MARINE

CURRENT ISSUES RELATING TO THE EL NIÑO/SOUTHERN OSCILLATION

Glenn R. Lussky (1)

NOAA/NWS/WRH/Scientific Services Division
Salt Lake City, UT 84147

ABSTRACT

The El Niño/Southern Oscillation (ENSO) probably has the most prominent impact on year-to-year climate variability of any event. Tremendous gains have been made in our knowledge of these events over the past decade. This paper describes and summarizes some of the published work on ENSO events that is applicable to the operational meteorologist. In addition, interest in the opposite phase of the ENSO event has been increasing recently, both in the scientific and public communities. While no conclusive research, to this date, has been presented regarding the climatic impact of these events, some hypotheses are being considered. This paper discusses a number of issues which are important to remember regarding these so-called "anti-ENSO" or "La Niña" events.

1. INTRODUCTION

The phenomenon termed El Niño by scientists today is really a misnomer, or so you might hear if you asked native Peruvians. To them, the El Niño comes along every year as a part of the annual cycle, with waters that warm southward along the northern South American coast during late fall and early winter (in the Northern Hemisphere). Because the waters typically warm along the Peruvian coast around Christmastime every year, the term El Niño was used, which means "the Christ Child" in Spanish. The Peruvian El Niño annually disrupts the areal bioclimate, especially with regard to the fishing industry, which declines during this season each year.

The term El Niño, as it has come to be accepted in scientific circles, refers to a phenomenon with an irregular cycle, occurring approximately once every 2 to 7 years, which affects sea-surface temperatures (SSTs) across the entire Pacific basin. It is related to the Peruvian El Niño in that (1) its effects are most prevalent during the Northern Hemisphere cold season, and (2) it exhibits a larger than normal increase in sea-surface temperatures. Beyond these comparisons, however, similarities weaken, for the Peruvian El Niño is simply a manifestation of the annual cycle along the South American coast. The scientific El Niño not only exhibits a greater than usual warming of sea-surface temperatures across the entire Pacific basin, but also has a much more profound impact on the global atmospheric circulation and climate.

2. EL NIÑO AND THE SOUTHERN OSCILLATION

The atmospheric circulation changes associated with the scientific El Niño are referred to as the warm phase of the Southern Oscillation. These circulation anomalies include (2):

1. Above-normal sea-level pressure in the Australia-Indonesia region together with a weaker than normal subtropical High in the southeast Pacific.
2. Weaker than normal low-level easterly winds in the equatorial central Pacific.
3. Sharply enhanced precipitation at equatorial stations east of 160°E.
4. Enhanced Hadley circulation in the central Pacific.
5. Circulation teleconnections to extratropical latitudes during the Northern Hemisphere winter season.

The Southern Oscillation (SO) received its name when Walker and Bliss (3,4) noted that if the sea-level pressure was high over the central and eastern Pacific, it was usually low over the Indian Ocean/Indonesia area, and vice versa. Accompanying the lower than normal pressure in the Indian Ocean/Indonesia area, precipitation tended to be greater than normal.

Measurement of the SO is usually defined in terms of the difference in pressure deviations from normal at Tahiti (in the eastern Pacific) and Darwin, Australia (Fig. 1). The positive phase of the SO occurs when the Indonesian Low and eastern Pacific subtropical High are stronger than normal, whereby precipitation is enhanced over Indonesia. The eastern Pacific remains drier than normal as a result. During the negative phase of the SO, the Indonesian Low and eastern Pacific subtropical High are weaker than normal, resulting in less precipitation than normal over Indonesia. The enhanced tropical convection shifts eastward to the central Pacific. The convection typically doesn't extend much past 160°W as the waters along the Equator normally remain relatively cold to the east of that location (Fig. 2). Along the South American coast, the weakened trades result in less coastal upwelling, causing the enhanced warming of the coastal waters. The coastal Peruvian bioclimate suffers the most during these years.

