On the Application of Satellite Data on Cloud Brightness to the Study of Tropical Wave Disturbances

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1. Brightness spectra

Recently there have been a number of attempts to utilize satellite-derived data on cloud brightness to define the dominant scales of motion in the tropics. Several of these studies have classified different types of disturbances in terms of time scale, or period. These results, summarized in Table 1, show almost a continuum of spectral peaks with periods ranging from 4-5 days to ~20 days, which is the longest period which can be resolved with the short data records which have been used.

We are of the opinion that much of this proliferation of spectral peaks stems from the fact that the time spectra of cloud brightness are highly variable from one local region to another and from one season to another. Within a given season, the cloud brightness at a particular grid point might exhibit a time spectrum with a well-defined peak, while the spectrum at a neighboring grid point shows a different peak, or perhaps no peak at all. In our experience the more data one averages, the less prominent the spectral peaks tend to become. As an example, we have computed spatially averaged time spectra of digitized cloud brightness based on data for 5°x5° squares of latitude and longitude for the period June–August, 1967. The spectra for individual squares were averaged over longitude from 120E to 170W for three latitude belts: the equator, the intertropical convergence zone, and the trade wind belt. The resulting spectra shown in Fig. 1 are rather featureless, despite the very prominent 4-6 day peak in the lower tropospheric wind data at stations throughout the tropical northwest Pacific during this particular season (Wallace, 1971).

There are a number of factors which may account for the poor correspondence between the cloud brightness spectra and the wind spectra:

1) The frequency distribution of cloud brightness is skewed toward low values (clear skies), particularly in dry regions. When the skewness is large, the shape of the brightness spectrum is strongly influenced by a relatively small number of occurrences of large brightness. Spectrum analysis is not well suited for dealing with this type of time series.

2) There is some time variability in the response of the cloud brightness sensor, particularly at the low frequencies. Efforts have been made to correct the data for this effect (e.g., see Taylor and Winston, 1968), but it is probably impossible to remove those fluctuations entirely. The extent to which instrument noise influences the time spectra of cloud brightness has not been investigated.

3) The correspondence between cloud brightness fluctuations and the passage of synoptic-scale waves is far from perfect. In dry regions, waves may pass without producing any cloudiness at all. Further confusion is caused by our inability to distinguish between those cloud types characteristic of disturbed weather, and those which are typically associated with dry, settled regimes.

Thus, it appears that the spectrum of cloud brightness is not particularly well suited as a basis for classifying tropical disturbances.

2. Propagation speed of cloud bands

A more successful approach to identifying and separating disturbance types in cloud brightness data is to discriminate between various zonally propagating waves on the basis of phase speed. This can be done either by direct visual inspection of time-longitude displays of cloud brightness data (Chang, 1970), or by means of various objective techniques. We have recently completed an extensive investigation based on a combination of objective techniques including cross-covariance and cross-spectrum analysis and a number of different filtering schemes. Aside from yielding some evidence of a standing wave oscillation in cloud brightness in the central Pacific region (see Wallace, 1971), this investigation produced little in the way of definitive new results. In a number of cases we were not even successful in verifying some of the features which are clearly evident from visual inspection of the time-longitude displays. We were led to conclude that, despite its subjectivity, the direct visual technique, which relies on pattern recognition, is a far more sophisticated tool for identifying predominant phase speeds than the objective techniques which have been used in studies of this type.

Previous studies based on visual inspection of time-longitude sections have all stressed features with phase speeds on the order of 6°-8° per day, westward (Chang, 1970; Tanaka and Ryugui, 1971; Sikdar and Suomi, 1971; Wallace, 1971; Reed and Recker, 1971). The
latter investigators showed convincing evidence that these are linked to forced Rossby waves in the wind field with maximum amplitude near the ITCZ. These westward propagating features are most clearly marked at latitudes near 10N over the ocean regions, but they often extend into subtropical latitudes during summer and they occasionally appear at equatorial latitudes (Wallace, 1970).

In the time-longitude sections for equatorial latitudes there is often a suggestion of eastward moving features, with phase speeds of 6°–8° longitude per day, superposed on the more familiar westward propagating cloud bands. Tanaka and Ryugui (1971) point out one such disturbance and a number of them are evident in the time-longitude sections shown by Wallace (1970). In an attempt to separate the eastward and westward moving features so that they can be seen more clearly we produced composite sections: one for the sum of the brightness at 5N and 5S and one for the difference. It was our hope that the sum section should tend to emphasize the eastward propagating disturbances, and the difference series the westward propagating ones. Our reasoning was based on the fact that the only one of the normal modes on an equatorial beta plane which propagates eastward with relatively low phase speeds is the Kelvin wave, which has even symmetry about the equator. We might expect that a disturbance which propagates eastward along the equator might bear some resemblance to a Kelvin wave, at least with regard to equatorial symmetry. On the other hand, the westward propagating Rossby modes may have either even or odd symmetry, so they should appear in both the sum and difference sections.

