P2.B12 **AUTOMATIC QUALITY CONTROL AND ANALYSIS OF AIRBORNE DOPPLER DATA: REAL-TIME APPLICATIONS, AND AUTOMATICALLY POST-PROCESSED ANALYSES FOR RESEARCH**

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1. INTRODUCTION

Beginning in 1982 with Hurricane Debby, the Hurricane Research Division (HRD) of the NOAA Atlantic Oceanographic and Meteorological Laboratory (AOML), in cooperation with the NOAA Aircraft Operations Center (AOC), has been collecting airborne Tail-Doppler-radar (TDR) data in Atlantic and Eastern Pacific tropical cyclones (TC). These data permit the depiction of the three-dimensional (3D) wind field in the TC core. Since then, the airborne Doppler radar has probed many dozens of TCs.

Manual quality control of these data sets is highly time consuming. Thus, a majority of the data have never been used in an analysis. Many man months are required to quality control all the TDR data for one sortie of one WP-3D aircraft in the TC. This need for manual quality control might have continued indefinitely, had a demand not developed for future assimilation of the airborne Doppler data to initialize operational hurricane models. The Environmental Modeling Center (EMC) of the National Centers for Environmental Prediction (NCEP) in NOAA, however, had determined that a proper initialization of the tropical-cyclone core could only be achieved with the high-resolution (~1 km), three-dimensional wind fields possible with the analysis of TDR data

2. AUTOMATIC QUALITY CONTROL

Several types of quality control must be performed on the NOAA WP-3D TDR (tail Doppler radar) data. These include:

1. Removal of the reflection of the main lobe by the sea surface.
2. Removal of the reflection of the side lobes by the sea surface.
3. Removal of the reflection of the "second-trip echo" by the sea surface.
4. Removal of Doppler data with low signal-to-noise ratio.
5. De-aliasing aliased ("folded") Doppler radial velocities.
6. Removal of the projection of the aircraft motion from the Doppler radial velocity measurements.

Until 2004, only (4), a simple less-reliable version of (5), and (6) were done automatically in the HRD Doppler I/O software. With the help of support of the NOAA Joint Hurricane Test bed (JHT), we developed our HRD quality control software, that automatically removed the reflections, data with low signal-to-noise ratio, and automatically de-aliased the Doppler data. The automatic de-aliasing works in a way much more reliable than the Bargen-Brown (1980) method we used in the past to produce data sets we edited manually.

To remove the sea surface reflection (1), the software makes a first guess about the location of the sea surface within a sweep of radar data. It then removes data at and below the azimuth where the azimuthal gradient becomes much larger, and does this for every range gate.

The removal of the side lobe reflection (2) is accomplished by looking at data located in a thin annulus near the radius equal to the altitude of the aircraft above the sea surface. If the reflectivity is weak near the annulus, then the data in the annulus are removed.

Removal of (3) is essentially accomplished by removing data with high spectral width, which is a QC already included in our data sets to be edited manually. (4) is straightforward.

The Doppler de-aliasing (5) is the most difficult process of all to do automatically, since so many factors can cause errors in the process. The single-ray de-aliasing method of Bargen and Brown (1980) is used in the first iteration of the QC. After the Bargen-Brown de-aliasing, a two-dimensional

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de-aliasing scheme is applied. The resulting Doppler radial velocities are used to produce a wavenumber 0 and 1 analysis. Such an analysis will tend to reduce the local effect of a small number of errors in the de-aliasing. The resulting wind field is used to “reseed” the Bargen-Brown de-aliasing whenever there is a radial gap in the data greater than 1 km. Then the data in this second round of QC is used to produce the 3D wind fields, and the radial-vertical cross-sections discussed later in this article. The quality controlled data are also written to a very large ascii text file. Included in this file are the full-resolution earth-relative Doppler radial velocities, quality controlled, with aircraft motion, and precipitation terminal fall speed subtracted, as well as pointing direction, and position of aircraft.

Starting in 2007, there was an option in the automatic QC to automatically determine the small angle errors in antenna pointing direction that can provide a systematic error in the analysis. This allowed changes in these corrections to be detected between storms or between seasons. This addresses the part of (6) that can not be determined without the automatic QC package.

