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CENTRAL REGION APPLIED RESEARCH PAPER 4-1

THE CURRENT CAPACITY FOR NOWCASTING

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1. Purpose

The purpose of this note is to evaluate the capacity of current data collection systems for use in NOWCASTING.

2. What is NOWCASTING?

It is important to know what is meant by the term NOWCASTING. Browning (1982), in a collection of papers entitled "Nowcasting," defines the term as follows:

> "a detailed description of the current weather along with forecasts obtained by extrapolation up to 2 hours ahead"

This definition is somewhat restrictive and fits the current use of Special Weather Statements (SPS) rather well.

The period beyond two hours out to 12 hours is termed "very-short-term" forecasting by Browning. McGinley (1986) uses the terms NOWCASTING and short-range forecastings interchangeably. His description of NOWCASTING involves:

> "close monitoring of all the latest data; predictive skills that recognize and foresee the most subtle changes in the atmosphere; conceptual models that encompass the structure and evolution of the phenomena; and a communicative system that can reach the user rapidly."

This latter definition is more satisfying than the former since it includes more than pure extrapolation and would permit NOWCASTs to extend beyond two hours, but remain within the 12 hour limit of the first period forecast.

This definition also highlights several elements that need to be addressed further. Specifically, this description mentions data sources, predictive skills and conceptual models.

3. Predictive Skills and Conceptual Models

The short-term (two to six hour) forecasting of atmospheric phenomena is more than pure extrapolation. As the McGinley definition implies, changes in atmospheric phenomena must also be anticipated. For lack of a more commonly agreed upon term, the phrase "dynamic extrapolation" will be adopted to describe the necessary predictive skills, i.e., most short term forecasts are a combination of extrapolation and anticipated dynamic and/or thermodynamic changes, more heavily weighted toward the former.

McGinley (1986) points out a "major problem in observational nowcasting." Specifically, it is "not the ability to interpret presentations of each source of data individually ... but [it] is one of assimilation ... the combining of all these data sets into one clear coherent picture of a phenomena." Conceptual models are one way of addressing the assimilation problem. (As an example, the Norwegian cyclone model is a conceptual model for synoptic scale data.)

Conceptual models can be used to anticipate changes in atmospheric phenomena. Although limited in number, such models are available for phenomena such as thunderstorms. The key to a successful NOWCAST becomes fitting the conceptual model to current observations in order to anticipate the short-term changes predicted by the model.

4. Data Sources

When discussing data sources, it is not a matter of just determining what data collection systems exist, but more importantly, what the resolution of these data sources are. Resolution refers to the smallest unambiguous change that can be measured by a data collection system (Thomson, 1986). Since NOWCASTING deals with phenomena down to the meso-gamma scale (Orlanski, 1975), observing systems, in order to be compatible with the conceptual models noted in the previous section, need a resolution comparable to the phenomena being forecast. Do such observing systems exist operationally today?

Table I lists the data sources currently available and an estimate of their ability to resolve mesoscale systems in time and space.

TABLE I: Data Collection Systems

	mesoscale resolution ability		phenomena
	temporal	spatial	observed
radar	yes	yes	precip
satellite	yes	yes	clouds
sfc data	yes	no	various
UA data	no	no	various
PIREPS	no	no	misc

Radar and satellite are the most promising sources for qualitative mesoscale data in today's operational environment. As stated by Beran and MacDonald (1982):

> "radar is the cornerstone of our present efforts to provide very-short-range services because of its ability to detect and track ... life cycles of less than 6 hours"
>
> "the combination of radar and satellite data ... promises a significant increase in our ability to deal with the mesoscale."

However, the key to successful use of satellite imagery and radar information is more than just extrapolation. Data analysis and synthesis must have a "dynamic" aspect to it. A forecaster must also keep in mind that these data sets are qualitative in nature and not all encompassing. Satellites sense many things but still have difficulty seeing low clouds at night and looking through cirrus shields. Similarly, just knowing where precipitation is occurring does not necessarily improve the forecast at point locations (May, 1986). Nevertheless, without radar and satellite data, NOWCASTING would not be possible.

The third important ingredient in NOWCASTING is surface data. Bodin (1982) lists the surface requirement as a 40 km, real-time network for forecasts out to two hours, and a 50 km, hourly network for two to six hour forecasts. Although good temporal resolution exists in the current hourly and special surface observing network, spatial resolution is lacking. Numerous mesoscale phenomena can traverse the current surface network without being detected.

Current data sources appear to provide only limited ability to quantitatively detect and describe mesoscale phenomena in the sense desired for NOWCASTING.

5. FT versus Areal NOWCAST

The terminal forecast (FT) is a forecast for one point in space where surface observations with good temporal resolution exist. The FT is a NOWCAST in the sense that it provides forecast changes continuously out to 12 hours. Radar and satellite data contribute significantly to our ability to predict these changes. Nevertheless, situations exist, e.g., stratus or fog formation, where lack of spatial resolution in surface data and temporal resolution in sounding data, hamper accurate forecasting of event occurrence. Poor verification statistics for IFR and LIFR occurrence testify to this.

When the single-point FT is expanded to an areal NOWCAST, lack of data resolution, particularly in surface observations, compounds the forecast problem. For example, it is difficult to accurately forecast temperatures and winds across an area without knowing what is routinely occurring through out the area. Specifically, an observation at Topeka is not necessarily representative of every location in Kansas zone 15. If the data collection system lacks resolution, the result is a generalized forecast that acts contrary to a main purpose of NOWCASTING, namely better forecast resolution in time and space.

6. Current Capabilities

In light of the current resolution of data collection systems, the ability to produce a true NOWCAST is limited. Qualitative radar and satellite information allow a fairly accurate extrapolation of existing phenomena. The "dynamic" aspect of the extrapolation process is a little more tenuous due to a lack of conceptual models and unfamiliarity with mesoscale forecasting methods (the few that exist). This ability to anticipate short-term changes is the difference between a good NOWCASTING program and a mediocre one. The initiation of a NOWCASTING program at the present time must be done with the caveat that forecast resolution is limited by the current observing systems.

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CENTRAL REGION APPLIED RESEARCH PAPER 4-2

A WIND STUDY FOR THE 1990 UNITED STATES OLYMPIC FESTIVAL

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1. Introduction

The 1990 United States Olympic Festival was held in the Minneapolis/St. Paul, Minnesota area from July 6 through July 15. The organizers of the Olympic Festival requested that the local National Weather Service Forecast Office provide the necessary wind information to assist them in planning the water sports events on area lakes. Specifically, the organizers of the Olympic Festival were most interested in wind speed and direction at 6:00 a.m., 9:00 a.m., Noon, 3:00 p.m., and 6:00 p.m. Local Daylight Time (LDT) for the first 15 days in July.

Two-way frequency distribution tables of wind speed and direction, frequency wind roses, and bar graphs for each of the selected times were constructed and analyzed from data taken from 1980 through 1989 inclusive. They were provided to the organizers of the Olympic Festival to assist them in planning the Olympic Festival events.

2. Procedure

The wind speed and direction data were extracted from National Weather Service Surface Aviation Observations (SAO's) for 6:00 a.m., 9:00 a.m., Noon, 3:00 p.m., and 6:00 p.m. LDT, at the Minneapolis/St. Paul, Minnesota International Airport. The wind speed and direction is a one-minute average of observed values from direct-reading dials and recorders (FMH No. 1, 1988). Two-way frequency distribution tables of wind speed and direction, described by Panofsky and Brier (1968), were constructed using eight compass points. The percentage of occurrences were calculated for each entry in the rows and columns, and is the number enclosed in parentheses to the right of the actual observed data (Figures 1 through 5). A summary two-way frequency distribution table for the entire data set was also constructed (Figure 6). Table A3-5 of FMH No. 1, was used to convert the wind speed in tens of degrees, as encoded on the Surface Aviation Observations (SAO's), to one of the eight compass points (Figure 7).

Beaufort Scale numbers were selected to serve as the class intervals for the data set. Table A10-5 of FMH No. 1 shows the wind equivalent of the Beaufort Scale (Figure 8).

TWO-WAY FREQUENCY DISTRIBUTION OF WIND SPEED AND DIRECTION
6 AM LDT

SCALE	SPEED, KTS	N	NE	E	SE	S	SW	W	NW	Σ
0	<1, CALM									12(8)
1	1-3	2(1.3)			4(2.7)	2(1.3)	3(2)	2(1.3)		13(8.7)
2	4-6	3(2)	1(.7)	6(4)	16(10.7)	6(4)	7(4.7)	2(1.3)	5(3.3)	46(30.7)
3	7-10	4(2.7)	5(3.3)	12(8)	8(5.3)	12(8)	4(2.7)	3(2)	7(4.7)	55(36.7)
4	11-16	4(2.7)		2(1.3)	2(1.3)	3(2)	8(5.3)	1(.7)	2(1.3)	22(14.7)
5	17-21						1(.7)			1(.7)
6	22-27						1(.7)			1(.7)
		13(8.7)	6(4)	20(13.3)	30(20)	23(15.3)	24(16)	8(5.3)	14(9.3)	150(100)

FIGURE 1

TWO-WAY FREQUENCY DISTRIBUTION OF WIND SPEED AND DIRECTION
9 AM LDT

SCALE	SPEED, KTS	N	NE	E	SE	S	SW	W	NW	Σ
0	<1, CALM									6(4)
1	1-3			1(.7)		4(2.7)				5(3.3)
2	4-6	5(3.3)	3(2)	3(2)	10(6.7)	7(4.7)	7(4.7)	6(4)	1(.7)	42(28)
3	7-10	6(4)	5(3.3)	8(5.3)	12(8)	9(6)	7(4.7)	5(3.3)	4(2.7)	56(37.3)
4	11-16	7(4.7)	2(1.3)	3(2)	5(3.3)	9(6)	10(6.7)	1(.7)	2(1.3)	39(26)
5	17-21					1(.7)	1(.7)			2(1.3)
6	22-27									
		18(12)	10(6.7)	15(10)	27(18)	30(20)	25(16.7)	12(8)	7(4.7)	150(100)

FIGURE 2

TWO-WAY FREQUENCY DISTRIBUTION OF WIND SPEED AND DIRECTION
NOON LDT

SCALE	SPEED, KTS	N	NE	E	SE	S	SW	W	NW	Σ
0	<1, CALM									2(1.3)
1	1-3			1(.7)		1(.7)	1(.7)			3(2)
2	4-6	4(2.7)	3(2)	4(2.7)	1(.7)	4(2.7)	2(1.3)	1(.7)	4(2.7)	23(15.3)
3	7-10	8(5.3)	4(2.7)	7(4.7)	9(6)	16(10.7)	8(5.3)	5(3.3)	5(3.3)	62(41.3)
4	11-16	3(2)	1(.7)	3(2)	7(4.7)	11(7.3)	9(6)	8(5.3)	8(5.3)	50(33.3)
5	17-21	1(.7)		2(1.3)		4(2.7)	1(.7)	2(1.3)		10(6.7)
6	22-27									
		16(10.7)	8(5.3)	17(11.3)	17(11.3)	36(24)	21(14)	16(10.7)	17(11.3)	150(100)

FIGURE 3

TWO-WAY FREQUENCY DISTRIBUTION OF WIND SPEED AND DIRECTION
3 PM LDT

SCALE	SPEED, KTS	N	NE	E	SE	S	SW	W	NW	Σ
0	<1, CALM									
1	1-3	1(.7)	1(.7)							2(1.3)
2	4-6	3(2)	1(.7)	1(.7)	4(2.7)	3(2)	2(1.3)	4(2.7)	1(.7)	19(12.7)
3	7-10	4(2.7)	3(2)	9(6)	12(8)	8(5.3)	3(2)	8(5.3)	3(2)	50(33.3)
4	11-16	5(3.3)		6(4)	4(2.7)	19(12.7)	9(6)	8(5.3)	12(8)	63(42)
5	17-21	2(1.3)			2(1.3)	5(3.3)	3(2)	2(1.3)	1(.7)	15(10)
6	22-27					1(.7)				1(.7)
		15(10)	5(3.3)	16(10.7)	22(14.7)	36(24)	17(11.3)	22(14.7)	17(11.3)	150(100)

FIGURE 4

TWO-WAY FREQUENCY DISTRIBUTION OF WIND SPEED AND DIRECTION
6 PM LDT

SCALE	SPEED, KTS	N	NE	E	SE	S	SW	W	NW	Σ
0	<1, CALM									
1	1-3								1(.7)	1(.7)
2	4-6	1(.7)	3(2)	3(2)	4(2.7)	2(1.3)	3(2)	5(3.3)	2(1.3)	23(15.3)
3	7-10	8(5.3)	1(.7)	3(2)	8(5.3)	12(8)	4(2.7)	5(3.3)	6(4)	47(31.3)
4	11-16	5(3.3)		2(1.3)	8(5.3)	21(14)	4(2.7)	15(10)	10(6.7)	65(43.3)
5	17-21	1(.7)		1(.7)		5(3.3)	2(1.3)		3(2)	12(8)
6	22-27						2(1.3)			2(1.3)
		15(10)	4(2.7)	9(6)	20(13.3)	40(26.7)	15(10)	25(16.7)	22(14.7)	150(100)

FIGURE 5

TWO-WAY FREQUENCY DISTRIBUTION OF WIND SPEED AND DIRECTION
SUMMARY

SCALE	SPEED, KTS	N	NE	E	SE	S	SW	W	NW	Σ
0	<1, CALM									20(2.7)
1	1-3	3(.4)	1(.1)	2(.3)	4(.5)	7(.9)	4(.5)	2(.3)	1(.1)	24(3.2)
2	4-6	16(2.1)	11(1.5)	17(2.3)	35(4.7)	22(2.9)	21(2.8)	18(2.4)	13(1.7)	153(20.4)
3	7-10	30(4)	18(2.4)	39(5.2)	49(6.5)	57(7.6)	26(3.5)	26(3.5)	25(3.3)	270(36)
4	11-16	24(3.2)	3(.4)	16(2.1)	26(3.5)	63(8.4)	40(5.3)	33(4.4)	34(4.5)	239(31.9)
5	17-21	4(.5)		3(.4)	2(.3)	15(2)	8(1.1)	4(.5)	4(.5)	40(5.3)
6	22-27					1(.1)	3(.4)			4(.5)
		77(10.3)	33(4.4)	77(10.3)	116(15.5)	165(22)	102(13.6)	83(11.1)	77(10.3)	750(100)

FIGURE 6

FIGURE 7

TABLE A3-5. WIND DIRECTION IN TENS OF DEGREES (TRUE)

8 Points of Compass	Tens of Degrees	16 Points of Compass	8 Points of Compass	Tens of Degrees	16 Points of Compass
N	36	N	S	18	S
N	01	N	S	19	S
N	02	NNE	S	20	SSW
NE	03	NNE	SW	21	SSW
NE	04	NE	SW	22	SW
NE	05	NE	SW	23	SW
NE	06	ENE	SW	24	WSW
E	07	ENE	W	25	WSW
E	08	E	W	26	W
E	09	E	W	27	W
E	10	E	W	28	W
E	11	ESE	W	29	WNW
SE	12	ESE	NW	30	WNW
SE	13	SE	NW	31	NW
SE	14	SE	NW	32	NW
SE	15	SSE	NW	33	NNW
S	16	SSE	N	34	NNW
S	17	S	N	35	N

FIGURE 8

TABLE A10-5. Wind Equivalent--BEAUFORT SCALE

Beau-fort #	MPH	KTS	International Description	Specifications
0	<1	<1	Calm	Calm; smoke rises vertically
1	1-3	1-3	Light Air	Direction of wind shown by smoke drift not by wind vanes
2	4-7	4-6	Light Breeze	Wind felt on face; leaves rustle; vanes moved by wind
3	8-12	7-10	Gentle Breeze	Leaves and small twigs in constant motion; wind extends light flag
4	13-18	11-16	Moderate	Raises dust, loose paper; small branches moved
5	19-24	17-21	Fresh	Small trees in leaf begin to sway; crested wavelets form on inland waters
6	25-31	22-27	Strong	Large branches in motion; whistling heard in telegraph wires; umbrellas used with difficulty
7	32-38	28-33	Near Gale	Whole trees in motion; inconvenience felt walking against the wind
8	39-46	34-40	Gale	Breaks twigs off trees; impedes progress
9	47-54	41-47	Strong Gale	Slight structural damage occurs
10	55-63	48-55	Storm	Trees uprooted; considerable damage occurs
11	64-72	56-63	Violent Storm	Widespread damage
12	73-82	64-71	Hurricane	

From the two-way frequency distribution tables of wind speed and direction, frequency wind roses (Figures 9 through 14) were constructed using the procedure described by Panofsky and Brier (1968). The wind rose gives the frequency distribution, simultaneously, of wind speed and direction, and treats the wind as a vector quantity with both magnitude and direction (Panofsky and Brier, (1968). The concentric circles serve to mark the wind speed intervals.

