A STUDY OF THE ECONOMIC BENEFITS OF METEOROLOGICAL SATELLITE DATA

SECOND ANNUAL REPORT

A REPORT

from the space science and engineering center
the university of wisconsin-madison
madison, wisconsin

A STUDY OF THE ECONOMIC BENEFITS OF METEOROLOGICAL SATELLITE DATA

SECOND ANNUAL REPORT

David Suchman
Brian Auvine
Barry Hinton

Space Science and Engineering Center
The University of Wisconsin
Madison, Wi. 53706

October 1978

The Second Annual Report on NASA Contract NAS 5-23706.

TABLE OF CONTENTS

I. INTRODUCTION

The goal of this program is to assess the value of meteorological satellites to a broad segment to the U.S. public. For reasons discussed below, we have limited our study to the GOES system, and its economic value to clients of a private weather consulting firm.

One problem associated with the creation of a new tool or technique is acceptance--making professionals and the public aware of the benefits of a new approach. Often, the formative experience is with the product in its early stages, when its capabilities are limited and its application not well understood. As a result, the true value of the new tool may not be widely appreciated. Meteorological satellites have evolved greatly from the early TIROS of 15 years ago to the SMS/GOES, NIMBUS, and NOAA satellites to today. However, adequate utilization techniques are still being developed.

Within the National Weather Service, the use of satellite soundings to replace or augment balloon soundings is receiving much attention. It is hoped that global satellite data may enable the forecast range to be extended. The efficacy of satellites for improving forecasts can, in principle, be determined from model assimilation studies. This test is the objective of the First Garp Global Experiment and is outside the scope of the present work.

Some methods are already available for utilization of GOES images for preparing detailed forecasts. Presently, such forecasts are largely the mission of the private community, the consulting firm. Moreover, the clients, or end users, of private weather services are identifiable, as are the uses of the meteorological information they receive. The clients' applications of the forecast are usually associated with economic factors--dollar savings--which motivate the client to pay for the service. Because the forecasts cost them money, and because they potentially yield benefits, we expect the clients to be more aware of the quality of service they receive, and to be more motivated to cooperate in a research program whose ultimate outcome might improve these forecasts. Consequently, in this program we have focused on the application of GOES images by one meteorological consulting firm, and the resulting economic benefit to their clients--a representative sample of the potential economic benefits of meteorological satellites. Since little use is presently made of satellite data by the cooperating firm, we have taken advantage of the possibility of a 'with' and 'without satellite data' comparison which will greatly aid in understanding the role of the satellite data in the mixture of radar, surface observations, radiosonde, aircraft observations etc., that are eventually combined in a given forecast.

Aside from reporting results and conclusions there are five major steps in the program:

(1) Find an established private weather service with a variety of clients, in which meteorological satellite data has not yet been used.

(2) Establish and document the current weather service supplied to the clients and establish a quantitative measure of the value of that service.

(3) Develop, jointly with the operators of the private weather

service, the facilities and techniques required to supply them with meteorological satellite data in the mode most likely to increase the value of the service to the clients.

(4) Install and activate the meteorological satellite data capability in the operator's place of business.

(5) After a suitable period, establish a quantitative measure of value of the augmented service.

A broader discussion of our methodology was given in the first annual report.

The first year we located an established firm, obtained their cooperation, as well as that of many of their clients. Thus we completed (1) and obtained preliminary information, necessary for (2), on the use of the forecasts and their consequences. We also worked out the data requirements and preliminary specifications for an image data display and analysis system based on the McIDAS (Man-Computer Interactive Data Access System) developed by SSEC.

Plans for the second year included: Assembly of forecasts and verifications for each weather season through the duration of the control period (fall of 1977); derivation of climatological statistics for all the areas studied to normalize the weather events studied to the 30-year means (mean conditions as well as number of storms, number of freezes, etc.) to allow the control period to be directly compared with the experimental period; use of the above data with the responses to our questionnaires and personal interviews to obtain economic benefits for each client.

A further goal was to assemble and test the McIDAS-2 hardware system by early fall. At about the same time, several employees of the consulting firm were to be trained on our McIDAS facility, and were to be the focal point of subsequent training on site. In summary, we hoped to complete (2), (3) and (4).

As documented in the present report, significant progress was indeed made on (2). Economic benefits have been calculated for the most important client groups. Detailed design, construction, integration, testing and trouble shooting of the McIDAS-2 system were also major tasks this year. The delivery of the system was much delayed from our earlier expectations, however, for two reasons. Due to manpower drainage to other programs, intensive work did not begin as soon as it should have, and certain of the components presented unforseen difficulties. In spite of this, we did train personnel of the cooperating firm in Madison in McIDAS usage. This gave us additional insight into how the system would be used and influenced our final decisions about which software capabilities should be included. At present, the system has been installed and is being integrated into forecast operations, principally through further on-site training. The net result is that (3) and (4) are substantially complete. The principal consequence of the delay has been to extend the control period to include the winter of 1977-78 as well as 1976-77; in other words we now have more work to do on (2).

We have already obtained much information of value to the meteorological community. Two papers have been prepared discussing part of our results. One is to be presented at the American Meteorological Conference on Weather Analysis and Forecasting and has been published in the conference proceedings.

We have submitted the second paper to the Bulletin of the American Meteorological Society. Manuscript copies of both papers have been included as appendices to this report.

Three tasks remain to complete the program. First we must complete the analysis of the control period--the no-satellite data cases. Secondly, using the same methods we must obtain the equivalent benefit data for the with-satellite cases beginning with fall 1978. Finally, these must be compared in a normalized form.

II. THE McIDAS SYSTEM

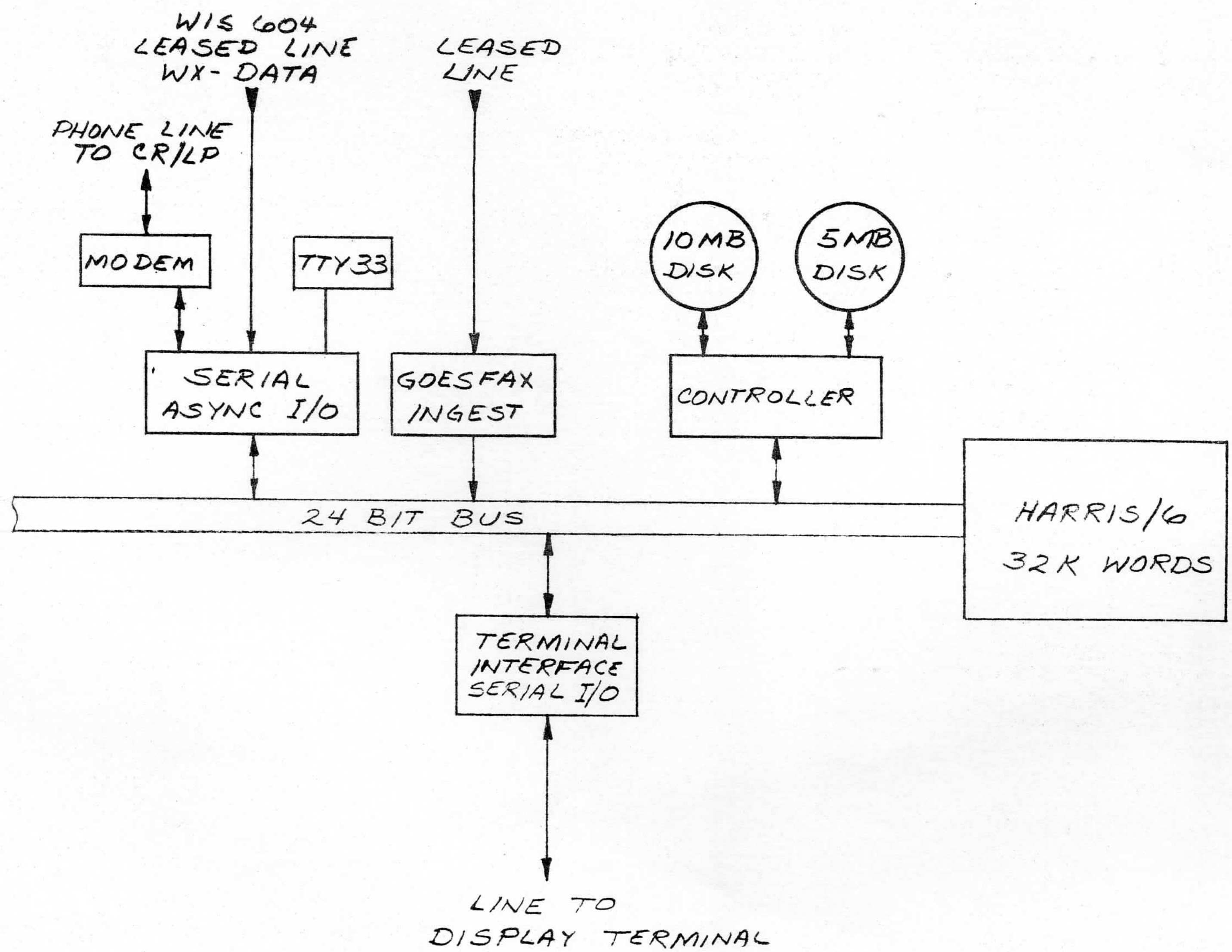
A. McIDAS Hardware

1. General

The satellite image display and processing system being constructed for this program is an updated version of the Man-computer Interactive Data Access System (McIDAS) developed at SSEC for tracking clouds on ATS-3 and later SMS/GOES images. McIDAS consists of two major parts: The processing section consisting of the main computer and data storage plus data ingest lines, and the display and operator interface section consisting of display storage devices, CRT monitors, cursor and graphics generators, joysticks and alphanumeric keyboard for command entry. The basic arrangement of the sections are shown in Figures 1 and 2.

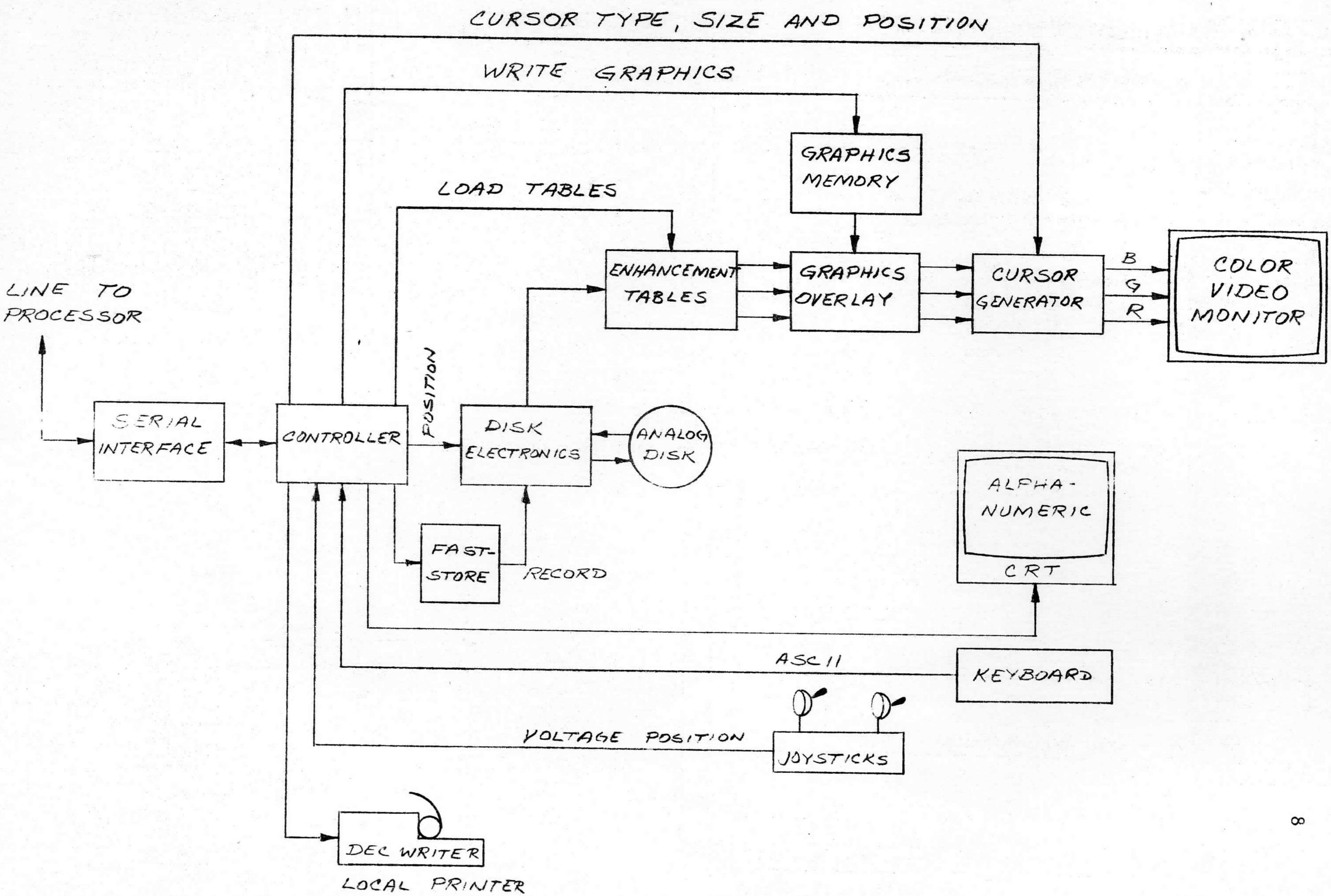
2. Processing section

The McIDAS processing section is based on a Harris "Slash 6" general purpose computer. The one used for this system contains 32K words (24 bit) of main memory and has available 16M bytes of digital disk storage. We plan to add an additional 16K words of memory in the near future. The main computer controls the data ingest lines which consist of a line for conventional weather data (surface and upper air) from the National Weather Service and the FAA (Service "A" and Service "C") and a line for sectorized GOES images. The computer also interfaces to a Teletype for local command input and will have a modem for interfacing to a remote card reader/line printer station located at SSEC. The main processing computer also has a bit serial



PROCESSOR

FIG. 1



DISPLAY TERMINAL

FIG. 2

interface for communicating with the display and operator interface section. The processing section is capable of supporting several display and operator interface sections, however, this system uses only one.

3. Operator console and image display section

The operator console and display section consists of an alpha-numeric CRT display and keyboard for sending commands to the processing section, image storage and display, a pair of joysticks for sending x-y position information to the processor, and the electronic circuitry for creating graphics and a cursor on the images plus color enhancement circuitry.

The images are stored on an analog disk. The disk used on this system is capable of storing 100 pairs of images. The signal from the disk is sent to an enhancement circuit which converts the signal voltage from the disk to three signal voltages for the three color guns on the video monitor. Normally equal amounts of blue, green and red are used to produce a black and white image. However, the functions converting signal level to color are arbitrary and may be used for false color enhancement to emphasize a particular feature. The three color signals are also sent to the control circuit for graphics and for the cursor so that these signals override the signal for the image.

B. McIDAS Applications Software

1. General

The majority of the applications software for this program is a subset of that already in use on SSEC's own McIDAS system. As a result, the process of transferring the software has not encountered any significant problems once hardware became available to run the programs. A few problems did occur because of the smaller disk and main memory available. These were easily overcome by reducing storage requirements or by more segmentation of a program.

2. Types of programs

The majority of applications programs on this system belong to one of the following groups:

1) Image handling. This group includes those for ingesting the satellite images, loading a display frame from a digital area, moving from one frame to another, and setting up frame loops.

2) Enhancement. These programs make entries to the enhancement tables to produce either color or gray scale enhancements. Table values may be entered by the keyboard or by the joystick.

3) Navigation. The navigation programs are used to align sequences of satellite images and for converting cursor position to latitude-longitude coordinates for tracking clouds.

4) Wind measurement. This group includes the WINDCO programs to measure cloud displacement winds and the CLDHGT program to determine a cloud's height from its infrared temperature.

5) Conventional data. Some of these programs automatically

monitor the conventional data line and store the data on disk. Others then allow listing and editing of file entries.

6) Graphics. These programs for generating overlay graphics on the WRRRM graphics device work with output from the winds and conventional data programs. Wind vectors or barbs can be plotted on the satellite images where they were measured. Conventional data, both surface and upper air may be contoured and plotted either on a U.S. or state map or over a satellite image. In addition to plotting on the WRRRM overlay graphics device, some plots may be written to a file which is then displayed on a frame.

III. INSTALLATION AND TRAINING

Prior to the completion of the McIDAS system in Madison, a trip was made to Bedford to inspect the proposed facilities for housing the computer system. It was decided to locate the terminal in one of the forecast rooms where it would be highly visible and easily accessible to the forecasters.

The location of the computer proved to be a more difficult problem. Weather Services is housed in a 200 year old house in relatively cramped quarters that are not suitable for the controlled environmental conditions needed to safely house computer equipment. Hence we designed and Weather Services constructed a special "computer room" in their basement which satisfied our basic specifications. After completion, Harris Corporation (who is providing hardware maintainance) inspected the facility and approved it.

Of major importance to the success of this project is the training of Weather Services personnel on McIDAS. If the system is to have an impact on forecasting, the staff must not only know how to use McIDAS, but must have a positive attitude toward the potential help that satellite imagery can have on weather prediction. With these aims in mind we had two forecasters here at SSEC for a one week period in October. These two people would in turn help other WSC staff to adjust to the use of the system during the installation and breaking in period at Bedford.

The specific training schedule included a daily round of demonstrations, discussion, and general use of McIDAS for both real time and recent weather situations. Emphasis over the last four days of training was on weather prediction.

The training proved to be successful. The forecasters were thoroughly familiarized with the specific operations and capabilities of the system and were able to suggest possible software modifications, which would be helpful to them and feasible for us. In addition, examination of real time data over the period gave the visitors evidence of how the satellite could provide improved information on predicting the development and progression of storms. We were encouraged by their ready acceptance of the satellite's utility and their intention to take advantage of system capabilities on a regular basis.

