First Annual Report on JHT Project entitled:

Real-Time Dissemination of Hurricane Wind Fields Determined from Airborne Doppler Radar Data

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NHC/TPC Point of Contact: Colin McAdie
EMC Points of Contact: David Parrish and Naomi Surgi

Accomplishments:

Milestone: Modify/develop software to read data in present AOC format into Gamache interpolation software

- Done and tested

Milestone: Develop software to remove noise, data with unacceptable spectral width, and reflectivity of the ocean surface, from the radar data stream. Agree with EMC about structure/nature of prototype superobs to be sent for assimilation of data

- PI became familiar with HRD radar software used to access information recorded in its original format by the P3 radar systems.
- Software was developed to remove the reflection of radar power by the sea surface. The preliminary testing has indicated success in this task.
- Software developed to remove speckles of data that may be near the signal to noise ratio, and yet have an inordinate effect upon the radar analysis. This also appears successful.
- Discussions were held with Dave Parrish of EMC concerning the type of data that should be sent back from the P-3 to EMC and formats are still to be worked out and tested.

Milestone: Present results at the Interdepartmental Hurricane Conference

- Done

Milestone: Develop and/or modify, and then incorporate, an automatic de-aliasing scheme

- Several minor bugs that affect the single-ray de-aliasing software in HRD code were discovered and repaired. This has helped the automatic de-aliasing somewhat.
- The single-ray de-aliasing scheme was modified to use a “guess” wind field to initialize the scheme whenever the nearest good Doppler observation is removed from the in-situ measurement of wind speed by several km. This has shown encouraging results in the de-aliasing of observations when the aircraft is in the eye and removed from the observations in the eyewall (large velocity gradients make this one of the most difficult regions to de-alias without such a guess).
- A two-dimensional de-aliasing routine has been developed that attempts to reduce azimuthal shears in radial velocity.
- The two-dimensional scheme has also been improved to reduce the difference between the averaged de-aliased velocities in half-sweeps and the average of the projection of the “guess” wind field on the same half sweeps.

Introduction

The goal of this JHT project is to provide information to the National Weather Service regarding winds in three dimensions near the core of the storm using the airborne Doppler radar. The expertise to synthesize quality-controlled Doppler measurements into three-dimensional analyses is already well developed at HRD; however, the means to quality control has always been from using "black box" software from NCAR, and doing much of the quality control manually, using people qualified to make judgments about which data are actually artifacts or will contribute to errors in the analysis. The analyses are also completed over a period that may span months or years, affording the analyst the luxury to mull over the data. Thus the analyses are performed in a laboratory using computers on the ground. Consequently, the major tasks to be accomplished to provide real-time data are 1) automatic quality control, 2) production of analyses aboard the aircraft, 3) successfully transmitting "superobs" (useful intelligent averages of the data that can be utilized by model assimilations), or other agreed-upon data, from the aircraft, and 4) transmitting and depicting the analyses conveniently for the very busy hurricane specialist.

Modifying 3-D analysis software to ingest "raw" AOC/SIGMET type radar data

For the P.I., the first major task was becoming familiar with the software that is employed regularly to ingest airborne radar data into analysis and depiction programs at HRD. Previously most of this software was not used for airborne Doppler analysis research, and instead the NCAR/ATD SOLO package was used to prepare data for ingestion into the HRD Doppler radar interpolation. SOLO is a research tool, but is not designed for real-time quality control, nor is its code understood completely by HRD scientists and programmers. Since SOLO was not developed at HRD, it was decided that the best plan was to modify HRD software that could directly read data written by the onboard AOC/SIGMET radar-data collecting software. Software written to ingest this data stream would be modified to include automatic quality control, and then the three-dimensional analysis code would be modified to ingest the result of the quality control software and produce an analysis, as well as "superobs" (intelligent averages) or thinned data.

For this milestone it is required to modify the three-dimensional software to ingest the automatically quality-controlled data stream. This is necessary in real time, and also for testing the quality control on a number of differing tropical-cyclone data sets. The ingestion has been tested on data obtained in Hurricane Humberto of 2001, and appears to be functioning properly. Figure 1 shows a comparison of the automatic analysis of single-aircraft Doppler data with the research analysis of the dual-aircraft Doppler data. All improvements made thus far to the automatic scheme are included in producing the second panel of Fig. 1. Further tests on other data sets will occur before the hurricane flight season.