Finally, the average wind speed and number of occurrences for each of the eight compass points were calculated and graphed (Figures 15 through 19). Figure 20 is a summary of the entire data set.

3. Results

The wind speed and direction data for the first 15 days of July from 1980 through 1989 inclusive, for the Minneapolis/St. Paul, Minnesota area, show several important characteristics which the organizers of the 1990 United States Olympic Festival needed to consider. One was the predominance of a southeast wind during the early morning hours (6:00 a.m. LDT), and then the predominance of a south wind from 9:00 a.m. through 6:00 p.m. LDT. As expected, the wind speed increases during the day. This is due to the transfer of higher momentum air from aloft down to the surface as the maximum air temperature is reached late in the afternoon. Frequently, this is between 5:00 p.m. and 6:00 p.m. LDT in the Twin Cities area during the summer months.

Organizers of the Olympic Festival needed to be aware of the secondary maximum or secondary prevailing wind which occurs in the data. Often, such a secondary maximum wind is most easily seen on the wind rose. For instance, based on the data for 6:00 a.m. LDT, a light (4 to 6 knots) southeast breeze is the prevailing wind, but a stronger (7 to 10 knots) northwest breeze is the secondary prevailing wind.

Note that the data include 20 occurrences of calm winds. Twelve of them (60%) occurred at 6:00 a.m. LDT, six (30%) occurred at 9:00 a.m. LDT, and two (10%) occurred at Noon LDT. Although the wind is said to be calm if there is "...an absence of apparent motion of the air" (Huschke, 1959), according to the Beaufort Scale, calm winds have a speed less than one knot. Since wind direction has little meaning for calm winds, the number of all the calm winds are combined in the wind rose regardless of wind direction and is plotted in the center of it.

4. Summary and Conclusions

Organizers of the 1990 United States Olympic Festival used the two-way frequency distribution tables, frequency wind roses and bar graphs to assist in their decision-making process for the scheduling of specific events on area lakes. For instance, during the early morning hours (6:00 a.m. through 9:00 a.m. LDT) there is a predominant light southeast wind. Light winds are conducive for relatively calm waters on area lakes and favor events such as canoeing, kayaking, and rowing.

6 AM LDT

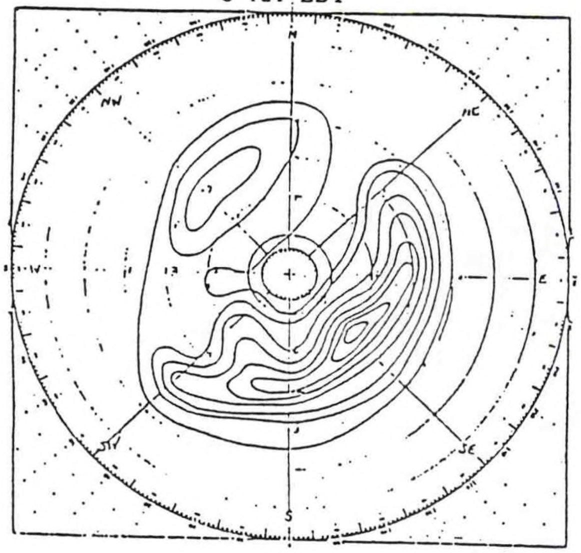


Figure 9

9 AM LDT

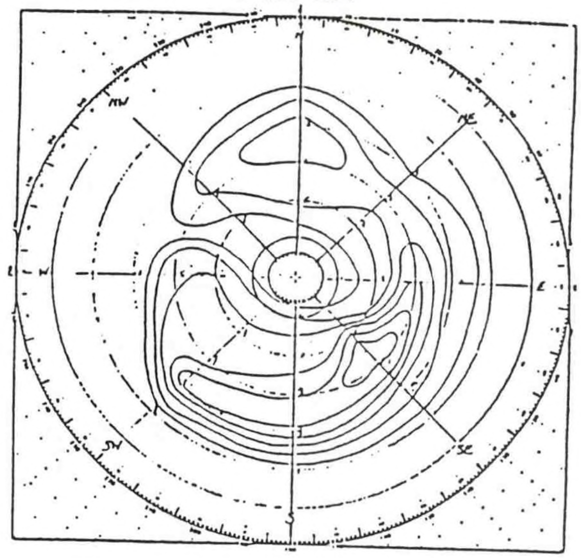


Figure 10

NOON LDT

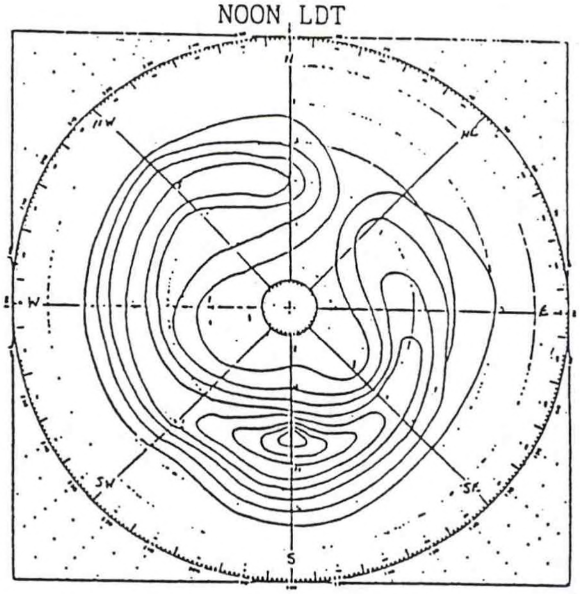


Figure 11

3 PM LDT

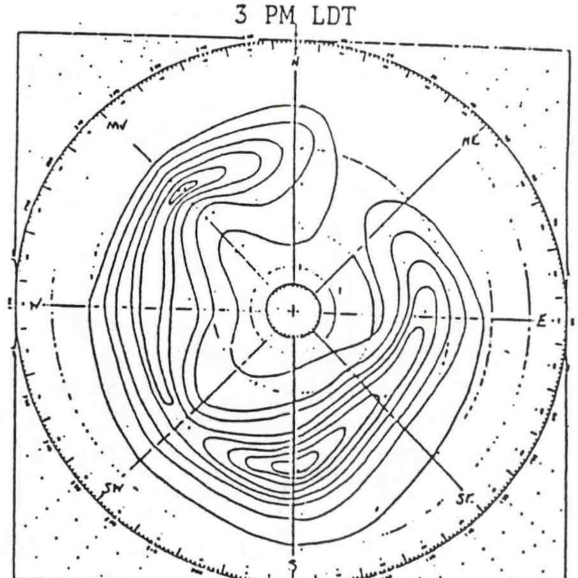


Figure 12

6 PM LDT

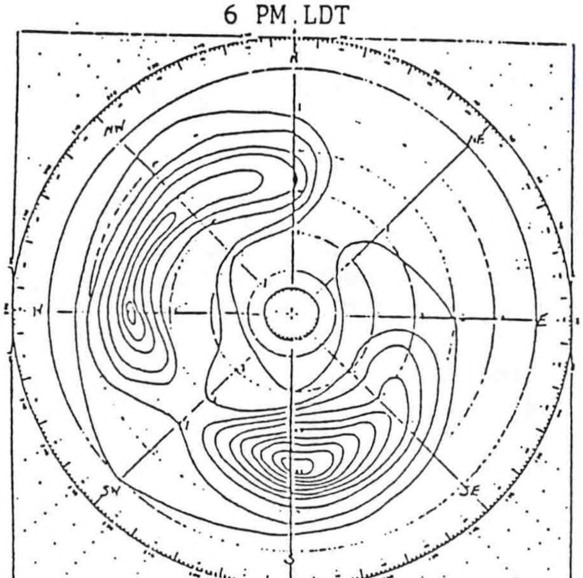


Figure 13

SUMMARY

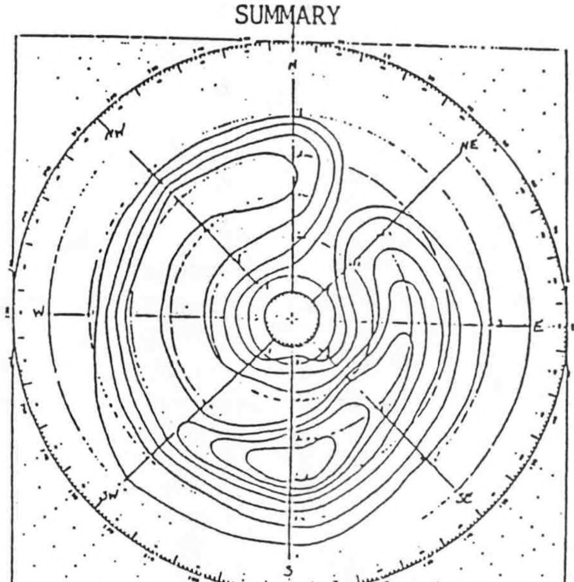
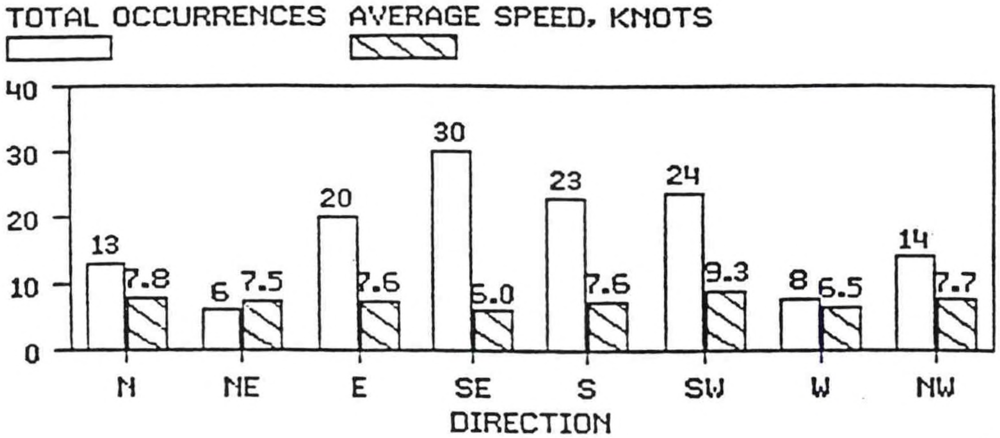
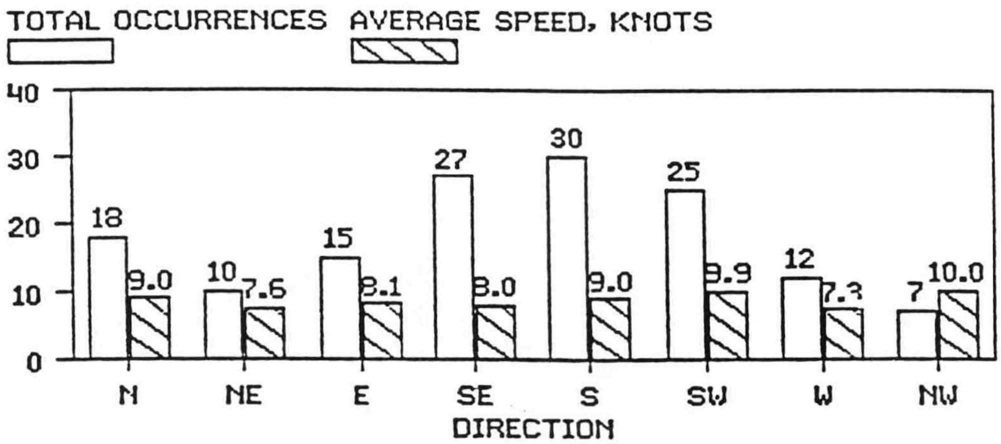


