1. Horizontal distributions of monthly mean quantities (I) : 12-year averages*

In this chapter, horizontal distributions of some selected variables are presented. Monthly average for 12 years is taken for each variable. Diabatic process related variables are exactly the mean of 12 years for a corresponding month. On the other hand, adiabatic fields (sea level pressure, geopotential height, wind field, temperature and water vapor mixing ratio) are stored once every 6 hours and those "instantaneous" data are used to calculate the means. 9-point spatial smoothing is applied to variables plotted in this chapter.

1.1 Sea level pressure

Figure 1.1 shows the mean sea-level pressure for each month. Contour interval is 4 mb. Values greater than 1020 mb are shaded; those less than 1000 mb dotted. In the Northern Hemisphere, the Siberian high is seen from October through February, although its center is located far to the south of the observed (Fig. 2.1.1). An Asian monsoonal low pressure area is found in July and August. Subtropical highs are located in the east of the Pacific Ocean and the Atlantic Ocean during summer. However, the southwestward extension of the ridge of the high over the Pacific Ocean is not well simulated, resulting in a northward displacement of the ridge near Japan. This is in accord with the excessive rainfall over the Pacific Ocean near 30° N, 180° E (Fig. 2.19.1). Highs over the eastern Pacific Ocean and over North America are combined to make one anticyclone system in the northern winter. Deep lows are situated in the northern parts of the Pacific Ocean and the Atlantic Ocean in winter. There is an excessive low-pressure zone in high latitudes during summer and autumn. This deficiency of the model is in accord with the excessive rainfall (Fig.1.8), the excessively wet ground condition (Fig. 1.15) in this season and the excessively low temperature over the arctic sea ice (Kitoh and Tokioka, 1986). In the Southern Hemisphere, a low pressure belt surrounds the Antarctic continent throughout the year. Subtropical highs have their centers over the continent in the southern winter and over the oceans in the southern summer.

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1.2 Geopotential height at 300 mb

Figure 1.2 shows the geopotential height distribution at 300 mb. Contour interval is 80 g.p.m. Additional contours of 9720, 9780 and 9800 g.p.m. are drawn with dashed lines. Three centers of anticyclones are clearly seen over the continents around 20° S in February. The northern counterpart over the western Pacific Ocean is the most dominant in the northern winter. This center moves its position from winter to summer between the western tropical Pacific Ocean and South China. In the Northern Hemisphere, anticyclones over Saudi Arabia and Mexico become stronger than the one over South China in summer. The former two anticyclones appear from July through September. The latter one moves its center rapidly in May, June and, again, September. These features are in good agreement with the observations.

1.3 Temperature at 800 mb

Figure 1.3 shows temperature at 800 mb. Contour interval is 5℃. Cold air lower than −30℃ is seen from November to March around eastern Siberia and the adjacent Arctic Ocean with the coldest (−35℃) contour in January. Temperature gradient around Japan is large from October to April. In the northern winter, cold surge around the eastern periphery of the Tibetan Plateau is evident, but it extends far south to the Indochina peninsula. The 20℃ contour appears in March in the Sahel region (15° N) and moves northward with time to the Sahara desert (25° N) until August. High temperatures in the northern summer observed over the Middle East (Fig. 2.11.1) are not reproduced in the model probably due to the wet ground condition. Temperature in the eastern part of the continents is lower than that in the western part in the northern winter. This symptom is less clear in the Southern Hemisphere continents, which is in good correspondence with the observation (Fig. 2.9.1).

1.4 Zonal wind at 200 mb

Figure 1.4 shows the wind velocity of the zonal wind at 200 mb. Contour interval is 10 m s^{-1} and values less than 0 m s^{-1} are dotted. Strong jets are located over Japan and eastern North America with peaks greater than 70 m s^{-1} and 60 m s^{-1}, respectively, in both January and February. Subtropical jets in the Southern Hemisphere are located at 30° S and 45° S in the southern winter and summer, respectively. The wind velocity of those jets is around 40 m s^{-1} and has less variation with season compared to those in the Northern Hemisphere. The maxima of jets tend to lie to the south or over the Southern Hemispheric continents, i.e., Africa, Australia and South America. Easterlies prevail in low latitudes with their maxima in the summer hemispheric side, although there exist westerlies in the central and the eastern Pacific Ocean.