For now the development of software to compress HRD wind analyses for transmittal over satellite data link has been postponed. It is possible that easily available software like "gzip" will be sufficient. Unless eventually desired by specialists, full analyses at many different levels will not be sent from the aircraft until a much "wider data pipe" is available. Instead, only subsets of the analysis of particular interest to the hurricane specialist will be sent.

Removing noise and sea-surface reflection

The first quality-control software developed was designed to remove the reflection of radar data by the sea surface. This reflection will contaminate the analysis of precipitation intensity, since the reflectivity of the rough sea surface can be much higher than the precipitation above it. Also the motion of the capillary waves on the sea surface is much closer to zero than to the wind motion directly above, and thus the returned surface velocities are also a contaminant in the wind analysis. Software employed by Mr. Peter Dodge (HRD), developed originally by Jacques Testud of CNRS/CETP, France, and Wen-Chau Lee of NCAR/ATD (Testud et al. 1996) to detect the ocean surface along each radar radial, was modified to remove the data from the surface and at all radii beyond. Since data in a given radar radial include scatter from objects located somewhat off the center of the beam, it was necessary to compare observations immediately above the detected surface to ensure that they were not still contaminated by sea-surface reflectivity. Also included in surface-reflection artifacts are reflections of the side lobes off the sea surface. These appear as an annulus of generally low-reflectivity artifacts approximately 2 km wide with a radius equal to the height of the aircraft above the sea surface. These are also removed in the new software. This software was developed and has been tested on two cases thus far. This addresses one of milestones in the project timeline.

In most airborne Doppler scans there are also data that are not continuous. They are usually collected at not much above the signal-to-noise ratio, or in regions where turbulence causes the spectral width of the observations to intermittently reach unacceptable levels. These "speckles," if not removed, can reduce the effectiveness of the automatic Doppler de-aliasing ("unfolding") software. The speckle removal appears to function well, based upon its use in several example cases. This addresses the same milestone as the tasks in the paragraph above.

Automatic De-aliasing

The major effort in the late winter and early spring (since the mid-year report) has been to improve the real-time de-aliasing software. To determine the relative velocity of airborne scatterers, the Doppler radar effectively compares the phase of reflected pulses with the expected return phase and determines a Doppler phase shift. In most past data sets that use a pulse repetition frequency (PRF) of 1600 per second, a phase shift of 180 degrees represents a relative motion of 12.88 m/s (known as the Nyquist velocity). Only phase shifts from –180 to 180 degrees can be measured unambiguously. Thus greater phase shifts from velocities higher than 12.88 m/s will be misinterpreted (or aliased or "folded"), as velocities between –12.88 and 12.88 m/s. The goal of the Doppler-analysis software is to correct these misinterpretations. The high winds in the tropical cyclone, and the even faster motion of the aircraft, require an accurate "unfolding" of this phase ambiguity. Well established methods exist that can remove most of the ambiguity, but some remains.

The first improvement made in de-aliasing was correcting a small bug in our implementation of the Bargen-Brown (Bargen and Brown 1980) simple single-ray de-aliasing scheme. The result was that sporadic badly de-aliased Doppler radials were now correctly de-aliased.

The next improvement was to produce a software module that attempts to reduce the azimuthal shear of the Doppler radial velocity. Segments of radials with slowly changing velocity were separated from other similar segments at points where there was a rapid change in velocity. Each segment was compared to the previous radial to insure that the average difference of that segment from the same segment on the previous radial was less than the Nyquist velocity. This produced very consistent velocity patterns wherever there were larger two-dimensional regions of contiguous velocities with imbedded bad velocities. Smaller regions (and those with more gaps) more remote from the radar are more difficult to de-alias properly.

