15.1 THE INTERACTIVE GRID ANALYSIS AND DISPLAY SYSTEM (IGrADS) FOR THE U.S. ARMED FORCES

R. Bruce Telfeyan*, Daniel M. Rozema, and Jeremy J. Wesely[&]

Headquarters, Air Force Weather Agency, Offutt Air Force Base, Nebraska

[&]NOAA/National Weather Service Hastings, NE

1. INTRODUCTION

Headquarters, Air Force Weather Agency (AFWA) at Offutt Air Force Base, Nebraska, declared the Mesoscale Model, Version 5 (MM5) (Chen et al. 2001a; Chen et al. 2001b; Barker 2004) operational on 28 October 1997. This achievement marked the initial operational capability of the Global Theater Weather Analysis and Prediction System (GTWAPS) program. AFWA currently runs the MM5 for seventeen 45 km theaters, eight 15 km nested theaters, and several 5 km nested theaters, dependent upon operational requirements for the Department of Defense (Figure 1). This provides coverage over 98 percent of the world's landmasses. The MM5 is scheduled to transition to the Weather Research and Forecast (WRF) model during 2005.

With the fielding of AFWA's MM5 production line, a huge suite of visualizations were staged for the US Air Force's Joint Air Force & Army Weather Information Network (JAAWIN) (https://weather.afwa.af.mil). Over 250,000 visualizations were created every 24 hours, using both Vis5D (from the University of Wisconsin-Madison Space Science and Engineering Center) and the Center for Ocean-Land-Atmosphere Studies' (COLA) Grid Analysis and Display System (GrADS) (Doty et al. 1995; Doty et al. 1997; COLA 2004) software visualization tools.

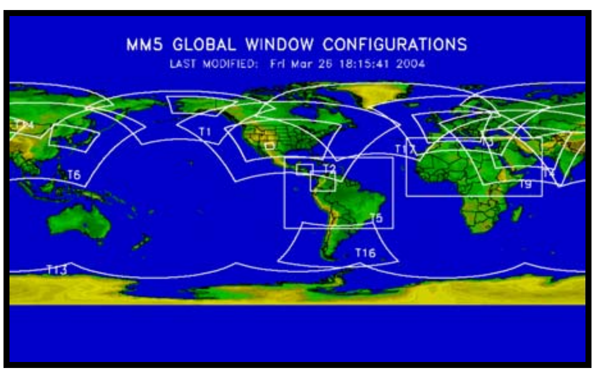

Figure 1. Recent AFWA MM5 theater configuration (March 2004).

* *Corresponding author address:* R. Bruce Telfeyan, HQ AFWA/DNXT, 106 Peacekeeper Dr, Suite 2N3, Offutt AFB NE 68113-4039; e-mail Bruce.Telfeyan@afwa.af.mil

Forecast maps on JAAWIN were grouped in nine separate categories: core, clouds, winds, temperature, contrails, hazards, precipitation, severe weather, and miscellaneous (Figures 2 and 3).

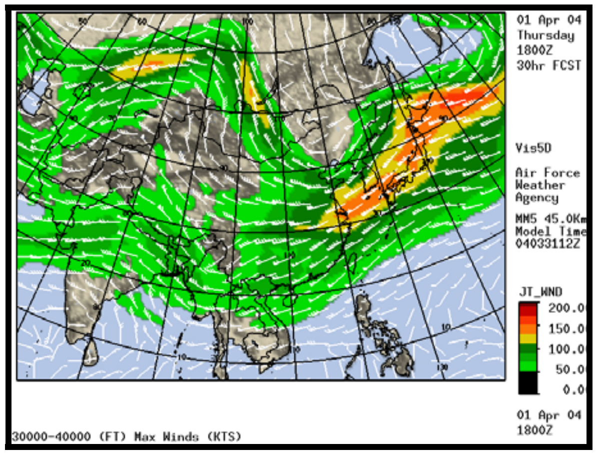

Figure 2. Sample AFWA Vis5D visualization.

In addition, roughly 2,400 meteograms were pre-staged (built with GrADS) based upon AFWA's MM5 and the National Center for Environmental Prediction's (NCEP) Medium Range Forecast (MRF) model, which is now known as the Global Forecast System (GFS) model.

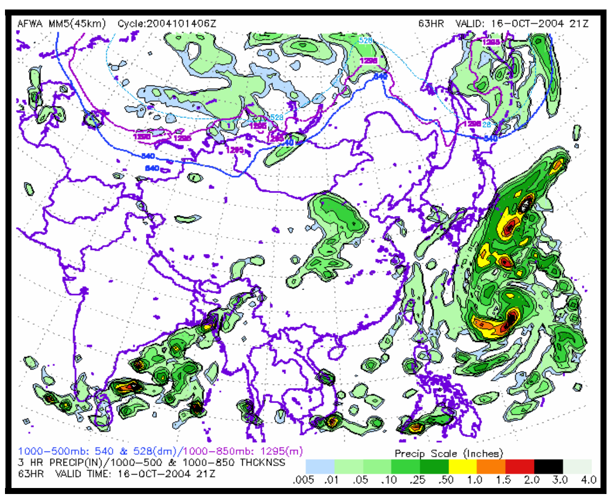

Figure 3. Sample AFWA GrADS visualization.

However, it became apparent that many of the pre-staged forecast charts were not being used frequently enough to warrant the significant associated resource requirements. Consequently, AFWA found it prudent to pre-stage a smaller core product line while still enabling the creation of needed specialized products through the use of an interactive tool, which saved large amounts of mainframe processing resources.

2. INITIAL EFFORT

AFWA's first interactive tool was known as the Interactive Meteogram and Skew-T (IMaST) program. This interactive tool allowed JAAWIN users to create meteograms and forecast skew-Ts based upon the AFWA MM5, NCEP Eta and MRF, and Fleet Numerical Meteorology and Oceanography Center's (FNMOC) Navy Operational Global Atmospheric Prediction System (NOGAPS) data (Figures 4 and 5).

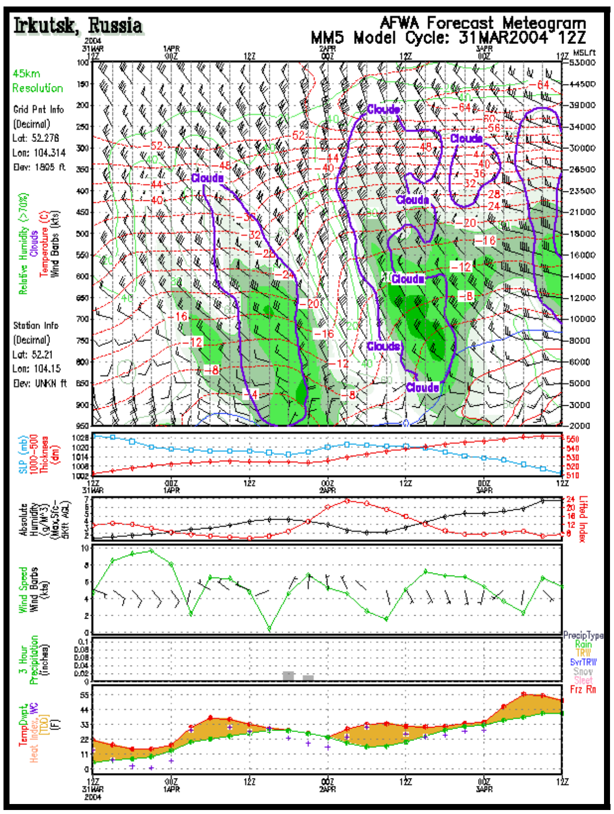

Figure 4. Sample MM5 meteogram created with IMaST (now IGrADS).

