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Atmospheric Boundary Layer Wind Data During the Period January 1, 1998 Through January 31, 1999 at the Dallas-Fort Worth Airport

Volume 1: Quality Assessment

J. Allen Zak
Vigyan, Inc., Hampton, Virginia

William G. Rodgers, Jr.
Lockheed Martin Engineering and Sciences, Hampton, Virginia

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Table of Contents

List of Figures

List of Tables

1.0 Introduction

The NASA Langley Research Center has been working with Ames Research Center on ways to increase capacity at major airports. The Aircraft Vortex Spacing System (AVOSS) is a program to demonstrate the potential for reduced spacing between landing and departing aircraft by predicting demise and movement of aircraft wakes and when they would cease to be a potential hazard to following aircraft (ref. 1). To be effective in wake vortex prediction the AVOSS algorithms require accurate wind input through the atmospheric lower boundary layer. Since a field deployment in late 1997, atmospheric boundary layer winds have been observed from a number of sensor systems and technologies in and around the Dallas-Fort Worth (DFW) Airport. They include two Doppler sodars, one at the north end of the airport and one at the south end, a UHF radar profiler, instrumented towers and Terminal Doppler Weather Radars (TDWRs). More complete descriptions of the sensors and their capabilities are provided in reference 2. An algorithm developed by MIT Lincoln Laboratory combined all observations into a single 15 minute or 30 minute mean wind profile and included an estimate of the variance at fixed altitudes. It is this profile process, herein called the AVOSS Winds Analysis System (AWAS), that is used by AVOSS for wake vortex predictions.

The AWAS data combination process, which is also described in reference 2, presented many challenges in its real-time implementation because of differences in input sensor technologies, averaging periods, locations, and sensitivities to precipitation, among other things. This was the first attempt to automate the production of a consensus profile in real-time. It is expected to be an evolutionary process with improvements provided as problems are identified. The quality of the AVOSS prediction depends heavily on the quality of the AWAS solution, which in turn depends on the quality of the sensor inputs. It is desired to run the AVOSS code on archived data for the period January 1998 through January 1999 when AWAS profiles are available and when they are judged to be reasonably representative of the winds over the airport for the time in question. Volume 1 of this report describes the Quality Analysis (QA) process applied to the AWAS wind profiles and the availability of useable data for AVOSS studies. Volume 2 documents the file processing and sorting accomplished for AVOSS application and presents files which can be automatically selected based on user-specified criteria.

2.0 Sensor Availability

Table 1 shows the percentage of all possible observations that were received and contained entries other than bad (or missing) values identified by "9999" in the files, from each sensor at the Dallas Fort Worth Airport. Every altitude up to 600 m and every time counted as an observation. Each system had certain capabilities and limitations. The sodars had to deal with a high noise environment at one of the busiest airports in the country. Sodars must be able to find and interpret a reflected acoustic signal from the atmosphere. There were times during strong temperature inversions when there was insufficient reflected signal strength to provide a valid wind measurement. Many of the sodar wind profiles above about 300 m were questionable. Also, heavy rain and strong wind adversely affected the sodar measurements. The percentage of non-9999 observations for the sodar at the north site ranged from 61 to 94 with the average of 79%. The 61% occurred in September. The corresponding range at the south sodar location was 64 to 91 with average for the 13 months of 82%. The minimum occurred in the south sodar in December. The radar profiler was affected by moderate or greater precipitation and by inversions as well. There were 95,040 altitudes and times potentially available in the analysis period (13 months), of which 76,276 were received with wind solutions for an overall percentage of 80. The towers were reliable sources of wind measurements from standard wind-vane anemometers when they reported. Unfortunately, a communications cable was cut and there were only 3 days of tower data received in August 1998 and only 17 days in September 1998. These missing observations account for the overall relatively low data receipt percentage (83) for the 13 months under study. The highest altitude available from the tower was 43 m. AVOSS requires wind inputs to 600 m. The TDWRs were separated by about 15 km, the closest at 5 km east of the north end of the airport runways and the farthest 20 km to the northeast. They were not adversely affected by precipitation, but were sensitive to the amount of scatterers (particulates) in the volume of air. Clean, dry, cold air in the winter had the most significant effect when wind solutions for large parts of the day were missing. The low average percentages for either TDWR (47% for DAL and 52% for DFW) was the result of missing data in the winter when there were not enough scatterers in the atmosphere for the Doppler processor to reach a wind solution.

Table 1: Percentage of wind data received other than 9999 (or missing) for each sensor system at the Dallas-Fort Worth Airport during the period January 1998 through January 1999.

Month	AWAS	Radar Profiler	N. Sodar	S. Sodar	43 m Tower	DAL TDWR	DFW TDWR
Jan 98	56	85	76	86	100	39	59
Feb	95	77	83	91	75	21	16
Mar	72	41	68	64	66	23	18
Apr	76	78	87	84	97	55	55
May	94	88	94	88	97	65	68
Jun	100	93	88	87	100	67	72
Jul	100	86	65	88	85	66	70
Aug	95	86	62	84	6	68	80
Sep	90	77	61	72	52	60	68
Oct	100	85	79	82	100	63	72
Nov	100	86	70	81	100	50	61
Dec	98	84	66	74	100	24	23
Jan 99	100	77	69	81	100	10	13
ALL	89	80	79	82	83	47	52

Lowest receipt frequencies of 10 and 13 percent for DAL and DFW, respectively, occurred in January 1999 when it was cold and relatively dry with only two days with reported precipitation. The TDWRs also covered a larger horizontal geographic area than the other sensors. Several times the TDWRs indicated different wind solutions from the other sensors at the airport. Finally, there were occasions when the AWAS profiles were missing. Overall, there were 474,288 AWAS wind solutions potentially available and 419,971 provided. Some of the missing profiles were the result of testing new algorithms designed to produce better wind profiles. Seasonable biases in the sensor availability are readily apparent in Table 1. The radar profiler, sodars, and TDWRs all had far fewer valid wind solutions during the colder and rainy winter months. Their performance was much better in May through November. Not apparent in table 1, however, are problems with the sodars when average wind speeds are greater than about 15 m/s. During those times, the volume of air in the sample space moves too far to be detected at the receivers. There is also a problem with wind noise near the surface at the sodars. Precipitation also adversely affects the radar profiler and sodars. Those occurrences are detected and noted during the Quality Assessment Process discussed next.

3.0 Quality Assessment Process

The judgment on the quality of the AWAS solution was a multi-step process as shown in Figure 1.

