W.J.

Operational Weather Forecasting for University of Wisconsin Physical Plants and Experimental Farms

by

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PROJECT REPORT

The forecasting and research described in this report has been supported by grants from the Graduate School of University of Wisconsin—Madison through the University-Industry Research program.

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Abstract

An ongoing three year project of operational weather forecasting for Wisconsin industry culminated this year in a program of weather forecasting for University of Wisconsin physical plants and experimental farms. The functional premise for the effort was that weather forecast information would be useful for the efficient operation of these units. Verification of the premise has proven to be difficult. A monetary estimate of the worth of forecast information could not be made for either group although each considered the forecasts to be adequate and useful input to their operational planning.

Recommendations are made concerning more complete analysis of forecast utilization by the users and the structure of future operational forecasting programs. Comparison of forecast accuracy against a standard such as the National Weather Service is considered essential. A stable funding base, partially supported by ongoing research programs within the Meteorology Department, is vital to maintaining a consistent operations program. Users within the public sector - State and University - and with whom forecasting research is important must be identified as recipients of future operational forecasting products.

Wm. Richard Barchet
Principal Investigator

December 1976

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INTRODUCTION

During the last 3½ years the Department of Meteorology has undertaken various projects in operational and applied meteorology and has received financial support for these projects from the Graduate School during part of this time. This report will review the accomplishments of the operational and applied meteorology effort with particular emphasis on the last year of the program.

Several facets of applied and operational meteorology were examined during this period. Two graduate students, supported by grants from the Graduate School, made substantial progress toward their Master's degrees with thesis topics in the area of agricultural meteorology. An operational forecasting program produced weather forecasts specifically tailored to the needs of the heating and physical plants of several UW-system universities and also for several UW-experimental farms.

Each of these topics will be presented in the body of this report. Conclusions and recommendations concerning operational and applied meteorology on this campus will be presented in the final section.

I. ACADEMIC ACTIVITIES

Graduate Student Research

The two research assistantships granted to this program for the period 1 July 1975 to 30 June 1976 were filled by Mrs. Gail Martell and Mr. Tom Fahey. Their reserach topics center on two very different topics; Mrs. Martell undertook a study of the economic impact of weather forecasts to the canning industry while Mr. Fahey began an investigation of the importance of dew and plant surface moisture on agriculture and the impact forecasts of these parameter may have on the industry. Although substantial progress on these topics was made during the one year grant period neither thesis is presently completed.

Mrs. Martell is farthest along on her Master degree requirements and successfully passed our comprehensive examination last spring. She still has much to do on her thesis, however, and the prospects of rapid progress are reduced as a consequence of obtaining a job in applied agricultural meteorology with E. F. Hutton in New York City. This employment opportunity arose from her activity in our applied meteorology program, her participation in a seminar on applied meteorology and contacts made in a course on climate change with Professor R. Bryson. Her work at E. F. Hutton involves the interpretation of meteorologic and climatic data in terms of the impact weather has on crop development, harvest yield and commodity demand; topics she has already examined for Wisconsin's canning industry.

Determining the value of a weather forecast to any industry is not an easy task; the canning industry requires an exceptionally complex analysis because of the long delay between a weather event and its ultimate consequences in yield, quality and profit. Typically many weather parameters are involved in a forecast to a canning company, each of which may have an impact on a different phase of their operation or may affect in different ways the variety of crops grown by or for the company. Mrs. Martell has made substantial progress toward identifying the weather parameters that influence major production steps and how these parameters affect the industry. One of the most critical parameters, and also a very difficult one to evaluate is the timing of forecast issuance with respect to when a particular operation must be carried out. For example, application of herbicides should in many instances be followed by rain to wash the chemicals into the soil and to activate their herbicidal action. A forecast of rain with adequate lead time to apply the material will be quite useful but a forecast with too little lead time will be of no use. A continuation of this example illustrates another formidable task in the evaluation of forecast value. Even if the forecast is made with adequate lead time and the herbicide is successfully applied, can a mometary value be assigned to its usefulness? Added to the difficulty of assessing the value of a correct forecast is the prospect of having to place a probability on making a correct forecast and evaluating the loss of forecast value as this probability decreases.

The inter-relation between these factors is schematically shown in Figure I-1 for one case of herbicide application. The value of a herbicide application in terms, say, of the dollars spent to treat a field times the fraction of field kept free of weeds (which may not be known for several weeks) increases up to the onset of rain because loss of the a volatile herbicide by evaporation decreases as the time separation between application and rain decreases. However, the minimum lead time required to apply the herbicide prior to rainfall is specified by the rate of application and area to be treated. The value of a correct forecast will thus gradually increase up to the minimum lead time from whence a sharp drop in value to essentially zero at the onset of rain. But the likelihood of a correct forecast will also show a dependence on the lead time before the event. In this case two potential forecast accuracies are given: one in which the forecaster has the best possible data set, i.e. surface, upper air, satellite, and radar; and the other being essentially a farmer's seat-of-the-pants forecast. The probability that the forecast is correct (or wrong) degrades the forecast value curve and gives this curve a maximum near or just after the minimum lead time break point. Of course the arguement for operational forecasting stems from an anticipated maximum substantially higher for the curved based on sound meteorological data, i.e. with guidance, rather than seat-of-the pants intuition.

Senarios such as this can be developed for various combinations of meteorological events and agricultural operations which must be performed by the canner or grower. Identification of these combinations, qualitative assessment of the shapes of the various curves involved, and a climatological estimate of the frequency with which these senarious are likely to be encountered are the major tasks which Mrs. Martell must complete to finish her thesis. It is very likely that the experience she gains in her new job will aid her in some of these tasks.

Mr. Fahey has made a remarkable amount of progress on his thesis in the nine months of support by the Graduate School. He has subdivided the topic of plant surface moisture and dew into 1) its physiological importance to plants and their diseases, 2) its impact on field operations, 3) techniques for its observation and measurement, and 4) methodologies for its forecasting. At present he is being supported by a project assistantship through the Department of Geography while preparing to take the master's comprehensive exam and continuing his academic and research programs.

Plant surface moisture, of which dew is the most noticeable form, plays a role in the epidemiology of several fungal diseases, noteably apple scab, and early and late blight on beans, potatoes and tomatoes. Some of these diseases are of major economic importance to Wisconsin agriculture. Models have been developed to formulate efficient fungicide application programs with numerous weather parameters among the input data. Dew has been recognized as an important piece of information but there is a very noticeable lack of routine dew observations on the scale necessary to make possible the incorporation of dew occurence, quantity, and duration into

