Multi-Scale Convective Systems during the Initial Phase of the 1986/87 El Niño

By Tsuyoshi Nitta

Meteorological College, Kashiwa, Chiba 277, Japan

Takanori Mizuno

Maizuru Marine Meteorological Observatory, Maizuru, Kyoto 624, Japan

and

Kiyotoshi Takahashi

Meteorological Research Institute, Tsukuba, Ibaraki 305, Japan

(Manuscript received 17 July 1991, in revised form 15 October, 1991)

Abstract

Temporal and spatial characteristics of tropical convective systems and their associated atmospheric circulations such as intraseasonal variations (ISV), super cloud clusters (SCC), twin cyclones and westerly wind bursts (WWB) developed during the initial phase of the 1986/87 El Niño are investigated.

Most ISVs originated in the Indian Ocean and propagated eastward through the western Pacific and consisted of SCCs, twin cyclones and WWBs. Time evolution and horizontal-vertical structure of major ISVs in 1986, which appeared to play an important role in the El Niño development, such as (1) twin cyclone in May, (2) severely enhanced ITCZ in August and (3) SCC in November which brought about a major El Niño development, are analyzed in detail.

It is suggested that the WWBs associated with the SCCs propagating eastward along the equator from the Indian Ocean toward the western Pacific region are blocked by the surface topography over the "maritime continent", especially over Sumatra.

1. Introduction

El Niño and Southern Oscillation (ENSO) phenomena have been known as the largest interannual variations in the tropical regions and give a significant impact on the global weather situations. It has been clarified by observational and theoretical studies that the development of an El Niño event (warm phase of ENSO) results from the amplification of the coupled ocean-atmosphere system. However, the features and mechanism of the initial phases of El Niño development are not well understood.

Recently, Lau *et al.* (1989) has demonstrated that tropical convective systems with different scales in time and space, such as ISV, SCC, twin cyclones and WWB, interact with each other and that these convective systems may play an important role in the initial phase of El Niño development. They speculated that WWB may be due to a direct re-

sponse of the low-level wind to the heat source associated with the eastward-propagating SCC and/or zonal wind intensification along the equator between the twin cyclones. Sui and Lau (1991) has further performed a case study analysis on multi-scale variabilities over the tropical western Pacific during the 1979 northern hemisphere winter and showed that the ISVs interacted with a number of regional and synoptic-scale phenomena in the maritime continent and western Pacific regions. However, detailed features of these convective systems, their interaction and roles in ENSO development have not yet been well examined.

Nitta and Motoki (1987; hereafter referred to as NM) analyzed the abrupt enhancement of SCC and WWB in November 1986 which were followed by the development of the 1986/87 El Niño. Nitta (1989; hereafter referred to as NT) further pointed to the importance of the development of a twin cyclone accompanied by a strong WWB in May 1986 for the

eastward expansion of high sea surface temperature (SST) toward the central Pacific from the western Pacific. These SCCs and WWBs which developed in the western Pacific appeared to be connected with convective systems in the tropical Indian Ocean, but convective systems in the Indian Ocean have not been analyzed in detail by comparison with those in the western Pacific.

In this paper we will review the observational results of convective activities, atmospheric circulations and SST developed during the initial phase of the 1986/87 El Niño, mostly based on the results by NM and NT. Also, we will present additional analyses with respect to propagating features of convective systems such as SCC, twin cyclone and WWB from the Indian Ocean through the Pacific Ocean. Here, SCC is defined as an ensemble of cloud clusters with a longitudinal scale of 10 to 20 degrees and a life time of about 10 days, observed near the equator (Nakazawa, 1988). A twin cyclone corresponds to cyclone pairs developed both in the equatorial northern and southern hemispheres symmetric to the equator (Keen, 1982; Nitta, 1989). We define WWB as a strong low-level westerly which has a time scale of several days or more and a spatial scale of several thousand kilometers (Keen, 1982; Nitta and Motoki, 1987; Sui and Lau, 1991).

Special attention will be focused on how convective systems in the equatorial Indian Ocean are connected with those in the equatorial western Pacific where major El Niño development occurs.

