Characteristics of the ITCZ over the Eastern Pacific, 5–8 June 1979

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ABSTRACT

The thermal and moisture structures of the ITCZ over the Eastern Pacific–Central American region have been studied during a selected four-day period in June 1979 (FGGE). Composite structures were constructed by using soundings gathered from dropwindsondes, tropical wind observing ships, and land stations. The composited temperature structure shows that the ITCZ is cold-cored at middle levels and warm-cored at upper levels. At low levels, there is neither a distinct maximum or a minimum in the ITCZ; instead, there is a gradual decrease in temperature as one crosses the ITCZ from north to south. The moisture shows that the ITCZ, as expected, is characterized by a maximum moisture content. The maximum dew-point depression differences between the ITCZ and the environment are found at middle levels. These composites indicate that the ITCZ structure over the Eastern Pacific–Central American region on 5–8 June 1979 is similar to that of the easterly wave. This similarity in structure suggests a corresponding similarity in energetics.

1. Introduction

The thermal and moisture characteristics of the Intertropical Convergence Zone (ITCZ) have been studied observationally by several investigators (Simpson, 1947; Estoque, 1975; Godbole and Ghosh, 1975; Estoque and Douglas, 1978; Riehl, 1979; Frank, 1983). With the exception of Riehl's (1979) study which used observations over Venezuela, all the studies used observations corresponding to maritime environments (over oceans or narrow land strips). The studies of the ITCZ over maritime environments show significant differences, even opposing findings, in the thermal structure. Simpson (1947) shows a cold-cored ITCZ structure all the way from the surface up to the 400 mb level; his study is based on radiosonde observations over Panama. In contrast, Estoque (1975) indicates an ITCZ thermal structure which is cold-cored at middle levels but warm-cored near the surface and at upper levels. His work is based on composited data from the Atlantic Tropical Experiment (ATEX) in the central Atlantic and from the Line Island Experiment in the Central Pacific. Godbole and Ghosh (1975) presented an ITCZ structure for the Indian Ocean which is based on radiosondes released from research vessels during MONEX-1973; the ITCZ is either 1) cold-cored from the surface up to 500 mb, with the coldest temperature being located in the southwest monsoon air mass just south of the ITCZ axis or 2) a transition zone from cold temperatures to the south and warm temperatures to the north. Estoque and Douglas (1978) found the ITCZ in the Eastern Atlantic during GATE to have a similar transitional structure at low levels as that over the Indian Ocean. However, at upper levels (500 and 400 mb) the GATE ITCZ is characterized by a slight temperature maximum. The magnitude is small compared to those generally observed in easterly waves. Above 400 mb, there is an indication of a minimum in temperature. Frank's (1983) composite structure based also on GATE data does not have the minimum temperature above 400 mb; instead, the entire upper atmosphere above 500 mb is characterized by a maximum of about 0.5°C. Below 500 mb, his composite does not show any evidence of a cold-cored structure; at low levels, the composite shows the same transitional structure found by Estoque and Douglas (1978).

The previous studies show that there are some variations in the thermal structure of the ITCZ. It is not clear whether these variations are real or whether they are simply a reflection of insufficient data. It is obvious, therefore, that additional research is needed to clarify this uncertainty and to determine whether there is a universal temperature structure of the ITCZ over maritime areas. The purpose of this paper is to present the observed structure of the ITCZ based on a selection of FGGE data during the intensive observational period of June 1979. The selected data were gathered over the extreme Eastern Pacific and Central America on 5–8 June 1979. The period which has been studied was selected for two reasons: 1) the existence of a vigorous ITCZ which remained more or less steady in the same area during the four-day period and 2) the availability of temperature and moisture observations of relatively higher density, both in time and in space, than at other times during the FGGE observational period. It is important to
note that this is the first work which involves the study of the thermal and moisture structure of the ITCZ in the eastern Pacific–Central America region. In order to obtain the ITCZ structure, we composited all the available temperature and moisture observations over the four-day period 5–8 June 1979 under the assumption of a quasi-steady state ITCZ. A typical cloud pattern for the ITCZ may be seen in Fig. 1 which shows a satellite picture for 1200 GMT 6 June 1979. Note in the picture that the ITCZ over the eastern Pacific-Central America area is characterized by an east–west oriented cloud band centered at about 10°N. The cloud pattern is very well defined and indicates a vigorous ITCZ with extensive areas of heavy convection and rain. However, in spite of the highly active ITCZ, no major synoptic-scale cyclonic circulation is indicated.

