SIXTH INTERNATIONAL WORKSHOP on TROPICAL CYCLONES

Topic 2.1 : **External Influences on Formation**

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Abstract:

2.1.1: Introduction

Understanding how tropical cyclones form and how the structure and intensity of these storms varies under the influence of larger-scale circulations is fundamental to improving forecasts and response plans in the current and future climate regimes. The climatological conditions present when they form have been well known since Gray (1968, 1979) and were summarized by Briegel and Frank (1997) and others: sea surface temperatures above about 26.5C with a deep ocean mixed layer; a positive low-level vorticity anomaly; weak and preferably easterly vertical wind shear; and a region of organized deep convection with moistened lower and middle levels. However, individual storms form infrequently and sporadically within large areas of favorable environmental conditions due to the effects of local flow perturbations.

The key to understanding tropical cyclogenesis lies in determining how the full range of tropical weather phenomena collectively produce the sufficient local conditions to form a storm. Further, it is essential to understand the relationships between the occurrence of genesis conditions locally and the basin-scale state of the atmosphere and ocean.

Most of the tropical cyclogenesis research since the previous IWTC has fallen in two general areas. One of these involves studies of the relationships between tropical wave activity, and the other is a look at changes in storm formation frequency within cyclone basins on time scales ranging from interannual to multi-decadal.

2.1.2 Tropical Waves and Cyclogenesis

The most active area of research on the genesis of individual storms during the past few years has been the role of tropical waves in cyclogenesis. Frank and Roundy (2006) argue that the favorable anomalies that produce most of the world's tropical cyclones are organized by one or more tropical waves, often as they interact with a monsoon trough and/or each other. It has been known for decades that the tropical atmosphere is perturbed by a variety of wave types, several of which are unique to the equatorial wave duct. These waves were analyzed analytically by Matsuno (1966), Zhang and Webster (1989), and others. However, they have always been difficult to study due to the paucity of conventional data over the tropical oceans. Spectral analyses and composite studies (e.g. –Reed et all, 1977) revealed some aspects of their structures in the real atmosphere, but it was not until improved models and data assimilation techniques were developed that the waves were resolved well enough in global analysis fields to permit detailed studies of their structures and behavior. Recent studies of tropical wave characteristics include Hendon and Liebmann (1991); Madden and Julian (1994); Takayabu (1994); Wheeler and Kiladis (1999); Wheeler and Webster (2000); Straub and Kiladis (2002); and Kiladis et al. (2005).

Roundy and Frank (2004 a,b,c) studied the climatology and properties of tropical waves on a global basis, and they analyzed the net effects of the various wave types upon rainfall variability in the tropics. They found that the waves play a larger role in modulating tropical rainfall patterns than had had been generally recognized, with individual wave types providing as much as 40% of the total rainfall variance in some regions. They also showed that interactions between wave types and between the waves and the background flow and topography are important features in the behavior and effects of the waves. Since the waves modulate the large-scale vertical velocity, vorticity, and vertical shear patterns, they can also have potentially large effects on tropical cyclone formation and structure.

There have been several recent observational case studies of the influence of tropical waves on tropical cyclogenesis – e.g.: Landsea (1993), Thorncroft and Hodges (2001), and others have studied the genesis of hurricanes in the Atlantic resulting from African waves. Molinari and Vollaro (2000), Maloney and Hartmann (2001), Liebmann et al. (1994), and others have showed effects of the MJO (Madden-Julian Oscillation) on North Pacific tropical cyclogenesis. Dickinson and Molinari (2002) analyzed events of cyclogenesis in the Northwest Pacific associated with Mixed-Rossby-Gravity waves, while Bessafi and Wheeler (2005) and Hall et al. (2001) analyzed the relationships between the MJO, other wave types, and cyclogenesis over the southern Indian Ocean and in the Australian region, respectively.

