9.11 A COMPARISON OF BOUNDARY LAYER WIND ESTIMATION TECHNIQUES

Rich DeLaura*, Rodney E. Cole, MIT Lincoln Laboratory, Lexington, Massachusetts
N. Andrew Crook, Juanzhen Sun, MMM/RAP

1. INTRODUCTION†

Accurate, short-term (0-2 hour) forecasts of convective initiation provide critical information about weather that has a major impact on aviation safety and system capacity. The Terminal Convective Weather Forecast (TCWF) algorithm is a key component of the FAA's operational Integrated Terminal Weather System (ITWS). Convective forecasts rely, in part, upon detection of convergence zones in the boundary layer. Detection of convergence requires accurate, high-resolution wind estimates, which may be based on measurements from many sources, including Terminal Doppler Weather Radar (TDWR), Next Generation Weather Radar (NEXRAD), Automatic Weather Observation System / Automatic Surface Observation System (AWOS/ASOS), aircraft (via the Meteorological Data Collection and Reporting System, MDCRS) and Low Level Wind Shear Alert System (LLWAS). These data may be directly analyzed, combined with satellite and sounding data or ingested into physical models that estimate winds and produce short term forecasts.

We compare two windfield estimation techniques: Terminal Winds (TWINDS) [Cole et. al., 2000], an optimal estimation algorithm developed at Lincoln Laboratory that is deployed operationally in ITWS, and Variational Doppler Radar Analysis System (VDRAS) [Sun and Crook, 2001], a 4DVAR algorithm developed and fielded by the Research Applications Program (RAP) at NCAR. These techniques differ markedly in their use of physical models: TWINDS applies no physical constraints to its analysis, while VDRAS uses a 4DVAR technique to fit the data with a boundary layer model as a strong constraint. The techniques also differ in their computational requirements: TWINDS requires substantially less computational power than VDRAS. We were able to run TWINDS at higher horizontal resolution and update rate (1km grid spacing, 5 minute update) than VDRAS (2km and 12 minutes).

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**Corresponding author address*: Rich DeLaura, MIT Lincoln Laboratory, 244 Wood Street, Lexington, MA 02420-9108, email: richd@ll.mit.edu

We studied algorithm performance over a four hour period on June 27, 2000 that produced many convective cells near the DFW airport. Data were available from 2 Doppler radars (FWS NEXRAD and DAL TDWR), MDCRS, LLWAS and AWOS/ASOS. The radar data were most critical. TWINDS and VDRAS analyses were performed using both FWS and DAL (double Doppler), and FWS and DAL separately (single Doppler). (We refer to our 2 radar configuration as "double" rather than "dual" in order to avoid confusion with traditional dual Doppler wind retrieval.) We examined several characteristics of both techniques: ability to detect convergence zones in the boundary layer; noise in convergence fields; and sensitivity to data coverage, radar viewing geometry and input parameterizations.

2. DESCRIPTION OF THE TECHNIQUES

2.1 TWINDS

TWINDS began field testing in 1992 at the Orlando International Airport as part of the development of ITWS. TWINDS creates two windfield estimates: a coarse resolution estimate (typically 10 km horizontal grid spacing, 25 or 50 mb vertical spacing, 15 or 30 minute update) and a fine resolution estimate (2 km or 1 km, 25 or 50 mb, 5 minute). In the analysis, 80 km gridded winds derived from the 40 km RUC-II model are interpolated to the coarse grid and combined with the previous coarse analysis to provide the background estimate for the current coarse analysis. The background is combined with data measurements in a Gauss-Markov least-squares analysis to produce a minimum-variance estimate of the winds at each grid point. The coarse analysis provides the starting point for a similar analysis on the fine resolution grid.

TWINDS can ingest measurements from multiple NEXRADs and TDWRs, and wind measurements from LLWAS, AWOS/ASOS and MDCRS. Radar data dominate the analysis when there is appreciable return. The algorithm is parameterized, allowing the user to specify error model characteristics, degree of data editing, data measurement influence windows, analysis firing frequency, etc. These parameterizations give the user substantial control over the smoothness and temporal response of the analysis output.

2.2 VDRAS

VDRAS performs a 4DVAR analysis to calculate winds at each point in the analysis grid. The analysis windfield satisfies exactly the atmospheric state equations (hard constraints), while minimizing a cost function that includes windfield error and spatial and temporal smoothing terms. The relative weighting of the cost function terms may be specified by the user.

VDRAS uses an adjoint method to calculate the optimal windfield. It is capable of producing short term forecasts, although this capability has not been rigorously tested so far. VDRAS can ingest data from single or multiple Doppler radars, and wind measurements from AWOS/ASOS, LLWAS and MDCRS.