2. Data

12-hourly global wind data on $2.5^\circ \times 2.5^\circ$ grids during the period from 1 January 1986 to 28 February 1987 analyzed objectively by the Numerical Prediction Division, Japan Meteorological Agency (JMA), are used to obtain wind variations associated with the convective systems. Outgoing Long-wave Radiation (OLR) data averaged daily at $2.5^\circ \times 2.5^\circ$ grids during the same period as wind data are utilized for measuring convective activities in the tropics.

3. General features of the 1986/87 El Niño

The evolution of oceanic and atmospheric anomaly fields during the 1986/87 El Niño was summarized by Kousky and Leetmaa (1989). Figure 1 shows their results of time-longitude sections of SST, OLR anomaly and zonal wind anomaly at 850 mb along the equator during the period from January 1985 to January 1988. Atmospheric and Oceanic anomaly fields in the tropical Pacific began to show characteristics of warm episodes during mid-1986. Warm SST regions higher than 28°C slowly expanded eastward during 1986 and reached the eastern end of the equatorial Pacific early in the following year. Negative OLR anomalies also began to

move eastward in early 1986 and reached the eastern Pacific in early next year. Anomalies of zonal winds at 850 mb varied with time scales of a few months during late 1985–early 1986, but westerly anomalies were shifted eastward to around 160°W in late 1986 and then continued to stay in the central Pacific near the dateline through 1987.

Figure 2 shows differences of OLR and winds at 850-mb and 200-mb levels between February 1987 (the mature phase of the El Niño) and February 1986 (the pre-El Niño phase). Large negative OLR anomalies exist in the equatorial central Pacific (160°E – 160°W , 10°N – 10°S) and low-level westerly anomalies spread toward the eastern edge of the negative OLR regions. Twin cyclonic circulation anomalies dominated the equatorial central Pacific regions (20°N – 20°S , 150°E – 150°W) at 850 mb, while a strong anticyclonic anomaly cell was found in Northwest Pacific around 40°N , 160°W .

At 200 mb, poleward wind anomalies emerged from the equatorial central Pacific where strong convection occurred. The northward divergent wind from the equator turned to the northwest direction joining into the anticyclonic circulation in the North Pacific. A wavetrain pattern similar to a Pacific-North America (PNA) pattern can be seen in the region from the North Pacific to North America. Strong westerly anomalies appeared in the equatorial regions from the eastern Pacific to the Atlantic Ocean.

The 1986/87 El Niño generally possessed mild characteristics in its strength and areal extent as compared with the 1982/83 El Niño. While the center of oceanic and atmospheric anomalies was shifted toward the far eastern Pacific during the mature phase of the 1982/83 El Niño (Gill and Rasmusson, 1983), the anomaly center for the 1986/87 El Niño generally lay in the central Pacific near the dateline.

4. Intraseasonal variations of convections and winds

The low-level wind anomalies shown in Fig. 1 fluctuated with time scales of a few months suggesting the existence of ISV, although 3-month running means were applied to the anomalies in Fig. 1.

In order to see the more detailed fluctuations over the western Pacific during the initial phase of the 1986/87 El Niño, NM and NT analyzed time-longitude sections of the 10-day mean SST and the 5-day mean winds at 850 mb along the equator during 1986, as shown in Fig. 3. Active convective regions derived from the Geostationary Meteorological Satellite (GMS) high-cloud amount data are also plotted in Fig. 3b. The warm SST region higher than 29.5°C was shifted westward during the period from January through May 1986, probably corresponding to the seasonal migration of SST distributions. Then the warmest SST region began to

Fig. 1. Time-longitude sections of (a) sea surface temperature, (b) anomalous outgoing long-wave radiation, and (c) 850 mb anomalous zonal wind (adopted from Kousky and Leetmaa, 1989). Shaded regions indicate SST higher than 28°C in (a), negative anomalies in (b) and positive anomalies in (c). Contour intervals are 1°C in (a), 10 W m⁻² in (b) and 1 m s⁻¹ in (c).

move eastward in May–June and reached the date-line in August. The relationship between the eastward movement of warm SST in late May–early June and the development of a twin cyclone has been discussed by NT and will be presented in Section 5. General evolution of SST as shown in Fig. 3a, such as eastward movement of the warm SST regions in 1986, is consistent with that described in Fig. 1a, although detailed features of SST variations differ from each other probably due to different data sources and different data processing.

