Mean state of the troposphere over south-east Asia and the East Indies, December 1978

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**Summary**

The mean state of the troposphere over south-east Asia from 8–30 December 1978 is described. In the lower troposphere, a jet was observed over the South China Sea extending south-westward from the Philippines. Evidence suggests that this north-easterly jet was supported by downstream blocking induced by the Borneo land mass. At the equator, the jet had the appearance of being channelled between the highlands of Borneo and Sumatra. On its left flank, near the west coast of Borneo, was a semi-permanent and quasi-stationary vortex. Being warm core, this vortex was probably maintained, in part, by latent heat release in cumulus convection.

By partitioning the data into means at 00 and 12 GMT, the intensity of the rising branch of the Hadley circulation over Borneo was shown to increase by a factor of two, from $-100 \times 10^{-5}$ to $-200 \times 10^{-5}$ mb s$^{-1}$, from 00 to 12 GMT.

1. Introduction

The winter monsoon experiment (WMONEX) was designed primarily for the study of regional-scale phenomena over south-east Asia from December 1978 through February 1979. It relied for the most part on an enhanced network of surface and upper air stations supplemented by a relatively small quantity of research ship, radar and aircraft data.

Studies of the mean state of the troposphere for the period of the winter monsoon have so far been relatively few. Mean fields of wind and kinematic variables are provided in Newell *et al.* (1972) and Murakami *et al.* (1981). The former presented a climatology for the northern winter. Their interest, however, was in the global rather than the regional-scale circulation. The latter presented twice daily and mean wind fields for WMONEX at 850 and 200 mb only.

This paper aims at a more complete description of the mean dynamic and thermodynamic structure of the regional-scale circulation for the period 8–30 December over the domain shown in Fig. 1. In view of the pronounced diurnal oscillation in cloudiness present in the equatorial cloud band (ECB) over the southern portion of the domain, it treats as separate fields the means for 00 GMT (08 LT) and 12 GMT (20 LT).

2. Data

(a) Gridded data

The components of the data set include edited and corrected First GARP Global Experiment (FGGE) level IIb data which have been supplemented in data-sparse regions by FGGE level IIIb $u$ and $v$ wind components, temperature and moisture from the European Centre for Medium Range Weather Forecasts (ECMWF) and 850 and 200 mb winds from Murakami *et al.*

The data set covers the period 8–30 December at nine mandatory levels (1000–150 mb), twice a day. The parameters include $u$ and $v$ wind components, relative vorticity, horizontal divergence, temperature and moisture. Vertical motion was computed by the
kinematic method from the averaged wind components. It was mass adjusted by applying a correction factor (constant with height) to the divergence. Zero mass exchange was assumed at 1000 and 100 mb.

The editing of level IIb data was an iterative process involving several steps. First, data from each station within the domain were tabulated in time–height format and summarized, level-by-level, in terms of mean, variance, skewness and kurtosis. Data considered to be unreasonable were flagged. Second, horizontal fields of wind, temperature and specific humidity were analysed at each level. Particular attention was given to data flagged in the first step. Inconsistent data were either deleted or replaced by interpolated values.

In addition to neighbouring points, the Murakami atlas was consulted before the data were inserted. As a third and final step, for the purpose of filling data gaps and holes, some level IIIb data were added after checking for consistency.

The relative densities of IIb and IIIb data are shown in Fig. 1. Level IIIb data were used primarily at the east, west and south boundaries of the domain and in the central part of the South China Sea (SCS).

The merged data sets were then gridded using an objective analysis scheme described in Barnes (1973). A 2° grid (~220 km) was chosen as roughly compatible with both the data density and the grid size of IIIb data (1·875°).
(b) Satellite data

Five-day-mean cloud cover for December was obtained from the Japanese Meteorological Agency (1979). This gives upper-level and total cloud cover over the ocean determined objectively from visible and infrared images of the Geostationary Meteorological Satellite-1 (GMS-1).

![Figure 2. Mean zonal (a) and meridional (b) wind components at 850 mb. Isopleths in m s⁻¹.](image)

3. TIME-AVERAGED FIELDS

(a) Features of the lower troposphere

The mean low-level flow (Fig. 2) is north-easterly over almost all of the SCS. Western flow regimes dominate the north-east and southern parts of the domain, strong easterlies occur in between (Fig. 2(a)). In the south, the transition between easterly and westerly flow takes place along the equator near the December mean position of the ECB (see Fig. 3(b)).

One of the most intriguing features is the existence of a low-level north-easterly jet. Winds in this jet peak at 8 m s⁻¹ in the latitude band 5-10°N near the Malay Peninsula.