3.0 CASE DESCRIPTION

The case study covered a four hour period (1900-2300 Z) on June 27, 2000. The analysis domain was a 120 x 120 km square, centered on the DFW airport. Two major storms, one to the NW, the other to the E, produced outflow rings that collided around 2100Z to produce a large cell in the ESE region of the analysis domain. The outflow ring from the NW collided with a second outflow in the SW corner of the analysis domain to produce a second large cell around 2200Z. Several smaller cells also developed along the outflow ring as it travelled across the analysis domain.

4. ANALYSIS

Data were available from several sources during the study period: one TDWR (DAL), one NEXRAD (FWS), the LLWAS network at DFW airport, AWOS/ASOS and MDCRS. Three separate VDRAS analyses were run, each using a different set of radar inputs: double (DAL and FWS), single TDWR (DAL) and single NEXRAD (FWS). All VDRAS analyses were run on an analysis grid with 2 km horizontal resolution, 350 m vertical resolution and a 12 minute update period.

Double and single Doppler TWINDS analyses were run with three different parameter sets: low resolution (2 km horizontal grid spacing, 50 mb vertical, 5 minute update); high resolution (1 km grid) and "smooth" (1 km grid, aggressive smoothing parameters). We compared VDRAS double output to TWINDS 2km double and smooth 1km double outputs; VDRAS single radar outputs are compared to corresponding TWINDS 2km outputs. Comparisons used the 950 mb level (~500 m) from TWINDS, and the 350 m level from VDRAS.

We made qualitative comparisons of convergence fields from both techniques to determine their ability to detect convergent zones in the boundary layer, the strength of the convergent signatures, noise in convergence fields and shortcomings. We compared single and double Doppler analyses to determine the quality of each technique's single Doppler windfield retrieval.

Figure 1 shows convergence fields from each analysis. Both techniques detected convergence at outflow boundaries that generated new convective cells. The 2 km TWINDS and VDRAS analyses, for single and double Doppler inputs, yielded similar convergence fields. VDRAS fields were generally less noisy and convergent features were stronger and more clear.

The 1 km dual TWINDS analysis with aggressive smoothing resolved more detail in the convergence field and produced stronger convergence features than either 2 km analysis, without an appreciable increase in noise.

Neither technique could generate convergence features in large regions where no radar data were available. The single NEXRAD analysis from both techniques missed a region of strong convergence in the ESE zone of the analysis domain, due to the absence of NEXRAD data there. Both techniques exhibited artifacts at boundaries between data rich regions and data voids in the single radar analyses. These artifacts were more evident in TWINDS, particularly in the 1km analysis. VDRAS was better than TWINDS at filling small data gaps, particularly in the single radar analyses, due to its global optimization and physical modeling.

We also defined two regions of particular interest ("convergence zones"), 10 x 10 km boxes enclosing areas in the ESE and SW of the analysis domain where outflow rings collided to produce significant cells. The 10 km domain size was chosen to be consistent with that typically used in convection initiation algorithms such as NCAR's AutoNowcaster. At each analysis time, we calculated mean convergence in each box, using convergence fields from each analysis. Time series plots of mean convergence are shown in Fig. 2.

5. CONCLUSIONS

It would be unwise to draw definitive conclusions from a single case. Instead, we summarize our observations:

1) Both techniques can resolve outflow boundaries and convergent zones in the boundary layer using single or double Doppler inputs, in regions of radar return.

2) Neither technique could detect convergence in large radar data voids, although VDRAS did a better job of filling small data gaps. We could not determine the capabilities of either system to detect convergent zones that are aligned along the baseline for double Doppler or along the radar beam for single Doppler calculations.

3) At 2km resolution, VDRAS convergence fields had stronger features and less noise than TWINDS. The double Doppler, smooth 1km TWINDS analysis had the strongest and best resolved convergence features, without an appreciable increase in noise.

4) TWINDS requires substantially less computational power and can run at higher spatial and temporal resolutions than VDRAS, given the same computational power. This may offer greater flexibility in tuning the detection of convergent features to the requirements of a downstream convective initiation algorithm.

This case study illustrates many of the similarities, capabilities and shortcomings of both techniques, though a full comparison will require study of additional cases. Our results indicate that either technique can provide boundary layer convergence fields that can be useful to convective initiation forecast algorithms.

