

P1.3 ANVIL FORECAST TOOL IN THE ADVANCED WEATHER INTERACTIVE PROCESSING SYSTEM (AWIPS)

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1. Introduction

Launch Weather Officers (LWOs) from the 45th Weather Squadron (45 WS) and forecasters from the National Weather Service (NWS) Spaceflight Meteorology Group (SMG) have identified anvil forecasting as one of their most challenging tasks when predicting the probability of violating the Lightning Launch Commit Criteria (LLCC) (Krider et al. 2006; Space Shuttle Flight Rules (FR), NASA/JSC 2004)). As a result, the Applied Meteorology Unit (AMU) developed a tool that creates an anvil threat corridor graphic that can be overlaid on satellite imagery using the Meteorological Interactive Data Display System (MIDDS, Short and Wheeler, 2002). The tool helps forecasters estimate the locations of thunderstorm anvils at one, two, and three hours into the future. It has been used extensively in launch and landing operations by both the 45 WS and SMG. The Advanced Weather Interactive Processing System (AWIPS) is now used along with MIDDS for weather analysis and display at SMG. In Phase I of this task, SMG tasked the AMU to transition the tool from MIDDS to AWIPS (Barrett et al., 2007).

For Phase II, SMG requested the AMU make the Anvil Forecast Tool in AWIPS more configurable by creating the capability to read model gridded data from user-defined model files instead of hard-coded files. An NWS local AWIPS application called AGRID was used to accomplish this. In addition, SMG needed to be able to define the pressure levels for the model data, instead of hard-coding the bottom level as 300 mb and the top level as 150 mb.

This paper describes the initial development of the Anvil Forecast Tool for MIDDS, followed by the migration of the tool to AWIPS in Phase I. It then gives a detailed presentation of the Phase II improvements to the AWIPS tool.

2. MIDDS Tool Development

The Anvil Tool in MIDDS was developed by the AMU in three phases. Phase I established the technical feasibility of developing an observations-based forecasting technique using the relationship between anvil length/lifetime and the average wind velocity and moisture content in the anvil layer (Lambert 2000). In

Phase II, the AMU developed a nowcasting anvil threat sector tool (Short and Wheeler 2002) that was transitioned into 45 WS and SMG operations. Using upper-tropospheric wind data from current rawinsonde observations, the tool created a graphic that showed the areas where thunderstorm formation could produce anvil clouds that would threaten a user-selected area of interest. After calculating the 300- to 150-mb layer-average wind velocity, the tool created a graphic with the following features:

- 20 NM standoff circle centered at the station of interest,
- 30 degree sector width, and
- One-, two-, and three-hour arcs in the upwind direction.

The graphic could be overlaid onto a weather satellite or radar image. In Phase III, the AMU added the capability of creating a graphic using Eta and Medium Range Forecast (MRF) model point data, in addition to rawinsonde observations (Wheeler and Short 2003).

The tool was modified again in the Updated Anvil Threat Corridor Forecast Tool task (Wheeler 2005) to accommodate changes in the data formats of the rawinsonde observations and model forecast data. Three changes had taken place since the Phase III task:

- The operational upper-air sounding system at Cape Canaveral Air Force Station (CCAFS) changed from the Meteorological Sounding System to the Automated Meteorological Profiling System (AMPS),
- The national model names changed from Eta to North American Mesoscale (NAM) and from MRF to Global Forecast System (GFS), and
- The model data format changed from Meteorological Data to Network Common Data Form (NetCDF).

In addition, the AMU created a graphical user interface (GUI) to allow easier access to the tool. The GUI was written in a scripting language called Tool Command Language (Tcl) and its associated GUI toolkit (Tk). The GUI's Main Menu allowed the user to select the label position, launch complex or site, color, date and time, and data type (Figure 1). The data types included rawinsonde observations, model data, and the 50 MHz profiler observation at Kennedy Space Center (KSC). The model data included the Rapid Update Cycle (RUC), NAM, and GFS forecasts.

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The sites available included all of the CCAFS and KSC launch complexes, Melbourne, Florida (MLB), Edwards Air Force Base, California (EDW), and White Sands Missile Range (WSD), New Mexico. In addition to

KSC, EDW and WSD are alternate Space Shuttle landing sites. The site selected is the focal point of the Anvil Threat Corridor graphic.

