Reply

GUOXIONG WU

Institute of Atmospheric Physics, Chinese Academy of Sciences, Beijing, China

NGAR-CHEUNG LAU

Geophysical Fluid Dynamics Laboratory/NOAA, Princeton University, Princeton, New Jersey

22 September 1992 and 21 October 1992

1. Introduction

We thank Lander (1993) for making the effort to comment on our paper (Wu and Lau 1992, hereafter referred to as WL). Lander's concerns with our work are mainly related to two issues. First, on the basis of his own analysis of the observational records, he questions the existence of any definitive relationship between El Niño–Southern Oscillation (ENSO) and tropical storm (TS) formation over the western North Pacific (WNP) in the real atmosphere. Second, he proposes a more detailed comparison of our model output with observations, particularly with regard to the actual number of TS for individual years in the satellite era, the seasonal dependence of the anomalous TS activity, and various regional circulation features over WNP.

2. Observed relationship between ENSO and TS formation

Lander's claim that ENSO events have small impact on tropical cyclone activity in WNP is clearly at odds with the observational findings reported by Chan (1985), Dong (1988), and Imai (1988). By applying different analysis techniques to various datasets for TS formation, the latter authors have independently concluded that warm ENSO events are accompanied by below-average TS formation in the WNP sector west of 160°E, and by above-average TS formation over the central North Pacific east of 160°E. The reverse situation is seen to prevail during cold events. The marked influences of observed ENSO episodes on typhoon frequency over WNP have also been confirmed by a multitude of studies recorded in the Chinese literature (e.g., Pan 1982; Li 1988). The discrepancies between Lander's results and the various works just cited stem from the factors described in the following subsections.

a. *Treatment of inhomogeneities in the observational records on TS occurrences*

As pointed out by Lander, the transition from aircraft reconnaissance to satellite monitoring has introduced considerable uncertainties in the record of tropical cyclone activity during the 1960–91 period. The raw time series of tropical cyclone frequency (Lander's Fig. 2a) is noted for the presence of long-term trends, as well as high-amplitude short-term fluctuations in the presatellite era. Lander removes the long-term trend by an unspecified method, but makes no attempt to treat the high-frequency variability prior to the mid-1970s. The linear correlation coefficients between various ENSO and TS indices (section 4 of Lander's comments) should therefore be viewed with these complications in mind. Furthermore, the limited number of years in the subperiods used in such computations renders these statistics susceptible to sampling fluctuations. The quartile analysis in Lander's table is performed using the raw tropical storm and typhoon data, with the low-frequency trends retained. We have repeated the computations by first detrending the storm data using Lander's subjective method (see the time series in his Fig. 2b), and estimated that the average annual number of typhoons is approximately 1.6 above the trend for the eight years with the highest Southern Oscillation index (SOI), whereas the mean yearly typhoon number is approximately 2.3 below the trend for the eight years with the lowest SOI. Hence, the findings based on the detrended data are more in accord with those reported in the earlier studies. This simple calculation illustrates that the detailed treatment of secular trends in the observed TS time series could lead one to draw drastically different conclusions on any relationship between ENSO and TS occurrence.

Chan (1985) partially circumvented the difficulties arising from long-term changes in the reconnaissance strategy by performing an objective cross-spectral analysis, and by focusing on the coherence and phase relationship between SOI and TS fluctuations residing within the period range of 3–3.5 years. Since the latter

---

Corresponding author address: Dr. Ngar-Cheung Lau, NOAA/ERL/GFDL, Princeton University, P.O. Box 308, Princeton, NJ 08542.

time scale is considerably shorter than that associated with the secular trends in the TS records, Chan's results are less subject to the influences of such trends. The approach adopted by Dong (1988) is to contrast the TS frequency for each 12-month El Niño period with the preceding and succeeding 12-month periods, thereby minimizing the impact of any long-term trends. Dong's analysis indicates that, without exception, the nine warm events in the 1951–82 period are characterized by a definite suppression of typhoon formation in WNP west of 160°E relative to the 12-month periods immediately before and immediately after each event. It is also noteworthy that the data source for Dong's study (Shanghai Typhoon Institute, China) is independent from that for the investigations by Chan and Lander (Joint Typhoon Warning Center, Guam).

b. Distinction between the variability in TS formation over the western and central North Pacific

In view of the findings by previous authors that the polarity of the correlation between ENSO and TS formation over WNP west of 160°E is opposite to that of the corresponding statistic for TS occurrences east of 160°E, we maintain that it is important to partition the North Pacific accordingly in any search for ENSO–TS relationships. The net effect of combining the western and central sectors of the Pacific in Lander's analysis would be the diminution of the correlation level between ENSO and TS indices. The appearance that the sites of TS genesis form a contiguous zone extending all the way to the date line should not deter one from making a distinction between TS variability over the western and central Pacific, as long as the latter division is justified by observational fact and physical reasoning. The ability of our model experiment to reproduce the observed east–west dipole in the correlation pattern between ENSO and TS formation in the Pacific (Table 4 and Fig. 12 of WL) deserves more credit than Lander allows.

c. Definition of the typhoon season

Noting that the absolute minimum in TS activity over WNP takes place in February, Lander defines the typhoon season as the period from March through January of the following year. He applies the same definition to all years in the 1960–1991 period. Since the temporal development of some of the ENSO events (the 1982–83 episode being an outstanding example) is not related to the seasonal cycle in an unique manner, and since the frequency of TS formation exhibits interesting lag relationships with the ENSO events (Chan 1985; Dong 1988), this rigid definition of the typhoon season might lead to situations in which two different phases of an ENSO cycle fall within a single March–January period, thus reducing the strength of the ENSO–TS correlation. Chan's cross-spectral analysis does not necessitate the definition of a typhoon season. Dong's method entails the identification of a different "El Niño year" for each event, which corresponds to the 12-month period with the highest mean sea surface temperature in the eastern equatorial Pacific for the event in question. By using the latter, more flexible definition, Dong (see his Fig. 2) demonstrates that the El Niño year for the 1972 warm event (which falls between May 1972 and April 1973) is indeed characterized by less TS formation over WNP west of 160°E than that occurring in the 12-month periods before and after the same event. This result may alleviate Lander's concerns about the ENSO–TS relationship for the 1972 episode (see end of his Section 4). In WL, the sea surface temperature anomaly over the eastern equatorial Pacific during August of each year was used as the ENSO index. This choice is justified by the fact that both the frequency of TS formation over WNP (Fig. 5 of WL), and the warm and cold events during the 1962–76 period (Fig. 7 of WL), attain maximum amplitudes in August.