These applications were created using the GrADS visualization tool (Doty et al. 1995; Doty et al. 1997; COLA 2004) and enabled the user to choose the location by entering the desired International Civil Aviation Organization (ICAO) designator, clicking on a map, or entering the desired latitude and longitude. Through the graphical user interface (GUI), the customer would also choose the numerical model, product type, forecast hour (for skew-Ts), and select a map projection (either a world map, MM5 theater maps, or the Eta domain). Field forecasters were unanimous in their enthusiasm and praise following IMaST's unveiling on 1 May 2001.

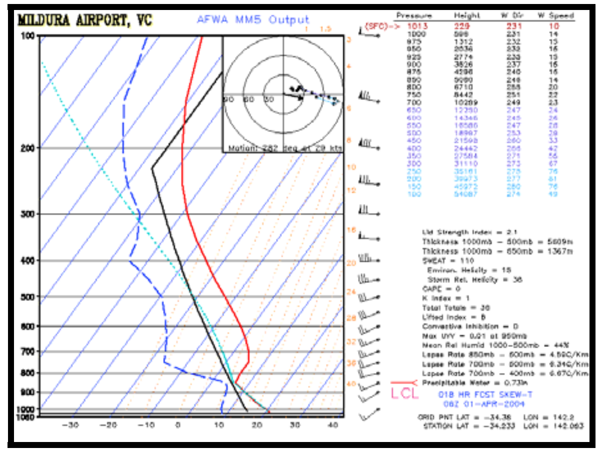

Figure 5: Sample forecast skew-T created with IMaST (now IGrADS).

An immediate benefit was a cessation of the addition of new pre-staged meteogram locations, as customers could create any location they desired on the fly. In addition, requests for new capabilities quickly began arriving and upon completion of the IMaST baselining, AFWA's Technology Exploitation Branch immediately set out to develop a much-expanded interactive tool. This new interactive capability was named "IGrADS" and the scope of its product line continues to expand.

3. THE GROWTH OF IGrADS

Customers were clamoring for many new products including capabilities to create vertical cross sections, forecast maps, user-defined meteograms, and numerous alphanumeric products. Therefore, the Visualization Team in AFWA's Technology Exploitation Branch responded by expanding the IMaST capabilities into a new tool that AFWA named Interactive GrADS, or IGrADS. The IGrADS product line has steadily grown so that, at present, it includes the following capabilities (note that all references or capabilities ascribed to MM5 and Eta are scheduled to transition to WRF during 2005):

3.1 *Map displays (within the GUI) provided by IGrADS:*

- World Map centered on Prime Meridian
- World Map centered on International Dateline
- All MM5 theater maps
- United Kingdom Meteorological Office (UKMO) Middle East domain
- Continental United States (CONUS) Eta domain

- Coupled Ocean/Atmospheric Mesoscale Prediction System (COAMPS) domain

3.2 *Meteorological model output available through IGrADS:*

- AFWA MM5
- AFWA Diagnostic Cloud Forecast (DCF) Algorithm (Eylander and Evans 2003; Norquist 2000)
- AFWA Advect Cloud Model
- NCEP GFS
- NCEP Eta
- US Navy NOGAPS
- US Navy COAMPS
- UKMO Middle East Theater
- AFWA Stochastic Cloud Forecasts
- AFWA Worldwide Merged Cloud Analysis

3.3 *Products offered by IGrADS:*

- Meteograms (MM5, Advect Cloud, GFS, Eta, NOGAPS, COAMPS, and UKMO)
- MM5 Army low-level meteograms
- MM5 severe weather meteogram
- GFS (0 to 180 hour and 192-384 hour) meteograms
- GFS and NOGAPS stratospheric meteograms
- User defined meteograms
- Forecast skew-Ts
- Vertical cross-sections
- Multiple leg cross-sections
- Forecast maps (color filled, contoured, both)
- Four-Panel Forecast Maps
- Alphanumeric output products

3.4 *Alphanumeric output products offered by IGrADS:*

- MM5-based
  - -- Forecast vertical profile
  - -- "FOUS" bulletin (similar to Eta and NGM output from NCEP)
  - -- RAOB bulletin
  - -- Precision airdrop wind profile
  - -- Chemical downwind message
  - -- Basic wind message
  - -- Field artillery forecast
  - -- Effective downwind message
- GFS-based
  - -- "FOUS" bulletin (0 to 180 hours at 3 hour intervals)
  - -- RAOB bulletin
  - -- Precision airdrop wind profile
  - -- Chemical downwind message
  - -- Basic wind message
  - -- Effective downwind message
- COAMPS-based
  - -- Basic wind message

Since its initial implementation on the unclassified version of JAAWIN in February 2002, hits on IGrADS have grown to nearly 90,000 per month (statistics courtesy of Mr. Kenneth Smith, HQ AFWA). This statistic reflects numbers of first time entry into IGrADS, not the total number of products generated, which is actually many times larger. IGrADS currently ranks as the tenth most frequently accessed product on JAAWIN. (IGrADS also is available on classified versions of JAAWIN.) Furthermore, the capability for forecasters to make charts tailored to their needs enabled AFWA to reduce the huge amount of pre-staged forecast charts by 25 percent, or from nearly 250,000 charts to 185,000 charts each day.

4. IGrADS INTERFACE / PRODUCTS

Access to IGrADS on the unclassified Internet is obtained at the URL within JAAWIN, https://weather.afwa.af.mil/igrads.html. This is a password-protected site except from ".mil" accounts. Those working from ".gov" accounts can obtain access to JAAWIN by applying for an account on-line. The opening GUI for IGrADS (Figure 6) contains a map for the desired domain (opening default is to a world map) with selection boxes for product, model, image size, location, forecast hour, ICAO designator, and a lookup ICAO search tool. Selection options vary depending on the product selected and the model chosen. In addition, IGrADS allows the user to bookmark frequently needed products and thereby avoid going through the GUI altogether. Many customers find this to be a time-saving technique.

Figure 6: Default IGrADS GUI with world map.

As one begins to use the various selection boxes, the options appear in drop-down menus (Figure 7).

