An Objective Method for the Identification of the Intertropical Convergence Zone

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ABSTRACT

A simple objective method for delineation of the ITCZ from daily 2.5 degree data on satellite measured outgoing longwave radiation and albedo is described. The method involves identification of grid points with a large fraction of deep convective clouds by imposition of a bispectral threshold and subsequent filtering to retain organized large-scale convection. The thresholds are derived so as to make the delineation by the objective method as close as possible to that from subjective scans by Sikka and Gadgil. The results of the objective method are similar to those obtained by McBride by subjective analysis of the winter monsoon region and Murakami's identification of convective regions based on pixel data.

1. Introduction

Organized convection in the tropics occurs primarily in the intertropical convergence zone (ITCZ). Most of the important phenomena in the tropics such as the El Niño or the monsoons involve major displacements of the ITCZ. Elucidation of the nature of the space-time variation of the ITCZ over different parts of the tropics is thus expected to yield insight into these phenomena. For such an endeavor an objective method for the delineation of the ITCZ is required. We report one such method in this paper.

With the advent of satellites it has become possible to study the variation of planetary scale convection over time scales ranging from the daily to interannual, by analysis of the relevent fields such as the outgoing longwave radiation (OLR). On the monthly and seasonal scales, major zones of convection are readily delineated as regions with low OLR, e.g., Fig. 1 for the convective zones in July. These regions occur around the axis of the mean equatorial trough (Riehl 1979) or the ITCZ (Fig. 1). Over the east Pacific, the latitudinal extent of the low OLR region is comparable to that of the prominent narrow zonal band of intense cloudiness associated with the ITCZ in the daily satellite imagery (e.g., Fig. 2a); however, the latitudinal extent of the convective region over the Asian monsoon zone in the mean summer distribution is almost three times as large. Over the central longitude of 90°E, the region from 10° north of the axis of the equatorial trough to about 30° to the south of this axis, is characterized by high convection and rainfall (Fig. 1 and Jaeger 1976; Rao 1976). In order to determine whether such a difference in the latitudinal scale arises from a difference in the structure of the basic system or in its space-time variation, it is necessary to analyze the subseasonal scale variation.

On the daily scale, the prominent zonal band of intense cloudiness in the satellite imagery of the Indian longitudes (Fig. 2b) markedly resembles that over regions such as the east Pacific (Fig. 2a). Sikka and Gadgil (1980, henceforth SG) analyzed such daily satellite imagery and data on the location of the monsoon trough. They showed that the system responsible for the large scale monsoon rainfall over the Indian region is similar in its essential dynamical characteristics to the ITCZ (Charney 1969), with intense low level convergence (associated with high cyclonic vorticity above the planetary boundary layer) and deep moist convection. Thus, understanding the nature of the variation of the ITCZ is as important for the monsoonal regions as for the rest of the tropics. The most prominent feature of the intraseasonal variation over this region is found to be poleward propagations of the ITCZ from the equatorial Indian Ocean onto the heated continent at intervals of 2–6 weeks throughout the summer (Fig. 3). The large latitudinal extent of the low OLR region over the Asian summer monsoon zone, vis a vis oceanic convective zones such as that over the east Pacific, is a consequence of the large meridional variations in the location of the ITCZ within the monsoon season.

In the first studies of the variation of tropical convection using digitized satellite data, monthly and seasonal mean fields of OLR were analyzed (e.g., Heddinghaus and Krueger 1981, Liebmann and Hartmann 1982, Lau and Chan 1983). Studies of intraseasonal variation based on daily data generally focus on the structure of specific modes such as the Madden–Julian

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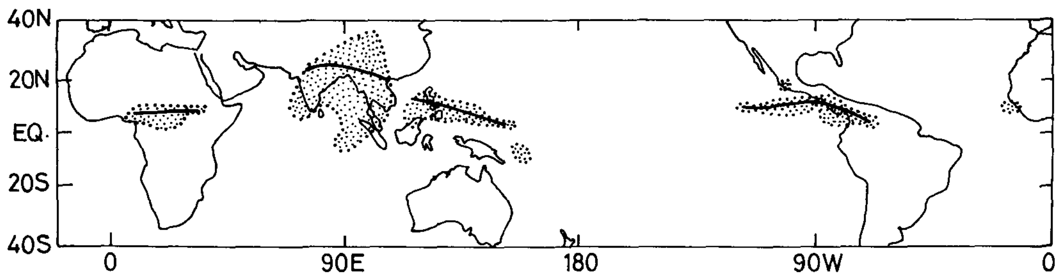

FIG. 1. Region with OLR < 220 W m^{-2} in the mean July OLR distribution (after Janowiak et al. 1985) and the axis of the equatorial trough (after Riehl 1979).