6. FUTURE WORK

A more complete comparison should include analysis of algorithm performance under different circumstances:

1) sparse radar return
2) radially aligned convergent features
3) poor radar data quality

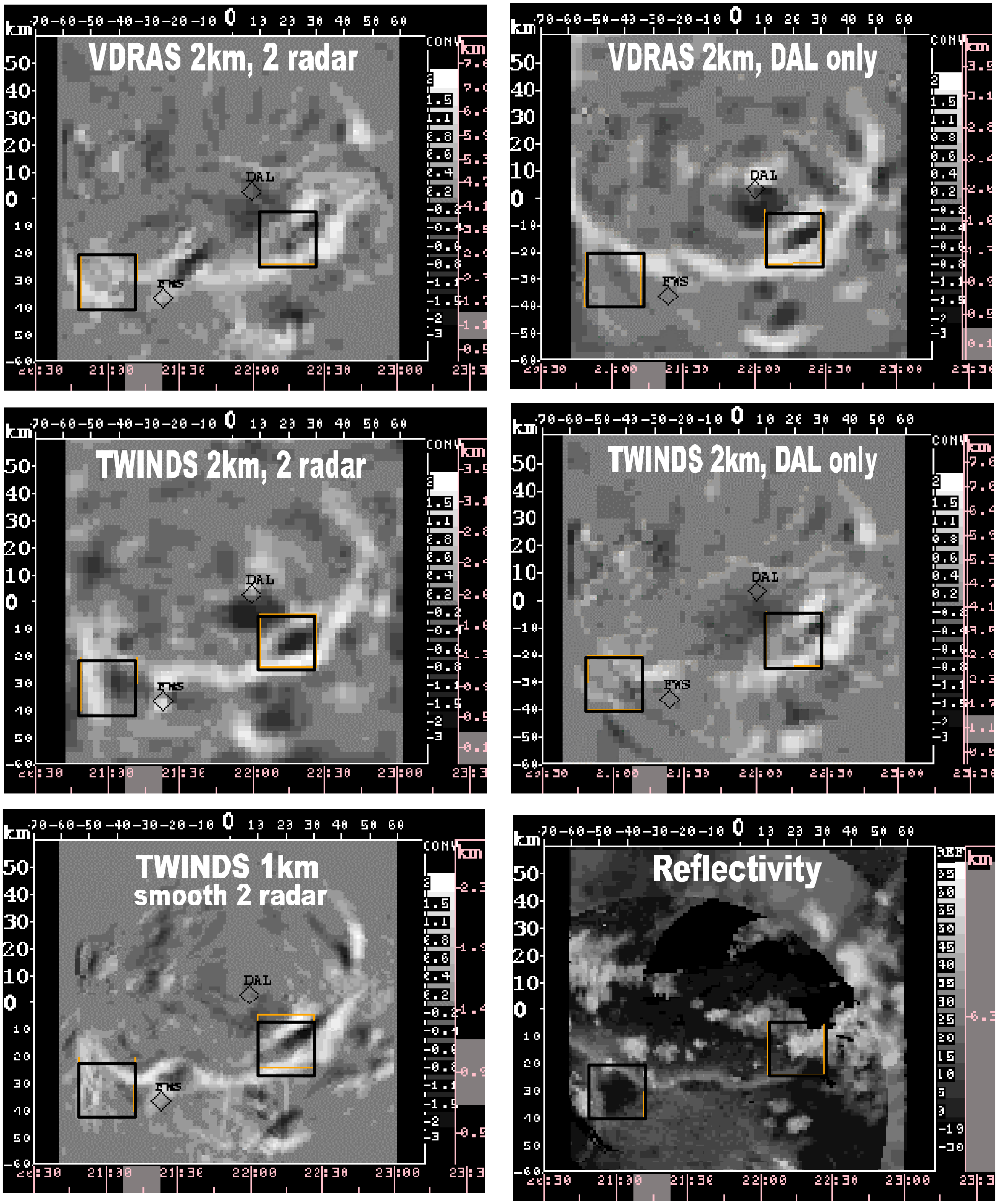

Figure 1. Convergence, reflectivity from 2122 Z, June 27, 2000. High reflectivity and convergence are white, low reflectivity and divergence, black. Black diamonds denote radars. Boxes denote analyzed convergence zones. VDRAS analysis is at 375 m, TWINDS at 950mb (~500 m). In the Convergence zone to the ESE, the large outflow ring from the NW has just collided with a smaller outflow from the E. Shadow rings in the SW corner of the DAL only analyses are convergence artifacts at the boundary of the radar data coverage.

