

P1.9

APPLICATION OF A BRATSETH ANALYSIS SCHEME INCLUDING DOPPLER RADAR DATA

Keith Brewster¹

Center for Analysis and Prediction of Storms
University of Oklahoma
Norman, OK

1. ANALYSIS GOALS

The Center for Analysis and Prediction of Storms (CAPS) requires a meso- and storm-scale analysis and assimilation system to support its efforts to develop and test the feasibility of real-time storm scale weather forecasting. The system must be as flexible in implementation as the CAPS Advanced Regional Prediction System (ARPS, Xue et al., 1995) and be modular with the model and accessory programs that retrieve unobserved variables from sequences of Doppler radar observations (Shapiro et al., 1996). For those situations and locations where there are insufficient data for the retrieval schemes, the system must also incorporate radial velocity and reflectivity data from Doppler radars.

Data interpolated from operational models and from separate analysis packages can be used to initialize ARPS. For example, the Rapid Update Cycle (RUC) model and the Oklahoma implementation of the Local Analysis and Prediction System (LAPS, Albers, 1995, Albers et al., 1996), OLAPS (Brewster et al., 1994), have been used. However, the loss of vertical resolution through interpolation becomes more of a problem as CAPS approaches an operational continuous assimilation system.

¹To meet these needs, the ARPS Data Assimilation System, ADAS, is under development at CAPS. Much of the functionality of its first stage, an analysis program, was used in a forecast exercise in the Spring of 1996 (Droegemeier et al., 1996, Xue et al., 1996). This paper documents the current features of the ADAS analysis and some plans for future development.

2. DATA SETS

Data for ADAS can come from any of a number of sources that are divided into four groups, 1) single-level data, composed mostly of surface observations such as SAO's, ASOS and the Oklahoma Mesonet, 2) sounding data, exemplified by rawinsonde observations and pro-

filer data, 3) radar radial velocity and reflectivity observations, 4) radar retrieval output, in the form of vertical profiles of wind, temperature, pressure, humidity and rainwater. Data from VAD wind profiles, aircraft data, and satellite-derived soundings can also be accommodated in those classes, but are not currently being used. Separately, some special techniques for using satellite data for cloud water specification are being developed, largely following that implemented in LAPS (Albers et al., 1996).

3. ANALYSIS SPECIFICATIONS

While some operational centers employ a Statistical (or Optimal) Interpolation scheme (OI), Bratseth (1986) has shown that a successive correction scheme can converge to OI. An iterative scheme offers computational savings in that large matrix solutions need not be found. Balancing and other adjustments can be made at the end of each iteration to control stability and other aspects of the evolving analysis. Iterations can be interspersed with model time-steps to form a dynamic initialization (nudging) process, or more detailed data can be introduced after a few iterations using broad-scale data. Like the OI scheme, the Bratseth interpolation methods allow accounting for the relative error between the background and the error in each observation source, and is relatively insensitive to large variations in data density. This type of scheme has been used successfully in research (e.g., Sashegyi et al., 1993) and operational mesoscale modeling (e.g., Lorenc', 1991).

Five variables are analyzed on the ARPS σ_z coordinate: u and v grid-relative wind components, pressure, potential temperature and RH^* . RH^* is a moisture variable analogous to dew-point depression:

$$RH^* = \sqrt{RH_{max} - RH} \quad (1)$$

where RH is the relative humidity and RH_{max} is the maximum relative humidity allowed (here set to 1.0; some might want to allow a greater value, for supersaturation). RH^* is selected over specific humidity due to the non-linear change in saturation specific humidity with height -- small absolute changes in surface specific humidity can cause unrealistic relative changes aloft in the 3-D observation weighting.

¹Corresponding author address: Keith Brewster, CAPS, SEC Room 1110, 100 E. Boyd, Norman, OK 73019; email: kbrewster@ou.edu

At this time, the vertical velocity, w , is diagnosed from the horizontal winds and a constraint that the wind velocity normal to the bottom (terrain) and top boundaries be zero. Any inconsistency between these constraints and the analyzed velocity field is resolved by assuming error in the horizontal divergence is linear with height, and the w field is adjusted after that error is removed. After w has been found for each column, the horizontal wind fields are relaxed with the condition that the total mass divergence is zero everywhere. This is to help ensure a smooth start for the ARPS model.