There exist variations of convective activities with time scales of 1–2 months in the western Pacific which appear to propagate eastward from the Indian Ocean (Fig. 3b). The active convection was generally accompanied by the low-level westerlies. The easternmost edge of the active convective regions and low-level westerly winds associated with the ISVs was gradually shifted eastward during the

period from spring to fall. This gradual eastward shift of active convection seems to correspond to that of a warm SST as described in Fig. 3a.

From late October to early November, an active convection propagated eastward from the Indian Ocean through the western Pacific accompanied by strong WWB. This convective system reached the central Pacific, crossing the dateline in December, and stayed in the central Pacific. Correspondingly, the low-level westerly winds dominated the whole equatorial western Pacific. It seems that the event which occurred in late October–November may correspond to the major onset event for the 1986/87 El Niño, although the gradual development of the warm phase of ENSO appeared before this event, as pointed previously.

To examine more detailed propagation features of low-level winds associated with the ISVs in the equatorial region from the Indian Ocean to the Pacific,

Fig. 2. Differences of (a) 850 mb winds and OLR, and (b) 200 mb winds and OLR, between February 1987 and February 1986. Light shaded regions denote negative OLR values less than -20 W m^{-2} and dark shaded regions denote a surface elevation higher than 1,500 m.

11-day running mean anomalies of the 850-mb winds were analyzed. Annual and semiannual variations were eliminated in this analysis. Figure 4 shows the time-longitude sections of wind anomalies along the equator. Dark and light shaded regions denote westerly and easterly anomalies greater than 3 m s^{-1} , respectively. The following results are obtained.

- (1) The low-level winds vary with a time scale of about 1–2 months corresponding to the ISVs.
- (2) Most westerly wind anomalies originated in the Indian Ocean and appear to propagate eastward through the western Pacific. Some of them, such as anomalies in May, can be traced up to the eastern Pacific.
- (3) Wind anomalies also show stationary features, in addition to the propagating features, with large

amplitudes in the Indian Ocean (60°E – 90°E) and in the western Pacific region (130°E – 180°E). Wind anomalies in these two regions generally show out-of-phase relationships which are consistent with the results of OLR obtained by Lau and Chang (1985, 1986) and others.

- (4) Westerly wind anomalies near the equator, while propagating from the Indian Ocean toward the western Pacific, became weakened over the maritime continent region (100°E – 130°E). This reduction of westerly anomalies does not appear in latitudes higher than about 10 degrees (not shown).

- (5) Strong westerly anomalies greater than 3 m s^{-1} (denoted by dark shaded regions) have spatial scales of about 30° – 50° longitude and time scales of about 10–15 days. These strong westerly anomalies may

Fig. 3. Time-longitude sections of (a) 10-day mean SST averaged over Eq. -5°N , and (b) 5-day mean winds at 850 mb averaged over 2°N – 2°S . The contour interval of SST is 0.5°C and high SST regions greater than 29.5°C are shaded in (a). Active convective regions are shaded in (b).

correspond to WWBs.

5. Structure of the major convective systems

In this section we examine structural features of the three major ISVs which seem to play an important role in the development of the 1986/87 El Niño. The first event is the case in May 1986 in which SCC originated in the Arabian Sea and propagated eastward through the eastern Pacific as shown in Fig. 4. The important role of WWBs associated with this convective system in the eastward expansion of the warm ocean surface water has been demonstrated by NT. The second event is the case in August 1986 in which the ITCZ was extremely amplified, extending zonally from the Indian monsoon region to the eastern Pacific. The third case corresponds to the “major onset event” and occurred in November. This case was extensively studied by NM.

5.1 Super cloud clusters and twin cyclones in May

Figure 5 shows 5-day mean maps of winds at 850 mb during late April–middle May. Active convective regions derived from OLR data (less than 200 W m^{-2}) are also hatched in the figure. During April 21–25 convective systems in the equatorial Indian Ocean became active, but low-level winds were still weakly easterly. In April 26–30 the convective systems were organized into SCC in the middle of the

equatorial Indian Ocean, having a longitudinal scale of 20–30 degrees, and propagated eastward accompanied by WWB. Then the SCC reached west of Sumatra with intensification of WWB (May 1–5) and developed into a twin cyclone (May 6–10).

The convective activity and the low-level westerlies became weakened when this system passed over the maritime continent region (100°E – 130°E), as will be shown in detail in Fig. 7. However, a new intense SCC suddenly appeared in the equatorial western Pacific to the east of 140°E in May 11–15. The SCC was then developed into a twin cyclone in May 16–20, accompanied by strong WWBs on the equator.