(1971) 30–50 day mode (e.g., Lau and Chan 1985). The approach adopted by SG in analysis of daily convection over the Indian monsoon zone is different in being system specific rather than mode specific. In the SG approach, first the ITCZ over the region of interest is delineated and then its variation with time is derived. When viewed thus, the variation within a season comprises a succession of events involving genesis of the

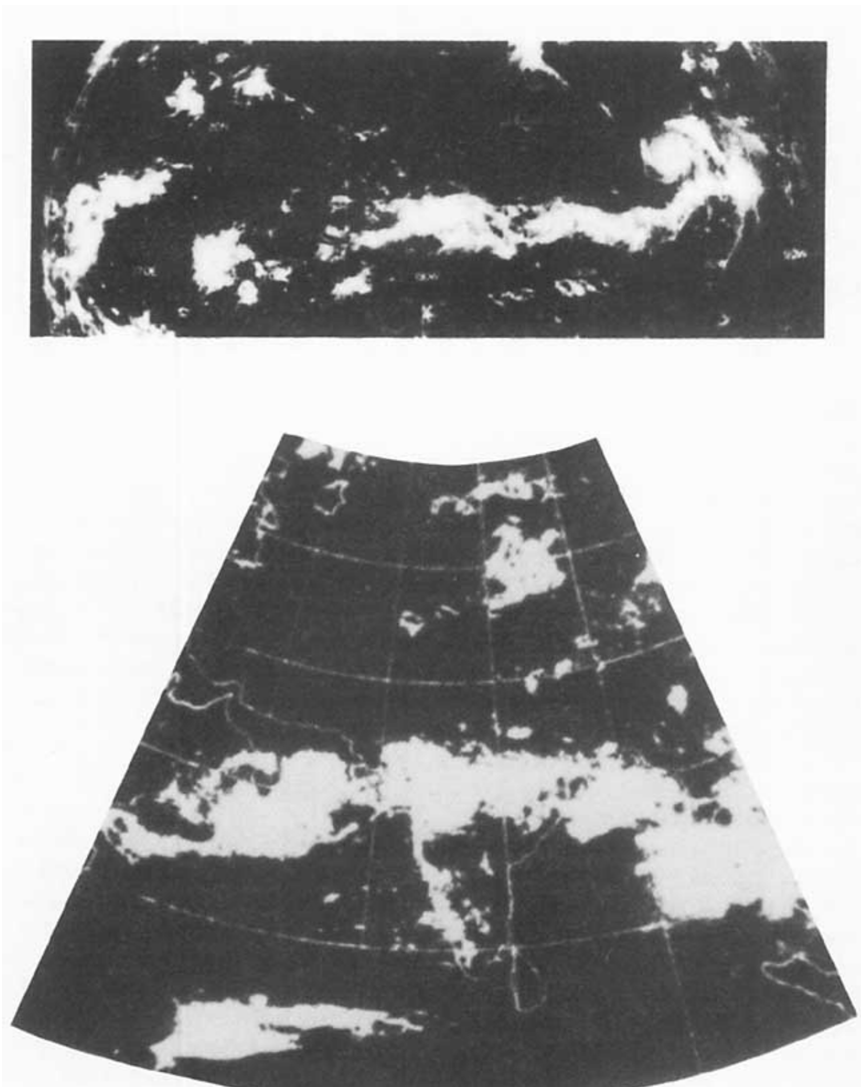

FIG. 2. NOAA visible satellite imagery of (a) the Pacific Ocean on 22 August 1972; (b) the Indian region on 8 July 1973.

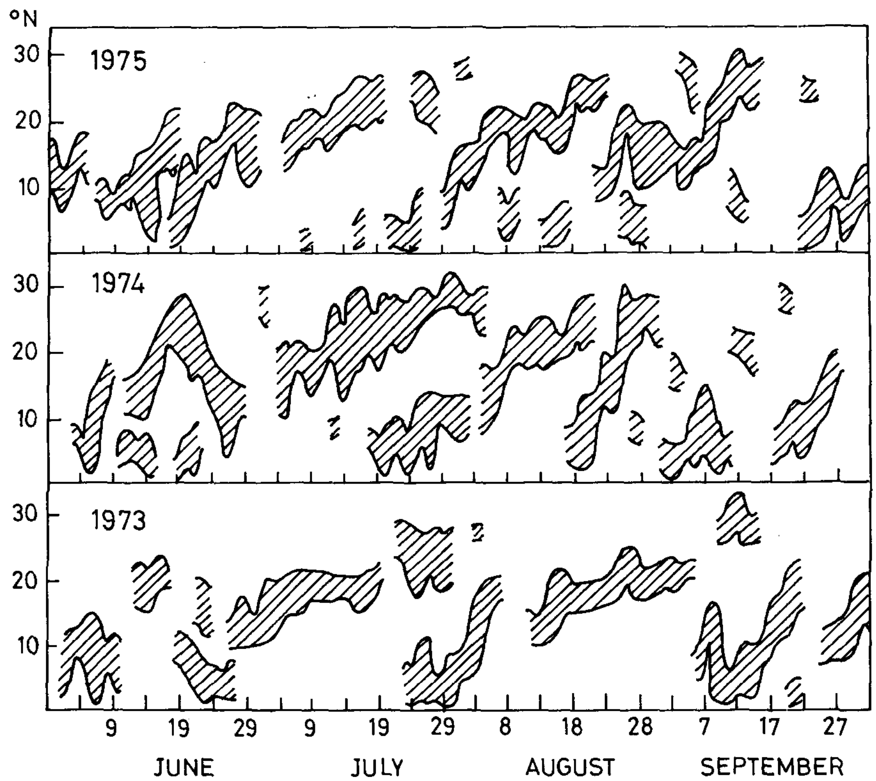

FIG. 3. Variation of the location and latitudinal extent of ITCZ at 90°E during the monsoon seasons of 1973–75 (after Gadgil et al. 1984).