Although the process leading to a judgment of specific U and V wind-component profiles was subjective, there were a number of guidelines and criteria followed for consistency and reproducibility.

3.1 Wind Input

First, there was an analysis of the availability and quality of the winds available from each of the sensor systems used as input to AWAS. Wind vectors were plotted for each sensor system separately and for the highest resolution available. For the sodars this was a 5 or 10 minute average and 20 to 50 meter vertical interval. Sodar winds were output every 5 or 10 minutes. The radar profiler produced a 25 minute average every 30 minutes at about 100 m vertical intervals. The towers provided 1 minute averages at various fixed levels every minute. For the TDWRs, 5 minute average winds were received every 5 minutes at 50 meter vertical intervals (ref. 2). Each plot contained a wind vector for each altitude and time measured. Typically, a 12 hour time period fit on a plot page so that changes over half a day could be seen at a glance. The DFW Airport surface weather observation was available to indicate periods of precipitation, thunderstorms, or fronts. Weather maps from National Weather Service analyses and aircraft observations from the Aeronautical Radio, Inc. (ARINC), Communications, Addressing and Reporting System) known as ACARS were often used to confirm sensor system behavior.

3.2 Sensor QA-1

Changes in wind direction of 50 degrees or speed of 5 m/s over altitude and time periods of 50 meters and 10 minutes, respectively, that were not associated with frontal passages, outflow boundaries, or small-scale pressure systems, were grounds for flagging the individual sensor input data (QA-1). These flags were annotations on the hard copy sensor system plots.

3.3 Sensor QA-2

Sensor wind vectors were converted to East-West (U) and north-south (V) components and compared to one another and to other weather information to confirm or refute wind changes. Another flag was identified if any sensor wind-component profile differed from the consensus mean by 5 m/s or greater (QA-2).

3.4 AWAS QA

Finally, there was an analysis of how well the AWAS software generated a wind profile and variance from the various wind inputs. The latter process involved the examination of plots for the wind components of all the sensors with the AWAS solution and variance superimposed. Since the main runways at DFW were oriented north-south, the U and V wind components were essentially cross winds and head winds, respectively. These plots were available every 15 minutes from January 1, 1998 to June 14, 1998, then at 30-minute intervals thereafter during times of AWAS availability. Only the period from 1200 to 0400 UTC (6 AM to 10 PM CST) was considered. The wind components from all sensors for the time nearest to the 15 or 30 minute analysis time were plotted and compared with the AWAS solution and variances. Software was used that allowed the manual or automatic cycling of times in each day. In this way the analyst could observe trends in the wind profiles. First (and obviously) there had to be an AWAS solution available. For a variety of reasons there were several periods when AWAS was not available. These were identified and no further checks were performed for these days. If the AWAS solution was available for any day but missing at any time or altitude, it was flagged with an "n" for that time or altitude. Wind profiles produced by AWAS were judged to be non-representative in either the U or V wind component when the solution differed from valid (unmarked) sensor consensus wind profiles by 3 m/s or greater in the absence of eddies or atmospheric features. A "b" was used to indicate such a difference. When AWAS introduced shears because it was adversely influenced by incorrect input data, those times and altitudes were also flagged with a "b". Furthermore, the variance was judged to be non-representative if its value was twice or more the value at preceding and subsequent times or altitudes in the absence of eddies. A "v" was used as a flag to indicate an unsupported high variance. The use of "v" was restricted to those times/altitudes when there was no "b" (or "n"). Examples of the many good profiles as well as some of some of these flagged occurrences will be presented next.

4.0 Examples and Discussion

Data from AWAS was not available until January 25, 1998. For the great majority of times, the AWAS solution was the very best possible, given the sensor inputs. One such example is shown in Figure 2 where the AWAS solution and variance are superimposed on the wind components from all sensor systems reporting winds. This solution represents a reasonable consensus of the inputs. There were occasions when an exaggerated shear in either or both the head wind or cross wind components was created in the region from 45 to 60 m. One example is shown in Figure 3. Notice the change in U component speeds between 45 and 60 m. The resultant flags for this case are shown in Table 2. This "shear" is a result of a combination of events. First there was a consistent and large amount of tower data below 45 m altitude. Secondly, there was limited data available above 45 m, and third, the north sodar data was wrong at this time and adversely influenced the solution at 60 m.

Table 2: Extracts of the flagged dates and times from the AWAS Spreadsheet

Date	Begin Time	End Time	Code	Remarks
17-Mar-98	1330	1330	b	Wrong profiles at 100 m due to TDWR
25-Apr-98	1200	2345	b	Wrong profiles due to strong winds
10-May-98	2015	2030	b	50 m shear exaggerated