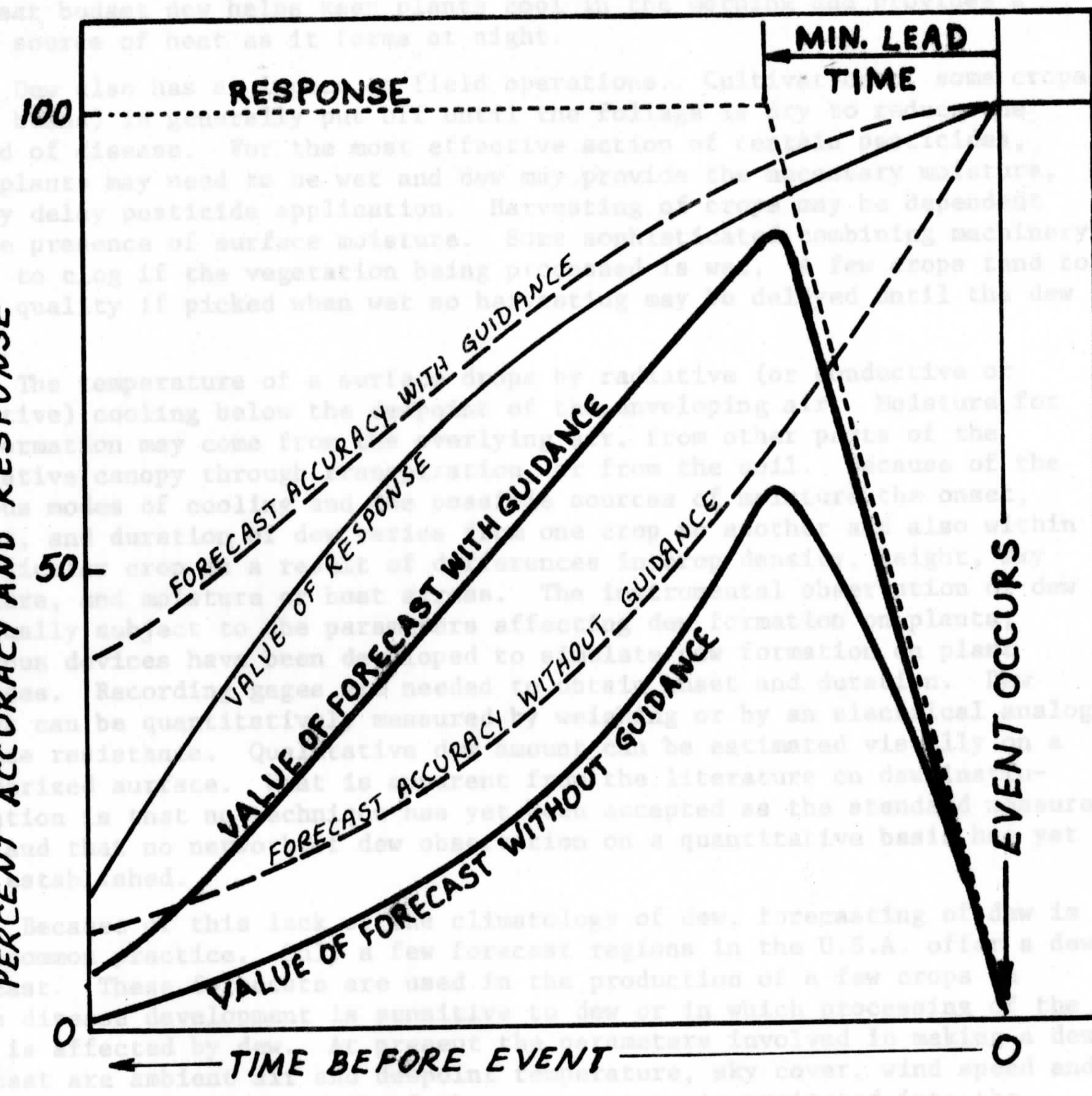

Fig. I-1: Forecast senario showing impact of forecast lead time and time to accomplish a response to the forecast on the value of forecasts with different levels of accuracy.

the models. Dew also affects plants by altering the plant water budget. In the heat budget dew helps keep plants cool in the morning and provides a small source of heat as it forms at night.

Dew also has an impact on field operations. Cultivation of some crops (e.g. beans) is generally put off until the foliage is dry to reduce the spread of disease. For the most effective action of certain pesticides, some plants may need to be wet and dew may provide the necessary moisture, or may delay pesticide application. Harvesting of crops may be dependent on the presence of surface moisture. Some sophisticated combining machinery tends to clog if the vegetation being processed is wet. A few crops tend to loose quality if picked when wet so harvesting may be delayed until the dew dries.

The temperature of a surface drops by radiative (or conductive or advective) cooling below the dewpoint of the enveloping air. Moisture for dew formation may come from the overlying air, from other parts of the vegetative canopy through transpiration, or from the soil. Because of the various modes of cooling and the possible sources of moisture the onset, amount, and duration of dew varies from one crop to another and also within a particular crop as a result of differences in crop density, height, sky exposure, and moisture or heat stress. The instrumental observation of dew is equally subject to the parameters affecting dew formation on plants; numerous devices have been developed to simulate dew formation on plant surfaces. Recording gages are needed to obtain onset and duration. Dew amount can be quantitatively measured by weighing or by an electrical analog surface resistance. Qualitative dew amount can be estimated visually on a standarized surface. What is apparent from the literature on dew instrumentation is that no technique has yet been accepted as the standard measurement and that no network of dew observation on a quantitative basis has yet been established.

Because of this lack of the climatology of dew, forecasting of dew is an uncommon practice. Only a few forecast regions in the U.S.A. offer a dew forecast. These forecasts are used in the production of a few crops in which disease development is sensitive to dew or in which processing of the crop is affected by dew. At present the parameters involved in making a dew forecast are ambient air and dewpoint temperature, sky cover, wind speed and previous precipitation. Each of these parameters is projected into the future and the forecaster then decides if the crop in question can cool to the dewpoint. Generally the forecast is in qualitative terms with little information on onset, duration, or amount of dew given.

It is quite clear from Mr. Fahey's present work that plant surface moisture is an important agricultural parameter affecting disease epidemiology and field operations. Forecasts of dew and plant surface moisture are likely to be valuable to agriculture in disease control programs and field management. However, the development of refined forecast techniques will not be possible without the establishment of dew observation network, the collection of a climatology of plant surface moisture on a variety of crops, and the synthesis of a physical model which translates the parameters relevant to dew formation into a quantitative forecast of onset, duration and amount. These tasks appear to be beyond the scope of Mr. Fahey's master thesis.

II. OPERATIONAL WEATHER FORECASTING FOR UNIVERSITY OF WISCONSIN PHYSICAL PLANTS

Introduction

As an outgrowth of the operational weather forecasting project which had been ongoing in the Department of Meteorology for nearly three years, we embarked in November 1975 on an experiment in providing weather forecasts to ten universities within the University of Wisconsin System. A major premise in this undertaking was that weather forecasts can be a valuable commodity if they contain pertinent information and are delivered in a timely fashion. This report summarizes the success of our project in providing appropriate forecasts and attempts to determine if the information provided had value.

Forecast preparation

The operations project was staffed by one full time meteorologist with extensive forecasting experience in our program and two or three part-time meteorologists who were graduate students in the Meteorology Department. These meteorologists assembled the weather data, analyzed this information, prepared the forecasts and conveyed the forecasts by telephone to the participating physical plants. A brief review of how a forecast is made follows.

Nearly all the weather data on which the forecasts are based is obtained from the National Weather Service (NWS) via tele-communication systems. Weather data arrives in several forms, each with some delay from the time of observation. Surface observations on the hour at most NWS offices arrive over a teletypewriter some 15 to 20 minutes after the hour; this is the most current form of data received and as a list of observations is in perhaps the least digestable form. We were fortunate that most of the universities are located in or near cities large enough to have an NWS observation station. However, to use this data for forecasting purposes it must be displayed as a map, or in two-dimensional form. An experienced meteorologist can do this for the northern mid-west in about 30 minutes for the major weather parameters: temperature, dewpoint temperature, barometric pressure, wind, cloudiness, and precipitation. Every three hours we receive from the NWS a facsimile map of surface weather conditions for the U.S.A, however, the map arrives some 90 minutes after the time of observation, hence for short range forecasts these maps are not very useful. During part of the project we did have access to the computer facility of the Space Science and Engineering Center which enabled us to obtain weather maps of the hourly observations automatically within minutes after the data arrived via the teletype. This facility was very useful for updating forecasts during rapidly changing weather.

Although the surface is where we are, most of the weather events that determine what happens at the surface are controlled by processes taking place far above the surface. Observations of weather parameters there is much more difficult hence routine data is available from the upper atmosphere only twice daily. Instruments for observing the weather are carried aloft by balloons at midnight and noon Greenwich Mean Time which for us means a morning and evening observation. The number of stations reporting such data are far fewer than those giving surface observations and in our area include Green Bay, WI, Peoria, IL and St. Cloud, MN. We receive the information in a coded teletype message 60-90 minutes after the observation and as a series of maps at different levels in the atmosphere on the facsimile circuit some 2 to 5 hours after the observation. These maps are quite important for interpreting the development and movement of weather systems, hence short range, one to twelve hour forecasts are best made after these maps are available.

Because of the complexities of the interaction between numerous weather factors, forecasts of longer range than 12 hours generally are best made after the NWS computers have digested the weather data and provided forecast maps over the facimile circuit. Such long range guidance is available some 4 to 5 hours after the upper air observations are made. Computer made forecasts actually do not give a detailed weather forecast of the type given to the physical plants. Rather they depict only the very large scale features of the projected weather patterns. Converting these broad impressions of what might happen into a weather forecast for a specific location requires the judgement and experience of meteorologists familiar with the weather in the forecast region.

For each physical plant a different combination of current weather, computer generated guidance, and local weather peculiarities must be considered before making the forecast. We attempted to tailor our forecasting to the needs of the physical plants with primary emphasis on their heating and cooling functions. This generally required being as specific as possible about when significant changes in the weather would occur and exactly how large such changes would be. Since communication of the forecasts to campuses throughout the state was to be by telephone, we modified the forecast forms we had previously used to best serve the needs of the physical plants. An example of such a form is given as Fig. II-1. With similar forms available at each participating physical plant it was possible to transmit a complete forecast and verify the previous forecast in less than 10 minutes per campus. Each physical plant then had a hard copy of our forecast for use in operations planning. Many of the physical plants felt that an early afternoon forecast was most useful for their operation; others asked for and received a morning forecast made as soon as the necessary data became available. All campuses received morning updates of the previous afternoon's forecast if significant departures from that forecast were anticipated. Similar updates were also issued at other times during the day when rapid weather developments warranted forecast revisions or when the changes were considered important for physical plant operation.