ITCZ, an active spell (which may involve propagation in space) and demise. The variations are found to be rather complex, with oscillations in location and intensity characterized by periods which vary considerably within the season as well as from year to year. For example, the period between successive poleward propagation ranges between a few days to 6–7 weeks (Webster 1983; Gadgil 1988). In the presence of such a diversity of time-scales, an approach which focusses on the system (such as the one used by SG for analysis of intraseasonal variations) rather than a specific mode should yield valuable insights.

The ITCZ over the Indian longitudes was delineated by SG as the maximum cloudiness zone by visual scanning of the visible and infrared imagery. This subjective approach has some advantages because it is relatively easy to identify regions with deep convective clouds from satellite imagery. Even the data on occurrence of highly reflective clouds was earlier generated from such subjective scanning (Kilonsky and Ramage 1976). Furthermore, the subjective approach fully uses the remarkable capacity of the eye to recognize coherent patterns even when the intensity is not uniform throughout and thus it is the ideal approach for a first analysis of variation of systems such as the ITCZ. Identification of the ITCZ over each region by visual scans, however, demands considerable effort; while the associated cloudband can be readily delineated, the intensity of convection cannot be easily estimated. For an extensive analysis of the variations of the ITCZ over different parts of the tropics, an objective analysis of digitized data would be preferable. Now that a large uniform data set for outgoing longwave radiation, etc., has been prepared (Gruber and Krueger 1984), such a systematic study can be undertaken, provided that coherent zones of intense cloudiness associated with the ITCZ can be objectively identified from these data. We suggest a simple method for accomplishing this task in this paper.

2. Procedure

In the ITCZ deep convective clouds are organized over large spatial scales. The longitudinal extent generally exceeds 1000 km and the latitudinal extent ranges from 200 to 800 km depending on the region and season (Ramage et al. 1981; Frank 1983; SG). Hence, the accuracy with which the ITCZ can be located in a subjective scan of the daily NOAA satellite imagery (viz., about 1 degree latitude in the location of the associated cloud band), has been found to be adequate (SG). Many features of the intraseasonal and interannual variation of tropical convection have been revealed by analysis of the satellite data on the 1 degree scale (Garcia 1986) and on the 2.5 degree scale (e.g., Liebmann and Hartmann 1982; Lau and Chan 1983). We therefore assumed 2.5 degree grid data to be adequate for delineating the ITCZ on the daily scale. For the delineation, we sought the simplest possible objective method which reproduces the essential steps in the subjective pattern recognition from satellite imagery and yields comparable results. This method involves identification of the 2.5 degree squares that have a large fraction of deep convective clouds and omitting those squares that are not organized over large spatial scales (i.e., >500 km).

3. Identification of cloudy squares

The 2.5 degree squares with a sufficiently large fraction of deep convective clouds can be identified from satellite derived parameters. Many studies have addressed this task (e.g., Reynolds and Vonder Haar 1975; Parikh and Ball 1980; Platt 1981). The most important satellite-determined features that distinguish one cloud type from another are (i) cloud top height, which determines the OLR, or the brightness temperature; and (ii) vertical extent of the cloud, which determines the albedo. The ranges of OLR and albedo for regions with homogeneous extensive clouds of different types is schematically shown in Fig. 4 (after Platt 1981). Deep convective clouds associated with tropical disturbances and thunderstorms appear at the low OLR, high albedo edge of the distribution. Stratocumulus and midlevel clouds have higher OLR. Hence variation of the OLR distribution on monthly and seasonal scales has been extensively analyzed to elucidate the variations of convective zones (Heddinghaus and Krueger 1980; Liebmann and Hartmann 1982; Lau and Chan 1983). But cirrus clouds also have low OLR. Thus regions with high level cirrus overlying nonconvective conditions are also characterized by low values of OLR. Morrissey (1986) has shown that this "cirrus

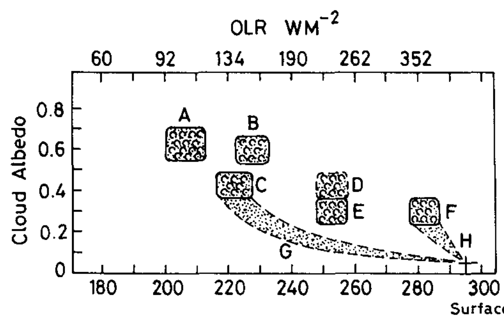

FIG. 4. Schematic of the histograms of several uniform "ideal" cloud types (after Platt 1981). A) Tropical disturbance; B) Convective thunderstorm; C) Cirrus; D) Midlevel cloud frontal; E) Midlevel cloud thin layers; F) Stratocumulus; G) Semitransparent high cloud-variable optical properties; H) Unfilled aperture.

contamination" can lead to a poor correlation between OLR and precipitation/moisture budget (i.e., precipitation–evaporation). We found that for a reasonably accurate delineation of the zone of deep clouding on a day-to-day basis, it is necessary to remove the cirrus contamination.