4.1 *Meteograms*

The meteogram was previously shown (Figure 4), as it was available in IMaST. The user-defined IGrADS meteogram (Figure 8) allows the customer to pick among fourteen sets of graphs instead of being limited to the standard five graphs that appear below the time-height cross-section graph at the top of the product (Figure 4). The user also has the option of adding turbulence, icing, potential temperature, and vertical velocity fields to, or in place of, the default temperature, relative humidity, cloud, and wind fields. For example,

Figure 7: IGrADS GUI with drop-down selection boxes.

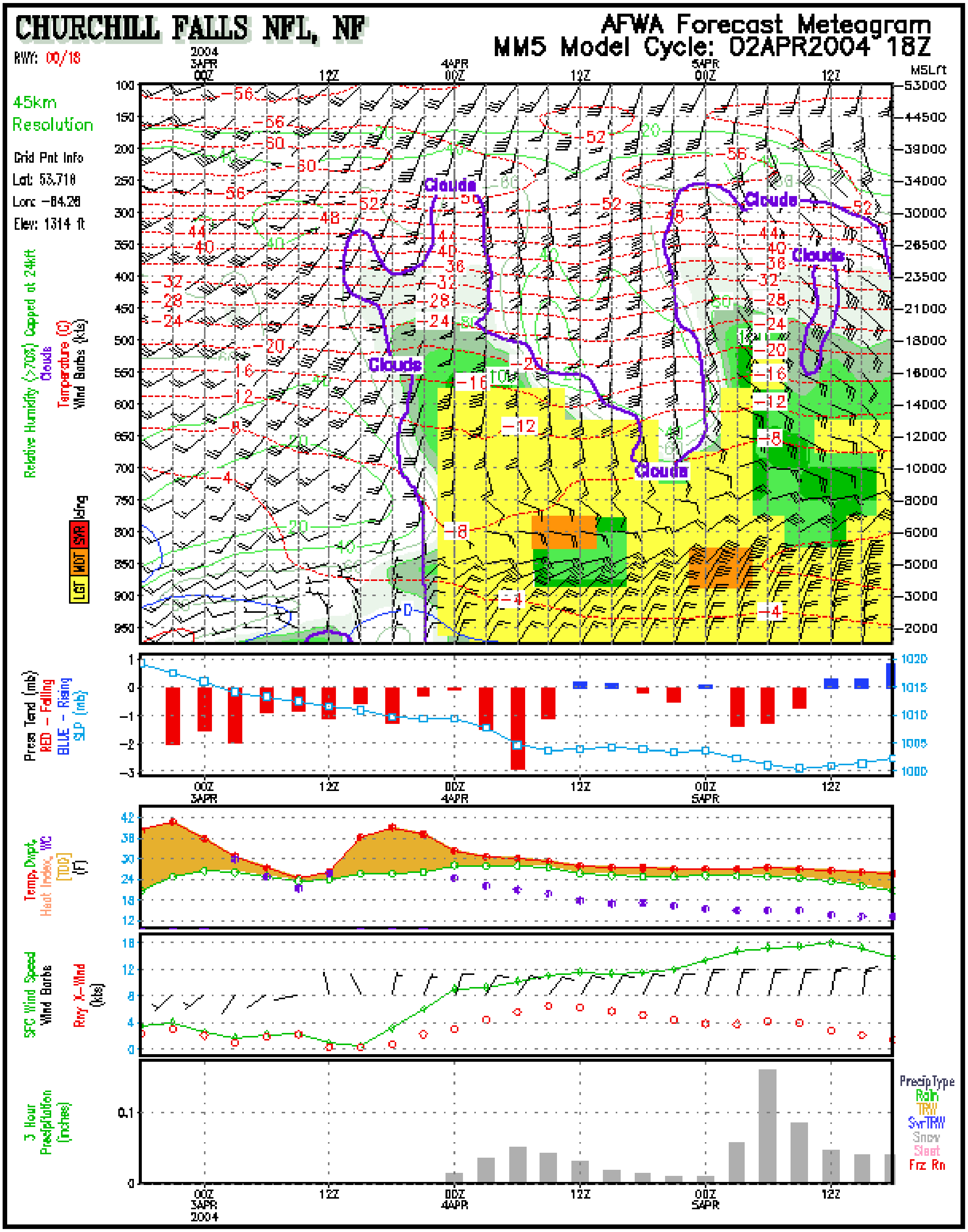

Figure 8. IGrADS user defined meteogram for Churchill Falls, Canada.

