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MAXIMUM AND MINIMUM TEMPERATURE FORECASTING TECHNIQUE FOR ALTA, UT

Mark Struthwolf - WFO Salt Lake City
Ed Carle - WFO Salt Lake City (Retired January 1999)

Introduction

Temperature forecasts are a critical element of the mountain forecast package that Weather Forecast Office Salt Lake City (WFO SLC) produces twice daily. While MOS guidance can assist forecasters in making temperature forecasts for specific city locations, remote sites at various elevations are rarely available. Although most mountainous areas are rather remote, diverse mountain sporting activities attract over a million recreationalists each year, especially in the Wasatch Mountains where there are 10 ski resorts. Adjustments to the lapse-rate derived temperature are made according to various other parameters including strength of warming or cooling, wind, sky condition, and time of year. A Tcl/Tk program has been developed that allows the forecaster to quickly employ this technique via a graphical user interface on AWIPS.

Methodology

Alta, Utah is used as a representative mountain site since daily maximum and minimum temperature data and official weather conditions are available twice daily. In addition, hourly temperatures are available from nearby remote temperature sensors. Satellite and hourly camera images from the base of Alta ski resort were used to supplement actual weather and sky conditions at the study location. The 700-mb level, with a standard atmospheric height of approximately 9900 feet, was selected as the level from which the lapse rate is calculated. Subtracting the 8700 foot elevation of the Alta Guard station (location of temperature measurements) from this level results in a 1200 foot layer. Applying a dry lapse rate of a constant (3.3 degrees C per 1000 feet) to this 1200 foot layer equates to nearly 4.0 degrees C change. However, a dry lapse rate is rarely reached in winter. Evaluating many so-called dry days, an average lapse rate closer to 3.0 degrees C per 1000 feet was considered more representative. This equates to a change of 3.6

degrees C through the 1200 foot layer. The moist atmosphere lapse rate, at this level, is approximately 2.0 degrees C per 1000 feet, resulting in a 2.4 degrees C warming through this layer. Consequently, only about a 1 degree C difference exists depending on which lapse rate is used through the 1200 foot layer. For ease of calculating and to maintain a 1 degree C spread, these figures are truncated down to 3 and 2 degrees C for dry and moist conditions, respectively.

These dry and moist temperature adjustments were then added to the 12 UTC analysis and 00 UTC forecast to acquire a base temperature. As data were collected during three winter seasons from early November 1995 until mid-April 1998, empirical temperature adjustments were made according to various parameters. These include both 12 UTC and 00 UTC Salt Lake City radiosonde 700-mb temperature and dewpoint depression, 700- mb wind direction and speed, sky conditions, and surface observations of maximum and minimum temperature from both the Alta Guard station (8700 feet) and Alta Ski Lifts (8600 feet). (Note; two sites were chosen for comparison purposes.) Noticeable temperature differences were sometimes recorded between these sites, especially on sunny days under tranquil conditions, due to the Alta Guard station's location on the south facing slope and the Alta Lift's site in the valley bottom.

The specifics of the decision tree for maximum temperature are listed in the paragraphs that follow:

The guidelines were broken down into four calendar segments according to time of year to accommodate change in both sun angle and exposure from November to mid-April. If the forecast 700-mb dewpoint depression is >6C the atmosphere is considered dry and 3C is added to the 700-mb temperature to accommodate the lapse rate between the Alta Guard and the 700-mb level. If the dewpoint depression is <=6C, the atmosphere is considered moist and 2C is added to the 700-mb temperature to accommodate the lapse rate. If the dewpoint depression changes from dry to moist or vice versa during a 12 hour period, it is the forecaster's discretion to determine the best profile to utilize.

The impact of the wind is broken down into two components,

1. northerly 700-mb wind component (270-89 degrees) and
2. southerly 700-mb wind component (90-269 degrees).

In the event of a trough or ridge passage, it is the forecaster's discretion to determine the best wind direction to use.

Daytime weather conditions are broken into three sub-categories,

1. clear or partly cloudy,
2. mostly cloudy or overcast, and
3. precipitation.

These data were collected from three sources; reports from Alta personnel (both sites), satellite, and hourly camera images. If variations in sky cover or breaks in precipitation occur, the weather condition allowing for the highest maximum temperature during that portion of the day was implemented.

Finally, the temperature trend is included as warming or cooling according to the forecast 700- mb temperature change from 12 UTC to 00 UTC.