Figure 6 shows three successive 10-day mean maps of SST during and after the development of the twin cyclone analyzed by NT. While the warm SST regions above 29°C were limited to the west of about 160°E in middle May (upper figure), the warm water pool along the equator spread eastward toward the dateline in late May (middle figure) and crossed the dateline in early June (lower figure). NT pointed out the possible linkage between the intensification of the WWB due to the development of the twin cyclone and the eastward expansion of the warm surface water.

The decrease of convective activity and WWB

Fig. 4. Time-longitude section of 11-day running means of anomalous 850 mb winds averaged in 2.5°N–2.5°S. Dark and light shaded regions denote westerly and easterly anomalies greater than 3 m s^{-1} , respectively.

during the period when SCC passed over the maritime continent can be seen clearly in Fig. 7, showing a time-longitude section of 850-mb winds and OLR along the equator obtained by daily datasets. Convection developed in the Arabian Sea in late April, propagated eastward with strong WWB, and reached near 100°E in early May where the Island of Sumatra is located. Convective activities were severely reduced over Sumatra and Borneo (100°E–

130°E) for the ensuing days and no WWB appeared there. Then new active convection, accompanied by strong WWB, developed in mid-May in the western Pacific around 140°E and propagated eastward to near the dateline.

In order to examine the vertical structure of the convective systems when propagating from the Indian Ocean to the western Pacific, 5-day mean height-longitude sections of zonal winds are shown

Fig. 5. 5-day mean maps of 850 mb winds during periods from 21–25 April to 16–20 May 1986. Shaded regions indicate active convective regions with OLR values smaller than 200 W m^{-2} .

Fig. 5. (Continued)

Fig. 6. Horizontal distributions of 10-day mean SST during 11–20 May (upper), 21–30 May (middle) and 1–10 June (lower). The contour interval is 1°C and shaded regions denote higher SST than 29°C.

in Fig. 8. When the SCC developed in the Indian Ocean (May 1–5), westerlies appeared in the lower-middle troposphere with maximum intensities around 850–700 mb, while easterlies were found above. There existed strong low-level easterlies and upper-level westerlies in the eastern Pacific which may correspond to a part of a large-scale east-west circulation. Winds were very calm throughout the troposphere in the western Pacific, especially over the maritime continent (100°E–130°E).

In May 6–10 when the intense twin cyclone developed just west of Sumatra, the WWB was greatly intensified and the vertical axis of the maximum westerlies inclined eastward with increasing altitudes. The zero line of zonal winds stand up almost vertically around 100°E where the Island of Sumatra is located. Upper easterlies moved a little eastward and downward over the maritime continent, but the low-level winds continued to be weak there.

In the next 5-day period (May 11–15) the strong WWB appeared in 140°E–160°E, corresponding to the development of the new SCC, as has been shown in Fig. 5. This SCC was accompanied by weak easterlies in the upper levels. The WWB was intensified further in May 16–20, probably due to the development of the twin cyclone. This intensification of the WWB may result in an eastward expansion of the warm SST toward the dateline, as discussed previously.

The above results suggested that the convective activity and its associated WWB seem to be blocked by the maritime continent especially by the Island of Sumatra. As shown in Fig. 16, there exist high mountains ranging northwest and southeast along the Island. It is probable that the eastward-propagating disturbances along the equator from the Indian Ocean are dynamically blocked by the surface topography over Sumatra and that they can not pass smoothly through to the western Pacific. Effects of the surface topography over the maritime continent on the eastward-propagating SCCs will be examined in more detail in the next section.

5.2 Intensification of ITCZ

This is the case in which the monsoon westerly flows in the Indian region were connected with the ITCZ in the Pacific and active convective regions expanded all over the region from the Indian region to the eastern Pacific along about 10°N–20°N. Figure 9 shows a map of winds at 850 mb and OLR on August 12, corresponding to the mature phase of this event. It can be seen that the zonal convective band spread out in the northern tropics from India-Southeast Asia to the eastern Pacific. Westerlies dominated the India-Southeast Asian monsoon regions and extended further eastward near the dateline in 5°N–15°N. There existed several vortices along the band, corresponding to tropical depressions. These vortices are associated with the westward propagating convection shown in a time-longitude section of daily OLR in Fig. 10 and may correspond to easterly waves in the tropical western Pacific, as have been analyzed by many authors. It may be quite rare that the ITCZ lines up from the Indian region to the Pacific region, like this event.