Even though this training took place well prior to the actual installation of the system, we expect these two people have gained sufficient familiarity with McIDAS to be useful in helping us undertake a similar training process at Weather Services itself.

Once completed, the McIDAS system was tested out in Madison prior to shipping and installation. The installation was performed in early September, 1978 during which all equipment was tested out, and the procedure for ingestion and navigation of satellite images from sectorized data was perfected. This was followed by a series of demonstrations of McIDAS capabilities for the WSC staff and the beginnings of training.

At that point, it became apparent that an on-site troubleshooter-engineer was needed to take care of routine maintainance not covered by the contract with Harris Corp. It would be highly impractical to have SSEC staff commuting to Bedford for every incident requiring service.

Consequently, at this point we are awaiting the selection of such an individual. This will be followed by his training and the completion of the onsite training of WSC personnel.

IV. CLIENT GROUP RESULTS

A. Snow and Ice

Of the 147 subscribers in our sample, we received a total of 70 complete replies (48%). The total group contains municipalities ranging in size from 5,000 to over 500,000 in population, counties, turnpike authorities, states, plus private industries and shopping centers (for parking lot clearance). The geographic range is from Maine to North Carolina and as far west as the Appalachians.

These 70 replies were then re-examined and recontacted by telephone. After further analysis, it was decided to keep 26 for our final analysis. These clients covered eight states from North Carolina to Massachusetts and break down like this:

States, Turnpikes, Counties: 6	Cities 50,000-100,000: 4
Cities >100,000 population: 8	Cities <50,000: 8

The sample is fairly representative of the group as a whole with a weighting towards the larger users, and the elimination of the small, private subscribers. In general, the weather forecast had a more measurable impact on the more populous clients, and hence, the bias of our sample.

The reasons for not selecting the other forty four give us an insight into the problems encountered in disseminating meteorological information. First, a few of the clients decided at some point that one questionnaire was enough, and they refused to cooperate further. About a dozen of the clients don't use the forecast at all. The reasons vary from preference for the National Weather Service since they are closer, the fact that their predecessor subscribed so they feel they should, to total ignorance of the product they are paying for.

For the rest of those returning the questionnaire, the forecast of adverse weather has little economic impact. Many of these are small townships who use the forecast for convenience: mobilization time is so short and costs are so minimal that they can wait until the last minute to prepare for a storm. The security of knowing that they will be contacted at any hour in case of an emergency is well worth the cost of the service. Others, in high snow regions, are always mobilized for adverse weather, or at worst, mobilize prior to a weekend or holiday.

A number of the respondants only react to storms when they are in progress. They will never mobilize for sanding until the snow begins to fall, and the plows are never brought out until a plowable amount is on the ground. Finally, we encountered many clients who seemed unpredictable: they either subscribed to other weather services or only occasionally listened to the WSC forecast. These people preferred their own interpretations to those for which they paid.

Calculations were made for losses due to incorrect forecasts for the 1976-1977 snow season. Over the mid-Atlantic states, the '76-'77 winter was, for the most part, normal or sub-normal as far as snow amounts. Most of the urban areas received few plowable snows, with amounts from any single storm not exceeding 5". Little snow was received after late January. Snow fall over New England was at, or slightly above normal both as to total amount and distribution. Most of the snow fell during December and January with a series of plowable storms beginning about Christmas. There was one major storm in both February and March, and the snow season ended with the surprise storm of May 9-10. The latter caught everyone by surprise but melted on its own within a day or two.

The two significant forecast parameters for snow forecasting are timing and amount within specified limits. The latter is used to determine what action will be taken--sanding/salting or plowing. Most clients sand when minimal amounts of snow fall, but plowing criteria varies from as little as 2" to as much as 4". Hence, a city that plows at 4" will have one course of action for any forecast less than 4", and a different one when amounts should be greater. In most cases a forecast of 4" produces the same action as one of 10". The exception is when outside contractors are called in, usually at a 6" or 8" forecast: they often require two to four hours notice and must be paid for a minimum amount of time (usually four hours) whether or not the storm materializes. Hence, forecast amounts can be translated into mobilization costs--what should be mobilized and who should be put on alert.

Timing is used to determine when the above occurs. During weekday work periods it is not that crucial, but at night, and weekends it determines which crews are held over and who is put on alert at premium wages. A storm that is delayed 12 hours can thus cost thousands of extra dollars.

Due to different criteria used for snow removal, a good forecast for one user could cause a major loss of money for another. Table 1 shows this variation for three governmental bodies, including possible monetary loss. City A plows at 4", and suffers its greatest monetary loss through unnecessary mobilization when plowing is not needed; City B plows at 2", and snow forecasts of less than that have little impact; State C also plows at 2", but the timing of storms can cause greater monetary losses. These criteria vary from client to client and seem to be arbitrarily set according to equipment available and the quality of the snow removal effort.

Most monetary or direct losses are due to overforecasting--being too prepared due to a storm forecast of earlier time of arrival or greater amounts than actually occurred. Many clients prefer to be conservative in their preparations and choose to be overly prepared. Underforecasting rarely results in direct losses because it is impossible to determine how much extra time is spent cleaning up after an unexpected storm. These losses are more indirect--loss of public goodwill, increased traffic accidents or slowdowns, delays in deliveries, etc. Though they cannot be directly quantifiable, their total economic impact may be greater in the long run.

Appendix A shows a series of actual WSC forecasts from the 76-77 season: Forecasts A and B are for a Boston suburb, and C is for two districts of a state highway commission. They are summarized in Tables 2 and 3, and are chosen to illustrate our calculation procedure. The December 29 storm (see Table 2) is an illustration of a gross underforecast which did not result in calculable direct losses--though

Table 1
Monetary Losses Due to Incorrect Snow Forecosts

City A

Forecast	Outcome	Additional Cost
less than 4"	no snow	$44/hr. + $750 (mob)
less than 4"	delay	$44/hr.
greater than 4"	no snow	$132/hr. + $750 (mob.)
greater than 4"	delay	$132/hr.
greater than 4"	less than 4"	$88/hr.
		Four hour minimum, 1.5 for overtime, 2 for holidays.

City B

no snow	significant snow	$150/hr.
greater than 2"	no snow	$1000/hr. + $150 (mob.)
greater than 2"	delay	$1000/hr.
greater than 2"	less than 2"	$1000/hr.
		If during regular hours (8 to 4:30), cost are 1/3 less & mob. cost. = 0

State C

less than 2"	no snow	$27,050/hr. + $9,800 (mob.)
greater than 2"	no snow	$27,050/hr. + $15,200 (mob)
greater than 2"	delay	$27,050/hr.
greater than 2"	less than 2"	$5,800 (mob.)
		1.5 for overtime

Table 2

<u>December 29</u>:

Total accumulation: 12"-16"

Snow: began at 3 A.M. became heavy by 9 A.M. and ended at 6 P.M.

<u>Forecasts</u>

Dec. 28	8 A.M.	snow beg. 9 A.M.	2"-4" by late P.M. 50% chance of 4"+
	1 P.M.	snow beg. 9 P.M.	1" by 1 A.M., 2"-4" by 6 A.M.
	9 P.M.	snow developing 3-6 A.M.	2"-4" by 9 A.M. Risk of 4"+ by afternoon
Dec. 29	9:30 A.M.	Expected accumulation 2"-4"	risk of 4"+
	11:30 A.M.	Total accumulation 10"-15".	

Table 2 (continued)

January 14

Snow began at 7 P.M., ended at 2 A.M. next morning

Total accumulation: 1.5"-2"

Forecasts

Jan. 13	9:30 A.M.	lt. snow 1"-3" beg. 1 A.M.	
	2:00 P.M.	snow beg. 3-6 A.M. 1"-3" by afternoon 55% chance of 4"+	
Jan. 14	9:30 A.M.	snow re-develop 9 P.M.	1"-3" by midnight 3"-5" by 3-6 A.M. 4"-6" by 9 A.M-Noon
	1:00 P.M.	snow developing 6-9 P.M.	3"-5" by 1-3 A.M. 6"-8" by 6 A.M.-9 A.M.
	10:20 P.M.		3"-4" by 3 A.M. 6"-8" by 6 A.M. 7"-9" by 9 A.M.

Unnecessary mobilization cost $3300

crews held over: 4 P.M. - 2 A.M. (when snow stopped)

10 hrs x 250/hr: $2500

contractors paid for 4 hours called: $7000

Total loss: $12,800

traffic was tied up and total cleanup time for regular crews and contractors was probably extended, no losses could be determined. The January 14 case (for the same city) shows the danger of overforecasts. Because the snow was supposed to reach plowable amounts during the evening, plows were mobilized unnecessarily ($3300), contractors were called in and paid when they weren't needed ($7000), and day crews were unnecessarily held over until the snow stopped at 2 AM (10 hours x $250/Hour = $2500). Total loss was $12,800 or close to 9% of the total seasonal snow budget. It should be noted that most clients would prefer to be overprepared (and lose money doing so) than be caught unaware.

Table 3 shows a series of forecasts for January 9. The forecast for over 3" of snow meant a plowable situation; its estimated beginning time caused day crews to be held over. Snow actually began at 5 P.M. with a total accumulation of 2.4", then changed to freezing rain and later to rain. Plows were mobilized (due to the forecast) at 5 P.M. Because it was at the end of the day shift crews were held over until the 5:30 A.M. forecast update. Since the client only plows when 3" are on the ground, it did not need to mobilize its plowing force or hold its crews over. The extra cost was $23,450 calculated from

$1250/hr (crew cost) x 1.5 (overtime) x 12.5 hours.

This extra money was expended for what appeared to be a good forecast by ordinary criteria.

There is a final situation in which an apparently bad forecast is really more than adequate. This would be in a case where a client

Table 3
Actual Snow Forecast And Outcome

Forecast:	10:10 AM	3"-6"	beginning 7-9 PM
	3:00 PM	3"-6"	beginning 3-5 PM
	9:40 PM	as above	
Next Day	5:30 AM	1"-2"	

Actual Conditions:

Snow began at 5 PM: total accumulation of 2.4" changed to freezing rain, then all rain during the night.

Plows mobilized at 5 PM & stayed until 5:30 AM update.

Plowing criteria: 3"

receives a forecast for 6" and the actual accumulation is 15". The 6" forecast implies that the subscriber put its entire plowing force into operation, and once this is done, total accumulation does not alter the procedure--the operation just takes longer.

The economic losses due to incorrect forecasts ranged from an average of under $10,000 for the smaller communities to over $100,000 for the larger subscribers--for many southern cities, the winter season had no plowable snows. This, in general, was from 5% to 10% of their annual snow budget. Half of the clients studied had over five bad forecasts that caused economic loss while only six subscribers had fewer than three. The number of erroneous forecasts not causing direct losses averaged about four, with most of these being under-forecasts (note that few clients received more than five or six plowable storms that winter).

To summarize, accuracy and timing are crucial in snow forecasting, and are especially critical near certain threshold values which are determined by each clients mode of operation. Outside these boundaries, the forecast is used mainly for convenience and, accuracy is less important than timing.

B. Electric Utilities

Of the eleven electric utility clients of Weather Services Corporation, found mostly in the Northeast, we have received eight completed questionnaires. These clients were studied from two perspectives, one involving the effect of snow, ice and wind on the maintenance of the highly vulnerable power system, and another involving the use of daily forecasting to predict and plan for peak loads. The former situations were done on a case study basis of which two will be presented here; the latter was done with the help of daily forecast forms and verifications over the summer months, when the utilities are most vulnerable to unexpected peak loads.

Peak load forecasting refers to the necessity for electric utilities to predict the maximum power usage on any given day. During the summer months, when power usage is often expected to exceed the amount of power available from other outside sources (many companies belong to a network which supplies all members with power), the utility must plan on generating its own extra power, usually from either steam or combustion turbines. Given plenty of warning, cheap steam turbines can be put on line; however, because such turbines have a long (12 hour) "warm-up" time, a company may be forced to use combustion turbines. These can be readied in a matter of minutes, but are twice as expensive as steam generators: 40 mills per kilowatt-hour as opposed to about 20 mills for steam. The economics of the situation are apparent: an over-forecast of degree days, temperature-humidity index or other measure of heat and humidity used by the company results in unneeded steam turbines being brought on-line. An underforecast results in the use of expensive combustion turbines. Power cannot be saved from day to day: once scheduled, it must be used.

There are a number of other factors which affect the economic impact of the weather forecast on these users. They are:

Tolerance--All companies have a certain amount of slack in their power usage such that they can tolerate unexpected fluctuations in temperature. This leeway can be as large as 10° but usually it is from 2° to 4°.

Size of the System--Naturally, very large systems covering population centers or even whole states are more vulnerable to temperature fluctuations than is a small system. The typical cost of a 1° error in the forecast above the aforementioned tolerance, is about $2000 but this can go as high as $3000 or as low as $300.

Critical Point--This is the point above which a utility must schedule the use of its own turbines. A forecast or actual weather above this point has a potential economic impact. Below this point, the system would not ordinarily schedule extra turbines and thus would not be vulnerable to forecast errors. Critical points are usually at a THI of 70-75, or about 85°F.

Given information on the tolerance, size, critical point and cost of turbine power generation, it is possible to calculate economic impact of the forecast on a given system. Such information was available from 3 of the 8 systems from whom questionnaires were received. The others were not used because they did not do peak load forecasting from WSC forecasts (3 clients); or their systems had large tolerances which made misforecasts highly unusual (2 clients).

An example of such a calculation is shown below:

Critical point at which extra turbines are added = 70 THI

Forecast at 8 AM, 7/1/77 for 3 PM 7/1/77

Temperature = 81°, R. Humidity = 64%

Actual Weather at 3 PM, 7/1/77

Temperature = 86°, R. Humidity = 69%

Since both the forecast and the actual weather exceeded 70 THI, an error of 5° would potentially cause economic loss. The system had a tolerance of 2° which means that the actual impact on the system was 3°. Each one degree error causes a 100 MW change in load. Multiplying this times the cost of power generation ($22.00/MW HOUR) gives a cost of $2200 per degree. Thus the extra cost of scheduling steam turbines to cover a high temperature that was 5° in error was $6600.

If the same error had been made in the 60° range, no loss would have been incurred since the critical point of 70 THI would not have been exceeded.

The results from these three utilities are summarized in Table 4 for the summer of 1977.

Table 4
Electric Utility Results

Company	Total No. of Misforecasts	Over-forecasts	Under-forecasts	Cost/deg.	Max Power Used (MW) (Measure of System Size)
A	11	8	3	$2205	4,425
B	38	29	9	$2200	2.932
C	43	23	20	$2000	5,760

	Mi^2 Serviced	Critical Pt	Tolerance	Total Loss due to forecasts
A	10,000	85°	4°	$55,125
B	1230	70 THI	2°	$281,600
C	2475	None	3°	$937,000

The losses to Company C are high because they are vulnerable to any misforecast, whatever the temperature. Company B exceeds Company A in losses because the former has a small tolerance and a low critical point. One may also note that the forecasts tend to err on the over-forecasting side, rather than under. Incidently, these calculated costs do not include manpower (to run extra generators) which is usually a negligible part of the total. The total losses for these companies were probably larger than average due to a summer which was slightly warmer than normal.

To proceed to the second part of our analysis, one documented case study we have obtained concerns the Northeastern snow storm of March 22-24, 1977. This storm was not forecast to affect the region as it did with up to 30" of snow over a two day period. In fact, even at the time that maximum electrical outages were being reported, the forecast was calling for only 1-2" of snow. The cost for hiring extra crews to service the affected area was in the hundreds of thousands of dollars. (One company estimated the cost to be $351,900) No forecast could have reduced this figure to zero; however, the failure to give adequate warning of the impending crisis no doubt took its toll in the slowness of the recovery. One company reported up to 59,930 outages at the peak of the storm on the 22nd, another reported 34,245. While this was reduced to 9,500 two days later, the remaining restoration was made difficult due to the inaccessibility of roads due to snow. Not until the 26th was full power restored. Speed in power restoration is, of course, highly desirable not only because of the inconvenience to the customer but also because the longer outages are allowed to last, the greater the likelihood that storm conditions, (snow and wind) will make quick restorations impossible. The importance of the forecast in this process is obvious.

Another storm of consequence occurred on October 16 to 20, 1977. This storm brought up to 14" of heavy wet snow to the mid-Atlantic region. Like the previous case, the magnitude of this storm was unpredicted with only 1-2" forecast around midnight on the 16th, just hours before the heaviest accumulations fell. Due to the weight of the snow, much damage resulted from falling limbs and trees. A total of 55,194 customers were eventually affected for periods ranging from two minutes to 72 hours. Total cost of this storm was $2,025,000.

Such examples could be multiplied although our point is clear. Forecast impact is very great on electric utilities and improvements in prediction could have dramatic results.

