Analysis of Data From TCS-08

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LONG-TERM GOALS

The long-term goals of this project are to understand better the mechanisms operative in tropical cyclogenesis and to transfer this knowledge to large-scale models in order to improve forecasts of tropical storm formation. Since convection constitutes the biggest uncertainty in this process, our focus is to understand how convection affects and is affected by cyclone-scale flows.

OBJECTIVES

Our objective in this segment of the program was to extend our vorticity budget analysis to a wider variety of developing and non-developing disturbances in the northwestern Pacific and to apply a thermodynamic analysis to these disturbances as well.

APPROACH

The TCS-08 field program provided a rich set of data including Eldora radar data and dropsondes from a variety of platforms. In order to be able to incorporate these results into a single product on which various analyses can be made, we developed a three-dimensional variational analysis (3-D Var) scheme for the winds and a separate 3-D Var analysis scheme for dropsonde thermodynamic data. These two analysis schemes work on identical grids and can therefore be merged to facilitate combined wind and thermodynamic analyses.

WORK COMPLETED

The 3-D Var analysis schemes, ng3dvar for winds and ngsonde for thermodynamics, have proven to be robust and reliable analysis tools. They are now publicly available as part of our Candis (C-language ANalysis and DISplay) package at

http://physics.nmt.edu/~raymond/software/candis/candis.html.

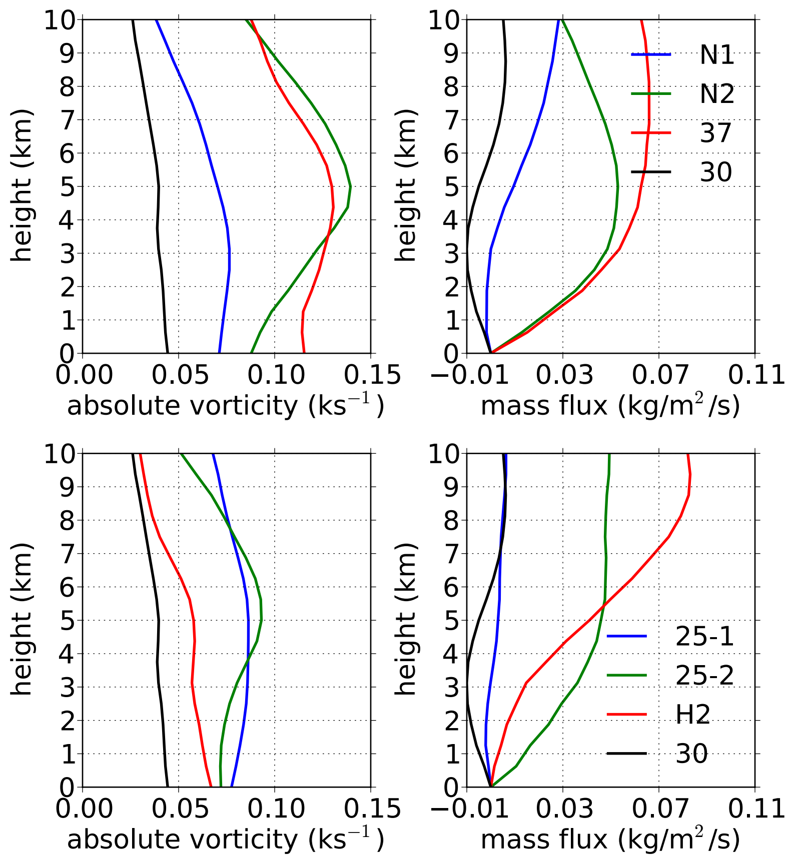

Figure 1: **Vertical profiles of absolute vorticity (left panel) and vertical mass flux (right panel) area-averaged over selected analysis regions. The upper panels show Nuri1, Nuri2, TCS037, and TCS030, while the lower panels show TCS025-1, TCS025-2, and Hagupit2. (TCS030 is included for comparison purposes.)**

We examined seven missions on five potential tropical cyclone precursor disturbances from TCS-08 which had both ELDORA Doppler radar data and dropsondes deployed from an elevation near 10 km. Of these five disturbances, one developed into a typhoon immediately (Nuri), one developed into a midget tropical cyclone after a few days (TCS037), one stagnated for a week before developing (Hagupit), and two did not develop at all (TCS025, TCS030). Thus, we have a good selection of rapid development, slow development, and no development.