4. BRATSETH SCHEME

The ADAS uses a successive correction scheme, known as the Bratseth method (Bratseth, 1986, Shashegyi, 1993). As in the OI method, correlations among the data must be specified. Typically the correlations are a function of separation distance. In ADAS, the correlation, ρ , as a function of horizontal spatial separation is modeled as a Gaussian:

$$\rho_{ij} = \exp\left(-|\bar{r}_{ij}|^2 / R^2\right) \quad (2)$$

where \bar{r}_{ij} is the displacement between two locations and R is the correlation distance factor. The total correlation is also affected by separation in the vertical. ADAS allows the vertical correlation to be specified as a function of height separation, Δz ,

$$\rho_{\Delta z} = \exp(-\Delta z^2 / R_z^2) \quad (3)$$

or, a function of potential temperature separation, $\Delta\theta$.

$$\rho_{\Delta\theta} = \exp(-\Delta\theta^2 / R_\theta^2) \quad (4)$$

This ability is important when analyzing single-level data such as surface observations, which should influence a deep layer at times when the well-mixed boundary layer is deep and only a shallow layer when there is a nocturnal inversion (large change in θ with height).

For data sources that, themselves, do not include an observation of θ , the potential temperature of the background at the height of observation is used in the correlation model.

Nearly all analysis control parameters are specified through an input file which also includes the input variables for the ARPS (ADAS makes use of the domain and terrain variables, for example). Expected errors for multi-level observations are specified as a function of height, and are read-in from tables, one per data source.

A previous study (Carr et al., 1996) concluded that the best successive-correction analysis is produced when the background field is first corrected for errors in the broad-scale features through the use of a long spatial

correlation function (large scaling distance in the correlation model), then several passes are done using the target spatial correlation function. For this reason, a large-scale analysis is done first, followed by analysis iterations at the proper observation resolution.

Through the namelist input, the correlation distance factor is set as a function of the iteration index. Furthermore, the distance factor may be set to be different for each analysis variable, as one may wish to analyze humidity at a smaller scale than pressure, for example.

5. TREATMENT OF DOPPLER RADIAL WINDS

The radial velocities are converted to increments to the background u and v wind components by subtracting the observed radial wind, v_r , from the dot product of the analysis wind and the observing angle (radar azimuth, ϕ). The imputed correction is assigned a direction parallel to the azimuth, i.e.

$$u'_j(x, y, \phi) = \sin \phi [v_{rj} - (\sin \phi u(x, y) + \cos \phi v(x, y))] \quad (5)$$

$$v'_j(x, y, \phi) = \cos \phi [v_{rj} - (\sin \phi u(x, y) + \cos \phi v(x, y))] \quad (6)$$

The correlation between two Doppler radial winds requires special treatment in that the correlation between two radial wind observations is affected by the azimuth angle separation between the data. As described by Cole and Wilson (1995),

$$\rho(v_{rj}, v_{rk}) = \cos(\phi_j - \phi_k) \rho(\bar{r}_{jk}) \quad (7)$$

So, for example, if radial velocities at a given point are available from two radars observing perpendicular to each other, the covariance model correctly indicates that the observations are not correlated.

Similarly for mixed data types, the correlation is reduced from that of two complete wind observations:

$$\rho(u'_j, u'_k) = \cos(\phi_j - \pi/2) \rho(\bar{r}_{jk}) \quad (8)$$

and

$$\rho(v'_j, v'_k) = \cos(\phi_j) \rho(\bar{r}_{jk}) \quad (9)$$

where u'_i and v'_i are increments from a radial wind observation and u'_i and v'_i are from a complete wind observation (e.g., an anemometer or a rawinsonde).

The radar data are read from WSR-88D Level-II data tape, a live WSR-88D broadband data stream, or a set of NEXRAD Information Dissemination Service (NIDS) base data files in radar coordinates. The data are remapped onto Cartesian grid points by averaging all data that fall in each grid volume.

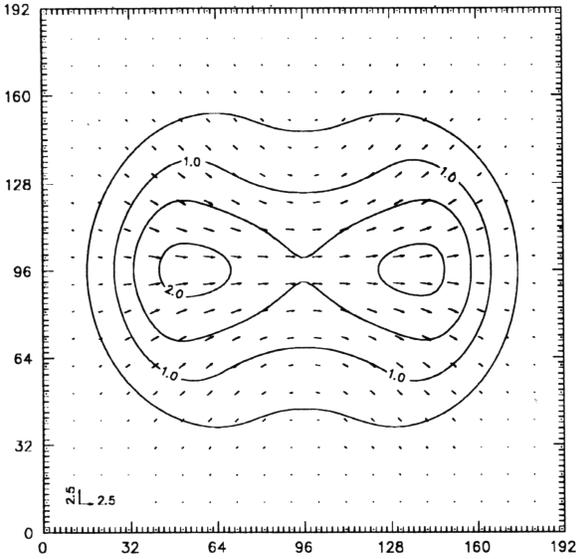


Figure 1. Bias in westerlies simulation . Analysis increments for the u wind increments (ms^{-1}) and wind increment vectors. Distance labels in km. Simulated radar is at center of plot.

