REAL-TIME MULTIPLE SINGLE DOPPLER ANALYSIS WITH NEXRAD DATA

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1. INTRODUCTION

As part of the Aviation Weather Development Program of the Federal Aviation Administration, a high resolution winds analysis system was demonstrated at Orlando International Airport (MCO) in the summer of 1992. The purpose of this demonstration was to illustrate the winds analysis capability possible from operational sensors in the mid '90s. An important part of the design of this system was the development of a procedure for the assimilation of Doppler data from multiple radars. This procedure had to be able to automatically handle regions with missing data from one or more radars, as well as avoid baseline instability. The two operational radars scanning the analysis region were the National Weather Service WSR-88D (NEXRAD) radar located approximately 65 km east and slightly south of MCO, and the MIT prototype Terminal Doppler Weather Radar (TDWR) located 7 km due south of the airport. The base data from these two Doppler radars were the major information component for the analysis system.

Our system includes the most recent improvements in the winds analysis portion of the Local Analysis and Prediction System (LAPS) developed by the Forecast Systems Laboratory (McGinley *et al.*, 1991). LAPS is designed to run locally on systems affordable for operational weather offices and takes advantage of all sources of local data at the highest possible resolution. Our implementation for the airport terminal region is called the Terminal-area LAPS (T-LAPS). LAPS formerly had a technique for the assimilation of data from a single Doppler radar. We have modified that technique for the assimilation of data from the two available radars. Our approach, using a Multiple Single Doppler Analysis (MSDA) technique, is more suited for unsupervised operational analysis than traditional Dual Doppler Analysis (DDA), because it is able to handle such problems as incomplete data and baseline instability. We will describe the T-LAPS analysis, with particular attention to our implementation of MSDA, and give some examples from our demonstration.

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2. LAPS WINDS ANALYSIS OVERVIEW

The LAPS winds analysis (Albers, 1992) uses a Barnes (1964) objective analysis scheme. The analysis acquires a background wind field and recent wind observations in the analysis region, and produces an analyzed wind field on a 3D grid. LAPS was designed to be computationally efficient and compatible with a background wind field provided by a previous analysis or numerical forecast model. For the demonstration only the horizontal winds were analyzed.

The steps in the analysis process are as follows:

1. For each observation, the difference between the u component of the observed wind and the u component of the background wind at the grid point nearest the observation is computed. Likewise, a difference is computed for the v component.
2. At each analysis point, weighted means of the u and v difference values are computed, to form a correction term which is an estimate of the vector difference between the actual wind and the background wind at that point. The weights depend on the horizontal and vertical distances from the observation location to the analysis point, a radius of influence that varies locally depending on the ambient data density, and sensor type.
3. The correction terms are added to the background wind to form the analyzed wind field.

Doppler radars measure the component of the wind only along the radar beam. Before the above process can be applied to Doppler radar data, the Doppler observations must be transformed into vector observations.

3. LAPS SINGLE DOPPLER ANALYSIS

This section details the process by which Doppler radar observations are brought into the LAPS analysis. The idea is to transform the single component observations from a Doppler radar into vector quantities, and then to use these vectors as additional observations.

The steps used to bring Doppler observations into the analysis are as follows:

1. An analyzed wind field is computed using the background wind field and the non-radar observations as discussed in

Section 2.
2. The wind field from Step 1 is adjusted at points with a Doppler wind speed estimate. At these points, the component of the wind along the radar beam is set to the Doppler value. The perpendicular component is unchanged.
3. The resulting wind vectors at points with a Doppler value are considered to be "radar vector observations".
4. The final analysis is computed from the original background wind field, the true vector observations, and the "radar vector observations" as described in Section 2.