Automatic methods used by the National Weather Service to de-alias WSR-88D data may also require that the wind field be consistent with the one developed from VAD (Velocity Azimuth Display—Browning and Wexler 1968) analyses (Eilts and Smith 1990), while locally following the continuity rules of de-aliasing. This prevents contiguous regions which otherwise have acceptable structure and gradient from having the proper structure while being incorrect by an average value roughly equal to 2 times the Nyquist velocity. This is an important improvement. A hurricane actually has a fairly well established radial profile that can be guessed, or determined from a VTD (Velocity Track Display) analysis (Lee et al. 1994, a hurricane derivative of the VAD analysis). This guess field can be used to make corrections of one or multiple folds (2 times the Nyquist velocity) to an entire contiguous region. Generally, the larger this contiguous region that is compared to a guess analysis, the more likely the proper de-aliasing will apply. This improvement was added to our two-dimensional de-aliasing scheme, and appears to work very well in improving the de-aliasing of radials obtained while the aircraft is within the radius of the eyewall (mostly in the clear). Examples of the improvements are shown in the accompanying Figures 2 and 3. It should be noted that the "guess" wind field used for the test is the research quality wind field for that case, but we will work to make a VTD guess available for real-time quality control during the hurricane season.

Miscellaneous

During the spring, the PI spent a week meeting with several members of NCEP/EMC, who are developing techniques to assimilate Doppler data into forecasting models. EMC will not be ready to assimilate airborne Doppler data this summer, so a transmission will only be a test of the means of communication. In discussions, the PI came to realize that even within EMC, the way to determine instrument-error covariance for the airborne Doppler radar is still to be determined. It appears that the best role of HRD in this process would be to help describe and estimate the types of errors, particularly the biases, and to do the best job possible in removing biases from the input data. The desire of EMC at this point is to get Doppler data from recent hurricanes (so the fields originally used in numerical forecasts are still easily retrieved from archives) that have been quality-controlled, so methods of assimilation and determinations of error covariances can be developed at EMC. Once the automatic quality-control software is stable, such sets will be compiled and made available to EMC. For now this replaces the original goal of determining instrument-error covariances at HRD to one of providing the best data and information to help EMC determine them.

Another discussion during this meeting at EMC is the structure of the data that will be transmitted from the aircraft. Two options exist, neither of which is yet the final one. The favored one at this time is to send the data as Doppler radials, with as much averaging and thinning as is necessary to fit into the available satellite data stream. The data will first be quality-controlled, then averaged and thinned, and then transmitted. Schemes for this thinning/averaging were discussed during the PI's visit to EMC, and will be tried in the test transmission this summer. A second option is to produce "superobs". These are averages for larger volumes that are obtained in such a way that they can accommodate various pointing directions in one average. This option tends to require less data throughput via satellite, but eliminates some of the information that can be used to refine the superob during assimilation. If the original data that were used to make the superob are still available at EMC, then portions of the data can be corrected or removed to increase the quality of the superob finally assimilated into the model. Thus the first option is favored if there is enough satellite throughput. The superobs are already developed. They are part of the fully-developed analysis software that HRD brought to this project.

The integration of this software on HRD's airborne workstations still remains to be done. The software will then be tested during the hurricane season. Analyses will be produced aboard the aircraft, but it is not expected that they will not be made available in real time to the specialists until the 2005 hurricane season. Thus IT support to allow these analyses to be seen by the hurricane specialists on their equipment is not needed in the 2004 season, nor are they likely to be available online until the 2005 hurricane season.

The next tasks to be done before the analyses and transmission can occur this summer are:

- Complete the development of real-time de-aliasing schemes and testing.
- Develop data trimming/averaging schemes
- Coordinate data type/format with EMC so that data can go through the NWS gateway and into EMC
- Migrate new software to airborne workstation

Remaining items on the timeline are:

- Aug.-Oct. 2004 - Produce real-time Doppler analyses automatically aboard aircraft during 2004 Hurricane Season
- Oct. 30, 2004 - Send prototype superobs or trimmed, radially averaged velocities to EMC
- Dec. 1, 2004 - Evaluate results from 2004 Hurricane Flight Season
- Feb. 1, 2005 - Second year mid-term report
- Feb. 1, 2005 - Modify code as necessary to make more dependable and automatic for year 2, including continued improvement of automatic de-aliasing in particular (automatic de-aliasing is the largest non-networking challenge of the project)
- Mar. 2005 - Present results at the Interdepartmental Hurricane Conference.
- Apr. 1, 2005 - Develop software and network capability to display wind analyses at TPC
- Jun. 1, 2005 - Develop inputs to H*Wind analysis to incorporate real-time airborne Doppler wind analyses—I suggest this one be removed since H*Wind is not an NWS analysis scheme
- Jun.-Jul. 2005 - Send real-time Doppler analyses automatically aboard aircraft during 2005 Flight Season. Display HRD real-time wind analysis at TPC—2005 Hurricane Season. Produce H*Wind analyses using incorporated HRD real-time winds—I also suggest this reference to H*Wind be removed.
- August 1, 2005 - Final project report
- Produce test Doppler-wind analyses aboard aircraft
- Send a superob or radial data, as well as analysis results, from the aircraft by Oct 31
- Develop capability to display analysis results easily for hurricane specialist

Note: A possible adjustment to the 2004 hurricane-season timeline may be necessary if the software changes to the onboard radar data system by AOC are made without sufficient time for HRD to adjust; however, it appears right now that the "old radar data system" will still be operating this year.

Proposal for second year funding

There are no plans to change the focus of the work that was promised in the original proposal, and therefore the proposed budget for year 2 remains the same, and is repeated here for convenience. The set of milestones for October 2004 to August 2005 reflect the original proposal. Because of the start time of the project (hurricane season of 2003) it is expected that the full improvements provided by this work will not be tested until the completion of year two (during the 2005 hurricane season). This was reflected in previous timelines sent by the PI.

One other detail that might be mentioned, however, that will be explored further during the remainder of this work is the utility of higher PRF (Pulse Repetition Frequency) or dual-PRF airborne Doppler observations. The results obtained thus far indicate that substantially less de-aliasing errors will be made if the Nyquist velocity is increased by either of these two changes to PRF. A particularly difficult de-aliasing challenge is presented by data collected in Hurricane Isabel of 2003. The winds in the eyewall were very high with substantial gradients, and the aircraft was far from the eyewall while flying in the eye (since the radius of the eye was greater than 50 km). One case was flown in which the Doppler data collected had dual PRFs of 3200 and 2133, resulting in a Nyquist Velocity of 52 m/s, a factor of 4 greater than in the observations of Hurricanes Olivia and Humberto shown in this report. There are other kinds of errors in dual-PRF analysis than standard de-aliasing errors. Unfortunately, with the present AOC radar system, these errors cannot be corrected, and must be removed. This removal software is not yet mature in the HRD package. The total number of errors at 3200/2133 is estimated to be less than 4% in convection (Jorgensen et al., 2000). The percentage will be higher in portions of the hurricane where vertical wind shear is particularly high. Eventually when the new radar system is installed, it may be possible to correct dual-PRF de-aliasing errors, but that will be beyond the scope of this work.

The other method of improving de-aliasing is to use a single PRF as high as 3200. This will give us a Nyquist velocity of 26 m/s, and should eliminate all but the worst de-aliasing challenges. The downside is that the maximum range of the radar is reduced to 46 km. Beyond 46 km, however, the vertical resolution of the radar becomes quite large, limiting its effectiveness in initializing the structure of the hurricane in models.

Other than testing the schemes in the hurricane season, the last remaining major activity to start is the depiction of analyses for the hurricane specialists. In late spring, or during lulls in the hurricane season, the PI will discuss with hurricane specialists the kind of analyses that could be available, and which might actually be of value to them. We will then work with NHC or the JHT IT people to get these analyses into the N-AWIPS system to make them most convenient.

Year 2 Budget

Personnel			mm	JHT Yr 2 Requested Amount
AOML	J. Gamache		3.0	21.9
AOML	P. Dodge		1.0	6.3
AOML	J. Griffin		1.5	13.3
AOML	S. Murillo		1.0	3.9
CIMAS	N. Carrasco		2.0	7.0
Total Salaries				52.3
Fringe Benefits		23.5% NOAA		10.7
		26% CIMAS		1.8
Total Salaries and Fringe Benefits				64.8
Indirect Costs		39% NOAA		21.8
		26% CIMAS		2.3
Total Labor Costs				88.9
Equipment				0.0
Travel	IHC meeting/MacDill trip/EMC			4.0
Publications	Operations/Training Manual			2.0
Other	Computing/Communications			6.0
Total				100.9