2. Data and procedure

The data used in this study consist of 62 upper air soundings of temperature and moisture from the following sources:

1) radiosondes from regular stations;
2) tropical Wind Observing Ships (TWOS) data from selected ships;
3) dropwindsondes released from high altitude aircraft.

Of the total number of soundings, 22% is made up of regular radiosondes released at Veracruz (Mexico), Swan Island, Grand Cayman, San Jose (Costa Rica), and Balboa (Panama). About 43% of the soundings are TWOS soundings from the ships Mariano Matamoros, Oceanographer and Unanue. Remaining soundings (35%) are dropwindsonde releases along routine FGGE flight tracks in the Eastern Pacific. The routine tracks are shown in Fig. 2. The use of soundings from various sources has always been the problem of systematic biases in the observations from one source with respect to the observations from the other sources. This problem was examined and no biases were detected. In fact, this was expected to be the case for the TWOS soundings from the three ships previously mentioned because all of them used the same type of sensors (Fleming et al., 1979). In addition, we found no significant differences when TWOS soundings were compared with radiosondes from regular stations. Regarding dropwindsonde soundings, Julian (1982) pointed out that temperature and moisture information from dropwindsondes was comparable to the one given by radiosondes from regular stations; we confirmed Julian’s statement in the course of analyzing our data.

For the purpose of the analysis, the region of observations may be divided into three sections—a central section in the vicinity of the ITCZ axis, a northern section and a southern section. Observations

![Infrared satellite picture at 1200 GMT 6 June 1979 showing the ITCZ cloud pattern.](image)
in the central section represent conditions in the ITCZ, the northern and southern sections represent the environment or the undisturbed regions in which the ITCZ is embedded. Figure 3 provides a summary of the various sections and the source of upper air soundings in the vicinity of the ITCZ axis as well as in the sections to the north and to the south of it. In terms of distribution of the soundings with respect to these three sections, the number of soundings are as follows: ITCZ axis and vicinity—26; northern section—9; southern section—27. Figure 3 shows, in addition, a schematic diagram of the typical cloudiness pattern associated with the ITCZ over the region of study for the period 5–8 June 1979.

Using the individual upper air soundings, we obtained representative values of the temperature and the moisture corresponding to each of the three sections mentioned here. These values are simply the averages of the individual values available at each mandatory level from 1000 to 200 mb. Because the averages were computed using data at mandatory levels, temperature and moisture variations whose vertical scale is smaller than the vertical distance between mandatory levels (e.g., trade wind inversions) are not reflected in the averaged values. In spite of using only mandatory levels, we feel that the averages are meaningful.

3. Results

Figure 4 shows a comparison of the averaged temperatures at various levels in the ITCZ and in the northern as well as the southern undisturbed sections. The figure also shows the differences between the ITCZ temperatures and the corresponding environmental temperature at the same level (ITCZ temperature minus environmental temperature). Note that the ITCZ is colder than its northern surroundings (Northern Trades) from 1000 mb up to 400 mb, with the largest negative difference of −1.9°C at 700 mb. Almost the same values (−1.8°C) are found at 1000 and 850 mb. At 300 and 250 mb, the ITCZ is warm-core with respect to its northern surroundings, the maximum warming being +1.1°C at 300 mb. However, at 200 mb, the ITCZ is colder than the northern environment, but only slightly (−0.2°C).

In regard to the comparison of the ITCZ temperatures with those of the southern environment, we find that the ITCZ is warmer at 1000 mb and at 850 mb. The fact that the ITCZ is warmer than its southern surroundings at these levels but colder than its northern surroundings at the same level implies a southward decrease in temperature as one crosses the ITCZ from the northern to the southern environment. A similar temperature decrease exists over the eastern Atlantic (Estoque and Douglas, 1978). At 700 and 500 mb, the ITCZ is colder than its surroundings; the largest cooling corresponding to a difference of −1.8°C is found at 700 mb. This temperature difference is almost the same as the corresponding difference for the northern environment. In the layer from 400 to 200 mb, the ITCZ is found to be warmer than the southern surroundings. The maximum warming (+2.3°C) is located at 300 mb. A corresponding maximum warming but smaller in magnitude (+1.1°C) is also found with respect to the northern environment.

