On the Origin of Monsoon

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Abstract

It is a long-held fundamental belief that the basic cause of monsoon is land-sea thermal contrast on the continental scale. Through general circulation model experiments we demonstrate that this belief should be changed. The Asian and Australian summer monsoon circulations are largely intact in an experiment in which Asia, maritime continent, and Australia are replaced by ocean. It is also shown that the change resulting from such replacement is in general due more to the removal of topography than to the removal of land-sea contrast. Therefore, land-sea contrast plays only a minor modifying role in Asian and Australian summer monsoons. This also happens to the Central American summer monsoon. However, the same thing cannot be said of the African and South American summer monsoons. In Asian and Australian winter monsoons land-sea contrast also plays only a minor role.

Our interpretation for the origin of monsoon is that the summer monsoon is the result of ITCZ's (intertropical convergence zones) peak being substantially (more than 10 degrees) away from the equator. The origin of the ITCZ has been previously interpreted by Chao. The circulation around thus located ITCZ, previously interpreted by Chao and Chen through the modified Gill solution and briefly described in this paper, explains the monsoon circulation. The longitudinal location of the ITCZ's is determined by the distribution of surface conditions. ITCZ's favor locations of higher SST as in western Pacific and Indian Ocean, or tropical landmass, due to land-sea contrast, as in tropical Africa and South America. Thus, the role of landmass in the origin of monsoon can be replaced by ocean of sufficiently high SST. Furthermore, the ITCZ circulation extends into the tropics in the other hemisphere to give rise to the winter monsoon circulation there. Also through the equivalence of land-sea contrast and

higher SST, it is argued that the basic monsoon onset mechanism proposed by Chao is valid for all monsoons.

1. Introduction

The notion that continental-scale land-sea contrast is the main reason that monsoon circulation exists has been a long-held fundamental belief (e.g., Wallace and Hobbs 1977, which was adopted by Holton 1992, Webster et al. 1998). The purpose of this paper is to point out that this notion should be changed substantially. The central idea of this notion states that in summer, radiative heating of the continent, say Asia, gives rise to a continental-scale thermal low and surrounding this thermal low in its southeast direction the low-level wind flows in from south-west. This low-level inflow creates a convergence of moisture, which maintains cumulus convection. And in winter, radiative cooling of continent gives rise to a thermal high and to its southeast the low-level wind is from northeast. Continental-scale land-sea contrast does undoubtedly exist. However, whether it really acts as the main driving force of monsoon has not been tested in numerical experiments and will be tested in this work. The results of our test demonstrate that a new explanation for the origin of monsoon is needed. There has been an increasing recognition in the recent years that monsoon is inextricably tied to the heating in the intertropical convergence zone (ITCZ) (e.g., Chao 2000 and Hoskins and Rodwell 1995). The origin of the ITCZ has been interpreted by Chao (2000). We propose that the main cause of monsoon is ITCZ's being substantially away from the equator. A brief qualitative explanation of why the off-equator ITCZ is the source of monsoon circulation can be offered based on the circulation field associated with the ITCZ heating (Chao and Chen 1999) and will be described in Section 3. The existence of the ITCZ's does not always have to rely on land-sea contrast on the continental scale. This is hinted in the fact that in February the ITCZ close to Australia (and its associated monsoon circulation) covers a longitudinal range several times as long as that of

Australia and thus cannot possibly be caused mainly by the land-sea contrast associated with Australia. Also the aqua-planet monsoons obtained in Chao (2000) and in Yano and McBride (1998) exhibits characteristics of observed monsoon, such as low-level westerly zonal wind components in the monsoon precipitation region and its neighborhood, wind reversal at upper levels, and cross equatorial flows. Yet, these cannot be used as an argument that the ITCZ in the Asian summer monsoon is not mainly due to land-sea contrast. One of the purposes of this work is to provide a convincing argument. The role of land-sea contrast in other monsoons will also be examined.

In this work the role of continental-scale land-sea contrast in the origin of monsoon is examined through numerical simulation with the Goddard general circulation model (Takacs, et al. 1994). The Asian and Australian monsoon circulations are obtained in a four-year integration and then the integration is repeated with Asia, the maritime continent, and Australia replaced by ocean. The sea surface temperature (SST) at each affected grid is specified as the SST at the first grid to its east that is an ocean grid in the first experiment. The latter integration shows that the monsoon circulation pattern over where south Asia and Australia were and the surrounding region has largely remained. The results discount land-sea contrast as the main cause of Asian monsoon. A third experiment is the same as the first (the control) except that the topography of Asia, the maritime continent, and Australia is reduced to zero. This experiment reveals that the difference between the first two experiments is generally due more to the removal of topography than to the removal of land-sea contrast. They show that the difference between the second and the third experiment is mainly in the longitudinal location of the maximum precipitation. Additionally, in Asian and Australian winter monsoons land-sea contrast also plays only a modifying role. Although land-sea contrast plays only a modifying role in Asian and Australian (and Central American) monsoons, additional experiments show that it is the main reason that ITCZ (and thus monsoon) exists in Africa, Mexico, and South America. Thus, monsoons can be classified into two groups depending on whether land-sea contrast plays a major role. It is also argued that the role played by land-sea contrast in monsoon is basically equivalent to that played by SST contrast.

The model used, the Goddard general circulation model, is described in the next section and the experimental results are presented in Section 2. Section 3 gives a brief qualitative explanation of why, according to our interpretation, monsoon can be interpreted as ITCZ located away from the equator in combination with its circulation field. As a result of this study, after minor modification to take into account land-sea contrast, the monsoon onset mechanism proposed by Chao (2000), which is based on ITCZ in an aqua-planet model with zonally uniform SST, can be applied to all places, not just western Pacific. Further discussions and a summary are offered in the last section.

2. Model and experiments

The latest version of the Goddard Earth Observing System general circulation model version 2 (GEOS-2 GCM) is used. A 4^{o} (longitude) x5^{o} (latitude) grid size and 20 levels are used with 4 levels below 850 hPa. This model uses the discrete dynamics of Suarez and Takacs (1995). The relaxed Arakawa-Schubert scheme (RAS, Moorthi and Suarez, 1992) is a main feature of the model. This scheme gives almost identical time-mean results as the original Arakawa-Schubert scheme at much reduced computational cost. RAS is used in conjunction with a rain-reevaporation scheme (Sud and Molod, 1988). The large-scale moist and dry convection remain the same as documented in Kalnay et al. (1983). The boundary layer and turbulence parameterization, a level 2.5 second-order closure model, is that of Helfand and Labraga (1988). Long wave radiation package is that of Chou and Suarez (1994). Short wave radiation package is that of Chou (1992) and Chou and Lee (1996). The prognostic cloud water parameterization of Del Genio et al. (1996) is used. Sea surface temperature, ground wetness, sea ice and snow are from observations (for details, see Takacs, et al. 1994.). Other features include land surface process parameterization (Koster and Suarez 1996) and gravity wave drag parameterization (Zhou et al. 1996).

The initial condition for the experiments is that of January 1, 1979. In all experiments the model was run for four years with observed boundary conditions, including the observed sea surface temperature (SST). Only the last three years of the output are used for analysis. After the control run, an experiment, E1, was run with all land grids between 60E and 180 (except Antarctic) replaced by ocean and the SST of each affected grid is specified as that of the first grid on its east side that is an ocean grid in the control. Fig. 1.b and 3.b shows the August rainfall and 850 hPa wind arrows of E1 averaged over the last three years. Clearly, in E1 the ITCZ associated with the Asian summer monsoon still exists. However, the precipitation region does not extend as far to the north (to cover regions where Tibet and southern China were) as in the control run (Fig. 1.a); this is very similar to the results obtained by Hahn and Manabe (1975) in a GCM experiment without mountains. The high precipitation in the Arabian Sea and the Bay of Bengal lessens in E1 and the precipitation pattern in Indian Ocean and western Pacific becomes more zonally uniform. The circulation field associated with this ITCZ in E1 shows southwesterlies in the ITCZ region, cross equatorial flow in the Indian Ocean, and Somali jet in the low-levels (Fig. 3.b), monsoon features observed in control (Fig. 3.a) and observation. In the regions where Tibet and southern China were there is an easterly region at low-levels. This feature is hardly detectable in the control run. Figs. 2.b and 4.b shows the same plots for February. The ITCZ and the associated circulations in the western Pacific and Indian Ocean in the southern hemisphere still exist. The low-level winds in regions where India was are from east-northeast. E1 shows that the Asian landmass is not a necessary condition for the existence of the Indian monsoon and the associated ITCZ. However the Asian landmass does play an important modifying role.

The removal of landmass in E1 removes both land-sea contrast and topography. In order to get some ideas about the separate impacts of these two different factors, E2 was conducted where all grids changed in E1 remain land grids but their topography is reduced to zero. E2 shows a precipitation field in the India Ocean area in August (Fig. 1.c) in general not too different from that of E1 (Fig. 1.b). The E2 precipitation pattern in the western Pacific and Indian Ocean is shifted eastward. This shift is also apparent in the 850 hPa wind field (Fig. 3.c) which shows that the westerlies associated with the ITCZ is shifted eastward changing form E1 to E2. The August precipitation in southern Indian Ocean is somewhat reduced in E1 (comparing with the control) and is further reduced in E2. Also the easterly region at low-level over Tibet and China is similar to that in E1 but extends further eastward into western Pacific. Moreover, the reduction of precipitation over Tibet and China remains. Thus the effect of removing Asian landmass is in general due much more to the removal of topography than to the removal of land-sea contrast, although in some small areas the opposite is true. However, one must be reminded of the fact that the land-sea contrast in E2 is not completely the same as that in the control, since the topography of the two experiments is different.

