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A PROPOSED POTENTIAL VORTICITY MECHANISM FOR SUB-TROPICAL CYCLOGENESIS AND TROPICAL TRANSITION

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1. Introduction

In spite of the fact that descriptions of the characteristics of sub-tropical cyclones have been documented in the literature as early as 1952, there has been much debate regarding forecasting them. When observing and forecasting sub-tropical (ST) cyclones, a consensus cannot always be reached regarding the extent of their tropical or extra-tropical characteristics. Indeed, cyclones with fairly ambiguous origins and/or structures have often been classified as sub-tropical. ST cyclones also often undergo transition to tropical cyclones. Since the weather produced by both sub-tropical and tropical cyclones is similar, members of the public recognize no real distinctions between these system types. For these reasons, operational tropical forecasters have recently begun to assign names to Atlantic warm season sub-tropical (ST) cyclones in the same way that tropical cyclones are named.

Simpson (1952) discussed the evolution of "Kona Storms" in the Pacific Ocean, and documented two originating mechanisms. The first case is the development of a Northern Pacific Kona low from an occluded cyclone which has been isolated from its source of cold air by a strong anticyclone to the north. The cyclone then becomes circularly symmetric. The second case is that of an upper cold low which induces cyclogenesis at the surface.

Ramage (1962) considers the case of an ST storm over the Pacific, and mentions that hybrid cyclones, and upper level "distal" cyclones may be related to the Kona storms of Hawaii, perpetuating the 'catch-all' status of ST cyclones.

A ST satellite recognition method was developed by Hebert and Poteat in 1975, and implemented by the US National Weather Service, as a complement to the Dvorak technique for tropical cyclone classification. Hebert and Poteat classify further sub-categories of ST cyclone in this document: low-level baroclinic lows which form east of upper troughs, and frontal waves.

Sub-tropical storms are frequent enough in occurrence in the Atlantic Basin that a forecast method for their development is warranted. Roth (2003) completed an exhaustive climatology of sub-tropical storms in the Atlantic basin over a fifty-one year period (1951-2001), documenting 218 ST cyclones. The study showed that ST cyclones have occurred in every month of the year, with late Atlantic hurricane season the most favorable time of year for development. The highest frequencies of occurrence were in October (20.2% of all cases), September (16.5 % of all cases) and November (13.8% of all cases).

The focus of this study will be cases of ST cyclones which develop from the interactions between upper cold lows and surface vorticity maxima, such as tropical waves, in the Atlantic tropical season.

Palmén (1949) indicated that upper cold low formation is a result of "cutting-off" of circulations from the main flow aloft. Rossby wave breaking along sheared trough axes is proposed by to be one mechanism for producing cut-off lows. Thorncroft *et al* (1993) described this process as being a result of anti-cyclonic shear equatorward of the mean zonal jet, associated with what they describe as baroclinic wave life cycle type 1 (LC1).

2. Observations

On October 10, 2000, an Atlantic cold front (extending from near Bermuda to central Cuba) became stationary. On October 12, the interaction between the weak surface front and a tropical wave resulted in development of a surface low along southern end of front. In addition, a high amplitude mid-latitude trough in the upper troposphere produced a cut-off cold low, which moved southward.

By October 14, the surface low had drifted north-northeast, deepened to 1003 hPa and moved north to about 800 n mi east of Cape Canaveral Florida (Fig. 1). On the 15th, the surface low turned westward, moving underneath the upper level cold low, where it remained stationary for 48 hours over warm (>28°C) waters. Thunderstorms developed and remained near the low level center.

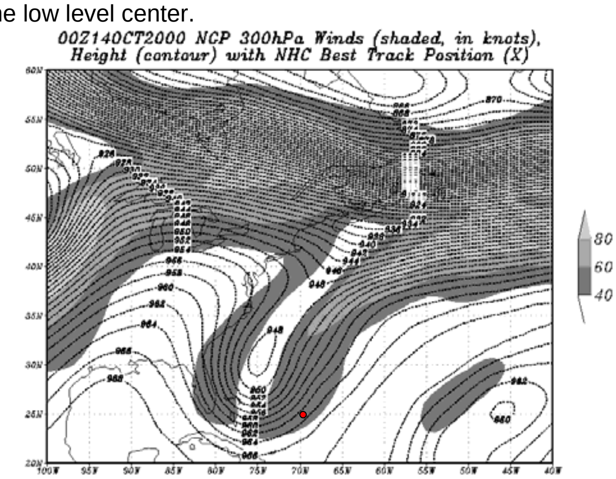

Figure 1 – NOGAPS model analysis of 300 hPa heights (contours) and winds (shaded contours).