The remapping algorithm is similar to the remapping in a WSR-88D implementation of LAPS developed jointly with FSL (Albers, 1995). The averaged variables are reflectivity factor (in dBZ), radial velocity, Nyquist velocity and observation time. The grid volumes are specified using the same parameters and routines as the grid volumes in the ARPS model. A minimum percentage data coverage of each grid box is required to create a valid average for that volume, and grid volumes which contain a high variance among the data are rejected. The remapped radar data are organized as columns of data and written to a file. Only those columns that contain grid-volumes with valid averages are written. Each column is identified by its latitude, longitude and source radar, so that the data may be used on a different grid than the grid on which they were originally collected. The remapping serves to thin dense data to the resolution of the analysis.

In ADAS, the radar data are compared to the background field and tested for folding. Since the Nyquist velocity can change during a volume scan, care is taken during the averaging process to insure that all data contributing to the average lie within the same Nyquist interval. That way, the average Nyquist value can be used to do the unfolding in the analysis quality control procedure. Data are rejected if, after unfolding, they differ from the background data by a user-specified threshold.

Although the radial winds are converted to u and v wind component corrections parallel to the radial at each point, the resultant analysis of these observations is not at all constrained in this way. By combining the infor-

mation from several locations, the local transverse wind component can be modified in the analysis. To demonstrate this effect, a background field of westerly winds is specified, with a magnitude of 8 ms^{-1} . Then, radial wind observations are simulated as if the actual wind were west at 10 ms^{-1} . Data are provided based on the WSR-88D clear-air scanning strategy, assuming complete coverage of winds 5-to-60 km from the radar site (center of grid). ADAS is run with those data as input (using 2 passes), resulting in the increments presented in Fig. 1 (a perfect analysis would have an increment of 2 ms^{-1} to the u component everywhere). As one might expect, the method is most successful in depicting the true wind to the east and west of the radar. Note, however, that changes are made to the u component to the north and south of the radar.

6. CONVERSION OF RADAR REFLECTIVITY TO MOISTURE VARIABLES

If one assumes there exists a threshold of radar reflectivity factor above which hydrometeors are present, one can then assume that, at a minimum, the relative humidity is high in the vicinity. In the ADAS, RH^* increments (corresponding to relative humidity of 90%) are created where the remapped reflectivity factor is above 20 dBZ and the background relative humidity is less than 90%. In this way, the observations will not create saturation, but if the data lie in a region of ascent, saturation will likely occur in the model.

For higher values of reflectivity, one can assume that a minimum level of cloud water is present. Since cloud water is distributed in the atmosphere with very small scales, the cloud water derived from the reflectivity is not analyzed in the same manner as other scalars. Instead, for each column in the analysis grid, the nearest remapped radar observation is found. Where a high reflectivity is observed, the cloud water is specified by:

$$qc_a = \max(qc_b, qc_{min}) \quad (10)$$

where qc_a is the analyzed cloud water, qc_b is the background cloud water and qc_{min} is the minimum cloud water assumed where the reflectivity is higher than a threshold. Currently a value of 25 dBZ is used as the threshold, and qc_{min} is specified as 1 gkg^{-1} .

7. REAL-TIME USE

ADAS was used as part of a system of initialization for the ARPS model during the Spring of 1996. In real-time the standard observations were used with the latest available RUC data. When convection was expected in the area of available data, the raw radar data from either the Oklahoma City WSR-88D broadband feed or one or more of the nearby WSR-88D sites available through

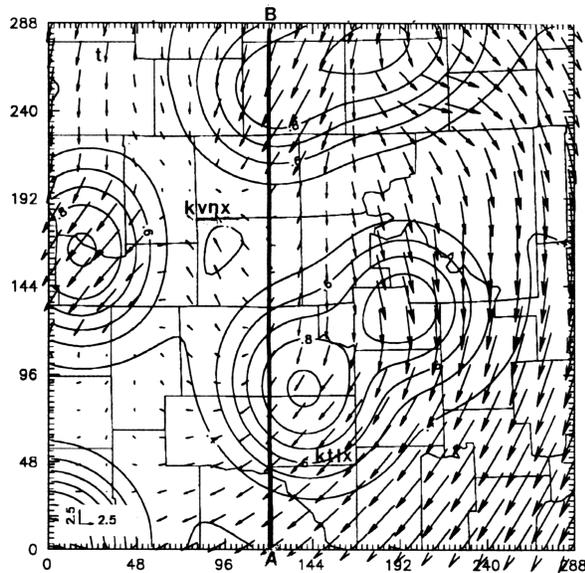


Figure 2 Plan view of $k=20$ level (approximately 2 km above the ground) for 1700 UTC 06 June 1996. Relative humidity (percent) and wind vectors (ms^{-1}). Line A-B indicates location of cross-section in Fig. 3.

