Applied Meteorology Unit (AMU)

Quarterly Update Report

Third Quarter FY-93

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1. Background

The AMU has been in operation since September 1991. A brief description of the current tasks is contained within Attachment 1 to this report. The progress being made in each task is discussed in Section 2.

2. AMU Accomplishments During the Past Quarter

The primary AMU point of contact is reflected on each task and/or sub task.

2.1. Task 001 Operation of the AMU (Dr. Taylor)

Development of Forecaster Applications (Mr. Wheeler)

The AMU has completed the development of a F-Key menu system to facilitate the display of text data on the Meteorological Interactive Data Display System (MIDDS). The menu system has been installed on the MIDDS Wide Word Workstation in the Range Weather Operations (RWO). An introduction to the menu system was given to all RWO forecasters during an April RWO station meeting, and additional training was provided to the forecasters on the use of the F-Key menu system in May.

The F-Key menu system allows forecasters to quickly review the numerous weather and forecast bulletins stored in the MIDDS system. In addition, the F-Key menu system demonstrates the capability and utility of a MIDDS function which enables rapid switching of image loops and graphics displays to facilitate customer briefings during operations.

The AMU completed a comprehensive listing, including description and examples of usage, of MIDDS command utilities and enhancements developed by the AMU during the past year. Using this documentation, the AMU is providing training on these utilities and enhancements for the RWO forecasters and launch weather officers. Subsequent to the training, the AMU will solicit input from the forecasters regarding suggestions for modifications to the command utilities and enhancements.

The F-Key menu system, the other command utilities and enhancements, and the associated documentation were also provided to SMG and MSFC.

2.2. Task 002 Training (Dr. Taylor)

During May, Ms. Yersavich attended Clarity Learning's "Visualization with AVS" training class in Concord, MA. The class provided important information about the paradigm used by AVS to process data and the purpose and nature of the major subsystems in AVS. Emphasis was placed on network development using modules, the types of modules that are available, the role of the modules within the network, and the modules' inputs and outputs. Attending this class provided Ms. Yersavich with a basic understanding of AVS and network development. This knowledge will reduce the amount of time required to become productive with AVS and will facilitate visualization of model data.

2.3. Task 003 Improvement of 90 Minute Landing Forecast (Dr. Taylor)

Sub Task 1: Two - Tenths Cloud Cover Study (Mr. Atchison)

During the past quarter, the AMU completed the Shuttle Landing Facility (SLF) cloud cover report. Key results from this investigation were included in the AMU's Second Quarter FY-93 report.

Permission to release the document within NASA has been granted and the document has been distributed within NASA. Distribution outside of NASA will occur as soon as approval is received from NASA Public Affairs Office.

Sub Task 2: Fog and Status at KSC (Mr. Wheeler)

The AMU completed and distributed the preliminary report on the SLF fog study in June. Key results from this investigation were included in the AMU's Second Quarter FY-93 report.

Also during the past quarter, the AMU has been analyzing data from the 5 year SLF data base to estimate false alarm rates for the fog precursors defined in the preliminary report. The AMU has been reviewing meteorological conditions at the SLF on days when some of the fog precursors were satisfied and fog did *not* occur. Results from these analyses are being used to revise the fog forecasting flow diagrams contained in the preliminary report. In addition, data from the 1992-93 fog season is being analyzed and the tables and graphs in the preliminary report are being updated.

The AMU is also working on a MIDDS utility that will use the NGM Point Analysis data to produce a forecast Fog Susceptibility Index (FSI). The results and updates will be incorporated into the final SLF fog report due this fall.

2.4. Task 004 Instrumentation and Measurement (Dr. Taylor)

Sub Task 3: Doppler Radar Wind Profiler

Implementation of MSFC DRWP Wind Algorithm (Ms. Schumann)

The primary emphasis during this last quarter was to prepare the software for and perform formal testing of the new wind algorithm software. Internal testing and minor software corrections comprised the software development effort during the quarter. The final drafts of the *Software Requirements Specification for the New Wind Algorithm in NASA's 50 MHz Doppler Radar Wind Profiler* and the *Software Test Procedures for the New Wind Algorithm in NASA's 50 MHz Doppler Radar Wind Profiler* were completed and delivered in May.

The AMU in conjunction with NASA KSC Instrumentation and Measurements Branch performed formal testing of the new wind algorithm software on June 14 and 15. The following people were present at the testing: Robin Schumann and Ann Yersavich of the AMU, Launa Maier and Jim Medina of NASA, and Mike Moore of NYMA, Inc.

Overall, testing was successful. Two minor errors were found in the MIDDS output program which would affect the format of the data transmitted to MIDDS. Also during testing, the question arose as to whether the option of sending MIDDS high altitude mode data (20 km - 90 km) should be available to the user. It was decided this posed too great a risk to the integrity of the MicroVAX-MIDDS interface and the option should be removed.

After formal testing was complete, the software errors found during testing were corrected and the option for switching the data sent to MIDDS from the low altitudes (2 km - 20 km) to the high altitudes (20 km to 90 km) was removed. In the process of modifying and internally testing the software, another software error in the quality control display was discovered. The error was corrected and the test procedures were modified to ensure they properly test for the conditions which lead to this particular software error.

Regression testing to ensure problems found during formal testing were corrected and software modifications made in response to those errors did not introduce new errors has been successfully completed. System level testing of the interface between the DRWP MicroVAX and the MIDDS will take place as soon scheduling can be worked out with the Eastern Range, MSFC, JSC, and KSC.

DRWP Meteorological Evaluation (Dr. Taylor)

The meteorological evaluation of the MSFC wind algorithm has been completed and the draft final report is currently in internal review. External review of the document should take place in August.

The data analyzed as part of this evaluation include 16 hours of profiler data from the following three time periods:

- 5 hours of profiler data from 12 September 1991.
- 5.5 hours of profiler data from 23 January 1992.
- 5.5 hours of profiler data from 20 February 1992.

Using the 16 hours of profiler data, wind profiles were produced using five different parameter configurations (Table 1) of the MSFC wind algorithm. For each configuration, 256 wind profiles were produced for a total of 1280 wind profiles. A subset of these wind profiles have been inter-compared to determine the optimum configuration of the MSFC wind algorithm parameters for operational use. In addition to the inter-comparisons, the MSFC wind algorithm profiles have been compared to 34 time proximate consensus averaged DRWP wind profiles and 11 time proximate jimsphere profiles. In order to compare the DRWP and jimsphere profiles, the jimsphere data were interpolated to the DRWP profile reporting levels.

A representative sample of the results from the comparisons of MSFC wind algorithm profiles to time proximate consensus averaged DRWP wind profiles and to time proximate jimsphere profiles was included in the AMU's second quarterly report for fiscal year 1993. The final report includes additional information regarding these analyses.

The following paragraphs of this document contain an excerpt from the final report regarding the results of the performance evaluation of different configurations of the MSFC wind algorithm. The evaluation has focused on optimizing key parameters (i.e., first guess window width, integration window width, and minimum acceptable signal-to-noise ratio) within the algorithm. The five configurations of the MSFC wind algorithm that were evaluated are presented in Table 1.

Table 1. MSFC Wind Algorithm Configurations

Configuration Number	First Guess Window Width (Frequency Bin #)	Integration Window Width (Frequency Bin #)	Minimum SNR (dB)
DRWP #1	6	10	-15
DRWP #2	6	20	-15
DRWP #3	12	10	-15
DRWP #4	6	10	-8
DRWP #5	12	20	-8

The MSFC wind algorithm uses the first guess window width in conjunction with the first guess velocity to constrain the range of frequency bins searched for the maximum signal (Figure 1). This first guess approach has the advantage of increasing the probability of the selected maximum signal being related to the wind velocity and decreasing the probability of the selected maximum signal being related to a side lobe or transient interference signal. Since the width of the first guess window affects the performance of the first guess technique, this evaluation has examined the impact of using different first guess window widths.

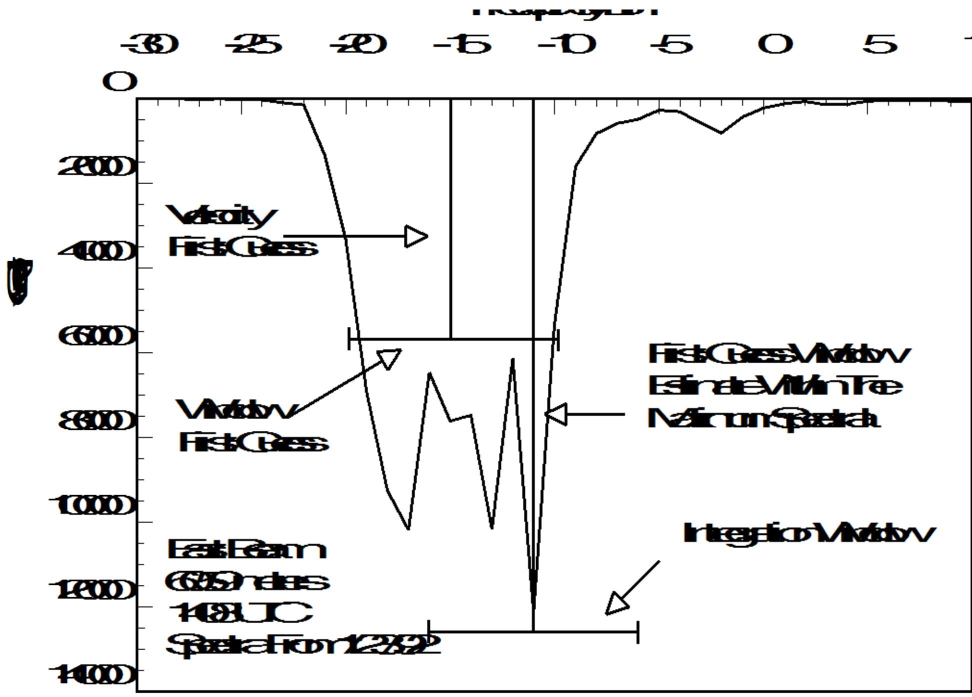

Figure 1. Example of how the first guess velocity, the first guess window width, and the integration window width are used to compute the spectral moments.