C. Gas Utilities

Gas utilities are vulnerable to many of the same factors as the electric utility although maintenance problems are not nearly as extreme. In general, the factors of threshold, system size and tolerence apply here as they do for electric companies. Out of a total of 33 WSC clients, we received 21 completed questionnaires. With these we attempted to study peak load forecasting problems. Like the electric utilities, gas companies can draw only so much from their pipelines; anything above this set amount must be provided from in-house supplies such as liquid natural gas (LNG), propane-air or storage facilities. These sources are generally more expensive to use (anywhere from $1.50/MCF to $3.50/MCF) than pipeline gas and therefore unneeded use of these due to forecast error will have an economic effect. Sometimes, generation of unneeded gas can be stored for the next day thus eliminating financial loss. In other cases, a company may have a special contract whereby gas can be provided through storage or pipeline on a few hours notice. But in many cases such flexibility is not available and the loss due to excess gas generated cannot be mitigated. Likewise, the failure to prepare for an actual peak load, will mean using either pipeline gas at penalty rates (up to 10 times more expensive), using storage gas that must eventually be replaced, or shutting off interruptible customers with a consequent loss of income. This latter possibility has become increasingly rare in recent years. Whereas at the start of this study in 1976, most gas companies had at least some interruptibles whose gas flow could be adjusted to compensate for unexpected peaks, current gas shortages have caused most companies to either cut their interruptables off completely (especially during winter months) or switch to a "priority" system of gas distribution. In a priority system, all customers are liable to a cutoff with large commercial customers being the first to go and smaller residential customers being last. Cutoff can be done on short notice thus giving the gas company great flexibility. Where such an operation is in effect, it has made calculation of monetary loss impossible unless one knows in exact detail the situation in regard to gas supply and allocation on a given day.

Of the 21 clients who returned questionnaires, 6 were usable for cost calculation. Another 7 were not used because of failure to provide sufficient information on their operations and 8 were clients using a flexible system of special contract, storage facilities, or priority allocation mentioned above. Generally these 15 clients are smaller utilities with less gas flow.

To illustrate, we will examine one forecast for a utility which receives forecasts for two cities within its service area. The critical point for this utility is 52 degree days (DD), arrived at by their send out and gas availability. They can tolerate a 1° error and need a lead time of four hours to adjust their operations. Table 5 shows the forecasts, updates and verifications; the 1200 forecast is the one used for verification. For city A, the error was 2°. Since they use 1875 thousand cubic feet/degree day (MCF/DD) and expensive gas is $3.50/MCF extra, the extra cost is 1875 x $3.50 = $6562.50

Table 5
Actual Gas Forecast And Outcome

	City W		City F	
	Forecast		Forecast	
	Temp.	Effective Degree Days	Temp.	Effective Degree Days
7:00 AM	15°	57	17°	55
12:00 Noon	16	55	18°	54
9:00 PM	19	53	22°	50

Actual: 20°; 53 DD. Actual: 23°; 49 DD.

Critical Point for Supplemental Gas: 52 DD

Need 4 Hours Lead time.

Can absorb 1° error

City W

(2° error - 1° tolerance) x

1875 MCF/DD = 1875 MCF.

1875 x $3.50/MCF extra

= $6562.50

City F

(5° error - 1° tolerance) x

625 MCF/DD = 2500 MCF.

2500 x $3.50/MCF extra

= $8750.00. +

Manpower Costs: $40/hr x 24 hrs

= $960.

Total: $8750 + 960 = $9710.

Total Loss: $16,272.50

(assuming a 1° tolerance). For city B, with a 5° error and a sendout of 625 MCF/DD, the cost for the gas is $8,750. In addition it cost them $40/HR x 24 hrs ($960) to man the peaking facility when it could have remained idle. Hence, total loss for the utility this day was $16,272.50. On the other hand, with a forecast of 50 DD and a verification of 42 DD this larger error would not have had any adverse economic impact because it was not in the critical temperature range.

The results from our calculations are summarized in Table 6. Notice that the critical points for gas companies are in degree days. These values are relatively uniform except for Company A which is in the South and evidently has a plant designed for a relatively small intake of pipeline gas. Because they are winter peaking, cold temperatures are usually responsible for turning a misforecast into an economic loss. This was especially true of the 1976-77 winter when temeratures much below normal were reported all along the East coast. The cost per degree varies more widely than with the electric utilities, being an effect of the great range in size among the gas companies. Unlike the electric utilities, misforecasts seem to come out more often as overforecasts, rather than under. The small losses for companies E & F are mainly due to their higher critical points. If these values had been lowered by even a few degrees, losses would have been substantially multiplied. For at least three of the companies (A, B & C), forecasting is responsible for a significant impact on their yearly budget.

Table 6
Gas Utility Results

Company	Total No. of Misforecasts	Over-forecasts	Under-forecasts	Cost/deg.	Max Gas Used (MCF)
A	22	7	15	$2500	144,000
B	12	4	8	$7000	260,000
C	25	12	13	$8750	206,000
D	7	2	5	$1540	52,328
E	1	1	0	$1995	36,000
F	1	1	0	$3125	91,878

	Mi^2 Serviced	Critical Pt (DD)	Tolerance	Total Loss due to forecasts
A	1025	28	3°	$122,500
B	1703	50	2°	$175,000
C	666	52	1°	$336,875
D	314	50	2°	30,800
E	150	55	2°	1,995
F	225	55	2°	9,375

D. Fuel Oil

A typical fuel oil company surveyed serves about 3900 customers, and delivers 6.6 million gallons annually using seven or eight drivers who work the equivalent of five and one half days per week.* Normal rate of pay ranged mostly within a dollar of $6.50 per hour, but drivers often work overtime at around $10.00 per hour. Within the heating season there are peaks in the demand for fuel delivery. Some firms handle this by the overtime mentioned above, while others switch burner repairmen or office personnel to delivery.

The typical fuel oil customer receives about 180 gallons per tank fill. This is done about 10 times, so he or she uses about 1800 gallons per year. The heating season in the northeastern U.S. has about 7500 EDD (an effective degree day (EDD) differs from a degree day in that it includes the effect of wind) so that a typical customer burns about 0.24 gallons per EDD. For cold days (50 EDD), this amounts to about 12 gallons per day. In terms of 50 EDD days, a three-to-four day tank reserve is 36 to 48 gallons. This is roughly consistent with the stated optimum fuel drop of 192 gallons (.70 tank capacity, 265 gallon tank) for most dealers. Since the actual drop is nearer 180, the typical customer actually carries almost seven days reserve. Most dealers prefer to plan deliveries three or four days in advance, though later adjustments can be made if necessary. This means that delivery rates are dependent on about eleven days of

---

*Not every firm responded to every question on our questionnaire, of the total of 52 possible respondents, 21 were usable because most of the essential information was supplied.

past, or verified, degree day data and up to three or four days of predicted degree day data. This suggests that predicted degree days would have to be 50 EDD (or 12 gallons of oil) in error over a four day period to cause, a noticeable risk of tanks dropping significantly below the 0.30 full level. The dealers surveyed expressed a significant concern for forecast errors more than 36.5 EDD in four days.

Figures 3a-c shows the predicted and actual EDD values for December through February 1977 using the last available forecast before delivery. One can see that the areas of disparity are relatively small compared with 50 EDD. On the other hand, if first available forecasts (up to four days ahead coinciding with the delivery planning cycle) were considered, fairly large disparities are occasionally found.

We previously reported that the effect of improved precipitation information on actual oil delivery would usually be more important than improved degree day forecasts. We have found that the overall skill of the forecasters has been good in general, but for those cases of greatest importance to fuel oil dealers, we found considerable room for improvement.

The oil dealers agree that up to four inches of snow will not stop their trucks because of the heavy load and large wheels. However, it does slow things down, so that over half the firms will try to pull ahead on especially difficult 'snow stops'. For snow over 4" this practice is nearly universal. Consequently, 4" is an important threshold value for snow forecasts. A 'good' forecast is one for

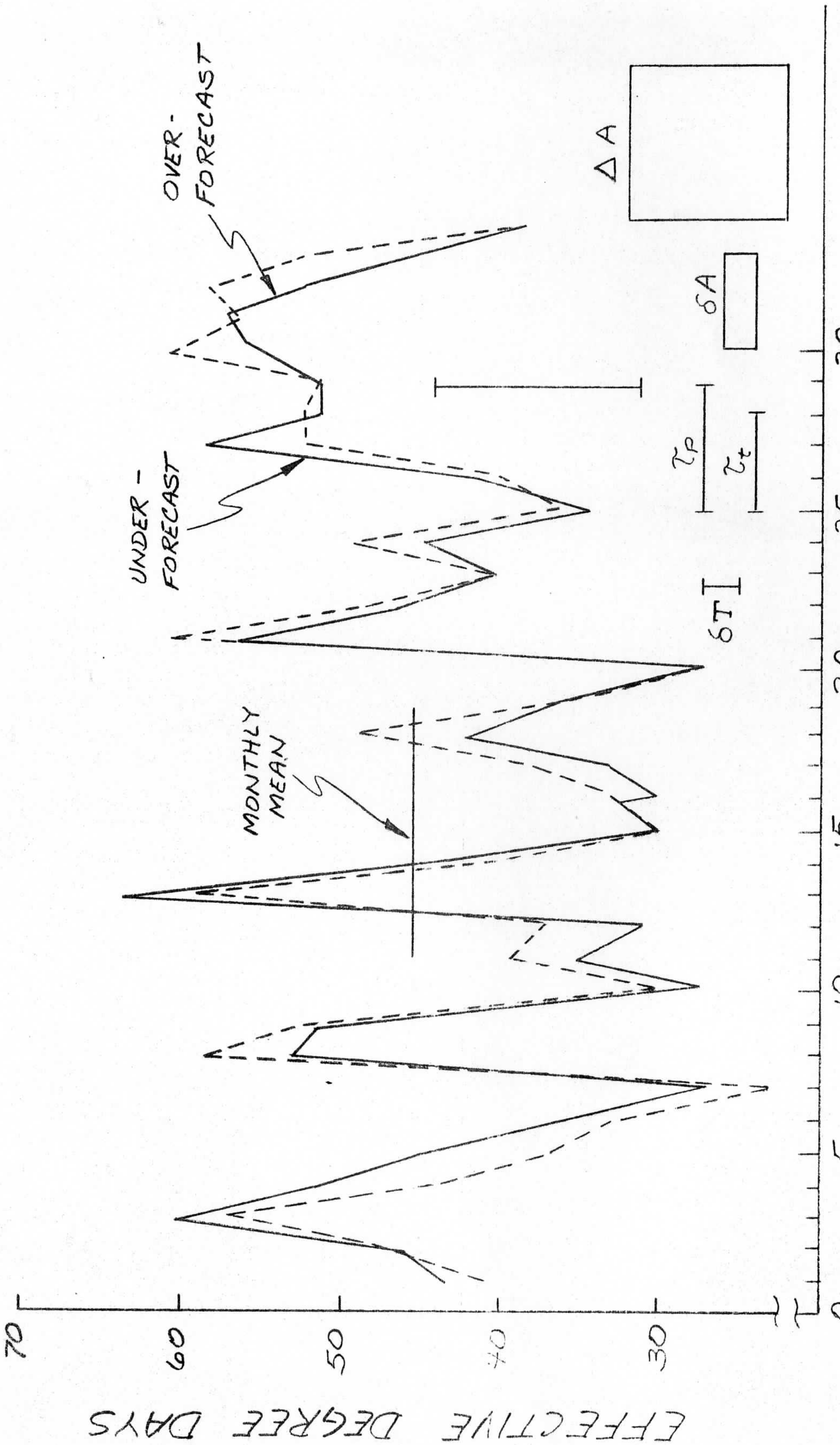

EFFECTIVE DEGREE DAYS
70
60
50
40
30
0
5
10
15
20
25
30
DAY OF DECEMBER, 1976
MONTHLY MEAN
UNDER-FORECAST
OVER-FORECAST
δT
τ_p
τ_t
δA
ΔA

FIG. 3a

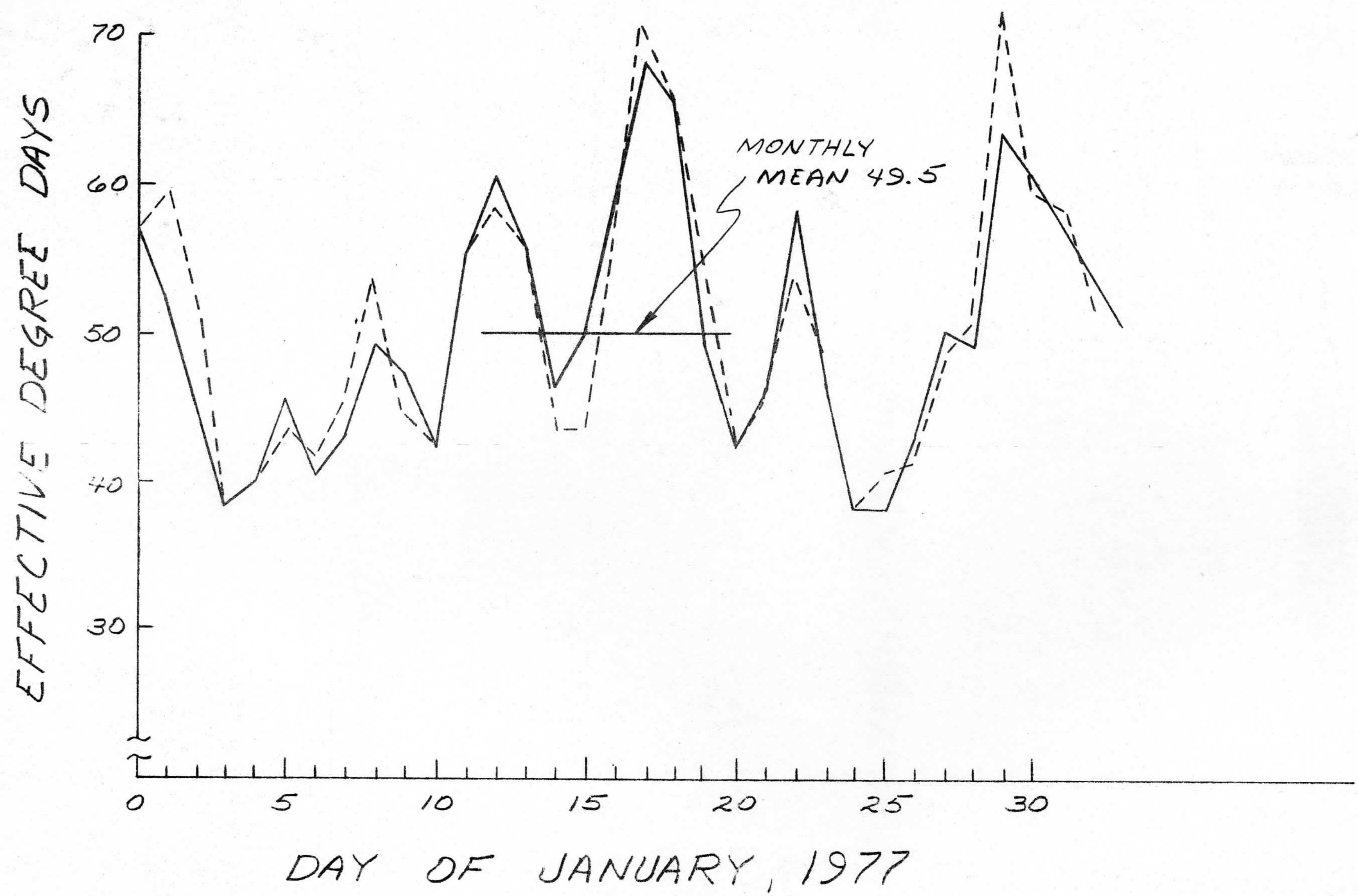

EFFECTIVE DEGREE DAYS
70
60
50
40
30
MONTHLY
MEAN 49.5
0
5
10
15
20
25
30
DAY OF JANUARY, 1977

FIG. 3b

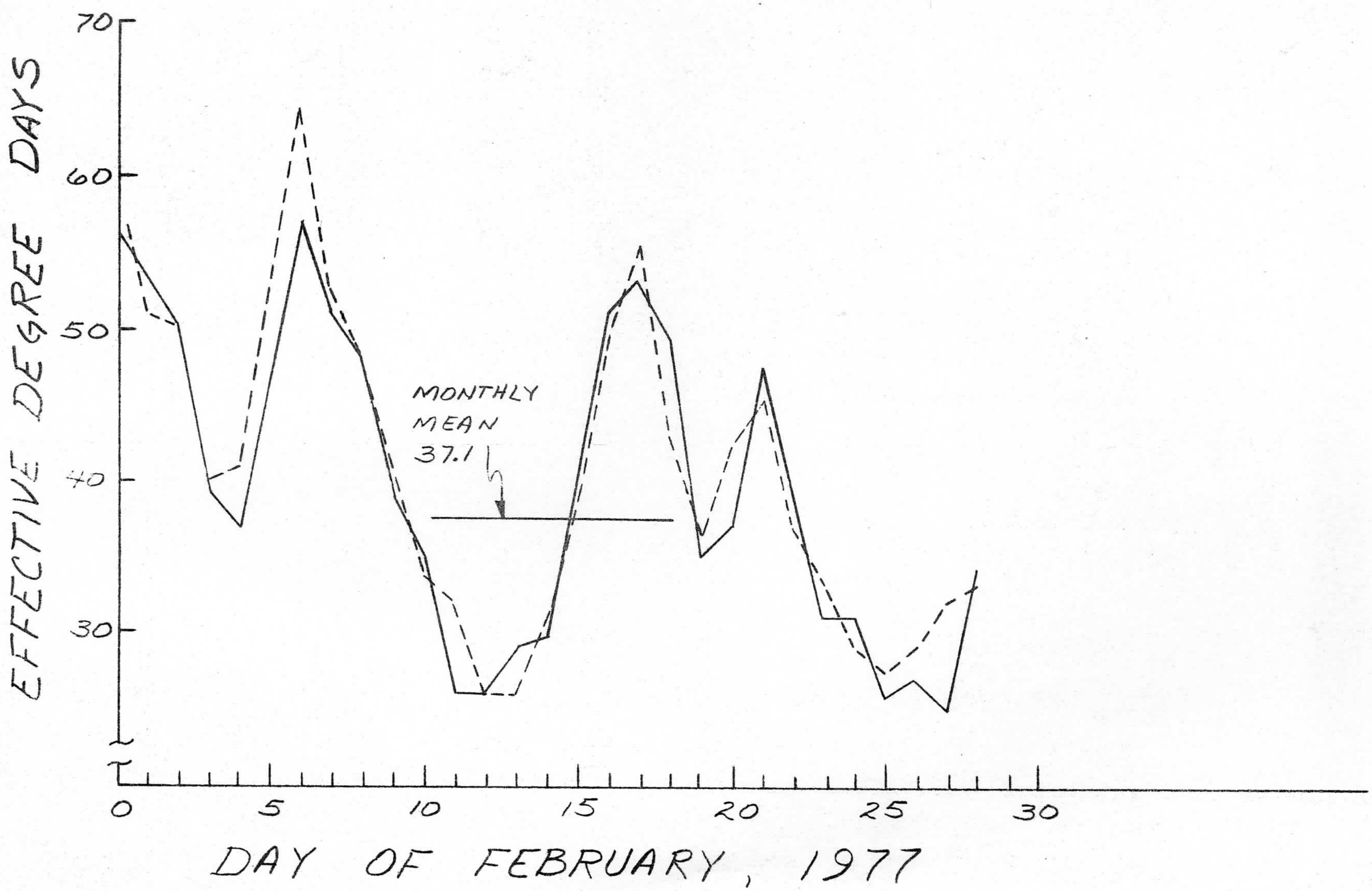

EFFECTIVE DEGREE DAYS
70
60
50
40
30
MONTHLY
MEAN
37.1
0
5
10
15
20
25
30
DAY OF FEBRUARY, 1977

FIG. 3C

which the forecast snow depth and the actual fall on the same side of the 4" mark.