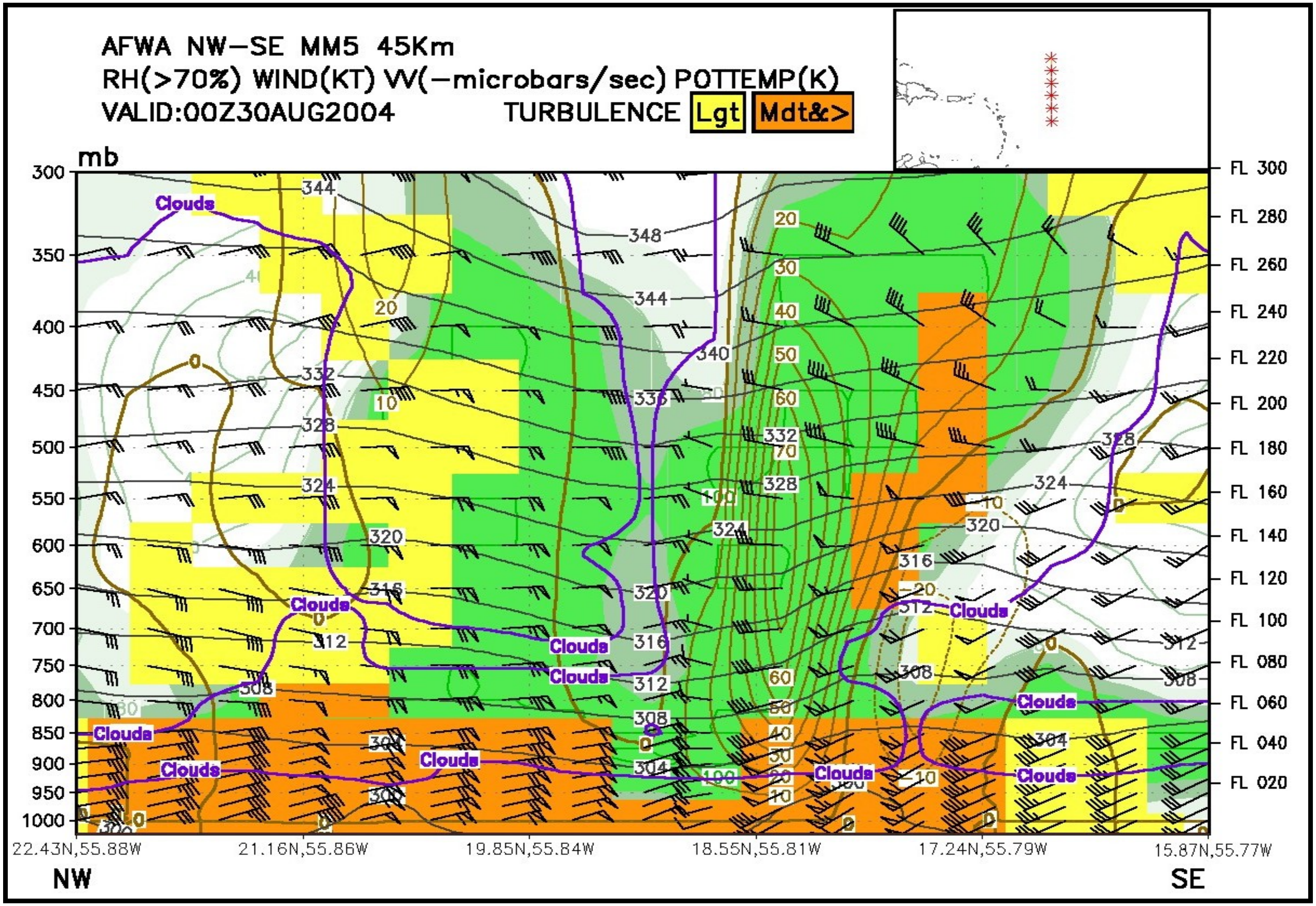

Figure 9. MM5 45 km vertical cross-section through the eye of Hurricane Frances, VT 30 Aug/00Z, showing turbulence, RH, vertical velocity, FL winds, and potential temperature.

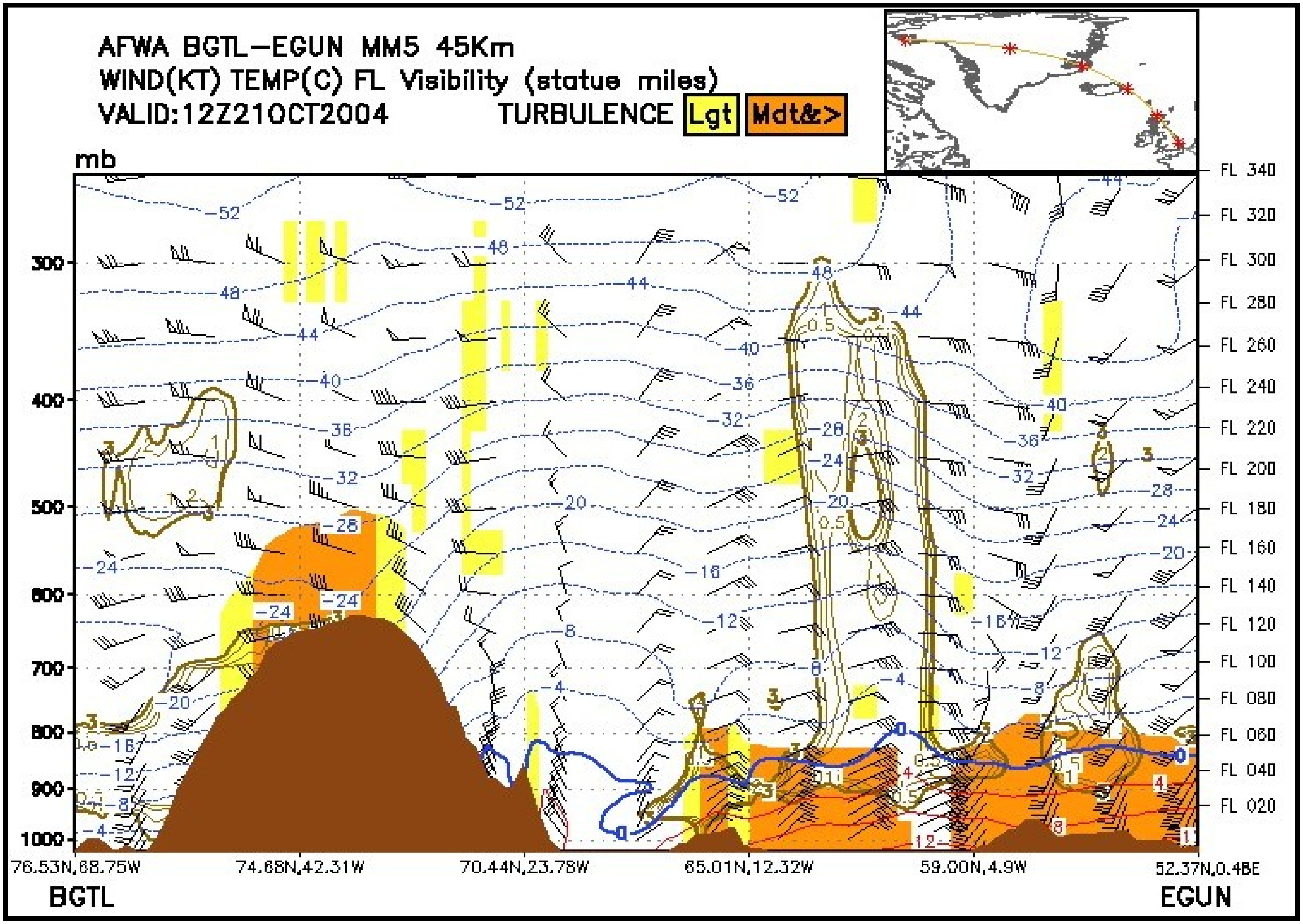

Figure 10. MM5 45 km vertical cross-section from Thule AB to Mildenhall AB with brown contours showing forecast flight level visibilities of 3 miles or less. Also shown are forecast wind barbs, temperatures, and turbulence.

a user-defined meteogram can have aircraft icing in the time-height cross-section, followed by pressure tendency, temperature, wind, and precipitation amount/type in the accompanying graphs (Figure 9).

4.2 *Vertical cross-sections*

Vertical cross-sections are currently available for the MM5, GFS, Eta, NOGAPS, COAMPS, and UKMO models. This product provides a point in time vertical cross-section between two points within the domain of the model (Figure 9). In addition, the user can choose the layer of the atmosphere to display, from the surface to the top of the model. The forecaster can also choose to display isotherms, isentrops, wind barbs, relative humidity, icing (MM5), turbulence (MM5), and clouds. By choosing more than one valid time, IGrADS will create a Java slideshow that will loop through the selected forecast hours. The visualization includes model surface terrain, the endpoints, with ICAOs (if provided by the requestor), and four intermediate points. An inset map in the upper right portion shows the cross-section route highlighting the path's intermediate points with red asterisks.

A new capability allows the user to display visibility by making use of an algorithm developed by Stoelinga and Warner (1999) on a vertical cross section (Figure 10). This capability is of great potential value for planning military air refueling operations.

Several Air Force weather stations have reported that they give aircrews a vertical cross-section print out as part of the pre-takeoff briefing. They also report very favorable feedback from aircrews about the product and instances where pilots have asked for the vertical cross section product when it was not offered to them. (E-mail feedback from Mr. Phil Eddy, Thule AB, Greenland.)

