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METEOGRAM ANALYSIS AND INTERPRETATION

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[Note: Because of the large number of figures, only the test will be published in hard copy. The figures can be accessed on the Web version at http://www.wrh.noaa.gov under Technical Attachments.]

1. Introduction

This technical application note describes how to make the best use of a meteogram. The forecaster's cookbook outlines the step-by-step technique for analyzing and interpreting meteograms with the best results. Other sections give the historical background and detailed descriptions of the analysis techniques shown in the cookbook.

Two main versions of forecast meteograms are discussed, the meteogram available from the Air Force Weather Agency (AFWA) using the MM5, AVN, NOGAPS, or MRF models; and the meteogram available from the Environmental Modeling Center (EMC) of the National Centers for Environmental Prediction (NCEP), using the ETA model. The AFWA meteograms use the same format regardless of the model used. Although previous Air Weather Service Technical Reports have mentioned the use of observed time trend charts for short-term forecasts, there exists no systematic discussion of the use, analysis, and interpretation of meteograms. This technical application note remedies that deficiency.

The military forecaster's emphasis on a point forecast, whether airfield, drop zone, or battlespace, makes the meteogram especially useful.

2. Background

History and Modern Development

J. H. Lambert (mathematician and scientist) and William Playfair (political economist), working in the late 1700's, used time-series plots in lieu of tables to describe data (Tufte, 1983). This technique marked the revival of a graphic display after nearly 800 years from the first known time-series use (Tufte, 1983). Over the two centuries since Lambert and Playfair, time-series graphs have been used frequently to show data, or data relationships, for a variety of variables (Tufte, 1983). The meteogram, also known as the meteorogram, is one application of the time-series graph (Landsberg, 1941; Saucier, 1955). Climate and weather are ideally suited for display using time-series techniques because of the way the variables change with time (Landsberg, 1941; Saucier, 1955).

The meteorograph recording of weather variables "as they happen" is simply another application of time-series. Examples are the barograph, wind, or thermograph traces, and early upper air soundings (Saucier, 1955; Huschke, 1959). The mechanical meteorograph, which was used to take the first atmospheric soundings above the surface, traced the data in a series of lines similar to the seismograph, became known as a meteorogram of the sounding data (Geer, 1996; Huschke, 1959; Saucier, 1955).

Saucier (1955) described the use of meteorogram charts to analyze surface weather data with respect to time. It is a simple extension to project these variables into the future using data from the forecast models and produce the modern meteogram. During the 1980's, military forecasters in the Third Weather Wing plotted the tabular Forecast Output (FOUS) data onto a graph known as a "cross-over chart." The cross-over chart was a way to read and interpret Limited Fine Mesh (LFM) model output data and forecast the time of the onset of precipitation or change in ceiling and visibility categories (3WW-FM 81-002). By plotting vertical velocity, lifted index, relative humidity, and thickness, the forecasters could determine the potential for the occurrence of precipitation and infer precipitation type from the thickness.

The cross-over charts used critical points to show when precipitation events would occur. As an example, the point in time where the increase of mid- and upper-level moisture coincided with an increase in vertical velocity was interpreted as the approximate time of precipitation onset for the station (Figure 1). Interpretation of the boundary layer wind direction or speed and the change in thickness led to a forecast of frontal passage, as well as its character, either warm or cold. A stability parameter aided the determination of potential for convective or non-convective activity. When hand plotting these charts, each model run was tedious and subject to neglect, leading to the eventual disuse of the technique. Other factors leading to disuse of the cross-over charts included the deactivation of Third Weather Wing and changes in the meteorological models used by Air Force forecasters by the early 1990's. These time-series graphs were an operational forerunner of the meteogram graphs now displayed automatically at a mouse click. Appendix A shows the similarities and differences of the cross-over chart and meteograms using examples built from mid-January 2001 data.

Meteograms have evolved to mean any group of meteorological variables graphed with respect to time, whether observed or forecast, usually confined to surface variables (Geer, 1996; Huschke, 1959), though some include time-height charts. Meteogram use increased in the 1990's with the growth of computing power. Now meteograms are created from various models and made available to forecasters through the Internet. In addition, researchers and operational forecasters have the capability to make meteograms for their local use on their local computing systems.