4. MULTIPLE SINGLE DOPPLER ANALYSIS

The Multiple Single Doppler Analysis (MSDA) developed for T-LAPS is a simple extension of the standard LAPS Doppler analysis. The steps used to bring multiple Doppler observations into the analysis are as follows:
1. An analyzed wind field is computed using the background wind field and the non-radar observations as discussed in Section 2.
2. The wind field from Step 1 is adjusted at points with a NEXRAD Doppler wind speed estimate. At these points, the component of the wind along the radar beam is set to the Doppler value. The perpendicular component is unchanged.
3. The wind field from Step 2 is adjusted at points with a TDWR Doppler wind speed estimate. At these points, the component of the wind along the radar beam is set to the Doppler value. The perpendicular component is unchanged.
4. The resulting wind vectors at points with at least one Doppler value are considered to be "radar vector observations".
5. The final analysis is computed from the original background wind field, the true vector observations, and the "radar vector observations" as described in Section 2.

At a point with two Doppler wind estimates, the measured radial component from TDWR will equal the radial component of the "radar vector observation". The difference between the radial component measured by NEXRAD and the corresponding radial component of the "radar vector observation" dependents on the angle between the two radar beams. When the angle is 90°, the difference is zero. As the angle decreases to 0°, the difference increases to the difference between the the TDWR and NEXRAD measurements, and at 0°, a "radar vector observation" is equal to the single Doppler "radar vector observation" computed from only the TDWR data. The TDWR data were chosen to follow the NEXRAD data in the MSDA process since the TDWR is located closer to the Orlando International Airport.

5. DISCUSSION OF MSDA AND DDA

In traditional dual Doppler analysis (DDA), a wind vector is computed at each analysis point with two Doppler observations. The resulting wind vector exactly agrees with both Doppler values. When the two radars have independent looks at the wind field, defined as 30° or more between the directions of the beams, DDA generates very accurate estimates of the wind. This points to two difficulties that arise with DDA in an analysis system which must produce an analysis at each grid point. First, not every grid point will have a Doppler return from each radar. Second, when the two radars do not have independent looks at the wind field, DDA becomes numerically unstable. This baseline instability gets progressively worse as the angle between the radar beams decreases. The first difficulty can be overcome, but will result in an increase in complexity relative to MSDA.

MSDA on the other hand, automatically handles incomplete Doppler data, and does not have a baseline instability. When two Doppler values are available at points where the two radar looks are independent, the "radar vector observation" is very close to the wind estimate produced by DDA. When the two radars do not have independent looks, MSDA produces a numerically stable "radar vector observation" with one high quality component, a Doppler measurement. The other component is derived from the non-Doppler data sources. At points with only one Doppler value, MSDA again produces a "radar vector observation" with one high quality component. Structural constraints imposed during the implied filtering in the final analysis step ensure that the wind structure in each of the sub-areas blends well.

Our implementation of MSDA was developed as a rapid prototype for this demonstration. As such, it has many desirable properties. However, it also has some weaknesses that we will address in the future. In regions with favorable geometry and returns from both radars, the "radar vector observations" are in close agreement with DDA, but are then smoothed by the analysis. When the two radars are looking in nearly the same direction, the NEXRAD data are largely overwritten by the TDWR data. This is true, for example, even when the analysis point is closer to the NEXRAD than the TDWR. This weakness could be alleviated with a weighting between the two radars to take into account the geometry of the analysis region. Each "radar vector observation" has a different level of quality due to whether the observation was built from one or two Doppler estimates, and the radar geometry at the observation location. This is not currently taken into account. Lastly, our implementation of MSDA can be used with any number of Doppler radars, but even with 3 or more Doppler radars it will have the weaknesses cited above.

Our MSDA implementation is equivalent to producing "radar vector observations" using weighted least squares with the following assumptions: the weights are inversely proportional to the error variance of the data, the TDWR error variance is infinitely small relative to the NEXRAD error variance, and the NEXRAD error variance is infinitely small relative to the error variance of the background wind field. This suggests optimization as a path to improving the MSDA technique. In addition, improvements are underway to generate a background wind field containing pre-derived dual Doppler wind vectors. This allows the existing analysis scheme to improve analyses in dual Doppler regions, by reducing the error in the background wind, and in single Doppler regions by increasing the accuracy of the tangential components of the "radar vector observations".