The dataset analyzed consists of daytime OLR and albedo over a 2.5 degree grid derived from the measurements by NOAA polar orbiting satellites for the region 20°S to 30°N during 1974–86. Corrections have been made for changes in the equatorial crossing time and changes in instrumentation (Gruber and Krueger 1984).

Figure 4 suggests that the stratocumulus and midlevel clouds can be filtered out by imposing a threshold on OLR in the range 180–210 W m^{-2} and the cirrus can be eliminated by an albedo threshold of about 0.5. Richards and Arkin (1981) have also shown that to estimate the fractional area covered with deep convective clouds from OLR data (from which the tropical precipitation is derived), the appropriate threshold is a brightness temperature of 240°K [i.e., OLR of about 190 W m^{-2}: Gruber and Krueger (1984)]. However, almost all the studies on the distribution of the different cloud types in the OLR and albedo space are based on data at the pixel scale which is typically 10 × 10 km. Whether the thresholds for the average values over 2.5 degree squares will be the same or less stringent depends on the detailed distribution of the pixels of the deep convective type in the OLR–albedo space and the typical value of the fraction of the square covered with such pixels in a tropical disturbance or an ITCZ.

Chou et al.'s (1986) study has revealed important features of pixels covered with deep convective clouds within the west Pacific ITCZ. At the tail of the distribution, the 5% of the pixels with minimum OLR (i.e., the tallest clouds) have a mean OLR of only 100 W m^{-2}. The mean OLR of the pixels identified as cloudy is about 135 W m^{-2}, and the fraction of such pixels in a 4 degree square within the ITCZ is over 70%. The average OLR for such 4 degree squares is less than 180 W m^{-2}. Thus the thresholds appropriate for delineating the ITCZ may not be much more stringent than those suggested by the pixel scale studies. This conclusion is also supported by the detailed study by Platt (1981). He studied the two-dimensional histograms generated from 2.5 km grid data for 500 × 500 km^2 regions characterized by the different cloud types observed in the tropics. When almost the entire area is within an intense tropical disturbance, most of the points have OLR less than 190 W m^{-2}, indicating a smaller average OLR.

The distributions of the 2.5 degree squares in the OLR-albedo space for a representative part of the Bay of Bengal (A: 10°–15°N, 85°–95°E) and a representative part of the continental region (B: 10°–20°N, 75°–80°E) during the peak summer monsoon month of July are shown in Fig. 5. The two-dimensional his-

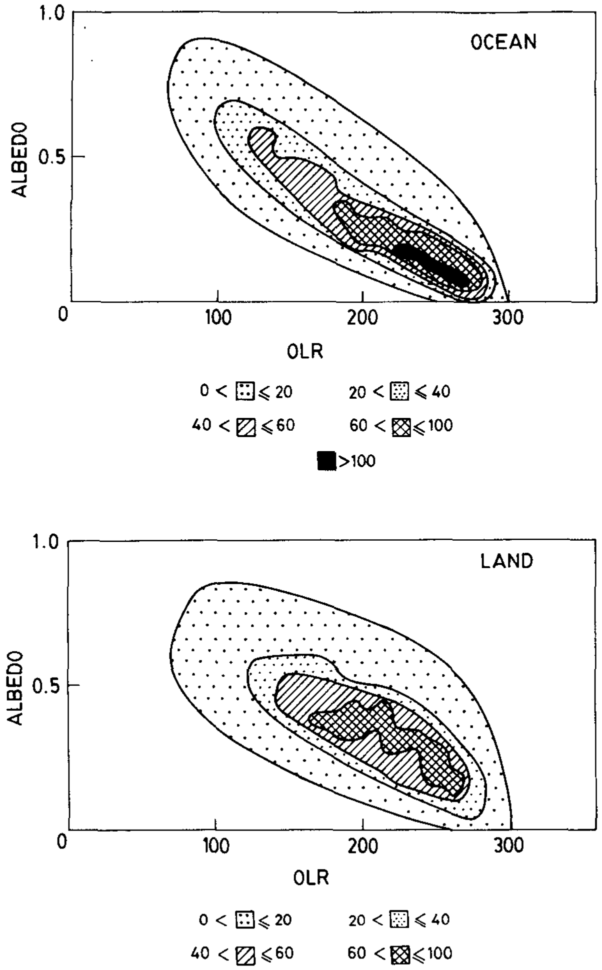

FIG. 5. Mean OLR–albedo histograms for July for a representative part of (a) the ocean A: 85°–95°E, 10°–15°N; (b) the continental region B: 75°–80°E, 10°–20°N.

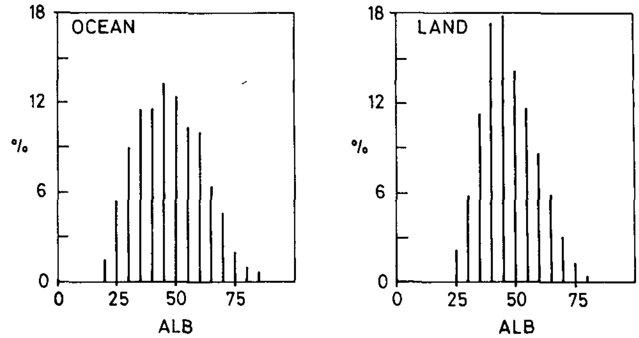

FIG. 6. Mean frequency distribution of albedo (in %) for OLR ≤ 200 W m^{-2} for July. (a) for region A of Fig. 5, (b) for region B of Fig. 5.