Daily maps of winds and OLR (not shown) indicated that the convective activity and the low-level southwesterly were strengthened over the Indian subcontinent and Southeast Asia in early August, the ITCZ in the Pacific were then amplified and convective systems in both regions became connected with each other in middle August.

Figure 10 shows a time-longitude section of daily 850-mb winds and OLR along 7.5°N–12.5°N during late July–early September. In general, phases of active convective regions with strong low-level westerlies moved eastward in August. However, this east-

Fig. 7. Time-longitude section of 850 mb winds and OLR averaged in 2.5°N – 2.5°S for 10 April–9 June 1986. OLR values smaller than 200 W m^{-2} are contoured with an interval of 20 W m^{-2} .

ward shift of convective regions did not occur uniformly but as pulses with an interval of about 10 days. There existed westward-moving convective systems along the ITCZ propagating from the central-eastern Pacific to the western Pacific, and these convective systems were merged into the eastward moving systems.

It may be interesting to examine the relationship between the active ITCZ in August and the El Niño development, since characteristic features of an El

Niño began to appear during mid-1986 as described in Section 1. Figure 11 shows anomaly maps of SST for August and September 1986, respectively. In August there existed positive anomalies of SST in the broad tropical regions between 20°N and 20°S covering the Pacific and Indian Oceans, although their amplitudes were not very large. It is probable that the enhanced ITCZ over these regions in August is due to an above-normal SST.

In September, positive SST anomalies in the

Fig. 8. Height-longitude sections of 5-day mean zonal winds at 850 mb averaged in 2.5°N-2.5°S during periods from 21-25 April to 16-20 May 1986. The contour interval is 5 m s⁻¹ and dark (light) shaded regions indicated greater westerlies (easterlies) than 5 m s⁻¹ wind speed.

Fig. 9. 850 mb winds on 12 August 1986. Shaded regions denote active convective regions with smaller OLR than 200 W m⁻².

Fig. 10. As in Fig. 7 but for 15 July–13 September 1986.

central-eastern Pacific were intensified, especially near the equator, while the tropical western Pacific was dominated by a negative anomaly. These anomaly distributions of SST in the tropical Pacific represent general characteristic features of El Niño. It may be speculated that the intense activities of the ITCZ in August may play some role in the intensification of equatorial SST through the interaction processes between the convective heating off the equator and the equatorial ocean dynamics. However, further observational and theoretical studies

will be needed to clarify these relationships.

5.3 Major onset event in November

As described in Fig. 3, the abrupt enhancement of SCC and WWB which occurred in the equatorial western Pacific in November 1986, resulted in the major development of the 1986/87 El Niño. Figure 12 shows a time-longitude section of 850-mb winds and OLR along the equator during mid-October to mid-December. There existed stationary active convection in the eastern part of the In-

Fig. 11. Monthly mean SST anomalies for August (upper) and September 1986 (lower). The contour interval is 0.5°C and negative SST anomalies are shaded. These figures are adopted from the Monthly Report published by JMA.

dian Ocean (90°E – 100°E) in late October, but a new convective system was generated in the Indian Ocean around 70°E on 26 October and propagated eastward, merging with the stationary convection around 90°E – 100°E . Then this convective system crossed the maritime continents with decreasing amplitude (~ 7 November), was amplified again around 130°E – 140°E (~ 10 November) and approached the dateline (~ 20 November). WWBs dominated the regions on and to the west of the convective system and moved eastward as the convective system moved eastward.

Figure 13 shows a similar time-longitude section of convective activity and 850-mb winds between 90°E and 170°W during 3 November–23 November in which the SCC propagated in the western Pacific (Nakazawa, 1988). The active convective regions (shaded in the figure) are determined three-hourly, based on the GMS equivalent black body temperature index. It can be seen very clearly that there are two different time and space scales, *i.e.*, the eastward-moving SCC and the westward-moving

cloud cluster. These results suggest the existence of a hierarchy of convective systems in the equatorial regions.