Nighttime minimum temperature forecasts follow a similar decision tree with a few exceptions. During the night, sky conditions are divided into four categories; the precipitation and the mostly cloudy or overcast categories remain unchanged, while the third category "partly cloudy or clear", is separated into two categories; one partly cloudy and the other clear. Wind direction is not considered. However, wind speed is, if 700-mb winds are 30 kts or greater, then the empirically derived temperatures are further adjusted.

Validation

To validate how much of an improvement this technique was having over the operational method of forecasting by the office, a verification study was initiated. Two years were chosen (dependent on best available data) from the three year period 1995-1997 winter-early spring seasons. These earlier years prior to 1998 were utilized to minimize any possibility of the technique being used operationally. Also, it must be noted that in the controlled environment of developing guidelines, the actual 12 UTC and 00 UTC 700-mb data and surface observations were used, while in the operational world, the 700-mb parameters and surface predictions are based on model forecasts. Consequently, any error in model forecasts could result in errors of sky condition, precipitation, and wind speed/direction all directly adversely affecting the temperature forecast. The largest temperature differences between the operational forecasts and observed occurred when the entire forecasts went awry; i.e. snow forecast and clear were observed and vice versa. In order to keep the comparison between the new technique and the operational method as clean as possible, days in which this happened were thrown out. This quality control enabled a better comparison.