3. ANALYSIS PRODUCTS

a. Three-dimensional analyses

Once the data are quality controlled, they are interpolated into a three-dimensional grid. This interpolation involves summations of the various cross products of the direction cosines, and the sums of the products of the Doppler radial velocities and the direction cosines. A cost function is then devised that is the sum of 1) the squared differences between the 3D wind analysis and its projection upon all the Doppler radial velocities, and 2) the squared values of 3D mass divergence (which should be 0) at all grid points. The problem is then a variational one. A more complete discussion of this scheme can be found in Gamache (1997) and Reasor *et al*. (2008). A very similar analysis scheme was devised by Gao *et al*. (1999). Examples of this analysis on the day Hurricane Katrina was at its maximum intensity is shown in Fig 1.

b. Vertical-radial cross-sections

A second type of analysis is the radial vertical cross section. In this type of analysis, grid cells equal to 150 m in the vertical and 1.5 km in the radial direction are determined. The azimuthal extent of the grid cell is 15 degrees. The wind field is considered constant throughout the grid cell that straddles the vertical plane defined by the aircraft

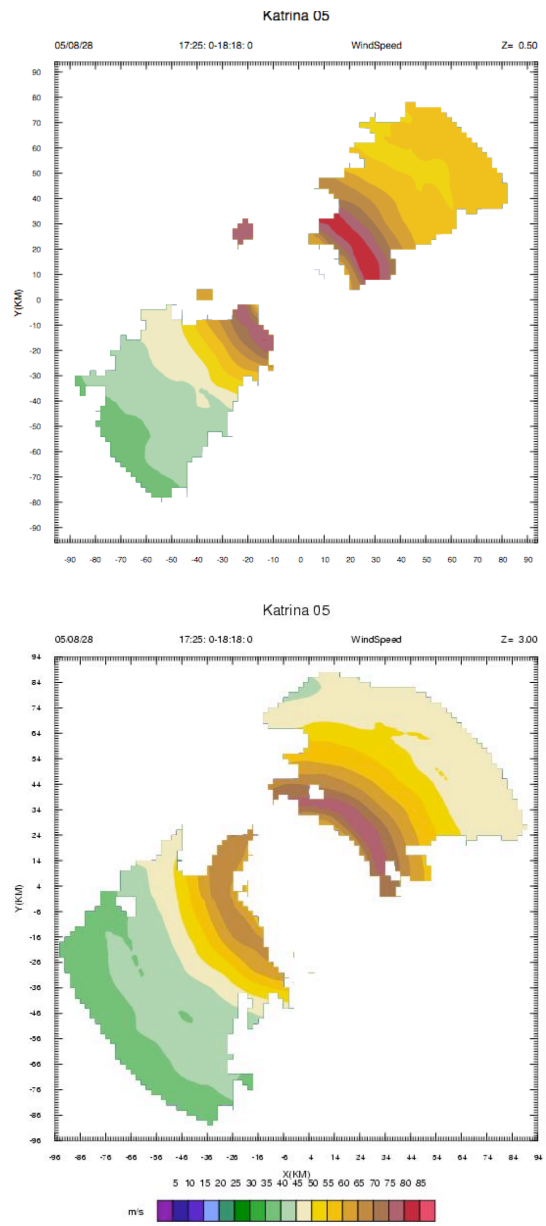

Fig. 1. Three-dimensional analysis of earth-relative wind speed for a single aircraft pass through the storm circulation center of Hurricane Katrina on 28 August 2005. Domain of analysis box is 192 x 192 km, centered on the circulation center. Horizontal grid resolution is 1.5 km. Top panel is at the 0.5 km level, and bottom panel is at the 3.0 km level.

track, and there are enough different pointing directions to completely solve for the velocity of precipitation in all three dimensions. A terminal fall speed is then subtracted from the precipitation motion to determine the air motion. Since mass continuity is not required for these analyses, the detail present in the original Doppler radial velocities is retained. An example of this analysis is shown in Fig 2.