Figure 14

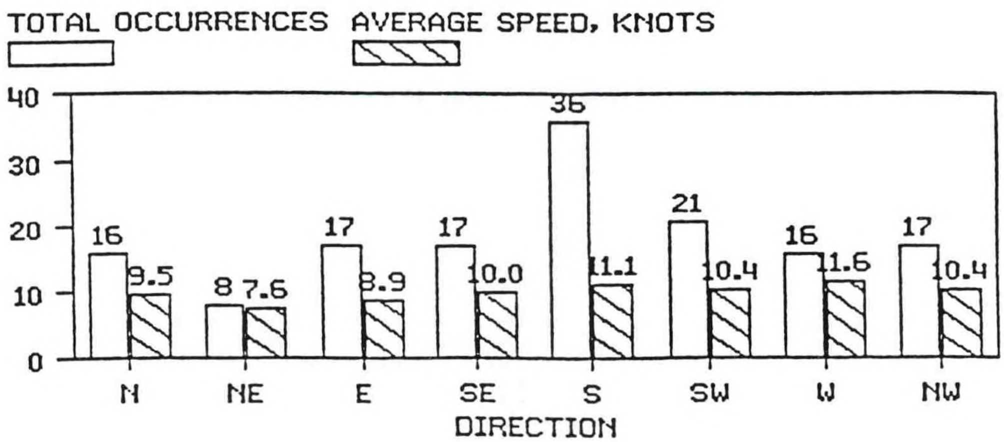
NUMBER OF OCCURRENCES AND AVERAGE WIND SPEED



6 AM
FIGURE 15

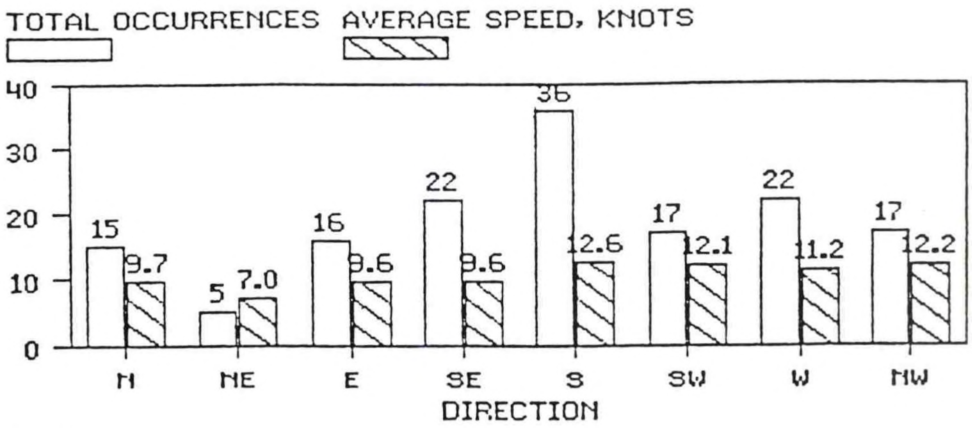


9 AM
FIGURE 16

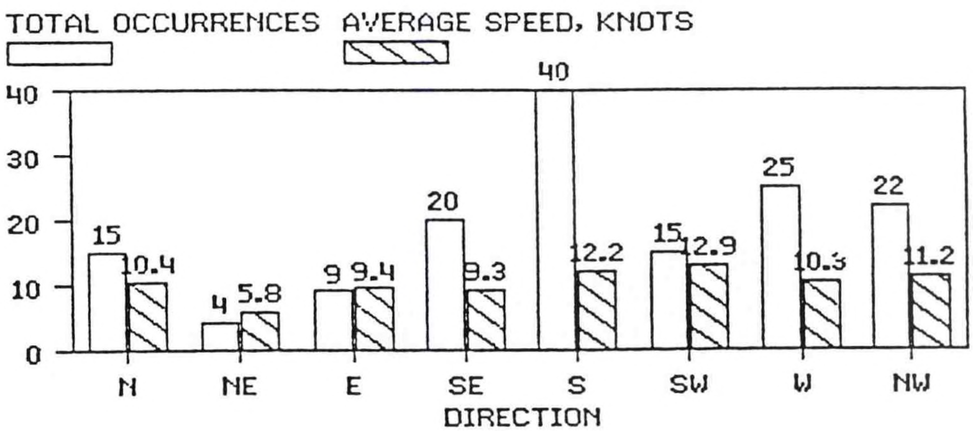


NOON
FIGURE 17

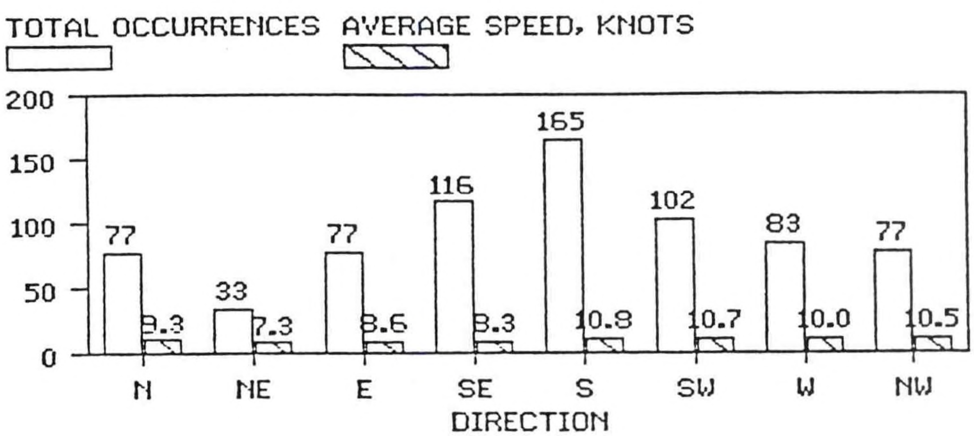
NUMBER OF OCCURRENCES AND AVERAGE WIND SPEED



3 PM
FIGURE 18



6 PM
FIGURE 19



ALL TIMES
FIGURE 20

The data show that as winds increase during the day they become more southerly. South or southwest winds have the greatest average wind speed for each of the time periods with the highest average wind speeds occurring at 6:00 p.m. LDT. The stronger, predominantly southerly winds later in the day allow for excellent sailing conditions, albeit rougher lake waters.

It should be noted that higher wind speeds may be attained on area lakes, especially Lake Minnetonka, than at the International Airport due primarily to two reasons. First, there is a difference of 90 feet in elevation between Lake Minnetonka (930 MSL) and the International Airport (840 MSL). The second reason deals with the difference in surface roughness between a body of water and land. The roughness length, defined as a measure of surface roughness, is less over an open body of water than over land. Figure 21 shows the value of different roughness lengths for wind speeds at 2 meters. In the case of water surfaces, roughness lengths are greater for higher wind speeds because of increased wave height or rougher water (Linsley et al., 1975). However, it should be noted that Ruggles (1970) showed an apparent discontinuity in this relationship with wind speeds from 3 to 19 knots because roughness length alternately increased and decreased as wind speed increased.

Three different theories can be appealed to in order to explain why a southeast wind is predominant in the morning while a southerly wind is the predominant wind in the afternoon. First, high pressure (relative to the land) is usually located over the cold waters of Lake Superior during the summer. The anticyclonic flow of air from this high center causes an east or southeast wind over the Twin Cities area. The light east or southeast surface wind would persist until differential heating causes the transfer of higher momentum air from immediately above the boundary layer (usually southerly in direction) to be mixed down to the earth's surface. Linsley et al. (1975) noted that during summer there is a tendency for southerly winds up to 5000 feet in the Plains west of the Mississippi River.

Second, due to the northward retreat of the Polar Jet Stream during the summer months, the active storm track is often across Canada. A southerly flow from the Gulf of Mexico often occurs with warm and humid air moving into Minnesota. Cold fronts extending from low pressure centers in Canada move eastward across Minnesota and bring a change in air mass from tropical to continental. The time of frontal passages in the Twin Cities area is often late in the afternoon or early in the evening. This may also account for the relatively large number of occurrences of northwest winds (the secondary prevailing wind) at 6:00 p.m. LDT.

Third, the surface wind has a tendency to back at night resulting in a southeast wind, and veer during the day resulting in a south or southwest wind because of the slope of the Great Plains. This phenomenon and other variations in wind have been widely researched. For example, Blackadar (1957) discussed diurnal wind variations as first explained by Espy, Koppen, and Wagner when he studied the growth of nocturnal inversions. Later, Bonner and Paegle (1970) discussed diurnal variations in boundary layer winds over the south-central

FIGURE 21

	Wind speed at z = 2 m (6½ ft)		Roughness length z_0		
	m/s	mi/h	cm	in.	Ref.
Open water	2.1	4.7	0.001	0.0004	25
Smooth mud flats	...	...	0.001	0.0004	26
Smooth snow on short grass	...	...	0.005	0.002	26
Wet soil	1.8	4.0	0.02	0.008	25
Desert	...	...	0.03	0.012	26
Snow on prairie	...	...	0.10	0.04	26
Mown grass:					
1.5 cm (0.6 in.)	...	...	0.2	0.08	26
3.0 cm (1.2 in.)	...	...	0.7	0.28	26
4.5 cm (1.8 in.)	2	4.5	2.4	0.94	26
4.5 cm (1.8 in.)	6–8	13–18	1.7	0.67	26
Alfalfa:					
20–30 cm (8–12 in.)	1.9	4.3	1.4	0.55	25
30–40 cm (12–16 in.)	1.9	4.3	1.3	0.51	25
Long grass:					
60–70 cm (24–28 in.)	1.5	3.4	9.0	3.54	26
60–70 cm (24–28 in.)	3.5	7.8	6.1	2.40	26
60–70 cm (24–28 in.)	6.2	13.9	3.7	1.46	26
Maize:					
90 cm (35 in.)	...	...	2.0	0.79	27
170 cm (67 in.)	...	...	9.5	3.74	27
300 cm (118 in.)	...	...	22.0	8.66	27
Sugar cane:					
100 cm (39 in.)	...	...	4.0	1.57	28
200 cm (79 in.)	...	...	5.0	1.97	28
300 cm (118 in.)	...	...	7.0	2.76	28
400 cm (157 in.)	...	...	9.0	3.54	28
Brush, 135 cm (53 in.)	...	...	14.0	5.51	29
Orange orchard, 350 cm (138 in.)	...	...	50.0	19.7	29
Pine forest:					
5 m (16 ft)	...	...	65.0	25.6	30
27 m (89 ft)	...	...	300.0	118.1	31
Deciduous forest, 17 m (56 ft)	...	...	270.0	106.3	30

SOURCE: Adapted from P. S. Eagleson, "Dynamic Hydrology." Copyright 1970, McGraw-Hill Book Company. Used with permission of McGraw-Hill Book Company.

United States during the summer months. They attributed diurnal variations in wind to the oscillation in the alternating thermal wind caused by the sloping terrain of the Great Plains warming and cooling at different rates.

Surface wind speeds also have a diurnal variation. This diurnal variation is significant only near the ground and is most pronounced during the summer. The surface wind speed is usually at a minimum around sunrise but increases to a maximum during the afternoon (Linsley et al., 1975).

5. Acknowledgements

Special thanks to Mr. Walter DeVoe (WSO St. Cloud, Minnesota) for constructing the bar graphs; to Mr. Richard Naistat (Lead Forecaster, WSFO Minneapolis, Minnesota) for his constructive comments and suggestions; and to Ms. Lynn Koskiniemi for her steady hand in tracing the frequency wind roses.

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CENTRAL REGION APPLIED RESEARCH PAPER 4-3

DETAILED ANALYSIS OF THE 1989-1990 WINDY SEASON COLD BIAS FROM THE LFM MOS-FIRST PERIOD MINIMUM TEMPERATURE FORECAST AT CASPER, WYOMING

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Casper, Wyoming

1. Introduction

The windy season at Casper, Wyoming extends from November through March as seen in Figure 1. These are months in which the mean wind speed exceeds the average annual wind speed of 12.9 mph.

Casper lies at the northern end of the "Wind Corridor" region, located along and near the Interstate-80 highway from Rock Springs to north of Laramie. The Red Desert area, between Rock Springs and Rawlins is the lowest region of the Continental Divide between Montana and New Mexico. Therefore, this region offers a convenient passageway for cold air from the plateaus of Utah and Nevada to pour across the Divide on its eastward journey to the Great Plains.

Strong pressure gradients in fall and winter created by weather systems propel the cold air across Wyoming through the Wind Corridor. As the air moves eastward, it is squeezed into a narrowing channel in the mountains to the northwest and south of Casper. This channelling intensifies the fall and winter winds.

Forecasting minimum temperatures at Casper during the windy season can be extremely challenging due to the variability of nighttime wind speeds. This study examines the relationship between wind speed and the LFM MOS forecasted minimum temperatures at Casper from August 1989 through March 1990.

2. Data and Analysis

Data from the LFM MOS 12Z run (FPC) for Casper was collected from August 1989 through March 1990. The forecasted minimum temperature from MOS was compared to the actual minimum temperature for Casper. Only the first period minimum from the 12Z run was used. As can be seen in Figure 2, a large percentage (63 percent) of the forecasts were too low. Only 30 percent of the forecasts were higher than the actual minimum temperature. The model forecasted minimums correctly seven percent of the time. What caused this greater than two to one significant cool bias? Is there a correlation between wind speed and the

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[1] *Now affiliated with WSO Amarillo, Texas.*

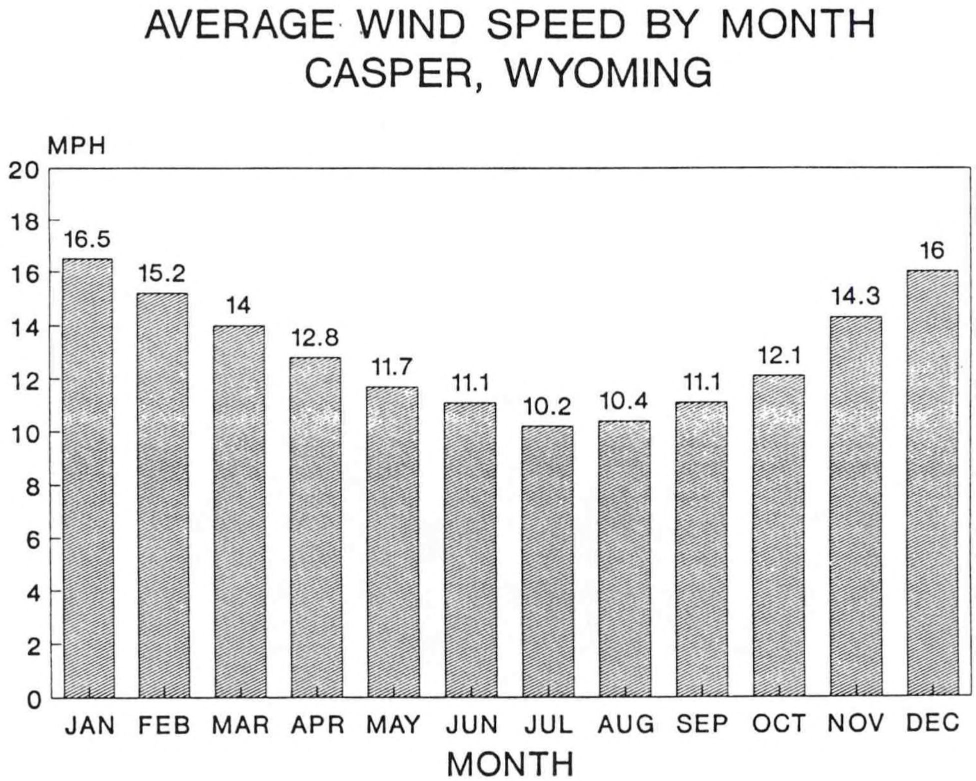


FIGURE 1

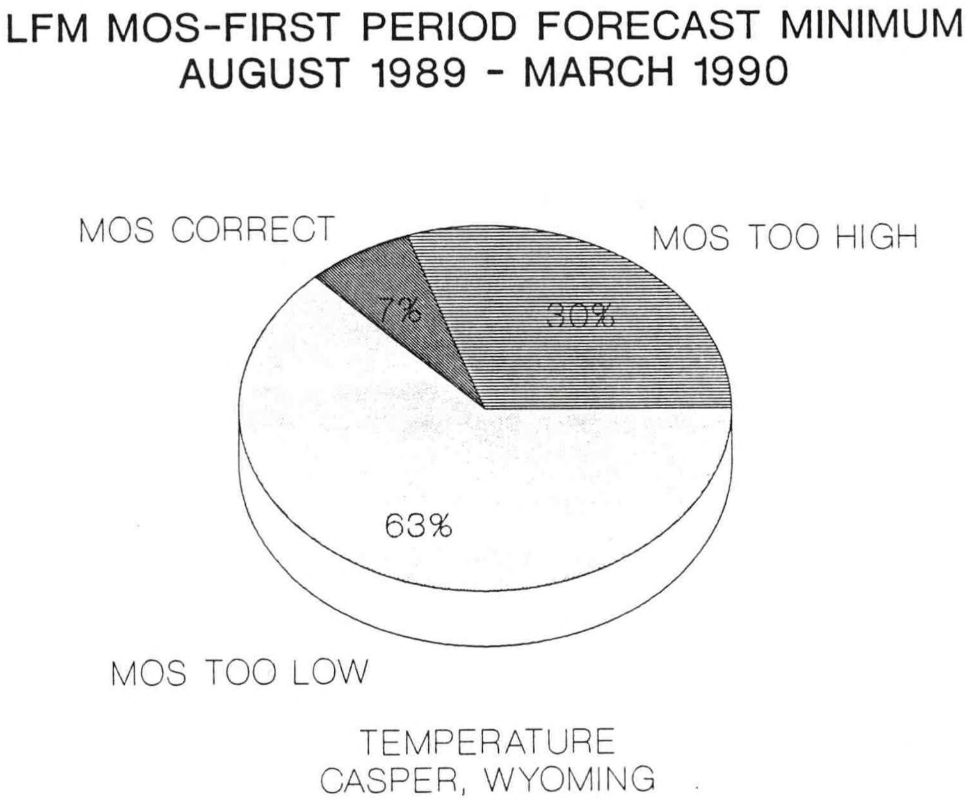


FIGURE 2

model's skewed forecasts? Data from August, September, and October were included in order to compare these months with the normally windier ones.

In Figure 3, the forecasts are broken down by month and by cool and warm bias. Data from October, November, December, and February were especially skewed with the ratio of cool to warm bias data in October greater than six to one. With the exception of October, the previously mentioned months are three of the four windiest at Casper. It seems possible that higher nighttime wind speeds helped to produce this cold bias.

In Figure 4, the absolute forecast error is graphed in terms of the cool versus warm bias. Six of the eight months showed a greater average error when MOS forecasted minimums too low. Of these months, October, November, December, and February showed the most striking difference. It is possible that the average error was not representative in the four highly skewed months because the data sample from forecasts too low was much greater than the data sample from the warm bias forecasts.