In general, this technique's error was 2.6 degrees F per max temperature forecast and 2.0 degrees F per min temperature forecast while the operational forecast errors were 4.1 and 3.8 degrees F, respectively. This technique's improvement over the operational forecasts for maximum temperatures ranged from 0.5 degrees F in December to as much as 2.2 degrees F in January. Minimum temperature forecast improvements varied from 1.3 degrees F in December to 2.1 degrees F in February.

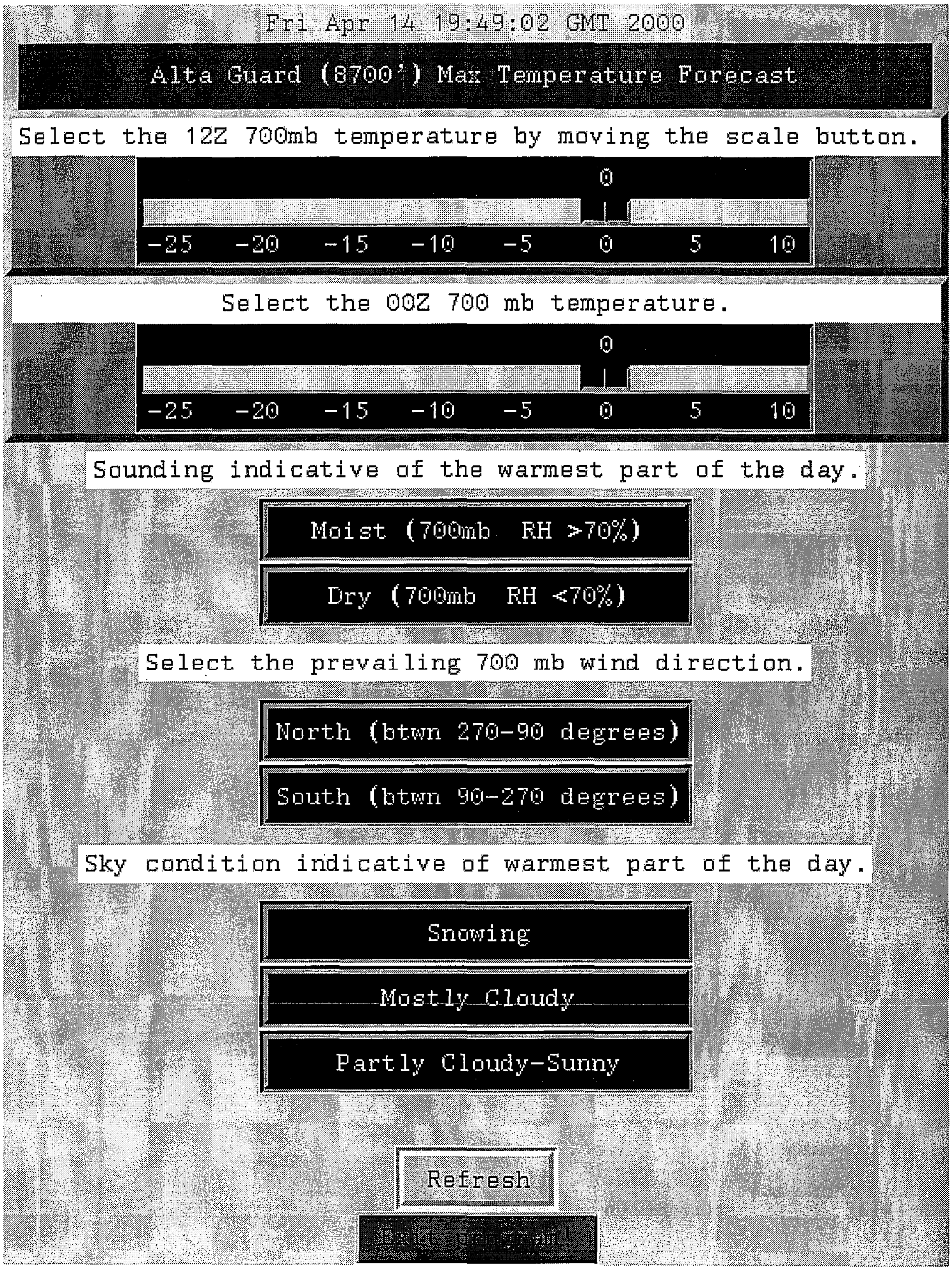
While the average improvement of less than 2 degrees per forecast may not be valued as operationally significant, especially knowing the actual 700-mb temperatures are used in the technique, the real improvement may have been realized in the decreased number of days that forecast errors exceeded 5 and 10 degrees F. (Note: Rarely did the 700-mb temperatures differ significantly enough between actual and forecast to produce these large errors in the surface temperatures). Results were separated into three categories: less than or equal to 5 degrees F, greater than 5 but less than 10 degrees F, and greater than or equal to 10 degrees F. There were a total of 336 maximum and 329 minimum temperature forecast comparisons made in this two-year study. During this time, 81 operational maximum temperature forecasts (25%) erred by more than 5 but less than 10 degrees F and 23 (7%) erred by 10 degrees F or more. Therefore, nearly 1/3 (32%) of all operational forecasts had substantial errors in excess of 5 degrees F. In comparison, the new technique results were much better; 44 forecasts (13%) erred between 5 and 10 degrees F and 2 (<1%) erred by 10 or more degrees F. This equates to less than 1/7 (14%) had substantial errors.