After the maximum signal has been selected, the MSFC algorithm computes the average Doppler shift based on the maximum signal strength and the integration window width (Fig 1). As with the first guess window, the width of the integration window affects the resulting average Doppler shift. If the window is too narrow, the peak of the wind velocity signal may not be included in the average Doppler shift integration. In contrast, if the window is too wide, side lobe and/or transient signal data may be included in the average Doppler shift computations. Since the width of the integration window affects the performance of the new wind algorithm, this evaluation has examined the impact of using different integration window widths.

The third and final parameter examined in this evaluation is the minimum acceptable signal-to-noise ratio (SNR). After the average Doppler shift has been calculated, the SNR is computed. If the SNR does not exceed the minimum acceptable value, the average Doppler shift and the other moments are recomputed using alternative approaches (e.g., using a different first guess velocity and/or smoothing the spectral estimates). If the new SNR still does not exceed the minimum acceptable value, the first guess velocity is propagated. Thus, the minimum acceptable SNR significantly impacts the results under weak signal conditions.

Spectral Data Analysis From 12 September 1991

Examination of the profiler data from 12 September 1991 indicates all five configurations generally produced very similar velocity estimates in strong signal regimes, and configurations #1, #2, and #3 produced very similar velocity estimates in all signal regimes. In particular, examination of five time coincident profiles produced by DRWP configurations #1, #2, and #3 indicates that 99% of the differences in velocity estimates between configurations #1 and #2 and between configurations #1 and #3 are less than 2 meters per second and 98% of the differences in velocity estimates are less than 1 meter per second. Consequently, the estimation of the average Doppler shift is substantially affected by changing the first guess velocity window width and/or the integration window width for only a few cases within the September 1991 profiler data. Three such examples are illustrated in Figures 2-4.

Figures 2 and 3 present two examples of how persistent interference signals near the atmospheric signal affect the performance of the five different MSFC wind algorithm configurations. In the example from the 4259 meter level (Figure 2), the atmospheric signal is centered on frequency bin -2, and the relatively weaker interference signals are centered on frequency bins ± 6. In this case, all of the configurations, except #2 which uses a narrow first guess velocity window width and a wide integration window width, produce good estimates of the average Doppler shift.

The results from the second example (Figure 3) are somewhat different. In this case, the interference signal located at frequency bin +6 is stronger than the atmospheric signal at frequency bin +2. Consequently, the average Doppler shifts produced by the configurations which use the wider first guess velocity window width (configurations #3 and #5) are shifted toward the stronger interference signal. The other configurations are less affected by the interference signal and produce better average Doppler shifts.

The spectral estimates in Figure 4 illustrate an example of a relatively broad spectrum width atmospheric signal which is indicative of a large degree of variability and/or turbulence within the sample domain. In this case, the MSFC wind algorithm configurations with large integration window widths (configurations #2 and #5) produce an average Doppler shift which is near the center of the broad atmospheric signal. The average Doppler shift produced by configuration #3 which has the large first guess velocity window width and the small integration window width is shifted toward the peak signal within the broad atmospheric return. The average Doppler shift produced by configurations #1 and #4 are of poorer quality and are shifted toward the weaker side of the atmospheric signal.

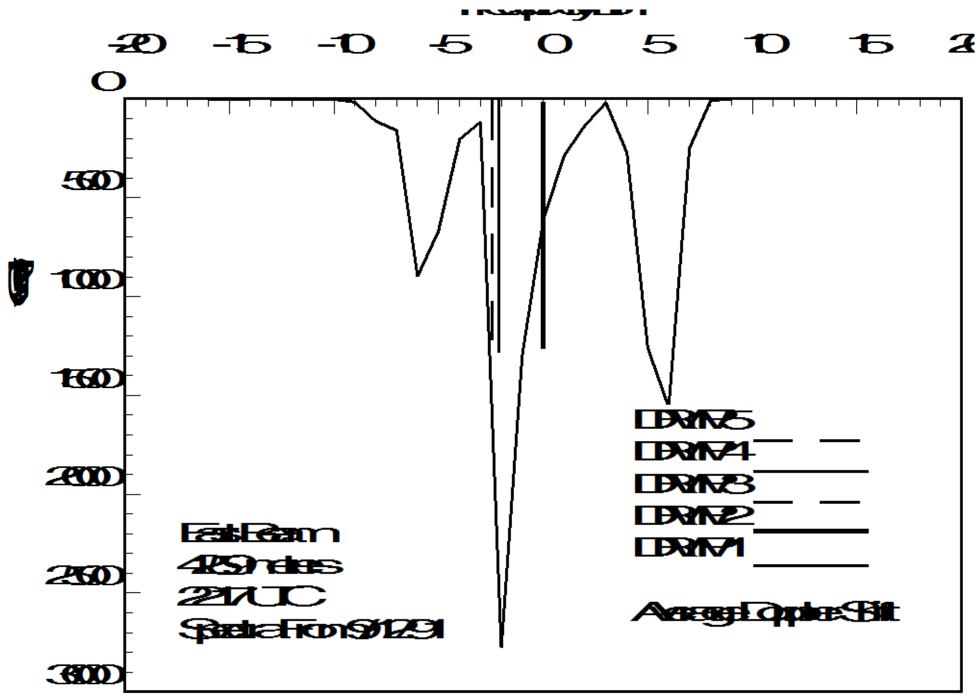

Figure 2. East beam spectral estimates from the 4259 meter level at 2217 UTC on September 12, 1991.

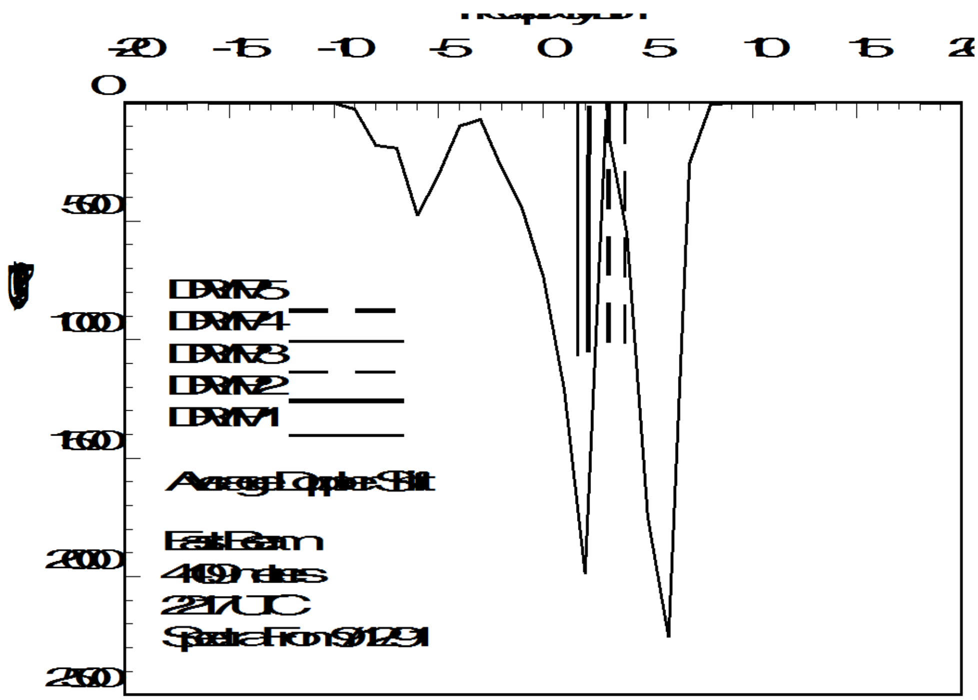

Figure 3. East beam spectral estimates from the 4409 meter level at 2217 UTC on September 12, 1991.

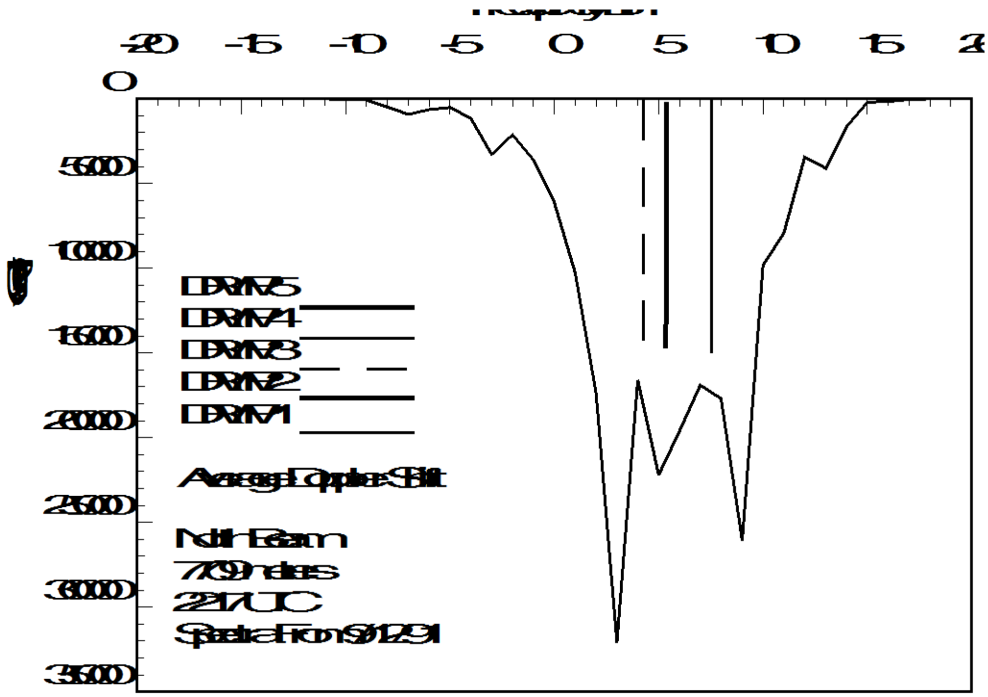

Figure 4. North beam spectral estimates from the 7709 meter level at 2217 UTC on September 12, 1991.