In an attempt to determine a correlation between wind speed and the tendency of the model to forecast minimum temperatures too low, the average wind speed was computed for two cases; on nights when the model forecasted too high, and on nights when the model forecasted too low. The results are illustrated by month in Figure 5. The average wind speed each night from 08Z to 12Z was used. Only five hours were used in order to limit the size of the data sample. It was also thought that this would be a representative sample of the average nighttime wind speed.

Each month in Figure 5 shows that the average nighttime wind speed was higher when MOS forecasted too low. This is not all that surprising because it seems logical that MOS would tend to forecast minimum temperatures too low on windier nights. The months which show greatest contrast in average wind speeds by cool and warm bias are November, January, February, and March with January showing the greatest disparity. The average nighttime wind speed in January when MOS forecasted too low was 16.3 knots. It appears from this graph that a relationship does exist between higher nighttime wind speeds and the observed tendency of the LFM MOS to forecast minimum temperatures too low.

Figures 6 through 13 are plots of average nighttime wind speed from 08Z to 12Z for each night versus forecast error on that night. Each month was plotted separately and the best fit line of the data was drawn. In each month, with the exception of December, the best fit line has a negative slope, indicating the model's tendency to forecast minimum temperatures with increasing cold bias error as average nighttime wind speeds increase. The correlation between forecast error and nighttime average wind speed appears to be low. However, the data indicates that MOS tends to have a significant cold bias on windier nights because most forecasts on these nights are too low.

In examining Figures 6 through 13 more closely, a threshold wind speed exists for each month above which the ratio of cold bias versus warm bias forecasts is considerably high. The following table gives the threshold average

LFM MOS 12Z RUN FIRST PERIOD MINIMUMS

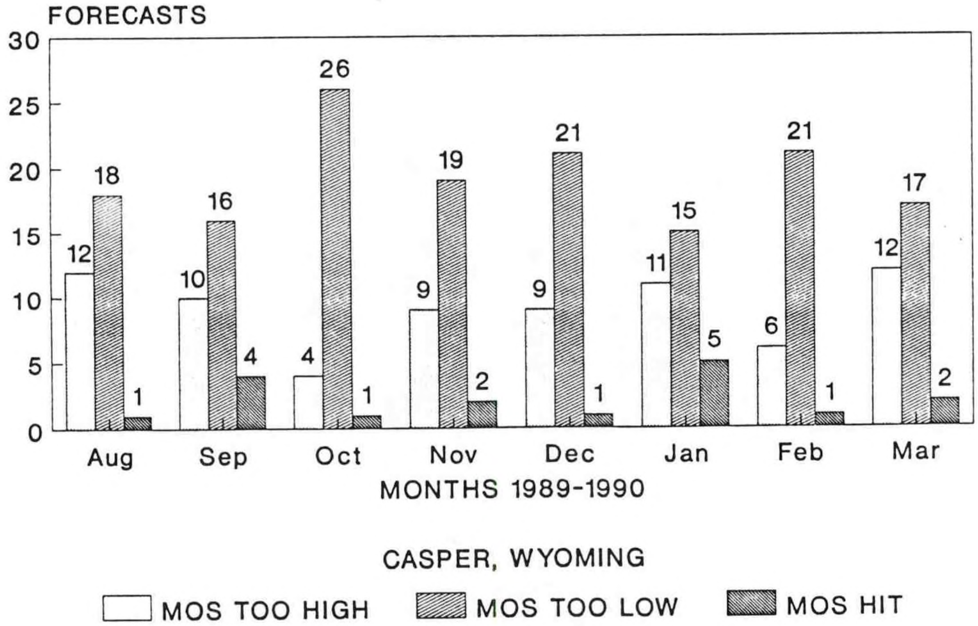


FIGURE 3

LFM MOS 12Z RUN FIRST PERIOD MINIMUMS AVERAGE FORECAST ERROR

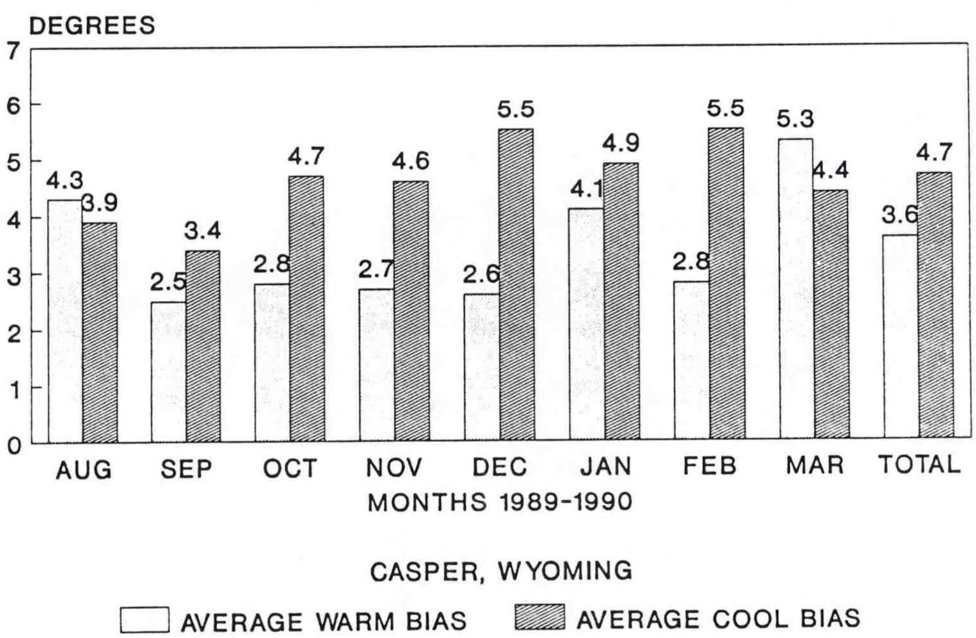


FIGURE 4

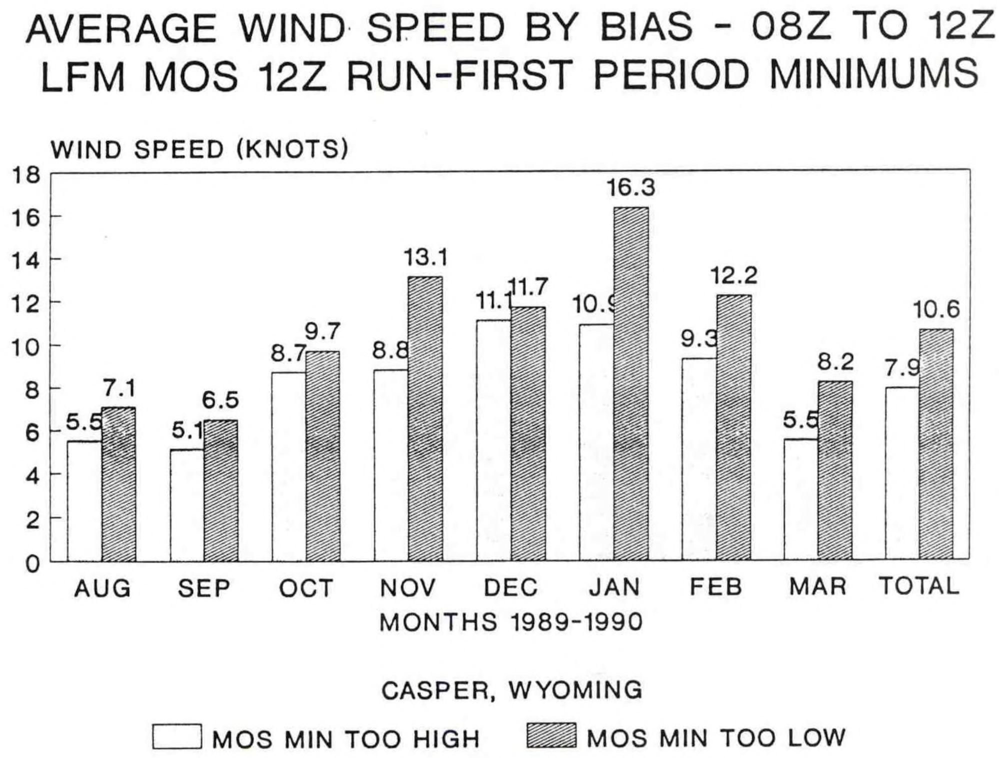


FIGURE 5

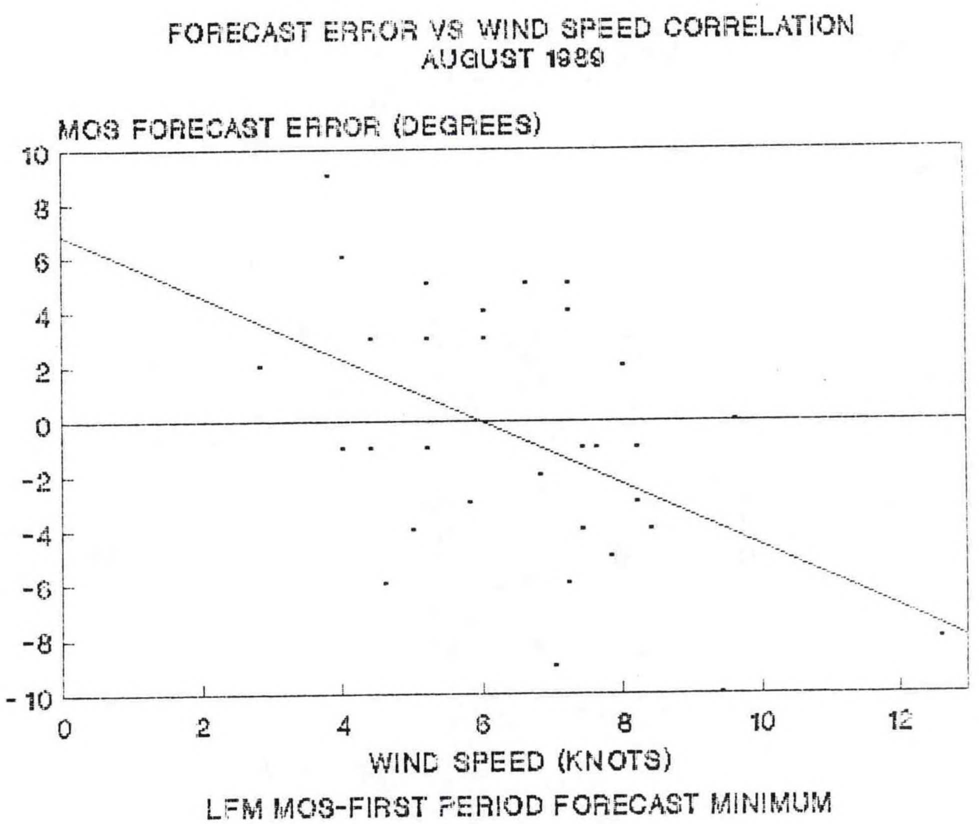


FIGURE 6

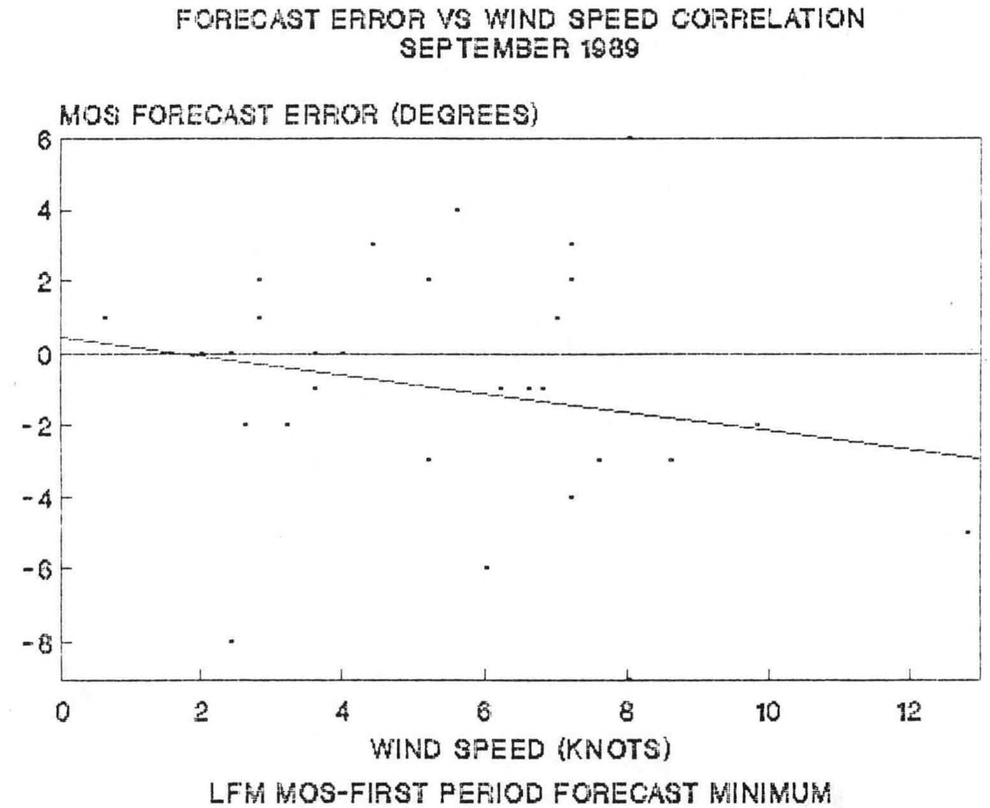


FIGURE 7

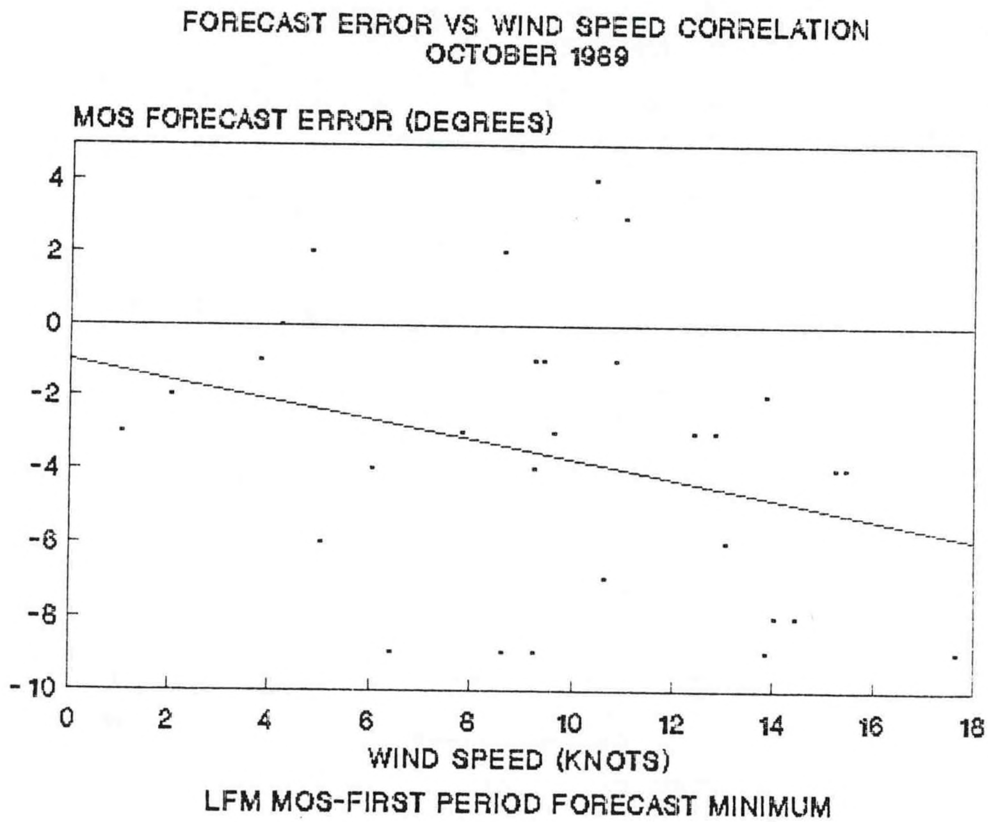
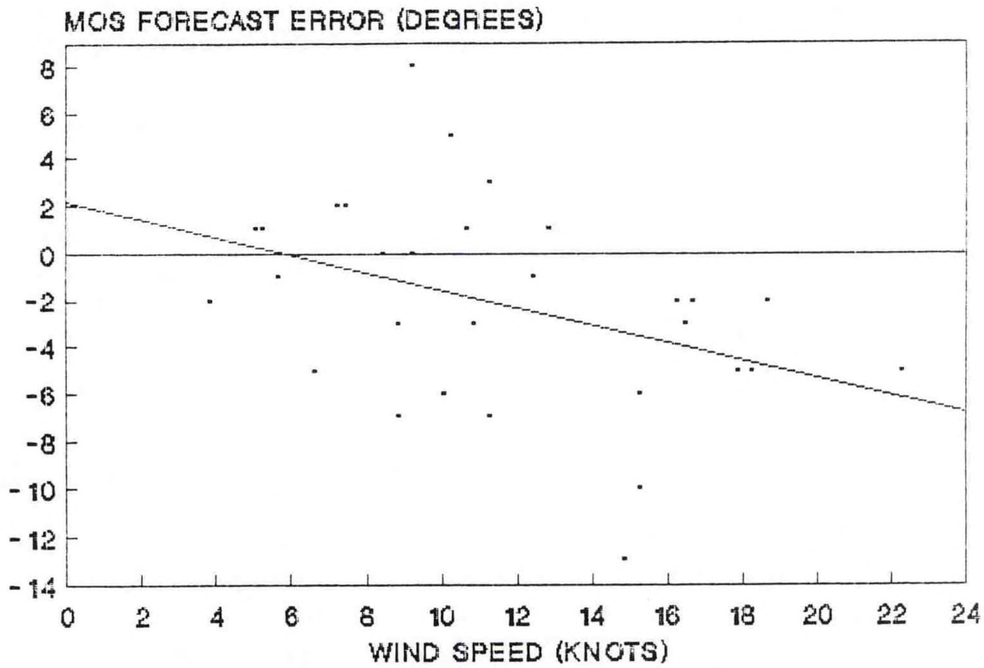


