Use of NRL P-3 and ELDORA in TPARC/TCS-08

David J. Raymond
Physics Department
New Mexico Tech
801 Leroy Place
Socorro, NM 87801

Award Number: N000140810241

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 objectives in this segment of the program are to obtain observations of the vertical transports of mass and momentum by convection and to see how these transfers vary with convective environment. The important environmental factors are thought to be the temperature and humidity profiles, the wind profile, and the surface fluxes of heat, moisture, and momentum. These transports are crucial for understanding the vorticity budget of developing tropical cyclones.

APPROACH

The Eldora Doppler radar on board the NRL P-3 aircraft was used to determine the flow patterns and reflectivity structure of moist convection in a wide variety of convective environments while dropsondes from from the P-3 itself, the Air Force Reserve C-130 aircraft, and on occasion the Taiwanese Dotstar aircraft and the German Falcon were used to define the convective environment. The Doppler lidar on board the NRL P-3 was used to obtain wind profiles both above and below the aircraft as well.

In order to be able to incorporate the results from a diverse set of sensors into a single product on which various analyses can be made, we have developed a three-dimensional variational analysis (3-D Var) scheme. Much of the work of this type has been directed to initializing numerical models, which is appropriate for improving model forecasts. Our work differs in that we wish to develop as comprehensive a picture of an observed system as possible without introducing model biases and preconceptions. Thus, we impose only the simplest possible constraints beyond the data itself, e. g., mass continuity, smoothness, small vertical velocity

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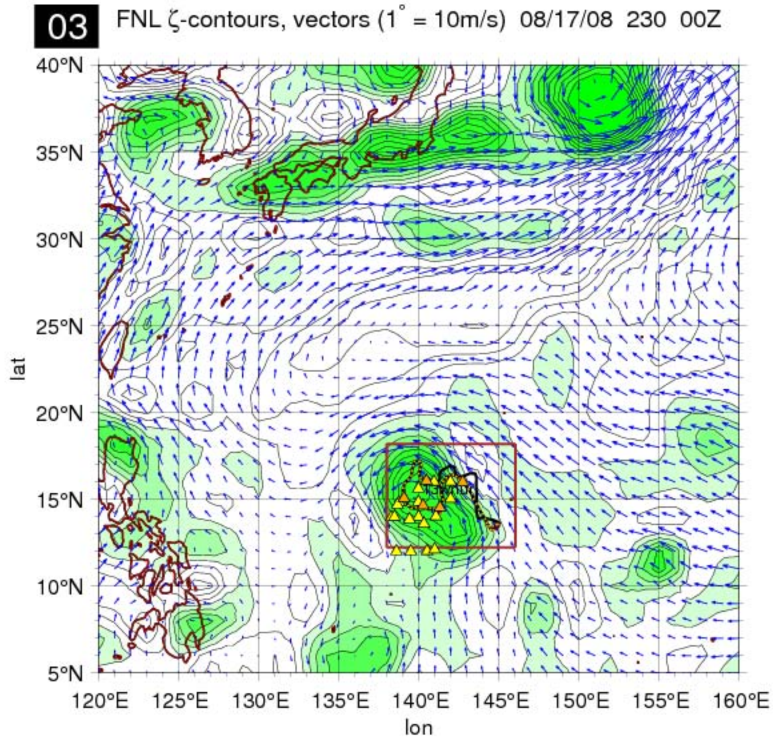

Figure 1: **Vorticity and winds from the NCEP FNL analysis with P-3 aircraft track and P-3 and C-130 dropsonde locations overlayed.**

in convection-free regions, etc. Model results are not used to provide an initial guess to the analysis.

WORK COMPLETED

We have completed the initial phase of the development and testing of the 3D-VAR scheme and have begun to use this tool to investigate the structure of the west Pacific tropical cyclones and typhoons observed in the field phase of TCS-08.

The 3D-VAR scheme is similar to that of Gao et al. (1999), but uses a novel technique to incorporate the radar data into the analysis. Instead of incorporating radial velocities directly, the system condenses all of the radial velocities in each grid box into a concise representation which retains as much information about the radar observations as possible while vastly reducing the volume of data and reducing noise. This information is then incorporated into the 3D-VAR scheme. Such a two-stage process both produces more reliable results than a single stage process and uses vastly less computer time.

