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# The AVOSS Winds Analysis System

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16. Abstract

Due to wake turbulence, aircraft operating in the terminal area must maintain minimum separations on instrument approaches. This can be a significant constraint on the airport arrival rate. NASA's Aircraft Vortex Spacing System (AVOSS) project was undertaken to develop the technology to dynamically change aircraft arrival separations based upon atmospheric conditions and an understanding of vortex behavior.

As part of this effort, a collection of meteorological sensor systems were deployed by Lincoln Laboratory and NASA at the Dallas/Fort Worth International Airport (DFW). These sensors, along with existing FAA and NWS systems, are used to create profiles of the atmosphere at the DFW airport. Scientific concept prototypes of the AVOSS was operated at Dallas/FT. Worth in the summer of 1997-2000.

The greatest challenge in preparing a single atmospheric profile for the wake vortex behavior models is merging data from sensors yielding different measurements of the same atmosphere. To meet this challenge, the AVOSS Winds Analysis System (AWAS) was developed to perform the data quality editing and fusion of sensor data.

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# ABSTRACT

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# 1. INTRODUCTION

The hazard that wake turbulence presents to following aircraft while operating in the terminal area requires the use of minimum separations between aircraft on final approach in weather that requires instrument approaches. This can be a significant constraint on the airport arrival rate. The National Aeronautics and Space Administration (NASA) Langley Research Center is developing the Aircraft Vortex Spacing System (AVOSS), designed to dynamically change aircraft arrival separations based upon atmospheric conditions and an understanding of vortex behavior [1, 2].

As part of this effort, a collection of meteorological sensor systems were deployed by Lincoln Laboratory and NASA Langley at the Dallas/Fort Worth International Airport [3[4]]. These sensors, along with existing FAA and NWS systems were used to create profiles of the atmosphere at the DFW airport. A scientific concept prototype of the AVOSS were operated at Dallas/FT. Worth in the summer of 1997. MIT Lincoln Laboratory set up an extensive suite of meteorological sensors, using two SODARs, a Doppler radar profiler, an instrumented 150 foot tower, and shorter towers in order to estimate the required atmospheric profiles. In addition, algorithms were developed to use the two FAA Terminal Doppler Weather Radars (TDWR) in Dallas as high resolution wind profilers, and to combine the wind data from the various sensors into a single wind profile.

The greatest challenge in preparing a single atmospheric profile for the wake vortex behavior models is merging data from sensors yielding different measurements of the same atmosphere. In post-processing, a human can interpret all of the data and create a profile based upon known sensor limitations and analysis of the data. However, the wake behavior models in the AVOSS system require real-time atmospheric profiles representing the state of the atmosphere [5]. To meet this requirement, an automated algorithm was developed to perform the data quality editing and fusion of sensor data. This algorithm, known as the AVOSS Winds Analysis System (AWAS), employs technology being used by the Integrated Terminal Weather System (ITWS) [6]. The final AWAS configuration provided atmospheric wind profiles representing thirty-minute means and variances at an update rate of five minutes. The AWAS processing was performed continuously at the AVOSS DFW field office.

## 2. WIND MEASUREMENT SYSTEMS

Atmospheric wind data are obtained in real-time by the AWAS from several data sources. These include a 150-foot instrumented tower, a Radian LAP-3000 profiler, two Remtech PA-2 sodars, and two nearby Terminal Doppler Weather Radars (TDWR). Most of these sensor systems are configured to operate at their optimum data collection parameters for wake vortex prediction and analysis.

The 150-foot instrumented tower is located on the south side of the DFW airport. The tower has five sensor packages that measure the wind speed and wind direction at a one-hertz rate, producing one-minute means every minute. The sensors are located on the tower at a height of 3, 10, 20, 32, and 43 meters. The tower data are of a very high quality and require very little data quality editing.

The Radian profiler, a 915MHz Doppler radar, is located on the north side of the DFW airport. It is operated at a 25-minute averaging period, with a 30-minute update rate. Because of the long averaging periond, the data from the profiler is on average 12.5 minutes old when it is received, and many small scale wind features that may affect individual wake behavior have been removed by the time averaging. The 25 minute wind averaging window allows for a five-minute Radio Acoustic Sounding System (RASS) averaging period prior to operation of the profiler wind mode. The profiler is configured to provide winds at a 97-meter vertical resolution from 145 meters to a maximum height measurement of 4,881 meters. The profiler performs quite well in the airport environment, except on days that are exceptionally clear, and requires very little data quality editing.

The Remtech PA-2 sodar is a Doppler sodar that operates at a range of frequencies near 2200Hz. There are two sodars operating at the DFW airport. The first is located on the north side of the airport, approximately 200 feet from the Radian LAP-3000 profiler. The second sodar is located on the south side of the DFW airport, approximately 200 feet from the 150-foot instrumented tower. The two sodars are operating at a 50-meter vertical resolution from 50 meters to a maximum height measurement of 600 meters, with an update rate of ten minutes. The actual maximum altitude does not always extend to 600 meters, for example when there is a strong temperature inversion below 600 meters. The 10 minute averaging period results in an observation that is in some sense 5 minutes old, and the averaging removes small scale wind features that may affect individual wake behavior.

The Remtech sodars perform better than expected in the high, airport noise environment; however, there are several phenomena that affect the performance of the sodars that require careful data quality editing. The sodars generally perform well between 100 and 400 meters. Ground clutter affects the data quality below 100 meters, and noise pollution affects measurements made above 400 meters. The most difficult data quality editing problem for the sodar is the occasional "ringing" that can occur when electromagnetic fields drown out the return signal. This causes the sodar to report winds much stronger than the real winds.

The TDWR is an operational FAA Doppler radar used to detect hazardous wind shear at the major airports in the US. In Dallas, there are two TDWRs: one providing coverage for the Dallas/Fort-Worth International Airport (DFW) and one covering the Dallas Love Airport (DAL). The DFW radar is located 22 kilometers to the northeast of the DFW airport. The DAL radar is located five kilometers to the northeast.

Since the TDWR data are not processed into vertical profiles by the ITWS, an algorithm was developed at Lincoln Laboratory to create vertical wind profiles for the the AVOSS program using the Gauss-Markov Theorem [7]. Profiles were created at the end of each volume scan from the TDWR, nominally every five minutes. The profiles have a 50-meter vertical resolution from 50 meters to 1,400 meters. The averaging period results in an observation lag of 2.5 minutes. The spatial smoothing is similar to a temporal smoothing of at least 30 minutes[1], again removing small scale wind features that may affect individual wake behavior.

The TDWR profiles provide consistent data during times of homogenous winds with numerous clear air reflectors. However, the TDWR can provide erroneous winds in a number of conditions. First, during times of nonhomogeneous winds, the radar can be influenced by wind fields not affecting the DFW airport. This is especially true during times of thunderstorm activity near the airport. Second, the TDWR performs poorly during times when there are few clear air reflectors. Finally, ground clutter can negatively affect the performance of the profile software, especially during periods of light winds.

