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Study of Airborne Doppler Radar Navigation Correction Using a Variational Technique

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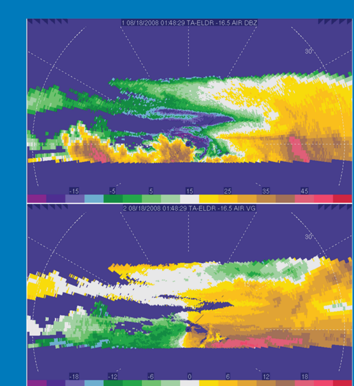
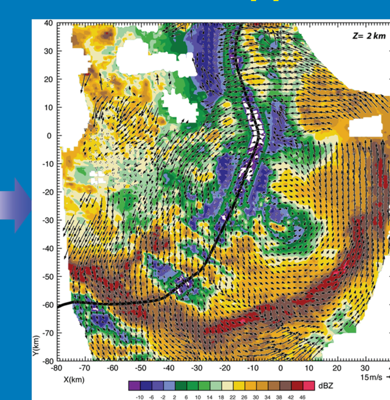
Introduction

Airborne Doppler radar data needs to go through a careful navigation correction procedure before accurate dual-Doppler synthesis can be obtained. Over the past two decades, separate techniques have been developed to correct navigation errors of ELDORA. The goal of this research is to develop a navigation correction algorithm, which can be used in future ELDORA field campaigns in realtime and in conjunction with the algorithm presented by Wolff et al. in these proceedings to quickly synthesize Dual Doppler data. It consolidates different techniques into one single algorithm that can be applied over all kinds of surface conditions including complex terrain and ocean. 1

The Goal of ELDORA Real-Time Dual-Doppler Project





- Navigation corrected and quality controlled sweeps on the aircraft that can be used to create near real-time Dual-Doppler syntheses for tactical decision making. 2

Methodology

- Based on a thorough literature review (i.e., Testud et al., 1995, Georgis et al. 2000, and Bosart et al., 2002), a variational method originated by Georgis et al. (2000) was selected and modified to be used for the future realtime navigation correction system
- This algorithm uses three constraints (the surface height, the surface velocity, and flight level winds) to derive 12 navigation correction factors of both the fore and aft radar
- The modified algorithm is able to use the new Cf/Radial format which was recently developed by NCAR/EOL for radar/lidar data 3

Cost Function for Navigation Correction

$$J=\underbrace{\frac{\sum_{n=1}^{N_{SURF}}\mu_{SURF}(n)\left[\sum_{i=1}^{12}\alpha_i(n)\Delta\Gamma_i-A(n)\right]^2}{\sum_{n=1}^{N_{SURF}}\mu_{SURF}(n)\left[A(n)^2\right]^{1/2}}}_{J_1}+\underbrace{\frac{\sum_{n=1}^{N_{SURF}}\mu_{SURF}(n)\left[\sum_{i=1}^{12}\beta_i(n)\Delta\Gamma_i-B(n)\right]^2}{\sum_{n=1}^{N_{SURF}}\mu_{SURF}(n)\left[B(n)^2\right]^{1/2}}}_{J_2}+\underbrace{\frac{\sum_{n=1}^{N_{SURF}}\mu_{NEAR}(n)\left[\sum_{i=1}^{12}\alpha_i(n)\Delta\Gamma_i-A(n)\right]^2}{\sum_{n=1}^{N_{SURF}}\mu_{NEAR}(n)\left[C(n)^2\right]^{1/2}}}_{J_3}$$