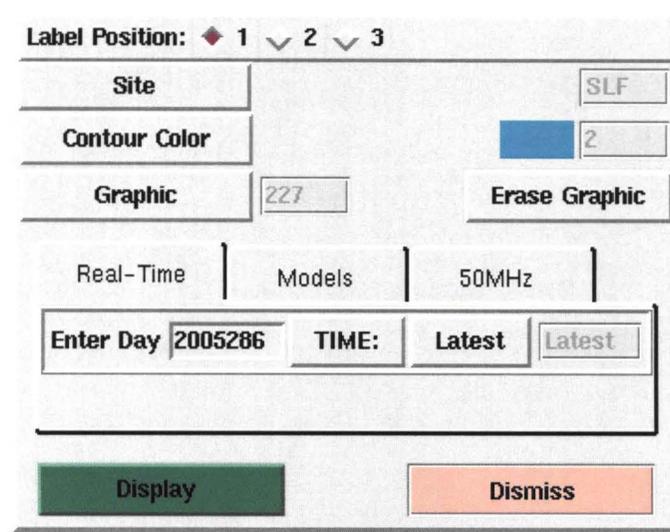


Figure 1. MIDDS Anvil Tool GUI's Main Menu.

3. AWIPS Anvil Forecast Tool, Phase I

The MIDDS Anvil Tool used code written in the McIDAS BASIC Language Interpreter (McBASI) programming language to calculate the 300- to 150-mb average wind velocity, as well as the latitude/longitude (lat/lon) points that make up the graphic (Barrett et al. 2007). To transition the tool from MIDDS, the AMU first rewrote the McBASI code into Tcl/Tk code. When run in AWIPS, the Anvil Forecast Tool first created and displayed a data entry GUI giving the user a choice of using rawinsonde observations ("RAOB"), model data ("Models"), or 50 MHz profiler data ("50MHz") (Figure 2). If rawinsonde or profiler data was selected, the user then selected a date and time of the observation. Otherwise, the user selected a model type (RUC, NAM, or GFS), the forecast model initialization time and the forecast hour. The user then selected a Site, which served as the focal point of the anvil threat corridor graphic. Finally, after selecting an observation Station (or Forecast Hour if model data was used), the 300- to 150-mb average wind was calculated.

After the layer-average wind was calculated, the user created the graphic by selecting the Make button. The tool first calculated the graphic's lat/lon points. Next, the tool stored the lat/lon points as a Shapefile, which is a Geographic Information System (GIS) file standard developed by Environmental Systems Research Institute, Inc. (ESRI 1998). The tool used version 1.2.10 of the Shapefile C library (Warmerdam 2007) to create the Shapefile.

A comparison between the MIDDS and AWIPS Anvil Tools can be seen in Figures 3 and 4 using the CCAFS rawinsonde, which is the closest upper-air observation to the Shuttle Landing Facility (SLF), at 1200 UTC, 7 March 2007. For the CCAFS rawinsonde observation, the MIDDS tool used data in AMPS format, while the AWIPS tool used data in the NWS upper-air format. Figure 3 shows the MIDDS graphic and Figure 4 shows the AWIPS graphic. There were slight differences between the AWIPS and MIDDS tools due to the different data formats. In this case, MIDDS calculated a layer-average wind speed of 80 kt, with a wind direction of 273°. AWIPS calculated a layer-average wind speed of 78 kt and a wind direction of 275°.