University of Wisconsin
Applied Meteorology Group
1225 West Dayton Street
Madison, Wisconsin 53706

262-4920 262-0778

Forecast Period: ________ ________ A.M. P.M. to ________ ________ A.M. P.M.
date time date time

A. GENERAL 24 HOUR FORECAST

____

____

____

B. 24 HOUR TEMPERATURE

1. Maximum ____ ° at ____ A.M. P.M.
2. Minimum ____ ° at ____ A.M. P.M.

C. DEGREE DAYS

3. HDD ______ (base 65)
4. CDD ______ (base 70)

D. PRECIPITATION

COVERAGE:

5. [ ] None (skip rest of section)
6. [ ] Widely Scattered
7. [ ] Scattered
8. [ ] Widespread

INTENSITY:

9. [ ] Light
10. [ ] Moderate
11. [ ] Heavy

TYPE:

12. [ ] Drizzle
13. [ ] Rain
14. [ ] Hail
15. [ ] Freezing Rain
16. [ ] Sleet
17. [ ] Snow
18. [ ] Rain ——— Snow
19. [ ] Snow ——— Rain

BEGINNING AT:

20. [ ] 6-9 A.M.
21. [ ] 9-12 A.M.
22. [ ] 12-3 P.M.
23. [ ] 3-6 P.M.
24. [ ] 6-9 P.M.
25. [ ] 9-12 P.M.
26. [ ] 12-3 A.M.
27. [ ] 3-6 A.M.

DURATION:

28. [ ] Intermittent/Showery
29. [ ] Continuous
30. [ ] Brief (1 hr.)
31. [ ] Less than 3 hrs.
32. [ ] 3 - 6 hrs.
33. [ ] 6 - 12 hrs.
34. [ ] 12 - 18 hrs.
35. [ ] 18 - 24 hrs.
36. [ ] More than 24 hrs.

ACCUMULATION:

Rain

37. [ ] Light (trace - 0.1")
38. [ ] Moderate (0.1-0.5")
39. [ ] Heavy (0.5" - up)

40 Snow

40. [ ] Light (trace - 2")
41. [ ] Moderate (2 - 4")
42. [ ] Heavy (4" - up)

Figure II-1: Weather forecast transmittal form for physical plants and experimental farms.

E. CLOUDS

	6 A.M.- Noon	Noon- 6 P.M.	6 P.M.- Midnight	Midnight - 6 A.M.
1. Amount of sky covered				

F. WINDS

	6 A.M. Noon	Noon 6 P.M.	6 P.M.- Midnight	Midnight - 6 A.M.
2. Direction (from which the wind is blowing)				
3. Average Speed (MPH)				
4. Maximum Wind Gusts (MPH)				

5. Calm Periods (winds less than 5 MPH) From ______ To ______ and From ______ To ______.

G. MOISTURE

	6 A.M.	Noon	6 P.M.	Midnight
6. Dewpoint Temperature				
7. Relative Humidity				

H. WARNINGS

	From	To
1. Cold Wave		
2. Heat Wave		
3. Heavy Rain		
4. Thunderstorm/Lighning		
5. Hail		
6. Tornadoes		
7. Glazing/Icing		
8. Heavy Snow		
9. Blizzard		
10. Blowing/Drifting Snow		
11. High Winds (Maximum Gust ____ MPH)		
12. Haze		
13. Fog		

I. ADDITIONAL COMMENTS

____

____

____

Weather Synopsis: NOV 75 to SEP 76

Within this eleven month period we went through one heating season and one cooling season. The heating season started out relatively mild with monthly mean temperatures generally above normal in November and December. February, March and April continued the above normal trend while January and May were slightly below normal. Some northern locations had normal or slightly below normal temperatures while the rest of the state enjoyed above normal temperatures. Moisture as rain or snow varied widely across the state with amounts generally below normal in the south and north while the center of the state was close to normal. However, snowfall for the season was generally less than normal. March produced heavy snow in the north and a devastating ice storm in the south. Some snow persisted into May.

The cooling season got off to a fast start with above average temperatures in June replacing the below normal readings from May. Monthly averages remained above normal through August with September near normal and October below normal. Far below normal precipitation was the rule statewide for the summer months. Yet some areas fortunate enough to receive the very spotty precipitation in July reported above normal totals for that month. The dry ground also gave rise to a greater daily spread in extreme temperatures with lower than normal minimums and significantly higher than normal maximums. Very local killing frost occurred in the north in late August while the first statewide major frost occurred on 22 September with another again on the 24th to end the growing season and start the next heating season.

Table II-1 give the observed monthly mean and climatic mean temperatures at NWS observing sites near participating universities; temperature trends at the campuses would be similar, especially with respect to departures from the climatic mean. Precipitation amounts observed at standard measuring sites in the vicinity of the universities are given in Table II-2 along with the departure from the normal precipitation amounts.

In space heating applications the departure of the outside air temperature from the interior temperature is recognized as a major factor in determining the heating demand. Usually the reference temperature is set at 65°F. Heating degree days are accumulated if the daily mean air temperature is less than 65°F and cooling degree days are accumulated when this threshold is exceeded in the daily mean temperature. Table II-3 presents degree day values for the forecast period. Sources of information vary widely. Zone information comes from the Office of State Planning and Energy and is an average over the zone based on hourly temperatures. Daily mean temperature data recorded at the physical plants and reported to the University of Wisconsin - Central Administration are used to give the values for the universities. Finally, the mean temperature reported by the National Weather Service observation station located in the same city as or near by the university is used to calculate a degree day value.

Table II-1: Climatic normal (top) and observed monthly mean (bottom) temperatures (°F) at NWS observing sites in the vicinity of participating universities for the period NOV 1975 to SEP 1976.

	EAU (RVF)	LSE	MSN	MKE	OSH	PKS	LNC (PLT)	STE	DLH (SUP)
NOV 75	32.0	35.4	34.7	36.5	35.4	38.8	36.3	33.9	28.4
	36.4	40.0	41.9	44.5	41.2	45.6	41.2	39.6	31.3
DEC 75	18.0	21.8	21.9	24.2	22.1	26.5	23.3	20.0	14.4
	19.3	23.7	25.5	27.9	23.0	30.5	25.6	21.6	11.8
JAN 76	11.7	16.1	16.4	19.4	17.0	22.3	18.2	14.8	8.5
	8.1	13.1	15.7	18.5	14.1	20.4	16.8	11.0	4.7
FEB 76	15.4	20.0	20.3	22.5	19.9	25.2	22.4	17.9	12.1
	24.9	29.0	28.4	31.1	26.2	31.7	29.3	24.9	20.7
MAR 76	27.3	31.1	30.2	31.4	30.0	34.0	31.5	28.9	23.5
	29.5	33.7	36.5	38.6	33.4	37.9	36.7	31.6	22.0
APR 76	44.5	47.6	45.3	44.7	45.2	46.3	47.9	45.1	38.6
	47.4	49.7	49.3	48.7	47.4	47.5	49.6	47.7	42.6
MAY 76	56.2	59.0	56.0	54.2	56.5	55.9	58.9	56.5	49.4
	54.8	56.8	54.3	52.6	54.5	52.4	55.7	54.8	50.5
JUN 76	66.1	68.5	65.8	64.5	66.7	66.4	68.3	66.2	59.0
	68.4	70.0	68.3	68.2	71.8	68.2	67.6	68.6	63.2
JUL 76	70.5	72.8	70.1	69.9	71.3	71.8	72.5	70.5	65.6
	73.1	74.4	73.4	72.6	73.6	73.2	72.0	71.3	66.1
AUG 76	68.4	71.4	68.7	69.2	70.0	71.5	71.2	68.9	64.1
	70.5	72.0	69.2	70.1	72.1	69.6	68.0	67.5	65.3
SEP 76	58.7	61.8	59.7	61.1	61.2	63.8	62.6	59.8	54.4
	59.1	62.3	58.0	62.2	61.6	61.7	59.3	49.9	56.1

Table II-2: Observed monthly precipitation (top) and departure from climatic normal (bottom) in inches at NWS observing sites in the vicinity of participating universities.

	EAU (RVF)	LSE	MSN	MKE	OSH	PKS	LNC (PLT)	STE	DLH (SUP)
NOV 75	5.40 4.06	3.07 1.62	2.79 0.92	2.83 0.82	2.68 0.79	3.23 0.82	4.32 2.43	3.09 1.12	4.19 2.46
DEC 75	1.16 0.16	0.70 -0.34	0.29 -1.18	1.70 -0.50	0.75 -0.64	1.54 -0.66	0.36 -1.07	1.68 0.37	0.64 -0.76
JAN 76	0.96 0.07	0.69 -0.27	0.56 -0.69	1.16 -0.47	1.54 0.43	1.18 -0.80	0.15 -1.08	1.10 -0.07	1.57 0.41
FEB 76	0.44 -0.27	0.64 -0.23	1.72 0.77	2.65 1.52	2.05 1.05	0.85 -0.61	1.68 0.73	1.65 0.64	1.05 0.20
MAR 76	3.21 1.67	2.82 0.80	4.75 2.82	6.93 4.69	4.70 2.97	7.56 4.80	3.78 1.66	2.83 1.01	3.67 1.91
APR 76	2.87 0.32	4.37 1.74	4.80 2.14	5.01 2.25	4.16 1.42	4.16 0.81	4.83 1.71	3.71 0.95	0.73 -1.82
MAY 76	1.22 -2.51	2.95 -0.75	1.95 -1.46	3.77 0.89	1.40 -1.92	3.26 -0.18	1.51 2.48	2.37 -1.60	0.15 -3.26
JUN 76	2.62 -1.57	1.82 -2.62	1.38 -2.95	2.27 -1.31	1.38 -2.18	1.08 -2.65	1.57 3.31	1.58 -2.62	6.16 1.72
JUL 76	2.69 -0.96	2.15 -1.37	1.46 -2.35	2.12 -1.29	3.46 0.08	2.90 -0.81	5.30 1.35	4.71 1.26	2.60 -1.13
AUG 76	1.23 -2.33	0.27 -2.75	1.99 -1.06	2.01 -0.67	1.00 -1.90	1.81 -1.41	2.64 -1.96	1.60 -1.94	1.43 -2.36
SEP 76	0.73 -2.64	0.80 -2.58	0.51 -2.85	1.70 -1.32	0.57 -2.78	0.95 -2.26	0.60 -3.20	0.69 -3.00	1.57 -1.49

Table II-3: Heating and cooling (-) degree day accumulations, base 65 for Wisconsin zones, Universities (*) and National Weather Service stations during forecast period.

