Forecasting

USING CLIMATOLOGICALLY FAVORED THICKNESS TO LOCATE THE AXIS OF HEAVIEST RAINFALL

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ABSTRACT

Heavy rainfall correlates favorably with a relatively narrow band of (1000-500 mb) thickness values which vary by season and geographical area. This study documents the relationship and attempts to provide insight in how to best use the relationship in quantitative precipitation forecasting.

1. INTRODUCTION

Great strides have been made in "operational" numerical modeling over the past 20 years. Unfortunately, the bulk of the improvement has come in the forecasting of the synoptic scale mass and thermal fields. Improvements in numerical model forecasts of precipitation and smaller scale features have lagged behind (Kaplan et al, 3).

Gridscale stratiform precipitation is often forecast relatively well by "operational" numerical models, convection is not. The higher threat scores found by Charba et al (4) during the cool season as opposed to those of the warm season can be attributed to this fact. Individual convective cells often occur on spatial scales below the resolution of the grid spacing in "operational" numerical models. Therefore, convection is not modeled in a realistic manner. Squall lines and mesoscale convective complexes can dramatically alter the location of low-level boundaries and moisture convergence, thereby helping to determine where subsequent heavy rainfall will occur. Operational numerical guidance rarely shows the necessary detail to adequately forecast these smaller scale convectively induced features (Maddox, 5 and Olson, 6).

Due to the shortcomings of the numerical models, quantitative precipitation forecasters often rely on empirical techniques to help locate where the heaviest rain is likely to fall. The rudiments for one of the most useful methods were developed at NMC during the 1960's when forecasters began to notice that the heaviest precipitation usually fell within a fairly narrow range of 1000 to 500 mb thickness values. Forecasters also observed that this preferred thickness ribbon for heavy rain varied by season and geographic location.

2. METHODOLOGY

All precipitation reports of one inch or more were collected from synoptic and hourly reporting stations for the 12-hr periods ending at 0600 GMT and 1800 GMT during the last three months of 1964, all of 1965, 1966, 1967 and 1968.

During each period, the location of reports of one inch or more of precipitation was compared to manually computed 1000-500-mb thickness values obtained from 0000 GMT or 1200 GMT data. All thickness values were computed in decameters. These units are employed throughout the paper when referring to thickness. 0000 GMT and 1200 GMT data were used for two reasons: Radiosonde data are regularly available at these times, and these times represent the midpoint of each precipitation period. Reports were limited to those occurring east of the Rockies and were grouped into six different geographical areas (see Fig. 1).

In cases when the 1000 to 500 mb thickness is rapidly changing (i.e., passage of a strong cold front), the midpoint of the 12-hr period may not accurately represent the thickness values at the time of heaviest rainfall. However, in most cases the difference is small, so the thickness value at the midpoint of the period is used for the sake of simplicity.

An exception to the standard procedure was made during the months of July and August when diurnal changes in thickness often overwhelm dynamically induced ones. For these months two changes were implemented: first, the 12-hr precipitation periods were altered to end at 0000 GMT and 1200 GMT, and second, corresponding midpoint thickness values were obtained by averaging values at the beginning and end of the 12-hr period.

The 12-hr precipitation reports and their corresponding thicknesses were separated by area (Fig. 1). The mean, median,