Results of E2 in February show the similar results (Figs. 2.c and 4.c.) They show that the northeasterlies in southern China, Indochina, and India, the central feature of Asian winter monsoon, remain in both E1 and E2. This reveals the relatively minor role of land-sea contrast in its impact on the Asian and Australian monsoons (in both summer and winter).

Experiments similar to E1 and E2 are done for the cases of removing American and African landmass and topography. In these experiments when a land grid is replaced by ocean the SST is specified by linearly interpolating the SST's of first ocean grids on east and west sides that are ocean grids in the control run. When interpolation cannot be done SST is copied from one side as done in E1. Fig. 5.b shows precipitation in the case of removal of the Americas. In August the precipitation region in Central America remains; but that in Mexico is reduced considerably. Fig.5.c shows that case of removal of topography in the Americas. The precipitation region in Central America shows little change from that in Fig. 5.b. The precipitation region in Mexico is still quite different from that of the control. Fig. 6.b shows the February results in the case of removing Americas. The precipitation region in South America disappears. The precipitation region in eastern Pacific just west of Central America is much enhanced. The SPCZ (southern Pacific convergence zone) extends further eastward. Fig. 6.c shows the February results in the case of removal of topography in the Americas. The precipitation region in South America is similar to that in the control. The enhancement in the eastern Pacific west of Central America remains. Thus it can be concluded the land-sea contrast plays a major role in the South American but not in the Central American monsoon. For the Mexican monsoon both orography and land-sea contrast appear to be important. Figs. 7 and 8 give the August and February 850 hPa wind fields for the three experiments.

Similar experiments of removal of the African (and Arabian) landmass and topography show that the land-sea contrast plays a major role in African monsoon. Figs. 9 and 10 show the corresponding precipitation in August and February and Figs. 11 and 12 850 hPa wind fields in August and February. In August without the African landmass precipitation in where Africa was disappears and the precipitation in the Asian and Central American monsoon increases. Also, Somali jet is not discernable in Fig. 11.b and is barely discernable in Fig. 11.c. This is consistent with the prevailing interpretation that Somali jet depends on the topography in east Africa for its existence. In February, Fig. 10.b shows that the SST in where southern Africa was is high enough to keep some precipitation. To summarize, our experimental results show that land-sea contrast plays a major role in monsoons in South America, Africa (excluding southern Africa), and Mexico and a minor role in monsoons in southern Asia (including India), Australia, and Central America. Thus for land-sea contrast to play a major role in monsoon the landmass has to be sizeable and covers the latitude of ITCZ. Also, the role of land-sea contrast can be replaced by ocean of sufficiently high SST.

As the main conclusion of these experiments, the conventional interpretation for the origin of monsoon, which depicts land-sea contrast on the continental-scale as the main cause, is problematic. In the following our interpretation for the origin of monsoon will be presented.

3. Monsoon as off-equator ITCZ and its associated circulation

To a large extent the Gill (1980) solution of linear response of circulation field to an imposed stationary heating field on a β-plane gives a fairly accurate depiction of tropical circulation surrounding a heating source. However his heating field has a cosine function in its longitudinal distribution. This can be modified by taking a running mean of the entire Gill solution in longitudinal direction to get a flat top zonal profile in the heating field (Chao and Chen 1999).

$$g(x) = \int_{x-5}^{x+5} f(x)dx / 10$$

Where f(x) is the Gill solution of L=2, and ε= 0.1. x is the nondimensional length in the zonal direction with unity equal to about 1000 km. The zonal running mean turns the Gill heating field closer to an ITCZ heating field; i.e., the zonal distribution of the heating field is now a cosine function with its top flattened and covers a much wider longitudinal domain. Fig. 13 shows the solution for the asymmetric heating case (i.e., the zonal running average of Gill's Figure 3.b). As explained by Chao and Chen (1999) the bulk part of the ITCZ heating area and the area to its immediate west are occupied by southwesterlies. This corresponds very well to the low-level southwesterly circulation field of the Indian summer monsoon. Quantitatively, the modified Gill solution, when given heating field of strength equivalent to what is observed, gives southwesterly of a magnitude comparable to the observed monsoon southwesterly. There is a cross equatorial flow converging toward the ITCZ. Also there is an easterly region to the north of the ITCZ whose maximum wind speed is not quite as large as that of the westerly component of wind in the ITCZ. Moreover, the Gill solution assumes a wind direction reversal at upper levels. When Fig. 13 is flipped upside down (such that the x-axis is still pointing to the east), the circulation field corresponds to that of an ITCZ to the south of the equator and there is northeasterlies north of the equator, a situation resembles the northeasterlies in the winter monsoon over India and Indochina when the ITCZ is just north of Australia. In summary the basic characteristics of monsoon such as; a wide precipitation region, southwesterlies covering the precipitation region and its neighborhood (northwesterlies in the southern hemisphere) at low-levels, cross-equatorial flow at low-level, and circulation reversal at high-levels; are all found in the off-equator ITCZ. Consequently, in our interpretation of the origin of monsoon we equate monsoon with the off-equator ITCZ and its associated circulations. The origin of the ITCZ has been discussed by Chao (2000).

4. Discussions and summary

Although we have used model data of only three years long, since the gross monsoon features are consistent in all three years, we can consider our results more than enough to prove our points. In fact, the claim that land-sea contrast is the main cause for monsoon can be discounted, if the data of just one year's model run without land-sea contrast show monsoon.

The easterlies in Tibet, southern China and the neighboring western Pacific in Figs 3.b and 3.c which are located north of the monsoon rainy region correspond to the easterlies north of the ITCZ in Fig. 13. Thus these easterlies can be considered as parts of the monsoon circulation. They appear to be interrupted by topography and cover only a very narrow range in Fig. 3.a.

Our interpretation of the origin of monsoon is considerably different from the textbook interpretation. To detail our interpretation further, let us consider an aqua-planet setting with zonally uniform SST. In summer the ITCZ is zonally uniform (in a time averaged sense over 10 days, for example) and at low-levels of the ITCZ region there are westerlies and winds flow across equator to converge to the ITCZ (See Figure 3 of Chao 2000). Thus this combination of precipitation and circulation has all the characteristics of monsoon (a zonally uniform aqua-planet monsoon) and thus can be called monsoon. The circulation pattern on the ITCZ side of the equator is the summer monsoon and that on the other side of equator is the winter monsoon. When zonally non-uniform SST is introduced into the setting, the ITCZ is no longer zonally uniform and prefers longitudinal ranges where the SST is high. Also when introduced, land, if covering the latitude of the ITCZ, is also a favorable location. Thus in our interpretation land-sea contrast, similar to zonally non-uniform SST, merely makes a zonally uniform ITCZ (in an aqua-planet with zonally uniform SST) zonally non-uniform. Fig. 10.b shows that the ITCZ in southern Africa remains, when Africa is replaced by ocean of sufficiently high SST. Had the SST specified for vacated South America (Africa) been much higher, Fig. 6.b (9.b) would have shown ITCZ rainy region and monsoon circulation there. Moreover, the circulation pattern associated with a zonally non-uniform ITCZ is well explained by the modified Gill solution as described in the preceding section.

Chao (2000) proposed a theory for monsoon onset based on numerical experiments on the ITCZ over an aqua-planet with zonally uniform SST. His theory identifies monsoon onset with the sudden jump of the latitudinal location of the ITCZ. He hypothesized that his theory is valid not only over the western Pacific, where the situation resembles aqua-planet, but also elsewhere in the tropics. Our present study, by the arguments that monsoon is the off-equator ITCZ and that the existence of the ITCZ does not have to rely on land-sea contrast and that land-sea contrast merely offers a favorable location for the ITCZ, gives support to his hypothesis. The two types of attraction on the ITCZ due to earth's rotation and latitudinal peak of zonally uniform SST (Chao 2000) still exist (with some modifications) when the presence of zonally non-uniform SST and land-sea contrast is taken into account. And his basic subcritical instability interpretation of monsoon onset does not change.

In summary this study demonstrates that the long-held fundamental belief that continental scale land-sea contrast is the main cause of monsoon has to be changed. Our experiments with a general circulation model show that continental-scale land-sea contrast is not the main cause of the Asian (including Indian) and Australian summer monsoons by demonstrating that the summer monsoons in these regions still exist, when Asia, maritime continent, and Australia are replaced by oceans. Also the effects of the removal of these continents are in general due much more to the removal of topography than to land-sea contrast. Nevertheless, further experiments show that land-sea contrast is crucial to the monsoons in Africa and South America. Also the role of landmass in the origin of monsoon can be replaced by ocean of sufficiently high SST. Our interpretation for the origin of monsoon is that the summer monsoon is the ITCZ and its associated circulation when the latitudinal location of the peak of the ITCZ is substantially (more than 10 degrees) away from the equator. The origin of the ITCZ has been interpreted by Chao (2000). Also, the circulation associated with the ITCZ has been interpreted by Chao and Chen (1999) and a brief description of it was offered in the preceding section. This circulation has all the characteristics of summer monsoon circulation. The longitudinal location of the ITCZ's is determined by the distribution of surface conditions. ITCZ's favor longitudinal locations of higher SST as in western Pacific and Indian Ocean, or tropical landmass, due to land-sea contrast, as in tropical Africa and South America. The ITCZ circulation extends to the tropics in the other hemisphere to give rise to the winter monsoon circulation there. Also through the equivalence of land-sea contrast and higher SST, it is argued that the basic monsoon onset mechanism proposed by Chao (2000) is valid for all monsoons.

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Figure Captions

Fig. 1 August precipitation averaged over last three years of the control run (top), of the experiment in which Asia, maritime continent, and Australia are replaced by ocean (middle), and of the experiment in which topography of Asia, maritime continent and Australia are reduced to zero (bottom).

Fig. 2 Same as Fig. 1 but for February.