Air Force forecasters can get meteograms from two sources at least twice a day; some are available up to four times daily. The Air Force Weather Agency (AFWA) produces meteograms from the MM5, AVN, NOGAPS, and MRF for locations around the world. The AFWA meteograms are available in a specific station format centered on military facilities or in an interactive format. For the interactive format, the user gives an ICAO identifier, or the latitude and longitude of the site, and the meteogram is calculated from the nearest model grid point. The Environmental Modeling Center (EMC) of the National Centers for Environmental Prediction (NCEP) produces static meteograms for the CONUS from the 60-hour ETA model. The AFWA meteograms are intended for operational use. The EMC meteograms are considered experimental and not maintained as operational tools.

Even though AFWA and EMC meteograms have their place and usefulness, it is still incumbent on the forecaster to recognize the limitations of each product. The total product on the web pages is called a meteogram. Strictly speaking, any graph of meteorological variables set against time is a meteogram. To illustrate this, look at examples of meteograms by Air Resources Laboratory (ARL), Figure 2 and Figure 2a. Contrast the ARL version with those from EMC and AFWA in Figures 3 and 3a.

The ARL meteogram consists of graphs with few visual references to interpret the data. The valid period is the entire model run period. The variables in the ARL meteogram are not necessarily displayed in common forecaster friendly units. National Weather Service forecasters have a time-series plot available within the AWIPS system similar to the ARL meteogram, with the same drawbacks as the ARL product. As shown by Figures 3 and 3a, the AFWA and EMC meteograms display the variables in forecaster friendly units, span the entire model run period, and display related quantities together for easy interpretation.

Why a Meteogram is Useful

Meteograms can provide guidance to forecasters for otherwise data-sparse locations and assist with forecast development by providing the forecaster with a snapshot of model performance and guidance in a graphic display. A meteogram also visually flags the timing of active weather and alerts the forecaster to make a closer evaluation of the model versus observed conditions for the area.

The meteogram is one of several initialization tools the forecaster can use to check the performance of the model on which it is based. The forecaster is reminded to use more than one tool to initialize and determine overall model performance. For instance, a forecast of precipitation without either cloud cover or indication of convective instability to support it means a problem may exist in the model. The presence of significant winds with a strong high pressure is another instance of model performance. These are negative indicators of model performance. On the positive side of the ledger would be a direct hit timing the wind direction switch associated with an increase in instability and onset of precipitation. The initialization process allows the forecaster to determine how much confidence to place in the model, and by inference, in the model products. Usually the meteogram shows a stable forecast pattern over successive model runs. This helps the forecaster maintain a sense of the continuity of the conditions over the location.

The meteogram provides a direct visualization of forecast conditions over the specific point. This is an excellent source of guidance to the forecaster, especially for those stations without MOS guidance available. The graphs are easy to read and interpret once the forecaster has an overall view of the model forecast from the traditional plan view charts. In addition, the forecaster can review several variables at the same time without using cumbersome map overlays.

Information Available on a Meteogram

Most forecast meteograms available to the forecaster have at least some common variables. The most used information is temperature and pressure, precipitation, winds, and relative humidity or mixing ratios. Some meteograms provided to the forecaster will include time-height cross-sections to accompany the surface graphs. From these graphs, the forecaster can glean additional information on diurnal cycles, timing of weather systems or other changes not related to the diurnal cycles, and infer potential cloud cover and vertical profiles. All this information helps the forecaster develop a point forecast.

3. Reading a Meteogram Effectively

The following discussion assumes the forecaster has initialized the model originating the meteogram, and has established some degree of confidence in its solution.

At first glance, the meteogram is a confusing mass of lines and colors. Further inspection shows that the display is a grouping of time-series graphs showing several variables with respect to time. The AFWA meteogram has a time-height profile in the same display as the surface variables. This contrasts with the product from EMC, which presents the time-height profile on another page. Either method of display works. Given that a military forecaster in the field may not have the time to download two pages of data for one location, the AFWA meteogram is the more efficient, since all the data is available at once, and readily tailored to the forecaster's requirements.

Reading a meteogram means knowing how to read and interpret time-series graphs showing how a quantity changes over time. The EMC meteograms present a clean, easy to read format. The AFWA meteograms are more cluttered, but with similar information. The forecaster needs to examine the chart axes to understand the data presented by a meteogram. Sometimes variables are plotted alone. Related variables plotted together help visualize their relationship to each other. Keeping track of the variable of interest is key to reading a graph. A color-coded line graph, provided competing lines are kept to minimum, is easier to read than a bar graph. The time scale on all the graphs should be the same so that reading data from several different levels of the meteogram is simplified, and relationships between variables easily determined.