A dominant feature in the relative vorticity field (Fig. 3) is the local region of strong positive vorticity off the north-west coast of Borneo. Its co-location with the 90% isoneph is striking. Daily streamline analyses during this period (Chang et al. 1981; Murakami et al. 1981) indicate a persistent, quasi-stationary vortex in the low-level wind field. The vortex has the appearance of being 'anchored' to the Borneo coast and according to Chang et al. (1982) the 850 mb vorticity increases synchronously with the occurrence of cold surges in the SCS.

(b) Features of the upper troposphere

The upper-level flow is, by and large, consistent with that expected from thermal wind balance. A pronounced poleward decrease of temperature (not shown) over this domain requires an increase in the westerly wind component with height (Fig. 4(a)). At 200 mb there is, in addition, a pronounced acceleration of the zonal wind component downstream from the Himalayas. The wind reaches a mean maximum speed in excess
of 55 m s\(^{-1}\) about 20° downstream from the Himalayan barrier. Murakami (1981) showed that flow separation occurred around the Himalayas and jet maxima were observed downstream where the flows merged.

The 200 mb \(v\) component (Fig. 4(b)) indicates southerly flow over most of the domain. The axis of maximum southerly wind lies NE–SW as does the axis of maximum northerly wind in the lower troposphere. The Hadley circulation is usually interpreted as a zonally symmetric flow in which air rises in the warm tropics and sinks in the cool subtropics (e.g. Lorenz 1983). In December over the SCS, it appears that the meridional circulation is enhanced along a NE–SW axis with the implication that in this limited domain the zonal symmetry of the classical Hadley circulation is severely distorted.

The 200 mb divergence (Fig. 5) shows a broad axis of upper tropospheric divergence within an area enclosed by the 60% isoneph (Fig. 3(b)). The area of convergence to the north of this coincides approximately with areas of less than 40% cloudiness showing
that at least the major features in the mean horizontal divergence are spatially consistent with the mean cloud field.

Cross-sections along 114°E of temperature anomaly and meridional wind component (Figs. 6(a), (b)) show the upper troposphere to be relatively warm and the lower half of the troposphere over China and the northern part of SCS to be relatively cool. A comparison with the $v$ component indicates that the circulation is transporting warm air poleward in upper levels and cool air equatorward in lower levels as would be expected in a thermally direct circulation.

4. **Mass field**

A cross-section of the mass-adjusted vertical motion along 114°E (Fig. 7) generally indicates rising motion in low latitudes and sinking in mid latitudes. The overall picture, however, is complicated by several regions of local rising and sinking motions. The strongest rising motion occurs within the ECB at the equator. On its poleward side near 5°N, the boundary between rising and sinking motion corresponds spatially with the maximum gradient in high-level cloud amount (which includes the areal coverage of both deep cumulonimbus and associated cirrus anvils) (Fig. 3(b)). It is suggested that mesoscale subsidence forced by the evaporation of hydrometeors in unsaturated air beneath anvils spreading polewards (Zipser 1977; Houze 1977; Fernandez 1982) contributes to the strong gradient in vertical motion observed here. To confirm this, of course, would require a study of the transient properties of the circulation.

Elsewhere, a region of weak rising motion is observed between 10 and 15°N. From an examination of GMS-1 infrared images (not shown) we conclude that this is likely to have resulted in part from the passage of a well-organized, long-lived and slow-moving convective disturbance which entered the Philippine Islands on 13 December and eventually dissipated near the Vietnam coast on 20 December.
In the northern latitudes over China, mean sinking motion is observed within the Siberian anticyclone poleward of 30°N.

5. Effects of Topography

(a) Diurnal variation

A pronounced diurnal oscillation has been observed in precipitation and cloudiness near Borneo (Houze et al. 1981) and in vertical motion at a point off the north-west coast of Borneo (Johnson and Prießnitz 1981). This prompted us to partition the gridded data into 00 GMT and 12 GMT means.

Cross-sections of vertical motion along 114°E at 00 and 12 GMT with the NMC gridded topography are shown in Fig. 8. Some very pronounced changes are observed.
Figure 7. Mean mass-adjusted vertical motion along 114°E in units of $10^{-3}$mb s$^{-1}$. Negative values indicate rising motion.

Figure 8. As in Fig. 7 except for 00 GMT (a); and 12 GMT (b).
to take place. In particular, the rising motion observed along the EBC over Borneo increased by a factor of two from roughly $-100 \times 10^{-5} \text{mb s}^{-1}$ to about $-200 \times 10^{-5} \text{mb s}^{-1}$. This is probably a direct result of diurnal heating of the Borneo land mass. The enhanced subsidence to be expected from conservation of mass is found immediately poleward of the upward cell. It occurs mainly in phase with strong ascent in that cell.