Fig. 3 Same as Fig. 1 but for 850 hPa wind arrows instead of precipitation.

Fig. 4 Same as Fig. 3 but for February.

Fig. 5 Same as Fig. 1 but for the removal of Americas (b) and the removal of topography of Americas (c).

Fig. 6 Same as Fig. 2 but for the removal of Americas (b) and the removal of topography of Americas (c).

Fig. 7 Same as Fig. 3 but for the removal of Americas (b) and the removal of topography of Americas (c).

Fig. 8 Same as Fig. 4 but for the removal of Americas (b) and the removal of topography of Americas (c).

Fig. 9 Same as Fig. 1 but for the removal of Africa (b) and the removal of topography of Africa (c).

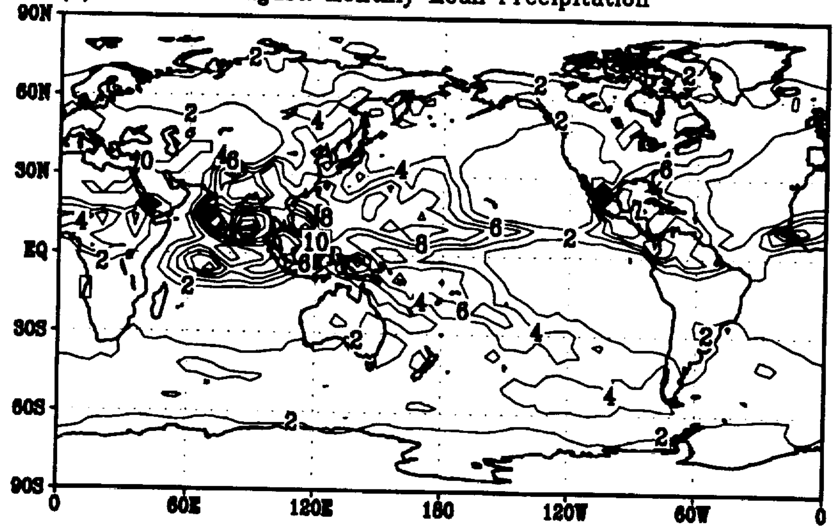
Fig. 10 Same as Fig. 2 but for the removal of Africa (b) and the removal of topography of Africa (c).

Fig. 11 Same as Fig. 3 but for the removal of Africa (b) and the removal of topography of Africa (c).

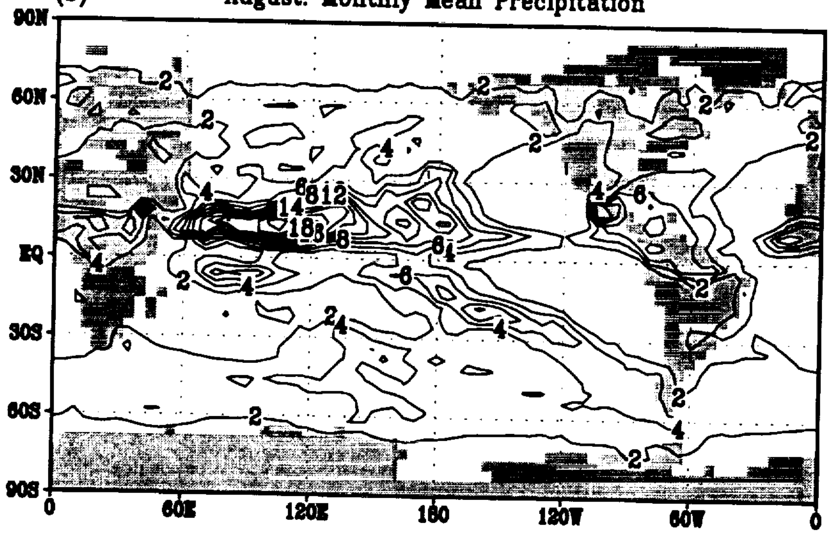
Fig. 12 Same as Fig. 4 but for the removal of Africa (b) and the removal of topography of Africa (c).

Fig. 13 Zonally running averaged Gill's solution (Gill's Fig. 3) in non-dimensional scale (unity in length is about ten degrees in dimensional scale). Wind arrows and heating field (in contours) are shown. Notice that the two axes are not of the same scale.

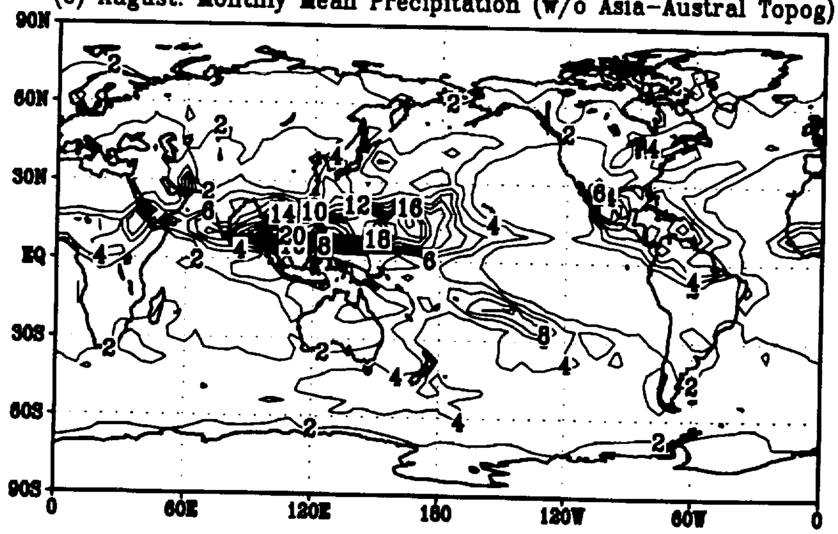
(a) August: Monthly Mean Precipitation

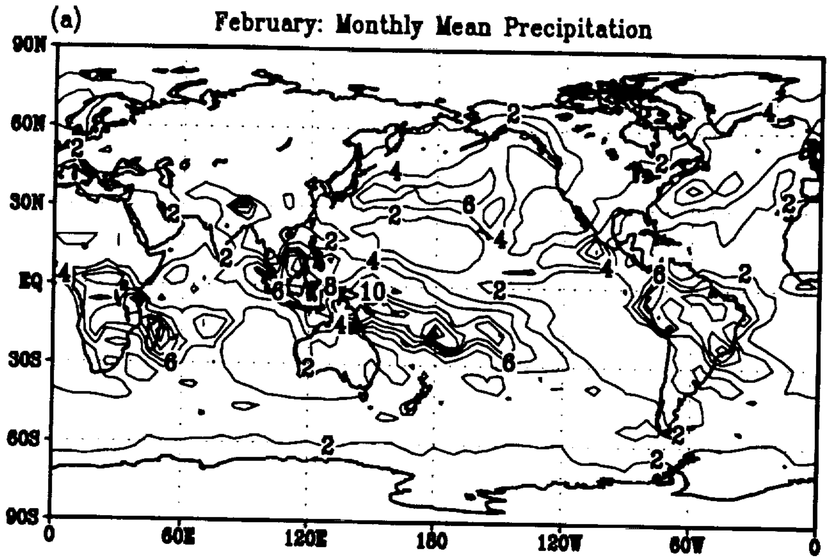


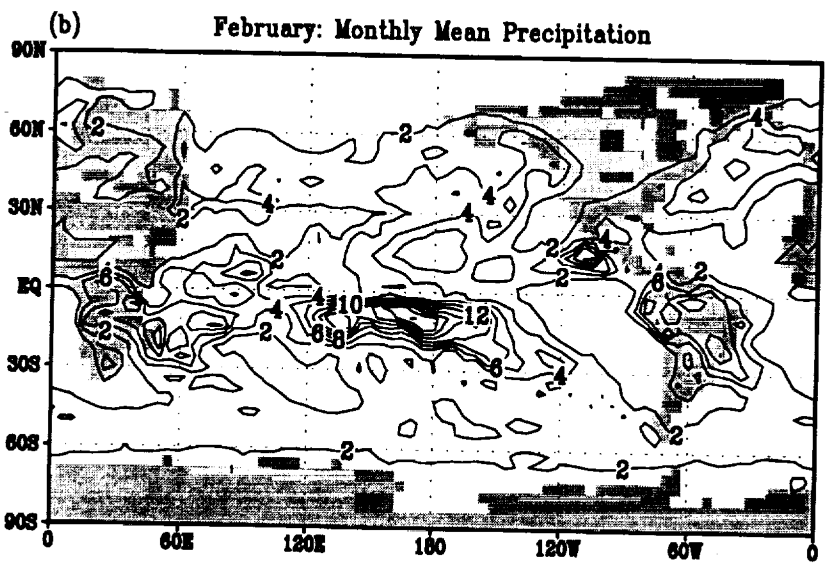
(b) August: Monthly Mean Precipitation

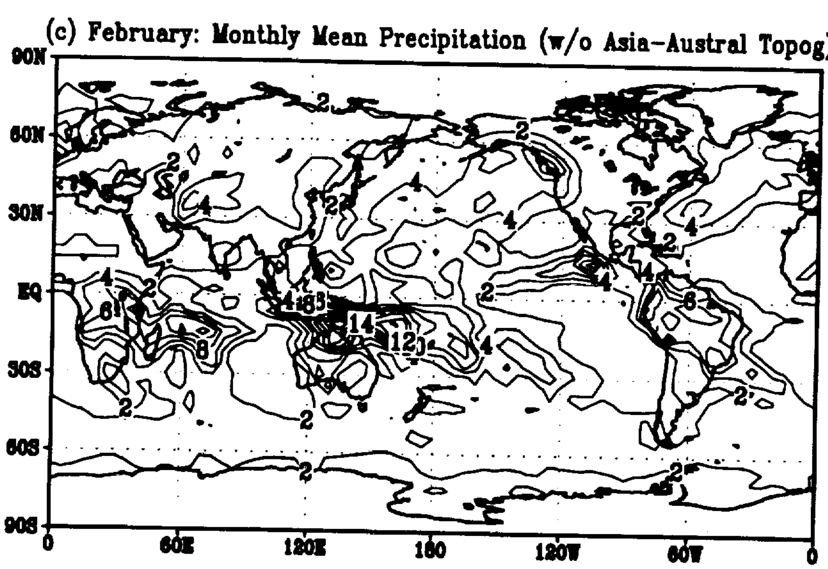


(c) August: Monthly Mean Precipitation (w/o Asia-Austral Topog)