Frank and Roundy (2006) analyzed relationships between tropical cyclone formation and tropical wave activity in each of the six global tropical cyclone basins. Using statistical and compositing techniques applied to spectrally filtered outgoing longwave radiation (OLR) data and reanalysis wind fields they were able to show that most tropical cyclones form in the convectively active portions of tropical waves, and that the phase relationship between the genesis location and each wave type is the same in every cyclone basin. All of the wave types except for Kelvin waves clearly played significant roles in tropical cyclone formation. The higher frequency waves were most important in the N. Hemisphere, while the MJO dominated S. Hemisphere genesis.

Based on the combined results of the above studies, it is clear that tropical waves have significant effects upon tropical cyclogenesis, and they almost certainly have significant effects on mature cyclones as well. It is time to examine in a quantitative fashion how the waves produce these effects. In order to do this it is necessary to combine observations of individual storms and their environments, knowledge of wave structures determined from the previously described statistical and compositing studies of waves, and high-resolution numerical simulations.

2.1.3 **Other Factors Affecting Genesis**

Several recent studies have examined environmental flow conditions at the time and place of genesis and the physical interactions between the large-scale flow and cyclone formation. Davis and Bosart (2003) examined baroclinically induced development of tropical cyclones and found that a sharp reduction in the vertical shear that resulted from diabatic heating was essential to the formation. Karyampudi and Pierce (2002) showed that several different synoptic-scale processes associated with the Saharan Air Layer can interact with midlevel wave vortices to form storms in the Atlantic. Molinari and Corbisiero (2004) analyzed the development of a hurricane core in a sheared environment. A modeling study by Bister (2001) showed that strengthened convection on the periphery of a developing storm tended to retard the core development.

There were also studies of new statistical techniques for forecasting genesis. Hennon et al. (2003,2005) explored improvements in statistical forecasting of tropical cyclogenesis in the North Atlantic using large-scale data and neural network techniques. McDonnell and Holbrook (2004) developed a Poisson regression model for forecasting genesis in the Southwest Pacific, while DeMaria et al. (2001) developed a genesis parameter for the North Atlantic.

2.1.4 Relationships Between Genesis and Basin-Scale Variations

Recent studies by Webster et al. (2005), Emanuel (2005), and Mann and Emanuel (2006) argue that tropical cyclones appear to have increased in number and intensity during the last century or so. They suggest that these changes could be related to small increases in the mean sea surface temperatures (SST) that have been observed during that period. While the problem of tropical cyclones in future climates is the focus of another working group, one aspect of the problem is important to this one. What are the relationships between long-term basin-scale circulation changes and the prevalence of the sufficient local conditions for tropical cyclone formation and intensity change?

Several recent studies have examined interannual changes in basin-scale circulations (including SST variations) and tropical cyclones, e.g. – Bell and Chelliah (2006), Goldenberg et al. (2001), Chelliah and Bell (2004), Hoyos et al. (2006), Wang and Chan (2002), Chan and Liu (2004) and others. Some of the studies have found correlations between basin-scale SST and storm number and intensities on interdecadal time scales but not on shorter time scales. Relationships between basin-scale SST variations and the conditions that cause cyclogenesis have not yet been established.

Some studies find that changes in basin-scale vertical shear patterns modulate the number of tropical cyclones that occur in a basin during a season, while others dispute this. Wang and Chan (2002) found that changes in spatial patterns of storm formation in the NW Pacific during El Nino could be attributed to increased vorticity in the monsoon trough and increased subsidence in the northwest portion of the basin.

2.1.5 Summary

Many questions remain. If SST changes are important to cyclogenesis, is this due to the direct, local thermodynamic effects on the incipient cyclone, or to changes in the location and intensity of convection and/or the large-scale dynamics? What kind of vertical wind-shear changes enhance or suppress genesis? Does tropical wave activity affect genesis differently as the large-scale circulation of a basin varies? What role do basin-scale circulation changes play in altering the intensity and configuration of monsoon troughs? A great deal of research is needed to answer these and similar questions, and there appear to be sufficient data available to make progress in this area.

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