FIGURE 8

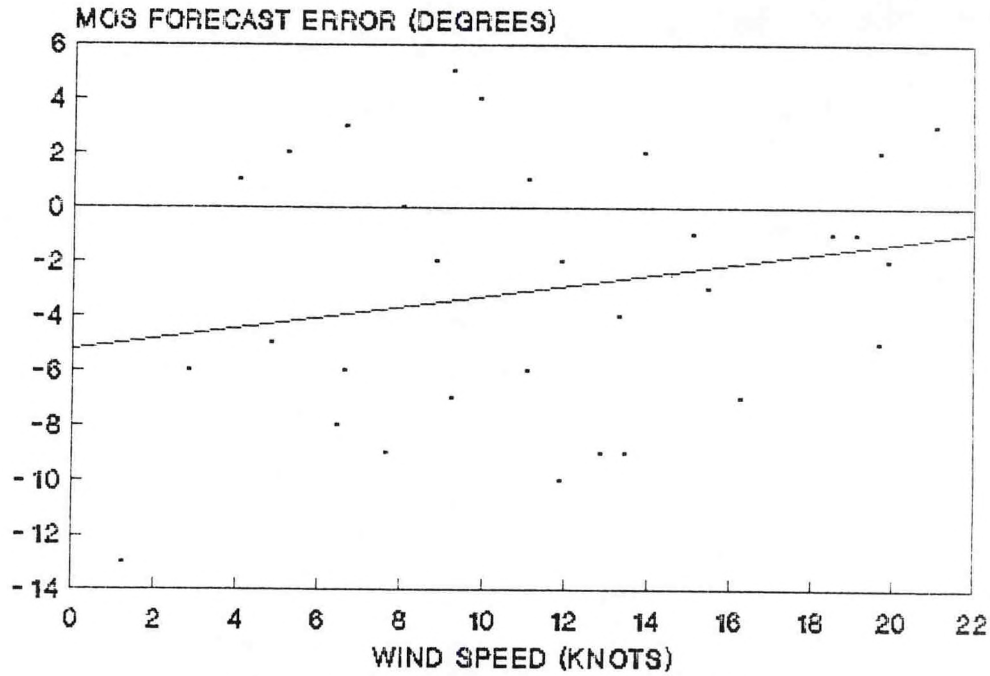
FORECAST ERROR VS WIND SPEED CORRELATION
NOVEMBER 1989



LFM MOS-FIRST PERIOD FORECAST MINIMUM

FIGURE 9

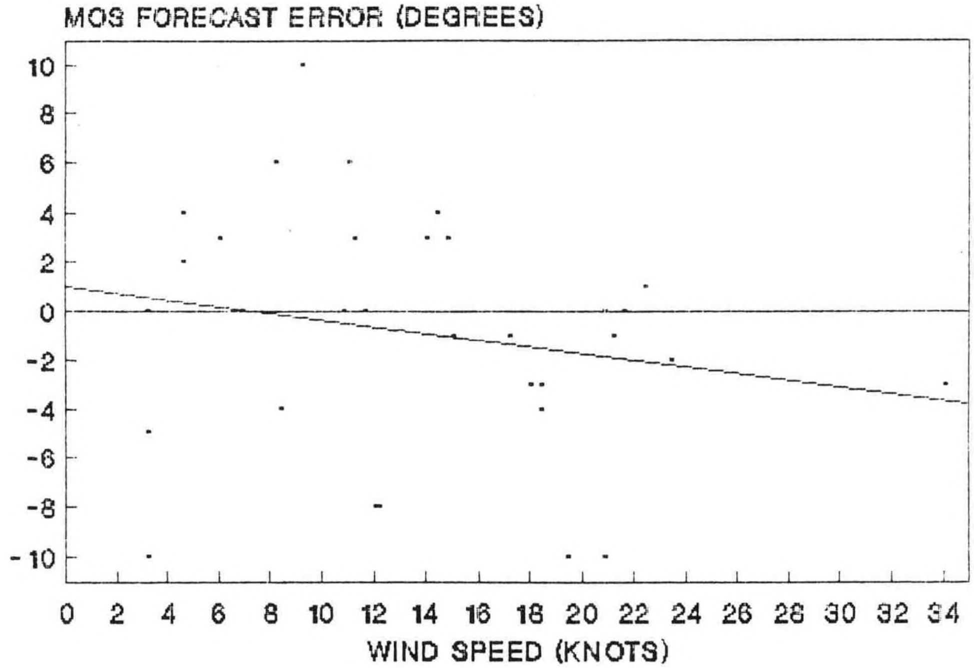
FORECAST ERROR VS WIND SPEED CORRELATION
DECEMBER 1989



LFM MOS-FIRST PERIOD FORECAST MINIMUM

FIGURE 10

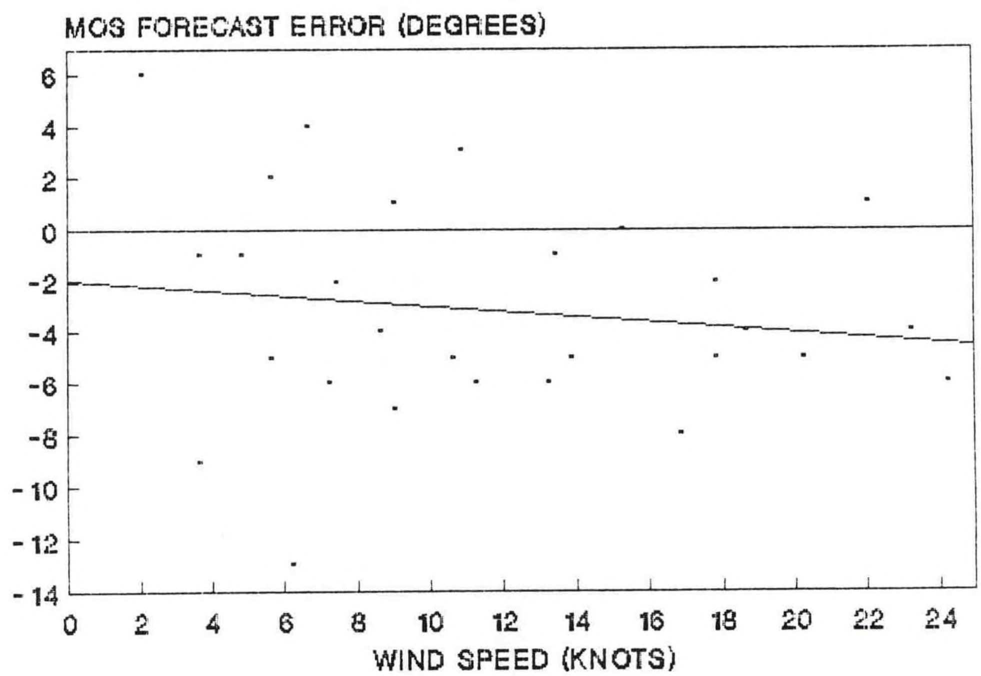
FORECAST ERROR VS WIND SPEED CORRELATION
JANUARY 1990



LFM MOS-FIRST PERIOD FORECAST MINIMUM

FIGURE 11

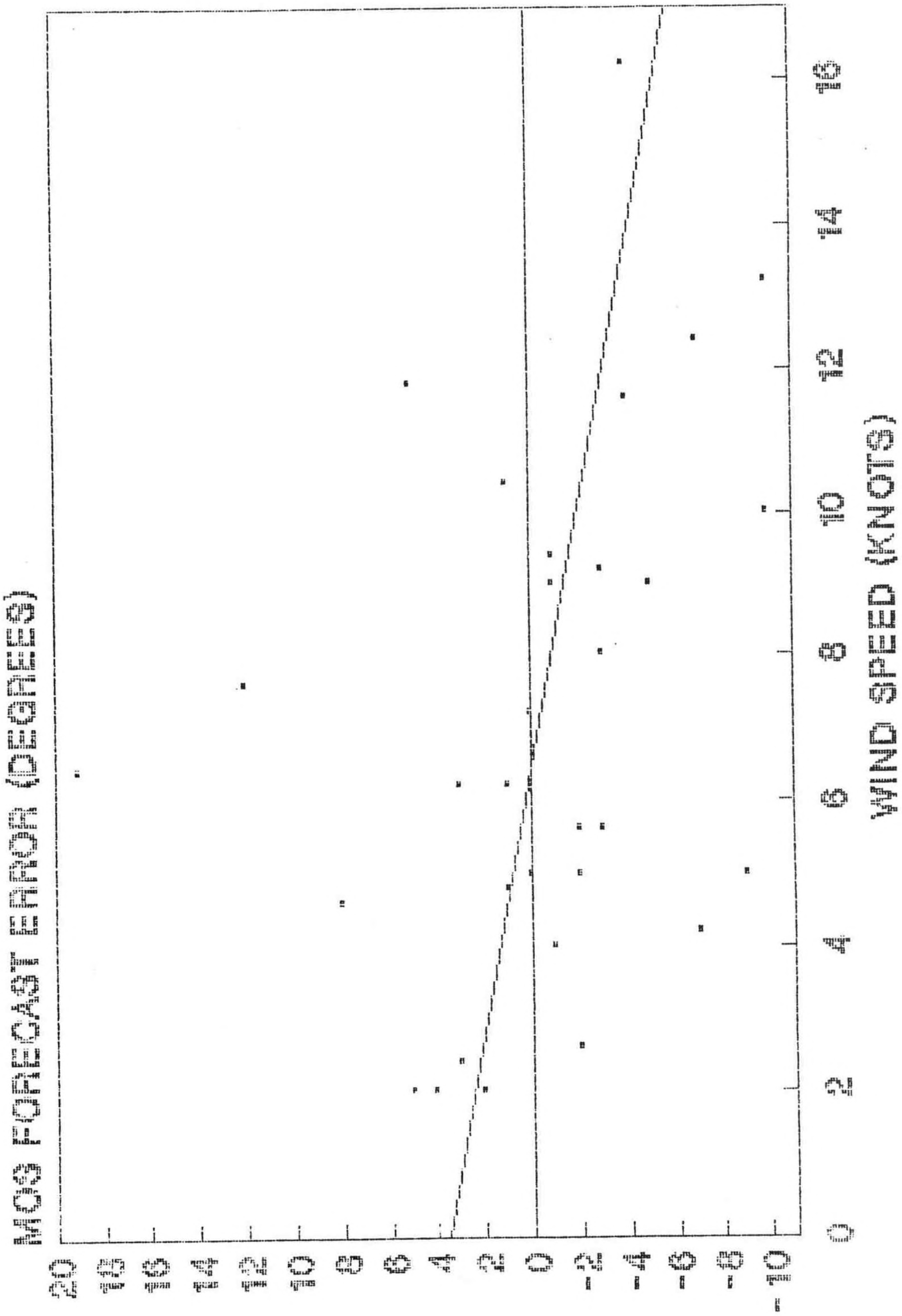
FORECAST ERROR VS WIND SPEED CORRELATION
FEBRUARY 1990



LFM MOS-FIRST PERIOD FORECAST MINIMUM

FIGURE 12

FORECAST ERROR VS WIND SPEED CORRELATION
MARCH 1990



LFM MOS-FIRST PERIOD FORECAST MINIMUM

FIGURE 13

wind speed for each month and the number of warm and cool bias forecasts on nights with average wind speeds higher than this threshold.

Month	Threshold wind speed (knots)	Forecasts too high	Forecasts too low
August	7.5	1	9
September	7.5	0	4
October	11.0	0	10
November	13.0	0	10
December	14.0	2	7
January	15.0	1	10
February	11.0	1	11
March	8.0	2	9

Collection of data over a number of years would allow the determination of a more precise threshold wind speed, assuming the model's cold bias continues. This threshold might help the forecaster more accurately predict minimum temperatures.

3. Conclusions

The data seems to show a relationship between the tendency of the LFM MOS to predict minimum temperatures too low as the average nighttime wind speed increases. However, this relationship only exists for this data set, so additional data from subsequent windy seasons must be collected in order to more fully substantiate the findings.

The average forecast temperature error is greater on nights with a cold model bias, especially during the windiest months. This indicates the model's difficulty in accurately forecasting minimum temperatures when the forecasts are too low and on windy nights. November and February were the two months in which a large bias occurred on both Figures 4 and 5, helping to prove this statement.

One possible cause of the cold bias of the LFM MOS in forecasting minimum temperatures could be that the model may consistently forecast wind speeds too low, especially on windy nights. While this was not tested in this study, the author noticed that forecasted wind speeds were commonly too low. Perhaps an additional predictor variable based on threshold nighttime wind speeds needs to be added to the minimum temperature forecast equation of the model in order to provide a more accurate forecast.

Other factors, such as cloud cover, wind direction, and snow cover may have helped to produce the cold bias. However, it appears that a major contributor to the cold bias stems from the model's inability to accurately incorporate moderately high wind speeds as a predictor for minimum temperatures.

4. Reference

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CENTRAL REGION APPLIED RESEARCH PAPER 4-4

THE USE OF RADAP II TO NOWCAST SEVERE THUNDERSTORMS IN EASTERN COLORADO

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1. Introduction to RADAP II and VIL

The National Weather Service has an automated system to digitize, process, and enhance operational data from weather radars. This system is called RADAP II, and it is installed at WSMO Limon and at 11 other network radars around the U.S. (Figure 1).

RADAP II takes control of the radar antenna every ten minutes and does a tilt sequence, scanning at the elevation angles of 0.5°, 2°, 4°, etc., until there are no more echoes detected, or the antenna is at 22° elevation. On the 0.5° scan, RADAP determines the intensity (VIP level) of the echoes. The RADAP VIP levels agree fairly well with the VIP levels reported on the manual radar observations. RADAP displays the VIP values on a gridded map which can be displayed on AFOS. From the tilt sequence RADAP calculates several products, including estimated vertical integrated liquid (VIL) content and the severe weather probability of the echoes.