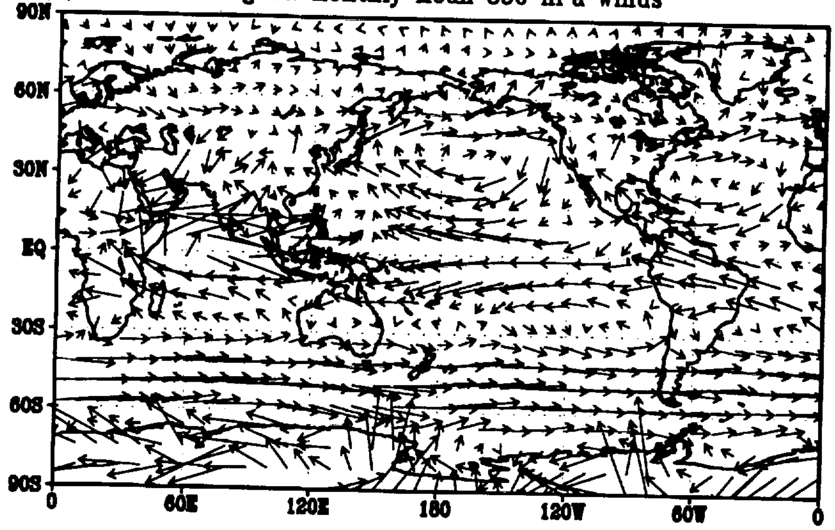



(a)
February: Monthly Mean Precipitation
90N
60N
30N
EQ
30S
60S
90S
0
60E
120E
180
120W
60W
0

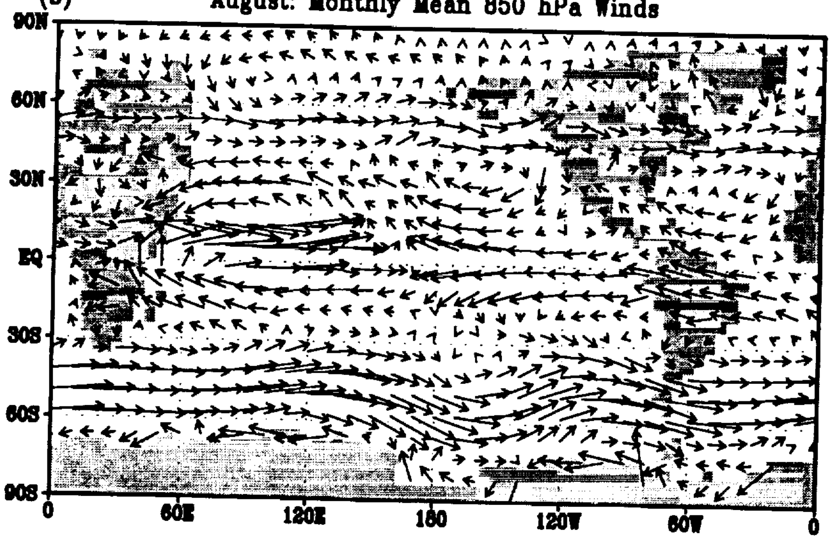

(b)
February: Monthly Mean Precipitation
90N
60N
30N
EQ
30S
60S
90S
0
60E
120E
180
120W
60W
0


(c) February: Monthly Mean Precipitation (w/o Asia-Austral Topog)
90N
60N
30N
EQ
30S
60S
90S
0
60E
120E
180
120W
60W
0

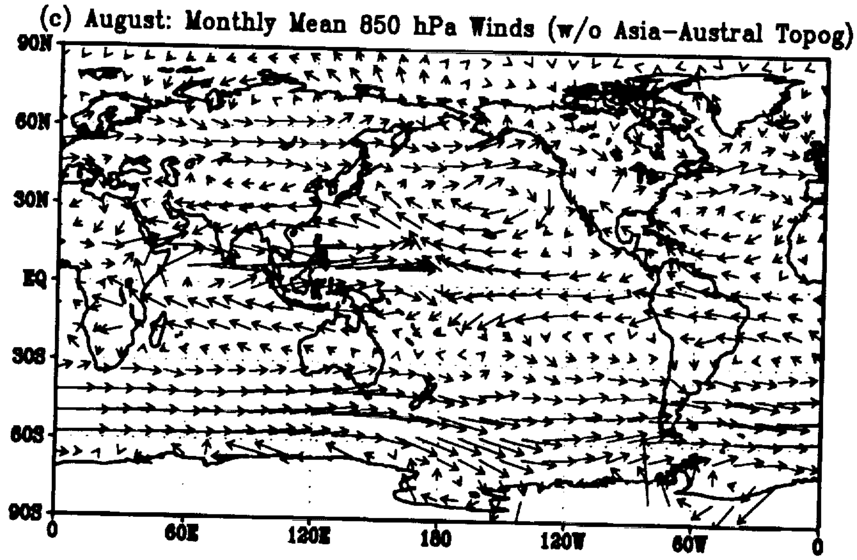
(a) August: Monthly Mean 850 hPa Winds



(b) August: Monthly Mean 850 hPa Winds



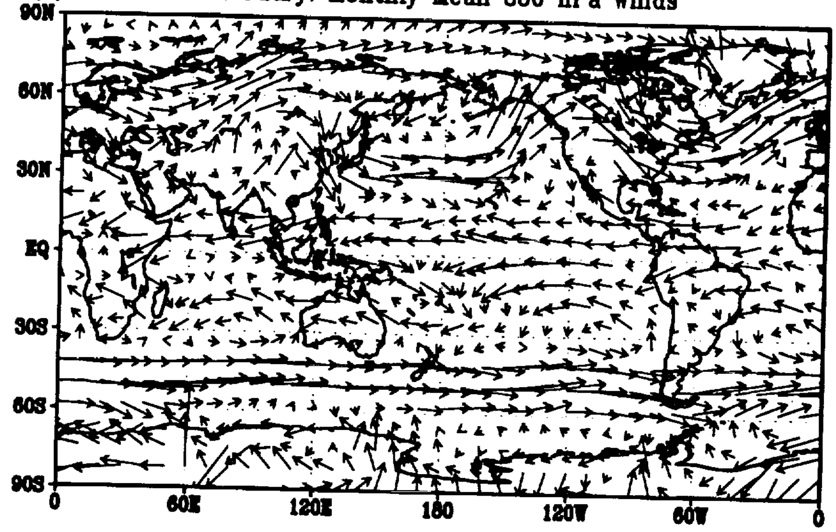
(c) August: Monthly Mean 850 hPa Winds (w/o Asia–Austral Topog)



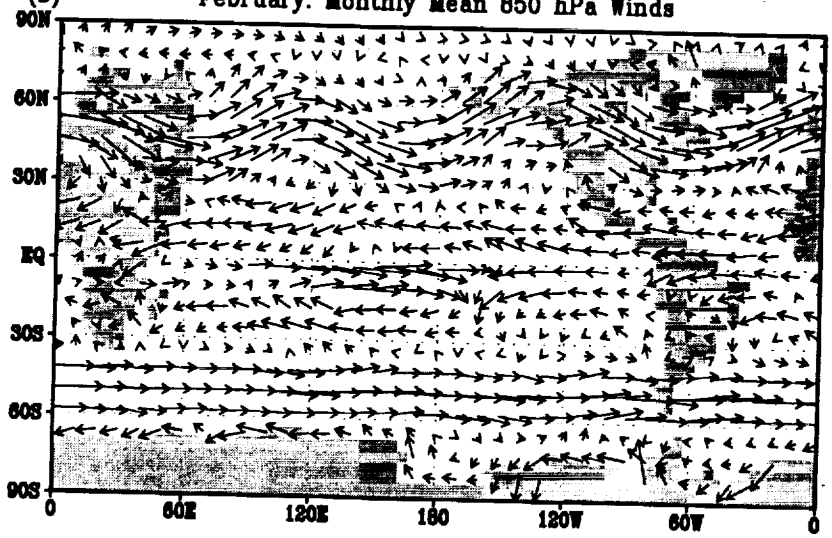
$\overrightarrow{30}$

4

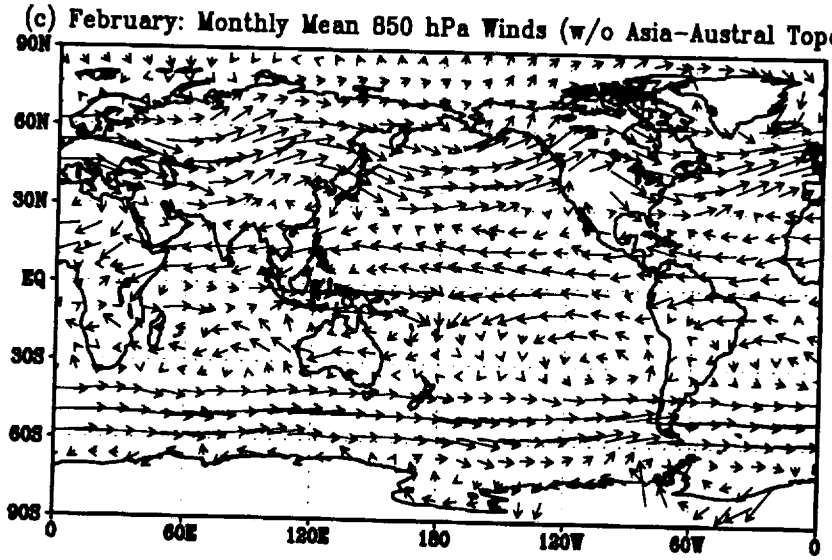
(a) February: Monthly Mean 850 hPa Winds