Spectral Data Analysis From 23 January 1992

Examination of the profiler data from 23 January 1992 indicates all five configurations generally produced very similar velocity estimates in strong signal regimes, and configurations #1, #2, and #3 produced very similar velocity estimates in all signal regimes. In particular, examination of four time coincident profiles produced by DRWP configurations #1, #2, and #3 indicates that 99% of the differences in velocity estimates between configurations #1 and #2 and between configurations #1 and #3 are less than 2 meters per second and 94% of the differences in velocity estimates are less than 1 meter per second. Consequently, the estimation of the average Doppler shift is substantially affected by changing the first guess velocity window width and/or the integration window width for only a few cases within the January 1992 profiler data. Three such examples are illustrated in Figures 5-7.

Figure 5 contains the spectral estimates from the 7259 meter level at 1530 UTC on 23 January 1992. This particular level is in the middle of a moderate shear zone in the north beam component and examination of the data above and below this level suggest the atmospheric signal of interest is centered around frequency bin - 31. As evidenced by the chart (Figure 5), none of the configurations return an average Doppler shift particularly close to the signal peak; however, configurations #2 and #5 produce the best results of the five configurations.

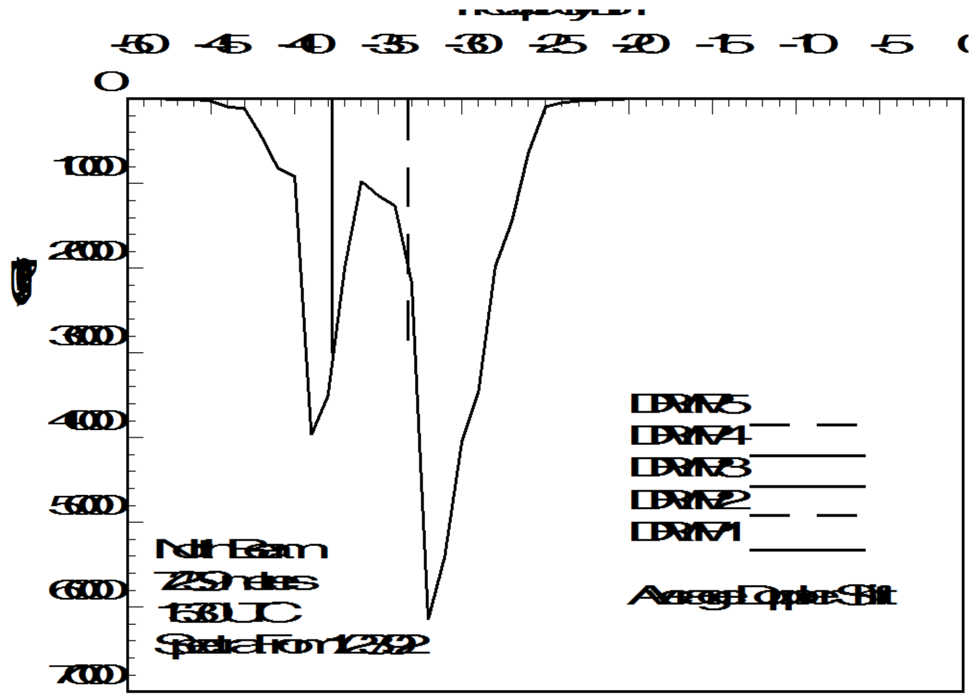

Figure 5. North beam spectral estimates from the 7259 meter level at 1530 UTC on January 23, 1992.

An example of the problems encountered when the atmospheric signal is near 0 is illustrated in Figure 6. In this case, examination of all available data including DRWP data from above and below the 3059 meter level and jimsphere information suggest the true north beam wind component is near 0 meters per second. However, there is not a strong return near frequency bin 0 because the ground clutter removal process has smoothed the spectral estimates around the zero Doppler shift. In spite of that, all of the configurations, except configuration #3, produce an average Doppler shift near frequency bin 0. Because of the large first guess velocity window width and the small integration window width, the average Doppler shift returned by configuration #3 is shifted toward the maximum signal at frequency bin 4. In these situations, a configuration with a wider integration window width is most likely to produce reasonable results.

The spectral estimates presented in Figure 7 illustrate an example where MSFC wind algorithm configurations based on small first guess velocity window widths and small integration window widths (i.e., configurations #1 and #4) do not perform as well as other configurations. In this example, all of the configurations based on large first guess velocity window widths and/or large integration window widths produce good average Doppler shifts.

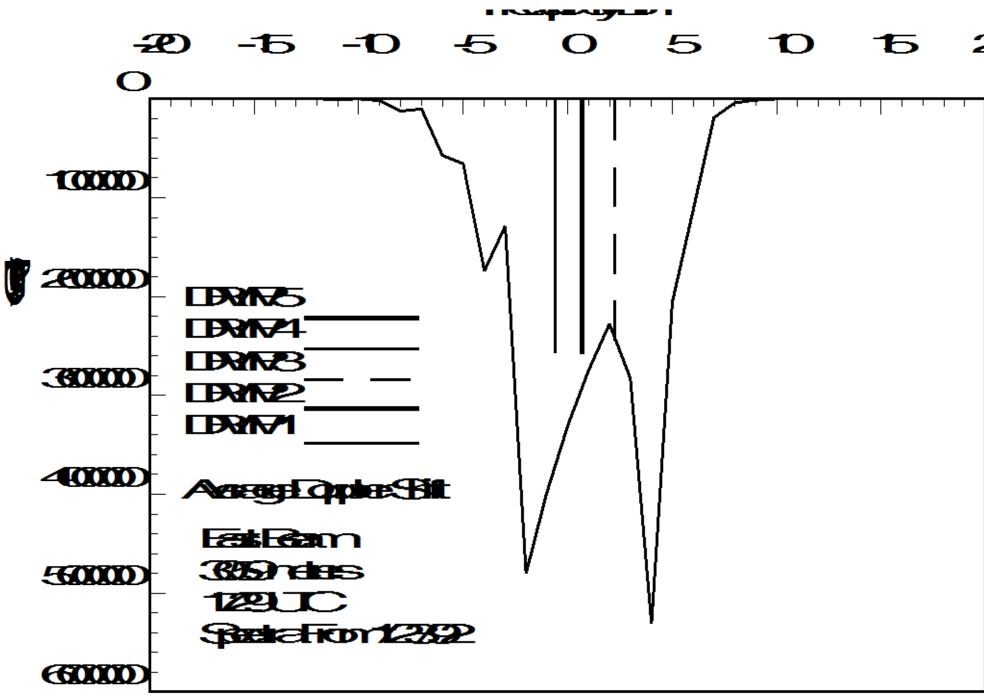

Figure 6. East beam spectral estimates from the 3059 meter level at 1729 UTC on January 23, 1992.

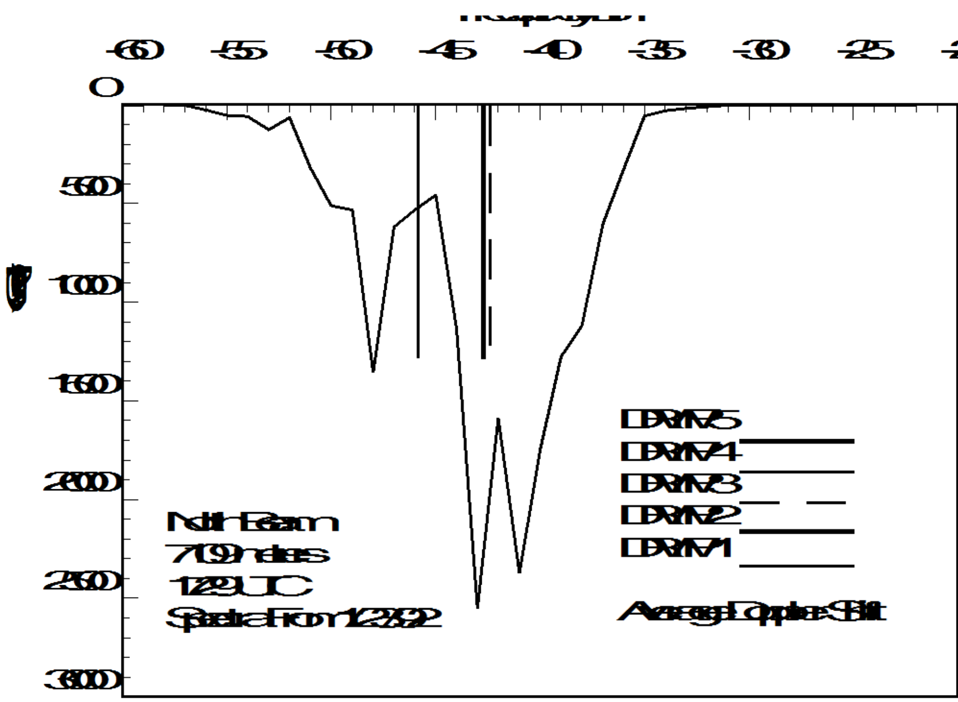

Figure 7. North beam spectral estimates from the 7109 meter level at 1729 UTC on January 23, 1992.