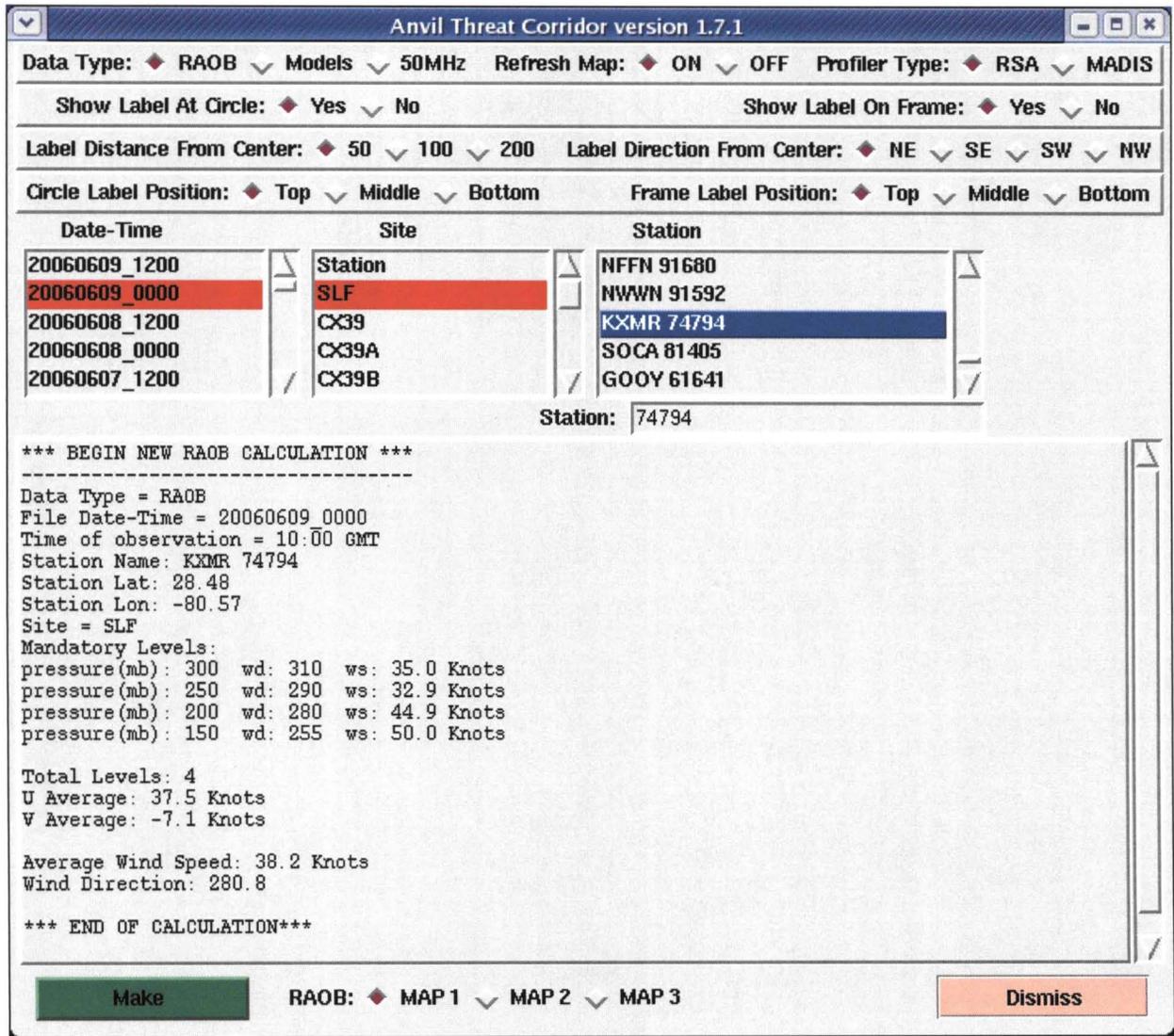


Figure 2. AWIPS Anvil Forecast Tool GUI from Phase I. The text box displays the input data used to calculate the layer-average wind velocity. In this example, the XMR rawinsonde observation from 1000 UTC on 9 June 2006 was used.

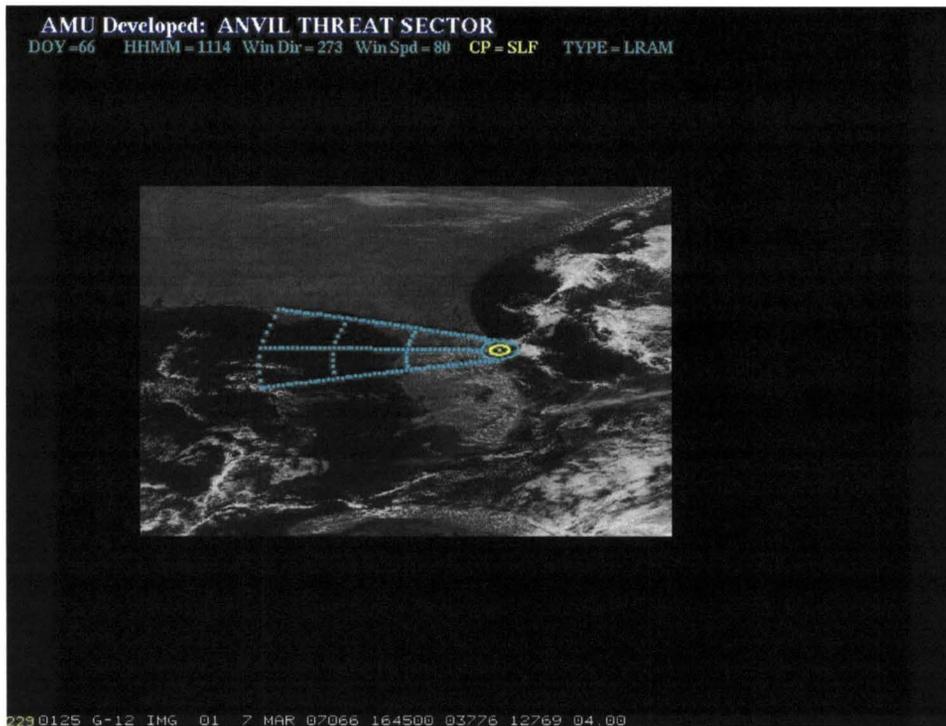


Figure 3. MIDDs tool graphic for the SLF at 1200 UTC, 7 March 2007.