(b) February: Monthly Mean 850 hPa Winds

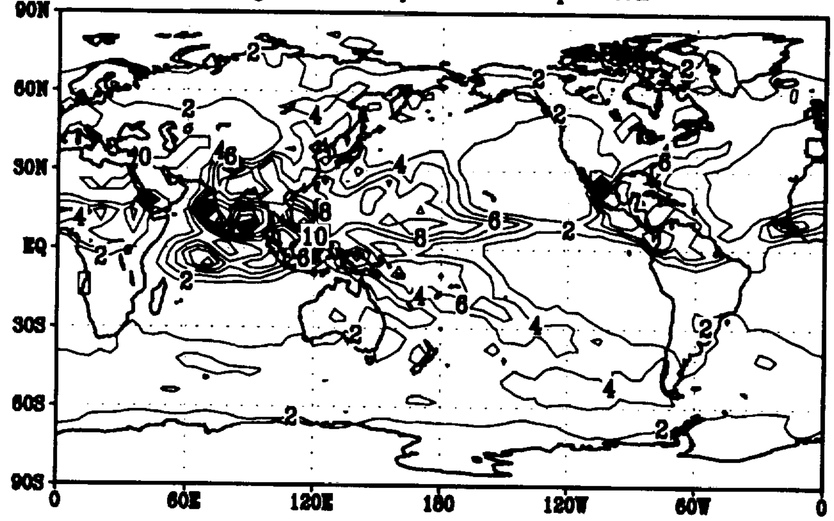


(c) February: Monthly Mean 850 hPa Winds (w/o Asia-Austral Topog)

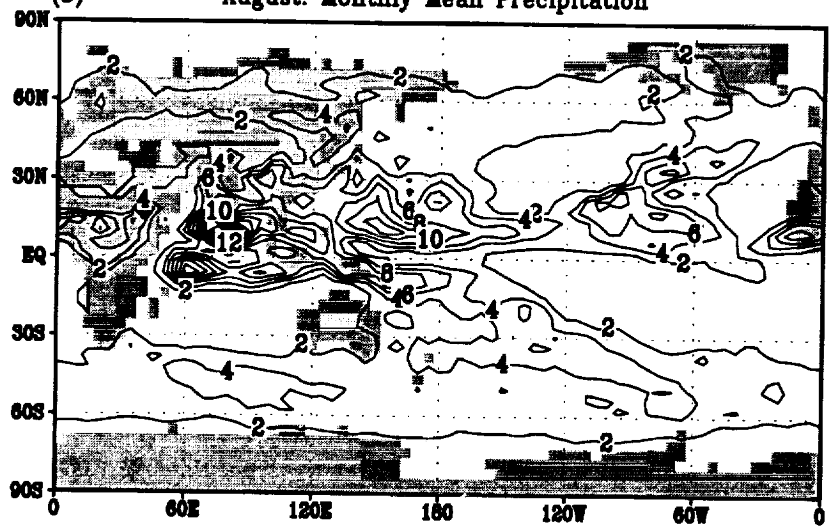


$\overrightarrow{30}$

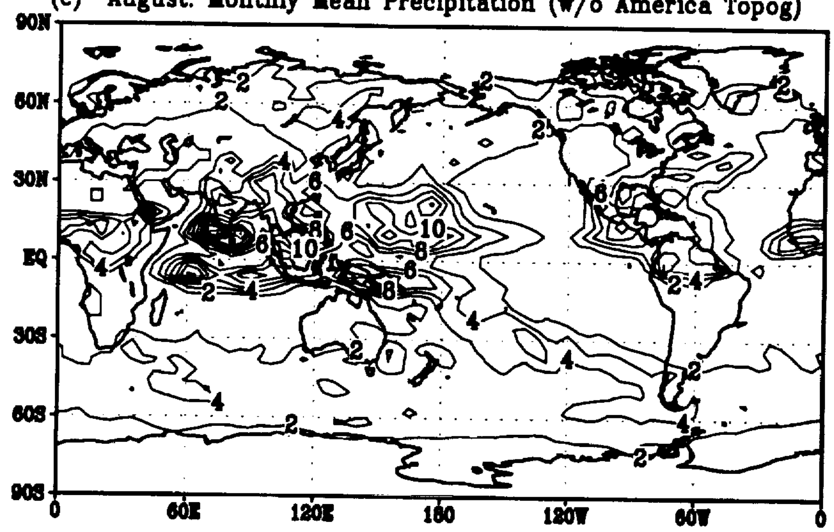
(a) August: Monthly Mean Precipitation



(b) August: Monthly Mean Precipitation



(c) August: Monthly Mean Precipitation (w/o America Topog)



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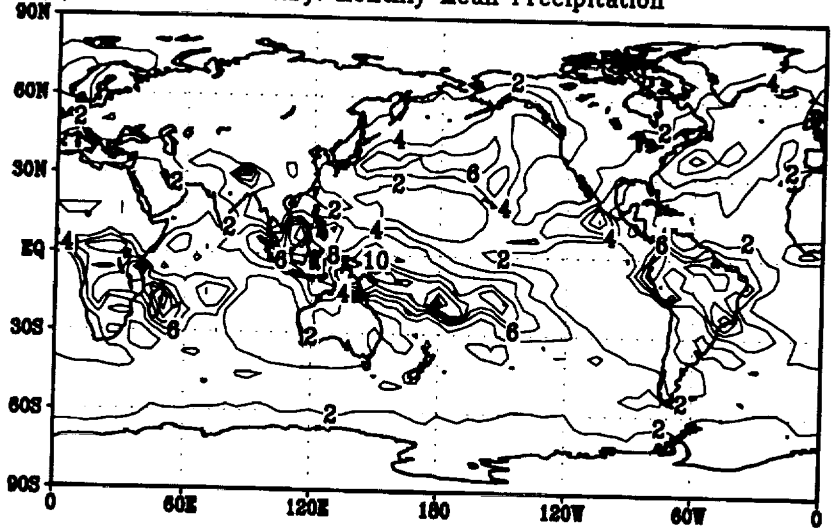
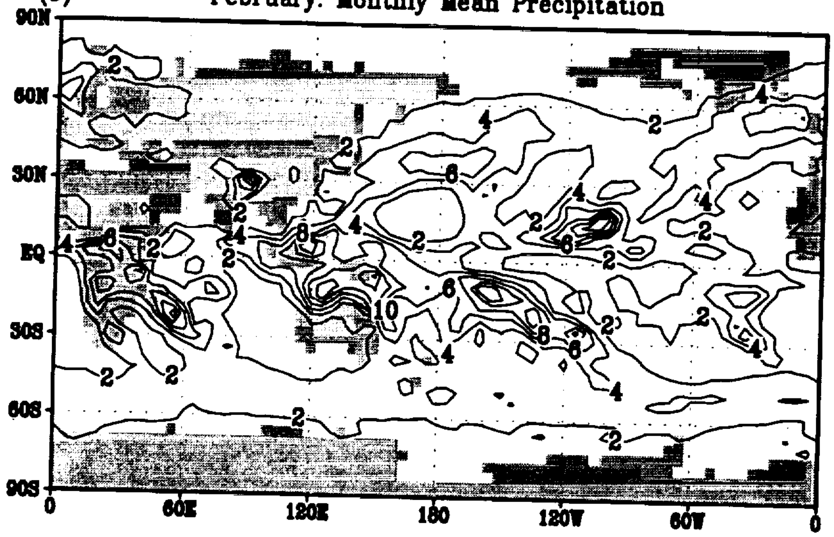
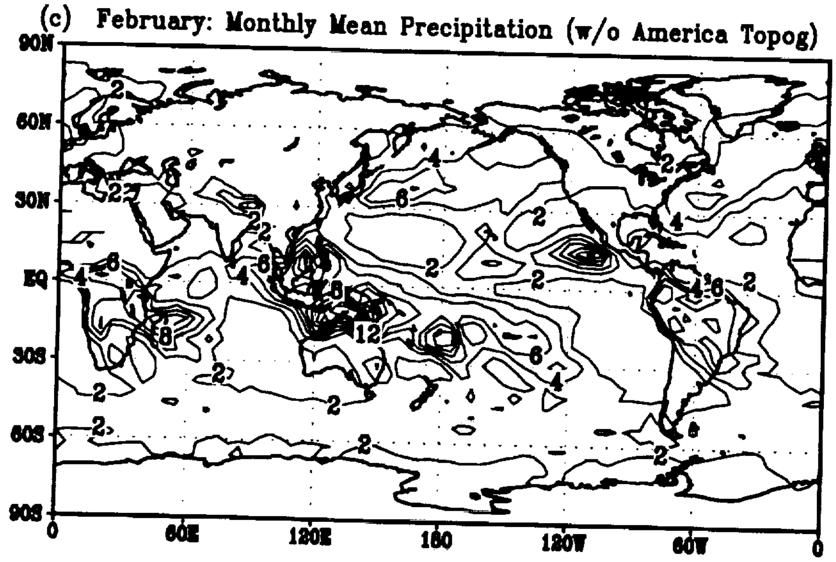
(a) February: Monthly Mean Precipitation