The discussion will look first at the surface variables displayed and how to interpret the graphs, and then progress to the time height display. The initial page of the EMC meteogram includes links to descriptions of the variables and the units used for the graphs. For instance, visibility is shown in miles even though the model calculations are done in kilometers.

Analysis Techniques

The forecaster sees only a fragmented view of the model grid point depicted in a meteogram if he or she only looks at individual sections of the meteogram without considering the relationships among the sections. The forecaster must have an appreciation of the individual section's performance in order to evaluate how the parts fit together. The way meteograms are presented to the user helps build the total viewpoint necessary to effectively apply the data to operational forecasts. The following three-step analysis pattern will help the forecaster make an orderly and progressive evaluation of a meteogram regardless of the source of the graph. This pattern reverses the usual forecast funnel technique by starting with the detail and moving to the general. Each step outlined in the next few paragraphs will be discussed in more detail. Refer to Figures 4 and 4a during the discussion of the parts of a meteogram.

Step One. Evaluate individual variables for trends. Determine which part of the variable graph reflects diurnal effects and which reflects changes due to the movement of weather systems past the point.

Step Two. Evaluate the "graph stack." Look for relationships among the variables. Note how changes in one variable cause changes in another, or result from changes in a third variable. Look for timing in the variable changes that indicate weather system passage.

Step Three. Evaluate the time-height chart. Determine what changes are occurring in the upper atmosphere. Look for elevated systems indicated by trends toward building ridges or digging troughs.

Evaluate Individual Variables

Each variable shown on the meteogram is displayed with respect to time on the horizontal axis. The vertical axis shows the range of the variable quantity and is scaled in a manner that aids readability. For example, temperature may have a range from 30 °F to 80 °F or if the forecast is for an arctic outbreak, -30 °F to 20 °F. The scale will change depending on the range of the forecast variable and may be shown on either the left or right hand vertical axis. A variable may have metric or English units depending on the meteogram producer.

Close inspection of the graph allows the forecaster to determine the model-forecast value of the variable for a specific time. This is a good substitute for MOS data. The forecaster must keep in mind a few differences between MOS and the meteogram. The MOS is statistically buffered against extremes. The meteogram is a raw display of model derived variables for a specific grid point and might not be adjusted to the local terrain and effects. For those regions lacking MOS data, meteograms fill the guidance gap. This application of the meteogram is taught quite well at the weather school. We will not repeat those lessons here.

Next, separate the diurnal effects from the movement of weather systems. Often these will appear inseparable until closer examination. The diurnal influence has a periodic variation based on the time of day. For example, the coolest part of the day will be in early morning, and the warmest in the late afternoon. A progressive weather system passing the point will modify the diurnal pattern. A warm front passing in the early morning followed by a cold front that afternoon will have the effect of reversing or at least minimizing the diurnal fluctuation. In contrast, a warm front in the late afternoon or evening followed by a cold front during the morning will emphasize and enhance the usual diurnal pattern. The forecaster needs to remember that time of year, changing seasons, or expected cloud cover can also mask the diurnal pattern by appearing to wash out the daily fluctuations.

Evaluate the Surface "Graph Stack"

This stage compares the time-series graphs of the individual variables to each other. The total model-forecast meteogram consists of multiple graphs of meteorological variables, all related to each other. The multiple graphs are the "graph stack." So far, the forecaster has only looked at the surface graphs. At this point, the forecaster moves beyond simply using the meteogram as a substitute for MOS guidance. He or she begins to evaluate model performance, develop a picture of the forecast pattern, and determine the atmospheric motions at the forecast point. The most critical factor to look for at this stage is timing of changes throughout the graph stack.

Timing is determined by reading the variable versus time (model forecast valid time) on the graph. To find the relationship among variables several graphs must be used simultaneously. Since the individual graphs are separate for ease of reading, the forecaster must learn to take elements from each to compare with the others. The practice of crossing between graphs in the surface graph stack is referred to as the "cross-over" principle. The onset of an event can then be related to the model time that the graphs each showed significant increases in variables known to influence each other. The occurrence of precipitation, for example, includes dependence on increased vertical velocity, instability, and atmospheric moisture. Once the forecaster is sure precipitation will occur; the type can be determined from the atmospheric temperature, stability, and available potential energy. In another example, the forecaster can estimate the time of the daily high and low temperature by comparing the surface temperature graph to the temperature advection, wind direction, and cloud depictions in the time-height chart section. The influence of the upper levels on the surface variables is another example of the cross-over principle most easily seen using meteograms. The AFWA meteograms are particularly useful in this respect since the time axes are united between the surface graph stack and the time-height chart cross sections.