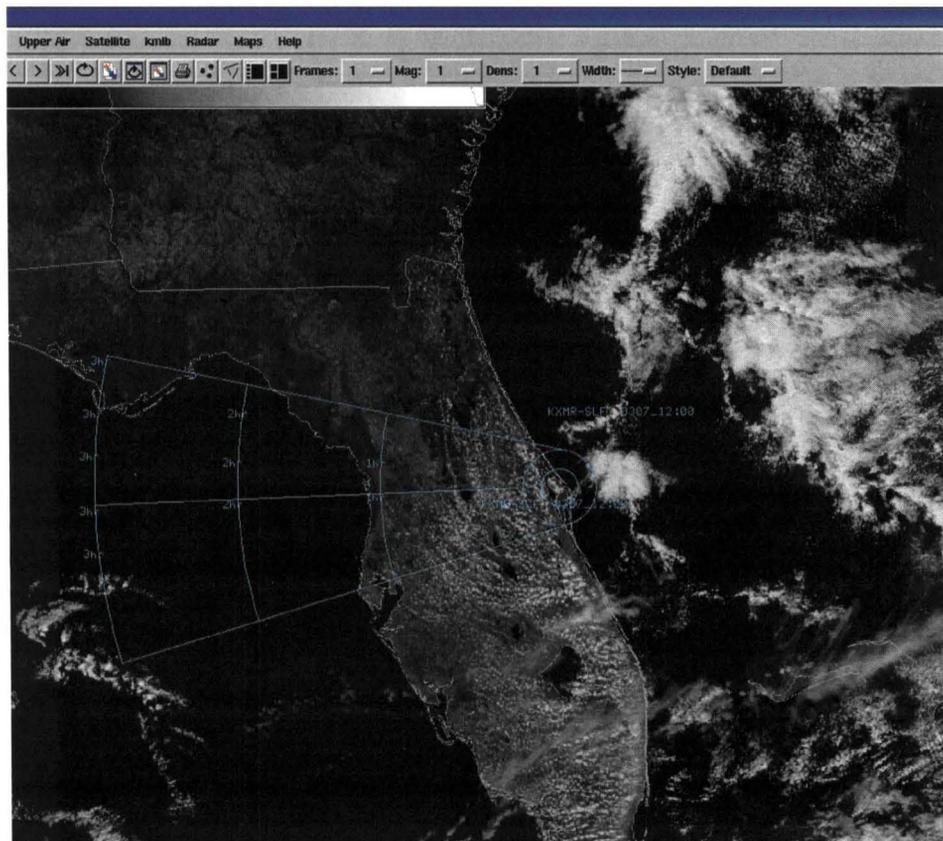


Figure 4. AWIPS tool graphic for the SLF at 1200 UTC, 7 March 2007.

4. AWIPS Anvil Forecast Tool, Phase II

The AMU made two improvements to make the AWIPS Anvil Forecast Tool more configurable. The first was to create "User Profiles" so users can define the model data files, atmospheric pressure levels, and other parameters used in the tool. The second was to modify the tool's source code to use an AWIPS application, AGRID, to make it easier to select and read gridded model data.

The initial GUI is displayed in Figure 5. A menu was added to allow the user to view the current User Profile or add a new User Profile. The label options for the graphic were incorporated into two new menus, "Circle Label Options" and "Frame Label Options". The "Site" listbox from the previous version of the tool (Figure 2) was renamed "Center of Plot".