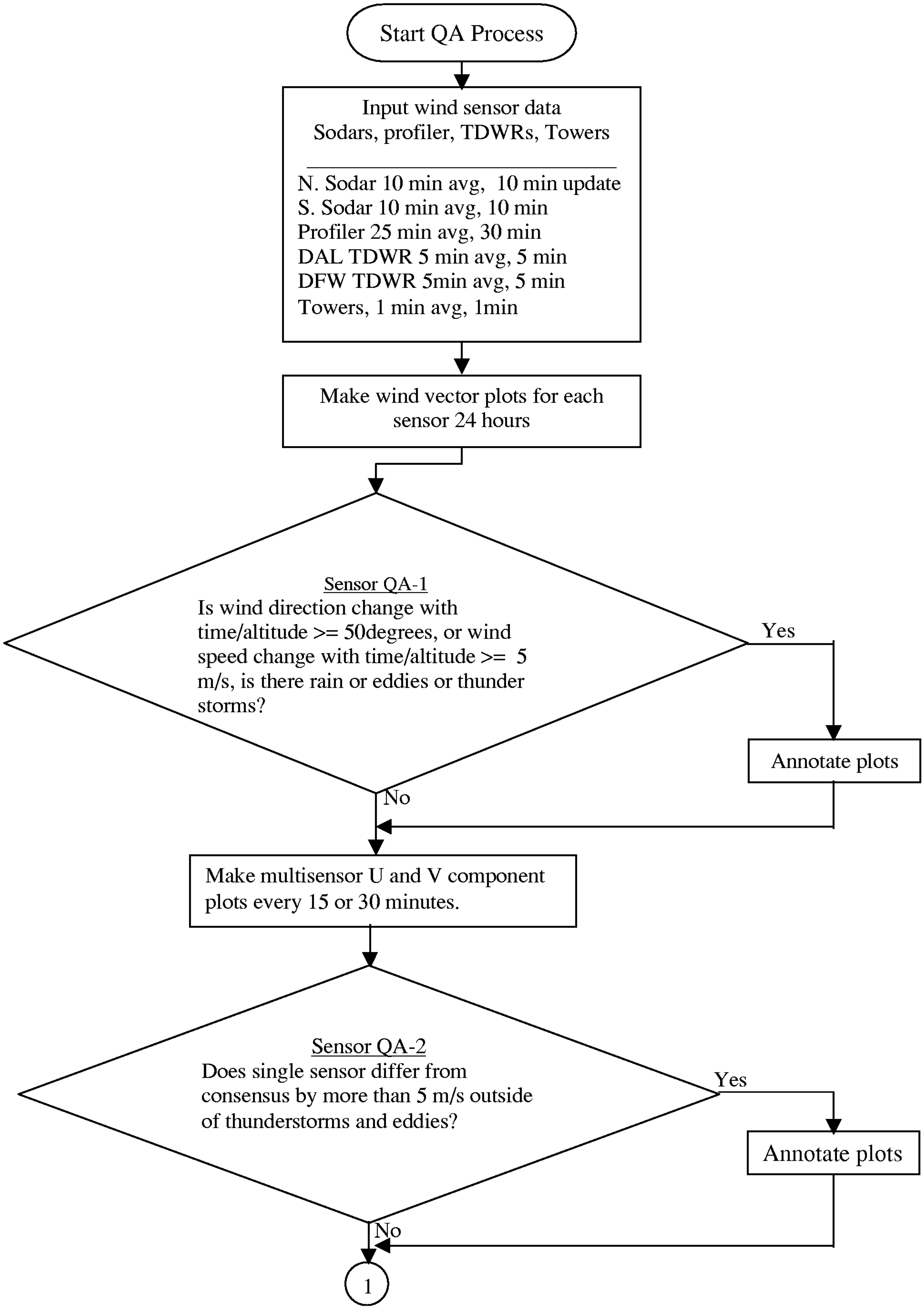
Below 45 m AWAS utilized 15 minute averages of one minute data for May 12, 1998, from anemometers on towers. At 60 meters, the next level with sensor data, there were only TDWR winds corresponding to a larger area average, and sodar winds for three 5 minute periods, half of which were incorrect at this time. The wind profiles represent mean winds over either a 15 minute or 30 minute period. Even when the mean profiles are correct, shears derived from them may not represent short-period shears along the approach corridor due to the localized and transient nature of many wind changes. Other problems were noted when the TDWR winds were out of line with the other sensors due the larger area of influence for the wind measurements (Fig. 4); the associated flags are also in Table 2. Another source of error in the sodars occurred when signal-to-noise ratios were too low in the high noise environment of the DFW airport. This was especially prominent in the cold winter months when a heater used to increase the temperature surrounding the speakers at the north sodar was not working. Sometimes the incorrect sensor data was recognized and ignored by AWAS, which produced a reasonable profile despite the incorrect sensor input as in Figure 3 between 100 and 350 m. At other times, the wrong data adversely influenced both the solution and variance as in Figure 5. Neither the sodars nor radar profiler work well in moderate or greater rain, so these periods must be identified. Also, the sodars do not work properly in winds greater than 15 m/s (30 kts) that occurred on several days (Fig. 6 and Table 2). April 25, 1998, is one example. In strong winds the volume of air being sampled by the sodar is blown away too fast for the reflected signals to reach the receiver. Also, in strong winds there is considerable surface "noise" that reduces signal to noise ratios. Finally, during afternoon eddies on sunny days, the variance was high at times due to differences in sensor system averaging and normal spatial variability of the winds. Since the variance should be high in these conditions, the AWAS profile was not flagged. A day with afternoon eddies is shown in Figure 7 when differences in cross wind and head wind components of the different sensors was caused by the changing wind directions at different sensor locations. Further results of this analysis process along with other data sorting are documented in Volume-2 for each day when wind profiles were available.

5.0 Potential Biases in the QA Results

Several characteristics of sensor behavior, data sorting, and the QA process itself resulted in unavoidable peculiarities (or biases) in the unflagged results. First, as was already mentioned, some of the wind sensors have difficulty in rain, yet that is most often when Instrument Meteorolgical Conditions (IMC) occur. IMC has been defined at DFW to be a ceiling of 5000 ft or below or a visibility of 5 miles or less. Therefore, the process, combined with sensor performance, will result in eliminating cases because it was raining (and usually IMC). Either the profiles may be wrong because an incorrect sensor was chosen in the AWAS analysis, or a reasonable profile may result with an unreasonable variance. In either case the AWAS files for those 15 or 30 minute periods during precipitation events will most likely be flagged. This in turn reduces the number of hours of IMC available for which AVOSS can provide the primary benefit. Since the period from 8 AM to 10 PM has been selected for processing, there will be a preponderance of unstable or neutral atmospheric conditions in the flagged and unflagged results. The early morning hours are the times of the most stable conditions, and these have been apriori excluded. From a sensor performance standpoint this is a welcomed exclusion because the sodars and radar profiler have some difficulties with inversions. Strong winds adversely affect the sodars which may influence the AWAS profiles or variance. Therefore, the resultant unflagged files will rarely include times when the wind blows greater than 15 m/s, yet this is when vortices most rapidly decay. There are several instances where the only problem is at a single altitude, such as 50 meters, even though the entire profile is flagged as unrepresentative. The sonic anemometers used to provide ambient atmospheric turbulence do not work well in precipitation or heavy fog. Therefore, the Turbulent Kinetic Energy (TKE) derived from that instrument may be incorrect and eliminated for those times. Resultant unflagged files will again have a preponderance of good (non-precipitating and non-foggy) weather days. Because many of the sensor problems result in abnormally high variance (and therefore a V flag), those unflagged cases may not include as many true high variance profiles as would normally be the case. However, extra care was taken to allow afternoon eddies to be legitimate high variance cases. Finally, all the sensors could be indicating the correct profiles for their averaging time period and volume of air sampled, and the resultant variance in the AWAS solution could be higher than a true wind variance experienced by the vortices near the end of the runway. That can occur because of the way variance was computed (it included variability among sensors or an estimate of the curve fit error). On the other hand, if the flags are disregarded, many cases of incorrect winds and shears would be included in the AVOSS results. Those might include the problems discussed in section 4.0 when a sensor indicated a wind speed and direction more than three times the true wind and the AWAS solution accepted the incorrect input. They might also include some incorrect altitudes accepted and others rejected for the same profile time period, the net result of which would be incorrect cross wind or head wind shears. The AWAS solution could also include arbitrary (canned) profiles if AWAS could not reach a solution because of incomplete sensor inputs or communications problems. Those cases would be identified as missing ("n") in the flag process.

