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AUTOMATIC DOPPLER ANALYSIS OF THREE-DIMENSIONAL WIND FIELDS IN HURRICANE EYEWALLS

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1. INTRODUCTION AND MOTIVATION

Since 1982 airborne Doppler observations have been collected in tropical cyclones during the hurricane season (Marks *et al.* (2003). Improvements in the radar hardware and recording software, and experience in how to operate the radar in this environment, have improved the quality of the observations since that introduction. Concurrently the power of computers has allowed variational methods to be used to improve the analysis of the observations into a three-dimensional grid.

A three-dimensional analysis scheme has been developed at the Hurricane Research Division (HRD) that is very similar to that described by Gao *et al.* (1999), and an earlier version of it has been described by Gamache (1997). This variational method consistently produces meteorologically reasonable fields that compare well with the original observations while closely satisfying the anelastic continuity equation. Using an airborne workstation developed within the last five years, a completely three-dimensional analysis with as much as 100,000 grid points can be completed within an hour. This capability makes the analysis ready for a transition to a more operational mode, and tests of such a transition are underway through the US Weather Research Program's Joint Hurricane Test Bed (JHT). The major challenges to accomplishing the transition are the data quality control (hereafter referred to as "editing") and satellite transmission of the data to the ground, rather than the real time use of the analysis software. Real-time quality control is also needed to permit data collected in real time to be sent to the National Weather Service for assimilation into numerical simulations, another requirement of this JHT project.

The three-dimensional analysis software ingests observations that have already been edited. Heretofore the editing has been performed manually by research scientists. This process can require up to 40-80 hours of an analyst's time for 15-20 minutes of observations. Obviously this process must be shortened greatly to allow observations to be analyzed or assimilated into National Weather Service simulations in real-time. Thus, development of a reliable automatic editing software suite is a major effort of this JHT project.

There is an obvious benefit, however, to the research community if the automatic editing can be made reliable, since it will shorten a 40-80 hour editing process to one that can generally be done within a day. The full-week time commitment has limited the utilization of this very valuable data set by the tropical-cyclone research community. The data could be used in many more case studies, as well as statistical studies, if they could be analyzed more quickly and efficiently.

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2. THE "EDITING" PROCESS

All of the radial-velocity data must be corrected while some of them must be removed. Examples of corrections that must be applied are (1) the complete removal of the projection of the aircraft motion on the observed Doppler velocity (which includes the determination of any systematic errors in the determination of aircraft attitude and motion), and (2) the "unfolding" of aliased wind velocities. The frequency of a radar pulse is shifted when it is reflected from precipitation moving inward or outward from the radar. A Doppler radar uses phase-shift to determine the frequency shift, and the maximum unambiguous phase shift is 180^o. On the WP-3D airborne radars the corresponding maximum unambiguous radial velocity (Nyquist velocity) is 12.88 - 25.76 m s^{-1}, much less than hurricane force. Thus the integer number of aliases for every observation must be determined and applied to the data to get the actual radial velocity. This is what is meant by "unfolding".

Examples of radar features that must be removed are those resulting from the reflection of the radar signal by the sea surface. The first of these (3) is the reflection by the sea surface of the power in the main lobe. This appears on the radar display as a line of strong reflectivity and sometimes as weather features that appear to be below the sea surface. A second feature is the reflection by the sea surface of the radar side lobes (4). This reflection appears as an artificial-looking approximately 2-km thick annulus of reflectivity with a mean radius equal to the height of the aircraft above the sea surface.

Another feature is "noise" (5). Noise will include data collected with a signal-to-noise ratio of 1 or less. It will also include radar return from regions where the turbulence is so high that the standard deviation of the wind velocity approaches the Nyquist velocity of the Doppler radar. The latter is seen in the first few hundred meters above the surface in a hurricane. Either type of noise must be removed to allow an accurate unfolding of the wind speed.

To date prototype real-time software have been developed for (3)-(5) at HRD. To accomplish (3), the technique developed by Testud *et al.* (1996, hereafter THL) first determines a good estimate of the ground. Then software looks at nearby bins above this surface to determine if they are dominated by surface reflectivity. Software to determine (1) has been derived from THL and developed for laboratory use at HRD. We plan to use it in real-time to determine the errors in aircraft attitude measurements.