The relationship between sea-level pressure and SST anomalies across the Pacific is insightful. During positive SO events, SST anomalies are usually negative in the central and eastern equatorial Pacific and positive over the Indian Ocean and Indonesia. The cool waters over the Pacific are consistent with the enhanced trade winds through that area. During negative SO events, the weakened trade winds upwell less cold water, resulting in positive SST anomalies throughout the central and eastern Pacific. These positive SSTs appear to be related to the aforementioned enhanced convection in the central, and occasionally, the eastern Pacific. Thus, there appears to be an intimate ocean-atmosphere link during the phases of the scientific El Niño and the Southern Oscillation. This coupled system is referred to as the El Niño/Southern Oscillation (ENSO). It is the ENSO event which this paper

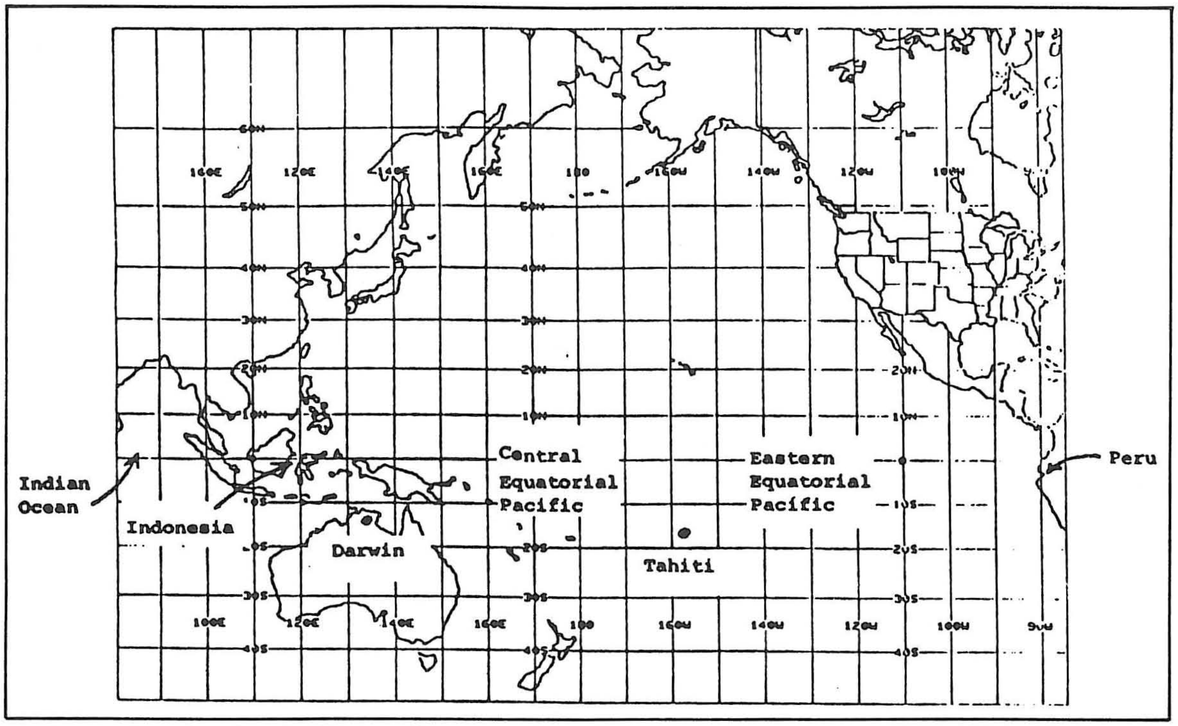

Fig. 1. Location of stations and areas referenced in the text.