4. Delineation of the ITCZ

In the ITCZ deep convective clouds are organized over large spatial scales. Hence, from the set of grid points which satisfy the threshold conditions, we filtered out those grid points that are not so organized by a simple method. Any grid point is surrounded by eight others, two at the same latitude, 2.5 degrees to the east or west; two at the same longitude, 2.5 degrees to the north or south; and four at a distance of 2.5 degrees in latitude and longitude. A grid point at which the threshold conditions were satisfied was retained as a "cloudy grid point" only when at least two of the eight neighbors also satisfied the threshold conditions. This implies retention of only the gridpoints within organized large scale convection [over scales > 500 km, i.e., LCSA, after Morrissey (1986)]. In general, after this filtering, about 80%–85% of the gridpoints were retained. The other grid points are taken to be "cloud-free." Since the grid scale of the data is reasonably large, this simple method was adequate for filtering out isolated cloudy gridpoints.

In the determination of the daily latitudinal extent of all the cloudbands at any longitude of interest on a day to day basis we make two assumptions. First, two cloudbands are considered to be distinct only when

tograms for other parts of the tropics are similar except for the east Pacific where in addition to the general pattern, a region with high OLR and high albedo caused by marine stratocumulus appears. In general, regions with low OLR do not necessarily have a high albedo (Fig. 6). When albedo is larger than 0.5, there are only a few grid points over the oceanic regions with OLR greater than 180 W m^{-2}, over land, OLR values as large as 250 W m^{-2} can occur (Fig. 7). Hence although the correlation between OLR and albedo is high, ranging between 0.6 to 0.9 in the different tropical convective zones, identifying regions with deep convective clouds associated with tropical disturbances and ITCZ (without the cirrus contamination) requires OLR as well as albedo limitations. We have determined the appropriate 2.5 degree thresholds by comparing delineations of the ITCZ based on different sets of thresholds in the range suggested by pixel scale studies with those obtained by subjective scanning of the imagery.

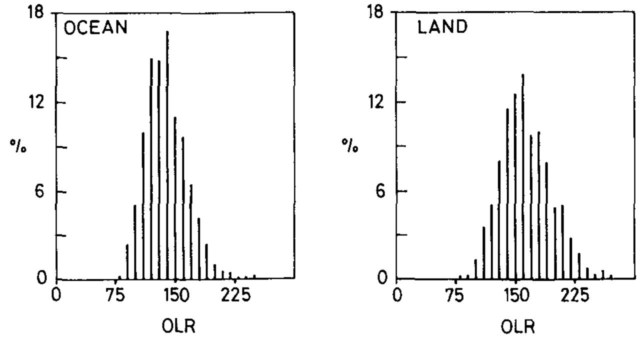

FIG. 7. Mean frequency distributions of OLR (in %) for albedo ≥ 0.5 for July. (a) for region A of Fig. 5, (b) for region B of Fig. 5.