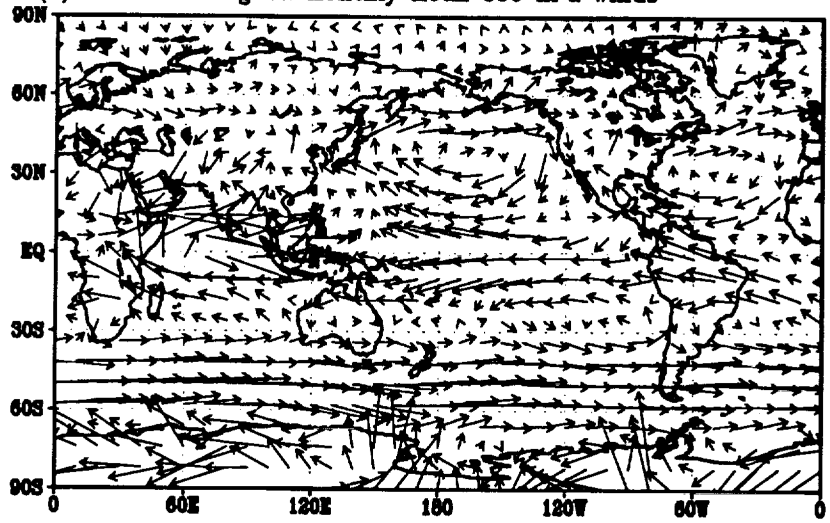
(b) February: Monthly Mean Precipitation



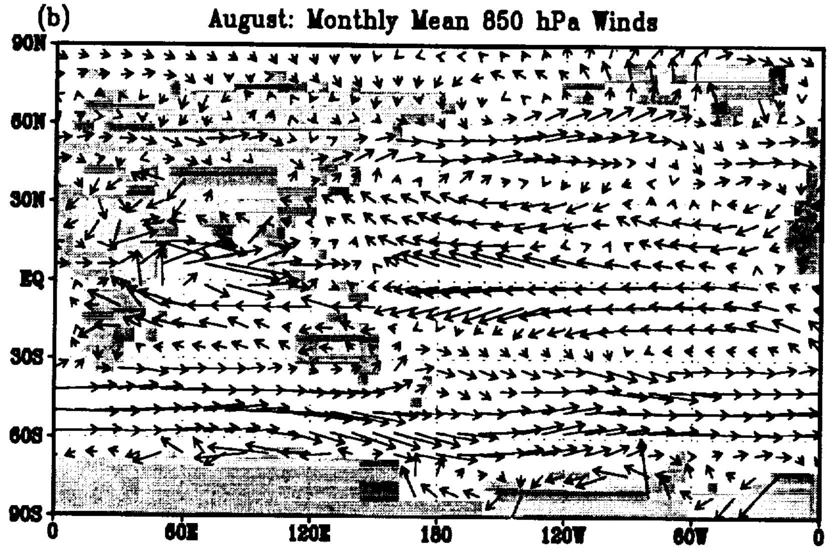
(c) February: Monthly Mean Precipitation (w/o America Topog)



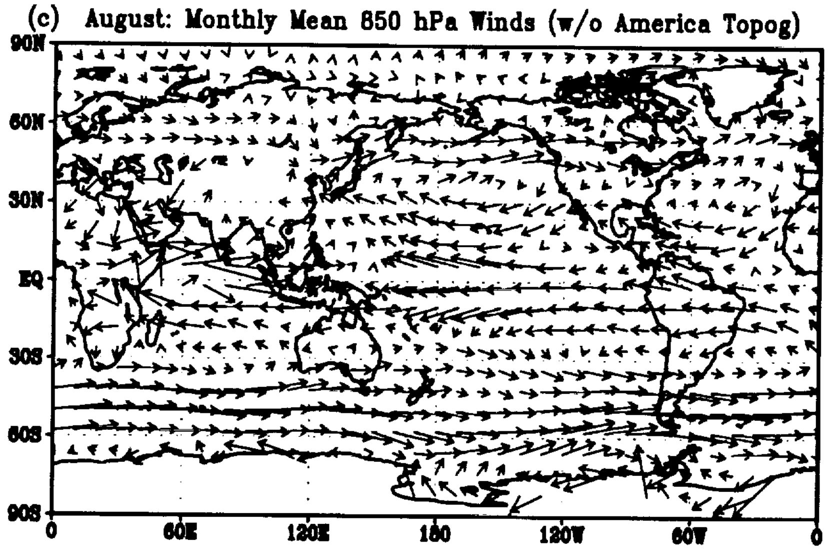
(a) August: Monthly Mean 850 hPa Winds



(b) August: Monthly Mean 850 hPa Winds



(c) August: Monthly Mean 850 hPa Winds (w/o America Topog)



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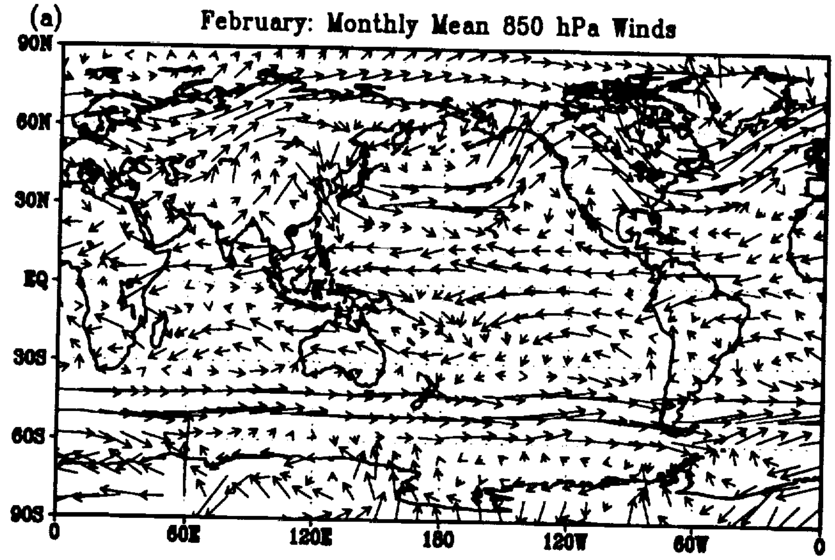
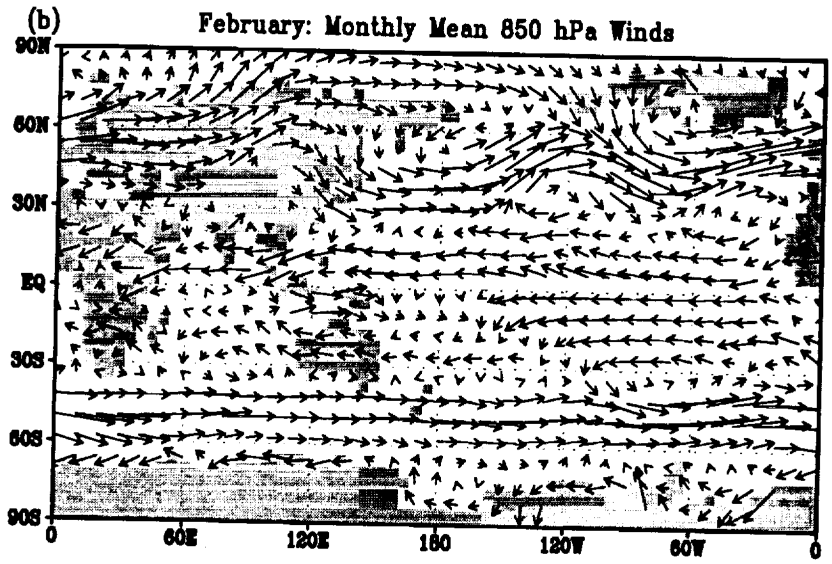
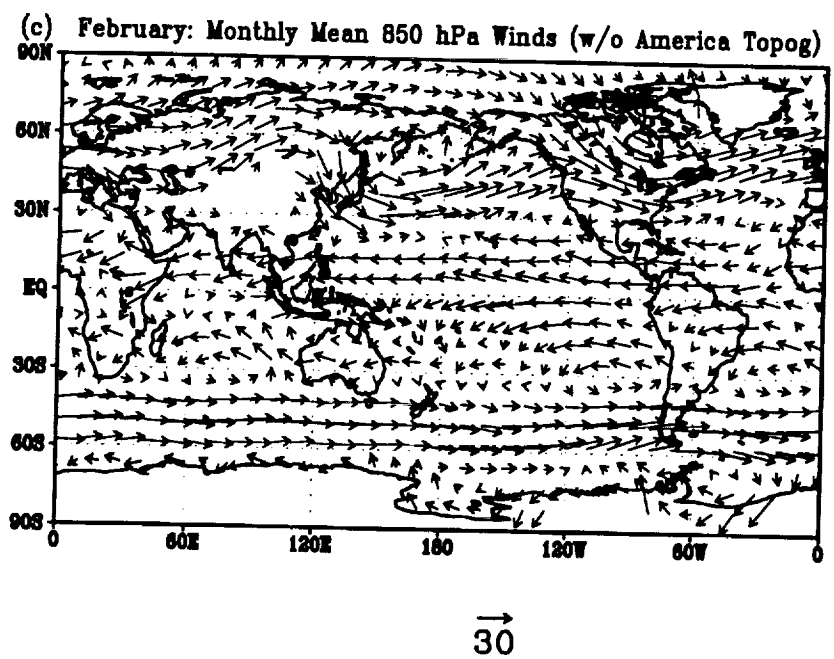
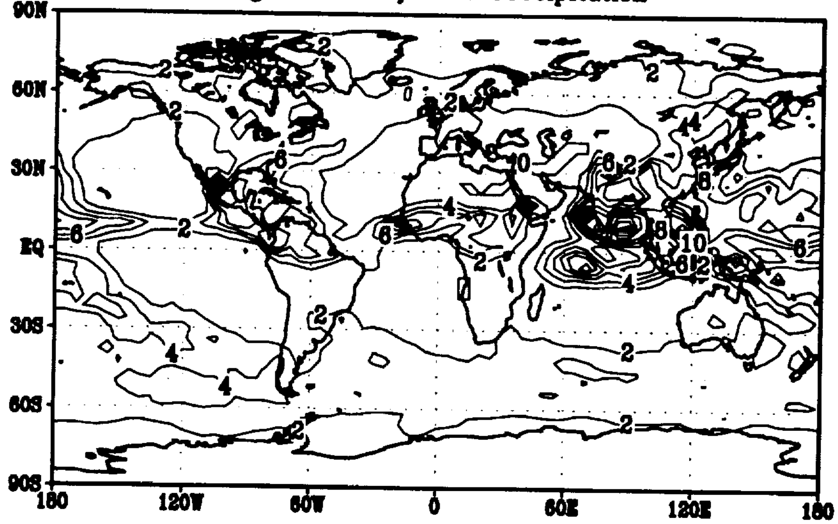