Evaluate the Time-Height Chart

Be careful to check which direction the time axis is depicted. The AFWA places the time axis in the same direction as the surface graph stack. The EMC reverses the time axis on the time-height chart relative to the surface graph stack. Both methods of depiction are equally valid, but require different mind-sets to interpret the information.

First, look for incoming changes in the upper levels. The upper level trend indicates weather systems, both aloft and at the surface, forecast to pass near the meteogram location. The wind barbs are the key indicators for changes. Generally in the Northern Hemisphere, a southwest wind barb implies a trough to the West, while northwest barbs indicate a ridge to the West. In the Southern Hemisphere, the reverse is true. The wind speed gives a clue to the location and depth of the jet stream, assuming it will be passing near the point. Elevated systems display the changing wind directions without extending those changes all the way to the time-height chart surface.

Interpretation Techniques

Now that the forecaster has reviewed and analyzed the data available on the meteogram, it is time to figure out what it means. Interpreting the data is fairly straightforward from this point.

Starting at the surface with the graph stack, interpretation follows the general pattern of the analysis. Meteogram interpretation looks at the three major components: diurnal pattern, weather trends, and severe weather indicators. We will look first at the overall diurnal patterns. A diurnal pattern unaffected by any weather systems will show cooling temperatures overnight with the coldest temperature around dawn. The pressure will have a similar transition through the day, with the lowest pressure in late afternoon. Temperature and pressure are inversely related; when air cools, pressure rises, and as pressure falls, air warms. Therefore, the lowest pressure should occur near the time of maximum heating for the day, and the highest pressure near the time of maximum cooling. Similarly, the time of maximum instability should coincide with maximum heating when the atmosphere is likely to have the most convective mixing.

Next, look for recent trends in the weather, such as frontal movement, or major pressure centers associated with synoptic level air masses. The time axis will generally extend to 60 hours or longer, which will cause the graphs to lose the detail needed for mesoscale effects on the variables charted. Weather systems moving past the point of the meteogram will alter the systematic changes associated with diurnal changes. The timing of the weather system will affect the intensity of the system relative to the diurnal trends. For instance, a polar air mass moving into an area in the early morning can exaggerate the nighttime cooling profile. The same cold air mass in the afternoon may simply keep the air from warming with the afternoon heating, and possibly cool it much earlier than otherwise may be expected on a diurnal cycle, creating secondary maximum and minimum temperatures. Additionally, the time of year is a factor. A cold air mass in the summer can mean a comfortably cool day, but in winter it can be bitterly cold.

Severe weather indicators are available on meteograms. The EMC meteogram shows the CAPE and CIN on the surface graph stack. These parameters show whether conditions are favorable for convection (positive CAPE), or stable and more favorable for fair weather. The AFWA has separate severe meteograms for displaying the severe weather parameters of stability indices, CAPE, and precipitation forecasts. The forecaster may interactively request severe meteograms for locations around the globe from the meteogram selection page. Interpretation of severe weather components on either the EMC or AFWA meteograms follows similar processes. The stability indicators, lifted or K index, CAPE, or CIN, should coincide with or slightly precede the potential for precipitation (quantitative precipitation forecast-qpf) shown on the graph stack. The forecaster needs to remember that not all instances of instability will result in severe weather, nor will a model detect all instances of severe weather, particularly if the outbreak is away from the station chosen for the meteogram. The AFWA interactive severe meteograms can be used to estimate the extent of a potential severe weather outbreak by using several such meteograms along a line or within a quadrant. The forecaster can interactively select meteograms for the region deemed most likely to have severe weather to investigate forecast conditions more closely. Another thing for the forecaster to remember is the influence of latitude, overall geography, and terrain on instability. For example, a CAPE of 1000 J/kg in the Southern states may mean convection but usually nothing severe. In Northern tier states, such as Montana, National Weather Service forecasters prepare the severe weather checklists and monitor conditions for a potential severe event when the CAPE approaches 1000 J/kg.

The next phase of interpreting meteograms is determining what the time-height charts really mean. This is the most likely place to see the mesoscale influences such as short waves passing over the meteogram point. The presence of a short wave will be made evident in the upper level wind patterns through the different levels of the atmosphere. The time-height chart, like the surface graph stack, should be examined for the diurnal patterns and weather trends.