Figures 14 and 15 show 5-day mean horizontal distributions of 850-mb winds and OLR and vertical distributions of zonal winds along the equator, respectively, when the convective system was located in the Indian Ocean (Oct. 26–30), maritime continent (Nov. 6–10) and the western-central Pacific (Nov. 16–20). During Oct. 26–30 (Figs. 14a and 15a), the SCC and the WWB developed in the equatorial Indian Ocean and the cyclonic circulation cell was found to its north. The WWB was confined to the lower troposphere below 500 mb in the Indian Ocean, but the low-level winds over the maritime continent were very weak. In the upper troposphere easterlies dominated the regions extending from the Indian Ocean to the western Pacific.

The convective system then moved eastward, crossing the Sumatra and Borneo regions during Nov. 6–10 (Figs. 14b and 15b). There were moderate WWBs at the 850- to 700-mb levels around

Fig. 12. As in Fig. 7 but for 15 October–14 December 1986.

110°E. However, these WWBs were not directly connected with those in the Indian Ocean but connected with the northwesterlies in the northern hemisphere. The low-level winds on and to the west of Sumatra were very weak. These results suggested that the WWBs were affected by the Island of Sumatra when crossing. On the other hand, upper easterlies over the maritime continent were intensified and moved smoothly eastward.

During Nov. 16–20 (Figs. 14c and 15c), the SCC propagated further eastward and approached the

dateline. The WWB was intensified again in the western Pacific and its vertical depth became deepened at the eastern edge of SCC (~170°E).

6. Blocking effects by surface topography

The results in the previous section suggested that the WWBs associated with the SCCs propagating eastward from the Indian Ocean may be blocked by the surface topography over Sumatra. Figure 16 shows the mean surface elevation along the Island of Sumatra, averaged over $1^\circ \times 1^\circ$. There exist

Fig. 13. Time-longitude section of active convective regions (shaded) and 850 mb winds averaged in 2.5°N–2.5°S (adopted from Nakazawa, 1988).

high mountains with a mean height of about 2,000 m between 5°N–5°S.

In order to examine the effects caused by the surface topography, 10 cases of 5-day means during which Indian SCCs reached just near the west of Sumatra are selected from the data during January 1986–February 1987 for composite analyses. Then, 5-day mean maps of OLR and winds for these 10 cases are averaged to obtain composite maps.

Figure 17 shows a composite map of 850-mb winds. Active convective regions with OLR less than 200 W m^{-2} are shaded in the figure. The SCC with spatial scales of about 2,000 km both in the east-west and north-south directions is located just west of Sumatra. Since 5 cases among 10 cases belong to the northern hemisphere summer (June–September), westerlies associated with the Indian monsoon appear clearly over the equatorial Indian Ocean in the composite winds. The WWBs are in-

tensified in the active convective regions, but appear to be blocked by Sumatra. There exist only weak easterlies over the equator to the east of Sumatra. Westerlies in the equatorial Indian Ocean turned to northwesterlies or northeasterlies in the equatorial southern hemisphere (0°–5°S), flowing along the coast of Sumatra. Westerlies penetrate through the northern edge of Sumatra (~5°N) toward the western Pacific, probably due to lower elevation, although the strength of westerlies becomes very weak in the western Pacific.

Figure 18 shows a composite height-longitude section of the zonal winds along the equator. The surface elevation over the maritime continents is also plotted in the figure. Westerlies corresponding to the Indian SCCs have maximum values around 80E° and at 850 mb. Decomposition of the zonal wind into divergent and rotational components (not shown) indicate that the rotational component (5–

Fig. 14. As in Fig. 5 but for 26-30 October, 6-10 November and 16-20 November 1986.

Fig. 15. As in Fig. 8 but for 26–30 October, 6–10 November and 16–20 November 1986.

6 m s^{-1}) is much stronger than the divergent component ($1\text{--}2\text{ m s}^{-1}$) at 850 mb in Fig. 18, suggesting that the WWB is largely due to the rotational components. These results for the SCC in the Indian Ocean are consistent with those of SCC in the western Pacific analyzed by Sui and Lau (1991). The low-level westerlies are limited to the west of Sumatra and a zero wind line stands almost vertically over Sumatra. There exist only weak easterlies in the lower troposphere on and to the east of Sumatra, suggesting blocking effects due to the surface topography.

On the other hand, easterlies dominated both the Indian Ocean and the western Pacific in the upper troposphere and there is no clear indication of topographic effects in the upper layer as in the lower layer. However, there are two maxima of easterlies, *i.e.*, one is at about 80°E , just over the maximum of the low-level westerlies, and the other is at about 130°E . It is not certain now whether this separation of the easterly maximum in the upper layer is due to the surface topography.