6. TWO EXAMPLES

The T-LAPS analysis region was 120 km x 120 km in the horizontal, centered on the Orlando International Airport, and extended from the surface to a height of 500 mb. The grid resolution was 2 km x 2 km x 50 mb, and the analysis was performed every 5 minutes.

This fine grid resolution and rapid update rate were achieved by using a "cascade of scales". First, the winds were analyzed to a 10 km x 10 km x 50 mb grid, every 30 minutes. All of the available data sources were used in this analysis, and the background wind field was derived from the Mesoscale Analysis and Prediction System (MAPS) (Benjamin *et al.*, 1991). Next, the final analysis was performed every 5 minutes, using only the Doppler data and automated ground station data, LLWAS and ASOS/AWOS, with the latest 10 km analysis providing the background wind field.

The figures show the analyzed winds at 400 ft AGL, and the NEXRAD reflectivity resampled to the 2 km grid. The winds are displayed on a 4 km grid to reduce visual clutter, and a 5 m/s wind arrow is shown for scale in the upper right corner of each figure. The airport runways are shown in the center. The four outlines are lakes, and the coast appears along the northeast in each figure. Both examples are from August 20, 1992.

Figure 1 shows the wind and reflectivity at 21:30 GMT. A gust front, shown by both a reflectivity thin line and a line of convergence in the wind field, is being produced by a storm off the coast to the southeast of the analysis region. Later in the day, this gust front collides with a line of decaying storms northwest of the airport, spawning a new convective storm system. Figure 2 shows the wind and reflectivity at 23:55 GMT associated with the new convective storm.

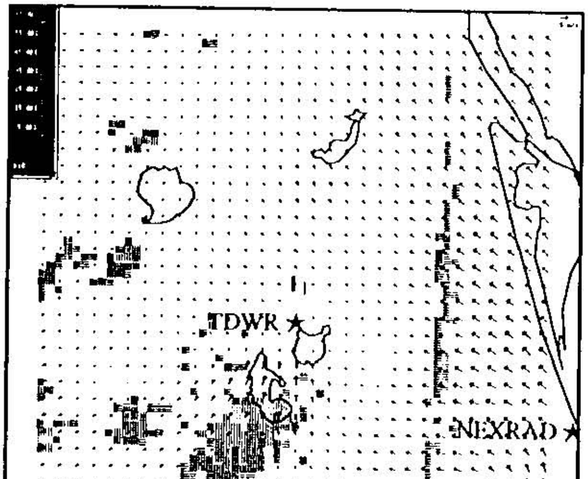

Figure 1. Wind and Reflectivity (Aug. 20, 1992 21:30 GMT)

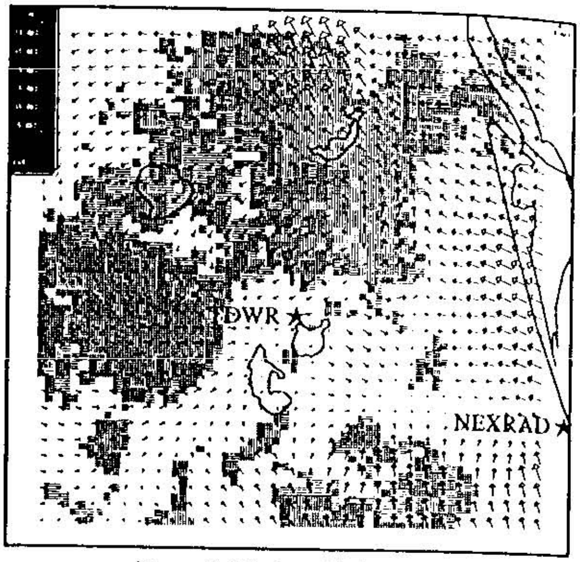

Figure 2. Wind and Reflectivity (Aug. 20, 1992 23:55 GMT)

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