AIR TEMPERATURE OBSERVATIONS and FORECASTS -- THEIR RELATIONSHIP TO THE PREDICTION OF SPRING SNOWMELT in the EAGLE RIVER BASIN, COLORADO

550-72

By

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"Snowmelt is the over-all result of many different processes of heat transfer. The quantity of snowmelt is, moreover, dependent upon the condition of the snowpack itself. As a consequence, the rigorous determination of snowmelt amounts is quite complex and certain simplifying assumptions are used in the practical computation of snowmelt. The relative importance of the various heat-transfer processes involved in the melting of the snowpack vary with time and locale." This direct quotation introduces the chapter on SNOWMELT in the publication SNOW HYDROLOGY, Corps of Engineers, 1956. The statement emphasizes, but certainly does not over-emphasize, the difficulties involved in snowmelt computation. To instrument a river basin with the necessary equipment to directly measure the atmospheric and snowpack conditions represented in even a simplified snowmelt equation would be an expensive undertaking. Where this has been done on an experimental basis, over 90% of the daily variability in clear-weather snowmelt has been accounted for, reference (1). Clear-weather melt is defined as that occurring during periods of no precipitation, but without restrictions on the amount of cloud cover.

Air temperatures measured in standard instrument shelters in or near forested, mountain river basins in the West have been used to derive acceptably accurate indices to snowmelt for many years. The following references include studies made for areas from several western states and western Canada: (2), (3), (4), (5), (6), and (7). It may seem somewhat surprising that in 1972, with almost universal computer capability for data handling, that most operational procedures for spring snowmelt prediction in the West still rely on air temperature as the only index during clear-weather melt conditions. On the other hand, the continuing use of air temperature alone may attest to the fact that its use meets most operational requirements.

In the Fraser Experimental Forest in western Colorado the use of daily maximum temperatures to index snowmelt has been found to be significantly better than the use of mean (average of maximum and minimum) and about equal to the use of the average of maximum and 'effective' minimum (where the 'effective' minimum was the actual minimum brought up to 32°F as the low threshold). Also, the correlation between "degree days" and the average of maximum and 'effective' minimum was not significantly better than the correlation between "degree days" and the daily maximum alone. This finding, described in Section 4, reference (5) was based upon an evaluation of hourly temperature records from thermographs in the same instrument shelters as the maximum and minimum thermometers. Comparison of "degree days" above a 32°F base, computed from the hourly temperature data, was made with daily maximum and the daily average of maximum and 'effective' minimum.

The key work when describing the use of air temperatures to predict snowmelt in western Colorado may be INDEX. Air temperatures near the ground surface during the warmest part of the day, when most mountain snowmelt occurs, represent one of the most conservative properties of the lower atmosphere. They are less conservative during the night when melt is usually negligible. It is frequently possible, for snowmelt forecasting purposes, to index the air temperature regime over an area of several thousand square miles by no more than a few observation sites. Although air temperatures have been shown to index clear-weather melt conditions effectively, reference (1), air temperatures will not index melt so effectively when major air mass changes are taking place. The occurrence of thick clouds, increased wind, significant changes in air moisture, and precipitation greatly complicate the indexing of the heat transfer processes which cause snowmelt. For that reason, it may well be true that a few air temperature observations are adequate for snowmelt prediction most of the time, and that when they are not adequate the addition of several more will add but little to improve snowmelt prediction.

