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IMPROVED PROCEDURE TO CORRECT AIRBONE DOPPLER RADAR DATA

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1. Introduction

Airborne Doppler radars have been extensively used in recent years for studying mesoscale events (e.g., Wakimoto and Bosart 2000; Atkins et al. 1998; Marks et al. 1992). Analyzing airborne Doppler radar data is complicated by the fact that the radar is mounted on a moving platform. Hence, the measured Doppler velocities contain both a meteorological component and a platform component of motion. For the NCAR ELDORA or the NOAA P3 tail Doppler radars, there are a total of nine parameters involved in computing the platform component of motion along each radar beam and the coordinate transformation to map each gate onto earth-relative coordinates. Accurately removing the platform component of motion from the measured Doppler velocities and mapping data onto earth-relative coordinates are the first two major steps toward a successful dual-Doppler wind analysis (Lee et al. 1994).

There are errors/biases associated with these parameters resulting from the uncertainties in the INS, mounting and calibration errors in the radar systems, and the physical separation between the INS and the radar system on board the aircraft. Because of the nine degrees of freedom, it is non-trivial to separate and correct the errors and biases in these nine parameters. Previously, these errors have been identified empirically by examining the error characteristics in the Doppler velocity pattern (Marks, personal communication).

Testud et al. (1995) (hereafter, referred to as THL) proposed a systematic approach to identify errors and biases by analyzing the residual velocities and distance returned from a flat and stationary earth surface as a function of rotation angle in each sweep. This variational procedure has performed well using the ELDORA data collected during the TOGA COARE experiment and has become a standard procedure at NCAR to identify the navigation errors contain within airborne tail Doppler radar data. However, the THL method encountered difficulties when applied to the FASTEX dataset over a moving ocean surface.

The purpose of this paper is two-fold. First, propose a method to determine tilt, drift and ground speed corrections over a moving earth surface. Second, discuss how these errors would affect the dual-Doppler winds and their derived quantities.

2. Resolve errors over a moving surface

When observing weather systems over the ocean, the motion in the surface adds another degree of freedom into the problem because the surface velocity cannot be assumed zero. The new correction methodology (coined the BLW method) is based on three criteria. First, the flight-level winds are statistically consistent with the dual-Doppler winds near the aircraft at flight level. Second, the dual-Doppler winds across the track have to be continuous. Third, the residual surface velocities in the left (right) fore radar should have approximately the same magnitude but opposite sign as the right (left) aft radar Doppler velocities owing to the moving surface. This approach can be applied when dual-Doppler winds are reliably retrieved near the aircraft for a long period of time (e.g., flying in extensive precipitation). This method can also be applied over a stationary earth surface.

The BLW method is an iterative process that follows four basic steps. First, select a straight flight leg at a near-constant altitude, preferable in an extensive precipitation region with little horizontal shear across the aircraft (i.e., the track should not coincide with a frontal zone or a gust front that violates the second criterion in the previous paragraph). Second, create a dual-Doppler wind synthesis centered at flight level. The origin of the analysis should be placed at the halfway point of the track and only the dual-Doppler winds within 1 km on either side of the aircraft would be selected for the comparison. It is preferable to choose one of the coordinate axes aligned with the mean aircraft track. The dual-Doppler analysis of a relatively long leg should be performed in segments to alleviate the altitude mapping errors in a Cartesian grid due the earth curvature. Third, map the flight-level winds to the nearest dual-Doppler grid points. The flight-level winds are usually sampled in 1-second intervals (~120 m in space) and the grid spacing for the dual-Doppler analysis

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[1] Brian Bosart was tragically killed in an automobile accident. This paper is published as a memorial to him.

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is normally ~500 m for the NCAR ELDORA data. Therefore, the flight-level winds should be filtered to match the spatial scale of the dual-Doppler winds. Fourth, compute the mean and standard deviation of the wind direction and wind speed between the flight-level winds and dual-Doppler winds over the chosen time period. If a discrepancy exists, adjust drift, ground speed and tilt then restart the process from step 2 until all three criteria are satisfied.

Several rules have been used as guidelines to adjust these parameters in the fourth step. Ground speed correction affects the along track component of the dual-Doppler wind field while the drift correction affects the cross-track component of the dual-Doppler wind field. For example, a positive ground speed correction increases the mean along-track wind speed and a positive drift correction shift the mean wind direction clockwise. Therefore, the drift, ground speed and tilt corrections can be estimated in order to satisfy the three criteria stated in this section.