Spectral Data Analysis From 20 February 1992

Examination of the profiler data from 20 February 1992 indicates all five configurations generally produced very similar velocity estimates in strong signal regimes, and configurations #1, #2, and #3 produced very similar velocity estimates in all signal regimes. In particular, examination of three time coincident profiles produced by DRWP configurations #1, #2, and #3 indicates that 98% of the differences in velocity estimates between configurations #1 and #2 and between configurations #1 and #3 are less than 2 meters per second and 91% of the differences in velocity estimates are less than 1 meter per second. Consequently, the estimation of the average Doppler shift is substantially affected by changing the first guess velocity window width and/or the integration window width for only a few cases within the February 1992 profiler data. Two such examples are illustrated in Figures 8 and 9.

The spectral estimates presented in Figures 8 and 9 are two examples of broad spectrum width atmospheric signals resulting from strong vertical wind shear. In both cases, the average Doppler shifts returned by the five MSFC wind algorithm configurations vary considerably because of the broad atmospheric signal. Although the average Doppler shifts returned by configuration #3 are closest to the signal maximum, examination of other data sources suggest the average Doppler shifts produced by configurations #2 and #5 may be the best. Clearly, the average Doppler shifts returned by configurations #1 and #4 using the small first guess velocity window width and the small integration window width are the poorest.

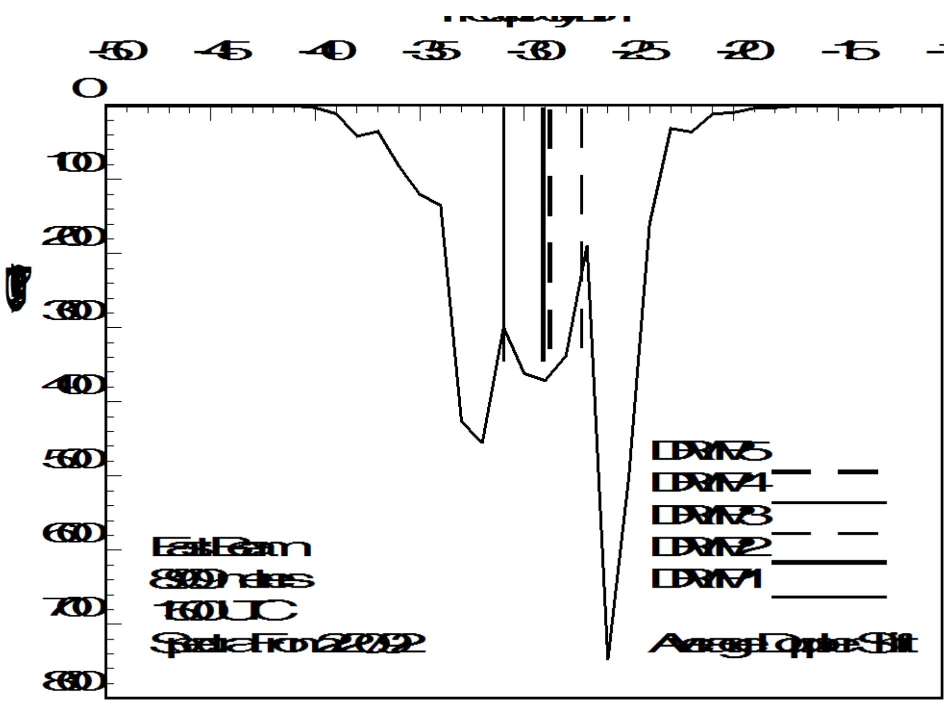

Figure 8. East beam spectral estimates from the 8909 meter level at 1500 UTC on February 20, 1992.

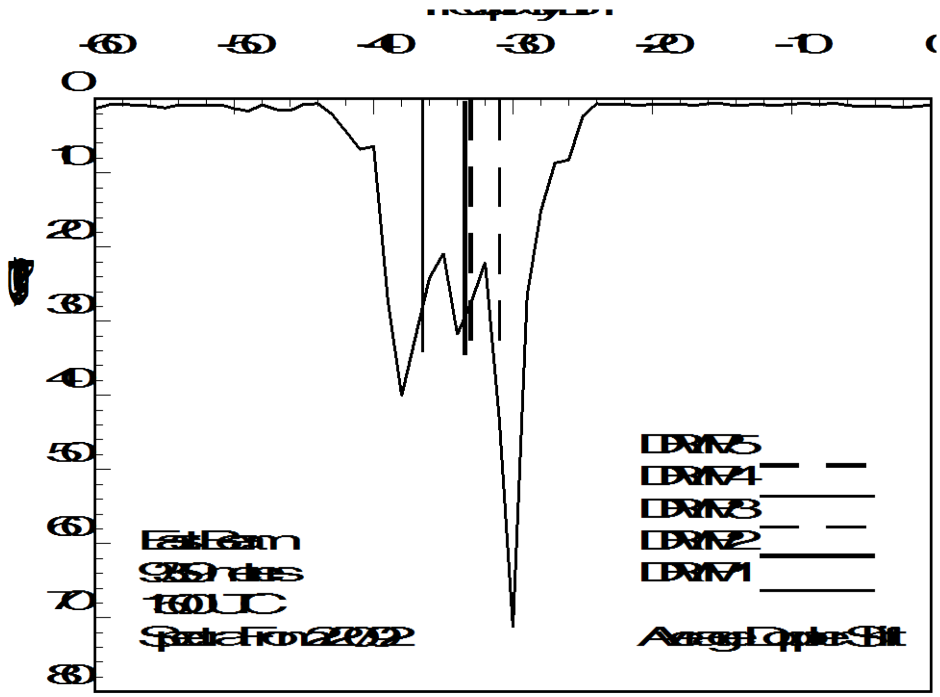

Figure 9. East beam spectral estimates from the 9359 meter level at 1500 UTC on February 20, 1992.

Spectrum Width Analysis

In addition to the effect upon the average Doppler shift calculations, the width of the integration window also affects spectrum width estimates. Obviously, a small integration window width will limit the size of the spectrum width estimate and possibly mask important information about the turbulence and/or shear within a layer. The spectrum width profiles presented in Figures 10 and 11 illustrate this point. The profiles suggest for layers with relatively little shear and/or turbulence (e.g., spectrum width values near 0.6 meters per second), the width of the integration window had little impact upon the estimated spectrum width. However, for layers with significant shear and/or turbulence, the width of the integration window has a significant impact upon the estimated spectrum width. In the case of the east beam jet core near 12 km, the spectrum width calculated using the larger integration window width (configuration #2) is twice as large as the spectrum width calculated using the smaller integration window width (configuration #3). There are also large differences in the estimated spectrum widths between the two different configurations in the 5 km to 7 km region, a region of significant vertical wind shear (figure not shown) for both the east and north beam profiles.

Summary

Based on the analysis of the spectral estimates and the average Doppler shifts and spectrum widths produced by the five different configurations of the MSFC wind algorithm, some conclusions can be drawn regarding the preferred configuration of the algorithm for operational use. First, it is apparent the lower minimum acceptable SNR used in configurations #1, #2, and #3 is the preferred choice. The configurations with the higher minimum acceptable SNR rejected solutions and propagated the first guess velocity in situations when the atmospheric signal is clearly detectable. Selecting a preferred configuration for the first guess velocity window width and the integration window width is not as straightforward.

First, it is important to recall changing the first guess velocity window width and/or the integration window width changed the resulting velocity estimates by less than 1 meter per second in more than 90% of the cases examined. Consequently, reasonable adjustments of these two parameters is not likely to produce substantial changes in the estimated average Doppler shift in most cases.

For the limited number of situations where the configuration of the first guess window width and the integration window width does affect the solution, examination of the spectral estimates suggests three principle reasons for the differing results. The primary reason is the presence of a broad atmospheric signal indicative of significant vertical shear and/or turbulence within the sample volume. A number of examples of this situation have been presented. A second reason is the inherent difficulty associated with estimating the wind velocity when the atmospheric signal is within the ground clutter. One example of this condition was described. The final reason is the presence of persistence interference signals, often hardware related, near the atmospheric signal. Two examples of this situation were presented.

For the “problem integrations”, analysis of the data indicates using a larger first guess velocity window width and a larger integration window width will generally produce the best results when the spectral estimates are characterized by either a broad atmospheric signal or an atmospheric signal within the ground clutter. This configuration will also tend to produce the best spectrum width estimates. However, when the “problem integration” is characterized by persistence interference signals near the atmospheric signal, a small first guess velocity window width and a small integration window width will generally produce the best results. The recommended configuration of the key parameters within the MSFC are contained in Table 2.