Estimated VIL is also displayed on a grid using numbers and letters to symbolize the values and can be called up on AFOS by RIPCLV. (As an example, the Appendix shows VIL maps from May 15, 1989.) VIL values are useful because severe storms frequently form aloft, build upward and then extend toward the ground (Figure 2). RADAP uses the whole rain column to calculate the VIL, so a high VIL may indicate high intensities aloft in the updraft of a developing thunderstorm. The equation used for calculating VIL is detailed in Figure 3.

The RADAP II manual defines the severe weather probability (SWP) of a cell as the probability of a given cell having severe weather associated with it sometime during its life. Severe weather is defined as winds greater than or equal to 50 knots, hail greater than or equal to 3/4 inch in diameter or the occurrence of a tornado. SWP is based on the VIP and VIL parameters and can also be displayed on AFOS.

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1 *Now affiliated with WSFO Cheyenne, Wyoming.*

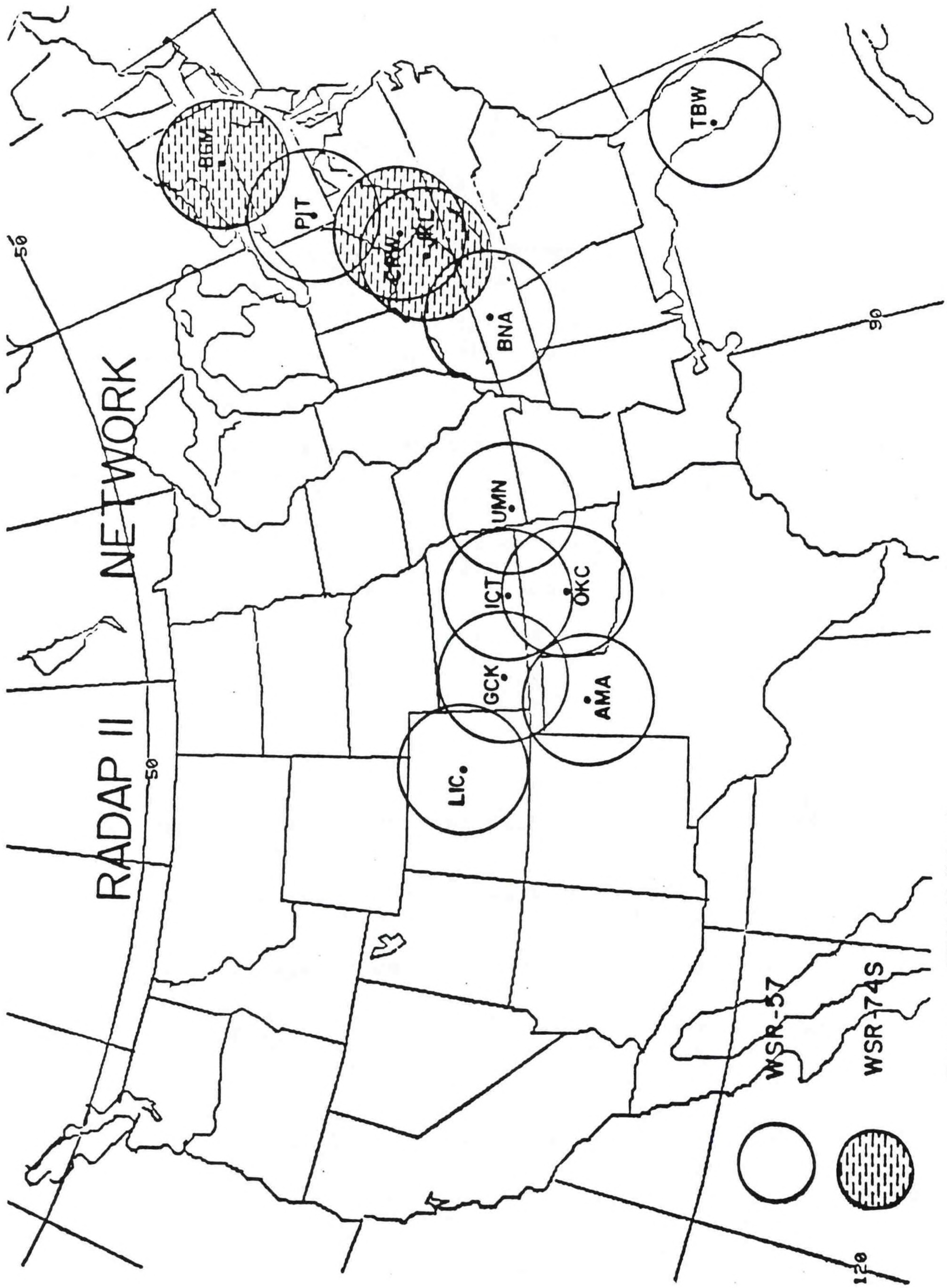


FIGURE 1. RADAP II Network.

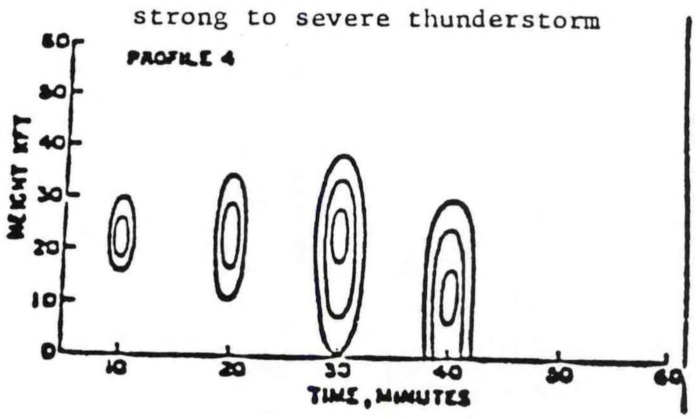


FIGURE 2. Temporal evolution of the radar echo associated with strong to severe thunderstorms.

4.8 Vertically Integrated Liquid Water Content (VIL). The data scans required for the Tops Map Program also provide information on the vertical intensity structures of the echoes. This information is used by the VIL Map Program to generate a grid map of estimated vertically integrated liquid water content values (figure 4-14). Each grid box is 3 nautical miles east-west by 5 nautical miles north-south. Each VIL Map grid value is a maximum VIL for that grid box.

The equation used to compute VIL is as follows:

$$VIL = \sum_{i=1}^{n} 3.44 \times 10^{-6} \frac{(Z_i + Z_{i+1})}{2} dh$$

where:

VIL is given in kg of water per square meter of surface area. Z_i = Reflectivity at level "i".

n = Number of height increments through the vertical extent of the echo.

dh = $h_{i+1} - h_i$ = height between two consecutive levels.

FIGURE 3. Calculation of VIL (from RADAP II Manual).

2. The Use of VIL to Nowcast Severe Weather

Devore (1983) used SWP and VIL values correlated with severe weather events from an eight month period in Oklahoma to develop the contingency SWP and RADAP's VIL values to arrive at the actual severe weather probability for an Oklahoma thunderstorm. The contingency table was tested on thunderstorms in Oklahoma in March, April, and May 1983. If warnings had been issued only on storms that were at or above the 50th percentile on the contingency table (above the heavy line), of 109 warnings issued, 92 would have verified with severe weather occurring and 17 would have been false alarms with no severe weather detected. Three severe weather events occurred that were not indicated by the table. Tornadoes were not used to verify severe weather events in this study.

Winston and Ruthi (1986) used the same data as Devore (1983) and concluded that RADAP II has demonstrated the ability to detect areas experiencing or soon to experience severe weather. The fact that RADAP updates the output every ten minutes made it an important guidance tool for operational forecasters. Realizing that the Devore study was done for spring thunderstorms in Oklahoma, the contingency table might have to be modified for thunderstorms in different climates and/or different seasons.

During the fall and winter of 1989-1990, the staff at Limon assembled data from all the severe hail events from the spring and early summer of 1989. These events from May 10 through June 30 for which VIL and SWP data are available are listed in the table. During that period there were 42 severe hail events for which VIL data was available at WSMO Limon. Of these, 81% had a VIL of 50 or greater associated with the large hail. The original intent of this study was to modify the Devore table to fit eastern Colorado thunderstorms. While high VIL's seemed to correlate well with large hail, as seen from the table, SWP's were less reliable. Thus, the author concentrated on how to use the VIL's to predict if a thunderstorm would produce severe size hail.

3. How to Use RADAP II in Eastern Colorado to Predict Large Hail

In April, May, and early June, VIL's of 35-45 may produce large hail and a VIL of 50 or more will almost always produce severe size hail. The first hail events of a day seem to set the hail size that can be expected from a certain VIL for the whole day. For example, if 3/4 inch hail on a certain day occurs with a VIL of 45, future similar VIL's are likely to indicate similar size hail. In Figure 5, May 15 is used to illustrate this criteria. All warnings that would have been issued on May 15 by this method were on time and verified with severe size hail. Of the 17 hail events listed on the table for May 10 through June 11, thirteen warnings issued by this method would have verified with severe size hail (76%) and four of the events would have occurred without warnings issued.

As spring turns to summer in mid to late June, the VIL's necessary to produce severe size hail increase to 50 or more and must persist for 20 minutes or larger. In Figures 6 and 7, June 24 and 29 are used to illustrate this hypothesis. On these two days, when persistent high VIL's started appearing each day, most of the warnings that would have been issued using this method

VIL \ SWP	10	20	30	40	50	60	70	80	90
55	100	100	100	100	100	100	100	100	100
50	45	60	70	80	85	90	100	100	100
45	30	45	50	55	65	75	85	100	100
40	20	30	35	40	50	65	80	95	100
35	10	20	25	30	40	50	65	85	100
30	5	10	15	20	25	30	45	70	100
25	0	5	5	10	15	25	40	60	100

Figure 4. Probability distribution nomogram showing observed frequency of severe-weather occurrence (percent) for specified values of vertically integrated liquid (VIL) in kg m^{-2} and severe-weather probability (SWP) in percent derived by RADAP II during 1982 (after Devore [1983]).

Figure 5

VIL's related to hail size for May 15, 1989 in eastern Colorado.

Time(Z)	Location	Hail Size	VIL
2010	Colorado City	1.00"	50
2021	SE of Greeley	.75"	45
2035	near Roggen	.75"	40
2100	Pueblo	.50"	40
0000(16th)	Springfield	.50"	25

An example of warning on VILs for May 15.

Warning criteria: For April, May and early June, warn on the VIL that produces severe size hail, OR a VIL of 45, whichever comes first.

At 2001Z a VIL of 50 was reported near Colorado City. At 2010, 1" hail was reported at Colorado City, so it might be possible that a VIL of 45 would produce .75" hail. So warn on VIL's of 45 (symbol 9) or more.

1. Warn south central and central Pueblo County 2001-2100Z on strength of 50 VIL at 2001.
   1" hail reported at 2010Z.
   .5" hail reported at 2100Z (non-severe with a VIL of 40).

2. Warn southern Weld County 2010-2110Z on strength of 50 VIL at 2010.
   .75" hail reported 2021Z.
   .75" hail reported 2035Z

VIL maps for this day are shown in the Appendix. After 2040Z no VIL's above 40 occurred.

VIL's may be called up on AFOS with RIPCLV.
VIP intensities may be called up with RIPCLI.
Severe Weather Probabilities (SWP) can be called up with RIPCLS.
Variable intensities which are especially useful for snow RIPCLQ.

Figure 6. An example of warning on VIL's for June 24, 1989.

Warning criteria: Issue a severe thunderstorm warning if the VIL of a storm is at least 50 for 20 minutes. General storm (maximum VIL core) movements were taken into account.

1. Warn S Yuma County 2111-2211.
   1.00-2.75" hail reported at 2115.

2. Warn central Arapahoe County 2130-2230.
   1.75" hail reported at 2140.
   1.75" hail reported at 2220.

3. Warn SE Yuma County-NE Kit Carson County 2201-2301.
   2.75" hail reported 2245.

4. Warn E Arapahoe County-SW Washington County 2230-2330.
   No severe hail reported.

5. Warn SE Yuma-N Kit Carson County 2300-0000.
   1.75" hail reported 2308.

6. Warn S central and SE Washington County 2330-0030.
   1.00" hail reported 0010.

The following warnings would have been issued following the above rule but no severe hail was reported. After attempting to contact spotters for information it would be logical to cease warning on VIL's until large hail is again detected.

7. Warn S Yuma County and NE Kit Carson County 0050-0150.
8. Warn NW and W central Kit Carson County 0050-0150.
9. Warn NE Lincoln County-SW Kit Carson County 0150-0250.
10. Warn S central Kit Carson County-N central Cheyenne County 0240-0340.
11. Warn W Cheyenne County 0320-0420.
12. Warn S central to SE Kit Carson County-N central to NE Cheyenne County 0340-0440.

By 0440Z all the high VIL's had moved into far western Kansas, where severe hail was reported between 0030Z and 0218Z (June 25). This would seem to indicate that severe hail occurs when the high VIL's first appear or move into a new area and high VIL's in the area behind the initial severe activity indicate mostly heavy rain and smaller hail. The later high VIL's were not caused by anomalous propagation or ground clutter and were reported as storms of DVIP 5 and 6 intensities on the manual radar observation. Winds in excess of 50 kts were not reported during the last SIX warnings either.

Figure 7. An example of warning on VIL's for June 29, 1989.

Warning criteria: Issue a severe thunderstorm warning if the VIL of a storm is at least 50 for 20 minutes. Maximum VIL core movements were taken into account and warnings were for a duration of one hour.

1. Warn eastern Morgan County 2240-2340Z.
   1.75" hail reported 2240. (VIL of 60 reported at 2210 but no further VIL data was available until 2240.)

2. Warn northern Las Animas County and SW Bent County 2240-2340.
   2.00" hail reported at 2335Z.

3. Warn central Cheyenne County 2311-0011Z.
   4.50" hail reported at 2330Z.

4. Warn central and NE Bent County and south central Kiowa County 2340-0040Z.
   1.75" hail reported 0020Z.

5. Warn SE Lincoln County and NW Kiowa County 2350-0050Z.
   No severe hail reported.

6. Warn central and south central Cheyenne County and north central Kiowa 0010-0110Z.
   1.75" hail reported 0018Z. 81 mph wind 0025Z.
   1.75" hail reported 0031Z. 70 mph wind 0010Z.

7. Warn central and NE Kiowa County 0040-0140Z.
   No severe hail reported.

8. Warn SE Cheyenne County 0050-0150Z.
   No severe hail reported.

After 0130Z, no more VIL above 50 or severe hail was reported.

Table 1. VIL histories of severe hail producing storms in eastern Colorado and western Kansas in 1989 within a 125 nm radius of Limon.