Figure 5 shows the comparison of moisture in the ITCZ to that in the surrounding environment. It may be seen, as expected, that the moisture in the ITCZ is larger than in both the northern and southern environments. This finding is seen at all levels up to 300 mb by the distributions of the dew-point depressions and their differences (environmental dew-point depression minus ITCZ dew-point depression). The largest differences in these depressions exist at the 500 mb level, being 20.4°C and 12.3°C with respect to the northern and the southern surroundings, respectively. Note also that, with the exception of the 1000 and 700 mb levels, the moisture differences are larger between the ITCZ and its northern surroundings than between the ITCZ and its southern surroundings.

Further evidences which confirm the thermal and the moisture structure shown in Figs. 4 and 5 may be seen in the maps of Figs. 6 and 7. These maps show conditions at middle levels (700 mb) and high levels (300 mb) for 6 June 1979. They are based on dropwindsonde observations taken at various times during the day, as well as on radioonde observations from ships and land stations at 1200 GMT. Figure 6 shows the 700 mb map for 6 June 1979. The map, undoubtedly, confirms the cold-core structure of the ITCZ at 700 mb which has been indicated by the average temperature values in Fig. 4. The map also confirms the maximum moisture (smallest dew-point depression) associated with the ITCZ, confirming the average values of Fig. 5. The map shows some
longitudinal variations which are, as expected, smoothed out in the averages in Figs. 4 and 5. In spite of these longitudinal variations, one can see that the general pattern of coldness and wetness exists at all longitudes along the ITCZ. Figure 7 shows the 300 mb map for 6 June 1979. The warm-cored structure of the ITCZ at this level is apparent in the map. The map shows temperatures in the southern environment which are colder than those in the northern environment; this is consistent with the findings in Fig. 4. The 300 mb map also shows the ITCZ to be more moist than the environment. Much larger moisture differences are found between the ITCZ and the northern environment than between the ITCZ and the southern environment; this moisture pattern is also consistent with the findings in Fig. 5. Some longitudinal variations are found in the 300 mb temperature and moisture distributions in the same way that they were found at the 700 mb level. However, the general patterns of temperature and moisture maxima in the ITCZ region appear to be valid at all longitudes in the 300 mb map.

The foregoing discussion concerning the temperature and moisture differences between the ITCZ and

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**Fig. 3.** Diagram showing region of study and location of upper air observations. Shaded area is typical ITCZ cloudiness pattern.

**Fig. 4.** Average temperatures in the ITCZ and in the environmental sections to the north and to the south.
its surroundings indicate that the differences are generally of the same signs relative to either the northern or the southern surroundings. The only differences in the signs are those found in the temperature at 1000 mb and at 850 mb. Since these differences are quite minor, it is meaningful to prepare a composite of the northern and the southern soundings. The purpose of doing this composite is to obtain a general picture of the environment for comparison with the ITCZ conditions. Since the number of soundings is much greater in the southern than in the northern environment (ratio 3:1), weighted averaging is used to determine the environmental temperature and moisture values. Weights of 0.75 and 0.25 are given to the southern and the northern environment, respectively, in the weighted averaging procedure. The results of the weighted averaging for temperature are shown in Fig. 8. It may be seen that the ITCZ is coldest (−1.8°C) relative to the environment at 700 mb. On the contrary, it is warmest (+1.9°C) with respect to the environment at 300 mb. At low levels, there is only a small temperature difference. The temperature differences (middle and upper levels) are generally larger than those of previous studies. The reason for the large differences in our study is that they represent conditions associated with a vigorous ITCZ. On the other hand, most previous studies involved long-period averages of ITCZ conditions, including strong and weak intensities. Figure 9 shows the corresponding moisture difference. As anticipated, the ITCZ is found to be more humid than the environment at all levels. The maximum dew-point depression difference (14.7°C) between the moist ITCZ and the relatively dry environment is located at 500 mb; the minimum difference (0.7°C) is located at 1000 mb.
4. Discussion and concluding comments

The results of the present study indicate that the Eastern Pacific ITCZ during 5-8 June 1979 is cold-core at middle levels and warm-core at upper levels. In general, this structure is in agreement with the results obtained by Estoque (1975) for the Central Atlantic and the Central Pacific. The only significant disagreement is in the fact that Estoque (1975) found a distinct warm-core structure at low levels. On the other hand, over the Eastern Pacific, the present study indicates a gradual decrease in temperature as one crosses the ITCZ from north to south. If one averages the low-level temperature values from the northern and southern environments, one finds that there is no significant temperature difference between the ITCZ and its environment. Therefore, one may conclude that, aside from some differences at low levels, the structure of the strong ITCZ studied in this paper appears to be similar to that of the easterly wave over much of the troposphere. Both the ITCZ in this study and the easterly wave have two common significant features: cold-core at middle levels and warm-core at upper levels. This structure is very different from the warm-core mature tropical cyclone and the classical Hadley cell.