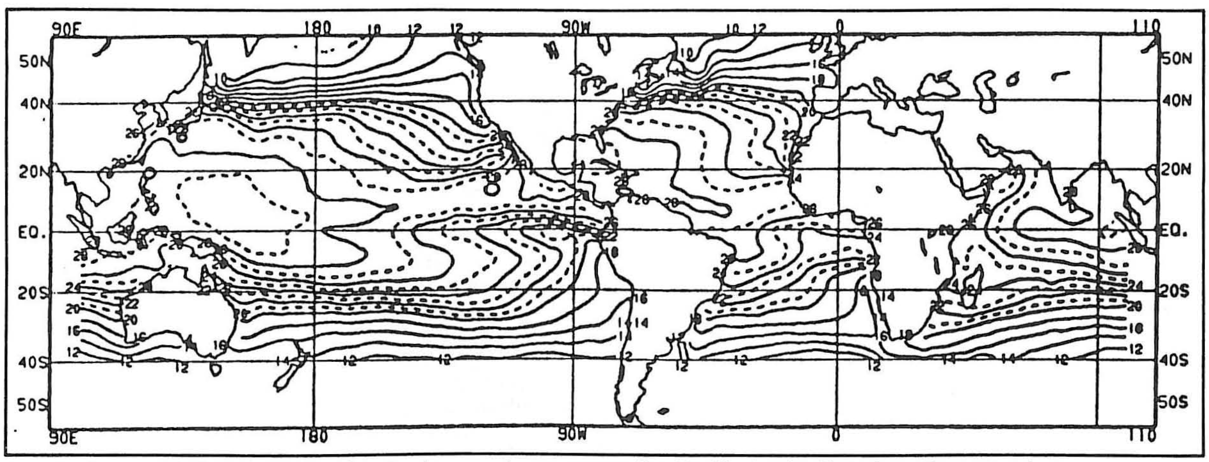

Fig. 2. Representative example of water temperatures across the Pacific basin. Note how the water is warm over the western Pacific and Indian Ocean, while temperatures cool eastward along the Equator in the eastern Pacific (5). Contour interval 2°C; above 20°C, odd contours are dashed.

addresses, as it is not just the warming of the coastal waters that we are concerned with, but rather, the global-scale circulation changes that accompany the basin-wide SST increases.

3. PROGRESSION OF THE "TYPICAL" ENSO EVENT

Horel and Wallace (2) analyzed in some detail the seven major negative SO events between 1950 and 1979 (note that these events did not include the extreme event of 1982–3). They termed the negative SO events as warm episodes, due to higher than normal SSTs in the central and eastern Pacific. The composite progression of the seven warm episodes is summarized in this section, with concentration on the Pacific SSTs and the circulation teleconnections to the Northern Hemisphere.

Normally, one of the first signs that an ENSO event may be beginning is the onset of anomalously warm water along the Peruvian coast. This warm water often first appears around the January time frame. Near the same time, the equatorial central Pacific also becomes warmer than normal. Corresponding to these water temperature changes, sea-level pressures rise in the western Pacific and fall in the eastern Pacific. During the spring months the coastal waters continue to warm dramatically, typically reaching a maximum positive anomaly by July.

The equatorial central Pacific SST anomalies continue to increase until early fall. The SST anomaly is usually at or near its maximum during much of the fall and winter seasons in the central Pacific. Central Pacific rainfall also increases strongly during this period, and is at its maximum during the late fall and winter seasons. Northern Hemispheric circulation teleconnections are strongest at the same time as the central Pacific SST and rainfall anomalies (approximately November through March).

4. MID-LATITUDE TELECONNECTIONS DURING WARM EPISODES

The upper tropospheric teleconnection pattern is represented by Figure 3 (from Horel and Wallace, 2). A wavetrain of circulation anomalies emanates from the equatorial central Pacific heat source (high SSTs, convection, latent heat release). This wavetrain is very similar to forced barotropic Rossby wavetrains modeled by Hoskins and Karoly (6). The apparent impact of the heat source on the Northern Hemisphere winter circulation field is to produce an anomalous upper level High over western Canada (and extending into the northwestern United States) and an anomalous upper level Low over the southeastern states. The impact on the western United States weather revolves around the anomalous High over western North America. Baroclinic waves often ride well up into Canada or else split along the coast, such that the dynamics are weak throughout much of the northwestern United States and southwestern Canada.

Ropelewski and Halpert (7) have examined the impact of the ENSO episodes on the North American temperature and precipitation patterns from 1875–1980. They created a 2-year envelope for each ENSO episode, spanning the period from the July before the Peruvian coastal warming began until the July after the maximum central Pacific warming has occurred. They composited the temperature and precipitation data for each of the 24 months, covering all ENSO events for which data was available at each station, and essentially computed the percentile rank of the temperature and precipitation composites for each month. From the 24-point time series of percentile ranks, they extracted the first harmonic, yielding the times when the impact is most strongly felt (both dry and wet, cold and warm). The amplitude indicates how strong the impact is at each location.