1.5 Streamline at 200 mb

Figure 1.5 shows the streamline at 200 mb. In the northern winter, there are pairs of anticyclones in low latitudes. Anticyclones in the Southern Hemisphere are stronger than those in the Northern Hemisphere over Africa and South America, while the reverse holds in the western Pacific Ocean and Australia. In the northern summer there are anticyclones over South Asia (the Tibetan high) and over Mexico with another weak high pressure belt at 10° S. Mid-oceanic troughs are present over the Pacific and the Atlantic Ocean in both hemispheres in January, and only in the northern Hemisphere in July. Cross-equatorial northerly flow exists over the Indian Ocean from May to September. On the other hand, there exists southerly flow over the maritime continent from December to February.

1.6 Streamline at 900 mb

Figure 1.6 shows the streamline at 900 mb. Overall features are consistent with the sea level pressure in Fig.1.1. A distinct feature is the seasonal progression of the monsoonal wind system. During the northern winter there is a strong anticyclonic flow around the Tibetan Plateau. The resultant easterlies prevail over the Indochina peninsula and the Indian Ocean. These easterlies weaken by the end of April, although there still exists an anticyclonic circulation over the Indochina peninsula. The Mascarene high is seen all year round over the South Indian Ocean around 30° S. Easterlies along the northern periphery of the Mascarene high begin to have a southerly component in April at the east coast of Africa. In May the monsoon circulation is clearly seen and in June it is fully established with a strong cross-equatorial flow, the Somali jet and westerlies over the Indian subcontinent. In September dry northeasterlies start to blow over the Indochina peninsula, while there still is a cross-equatorial flow from the Southern Hemisphere along the east coast of Africa. An anticyclonic circulation is established in October with the low-level easterlies over the Indian subcontinent and the cross-equatorial flow over the Indian Ocean reverses its direction in November and remains northerly until next March.

The dry northerly flow begins to blow across the equator in November over the maritime continent. It penetrates into Australia in December, accompanying a cyclonic circulation in the northwest of Australia. This system lasts for two months and begins to fade out in February.

Strong cross-equatorial flow from the Northern Hemisphere to the Southern Hemisphere prevails over South America from December through March and in the reverse direction from May through August. The latter is a part of a large anticyclonic system over the eastern South Pacific Ocean and South America. Probably due to the insufficient representation of the narrow Andes especially over Peru, easterlies prevail over Brazil and Peru in the southern winter.

1.7 Velocity potential at 200 mb

Figure 1.7 shows the velocity potential and its divergent wind at 200 mb. Contour interval of the velocity potential is 10^6 m^2 s^{-1}. The divergent center is located over the central equatorial Pacific Ocean near the dateline from October through March and over the maritime continent and the Indochina peninsula in the rest of the year. Distributions of divergent and convergent centers observed in January and July (Figs. 2.13.1 and 2.15.1) are well reproduced in the model. However, those in the transition seasons in the model are different from the observed (Figs. 2.14.1 and 2.16.1).

The rapid transitions of the center occur between March and April and between September and October in the model. The former transition is quicker than the latter. This transition is also seen from the movement of the heavy cumulus precipitation area in Fig. 1.9. Convergent centers are situated over the Tibetan Plateau in the northern winter and over the broad area from the eastern Pacific Ocean through the Atlantic Ocean to Africa all the year round. However, the latter center of convergence tends to form a single strong system over the Atlantic Ocean in the northern summer and tends to split into two centers over the eastern Pacific Ocean and over Africa in winter.

Strong divergent wind is simulated over the western Pacific Ocean from November through February and over the south Indian Ocean from May through August, corresponding to the Asian winter and summer monsoons.