Fuel oil dealers want to know far enough in advance about heavy snows so they can pull a whole day's deliveries ahead. Generally, this would take about 36 hours warning. Snows of the order of 10 inches would require still more warning. In addition, to be useful, the forecast should not have less than 50 percent probability associated with it (the warning time is effectively counted from the time the forecast achieves >60 percent probability).

When considering all the factors that were important to the fuel oil dealers it was found that there were only a small number of potentially significant weather events to monitor. We found that day of the week and previous weather modify the effects of forecasts. Projections for Mondays, or days after holidays, depend more on forecasts than do normal work days; previous weather may determine whether deliveries are current or have fallen behind. A Friday forecast of 4" of snow for Saturday, for example, would have no effect if 12" had been received on Thursday, because delivery efforts would already be backed up. Finally, for snows much greater than 4", the available response time was often too short to get far enough ahead on deliveries. It simply takes more than two or three days to recover from a 10" snow. Of the ten principal events examined, five forecasts exceeded the threshold criteria set forth above. Only one of the precipitation forecasts was totally incorrect on a qualitative basis. Thus for general purpose use these forecasts would be considered good.

Quantitatively however, only five of the forecasts were good. The above results apply to three geographical areas and affect 16 of the firms available for study (out of 21 total).

For a December storm, for example, we can estimate that an hour of overtime worked before the storm would be worth about four times as much as an hour of overtime worked after the storm which left about 11" on the ground. This is supported by the fact that a lesser snow (4-6") cuts delivery rates in half, and secondly many companies placed two men on a truck because of the very difficult hose pulls. Consequently, a 'typical' oil company employing 7.5 drivers at the overtime rate of $10 per hour, had the opportunity to put in six to eight hours of overtime ahead of the storm and save $1350 to $1800 in delivery costs. The aggregate savings to the 16 firms in this area for the three large snowfalls during the 76-77 winter season came to about $60,000. The benefits could have been much greater with more lead time. Firms did not return to a normal delivery schedule for as long as a month after the January 7-10 storms.

E. Commodities

Since our last annual report we have uncovered few commodities--weather situations potentially relevant to the type of satellite data to be made available in this project. However, for illustrative purposes three situations merit brief discussion. One is the recent five month Brazilian drought which cut back that country's production of soybeans, corn and wheat. While the impact of the corn and wheat shortfall on U.S. markets is minor, Brazil has become the world's number two producer of soybeans (after the U.S.). One of the salient features of this relationship is that the Brazilian growing season is offset from the U.S. season by six months, hence the final projections of the Brazilian crop influence U.S. plantings.

On the other hand some take a dim view of official estimates as a sole source of information. Soybean Digest (July/August 1978) notes that the officially reported 1977 Brazilian soy crop was 27 percent below preliminary USDA expectations. Food Manufacturing (May 1978) asked rhetorically whether the Brazilians might not be 'talking the price up'--that the effects of the five month Brazilian drought had been over estimated by Brazilian sources. At any rate, the drought probably influenced U.S. farmers' plans; they upped their acreage 7.3 percent (Soybean Digest, May/June 1978).

A second situation of interest has been the late planting of the U.S. corn crop due to a wet spring. Farm Journal also felt bullish on corn (from the U.S. farmer's point of view) because of higher than expected acreages set aside in government programs, less competition from feeding wheat and more favorable exports due to the weak dollar (hence cheaper U.S. grain on the world markets). Things can turn around rapidly however. The 22 July 1978 Wallaces Farmer (and many other publications) discussed the USDA crop survey based on farm data to June 11 adjusted for weather conditions to July 1. This crop estimate was "surprisingly high in spite of the wet spring." For several days following this estimate, the price of corn dropped steadily.

Thus official crop estimates have a direct market impact. How valid are they? Official estimates sometimes change significantly even after the crop is in. Last fall Leonid Brezhnev announced that USSR wheat production was 194 million metric tons while official U.S. estimates called for 215 million.

Domestically, one can monitor conventional weather data or verify government estimates by the 'windshield method' (i.e. on site inspection). The greatest value of satellite data would be in less readily accessible areas (e.g. Brazil) or virtually inaccessible areas (USSR, China). The private sector would like official estimates based on improved data, and estimates arrived at independently of government projections to have a broader base of information.

Research projects at the University of Wisconsin (Wiley, Martin, Stout 1978) are investigating the use of GOES satellite data for rain estimation. This method has not been developed to an operational level, but its development would provide a means of monitoring rainfall independently of conventional data for situations like the Brazilian

F. Marine Weather

We have begun processing the forecast materials for one of these clients, the barge towing firm. Based on examination of these forms and further discussions with the client we have developed the following verification and evaluation method. We have not, as yet, been able to proceed any further because of the lack of exactness of the client's response.

The primary activity of this particular company involves transport between fixed points. Often the cargo is coal in large open hopper barges. Push towing is preferred. Typically, two forecasts are issued each day (830 and 1530 GMT). Both forecasts are broken into several segments three to six hours long, as needed. Usually, both extend through 2400 GMT the following day. Forecast parameters include: General weather; visibility; wind, speed with direction on 16 compass points; speed of gusts; seas; and remarks.

Typically, three zones are forecast. The first is Philadelphia Harbor, Delaware Bay and the Upper Chesepeake Bay. The second is the lower Chesepeake Bay and the remaining one is Cape May to Providence.

Fig 4 shows a set of stations suitable for verifying the forecasts. The client does not maintain an independent log of verifications. The critical parameters are, according to the client, wind speed, and to a lesser extent direction. For the Cape May to Providence leg one can see from the map that winds blowing out of the west to northwest will be less effective in setting up short 'choppy' waves which are much more important than swell. This is the reason the client is much more

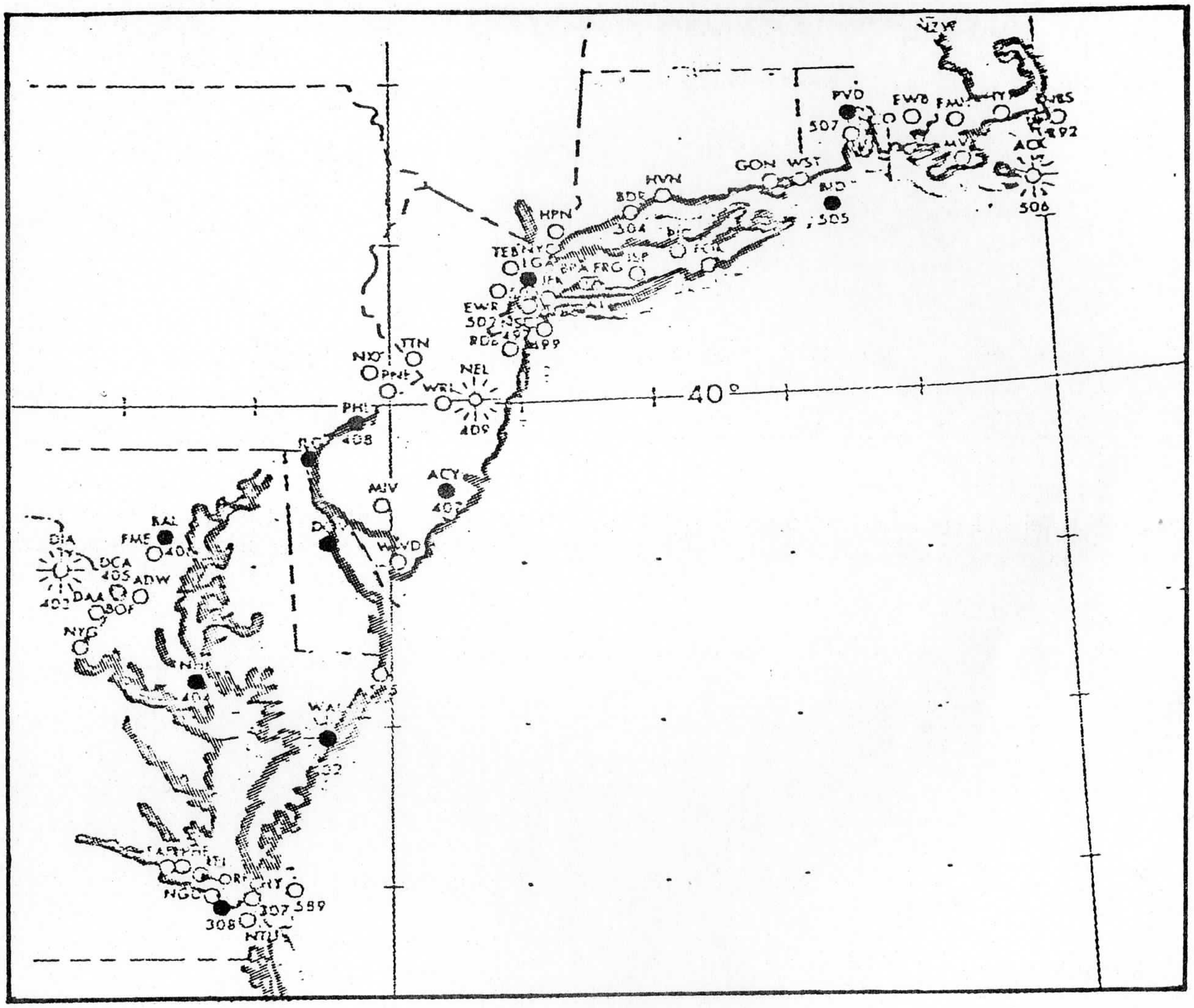


Fig. 4. Verification Data Sources. The stations shown as black dots can be used to infer conditions on Chesapeake Bay, Delaware Bay, Philadelphia Harbor, and Cape May to Providence.

interested in the 'winds' part of the forecast than the 'seas' portion. Except for the obvious effect on visibility, general weather is of no consequence.

The forecasts are not phrased in probabilistic language, but a range of expected values may be given. For example, on 29 April 1977 the forecast called for winds out of the north 15-20 kt between 900 and 1300 GMT in the upper Chesapeake Bay. In the lower Bay the spread was wider, 15-25 kt out of the north. According to the client, one of the shortcomings of present forecasts is the tendency to a large spread in forecast values. The range of greatest interest is roughly speeds over 20 kt. Thus our model of client behavior must include not only the effect of forecast values, but we should consider also the spread of values. It is possible that satellite data could materially improve the shorter range portion of the forecasts and bring about a reduction of the spread of values, making the forecasts more useful to the client.

Without any refinements, our tentative model will be that the client suspends operations for those periods when the maximum speed cited and the minimum cited average to more than 25, or the minimum speed given is over 20. We will ignore the 'seas' forecast, as the threshold values fall below those usually documented in the <u>Mariner's Weather Log</u>. However, the latter is useful for background information for the more important events.

In cases where more detailed verification is required, marine weather reports extracted from the Miscellaneous Surface Data bulletins could be used. Typically, these reports give general weather and visibility plus wind speed and direction (16 points), 'waves' and 'remarks'.

The obvious, direct economic loss to the barge operator is the wages of the crew during periods when prohibitive conditions are forecast, but do not prevail. However, there is a further economic value of the time lost. If none were lost, more loads could be transported, hence more revenue generated. Therefore, the lost time should also be multiplied by a significant fraction of the rate at which transport generates a net economic value (revenue less operating costs excluding those attributable to lost time itself), and the result added to lost wages.

Due to the large increase in the oil company clients of WSC because of the opening of the Baltimore Canyon area to exploratory drilling, we have not been able to make any significant progress in this area. As the situation stabilizes, a case study approach may be the most rewarding.

G. Miscellaneous Clients

There is little to be reported on our miscellaneous clients. For both the construction companies (2) and an automobile club, a compilation of forecasts possibly having economic effects was sent to those clients. The automobile club was unable to correlate these forecasts with their payroll costs although cold or rainy weather can cause the club to call in extra personnel to handle service calls. Since workers with different salaries are called in on different days in random fashion, the economic picture is very confused. Furthermore, misforecasts that seemed to indicate possible effects on the club proved to be inconsequential due to the timing or magnitude of the error.

Insufficient data has been returned from the construction companies on which an analysis can be based. We plan to pursue this further.

V. CLIMATOLOGICAL WORK

To test or measure both forecast skill and resultant economic benefit-loss of sequences of forecasts from different years, we must eliminate the effects of year to year weather variations on the results. For example, in the case of snow plowing, we are most concerned with the cases for which snow near or above the threshold plowing criteria might reasonably have been forecast. Similarly, for heating degree days we are more interested in cases near the threshold for the procurement or generation of supplemental gas.

If in one year there are five plowable storms and the next season fifteen, the economic losses cannot be directly compared--they must be normalized to some common point, and then compared. The same is true for temperature forecasts. What cannot be done is to determine whether these plowable storms were difficult to forecast because that would be purely subjective.

A more general approach would be to estimate the difficulty of the forecast season as a whole, using total season snowfall or the season's total of heating degree days as bases for comparison. Thus, a season with a full standard deviation or more snowfall above the long term mean would present a greater number of forecast opportunities. Similarly, a season with a higher mean value of heating degree days would be expected to have more forecast opportunities near the threshold value. These long term statistics are more easily found than the number of storms of a given amount. The final interpretations of the results of this program are likely to use a combination of approaches. In anticipation of this we have, for the snow and ice example, taken note of both the number of forecasts producing losses, and the number of bad forecasts not producing losses.

We have acquired several series of NOAA publications for verification of forecasts and as source material for normalization statistics. To date we have obtained for each city, or location required the monthly recorded snowfall, its distribution by storm as well as uniform 30 year means of the monthly snowfall. Using these, monthly departures for the control period have been obtained. We have generated the standard deviations from the individual years, data making use of the 30 year reference period, and expressed the monthly departures in terms of percent of the monthly standard deviation.

We have also obtained statistics for the temperature sensitive operations. We now have both 30 and 40 year means and standard deviations of monthly average temperatures as well as the control period monthly average departures from long term average values of daily maximum, daily minimum and daily average temperatures. The 30 yr. base is used for T_{max} and T_{min}, a 40 yr. base for T_{ave}. The T_{ave} departure has also been obtained as a percent of the standard deviation of the 40 individual years in the base period. Finally, departures and standard deviations are available from a 20 yr. base of heating degree days and an 8 year base of cooling degree days for many locations. The official source documents used for data on normals and departures from normal are summarized below.

Source Documents From NOAA

Climatological Data: Data, issued monthly, listed by station name and climatological division, for each state or geographical region. Monthly average data for T_{max}, T_{min}, T_{ave}, mean departure from normal, degree days for month, number of days with T>90F, T_{max} <32F and T_{min} <32F and T_{min} <0. For precipitation, the total accumulation and the departure from normal are given. For snow and sleet the total accumulation is given, the maximum depth on the ground and the number of days with snowfall exceeding 0.10, 0.50 and 1.00 inches. Daily data are given for precipitation, T_{max}, T_{min}, snowfall and snow on ground.

Climatological Data - Annual Summary: This gives average temperatures and departures from normal for each month, total precipitation and departure from normal for each month. Temperature extremes and freeze data include highest and lowest temperature with dates, dates of last spring T_{min} less than 16, 20, 24, 28 and 32F as well as the first fall T_{min} less than 32, 28, 24, 20 and 16F.

Local Climatological Data: Issued monthly for each station, summarizes daily data including T_{max}, T_{min}, T_{ave}, departure from normal, heating degree days, and cooling degree days. Precipitation data include snow and ice pellets on the ground at 7 a.m., daily water equivalent of precipitation, daily depth of snow and ice pellets. Also given are daily average pressure, daily average resultant wind vector, average speed, speed and direction of the fastest mile, minutes of sunshine, percent of possible, average daytime sky cover in tenths. Water equivalent of precipitation is also given hourly. There are three hourly observations of sky cover, ceiling, visibility, dry bulb, wet bulb and dewpoint temperatures, relative humidity, wind speed and direction as well as current weather.

Climatography of the United States No. 20: These are issued for individual stations and summarize means and extremes. Some cover 1951-1972, 1931-1960, 1948-1971 etc. The formats of the temperature and precipation data resemble the monthly summaries. T_{max}, T_{min}, and T_{ave} are also given by month for the individual years. Monthly normals are given for temperature, precipitation, heating and cooling degree days. Total precipitation and snowfall totals are given monthly by year for the period. There are freeze and precipitation probability tables.