On October 17th, AMSU data also showed a weak warm core aloft and outflow at upper levels. 0000 UTC satellite classifications suggested enough tropical characteristics to name this system Tropical Storm

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Michael. At 1800 UTC Michael strengthened to a hurricane, based on flight data.

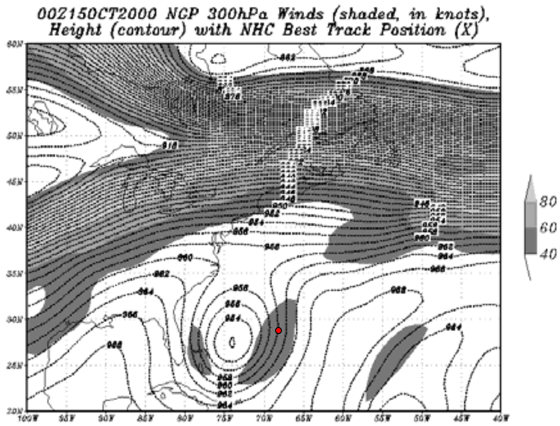

Figure 2

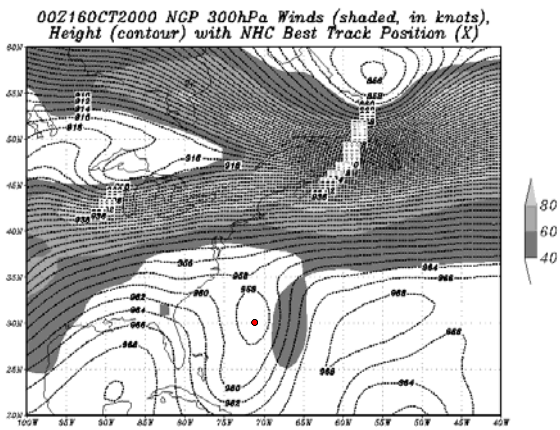

Figure 3

3. Conceptual Model

Based on the summary of conceptual models presented by Davis and Emanuel, we propose that 'sub-tropical cyclogenesis' (henceforth referred to as STCG), is a 4-step mechanism, involving Types A and B, as outlined by their paper.

The first stage of STCG is the intensification of pre-existing lower and upper PV anomalies by baroclinic instability. This is often the explanation offered for cyclogenesis along frontal boundaries in the mid-latitudes. This general idea is consistent with the relative positioning of upper troughs and their associated surface depressions, in Norwegian cyclone models, conveyor-belt theory, and baroclinic wave life cycles (Thorncroft *et al*, 1993). Secondly, the amplified upper trough PV anomaly becomes cut off from the mean flow, via equatorward Rossby wave-breaking. In the third stage these cut-off features become embedded in a region of much greatly reduced or negligible vertical shear. This allows the advection of the surface low into the centre of the upper circulation. Finally, superposition of the PV anomalies allows them to both grow rapidly by direct reinforcement of each others' circulations. This process will clearly be most efficient in areas of enhanced (Rossby) penetration depth.

If significant air-sea heat fluxes are associated with the surface feature, the lower warm core/upper cold core hybrid cyclone may be deemed a sub-tropical storm. Wraparound convection and the resultant release of latent heat may provide the mechanism for heat transport from the surface to the upper levels of the cyclone. This may provide enough warming at upper levels for the cyclone to eventually undergo tropical cyclogenesis.

The developments of Hurricane Karen in 2001, and Tropical Storm Florence in 2000 were also examined and fit this conceptual model for sub-tropical cyclogenesis.

4. Conclusions

A conceptual model of sub-tropical cyclogenesis is presented, based on synoptic scale observations of Sub-Tropical Storm Michael, the precursor to a landfalling hurricane. Numerical modelling studies will continue to determine the importance of each aspect/stage of the conceptual model.

This study is relevant to forecasting in coastal regions, tropical and sub-tropical islands. The impacts of landfalling hurricanes of sub-tropical origin, such as Gustav, Karen, Florence and Michael, demonstrate the necessity for understanding sub-tropical cyclogenesis, and subsequent sub-tropical to tropical transition.

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