16.1 WHAT ROLE TO TROPICAL CYCLONES PLAY IN THE GENERAL CIRCULATION?

William M. Frank
Penn State University, University Park, PA

1. INTRODUCTION

This paper and the accompanying talk address the issue of why the average global number of tropical cyclones (TCs) is between 80-90? Frank and Young (2007) showed that the spatial patterns of interannual variability do not show evidence that the global number of TCs is self limiting. Enhanced TC activity in one ocean basin is not associated with reduced net totals in the other basins. There are several global circulation anomaly patterns that result in TC-number correlations and anti correlations between individual basins (the most famous being ENSO). However, there is no indication that the storm activity in one basin significantly affects the activity in others.

As defined here, tropical cyclogenesis occurs when a rotating convective weather system in the tropics reaches sufficient strength that it is able to self intensify through its interaction with the ocean (e.g. – a WISHE instability has been triggered). This usually occurs at about the time a system becomes classified as a tropical depression. The annual number or genesis events within a basin reflects the number of times that the sufficient conditions are achieved. What determines this number?

TCs may influence the atmosphere and ocean (the latter via cold-water upwelling) within a basin in ways that could affect subsequent genesis events in the same basin. However, it is the author's opinion that these effects are relatively small and tend to occur far from the prime genesis areas. They are neglected here.

2. GENESIS AND MONSOON TROUGHS

The climatological conditions associated with tropical cyclogenesis have been well established since Gray (1968). While exact expressions of these conditions vary slightly, in essence they consist of warm sea surface temperatures, anomalously high low-level vorticity, weak and preferably easterly vertical wind shear (often flanked by higher shear to the north and south), and a sustained region of active convection that includes enhanced humidity in the lower and middle troposphere.

Genesis is often thought to occur when some anomalously favorable combination of these conditions occurs locally, though the range and magnitudes of these sufficient conditions are not well mapped out. It is often stated that most of the climatological conditions associated with genesis occur frequently over vast areas of the tropical oceans. Why, then, aren't there more of them?

One way to look at the problem would be to do a joint probability study using the probability of occurrence of the likely genesis parameters and taking into account their interdependence. However, the premise of this author is that the frequency of TC genesis is limited primarily by a single parameter – the ability of the tropical atmosphere to produce sufficient low-level vorticity anomalies. Further, the necessary supply of vortices is controlled largely by a single feature of the general circulation – the monsoon trough (MT) portions of the ITCZ (Intertropical convergence zone). A MT is defined as a region of the ITCZ that has westerly flow equatorward of the trough axis. (A trade-wind trough, or TWT, has easterly flow both north and south of the axis.)

From at least as far back as Gray (1968) it has been known that most of the Earth's tropical cyclones form within, or a short distance poleward from, a MT. For example, Briegel (2002) showed that over a five-year period 85% of all TCs that formed in the NW Pacific formed within 10 degrees of the ITCZ, overwhelmingly in the MT portion. The major exceptions would be storms in the NW Pacific and N Atlantic that form poleward of about 20 degrees N. The situation is also arguable in other parts of the N. Atlantic, since much of the MT occurs over land. The waves generated over Africa usually don't usually achieve genesis until they have traveled some distance to the west of the MT region. Still, from a global perspective the annual storm number is dominated by MT-related genesis.

The axis of a MT lies close to the axis of maximum SST, though they do not always precisely coincide. There is always plentiful, sustained convection and high humidity there. The nature of the MT circulation is such that there is always a line of weak vertical wind shear roughly along its axis. Low-level relative vorticity varies with time, but on average it is about three times higher in a MT than in a TWT (e.g. – Briegel, 2002). Hence, all of the usual thermodynamic and vertical shear parameters are satisfied within a MT on almost any given day. The primary limiting factor appears to be the low-level vorticity which only occasionally reaches the necessary magnitude.