6.0 Summary and Conclusions

An analysis and quality assessment of measured wind and turbulence data, and of wind profiles produced by merging the measured sensor data, was performed to identify the data that was the most representative of the true atmospheric conditions. The wind profiles and turbulence data are required by AVOSS in order to provide valid estimates of wake vortex positions with respect to selected landing approach corridor locations. As in any real-time operation, imperfections in sensor measurements and in the wind-profile merging process can produce erroneous or misleading results. Although the analysis focused on identifying errors, it was determined that the majority of the wind profiles and turbulence data were valid representations of the true conditions. This assessment provided a valuable knowledge base from which improvements have been made, and will continue to be made, in optimizing sensor performance in the variance estimates and in the AWAS algorithms for the final solution.


Start QA Process
Input wind sensor data
Sodars, profiler, TDWRs, Towers
N. Sodar 10 min avg, 10 min update
S. Sodar 10 min avg, 10 min
Profiler 25 min avg, 30 min
DAL TDWR 5 min avg, 5 min
DFW TDWR 5min avg, 5 min
Towers, 1 min avg, 1min
Make wind vector plots for each sensor 24 hours
Sensor QA-1
Is wind direction change with time/altitude >= 50degrees, or wind speed change with time/altitude >= 5 m/s, is there rain or eddies or thunder storms?
Yes
Annotate plots
No
Make multisensor U and V component plots every 15 or 30 minutes.
Sensor QA-2
Does single sensor differ from consensus by more than 5 m/s outside of thunderstorms and eddies?
Yes
Annotate plots
No
1

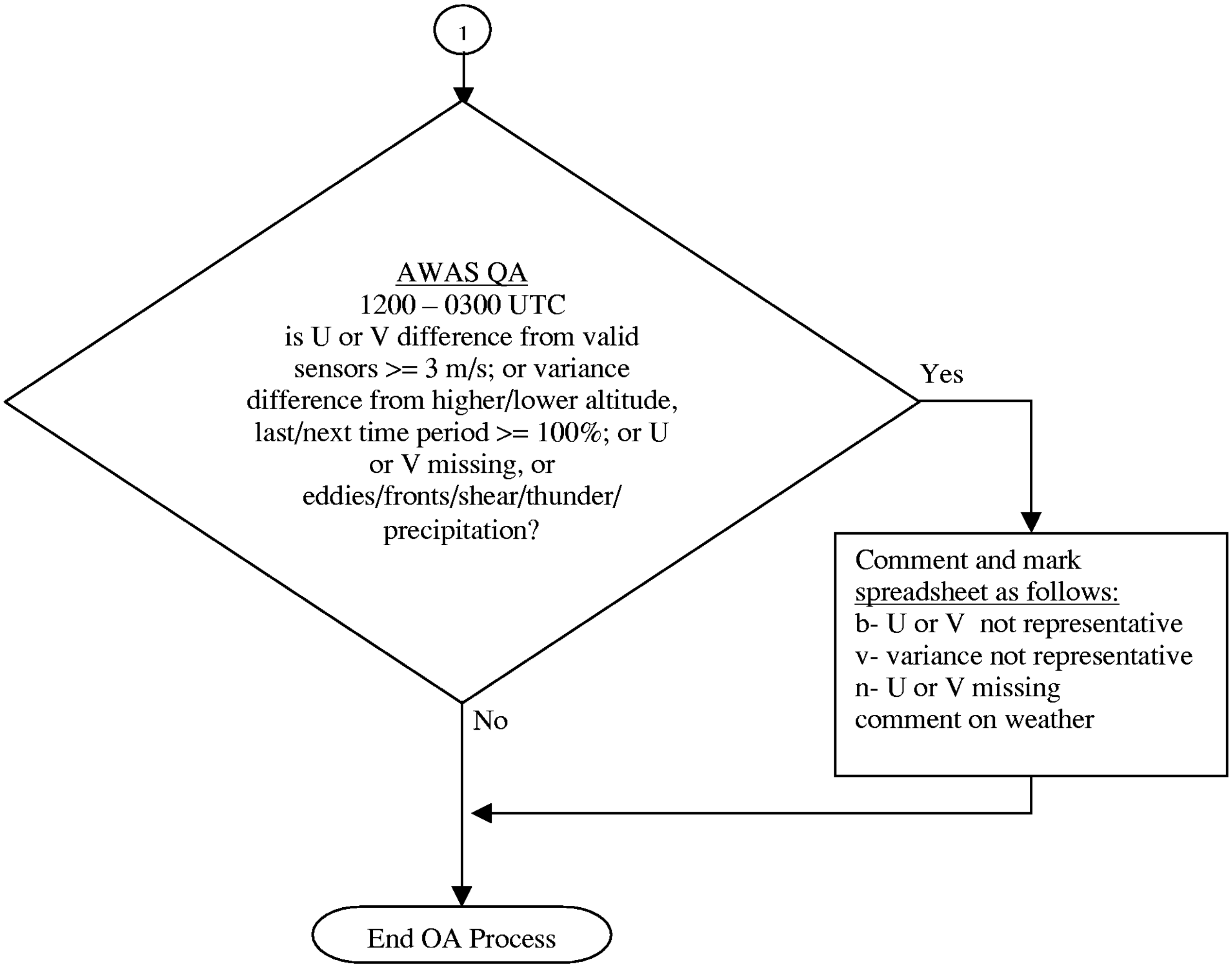


Figure 1: The Analysis Process.

