyachenko. Zenith angle and spectral and seasonal dependences are well covered with global albedo maps for four months. These maps have some incomplete contours and tropical forests are given an albedo of 0.18, well above the 0.12–0.13 favoured in the text. A. Baumgartner discusses water balance equations at some length, quotes a set of parametrizations for evaporation and run off having little in common with those given by Carson or Eagleson and notes the large discrepancies between two recent calculations of the global water balance with mean precipitations differing by 15%.

Finally, K. Itten contributes a clear statement of the basic principles of remote sensing of albedo, cloud cover and several land surface quantities with an assessment of the current (1981) status.

In summary, this volume contains a wealth of information, much of it of value to anyone concerned with the physics of the land surface. Of the 560 pages, 74 are occupied by reference lists — these are separate for each chapter so there will be overlaps. The book stands between a conference proceedings and a textbook. The topics have been selected in a coherent, well-directed manner as with a textbook, though there are omissions — frozen soil is explicitly omitted by Kuhn — and some subjects are not where one might expect to find them — momentum flux is only covered under GCMs (Carson) and global data sets (Perrier). The book draws on the expertise of several writers, who have on the whole done a sound job and so should achieve more than a textbook with one author. However, there is little apparent attempt at editorial control after the original planning so that there are overlaps (e.g. Bouchet's advection–aridity approach to evaporation is discussed by Dooge, Eagleson and Perrier); there is no index, no common use of symbols, and several typefaces are used. It is perhaps more a reference book than a textbook, but here of course the lack of an index is a significant drawback. Nevertheless, for the modeller who needs to know about land surface processes and parametrizations, it is a unique collection of papers to which he will make frequent reference.

P. R. Rowntree

Dynamics of the middle atmosphere, edited by J. R. Holton and T. Matsuno. 150 mm × 240 mm, pp. viii + 543, *illus*. Terra Scientific Publishing Company (TERRAPUB), Tokyo and D. Reidel Publishing Company, Dordrecht, Boston, Lancaster, 1984. Price Dfl 220, US $ 89.50.

Most dynamical meteorologists are concerned with winds in the troposphere, which contains about 90% of the mass of the atmosphere and extends from the earth's surface to a height of about 10 km. For many years, studies pertaining to higher levels in the earth's atmosphere (stratosphere, mesosphere, ionosphere, etc.) and to the atmospheres of the other planets were often regarded as whimsical and possibly even suspect 'fringe' activities of a few people who might, one day, see the light and join the mainstream of tropospheric dynamics. But many able young scientists who entered meteorology in the past two decades were attracted to the problems concerning the dynamics of the stratosphere and mesosphere, and their impact on the subject is evident in this book, edited by two of their number, as a record of the proceedings of a USA–Japan seminar held in Honolulu in November 1982.

Recent work on the middle atmosphere has been stimulated by questions concerning possible anthropogenic perturbations of the stratospheric ozone layer, posed at a time when techniques of observation, particularly those involving the use of satellite-borne instruments, were being improved, and advances in basic theory, particularly of wave mean flow interactions, were being made. Studies of dynamical phenomena were central to the seminar, with radiation and chemistry entering only in the context of dynamical problems.

The book comprises six main sections, starting with one on gravity waves, the importance of which in upper-atmospheric studies was first appreciated by Hines 25 years ago. This is the largest section in the book and includes contributions by Lindzen, Walterscheid, Schoerberl, Strobel, Horota, Balsley, Eckland, Fritts, Yamanaka, Tanaka, Hayashi and Matsuno. Next comes a short section comprising four articles on tides and free oscillations by Kato, Aso, Vincent, Miyahara, Hirota and Hirooka. Large-scale waves and wave mean flow interactions are treated in the third section, with contributions by Plumb, Takahashi, Miyahara, Gille, Lyjak, Kanzawa and Matsuno. The shortest section is headed 'Radiation' and consists of a single article by Leovy on infra-red radiation exchange. Fifth come four articles by Holton, Mahlman, Andrews, Hartmann, Matsuno, Murgatroyd, Tung and Hasebe, on the transport of tracers, and the book ends with three articles on modelling, by Geller, Mahlman, Umschied, Tokioka and Yagai, an author index, and a subject index.

As one would expect of the proceedings of a meeting of active workers in an important and challenging comparatively new field of atmospheric science, this book contains a great deal of interesting material on observations and on attempts to make sense of them in terms of basic dynamical processes. Aimed at research workers, the book makes few concessions to the general reader, so that experts in the field will buy it and others will skim through it in their libraries.

R. Hide

Books received

The listing of books under this heading does not preclude a review in the Meteorological Magazine at a later date.

Atmospheric thermodynamics, by J. V. Iribarne and W. L. Godson (Dordrecht, Boston, London, D. Reidel Publishing Company, 1981) is the second edition of a textbook originally published in 1973. It contains a review of general thermodynamics and includes the basic formulas for open and heterogeneous systems. One chapter introduces new material while more than half the book deals with problems of direct application to meteorology: aerological diagrams, basic processes occurring in the atmosphere, atmospheric statics, integration of the hydrostatic equation and a rather extensive consideration of the vertical stability, including the different methods for analysing it, rate of precipitation, and energy relations and conversions in the atmosphere.