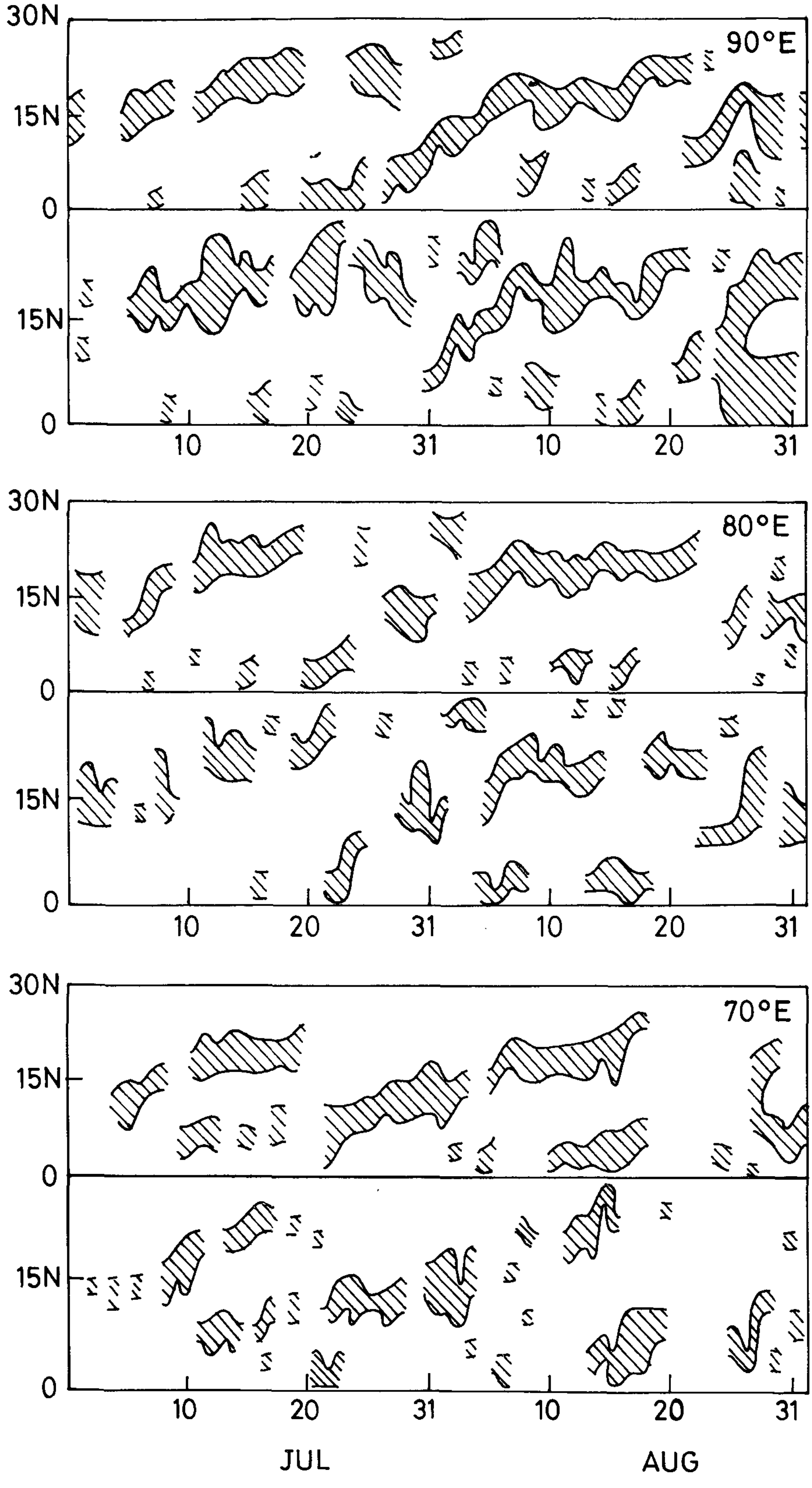

FIG. 8. A comparison of the variation of the ITCZ during July–August 1975 at 70°, 80°, 90°E derived by the subjective scans (above) and from our algorithm (below).