*VILs are represented by their grid symbols as follows:

Code Value....	1	2	3	4	5	6	7	8	9	A	B	C	D	E	F	G
VIL(Kg/M**2)..	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80

Time of Event(Z)	Location	Hail Diameter	Max VIL*	SWP %	Map Time(Z)
2045	Littleton	1"	9		2020
5/10			8		2030
			9		2040
2100	intersection	1.75"	8		2030
5/10	I25 and I225		9		2040
			8	40	2050
2015	16 mi. N of	1.75"	1		1950
5/12	Stoneham		3		2001
2215					
5/14	Las Animas	1.5"	9	50	2150
			8		2230
2328	Hasty	1.5"	7		2250
5/14			7		2310
			7	40	2324
			7	60	2330
2010	Colorado City	1"	A		2001
5/15			A	10	2010
			A	60	2021
2021	SE of Greeley	.75"	8		2001
2035	near Roggen	.75	A	20	2010
5/15			9		2021
			A	60	2040
0735	Haxtun	.75"	A	20	0640
5/21			C	40	0730
			B	20	0740
0000-	8 N of Eads	2.75"	C	90	2320
0010	6 N of Eads	1.75"	E	70	2352
5/22	3 E of Eads	2.5"	D	90	0042
0109	Holly	1"	F	80	0052
5/22			C	90	0120

Time of Event(Z)	Location	Hail Diameter	Max VIL*	SWP %	Map Time(Z)
2200 6/3	Denver	1"	3		2122
			5	50	2130
			7	30	2140
			9	20	2210
1930 6/6	Calhan	1.75"	3		1810
			9		1840
			A	50	1850
			A		1900
			A	50	1910
2155 6/10	Springfield	1"	1		2100
			6	10	2130
			4		2140
			7	10	2150
			7	20	2201
0120 6/11	12 W. of Leoti, KS	1"	D	40	0100
			D	60	0120
2115 6/24	Idalia	1-2.75"	D	90	2111
			D	90	2130
			D	90	2140
			C	80	2150
2245 6/24	Idalia	2.75"	D	90	2201
			E	90	2210
			A	90	2230
			B	80	2240
2140 6/24	35 nm SE Stapleton	1.75"	B	40	2111
			C	30	2130
			A	50	2140
			B	40	2150
2220 6/24	Deer Trail	1.75"	B	40	2150
			9		2201
			B	80	2210
			A	50	2230
2308 6/24	SE Yuma County	1.75"	C	70	2300
			B	90	2310
			E	90	2330
0010 6/25	Cope	1"	D	70	2310
			F	70	2330
			F	90	2340
			C	90	0010

Time of Event(Z)	Location	Hail Diameter	Max VIL*	SWP %	Map Time(Z)
0030-0040	16N Goodland KS	3"	E	90	2330
6/25	10SSE Bird KS	.75"	D	90	2340
	S of Sherman	2-3"	D	90	0010
	County Line KS		C	10	0030
			A	20	0040
0010	12N Goodland KS	2"	C	10	0030
6/25			A	20	0040
			B	90	0050
			A	50	0101
			A	40	0110
0150	15NW Goodland KS	.75"	B	40	0110
6/25			7		0130
			8		0140
			B	80	0150
0218	17 NNE Goodland	1"	9	90	0130
6/25	Kansas		8	60	0140
			B	40	0150
			C	80	0210
1850	Kassler	2"	B	40	1820
6/26			9	30	1830
			6	30	1840
			B		1902
1950	Louviers	1"	B		1902
6/26			A	50	1934
			9	50	1950
2335	Bellview	.88"	5	50	2310
6/26			5	50	2330
			7		2340
2310	Sedgwick	1.5"	4		2230
6/28			C	60	2252
			D	90	2310
2240	Brush	1.75"	C		2210
6/29			9		2240
2330	Kit Carson	4.5"	D		2250
6/29			E		2311
			C		2320
			D		2330
2335	10SE Las Animas	2"	D		2250
6/29			F		2311
			E		2320
			E		2330

Time of Event(Z)	Location	Hail Diameter	Max VIL*	SWP %	Map Time(Z)
0018 6/30	Kit Carson	1.75"	B	60	2340
			C	90	2350
			B	90	0003
			B	90	0022
0020 6/30	6N Wiley	1.75"	E	80	2330
			E	80	2340
			B	20	2350
			B	40	0003
			9	80	0022
0025 6/30	2S Cheyenne Wells	1.75"	9	50	0022
			B	70	0030
0031 6/30	7S Cheyenne Wells	1.75"	C	70	0030
2200 6/30	near Stratton	1.75"	B	50	2140
			8		2200
0040 7/1	Brush	1"	E	70	2350
			E	80	0001
			E	60	0010
			E	60	0021
			D	40	0030
			C	50	0040

verified with severe size hail reported after the warning issuance time. No severe hail events were missed using this technique. However, the false alarm rate increased with the passage of time. Possibly a higher freezing level within the air column because of mixing after the first hail-producing storms had passed resulted in only heavy rain and small hail where the subsequent high VIL's are noted. Preliminary examination of the VIL and hail data for July and August indicated that this trend for less hail in high VIL storms is quite prevalent in mid to late summer.

4. Summary and Conclusion

After trying the suggested VIL warning criteria on thunderstorms in eastern Colorado that occurred between May 10 and June 30, it was found that warnings on VIL's of 50 or more resulted in a high percentage of verified severe hail events with the following qualifications:

<u>Spring</u>: April - mid June; warn on a VIL of 45 as soon as it is observed. Warn on lower VIL's if they have already indicated severe hail earlier that day.

<u>Early Summer</u>: Early to mid June - early July; warn on a VIL of 50 or more if it is sustained for 20 minutes. However, after the initial action on a severe thunderstorm day, high VIL's may not indicate large hail.

By observing and judiciously using VIL data from RADAP II, forecasters can increase the timeliness of their severe thunderstorm warnings in spring and early summer. The WSR-88D (NEXRAD) will have a VIL product similar to RADAP II, so the more that can be learned about VIL data now, the smoother the transition to the new technology will be.

5. References

Devore, D.R., 1983: The Operational Use of Digital Radar Data. <u>Preprints, 13th Conf. on Severe Local Storms</u> (Tulsa, OK), Amer. Meteor. Soc., 21-24.

National Weather Service, 1984: <u>Operating Instructions for RADAP II</u>, Federal Meteorological Handbook 7, Part C, Section III, Issue No. 19-WSH, p. 58.

Winston, H. A., and L. J. Ruthi, 1986: Evaluation of RADAP II Severe Storm Detection Algorithms. <u>Bull. of Amer. Meteor. Soc.</u>, <u>67</u>, 145-150.

APPENDIX

```
TTAAO0 KLIC 152108

LIC  VIL MAP 2001Z,  MAY 15, 1989

CODE VALUE......   1   2   3   4   5   6   7   8   9   A   B   C   D   E   F

VIL(KG/M**2)....   5  10  15  20  25  30  35  40  45  50  55  60  65  70  75  8

     60  48  36  24  12   0  12  24
      W...W...W...W...W...*...E...E

60N       *   3
55N     *   283
50N    *    66       * * * * * *
45N  *           *                *
40N            *
35N          *
30N         *
25N        *          * * * * *
20N       *         *          *
15N       *        *             *
10N      *        *               *
 5N      *       *
 0S      *       *        *
 5S      *       *
10S      *        *               *
15S       *        *             *
20S 483   *         *          *
25S   563  *          * * * * *
30S         *
35S          *
40S *          *
45S  *           *                *
50S    *             * * * * * *
55S     *
60S       *
65S         *
70S     239    * *
75S *   29A92       * * * * * * *
80S  *   384
85S   *7
90S     77*

      W...W...W...W...W...*...E...E
     60  48  36  24  12   0  12  24
```

```
LIC  VIL MAP 2100Z,  MAY 15, 1989

CODE VALUE......   1   2   3   4   5   6   7   8   9   A   B   C   D   E
VIL(KG/M**2)....   5  10  15  20  25  30  35  40  45  50  55  60  65  70

     72  60  48  36  24  12   0  12  24
      W...W...W...W...W...W...+...E...E
80N      *                12
75N    *                * 1* * * * *
70N  *             *442 1
65N *           *   74
60N           *
55N         *
50N        *             * * * * * *
45N      *           *                *
40N     *          *
35N    *         *
30N    *        *
25N   *        *          * * * * *
20N 1*        *         *          *
15N 2*        *        *             *
10N  *       *        *               *
 5N  *       *       *
 0+  *       *       *        *
 5S  *       *       *
10S  *       *        *               *
15S  *        *        *             *
20S  *  473   *         *          *
25S   *  573   *          * * * * *
30S    *  1     *
35S    *         *
40S     *          *
45S      *        1  *                *
50S        *   1211      * * * * * *
55S         *  12542
60S           *  5883
65S *           * 111
70S  *          132* *
75S    *         351    * * * * * * *
80S      *      112
85S        *   12 1
      W...W...W...W...W...W...+...E...E
     72  60  48  36  24  12   0  12  24
```

```
LIC  VIL MAP 2110Z,  MAY 15, 1989

CODE VALUE......    1   2   3   4   5   6   7   8   9   A   B   C   D   E
VIL(KG/M**2)....    5  10  15  20  25  30  35  40  45  50  55  60  65  70

     72  60  48  36  24  12   0  12  24
      W...W...W...W...W...W...+...E...E
80N      *                12
75N    *                1* * * * * *
70N  *             *342
65N *           *   1
60N           *
55N         *
50N        *             * * * * * *
45N      *           *                *
40N     *          *
35N    *         *
30N  11*        *
25N   *        *          * * * * *
20N 33        *         *          *
15N 11        *        *             *
10N  *       *        *               *
 5N  *       *       *
 0+  *       *       *        *
 5S  *       *       *
10S  *       *        *               *
15S  *        *        *             *
20S  *  483   *         *          *
25S   *  653   *          * * * * *
30S    *        *
35S    *         *
40S     *          *
45S      *       1   *                 *
50S        *    111       * * * * * *
55S         *    3447
60S           *  24772
65S  *          *121
70S   *          1332*
75S     *         21     * * * * * * *
80S       *      222
85S         *    2
       W...W...W...W...W...W...+...E...E
      72  60  48  36  24  12   0  12  24
```

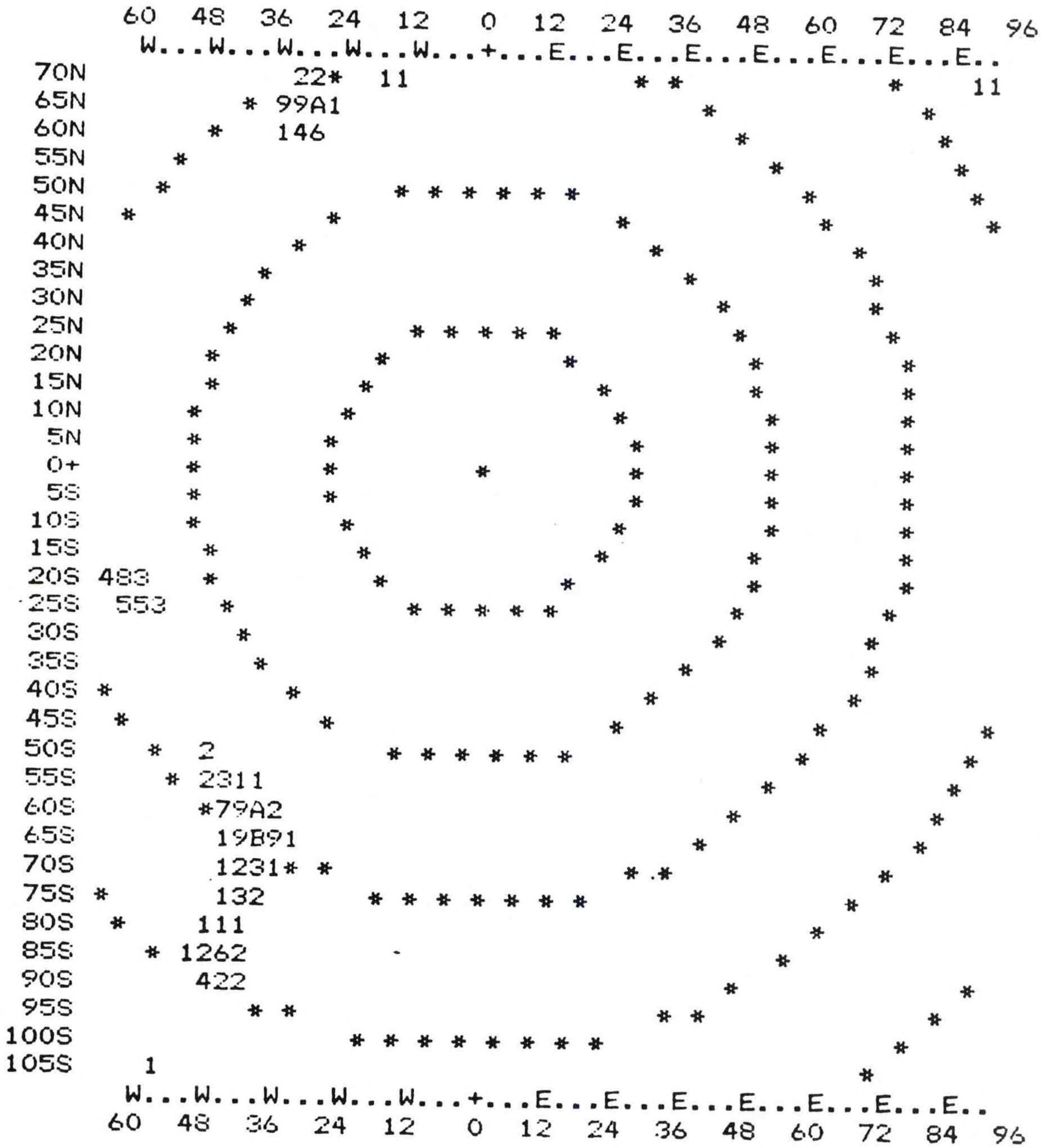
```
LIC  VIL MAP 2021Z,  MAY 15, 1989

CODE VALUE......    1   2   3   4   5   6   7   8   9   A   B   C   D   E
VIL(KG/M**2)....    5  10  15  20  25  30  35  40  45  50  55  60  65  70

     60  48  36  24  12   0  12  24
      W...W...W...W...W...+...E...E
70N            * *    22
65N         * 2    21111
60N       *  393
55N     *    19
50N    *             * * * * * *
45N  *           *                *
40N            *
35N          *
30N         *
25N        *          * * * * *
20N       *         *          *
15N       *        *             *
10N      *        *               *
 5N      *       *
 0+      *       *        *
 5S      *       *
10S      *        *               *
15S       *        *             *
20S 583   *         *          *
25S  873   *          * * * * *
30S          *
35S           *
40S *           *
45S  *            *               *
50S     *             * * * * * *
55S      *
60S       131
65S        49A*
70S        59A5 * *
75S *      154       * * * * * * *
80S   *
85S     * 111
90S      124*
95S       3   * *
       W...W...W...W...W...+...E...E
      60  48  36  24  12   0  12  24
```

LIC VIL MAP 2040Z, MAY 15, 1989

CODE VALUE......	1	2	3	4	5	6	7	8	9	A	B	C	D	E
VIL(KG/M**2)....	5	10	15	20	25	30	35	40	45	50	55	60	65	70



CRH SSD

CENTRAL REGION APPLIED RESEARCH PAPER 4-5

AN ANALYSIS OF 100 YEARS OF TEMPERATURE DATA AT CONCORDIA, KANSAS

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1. Introduction

The "Greenhouse Effect" became an important issue in the decade of the 1980's as the overall global temperatures appear to be rising due to this effect. A previous paper released by Daseler and Weiland (1990) showed that although the decade of the 1980's had considerable temperature variations regarding the number of record highs and lows, other decades in the past since the 1870's had seen just as much variation and, in some instances, even greater temperature extremes. Thus, it was decided to see if the temperatures at Concordia, Kansas have shown any net warming or cooling in the last 100 years (1890-1989).

2. Methods and Data

Temperature trends were evaluated by first finding a mean monthly temperature by decade for the 100 year period from 1890 to 1989. The actual 100 year mean temperature for each month was then compared to the average mean monthly temperature for each decade from the 1890's through the 1980's. Bargraphs (Figures 1 through 3) were plotted to show the results. For example, in Figure 1a, which represents January, the actual mean monthly temperatures for each decade were plotted with respect to the 100 year average mean monthly temperature represented by the solid straight line. The shaded bars represent decades where the mean monthly temperature was below the 100 year average and the unshaded bars show mean monthly temperatures above the 100 year average. In addition, the values above each bar are the actual mean monthly temperatures for each decade, while the value to the right of the solid straight line represents the 100 year average mean monthly temperature.