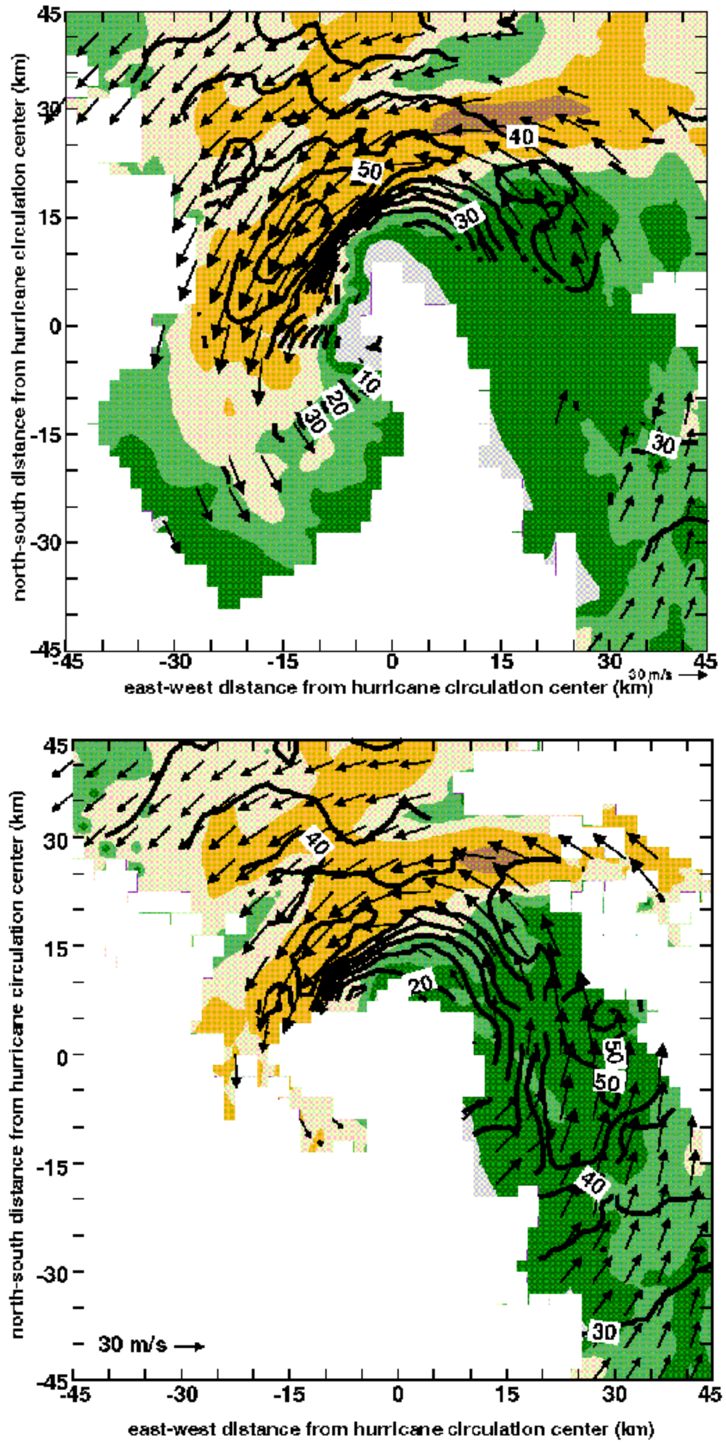

Figure 1. Analyses of wind and reflectivity from a research quality data set (top panel) and from the latest version (15 May 2004) of the automatic analysis software being developed for the JHT project. Analysis is from 2326 GMT on 23 September 2001. Contours are gray < 0, dark green 0-10, lighter green 10-20, 20-30 light brown, 30-40 orange, and brown 40-50 dBZ. Drawn contours display wind speeds in m/s. The research quality data includes data from both P-3 aircraft while the automatic analysis includes data from only one aircraft, One aircraft observed greater reflectivity than the other. Note, however, that the wind analyses are similar, which is a hopeful sign for the automatic Doppler analysis of the wind field.