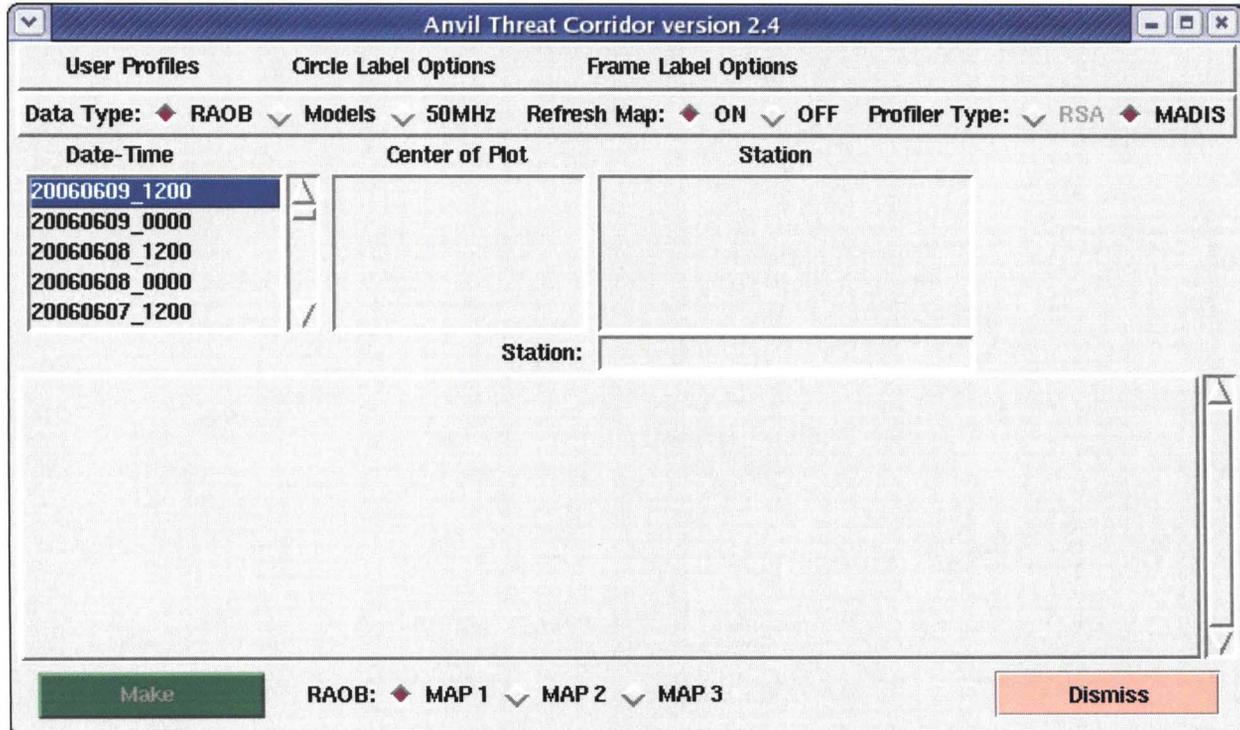


Figure 5. The new AWIPS Anvil Tool GUI developed in Phase II.

4.1. User Profiles

A User Profile is a text file that defines several parameters previously hard-coded into the tool's source code. User Profiles make the tool more configurable and easier to maintain and update, since the parameters are easier to change. All of the User Profiles are stored in the installation directory, with a filename extension of

".profile". When the tool is started, the user is prompted to select a User Profile. A new User Profile can be created through the GUI or by creating a new file with a text editor. User Profiles can only be modified with a text editor. The tool must be restarted to change the current User Profile. The tool's installation files include a default User Profile named default.profile (Figure 6).

```
Current User Profile

# default.profile
# Global variables
innerRadius 10
outerRadius 20

minSigW 9000
maxSigW 14000
topMan 150
bottomMan 300

numLaunchSites 9
CX39 28.6269 -80.6213 74794
CX39A 28.6083 -80.6041 74794
CX39B 28.6269 -80.6213 74794
CX40 28.562 -80.5772 74794
CX41 28.5835 -80.5829 74794
CX37 28.531 -80.5671 74794
CX17 28.4458 -80.5656 74794
CX17A 28.4472 -80.5649 74794
CX17B 28.4458 -80.5656 74794

numLandingSites 3
SLF 28.617 -80.683 74794
EDW 34.92 -117.9 72381
WSD 32.9 -106.4 72269

numLocations 1
MLB 28.1 -80.65 74794

# Model variables
RUCpath /data/fxa/Grid/SBN/netCDF/CONUS211/RUC
NAMpath /data/fxa/Grid/SBN/netCDF/CONUS211/Eta
GFSPath /data/fxa/Grid/SBN/netCDF/CONUS211/AVN
Models1Key 1325
Models2Key 1326
Models3Key 1327
interFlag 0

# RAOB variables
RAOBpath /data/fxa/point/raob/netcdf
RAOB1Key 1319
RAOB2Key 1320
RAOB3Key 1321

# 50MHz profiler variables
RSA 0
MADIS 1
RSAPath /data/fxa/LDAD/profiler/50mhz/netCDF
MADISpath /data/fxa/LDAD/profiler/netCDF
MADISid KSCFL
Profiler1Key 1322
Profiler2Key 1323
Profiler3Key 1324
RSAName stationName
MADISname providerId

OK
```

Figure 6. The default User Profile in the AWIPS Anvil Tool, Phase II.