The means and departures from normals will be continually updated as the program progresses. The detailed normalization procedures will be worked out (for snow and ice and degree-day cases) using the two control seasons, before comparisons are made with the 'with satellite seasons.'

VI. THIRD YEAR PLANS

Due to the delay in installing the McIDAS system in Bedford, we have an additional control year on which statistics can be compiled for all clients. This will provide a number of advantages to us in our analysis. First, while our techniques for each client have already been worked out, we will be able to recheck our methods on an additional set of data. Second, we will, after normalizing for weather variability between the two years, be able to compare results to see how different the economic loss was for each year and for each client. This will give some measure of how random variability and differences in the quality of forecasting affect the results apart from the simple climatic changes over the two year period. We have supposed these factors to be relatively small; however, this approach will provide concrete verification of these assumptions.

The McIDAS system has nearly been installed, and training of WSC staff will follow. By the start of the 1978-79 snow and ice season we will be able to monitor the use of satellite data in Weather Services' predictions. This will be done not only by examining the overall quality of the forecasts as compared (after normalization) to the previous years, but also by watching for suitable case studies where we can document specific uses of satellite data in predicting significant weather events, especially those where the potential losses to clients are great.

VII. PERSONNEL

During the past year the program has been contributed to by three meteorologists--Dr. David Suchman, Dr. Barry Hinton, and Mr. Brian Auvine. In addition, Mr. David Floyd assisted with the client contact and forecast verification, and Mr. Russell Dengel with the climatological statistics. The engineering work was principally performed by Robert Norton, Chris Davis, Gary Banta, Robert Oehlkers, Eldon Grindey and a large number of students. System software was provided by John Benson and Ralph Dedecker, while user software was adapted by Gary Chatters.

With the completion of the engineering phase, most of the work during the coming year will be performed by the three meteorologists.

VIII. SUMMARY

The past year has seen continued progress in our primary goal: determining the economic impact of satellite data. We have been working in cooperation with Weather Services Corporation in analysis of the control year data, an analysis which has included a study of the operations and quality of forecasting for snow and ice clearing, gas and electric utility, commodity, and fuel oil clients. These control year results have been for the most part completed and summarized in this report.

Despite delays in the installation of the interactive computer system, we should, in the next year, be able to collect statistics and case study information on the same clients that were included in the control year data. A comparison of the results from both the control year and the period of satellite data usage, normalized for year to year differences in weather, should lead to a successful conclusion to this study.

References

Diak, George, 1978: Models for the Determination of Soil and Plant Moisture Parameters Using Remotely Sensed Temperature Data, Studies of Soundings and Imaging Measurements, Final report on NAS5-24136, Space Science and Engineering Center, University of Wisconsin, Madison.

Stout, John, David W. Martin and Dhirendra N. Sikdar, 1978: Rainfall Estimation from Geostationary Satellite Images over the GATE Area, Final Report on NOAA grant 04-5-158-47, Space Science and Engineering Center, University of Wisconsin, Madison.

APPENDICES

APPENDIX A: SAMPLE SNOW FORECASTS

Forecast A

WEATHER SERVICES CORPORATION
131A GREAT ROAD, BEDFORD, MASSACHUSETTS 01730

OPERATIONAL WEATHER FORECAST

Multiple Listing Dec. 28 815 AM

1 ☐ DAILY FORECAST
2 ☐ PRELIMINARY FORECAST
3 ☐ FORECAST
4 ☐ SUPPLEMENTARY
5 ☐ REVISED FORECAST
6 ☐ WEEK-END OUTLOOK

		TODAY	GENERAL WEATHER	* TEMP.	WINDS	GUSTS	
7		1AM-3AM					
8		3AM-6AM					
9		6AM-9AM					
10	✓	9AM-NOON	light snow	12	NNE 5-10		T-1"
11		NOON-3PM					
12	✓	3PM-6PM	Snow occ'nly Moderate	20	NNE 10-15		2-4" ~~3-6~~
13		6PM-9PM					
14	✓	9PM-MID.	Becmg light snow	18	NNW 15	25	[illegible]
15		REMARKS:	* Temperatures relate to the last hour of the 3-hour Forecast Period.				

[redacted] 4"+
50%

		TOMORROW	GENERAL WEATHER	* TEMP.	WINDS	GUSTS	
16	✓	1AM-3AM	Snow Forecast	17	N 15	30	
17	✓	3AM-6AM	P Cloudy	15		35	
18		6AM-9AM					
19		9AM-NOON					
20	✓	NOON-3PM	Tapering to P Cldy	20		35	
21		3PM-6PM					
22		6PM-9PM					
23	✓	9PM-MID.	Taper	12	X	30	
24		REMARKS:	* Temperatures relate to the last hour of the 3-hour Forecast Period.				

25 ✓ REMARKS:

P. Cloudy max 17
min 10

OK

WEATHER SERVICES CORPORATION
131A GREAT ROAD, BEDFORD, MASSACHUSETTS 01730

OPERATIONAL WE[illegible]R FORECAST
Multiple Listing

Dec. 28 1300

1 ☐ DAILY FORECAST
2 ☐ PRELIMINARY FORECAST
3 ☐ FORECAST
4 ☐ SUPPLEMENTARY
5 ☐ REVISED FORECAST
6 ☐ WEEK-END OUTLOOK

TODAY			GENERAL WEATHER	* TEMP.	WINDS	GUSTS	
7		1AM-3AM					
8		3AM-6AM					
9		6AM-9AM					
10		9AM-NOON					
11	✓	NOON-3PM	Cloudy, few flurries	19	N 5-10		T
12		3PM-6PM					
13		6PM-9PM					
14	✓	9PM-MID.	Ocnl S- dofg	20	N 10		T
15		REMARKS:	* Temperatures relate to the last hour of the 3-hour Forecast Period.				

TOMORROW			GENERAL WEATHER	* TEMP.	WINDS	GUSTS	
16	✓	1AM-3AM	S	21	NNE 10	15	1-2
17		3AM-6AM					
18	✓	6AM-9AM	Becmg Ocnl S-	19	NNW 15	25	2-4
19		9AM-NOON					
20	✓	NOON-3PM	PC	15	NW 18	30	
21		3PM-6PM					
22	✓	6PM-9PM	Fair	10			
23		9PM-MID.					
24		REMARKS:	* Temperatures relate to the last hour of the 3-hour Forecast Period.				

Low 5-10

25		REMARKS:

WEATHER SERVICES CORPORATION
131A GREAT ROAD, BEDFORD, MASSACHUSETTS 01730

OPERATIONAL WEATHER FORECAST

Multiple Listing

Dec. 28 : 2045

1 ☐ DAILY FORECAST
2 ☐ PRELIMINARY FORECAST
3 ☐ FORECAST
4 ☐ SUPPLEMENTARY
5 ☐ REVISED FORECAST
6 ☐ WEEK-END OUTLOOK

		TODAY	GENERAL WEATHER	* TEMP.	WINDS	GUSTS	
7		1AM-3AM					
8		3AM-6AM					
9		6AM-9AM					
10		9AM-NOON					
11		NOON-3PM					
12		3PM-6PM					
13		6PM-9PM					
14	✓	9PM-MID.	Cloudy Occl S-	19	N 5-10		T
15		REMARKS:					

* Temperatures relate to the last hour of the 3-hour Forecast Period.

		TOMORROW	GENERAL WEATHER	* TEMP.	WINDS	GUSTS	
16	✓	1AM-3AM	Occl S-	21	N10		T
17	✓	3AM-6AM	S dvlpg	22	N10-15		T-1
18		6AM-9AM					
19	✓	9AM-NOON	S	25	N15	20	2-4
20		NOON-3PM					
21	✓	3PM-6PM	S	24	N15	30	
22	✓	6PM-9PM	Becmg Occl flurries	22	NW 15	30	
23	✓	9PM-MID.	Becmg P.C.	19	NW 15	25	
24	✓	REMARKS:					

* Temperatures relate to the last hour of the 3-hour Forecast Period.

Clearing, low near 10°. Risk of 4"+ during Wed aftn

25		REMARKS:

WEATHER SERVICES CORPORATION

131A GREAT ROAD, BEDFORD, MASSACHUSETTS 01730

OPERATIONAL WEATHER FORECAST

Multiple Listing Dec. 29: 0930

1 ☐ DAILY FORECAST
2 ☐ PRELIMINARY FORECAST
3 ☐ FORECAST
4 ☐ SUPPLEMENTARY
5 ☐ REVISED FORECAST
6 ☐ WEEK-END OUTLOOK

TODAY			GENERAL WEATHER	* TEMP.	WINDS	GUSTS	added
7		1AM-3AM					
8		3AM-6AM					
9		6AM-9AM					
10	✓	9AM-NOON	S early Melt	22	N10-15		1-3
11		NOON-3PM					
12	✓	3PM-6PM	Becmg intmt S	22	N15		5-7
13	✓	6PM-9PM	Cloudy end SW-	21	N15		—
14		9PM-MID.					
15	✓	REMARKS:	* Temperatures relate to the last hour of the 3-hour Forecast Period.				

Total Snow Accum 7-9

TOMORROW			GENERAL WEATHER	* TEMP.	WINDS	GUSTS	
16	✓	1AM-3AM	Cloudy, few flurries	15	NW15	30	
17	✓	3AM-6AM	PC	15	NW15	35	
18		6AM-9AM					
19		9AM-NOON					
20	✓	NOON-3PM	Fair	18	NW18	35-40	
21		3PM-6PM					
22		6PM-9PM					
23		9PM-MID.					
24	✓	REMARKS:	* Temperatures relate to the last hour of the 3-hour Forecast Period.				

Fair at nite, low 5°

25		REMARKS:

P.C. 18/5

OK

WEATHER SERVICES CORPORATION
131A GREAT ROAD, BEDFORD, MASSACHUSETTS 01730

OPERATIONAL WEATHER FORECAST
Multiple Listing

Dec. 29: 1115

1 ☐ DAILY FORECAST
2 ☐ PRELIMINARY FORECAST
3 ☐ FORECAST
4 ☐ SUPPLEMENTARY
5 ☐ REVISED FORECAST
6 ☐ WEEK-END OUTLOOK

		TODAY Wed	GENERAL WEATHER	* TEMP.	WINDS	GUSTS	
7		1AM-3AM					
8		3AM-6AM					
9		6AM-9AM	CLDY S.	19	N 7		
10		9AM-NOON					
11		NOON-3PM	CLDY S	21	N 10		
12		3PM-6PM					
13		6PM-9PM	CLDY S → Flurries	20	N-NW 12	16	
14		9PM-MID.					
15		REMARKS:	* Temperatures relate to the last hour of the 3-hour Forecast Period.				

ACC 2-4" 50% RISK 4+

		TOMORROW Thur	GENERAL WEATHER	* TEMP.	WINDS	GUSTS	
16		1AM-3AM	CLDY - P.C.	16	NW 15	23	
17		3AM-6AM	MIN	13			
18		6AM-9AM	P.C.	16	NW 19	30-35	
19		9AM-NOON					
20		NOON-3PM	C.C. ⊙SW'S	18	NW 22	35-45	
21		3PM-6PM					
22		6PM-9PM	V.C. Few S--	13	NW 18	30	
23		9PM-MID.					
24		REMARKS:	* Temperatures relate to the last hour of the 3-hour Forecast Period.				

MIN 3

25		REMARKS:

Fri

P.C. . . . .

MAX 18
MIN 0

NW 10-18 GUST 25

Forecast 8

WEATHER SERVICES CORPORATION
131A GREAT ROAD, BEDFORD, MASSACHUSETTS 01730

OPERATIONAL WEATHER FORECAST
Multiple Listing

Jan. 13 0930

1 ☐ DAILY FORECAST
2 ☐ PRELIMINARY FORECAST
3 ☐ FORECAST
4 ☐ SUPPLEMENTARY
5 ☐ REVISED FORECAST
6 ☐ WEEK-END OUTLOOK

		TODAY Thu	GENERAL WEATHER	* TEMP.	WINDS	GUSTS	
7		1AM-3AM					
8		3AM-6AM					
9	✓	6AM-9AM	Fair	13	NW-W 14		
10		9AM-NOON					
11	✓	NOON-3PM	Fair to p.c	20	W-NW 17		
12		3PM-6PM					
13	✓	6PM-9PM	Inc Clouds	15	N 10		
14		9PM-MID.					
15		REMARKS:	* Temperatures relate to the last hour of the 3-hour Forecast Period.				

		TOMORROW Fri	GENERAL WEATHER	* TEMP.	WINDS	GUSTS	
16	✓	1AM-3AM	Intermittent light S-	18	NE 7		
17	✓	3AM-6AM	" "	19	NE 9		
18	✓	6AM-9AM	S- or flurries end	23	NE-NW 10		Total
19	✓	9AM-NOON	Var Clouds	27	NW 10		1-3"
20		NOON-3PM					
21	✓	3PM-6PM	p.c to cldy	25	NW 10		
22		6PM-9PM					
23	✓	9PM-MID.	M Cldy	24	NW-N 9		
24		REMARKS:	* Temperatures relate to the last hour of the 3-hour Forecast Period.				

S- dev after midnite

25 REMARKS: Sat

Snow during the day, may mix with E/R. Max 28-33 Winds E-SW 12-18 G30

WEATHER SERVICES CORPORATION
131A GREAT ROAD, BEDFORD, MASSACHUSETTS 01730

OPERATIONAL WEATHER FORECAST
Multiple Listing

Jan. 13 1400

1 ☐ DAILY FORECAST
2 ☐ PRELIMINARY FORECAST
3 ☐ FORECAST
4 ☐ SUPPLEMENTARY
5 ☐ REVISED FORECAST
6 ☐ WEEK-END OUTLOOK

TODAY			GENERAL WEATHER	* TEMP.	WINDS	GUSTS	
7		1AM-3AM					
8		3AM-6AM					
9		6AM-9AM					
10		9AM-NOON					
11		NOON-3PM					
12	✓	3PM-6PM	Fair	15	NW 10		
13		6PM-9PM					
14	✓	9PM-MID.	Incrg Cloud	10	L&V		
15		REMARKS:	* Temperatures relate to the last hour of the 3-hour Forecast Period.				

TOMORROW			GENERAL WEATHER	* TEMP.	WINDS	GUSTS	
16	✓	1AM-3AM	Cloudy	12	SE 5-6		
17	✓	3AM-6AM	S dvlpg	16	SE 5-10		T-<1
18	✓	6AM-9AM	S-	20	E 10		1
19		9AM-NOON					
20	✓	NOON-3PM	Becmg flurries	27	NE 10-15		1-3
21		3PM-6PM					
22	✓	6PM-9PM	Ocnl flurries	27	NE 10-15		
23		9PM-MID.					
24	✓	REMARKS:	* Temperatures relate to the last hour of the 3-hour Forecast Period.				

Risk of S redeveloping aftermidnite with about 55% risk of 4"+

25		REMARKS:

WEATHER SERVICES CORPORATION
131A GREAT ROAD, BEDFORD, MASSACHUSETTS 01730

OPERATIONAL WEATHER FORECAST

Multiple Listing

Jan. 14 0930

1 ☐ DAILY FORECAST
2 ☐ PRELIMINARY FORECAST
3 ☐ FORECAST
4 ☐ SUPPLEMENTARY
5 ☐ REVISED FORECAST
6 ☐ WEEK-END OUTLOOK

		TODAY Fri	GENERAL WEATHER	* TEMP.	WINDS	GUSTS	
7		1AM-3AM					
8		3AM-6AM					
9	✓	6AM-9AM	Cloudy Intermitt S-	17	S-SW 5		1/2-3/4"
10		9AM-NOON					
11	✓	NOON-3PM	M Cloudy few flurries	26	SW-SE 8		1" or less
12		3PM-6PM					
13	✓	6PM-9PM	Cloudy	25	SE-E 6		
14	✓	9PM-MID.	Snow re-dev	28	E-NE 8		1-3"
15		REMARKS:	* Temperatures relate to the last hour of the 3-hour Forecast Period.				

		TOMORROW Sat	GENERAL WEATHER	* TEMP.	WINDS	GUSTS	
16		1AM-3AM					
17	✓	3AM-6AM	Snow	29	NE 9-12		3-5"
18		6AM-9AM					
19	✓	9AM-NOON	S- or S/R- mixed	32	NE 10	18	4-6"
20		NOON-3PM					
21	✓	3PM-6PM	S- end.	30	NE-NW 14	22	
22		6PM-9PM					
23	✓	9PM-MID.	Cloudy-p.c.	26	NW 14	18	
24		REMARKS:	* Temperatures relate to the last hour of the 3-hour Forecast Period.				

25 REMARKS: Sun

p.c to fair

Max 26-31 Wind NW 10-16

WEATHER SERVICES CORPORATION
131A GREAT ROAD, BEDFORD, MASSACHUSETTS 01730

OPERATIONAL WEATHER FORECAST

Multiple Listing

Jan. 14 1300

1 ☐ DAILY FORECAST
2 ☐ PRELIMINARY FORECAST
3 ☐ FORECAST
4 ☐ SUPPLEMENTARY
5 ☐ REVISED FORECAST
6 ☐ WEEK-END OUTLOOK

		TODAY	GENERAL WEATHER	* TEMP.	WINDS	GUSTS	
7		1AM-3AM					
8		3AM-6AM					
9		6AM-9AM					
10		9AM-NOON					
11	✓	NOON-3PM	Cloudy chance flurry	25	SE 5-10		
12		3PM-6PM					
13	✓	6PM-9PM	Snow devlpg	27	ESE 5-10		<1
14		9PM-MID.					
15		REMARKS:	* Temperatures relate to the last hour of the 3-hour Forecast Period.				