Results from Ropelewski and Halpert's work are shown in Figures 4A and 4B. In these figures, the harmonic dial represents the 24-month period mentioned above, where an arrow pointing left would indicate a precipitation (or temperature in Fig. 4B) maximum at the time when the positive SST anomalies are normally first evident along the Peruvian coast (January of year 0). As another example, an arrow pointing down would indicate a minimum in the precipitation (or tem-

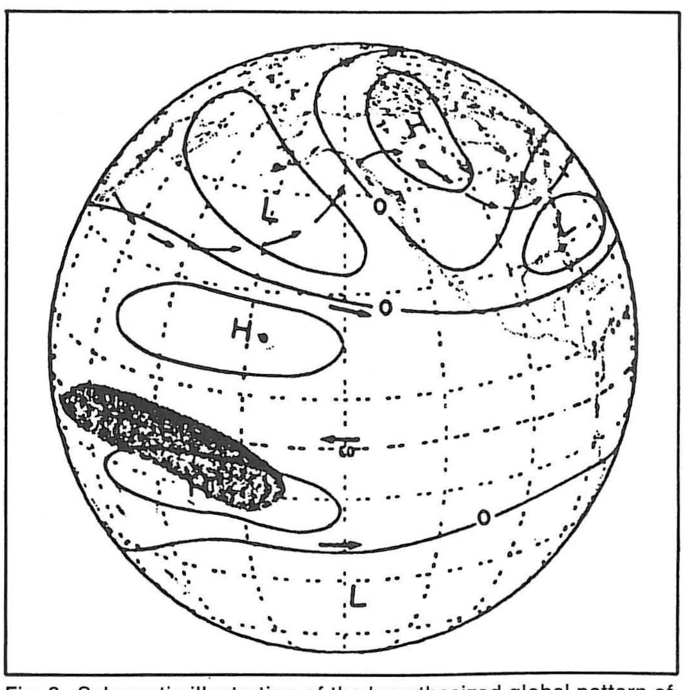

Fig. 3. Schematic illustration of the hypothesized global pattern of middle and upper tropospheric height anomalies (solid lines) during the Northern Hemisphere winter which falls within an episode of warm sea-surface temperatures in the central and eastern equatorial Pacific basin. The dark arrows reflect the enhanced subtropical jets and equatorial easterlies near the heat source. The lighter arrows depict a mid-tropospheric streamline as distorted by the anomaly pattern, with pronounced ridging over western North America. Shading indicates the region of enhanced high cloudiness and rainfall (2).

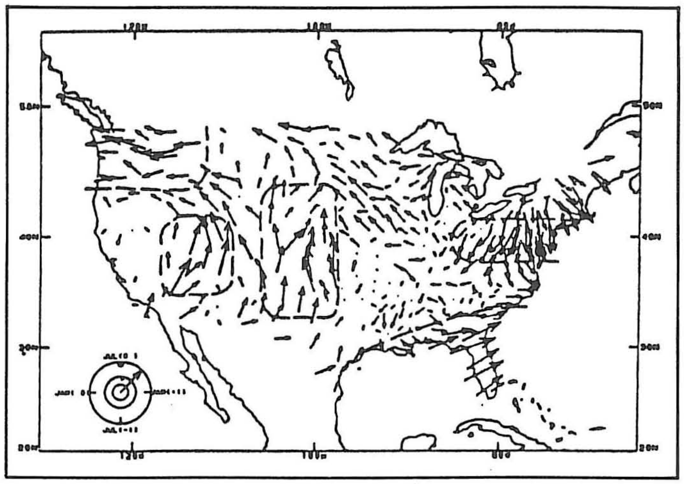

Fig. 4A. Station vectors based on a 24-month harmonic fitted to ENSO precipitation composites. Vectors represent stations with at least seven ENSO events included in the composite. Outlined areas show strong consistence between events. Vector magnitudes represent amplitude of first harmonic (in percent). Vector direction represents the time (as illustrated by the harmonic dial) when the monthly precipitation had the strongest positive response. Positive SSTs first appear during December of year −1 and are strongest around December of year 0 (7).

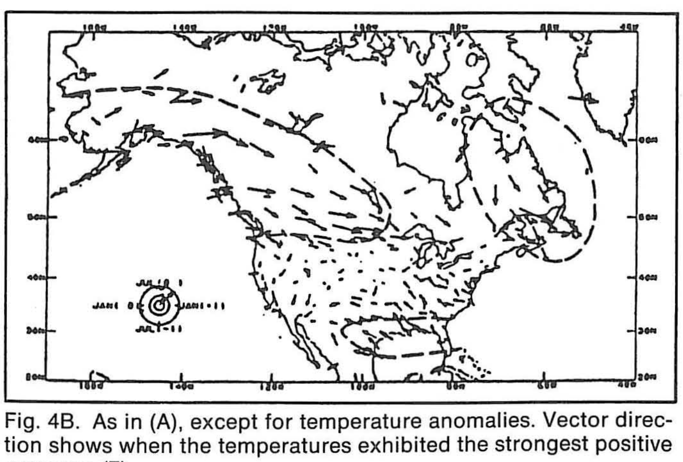

Fig. 4B. As in (A), except for temperature anomalies. Vector direction shows when the temperatures exhibited the strongest positive response (7).