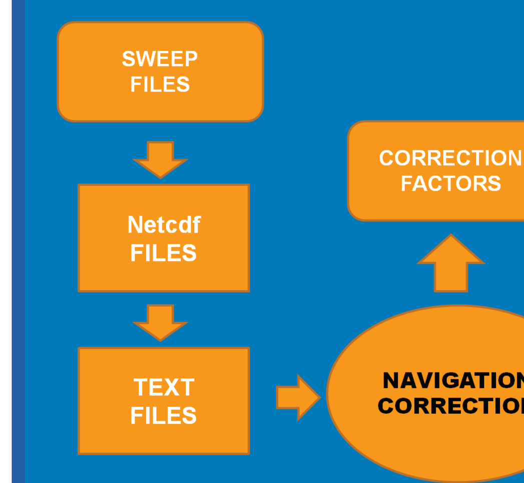
J1: Surface Height

J2: Surface Velocity

J3: In-Situ Winds

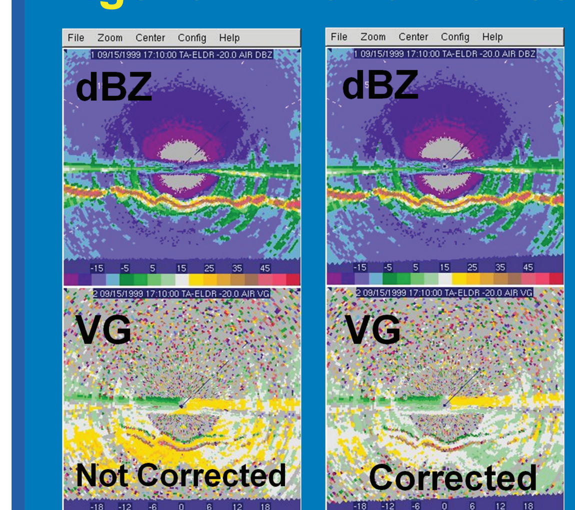
The algorithm can pick which cost function to use depending on the surface conditions (complex or flat terrain, land or ocean) 4

A Flow Chart for Testing the Algorithm



- Sweep files are converted to Cf/Radial-compliant netCDF files
- Variables necessary for navigation correction are extracted to text files
- Variational navigation correction code reads in the text files and produces correction factors 5

Algorithm Performance (Complex Terrain)



	Mean	STD
Dz_Surf (km) Before/After Corr.	-0.162/-0.007	0.558/0.149
VDOP_Surf (m/s) Before/After Corr.	1.494/0.036	1.332/0.620

- Left panel shows the original data; right panel shows the corrected data. Notice the surface velocity was reduced to near zero after the correction.
- The table shows the reduction of mean and standard deviation of radar-derived surface height minus DTM and the surface velocity before and after the correction. 6

Examples of Derived Corr. Factors (MAP)

Correction Factors	Guess	Residual	Guess+Residual
TILT_aft (deg)	0.235	-0.221	0.014
TILT_fore(deg)	-0.015	0.009	-0.006
TOTA_aft (deg)	-1.859	1.912	0.053
TOTA_fore(deg)	-2.532	2.535	0.003
PITCH (deg)	-1.445	1.422	-0.023
HEADING (deg)	0.179	-0.285	-0.106
RANGE_DELAY_aft (m)	60	-152	-92
RANGE_DELAY_fore (m)	47	-140	-93
D_XWE (m)	-248	226	-22
D_YNS (m)	456	-416	40
D_Zacft (m)	-33	56	23

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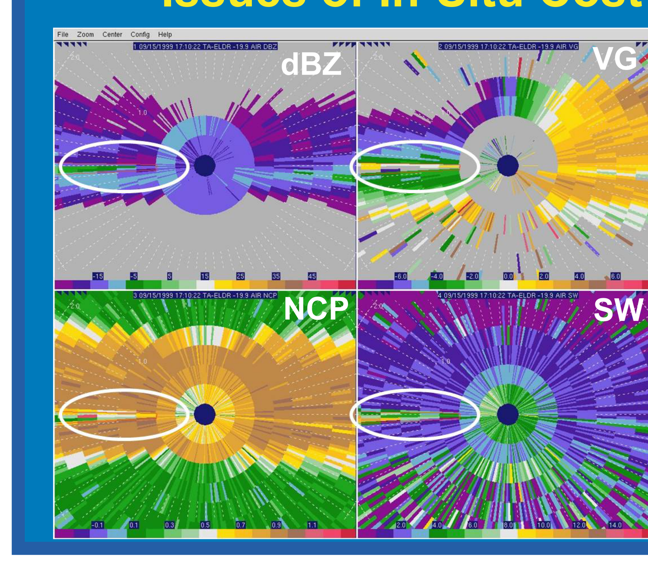
Issues of In-Situ Cost Function



- The variational algorithm's original settings could include bad data as circled in the left figure in the cost function calculations.
- Data quality may be the reason that the in-situ cost function alone could not provide reliable correction factor retrievals using the variational method. 8

Data Quality's Impact on In-Situ Cost Function

Test 1 : (NCP=0.25, SW=5.0, D_Max=5.0, D_Min=5 gates, Sin(ELE) < 0.1)