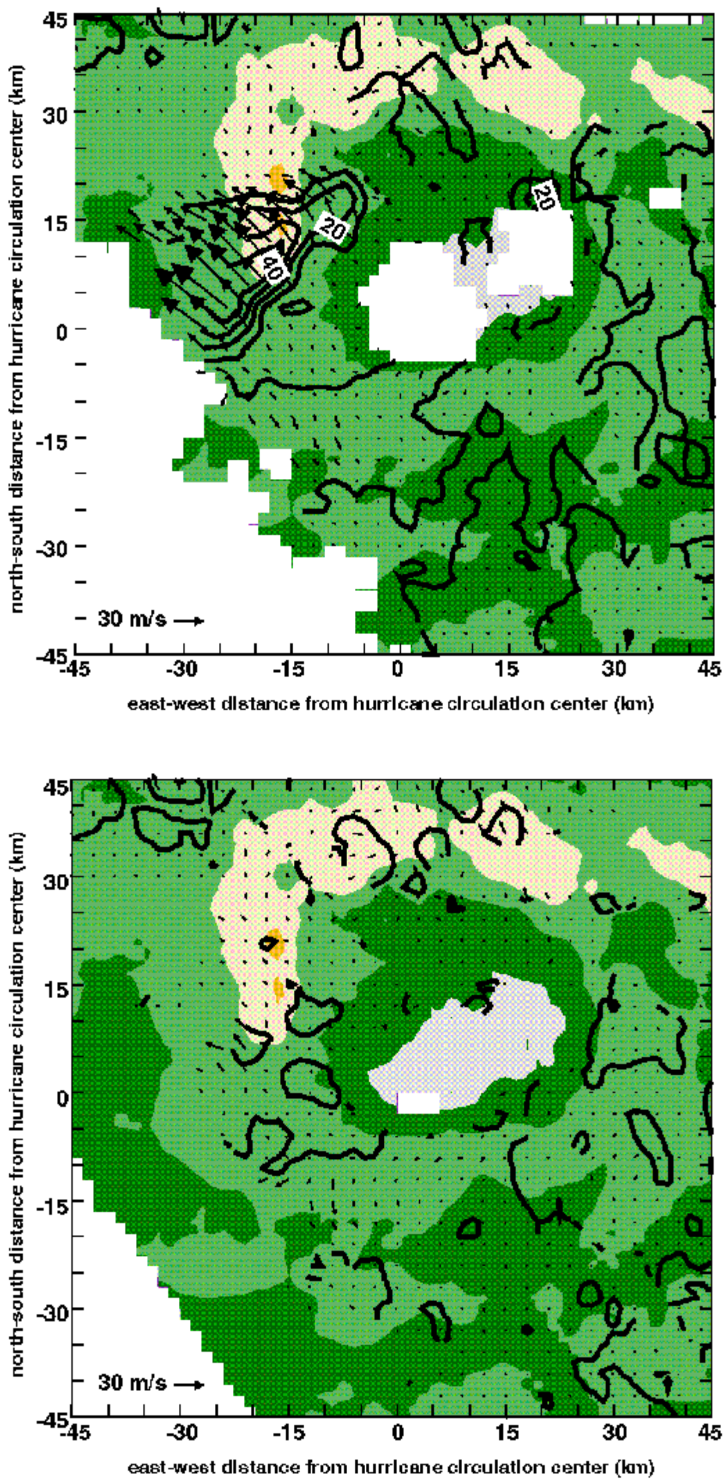

Figure 2. Comparison of errors (represented as the difference between the automatic analysis and the research-quality analysis) for the one-dimensional Bargen-Brown (top panel) and present HRD two-dimensional de-aliasing scheme (bottom panel). The research quality wind field was used as the guess field to seed the two-dimensional de-aliasing in lieu of the a guess wind field or a VTD analysis. Such tests will be made in the next few months. Contours and vectors are displayed in the same manner as in Fig. 1.