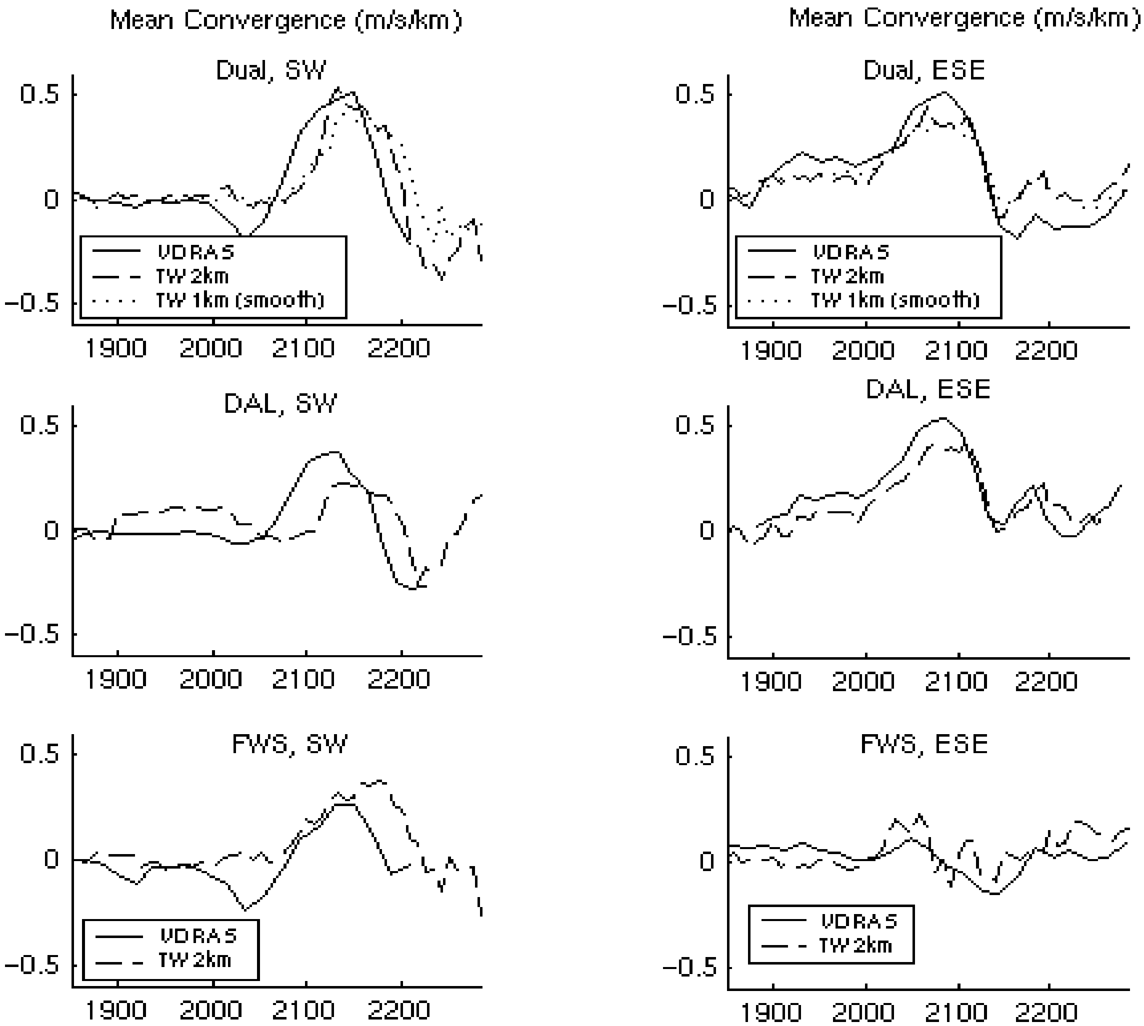

Figure 2. Mean convergence vs. time in convergence zones. Dual, DAL and FWS refer to radars used in the analysis. ESE and SW denote the convergence zones. The SW zone falls in a gap of DAL's scan coverage. VDRAS detects convergence better in the DAL analysis because its global optimization fills data gaps better.

Further algorithm studies should include

1) coupling of TWINDS or VDRAS to algorithms such as ITWS Machine Intelligent Gust Front Algorithm (MIGFA) for detecting convective initiation
2) use of simple physical models and/or global optimization in TWINDS to improve hole filling and reduce nois e
3) sensitivity study of VDRAS parameters, including cost function weights and physical characteristics
4) assessment of VDRAS short-term forecasts
5) comparison of 3D and 4DVAR to detemine costs and benefits of 4DVAR in convergence detection
6) improvements in the signal to noise ratio in convergence fields via post-processing

7. REFERENCES:

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