	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
Zone 1	1004	1617	1819	1270	1269	649	413	86	23	93	336
								−44	−81	−82	−17
SUP*	1017	1556	1752	1264	1271	774	549				
DLH	1011	1649	1869	1285	1333	672	450	54	−34	−9	267
Zone 6	784	1324	1588	1112	1031	587	395	25	3	53	253
							−1	−103	−188	−84	−33
OSH*	756	1277	1609	1146	1008	540	319				
OSH	714	1302	1569	1125	980	528	326	−204	−267	−220	102
Zone 7	847	1372	1703	1158	1036	500	277	22	3	24	220
							−2	−136	−227	−160	−34
EAU*	840	1330	1745	1160	1070	519	279				
EAU	858	1417	1764	1163	1100	528	316	−102	−251	−170	177
LSE*	783	1265	1600	1039	964	460	254				
LSE	750	1280	1609	1044	970	459	254	−150	−291	−217	81
RVF*	927	1352	1671	1172	1097	621	415				
Zone 8	804	1371	1661	1164	1069	544	331	19	3	37	246
							−2	−113	−208	−113	−31
STE*	795	1345	1648	1137	1051	534	322				
STE	762		1674	1163	1035	519	316	−108	−195	−78	258
Zone 9	720	1210	1513	1046	875	478	285	19	1	46	206
							−3	−124	−235	−121	−30
PLT*	855	1203	1504	1030	893	456	257				
Zone 10	690	1181	1496	1028	846	483	299	23	0	31	203
							−3	−125	−247	−135	−25
MNS*	687	1217	1820	1056	877	477	333				
MNS	693	1224	1528	1061	883	471	332	−99	−260	−130	210
Zone 11	617	1109	1428	966	801	490	369	34	1	14	119
							−5	−131	−225	−155	−42
MKE*	690	1147	1426	986	837	510	372				
MKE	615	1150	1441	983	818	489	384	−96	−236	−158	84
PKS*	627	1063	1407	974	825	486	372				
PKS	582	1069	1383	966	840	525	391	−96	−254	−143	99

It is significant to note that discrepancies exist between the various values; typically less than 20%. These are primarily due to differences in location of the thermometers and to different approaches to calculating the degree day value. Degree days based on the university observations are used in later discussions of fuel use.

Verification of Forecasts

In forecasting for remote locations it is important for the forecaster to maintain close contact with the weather of that remote location. Even though most of the universities for which we forecasted were near NWS observation offices, we obtained current weather and forecast verifications directly from the physical plants. There verifications usually concerned the extremes of air temperature and the occurrence of precipitation. Most physical plants did not have instruments to verify other parameters quantitatively although we were able to obtain qualitative impressions about the weather.

For the analysis of our forecast accuracy we divided the total forecast period into the heating season November to May and the cooling season June to September. Quantitative assessment of forecast temperatures are presented in Tables 4 to 7 showing the frequency of occurrence of forecasting errors versus the departure of the forecast temperature (or heat unit) from the observed temperature, i.e. positive departures meaning the forecast temperature exceeded the observed temperature . Separate tables for maximum and minimum temperature and heat unit forecasts are given. Also included in each of these tables is a composite distribution of the forecasting error for all campuses. The heat unit accumulation (base 65), Tables 8 and 9, shows a narrower spread than the forecasts of the extremes of temperature indicating more confidence can be placed on estimates of daily mean temperature than on the extremes. For heating plant operation this may have significance with respect to the usefulness of the forecasts. These tables (4-9) further summarize the accuracy of the temperature forecasts by giving the mean and standard deviation of the forecasts from the observed values in the two seasons. Here it is seen that the heat units show lower values of the standard deviation than the extremes. Also, the tables demonstrate an improvement of forecast accuracy in the summer season after the forecasters had gained experience and familiarity with the pecularities of the forecast regions. The consistently better performance of forecasting the morning minimum temperature is understandable since this temperature is forecasted some 16-18 hours in advance while the afternoon high is a 20-24 hour forecast from the time at which the forecasts are usually posted.

Verification of the precipitation forecast is very difficult; a single spot observation of precipitation is difficult to interpret. However, we had radar facsimile maps showing precipitation regions over the state. During precipitation events these charts were regularly monitored and forecast verification was based on the presence of a radar echo over the forecast

Table II-4: Percentage occurrence of maximum temperature forecast error in NOV - MAY 1975/76 heating season with mean and standard deviation (°F).

ERROR °F	EAU (RVF)	LSE	MSN	MKE	OSH	PKS	PLT	STE	SUP	ALL
-17			1	2		1	1		1	0.7
-15			1		3	1	1	1	1	0.9
-13	1		2	1	6	1	1	1	2	1.7
-11	1	3	3	5	2	4	1	4	4	3.0
- 9	4	3	10	7	8	7	6	4	4	5.9
- 7	8	8	5	11	7	14	8	6	4	7.9
- 5	7	11	11	12	10	14	19	11	8	11.4
- 3	12	11	13	8	19	4	12	17	9	13.0
-1,0,+1	21	31	21	27	19	22	19	22	16	22.0
3	13	7	15	7	5	10	11	4	18	10.0
5	8	11	7	6	8	7	7	9	13	8.4
7	5	7	3	7	2	6	6	11	9	5.1
9	4	4	3	3	7	4	3	4	4	4.0
11	2	2	1	3	2	2	1	2	4	2.1
13	1	1	1	1	1	1	1	1	1	1.0
15			1		1		1			0.3
17			1			1		1		0.3
Mean	-0.02	-0.04	-1.12	-1.34	-1.60	-1.23	-0.98	-0.18	+0.26	-0.82
St.Dev.	4.37	4.53	5.72	5.69	6.21	5.84	5.22	5.30	5.57	5.30

Table II-5: Percentage occurrence of forecast error for daily maximum temperature in JUNE - SEPT 1976 cooling season with mean and standard deviation (°F).

ERROR °F	EAU	LSE	MSN	MKE	OSH	PKS	PLT	STE	SUP	ALL
-19	1								1	0.2
-17										
-15							1			0.1
-13	4	1	1	2	2			1	4	1.7
-11	1	3	4	2	6	6		1		2.6
- 9	4	2	4	1	8	6	5	2	1	3.7
- 7	6	7	9	13	14	6	11		11	8.6
- 5	11	8	12	10	11	5	7	11	6	9.0
- 3	18	14	9	13	20	21	10	14	10	14.3
-1,0,+1	31	20	20	23	18	23	29	23	25	23.6
3	15	14	11	12	11	11	15	23	12	13.8
5	6	11	8	13	6	14	6	15	13	10.2
7	1	3	2	7	4	5	11	6	8	5.2
9	2		1	2	2	2	4	1	7	2.3
11		2	2	1	1	1	1	1	2	1.2
13								1		0.1
Mean	-1.30	-0.38	-1.10	-0.52	-2.20	-0.72	-0.06	+0.08	+0.34	-0.66
St.Dev.	4.13	3.93	4.31	4.44	5.17	4.52	4.50	3.82	5.18	4.50

Table II-6: Percentage occurrence of minimum temperature forecast errors in NOV - MAY 1975/76 heating season with mean and standard deviation (°F).

ERROR °F	EAU	LSE	MSN	MKE	OSH	PKS	PLT	STE	SUP	ALL
-19	1								1	0.2
-17									1	0.1
-15	1	1			1			1	1	0.6
-13	1	1		1		1	1	2	2	1.0
-11	3	3	1	5	4	2		2	5	2.8
- 9	6	7	2	1	6	1	2	5	6	4.0
- 7	7	9	7	9	10	4	3	12	11	8.0
- 5	11	10	8	13	10	13	4	16	9	10.4
- 3	16	12	21	17	20	19	16	14	12	16.3
-1,0,+1	21	22	24	32	20	26	35	19	26	25.0
3	14	11	12	8	9	17	17	6	7	11.2
5	9	11	11	6	9	9	8	9	7	8.8
7	4	5	8	5	8	6	9	5	4	6.0
9	4	4	2	1	1	1	3	2	2	2.2
11	1	3	2	1	2	1	1	2	2	1.7
13	1	1	1	1		1	1	1	1	0.9
15								1		0.1
17								1		0.1
19								1		0.1
Mean	-0.96	-0.52	+0.22	-0.70	-1.12	-0.18	+0.72	-0.12	-1.82	-0.49
St.Dev.	5.18	5.22	4.04	4.31	4.81	3.96	3.83	5.78	5.74	4.82

Table II-7: Percentage occurrence of forecast error for minimum temperature in JUNE - SEPT 1976 cooling season with mean and standard deviation (°F).