We extended the vorticity analysis done on the Nuri case study (Raymond and López Carrillo 2011) to all of the above cases. Vorticity structure, vertical mass flux profiles, and vorticity tendencies were calculated for each. The vorticity and mass flux profiles are shown in figure 1 and the vorticity tendencies are shown in figure 2. Note that the systems that developed immediately (Nuri2, TCS037) had strongly positive vorticity tendencies at low levels, whereas the tendencies in the other cases were weaker. TCS025 was a marginal case which was initially promising, but then collapsed. Comparing these two figures shows that positive vorticity

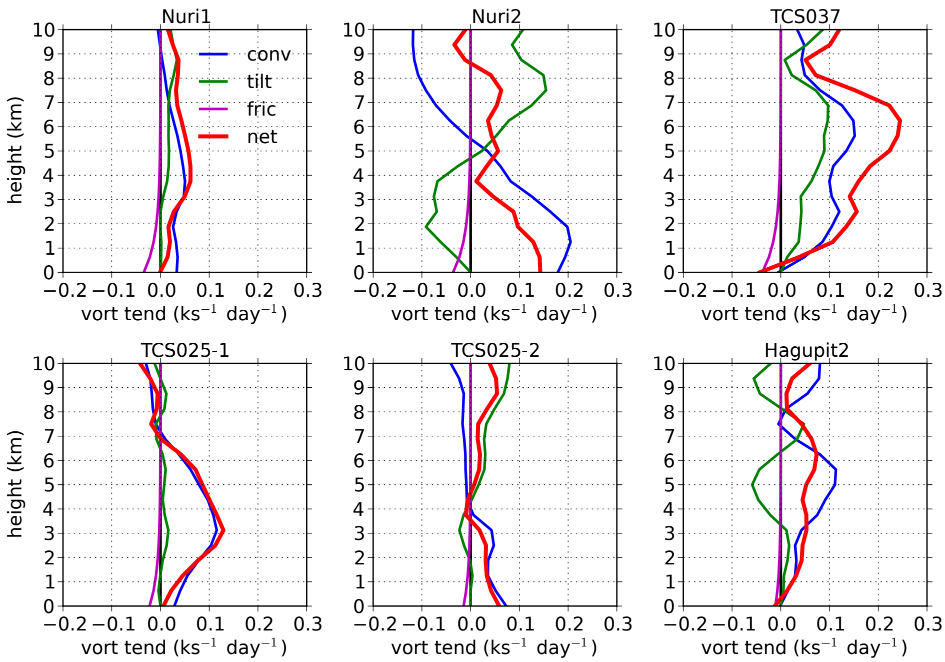

Figure 2: **Mean profiles of total vorticity tendency (red) and its individual components (blue: vorticity convergence; green: tilting; magenta: friction) for all missions except TCS030.**

tendencies at low levels are associated with mass flux profiles which increase rapidly with height in the lower troposphere. This increase with height corresponds to strong mass inflow at low levels, which promotes vorticity convergence and spinup, so the correlation is not accidental.

In addition, we performed a thermodynamic analysis using the dropsondes, from which we obtained three-dimensional fields of temperature and humidity. From this we calculated moist and saturated moist entropy. The saturation fraction (precipitable water divided by saturated precipitable water) and an instability index (saturated moist entropy in $1-3$ km layer minus saturated moist entropy in $5-7$ km layer) were then calculated. Both of these parameters were shown to be important to the nature of convection in the cloud-resolving model simulations of Raymond and Sessions (2007). In particular, higher saturation fraction and lower instability index led to heavier precipitation. In addition, lower instability index produced a decrease in the elevation of the maximum in the vertical mass flux profile.

Figure 3 shows sample sounding profiles for the Nuri2 and Hagupit cases (Raymond, Sessions, and López 2011). Comparison with the right panels of figure 1 shows that Nuri2, with its low instability index, exhibited exhibited strong vertical mass flux at low levels, whereas the high instability index case of Hagupit2 did not. This supports the computational results of Raymond and Sessions (2007).

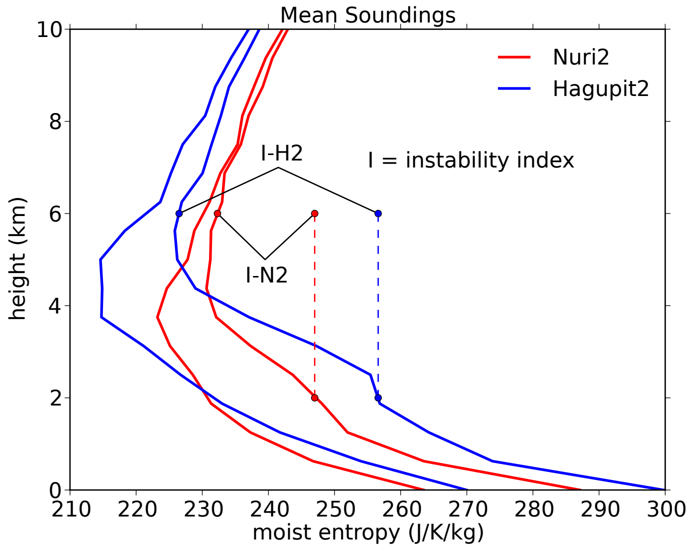

Figure 3: **Soundings for developing (Nuri2) and stagnating (Hagupit2) disturbances. The instability index for the developing case is much smaller.**

Differences in the vertical profile of saturated moist entropy reflect differences in the vertical temperature profile. Smaller instability index is related geostrophically to the existence of significant mid-level vorticity, since the balanced response to a mid-level vortex is a cold anomaly below and a warm anomaly above the vortex. The upper panel of figure 4 does indeed show an inverse correlation between mid-level vorticity and instability index for a combination of TCS-08 and PREDICT (Pre-Depression Investigation of Cloud Systems in the Tropics; http://www.eol.ucar.edu/projects/predict/) data. As the bottom panel of figure 4 shows, positive vorticity tendency at low levels is also correlates with low instability index.