Table 2. Recommended DRWP Configurations

Characteristics of Spectral Estimates	First Guess Window Width (Frequency Bin #)	Integration Window Width (Frequency Bin #)	Minimum SNR (dB)
Absence of Persistent Interference Signals Near the Atmospheric Signal	12	20	-15
Presence of Persistent Interference Signals Near the Atmospheric Signal	6	10	-15

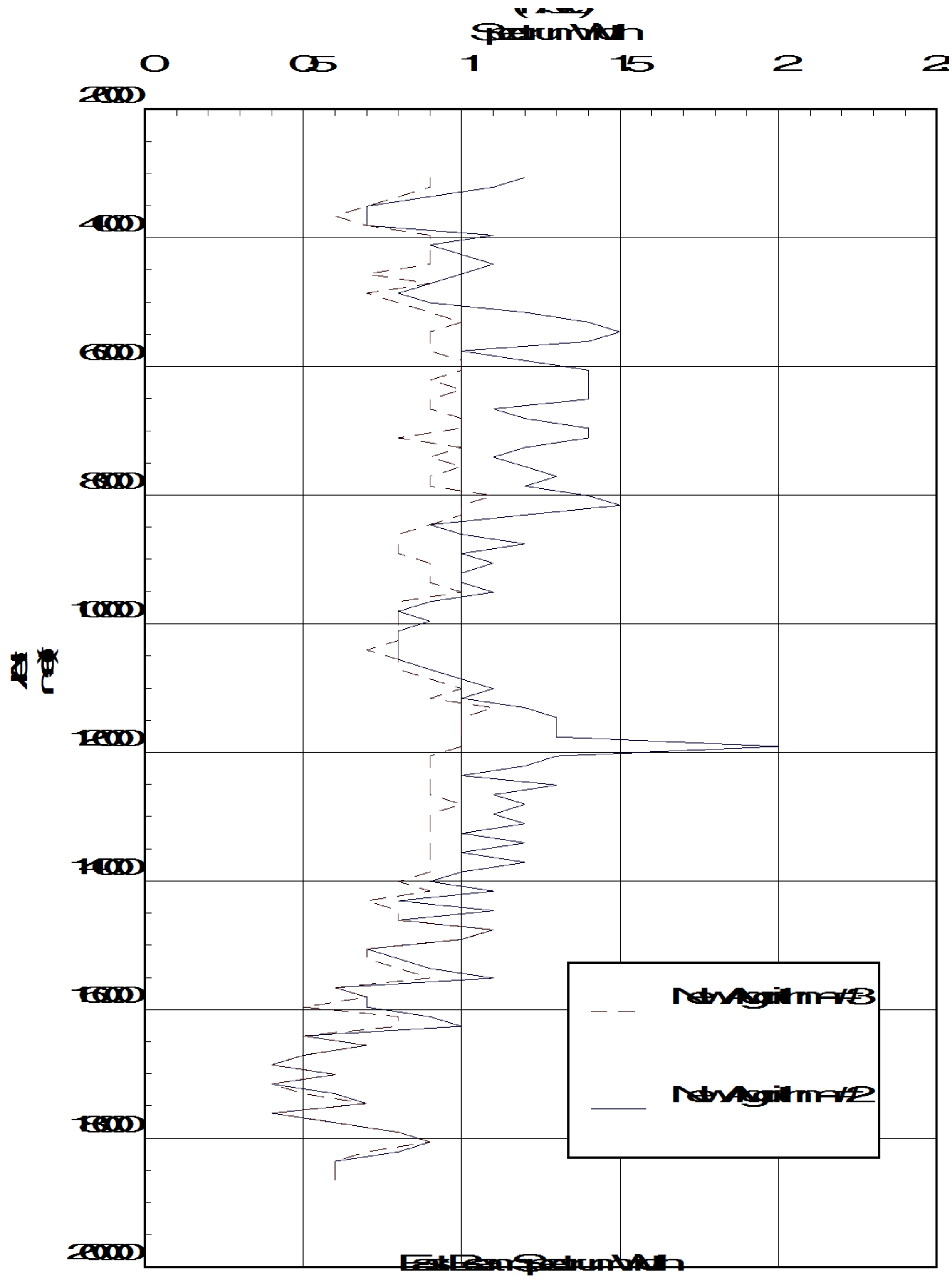

Figure 10. East beam spectrum width profiles at 1729 UTC on 23 January 1992 for MSFC wind algorithm configurations #2 and #3.

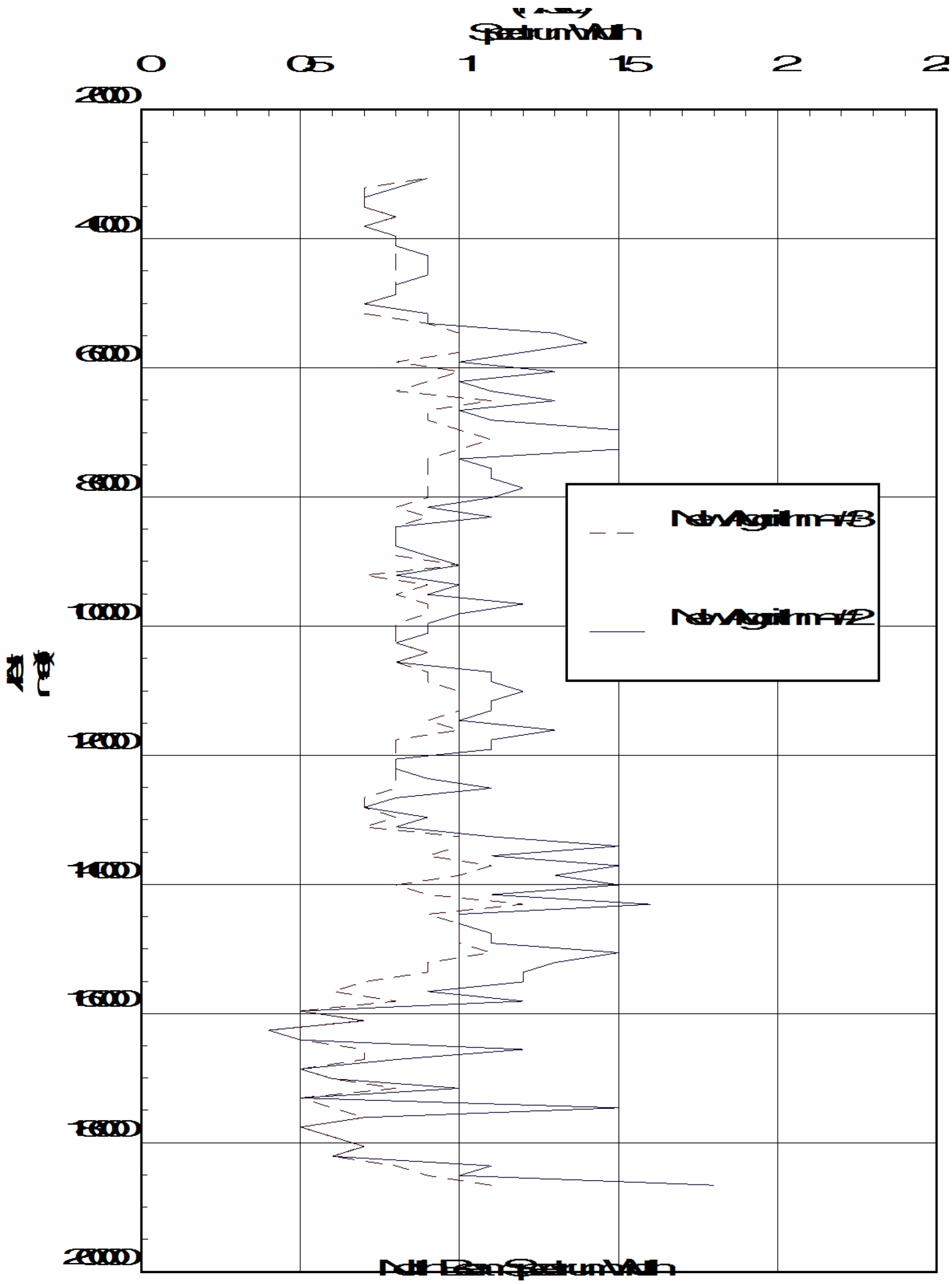

Figure 11. North beam spectrum width profiles at 1729 UTC on 23 January 1992 for MSFC wind algorithm configurations #2 and #3.

Sub Task 7: ASOS Evaluation (Ms. Yersavich)

Representatives from the SMG, RWO, and the AMU participated in a teleconference on 27 May 1993 to reach consensus on the AMU's ASOS Evaluation Work Plan. The major components of the ASOS Evaluation work plan which were discussed and agreed upon include:

- Documenting the observation requirements for the Shuttle Landing Facility (SLF),
- Determining what components of the observation requirements could be satisfied by ASOS, and
- Documenting the performance characteristics, reliability, and maintainability of ASOS.

During June, the acquisition of documentation concerning the surface observation requirements for the support of shuttle launch and landing operations, airfield operations, and the SMG's shuttle weather support simulations was completed. After the observation requirements were extracted from the documents, the requirements were compared to ASOS capabilities to determine which components of the observation requirements could be satisfied by ASOS and which components must be met by other means (e.g., human augmentation, additional sensors, etc.). Tables 3, 4, and 5 contain comparison results of ASOS capabilities versus surface observation requirements for the various operations and simulations. The following conventions are used in the comparison tables:

√ :The requirement is satisfied by ASOS.

√- :The requirement is partially satisfied by ASOS.

- :The requirement is not satisfied by ASOS.

During the next quarter, the AMU will investigate other means of satisfying the observations requirements which cannot be satisfied by ASOS. In addition, ASOS measurement accuracy and system reliability and maintainability will be documented using the results of previous investigations of system performance including comparisons of ASOS data to manual observations. The draft report of this investigation should be completed in August.

Table 3. Relationship of ASOS and Manual Observing Capabilities To Airfield Operations Surface Observation Requirements*

Airfield Operations Observation Requirements	Manual	ASOS	Comments
Standard:			
Observations when Aircraft / Missile Mishap Occurs	√	√ -	
Ceiling	√	√ -	ASOS can report ceilings up to 12, 000 feet only
Sky Conditions	√	√ -	ASOS can report sky conditions up to 12, 000 feet only
Prevailing Visibility	√	-	ASOS can determine (point) visibility at the sensor location only
Present Weather	√	√	
Temperature & Dew Point	√	√	
Wind Direction & Speed	√	√	
Altimeter Setting	√	√	
Remarks	√	√ -	ASOS remarks include varying conditions (wind direction, ceiling, sky condition, visibility), pressure changes, max/min temperature, hourly and accumulated precipitation
Special:			
Tornado, Funnel Cloud, or Waterspout	√	-	Cannot be detected by ASOS
Thunderstorm	√	-	Cannot be detected by ASOS (algorithm development in progress)
Wind Shifts and Peaks	√	√	
Precipitation Begin or Ends	√	√	
Hail Begins or Ends	√	-	ASOS cannot detect hail and will generally report hail as heavy rain
Freezing Precipitation Begins or Changes	√	√ -	ASOS will report freezing precipitation as either rain or snow depending on scintillation pattern

* Assessment assumes standard ASOS configuration. Many of the ASOS observation deficiencies can be remedied by hardware and/or software additions/modifications. Potential solutions will be included in next quarterly report.