A User Profile contains the following parameters:

- **innerRadius** - the radius, in NM, of the inner circle of the graphic,
- **outerRadius** - the radius, in NM, of the outer circle of the graphic,
- **minSigW** - the height, in m, of the lowest significant level used to calculate the layer-average wind velocity (used in RAOB and 50MHz data types),
- **maxSigW** - the height, in m, of the highest significant level used to calculate the layer-average wind velocity (used in RAOB and 50MHz data types),
- **topMan** - the top mandatory level, in mb, used to calculate the layer-average wind velocity (used in RAOB and Models data types),
- **bottomMan** - the bottom mandatory level, in mb, used to calculate the layer-average wind velocity (used in RAOB and Models data types),
- **numLaunchSites** - the number of vehicle launch sites displayed in the Center of Plot listbox. The launch sites are listed after this parameter. Each launch site contains a name, lat/lon, and 5-digit identifier of the closest RAOB,
- **numLandingSites** - the number of vehicle landing sites displayed in the Center of Plot listbox. The landing sites are listed after this parameter. Each landing site contains a name, lat/lon, and 5-digit identifier of the closest RAOB,
- **numLocations** - the number of non-launch/landing sites displayed in the Center of Plot listbox. The locations are listed after this parameter. Each location contains a name, lat/lon, and 5-digit identifier of the closest RAOB,
- **RUCpath** - the directory containing the RUC model files,
- **NAMpath** - the directory containing the NAM model files,
- **GFSpath** - the directory containing the GFS model files,
- **Models1Key** to **Models3Key** - the product keys for the model Shapefiles,
- **interFlag** - set to 0 to use the nearest grid point to the center of plot location and set to 1 to interpolate from the four surrounding grid points (used in Models data type),
- **RAOBpath** - the directory containing the RAOB files,

- **RAOB1Key** to **RAOB3Key** - the product keys for the RAOB Shapefiles,
- **RSA** - set to 1 to use RSA profiler data and set to 0 to not use RSA profiler data,
- **MADIS** - set to 1 to use MADIS profiler data and set to 0 to not use MADIS profiler data,
- **RSAPath** - the directory containing the RSA profiler files,
- **MADISpath** - the directory containing the MADIS profiler files,
- **MADISid** - the identifier for the KSC profiler in the MADIS profiler files,
- **Profiler1Key** to **Profiler3Key** - the product keys for the profiler Shapefiles,
- **RSAname** - NetCDF variable name for the profiler names in the RSA profiler files, and
- **MADISname** - NetCDF variable name for the profiler names in the MADIS profiler files.

4.2. Installation and Use of AGRID

The tool was updated to use the NWS AGRID application to make it easier to select and read gridded model data. The application is a package of routines to read or write AWIPS NetCDF gridded data files and is written in the Perl programming language. The AGRID software and user instructions are available from the AWIPS Local Applications Database (<http://www.nws.noaa.gov/mdl/awips/>). The AMU installed AGRID on a Linux machine running AWIPS client and server software. The AMU wrote three Perl scripts to read gridded model data with AGRID:

- **getModelLevels.pl** - Reads the pressure levels that contain wind data,
- **getModelData.pl** - Reads the u- and v-wind components of the wind at a particular lat/lon, forecast hour, and pressure level, and
- **getModelRealUV.pl** - Converts the grid-relative u- and v-wind components to north-relative u- and v-wind components.

Using the AGRID software, the tool performs the following procedures to calculate the layer-average wind velocity using gridded model data:

- a) Get a list of mandatory pressure levels with the **getModelLevel.pl** script. If no levels are returned, display the error message "No model levels have uv wind components". Otherwise, parse out the levels between the top and bottom mandatory levels defined in the User Profile;

- b) Read the u- and v-wind components from each level that was obtained in Step a with the getModelData.pl script. The script can either use the closest grid point to the lat/lon point, or interpolate from the surrounding four grid points;
- c) Calculate the layer-average u- and v-wind components. Add the u- and v-wind components from each level, and then divide by the number of levels;

- d) Convert the grid-relative layer-average u- and v-wind components to north-relative components, with the getModelRealUV.pl script; and
- e) Convert the north-relative layer-average wind velocity from u- and v-wind components to wind speed and direction.