For operational use, the selection of air temperature observation sites for snowmelt forecasting consists of examining the high quality temperature records of the past and correlating them with snowmelt and the snowmelt hydrograph. For the Eagle River Basin

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in Colorado, the record at the Eagle Airport, elevation 6500 feet, located in the lower central part of the basin, proved to be adequate. This single station indexed the snowmelt hydrograph for the several years tested about as well as any combination of two or more stations in the basin. The Eagle station is a National Weather Service installation, operated by the Federal Aviation Administration. In addition to daily maximum and minimum data, hourly temperatures are operationally available. For real-time forecasting purposes this addition of hourly information is valuable when the temperature distribution throughout the day is greatly different from the normal. But, as yet, the application of hourly temperature data to snowmelt forecasting in the Eagle Basin has not been completely nor objectively studied. Figure 1 is a map of the Eagle River Basin and Figure 2 shows the daily maximum temperature regime in the spring of 1971. Figures 3 and 4 depict air temperature-snowmelt runoff relationships for the years 1970 and 1971 during the main melt months of May and June. Precipitation plotted at the top of these figures is that which occurred at Climax 2NW, a station near the continental divide at the top of the basin at an elevation of 11,300 feet. Figure 3 illustrates the application of a standard temperature index, based upon the daily maximum temperature at Eagle, for the 1970 snowmelt season. As the basin snowcover is depleted after the major late May rise, the temperature-runoff relationship becomes progressively worse. But, during the long period of clear-weather melt conditions during May, most of the variability in the snowmelt runoff is accounted for by the temperature index.

Figure 4 depicts a less refined and less accurate temperature index for the 1971 snowmelt months of May and June. Compared to 1970, the major peak is about a month later and from a higher elevation snowpack. The three-day running total of temperature excess above a threshold base used to index the snowmelt hydrograph was chosen to illustrate the importance of correct temperature trend forecasts for snowmelt hydrograph prediction. In the Eagle River Basin if the total amount of temperature excess above a threshold base is forecast quite accurately for the next three days, the individual daily verifications seem to be of secondary importance. Figure 4 provides an interesting comparison with Figure 9, which shows a verification of three-day temperature forecasts.

Since air temperatures are used to index snowmelt and the snowmelt hydrograph, it follows that forecasters who use anything less than the highest quality air temperature forecasts available during the spring snowmelt period are certainly <u>not</u> maximizing the temperature-snowmelt relationship. It is important for hydrologists and river forecasters to understand the "state of the science" in temperature forecasting. The "state of the science" certainly is not perfect temperature forecasts for the next several days, yet it far exceeds an assumption of persistence or seasonal normal for the next several days. There is today, as there always has been, some difference in forecasters' abilities to predict the weather. But, the real measure of progress in weather forecasting lies in the increasing capability to objectively predict the general air circulation of the lower atmosphere. This is especially true in the case of air temperature forecasts, whose prediction is more directly related to the general circulation that is the forecast of precipitation.

Figure 5, 6, 7 and 8 illustrate the improvement in recent years in temperature forecasting. Figure 5 shows the improvement in general circulation prognoses; Figure 6 the actual verification of errors in temperature forecasts at Salt Lake City, Utah with time; Figure 7 an error analysis of computer produced temperature forecasts, and Figure 8 the improvement since 1966 in 48-hour temperature prediction. In Figure 7 it will be noted that beyond four days from the last observed data there is little skill in temperature forecasting, as the forecast errors approach those resulting from the assumption the "normal" will occur. It probably would not be correct, however, to infer from this figure that for <u>all</u> weather situations temperature forecast skill disappears within four or five days from the last observed data. But, the decay in skill indicated is very real and it should be recognized as a "state of the science" problem.

Figures 9 and 10 illustrate the forecast verification of three-day maximum temperature forecasts furnished to the River Forecast Center by the Weather Service Forecast Office at Salt Lake City, located adjacent to the RFC, in May and June of 1971. It can be seen that significant errors in the trend of temperature for three-day forecast periods were infrequent when each point is viewed as the verification of the three-day forecast total of the amount of heat above a 50 degree base at Eagle or Salt Lake City. It is my conclusion that the three-day temperature forecasts illustrated in Figure 9 and 10 reflect the "state of the science".

