P2.5 SHORT-TERM FORECASTS AT KENNEDY SPACE CENTER USING THE ARPS DATA ANALYSIS SYSTEM

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1. INTRODUCTION

"There is a need to develop local analysis systems that incorporate all data sources and provide high-resolution gridded fields appropriate for forecaster and numerical model use." This recommendation was one of several made by a National Research Council panel assembled to review weather support to the Space Shuttle program (National Research Council, 1988). The panel made this recommendation following the Challenger accident in January 1986 and the Atlas-Centaur 67 launch failure (Christian et al., 1989) after reviewing the large number of observing systems used at Kennedy Space Center (KSC) at that time. The panel felt that the "abundant and diverse types of data may confuse weather personnel" unless data from all sources were assimilated and transformed into "high-resolution gridded fields of understandable variables" (National Research Council, 1988).

During the thirteen years subsequent to the National Research Council report, the challenge facing the forecaster has not disappeared. New geostationary satellites have been fielded which provide 1-km resolution visible imagery, as well as 4 other channels of imagery, at time intervals as short as 1 minute. The National Weather Service (NWS) also completed the deployment of a network of Doppler weather surveillance radars providing the forecaster approximately 60 products every 5-6 minutes per radar site. In addition, a well-instrumented mesoscale network of wind towers and profilers at the KSC provides weather information at high spatial and temporal resolution (a full set of data from all instruments every 15 minutes with 4-km horizontal spacing and vertical spacing on the order of 150 m from the surface to 18 km). NWS Spaceflight Meteorology Group (SMG) forecasters, responsible for issuing Space Shuttle landing forecasts (Brody et al. 1997), find integrating this vast amount of information to be a challenge. Mental and manual techniques for assimilating the data are also time-consuming and contain subjective interpretation. For example, researchers have demonstrated that nowcasts of thunderstorm initiation required detailed boundary layer, radar, and cloud observations (Mueller and Wilson 1989; Wilson and Mueller 1993). These researchers also found forecaster techniques for integrating the data and making short-term forecasts were manually intensive and frequently error prone.

Recent developments in data assimilation models and computing systems have made it possible to routinely run a data assimilation system at a local forecast office with relatively inexpensive computer hardware. A data assimilation model provides the capability to quality control the data and produce automated gridded analyses at high temporal resolution. Currently, the NWS Advanced Weather Interactive Processing System (AWIPS) includes the Local Analysis and Prediction System (LAPS) to provide forecasters with hourly mesoscale analyses (Albers et al. 1996). In addition to the AWIPS LAPS analysis, SMG forecasters have access to analyses produced by the Advanced Regional Prediction System (ARPS) Data Analysis System (ADAS) (Brewster 1996). The SMG ADAS configuration provides forecasters with an analysis every 15 minutes at higher spatial resolutions than the LAPS analysis.

This paper will address the use of the ADAS analyses as a tool for short-term forecasting of Space Shuttle flight hazards. Section 2 describes the SMG ADAS configuration and data sources integrated into the analysis. Section 3 discusses the operational utility of the ADAS analyses. Planned improvements to the ADAS analysis are discussed in Section 4, and Section 5 provides a brief summary.

2. ADAS CONFIGURATION, DATA SOURCES, AND DISPLAY

The SMG ADAS analyses are generated on both a 10-km and 2-km grid centered over the Shuttle Landing Facility at KSC. The 10-km (2-km) grid covers an area of 500 x 500 km (200 x 200 km) with 30 vertical levels from the surface to about 16.5 km above ground level. An ADAS analysis is produced every 15 minutes at 0, 15, 30, and 45 minutes past the hour over each grid. The analysis is run 9 minutes after the analysis time and uses data received in a 15-minute window centered on the analysis time. The SMG ADAS system is currently configured to ingest the real-time data shown in Table 1.

The ADAS analysis grids are output into the General Meteorological Package (GEMPAK) format. The forecaster can interactively display and manipulate the grids using GEMPAK programs and the GEMPAK Analysis and Rendering Program (GARP) graphical user interface. This software allows the forecaster to display plan view and cross sections of meteorological variables as well as vertical profiles of the data. Some products displaying weather information significant to Shuttle landing forecasts are automatically created and converted into graphic images for viewing. The ADAS products shown on the SMG web page (http://www.srh.noaa.gov/ smg/smgwx.html) are examples of these products produced in real-time.

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Table 1. A list of the real-time data and their characteristics that are ingested into the ADAS at SMG.

