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ITWS GRIDDED ANALYSIS

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1. INTRODUCTION

The Integrated Terminal Weather System (ITWS) (Ducot, 1993, Evans and Clark, 1993) brings together data from a number of FAA and non–FAA weather sensors to provide knowledge of the weather in an extended region surrounding an airport. ITWS supports a variety of new products designed to increase airport capacity and improve safety.

The ITWS gridded analysis system provides an analysis of several state–of–the–atmosphere variables: wind, temperature, pressure, and humidity. The Local Analysis and Prediction System (LAPS) (McGinley *et al.*, 1991), developed by NOAA/ERL/FSL provides the basic concepts and the initial prototype. The LAPS analysis combines data from the Mesoscale Analysis and Prediction System (MAPS) (Benjamin, *et al.*, 1991) with observations from a variety sensors, such as wind profilers, ground stations, and aircraft. Several enhancements are being added to LAPS, creating an analysis system that is appropriate for terminal–area sensors and the temporal and spatial scales required for terminal operations.

There are several aviation weather products that depend on this gridded analysis system. First, the gridded horizontal winds and temperature fields are directly used as the winds and temperature fields for the Terminal Air Traffic Control Automation – Center TRACON Advisory System (TATCA–CTAS) (Seagull, 1990). A high–resolution wind analysis is also used as the background for ITWS runway winds products. Short–term wind nowcasts, up to 30 minutes, to support these products are being investigated. The full gridded analysis is the backdrop for the development of a variety of ceiling and visibility products (Wilson, *et al.*, 1993).

The prototype terminal–area winds analysis system is derived from the LAPS winds analysis. There are two important enhancements. The first is the development of a Multiple Single Doppler Analysis (MSDA) procedure for the assimilation of Doppler data from multiple radars. The MSDA procedure is an extension of the LAPS single Doppler analysis. The second is the development of a "cascade of scales" to allow the analysis to step from MAPS, with a grid resolution of 60 km and an update rate of 3 hours, to an analysis with a grid resolution of 2 km and an update rate of 5 minutes. LAPS and the prototype ITWS terminal–area wind analysis system have incorporated these enhancements.

In 1992, a prototype terminal gridded winds analysis was tested at Orlando International Airport. Successful field operations from August 17 until September 25 featured the first real–time analysis using Terminal Doppler Weather Radar (TDWR) (Merritt, *et. al.*, 1989) and the National Weather Service WSR–88D (NEXRAD) (Crum and Alberty, 1993) data. An improved system will operate at the Orlando airport this summer.

We describe the prototype winds analysis, with particular attention to our implementation of MSDA and the cascade of scales, and give some examples from our 1992 demonstration.

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2. LAPS WINDS ANALYSIS OVERVIEW

LAPS is designed to run locally on systems affordable for operational weather offices. The LAPS horizontal winds analysis (Albers, 1992) uses a single iteration Barnes (1964) objective analysis scheme with a radius of influence which depends on the local data density. 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 uses a 600 km x 600 km horizontal domain and a vertical extent to 100 mb, and a horizontal resolution of 10 km and a vertical resolution of 50 mb. LAPS is designed to be compatible with a background wind field provided by a previous analysis or numerical forecast model. The standard practice is to use the MAPS forecasts as the background field.

The steps in the analysis process are as follows:

- Compute differences between observations and background (Δobs)
- Analyze Δobs to each grid point
- Add analyzed Δobs to the background

For each observation, the difference between each component of the observed horizontal wind and the corresponding component of the background wind at the grid point nearest the observation is computed. These differences are corrections to the background at the observation locations.

Next, the corrections at the observation locations are analyzed to each grid point by a weighted mean. This gives correction terms which are estimates of the vector difference between the actual wind and the background wind at each grid point. The weights depend on the horizontal and vertical distances from the observation location to the analysis point, a radius of influence that varies depending on the local data density, and sensor type. The correction terms are then 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, LAPS transforms the Doppler observations into velocity vectors, which are treated as additional observations.

3. LAPS SINGLE DOPPLER ANALYSIS

We first review the process by which Doppler radar radial velocity observations are brought into the LAPS analysis. The idea is to transform the radial velocity 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:

- Perform preliminary analysis
- Construct "radar vector obs"
- Perform final analysis

The preliminary analysis is performed as discussed in Section 2. using the background wind field and the non–radar observations.

The velocity vectors, or "radar vector observations", are constructed from the preliminary analysis by adjusting the wind field 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 component perpendicular to the radar beam is unchanged. The resulting wind vectors at points with a Doppler value are considered to be "radar vector observations".