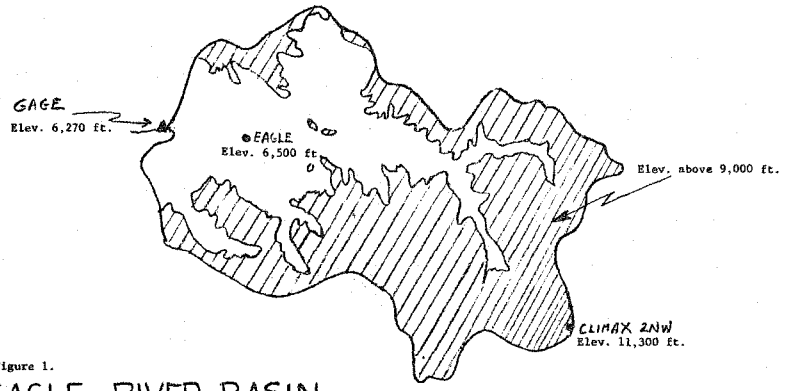


Figure 1.

EAGLE RIVER BASIN

944 SQ MI.

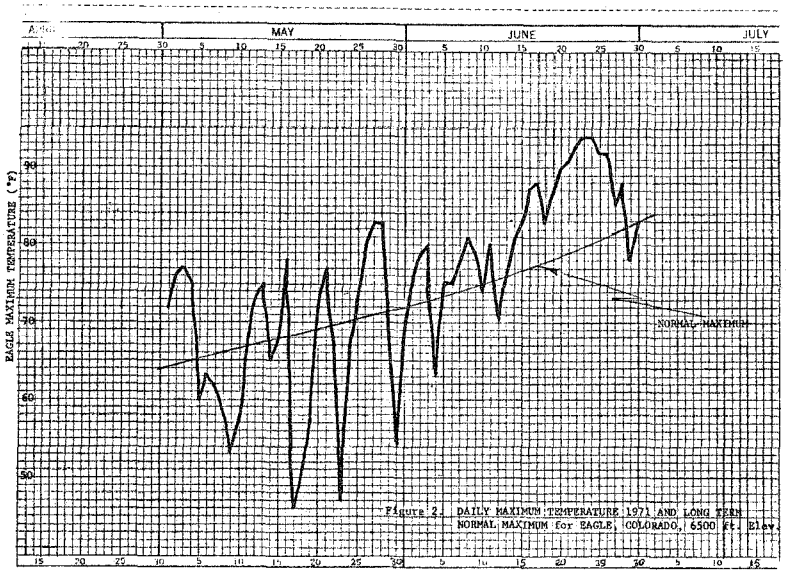


Figure 2. DAILY MAXIMUM TEMPERATURE 1971 AND LONG TERM NORMAL MAXIMUM for EAGLE, COLORADO, 6500 ft. Elev.