Computations of divergence based on the composite winds (not shown) indicated that there exist intense convergence at 850 mb and divergence at 200

Fig. 16. Surface height distribution along the Sumatra Island averaged in $1^{\circ}\times 1^{\circ}$ areas. X and numerals above indicate heights for individual high mountains.

mb just west of Sumatra, suggesting the existence of strong upward motion. This upward motion may be generated, not only by the latent heat release in the SCC, but also forced dynamically by the surface topography over Sumatra.

7. Summary and conclusions

Characteristic features of time and spatial variations of tropical convective systems such as intraseasonal variations, super cloud clusters, twin cyclones and westerly wind bursts developed during the initial phase of the 1986/87 El Niño are reviewed and new observational results of blocking effects by the surface topography over Sumatra on the eastward-moving SCCs are presented.

In a gross sense, the atmosphere-ocean conditions in the tropical Pacific gradually developed into the El Niño condition through mid-1989 to early 1987. However, their stages fluctuated, affected mainly by the intraseasonal variations. Most ISVs originated from the Indian Ocean and propagated eastward through the western Pacific regions. These ISVs consist of super cloud clusters, sometimes twin cyclones, accompanied by low-level westerly wind bursts.

The horizontal and vertical structure of the major ISVs in 1986, which seemed to affect the El Niño development, are investigated. The SCC which developed in the Indian Ocean in late April propagated eastward and was transformed into a twin cyclone to the west of Sumatra in early May. After weakening over the maritime continent, a new SCC and twin cyclone accompanied by strong WWB were again developed in the tropical western Pacific in mid-May. Warm SST regions higher than 29°C moved eastward along the equator through the dateline, corresponding to the intensification of the WWB.

Fig. 17. Composite map of 850 mb winds for cases in which Indian SCC approached Sumatra. Active convective regions with smaller OLR than 200 W m^{-2} are light shaded. Dark shaded regions denote high surface elevation areas.

Fig. 18. As in Fig. 8 but for composite results. Surface elevation averaged over $1^\circ \times 1^\circ$ along the equator is also plotted.

During August the ITCZ was greatly amplified, extending zonally from the Southeast Asia to the eastern Pacific. Several tropical disturbances and typhoons were developed along the ITCZ. After this event, positive SST anomalies in the equatorial Pacific were intensified, showing the characteristic SST distributions of El Niño. It is suggested that the intensification of the ITCZ may have some effects on the subsequent development of the equatorial SST, but further investigation may be needed to clarify this point.

A major development of the 1986/87 El Niño occurred in November 1986, when the SCC propagated from the Indian Ocean to around the dateline. The SCC was generated in the equatorial Bay of Bengal in late October and propagated eastward toward the western Pacific with weakening over the maritime continent. A new SCC developed in the western Pacific in early November, propagated further eastward and approached the dateline in late November. Several twin cyclones were generated at the eastern edge of the SCC, and WWBs were intensified along the equator. After this event the convection center was shifted toward the equatorial central Pacific from the western Pacific, resulting in the major El

Fig. 19. Schematic picture when convective systems propagate along the equator from the Indian Ocean to the western Pacific. Light shaded regions denote convective regions and arrows indicate low-level winds.

Niño onset.

Case study analyses of ISVs indicated that the convective activity and WWBs appeared to be weakened over the maritime continents (100°E – 130°E), when SCCs moved along the equator from the Indian Ocean to the western Pacific. Composite analyses, based on 10 SCCs, revealed that the low-level westerlies are blocked by the surface topography over Sumatra.

Figure 19 shows schematic pictures of convective systems and low-level winds which propagate along the equator from the Indian Ocean to the western Pacific. The convective system generated in the Indian Ocean is developed into a SCC and propagates eastward. When the SCC approaches Sumatra, the WWB associated with SCC is blocked by the elevated topography over Sumatra and the low-level disturbance is unable to cross the Island smoothly. It may sometimes happen that an Indian SCC is transformed into a twin cyclone near the west of Sumatra.