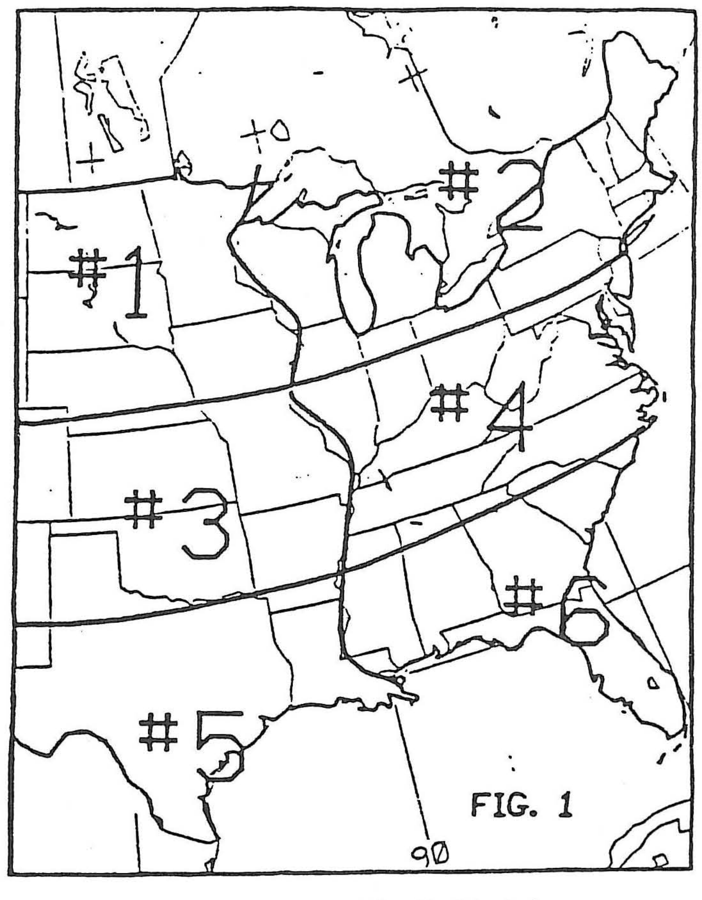

Fig. 1. The climatological areas defined in this study.

mode, and standard deviation were then calculated for each month for each area.

Each mean was calculated by summing the observed thickness values where an inch or more of rain was reported and dividing by the total number of observations. The mean represents a simple arithmetic average thickness value for heavy rain.

The median values are defined as those for which half the observed 12-hr heavy rainfall events occurred at higher thickness values and the other half occurred at lower ones. Medians were found for each month in each area. When an even number of observations were present, sometimes no value fell at the exact midpoint. In these cases, the median offered is an average between the two thickness values which were closest to being located exactly halfway between the other observations.

Each mode given is the most frequently observed thickness value where an inch or more of precipitation was reported in 12-hours during each month over a particular region.

The standard deviation for each area and month was determined in two steps. First, by squaring the differences between the observed and calculated mean thickness values, then, by summing the squared differences and dividing by the total number of observations.

3. RESULTS

The mean "thickness for heavy rain" shows a fairly predictable seasonal variation. Not surprisingly, the mean is generally lowest for each area during December, January, February and March (see Tables 1–6), usually reaching its nadir during January. The highest mean thickness values occur during July and August with June trailing slightly behind. During summer, the highest preferred thickness values are found across the Great Plains (Areas 1, 3, and 5) where the highest mean thickness values are found and where instability is usually greatest. Much of the rest of the year, higher mean or "preferred" thickness values are found across the South (Areas 5 and 6).

Marked month-to-month changes in the preferred thickness occur for each area. In June, the mean preferred thickness in Area 1 is 569.0. By July, it jumps to 575 but settles back to 571.2 in August. During the 4 years of the study, Area 1 rarely received an inch of precipitation in 12-hr during any of the months between November and March, inclusive. Seasonal variations are least pronounced near the Gulf of Mexico (Areas 5 and 6, Tables 5 and 6) where moisture is more readily available throughout the year. Still, the favored thickness over this area, varies between the upper 550's and lower 560's during winter to the mid 570's during summer.

During most months and over most areas, the mode is generally a little higher than the mean. The reason is simple. The frequency of heavy precipitation drops off quickly at higher thickness values and is more spread out at lower ones. Table 2 illustrates this idea. All months but March, September, and October exhibit higher modes than means. Usually, the median falls somewhere in between.

For each mean a standard deviation was computed. The standard deviation acts as a benchmark showing how much the observations are spread out along different thickness values. Most of the time, the standard deviation is greatest during the winter months and is greatest for the northern areas.

The standard deviations vary from 1.6 during August for Area 6 to over 9 during November for Area 2. Months with higher deviations generally exhibit stronger thickness gradients and stronger dynamics. Months with lower deviations usually have weaker thermal gradients with precipitation probably being determined to a greater extent by thermodynamical processes. Areas and months with deviations above 5.5 probably lend themselves poorly to determining a "climatologically favored thickness for heavy rain." When deviations are this high, observed occurrences of 1 inch or more are spread across too large a range of thickness values for the mean to give much help in pinpointing where the heaviest rain may occur.