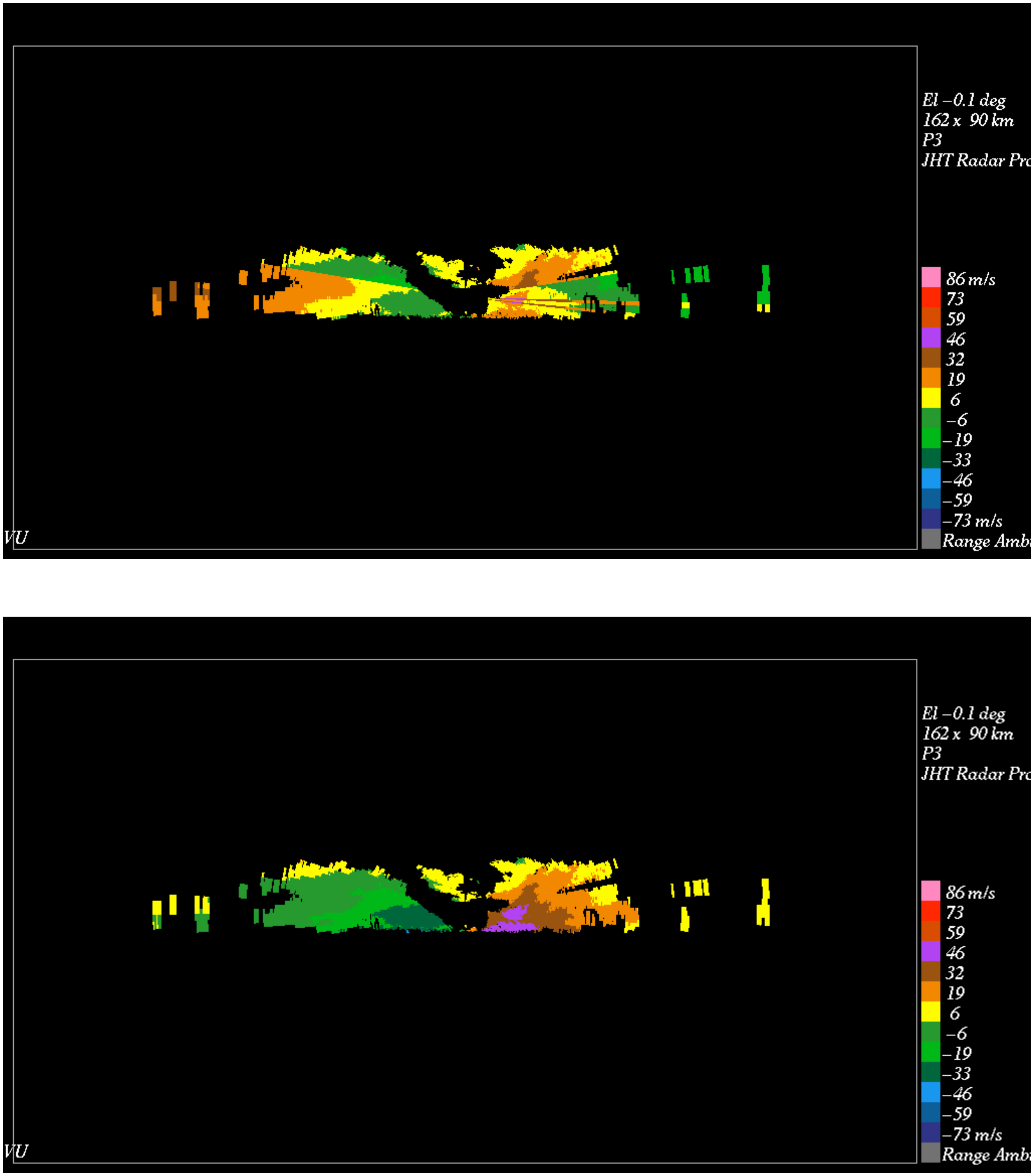

Figure 3. Comparison of Bargen-Brown de-aliasing (top panel) with HRD two-dimensional de-aliasing with guess wind field (bottom panel) in Hurricane Olivia on 24 September 1994. Again the guess field is the research-quality wind field in lieu of an actual guess profile or a VTD, since these methods have not yet been implemented. The colors represent radial velocities of precipitation either toward (negative values) or away (positive values) from the radar. The value of a good guess field to seed the de-aliasing is illustrated in this figure.

References

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