This author's hypothesis is that the annual global storm number is determined by the climatology of the monsoon troughs. The MTs comprise the primary feature of the general circulation that is capable of sustaining deep convection long enough to produce sufficient low-level vorticity to trigger genesis. Ferriera and Schubert (1997) and others have shown that an active MT can produce enough vorticity to become barotropically unstable, resulting in ITCZ breakdown into individual waves and then vortices. Several observational studies and at least one modeling study have indicated that a symmetric ITCZ has a characteristic recycling time on the order of 14-20 days. Frank and Roundy (2006) suggested that most TC genesis cases in the world are triggered by tropical waves interacting with a MT, which might somewhat speed up the cycle at specific locations.

In addition to an apparent vorticity recycling time, a MT also appears to have a characteristic length scale for TC genesis. The NW Pacific MT has a known genesis hot spot at its eastern-most point ("confluence point), where the sign of the zonal winds changes on the equatorward side. There is also a preferred secondary genesis location on the order of 1500 km to the west of the confluence point. This distance is approximately what one observes and would expect for ITCZ breakdown or related wave interactions.

Going somewhat out on a limb, it is proposed that the annual number of tropical cyclones in any given basin (N) should be approximately equal to the product of the number of MT cycles per month (about 2), the number of months that the MT is "active" (i.e. – of sufficient strength to produce TCs), and the length of the trough. That is:

$N = 2 \times M \times L$

where M is the average number of months per year in which the MT is active (defined arbitrarily as months in which the basin averages one or more TCs), and L is expressed in terms of a scale unit (arbitrarily set at 2000 km here). These choices and definitions are obviously subjective, but for purposes of illustration the predicted and observed numbers of TCs in each basin for two periods are shown in Table 1. It must be emphasized that the determination of the length of the MT in each basin is highly subjective and probably inaccurate. The author plans to do a proper climatology of this variable in the future. Note that the 2000 km scale length used in Table 1 is longer than the 1500 km length reported in Briegel and Frank (1997). Reducing the scale length would increase the number of predicted TCs.

3. CONCLUSIONS

The argument presented here is that the climatology of the Earth's monsoon troughs is the primary factor determining the global number of tropical cyclones. In particular, it is the ability of these monsoon troughs to spin up low-level vortices that appears to be the primary factor limiting the global number of TCs to 80-90 per year. The necessary thermodynamic and shear conditions are much more common and would appear to have the capacity to support a larger population of storms. If this argument is correct, it would imply that changes in the number of tropical cyclones in altered climate regimes would depend upon changes in the strength of the Hadley circulation and the location and configuration of the ITCZ in each basin.

4. References

Briegel, L. M., 2002: The structure and variability of the ITCZ of the western North Pacific. PhD dissertation, The Pennsylvania State University, 198 pp.

Briegel, L. M., and W. M. Frank, 1997: Large-scale forcing of tropical cyclogenesis in the western North Pacific. Mon. Wea. Rev., 125, 1397-1413.

Ferreira, R. N., and W. H. Schubert, 1997: Barotropic aspects of ITCZ breakdown. J. Atmos. Sci., 54, 261-285.

Frank, W. M., and P. E. Roundy, 2006: The role of tropical waves in tropical cyclogenesis. Mon. Wea. Rev., 134, 2397-2424.

Frank, W. M., and G. S. Young, 2007: The interannual variability of tropical cyclones. Mon. Wea. Rev., 135, 3587-3598.

Gray, W. M., 1968: Global view of the origin of tropical disturbances and storms. Mon. Wea. Rev., 96, 669-700.

	NATL	NEPAC	NWPAC	NIO	SHEM	Total
TC 1968-1989	**10**	**17**	**26**	**5**	**26**	**84**
TC 1985-2003	**11**	**17**	**32**	**5**	**29**	**93**
L (2000 km)	1	1	2	0.5	4	8.5
Active Months	4	5	6	5	5	
2 x M x L	**8**	**10**	**24**	**5**	**20**	**67**

Table 1: Number of best-track tropical storms per basin (first two rows), approximate mean length of the MT in scale units of 2000 km, the number of months the MT is active, and the predicted total storm number (last row).