4. OPERATIONAL FORECAST APPLICATIONS

The differences between the mean and mode establish the way a forecaster should use the information offered in the tables to determine what thickness values will be favored for heavy precipitation. In general, the axis of maximum rainfall will straddle both the mean and the mode. When they are separated by a relatively large gap (ie. Area 1 during July), the axis of heaviest precipitation will most likely be bound by and include the mode on one side and the mean on the other. When the mean, median and mode are grouped closely together, the best guess for where the axis of heaviest rainfall will fall is centered around these values but will extend past them on both the upper and lower ends.

Standard deviations below 5.5 indicate enough grouping of observations for a forecaster to use a climatologically favored thickness channel based on Tables 1 through 6.

A forecaster must be careful to take into account the amount of available moisture for each each individual case before selecting the thickness where the axis of heaviest rain is likely to fall. Unseasonably high amounts of available moisture (precipitable water values 150% of normal or greater) are often found with heavy rain. However, at times, when high precipitable water values are spread over an unusually large area, the axis of heaviest rain shifts to higher thickness values than suggested by the mean given in the table. At these times the axis of heaviest rain often straddles the mode.

When applying this technique, it is important to make a careful evaluation of the projected thickness values at the time of the expected precipitation occurence. This is especially true of summer nocturnal activity.

Once a precipitation outbreak commences, a model-of-the-day concept often works well when applying the preferred thickness method. Heavy precipitation outbreaks tend to occur along the same thickness channel where the first convection begins. New cells often reform and track over this same thickness channel for the duration of the precipitation event.

Development or deepening of a weather system is usually a signal to depart from preferred thickness values, as the strong upward motions and dynamics are sufficient to cause heavy precipitation amounts at almost any thickness value. The initial outbreak of precipitation associated with a large cyclonic system tends to develop towards lower thickness values than the climatological mean. This effect partially accounts for the higher deviations observed during the winter months.

Synoptic scale stratiform overrunning precipitation generally develops at the lower range of preferred thickness values. This applies to either stable nondeveloping waves or to cyclogenesis.

During the latter stages of a cyclonic storm, higher moisture and instability tend to force a shift of the heavier precipitation towards higher thickness values (usually near but sometimes slightly above the climatological mean). This situation occurs most often in association with prefrontal squall line activity across the Plains and southern states. The one type of overrunning phenomenon which does not usually occur at a lower range of thickness values is summertime mesoscale convective complexes and systems. Rainfall during these events usually occurs at a higher range of values. In these mesoscale events, straddling

Table 1. Monthly mean, median, mode and standard deviation of the observed thickness values for 12-hr precipitation events of 1-in or more for Area 1.

	Mean	Median	Mode	Standard Deviation
Jan.		NO	CASES OBSERVED	
Feb.		2	CASES OBSERVED	
Mar.		6	CASES OBSERVED	
Apr.	553.3	552	553	5.5
May	560.2	561	565	7.4
June	569.0	570	570	5.3
July	575.0	576	579	4.6
Aug.	570.2	570	570	4.8
Sept.	566.5	567	569	5.1
Oct.	557.9	557.5	557	5.0
Nov.		6	CASES OBSERVED	
Dec.		3	CASES OBSERVED	

Table 2. Same as Table 1, but for Area 2.

	Mean	Median	Mode	Standard Deviation
Jan.	546.0	548	548*	6.6
Feb.	548.5	551	551	7.3
Mar.	548.6	548	548	4.2
Apr.	555.3	556	558	5.3
May	558.3	559	559*	6.6
June	567.9	568	568	4.4
July	571.1	572	575	4.8
Aug.	570.3	571	572	4.0
Sept.	565.9	566	565	4.5
Oct.	558.0	559	557	7.0
Nov.	554.2	555	556	9.6
Dec.	552.0	553	553	6.7

*Jan. also has mode of 543 while May has additional modes of 561 and 552.

Table 3. Same as Table 1, but for Area 3.

	Mean	Median	Mode	Standard Deviation
Jan.	555.0	556	559	4.6
Feb.	555.3	555	557	4.5
Mar.	556.0	557	558*	4.8
Apr.	562.2	562	565	3.9
May	566.6	567	567	4.4
June	572.7	573	573	3.9
July	577.4	578	578	3.6
Aug.	575.5	576	576	3.0
Sept.	570.7	571	571	3.9
Oct.	564.0	565	564	5.8
Nov.	559.3	559	559	3.9
Dec.	556.3	558	558	4.5

*Mar. also has a mode of 553.