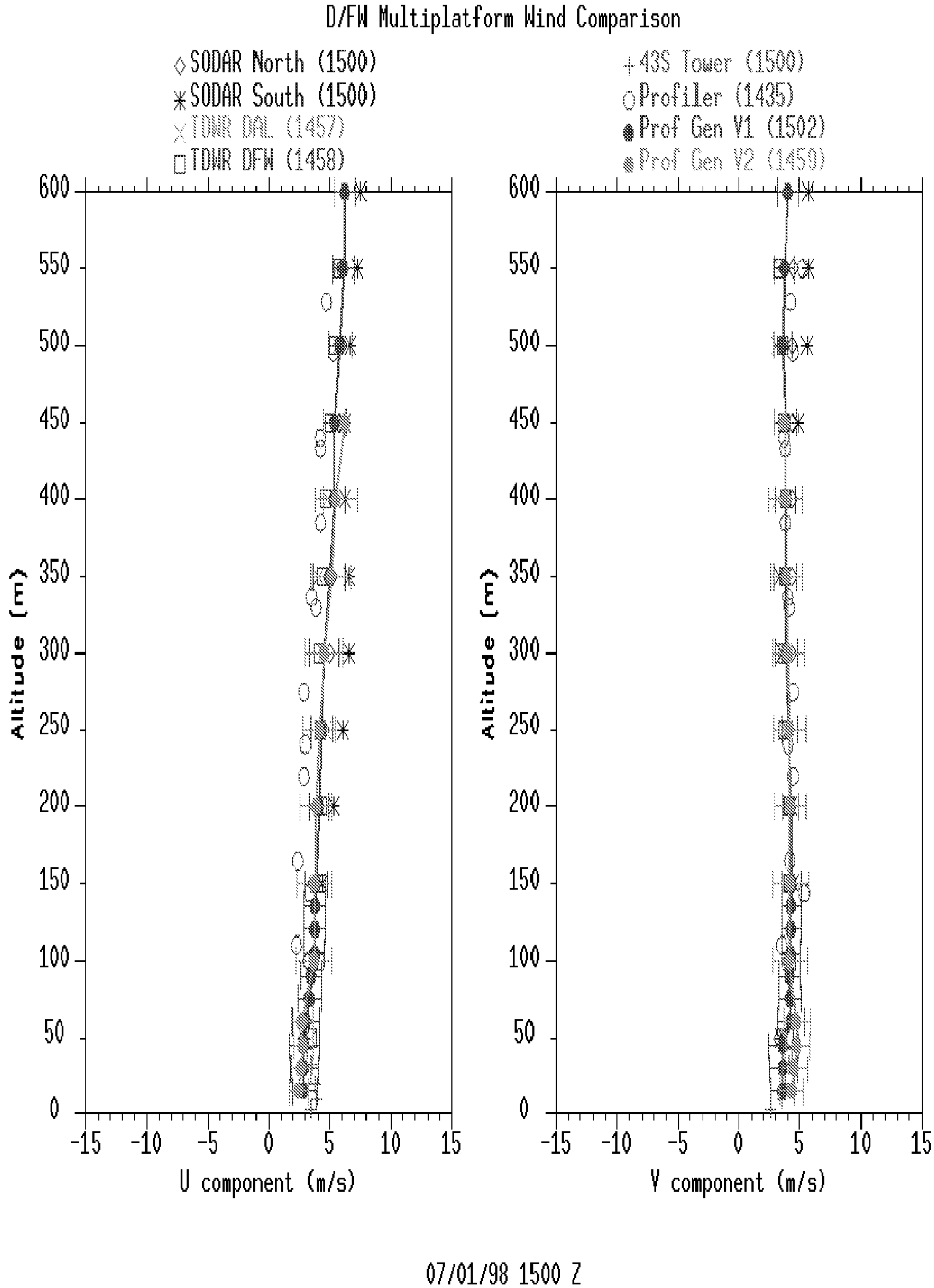


Figure 2: Multisensor plot of orthogonal wind components for the date and time shown.

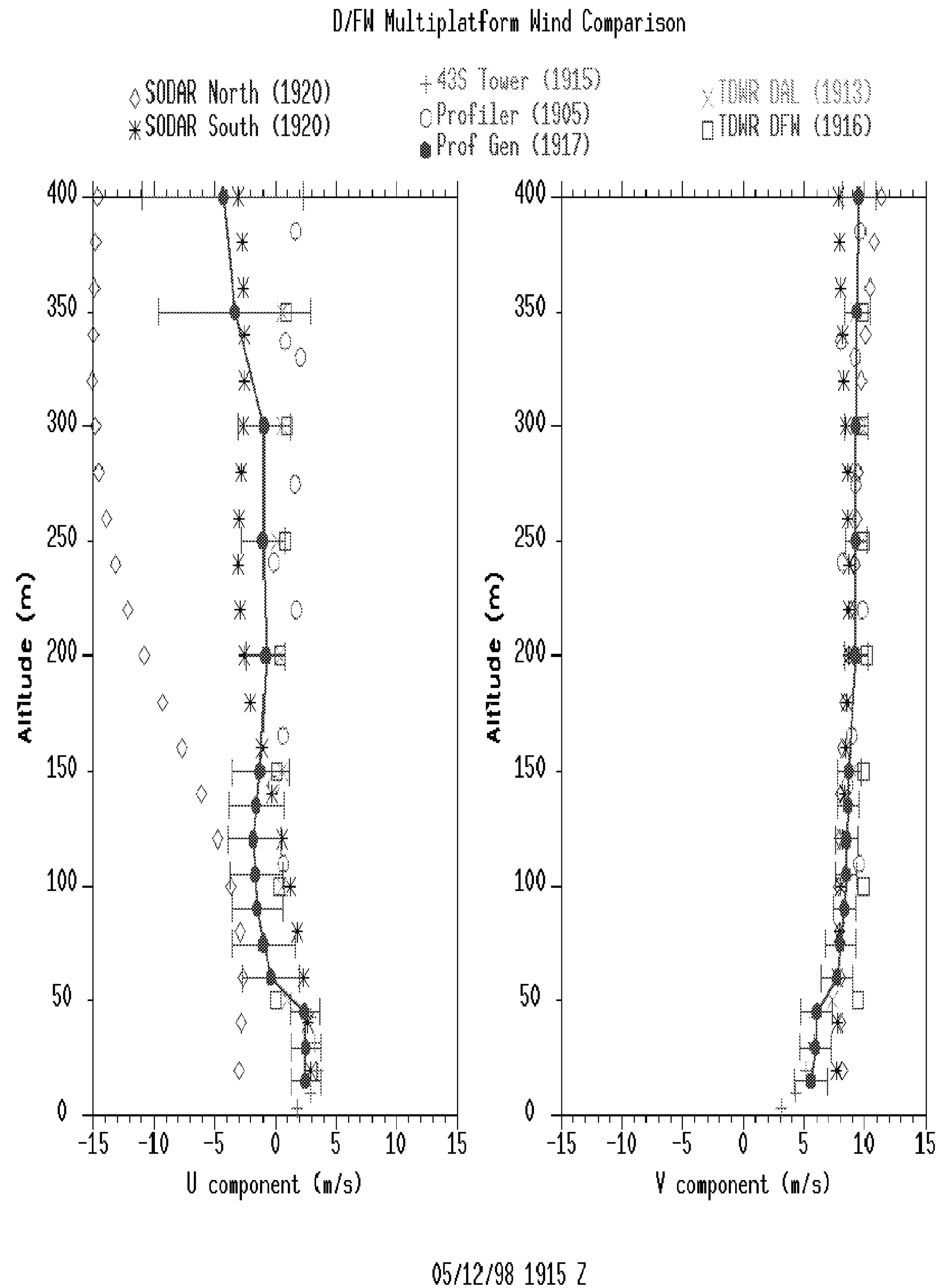


Figure 3: Multisensor plot of orthogonal wind components illustrating anomalous shear at 50 m for the date and time shown.