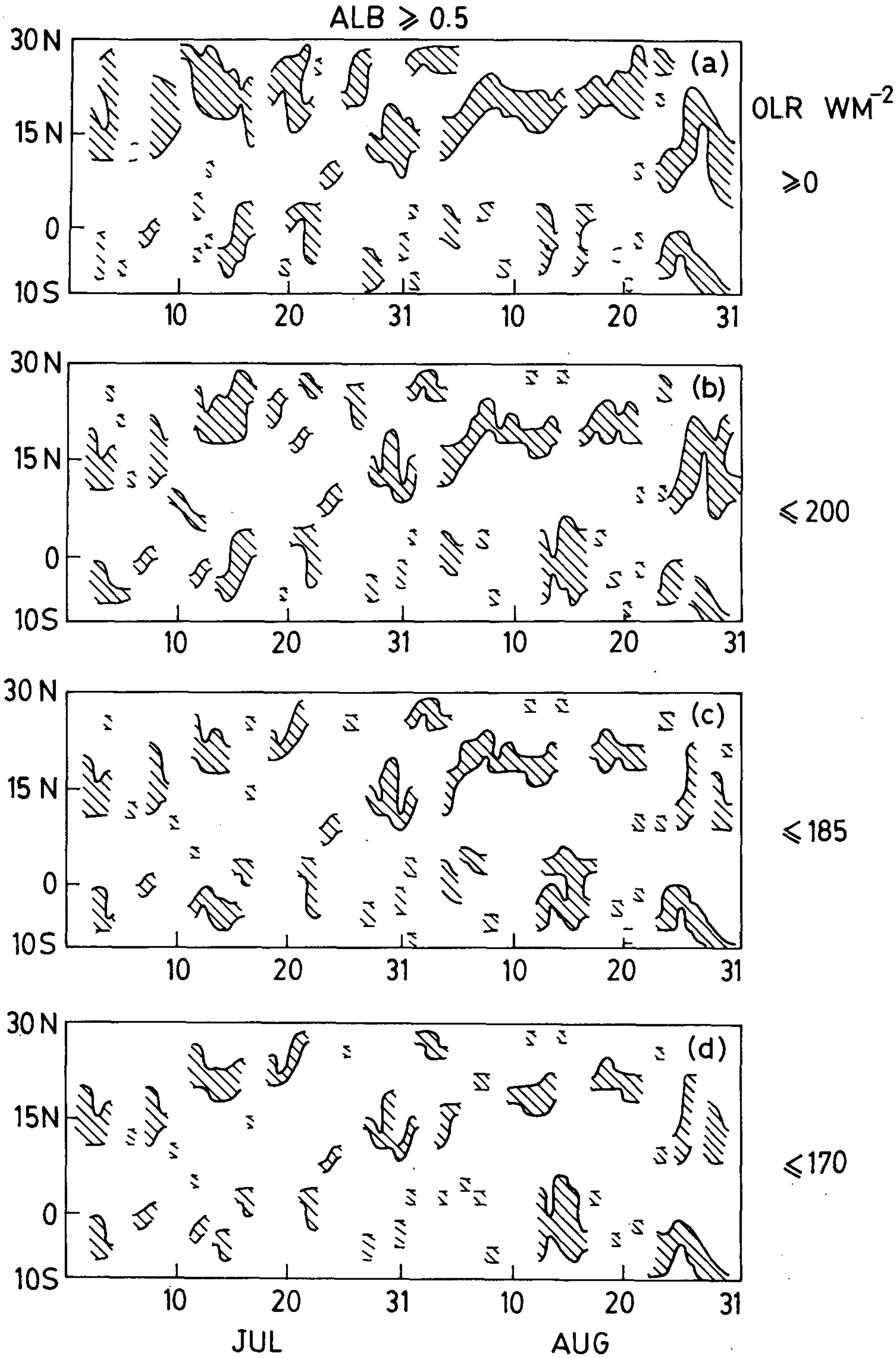

FIG. 9. Variation of the ITCZ at 80°E during July–August 1975 for albedo of 0.5 and OLR ≤, from top, ∞, 200, 185, 170.

they are separated by at least three consecutive cloud-free grid points, i.e., by at least 750 km. Second, gaps of one or two cloud-free grid points within a cloudy zone are ignored.

Occasionally parts of the cloudy zone may not be as intense as the rest and so the threshold criteria may not be satisfied at all the longitudes within what the eye sees as a coherent cloud band. In cases when the

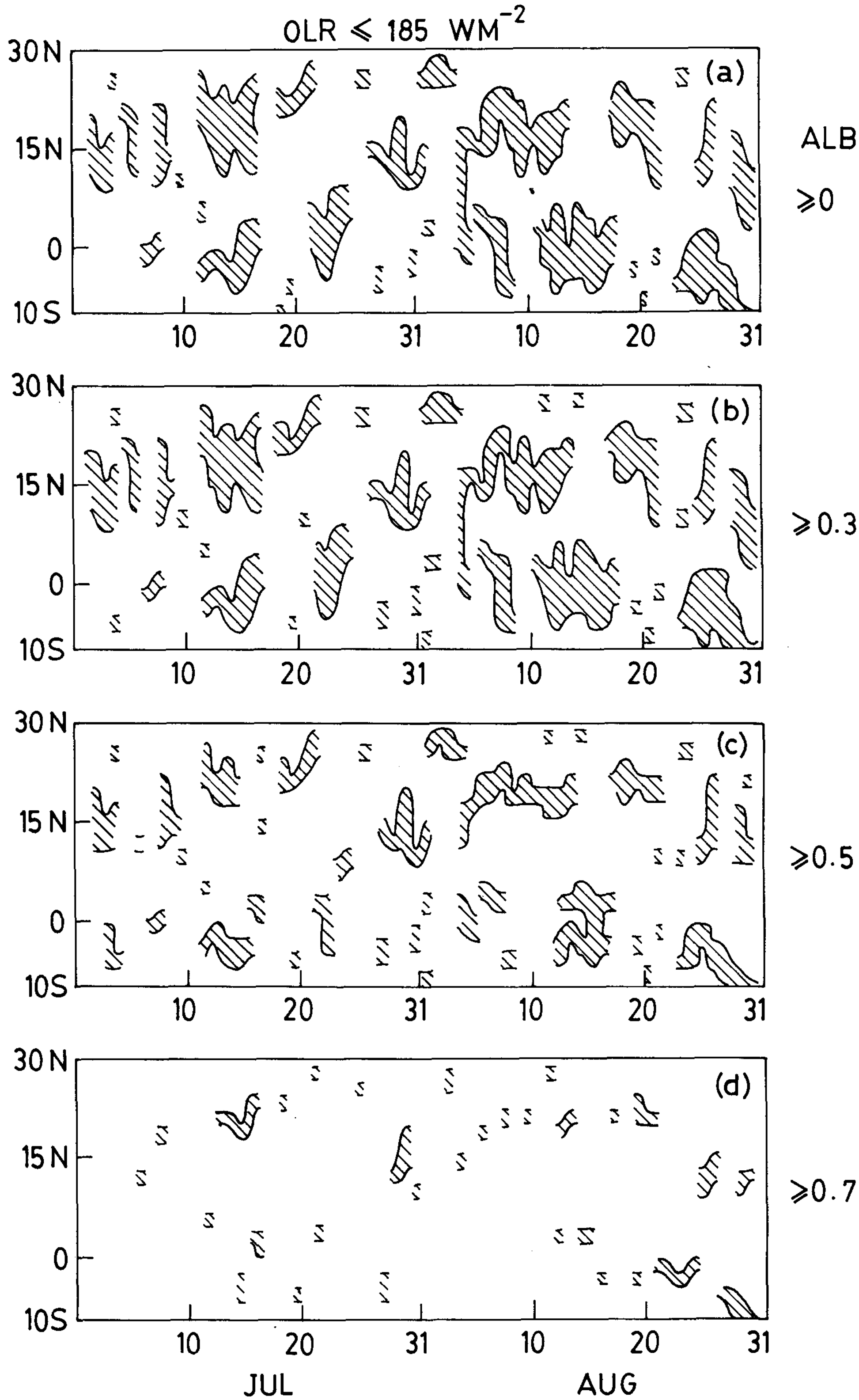

FIG. 10. Variation of the ITCZ at 80°E during July–August 1975 for OLR of 185 W m^{-2} and albedo ≥, from top, 0.0, 0.3, 0.5, 0.7.

band is not present over the longitude of interest, the occurrence of the band at 2.5 degrees east and west of the central longitude is also tested. Of these cases, those in which the band is present at one (both) neighboring longitude(s), the latitudinal extent at the central longitude is taken as that (average of the two) longitude(s).