3. Results

Figures 1 and 2 show the scatter plot of the u and v components between the corrected dual-Doppler wind and the in situ wind components in FASTEX and VORTEX. The corrected data show a slope closer to 1 (a perfect fit), a significant improvement from the uncorrected dataset. The maximum RMS errors are about 0.6 m/s in the corrected data which are about 30% better than those runs without corrections.

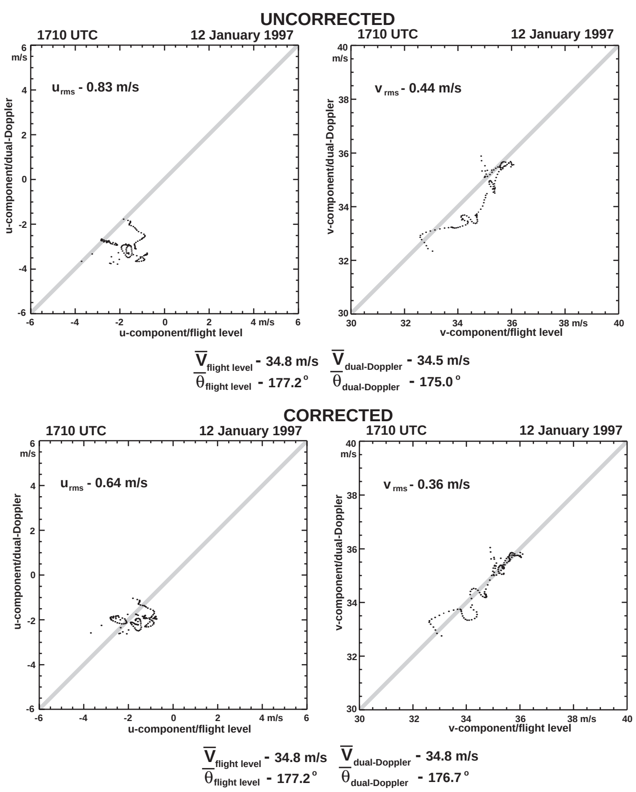

Figure 1: The scatter plot of u (cross track) and v (along track) component of the wind between the in situ and dual-Doppler winds for 12 Jan. 1997 data. θ and V represent the wind direction and wind speed.

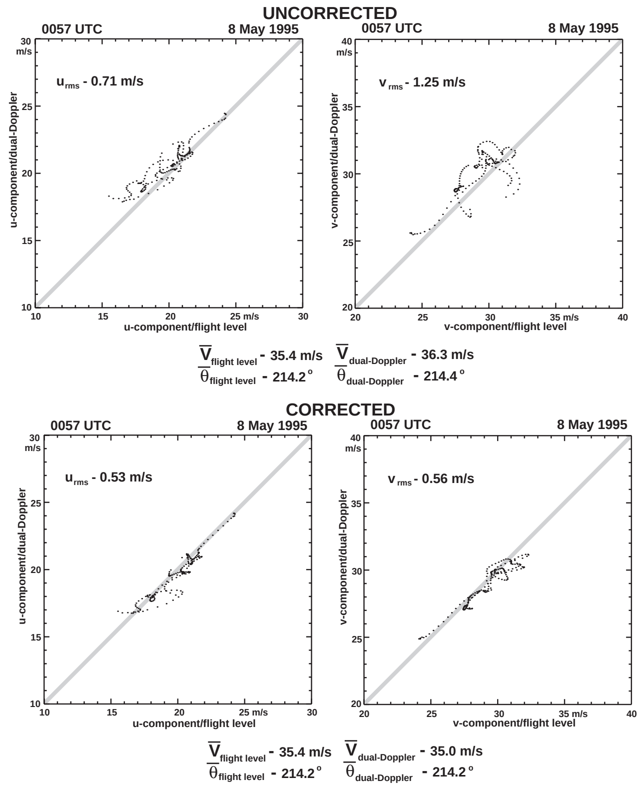

Figure 2: Same as Figure 1 but for 8 May 1995 data.

Figure 3 compares the wind field and isogons of the corrected (right panel) and uncorrected (left panel) data in FASTEX IOP2, 12 January 1997. The differences in the wind fields are striking. The corrected data show a distinct discontinuity across the front which is less apparent in the uncorrected data. This difference is clearly shown in the isogon plots. Interestingly, the vorticity field (not shown) near the frontal zone does not show much of a difference between the corrected and uncorrected data. However, it is evident that the uncorrected data produces more spurious vorticity minima near the flight track and in the warm sector.