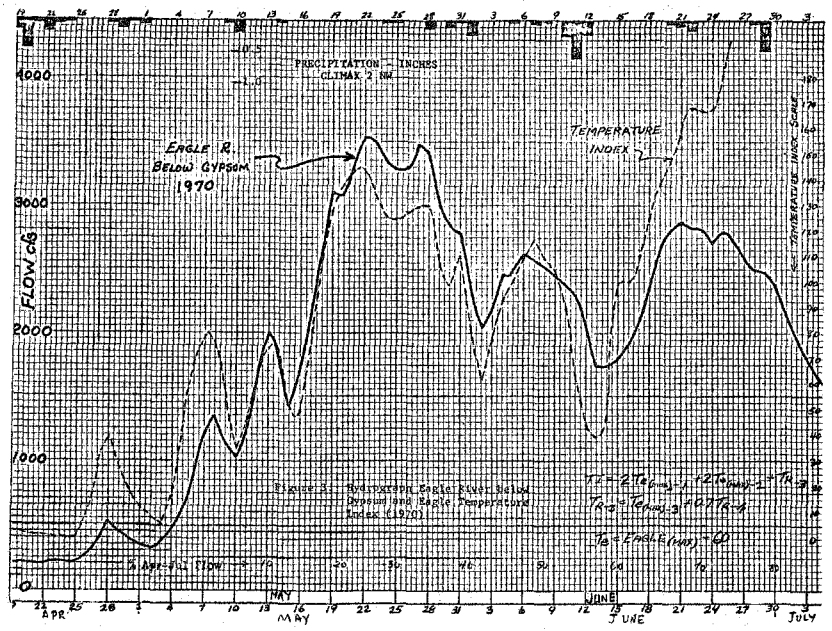


Figure 3. Hydrograph Eagle River Below Gypsum and Eagle Temperature Index (1970)

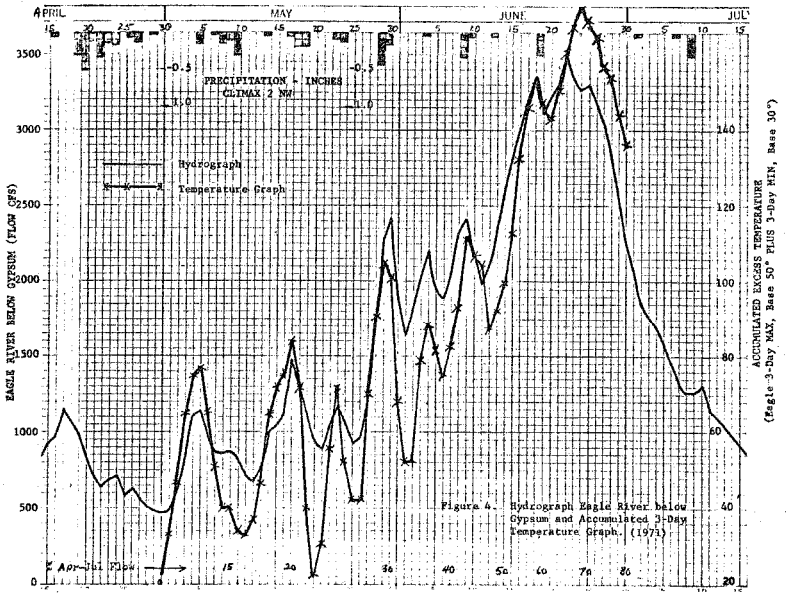


Figure 4. Hydrograph Eagle River below Gypsum and Accumulated 3-Day Temperature Graph. (1971)

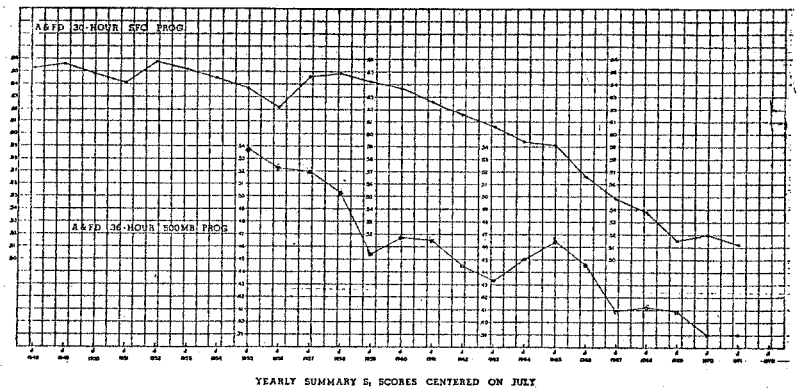
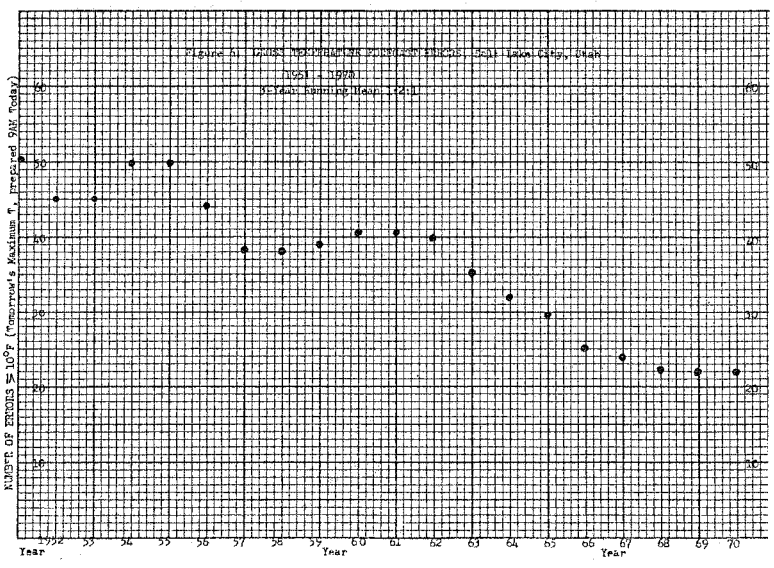