Table 4. Same as Table 1, but for Area 4.

	Mean	Median	Mode	Standard Deviation
Jan.	553.5	553	553	4.8
Feb.	554.6	555	554	5.7
Mar.	556.2	557	559	5.0
Apr.	559.2	561	560	4.9
May	564.8	565	569*	4.9
June	570.3	571	571	3.6
July	573.0	573	574	3.3
Aug.	573.2	573	573	2.8
Sept.	568.8	569	567	4.1
Oct.	564.8	564	561	5.0
Nov.	557.4	558	558	4.8
Dec.	557.6	558	561	5.0

*May also has a mode of 567

Table 5. Same as Table 1, but for Area 5.

	Mean	Median	Mode	Standard Deviation
Jan.	557.2	559	560	4.3
Feb.	559.3	560	560	4.4
Mar.	559.8	560.5	561	4.1
Apr.	564.9	565	563	4.0
May	568.9	569	568	3.3
June	573.7	574	573	2.3
July	575.0	575	575	3.8
Aug.	575.6	576	576	2.3
Sept.	574.6	575	575	2.8
Oct.	570.5	571	573	3.9
Nov.	564.4	564	564	3.0
Dec.	561.8	561	561	4.2

Table 6. Same as Table 1, but for Area 6.

	Mean	Median	Mode	Standard Deviation
Jan.	559.0	560	563	4.8
Feb.	561.2	561	564	3.5
Mar.	562.2	562	565	3.4
Apr.	564.8	564	564	3.0
May	567.8	568	567	3.7
June	573.1	573	573	2.4
July	574.4	574	574	2.1
Aug.	574.5	575	575	1.6
Sept.	573.8	574	572	2.8
Oct.	571.4	572	572	3.5
Nov.	563.5	564	564	4.7
Dec.	563.1	564	565	4.0

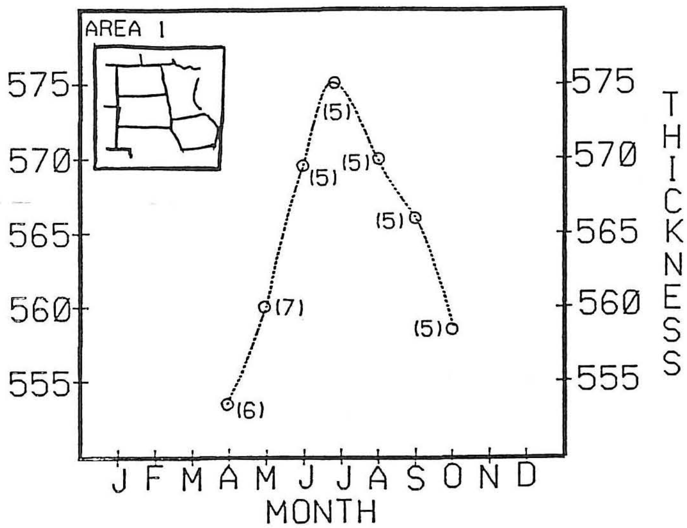

Fig. 2. Mean 1000-500 mb thickness values for 12-hr precipitation events of 1-in or more for Area 1. Values in parentheses are rounded standard deviations.

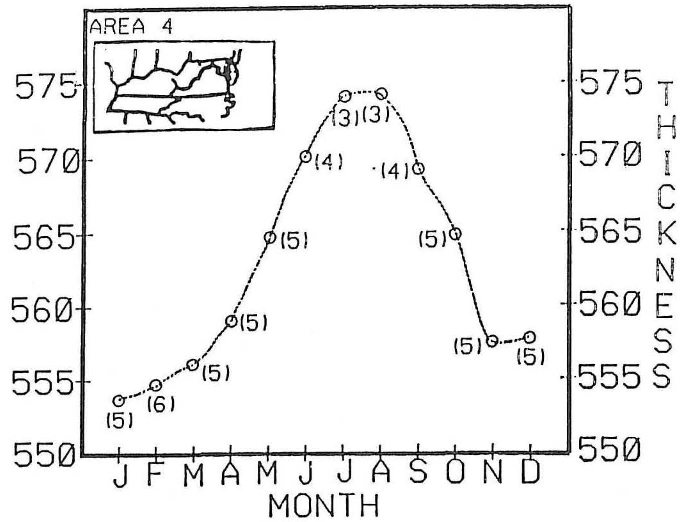

Fig. 5. Same as Fig. 2, but for Area 4.