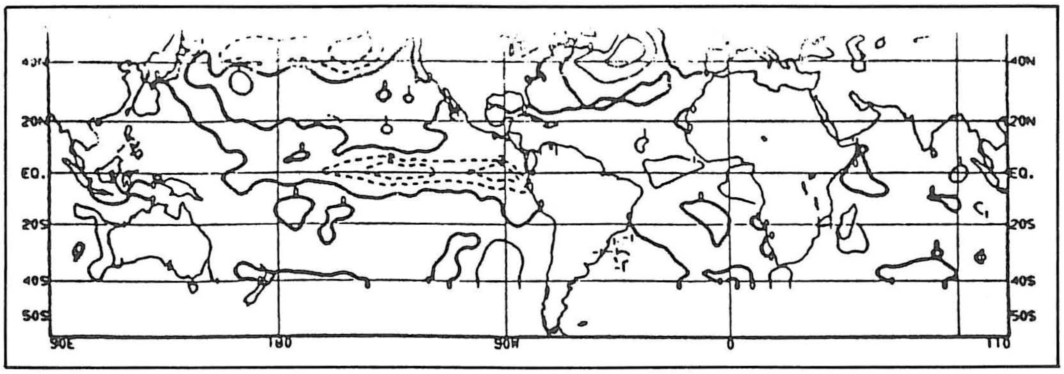

Fig. 5. Sea surface temperature anomalies, July 1988. Contour interval is 1°C with negative anomalies dashed (10).

perature) anomaly during the summer (July of year 0) preceding the maximum SST anomalies throughout the Pacific basin (January of year 1).

Figures 4A and 4B indicate that throughout the northwestern states and into Montana and North Dakota, precipitation is lightest in the months surrounding the January during which the Pacific basin SSTs are most anomalously warm. The temperature analysis shows that at the same time, the northwestern United States and southwestern Canada are typically warm. Over the southeastern United States, their analysis indicates a relatively cool, wet period during these same months. All of these results, not coincidentally, are consistent with those depicted in Horel and Wallace (2), with the anomalous upper level ridge over western Canada and anomalous trough over the southeastern states.

It should also be noted that Figures 4A, B show areas that experience wetter or drier than normal summers during the ENSO events. This result is very interesting, as most research work up to this time has indicated that mid-latitude circulation anomalies during the Northern Hemisphere summer are not very significant statistically, even during the warm episodes. However, while circulation anomalies may not be significant, those that exist are apparently important enough to produce consistent ENSO event precipitation anomalies.

The temperature and precipitation anomalies during the winter of 1987–88 fit in very nicely with the analyses described here, especially with respect to the anomalously dry and warm weather experienced across the northwestern United States and southwestern Canada.

5. THE COLD EPISODES

The cold episode is defined as the time during which the equatorial central and eastern Pacific SSTs are colder than normal. During these times, convection over the Indian Ocean and Indonesia is typically enhanced. Essentially, these cases exhibit a flip-flop in Pacific SST and sea-level pressure anomalies from those evident during the warm episodes. We are, thus, looking at the opposite phase of the SO. This phase has been referred to as the "anti-El Niño" or the "La Niña", depending on who you talk to. During the summer of 1988, the media picked up on La Niña (meaning "the girl"), which as a result, may become the catch phrase for this phase of the SO.

Through the mid-1980s, the cold episodes did not receive a lot of specific attention in the literature. However, over the past couple of years, and especially during 1988, we have begun to hear about the implications that these La Niña events may have for our weather. There are a number of important issues which should be addressed here.

1. How often does La Niña occur?

   An article in Time magazine (8) suggests that no La Niña has occurred before 1988 since satellite data gathering techniques existed. Such a statement is disputable. Following each ENSO episode, a cold event usually occurs. As inferred from the June 1984 SST anomaly map (9), there was a La Niña in 1984 following the strong ENSO episode of 1982–83.