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[1] The data collection varies from a minimum of 20km x 20km, to a maximum of 120km x 120km, depending on altitude and data density, with smaller windows at lower altitudes and when data are plentiful. Data towards the center of the data window are weighted more heavily.

# 3. SYSTEM OVERVIEW

The data from the different sensors provide information of different type, vector or single component, of different scale, of different quality, and for different vertical regions. No one sensor provides wind measurements of sufficient resolution, accuracy, or vertical extent in all weather conditions. To account for these differences, a statistical technique based on the Gauss-Markov Theorem is used to compute the profile of wind values. The mathematics of this technique are discussed more fully in [8]. This technique is used on each Doppler radar individually to generate wind profiles for each radar from the radial wind components measured by a Doppler radar. The technique is used again, this time on full wind vector data, to build the final wind profile from the measurements from the various sensors.

The requirements for the real-time AVOSS Winds Analysis System (AWAS) are as follows:

- The system will produce a profile for:
  - mean headwind and mean crosswind
  - standard deviation of headwind and crosswind
  - d(crosswind)/dz, or change in crosswind with altitude
- Each profile will provide these estimates from the ground up to 1400 m AGL.
- Each profile will have vertical resolution of 15 meters to 150 meters, and a vertical resolution of 50 meters above 150 m.
- Each estimate will represent a regional average (nominally equivalent to a 30 minute running average).

Figure 1 provides a high level overview of the process flow and the primary data flow for the AWAS. The various sensors are shown across the top along with their update rates, vertical resolution, and the maximum altitude of their data. The TDWR data are processed to construct profiles of mean wind, error variance of the mean wind, and wind field variability. The wind information from the TDWR processing, along with the wind information from the other sensors feed into a data buffer. The data buffer holds all the information for the previous 30 minutes. Data from the buffer collectively feed into the remaining processing functions every five minutes. The processing modules depicted in Figure 1 are:

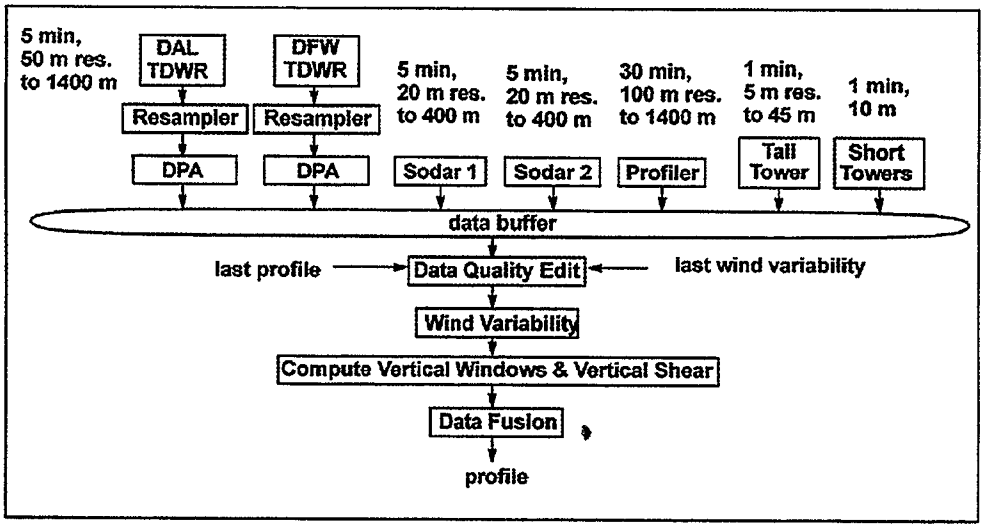


*Figure 1. Process flow and primary data flow for the AVOSS winds analysis system.*

1. **Resampler**: The resampler processes the radial wind components measured by a TDWR. The data are smoothed using a median filter to remove outliers. Additional data quality editing takes place to remove ground clutter contamination. Finally, the data are resampled onto a 2 km horizontal resolution, 50 m vertical resolution Cartesian grid.

2. **Doppler Profile Analysis (DPA)**: The DPA takes in a set of wind component estimates from a single resampler and produces a profile of estimates of the horizontal winds, estimates of the error variances for the wind estimates, and estimates of the wind field variability. The estimates of headwind and crosswind are extracted from the radial wind components using the Gauss-Markov Theorem, as are the estimates of the error variances. The wind field variability estimates are computed by comparing the radar measured radial velocities to the corresponding radial component of the estimated mean wind. The size of the region over which data are collected varies between 20 km and 60 km, depending on profile altitude when data are plentiful. When data are sparse, the window sizes can grow to a maximum of twice as large. At a range of 10 km from the radar, the beam width for a TDWR radar is 87 m, and the beam width scales linearly

with distance from the radar. However, the effective resolution of the profile is greater than the beam width of the most distant data, since the data nearer the radar are more heavily weighted. The DPA is only run at a given altitude, if there are at least a minimum number of observations on that level, nominally 40 observations.

3. **Data quality edit**: Each data value is judged by factors such as continuity in time and consistency with other sensors. The various factors are combined to give a final quality value, and a threshold is then applied.

4. **Wind variability**: The original wind variability module took in the various wind measurements and estimated the variation of the wind about the mean wind by simply computing the RMS difference between the various measured winds and the wind profile. The DPA wind variability estimates were not used, as their accuracy has not yet been verified. Because the sensor variance does not measure the variability in the fine scale winds, the final configuration simply used the tower variances of the one minute mean wind and extrapolated upwards.

5. **Compute vertical windows and vertical shear**: The compute vertical windows module computes the vertical extent of the data window to use for each analysis level. A byproduct of this is the vertical shear in the wind. At each analysis level, the data values in a vertical window are examined to see if they exhibit nearly linear shear by fitting a line to the data and checking the resulting fit to the data. The window is increased from a minimum to a maximum extent to find the largest extent over which the data show a linear shear. This extent is then the vertical window used for the given analysis level, and the slope of the associated line is the shear.

6. **Data fusion**: The data fusion module is based on the Gauss-Markov Theorem.

   It is important to the AVOSS performance that the wind estimates, plus or minus the reported errors, represent the range of wind conditions that a wake may encounter over the following 15 minutes or more. There are two factors that affect the reported errors in the mean wind. The first is the error in the estimate of the mean wind. The second is the wind variability, or more precisely, the variance of the wind about the mean. The measure of the standard deviation in the wind estimate as experienced by AVOSS is the square root of the sum of the error variance in the reported mean wind and the variance of the wind about the mean wind.

   In general, the DPA profiles and AWAS profiles are of high quality, although their accuracy has not yet been quantified. Figures 2 through 4 show examples of the AWAS data and profiles on three days. Separate profiles for the $u$ and $v$ wind components (east or crosswind and north or headwind, resp.) are given. The legend in the upper left corner of each figure shows the symbols used for the different sensors. The frequently updated tower data appear as a smear at the bottom of the profiles.