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 ITWS gridded winds analysis has inputs from multiple Doppler radars, requiring the enhancement of LAPS. A procedure for the assimilation of Doppler data from multiple radars was developed for this purpose. This procedure, a Multiple Single Doppler Analysis (MSDA) technique, is more suited for unsupervised operational analysis than traditional Dual Doppler Analysis (DDA) (Armijo, 1969), because it is able to automatically handle such problems as incomplete data and 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 Multiple Single Doppler Analysis (MSDA) developed for the prototype ITWS gridded wind analysis is a simple extension of the original LAPS Doppler analysis. The procedure used to bring multiple Doppler observations into the analysis only differs from the single Doppler procedure in the construction of the "radar vector observations".

In MSDA, the "radar vector observations" are constructed from the preliminary analysis by first adjusting the wind field 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 NEXRAD Doppler value. The component perpendicular to the radar beam is unchanged. Next, the resulting wind field 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 TDWR Doppler value. The component perpendicular to the radar beam is unchanged. The resulting wind vectors at points with at least one Doppler value are considered to be "radar vector observations".

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; the "radar vector observation" agrees exactly with both Doppler values. 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, where the most accuracy is required.

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, for example at points near the baseline between the two radars, DDA is 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. The smoothing inherent in a single iteration Barnes analysis ensures that the wind structure in each of the sub-areas blends well.

Our implementation of MSDA was developed as a rapid prototype for the 1992 demonstration. It has some weaknesses that we are addressing. 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. The "radar vector observations" have different levels of quality. This depends on whether an 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.

6. CASCADE OF SCALES

LAPS has traditionally derived its background wind field from MAPS forecasts, available on three hour intervals, and produced an analysis with a 10 km grid resolution and an update rate of 60 minutes. This is consistent with the density of observations in the domain for which LAPS was developed. The reduction in spatial scale is 6:1, and the reduction in temporal scale is 3:1.

The terminal winds analysis is dominated by Doppler weather radar data in the planetary boundary layer. Above the planetary boundary layer, the only observations are scattered aircraft reports. The radars provide sufficient fine-scale winds information to support a 2 km analysis and a 5 minute update rate in regions with sufficient Doppler returns. Outside of this region the data do not support this fine scale analysis.

This situation is handled by a "cascade of scales". First, an analysis is performed with a 10 km horizontal resolution, a 50 mb vertical resolution, and 30 minute update rate utilizing all of the data sources. This is very similar to the traditional LAPS winds analysis. The current 10 km analysis is then used as the background field for an analysis with a 2 km horizontal resolution, a 50 mb vertical resolution, and an update rate of 5 minutes. Only Doppler radar data and recent surface data are used in the 2 km analysis. The aircraft reports and other surface data are not used due to data latency. The analysis domains used for the cascade of scales at the Orlando test bed are shown in Figure 1.

The 10 km analysis uses a background derived from MAPS. The background field is produced by bi-linear interpolation in time between the two MAPS forecasts that bracket the analysis time. The Doppler data are smoothed by applying a median filter with a 1 km^2 footprint to the base data, then resampled to the 10 km grid by taking the mean value in a 10 km square cell centered on each grid point. All data are required to have collection times within 90 minutes of the analysis time. This gives a reduction in spatial and temporal scales of 6:1.

The background for the 2 km analysis is the most recent 10 km analysis. The Doppler data are smoothed by applying a median filter with a 1 km^2 footprint to the base data and resampled to the 2 km grid by taking the value at the gate nearest the grid point. Currently, the only surface data in the 2 km analysis come from the Low Level Wind Shear Alert System (LLWAS)(Wilson and Gramzo, 1991) anemometer network located at the airport. On grid levels with no observations (surface or Doppler), the analysis is the 10 km analysis. This gives a further reduction in spatial scale of 5:1 and temporal scale of 6:1.

7. THE ORLANDO TEST BED

The wind data sources in the Orlando test bed are:

- TDWR prototype Doppler radar
- NEXRAD Doppler radar
- ASOS/AWOS automatic observing stations
- LLWAS anemometer network
- SAO hourly observations
- ACARS aircraft observations

The Doppler radars complete their volume scans every 5 to 6 minutes. The Automated Surface Observing System (ASOS)(ASOS Program Office Staff, 1991) and the Automated Weather Observing System (AWOS) provide updates every 20 minutes, and LLWAS provides updates every 10 seconds. The LLWAS network is located at the airport and contains 14 sensors with a spacing of 2–3 km. The SAO's are updated on the hour. The ACARS (Brewster *et al.*, 1989) reports occur with variable spacing, averaging about 10/hour during the hours of operation.