1.8 Precipitation

Figure 1.8 shows the precipitation rate. Contours of 1, 2, 5, 7.5 and 10 mm day^{-1} are drawn. Values greater than 5 mm day^{-1} are shaded and those less than 1 mm day^{-1} dotted. Basic characteristics of observed climatological features (Figs. 2.17.1, 2.18.1, 2.19.1 and 2.20.1) are well simulated in the model. However, differences are found regionally, e.g. exaggerated precipitation over the summer continents and precipitation maximum not over Assam but over the Indian Ocean in July.

A well-organized precipitation area is found in the tropics except for over the eastern Pacific Ocean where sea surface temperature is low. Precipitation over the Atlantic Ocean is also less compared to that zonally averaged. Heavy precipitation greater than 10 mm day^{-1} is simulated over the Indian Ocean around 10° N in May, June and July; over the equatorial Indian Ocean, South Africa and Brazil in the northern winter. In that season are also found large precipitation areas over the northern Pacific Ocean and the northern Atlantic Ocean, which correspond to cyclonically active areas. The precipitation in the baroclinic zone of the Southern Hemisphere is uniform in the zonal direction due to the absence of prominent stationary circulations. Excessive precipitation is found over the Eurasian continent and the North America in June and July. Precipitation is also excessive around the dateline between 20° N and 30° N in the northern summer, accompanying the northward displacement of the subtropical high (Figs. 1.1 and 1.6) and its dry zone.

1.9 Cumulus precipitation

Figure 1.9 shows the precipitation rate by cumulus convections which have their roots in the planetary boundary layer (PBL). Contours are the same as in Fig. 1.8. A comparison of Figs. 1.8 and 1.9 reveals that precipitation in low latitudes is mostly caused by cumulus precipitation. Excessive rainfall over continents at high latitudes in the Northern Hemisphere from June through August noted in Chapter 1.8 is due to cumulus precipitation.

1.10 Evaporation

Figure 1.10 shows the surface evaporation rate with the same contours as in Fig. 1.8. Large evaporation is simulated over the central and the western Pacific Ocean and the Indian Ocean in low latitudes. Evaporation from the Arabian Sea is relatively small in August, September and October. Off the east coast of Japan and North America, there exist heavy evaporation areas due to cold surges in the colder months of the year. The same situation is found with less magnitude off the east coast of South Africa and South America. Also noted is a peak of evaporation to the northwest of Australia in June and July by the dry southeasterlies from inland Australia (see Figs. 1.6 and 1.17). Evaporation over continents in the summer hemispheres is exaggerated.

1.11 Sensible heat flux

Figure 1.11 shows the sensible heat flux from the surface. Contour interval is 50 W m^{-2} and negative values are dotted. Large positive sensible heat flux is seen off the east coast of Japan and North America in winter months. Also large are the fluxes over the oceans around the sea ice/ocean boundaries in both hemispheres in the winter seasons. Over the continents, large sensible heat flux is simulated in the Sahara Desert throughout the year, the southern part of Africa and South America in winter, and Australia in summer. Negative sensible heat flux is found over the continents in winter hemispheres and over some parts of the oceans.

1.12 Total diabatic heating rate

Figure 1.12 shows the vertically integrated net atmospheric heating rate by diabatic processes. Contour interval is 50 W m^{-2} and positive values (atmosphere is heated diabatically) are shaded. The condensational heating and the net radiational heating (actually cooling) are main contributors to the net atmospheric heating/cooling. As the latter is rather uniform in space, the spatial pattern of the net atmospheric heating resembles that of the condensational heating (Fig. 1.8). The sensible heat flux convergence (Fig. 1.11) is also substantial regionally, e.g. the desert regions and off the east coasts of the continents and the sea ice/ocean boundaries in winter. The atmosphere is diabatically cooled in polar regions, subtropical high pressure areas, the eastern Pacific Ocean and the Atlantic Ocean in low latitudes and the continents in winter hemispheres. The western part of the Tibetan Plateau becomes a heat source in April, although the eastern part of it remains a heat sink until June mainly due to the late disappearance of snow cover (Fig. 1.14).