4.3 *Multiple leg vertical cross-sections*

The multiple leg cross-section is similar to the vertical cross-section with two enhanced capabilities. Specifically, three terminals (or ICAOs) can be selected and a different valid time chosen for each leg of the cross section. The same set of models and parameters are available for this product (Figure 11).

4.4 *Forecast maps*

On IGrADS, forecast maps allow for display of four parameters, one color filled and three as "contour line" fields. The user can determine the maximum and minimum value for each parameter as well as the interval, the contour color, and line thickness (or wind barb density). Output from seven models (AFWA MM5, AFWA MM5 DCF algorithm, GFS, Eta, NOGAPS, COAMPS, and UKMO) can be visualized. All the model output Grib parameters are available to choose from and with the large number of permutations of models and parameters, literally hundreds of millions of

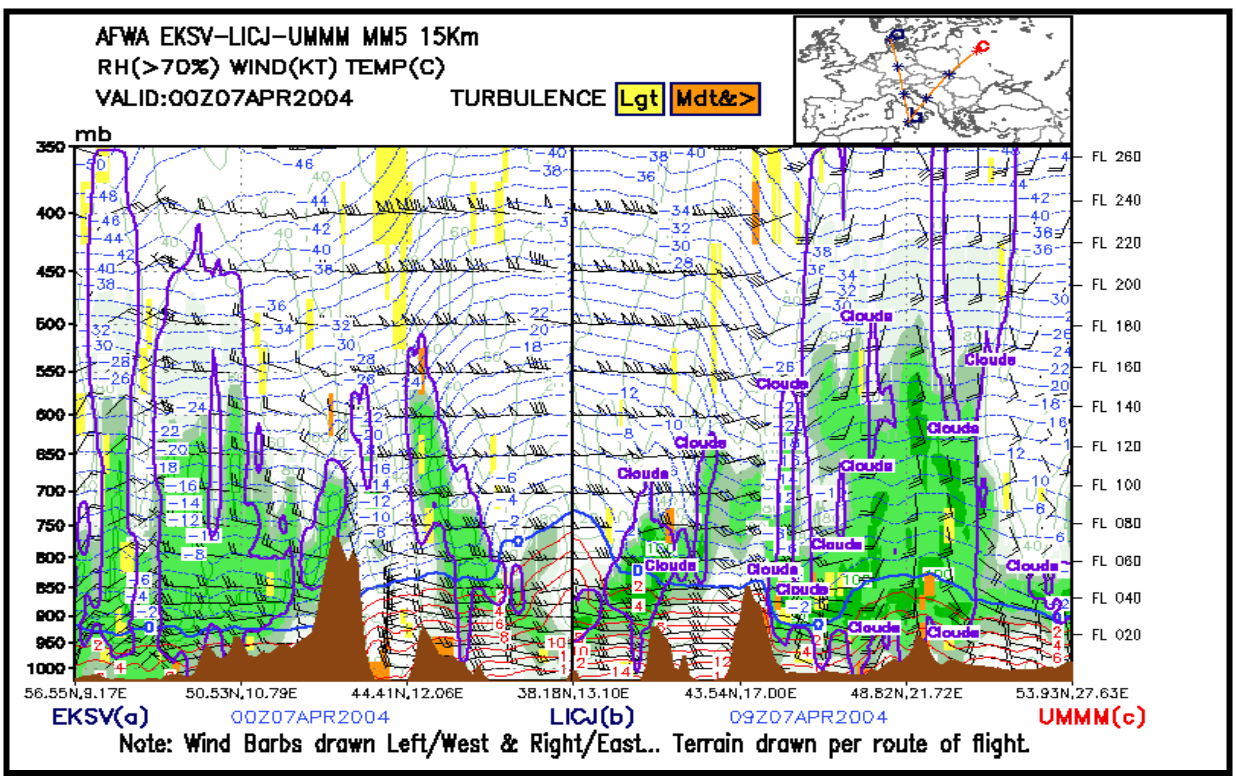

Figure 11. Multi Leg Vertical Cross-Section; Skive, Denmark to Palermo, Italy to Minsk, Belarus, MM5 15 km resolution.

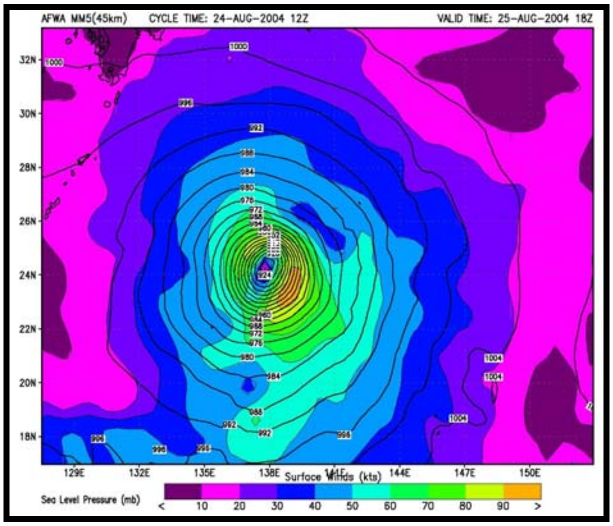

Figure 12. Super Typhoon Chaba (30 hr forecast valid 25 Aug 04/1200Z), South of Japan with Sea Level Pressure (black), and surface winds (knots) (color-filled).

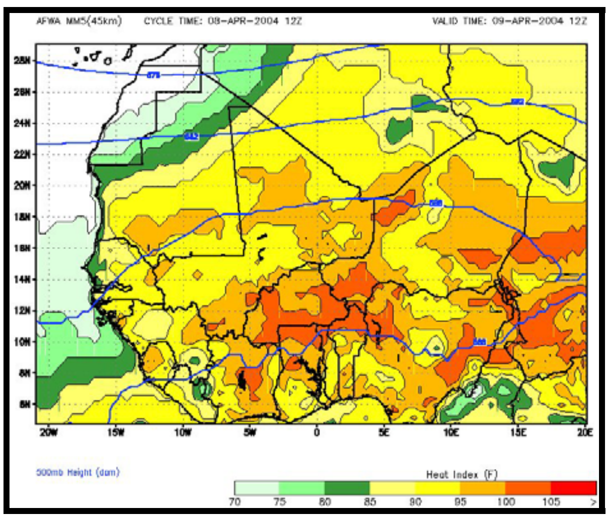

Figure 13. Heat index (^{o}F) and 500-mb heights, AFWA MM5 (45 km).

different forecast maps can be created to fit the forecasters' specific needs. Furthermore, the maps can default to display the entire theater, or the forecaster can draw a rectangle within the theater (or enter pairs of coordinates) to define the desired map (Figures 12-17).