2. What impact does the La Niña have on the mid-latitude circulation?

   There are a number of points that need to be addressed to try to understand the answer to this question. First, the Intertropical Convergence Zone (ITCZ) is generally located north of its normal position during cold events. The waters in the area of the ITCZ (around 15°N) may be warmer than normal. SST anomaly maps derived at the Climate Analysis Center (Fig. 5) indicate that weak positive anomalies existed around 15°N during the summer of 1988. Simulations by Trenberth et al. (11), using a global primitive-equation model, suggest that this displaced ITCZ and its associated convection may have set up a circulation pattern during the summer of 1988 that kept much of the storminess north of the United States. (Figs. 6A, B). These are, however, very preliminary model results. It would be important to note if observations from past cold episodes support these model results as a common mid-latitude signature.

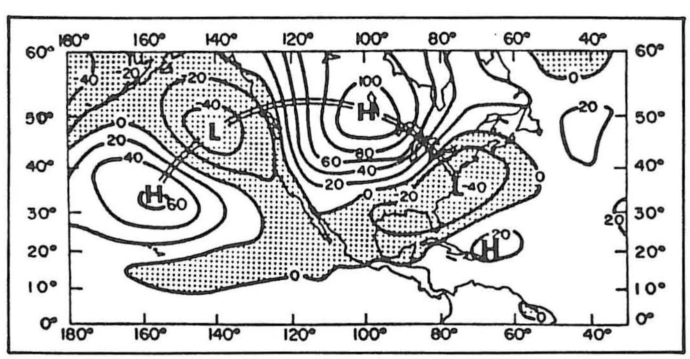

Fig. 6A. Geopotential height anomalies (a) at 300 mb for April-May-June 1988. Contours are every 20 m; negative values are stippled (11).

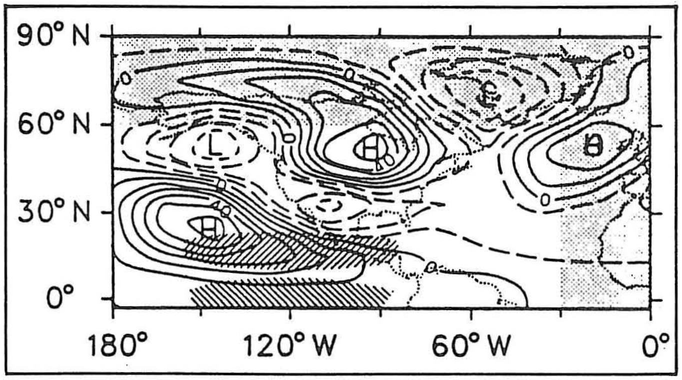

Fig. 6B. Geopotential height anomalies (b) at 300 mb resulting from a model simulation. Model is linearized about June conditions and forced by heating in the northern hatched region and cooling in the southern hatched region in the eastern Pacific. The stippled area denotes the region not shown in Figure 6a. Contours are every 10 m; negative contours are dashed (11).

Second, past research has indicated that mid-latitude circulation anomalies do appear to correlate well with anomalous convection over the Pacific during the Northern Hemisphere winter. During the summer, correlations are quite weak, especially between the mid-latitude Pacific and North America. Thus, this implication that there is a connection between the cold episode and mid-latitude circulation anomalies is very different than previous studies have indicated and comes as somewhat of a surprise. If it is the cold water (or stronger trade winds) which forces the convection north of its normal position, it is possible that a certain threshold of anomalously cold water (or wind speed) must be reached before the teleconnections are manifest. During the 1988 summer, the equatorial eastern Pacific SSTs were over 2°C below normal in some locations.

These first two points really lead us to the question of what forces the anomalous circulation. The media has been intrigued by the cold waters in the eastern Pacific, comparing and contrasting the cold events to the warm events. The natural assumption is that if the warm waters force one set of responses, the cold water will force another. But this assumption has a weakness in that it uses the cold waters as a forcing mechanism, which is not consistent with the forcing of the warm events.

Much of the current theory regarding warm events speculates that the enhanced convection in the central Pacific during a warm event causes the mid-latitude circulation response by releasing a great deal of (latent heat) energy into the atmosphere. This energy is transported via the Hadley circulation and is dispersed through the wavetrain described earlier. If, indeed, the forcing mechanism is the enhanced convection, then we should concentrate on areas of enhanced convection from which a mid-latitude response is generated, even during a cold event.