		TOMORROW	GENERAL WEATHER	* TEMP.	WINDS	GUSTS	
16	✓	1AM-3AM	S, occnl mdt	28	NE 10-15		5-6"
17		3AM-6AM					
18	✓	6AM-9AM	S tapering off	29	NNE 15	25	6-8"
19	✓	9AM-NOON	Becmg PC	33	NNW 15	25	
20	✓	NOON-3PM	PC	33	NW 15	25	
21		3PM-6PM					
22		6PM-9PM					
23		9PM-MID.					
24	✓	REMARKS:	* Temperatures relate to the last hour of the 3-hour Forecast Period.				

Fair at nite, low 10-15°

25 ✓ REMARKS: Sunday

Vrbl Cloud

20/10

WEATHER SERVICES CORPORATION
131A GREAT ROAD, BEDFORD, MASSACHUSETTS 01730

OPERATIONAL WEATHER FORECAST
Multiple Listing

Jan 14: 1015 PM

1 ☐ DAILY FORECAST
2 ☐ PRELIMINARY FORECAST
3 ☐ FORECAST
4 ☐ SUPPLEMENTARY
5 ☐ REVISED FORECAST
6 ☐ WEEK-END OUTLOOK

		TODAY	GENERAL WEATHER	* TEMP.	WINDS	GUSTS	
7		1AM-3AM					
8		3AM-6AM					
9		6AM-9AM					
10		9AM-NOON					
11		NOON-3PM					
12		3PM-6PM					
13		6PM-9PM					
14	✓	9PM-MID.	S	19	N5-10		1-2
15		REMARKS:	* Temperatures relate to the last hour of the 3-hour Forecast Period.				

		TOMORROW	GENERAL WEATHER	* TEMP.	WINDS	GUSTS	
16	✓	1AM-3AM	S, briefly Mdt	18	N10-15		3-4
17	✓	3AM-6AM	S.	17	"		6-8
18	✓	6AM-9AM	S, only Intmt	18	N10	20	7-9
19	✓	9AM-NOON	S ending	21	|	|	
20	✓	NOON-3PM	Bcmg PC	25	|	|	
21		3PM-6PM	|				
22		6PM-9PM					
23		9PM-MID.					
24	✓	REMARKS:	* Temperatures relate to the last hour of the 3-hour Forecast Period.				

Fair. PC   Min temps: 10-15
at nite.

25		REMARKS:

OK

OM

SATURDAY 1/8/77
1500EST FORECAST

FORECAST C

SATURDAY...INCREASING CLOUDS TONITE WITH CHANCE OF A LITTLE LITE SNOW OR FLURRIES DEVELOPING IN WESTERN G AND H AFTER 3AM, LOWS RANGING FROM 5-15 MOUNTAINS TO 15-25 REST OF AREA. VARIABLE WINDS LESS THAN 10MPH TONITE.

FOR ZONES NORTHWEST HALF OF D ALL OF E AND F
SUNDAY/MONDAY: CLOUDY SUNDAY WITH RISK OF A FLURRY OR 2 DURING THE DAY WITH STEADY LITE SNOW DEVELOPING IN THE EVENING POSSIBLY BECOMING OCCASIONALLY MODERATE AFTER MIDNITE SUNDAY THEN ENDING AS A FEW FLURRIES MONDAY AFTERNOON. TEMPS THRU THE PERIOD 22-32 WITH COLDEST TEMPS IN ZONE F. NORTH TO NORTHEAST WINDS AT 7-14MPH SUNDAY INCREASING TO 12-20 SUNDAY NIGHT AND POSSIBLY TO 15-30MPH MONDAY MORNING BEFORE SHIFTING INTO THE NORTHWEST MONDAY AFTERNOON. ACCUMS FROM THIS STORM MAY RUN BETWEEN 4-8 INCHES.

SOUTHEAST HALF OF D, NORTH HALF OF B
SUNDAY/MONDAY: CLOUDY SUNDAY WITH CHANCE OF A FLURRY OR 2 , THEN STEADY LITE SNOW DEVELOPING SUNDAY EVENING CHANGING TO A MIXTURE ALL OR RAIN MONDAY MORNING, THEN ENDING BRIEFLY AS SNOW MONDAY AFTERNOON. TEMPS NEAR 30 SUNDAY RISING TO 32-35 SUNDAY NIGHT AND MONDAY MORNING FALLING INTO UPPER 20'S MONDAY AFTERNOON. NORTH TO NORTHEAST WINDS AT 7-14MPH SUNDAY INCREASING TO 12-25MPH SUNDAY NIGHT AND POSSIBLY 18-35MPH MONDAY MORNING BEFORE SHIFTING TO NORTHWEST MONDAY AFTERNOON. ACCUMS EXPECTED TO RUN BETWEEN 1-3 INCHES OF SLUSHY SNOW.

SUNDAY, JAN 9, 1977, 1010EST

REMARKS...

STORM CURRENTLY DEVELOPING VICINITY OF CENTRAL LOUISIANA WILL MOVE EAST TO EAST-NORTHEAST NEXT 6-12 HOURS, THEN START TURN TO THE NORTHEAST, LIKELY MOVING OVER THE VIRGINIA/NORTH CAROLINA COASTAL SECTIONS HEADING TOWARD SOUTHERN NEW ENGLAND MONDAY. STILL A LOT OF QUESTIONS AS TO THE EXACT TRACK AND SUBSEQUENTLY THE PRECIPITATION AMOUNTS AND TYPE. THERE ARE SUGGESTIONS THAT STORM WILL BECOME MONUMENTAL IN NATURE, WITH HEAVY PRECIPITATION ALONG ALL OF THE EASTERN SEABOARD. RAIN/SNOW LINE LIKELY TO SET UP NEAR THE BALTIMORE/WASHINGTON AXIS, AT THIS TIME WE FAVOR JUST WEST FOR FINAL LINE.

ZONES F AND E...

FEW FLURRIES DEVELOPING DURING THE AFTERNOON. SNOW DEVELOPING EARLY EVENING, VICINITY OF 7-10PM THIS EVENING. SNOW THEN BECOMING OCCASIONALLY MODERATE TO HEAVY, WITH SLEET AND BORDERLINE FREEZING RAIN MIXING IN OVER EASTERN E AND SOUTHEASTERN F DURING THE EARLY MORNING HOURS, LIKELY TO ALL MIXTURES OF SLEET AND BORDERLINE RAIN THOSE AREAS BY DAYBREAK MONDAY, BUT THEN LIKELY BACK TO ALL SNOW AGAIN PRIOR TO ENDING MONDAY LATE AFTERNOON. PRELIMINARY SNOW ACCUMULATIONS RANGING FROM 10-15 INCHES WESTERN BORDER AREAS OF F TO 3-6 INCHES EASTERN E AND SOUTHEASTERN F. RISK OF SOME ADDED ACCUMULATION LATTER AREAS AFTER CHANGEOVER. TEMPERATURES DURING TONITE BORDERLINE 30-33, BUT STARTING TO DROP OFF AFTER SUNRISE, DROPPING INTO THE UPPER TEENS AND LOW 20,S MONDAY. WINDS BECOMING NORTHEAST 15-20 AND GUSTY TONITE AND NORTHERLY 20-25 AND GUSTY MONDAY.

ZONES D, NORTHERN B AND C...

CHANCE FEW FLURRIES AFTERNOON. SNOW DEVELOPING 7-9PM C AND REMAINDER BY 10-11PM. SNOW CONTINUING FOR ABOUT 6-7 HOURS, THEN BECOMING MIXTURES OF SLEET/SNOW/BORDERLINE RAIN. ACCUMULATIONS THRU THAT TIME 3-6 INCHES. RAIN HEAVY AT TIMES INTO MONDAY FORENOON, THEN RISK OF BACK TO SNOW AGAIN PRIOR TO ENDING MONDAY AFTERNOON. TEMPERATURES IN SNOW NEAR 30-32, THEN IN MIDDLE 30,S IN MIXTURES, BUT DROPPING INTO 20,S MONDAY LATE FORENOON AND AFTERNOON. WINDS SIMILAR TO F AND E ABOVE.

STORM FOLLOW UP AND SCHEDULED FORECAST......

REMARKS.........STILL NO BASIC CHANGES TO FORECAST THINKING ALTHOUGH TIMING OF SIGNIFICANT PRECIPITATION MUST BE ADVANCED SOMEWHAT.

ZONES F AND E......OCCASIONAL LIGHT SNOW DEVELOPING CURRENTLY SHOULD BECOME STEADIER 4-7 PM AND OCCASIONALLY MODERATE AT TIMES DURING THE EVENING AND NIGHT. SLEET AND BORDERLINE FREEZING RAIN MIXING IN FROM THE SOUTHEAST DURING THE EARLY MORNING HOURS, LIKELY BECOMING MOSTLY OR ALL NON-FREEZING RAIN AND SOME SLEET DURING THE FORENOON BUT CHANGING BACK TO SNOW PRIOR TO ENDING MONDAY AFTERNOON. ACCUMULATIONS RANGING FROM POTENTIAL 10-15 INCHES WESTERN BORDER AREAS DOWN TO 3-6 INCHES SOUTHEASTERN PORTIONS WITH FINAL FIGURES THERE DEPENDENT ON MIX OF PRECIPITATION AND EXTENT OF RAIN. TEMPERATURES 27-30 THIS EVENING RISING TO 30-34 DURING THE EARLY MORNING HOURS AND MONDAY FORENOON DROPPING OFF TO THE 20'S MONDAY AFTERNOON AND 5-12 OVERNIGHT. WINDS NORTHEAST INCREASING TO 10-18 MPH BY MIDNIGHT BECOMING 12-20 MPH GUSTY 25 MPH LATE TONIGHT AND MONDAY MORNING SHIFTING TO NORTHWEST 20-30 MPH AND GUSTY BY MONDAY AFTERNOON, SLOWLY DIMINISHING AT NIGHT.

ZONES D, NORTHERN C AND B.......OCCASIONAL LIGHT SNOW SPREADING EASTWARD ACROSS THE AREA CURREN TO 5 PM BECOMING THICKER BY 5-8 PM AND OCCASIONALLY MODERATE DURING THE LATE EVENING. PRECIPIATION LIKELY BECOMING MIXTURE OF SNOW/SLEET AND BORDERLINE RAIN BY 2-4 AM MONDAY AFTER ACCUMULATIONS OF 3-6 INCHES OR SO. RAIN HEAVY AT TIMES INTO THE FORENOON OR MIDDAY THEN RISK OF RAIN CHANGING BACK TO A PERIOD OF SNOW BEFORE ENDING DURING THE EARLY OR MID AFTERNOON. TEMPERATURES 30-32 DROPPING TO 28-31 THIS EVENING, RISING TO 34-38 DURING THE AM MONDAY, BUT DROPPING BACK INTO THE 20'S DURING THE AFTERNOON AND TO THE TEENS AT NIGHT. WINDS NORTHEAST INCREASING TO15-20 MPH GUSTY 30 MPH BY LATE TONIGHT SHIFTING TO NORTHWEST 20-30 MPH AND GUSTY MONDAY AFTERNOON, DIMINISHING SLOWLY AT NIGHT.

1-9-77 2140 EST

ZONES E AND F
SNOW BECOMING OCCASIONALLY MODERATE AT TIMES TONIGHT. SOME SLEET AND FREEZING RAIN MIXING MIXING OVER SOUTHEASTERN PORTIONS DURING THE EARLY MORNING HOURS. PRECIPITATION BECOMING ALL SNOW MONDAY AFTERNOON AND ENDING LATE AFTERNOON OR BY EVENING. ACCUMULATIONS RANGING FROM 10-15 INCHES WESTERN AND NORTHERN F AND NORTWESTERN E TO 3 TO 6 INCHES WHERE FREEZING AND RAIN BECOME MIXED. TEMPERATURES MID TO UPPER 20S RISING TO LOW 30S SOUTHEASTERN PORTIONS DURING THE EARLY MORNING HOURS. THEN DROPPING INTO THE MID 20S DURING THE AFTERNOON MONDAY. CONSIDERABLE DRIFTING AND BLOWING SNOW DURING THE DAY MONDAY. WINDS EAST TO NORTHEAST 10-20 MPH TONIGHT AND NORTH TO NORTHWEST 15-25 MPH WITH HIGHER GUSTS DURING THE DAY MONDAY.

ZONES B,C AND D
MIXTRES OF SNOW, SLEET AND FREEZING RAIN WITH BOARDERLINE TEMPERATURES. BECOMING ALL SNOW BEFORE ENDING MID TO LATE AFTERNOON. ACCUMULATION 3-6 INCHES. RISK OF RAIN HEAVY AT TIMES DURING THE FORENOON WITH TEMPERATURES IN THE 32-34 DEGREE RANGE. , WINDS NORTHEAST 10-20 MPH TONIGHT BECOMING NORTH TO NORTHWEST 15-25 MPH WITH HIGHER GUSTS BY AFTERNOON MONDAY.

ZONES E AND F

MIXTURE OF RAIN, FREEZING RAIN AND DRIZZLE DURING THE NEXT 3-6 HOURS, SOME ICING VALLEY AREAS, ESPECIALLY ZONE F. TURNING COLDER DURING THE AFTERNOON WITH PRECIPITATION CHANGING TO SNOW. SNOW BECOMING FLURRIES THIS EVENING AND ENDING IN THE LATE EVENING. ACCUMULATIONS 1-3 INCHES, LOCALLY 3-5 INCHES HIGHER ELEVATIONS W PORTIONS.

TEMPERATURES IN THE UPPER 20,S WESTERN LOW AREAS TO MID 30,S E PORTIONS TODAY, DROPPING INTO THE LOW TO MID 20,S BY EVENING. OVERNITE LOWS IN THE MID TO UPPER TEENS. EASTERLY WINDS 5-15 MPH, BECOMING VARIABLE LATER THIS MORNING AND SHIFTING TO WEST AND NORTHWESTERLY, INCREASING TO 20-30 MPH THIS AFTERNOON, GUSTY TO 45 MPH THIS EVENING AND TONITE.

TUESDAY...PTLY CLOUDY, WINDY AND COLD. A FEW LITE SNOW SHWRS W PORTIONS DURING THE DAY. LOWS TUE MORNING IN THE UPPER TEENS TO LOW 20,S. HIGHS IN THE 20,S. WESTERLY WINDS 18-25 MPH AND GUSTY.

ZONES B, C AND D

RAIN, OCCASIONALLY MODERATE TO HEAVY AT TIMES E PORTIONS THIS MORNING, MIXING WITH AND CHANGING TO SNOW THIS AFTERNOON, DIMINISHING TO SNOW SHWRS BY EVENING. ACCUMULATIONS OF ABOUT 1-2 INCHES W AND NW PORTIONS, LITTLE, IF ANY E AND SE PORTIONS. TEMPERATURES IN THE MID 30,S WEST TO LOW 40,S EAST, DROPPING INTO THE MID 20,S WEST AND LOW 30,S EAST BY LATE AFTERNOON. WINDS VARIABLE, BECOMING WESTERLY 20-30 MPH AND GUSTY THIS AFTERNOON.

TUESDAY...VARIABLE CLOUDINESS AND COLDER. LOWS TUE MORNING IN THE LOW TO MID 20,S. HIGHS IN THE UPPER 20,S TO NEAR 30. WINDS WEST TO NORTHWEST 18-25 MPH, GUSTY TO 45 MPH DURING THE DAY, DIMINISHING SLOWLY AT NITE.

APPENDIX B: THE ECONOMIC EFFECTS OF PRIVATE METEOROLOGICAL FORECASTING (SUBMITTED TO BAMS)

THE ECONOMIC EFFECTS OF PRIVATE METEOROLOGICAL FORECASTING

David Suchman
Brian A. Auvine
Barry H. Hinton

Space Science & Engineering Center
University of Wisconsin
Madison, Wisconsin 53706

Abstract

Private meteorologists provide specialized services to a wide variety of industrial and governmental clients. These services, whether forecasts or current weather data are tailored to the specific needs of the subscribers, and have a wide economic impact if used properly.

The users of private forecasts include governmental bodies concerned with snow and ice removal, gas and electric utilities, commodities dealers and brokers, oil companies, construction companies and many others. Though many subscribe for financial reasons, others use it mainly for convenience. A surprisingly large number of clients, however, really don't understand the information they receive and consequently, do not use it to its greatest advantage.

Accuracy of forecast products, and timing at specific locales are the two crucial needs of the users of applied weather forecasts. For example, a municipal street department, in order to most efficiently use its crews, needs to know when the precipitation will start, the form it will take, and when it will become heavy. A failure to call crews out on time can cause costly delays, inconvenience and dangers to the public; alerting them too soon can cost thousands of dollars in manpower and equipment waste. The exact timing and accuracy of temperature conditions can be worth thousands to utility companies needing to know the optimal time to put "on line" more expensive sources of power. Analogous situations hold for other client groups, but each client has its own "critical" region where forecast accuracy can have a great economic effect.

1. Introduction

Meteorological information specially tailored to the needs of both the public and private sectors of the economy has become increasingly in demand in recent years. As industrial and business operations generally become more efficient, well-planned, and technical in nature, the effect of small environmental changes have become of obvious importance to the overall success of an operation. Many, if not most jobs are weather sensitive either directly or indirectly. As the public has become more aware of how weather affects their personnel, equipment, and timetables, they, of course, desire to control these effects as much as possible. On the other side, meteorologists are becoming better equipped to satisfy these desires through advances in communications, real time weather depiction, and improved forecast techniques.