Figure 5. - Annual average S1 scores [51] for 30 hr sea level (upper curve) and 36 hr 500 mb (lower curve) forecasts. The S1 score is roughly a measure of normalized RMS vector error of pressure gradient. The area of verification for both levels covers North America. The two curves are plotted on the different scales shown. The scale for sea level is the one labelled from .50 to .66, the scale for 500 mb from .39 to .54. To calibrate the scores in terms of practical skill, a sea-level forecast with a score of .30 is virtually perfect, one with a score of .80 is worthless. For 500 mb, .20 represents a virtually perfect forecast, .70 worthless.



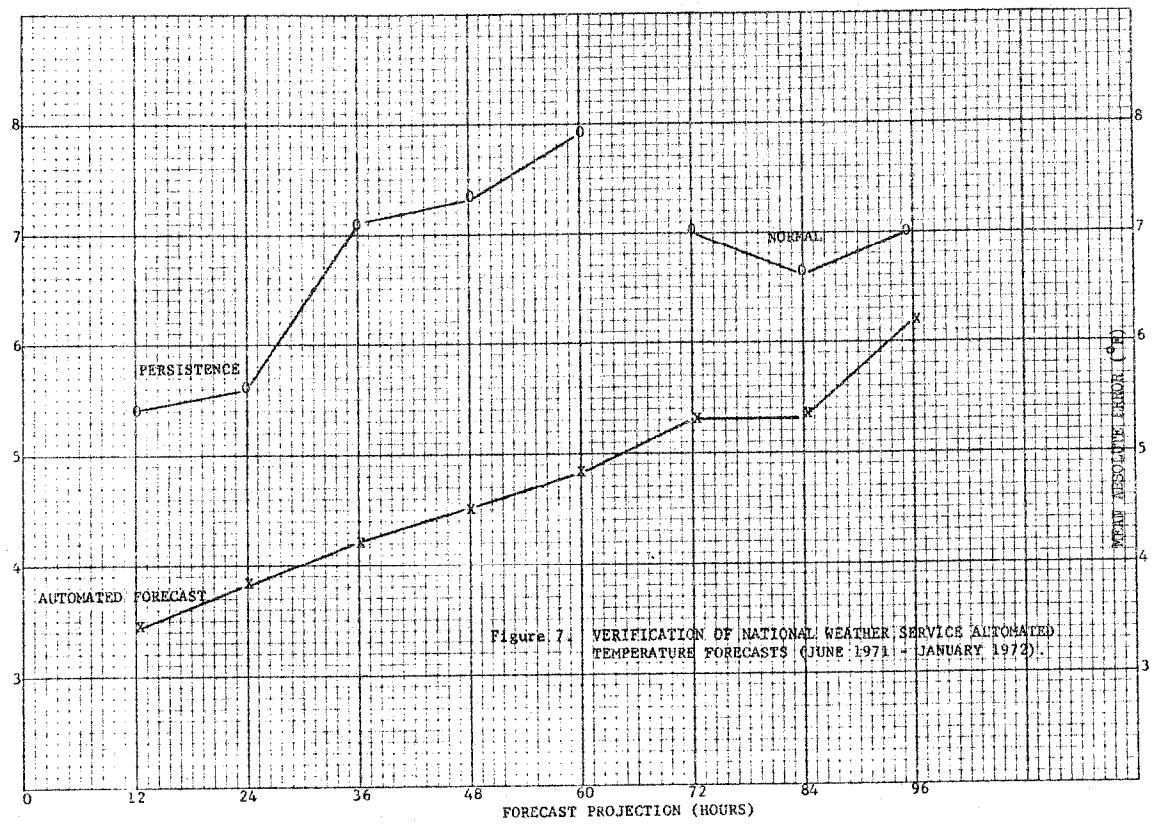


Figure 7. VERIFICATION OF NATIONAL WEATHER SERVICE AUTOMATED TEMPERATURE FORECASTS (JUNE 1971 - JANUARY 1972).