Our study also shows that the error in each of these eight parameters affects the dual-Doppler radar winds and their first derivative quantities in a somewhat different manner. This individual effect is investigated by artificially adding 0.5° to a single angle parameter, then comparing the new dual-Doppler analysis with the analysis using the best correction factors. There is a greater sensitivity to wind direction from errors in either drift or tilt while roll/rotation error has a relatively minor effect (not shown). The errors in the vorticity and vertical velocity fields are primary produced by either roll/rotation or tilt errors. Pitch errors play a secondary effect in all these fields. It is not surprising that the wind field and first derivatives are sensitive to roll/rotation errors. The mapping error violates the dual-Doppler radar analysis assumption that two components are measured from the same volume. The tilt angle error is another large error source because it affects both mapping and the aircraft motion component. It is interesting that the first order derivatives are not sensitive to the drift or ground speed errors. In fact, drift or ground speed errors tend to change wind direction or wind speed uniformly in the domain. Therefore, the derivative fields are not affected. Please note that these error analyses only evaluate the effect of a single parameter. The combined effects on more than one parameter are more complicated because of non-linear effects.

4. Summary

This paper discusses a method to identify navigation errors embedded in the airborne Doppler radar data over a moving earth surface to complement the THL method. The dual-Doppler winds derived from these corrected Doppler velocities are superior to those winds derived from the uncorrected data. This study also shows that the tilt angle corrections can vary in different projects. It is not clear why this is the case. Nevertheless, the method presented in this paper is able to help future airborne Doppler radar users to identify and fine-tune these errors to obtain a more accurate dual-Doppler analysis.

Acknowledgment

This research is partially sponsored by the National Science Foundation under Grant ATM-9801720.

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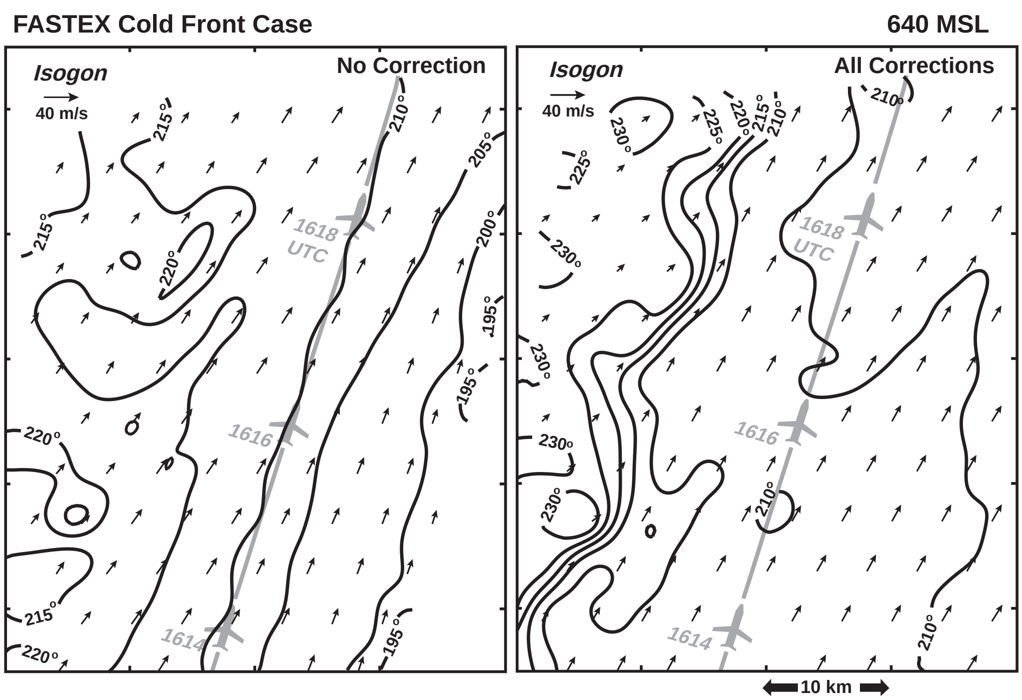

Figure 3: The dual-Doppler vectors and isogons for the uncorrected case (left) and the corrected case (right) for the 12 Jan. 1997 data. The thick gray line and the aircraft symbols indicate the flight track of the NCAR Electra. Isogons are in 5^o intervals.