The maintenance of this thermal structure may be explained in terms of certain physical processes: the cold-core at middle levels as the combined effect of adiabatic cooling due to upward motions (forced convection) and cooling by the evaporation of rain and the melting of ice. Cooling by forced convection is due to the occurrence of upward motion in layers of stable stratification. The cooling by evaporation of rain and melting of ice has been indicated by Leary and Houze (1979) in their study of mesoscale rainfall in the ITCZ. It is surprising that the midlevel cooling is not reflected in Frank’s (1983) composited ITCZ structure. The warm core at upper levels is due to the release of the latent heat of condensation by deep cumulus towers. The cooling and warming processes tend to be balanced by horizontal diffusion and transport processes. The general southward decrease in temperature across the ITCZ, found at low levels, is due to the cooling of the air by the cold sea surface waters south of the ITCZ. The cold waters are associated with the Humboldt Current and are a rather permanent feature in the equatorial eastern Pacific, except during the El Niño events when warm waters are present. Therefore, the observed southward decrease in temperature across the ITCZ may not exist under El Niño conditions.

In regard to the energetics of the ITCZ, the apparent similarity between the structures of the ITCZ studied in this paper and the easterly waves in the Caribbean and in the Central Pacific suggests similar energetics. The energetics of these particular waves have been studied observationally by Riehl (1967) and Nitta (1972), as well as theoretically by Estoque and Lin (1977). All of these studies are in general agreement concerning important features of the sequence of energy transformations. The first element of this sequence is the generation of available potential energy.

![Figure 8](image_url)

**Figure 8.** Average temperatures in the ITCZ and the composited temperatures in the environment.

![Figure 9](image_url)

**Figure 9.** Average dew-point temperature depressions in the ITCZ and the composited dew-point temperature depressions in the environment.
in the upper troposphere, which is immediately transformed to kinetic energy. In turn, this kinetic energy is exported to lower levels in order to provide the kinetic energy supply for the middle troposphere. This supply of kinetic energy enables the ITCZ to compensate for the losses due to conversion of kinetic into available potential energy in the middle troposphere and to frictional dissipation. It is possible that this supply of kinetic energy is more than enough to compensate for these losses; the excess is presumably transported outside of the ITCZ, as suggested by Frank (1983). The mechanism responsible for the export of kinetic energy from the upper to middle layers is the vertical flux of potential energy (sometimes called pressure interaction process).

It is interesting to note that the important features of the energetics of our ITCZ as well as those of the easterly waves (Caribbean and Central Pacific) described here are very similar to the ones found by Kung and Burgdorf (1978) for large-scale disturbances over the GATE A-B scale area of the Eastern Atlantic. The area is in the general vicinity of the climatological location of the ITCZ during the GATE observational period. Using GATE upper air data, Kung and Burgdorf (1978) found that the conversion of eddy available potential energy above the middle troposphere is the primary source of kinetic energy in this area. The level of maximum conversion is located in the 200–400 mb layer. The energy released through this conversion is transported vertically, converging in the layers above and below through the pressure interaction process.

Finally, it is interesting to note that the results of other GATE studies on the energetics of wave disturbances in the vicinity of the ITCZ (Norquist et al., 1977; Reed, 1979) do not seem to agree with the main features of the energetics indicated by our ITCZ study. In the study by Norquist et al. (1977), the energetics have been analyzed for two regions, separately: one over the GATE ocean observational region; the other over the African continent. The findings corresponding to the ocean show that the kinetic energy of the synoptic scale waves is derived solely from the barotropic conversion process; the condensation heating appears to oppose instead of promote the growth. The results of this study by Norquist et al. (1977) seem to contradict the results of the study by Kung and Burgdorf (1978). Since both studies are based on GATE observations, we cannot understand the apparent contradiction.

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