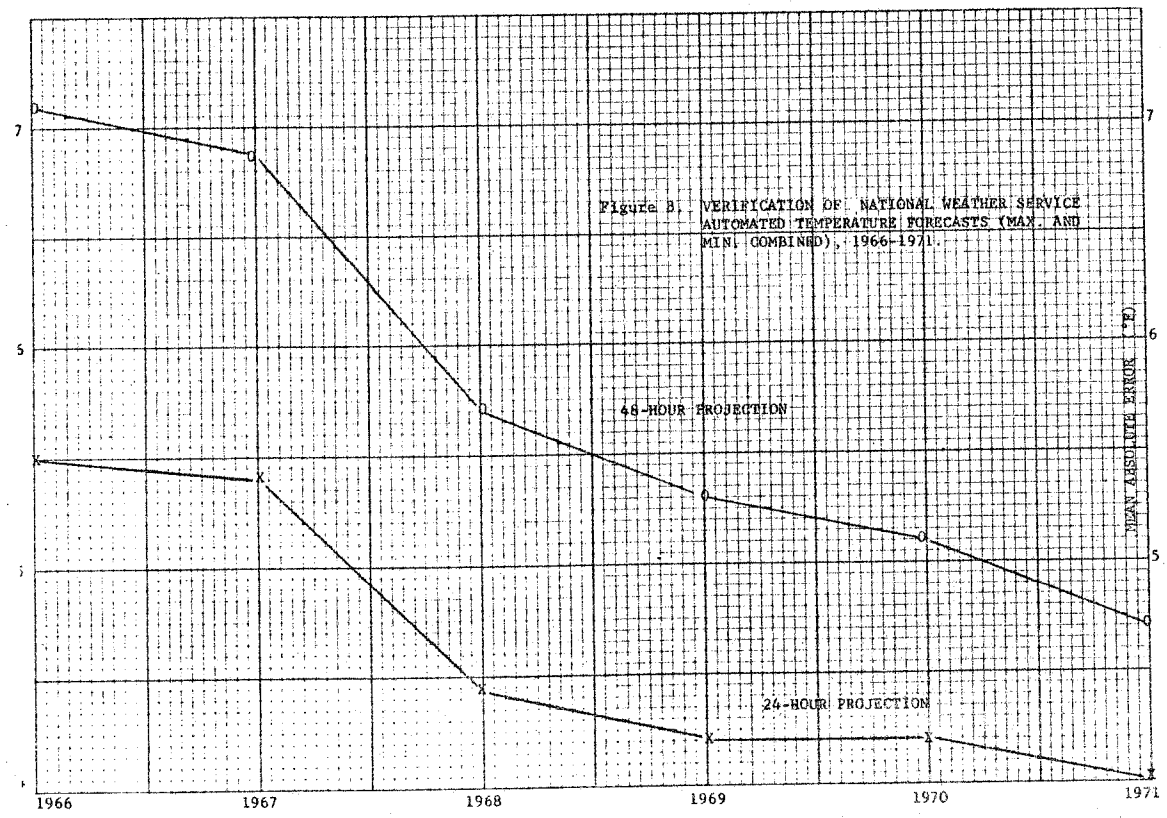


Figure 8. VERIFICATION OF NATIONAL WEATHER SERVICE AUTOMATED TEMPERATURE FORECASTS (MAX. AND MIN. COMBINED), 1966-1971.

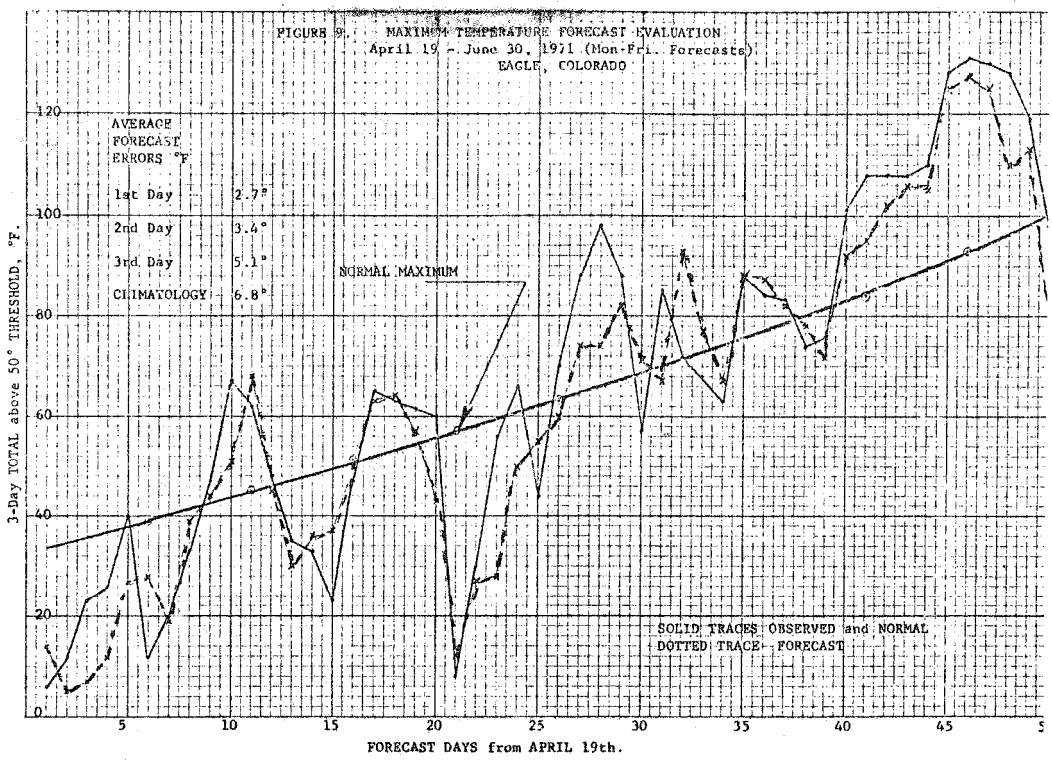


FIGURE 9. MAXIMUM TEMPERATURE FORECAST EVALUATION
April 19 - June 30, 1971 (Mon-Fri. Forecasts)
EAGLE, COLORADO
AVERAGE FORECAST ERRORS °F
1st Day 2.7°
2nd Day 3.4°
3rd Day 5.1°
CLIMATOLOGY 6.8°
NORMAL MAXIMUM
SOLID TRACES OBSERVED and NORMAL
DOTTED TRACE - FORECAST
3-Day TOTAL above 50° THRESHOLD, °F.
FORECAST DAYS from APRIL 19th.