Over China, the vertical motion changed sign from weak descent at 00 GMT to weak ascent at 12 GMT. We put forward the hypothesis that the topography of southern China acts as an elevated heat source during the daytime leading to the observed rising motion in the afternoon or early evening. At night, subsidence would be required to compensate (by adiabatic warming) the radiational cooling above the elevated plateau. A detailed heat balance study would help to determine whether there was a simple balance between diabatic sources and sinks and vertical motion (as stated above) or whether the changes were caused by a diurnal variation in sensible heat transport near the coast line.

(b) Flow modification

Since the low-level flow during cold surges extends to areas south of the equator, it would appear that cold surges enhance the cross-equatorial mass transport. With the objective of determining the magnitude and preferred locations of this transport, cross-sections along the equator are presented, Fig. 9. The section along the equator intersects Borneo and Sumatra, the surface elevations of which are included in the figure.

The mean meridional mass flux ($u$ component) is from the northern into the southern hemisphere between the surface and middle troposphere and vice versa in the middle to upper troposphere. The level of transition is near 600 mb. By far the largest mass flux into the southern hemisphere occurs at low levels (about 850 mb) in the longitude band between 100 and 110°E. The flow has the appearance of being confined between the highlands of Borneo and Sumatra. It is clear that relief exerts a very strong influence on the mean low-level flow into the southern hemisphere.

The low-level jet in the $u$ component along the equator leads to the local region of strong cyclonic vorticity ($20 \times 10^{-6} \text{s}^{-1}$) observed slightly to the west of Borneo (see Fig. 3(a)). This vorticity maximum occurs in the same region as the quasi-stationary, semi-permanent vortex analysed in the low-level windfields of Chang et al. (1981) and Murakami et al. (1981). Strong rising motion and a positive temperature anomaly are indicated in the eastern section of the vortex. An examination of the low-level flow during cold surges shows that the flow, which is initially anticyclonic leaving China, acquires strong cyclonic curvature while being channelled between Borneo, the Malay Peninsula and Sumatra. The configuration of these land masses may be responsible for the existence of the cyclonic vortex off the west coast of Borneo. Further, latent heat release in cumulus convection (released by low-level convergence effected by the vortex) could act to maintain the cyclonic circulation.

The cross-section of meridional wind component along 114°E (Fig. 6) shows a maximum northerly component in the central SCS near 15°N, which reduces to near zero over Borneo at low levels, thus implying that Borneo acts as a barrier to the low-level flow. The deceleration of the flow occurs well upstream from Borneo. Further, the Borneo mountains form a dividing line between low-level westerlies to the south and low-level easterlies to the north (Fig. 2(a)). The topographic features of Borneo and Sumatra and the heat source of Borneo may therefore be responsible for both the maintenance of the cyclonic vortex on the west coast of Borneo and the presence of the low-level jet in the north-easterlies to the north of Borneo. Except that the main downstream heat source is located on the equator, this appears to be a winter monsoon
Figure 9. Cross-sections along the equator for (a) temperature anomaly; (b) meridional wind component; (c) vertical motion; (d) relative vorticity. To the right of (b) is a vertical profile of zonal average of December mean $v$ component along the equator. The topography is included in each figure representing Sumatra (left) and Borneo (right). Note that individual peaks with elevations above 850 mb have been smoothed in both land masses by the gridding algorithm.
analogue to the west Indian Ocean–Asian heat source circulation of the summer monsoon (see Krishnamurti et al. 1981).

6. Summary

Dynamic and thermodynamic fields of objectively analysed data were used to examine some mean features of the regional-scale circulation during December of the 1978/79 winter monsoon over south-east Asia. In addition, diurnal differences in the regional-scale circulation were studied by partitioning the data into means at 00 GMT (08 LT) and 12 GMT (20 LT).

The mean vertical motion along 114°E indicated strong rising motion within the ECB over Borneo and sinking motion at higher latitudes over central China. Superimposed on this were regions of local sinking and rising motions which may have been related to regional-scale features in the cloud field.

Large changes were found in the vertical motion fields at 00 and 12 GMT. Rising motion over Borneo was twice as strong at 12 GMT as at 00 GMT. Over China, the vertical motion changed sign from sinking at 00 GMT to rising at 12 GMT.

The highlands of Borneo, the Malay Peninsula and Sumatra exerted a strong influence on the low-level flow in the SCS and at the equator. The interhemispheric mass flux was concentrated in a low-level northerly jet between Borneo and Sumatra. As a result, a persistent cyclonic vortex was set up to one side of this narrow channel. Further, the vortex possessed a warm core with the implication that latent heat release was a significant factor in addition to the relief in the maintenance of the vortex.

Lastly, the north-easterly flow in the central part of the SCS possessed a distinct jet structure at low levels. It was hypothesized that this feature was supported by downstream blocking forced by the highlands of Borneo.

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