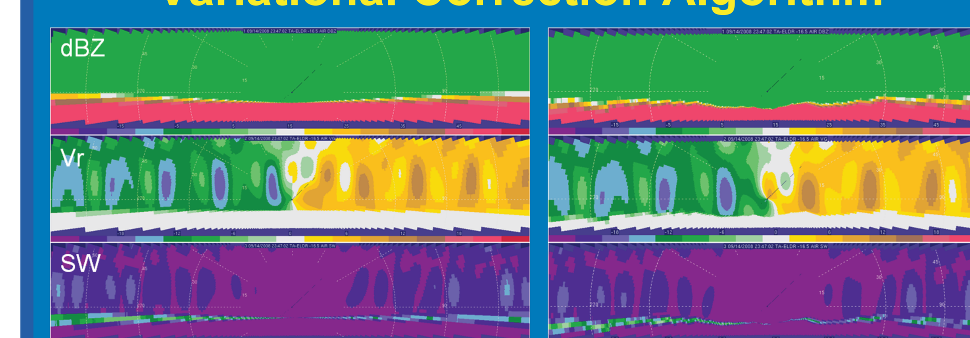
Test 2 : (NCP=0.60, SW=3.0, D_Max=3.0, D_Min=3 gates, Sin(ELE) < 0.2)

In-Situ cost funciton dVDOP_insitu (m/s):
Test 1: mean = -1.531, STD = 31.851
Test 2: mean = 0.031, STD = 1.863

Doppler velocity minus In-Situ winds projected on Doppler velocity (m/s):
Just show left side of the aft radar as an example:
Test 1: mean = -13.430, STD = 34.462
Test 2: mean = -0.578, STD = 2.415

- *By getting rid of poor quality data, the agreement between Doppler winds and projected in-situ winds is improved greatly* 9

Analytic ELDORA Data for Testing Variational Correction Algorithm



Flat Terrain | Complex Terrain

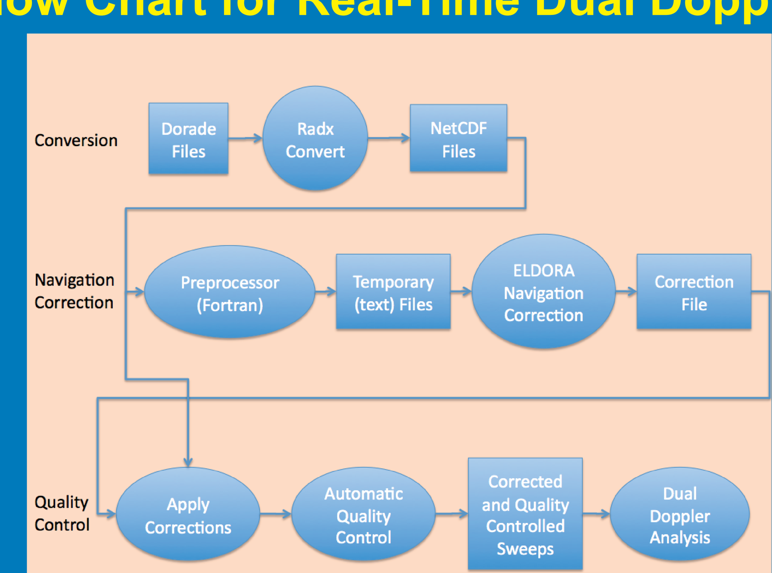
- *With known navigation errors specified in the analytic ELDORA data, it is fairly straight-forward to verify if the algorithm works* 10

Test of Navigation Correction Code Using Analytic ELDORA Data

	Rota-Aft (deg)	Rota-Fore (deg)	Pitch (deg)	Heading (deg)	Range-Delay-Aft (m)	Range-Delay-Fore (m)	Ground-Speed (m/s)
Synthetic Truth	-1.5	-1.5	-0.5	-0.2	20	20	-1.00
Retrieved	-1.466	-1.473	-0.5	-0.002	18	17	-1.11

- The test was done using the flat terrian synthetic ELDORA data. Since TILT and Ground-Speed can not be determined unambiguous at the same time over flat terrian, this test was done by assuming TILT correction was zero. 11

Flow Chart for Real-Time Dual Doppler



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Summary and Future Work

- A variational navigation correction algorithm adopted from Georgis et al. (2000) was modified and tested so that it can be used in real-time dual-Doppler synthesis during future ELDORA field campaigns.
- The algorithm works well over both complex terrian and flat terrain by using the surface height and surfcae velocity cost functions.
- The in-situ cost function does not work very well, probabaly as a result of inclduing bad data points as well as designing of the cost function. 13

Summary and Future Work (Continued)

- The performance of the algorithm was further confirmed by using synthetic ELDORA data.
- A proto-type of real-time dual-Doppler system that combines navigation correction and automatic quality control code together was created and tested.
- Future work includes improving the in-situ cost function and developing a fully functional real-time dual-Doppler software system. 14

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