ERROR °F	EAU	LSE	MSN	MKE	OSH	PKS	PLT	STE	SUP	ALL
-15					1					0.1
-13	1	1					1	1		0.4
-11	1	1	2	1	1			4	1	1.2
- 9	6	6	6	4	4	5		2	8	4.6
- 7	7	12	6	4	12	4	8	4	6	7.0
- 5	10	12	7	17	15	14	12	11	13	12.3
- 3	13	23	12	26	12	21	10	17	20	17.1
-1,0,+1	33	27	25	32	30	36	29	23	20	28.3
3	13	7	23	8	13	12	18	18	12	13.8
5	8	7	7	6	8	5	15	10	13	8.8
7	5	4	8		5	4	4	5	4	4.3
9	1		1	2	1		2	2	1	1.1
11		1	1				1	4	1	0.9
13	1									0.1
15										
17			1							0.1
Mean	-0.70	-1.42	0.00	-1.30	-1.16	-0.94	+0.06	-0.08	-0.84	-0.74
St.Dev.	4.07	4.16	4.33	3.36	4.12	3.23	3.67	4.47	4.10	3.94

Table II-8: Percentage occurrence of daily heat unit accumulation in NOV - MAY 1975/76 heating season.

ERROR H.U.	EAU	LSE	MSN	MKE	OSH	PKS	PLT	STE	SUP	ALL
-15	1					1				0.2
-13				1		1	1			0.3
-11	1			1	1	1	1	2	2	1.0
- 9	1	1	6	3		3	3	3	3	2.6
- 7	6	5	4	6	4	4	3	8	7	5.2
- 5	7	6	7	8	6	9	10	9	8	7.8
- 3	13	12	17	11	11	10	17	7	16	12.7
-1,0,+1	28	53	31	25	32	31	32	25	27	31.6
3	17	12	14	14	19	10	14	19	12	14.6
5	14	6	12	15	9	16	11	13	11	11.9
7	8	1	5	11	10	8	3	9	6	6.8
9	1	2	3	6	6	4	4	3	5	3.8
11	1	1	1		2		1	1	2	1.0
13								1	1	0.2
15	1								1	0.2
Mean	+0.48	-0.06	+0.06	+0.66	+1.22	+0.24	-0.06	+0.46	+0.40	+0.38
St.Dev.	4.10	2.82	3.78	4.36	3.93	4.24	3.83	4.35	4.62	4.02

Table II-9: Percentage occurrence of daily heat unit accumulation forecast error in JUNE - SEPT cooling season with mean and standard deviation.

ERROR H.U.	EAU	LSE	MSN	MKE	OSH	PKS	PLT	STE	SUP	ALL
-13	1				1				1	0.3
-11	1		2							0.3
- 9	4		4	4	4	2	2	1	1	2.4
- 7	4	2	2	5	10	2	8	2	5	4.4
- 5	11	7	12	11	15	15	7	7	11	10.7
- 3	17	20	19	25	18	20	14	12	19	18.2
-1,0,+1	35	49	39	33	30	35	39	33	27	35.6
3	20	18	13	14	11	17	14	27	15	16.6
5	5	4	5	7	6	6	10	6	10	6.6
7	2	1	2	1	5	2	4	7	10	3.8
9	1				1			4	1	0.8
11			1				1			0.2
Mean	-0.76	-0.22	-0.86	-0.94	-1.16	-0.58	-0.18	+0.80	+0.06	-0.41
St.Dev.	3.44	2.09	3.32	3.03	3.82	2.74	3.23	3.17	3.58	3.18

location; a radar echo, however, does not guarantee that rain was observed at the ground. The problem of forecasting and verifying precipitation is further complicated by the need to classify precipitation events as wide spread, scattered, or widely scattered. The contingency tables given in Tables 10 and 11 show how our forecasts matched observed precipitation patterns and give the number of occurrences in each category. Numbers occupying the diagonal from top-left to bottom-right give the number of perfect forecasts. In general most of the errors arise when widely scattered precipitation is forecast and no rain is observed. Forecasting no rain generally involves clearly defined weather situations while forecasts of widely scattered precipitation are usually made in the "iffy" situations and hence are more likely to be in error toward the no rain side. Accuracies generally improve as the likelihood of precipitation increases; however, the summer period drought provided very few opportunities to forecast scattered precipitation and no instance of wide spread precipitation.

Table II-12 summarizes the precipitation forecasting using two measures of forecast accuracy. Here accuracy is defined as the fraction of forecasts of rain or of no rain that were correct. These values express the confidence which can be placed on the precipitation forecast. However, such a measure of success does not account for the likelihood that a forecast may be correct by chance. The climatological probability of making a correct forecast can be removed from the evaluation of success to give a skill score. The skill score can range from zero, no skill, to unity, perfect skill. Scores indicate our skill in precipitation forecasting is significantly better than a forecast based only on climatology. Furthermore, as expected, our skill in predicting the proper catagory of precipitation occurrence produces a lower skill score than if only the skill of predicting rain or no rain is considered.

Impact of Forecasts on Physical Plants

Throughout this project we concentrated on providing the best possible service to the physical plants. Little attention was given on our part to how these forecasts were incorporated into the operation of the physical plants. We had hoped to receive this information back from the supervisors of these plants as responses to questionaires orginated by us.

Two questionaires were sent to the participating physical plants. The first in January 1976 obtained the perceptions of our forecasts for a very short period. In general these were very favorable; the forecasts were considered useful to the physical plants and other campus units. No concrete response was given to a request for an estimate of the dollar value of the forecasts or of its value in specific instances.

The second questionaire in early May was returned by only half of the campuses served. Although this questionaire was not necessarily of optimum design to learn how our forecasts were being used, it was rather clear that even the physical plant supervisors found it difficult to pin point how the

Table II-10: Precipitation forecast contingency tables with number of forecasts in each category for NOV - MAY heating season.

OBSERVED PRECIPITATION

FORECAST PRECIPITATION

	EAU (RVF)				LSE				MSN			
	N	WS	S	W	N	WS	S	W	N	WS	S	W
N	51	9	1	1	61	7	2	0	53	5	2	2
WS	12	22	7	0	15	12	2	0	10	20	8	1
S	4	5	9	2	7	7	19	0	2	3	20	2
W	0	2	2	13	0	1	1	10	1	1	1	10

	MKE				OSH				PKS			
	N	WS	S	W	N	WS	S	W	N	WS	S	W
N	43	8	3	1	43	12	2	1	44	7	3	1
WS	10	20	8	0	7	19	12	0	12	22	4	0
S	3	3	23	1	0	4	19	5	2	4	22	2
W	0	4	2	13	0	1	2	14	0	4	1	13

	PLT				STE				SUP			
	N	WS	S	W	N	WS	S	W	N	WS	S	W
N	54	2	2	0	48	8	5	0	41	11	2	0
WS	13	21	5	0	8	21	6	0	16	25	6	0
S	6	4	17	1	1	5	21	2	4	3	13	1
W	1	0	0	14	0	1	3	12	1	2	2	13

N = NONE, WS = WIDELY SCATTERED, S = SCATTERED, W = WIDE SPREAD

Table II-11: Precipitation forecast contingency tables with number of forecasts in each category for JUNE - SEPT 1976 cooling season.

OBSERVED PRECIPITATION (columns) / FORECAST PRECIPITATION (rows)

	EAU			LSE			MSN		
	N	WS	S	N	WS	S	N	WS	S
N	26	8	1	25	9	0	27	6	1
WS	2	22	1	7	13	2	5	22	1
S	0	1	2	1	7	2	0	2	0

	MKE			OSH			PKS		
	N	WS	S	N	WS	S	N	WS	S
N	26	6	0	25	8	0	25	7	0
WS	2	26	2	4	22	2	2	26	2
S	0	1	1	0	2	1	0	1	1

	PLT			STE			SUP		
	N	WS	S	N	WS	S	N	WS	S
N	24	7	1	28	3	1	20	5	2
WS	7	22	1	4	23	1	4	26	1
S	0	2	0	0	2	2	1	2	3

N = NONE, WS = WIDELY SCATTERED, S = SCATTERED

Table II-12: Precipitation forecast accuracy and skill scores for winter and summer seasons 1975/76 at participating UW physical plants.