Problems and prospects in long and medium range weather forecasting, edited by D. M. Burridge and E. Källén (Berlin, Heidelberg, New York, Tokyo, Springer-Verlag, 1984. DM 45, US$ 17.50) surveys some aspects of the problem of atmospheric predictability and provides elements of the theoretical background, examples of operational forecasting systems and predictability experiments with general circulation models. Basic theoretical concepts and ideas are covered in the introductory chapter. Other theoretical topics include solitons, modons and bifurcation mechanisms — relatively novel concepts in the field of atmospheric predictability. The chapters on numerical prediction discuss the scientific and practical problems of making ten-day forecasts and the possibilities of using deterministic general circulation models to predict, beyond the theoretical limit of predictability, the largest scales and long-term averages.

Weathering, by Cliff Ollier (London and New York, Longman, 1984. £11.50) is a second edition which has been published to take account of the recent developments in the subject and to provide the most up-to-date text available. It considers the breakdown and alteration of material near the earth's surface into products that are more in equilibrium with the newly imposed physico-chemical conditions. The processes at work, the material operated upon (rocks, minerals and clay minerals) and the products of weathering, including soil profiles, weathering profiles and some landforms are all considered in this account together with the time factor which is treated on the geological scale.

Eddies in marine science, edited by Allan R. Robinson (Berlin, Heidelberg, New York, Tokyo, Springer-Verlag, 1983. DM 120, US$ 49.60) surveys the results of recent research in eddy science and explores its implications for ocean science and technology. It attempts a comprehensive review suitable for a wide audience of marine scientists. The investigation of eddy-current phenomena is rapidly advancing; however, many of the most fundamental dynamical questions of eddy dynamics are still not understood. The book therefore intends to contribute to a global synthesis, to facilitate further research into eddy dynamics, and to encourage practical application. The knowledge of the physical science of eddies has important implications for biological, chemical and geological oceanography, for modern ocean science and for practical activities in the sea including exploitation and management of the marine environment and its resources.

Atlantic hydrophysical polygon-70, edited by V. G. Kort and V. S. Samoilenko (Rotterdam, A. A. Balkema Publishers, 1984. £15.50) includes the main results of hydrophysical and aerometeorological research on the Atlantic hydrophysical polygon. Projects and studies on the following subjects were carried out: space-time variability of oceanological fields under conditions of the open ocean; thermohaline structure of water masses; dynamic and thermal interaction between ocean and atmosphere; and meteorological phenomena in the tropical zone of the ocean. Also investigated were acoustic, geophysical, hydrochemical and biological matters and the radioactivity of the air environment.

Nuclear winter, by Mark A. Harwell (Berlin, Heidelberg, New York, Tokyo, Springer-Verlag, 1984. DM 54) is an authoritative account of the consequences of nuclear war for humans and the environment.

It is the first comprehensive analysis of the world after nuclear war that includes both effects on humans and the phenomenon of nuclear winter. Basing his work on realistic scenarios, the author presents new quantification of the direct effects of such a war, its impact on society and agriculture, and detailed analyses of the major effects of temperature and light reductions, radiation, ultraviolet light increases, and numerous other environmental stresses. This unique book draws on virtually all the sciences in giving the reader a description of life on earth in the days, years and decades after a nuclear war.

Awards

We are pleased to record that:

Dr K. A. Browning, FRS, Head of the Meteorological Office Radar Research Laboratory at Malvern, has been awarded the Jule G. Charney Award by the American Meteorological Society for fundamental contributions to our understanding of severe convective storms, the kinematics of fronts and cyclonic storms, and the methodology of Doppler radar observations.

Dr A. E. Gill of the Dynamical Climatology Branch has been awarded the Charles Chree Medal by the Institute of Physics. This award is made every two years.

Obituary

We regret to record the death of Eric Stirland, TTO II of the Operational Instrumentation Branch (Met O 16), on 7 December 1984.

Eric Stirland joined the Office as a Radio Technician in 1956 having spent some time in the electronics industry. After several years servicing a range of meteorological equipment on bases in the United Kingdom and abroad he was posted to the newly formed Cloud Physics Branch as a TTO III in 1967. He remained in that Branch for 17 years, during which time he was promoted to TTO II. During this period the emphasis of cloud physics research changed from laboratory-based studies to field experiments and Eric was involved in a wide range of practical tasks culminating in the development of a dropsonde for deployment from the C130 aircraft of the Meteorological Research Flight. He will be remembered for the patience and thoroughness with which he carried out his duties, often under arduous conditions, and for his willingness to carry out duties which involved many different skills. Eric returned to Met O 16, in order that he would become familiar with the developments in the operational instrumentation area, only a few months before his death.

Eric Stirland was popular among his colleagues and his advice and help were frequently sought. He had a keen interest in the well-being of his fellow technicians, was an active member of AGSRO and has served on Branch Council.

When not working Eric's main interests were his garden and his car, both of which were maintained with care and attention. His car, bought on return to Bracknell from Aden in 1967, and still in regular use after nearly 18 years, is a witness to his patience and skill.

Correction

Meteorological Magazine, January 1985, p. 32, 16th line from top of page, first word. For 'necessary' read 'unnecessary'.

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CONTENTS

NOTICE

It is requested that all books for review and communications for the Editor be addressed to the Director-General, Meteorological Office, London Road, Bracknell, Berkshire RG12 2SZ and marked 'For Meteorological Magazine'.

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