In Figure 2 all the measurements are in good general agreement and the output profile has good resolution, capturing several changes in the wind at different altitudes. In Figure 3 the profile again has good resolution, but the measurements are not in as good general agreement. In particular, the sodars provides erroneous values in the $u$ component. These sodar wind values have been discarded by the data quality editing indicated by their being displayed as black. This sort of behavior by the sodars is common, especially above 400 m. For this reason, sodar data above 400 m are always removed. The profile in Figure 4 also shows good resolution, but the observations show a greater spread in values than in Figures 2 and 3. The DPA values from the two separate radars are in very good agreement, but show a $u$ component a few m/s stronger than the profiler. Again, the sodars are providing poor quality data ($v$ component).

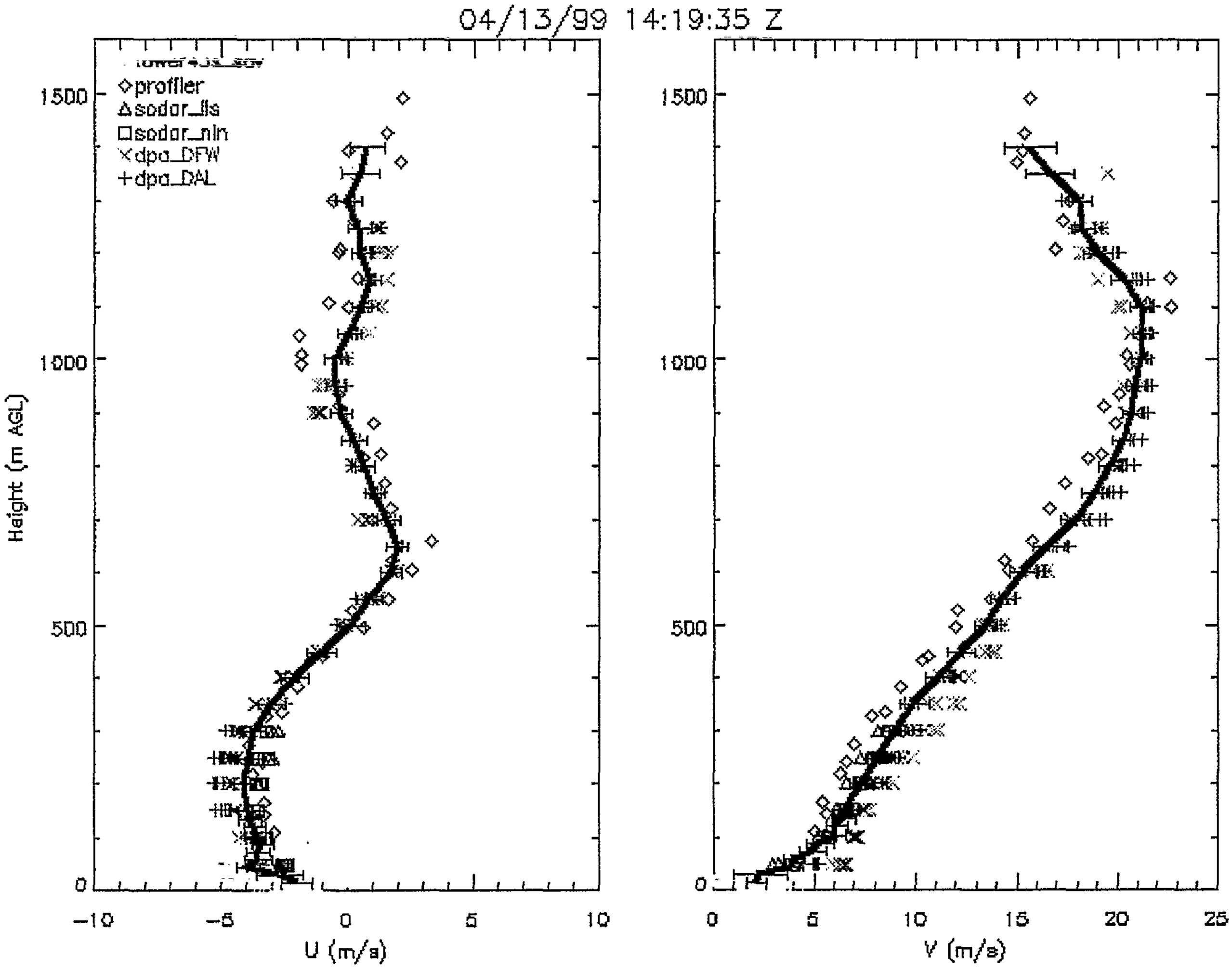


*Figure 2. Measurements and the AWAS Profile on April 13, 1999 at 14:19:35Z.*

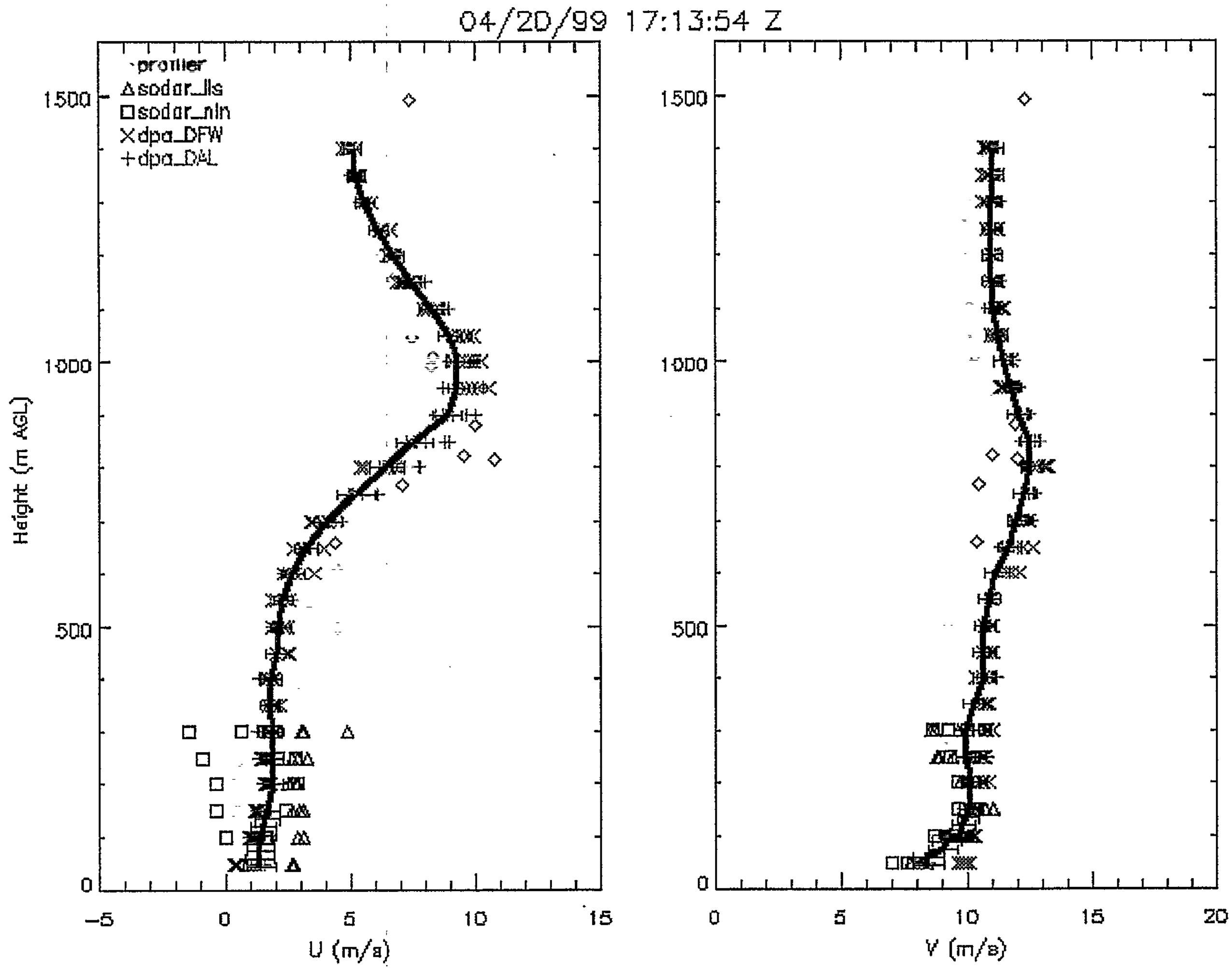


*Figure 3. Measurements and the AWAS profile on April 20, 1999 at 17:13:54Z.*

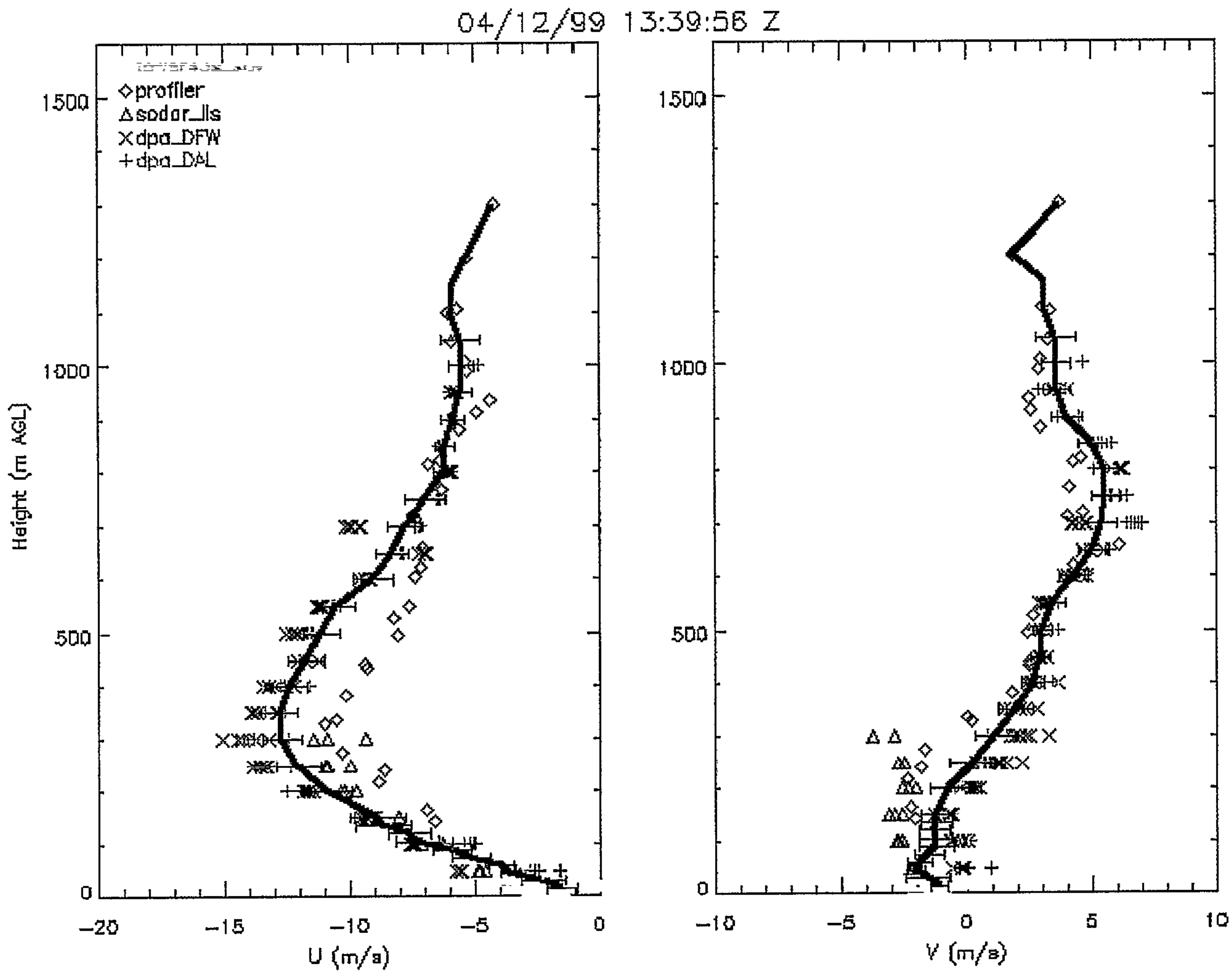


*Figure 4. Measurements and the AWAS profile on April 12, 1999 at 13:39:56Z.*

# 4. THE GAUSS-MARKOV ANALYSIS

The Gauss-Markov Theorem states that given the unbiased measurement vector **d**, and a linear transformation **A** from the unknown data vector **x** to the data vector **d** of the form $\mathbf{Ax} = \mathbf{d}$, the linear minimum variance estimate of **x** is given by:

(1) $\mathbf{x} = (\mathbf{A}^t\mathbf{C}^{-1}\mathbf{A})^{-1}\mathbf{C}^{-1}\mathbf{A}^t$, where **C** is the positive definite error covariance matrix.

Further more, the error covariance of the estimate **x** is given by:

(2) $(\mathbf{A}^t\mathbf{C}^{-1}\mathbf{A})^{-1}$

We take the error covariance matrix **C** to have the form **S** + **D**, where **S** is the sensor error matrix and **D** is the displacement error matrix. The sensors are assumed to be independent of each other so **S** is diagonal, with the (i,i) entry set to the sensor error variance and the other entries set to zero. In the original AWAS each sensor value was used only once and persisted through a feedback of the last profile as an initial estimate, in which case the (i,j) entry in the matrix **S** is zero, the error correlation for two independent observations. In the final AWAS, this was changed so that the data are explicitly stored in a buffer for 30 minutes, so that in general more than one observation from a given sensor is used. In this case the (i,j) entry, where observation i and observation j are from the same sensor should, not be zero. The error due to this discrepency is that sensors with rapid updates carry more weight than warrented. To account for this, the sensor error for the observations from a given sensor are divided by the nominal number of observations from that sensor in the 30 minute time window. This is approximately the same as assuming the error correlation from consecutive observations from the same sensor have correlation equal to one. A more rigorous treatment of this error could be had by modeling the correlation in errors from repeat observations.