The task of the meteorological consulting firm is to provide the technical information to meet the client's needs, which, because of their highly detailed and specialized nature cannot be provided for by the National Weather Service. Consulting covers many diverse areas, providing meteorological advice on instrumentation, weather modification, advertising and marketing, statistical analyses, surveys and field studies, data processing, legal advice, radio and television programming, as well as short and long term forecasting for various business and industrial operations. In this paper we intend to concentrate on the short term. In particular, we will examine some of the clients typically served by the private consultant in terms of their weather sensitive operations, their use of the forecast, and the benefits, economic or otherwise, gained from such use. One reason for choosing this area of concentration is that the benefits of the consultation are more easily quantifiable. Forecasts are typically issued on a routine basis, allowing the collection of an adequate data sample, and these forecasts are applied to specific practical problems about which a decision must be made, usually in a relatively short period of time (hours, or at most, days). Furthermore, these decisions, as, for instance, in the case of a city department responsible for plowing snow, have direct economic consequences. Another reason for addressing the area of operational forecasting has been our experience that this function of meteorological consulting is not well understood by the public, the general meteorological community, and in some cases by the client users themselves. Hopefully, we can clarify the relationship between the service the consulting firm provides and the possible uses to which such information can be put by the user.

2. Collection and Analysis of Data

Having identified a reputable consulting firm with a large and varied clientele who received regular operational forecasts, we proceeded to break down these clients into smaller groups who had similar needs and activities. These groups included governmental bodies concerned with snow and ice removal, gas utilities, electric utilities, fuel oil companies, commodities dealers, processors and brokerage houses, and a miscellaneous group including oil prospecting companies, an automobile club, and several construction firms. The total number of clients initially surveyed was over 400. Our next step was to contact most clients by means of a questionnaire specially designed for each group. Questions were written on the basis of some preliminary inquiries put to the clients. The final questionnaire was then reviewed by a person knowledgeable in the clients' area before being sent out in some cases. Several questions were included to obtain a general description of client activities in terms of size, budget, manpower, equipment, and facilities, followed by questions on the use of the consulting service's forecast. In particular we were interested in those operational decisions directly affected by the weather or weather forecasts and the process used to arrive at these decisions, the deadline for such actions, and the financial losses or benefits incurred by alternate decisions. We obtained over a 50% rate of return on the questionnaires. This was obtained by telephoning the clients and sending follow-up letters to explain the purposes of our research and our need for prompt replies. After a questionnaire was returned, it was usually followed up by a phone call to clarify answers or add further information which seemed appropriate based on the particular client's situation. In some cases, personal visits were made to a client to get a first hand view of their operations. (For more details see Suchman et al., 1977).

3. Some General Observations About User Clients

While a major motivation for subscribing to a weather service is financial, and we shall say more about this later, we should also mention some of the other reasons people feel the need for specialized information. A prime interest to many subscribers is the convenience and increased sense of security with which short term planning can be effected. Dispatchers and administrators often have scheduling problems which can be handled at the last minute should a weather emergency arise, but these people would rather have a greater lead time in preparation. For instance, weekend contingency plans can be readied should a storm appear likely, with crews alerted to that possibility. Should the storm not occur, the monetary loss is not as significant as the problems that would arise from a surprise storm catching the crew unprepared.

Other subscribers feel more secure if they have multiple sources of weather information; thus they may even consult with two firms plus the National Weather Service in their planning. The drawback to this approach arises if these sources conflict in their interpretations. The user may be prone to plan according to the source he or she wants to believe, having no objective way of choosing between them. In reality, some clients always prepare for the worst, while others will wait to act until the storm has begun.

We found that a few subscribers did not really know what to do with the information received from a consulting service. Sometimes the decision to subscribe is made at some higher level while the people responsible for making operational decisions have not been adequately briefed on the use or need for the service. In many cases, forecasts could be used to better advantage if a greater effort were made to educate the user as to the applications or limitations of the consultant's service. Finally, some clients feel that subscription to a weather service looks good on the record regardless of how well the information is actually being utilized. They can assure the public or others who review their operation that they are availing themselves of all possible means that would aid their performance. In addition, they have someone to blame should mistakes be made in decision-making.

4. Consulting Firm Operations

Meteorological consulting firms vary considerably in the manner in which they organize their operations and in the facilities they command. There is no minimum standard to which they must conform. Although the American Meteorological Society has a Certified Consulting Meteorologist program (CCM), consisting of certain professional and ethical standards to which a member must adhere, consulting meteorologists may and do operate without this certification. There are no restrictions to prevent any person whatever his background from setting up an operation in his basement and using a dart board to prepare the forecast. There are, however, many competent meteorologists in consulting who are not CCM's simply because they have not had the time, nor felt the need to go through the process of applying for certification. Unfortunately, many clients choose consulting firms solely on the basis of their fee schedule, rather than on their competance in the field. The example that follows is patterned after the operations of the cooperating consulting firm.

Operational forecasting is divided into two areas: Daily or routine forecasting and storm or emergency forecasting. Routine forecasts include such items as temperature, degree days, humidities, and cloud cover which are sent out several times daily to utilities, fuel oil companies construction companies and others. Forecasts are made for specified times or for three hour intervals and cover periods of up to 72 hours. Storm forecasts are only sent out as the need arises and can include notice of such events as snowfall, flooding, high winds, or thunderstorms. These forecasts give expected time of arrival plus or minus a few hours, intensity, areal coverage, and ending times.

Depending on the level of service for which the client is willing to pay, these reports may be sent out by phone or teletype once a day or every few hours, with updates sent as needed. Some of the clients whose geographical area of responsibility is wide may require forecasts by districts. A major advantage to the client is the freedom to telephone the forecaster if additional information or clarification is needed. These forecasts are usually tailored to the peculiarities of a client's needs, e.g. areas prone to flooding, hills that ice up rapidly, highly vulnerable power lines, etc.

Operations are staffed 24 hours a day with extra personnel added if need warrants. The same forecaster does not always work with the same client, although they generally specialize to handle certain types of clients. When first employed, forecasters work under the supervision of senior staff members.

Basic data facilities include the National Weather Service (NWS) and Federal Aviation Administration teletype circuits which supply hourly surface and upper air synoptic data from most North American stations; facsimile machines reproduce NWS maps and analyses. Satellite data is becoming more widely used. Pictures in facsimile format from government transmission lines can provide such data as often as once every one half hour in the visible and infrared. Radar can be provided even more frequently (up to a five minute frequency) from certain NWS stations in the U.S. by means of a dial-up facsimile system. Finally, the computer is beginning to make itself felt in many private agencies, supplying instantaneous data recall and display, mapping, data storage, and calculation of derived quantities such as streamlines, divergence, or degree days. Such systems are likely to become more widely used in the future.

5. Client Group Results

A. Snow & Ice

The storm or emergency forecasting group mainly supplies governmental bodies (city, state and county transportation and public works departments) with snow and ice storm forecasts in winter, and alerts for heavy rains, high winds and severe weather during the other seasons.

To illustrate the economic impact of these forecasts, a snow and ice situation will be discussed in detail. The importance of these forecasts rests in the decisions of whether to plow or sand, when to mobilize equipment for these operations, when to keep people on alert or send them out and whether and when to call out contractors. Contractors are often called in very heavy (>6") snow situations, but often require 4 hours notice, and must be paid a minimum amount whether they work or not. If they are not called in on time, they may work for other secondary clients and not be available when needed. Failure to act on time can prolong the cleanup process, cause traffic tie-ups and incur wrath from the public. On the other hand, being overly prepared can result in expending large sums of money for nothing, or work that needn't be done.

Since public works budgets correlate with expenditures of past winters, an unusually hard season can put a strain on operations--hence a greater need to use money frugally. Each body has its own requirements for mobilization, for securing outside help, and for the application of sand or salt. Because snow is rare in the south, even a minor storm can cause major disruptions. Consequently, many southern cities spend relatively large sums of money every year to prepare for snow though their total annual accumulation may not reach 5". On the other hand, one mid-Atlantic city never plows because (we were told) the plows themselves cause more damage than a snow pile-up could.

There are two other singificant points. First, many of the clients surveyed use the forecast for convenience only (i.e. they want to know about approaching storms, although their operations are minimally affected by this information). Secondly, as mentioned previously, some out of mistrust, ignorance, or a lack of communication, use the forecast product ineffectively. For example, several municipalities that are located at some distance from the consulting firm do not believe the forecasters understand the weather in their area; when storms arise they will contact the local weather bureau office rather than the service they are paying for. Others, will not believe snow forecasts unless the snow is currently falling. These clients do not understand what they are getting or do not want to. Finally, public officials are very reluctant to admit to misspending money or making mistakes; in fact, they may not realize it is happening until specifics are discussed.

Due to the differing criteria used for snow removal, a good forecast to one user could cause a major loss of money for another. Table 1 shows this variation for three governmental bodies, including possible monetary loss. City A plows at 4", and loses money due to unneccessary mobilization costs when plowing is not needed; City B plows at 2", and forecasts of snows less than 2" have little impact; State C also plows at 2", but timing has a more profound monetary effect. These criteria vary from client to client and seem to be arbitrarily set according to equipment available and the quality

Table 1
Monetary Losses Due to Incorrect Snow Forecosts

City A

Forecast	Outcome	Additional Cost
less than 4"	no snow	\$44/hr. + \$750 (mob)
less than 4"	delay	\$44/hr.
greater than 4"	no snow	\$132/hr. + \$750 (mob.)
greater than 4"	delay	\$132/hr.
greater than 4"	less than 4"	\$88/hr.
		Four hour minimum, 1.5 for overtime, 2 for holidays.

City B

no snow	significant snow	\$150/hr.
greater than 2"	no snow	\$1000/hr. + \$150 (mob.)
greater than 2"	delay	\$1000/hr.
greater than 2"	less than 2"	\$1000/hr.
		If during regular hours (8 to 4:30), cost are 1/3 less & mob. cost. = 0

State C

less than 2"	no snow	\$27,050/hr. + \$9,800 (mob.)
greater than 2"	no snow	\$27,050/hr. + \$15,200 (mob)
greater than 2"	delay	\$27,050/hr.
greater than 2"	less than 2"	\$5,800 (mob.)
		1.5 for overtime

of the snow removal effort. Most monetary or direct losses[1] are due to overforecasting--being too prepared. Though a forecast may completely miss a storm, the direct losses are usually not significant (aside from a longer cleanup time); however, the indirect effects on industry and transportation are very pronounced, and possibly more important.

To underscore the need for accuracy in certain situations, we will use the following actual case as an example. Table 2 shows a series of forecasts received by client D whose operations cover a large geographic area. The forecast for over 3" of snow meant a plowable situation; its estimated beginning time caused day crews to be held over. Snow actually began at 5 P.M. with a total accumulation of 2.4", then changed to freezing rain and later to rain. Plows were mobilized (due to the forecast) at 5 P.M. Because it was at the end of the day shift, day crews were held over until the 5:30 A.M. forecast update. Since this client only plows when 3" are on the ground, it did not need to mobilize its plowing force or hold the crew over. The extra cost was $23,450 calculated from

$1250/hr (crew cost) x 1.5 (overtime) x 12.5 hours.

This extra money was expended for what appeared to be a good forecast by ordinary criteria.

On the other hand if they had received a forecast for 6" which is above everyones plowing threshold, and received 20", no loss would have been incurred. Once a client puts its full plowing force into operation,

---

[1]Direct costs are those easily quantifiable in dollars. Other benefits such as convenience, goodwill from the public, reduction of traffic accidents or slowdowns, etc. are considered indirect, though they may eventually translate into economic gain.

Table 2
Actual Snow Forecast And Outcome

<u>Forecast</u>:	10:10 AM	3"-6"	beginning 7-9 PM
	3:00 PM	3"-6"	beginning 3-5 PM
	9:40 PM	as above	
Next Day	5:30 AM	1"-2"	

<u>Actual Conditions</u>:

Snow began at 5 PM: total accumulation of 2.4" changed to freezing rain, then all rain during the night.

Plows mobilized at 5 PM & stayed until 5:30 AM update.

Plowing criteria: 3"

the total accumulation does not alter the procedure. The operation just takes longer. Thus, contrary to what many believe, our findings show that for the "Blizzard of '78", the underforecast of snow accumulation had little affect on the cost of plowing operations which could have been avoided by a different forecast.

To summarize, accuracy and timing are crucial in snow forecasting, and are especially critical near certain threshold values which are determined by each client's mode of operation. Outside these boundaries, the forecast is used mainly for convenience and accuracy is less important than timing.

B. Gas Utilities

An analogous situation holds for gas utilities, each of which has its own critical points for load forecasting. Most companies have a fixed amount of a gas which they can take from pipelines. This amount is regulated by the Federal Government, and contract gas is usually not enough to meet their total heating season needs. Moreover their maximum rate of withdrawal may be more than can be supplied via the pipeline to meet peak demands. Supplemental gas, either ordered on short notice at a premium penalty price, or obtained by peak shaving (gasifying liquid stored gas) from propane or LNG gas, is much more expensive than pipeline gas (by at least a factor of 2). Hence, the companies must know exactly when and how much of their allocated gas is to be used, to avoid sending out expensive supplemental gas unnecessarily, or to avoid penalty rates for drawing gas over the limit; these latter rates are even higher than that for peak shaving gas. In addition, they must know when "interruptible" customers should be shut off to avoid selling them expensive gas at low prices. Due to shortages in gas supplies, many companies now have priority classes of users whose supply depends on the amount of cheap gas available on a given day.

Consequently each gas company has a critical area when they need to dip into their more expensive gas, and hence a timely accurate forecast is needed when the temperatures are in that range. To illustrate, we will examine one forecast for a utility which receives forecasts for two cities within its service area. The critical point for this utility is 52 degree days (DD), arrived at by their send out and gas availability. They can tolerate a 1° error and need a lead time of four hours to adjust their operations. Table 3 shows the forecasts, updates and verifications; the 1200 forecast is the one used for verification. For city A, the error was 2°. Since they use 1875 thousand cubic feet/degree day (MCF/DD) and expensive gas is $3.50/MCF extra, the extra cost is 1875x$3.50 = $6562.50 (accounting for the 1° tolerance). For city B, with a 5° error and a sendout of 625 MCF/DD, the cost for the gas is $8,750. In addition it cost them $40/HRx24 hrs ($960) to man the peaking facility when it could have remained idle. Hence, total loss for the utility this day was $16,272.50. On the other hand, with a forecast of 50 DD and a verification of 42 DD this larger error would not have had any adverse economic impact because it was not in the critical temperature range.

C. Electric Utilities

Electric utilities face many of the same problems that the gas

Table 3
Actual Gas Forecast And Outcome

	City W Forecast Temp.	City W Forecast Effective Degree Days	City F Forecast Temp.	City F Forecast Effective Degree Days
7:00 AM	15°	57	17°	55
12:00 Noon	16	55	18°	54
9:00 PM	19	53	22°	50

Actual: 20°; 53 DD.

Actual: 23°; 49 DD.

Critical Point for Supplemental Gas: 52 DD

Need 4 Hours Lead time.

Can absorb 1° error

City W

(2° error - 1° tolerance) x 1875 MCF/DD = 1875 MCF.

1875 x $3.50/MCF extra cost of gas = $6562.50

City F

(5° error 1° - tolerance) x 625 MCF/DD = 2500 MCF.

2500 x $3.50/MCF extra cost of gas = $8750.00. +

Manpower Costs: $40/hr x 24 hrs = $960.

Total: $8750 + 960 = $9710.

Total Loss: $16,272.50

companies do. Since most electric companies service wide areas with large clientele, any slight change in their efficiency would be magnified many times. Weather forecasts are used in three areas of operation: 1) winter load forecasting, in regions where electric heating is prevalent; 2) summer load forecasting, in areas of high air conditioning usage; and 3) storm alerts for maintaining and repairing equipment.

Electric company transmission equipment is very sensitive to weather extremes because much of it is above ground and exposed. In winter, heavy snow, extreme cold, high winds, and (most important) ice storms damage electrical systems; in summer, severe weather, including high winds, hurricanes, and lightning, often disrupt electrical power. Though an accurate forecast cannot always prevent disruption, it can allow utilities to alert their own crews to catch trouble when it develops (e.g. cutting down dangerous tree limbs during ice storms), to alert crews from nearby systems, and in general to restore power at the fastest rate possible.

After an alert of an impending storms, many utilities will hold over their own crews and call in crews from nearby unaffected areas who have to be transported, housed and paid premium wages. A false alert can cost tens of thousands of dollars per hour. A missed storm can result in widespread outages and long waits for restoration. Hence timing, temperature, winds and precipitation amounts are all critical.

D. Fuel Oil Companies

Fuel oil delivery companies, need three kinds of information. First, an accurate history of parameters related to the consumption rate of fuel oil for each customer. The variation of the rate of comsumption is primarily due to space heating. Consequently, the heating degree days accumulated since a customer's tank was filled, together with the customer's consumption per heating degree day (K factor), allow the dealer to estimate the quantity of fuel remaining in the customers tank. This permits the dealer to determine which customers will soon need servicing. Many firms subscribe to computerized data processing services, which use degree day accounting to project delivery dates. These services may even generate the driver's delivery tickets, and update the customer's K-factor, in addition to the more usual cost-inventory accounting.

Second, predictions of heating degree days several days in advance allow a dealer to determine if he needs to increase his level of effort above normal to prevent run-outs. This situation is especially important preceding holidays or week-ends. These forecasts need to be accurate because run-outs produce extremely dissatisfied customers. Unlike gas and electric energy suppliers, fuel oil is a competative industry whose customers can switch to a firm with better delivery service, or lower prices. Over forecasting results in holding drivers for unnecessary overtime and in unneeded call backs on Sundays or holidays. This typically increases service costs 50 to 100 percent. In effect, the combined accuracy of the past degree days, predicted degree days and K-factor can be evaluated when the customers tank is refilled. Predicted degree days also play a role, since deliveries are normally scheduled several days in advance. If the calculated and actual tank reserve consistently agree, the weather service gains credibility and the oil dealer may have enough confidence to reduce the normal customer reserve capacities for which they aim. Some dealers are thus able to make one or two less stops per year at each customer's tank. In the Northern States the annual number of stops ranges from about 8 to 15 (sample mean 9.96). Thus, a dealer can save 10 to 20 percent of his direct delivery costs by using a reliable weather service.