During a La Niña, the strongest heat source normally extends from the Indian ocean approximately to the Indonesian subcontinent. The global, satellite-derived outgoing longwave radiation (OLR) field for the month of July 1988 (Fig. 7), during which much of the country was in the throes of the drought, reveals that anomalous convection (inferred by the negative OLR anomaly values) was much greater and more extensive over the Indian Ocean and Indonesia than it was over the eastern Pacific ITCZ. This heat source would be especially strong during a summertime La Niña, where the annual cycle and cold event are working together to produce precipitation in the Far East (this particular combination likely played an important role in the late summer 1988 flooding in Bangladesh).

Along the ITCZ in the eastern Pacific (around 15°N), negative OLR anomalies were quite small (less than 15 Wm^{-2}) during July 1988, as they also were during May and June. Such small anomalies are considered within the "noise level" by some scientists. Still, in the Trenberth et al. (11) study, where they used only a small forcing as suggested by these anomalies, they were able to obtain tropospheric circulation anomalies that were similar to those observed. More work needs to be done to determine the relationship, if any, between cold events and mid-latitude circulation during both the summer and winter seasons. Likewise, researchers must resolve whether previous studies would show more similarity to those of Trenberth et al. (11) if they were performed differently. Evidence that supports these new results would further indicate the potential not only for improved diagnosis of the forcings which exist, but also improved forecasting in extended ranges.

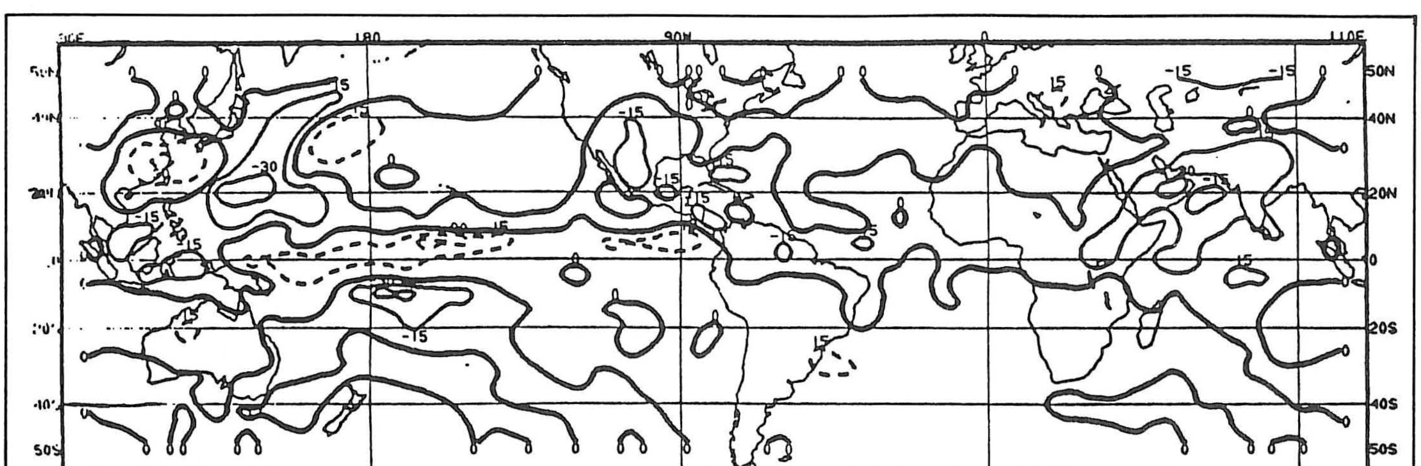

Fig. 7. Outgoing longwave radiation anomalies, July 1988. Contour interval, 15 W/m². Positive anomalies are dashed (10).

6. CONCLUSIONS

Over the past decade, we have learned a great deal about the global-scale impacts that ENSO events have on the atmosphere. A few of the current issues have been presented here in a very basic form. There are still many details which need more attention. These include the dependence of the mid-latitude circulation on the size, shape, location and magnitude of the equatorial thermal forcing. Proper modeling of ocean-atmosphere feedback mechanisms is essential, along with an accurate depiction of the initial conditions. We forecast for a relatively small area of the globe, and subtle changes in the forcing mechanism can have a profound effect on what weather we experience.