Simple Bargen and Brown (1980) type B de-aliasing (where each Doppler radial-wind observation is dealiased by comparing with the mean of several already-dealiased observations closer to the radar, or to the wind at the radar) is already included in the software, but it is often insufficient to fully de-alias the data. A real-time airborne de-aliasing routine is being developed presently to address concern (2) by requiring two-dimensional consistency within a contiguous region of data. Finally the expected wind hurricane structure will be used to ensure that that even internally consistent quality-controlled observations are also consistent with that assumed structure.

3. PRELIMINARY TEST

Much remains to be done in developing the real-time editing software; however, we will show the first test of the software on an actual case. We expect to have done more thorough testing by the conference three months from now. On 23 September 2001, Hurricane Humberto was probed by both NOAA WP-3D aircraft, as well as NASA aircraft. The radar on one of the P3 aircraft, N42RF, was scanning in cones with an axis of rotation along the fuselage, and a tilt 20^{o} fore or aft of the plane perpendicular to the fuselage in what is called the Fore/Aft Scanning Technique, or FAST (Gamache *et al.* 1995 and Jorgensen *et al.* 1996). FAST is a requirement for real-time fully-three-dimensional Doppler wind analysis from one aircraft. The radar on N43RF was scanning normal to the flight track, but provided independent observations. Figure 1a shows the field produced by wind-analysis software using a manually-edited "research-quality" data set that employed data from both aircraft. Figure 1b shows the real-time analysis applied only to N42RF data. It is clear that in this particular case, the real-time quality control software produced a wind analysis that is very similar to the one from manual editing.

4. SUMMARY

We have given a brief description of this project to produce a real-time airborne Doppler analysis of winds in the hurricane core, and have shown preliminary results. Work to improve the data editing, particularly the automatic de-aliasing, will be performed intensively in the next three months. Much more complete results will be shown at the conference.

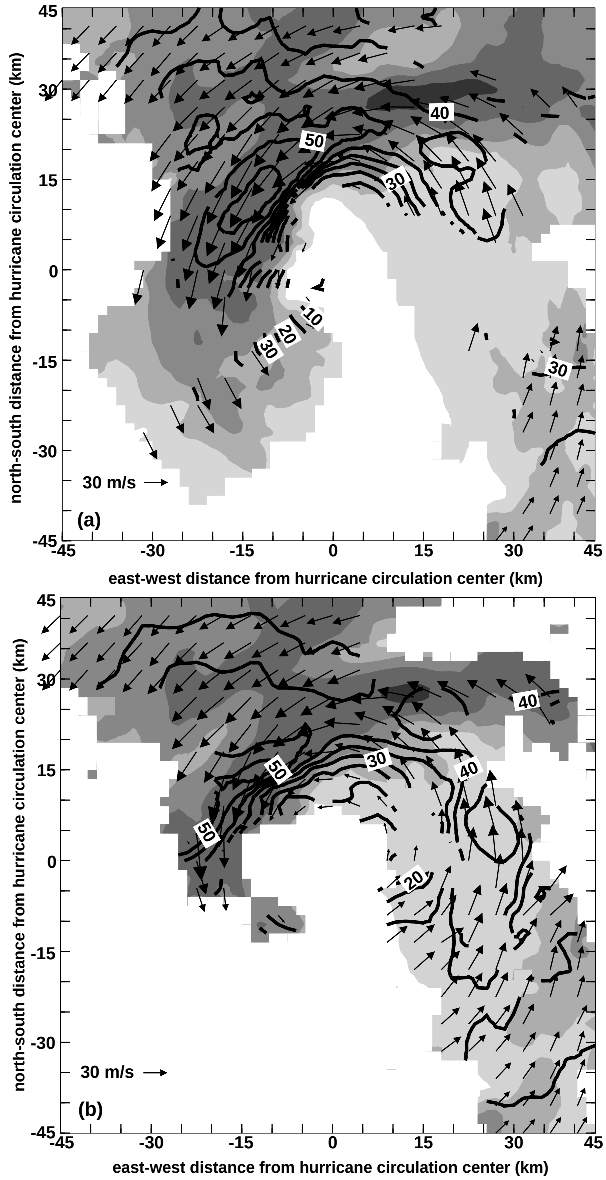

Fig. 1. Wind field and radar reflectivity for 2026 UTC on 23 September 2001 in Hurricane Humberto. Vector scale for wind arrows is in lower-left corner of panels. Solid contours give wind speed in m s^{-1}. In increasing darkness shaded contours represent radar reflectivities of 0-10, 10-20, 20-30, 30-40, and > 40 dBZ.

5. REFERENCES

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