The results for the 1967 and 1970 summer seasons are shown in Figs. 2 and 3. As expected, the eastward propagating features are largely confined to the sum series. These are particularly noticeable during the 1970 season, and over the Asian sector. The section for the equator (not shown) is very similar to that for the sum series.

It is possible to obtain an indication of the frequency of the eastward propagating disturbances by counting the number of cloud bands crossing a given longitude over the three-month period. If we include the weak and poorly organized bands, we arrive at a total of 8–10 waves in 92 days, or a wave frequency of ~0.1 cycle per day (cpd). Assuming a phase speed of ~7° per day, this is consistent with a zonal wavelength of ~8000 km. This is far too short a wavelength to suggest any direct identification of these cloud bands with the eastward propagating Kelvin waves observed in the lower stratosphere.

In an attempt to gain some insight into the nature of these eastward propagating disturbances, we examined the relationship between cloud brightness and zonal wind at Singapore, the one equatorial station in the Asian sector for which data were readily available. The zonal wind component was chosen because of symmetry considerations. (Waves whose vertical motion fields have even symmetry about the equator should not produce any meridional wind fluctuations at equatorial stations.) If the disturbances in question are Kelvin waves, then brightness and zonal wind fluctuations with periods near 10 days should be approximately in quadrature, with maximum brightness leading the peak westerly wind at lower tropospheric levels by ~1/4 cycle. This configuration would result in low-level convergence coincident with maximum brightness.

Cross-spectrum analysis was performed, using daily data for the periods June–August, 1967 and 1970, using 5 lags. The results for the 0.10-cpd frequency band are shown in Table 2. There is significant coherence between brightness and 700-mb wind for both years, with that for 1970 being higher, as expected. The phase relationships are consistent for the two years with brightness leading zonal wind by about ~1/4 cycle, which is fairly close to the expected ~1/4 cycle. The coherences for the 850-mb level are below the 95% significance level. Similar calculations for the 200- and 150-mb levels (not shown) did not indicate any consistent relationship between zonal wind and brightness.

The results for the 700-mb level are encouraging, though not by any means definitive. There is a possi-

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**Table 1. Spectral peaks in cloud brightness.**

<table>
<thead>
<tr>
<th>Period range (days)</th>
<th>Investigators</th>
<th>Method</th>
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<tbody>
<tr>
<td>~12.25</td>
<td></td>
<td></td>
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<tr>
<td>~16.07</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7-8</td>
<td>Sikdar and Suomi</td>
<td>Visual inspection, average percent cloud cover in region 0-15N, 120–180W, April 1967.</td>
</tr>
</tbody>
</table>

![Fig. 1. Time spectra of digitized cloud brightness for 5°×5° squares of latitude and longitude for the period June–August, 1967. Spectra are averaged over longitude for the 15 grid points from 120E to 170W and over latitude as indicated in the figure.](image-url)
bility of other interpretations; for example, Yanai and Murakami mentioned oscillations in the zonal wind component at equatorial Pacific stations during the spring of 1962, which they first interpreted in terms of a westward propagating Rossby wave mode (Yanai and Murakami, 1970a), and later in terms of an eastward propagating Kelvin wave with a 20,000 km wavelength (Yanai and Murakami, 1970b).

3. Conclusions

Objective analysis of cloud brightness data has failed to produce a clear definition of the predominant scales of motion in the tropics. Subjective classification of disturbance types on the basis of the speed of propagation of their associated cloud bands appears to us to be the most effective means available at this time for accomplishing this purpose. On the basis of this classification scheme, we find two basic types of zonally propagating, synoptic-scale disturbances which influence cloud brightness in the tropics: 1) Rossby waves, with phase speeds ranging from \(5^\circ-10^\circ\) longitude per day, westward, and 2) Kelvin-like waves which move eastward at \(5^\circ-10^\circ\) per day within a narrow band of latitude centered on the equator. Further work will be needed to define the structure of these waves.

We have expressed a number of reservations regarding the use of objectively analyzed cloud brightness data as a basis for classifying tropical disturbances. To conclude on a more positive note, we would like to emphasize the potential importance of this type of data with respect to the problem of synoptic analysis in the tropics. Despite the lack of discrimination between different types of cloudiness, the area-averaged cloud brightness shows a surprisingly good correspondence with vertical motion; better, in fact, than rainfall or
the vertical profile of relative humidity (Wallace, 1971). It is likely that the correspondence will be even better in the case of infrared and enhanced cloud brightness data which will soon be available on a routine basis. Thus, it may be possible to derive at least a rough estimate of the vertical motion field over the whole tropics, based entirely on satellite data. When integrated with wind and temperature data in numerical prediction models this information may make a significant contribution toward improving synoptic analysis over large areas where ground based coverage is minimal.

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REFERENCES