Significant improvement was also realized for minimum temperatures using the new technique. Out of 329 minimum temperature forecasts, 62 (19%) erred by more than 5 but less than 10 degrees F, and 14 (4%) that erred by 10 degrees F or more. Therefore, nearly 1/4 (23%) of all operational forecasts had substantial errors in excess of 5 degrees F. In comparison, this new technique only had 13 forecasts (4%) in which errors greater than 5 degrees F occurred.

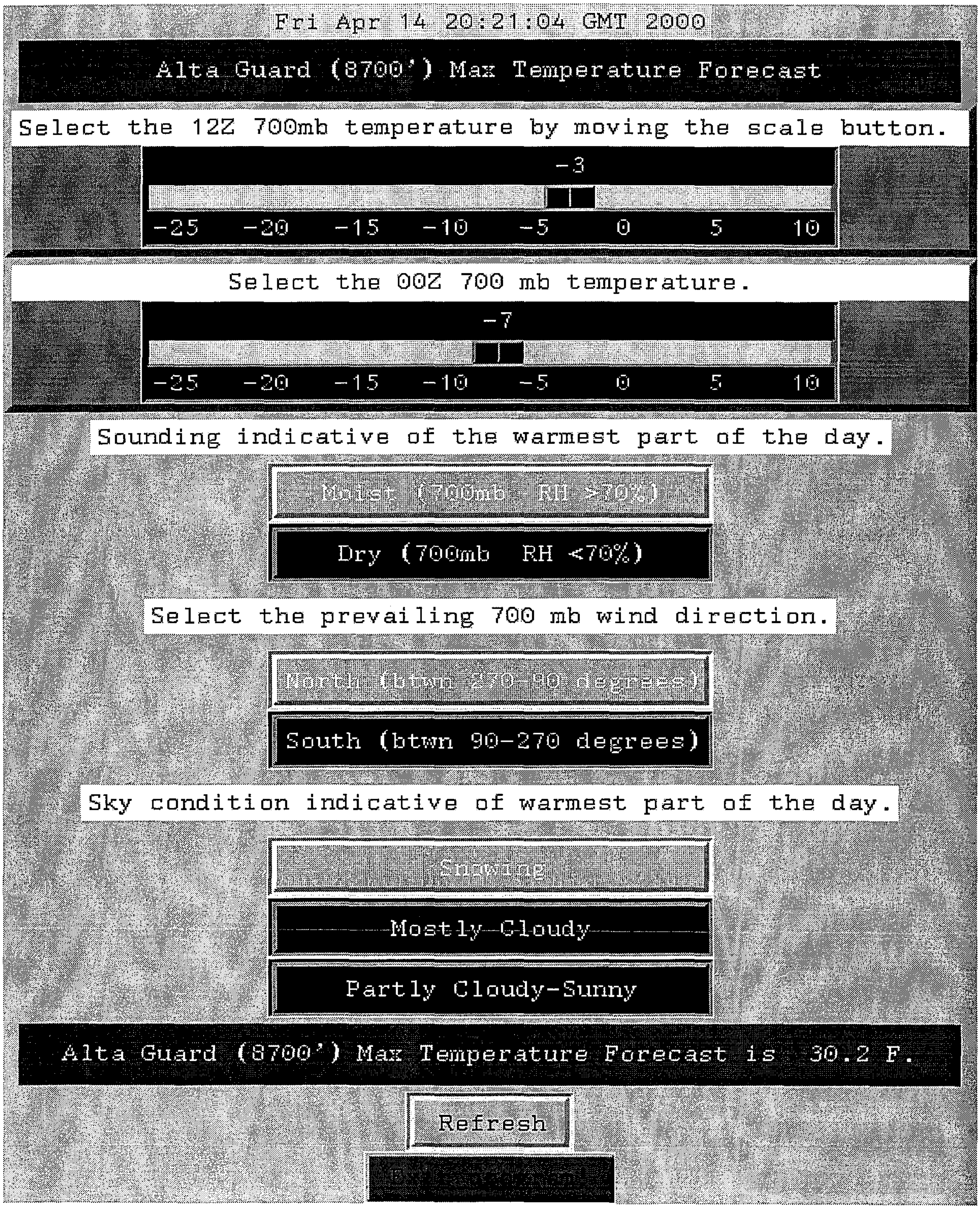
The best results were noted during precipitation days where the average error was less than 2 degrees F for November through February and less than 4 degrees F in March and April. Temperature forecasts suffered most during sunny tranquil days when super adiabatic conditions occurred, especially at the Alta Guard with its southern exposure, likely causing abnormally large temperature spikes. Some forecast errors as great as 12 degrees F were observed on sunny days and are presumed to be associated with this phenomena. The best results for minimum temperature forecasting appeared to occur during cloudy nights when both Alta Guard and Alta Lifts were within a few degrees of each other. However, on clear nights, temperatures could vary as much as 5-10 degrees between the Guard and Lifts, due to their locations on the hillside and valley bottom, respectively.