3. Rationale of our modeling approach

When we stated in WL that it is difficult to isolate the influence of ENSO events on TS activity by using observational data alone, we were actually referring not just to the aforementioned problems related to data quality and details of analysis techniques, but also to the more fundamental issue that the variability in TS formation in the real atmosphere is attributable to many dynamical and thermodynamical processes. Some of these processes are directly related to ENSO cycles, while some are linked to other phenomena occurring simultaneously in the complex climate system. A case in point is the occurrence of three consecutive warm ENSO events in the 1976–87 period, but no prominent cold event in the same period. This interdecadal signal coincides with corresponding changes in the planetary-scale circulation and temperature patterns in the Northern Hemisphere, and may complicate the search for a greenhouse effect and global warming (Trenberth 1990). The absence of cold events may also lead to a rather different set of relationships between ENSO and TS formation during 1976–87 (see some of the correlation statistics for this era in Lander's section 4). Hence, even with perfect data and optimal analysis methods, the assessment of the sole impact of ENSO on TS formation using observations alone is by no means a straightforward exercise. On the other hand, the virtue of a general circulation model (GCM) is that it provides for a controlled environment in which the effects of different mechanisms can be evaluated one by one. By adopting the experimental design described in WL, we were able to examine the modulation of the frequency of TS formation by the ENSO-related sea surface temperature changes only. Other possible contributory factors of TS variability, such as greenhouse warming and stratospheric oscillations, have been explicitly eliminated. The 1962–76 period examined in WL has been selected on account of the active ENSO cycles in that era, with comparable number of warm and cold events.

4. Comparison between model output and observations

With regards to Lander's second concern for more stringent verification of model output, we emphasize that the primary objective of WL is not to reproduce the exact number of TS occurrences in each year or each month through the duration of the experiment, but to confirm the existence of a *statistical* relationship between ENSO and TS formation in this particular model context. To the extent possible, WL have compared the climatology and interannual variability of the model-simulated TS behavior with the existing observational literature. The multiple mechanisms contributing to TS activity in the real atmosphere, the sensitivity of the quantitative results to the selection criteria of TS in the model atmosphere, as well as the crude resolution and other limitations of the GCM used in our experiment, do not warrant a comparison among the observed and simulated data with the degree of precision suggested by Lander. As noted in the preceding section, a large portion of the satellite era coincides with a prominent decadal signal in ENSO variability and hemispheric circulation changes, an analogous GCM integration conducted exclusively for this unusual period, as proposed by Lander, might not yield representative results. We agree with Lander that the intraseasonal behavior of TS activity and the nature of the ambient circulation are important considerations for evaluating the fidelity of model performance. Some information on the seasonal dependence of the variations in TS activity over WNP has been provided in Fig. 13a of WL. The largest changes in simulated TS frequency during El Niño and La Niña years appear to occur during the June–September period. The prevalence of anomalous surface easterlies and anticyclonic flow over tropical WNP during cold events, as noted by Lander, is discernible in the model composite pattern shown in Fig. 14b of WL. The tendency for the Asian summertime monsoon trough and surface westerlies to extend eastward during warm episodes, also pointed out by Lander, is evident in the composite chart based on the same experiment (see Fig. 10c of Lau 1985).

REFERENCES

Chan, J. C. L., 1985: Tropical cyclone activity in the northwest Pacific in relation to the El Niño/Southern Oscillation phenomenon. *Mon. Wea. Rev.,* **113,** 599–606.

Dong, K., 1988: El Niño and tropical cyclone frequency in the Australian region and the northwest Pacific. *Aust. Meteor. Mag.,* **36,** 219–225.

Imai, I., 1988: ENSO and typhoons. *Proc. Spring Meeting of Japanese Meteor. Soc. Japan,* Meteor. Soc. Japan, Kastiwa City, Japan, p. 141. [In Japanese.]

Lander, M. A., 1993: Comments on "A GCM simulation of the relationship between tropical storm formation and ENSO." *Mon. Wea. Rev.,* **121,** 2137–2143.

Lau, N-C., 1985: Modeling the seasonal dependence of the atmospheric response to observed El Niños in 1962–76. *Mon. Wea. Rev.,* **113,** 1970–1996.

Li, C., 1988: Actions of typhoon over the western Pacific (including the South China Sea) and El Niño. *Adv. Atmos. Sci.,* **5,** 107–115.

Pan, Y. H., 1982: The effect of the thermal state of equatorial eastern Pacific on the frequency of typhoon over western Pacific. *Acta Meteorol. Sin.,* **40,** 24–34. [in Chinese with English abstract.]

Trenberth, K. E., 1990: Recent observed interdecadal climate changes in the Northern Hemisphere. *Bull. Amer. Meteor. Soc.,* **71,** 988–993.

Wu, G-X., and N-C. Lau, 1992: A GCM simulation of the relationship between tropical-storm formation and ENSO. *Mon. Wea. Rev.,* **120,** 958–977.