4.5 *Four-Panel Forecast Maps*

This function allows customers to create pre-configured four-panel charts that are reminiscent of model output facsimile charts from that era. Presently, there are five types of four-panel charts that forecasters can select:

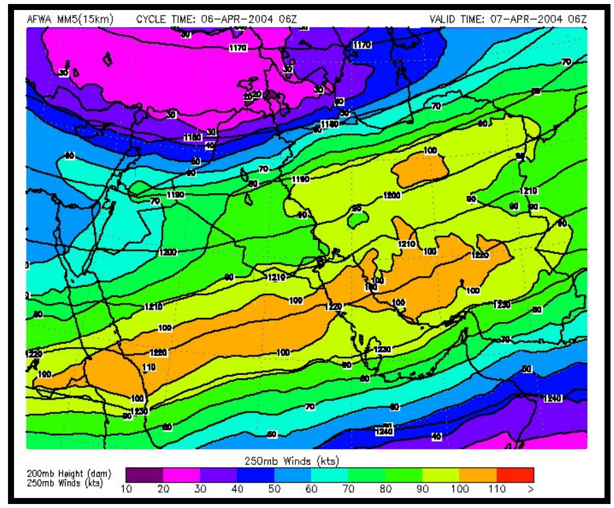

Figure 14. 250-mb wind velocities (color filled) and height contours (black), AFWA MM5 (15 km).

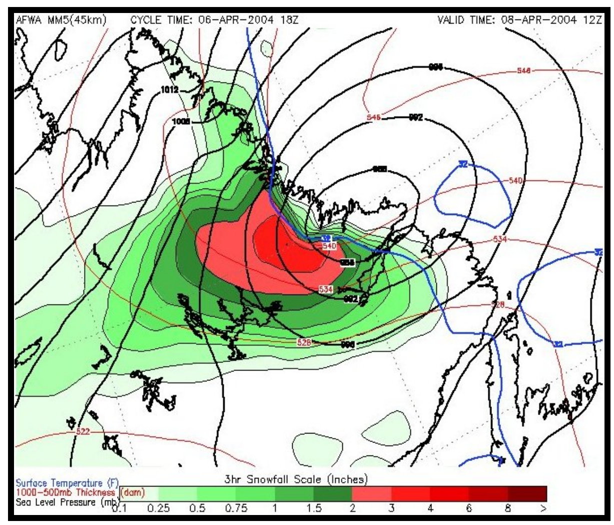

Figure 15. Three-hour snowfall accumulation (color filled), sea level pressure (black), 1000-500-mb thickness (red), and surface freezing line (blue), AFWA MM5 (45 km).

- Standard forecast: (1) 500-mb heights, winds, and relative vorticity; (2) 700-mb heights, relative humidity, and vertical velocity; (3) Sea level pressure,1000-500-mb thickness, and three-hour accumulated precipitation; and (4) 825-mb heights, wind barbs, and relative humidity.

- Severe Weather #1: (1) Total totals; (2) SWEAT Index; (3) K-Index; and (4) CAPE.

- Severe Weather #2: (1) Best Lifted Index; (2) Energy Helicity Index; (3) Potential hail size; and (4) Convective inhibition.

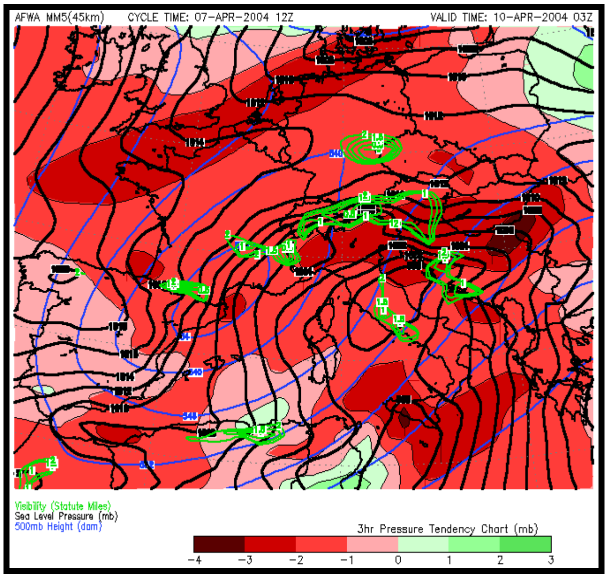

Figure 16. Three-hour pressure tendency (color filled), sea level pressure (black), 500-mb heights (blue), and surface visibility <= 2 miles (green), AFWA MM5 (45 km).

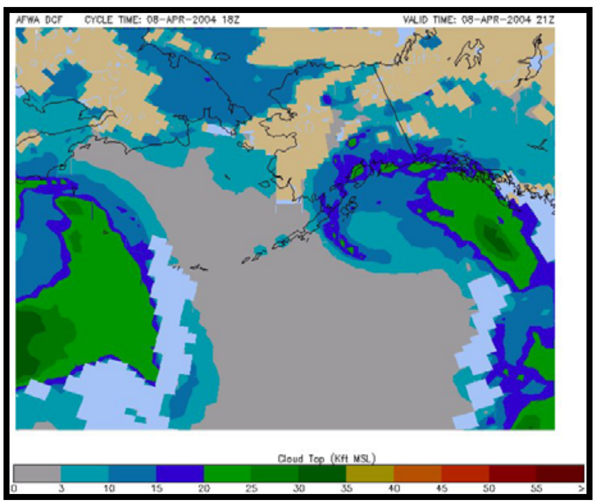

Figure 17. Diagnostic cloud forecast cloud top product, AFWA MM5 (45 km).

- Aviation Takeoff/Landing: (1) Surface winds (barbs/colorized velocity); (2) Low level turbulence (surface to 4,500 feet AGL); (3) Three-hour accumulated precipitation, surface freezing contour, and 1000-500-mb 540-dm contour; and (4) Surface visibility.

- Winter weather: (1) 1000-500-mb thickness, 700–mb wind barbs, and three-hour accumulated precipitation; (2) 1000-850-mb thickness, 925-mb wind barbs, and three-hour accumulated snowfall; (3) Equivalent wind chill temperature, surface wind barbs, and surface visibility, and (4) Surface temperature and color filled surface weather threats (heavy rain, snow, freezing precipitation, strong winds, and severe thunderstorms).

Samples of the four-panel forecast maps appear in Figure 18, 19, and 20.

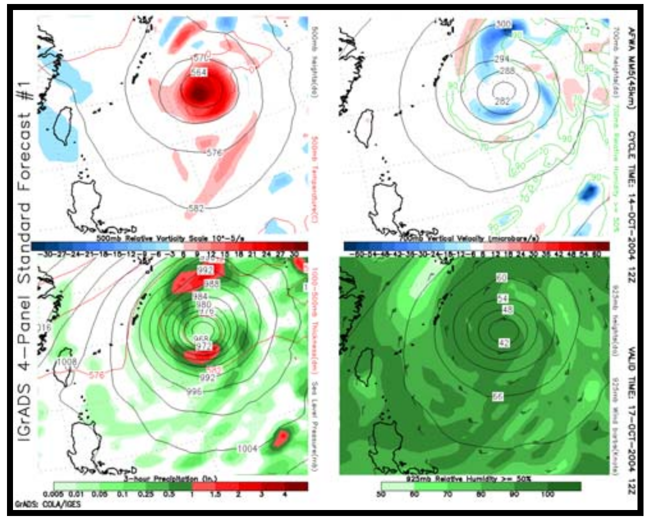

Figure 18. Four-panel "standard forecast" charts depicting Typhoon Tokage at 500-mb, 700-mb, surface, and 925-mb (forecasts valid 17 Oct 04/1200Z), AFWA MM5 (45 km).