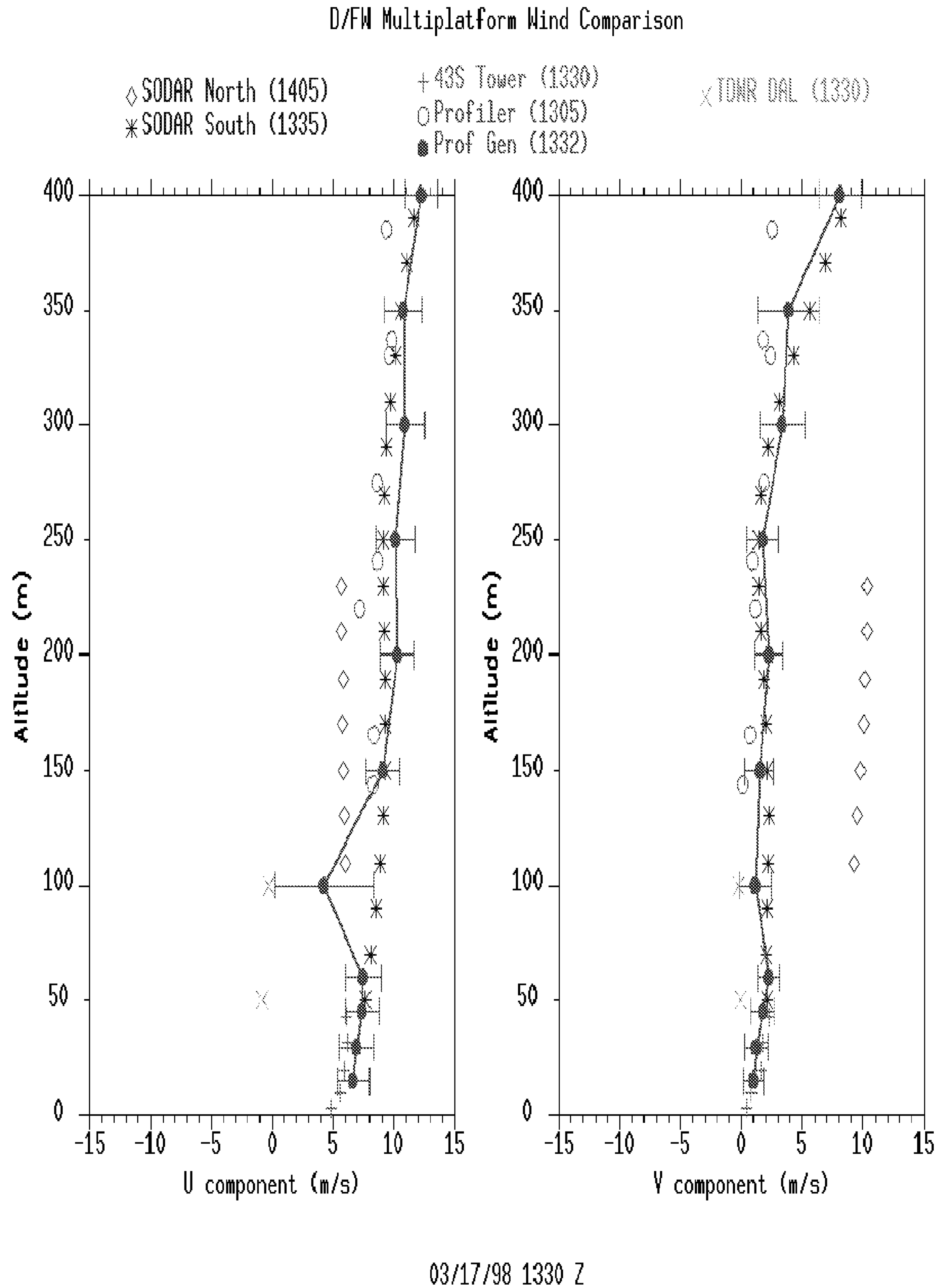


Figure 4: Multisensor plot of orthogonal wind components illustrating TDWR influence at 100 m for the date and time shown.