The displacement error correlation matrix accounts for two errors. The first error arrises from the fact that observations are not located at the profile location, that is the observations have a displacement relative to the profile location. We take this error to have the form in equation 3, where the distance is between the observation and profile location. These values form the diagonal elements of **D**.

(3) displacement error = K1x horizontal distance + K2 x vertical distance + K3 x age.

The off-diagonal elements are formed from the diagonal elements using equation 4.

(4) $D(i,j) = \sqrt{D(i,i)D(j,j))}$ correlation(i,j),

where the correlation function is based on the distance between the two observations and is given by equation 5.

(5) correlation(i,j) = exp-(K1x horizontal distance + K2 x horizontal distance + K3 x age)

So the error correlation is one for observations that are colocated and decreases to zero as the observation move far apart.

## 4.1 THE DOPPLER PROFILE ANALYSIS

The Doppler Profile Analysis (DPA) takes in radial velocity data from a single radar and produces a vertical profile of (u,v) wind vectors with values every 50 meters. In the application of the Gauss-Markov Theorem, the unknown vector is (u,v) at a fixed altitude, and equation (1) has the form in equation 6. The initial estimate to start is (0,0) and is the value from the previous DPA after the algorithm is running.

$$(6) \quad \begin{bmatrix} 1 & 0 \\ 0 & 1 \\ \cos(\theta_1) & \sin(\theta_1) \\ \bullet & \bullet \\ \bullet & \bullet \\ \bullet & \bullet \\ \cos(\theta_n) & \sin(\theta_n) \end{bmatrix} \begin{pmatrix} u \\ v \end{pmatrix} = \begin{bmatrix} u_{initial} \\ v_{initial} \\ RadialVel_1 \\ \bullet \\ \bullet \\ \bullet \\ RadialVel_n \end{bmatrix}$$

The radial velocities are preprossesed through a median filter with approximately a 1 km x 1 km footprint, and placed on a 2 km grid. For the grid level at altitude Z, all radial velocities with altitudes between Z-25 m and Z+25 m are used. The radial velocities are checked against the radial velocity as computed from the last profile. If these two values match to within a tolerance, the velocity is used. The tolerance is given by equation 7.

(7) tolerance = min ( max( min tolerance, 2$\sigma$), max tolerance),

where $\sigma$ is the RMS of difference between the measured radial velocities in the last run of the DPA and the corresponding radial velocities computed from the last profile. That is, $\sigma$ represents the variability of the radar data. The min tolerance value keeps the tolerance value from going to zero, in which case no data are kept, and the max tolerance value keeps the tolerance from getting so large during times of bad radar data that all data are kept. The profile of $\sigma$ values is output, along with the profile of (u,v) and the profile of u and v variance (see equation 2).

# 5. DATA QUALITY EDITING

Meteorologists familiar with the data use many factors to determine if an observation is valid. These include such factors as the vertical continuity of the data during a consensus period, the temporal continuity of a sensor's observations, various parameters provided by the sensors such as noise level and number of returns, a visual inspection of the data in comparison with observations from other sensors at the same altitude, and the past performance of the particular sensor. Given this information, it was decided to use a fuzzy logic approach in the data quality editing scheme.

To employ fuzzy logic, a series of "detectors" are defined for each sensor. For each observation, the detector performs a predefined set of operations and then applies a scoring function to the output of the operations. From the template function, a value between zero and one is produced that is representative of the quality of the observation, based upon a particular detector. Once each detector produces this value, known as an "interest" value, all of the interest values are averaged to produce a final interest value for an observation. The final step is to apply a threshold to each interest value, filtering out data with an interest value less than the threshold.

Six detectors are used in determining the interest value for an observation. These detectors are:

1) vertical continuity,

2) temporal continuity,

3) buddy check,

4) previous AWAS comparison,

5) historical performance, and

6) anticipation.

Detectors specific to particular sensors are also defined. For the TDWR data, a detector is defined to check the number of points used at each level. For the sodar data, three detectors are used. These are: noise value, number of validations, and number of spurious returns. By defining the detectors that best apply to individual sensors, an interest value is obtained.

The "vertical continuity" detector assumes that all data from an individual sensor during each update should exhibit linear behavior in the vertical. At each observation, a vertical search window is defined that is sensor dependent. All data within the window are then fit to a line, and the root mean square (RMS) residual is computed using all of the observations. Using the line fit, an estimate is made of the wind at the altitude of the observation. Finally the difference between the observation and the estimate is computed. Dividing the difference by the fit residual produces the final value to be used in the interest function. The scoring function for the vertical continuity detector is shown in Figure 5.

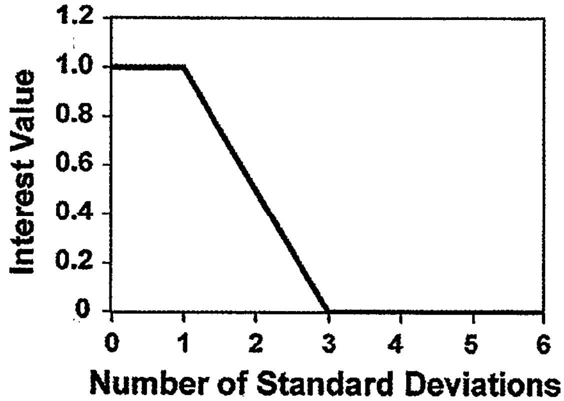


*Figure 5. Vertical Continuity Detector Scoring Function.*

The resultant interest value for one standard deviation from the estimate would be a value of 1.0, indicating the observation is of good quality. The resultant interest value for two standard deviations would be 0.5, indicating no opinion, and three standard deviations would yield a value of 0.0, indicating invalid data.

The "temporal continuity" detector uses the same method described in the vertical continuity detector; however, the data used in the detector and the scoring function are different. For the temporal continuity detector, a sensor-specific time history of data is used in the linear fit, typically on the order of the last six consensus periods. For the sodars, operating at a ten-minute average, the last sixty minutes of data will be used. The interest function is shown in Figure 6.

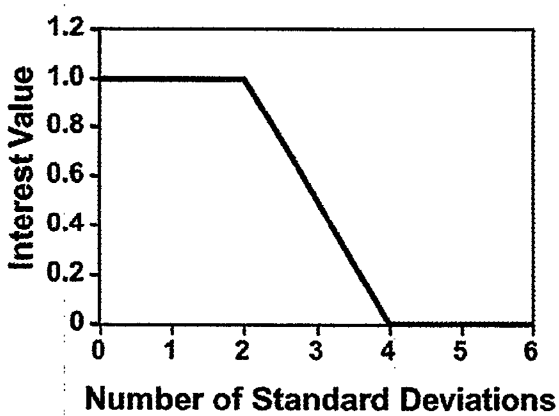


*Figure 6. Temporal Continuity Detector and Buddy Check Detector Scoring Functions.*

The "buddy check" detector begins by collecting all sensor data within a specified altitude and time range of an observation, excluding observations from the same sensor. Then the same method as in the vertical and temporal continuity checks is applied to produce an interest value. The buddy check detector scoring function is also shown in Figure 6.