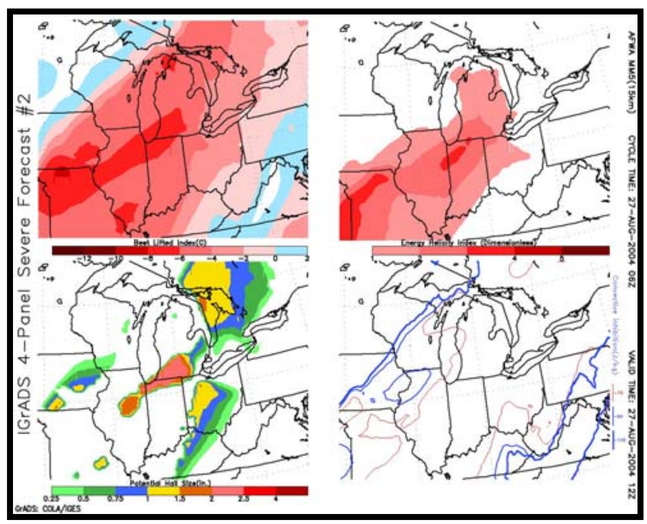

Figure 19. Four-panel "severe weather forecast #2" charts depicting best lifted index, energy helicity index, potential hail size, and convective inhibition (forecasts valid 27 Aug 04/1200Z), AFWA MM5 (15 km).

4.6 *Alphanumeric output*

Many IGrADS customers shared desires and requirements for alphanumeric meteorological model output in both existing and newly devised formats. The most significant advantage that IGrADS provides is that the user can specify the location and valid time and not