In some cases, no new system can develop in the western Pacific after the convective systems in the Indian Ocean are damped over the maritime continent. However, in some other cases a new SCC is generated to the east of Borneo, probably due to the effects of the upper-level disturbances which can smoothly cross Sumatra and Borneo. It may be interesting to examine in what situations SCCs propagating from the Indian ocean are damped or develop again in the western Pacific, and further studies relating to these points are needed in future.

There also exist high mountains in the maritime continents and not just over Sumatra, and hence the above topographic effects may occur not only over Sumatra but also over other islands such as Borneo. The evidence of reduced convective activity over the maritime continent obtained in this study are consistent with those of OLR variance analyses by Lau and Chan (1988). Since SCCs and WWBs in the equatorial western Pacific are thought to play important roles in the development of ENSO, further detailed observational and theoretical studies are desirable in the future to clarify how the surface topography over the maritime continents affect the convective systems.

Acknowledgments

We thank Drs. Masato Murakami and Tetsuo Nakazawa for many stimulating discussions throughout this study.

References

- Gill, A.E. and E.M. Rasmusson, 1983: The 1982–83 climate anomaly in the equatorial Pacific. *Nature*, **306**, 229–234.
- Keen, R.A., 1982: The role of cross-equatorial tropical cyclone pairs in the southern oscillation. *Mon. Wea. Rev.*, **110**, 1405–1416.
- Kousky, V.E. and A. Leetmaa, 1989: The 1986–87 Pacific warm episode: evolution of oceanic and atmospheric anomaly fields. *J. Climate*, **2**, 254–267.
- Lau, K.M. and P.H. Chan, 1985: Aspects of the 40–50 day oscillation during the northern winter as inferred from outgoing longwave radiation. *Mon. Wea. Rev.*, **113**, 1889–1909.
- Lau, K.M. and P.H. Chan, 1985: Aspects of the 40–50 day oscillation during the northern summer as inferred from outgoing longwave radiation. *Mon. Wea. Rev.*, **114**, 1354–1367.
- Lau, K.M. and P.H. Chan, 1988: Interannual and intraseasonal variations of tropical convection: a possible link between the 40-day mode and ENSO? *J. Atmos. Sci.*, **45**, 506–521.
- Lau, K.M., L. Peng, C.H. Sui and T. Nakazawa, 1989: Dynamics of super cloud clusters, westerly wind bursts, 30–60 day oscillations and ENSO: an unified view. *J. Meteor. Soc. Japan*, **67**, 205–219.
- Nakazawa, T., 1988: Tropical super cloud clusters within intraseasonal variations over the western Pacific. *J. Meteor. Soc. Japan*, **66**, 823–839.
- Nitta, Ts. and T. Motoki, 1987: Abrupt enhancement of convective activity and low level westerly wind burst during the onset phase of 1986–87 El Niño. *J. Meteor. Soc. Japan*, **65**, 497–506.
- Nitta, Ts., 1989: Development of a twin cyclone and westerly bursts during the initial phase of the 1986–87 El Niño. *J. Meteor. Soc. Japan*, **66**, 677–681.
- Sui, C.-H. and K.-H. Lau, 1991: Multi-scale phenomena in the tropical atmosphere over the western Pacific. (submitted to) *Mon. Wea. Rev.*

1986/87 エルニーニョ 発生期における多重構造を持った対流の組織活動

新田 勲

(気象大学校)

水野孝則

(気象庁舞鶴海洋気象台)

高橋清利

(気象研究所)

1986/87 エルニーニョ 発生期に起きた、様々な対流活動と流れの場に関する、時間・空間変動の特徴について調べた。この時期、インド洋から太平洋にかけての熱帯域では、季節内変動 (ISV)、超雲集団 (SCC)、双子低気圧、西風バーストが発生、発達、消滅を繰り返した。

多くの季節内変動は、インド洋で発生し、超雲集団、双子低気圧、西風バーストを伴って、西部熱帯太平洋へと伝わって行く。1986 年に発生した季節内変動の中で、エルニーニョ の発達に重要な役割を果たしたと思われる、(1) 5 月の双子低気圧、(2) 8 月に発達した ITCZ、(3) 本格的なエルニーニョ の発達と関係した 11 月の超雲集団、の 3 例について詳しい時間変化と水平-垂直構造を調べた。

超雲集団が赤道をインド洋から西部太平洋に東進する過程で、下層の西風バーストが海洋大陸上、特にスマトラの地形によって大きく影響を受けることが明らかになった。