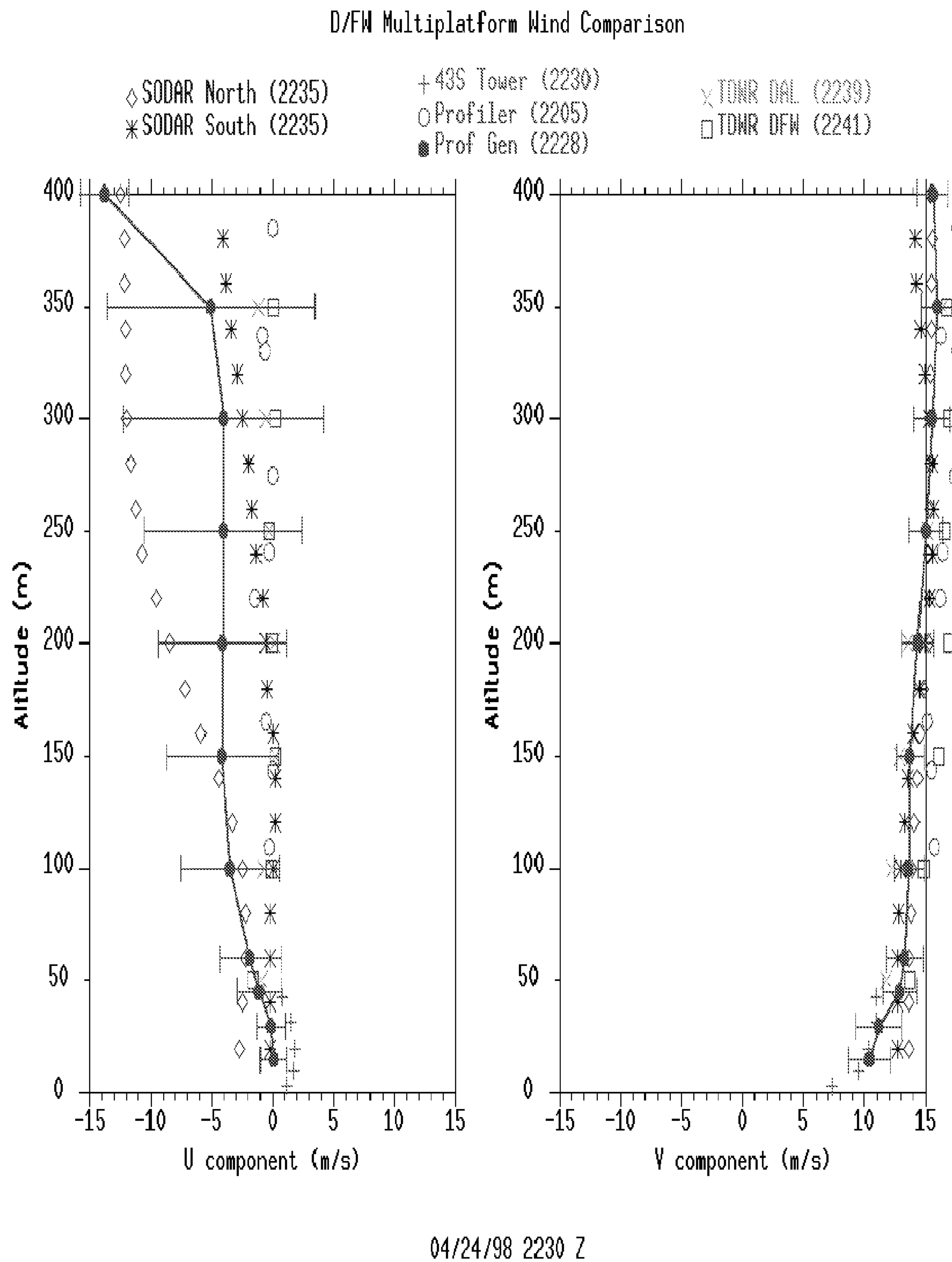


Figure 5: Multisensor plot of orthogonal wind components illustrating the influence of incorrect sodar winds for the date and time shown.

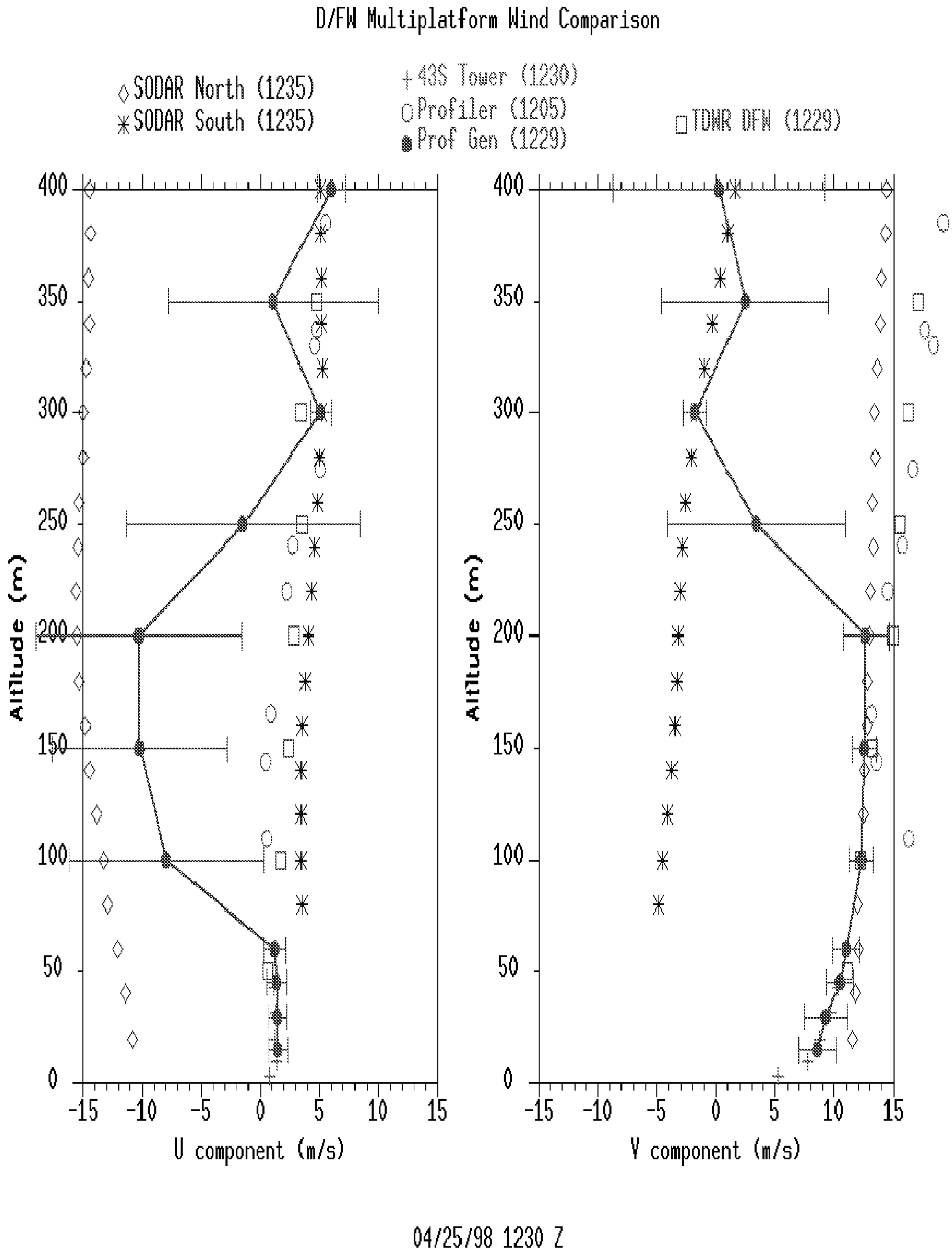


Figure 6: Multisensor plot of orthogonal wind components illustrating effects of strong winds on sodar performance and on the resultant profile for the date and time shown.