Observational Data Source	Data Characteristics
Background Field	RUC 3 to 6 hour forecasts, linearly interpolated in time every 15 minutes. (2-km analysis uses 10-km analysis as background)
Satellite	1-km resolution visible imagery (day time only) and 4-km resolution infrared imagery.
Doppler weather radar	NEXRAD Information Dissemination System (NIDS) data for Melbourne, Tampa Bay, Jacksonville, and Miami. Only reflectivity and velocity data are used. The four lowest elevation angles are used for Melbourne; other sites use the two lowest elevation angles.
Surface observations	Routine and Special aviation observations. Ship and buoy data over water.
Kennedy Space Center / Cape Canaveral Air Force Station Mesonet data	Tower-based measurements of temperature, dewpoint, and winds at various levels from surface to 150 m at locations within about 30 km of the Shuttle Landing Facility.
Kennedy Space Center 50-MHz profiler	Winds from 2 km to 18.6 km AGL.
Cape Canaveral Air Force Station 915-MHz profilers	Winds from 0.12 km to 3-4 km AGL.

3. OPERATIONAL UTILITY

SMG forecasters are responsible for issuing all landing forecasts for the Space Shuttle missions. The acceptable conditions for landing the Shuttle are documented in the Space Shuttle Flight Rules (NASA 1999). Table 2 contains a summary of some particular rules related to clouds, thunderstorms and precipitation. Two of the most important forecasts are the pre-launch return-to-launch-site forecast and the de-orbit burn landing forecast issued about 35-minutes and 90-minutes, respectively, prior to the expected landing time. Forecasters must use data throughout the state of Florida and offshore waters to fully evaluate the flight rules and develop the forecast. This evaluation area is necessary given the time from the issuance of the forecast to the time of landing and the large area (30-nautical mile radius around KSC) over which the weather conditions must be acceptable.

A cloud ceiling display for 1400 UTC 26 April 2001 (Figure 1) developed using ADAS cloud analysis scheme (Zhang et al. 1998) is shown as an example of the use of the grid analysis to monitor Space Shuttle flight rules. As noted in Table 2, clouds ceilings below 8000 feet are a “No-Go” condition for a Shuttle landing at the end of a mission. The cloud ceiling display provides the forecaster with a quick look at all ceilings below 10,000 feet to help the forecaster monitor areas that are near or below the “No-Go” ceiling threshold. Once an area of “No-Go” ceilings has been identified by the ADAS analysis, the forecaster can then use the successive grid analyses to track the movement and development of the cloud ceilings. It is not the authors’ intent to suggest that the ADAS analysis is a substitute for looking at the raw data. Rather, the analyses are a tool to help the forecaster sift through the vast amount of data and focus their efforts on the most important pieces of information. The ADAS cloud ceiling display shown in Figure 1 may help the forecaster focus on examining the surface observations to the north-northeast of Tampa Bay (TBW) as well as the Tampa Bay radar. Periodic review of the grid analyses can also alert the forecaster to monitor particular data sources that may have been overlooked due to the volume of data and the tight time constraints involved in Space Shuttle support.

Cloud top height displays (not shown) have also been developed to assist SMG forecasters in Space Shuttle landing forecasts. Cloud top height is an important consideration for evaluating the potential for electrification with the clouds, both for thunderstorms as well as stratiform clouds that may pose a triggered lightning threat. On a launch or landing day with rain showers present in Florida, SMG forecasters can expect multiple weather radars completing volume scans every 6 minutes and geostationary satellite imagery approximately every 7 minutes (on average in rapid scan operations). ADAS derived cloud height products are valuable since they routinely represent an analysis combining the satellite imagery with the radar data from the radar sites surrounding KSC. It is quite a challenge for the forecaster to routinely review all these data within the time constraints imposed by Shuttle operations.

SMG also issues forecasts of flight level winds for the landing time (Bellue et al, 1996). Space Shuttle flight controllers use the forecasts and upper level wind observations to ensure the Shuttle lands with an acceptable margin of safety considering the kinetic energy and controllability of the vehicle. ADAS analyses can be used to provide an integrated profile of flight level winds experienced by the Shuttle on descent. Historically, a rawinsonde launched at Shuttle landing time has been considered the best estimate of the wind experienced by the Shuttle during landing. However, the rawinsonde has both spatial and temporal differences between the balloon location and the location of the Shuttle’s descent path.

Table 2. A list of the weather constraints that restrict Space Shuttle landings.

Weather Constraint	Threshold	Purpose
Ceiling	>8000 feet	Provide astronaut commander sufficient time to visually acquire runway and landing aids
Thunderstorms (including attached non-transparent anvils and cumulus clouds above –20C) and Precipitation	None with 30 nm of center of runway or within 10 nm horizontally of flight path	1) Avoid damage to vehicle by natural or triggered lightning 2) Avoid structural damage and control problems due to turbulence 3) Avoid damage to thermal control system (“heat tiles”)
Detached non-transparent anvils less than 3 hours old	None within 20 nm of center of runway or within 10 nm horizontally of flight path	Avoid damage to vehicle by natural or triggered lightning

ADAS provides an objective method to combine the 50-MHz Doppler radar wind profiler and five 915-MHz wind profilers surrounding KSC into an integrated wind profile along the Shuttle’s actual flight path.