A forecaster has to be aware of the different styles of presenting the time axis on the time-height sections. This is because some are reversed from the time axis of the corresponding surface graph stack. The best way to interpret the time-height chart depends on the direction of the time axis. If the time axis is the same as the surface graph stack, then interpretation is a straightforward three-dimensional snapshot of meteorological variables extending from the surface into the upper atmosphere, and can be interpreted similar to a sounding above a point, whether observed or forecast. On the other hand, if the time-axis is reversed to the surface graph stack, the data must be interpreted in another manner. A reversed time axis will have the model run time on the right and the forecast times extending leftward in what appears an "upstream" direction on the page. In effect, this form of time-height chart becomes a trajectory display without indicating the source levels for the parcels. The extension of meteorological variables into the upper levels is valid, but not nearly as simple to read as before.

The trajectory effect of a reversed time axis means that a parcel will be arriving over the meteogram point from an upstream location in the direction indicated by the wind barb and will accelerate (or decelerate) to the speed shown on the barb as it crosses the point. The upstream location would be northwest of the station if the wind barb were oriented northwest, and east for an easterly barb. The time-height chart gives no indication of the original level of the air parcel crossing the station; however, given the temperature contour and some creative thinking one could infer the origin. A cooling contour would indicate a slight lift and warming a slight sinking. By inference then, a parcel crossing the station in a cooling air mass is rising from some level below the one where it crosses the station. Similarly, a warming parcel is descending from some level above where it crosses the point. This inference assumes there are no other factors influencing the change in temperature. The time that a parcel will cross the 00-hour point is the number of forecast hours from the model run time.

The depiction of relative humidity and the general flow of the upper level winds are two other keys to deciphering the forecast conditions from the time-height chart. These are easily interpreted regardless of the time axis direction. The relative humidity display is usually a contour of mixing ratio converted to a humidity value. The forecaster needs to check to see if there will be clouds (in the form of filled relative humidity or mixing ratio contours) when precipitation is forecast on the surface graph stack. If there is precipitation without clouds, it will be convective in nature, or the model may have an error someplace in its forecast. Precipitation does not have to be forecast for every cloud.

The upper level flow, including the position and depth of the jet stream can be concluded from the wind barbs. For this, the wind barbs are arranged in a vertical profile, similar to the display of a VAD wind profile on the WSR-88D, or various mesonet profilers around the CONUS. Interpretation is straightforward. The wind direction and speed shown by the barb combined with the barbs above and below presents the height and strength of the upper level winds as forecast by the model. Comparing these to an observed sounding, profiler output, or the VAD wind profile, gives an indication of the accuracy of the upper level wind forecast. Since the upper level winds are also the steering winds for most weather systems, the general upstream direction for incoming fronts, upper level short waves, or other features can be located.

<u>Caveats to Remember</u>

Meteograms must be considered with five major caveats in mind. First, the meteogram is only valid for a single point. Second, the graphs are valid for the model grid point closest to the selected station shown. Third, the data have no statistical enhancements like other forms of guidance. Fourth, the direction of the time axis in a time-height chart focuses attention on the data in different ways. Finally, the meteogram data comes directly from the model and may or may not have a correction to the actual terrain surface from the model surface. The lack of correction to the actual terrain from the model surface leads to biases in the model data, which are reflected in the meteogram. Significant differences between the model surface and the station surface affects the meteogram usefulness to the forecaster. All of these caveats can reduce the accuracy or reliability of the model forecast as shown using a meteogram.

<u>More Examples of Meteograms</u>

Figures 5 and 5a are examples of meteograms over Texas. Note how the meteograms differ from those in Figures 4 and 4a from northeast Montana. The forecaster must be careful to also note the model surface elevation and compare that to the actual station elevation. Look at Figure 6 for RAF Mildenhall in the United Kingdom, and Figure 7 is for

Osan AB in the Republic of Korea. The RAF Mildenhall is located toward the eastern side of England. Osan AB is on the western side of the Korean Peninsula, south of the City of Seoul. Note the similarities and differences in the figures. Even though the stations are half the world away from each other, the meteograms are easily interpreted using the techniques described in this technical application note. Meteograms are interpreted the same way regardless of the location because they are visual displays of model data at specific grid points.