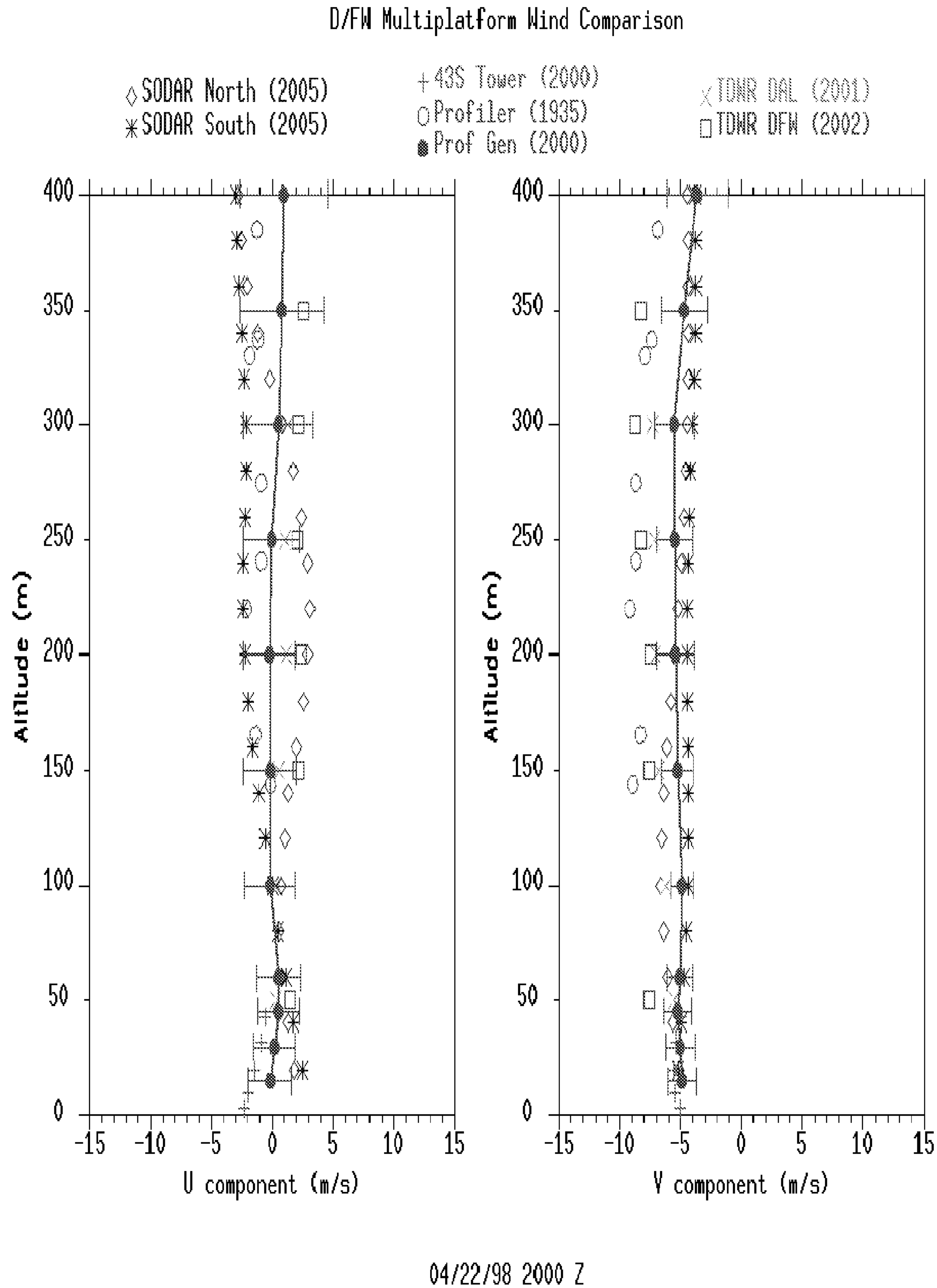


Figure 7: Multisensor plot of orthogonal wind components illustrating differences due to eddies; all sensor wind measurements are correct (see text).

Abbreviations

9999	missing data
ACARS	ARINC Communications, Addressing, and Reporting System
ARINC	Aeronautical Radio, Inc.
AVOSS	Aircraft Vortex Spacing System
AWAS	AVOSS Winds Analysis System
DAL	Dallas (Love Field) Airport
DFW	Dallas-Fort Worth International Airport
IMC	instrument meteorological conditions
MIT	Massachussetts Institute of Technology
NASA	National Aeronautics and Space Administration
QA	quality analysis
TDWRs	Terminal Doppler Weather Radars
TKE	turbulent kinetic energy
U component	east-west wind component (positive toward east)
UHF	Ultra High Frequency (electromagnetic signal)
UTC	Universaile Tempes du Coordinaire' (universal time)
V component	north-south wind component (positive toward north)

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1. Hinton, D. A., 1995, "Aircraft Vortex Spacing System (AVOSS) Conceptual Design", NASA Technical Memorandum 110184, NASA Langley Research Center, Hampton, VA.

2. Dasey, Timothy J.; Rodney E. Cole, et. al., 1998, "Aircraft Vortex Spacing System (AVOSS) Initial 1997 System Deployment at Dallas/Ft. Worth (DFW) Airport", Project Report NASA/L-3, Lincoln Laboratory, Massachusetts Institute of Technology, Lexington, MA.

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13. ABSTRACT (Maximum 200 words)
The quality of the Aircraft Vortex Spacing System (AVOSS) is critically dependent on representative wind profiles in the atmospheric boundary layer. These winds observed from a number of sensor systems around the Dallas-Fort Worth airport were combined into single vertical wind profiles by an algorithm developed and implemented by MIT Lincoln Laboratory. This process, called the AVOSS Winds Analysis System (AWAS), is used by AVOSS for wake corridor predictions. During times when AWAS solutions were available, the quality of the resultant wind profiles and variance was judged from a series of plots combining all sensor observations and AWAS profiles during the period 1200 to 0400 UTC daily. First, input data was evaluated for continuity and consistency from criteria established. Next, the degree of agreement among all wind sensor systems was noted and cases of disagreement identified. Finally, the resultant AWAS solution was compared to the quality-assessed input data. When profiles differed by a specified amount from valid sensor consensus winds, times and altitudes were flagged. Volume one documents the process and quality of input sensor data. Volume two documents the data processing/sorting process and provides the resultant flagged files.

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