Table 1 illustrates several differences between the current (Phase II) and previous (Phase I) versions of the tool that resulted from the use of AGRID.

Table 1. Differences between Phase I and Phase II of the tool resulting from AGRID.

Feature	Phase I (uses ncdump utility to read gridded model data)	Phase II (uses AGRID to read gridded model data)
Source code complexity	<u>More complex.</u> The entire NetCDF file must be parsed to get the u- and v-wind components for the lat/lon point.	<u>Less complex.</u> The getModelData.pl script can directly read the u- and v-wind components for the lat/lon point.
Speed	<u>Slower.</u> The entire NetCDF file must be read into memory and then parsed. The amount of time to read the model data is dependent on the size of the file.	<u>Faster.</u> Only the required model data is read from the file. The amount of time to read the model data is independent of the size of the file; it is related to the number of pressure levels used to calculate the layer-average wind velocity.
Number of center of plot locations in graphic that are allowed	<u>Limited.</u> The center locations are limited to the lat/lon points in which the grid points have already been manually calculated and hard-coded into the tool.	<u>Unlimited.</u> The tool can automatically calculate the corresponding grid point for any lat/lon point in the model domain.
Accuracy of grid point location	<u>Probably less accurate.</u> The grid point corresponding to a lat/lon point is manually calculated by printing out the model domain, then counting the number of grid points in the x- and y-direction.	<u>Probably more accurate.</u> AGRID automatically calculates the grid point corresponding to a lat/lon point. It uses an algorithm that takes the model domain size, projection, and lat/lon as input. The output is the corresponding grid point.
Able to use the nearest grid point to the lat/lon point	<u>Yes.</u> The grid point closest to the lat/lon point is manually calculated.	<u>Yes.</u> AGRID can calculate the grid point closest to a lat/lon point.
Able to interpolate model data from the surrounding four grid points	<u>No.</u> The tool can only read model data from the closest grid point to a lat/lon point.	<u>Yes.</u> AGRID can calculate the four grid points surrounding a lat/lon point, then interpolate the data from the four grid points.
Able to change the model files that are used	<u>No.</u> The manually-calculated grid points cannot be used for other model files, since the model domain size and projection affects the grid point.	<u>Yes.</u> AGRID can calculate the grid point for a lat/lon point, based on the model domain size and projection.
Able to change pressure levels	<u>No.</u> The pressure levels are hard-coded into the source code, since the tool cannot dynamically read which pressure levels are available for u- and v-wind components.	<u>Yes.</u> AGRID can dynamically read which pressure levels are available for u- and v-wind components.

4.3. Testing the Tool

After the initial development of the Phase II version of the tool was completed, a draft copy of the User Guide (Barrett and Bauman, 2008) was written. Two members of the AMU, Dr. Bauman and Mr. Dreher, then evaluated the tool and User Guide. They did not find problems with the tool, but had suggestions on how to improve the User Guide. After the User Guide was updated, SMG evaluated the tool and User Guide. They had more suggestions on improving the User Guide and suggested that the AMU make the creation of User

Profiles more user-friendly and increase the size of the GUI. Subsequently, the AMU modified the tool so default entries are displayed during the creation of a User Profile and increased the minimum size of the GUI.

The final testing of the tool was then performed by the AMU. During the development of the test plan, several more improvements were made to the tool. These include the following:

- The default profiler type is now “MADIS” instead of “RSA”, since only MADIS profiler data are available at SMG,
- The tool now displays whether the model data were interpolated from the surrounding four grid points or the nearest grid point was used,
- If the input wind data are missing, the layer-average wind velocity will be reported as missing. Previously, a default wind speed of 0.5 kt and wind direction of 270° was reported. The tool also now prevents the user from creating a graphic based on missing data; and
- A bug was fixed in which the tool did not check for missing levels in the model data.

After the final testing was completed, the AMU updated the User Guide and installation instructions and delivered them, along with the tool and test results, to SMG for operational use. After receiving the tool, SMG updated the default User Profile to change the filepath of the GFS model data and add landing sites. A display of the tool's graphic in the SMG AWIPS is shown in Figure 7. The test results can be requested from the AMU. The installation instructions are in Appendix A of Barrett (2008).