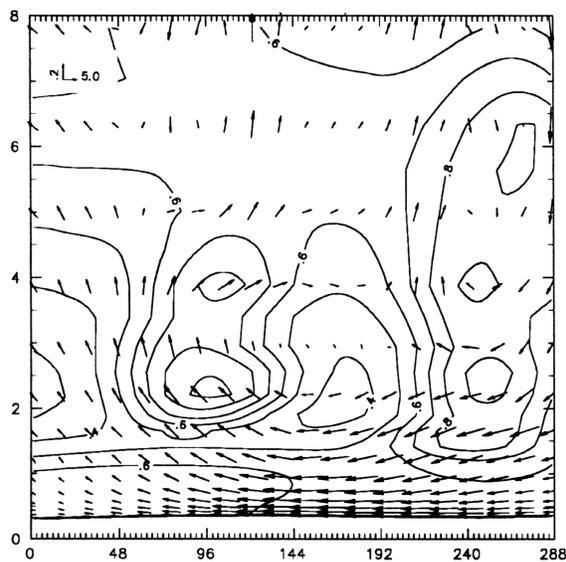


Figure 3 Y-Z cross-section along $x=120$ km of field presented in Fig. 2.

NIDS were added. Separately, single-Doppler retrieval data were prepared for studies in post-real-time.

Figure 2 shows a sample ADAS plan view from 6 June 1996 when NIDS data from Vance Air Force Base (KVNXX) and KTLX data were used to initialize ARPS with a decaying storm on the Kansas Oklahoma border. Fig 3 is a Y-Z cross-section through the domain showing the outline of that storm and nearby areas of rising motion in high relative humidity.

8. FUTURE PLANS

Besides the addition of information from satellite data mentioned previously, future work will largely focus on using the scheme in a continuous assimilation mode.

9. ACKNOWLEDGMENTS

CAPS is funded by grant ATM91-20009 from the National Science Foundation (NSF), and by a supplemental grant through the NSF by the Federal Aviation Administration. Discussions with Dr. Fred Carr have been helpful in developing ADAS.

10. REFERENCES

- Albers, S., 1995: The LAPS wind analysis. *Wea. and Forecasting*, **10**, 342-352.
- Albers, S., J. McGinley, D. Birkenheuer and J. Smart, 1996: The Local Analysis and Prediction System (LAPS): Analysis of clouds, precipitation and temperature. *Wea. and Forecasting*, 273-287.
- Bratseth, A.M., 1986: Statistical interpolation by means of successive corrections. *Tellus*, **38A**, 439-447.
- Brewster, K., F. Carr, N. Lin, J. Straka, and J. Krause, 1994: A local analysis system for initializing real-time convective-scale models. *Preprints, Tenth Conf. on Num. Wea. Prediction*, Amer. Meteor. Soc., 596-598.
- Carr, F., J. Krause, and K. Brewster, 1996: *Application of the Bratseth scheme to high resolution analyses in inhomogeneous data regions. This volume.*
- Cole, R. and F.W. Wilson, 1995: ITWS Gridded Winds Product. *Preprints, Sixth Conference on Aviation Wea. Systems*, Amer. Meteor. Soc., 384-389.
- Droegemeier et al., 1996: The 1996 CAPS operational testing period: real-time storm-scale NWP, Part 1: Goals and methodology. *Preprints, 11th Conf on Num. Wea. Prediction.*, In press.
- Lorenz, A.C., R.S. Bell and B. MacPherson, 1991: The Meteorological Office analysis correction data assimilation scheme. *Quart. J. Roy. Meteor. Soc.*, **117**, 59-89.
- Sashegyi, K.D., D.E. Harms, R.V. Madala, S. Raman, 1993: Application of the Bratseth scheme for the analysis of GALE data using a mesoscale model. *Mon. Wea. Rev.*, **121**, 2331-2350.
- Shapiro, A., L. Zhao, S. Weygandt, K. Brewster, S. Lazarus and K. Droegemeier, 1996: Initial forecast fields created from single-Doppler wind retrieval thermodynamic retrieval and ADAS. *Preprints, 11th Conf on Num. Wea. Prediction*, AMS, Boston. In press.
- Xue, M., K. Droegemeier, V. Wong, A. Shapiro and K. Brewster, 1995: *ARPS Version 4.0 User's Guide*. Center for Analysis and Prediction of Storms, University of Oklahoma, 100 E. Boyd, Suite 1110, Norman, OK 73019.
- Xue et al., 1996: The 1996 CAPS operational testing period: real-time storm-scale NWP, Part II: Operational summary and sample predictions. *Preprints, 11th Conf on Num. Wea. Prediction.*, In press.