(a) February: Monthly Mean 850 hPa Winds
90N
60N
30N
EQ
30S
60S
90S
0
60E
120E
180
120W
60W
0

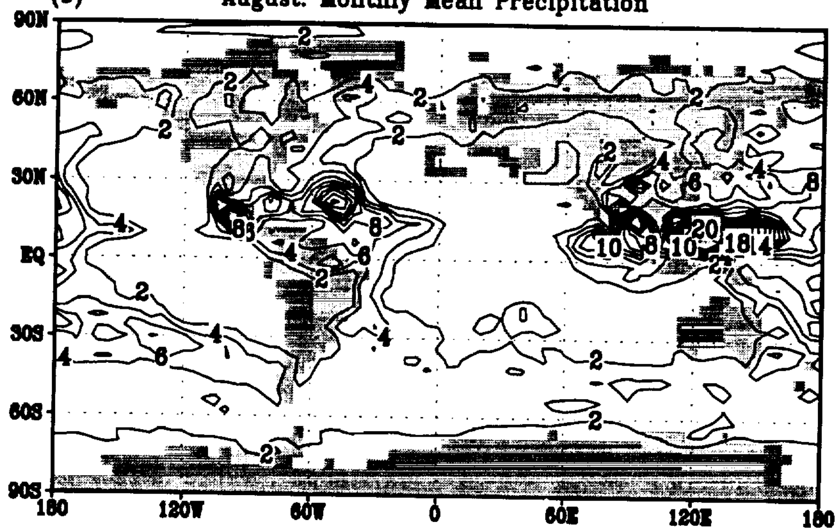

(b) February: Monthly Mean 850 hPa Winds
90N
60N
30N
EQ
30S
60S
90S
0
60E
120E
180
120W
60W
0


(c) February: Monthly Mean 850 hPa Winds (w/o America Topog)
90N
60N
30N
EQ
30S
60S
90S
0
60E
120E
180
120W
60W
0
30