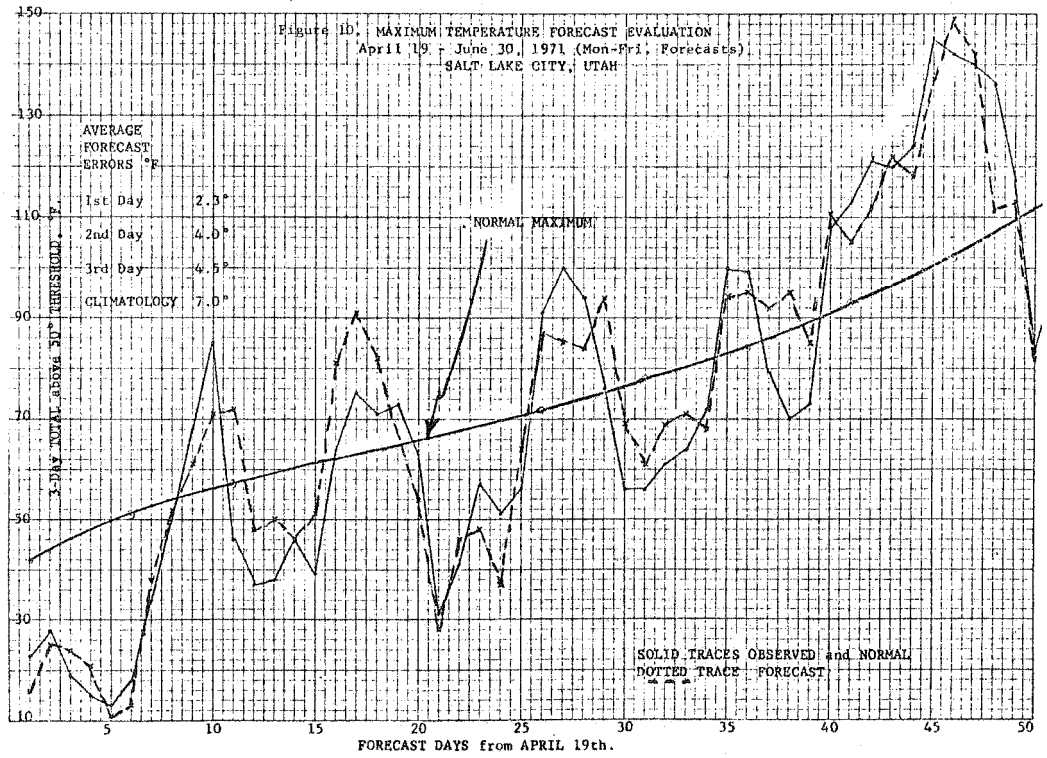


Figure 10. MAXIMUM TEMPERATURE FORECAST EVALUATION
April 19 - June 30, 1971 (Mon-Fri. Forecasts)
SALT LAKE CITY, UTAH
AVERAGE FORECAST ERRORS °F
1st Day 2.3°
2nd Day 4.0°
3rd Day 4.5°
CLIMATOLOGY 7.0°
NORMAL MAXIMUM
SOLID TRACES OBSERVED and NORMAL
DOTTED TRACE - FORECAST
3-Day TOTAL above 50° THRESHOLD, °F.
FORECAST DAYS from APRIL 19th.

Summary:

1. A simple temperature index to snowmelt performs quite well in the Eagle River Basin in Colorado in the spring snowmelt season during clear-weather melt conditions.

2. During weather situations where a significant change of air mass is occurring, air temperatures are likely to be a poorer index to snowmelt than during relatively stable, dry periods. Therefore, additional air temperature data for a given river basin might not significantly improve snowmelt prediction during such periods.

3. The predictability of air temperatures in a time frame of the next several days is improving as the general circulation prognoses improve.

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