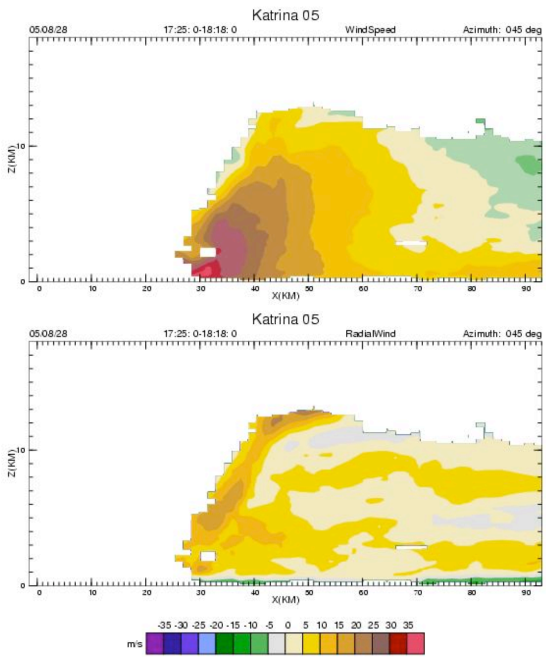

Fig 2. Vertical-radial cross-sections along the heading of 45 degrees from the circulation center of Hurricane Katrina on 28 August 2008. The top panel shows the total wind speed (not tangential wind), and the bottom panel shows the radial wind, defined positive outward from the storm circulation center. Both wind fields are earth relative, and do not account for storm motion.

4. AOML/HRD HURRICANE-DATA WEB SITE

At AOML/HRD, a data web site has been set up to provide users with data files and graphics. The site allows students, professors, other researchers, policy makers, and general registered visitors to see the structure and intensity of wind, precipitation, temperature and humidity in tropical cyclones. Data files are organized according to year and storm.

Included in these files are the Doppler-derived 3D analyses and vertical-radial cross-sections of wind, as well as the ascii form of the quality-controlled radial velocities. The analyses are done at a resolution not possible in real-time aboard the aircraft. A domain of 44 x 44 x 37 grid points (0 – 18 km level at 0.5-km intervals) is the maximum allowed by the memory on the present aircraft workstation, as well as by the time constraint to produce a real-time analysis. The same automatic analysis, however, can be used at a higher resolution. This allows analysis of many data sets that would never have been processed in the past. It is hoped that airborne-Doppler analysis can be performed on all data collected by WP-3D radars that are operated in fore/aft scanning or that have the French built dual-beam antenna aboard. This would provide automatic analyses back to 1991. At the writing of this preprint, analyses and QC data for the storms and hurricanes probed by NOAA aircraft in 2004 and 2005 are on the web site. The 2006 data have been processed, as have much of the data in 2007. It is hoped that by the time attendees of the conference return home, all of the possible 2006 and 2007 analyses and data will be on the web site.

5. REFERENCES

AOML/HRD data web site: *http://www.aoml.noaa.gov/hrd/data2.html*

Bargen, D. W., and R. C. Brown, 1980: Interactive radar velocity unfolding. *Proc. 19th Conference on Radar Meteorology*, Miami, Amer. Meteor. Soc., 278-283.

Gamache, J. F., 1997: Evaluation of a fully three-dimensional variational Doppler analysis technique. *Preprints, 28 th Conf. On Radar Meteorology*, 9-13 Sept. 1997, Austin, AMS.

Gamache, J. F., 2005: Final report on JHT project entitled: Real-Time Dissemination of Hurricane Wind Fields Determined from Airborne Doppler Radar. *http://www.nhc.noaa.gov/jht/2003-2005reports/DOPLRgamache_JHTfinalreport.pdf*

Gao, Jidong, Ming Xue, Alan Shapiro, Kelvin K. Droegemeier, 1999: A Variational Method for the Analysis of Three-Dimensional Wind Fields from Two Doppler Radars. *Mon. Wea. Rev*: **127**, 2128–2142.

Reasor, P., M. Eastin, and J. Gamache, 2008: Rapidly intensifying Hurricane Guillermo (1997). Part I: Low-wavenumber structure and evolution. Submitted for publication in *Mon. Wea. Rev.*