Table 4. Relationship of ASOS and Manual Observing Capabilities To Shuttle Operations & Simulations Surface Observation Requirements*

Shuttle Operations & Simulations Surface Observation Requirements	Manual	ASOS	Comments
Standard:			
Cloud Amount / Heights	√	√ -	ASOS can report cloud information up to 12, 000 feet only
Visibility	√	√ -	ASOS detects point visibility rather than prevailing visibility
Restriction to Visibility	√	√	ASOS reports restrictions to visibility as either fog or haze
Sea Level Pressure	√	√	
Temperature & Dew Point	√	√	
Wind Direction & Speed	√	√	
Altimeter Setting	√	√	
Properly Identified Wind Data from each Runway Sensor	√	-	Cannot be performed by ASOS
Sector Visibility	√	-	Cannot be determined by ASOS
Cloud Cover that can Impact Landing Field / Runway	√	-	Cannot be determined by ASOS
Advection or Dissipation of Significant Cloud Cover	√	√	
Cloud Description, Position and Movement	√	-	Cannot be determined by ASOS
Cloud Cover in Tenths for all Layers	√	-	Cannot be determined by ASOS
Special:			
Ceiling falls below 8, 000 feet	√	√	
Visibility falls below 7 miles	√	√	
When Thunder Begins	√	-	Cannot be detected by ASOS (algorithm development in progress)

When any Precipitation Begins or Ends	√	√	

* Assessment assumes standard ASOS configuration. Many of the ASOS observation deficiencies can be remedied by hardware and/or software additions/modifications. Potential solutions will be included in next quarterly report.

Table 5. Relationship of ASOS and Manual Observing Capabilities To Spaceflight Meteorology Group & Flight Director's Surface Observation Requirements*

Spaceflight Meteorology Group & Flight Director's Surface Observation Requirements	Manual	ASOS	Comments
Standard:			
Ceiling	√	√ -	ASOS detects ceilings up to 12, 000 feet only
Sky Conditions	√	√ -	ASOS reports sky conditions up to 12, 000 feet only
Prevailing Visibility	√	-	ASOS can determine (point) visibility at the sensor location only
Present Weather	√	√	
Temperature & Dew Point	√	√	
Wind Direction & Speed	√	√	
Altimeter Setting	√	√	
Remarks	√	√ -	ASOS remarks include varying conditions (wind direction, ceiling, sky condition, visibility), pressure changes, max/min temperature, hourly and accumulated precipitation
Tenths of Cloud Cover below 10,000 feet	√	-	Cannot be determined by ASOS
Special:			
Tornado, Funnel Cloud, or Waterspout	√	-	Cannot be detected by ASOS
Thunderstorm	√	-	Cannot be detected by ASOS (algorithm development in progress)
Wind Shifts	√	√	
Precipitation Begin or Ends	√	√	
Hail Begins or Ends	√	-	ASOS cannot detect hail and will generally report hail as heavy rain
Freezing Precipitation Begins or Changes in Intensity	√	√ -	ASOS will report freezing precipitation as either rain or snow depending on scintillation pattern

* Assessment assumes standard ASOS configuration. Many of the ASOS observation deficiencies can be remedied by hardware and/or software additions/modifications. Potential solutions will be included in next quarterly report.

2.5. Task 005 Mesoscale Modeling (Dr. Manobianco)

The AMU is tasked with the evaluation of numerical modeling systems to determine their utility for operational weather support to ground and spaceflight operations. The weather support at KSC requires short-range (2-12 h) localized and accurate forecasts of winds, clouds, (including ceilings and fog) and severe weather such as heavy rain, lightning, and low visibility associated with thunderstorms. In order to meet the operational forecasting needs at KSC, NASA funded Mesoscale Environmental Simulations and Operations (MESO), Inc. to develop a version of the Mesoscale Atmospheric Simulation System (MASS). At the completion of this project, MASS was delivered to the AMU (March 1993) for evaluation and transition. This section describes the components and capabilities of MASS and the AMU's initial efforts in getting the system to run on a real-time basis. Primary AMU activities during the past quarter include:

- Developing McBasi commands to transfer data from MIDDS to the AMU computers for model initialization,

- Developing software to reformat the MIDDS data for model initialization, and

- Installation of the GEneral Meteorological PAckage (GEMPAK) developed at NASA's Goddard Space Flight Center (GSFC) on the AMU computers to display two-dimensional (2D) model output.

Introduction

The development and evolution of convection over Florida is strongly influenced by the fine-scale detail in three-dimensional moisture fields over the Florida peninsula and adjacent data sparse regions of the Western Atlantic Ocean and the Gulf of Mexico. Furthermore, in the absence of strong dynamical forcing, the preferred areas for convective generation are determined more by local factors such as the distribution of land and water, soil moisture, land use, type and amount of vegetation, and presence of sea- or land-breeze circulations. Mesoscale modeling systems must have sufficient horizontal resolution to resolve the detail in surface characteristics and localized circulations as well as the capability to incorporate data that can be used to define the mesoscale moisture structure.

One of the difficulties with mesoscale modeling is that the spatial and temporal resolution of observational data is not always sufficient to define the 3D structure of the mesoscale circulations at the time of model initialization. A particular data type is usually available only in a portion of model domain, and it may not measure the 3D distribution of all atmospheric variables at the same time as other data types. The process of four-dimensional data assimilation (FDDA) has evolved over the years to incorporate the different types of current and past data into numerical models. FDDA techniques are designed to combine data at asynoptic times and at different resolutions. This process requires the use of analysis and data retrieval techniques to produce a 3D data set that resolves mesoscale features and can be used to initialize the model.

Given the recent development of computer workstations with sufficient memory and processing speed, it is now possible to run mesoscale models and provide real-time forecasts at a fraction of the cost that would be required to run these models on mainframe supercomputers such as the CRAY-YMP or CRAY-2. MESO, Inc. delivered a Stardent 3000 computer and MASS to the AMU during the last week of March 1993. The Stardent 3000 is a moderately-priced workstation with 64 MB of memory and two central processors each containing both a scalar processing unit and vector processing unit (VPU). VPUs are typically found on supercomputers and are designed to accelerate the computational speed of calculations which require the same operation on a long stream of operands. The MASS software performs these type of calculations, therefore the design of the Stardent 3000 is especially suited for running MASS and other similar modeling codes.

During their initial model development and testing phase, MESO, Inc. chose a model configuration that allowed for two coarse grid and two fine grid runs per day for 102 real-time simulations performed during the period 30 July through 16 November 1992. This configuration was determined based upon the availability of real-time data, the time required to run the model, and the time at which convection occurs most frequently. MESO, Inc. was able to execute one forecast cycle consisting of a 24-hour course grid run (45 km horizontal resolution) and a 12-hour fine grid run (11 km horizontal resolution) with 20 vertical layers in 6.75 hours on the Stardent by restructuring the code and exploiting the vector and parallel-processing capabilities of the system. The analysis of MESO Inc.'s benchmark simulations suggests that the acquisition of additional processors will substantially reduce the time required to run the model and produce real-time forecast products. The AMU has submitted paperwork to purchase two additional processors from Kubota Pacific so that the Stardent 3000 will ultimately have four processors.

MASS Description

The two major components of MASS are a data pre-processor and a three-dimensional (3D) mesoscale model. Brief descriptions of the pre-processor and the numerical weather prediction model are presented in the following subsections.

Pre-Processor

The pre-processor contains a number of software modules that ingest a diverse mixture of processed and raw data files and convert them to a format that the model can use to specify the initial and boundary conditions for a simulation. The pre-processor performs the following functions:

- Generates grid characteristics which are the boundaries of the model domain and the horizontal resolution.

- Generates surface characteristics which are terrain height from a ~9 km resolution US Central Intelligence Agency global data set, land use or land cover from the US Geological Survey (USGS) 200-400 m resolution data set using the Anderson Level II classification scheme, and fractional vegetation from the Normalized Difference Vegetation Index (NDVI). The NDVI is calculated using ~1 km resolution data collected by the Advanced Very High Resolution Radiometer (AVHRR) instrument aboard the TIROS-N series of National Oceanic and Atmospheric Administration (NOAA) satellites.

- Ingests and quality controls atmospheric data.

- Horizontally interpolates the data to the model grid.

- Performs an objective analysis that provides initial values of atmospheric and surface variables at model grid points from the irregularly-spaced data at different observing locations.

The in-situ and remotely-sensed data sources presently used to initialize the MASS model are obtained from the MIDDS system and transferred directly to the Stardent 3000 computer. Data extracted from MIDDS on a scheduled basis include:

- Gridded fields of temperature, relative humidity, horizontal winds, and geopotential heights from one of the National Meteorological Center's (NMC) numerical models.

- Wind, temperature and moisture from rawinsondes.

- Velocity measurements from KSC's 50 MHz Doppler wind profiler.

- Surface observations including temperature, winds, dew points, and clouds from land-based stations, ships, and buoys.

- Winds, temperatures, and dew points at specific levels up to ~160 m as observed every five minutes by the mesoscale network of instrumented towers surrounding KSC.

- Sea surface temperatures from buoys, ships and coastal stations.

- Manually digitized radar (MDR) data.