The "previous AWAS comparison" detector determines the nearest AWAS altitude to the observation of interest and compares the last AWAS profile at that altitude with the observation. This detector uses the simplistic statistical approach previously mentioned to determine the number of standard deviations from the mean that the current observation lies. The scoring function shown in Figure 7 is then applied to produce the interest value. The previous AWAS comparison detector scoring function allows for a greater error in the observation due to errors that may have existed in the last AWAS profile.

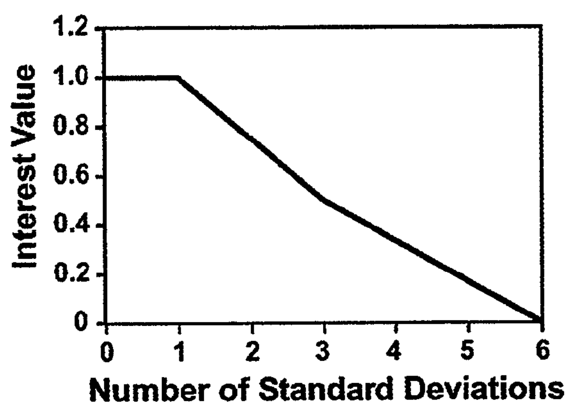


*Figure 7. Previous AWAS Comparison Detector Scoring Function.*

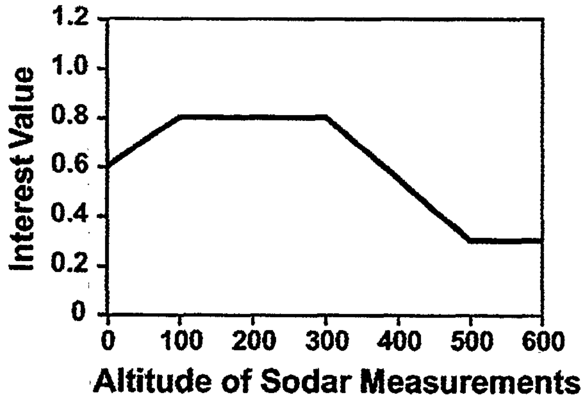


*Figure 8. Historical Detector Scoring Function.*

The "historical" detector uses sensor-specific scoring functions that provide an interest value that is representative of the subjective analysis that meteorologists would apply about knowledge of past sensor performance. For instance, Figure 8 shows the historical detector scoring function for the two sodars. Between 100 and 300 meters, an interest value of 0.8 is assigned to the detector. This can be thought of as setting the interest value to 0.8, because 80% of the time the sodar produces good quality data at this altitude for this sensor. From 500 to 600 meters the sodar produces valid data only 30% of the time, hence the low interest value of 0.3. All sensors are configured with different historical detector scoring functions. For instance, the 150-foot instrumented tower has a flat interest template of 1.0 for all altitudes.

The final general-use detector is the "anticipation" detector. This detector assumes that the performance of a sensor at each observation is unlikely to change with time. For this detector, the interest value is set to the final interest value for this sensor at this altitude from the last observation.

The sensor-specific detectors use information provided by a sensor that are related to data quality. For the TDWR sensors, this information is the number of data points used in the observation. Figure 9 is the scoring function for the TDWR. For the sodars, this information is the noise level, the number of validations, and the number of spurious returns on each beam. Figure 10 is the scoring function for the sodar noise detector. The sodar number of validations and spurious return detectors are not shown.

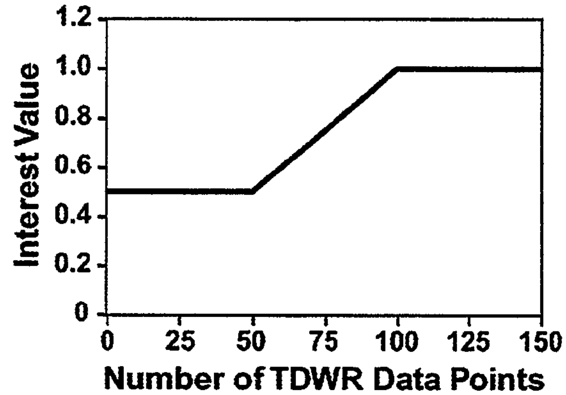


*Figure 9. TDWR Data Points Detector Scoring Function*

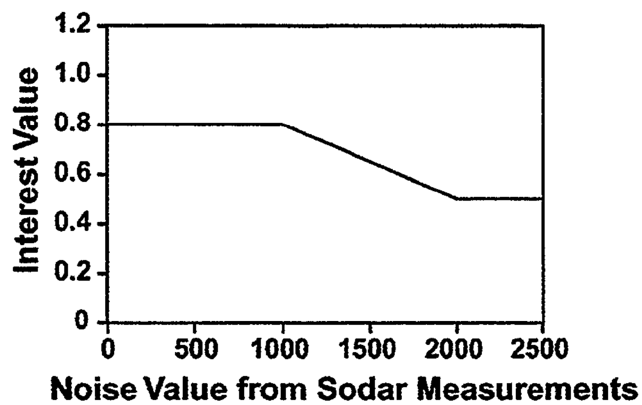


*Figure 10. Sodar Noise Value Detector Scoring Function.*

# 6. PERFORMANCE ISSUES

A detailed comparison of the AWAS profiles to independent observations was not performed. The system was observed carefully, and in general performed the job of producing accurate profiles. The use of the Gauss-Markov Theorem for winds analysis in another application is validated in[9]. However, there are several performance issues that were noted.

The DPA profiles generated from data from the two independent TDWRs generally agree very closely. Since the data are independent, agreement is taken to imply that the profiles accurately represent the wind profile at the scales that are captured by this product. The agreement breaks down when there is convective weather within the data collection range due to the fact that the uniform horizontal wind hypothesis does not hold. This is expected behavior. It is expected that AVOSS will not operate with convective conditions within 15 nmi. of the airport because it is known that the wind conditions will not be persistent enough to count on persistent wake behavior. Nonetheless, it would be helpful for the system to recognize convective situations so that improved data quality editing of the DPA can be performed. This recognition could come from the TDWR reflectivity data, from a co-located ITWS, or from the TDWR velocity field by directly measuring the degree to which the uniform wind hypothesis holds.

The orginal AWAS updated the profile by using new observations to modify the existing profile. Generally, this results in a set of observations where each is from a different sensor, so the error covariance matrix uses the assumption that observational errors are uncorrelated. Late in the experiment, the AWAS was changed to average observations in an explicit 30 minute time window. Now sensors provide multiple observations, and for best performance the software should be updated so that observations from the same sensor are assumed to have correlated error. The issue is that without this change, observations from rapidly updating sensors are given too much weight. This is currently addressed in an ad hoc way by simply increasing the assumed sensor error variance for rapidly updating sensors. This ad hoc method does not result in a true minimum error variance solution.