	NOV 75 - MAY 76			JUN - SEP 76		
	Accuracy	Rain/No Rain	Category	Accuracy	Rain/No Rain	Category
EAU (RVF)	0.81	0.61	0.52	0.83	0.66	0.63
LSE	0.78	0.57	0.54	0.74	0.48	0.33
MKE	0.82	0.69	0.58	0.87	0.63	0.68
MSN	0.84	0.63	0.68	0.81	0.75	0.55
OSH	0.84	0.67	0.55	0.81	0.63	0.54
PKS	0.82	0.63	0.60	0.86	0.72	0.65
PLT	0.83	0.66	0.64	0.77	0.53	0.47
STE	0.84	0.68	0.61	0.87	0.75	0.69
SUP	0.76	0.50	0.51	0.81	0.61	0.59
ALL	0.82	0.63	0.58	0.82	0.64	0.57

forecasts affected their operation. What were identified were the weather parameters which were of main concern; temperature, especially periods of very low temperature received the most attention. A few supervisors also included wind as an important factor. Long range, four to five day outlooks, or more detailed, hour by hour, forecasts were not thought to be any more useful than the twenty-four hour forecasts given in the program. Some supervisors indicated that although temperature was important and its forecast useful, there were no alternative actions available to take based on the forecast.

This very problem had concerned us when we proposed the forecasting program. Forecasts can have a value only if there are alternative responses to the forecast. Temperature along with many other weather as well as non-weather factors govern the demands placed on the heating system. In general, the physical plants have very little control over the demand, they are only able to respond to and meet this demand. Physical plants with few boilers and limited alternate fuels have a severely constrained set of responses with which to meet the imposed demands. We did not attempt to identify these responses for the physical plants or determine how the forecast information could be used to optimize the response. It is obvious, in hindsight, that we should have played a larger role in initiating such studies.

Several physical plants indicated summer season forecasts would be as useful if not more so than winter season forecasts. Grounds, maintenance, construction and athletic units made use of our forecasts to schedule their activities. While forecasts were again considered useful for planning a variety of activities, it was very difficult to assign a value to the forecast. The greatest obstacle to doing this involves projecting a "what if you didn't have the forecast" scenario and evaluating the cost of the scenario relative to what actually happened. An example would be planning to pour concrete or to seal a roof. Only if such work is planned before a forecast is received and if the forecast indicates the job should be postponed can a value be placed on the forecast; even then the forecast must be correct for its full value to be realized.

Fuel Use Analysis

An indirect measure of the impact of forecasts on the operation of the heating plants can be obtained by comparing fuel use during the period in which forecasts were available to use outside this period. Improved fuel economy could then be interpreted as a positive indication of forecast utility. Unfortunately, the analysis of the fuel use data is not as simple as this hypothesis makes it appear.

The conventional analysis of fuel use is based on the premise that temperature is the dominant parameter that specifies the demand for heat. Of course, it is readily conceded that wind, sunshine, humidity, population, and use patterns all contribute to the demand. These parameters essentially contribute "noise" to an analysis based on fuel use as a function of the departure of temperature from a base value of 65°F.

The effect of this noise can be seen in Table II-13 in which fuel use, expressed as BTU of energy consumed by the heating plants and normalized by the cubage heated, is divided by the heating degree days accumulated in each month of the heating season. The variation of this ratio indicates a non-uniformity of the "noise" contribution at different seasons of the year and points out the difficulty of using annual or heating season averages to express the effect of temperature on fuel use. Although year to year variations exist the large inter-campus variability causes the differences found to have little statistical significance.

The variation of energy use per heating degree day among campuses is clearly seen in Table II-14 when given as an average for the heating season, September to May. A large standard deviation is evidence of large seasonal differences in the response to heating degree days. Relatively small year to year differences and a large standard deviation preclude placing much confidence in the observed differences.

One other conventional analysis was applied to the fuel consumption data. Monthly fuel use was linearly regressed against heating degree days accumulated in the month. The linear regression yields an intercept value which can be interpreted as the base line fuel use with no degree days accumulated and a slope value which indicates the additional fuel used above the baseline per accumulated degree day. The results of this analysis are shown in Table II-15. A third parameter, the correlation coefficient is included; values close to unity indicate the data points cluster around the straight line defined by the intercept and slope. A value of the correlation coefficient less than 0.8 signifies a large scatter of the data about the prescribed line.

Similar interpretation can be given to changes in the intercept and slope: lower values mean more efficient use of fuel. Examination of Table II-15 reveals that some campuses showed significant improvements in the intercept value but only minor changes in the slope. However, both values must be considered in evaluating the amount of energy needed to meet a given heating degree demand. As the number of degree days increase the slope parameter becomes increasingly important.

Fuel comsumption was also examined for the summer cooling season. However, no consistent relationship between fuel use and temperature was found. Electrical energy consumption was also included in an effort to demonstrate that air conditioning demand was related to the accumulated cooling degree days. The results, although largely quite inconclusive and hence not presented here, did show that fuel use increased at campuses with central air conditioning during summer after spring and fall minima. Also, the high values of energy density per heating degree day shown in Tables II-13 and II-14 can be largely attributed to the spring and fall air conditioning demand that usually coincides with low heat unit values in these months.

The analysis of fuel use presented here demonstrates the inadequacy of using temperature alone as a measure of demand on a heating system. The year

Table II-13: Monthly average (top) and standard deviation (bottom) in BTU/ft^3-HDD of fuel use per degree day for all participating physical plants in BTU/ft^3-HDD.

MONTH	73/74	74/75	75/76*
SEP	4.80 2.55	2.90 1.24	3.08 1.50
OCT	2.66 0.67	1.86 0.43	2.23 0.68
NOV	1.40 0.19	1.35 0.19	1.41 0.24
DEC	1.10 1.12	1.25 0.19	1.19 0.24
JAN	1.19 0.20	1.25 0.25	1.19 0.20
FEB	1.19 0.18	1.21 0.20	1.33 0.19
MAR	1.31 0.19	1.27 0.26	1.41 0.23
APR	1.57 0.33	1.43 0.23	1.74 0.36
MAY	1.82 0.43	3.74 1.81	2.18 0.61

*Forecasts available for period NOV - MAY

Table II-14: Heating season average (top) and standard deviation (bottom) of monthly energy density per heat unit accumulation in BTU/ft^3-HDD for three heating seasons.

	73/74	74/75	75/76*
EAU	2.12 1.41	1.99 1.17	1.91 0.82
LSE	1.93 1.16	1.74 0.81	1.83 0.73
MSN	2.34 1.68	2.54 1.72	2.28 1.10
MKE	2.75 2.79	2.32 1.27	2.64 1.51
OSH	1.39 0.81	1.13 0.30	1.35 0.38
PKS	2.17 1.87	1.45 0.65	1.56 0.58
PLT	1.79 1.03	1.41 0.39	1.64 0.77
RVF	1.82 0.99	1.75 0.74	1.52 0.28
STE	1.55 0.59	1.43 0.47	1.48 0.41
SUP	1.28 0.27	1.31 0.24	1.25 0.12

*Forecasts available for period NOV - MAY.

Table II-15: Linear regression analysis of energy density (BTU/ft^3) versus heating degree day accumulation over heating season; slope of regression line in BTU/ft^3-HDD given at top, intercept of line at zero HDD in BTU/ft^3 in center, and correlation coefficient at bottom.

	73/74	74/75	75/76
	0.657	0.778	0.706
EAU	699	785	712
	0.983	0.983	0.971
	0.903	0.985	0.855
LSE	450	379	455
	0.938	0.995	0.991
	0.708	0.648	0.867
MSN	792	969	751
	0.925	0.953	0.976
	0.666	0.924	0.916
MKE	838	724	851
	0.790	0.959	0.924
	0.617	0.503	0.713
OSH	380	423	358
	0.989	0.980	0.996
	0.762	0.648	0.719
PKS	538	444	417
	0.921	0.972	0.883
	0.789	0.806	0.894
PLT	434	418	325
	0.990	0.996	0.983
	0.791	0.912	1.097
RVF	606	564	311
	0.940	0.895	0.969
	0.732	0.750	0.739
STE	448	412	453
	0.974	0.988	0.979
	0.908	0.854	1.089
SUP	305	394	145
	0.973	0.995	0.984

to year and campus to campus variation of fuel use efficiencies allows us to draw this conclusion: weather forecasts, incorporated into the operation of a heating plant as in the 1975/76 heating season, can not be held responsible (or given credit) for the observed changes in fuel consumption from prior years.

III. OPERATIONAL WEATHER FORECASTING FOR UNIVERSITY OF WISCONSIN EXPERIMENTAL FARMS

Introduction

Since the inception of the operational weather forecasting project in the Department of Meteorology over three years ago we have provided forecasts to some of the Experimental Farms. This year, with our funding being entirely provided by the University of Wisconsin, we expanded our program with the Farms to include six farms. The Experimental Farms made our forecasts available to local agricultural interests and country agricultural extension agents. At Ashland and Sturgeon Bay our forecasts were carried by local radio stations. Forecasting for the Experimental Farms was begun in April and continued through September covering most of the growing season.

Forecast Preparation

The same team of meteorologists that prepared forecasts for the physical plants also prepared the forecasts for the Experimental Farms. Usually two forecasts were issued per day, one in the morning and another in the afternoon. Forecasts were again transmitted over the telephone using the same forms as for the heating plants.