- GOES visible (VIS) and infrared (IR) data.

The gridded fields are used as a first-guess for the objective analysis of upper air and surface data and for the specification of lateral boundary conditions throughout the forecast. The manually digitized radar (MDR) data and areal coverage of precipitation from conventional radar sites are used to derive two dimensional fields of precipitation rates. The assimilation of these precipitation rates into the MASS model helps reduce the spin-up of condensation and precipitation during the first few hours of the forecast. Geosynchronous IR and VIS satellite data provide mesoscale detail about the areal coverage of clouds and cloud height (as determined from IR cloud-top temperatures) every 30 minutes at a horizontal resolution of $\leq$ 4 km. MESO, Inc. has developed a scheme that enhances the 3D moisture analysis by creating synthetic relative humidity profiles from a combination of MDR data, visual cloud observations, and IR satellite data. The high resolution satellite and radar data can resolve mesoscale details in the 3D moisture fields especially on the 11 km grid over the data sparse regions off the east and west coasts of Florida.

The AMU is in the process of writing software to reformat the MIDDS data for incorporation into the pre-processor. The routines to process rawinsonde, surface, buoy and ship, KSC Doppler wind profiler, KSC mesonet tower, and VIS and IR satellite data have been tested and implemented on the Stardent 3000. The additional software needed to reformat the MDR data will be completed shortly. The current process for transferring NMC gridded data fields from MIDDS to the Stardent requires saving numerical values to a graphics window. This method is inefficient and potentially unreliable. The AMU has obtained a routine from John Pyatt at the University of Wisconsin (SSEC) that searches for and extracts specified grids from MIDDS data files. This software is being modified and tested in order to remedy the problem with retrieving NMC gridded data fields from MIDDS files.

At the fiscal year 1994 AMU Tasking and Priorities Meeting held in late June, the Weather Support Community agreed that the highest initial priority under this subtask should be to complete the reformatting of the MIDDS data, run the MASS pre-processor to produce a 3D mesoscale analysis, and transfer this analysis product into MIDDS for transmission to SMG and Range Weather Operations. The forecasters can then compare the high-resolution MASS initial analysis with those produced by NMC’s regional models such as the Nested Grid Model (NGM) or Eta model at a horizontal resolution of 80 km. It is anticipated that the MASS analyses will resolve the fine-scale structure (especially in the moisture fields) better than the NMC analyses since the pre-processor will use a horizontal grid resolution as fine as 11 km and will incorporate more mesoscale data.

Figures 12 and 13 are examples of analyses that are derived from MASS using the pre-processor on the 45 km grid (coarse grid) covering the southeastern United States. The pre-processor generated these initial conditions using the relatively coarse resolution Medium Range Forecast (MRF) gridded fields, and rawinsonde, surface, buoy, ship, KSC wind tower, and KSC wind profiler data at 0000 UTC 15 July 1993. When the problem with the retrieval of MIDDS gridded data has been solved, the model will be initialized with gridded data from the higher resolution NGM, Eta or Mesoscale Atmospheric Prediction System (MAPS) analyses. Due to the fact that the MDR data reformatting has not been completed, the 3D moisture re-analysis was not performed. Additionally, the pre-processor was not run over the 11 km fine grid domain covering the Florida peninsula and adjacent coastal waters. Therefore, the analyses shown in Figures 12 and 13 do not incorporate the high resolution IR satellite and radar data that is used to enhance the 3D moisture fields.

Model (Version 5.5)

The MASS model is formulated from a set of differential equations based upon the principles of conservation of momentum, energy, and mass and the ideal gas law. There are seven equations for seven prognostic variables which are temperature, water vapor mixing ratio, horizontal wind components, surface pressure, cloud water/ice mixing ratio, and rain water/snow mixing ratio. The equations are solved over a limited area domain using finite difference approximations on a Cartesian grid mapped to a polar stereographic or mercator image plane. The model is hydrostatic, meaning that the vertical acceleration term in the momentum equation is assumed to be small in comparison to the buoyancy (vertical pressure gradient) and gravity forces. As a result, MASS is not well suited for modeling individual thunderstorms at horizontal resolutions on the order of 1-5 km where the vertical accelerations associated with convective-scale motions cannot be ignored.

Figure 12. Analyses for 0000 UTC 15 July 1993 derived from the MASS pre-processor on the 45 km coarse grid. Panel (a) contains surface wind speed and direction (half barb = 5 kt; full barb = 10 kt) and temperature (°F). Panels (b), (c), and (d) contain wind speed, wind direction, temperature (˚C; negative values dashed) and relative humidity (RH) at (b) 850 mb, (c) 700 mb, and (d) 500 mb. The dark (light) shading in panels (b)-(d) denotes RH values between 70-80% (50-60%). The analyses do not incorporate the high resolution IR satellite and radar data that is used to enhance the 3D moisture fields.

Figure 13. Analyses for 0000 UTC 15 July 1993 derived from the MASS pre-processor on the 45 km coarse grid. Panel (a) contains the K index. Panels (b), (c), and (d) contain vertical velocity (μb s^{-1}; negative values or upward motion shown by dashed lines) and moisture convergence (x 10^{-5} gm kg^{-1} s^{-1}) shown by the shaded regions at (b) 850 mb, (c) 700 mb, and (d) 500 mb. The values of moisture convergence are shaded at intervals of 2 x 10^{-5} gm kg^{-1} s^{-1} beginning with the lightest shading at 2 x 10^{-5} gm kg^{-1} s^{-1}. The analyses do not incorporate the high resolution IR satellite and radar data that is used to enhance the 3D moisture fields.

The model includes detailed representations of the physical processes governing the exchange of mass, momentum, and energy between the earth's surface and the atmosphere. The MASS model surface and radiation parameterizations contain schemes to simulate the surface energy budget, surface hydrology over land, and long and short wave radiation. The surface energy budget predicts the ground temperature based upon a balance between net radiation, sensible and latent heat fluxes, and heat flux from the deep soil layer. The latent heat flux consists of evapotranspiration by plants and evaporation from the top soil layer and ground cover reservoir. The surface energy budget is closely coupled with the soil moisture budget which is modeled using a shallow soil layer (5 cm), a deep (5 - 30 cm) soil layer which is assumed to contain the majority of the plant roots, and a cover moisture reservoir which retains intercepted precipitation. The high-resolution NDVI data is used by the model to modulate the amount of evapotranspiration and to parameterize rainfall interception by the vegetation canopies and the depth of the cover moisture. Additionally, the land use type for a given location forms the basis for the model's specification of short wave albedo, long wave emissivity, surface roughness, fraction of bare soil, and rainfall interception and cover reservoir constants.

The atmospheric water in the MASS model can be handled using two options for grid scale moisture physics. The diagnostic moisture scheme computes grid-scale precipitation by successively evaluating each layer for the production of condensate beginning at the top of the model. On the other hand, the prognostic scheme uses explicit conservation equations for cloud water or cloud ice and rainwater or snow which include the effects of cloud microphysical processes. The latter approach is computationally expensive but allows for the explicit representation of clouds in the model. Since the MASS model is hydrostatic and is not designed to represent individual thunderstorms (< 1 km), it should include a moist convective parameterization or cumulus scheme. The cumulus parameterization calculates changes in the grid-scale dependent variables (e.g. temperature, moisture, etc.) due to convective updrafts and downdrafts on scales which cannot be resolved by the model. If a cumulus parameterization is not used at scales on the order of 11 km, the absence of vertical momentum, energy, and moisture transports by sub-grid scale cloud motions can result in a spurious feedback process which may force the model to predict the unrealistic amplification of convective systems.

MASS Post-processing

The MASS model software reads the initial and boundary condition data provided by the different components of the pre-processor, executes the simulation, and generates a set of output files that are used to examine and analyze the results of the forecast. The development of a post-processing system is required to display model output and derive diagnostic quantities (e.g. convective indices) from observations or model output for use by operational forecasters. The AMU is currently using GEMPAK to display two-dimensional (2D) pre-processor and model output. GEMPAK was installed on the Stardent 3000 computer by the AMU in May 1993. GEMPAK provides publication quality graphics and powerful diagnostic capabilities. This software package will be useful both for examining data output by the pre-processor and mesoscale model and for evaluating the model when it begins running on a daily basis. (Note: GEMPAK was used to generate Figures 12 and 13).

Additional 3D and 4D data visualization capabilities will be provided by the Applications Visualization System (AVS) which was delivered with the Stardent computer. Mesoscale models produce large volumes of data which forecasters must be able to examine and comprehend under operational time constraints. For this reason, the use of visualization packages is highly desirable for viewing, interpreting, and evaluating model output. Since there are presently only two AVS networks resident on the Stardent for processing model output, the AMU will construct additional networks or acquire pre-existing networks from other research groups who are using AVS to display model output. (An AVS network is group of software modules that are coupled together in order to produce graphical displays). A close interaction with the forecasters will be crucial in determining the format and type of products derived from model output that are most useful for weather support of spaceflight operations.

The MASS has been tailored specifically for short-range forecasting in the vicinity of KSC. To accomplish this, the model domain has been limited to increase the number of horizontal grid points (and therefore grid resolution). Additionally, the pre-processor incorporates mesoscale data (e.g. from wind profilers, towers, radars, etc.) which are important for model initialization and model verification. The AMU will be evaluating the model performance in forecasting the short-range weather at KSC. In order to accomplish this task, it is necessary to specify a run-time configuration for the MASS model which includes the source of boundary conditions, physical parameterization options, schedules for data assimilation, and length and attributes of fine and coarse grid runs. MESO, Inc.'s initial configuration of two course grid and two find grid simulations per day should be acceptable for performing real-time forecasts during the AMU's model evaluation phase.

