4. Mean annual variations : Latitude-time cross sections*

In this chapter, a series of latitude-time cross sections for zonal mean variables are shown. Analysis was made as follows. Firstly, "10-day means" of each month are calculated for the entire data. Note that the third "10-day mean"for February is actually an 8-day mean and those for January, March, May, July, August, October and December are 11-day means. As a result, one year consists of thirty-six "10-day means". Secondly, the 12-year mean of "10-day mean" values is calculated. The plottings in this chapter are based on these data. Two years are repeated in the figures for convenience. The oridinate is latitude. The abscissa denotes month. Tick marks are placed at the middle "10-day" period of each month. Figures for observations are also shown for some variables. Observed data used in this and next chapters are the 6-year NMC analyses during the period from January 1978 through December 1983. The figures are made with the same procedure as that for the simulated results.

Variables shown in this chapter are solar flux at the surface, solar heating rate, long-wave heating rate, total radiational heating rate, total cloudiness, precipitation rate, cumulus precipitation rate, evaporation rate, sensible heat flux at the surface, total diabatic heating rate, surface air temperature, sea-level pressure, zonal wind at 200 mb, 500 mb, 800 mb and meridional wind at 200 mb.

4.1 Solar flux at the surface

Net solar flux at the surface is shown in Fig. 4.1. The contour interval is 20 W m^{-2}. The shading denotes a polar night region. The values greater than 200 W m^{-2} are dotted.

The seasonal change of the solar flux generally follows the sun's position. Polar night regions are seen in winter polar regions. Maximum values appear in the summer subtropics. The value in the Southern Hemisphere is about 7% larger than that in the Northern Hemisphere, because the sun-earth distance is longer in the Northern Hemisphere summer. In the Northern Hemisphere summer, the local maximum is found near the North Pole due to the long duration of sunshine hours. On the other hand in the Southern Hemisphere, solar flux at the surface decreases monotonically toward the South Pole because of the high albedo over Antarctica. The high albedo over Antarctica and its surrounding sea ice makes a sharp

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gradient of the solar flux at the edge of sea ice (60–70° S) in summer. Note that the solar insolation at the top of the atmosphere has a maximum at the summer pole. In the tropics and Northern Hemisphere mid-latitudes, the winter-to-summer transition gradually takes place. On the other hand, the summer-to-winter transition is more rapid. In September, the double maxima can be seen in the tropics, which is probably due to the maximum cloudiness at 10° N (see Fig. 4.5).

4.2 Solar heating rate

Fig. 4.2 shows the heating rate of the vertical air column due to solar radiation. The contour interval is 10 W m^{-2}. The seasonal change approximately follows that of solar insolation at the top of the atmosphere. However, the maximum is not found over the summer South Pole owing to the high-elevated surface and low moisture.

4.3 Long-wave heating rate

Fig. 4.3 shows the heating rate of the vertical air column due to long-wave radiation. The contour interval is 10 W m^{-2} . All values are negative. Large coolings are calculated over regions where the surface temperatures are high (see Fig. 4.10). Low cloudiness near the subtropics also contributes to the high cooling rate there (see Fig. 4.5). In the extratropics of the Northern Hemisphere, the seasonal change is large and the large cooling rate is simulated in summer. In the extratropics of the Southern Hemisphere, the seasonal change is small.

4.4 Total radiational heating rate

Fig. 4.4 shows the heating rate of the vertical air column due to total radiation (the sum of the values in Fig. 4.2 and Fig. 4.3). The contour interval is 10 W m^{-2}. All the values are negative. Namely, the atmosphere is being cooled by the radiational process. The cooling is larger in low latitudes than in high latitudes. The cooling maximum lies in the winter subtropics (10–20° N/S). In the extratropics, the cooling is large in autumn and winter and small in spring and summer.

4.5 Cloudiness

Total cloudiness is shown in Fig. 4.5. The contour interval is 5%. The values greater than 70% are shaded; those less than 20% are dotted. Large cloudiness is simulated in high latitudes and small cloudiness is simulated in the subtropics. Since shallow cumuli are not included in the cloudiness in the model, the cloudiness in low latitudes is smaller than the observation. In the Southern Hemisphere, the seasonal change is small and large cloudiness exceeding 80% persists at 60° S, the equator side of the low pressure belt surrounding Antarctica (see Fig. 4.11.1).

4.6 Precipitation

Fig. 4.6.1 shows the total precipitation rate and Fig. 4.6.2 shows the precipitation due to cumulus convection. The contour interval is 1 mm day^{-1}. The values greater than 5 mm day^{-1} are shaded; those less than 2 mm day^{-1} are dotted. During the warm season (April to November), the maximum lies around 10° N, while it lies around 5° S during the rest of the year. The transitions are not gradual and take place in early April and early December. The secondary maxima are seen in middle latitudes of both hemispheres. Most of the precipitation in low latitudes is caused by cumulus convection, which also contributes half of that in the northern summer middle latitudes. The precipitation due to middle-level convection is quite small. Thus the rest of the precipitation (total minus cumulus) is primarily caused by large-scale condensation.

4.7 Evaporation

Fig. 4.7 shows the evaporation rate. The contour interval, shading and dotting are the same as in Fig. 4.6.1. Maxima are located at 10° N and 15° S. The largest value appears at 10° N in early winter, reflecting the large evaporation over the Bay of Bengal and the South China Sea, which is caused by the violent cold anticyclonic flow around the Tibetan Plateau. Negative values are simulated over winter Antarctica.