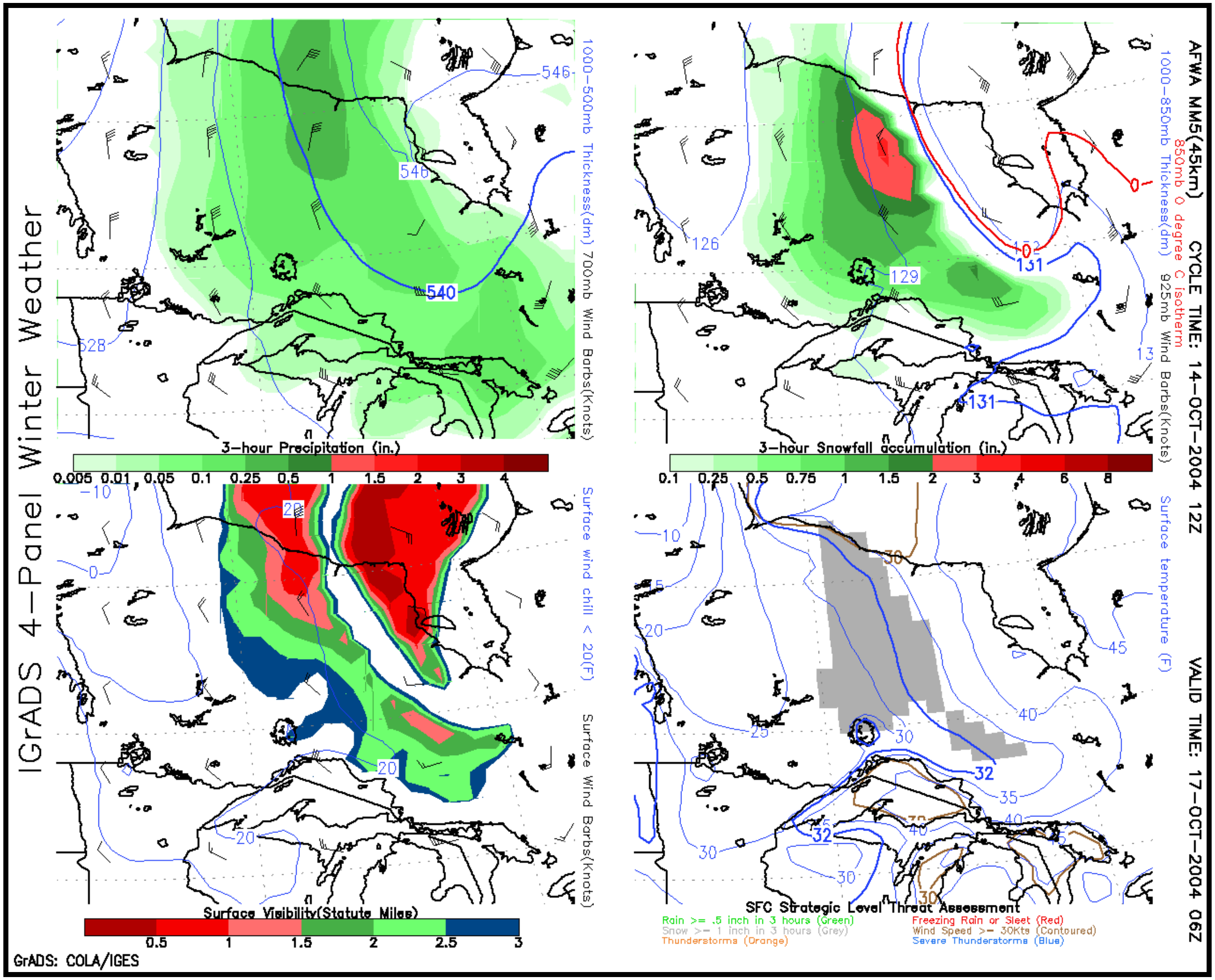

Figure 20. Four-panel “winter weather” charts depicting three-hour accumulated precipitation, 3- hour accumulated snowfall, surface visibility, and surface temperature (forecasts valid 17 Oct 04/0600Z), AFWA MM5 (45 km).

```
38.75N 141.35E
OUTPUT FROM MM5 15KM 06Z Oct 20 04
TTPTTR1R2R3 VVVLI PSDDFF HHT1T2T3W CIGVIS
/////999999 18503 990216 68151413  009010
09213969898 38301 910328 73171616R 012028
12135949999 49798 870330 71151615X 006040
15071859398 15103 830133 69151213T 021116
18049848792 11910 903223 62141109R 060083
21007778388 11508 963122 57141108R 044124
24000616771 04404 023015 57161109  ---124
27000625446 -1509 072812 59151109  ---124
30000726951 01910 112809 58131010  ---120
33000869185 -0906 132607 57131008  ---054
36000858177 00306 142409 56141008  ---044
39000889799 05804 151810 55141109  021047
42000839192 -3903 151910 53151210  026098
45000828177 -3602 131813 53151211  069098
48025939596 08300 132010 52141109R 026034


Model output parameters are based on the 15KM MM5 model.

Bulletin data derived from model Grid Point 38.667N and 141.256E

TT    # hours past models 00hr; e.g., 03 would be the 3-hour forecast
      from MM5 analysis
PTT   Quantitative precipitation forecast in format x.xx inches.  024
      is 0.24 inches; 123 is 1.23 inches
R1    Relative humidity at 500 ft AGL (100 shown as 99)
R2    Relative humidity at 2000 ft AGL (100 shown as 99)
R3    Relative humidity at 3000 ft AGL (100 shown as 99)
VVV   Vertical velocity at 700 MB in tenths of microbars per second.
      029 is 2.9 microbars per sec.  Positive values denote rising
      air; Negative values denote sinking air
LI    Lifted index.  Negative values are denoted by "9s"; e.g., 97
      is a LI of -3
PS    Sea Level pressure in millibars.  28 would be 1028mb; 94 would
      be 994mb
DDFF  Wind speed (knots) and direction.  3325 would be winds from 330
      degrees at 25kts
HH    1000-500mb thickness in meters.  52 would be 5520m; 40 would be
      5400m
T1    Temperature in degrees C at 500 ft AGL.  Negative values are
      subtracted from 100; e.g. 92 would be -8C
T2    Temperature at 2000 ft AGL
T3    Temperature at 3000 ft AGL
WX    Present weather (prototype capability includes rain (R), snow
      (S), ice pellets (P), freezing rain (Z),  thunderstorms (T) and
      severe thunderstorms (X)) Note: This element is not displayed
      for the initial forecast hour.
CIG   Ceiling in hundreds of feet; e.g., 003 is 300 feet; 030 is 3000
      feet, and 100 is 10000 feet.
VIS   Visibility in tenths of statute miles (SM); e.g., 005 is 1/2 SM;
      030 is 3 SM and 100 is 10 SM.
```

t

Figure 21. MM5 FOUS bulletin for Bangor ME. The legend for decoding the bulletin is attached to each product.

be tied to existing pre-staged bulletins. For example, upon customer request, IGrADS will create two products similar to NCEP's Eta and NGM FOUS bulletins. These text products are based upon AFWA's MM5 and NCEP's GFS and can be built for any ICAO or location within the model's domain (world-wide for the GFS) (Figure 21). In creating the bulletins through IGrADS, the software accesses the nearest neighbor gridpoint (in GrADS coordinate space) to the requested location. In addition to the elements typically found in the NCEP bulletins, the FOUS product also has columns for precipitation type, ceiling, and visibility. Instead of relying on existing ICAO locations, the capability to create these products for any desired point within the domain of the model has directly addressed customer requests.

Other alphanumeric products include a forecast RAOB bulletin, a precision airdrop wind profile, and chemical downwind messages (for hazardous releases). AFWA recently added a product tailored specifically for U.S. Army field artillery use, which has resulted in significant reductions of artillery range errors (Mitchell 2003). In fact, range errors decreased by as much as 195 m resulting in substantially more accurate targeting (Mitchell 2003). This product provides temperature, wind, and pressure information in the precise format that Army field artillery is trained to use. Furthermore, the US Army is in the process of incorporating the use of IGrADS into the formal training and doctrine for their field artillery forces. The high resolution and near world-wide land coverage provided by AFWA's MM5 combine to make it a perfect match for both the U.S. Army's and U.S. Air Force's mission requirements.

5. CONCLUSION

IGrADS has proven to be an extremely popular and effective interactive numerical weather forecast visualization tool. It gives forecasters the ability to create products tailored to address their specific mission requirements and deliver the requested product quickly, typically within 30 seconds of making the request. IGrADS is available over the Air Force Weather Agency's webpage, JAAWIN (on three security levels). This interface was developed at HQ AFWA and has been operational since early 2002. It is available to anyone with ".mil" access to the web and by password through ".gov" accounts for official use.

The interface enables forecasters to create (potentially) many hundreds of millions of varieties of visualized or alphanumeric products designed to meet their customers' needs. These products range from meteograms, skew-Ts, vertical cross-sections, forecast maps, and seven different types of alphanumeric meteorological output. Forecasters have the option of choosing from among eight different forecast models with worldwide coverage for two. The most extensive product lines are available for AFWA's MM5. As noted, this will be supplanted with WRF once that model is declared operational.

REFERENCES

Barker, D. M., W. Huang, Y. R. Guo, A. J. Bourgeois, and Q. N. Xiao, 2004: A Three-Dimensional Variational Data Assimilation System for MM5: Implementation and Initial Results. *Mon. Wea. Rev.,* **132**, 897–914.

Chen, F., and J. Dudhia, 2001a: Coupling an Advanced Land Surface–Hydrology Model with the Penn State–NCAR MM5 Modeling System. Part I: Model Implementation and Sensitivity. *Mon. Wea. Rev.,* **129**, 569–585.

----, and ----, 2001b: Coupling an Advanced Land Surface–Hydrology Model with the Penn State–NCAR MM5 Modeling System. Part II: Preliminary Model Validation. *Mon. Wea. Rev.,* **129**, 587–604.

COLA, cited 2004: Grid Analysis and Display System (GrADS). [Available online at http://grads.iges.org/grads/]

Doty, B. E., T. Holt, and M. Fiorino, 1995: The Grid Analysis and Display System (GrADS). [Available online at: ftp://grads.iges.org/grads/beta/doc/gadoc151.pdf]

-----, J. L. Kinter III, M. Fiorino, D. Hooper, R. Budich, K. Winger, U. Schulzweida, L. Calori, T. Holt, and K. Meier, 1997: The Grid Analysis and Display System (GrADS): An update for 1997, Proceedings, 13th International Conference on Interactive Information and Processing Systems for Meteorology, Oceanography, and Hydrology, American Meteorological Society, February, Long Beach, California.

Eylander, J. B., and R. Evans, 2003: Evaluation of the operational Diagnostic Cloud Forecast (DCF) model. Preprints, The Battlespace Atmospheric and Cloud Impacts on Military Operations (BACIMO) conference, Monterey, CA. pp 1-10 [Available online at: http://www.nrlmry.navy.mil/bacimo2003/proceedings/P%202-22%20Eylander.pdf]

Mitchel, J. D., 2003: Afghanistan firing artillery accurately with Air Force met support. *Field Artillery*: Jan-Feb 2003, pp. 38-41

Norquist, Donald C. 2000: Cloud Predictions Diagnosed from Global Weather Model Forecasts. *Mon. Wea. Rev.,* **128,** 3538–3555.

Stoelinga, M. T., and T. T. Warner, 1999: Nonhydrostatic, mesobeta-scale model simulations of cloud ceiling and visibility for an East Coast winter precipitation event. *J. Appl. Meteor.,* **38**, 385-404.