The dropsonde winds are added to the mix of radar radial velocities where radar data exist. In grid boxes where radar data do not exist, the dropsonde winds become the only data source.

The actual 3D-VAR calculation is done by minimizing a penalty function using freely available conjugate gradient minimization software. The penalty function not only forces the analysis to match the observations, it also enforces mass continuity as a weak constraint. Gradually

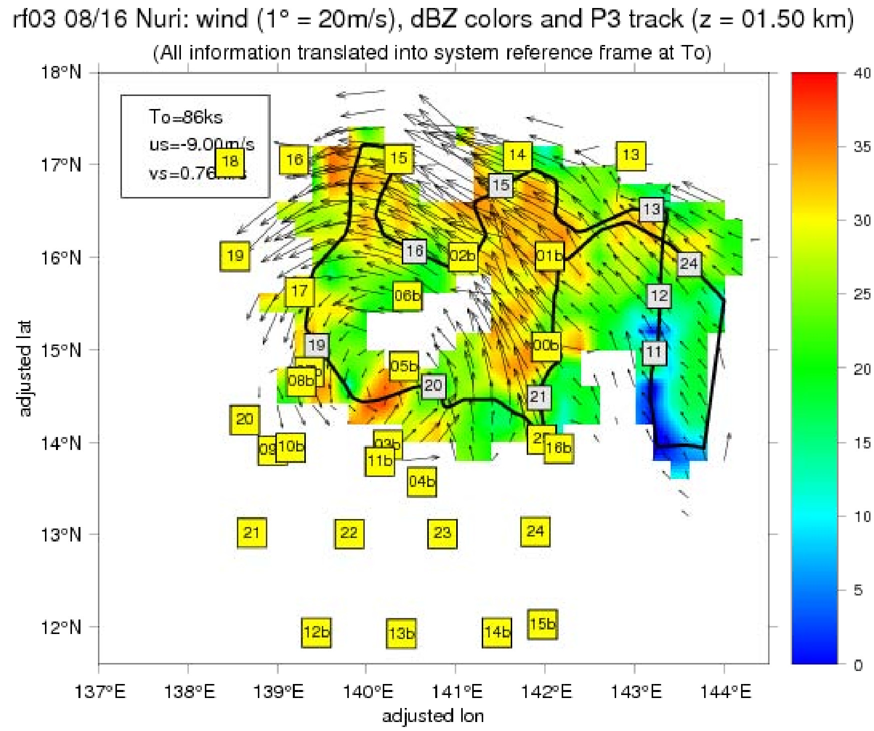

Figure 2: **View of Eldora radar reflectivity, Doppler winds, aircraft track, and P-3 and C-130 dropsonde locations for tropical cyclone Nuri on 16 August 2008. The level is 1.5 km.**

increasing the strength of the mass continuity penalty during the analysis ensures that mass continuity is well satisfied by the final analysis field. In addition, a smoothing function acts as a low-pass filter which removes high-spatial-frequency degrees of freedom which are not constrained by the data.

Though we have not yet incorporated the observations from the Doppler lidar on board the NRL-P3 aircraft into the 3-D VAR analysis, this addition should be relatively easy to accomplish. We intend to pursue this goal during the third year of the project.

As an aid to data analysis, graduate students Michael Herman and Jorge Cisneros have developed graphical summaries of TCS-08 missions which are available on the web page `http://patka.nmt.edu/tcs08/catalog.html`. Figure 1 shows the 850 hPa winds and vorticity with P-3 and C-130 dropsonde locations along with the P-3 aircraft track during the mission of 16 August 2008. Figure 2 shows a closeup view of tropical cyclone Nuri on this date with the locations (relative to the moving storm) of all dropsondes. These plots are available at all analyzed radar levels and for all TCS-08 missions; they are extremely useful for developing plans for further analysis.