Once the MDR data reformatting is completed, all data sources needed by the pre-processor will be available on the Stardent, and the model can be run on a regular basis. The model will be capable of providing short-range forecasts of its prognostic variables (such as wind, temperature, surface pressure, relative humidity, cloud/rain water, vertical velocity) and diagnosed quantities (such as stability indices, estimates of ceiling, cloud cover, etc.) at scales on the order of 11 km. The output from the model will be available at a much higher temporal frequency which will facilitate forecasting the rapid evolution of mesoscale weather systems. MESO, Inc. has also combined output from the MASS model with observed variables to develop a Mesoscale Statistical-Dynamical Thunderstorm Prediction System (MSTPS) capable of generating hourly probability forecasts of specific thunderstorm-related events at KSC over small space-time windows (11 km; 1-2 h). The development of the statistical model equations and the application of the MSTPS are discussed at length in MESO, Inc.'s final report that was delivered to NASA KSC in June 1993. The AMU will review this approach, make modifications as required, and then apply MSTPS during the real-time model assessment phase to determine how useful the system is in forecasting thunderstorm-related phenomena. The AMU's evaluation of MASS and the MSTPS will be completed by December 1994.

3. Project Summary

Based on an AMU Tasking and Priorities Meeting held on 8-9 October 1992 and subsequent teleconferences and memorandums, the AMU tasks and priorities for FY 1993 were established in late December 1992. The FY 1993 tasking includes the completion of tasks started in FY 1992 and a number of new tasks which have already been or will be started in FY 1993. A brief description of the current tasks is contained in Attachment 1.

The FY 1994 AMU Tasking and Priorities Meeting was held on 1-2 July 1993 and new and revised tasking will be issued to the AMU during the fourth quarter of FY 93. An updated task description will be included with the FY 93 fourth quarter report.

Part of the AMU efforts this past quarter focused on ongoing FY 1992 tasks. This includes the two tenths cloud cover investigation, the KSC fog and stratus study, the implementation and evaluation of the MSFC wind algorithm in NASA's 50 MHz DRWP, and the development of McBasi routines to enhance the usability of the MIDDS for forecasters at the RWO and SMG. The two tenths cloud cover investigation has been completed and distribution of the final report is awaiting permission from the NASA Public Affairs Office. Significant progress has been made on the implementation and evaluation of the MSFC wind algorithm in NASA's 50 MHz DRWP and that effort should be completed in the fourth quarter of FY 93. The KSC fog and stratus study will also be completed in the fourth quarter of FY 1993. The MIDDS enhancement task is an ongoing effort with product deliverables as required.

FY 1993 tasks which have received attention this past quarter include the evaluation of the MASS mesoscale model, the ASOS evaluation, and the acquisition of the RAMS model. This past quarter, AMU efforts focused on modifying the MASS model ingesters to handle data from MIDDS. Although not completed, significant progress has been made in this area. This effort will continue in the fourth quarter of FY 93. The AMU also started the ASOS evaluation task this past quarter. The ASOS evaluation task will be completed in the fourth quarter of FY 93. Also during this past quarter, ENSCO, Inc. subcontracted with ASTeR, Inc. to acquire and modify the RAMS model for use at Kennedy Space Center. Since this effort began in June, no significant activity has occurred yet. Status of this effort will be included in the FY 93 fourth quarter report.

This next quarter the AMU will start work on a number of the new FY 1993 tasks including:

- LDAR evaluation,
- Melbourne NEXRAD evaluation, and
- Forecaster guidance tools development.

Attachment 1: AMU FY-93 Tasks

Task 1 AMU Operations

- Operate the AMU. Coordinate operations with NASA/KSC and its other contractors, 45th Space Wing and their support contractors, the NWS and their support contractors, other NASA centers, and visiting scientists.

- Establish and maintain a resource and financial reporting system for total contract work activity. The system shall have the capability to identify near-term and long-term requirements including manpower, material, and equipment, as well as cost projections necessary to prioritize work assignments and provide support requested by the government.

- Monitor all Government furnished AMU equipment, facilities, and vehicles regarding proper care and maintenance by the appropriate Government entity or contractor. Ensure proper care and operation by AMU personnel.

- Identify and recommend hardware and software additions, upgrades, or replacements for the AMU beyond those identified by NASA.

- Prepare and submit in timely fashion all plans and reports required by the Data Requirements List/Data Requirements Description.

- Prepare or support preparation of analysis reports, operations plans, presentations and other related activities as defined by the COTR.

- Participate in technical meetings at various Government and contractor locations, and provide or support presentations and related graphics as required by the COTR.

- Design McBasi routines to enhance the usability of the MIDDS for forecaster applications at the RWO and SMG. Consult frequently with the forecasters at both installations to determine specific requirements. Upon completion of testing and installation of each routine, obtain feedback from the forecasters and incorporate appropriate changes.

Task 2 Training

- Provide initial 40 hours of AMU familiarization training to Senior Scientist, Scientist, Senior Meteorologist, Meteorologist, and Technical Support Specialist in accordance with the AMU Training Plan. Additional familiarization as required.

- Provide KSC/CCAFS access/facilities training to contractor personnel as required.

- Provide NEXRAD training for contractor personnel.

• Provide additional training as required. Such training may be related to the acquisition of new or upgraded equipment, software, or analytical techniques, or new or modified facilities or mission requirements.

Task 3 Improvement of 90 Minute Landing Forecast

• Develop databases, analyses, and techniques leading to improvement of the 90 minute forecasts for STS landing facilities in the continental United States and elsewhere as directed by the COTR. Specific efforts will be designated as numbered subtasks. The two initial subtasks are specified below. Additional sub tasks will be of similar scope and duration, and will be assigned by technical directives issued by the COTR.

• Subtask 1 - Two Tenths Cloud Cover

•• Develop a database for study of weather situations relating to marginal violations of this landing constraint. Develop forecast techniques or rules of thumb to determine when the situation is or is not likely to result in unacceptable conditions at verification time. Validate the techniques and transition to operations.

• Subtask 2 - Fog and Stratus At KSC

•• Develop a database for study of weather situations relating to marginal violations of this landing constraint. Develop forecast techniques or rules of thumb to determine when the situation is or is not likely to result in unacceptable conditions at verification time. Validate the techniques and transition to operations.

Subtask 3 - Two Tenths Cloud Cover Data Base

•• The 0.2 cloud cover sub task is extended to include maintenance of its associated data base indefinitely. This shall include keeping the data base current and accessible.

Subtask 4 - Forecaster Guidance Tools

•• The 0.2 cloud cover sub task is extended to include development of forecaster guidance tools including those based on artificial neural net (ANN) technology.

Subtask 5 - PBL Post-Sunrise Winds

•• Commence a study of the PBL post-sunrise wind field at KSC by compiling the requisite data base.

Task 4 Instrumentation and Measurement Systems Evaluation

• Evaluate instrumentation and measurement systems to determine their utility for operational weather support to space flight operations. Recommend or develop modifications if required, and transition suitable systems to operational use.

• Subtask 3 - Doppler Radar Wind Profiler (DRWP)

•• Evaluate the current status of the DRWP and implement the new wind algorithm developed by MSFC. Operationally test the new algorithm and software. If appropriate, make recommendations for transition to operational use. Provide training to both operations and maintenance personnel. Prepare a final meteorological validation report quantitatively describing overall system meteorological performance.

• Subtask 4 - Lightning Detection and Ranging (LDAR) System

•• Evaluate the NASA/KSC Lightning Detection and Ranging (LDAR) system data relative to other relevant data systems at KSC/CCAFS (e.g., LLP, LPLWS, and NEXRAD). Determine how the LDAR information can be most effectively used in support of NASA/USAF operations. If appropriate, transition to operational use.

• Subtask 5 - Melbourne NEXRAD

•• Evaluate the effectiveness and utility of the Melbourne NEXRAD (WSR-88D) operational products in support of spaceflight operations. This work will be coordinated with appropriate NWS/FAA/USAF personnel.

• Subtask 6 - SLF Wind Sensor Siting

•• Commence a study of the siting of the wind sensors at the Shuttle Landing Facility (SLF) by assembling the appropriate data base.

• Subtask 7 - ASOS Evaluation

•• Evaluate the effectiveness and utility of the ASOS data in terms of spaceflight operations mission and user requirements.

Task 5 Mesoscale Modeling

• Evaluate Numerical Mesoscale Modeling systems to determine their utility for operational weather support to space flight operations. Recommend or develop modifications if required, and transition suitable systems to operational use.

• Subtask 1 - Evaluate the NOAA/ERL Local Analysis and Prediction System (LAPS)

•• Evaluate LAPS for use in the KSC/CCAFS area. If the evaluation indicates LAPS can be useful for weather support to space flight operations, then transition it to operational use.

• Subtask 2 - Install and Evaluate the MESO, Inc. Mesoscale Forecast Model

•• Install and evaluate the MESO, Inc. mesoscale forecast model for KSC being delivered pursuant to a NASA Phase II SBIR. If appropriate, transition to operations.

• Subtask 3 - Acquire the Colorado State University RAMS Model

•• Acquire the Colorado State University RAMS model or its equivalent tailored to the KSC environment. Develop and test the following model capabilities listed in priority order:

1) Provide a real-time functional forecasting product relevant to Space Shuttle weather support operations with grid spacing of 3 km or smaller within the KSC/CCAFS environment.

2) Incorporate three dimensional explicit cloud physics to handle local convective events.

3) Provide improved treatment of radiation processes.

4) Provide improved treatment of radiation processes.

5) Demonstrate the ability to use networked multiple processors.

Evaluate the resulting model in terms of a pre-agreed standard statistical measure of success. Present results to the user forecaster community, obtain feedback, and incorporate into the model as appropriate. Prepare implementation plans for proposed transition to operational use if appropriate.