Tcl/Tk Program

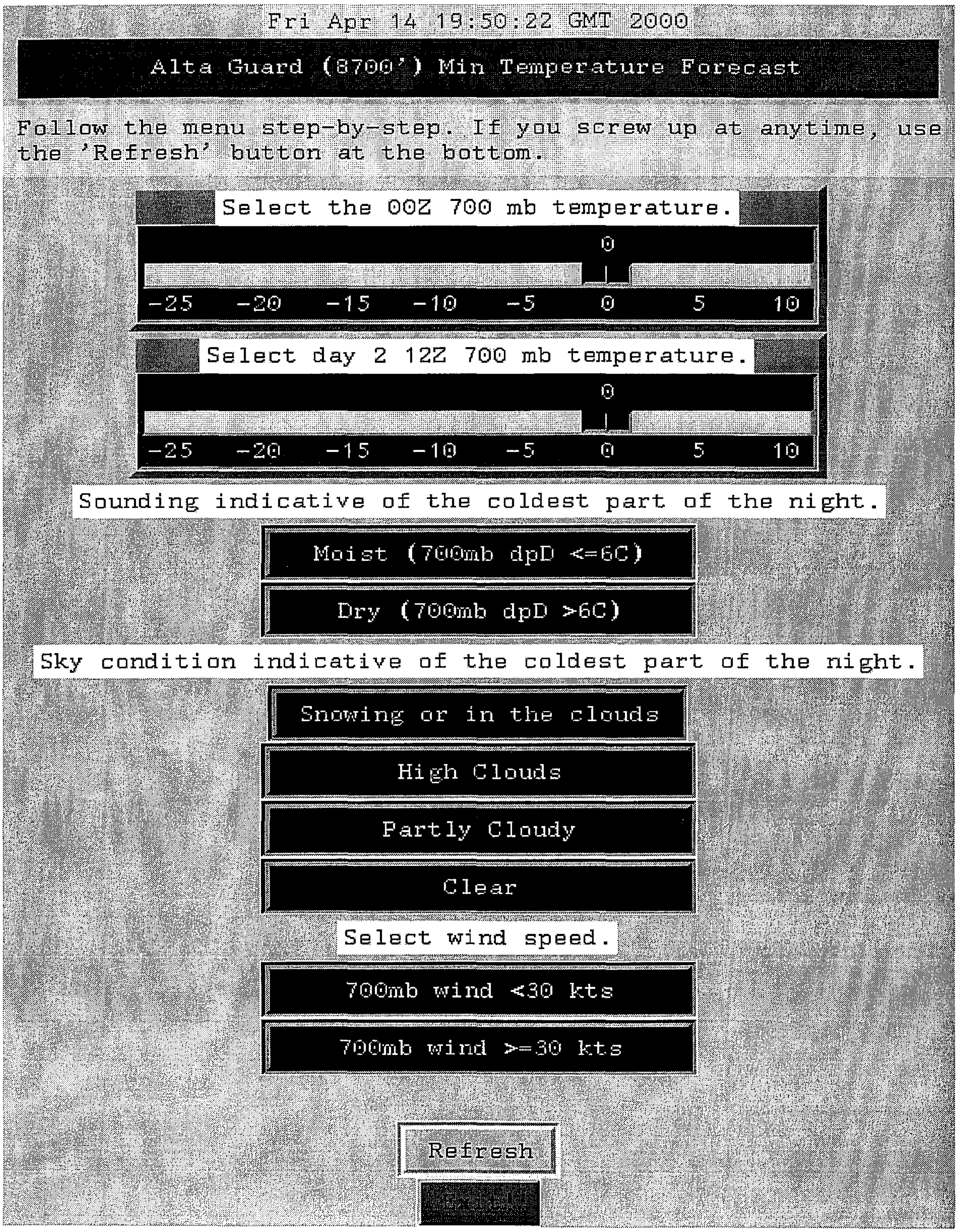
The graphical user interface (GUI) for the Alta temperature forecast program is shown below.


Fri Apr 14 19:49:02 GMT 2000
Alta Guard (8700') Max Temperature Forecast
Select the 12Z 700mb temperature by moving the scale button.
0
-25 -20 -15 -10 -5 0 5 10
Select the 00Z 700 mb temperature.
0
-25 -20 -15 -10 -5 0 5 10
Sounding indicative of the warmest part of the day.
Moist (700mb RH >70%)
Dry (700mb RH <70%)
Select the prevailing 700 mb wind direction.
North (btwn 270-90 degrees)
South (btwn 90-270 degrees)
Sky condition indicative of warmest part of the day.
Snowing
Mostly Cloudy
Partly Cloudy-Sunny
Refresh

The forecaster moves the slider bar at the top for the 700 mb temperature, and then selects the appropriate button for the other parameters. When the last button is selected, the forecast temperature is shown at the bottom of the GUI, as seen below.



The forecaster can select 'Refresh' to re-enter different values. An example of the GUI for the minimum temperature forecast program is similar and is shown below.



Summary

An empirical study of forecast parameters that might be useful for forecasting maximum and minimum temperatures at Alta, Utah led to the creation of a decision tree approach. The skill of the decision tree was compared to the actual forecasts that were made over a three-year period, and found to be superior, particularly in reducing large magnitude errors. Creation of Tcl/Tk program in the AWIPS environment made use of the decision tree very quick and easy for the forecast staff, and facilitated the incorporation of these research results into a real-time technique at the Salt Lake City WFO.

References

(1) Chris Gibson, Lead Forecaster, SLC, has developed NGM MOS equations for Alta.