RESULTS

Our initial analysis efforts have concentrated on the first three missions investigating the development of typhoon Nuri. Figure 3 shows a view focused on the center of Nuri at the stage presented in figures 1 and 2. The winds are relative to the motion of the storm, so

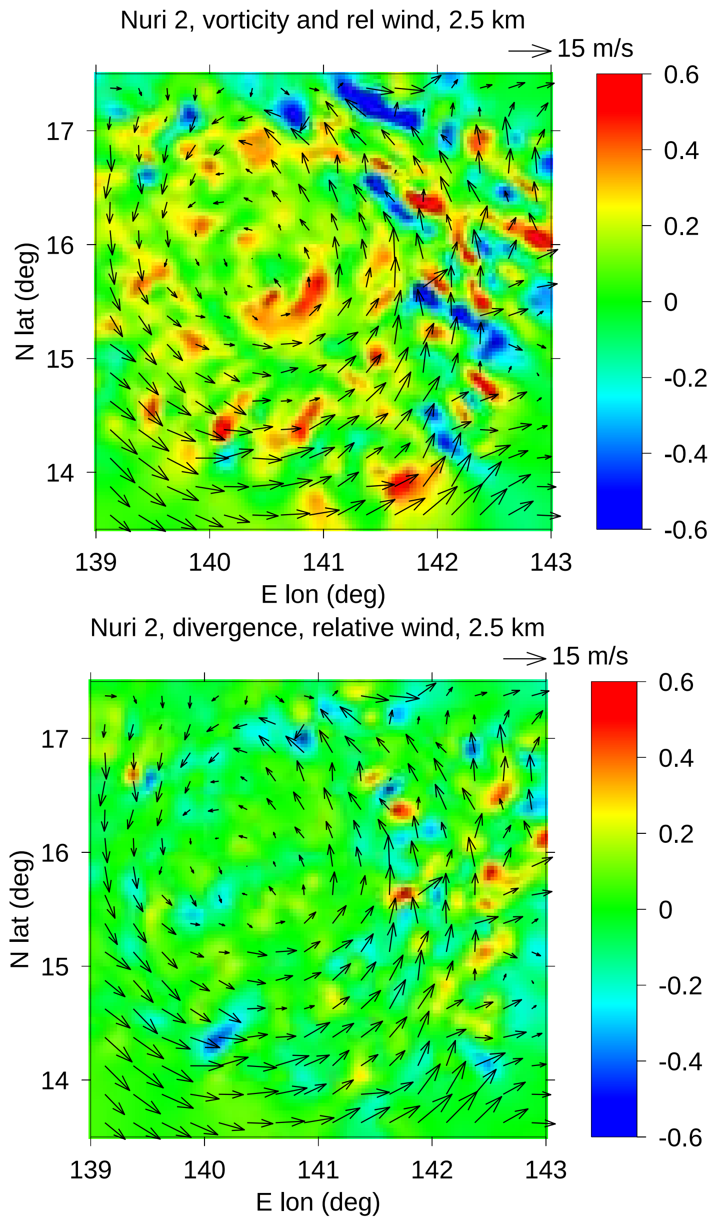

Figure 3: **Tropical cyclone Nuri on 16 August 2008 (RF-03). Upper panel: Absolute vorticity (color scale, 1/ks) and storm-relative wind vectors at a height of 2.5 km. Lower panel: Divergence (color scale, 1/ks) and relative winds. Output of 3D-VAR analysis of radar and dropsonde data.**

the center of the circulation is also the center of the storm. The color shading indicates the vertical component of absolute vorticity in the upper panel and the horizontal divergence in the lower panel, derived from the 3D-VAR analysis. Both the vorticity and the divergence are quite "grainy", with both positive and negative excursions of magnitude ten times the value of the Coriolis parameter. Note that the strongest negative vorticity excursions and the most extensive convection (indicated by the convergence/divergence patterns) are limited to the north and east peripheries of the storm. There is also the hint of an eye forming in the vorticity field around the circulation center. The vorticity perturbations are not correlated with the pattern of convergence, indicating that they are fossil patterns generated by previous strong convection or other processes.

IMPACT/APPLICATIONS

As yet we report no applications, as we are still in an early stage of the data analysis.

RELATED PROJECTS

This project is related to work being pursued under a grant from the National Science Foundation entitled "A Rational Approach to Cumulus Parameterization in Large-Scale Models". In this project the feasibility of using a cloud-resolving numerical model in "weak temperature gradient mode" to test cumulus parameterizations is being explored. Data from the TCS-08 field program will be used to test the cloud-resolving model.

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Gao, J., M. Xue, A. Shapiro, and K. K. Droegemeier, 1999: Variational method for the analysis of three-dimensional wind fields from Doppler radars. *Mon. Wea. Rev.*, **127**, 2128-2142.