3. Results

At first glance, there appears to have been many decades during the past 100 years which departed significantly from the long term mean (100 year) value. This is similar to the results of Daseler and Weiland (1990) at Cheyenne, Wyoming. For example, the month of January (Figure 1a) during the decades of

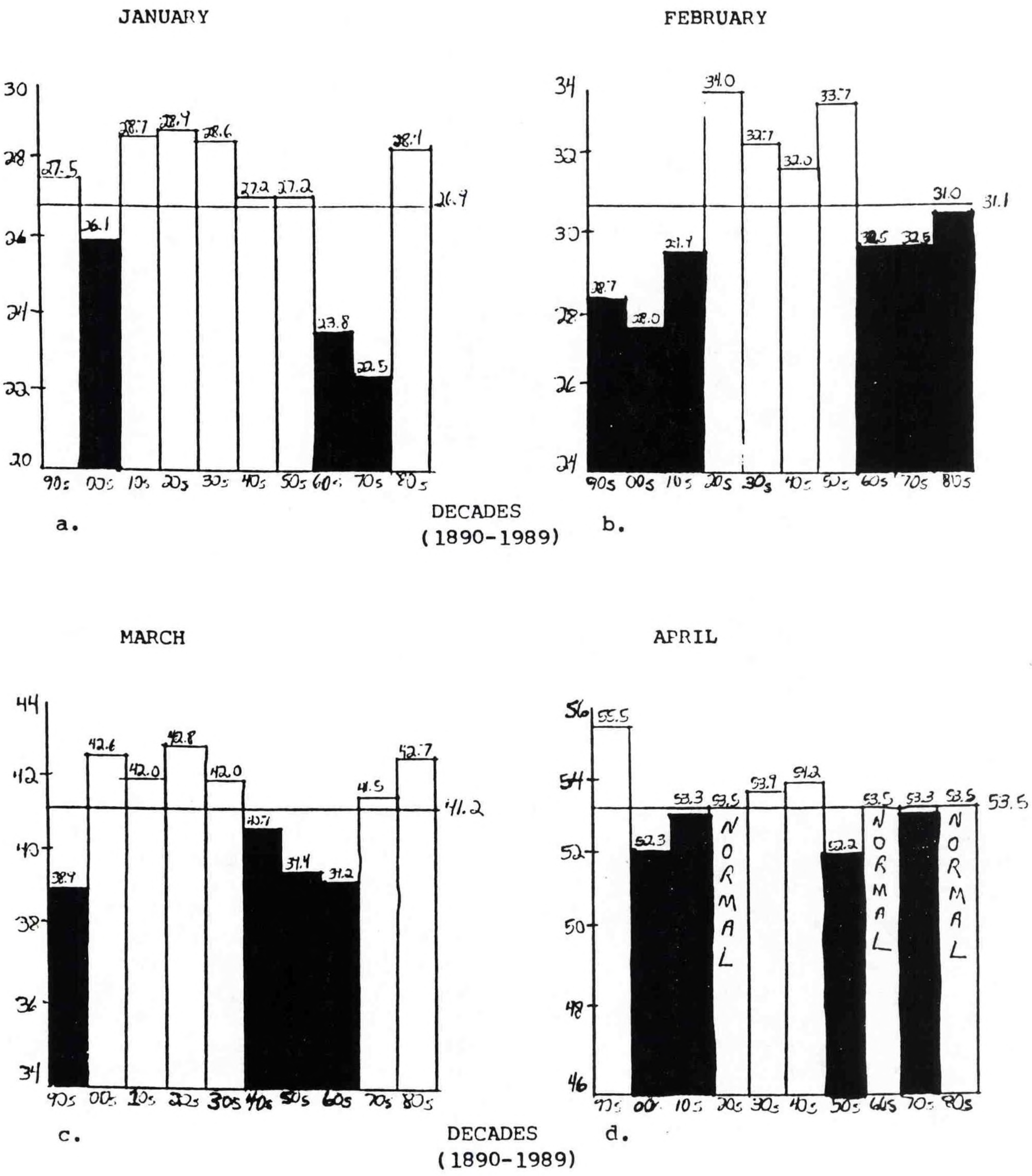
JANUARY
27.5
26.1
28.7
28.9
28.6
27.2
27.2
23.8
22.5
28.1
26.9
90s 00s 10s 20s 30s 40s 50s 60s 70s 80s
a.
FEBRUARY
28.7
28.0
29.7
34.0
32.7
32.0
33.7
29.5
29.5
31.0
31.1
90s 00s 10s 20s 30s 40s 50s 60s 70s 80s
b.
DECADES
(1890-1989)
MARCH
38.9
42.6
42.0
42.8
42.0
40.7
39.4
39.2
41.5
42.7
41.2
90s 00s 10s 20s 30s 40s 50s 60s 70s 80s
c.
APRIL
55.5
52.3
53.3
53.5
53.9
54.2
52.2
53.5
53.3
53.5
53.5
NORMAL
NORMAL
NORMAL
90s 00s 10s 20s 30s 40s 50s 60s 70s 80s
d.
DECADES
(1890-1989)

Figure 1

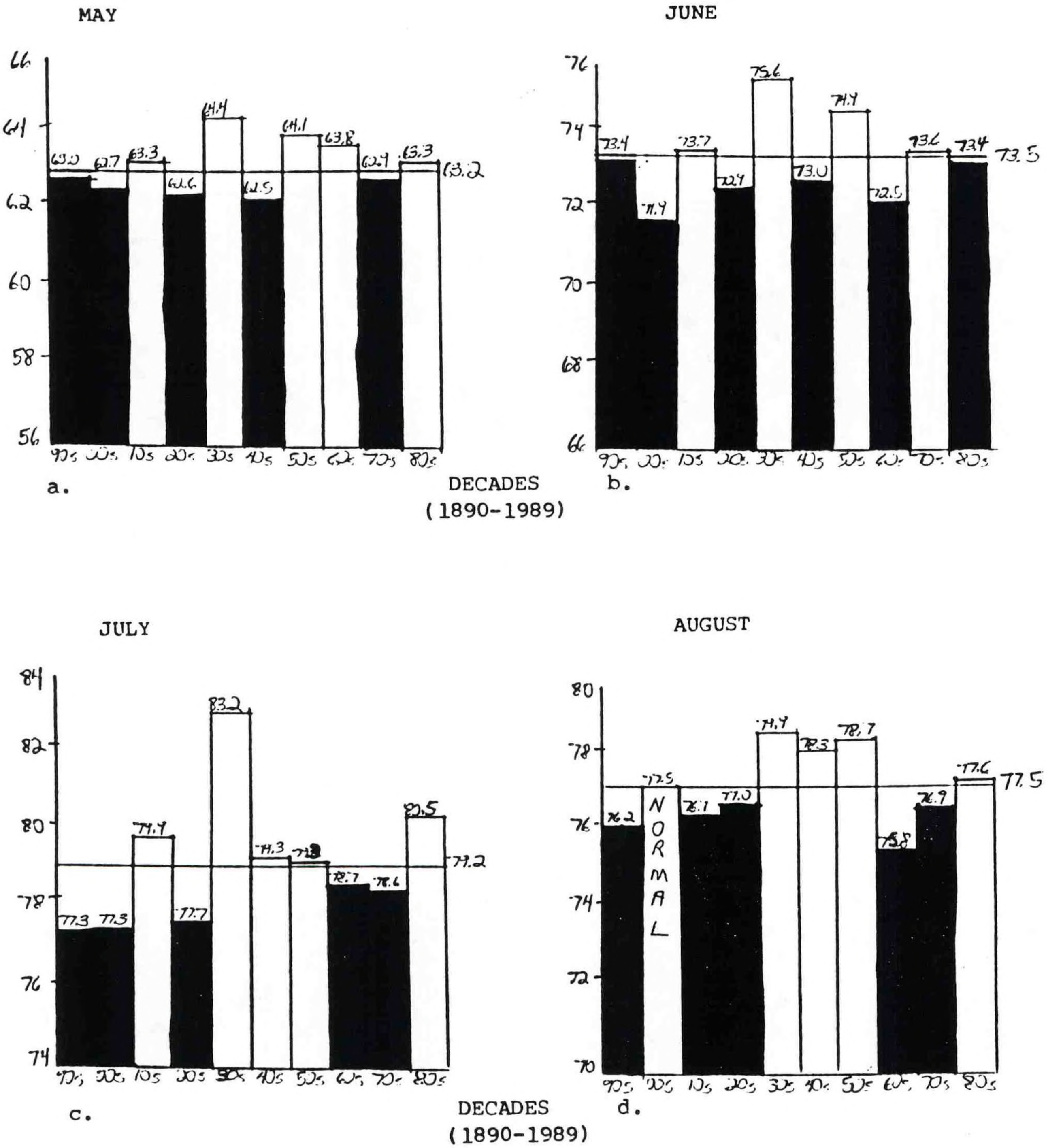
MAY
66
64
62
60
58
56
63.0
62.7
63.3
62.6
64.4
62.5
64.1
63.8
62.9
63.3
63.2
90s 00s 10s 20s 30s 40s 50s 60s 70s 80s
a.
JUNE
76
74
72
70
68
66
73.4
71.4
73.7
72.4
75.6
73.0
74.4
72.5
73.6
73.4
73.5
90s 00s 10s 20s 30s 40s 50s 60s 70s 80s
b.
DECADES
(1890-1989)
JULY
84
82
80
78
76
74
77.3
77.3
79.4
77.7
83.2
79.3
78.7
78.6
80.5
79.2
90s 00s 10s 20s 30s 40s 50s 60s 70s 80s
c.
AUGUST
80
78
76
74
72
70
76.2
77.5
76.1
77.0
79.4
78.3
78.7
75.8
76.9
77.6
77.5
N
O
R
M
A
L
90s 00s 10s 20s 30s 40s 50s 60s 70s 80s
d.
DECADES
(1890-1989)

Figure 2

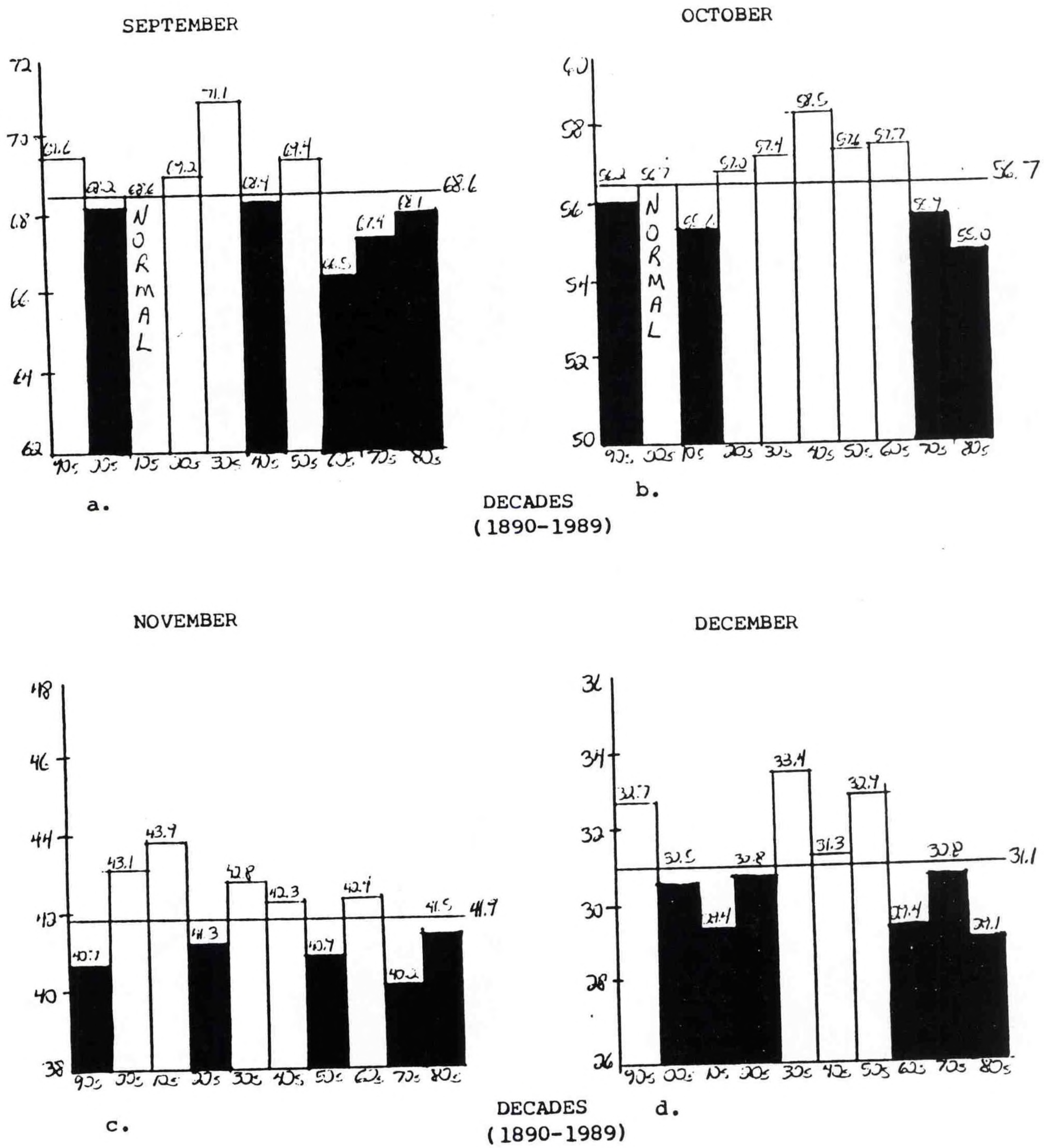
SEPTEMBER
OCTOBER
NOVEMBER
DECEMBER
NORMAL
68.6
56.7
41.7
31.1
71.1
58.5
43.9
33.4
a.
b.
c.
d.
DECADES
(1890-1989)
DECADES
(1890-1989)

Figure 3

the 1960's, 1970's, and 1980's, and (Figure 2c) the month of July during the 1920's and 1930's, shows significant departures. In addition, there is some evidence that the mean monthly temperatures may exhibit some type of cycle. For example, the month of February (Figure 1b) shows that mean monthly temperatures were below normal during the decades of the 1890's, 1900's, and 1910's, then above normal from the 1920's through the 1950's, and once again were below normal from the 1960's through the 1980's. Furthermore, the months of March (Figure 1c), July (Figure 2c), and December (Figure 3d) also may show some type of cyclic temperature pattern.

Another unexpected result was the decade of the 1930's (which has been labelled the "Dust Bowl" years throughout the Central Plains), where the mean monthly temperature for each month of that decade was above normal. This was the only decade in which this occurred, and there were no decades where the mean monthly temperatures were all below normal. Thus, the decade of the 1930's was the warmest on record for Concordia, Kansas, and, if examined, weather stations across the region would probably show this result as well.

Finally, after looking at the bargraphs carefully it appeared that over the past three decades (1960's through the 1980's) the overall mean monthly temperatures were showing some signs of a net cooling instead of a net warming. To investigate this hypothesis, calculations were made for the 70 year mean temperature (1890-1959) versus the 30 year mean temperature for the past 30 years (1960-1989). After making the calculations, it was found that the 70 year mean temperature was 53.9°F, while the 30 year mean temperature was 53.2°F. This is a net cooling of 0.7°F. While little can be said about the "Greenhouse Effect" by evaluating 100 years of data at one station, it is interesting that Concordia has experienced a slight cooling during the past 30 years.

4. Conclusions

This study has indicated some rather interesting temperature patterns during the past 100 years at Concordia, Kansas. However, the most important result of this study has been the discovery that the average mean yearly temperature for the past 30 years (1960-1989) was 53.2°F compared to 53.9°F during the preceding 70 years (1890-1959), thus the average mean yearly temperature during the last 30 years has cooled by 0.7°F. It would be interesting to see other results from other weather stations in the United States where temperature records go back 100 years or more since the results from this study were somewhat surprising.

5. Reference

Daseler, J. A. and Weiland, M. S., 1990: How Did the 1980s Compare Temperature-wise with Previous Decades at Cheyenne, Wyoming? Central Region Technical Attachment 90-27, available from National Weather Service Central Region, Scientific Services Division, Kansas City, MO.