The wind profile tended to have a kink at the top of the tower, as the profile transitions from great amounts of tower data to the more sparse data aloft. This is due to the fact that the tower data are not considered to have correlated errors. Again, modifying the error matrix to account for the error correlation in measurements from the same sensor should help.

The current error variance values are estimated from the tower observations. Since wakes live on the order of a 30 seconds to two minutes, transient features that exist for only a few seconds will not significantly affect wake transport, and these features should not influence the wind variance estimates. Features that last approximately one minute or longer should influence the wind variance estimates. Unfortunately, with the exception of the tower data, the wind observations do not contain wind features that exist for less than several minutes to tens of minutes, depending on the sensor, and so the observations above the tower can not be used in the wind vaiance estimates above the tower. In principle the Doppler radar data could be used, but we found that the TDWR data contain too much noise to provide reliable estimates. We did not have time to fully investigate the Doppler profiler data.

# APPENDIX A
## NOMINAL AWAS PARAMETER VALUES

```
INTEREST_THRESH 0.70        # qc-control threshold applied to combined quality value

TIMER_INTERVAL  300     # time between analyses (seconds)
#
ANAL_RES     6     # number of different analysis (vertical) resolutions
ANAL_RES1      15      # analysis resolution (meters)
ANAL_RES2      15
ANAL_RES3      15
ANAL_RES4      15
ANAL_RES5      15
ANAL_RES6    50
#
START_WINDOW1  15
STOP_WINDOW1   45
START_WINDOW2  60
STOP_WINDOW2   60
START_WINDOW3  75
STOP_WINDOW3      90
START_WINDOW4 105
STOP_WINDOW4  120
START_WINDOW5 135
STOP_WINDOW5  135
START_WINDOW6 150
STOP_WINDOW6 1400

MIN_VERT_DIST_THRESH1   30.0 # starting vertical window size (m) to consider an obs for a given analysis level.
MAX_VERT_DIST_THRESH1   30.0 # maximum vertical window size. (m)
VERT_DIST_STEP1            10.0 # how much to increase vert window with each pass ...
MIN_VERT_DIST_THRESH2   40.0 # starting vertical window size (m) to consider an obs for a given analysis level.
MAX_VERT_DIST_THRESH2   40.0 # maximum vertical window size. (m)
VERT_DIST_STEP2            10.0 # how much to increase vert window with each pass ...
MIN_VERT_DIST_THRESH3   80.0 # starting vertical window size (m) to consider an obs for a given analysis level.
MAX_VERT_DIST_THRESH3   80.0 # maximum vertical window size. (m)
VERT_DIST_STEP3            10.0 # how much to increase vert window with each pass ...
MIN_VERT_DIST_THRESH4  100.0 # starting vertical window size (m) to consider an obs for a given analysis level.
MAX_VERT_DIST_THRESH4  100.0 # maximum vertical window size. (m)
VERT_DIST_STEP4            10.0 # how much to increase vert window with each pass ...
```

```
MIN_VERT_DIST_THRESH5  130.0 # starting vertical window size (m) to consider an obs for a
given analysis level.
MAX_VERT_DIST_THRESH5  130.0 # maximum vertical window size. (m)
VERT_DIST_STEP5         10.0 # how much to increase vert window with each pass ...
MIN_VERT_DIST_THRESH6  100.0
MAX_VERT_DIST_THRESH6  200.0
VERT_DIST_STEP6        50.0
#
VERT_COEF1   0.1        # distance weighting coefficient
HORIZ_COEF1  0.000075   # distance weighting coefficient
AGE_COEF1    0.003      # age weighting coefficient
VERT_COEF2   0.1
HORIZ_COEF2  0.000075
AGE_COEF2    0.003
VERT_COEF3   0.1
HORIZ_COEF3  0.000075
AGE_COEF3    0.003
VERT_COEF4   0.1
HORIZ_COEF4  0.000075
AGE_COEF4    0.003
VERT_COEF5   0.1
HORIZ_COEF5  0.000075
AGE_COEF5    0.003
VERT_COEF6   0.1
HORIZ_COEF6  0.000075
AGE_COEF6    0.003
VERT_COEF7   0.1
HORIZ_COEF7  0.000075
AGE_COEF7    0.003
VERT_COEF8   0.1
HORIZ_COEF8  0.000075
AGE_COEF8    0.003
VERT_COEF9   0.1
HORIZ_COEF9  0.000075
AGE_COEF9    0.003
VERT_COEF10  0.1
HORIZ_COEF10 0.000075
AGE_COEF10   0.003
VERT_COEF11  0.05
HORIZ_COEF11 0.000075
AGE_COEF11   0.003
VERT_COEF12  0.05
HORIZ_COEF12 0.000075
AGE_COEF12   0.003
VERT_COEF13  0.05
HORIZ_COEF13 0.000075
AGE_COEF13   0.003
VERT_COEF14  0.05
```

HORIZ_COEF14 0.000075
AGE_COEF14 0.003
VERT_COEF15 0.05
HORIZ_COEF15 0.000075
AGE_COEF15 0.003
VERT_COEF16 0.05
HORIZ_COEF16 0.000075
AGE_COEF16 0.003
VERT_COEF17 0.05
HORIZ_COEF17 0.000075
AGE_COEF17 0.003
VERT_COEF18 0.05
HORIZ_COEF18 0.000075
AGE_COEF18 0.003
VERT_COEF19 0.05
HORIZ_COEF19 0.000075
AGE_COEF19 0.003
VERT_COEF20 0.05
HORIZ_COEF20 0.000075
AGE_COEF20 0.003
VERT_COEF21 0.05
HORIZ_COEF21 0.000075
AGE_COEF21 0.003
VERT_COEF22 0.05
HORIZ_COEF22 0.000075
AGE_COEF22 0.003
VERT_COEF23 0.05
HORIZ_COEF23 0.000075
AGE_COEF23 0.003
VERT_COEF24 0.05
HORIZ_COEF24 0.000075
AGE_COEF24 0.003
VERT_COEF25 0.05
HORIZ_COEF25 0.000075
AGE_COEF25 0.003
VERT_COEF26 0.05
HORIZ_COEF26 0.000075
AGE_COEF26 0.003
VERT_COEF27 0.05
HORIZ_COEF27 0.000075
AGE_COEF27 0.003
VERT_COEF28 0.05
HORIZ_COEF28 0.000075
AGE_COEF28 0.003
VERT_COEF29 0.05
HORIZ_COEF29 0.000075
AGE_COEF29 0.003
VERT_COEF30 0.05

```
HORIZ_COEF30 0.000075
AGE_COEF30   0.003
VERT_COEF31  0.05
HORIZ_COEF31 0.000075
AGE_COEF31   0.003
VERT_COEF32  0.05
HORIZ_COEF32 0.000075
AGE_COEF32   0.003
VERT_COEF33  0.05
HORIZ_COEF33 0.000075
AGE_COEF33   0.003
VERT_COEF34  0.05
HORIZ_COEF34 0.000075
AGE_COEF34   0.003
VERT_COEF35  0.05
HORIZ_COEF35 0.000075
AGE_COEF35   0.003
#
FIT_THRESHOLD           0.5
#
MAX_OBS_AGE       1800    # discard any obs older than 30 minutes...
#
TOWER_SURFACE_FACTOR    0.2 # surfaces factors deal with what weight to give observations...
PROFILER_SURFACE_FACTOR 0.2 # ... based on the amplitude of the observation
SODAR_SURFACE_FACTOR    0.2
DPA_SURFACE_FACTOR      0.2
RADAR_SURFACE_FACTOR    0.2
MIN_SIGMA_THRESH        1.0
SIGMA_MULT_VAL          2.5
DEFAULT_TOWER_VAR       1.0
DEFAULT_SODAR_VAR       1.0
DEFAULT_PROFILER_VAR    1.0
DEFAULT_DPA_VAR         1.0
```