In addition to the above observational work, we have initiated a theoretical study (Raymond and Herman 2011) on frictional convergence in the atmospheric boundary layer. This work was prompted by the need to determine the relative importance of frictional and convectively induced convergence in weak tropical storm precursor disturbances and is at an early stage of development.

RESULTS

The above-described observations support the following sequence of events for tropical cyclogenesis:

- Normal tropical conditions favor top-heavy convective mass flux profiles.
- Top-heavy mass flux profiles cause spinup of a mid-level vortex.
- A mid-level vortex results in a smaller instability index.
- Smaller instability index promotes convection with a bottom-heavy mass flux profile.

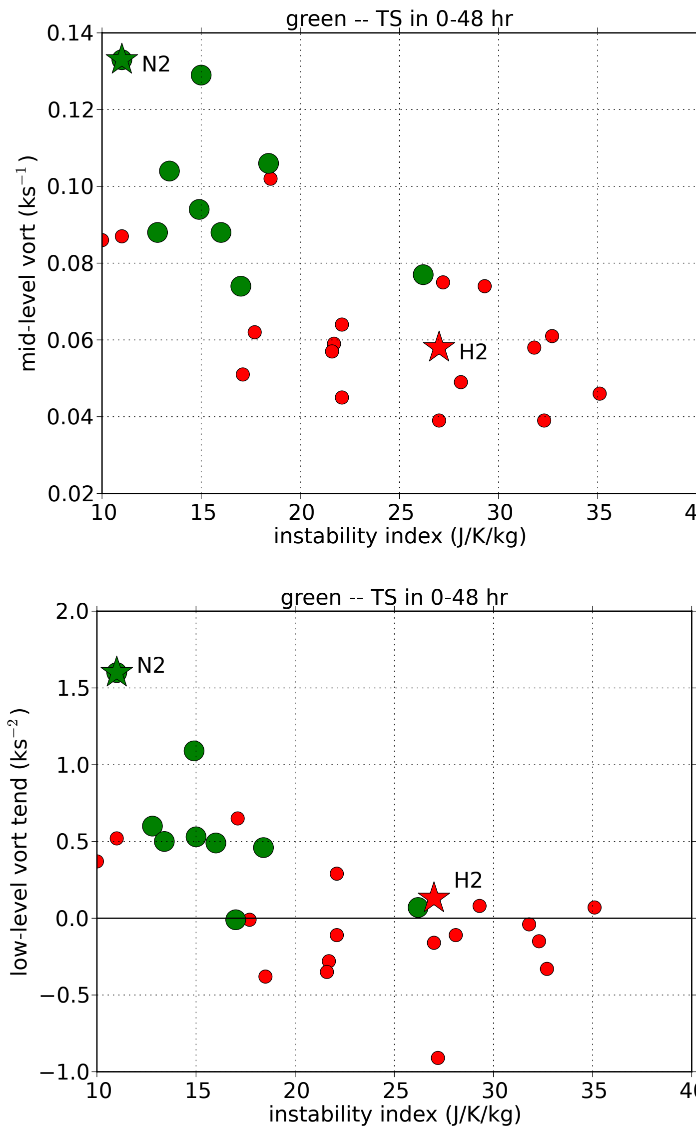

Figure 4: **Mid-level vorticity (upper panel) and low-level vorticity tendency (lower panel) as a function of instability index for a combination of TCS-08 and PREDICT case studies of potential tropical cyclones.**

- Bottom-heavy convection promotes low-level spinup and tropical cyclogenesis.
- Cloud-resolving model results support the relationship between instability index and mass flux profile.

Interrupting this sequence at any point will keep genesis from happening.

IMPACT/APPLICATIONS

If the above sequence of events for tropical cyclogenesis withstands scrutiny, then it will provide a useful conceptual framework for forecasting cyclogenesis.

Many of the lessons learned in this work have broader applicability to tropical convection in general. The knowledge generated should help in the effort to constrain the behavior of convective parameterizations in global models, thus enhancing the ability of these models to forecast tropical weather.

RELATED PROJECTS

The current project is related to work being pursued under a grant from the National Science Foundation entitled “Cumulus Convection and Large-Scale Tropical Flows”. The purpose of that NSF grant is to refine and extend our understanding of the thermodynamic control of convection and to begin to apply these results to a broader range of tropical disturbances. In addition to the Madden-Julian oscillation, we are particularly interested in equatorial Kelvin waves, tropical easterly waves, and the developmental stages of tropical cyclones. TCS-08 results will advance the purposes of this grant and expertise developed under this and previous NSF support will benefit our Office of Naval Research project as well.

We also have NSF support for our role in the PREDICT project with a grant entitled “Vorticity and Thermodynamic Budgets in Easterly Waves – PREDICT Participation”. The field program for PREDICT concluded one year ago after obtaining extensive dropsonde data on a number of pre-tropical-depression disturbances as well as a number of non-developing systems. Results from this project complement and strengthen our TCS-08 results as figure 4 indicates.

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