The 1982–83 ENSO event is a good example of how different ENSO events can be. It was the most intense ENSO event in recent history, producing strong convection in the Pacific as far east as 130°W. The resultant circulation included a very strong subtropical jet to the north of the convection and produced very wet conditions from California, through Utah and into the upper Midwest. This provides a stark contrast to the "typical" mid-latitude response to an ENSO event. Wherein lies the boundary between the "normal" ENSO and the 1982–83 event? This is the type of question that also needs to be answered.

ENSO events are not all the same; similarly, the so-called La Niña episodes likely vary from event to event. We need to clarify what forces the atmosphere during the anti-El Niño episodes. The atmospheric circulation response to the forcing mechanisms during the cold events also likely varies from event to event, in accordance with the forcing, much as the circulation varies between ENSO events. Research is just beginning to surface on these topics. We will likely hear a lot more about them over the next few years.

ENSO events do have a significant impact on society. Perhaps the most important influence the ENSO events have is that during a particular event, one general circulation pattern tends to be preferred. As such, dry areas often become too dry and wet areas are often too wet. This appears to be the case for all ENSO events. Where a particular forecast area falls into the preferred circulation pattern has a great deal to do with the weather anomalies that occur at that location. While some areas appear to have distinct preferences for temperature and precipitation anomalies during ENSO events, other areas seemingly do not. Additionally, variance in the forcing between ENSO events likely causes differences in the resultant mid-latitude circulation of each event. While we can generalize about how we expect the weather to act in certain areas during ENSO events, we cannot yet be certain about anything just knowing that an ENSO event is in progress.

But we are gaining knowledge. As we continue to learn, and then recognize how to apply that knowledge, we make progress in our efforts to provide more accurate forecasts. To paraphrase from Trenberth et al. (11), "the combination of understanding of the processes involved and using improved models raises the possibility of producing more reliable predictions of short-term conditions a season or two ahead." This may be realistic, and would be a tremendous gain in the efforts of extended range forecasting, with implications which may reach beyond the ENSO and anti-ENSO events.

ACKNOWLEDGMENTS

I thank John Horel, University of Utah, and Klaus Weickmann, ERL/ARL/Climate Research Division, for sharing their input and expertise with me on this subject.

NOTES AND REFERENCES

1. Glenn Lussky is a meteorologist with the National Weather Service, Western Region Headquarters in Salt Lake City, Utah. He received a B.S. in Meteorology in 1980 and M.S. in Meteorology in 1983, both at the University of Wisconsin-Madison. His current research interests include assessment and utilization of global-scale diagnostics in operational forecasting and the operational impact of symmetric instability diagnosis.

2. *Horel, J. D., and J. M. Wallace, 1981: Planetary-Scale Atmospheric Phenomena Associated with the Southern Oscillation.* Mon. Wea. Rev., *109, 813–829.*

3. *Walker, G. T., and E. W. Bliss, 1932: World Weather V.* Mem. Roy. Meteor. Soc., *4, 53–84.*

4. *Walker, G. T., and E. W. Bliss, 1937: World Weather VI.* Mem. Roy. Meteor. Soc., *4, 119–139.*

5. *CAC, 1985:* Climate Diagnostics Bulletin. *NOAA/NWS/NMC/ Climate Analysis Center, Washington, D.C., September.*

6. *Hoskins, B. J., and D. Karoly, 1981: The Steady Linear Response of a Spherical Atmosphere to Thermal and Orographic Forcing.* J. Atmos. Sci., *38, 1179–1196.*

7. *Ropelewski, C. F., and M. S. Halpert, 1986: North American Precipitation and Temperature Patterns Associated with the El Niño/Southern Oscillation (ENSO).* Mon. Wea. Rev., *114, 2352–2362.*

8. *Linden, E., 1988: Big Chill for the Greenhouse.* Time, *October 31, 1988.*

9. *CAC, 1984:* Climate Diagnostics Bulletin. *NOAA/NWS/NMC/ Climate Analysis Center, Washington, D.C., July.*

10. CAC, 1988: Climate Diagnostics Bulletin. *NOAA/NWS/NMC/ Climate Analysis Center, Washington, D.C., August.*

11. *Trenberth, K. E., G. W. Branstator, and P. A. Arkin, 1989: Origins of the 1988 North American Drought.* Science.