Figure 1 shows the domains of analyses and sensor locations for the 1992 Orlando prototype. The 10 km and 2 km analysis regions are shown as squares centered on the airport. The dimensions are 180 km x 180 km and 120 km x 120 km respectively. The background field for the 10 km analysis was derived from the wind estimates on the 6x6 sub-domain of the MAPS grid shown. The TDWR radar is located near the center of the 2 km domain, and the NEXRAD radar is located near the southeast corner of the 2 km domain. Aircraft reports were available primarily along arrival and departure routes.

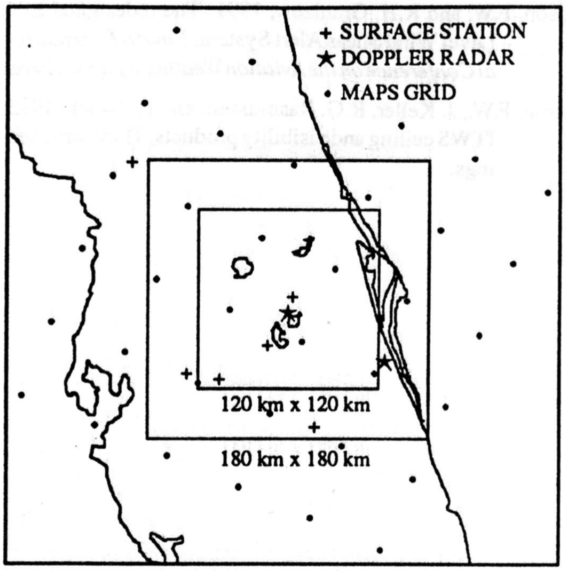

Figure 1. T–LAPS Domain and Sensor Locations

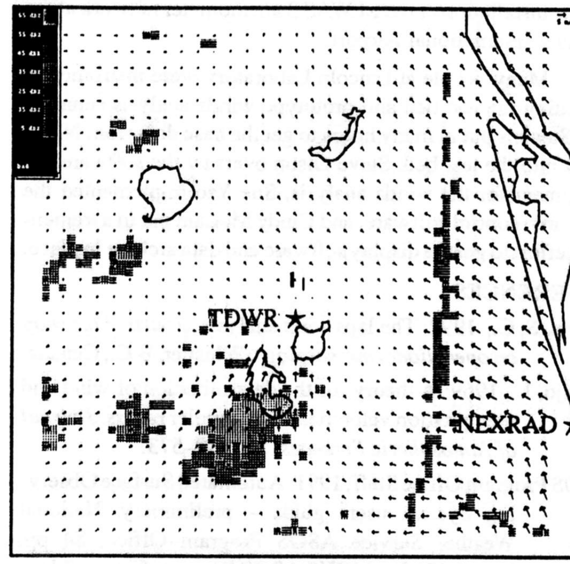

Figure 2. Wind and Reflectivity
(Aug. 20, 1992 21:30 GMT)

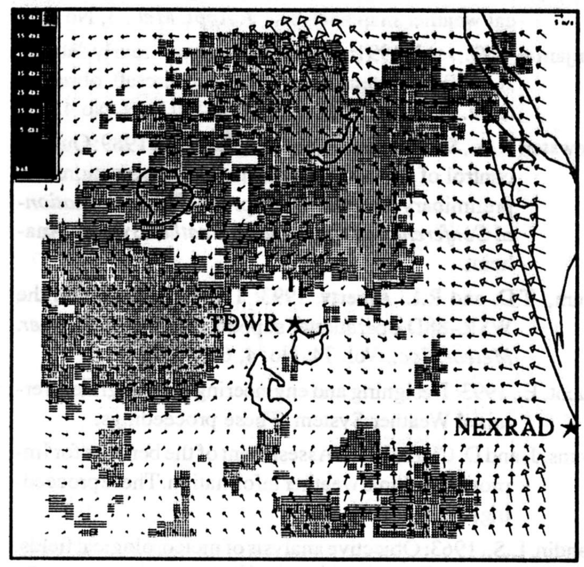

Figure 3. Wind and Reflectivity
(Aug. 20, 1992 23:55 GMT)

8. TWO EXAMPLES

Figures 2 and 3 show the domain of the 2 km analysis, the 2 km 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 2 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 3 shows the wind and reflectivity at 23:55 GMT associated with the new convective storm.

9. FUTURE WORK

We are taking a two track approach to improving the winds analysis. FSL is developing a modification to the MSDA procedure 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". FSL is also developing variational techniques for multiple Doppler analysis.

Lincoln Laboratory is developing an analysis technique called Optimal Estimation (OE) that is an extension of both Optimal Interpolation (Gandin, 1963) and DDA. Optimal Estimation uses Doppler data directly instead of using "radar vector observations". Like MSDA, Optimal Estimation automatically handles problems such as incomplete data and baseline instability. Like Optimal Interpolation, Optimal Estimation accounts for correlated errors in the data.

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