Figures 2 and 3 compare the wind profile extracted from the ADAS analysis to a wind profile from the rawinsonde launched at 1400 UTC 25 April. Due to the real-time lag in receiving rawinsonde data, these data are not currently integrated into the ADAS analysis. However, the rawinsonde data can provide an independent source to estimate the accuracy of the analysis. The ADAS grid point nearest to the rawinsonde launch facility was chosen to provide the wind profile from the analysis. As a result, this comparison will contain some temporal and spatial discrepancies due to the fact that the balloon was launched at the time of the grid analysis, but rose at a rate of approximately 5 m/s, and was blown down wind from the balloon launch site. Considering this fact, the differences between the grid wind profile and the rawinsonde winds are relatively small. In this instance, the mean absolute deviation of the wind speed was less than 0.5 m s^{-1} with absolute differences ranging from 0.02 to 1.26 m s^{-1}. The mean absolute difference of the wind direction was 15.4 degrees with a range of 1.5 to 32.6. These differences are comparable to the accuracy of the rawinsonde system. Of course, a more extensive study involving numerous comparisons of grid and rawinsonde winds would be needed to provide a good estimate of the representative differences.

4. PLANNED IMPROVEMENTS

Subjective assessment of the ADAS analyses over the past six months has highlighted some possible areas for improvement. The SMG ADAS configuration has difficulty with the low-level cloud analysis particularly during the winter when the sea-surface temperatures are often warmer than the land. Forecasters perceived that the surface observations had too much spatial influence on the cloud analysis and stated that the surface observations overwhelmed the finer scale information available from the satellite and radar data. Also, the surface wind analysis appears to have a positive speed bias. Finally, the upper level winds outside of the immediate area of KSC do not appear significantly different than the RUC background fields due to the lack of upper-air information in the current data ingest.

SMG is working with the NASA Applied Meteorology Unit (AMU) and the NWS Forecast Office at Melbourne, FL to overcome these limitations. Some configuration changes that may improve the quality of the analyses include:

- Replacing the 10-km background fields with 1-3 hour RUC forecasts rather than 3-6 hour RUC forecasts, and using the native RUC vertical coordinates rather than pressure coordinates. These changes may improve the background surface wind fields.
- Incorporating ACARS data to improve upper level wind analyses.
- Incorporating Level II Doppler weather radar data from Melbourne to improve the resolution of cloud features and the accuracy of the wind analyses.
- Modifying the ADAS configuration parameters to optimize the analysis of the various data sources.

In addition to improving the quality of the analysis, SMG forecasters need better tools to visualize the data. GEMPAK can be used to create some very effective graphic displays and additional graphics tailored for evaluating Space Shuttle Flight Rules will be developed. The ADAS grids will also be output in Grid in Binary (GRIB) format. The GRIB files can then be ingested into the SMG AWIPS system for display. This will allow the forecaster to integrate the grid analysis with other information and use all the mesoscale forecasting tools available in AWIPS. For example, the point and line tool in AWIPS could be used to extrapolate weather features seen in ADAS gridded displays.

Forecasters also need automated alert messages that are generated based on the grid analysis. For example, an alert could be generated to notify the forecaster of the development of high winds within a specified forecast area. This alert monitoring and generation process is needed at the completion of each analysis cycle. Automated alert monitoring and notification can help ensure all flight rule conditions are fully evaluated by the forecast team. This alert feature is not currently present in either the SMG ADAS configuration or the AWIPS LAPS at this time.

5. CONCLUSION

This paper discussed the configuration and characteristics of the ADAS at SMG to support short-range forecasting problems for the Space Shuttle. ADAS provides the forecaster with an integrated analysis that incorporates the mesoscale data available at the Kennedy Space Center. Graphical displays have been developed to assist forecasters in evaluating and predicting Space Shuttle specific weather constraints. Additional work is needed to improve the quality of the analysis and to develop improved graphical displays.