4.8 Sensible heat flux at the surface

Fig. 4.8 shows the sensible heat flux at the surface. The contour interval is 10 W m^{-2}. The values greater than 30 W m^{-2} are dotted; negative ones are shaded. The most prominent feature is the large upward sensible heat flux over the low pressure belt around Antarctica and the large downward flux over Antarctica in winter. In the Northern Hemisphere winter, a large sensible heat flux is calculated at 40° N, 60° N and 75° N. The maximan at 75° N is mostly caused by the large flux over the Barents Sea, where no sea ice is formed even in winter. The maximum at 60° N in early winter is mostly due to the large contribution over the Sea of Okhotsk. The large flux to the east of Japan and the east of the U.S. produces the maximum at 40° N.

4.9 Total diabatic heating rate

Fig. 4.9 shows the total diabatic heating rate of the vertical air column. The contour interval is 20 W m^{-2}. Negative values are shaded. The global average of this quantity should be zero unless the globally averaged internal energy of the atmosphere changes in time. Positive heatings are seen in low latitudes and middle latitudes. Negative heatings are seen in the subtropics and high latitudes. The heating pattern is mainly controlled by the precipitation in the tropics and mid-latitudes. Sensible heat flux plays a major role in the high latitudes of the Southern Hemisphere.

4.10 Surface air temperature

Surface air temperature is shown in Fig. 4.10. The contour interval is 5 K. The values greater than 290 K are dotted; those less than 250 K are shaded. The highest value is found at 10° N in early summer. In middle latitudes, the seasonal change of the surface air temperature is large in the Northern Hemisphere and small in the Southern Hemisphere because oceans occupy most of the area in the Southern Hemisphere. In the North Pole region, the date of the maximum temperature roughly coincides with the summer solstice. The maximum is delayed as we go equatorward. However, the date of the minimum temperature occurs in February and March in the North Pole region. In the Southern Hemisphere, the large meridional gradient is conspicuous at 60–70° S in winter. During the polar night, the temperature change is small over Antarctica ("coreless winter").

4.11 Sea level pressure

Fig. 4.11.1 shows the sea level pressure for the simulation. The contour interval is 5 mb. The values greater than 1020 mb are dotted; those less than 1000 mb are shaded. Fig. 4.11.2 shows geopotential heights at 1000 mb for the observation. The contour interval is 40 g.p.m. The values greater than 160 g.p.m. are dotted; the negative ones are shaded. The seasonal change is well simulated by the model. In the Northern Hemisphere, the annual variation is dominant, while the semi-annual variation is noticeable in the Southern Hemisphere. The phases of annual and semi-annual oscillation in the simulation accord with the observation (see also Hsu and Wallace, 1976). In general, the low around 60° N is too deep and the high at the North Pole in spring is too high.

4.12 Zonal wind

Simulated zonal winds at 200 mb, 500 mb and 800 mb are shown in Figs. 4.12.1, 4.12.3 and 4.12.5, respectively. The observed zonal winds at 200 mb, 500 mb and 850 mb are shown in Figs. 4.12.2, 4.12.4 and 4.12.6, respectively. The contour interval is 5 m s^{-1} in Figs. 4.12.1 — 4.12.4, and 2.5 m s^{-1} in Figs. 4.12.5 and 4.12.6. The values greater than 40 ms^{-1} are shaded in Figs. 4.12.1 and 4.12.2. Those greater than 20 m s^{-1} are shaded in Figs. 4.12.3 and 4.12.4. Easterly regions are dotted in Figs. 4.12.1 — 4.12.6. In the Northern Hemisphere, the strong westerly jet lies in around 30° — 40° N in winter. Weak easterlies prevail in the polar middle and lower atmosphere throughout the year.

In the Southern Hemisphere at 200 mb, a strong westerly jet appears at 30° S in winter and a moderate one can be seen at 45° S in summer. On the other hand, at 500 mb and 800 mb, a strong westerly appears in summer. During the winter of the Southern Hemisphere, the weak double jet structure is simulated (see also Fig. 3.2.1). The simulated seasonal variation of zonal winds in the Southern Hemisphere accords with the observation.

In the tropics, an upper easterly jet and a lower westerly are seen at 10° N in Northern Hemisphere summer. In Southern Hemisphere summer, a strong upper easterly and a lower weak easterly are seen at 10° S. In the observation, no upper easterly can be seen. These seasonal changes of the zonal wind in the tropics are associated with the Northern Hemisphere summer and winter monsoons. The north-south asymmetry of the zonal flow in the tropics is ascribed to the fact that the Northern Hemisphere summer monsoon is more prominent than that of winter. The simulated seasonal change agrees with observations, except for the absence of upper easterlies at 10° S in the Southern Hemisphere summer.

4.13 Meridional wind

Fig. 4.13.1 shows the simulated meridional wind at 200 mb, and Fig. 4.13.2 the corresponding observation. The contour interval is 0.2 m s^{-1}. Negative values (northerlies) are shaded. The meridional wind at 800 mb is almost opposite to Fig. 4.13.1 and not shown here. A three-cell structure is clearly seen. The seasonal change is clearly seen in the tropics and the summer-to-winter transition is more abrupt than the winter-to-summer transition. In the observation, summer northerlies in the tropics are stronger than winter southerlies, which implies that the summer monsoon is more intense than the winter monsoon. On the other hand, Fig. 4.13.1 suggests that the simulated summer and winter monsoons have similar intensity. See also Fig. 3.4.1 and Fig. 3.4.2.