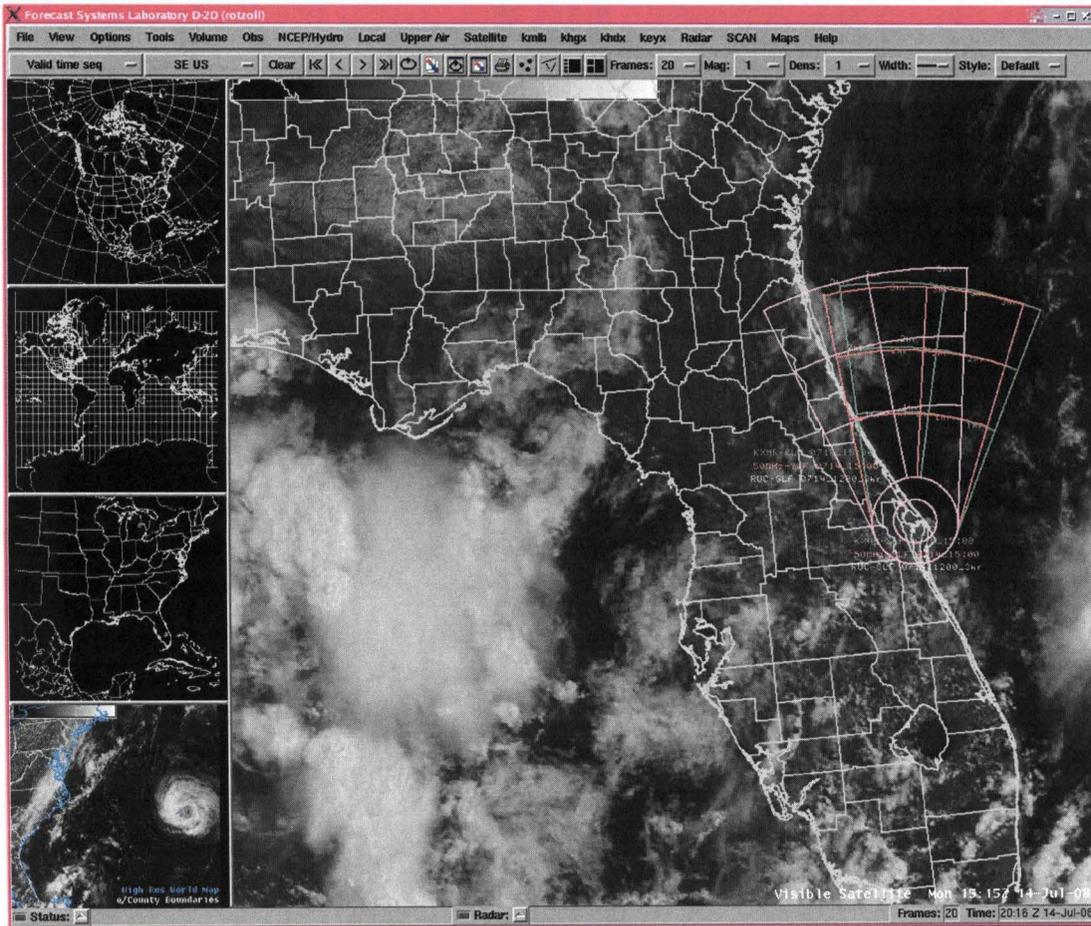


Figure 7. Display of the AWIPS Anvil Forecast Tool Phase II graphic in the SMG AWIPS.

5. Summary

The 45 WS LWOs and SMG forecasters have identified thunderstorm anvil cloud forecasting as one of their most challenging tasks when predicting the probability of LLCC and FR violations. The AMU developed a tool that creates an anvil threat corridor graphic based on observed or forecast upper-level winds. Since SMG uses AWIPS as one of their primary forecasting systems, the AMU transitioned the tool from MIDDs to AWIPS. For Phase II, SMG requested the AMU make the AWIPS Anvil Forecast Tool more configurable to permit the user to read model gridded data from user-defined files instead of hard-coded files. SMG was also interested in defining the pressure levels used to calculate the layer-average wind velocity, instead of hard-coding the bottom of the layer as 300 mb and the top of the layer as 150 mb.

In order to make the tool more configurable, the AMU made two improvements. The first was to create User Profiles. A User Profile is a text file that defines several parameters previously hard-coded into the source code, such as significant and mandatory levels, center locations for the overlay graphic, and file paths for model, rawinsonde, and profiler data. When the tool is started, the user is prompted to select a User Profile. A new User Profile can be created either through the GUI or a text editor. The second improvement was to modify the tool to read gridded model data with the NWS AGRID software. Using AGRID allows the user to more easily change the pressure levels and model files, read model data faster, use an unlimited number of center locations, and interpolate the model data from the surrounding four grid points.

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