6. Acknowledgements

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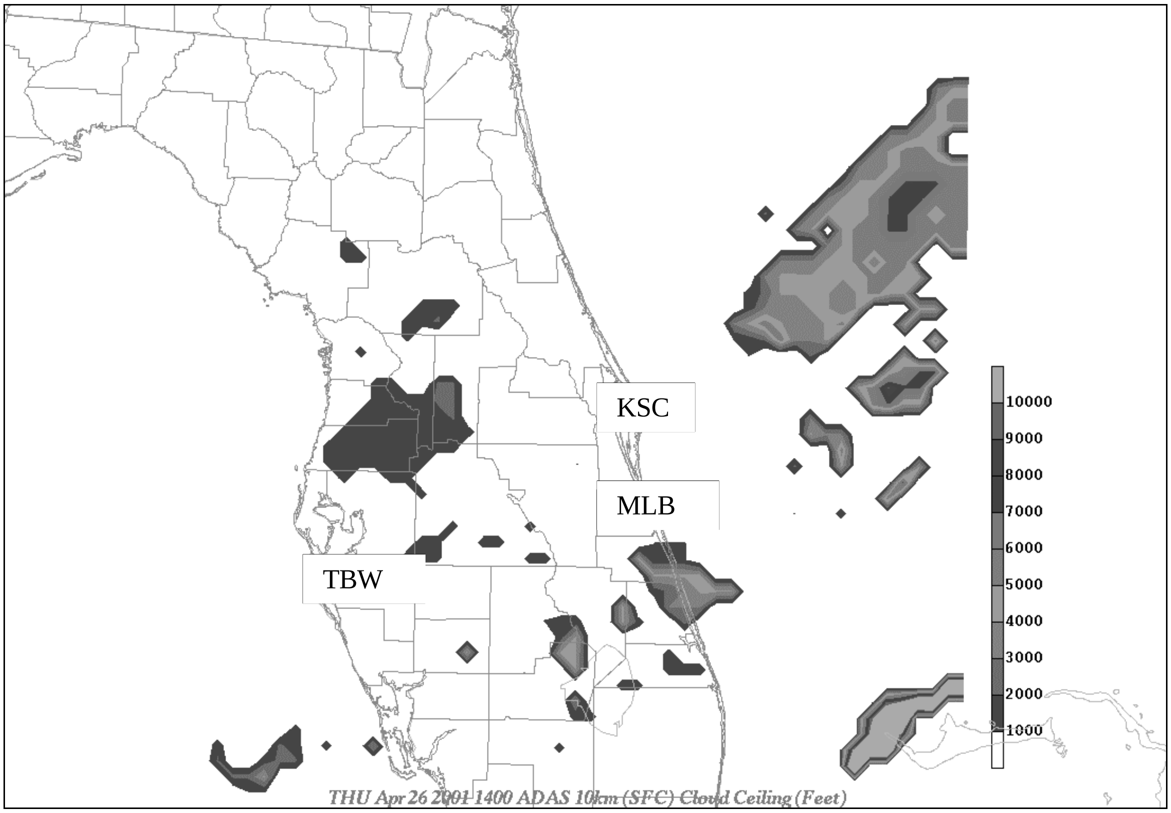

Figure 1. Cloud ceiling (feet) for 1400 UTC on 26 Apr 2001. Only cloud ceilings less than 10,000 feet are shown. Locations shown are Kennedy Space Center (KSC), Melbourne (MLB), and Tampa Bay (TBW).

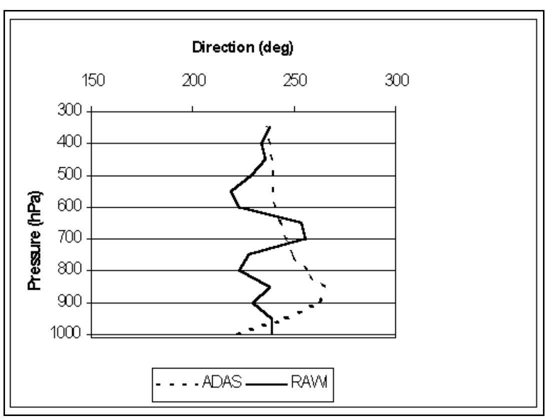

Figure 2. Comparison of ADAS wind direction versus pressure to the corresponding rawinsonde (RAWI) for 1400 UTC 25 April 2001.

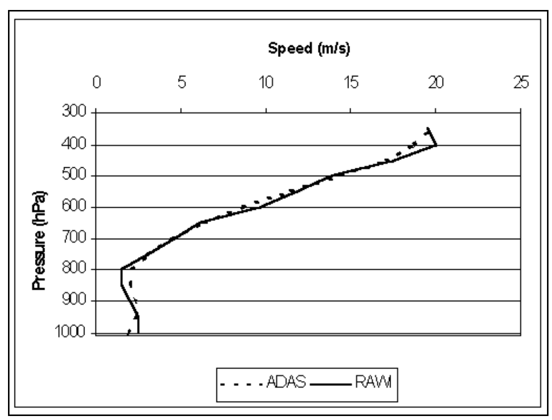

Figure 3. Comparison of ADAS wind speed versus pressure with the corresponding rawinsonde (RAWI) for 1400 UTC 25 April 2001