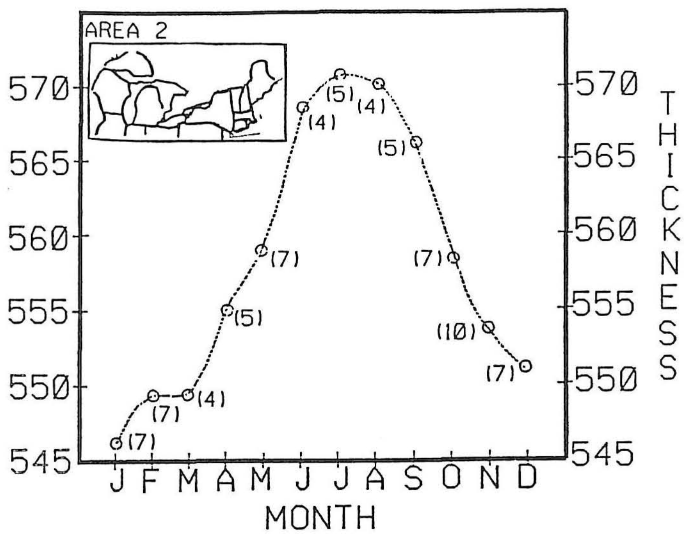

Fig. 3. Same as Fig. 2, but for Area 2.

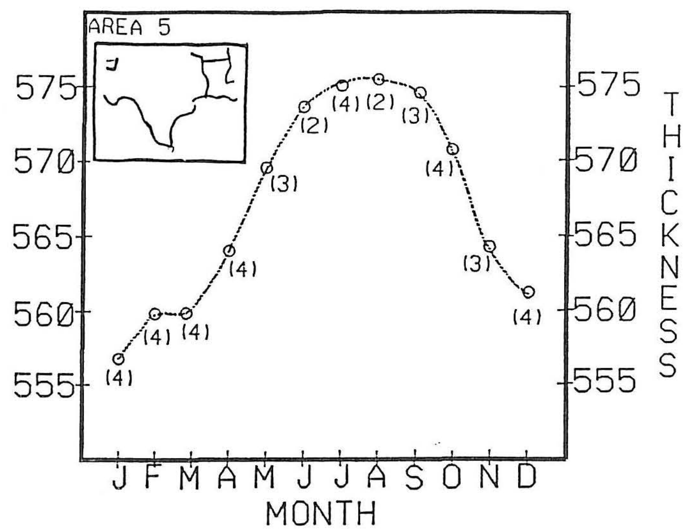

Fig. 6. Same as Fig. 2, but for Area 5.

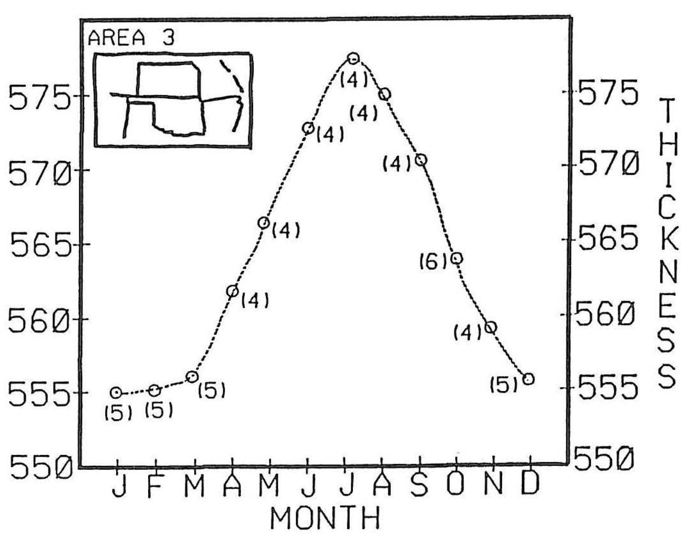

Fig. 4. Same as Fig. 2, but for Area 3.