The results for the summer of 1975 using a variety of thresholds were compared with those obtained earlier (SG). It was found that an OLR threshold of 185 W m^{-2} (i.e., brightness temperature close to 240 K, implying 2.5 degree average cloud top height of about 300 mb) and an albedo threshold of 0.5 give results which are closest to those obtained by visual scan of satellite imagery (Fig. 8). The delineation of the ITCZ by the objective method is remarkably similar to that by the subjective method. The subjectively identified cloud bands, however, are slightly more coherent in time. This may be because the delineation by subjective scans involved identification of the maximum cloudiness zone and did not incorporate information on the intensity of convection. In general, the presence/absence of cloudband as determined by the subjective and objective methods show a high degree of overlap. The maximum overlap of 85% occurs at 90°E in the monsoon zone (north of 15°N) while at 80°E it is 69%. The chi-square test for the 2.5 degree scale rejected the hypothesis that such a good agreement is obtained by chance alone at 0.005 level of significance.

The results are not too different for OLR thresholds in the range 170–200 W m^{-2} (Fig. 9) and albedo thresholds in the range 0.4–0.5. For less stringent albedo thresholds, the cloud bands appear to be unrealistically wide with a merger of the oceanic and continental bands on some days (Fig. 10). For more stringent OLR and albedo thresholds the number of days of ITCZ occurrence is drastically reduced. For thresholds of 170 (200) W m^{-2} for OLR and 0.5 for albedo, the overlap at 90°E decreases to 75 (83)% and at 80°E to 59 (64)%. For a threshold of 185 W m^{-2} for OLR and 0.3 (0.7) for albedo, the overlap decreases to 80 (63)% at 90°E and 61 (47)% at 80°E.

Murakami's (1983) method for delineating regions of intense convection is based on the mean and standard deviations of equivalent blackbody temperature on 1 degree square mesh derived from OLR data with a resolution of about 5 km. The squares with standard deviation > 5 K are taken to be convective; the intensity index of convection depends on the mean values of the cloud top temperature for clouds higher than 400 mb. The zones characterized by high index of convection during July 1979 by this criterion are shown in Fig. 11a (after Murakami 1987). The region characterized by a high frequency of occurrence at the deep clouds delineated using our simpler bispectral threshold method is remarkably similar (Fig. 11b). The variation of the cloud band at 140°E during January–March 1979 derived by the method used here was also found to be similar to that derived by subjective scanning of

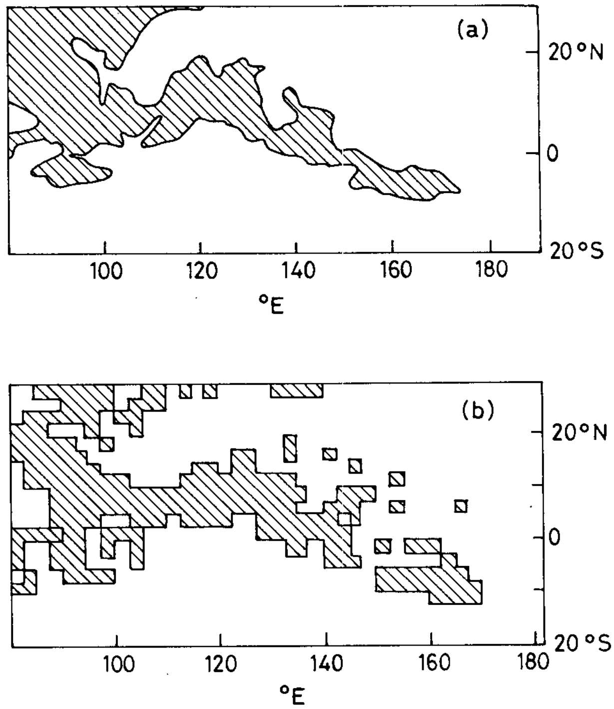

FIG. 11. (a) Region characterized by high index of convection for July 1979 after Murakami (1983). (b) Region characterized by a high frequency of occurrence of deep convective clouds (i.e., OLR $\leq$ 185 W m^{-2} and albedo > 0.5) during July 1979.

the imagery by McBride (1987). Thus the simple method developed here appears to be adequate for studying the nature of the variation of the ITCZ over different parts of the tropics.

5. Summary and conclusions

A simple method developed for delineation of the ITCZ from daily 2.5 degree data on OLR and albedo involves the following steps. First, the squares with a large fraction of deep convective clouds are identified by applying the thresholds OLR < 185 W m^{-2} albedo > 0.5. Then from amongst these, isolated grid points are filtered out by retaining only those squares for which the threshold conditions are satisfied by at least two of the eight neighboring squares. In derivation of the variation of the ITCZ at specific longitudes, the latitudinal extent is estimated by spatial smearing between the central longitude and the longitudes 2.5 degrees at the east and west. This simple method is found to be adequate for delineation of the ITCZ on a day to day basis.

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