The Weather: APR to SEP 1976

Rather than present a synopsis of the growing season weather only tabulated values of average and normal temperatures, Table III-1 and monthly precipitation with departures from normal in Table III-2 are given for the participating farms. For a weather synopsis the reader is urged to consult the "Weekly Crop and Weather Report" (WCWR) published by the Wisconsin Statistical Reporting Service.

Except for May, temperatures during the growing season averaged above normal state wide under sunnier than normal skies. Conversely, precipitation for May, June, August and September was far below normal while spotty rains in July brought some localities above normal rain for that month. The above average temperatures were closely correlated with drier than normal conditions except in May which was both colder and drier.

The growing season, when constrained to lie between the last and first shelter temperature less than 32°F, varied widely. Table III-3 shows the dates of first and last frosts and the growing season length in days. The accumulated growing degree days, base 50°F, for each month are also in Table III-3 with the months of May and September divided by last and first frost, respectively. Degree day accumulations shown here are lower than those in the WCWR because of slightly different computation techniques. Ours are based on a mean daily temperature in excess of 50°F while the modified calculation in the WCWR allow accumulation if the daily maximum temperature exceeds the base value. The main differences are found early and late in the growing season.

Table III-1: Climatic normal (top) and monthly mean (bottom) temperatures (°F) at the participating Experimental Farms during the 1976 growing season.

	A R L	A S H	H N K	L N C	M F I	S G B
APR	46.9	39.7	45.3	47.9	43.6	42.4
	48.9	43.8	48.4	49.6	46.4	44.5
MAY	57.6	50.4	56.8	58.9	54.9	52.2
	55.4	51.1	55.4	55.7	53.4	51.0
JUN	60.4	60.4	66.3	68.3	64.0	62.5
	69.2	64.8	68.7	67.6	66.8	66.1
JUL	66.9	66.9	70.4	72.5	68.2	68.3
	73.2	68.6	71.4	72.0	71.3	70.1
AUG	65.4	65.4	69.2	71.2	66.5	67.5
	68.1	68.2	67.6	68.0	66.9	66.4
SEP	56.4	56.4	59.9	62.6	57.6	59.3
	58.4	56.6	58.2	59.3	57.5	59.2

Table III-2: Monthly (top) precipitation totals and departure from the climatic normal (bottom) in inches at the participating Experimental Farms during the 1976 growing season.

	ARL	ASH	HNK	LNC	MFI	SGB
APR	4.38	0.95	3.44	4.83	5.30	1.96
	1.52	-1.66	0.73	1.71	2.53	-0.86
MAY	1.28	0.72	1.37	1.51	2.41	3.57
	-2.21	-3.10	-2.47	-2.48	-1.99	0.49
JUN	0.82	4.58	1.46	1.57	1.14	0.72
	-3.26	0.47	-2.04	-3.31	-3.21	-2.66
JUL	4.61	1.36	2.95	5.30	5.50	2.38
	0.62	-2.84	-0.46	1.35	2.28	-0.87
AUG	3.31	3.82	0.79	2.64	0.70	1.37
	0.15	-0.28	-2.18	-1.96	-3.11	-1.70
SEP	(4.17)	0.86	0.42	0.60	0.69	0.68
		-2.43	-3.32	-3.20	-3.27	-2.87

Table III-3: Dates of last and first frost, length of growing season and growing degree days, base 50°F, during the period 1 APR to 30 SEP.

		ARL	ASH	HNK	LNC	MFI	SGB
LAST FROST		5/8	5/26	5/18	5/8	5/8	5/19
FIRST FROST		9/22	9/2	9/22	9/22	9/22	9/24
DAYS		137	99	121	137	137	128
GROWING DEGREE DAYS, BASE 50							
APR		82	27	80	91	61	30
MAY	BEFORE	12	80	70	15	23	34
	AFTER	188	25	127	186	126	64
JUN		576	444	561	528	504	483
JUL		719	577	663	682	660	623
AUG		561	564	546	558	524	508
SEP	BEFORE	270	6	276	290	208	305
	AFTER	22	233	28	30	14	16
TOTAL APR-SEP		2430	1956	2351	2387	2120	2063
TOTAL GROWING		2314	1625	2173	2251	2022	1983

Forecast Verification

When forecasts were conveyed to the Farm offices we received in turn information concerning the verification of previous forecasts. The analysis of this section concerns forecasting daily temperature extremes, heat unit accumulations and the occurrence of precipitation. Temperature and heat unit forecast verifications are expressed as departures of the forecast temperature from the observed temperature; a positive deviation meaning the forecasted temperature exceeded the observed temperature. Precipitation verification was based on an analysis of radar facsimile maps obtained routinely during precipitation days. The distribution of radar echos was used to idenfity the precipitation class: Wide spread, Scattered, Widely Scattered, and None. We took the presence of a radar echo over the observing site to be an indication that precipitation was received; however, it is possible that the official rain gauge at the Experimental Farm did not receive rain whenever a radar echo was situated overhead.

The percentage of maximum temperature forecasts falling into error bins 2°F wide is given in Table III-4 while Table III-5 gives similar data for the minimum temperatures. Forecast accuracy is based on the afternoon forecast so that 16-18 hours elapse before the minimum is usually observed while 20-24 hours elapse for the maximum temperature. This discrepancy in lead time partially explains the lower standard deviation associated with the minimum temperature forecasts. Forecasts for the temperature extremes showed greater error spread than did the forecasts of heat unit accumulation shown in Table III-6. The spread of forecast error is summarized by the standard deviation of the forecast error at the bottom of these tables for the temperature extremes and heat units. The excellent accuracy of the heat unit forecasts is clearly seen in Table III-6. One reason for this is that the dry weather gave rise to a greater range in temperature with lower minima followed by higher maxima so that our forecast errors of the extremes cancelled in computing the average used to obtain the heat unit accumulation.

Contingency tables showing how forecasts in the four precipitation catagories verified are given in Table III-7. No wide spread precipitation was forecasted or observed during the seven month period in which forecasts were issued. Values lying along the diagonal from upper-left to lower-right represent perfect forecasts. However, in general the measure of success is whether rain or no rain was observed when the same was forecast. Three different measures of precipitation forecast success are given in Table III-8. Accuracy is taken to be simply the number of correct rain and no rain forecasts divided by the total number of forecasts. Although quite respectable at 82% this measure also includes the climatological probability of success. The skill score gives the percentage accuracy with the climatological average removed, hence skill scores are lower than the raw accuracy. Requiring the forecast to also prescribe the proper catagory further degrades the score although these values are still respectable.

Table III-4: Percentage occurrence of maximum temperature forecasting errors for the Experimental Farms during APR - SEP 1976 with mean and standard deviation (°F).

ERROR	A R L	A S H	H N K	L N C	M F I	S G G	ALL
-17					1		0.2
-15		1	1				0.3
-13		2		1			0.5
-11	1	1	2	1	2	2	1.5
- 9	3	9	2	2	4	5	4.2
- 7	2	5	7	6	5	14	6.5
- 5	7	14	8	16	10	10	10.8
- 3	18	15	9	21	17	21	16.8
-1,0,+1	33	24	37	21	30	26	28.5
3	19	11	16	10	15	13	14.0
5	8	5	13	7	10	4	7.8
7	6	4	4	4	6	4	4.7
9	1		2	3		2	1.3
11					1		0.2
13		1		2			0.5
Mean	0.04	-1.22	-0.18	-0.60	-0.56	-1.44	-0.72
ST.Dev.	3.21	4.51	3.85	4.13	3.79	4.07	4.01

Table III-5: Percentage occurrence of minimum temperature forecasting error for the Experimental Farms during APR - SEP 1976 with mean and standard deviation (°F).

ERROR	A R L	A S H	H N K	L N C	M F I	S G B	ALL
-13		1		1			0.3
-11		2			1		0.5
- 9	2	2	5	1	2	1	2.2
- 7		5	5	4	5	5	4.0
- 5	10	12	12	9	13	10	11.0
- 3	15	19	14	14	11	19	13.7
-1,0,+1	38	21	33	25	36	24	29.5
3	15	18	14	25	11	23	17.7
5	8	10	9	13	11	7	9.7
7	5	5	4	4	5	4	4.5
9	5	1	3	2	5	4	3.3
11	1	1	1	2	1	1	1.2
13	1	3		2			1.0
Mean	0.68	-0.04	-0.24	+0.81	+0.16	+0.26	+0.30
St.Dev.	3.58	4.43	3.72	4.02	3.85	2.87	3.77

Table III-6: Percentage occurrence of heat unit forecasting error for the Experimental Farms during APR - SEP 1976 with mean and standard deviation (°F).