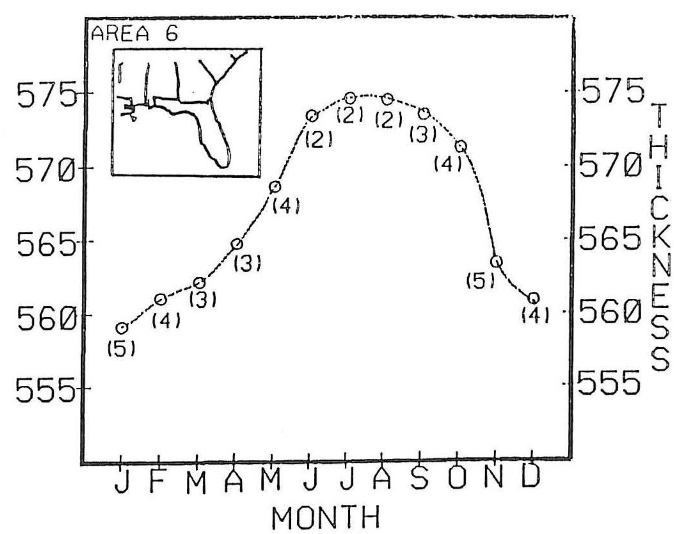

Fig. 7. Same as Fig. 2, but for Area 6.

the mean and mode will probably give a forecaster a good guess at the "favored thickness channel" for heavy precipitation. Hurricanes and tropical storm rainfall also generally occur at higher thickness values than the climatological mean.

As alluded to earlier, another interesting and useful fact emerged during the collecting and analyzing of the data. Frequency of heavy rainfall decreases sharply at higher thickness values. Organized areas of an inch or more of rain in a 12-hr period were rarely observed at thickness above 582 during summer or above 565 during winter.

Another way of looking at the preferred thickness is given in Figs.2-7 which show the mean thickness for each month over each area. These graphs offer a quick and easy method of determining the preferred thickness for heavy rain. A forecaster can take the mean thickness given by the appropriate graph and find that same thickness forecast on the numerical model that he or she feels has the best thickness forecast that given day. Without strong forcing, the axis of heaviest rain usually occurs along this thickness. The bracketed number located next to each mean thickness value plotted on the graph gives the standard deviation rounded to the nearest whole number.

5. CONCLUSIONS AND SUMMARY

Precipitation tends to occur along climatologically favored thickness values which vary during the year. The mean, mode and median thickness values presented in Tables 1-6 are helpful in determining the range of thickness values that will be the most favored for an inch or more of precipitation during a 12-hr period. The tables and graphs are most useful when synoptic scale dynamics are relatively weak and precipitation is being driven largely by mesoscale or thermodynamic processes. During the summer, the Great Plains and Upper Midwest are particularly suited to using the concept of preferred thickness. In summer, conventional parameters are often at odds with one another, and boundaries are often indistinct, making forecasting difficult at best. The tables or graphs also supply useful information across the South (Areas 5 and 6) during winter.

Using the thickness values offered in the table to help forecast heavy precipitation is especially attractive since thickness fields are usually fairly well forecast by numerical models (especially the LFM). Often, errors at the surface and 500 mb tend to cancel each other leaving the 1000-500 mb thickness with only small errors. Using a narrow range of thickness values determined from the tables or graphs and finding that thickness band on an operational numerical model forecast can provide a forecaster with a good first guess at where the heaviest rainfall may occur.

Climatologically favored thickness values are no panacea ensuring a "good" precipitation forecast. A meteorologist still needs to think in terms of where low-level boundaries and upper level impulses are located, and where the best moisture inflow is found before embarking on a forecast. All things being equal, convection and the heaviest rain will occur along and as a result of these features. However, cases when boundaries are weak but where moisture is deep and the atmosphere is unstable favor the use of "climatologically favored thickness values" as a good alternative to throwing a dart or blindly following numerical guidance when trying to pinpoint the axis of heaviest rainfall.

Similar correlations of 850 and 700 mb temperatures to heavy rainfall would probably provide forecasters with additional forecast tools. Warm temperatures in the mid levels have long been considered limiting factors in convective development and may explain why heavy rain is not likely at thickness values above 582. Heavy Precipitation Unit forecasters generally consider the atmosphere to be "capped" when 700 mb temperatures exceed 12°C.

ACKNOWLEDGMENTS:

The authors would like to thank Joe Palko and Carin Goodall for preparing the graphics and would like to thank Frank Brody for his ideas and comments about the project.

NOTES AND REFERENCES

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