1.13 Cloudiness

Figure 1.13 shows the cloudiness. Two types of clouds are incorporated in the model. Clouds associated with the grid-scale supersaturation and those with the sub-grid-scale penetrative cumulus convections. In those cases we assume that the cloud fills the grid box entirely and that the cloudiness is 1.0. Cloudiness of shallow cumuli whose tops are below 400 mb is set to 0.0. Contour interval is 20%. Values greater than 80% are shaded and those less than 20% dotted. Generally, cloudiness is large in high latitudes and has its minima in the subtropics. The model overestimates the cloudiness in high latitudes due to the excess of shallow clouds by the grid-scale condensation and underestimates it in low latitudes probably due to neglecting the shallow cumulus with its top below 400 mb.

1.14 Snow depth

Figure 1.14 shows the snow depth distribution. Contours are drawn for 1, 5, 10 and 50 cm and values greater than 10 cm are shaded. Note that snow-covered areas whose snow depth is less than 1 cm are not shown in this figure. In the Northern Hemisphere, the snow-covered area is most extensive in March. It begins to retreat in April. It still covers the Tibetan Plateau, Siberia and Alaska in June. Although model August is the month when there is no snow-covered area with greater than 1 cm snow depth in the Northern Hemisphere except for Greenland where the permanent ice sheet ground condition is specified, the snow-covered area is the minimum in July, when snow still exists in parts of the Tibetan Plateau, the northeastern Siberia and Alaska. In model August the snow-covered area begins to spread southward and occupies the major part of the Eurasian continent at the end of October. In the Southern Hemisphere, only the southernmost part of South America is covered by snow in winter with a depth of less than 1 cm. As seen in the maps, snow over Greenland and Antarctica never disappears even in summer. Actually snow depth over those regions are increasing during the integration, corresponding to the observation where ice sheets are being formed.

1.15 Ground wetness

Figure 1.15 shows the ground wetness. Ground wetness is predicted by considering ground hydrology with the uniform maximum water content of 15 g cm^{-2} in the ground. Contours of 10, 30, 50, 70 and 90% are drawn and values less than 50% are dotted. Extensive dry areas are found over the continents in the subtropics. Over the land which is covered by snow in winter, it generally begins to dry after the complete disappearance of snow cover with the maximum 15 g cm^{-2} water content.* It takes time for the ground to be sufficiently dry, even if the local surface evaporation surpasses the precipitation. In July the ground in the Northern Hemisphere is extremely wet compared with the observed, that is, wetter by more than 50%.

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*Owing to a coding error, the ground water content was set to the maximum 15 g cm^{-2} whenever a snowfall occurred irrespective of the past history of the ground wetness. This error must have a large influence on the model climate over regions where snow falls intermittently or snow depth is not enough, through a ground wetness/evaporation/precipitation link. The effect of the error is under investigation.

1.16 PBL depth

Figure 1.16 shows the depth of the PBL. Contour interval is 20 mb and values greater than 140 mb are shaded. Generally, the PBL is deeper over the oceans than over the continents. The nocturnal shallowing of the PBL seems to be responsible for this, because the atmosphere usually becomes stable at night over the continents. The PBL is deep over areas of large cyclonic activity, i.e., off the east coast of Japan, North America and South America in their winter months. Deep PBL is located at the Bay of Bengal in winter. It is deep all the year round over the equator side of the circum-Antarctic low pressure belt. Other maxima are found off California and off Peru.

1.17 Water vapor mixing ratio at 900 mb.

Figure 1.17 shows the distributions of the water vapor mixing ratio at 900 mb. Contour interval is 1 g kg^{-1} and values greater than 11 g kg^{-1} are shaded. In January moisture is abundant over the Indian Ocean, the central and southern portions of Africa, the Amazon Basin, the Australian Mediterranean Sea (the Timor Sea and the Arafura Sea) and the belt extending from there to the dateline at the equator and east-northeastward, corresponding to the ITCZ. The contour of 10 g kg^{-1} moves northward over the western Pacific Ocean in May. In June it has a kink to the south of Japan, which resembles the Baiu-front. It reaches Japan in July and August to form the wettest region at this latitude.