# APPENDIX B
# DPA PARAMETERS

```
wv_radar1_variance          4.0
wv_radar1_qc_rms_multi       4.0
wv_radar1_min_level_obs     50
wv_radar1_min_quad_obs       10
wv_radar1_cl_thresh_mult     0.20
wv_radar1_cl_thresh_min      0.50
wv_radar1_cl_thresh_max       3.00

##########################################################################
#
# The following information is the information used by dpa to
#    determine the error coefficients for each level.
#
##########################################################################
#
dpa_level1_height        50
dpa_level1_hor_coeff     0.00004
dpa_level1_age_coeff     0.003
dpa_level1_min_window     5
dpa_level1_max_window     10
dpa_level2_height        100
dpa_level2_hor_coeff     0.00004
dpa_level2_age_coeff     0.003
dpa_level2_min_window     5
dpa_level2_max_window     10
dpa_level3_height        150
dpa_level3_hor_coeff     0.00004
dpa_level3_age_coeff     0.003
dpa_level3_min_window     5
dpa_level3_max_window     10
dpa_level4_height        200
dpa_level4_hor_coeff     0.00004
dpa_level4_age_coeff     0.003
dpa_level4_min_window     5
dpa_level4_max_window     10
dpa_level5_height        250
dpa_level5_hor_coeff     0.00004
dpa_level5_age_coeff     0.003
dpa_level5_min_window     5
dpa_level5_max_window     10
dpa_level6_height        300
dpa_level6_hor_coeff     0.00004
```

```
dpa_level6_age_coeff     0.003
dpa_level6_min_window     5
dpa_level6_max_window     20
dpa_level7_height       350
dpa_level7_hor_coeff     0.00004
dpa_level7_age_coeff     0.003
dpa_level7_min_window     5
dpa_level7_max_window     20
dpa_level8_height       400
dpa_level8_hor_coeff     0.00005
dpa_level8_age_coeff     0.003
dpa_level8_min_window     5
dpa_level8_max_window     20
dpa_level9_height       450
dpa_level9_hor_coeff     0.00005
dpa_level9_age_coeff     0.003
dpa_level9_min_window     5
dpa_level9_max_window     20
dpa_level10_height       500
dpa_level10_hor_coeff     0.00005
dpa_level10_age_coeff     0.003
dpa_level10_min_window     10
dpa_level10_max_window     20
dpa_level11_height       550
dpa_level11_hor_coeff     0.00005
dpa_level11_age_coeff     0.003
dpa_level11_min_window     10
dpa_level11_max_window     20
dpa_level12_height       600
dpa_level12_hor_coeff     0.00006
dpa_level12_age_coeff     0.003
dpa_level12_min_window     10
dpa_level12_max_window     20
dpa_level13_height       650
dpa_level13_hor_coeff     0.00006
dpa_level13_age_coeff     0.003
dpa_level13_min_window     10
dpa_level13_max_window     20
dpa_level14_height       700
dpa_level14_hor_coeff     0.00006
dpa_level14_age_coeff     0.003
dpa_level14_min_window     10
dpa_level14_max_window     20
dpa_level15_height       750
dpa_level15_hor_coeff     0.00006
dpa_level15_age_coeff     0.003
dpa_level15_min_window     10
dpa_level15_max_window     20
```

dpa_level16_height 800
dpa_level16_hor_coeff 0.00006
dpa_level16_age_coeff 0.003
dpa_level16_min_window 10
dpa_level16_max_window 20
dpa_level17_height 850
dpa_level17_hor_coeff 0.00006
dpa_level17_age_coeff 0.003
dpa_level17_min_window 10
dpa_level17_max_window 20
dpa_level18_height 900
dpa_level18_hor_coeff 0.00006
dpa_level18_age_coeff 0.003
dpa_level18_min_window 10
dpa_level18_max_window 20
dpa_level19_height 950
dpa_level19_hor_coeff 0.00006
dpa_level19_age_coeff 0.003
dpa_level19_min_window 10
dpa_level19_max_window 20
dpa_level20_height 1000
dpa_level20_hor_coeff 0.00006
dpa_level20_age_coeff 0.003
dpa_level20_min_window 15
dpa_level20_max_window 30
dpa_level21_height 1050
dpa_level21_hor_coeff 0.00006
dpa_level21_age_coeff 0.003
dpa_level21_min_window 15
dpa_level21_max_window 30
dpa_level22_height 1100
dpa_level22_hor_coeff 0.00006
dpa_level22_age_coeff 0.003
dpa_level22_min_window 15
dpa_level22_max_window 30
dpa_level23_height 1150
dpa_level23_hor_coeff 0.00006
dpa_level23_age_coeff 0.003
dpa_level23_min_window 15
dpa_level23_max_window 30
dpa_level24_height 1200
dpa_level24_hor_coeff 0.00006
dpa_level24_age_coeff 0.003
dpa_level24_min_window 15
dpa_level24_max_window 30
dpa_level25_height 1250
dpa_level25_hor_coeff 0.00006
dpa_level25_age_coeff 0.003

| | |
|---|---|
| dpa_level25_min_window | 15 |
| dpa_level25_max_window | 30 |
| dpa_level26_height | 1300 |
| dpa_level26_hor_coeff | 0.00006 |
| dpa_level26_age_coeff | 0.003 |
| dpa_level26_min_window | 15 |
| dpa_level26_max_window | 30 |
| dpa_level27_height | 1350 |
| dpa_level27_hor_coeff | 0.00006 |
| dpa_level27_age_coeff | 0.003 |
| dpa_level27_min_window | 15 |
| dpa_level27_max_window | 30 |
| dpa_level28_height | 1400 |
| dpa_level28_hor_coeff | 0.00006 |
| dpa_level28_age_coeff | 0.003 |
| dpa_level28_min_window | 15 |
| dpa_level28_max_window | 30 |

# GLOSSARY

| | |
|---|---|
| AVOSS | Aircraft Vortex Spacing System |
| DAL | Dallas Love Airport |
| DFW | Dallas Fort-Worth International Airport |
| DPA | Doppler Profile Analysis |
| ITWS | Integrated Terminal Weather System |
| NASA | National Aeronautics and Space Administration |
| RASS | Radio Acoustic Sounding System |
| RMS | root mean square |
| TDWR | Terminal Doppler Weather Radar |

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