Air Force Weather forecasters have a variety of meteograms available to them through the Joint Air Force and Army Weather Information Network (JAAWIN) from AFWA. Figures 8 and 9 are examples of user-defined or severe weather meteograms for locations in CONUS and Europe. The user is able to specify which variables to display in the meteogram. Figures 10 and 11 show severe weather meteograms, one for Osan AB, Korea and the other for Randolph AFB, Texas. Other meteograms available include those designed specifically for supporting Army missions. Each meteogram is interpreted using the same method and technique described above.

4. Conclusion

The meteogram is a very useful tool for the forecaster interested in a single point forecast using model data. It is only one tool. A forecaster can achieve the same point forecast by overlaying several plan view charts of different variables to arrive at conditions near or over the point in question. It is also possible to use model forecast soundings to depict conditions forecast at a point. These are valid and time-honored forecasting techniques, but they are also cumbersome to use. One or two screens of data display meteograms. Several screens of data are needed to display forecast sounding loops. In general, meteograms will help the forecaster time features crossing the station more precisely than using only a plan view chart, or series of charts. Even so, the forecaster must remember that meteograms are just one forecast tool and will use others at his or her disposal as well. A forecaster, using satellite imagery and a meteogram, and applying his or her knowledge of hemispheric weather patterns, storm motion, model performance, and basic topographic effects, can develop an accurate point forecast supporting the military mission. Knowing the forecast conditions through all levels for a point helps the forecaster provide better forecasts for drop zones; battlefield conditions including smoke dispersal, and airfield operations.

5. Acknowledgments and Notes

The author thanks the staffs of AFWA/DNTT and AFWA/DNXT, and Geoff Manikin of NCEP's Environmental Modeling Center for their assistance and comments on this technical application note. Two Appendices accompany this note and are designed to emphasize and reinforce the ideas presented here.

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The Forecaster's Cookbook
Meteogram Analysis and Interpretation

- Check the model run time. This is the same as the initial hour on the meteogram time axis.

- Make sure the meteogram is for the correct location.
  - If using the AFWA meteogram for the MM5, AVN, NOGAPS, or MRF, use the interactive point/click method or enter an ICAO to get as close to the interest point as possible.
  - If using the EMC ETA-model meteogram (CONUS only), select a "star" nearest to the interest location or use the station identifier number in the URL line of your browser.

- Analyze the surface graphs and graph stack.
  - Check the trends of individual variables.
  - Look for relationships between the variables.
  - Recognize the units used for each variable.

- Analyze the time-height chart.
  - Check the trends and relationship with the surface variables.
  - Check which way the time axis is oriented and know what it means.
  - Time axis same as the surface graph stack: vertical profile similar to a sounding.
  - Time axis reversed to the surface graph stack: a trajectory effect is implied.

- Interpret the meteogram as a whole.
  - Surface graph stack.
  - Time-height chart.
  - Infer the progression of weather systems past a point.
  - Develop the point forecast for your mission using the model forecast clouds, precipitation, temperature, pressure, and winds.
  - Determine the potential for severe weather during the mission time frame.

- Caveats to remember.
  - Data is valid for a single point only.
  - Data is valid for the grid point nearest to the meteogram location.
  - Data has no statistical enhancement like other forms of guidance do.
  - May not be corrected to the actual terrain surface when the model surface differs from real life.

Appendix A: Examples of Time-Series Charts: "Cross-Over Charts" and Meteograms

The following time-series graphs show the close relationship between the modern computer generated meteogram and the earlier hand-plotted charts once used by military forecasters. Figures A-1 and A-1a display the original FOUS bulletins from which the "cross -over charts" were plotted. The bulletin date is 12Z on 18 January 2001, and the data for Omaha, Nebraska, and Washington, D.C., are plotted in Figures A-2 and A-3, respectively.

Figures A-4 and A-5 show the EMC meteograms from the ETA model for the same date, time, and locations as for A-2 and A-3 above.

Figures A-6 and A-7 show the AFWA MM5 model meteograms for the same date, time, and places as above.

The valid time for the cross-over charts extends from the zero hour forecast to 48 hours later. The much longer valid times on the meteograms enable the forecaster to detect weather changes later in the forecast cycle.

Appendix B: Exercises Demonstrating Meteograms Use and Interpretation

This appendix is a self-running slide show module designed to review the techniques discussed in the main body of this technical application note. The forecaster is led through the analysis and interpretation of a meteogram, and has a variety of exercises to practice the concepts presented. The module concludes with the forecaster making a point forecast from only a satellite image and a meteogram.