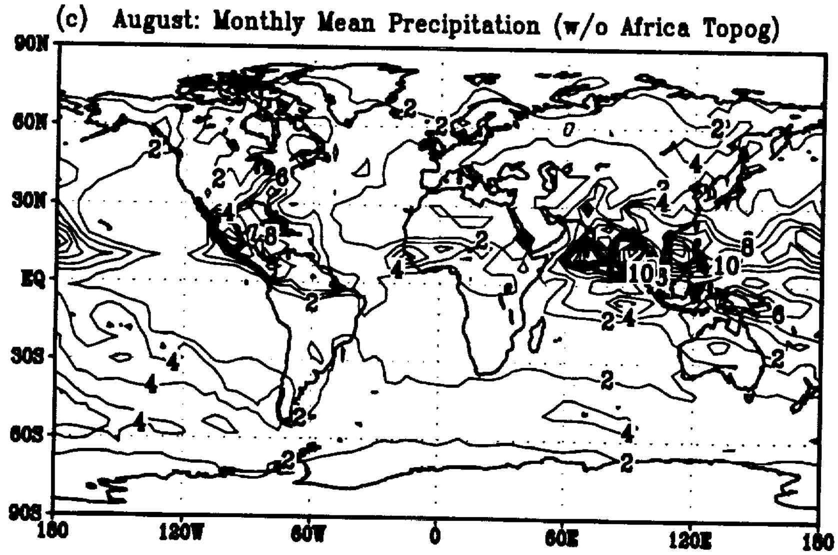
(a) August: Monthly Mean Precipitation

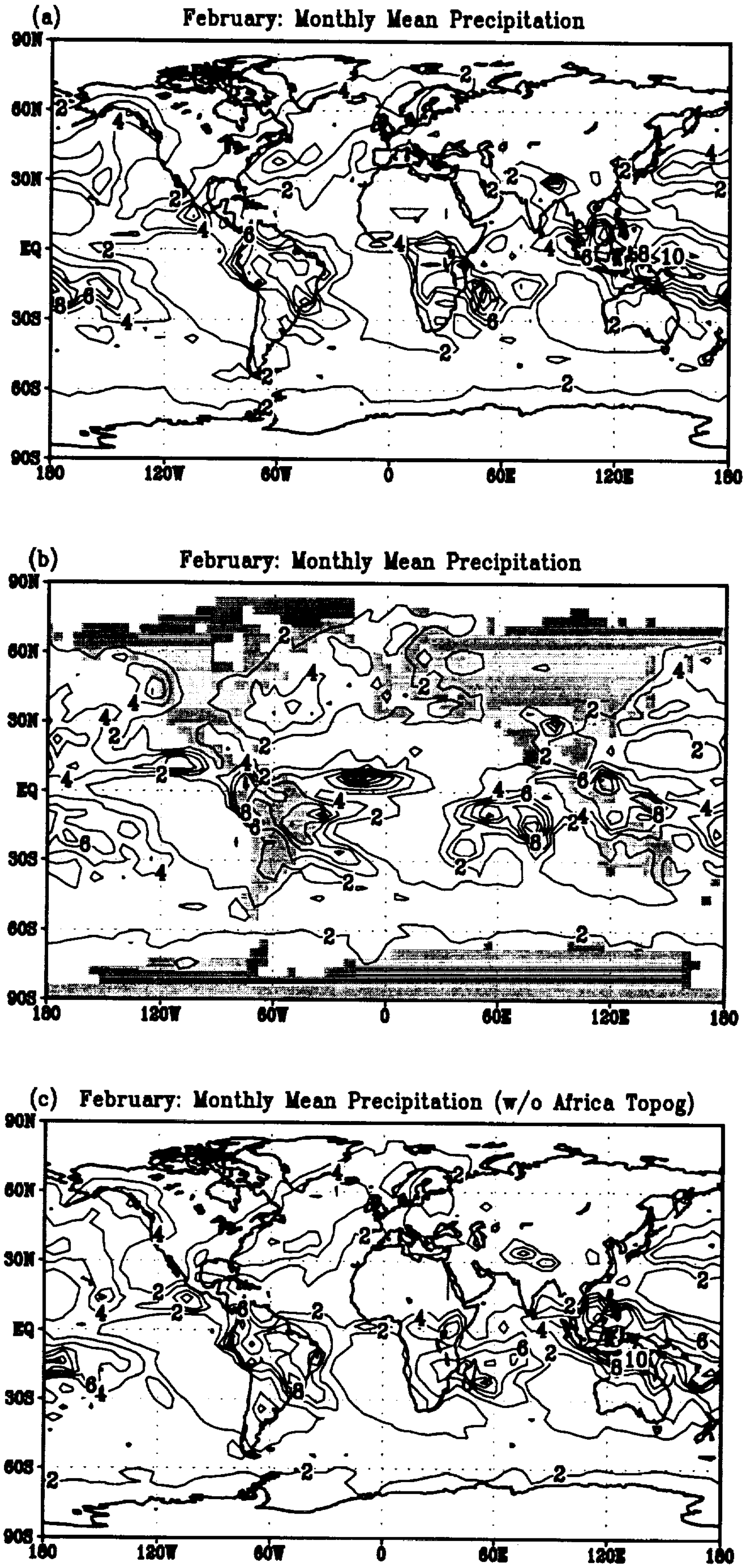


(b) August: Monthly Mean Precipitation

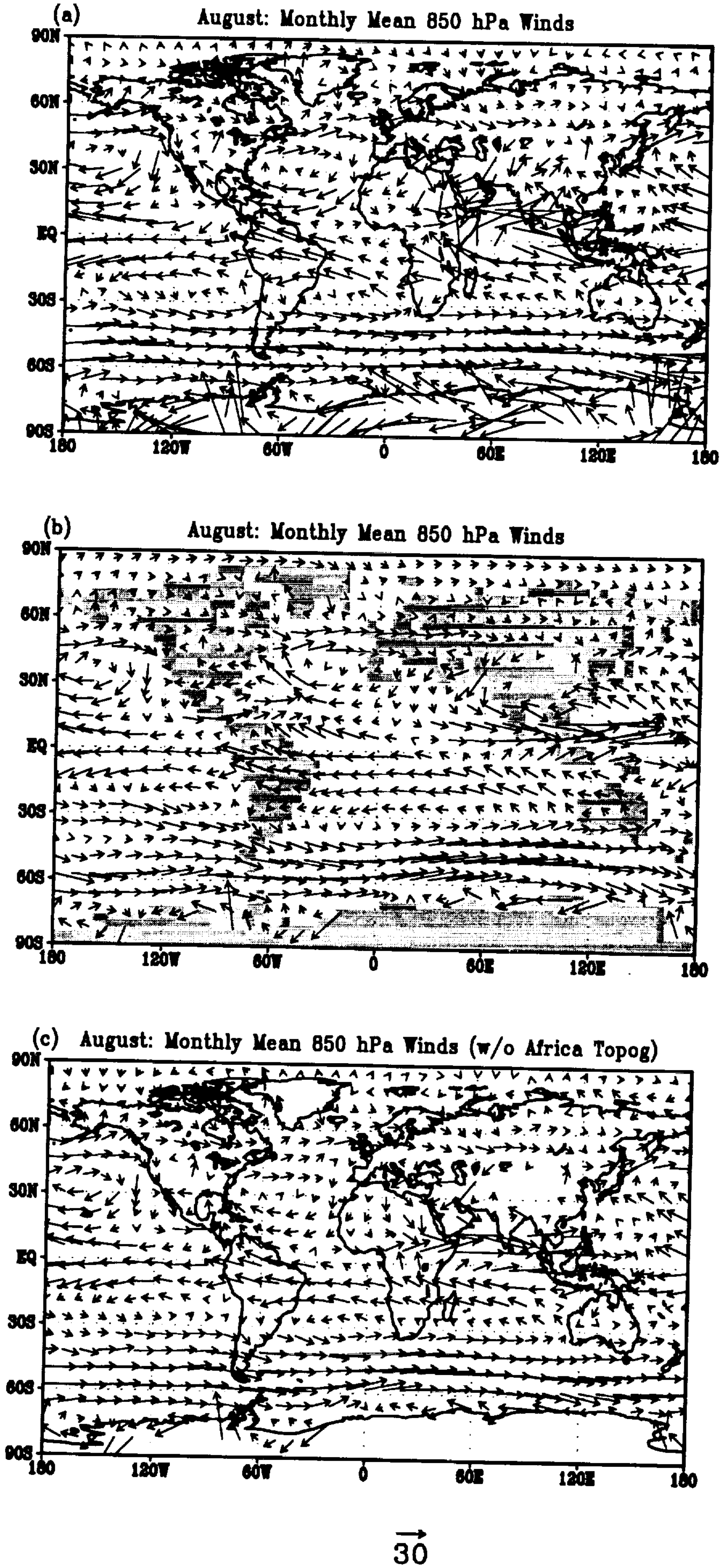


(c) August: Monthly Mean Precipitation (w/o Africa Topog)



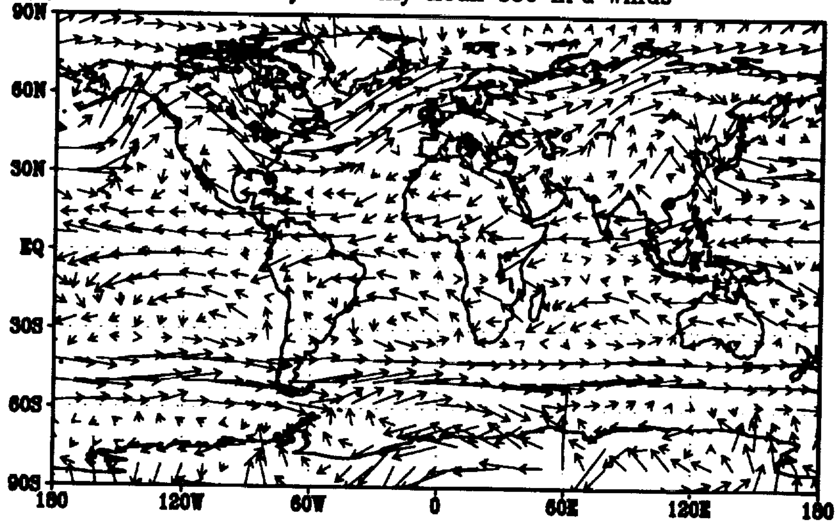

(a) February: Monthly Mean Precipitation
90N
60N
30N
EQ
30S
60S
90S
180
120W
60W
0
60E
120E
180
(b) February: Monthly Mean Precipitation
(c) February: Monthly Mean Precipitation (w/o Africa Topog)

11

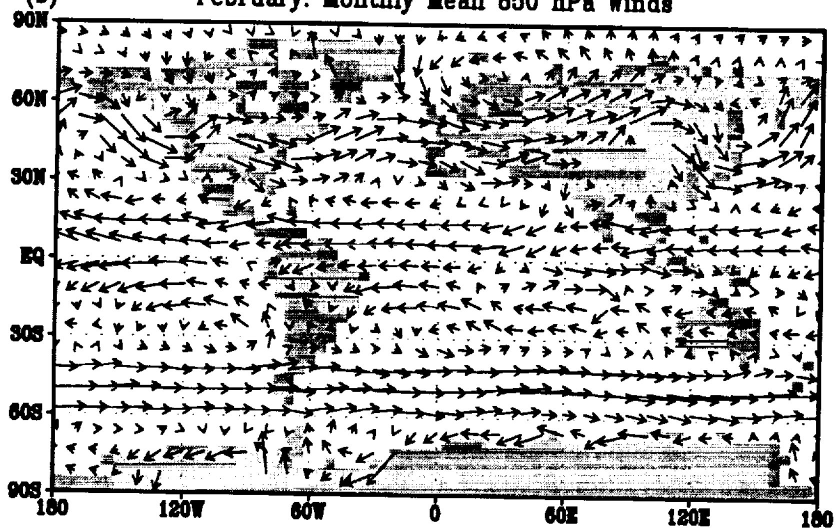


(a)
August: Monthly Mean 850 hPa Winds
90N
60N
30N
EQ
30S
60S
90S
180
120W
60W
0
60E
120E
180
(b)
August: Monthly Mean 850 hPa Winds
90N
60N
30N
EQ
30S
60S
90S
180
120W
60W
0
60E
120E
180
(c)
August: Monthly Mean 850 hPa Winds (w/o Africa Topog)
90N
60N
30N
EQ
30S
60S
90S
180
120W
60W
0
60E
120E
180
30

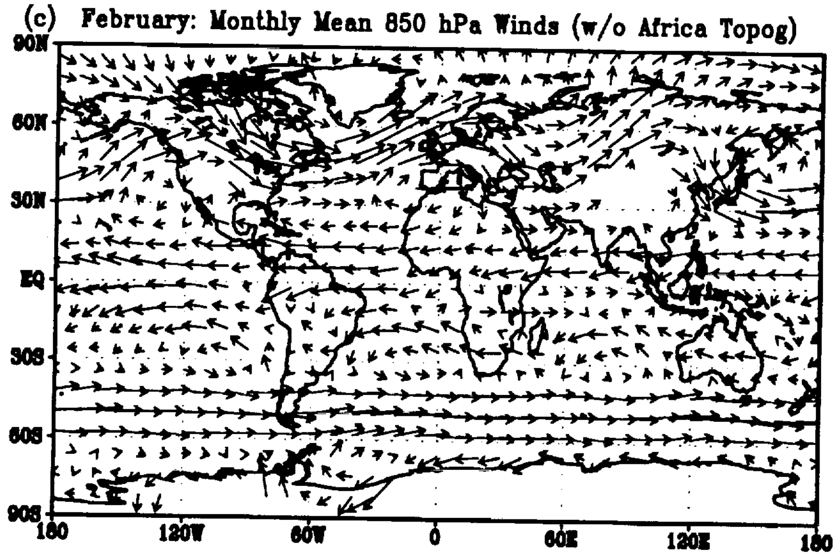
(a) February: Monthly Mean 850 hPa Winds



(b) February: Monthly Mean 850 hPa Winds



(c) February: Monthly Mean 850 hPa Winds (w/o Africa Topog)



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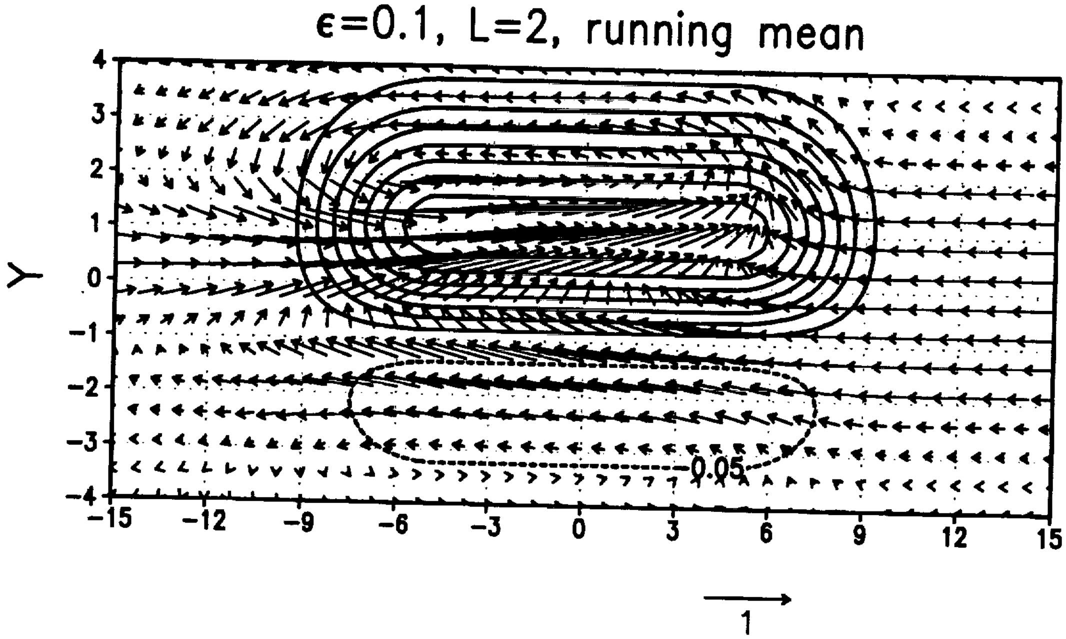
ϵ=0.1, L=2, running mean
Y
4
3
2
1
0
−1
−2
−3
−4
−15
−12
−9
−6
−3
0
3
6
9
12
15
-0.05
1