ERROR	ARL	ASH	HNK	LNC	MFI	SGB	ALL
-13						1	0.2
-11	1		1				0.7
- 9					1		0.2
- 7	2	2	2	2		2	1.7
- 5	1	14	6	3	3	7	5.7
- 3	13	20	14	12	14	25	16.3
-1,0,+1	53	50	47	50	59	51	50.0
3	27	8	20	25	15	10	17.5
5	2	2	8	7	7	3	4.8
7	1	4	1	1		1	1.3
Mean	+0.16	-0.40	+0.04	+0.36	+0.10	-0.64	-0.08
St.Dev.	2.24	2.42	2.38	2.24	1.78	2.34	2.26

Table III-7: Precipitation forecast verification contingency tables for Experimental Farms during APR - SEP 1976.

OBSERVED PRECIPITATION (columns); FORECAST PRECIPITATION (rows)

ARL

	N	WS	S
N	63	11	0
WS	11	27	5
S	1	5	3

ASH

	N	WS	S
N	54	6	3
WS	13	38	3
S	1	5	1

HNK

	N	WS	S
N	57	12	0
WS	12	29	7
S	1	4	4

LNC

	N	WS	S
N	61	11	1
WS	11	28	6
S	0	6	3

MFI

	N	WS	S
N	56	11	1
WS	9	33	6
S	1	3	5

SGB

	N	WS	S
N	56	11	0
WS	9	37	4
S	2	5	2

Table III-8: Precipitation forecast accuracy and skill scores for Experimental Farms during APR - SEP 1976.

	Accuracy	Skill Scores: Rain/No Rain	Skill Scores: Categories
ARL	0.82	0.62	0.51
ASH	0.81	0.63	0.54
HNK	0.80	0.61	0.48
LNC	0.82	0.63	0.49
MFI	0.82	0.65	0.56
SGB	0.83	0.65	0.53
ALL	0.82	0.63	0.52

Forecast Utilization

This is the third growing season during which some of the Experimental Farms have received weather forecasts from our operation forecasting project. With this experience the Farms were quickly able to incorporate the forecasts into their operations planning. In contrast to the physical plant situation in which responses were limited and relatively insensitive to the weather, operation of the Experimental Farms depends greatly on what the weather will permit.

Early in the growing season precipitation forecasts were used to plan field operations such as plowing and planting. Temperature and heat unit forecasts were used to schedule planting intervals for some crops and test plots. During the growing season researchers with a wide range of interests had access to the forecasts. Pesticide and fertilizer application frequently were scheduled according to forecasts of wind and rain. Irrigation of test plots was also phased with rain forecasts although in this relatively dry year irrigation was used almost constantly where available. It takes much too much room to document how each of the research experiments at the Farms made use of the forecasts. Obviously not all were very concerned with the forecasted weather, yet many experimenters had projects that benefited from forecast information.

A secondary application of the forecasts was made by the Ashland and the Pennineula (Sturgeon Bay) Farms. In order to reach the local agricultural community these farms made their forecasts available to local radio stations. These stations broadcast the forecast for local use. Letters received from these stations indicated the area farmers were very interested in the forecasts and felt the forecasts were generally an improvement over forecasts from other sources. This comes as no surprise, especially at Ashland, since the National Weather Service empasizes the more populated urban regions. Also, stations serving rural communities with a relatively small audience can not afford to subscribe to commercial weather forecast services hence the forecasts offered by the Experimental Farms were very attractive.

How forecasts were utilized outside of the Experimental Farms is not well known. Ashland county has a considerable dairy industry and forage crops are of major importance. Field work, especially hay making are prime tasks for which forecast information would be valuable. In the Sturgeon Bay area a wide range of potential users exists. Orchardists would find rain and wind forecasts valuable for scheduling spray applications. With Green Bay and Lake Michigan nearby, boating enthusiasts as well as other recreation interests may have found the forecasts useful. However, we had cautioned such users against applying the forecasts to regions far removed from Sturgeon Bay for the weather can vary dramatically across and from end to end of the Door County pennisula.

IV. CONCLUSIONS AND RECOMMENDATIONS

The operational forecasting project within the Department of Meteorology has, for the third year, maintained a very respectable forecasting record for sites distributed state-wide and for users ranging from canners to physical plants and experimental farms. Most users appear satisfied with the mode of forecast delivery as well as with the forecast accuracy. It is presumed most users have compared our forecasts with those available from other sources and found ours to be better suited for their needs. Unfortunately, for lack of manpower, we did not engage in the tabulation of NWS zone forecasts for Wisconsin. We recommend that in future operational forecasting projects the forecast evaluation task also include a parallel evaluation of NWS forecasts for the same sites. This would provide an independent gage against which to measure our forecast skill.

The bulk of this report dealt with our forecasting program to the physical plants of ten University of Wisconsin system campuses. Responses to questionnaires revealed the difficulty of incorporating weather forecast information into the operation of the heating plants. Limited responses such as number and size of boilers on line or type of fuel used make heating plant operation relatively insensitive to forecast information but still dependent on the current weather. Fuel use records for one single heating season during which forecasts were available are not sufficient to identify any impact on fuel consumption. The historical records of fuel use span a relatively short period in which large changes frequently have taken place; i.e., new construction, new heating plant equipment, enrollment changes, and lastly the "energy shortage". Such changes have produced a historical data base against which all comparison must be made with extreme caution.

There are, however, physical plant and other campus activities that are more sensitive to forecast information. Many phases of grounds maintenance and landscaping, building construction and repair, and road work can benefit from scheduling in accord with the predicted weather. While many such uses can be identified it still remains exceptionally difficult to assess in monetary terms the value of the forecasts.

In light of these problems we recommend that each UW physical plant examine the operation of its heating (and cooling) plant with specific attention to the impact of weather during the 10 months of forecast availability. It should also be possible to include in this analyses other physical plant activities and perhaps other campus activities on which 24-hour weather forecasts had direct impact. These can be centrally consolidated by the Division of Architecture and Engineering of UW-Central Administration.

The Experimental Farms present a much different problem than the physical plants. Farm supervisors are quite in tune to the weather and have numerous responses to forecast information. After three growing seasons with forecasts available the farms had confidence in the forecast's accuracy and so were readily able to incorporate the forecast into their operations planning.

While utility of the forecasts to their operations was clearly demonstrated, the difficulty of placing monetary value on the forecast remains the same as for the physical plants. Of particular difficulty is the evaluation of the benefits the various research users of farm experimental plots derived from the forecasts. Here, too, it may not be possible to put a monetary value on such benefits.

We recommend that each Experimental Farm examine its operations for the 1976 growing season and identify weather scenarios for which 24-hour forecasts permitted beneficial alternative responses. This analysis should also include the number of researchers aware of the availability of forecasts at the farm and how these investigators incorporated forecast information into their research programs. The Ashland and Penninsula farms should include in their analysis an evaluation of the impact of the radio broadcasts to area farmers and other users. These reports can be consolidated by the Department of Experimental Farms in Madison.

In addition to its success in providing forecasts to University users, the operational meteorology program has met several other goals. One major accomplishment concerns the on-the-job training of forecast personnel. The list of Meteorology Department graduates and continuing students that have obtained employment as a direct result of experience gained while with our operational forecasting project is impressive. Presently seven out of eleven persons involved are employed as meteorologists in either private enterprise (4) or by Federal government (3). Two others were in private practice but are now seeking more stable jobs. One returned to graduate school and one other left the field. This training component will be sorely missed by the Department during this interim lapse of an active forecasting project.

The operation forecasting project has also met its goal of providing a weather service to University of Wisconsin users during its period of sponsorship by the University. Previous to this funding mode the project was nearly self-supported by extramural funds from private industry. In this mode we were able to stimulate considerable interest in weather forecast services to the canning industry in Wisconsin. After we withdrew from this sector several private meteorologists were able to capitalize on the markets developed by our activities.

During most of the operational forecast project our forecasters essentially applied standard techniques to convert current weather pattern evolution and NWS computer forecast guidance into forecasts for specific sites. While such procedures were successful the project itself offered the possibility of incorporating state-of-the-art satellite data and real time processing into its forecast preparation. Much of this potential was lost with the failure of the antenna by which satellite pictures were received by the Space Science and Engineering Center (SSEC). However, considerable use was made of the computer facility at SSEC to process hourly surface observations. The capability to test experimental approaches to forecasting standard or special weather parameters was not tapped. Other research programs within the Department made little use of this forecasting resource. Thus, although serving many users outside the Department of Meteorology, research and academic activities within the Department derived few direct benefits from the operational forecasting project.

Our recommendations concerning an operational forecasting project are thus directed toward the service such a project can provide and towards its funding. We recommend that future operational forecasting projects be funded by University, State or Federal monies which permit the Department of Meteorology to determine the distribution of forecasts. The funding must be relatively secure to ensure project stability and continuity of forecast quality. Projects serving any one user for less than three years will likely produce inconclusive results. All forecasting projects should be part of a broader research program which may, for instance, involve advanced forecasting techniques, new data bases, new forecast parameters, or specific user application of forecast data. Portions of the grant monies supporting such projects should provide for the needed forecast services. Finally, the forecasting project should continue to provide intensive training in the art and science of forecasting for Department of Meteorology students and graduates.

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