Third, dealers need to know about approaching weather conditions which will impair normal delivery. This includes freezing rain and heavy snow, but could include other conditions occasionally. Many deliveries must be made on narrow residential streets and on rural, or semi-rural roads which have low priority for sanding, plowing or snow removal. Moreover, due to restricted hose lengths, trucks must anticipate conditions in the customers lane or driveway. If there is no other alternative, drivers must deliver 10-15 gallons, by hand-carrying 5-gallon cans. For this reason most dealers have a list of difficult 'snow stops' which are serviced with higher priority in the face of a winter storm forecast. In this situation a poor forecast, whether an underforecast or over-forecast, will result in higher delivery costs, especially if drivers worked overtime to get ahead unnecessarily.

At present, because most dealers operate with conservative reserves in the customers tanks, because a large component of the working degree days figure is based on verified past data, and because the accumulation is effectively corrected each time a customer is refilled, the main benefit-loss variability is associated with anticipating and responding correctly to weather's impact on street and road conditions.

E. Commodities

To meet the economic need for means of procuring, storing and distributing both raw and processed products, commodity markets have developed on global as well as regional scales. Weather has a demonstrated impact on many of these: fruits, vegetables, food and feed grains, are key examples. But there are significant activities in coffee, tea, oil, seeds, cocoa beans, hides, among many other products. These markets arise when there is a significant possibility of supplies being mismatched to demand. To appreciate commodity markets adequately, one should consider the whole chain from producer to consumer outlets. Because of its overall impact, people at each link of this chain are interested in commodity weather information. Many larger firms are vertically integrated, or active at more than one level.

Customers of a private weather service may be trading, both buying and selling, on the futures market, looking for a favorable trading opportunity. Such an opportunity sometimes hinges on an accurate forecast of an unusual event, such as the destruction of a significant portion of an entire citrus, or coffee crop by an unexpected freeze. We found that one firm made at least a five figure profit based on a single forecast prior to the Florida citrus freeze of 1977. These opportunities are rare, but traders must know about them. The more usual use of weather data is interpretation of actual weather's impact on the progress of a crop. Companies who make purchases of actual commodities (rather than contract for future delivery) or who are dependent on these, as truckers, railroads and shipping companies, use weather data to assess the anticipated cost-price situation, or demand for their services. Similarly, bulk processors and producers of end products want weather information affecting the cost-price and supply-demand pictures of their raw materials to aid in procurement, production and marketing plans.

Futures operations are very flexible; buyers can get in, or out of a market quickly. Spot purchasers, and shippers, on the other hand, must always provide a market. This operation is very sensitive to current actual supply and demand, as well as future expectations. Bulk processors find that although the price of the raw commodity is a big factor in their profit picture, they must maintain throughput, even at unfavorable prices, to keep their plants running efficiently, and to keep a competitive position with their customers. To change plant capacity by hiring new labor, shutting down, or opening new production facilities takes a relatively long lead time. Processors deal in big markets, and products are indistinguishable to a high degree. Therefore, due to competative forces, they may not be able to pass all costs on and cannot afford to misjudge the markets. The best possible information on actual weather related growing conditions before the crop is ready for harvest is a key ingredient in these long range decisions. Forecasts play a minor role. Producers of consumer products, or the consumer divisions of vertically integrated companies, are usually less directly influenced by raw commodity prices (hence weather). This is because their total costs ordinarily are determined to a greater extent by advertising, labor, packaging, and delivery costs. However, the strategy of these companies tends to be built around brand names and over-the-counter promotion. This results in products that are somewhat interchangeable, but not necessarily indistinguishable. They desire to maintain a long term position in the market, often through customer loyalty. To achieve this in a competitive market, the company may not be able to pass on the total cost increase if it buys in an unfavorable market. If they are adequately prepared, including the most accurate information on expected weathers effect on raw material availability, they will be in as good or better position than the competition, or even may be able to adapt the product (e.g. switch from soy oil to coconut oil).

In summary, commodities clients need a whole spectrum of weather information ranging from detailed forecasts in concentrated production areas to large scale weekly or monthly summaries in key areas over the globe. Suitable products can be designed to fit the clients needs by a private weather consultant who has access to world weather data as well as domestic. It is difficult to attribute a specific value to weather data that is used in decision making. This is because the decisions are based on a slow accumulation of information.

F. Marine Operations

The cooperating firm had a small number of clients involved with two kinds of weather sensitive marine activities. One of these, barging, has become a major factor in coastal (up to several hundred miles off shore) transport in the last decade, and is still rapidly increasing in importance. Except for pipelines, it is the lowest cost transportation per ton mile when distances of 100 to 1500 miles are covered. Certain reaches of the intracoastal waterways are open to ocean tides, wind driven currents and waves, as are the offshore routes. Tug-tow combinations are subject to transverse strains without the structural strength of a ship, consequently there is increased vulnerability to weather factors, and a need for good predictions of wind and waves.

The function of these forecasts is to minimize the risk of catastrophic loss on the one hand, and the monetary loss due to wages, depreciation, and finance costs wasted while the tow stays in port, to avoid conditions which do not materialize. Manning costs are the order of a few hundred dollars per day. Interest, and depreciation costs for a tug and tow can also be as high as several hundred dollars per day.

The second type of marine forecast use is for offshore exploration involving the towing of very sensitive instruments by a small motor vessel. The half-million dollar investment in these instruments must be protected from loss, which could occur under conditions much less than those which would endanger the towing vessel. However, under threat of severe conditions the vessel must leave station and seek refuge in port. Thus, as for the barge lines, the purpose of the weather forecast is to safeguard against catastrophic loss (of crew, instruments or ship) while minimizing lost time. The direct cost of this lost time might be estimated from the $9,000 per day operating cost of the ship. However, the client informed us that the equipment, skilled, crew and geophysicists are scarce resources, whose value to the company exceeds by a large factor their direct operating cost. The future competitive position of the company depends upon rapid accurate exploration, and one day's exploration time missed can cost an oil company into the millions in lost "competative advantage."

6. Discussion

The illustrations presented here are just examples of how one meteorological consulting firm can benefit users economically in a wide range of industries and governmental concerns. It is not intended to be more than that: all consultants operate differently--they disseminate different products which are received and processed in different manners than described here. The end results are the same: more efficient operation, and the leaving of fewer decisions to chance.

All of the client groups that were contacted were not discussed, due to a lack of space. Construction companies, ski and yacht resorts, transportation companies, and air transport users all have needs for timely and accurate weather forecasts. A final group, the media, was also not mentioned. Although accuracy is important, the media do not have a significant effect on organized economic decision making. In the race for viewer appeal, meteorological professionalism in the media is often of secondary importance.

Although the illustrations presented above are of cases in which poor forecast information resulted in losses to subscribers, the vast majority of forecasts we encountered potentially resulted in savings far in excess of any fees paid by the subscribers for the services. The reason for presenting our findings in that form is that losses are easily calculable; savings are difficult to calculate because one would have to hypothesize actions that did not occur (if the forecast were not received). We could not fairly assume that "wrong" decisions would have been made were the consulting service not used. In addition, we have assumed consistency of action--that once a procedure is set, it is always followed. This is probably not true in practice for each individual case, but it was impossible to monitor actions due to every forecast. We assumed that the client's behavior conforms to his questionnaire response.

In summary, private forecast services meet very important needs--they provide specific, localized and interactive forecasts geared to the needs of their subscribers. The accuracy and timeliness of these forecasts have economic ramifications within specified temperature and precipitation ranges that depend upon the needs of the users. These "critical points" vary from client to client even within the same industry. Beyond these regions, the interactive nature of the service is its most important asset. Finally, private weather services are most valuable when the subscriber is fully aware of the significance of the information they are receiving and what it can be used for.

Acknowledgements

Data analysis was performed by David Floyd, the manuscript was reviewed by Thomas O. Haig and Peter Leavitt, and typing was performed by Angela Crowell. We greatly appreciate the cooperation of all the industries, utilities and governmental bodies which were contacted during this study. The research is supported by the National Aeronautics and Atmospheric Administration under contract NAS5-23706.

Reference

Suchman, D., B. Auvine and B. Hinton, 1977: A Study of the Economic Benefits of Meteorological Satellite Data. First Annual Report on Contract NAS 5-23706.

APPENDIX C:

THE USE OF AN INTERACTIVE COMPUTER SYSTEM IN APPLIED METEOROLOGICAL FORECASTING:

Preprint: Conference on Weather Forecasting and Analysis and Aviation Meteorology, October 16-19, 1978, Silver Spring, Md., pp. 215-218.

THE USE OF AN INTERACTIVE COMPUTER SYSTEM IN APPLIED METEOROLOGICAL FORECASTING

David Suchman
Brian Auvine
Barry Hinton

University of Wisconsin
Madison, Wisconsin 53706

Interactive computer systems have the potential for being a very useful tool in meteorological forecasting. In this paper we intend to present the application of one such system, McIDAS, (Man-computer Interactive Data Access System), developed at the University of Wisconsin-Madison in a few typical forecast situations with the intention of illustrating the capabilities presently available.

It is not possible here to present a complete outline of McIDAS hardware and software. For further information we refer you to Hilyard (ed., 1977). A brief summary of present McIDAS capabilities include the ability to: receive full resolution digital radar and real time satellite visible and infrared imagery, and display these on video and loop them; provide accurate latitude and longitude gridding which can be overlaid on the satellite images in the form of geographical maps or grids; ingest all Service A and C data for later recall either in its original form as overlays to the satellite image; isopleth any of these data or calculate derived quantities such as divergence, vorticity or equivalent potential temperature and display these in analyzed form; enhance any part of the brightness spectrum and display the image so as to bring out particular features of interest; and calculate the speed and direction of any cloud or cloud feature.

There are two clear benefits of such a system over conventional methods of data handling. One of these is simply the ability of the user to quickly display and analyze the portions of the incoming data of immediate interest. In many forecasting situations with time being in short supply, it is clearly helpful to the forecaster to have analyses of his or her own choosing for immediate use--analyses which might ordinarily be too time consuming or of doubtful utility.

Another major benefit of this system is the ability to compare diverse sources of data, in particular satellite and conventional data. Satellite imagery is most useful when it can be transposed onto surface or upper air temperature, moisture or wind analyses as an aide to interpreting the complex cloud patterns. Together the two data sources can reveal trends which might easily be obscured or ambiguous with only one source. Some examples of what can be done using such techniques follow.

Fig. 1 shows visual imagery photographed from a video display. This image was obtained from the NOAA operational GOES satellite at 1500 GMT on 14 Oct. 1977. The coastal storm in this picture poses a number of forecasting problems: for illustration purposes we confine ourselves to two of these. The first is the forecasting of 'clearing'. The time and area of clearing are of interest because of their influence on surface temperature and thus on utility load forecasting. Pictures, similar to that shown can be obtained every hour, or half hour and the motion and growth of the clear areas monitored. Variations of this kind produce a rather small associated change in power or gas demand--of the order of a few percent. If, however, a gas company were operating near its critical value of degree days, even a small change might require a decision to order (or not order) expensive supplemental gas to be supplied along with the maximum allotted pipeline natural gas. As can be seen in the figure, the clear tongue has encircled 285° of the closed surface low. The edge of the clearing is located over the Atlantic, and could not be precisely defined by land based surface observations. Looping of the images indicate that this tip of clear air is moving NNW toward Pennsylvania, Massachusetts and New York. It can easily, and quantitatively be tracked on the video images.

A few stations showed precipitation at the time of this image. Precipitation is usually associated with thicker and higher clouds. Thickness can be qualitatively estimated from the visible brightness, while height is related to IR- brightness as illustrated in fig. 2. Note the spatial differences between the low and high cloud clearing. In direct transmission of the stretched VISSR data one can obtain simultaneous visible and IR, though users of sectorized data receive them on alternate half hours. In any case, for images on 14 October, the hypothesis that precipitation was associated with locations of bright visible and IR images was verified at 1500 GMT by plotting hourly surface weather symbols on the satellite pictures. Once this association was made the precipitation areas could be tracked and extrapolated to give the time of onset (or termination) of precipitation in specific areas. Precise precipitation forecasts are of interest to many private forecast users, especially

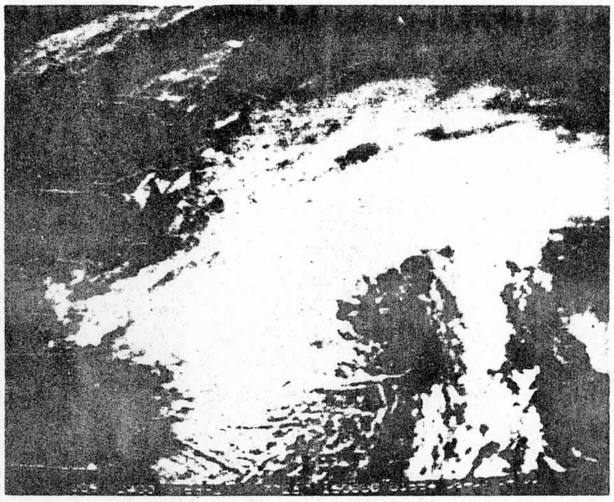


Figure 1. GOES satellite visible image as seen on McIDAS for 1500Z, October 14, 1977. This picture is 4 to 1 reduced resolution and also shows a computer generated superimposed map of the Eastern United States.

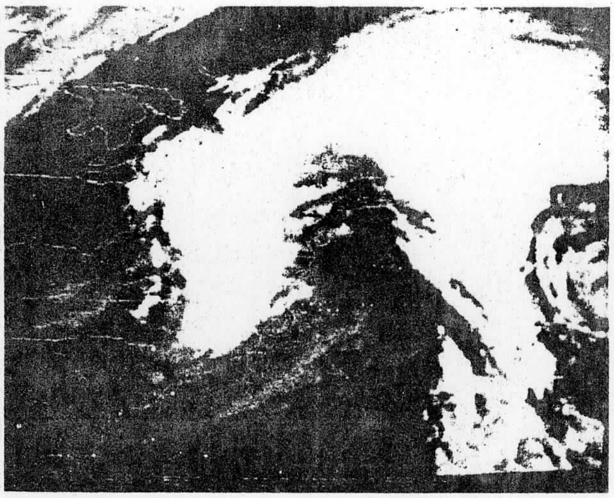


Figure 2. Same as figure 1, except that an infrared picture for 2030Z is shown.

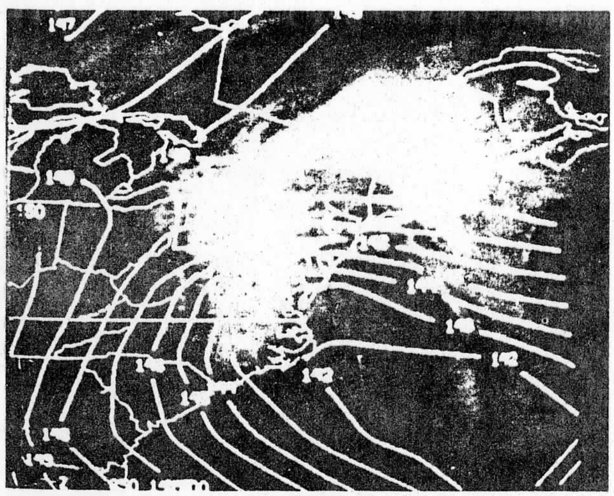


Figure 3. Infrared 2030Z, October 14, 1977 image with a U.S. map and 850 mb. height analysis overlaid.

maintainance, construction, sporting events and other outdoor activities.

It is possible to go to a somewhat more physical approach than simple extrapolation. For example, surface pressure can be superimposed on the satellite image and the progress of cloud features can be monitored together using the hourly service A data. Similarly one can look at surface winds or derived parameters such as θ_e, surface divergence, or vorticity which are valuable for short range prediction of severe weather situations.

One is not restricted to surface data however. As shown in fig. 3, upper air data, for example 850 mb height, can be used. One can also obtain upper level winds, divergence, thickness, and vorticity among many other options. These can be gridded, contoured and displayed minutes after they are received.

Using upper air data, forecasters can prepare longer range outlooks and forecasts. Here again, however, it has been found useful to associate these fields with patterns of cloud features which can be tracked hourly, or half hourly, while the upper air data are usually available only twice daily. This is quite useful for detecting departure of the developing situation from the forecast, and the consequent need for updating or revising a forecast.

Fig. 4, visible imagery, was obtained for 1700 GMT on 7 June 1978. Fig. 5 is the corresponding simultaneous IR picture. Together, they illustrate a polar cold front delineated by a cloud band. The change in surface temperature and precipitation associated with the passage of such a front might be of interest to a utility load dispatcher. Fig. 6 shows how the cloud pattern is associated with surface temperature. Tracking the front will allow an extrapolation several hours into the future, while upper air data, can be considered for longer forecast periods.

The third situation, shown in fig. 7 represents a area in which the forecast of severe convective storms would be expected. Virtually every user in the affected area would be interested in the forecast. It might be used to dispatch emergency crews, secure equipment, materials and buildings, terminate outdoor activities and the like. This case occurred on 20 May 1977 over Kansas and Oklahoma. From the visible image alone along with surface streamlines we can see the cylonic current of descending air and convection originating from the tip of this tongue as if it were lifting surface air. To the southeast apparent Helmholtz, or gravity waves give evidence of a low level inversion, or at least a very stable layer. Also quite evident in this picture is the cirrus from mature convection. In the original video images one can see that this is dotted with over-shooting towers. For more precise cell location and tracking, it is very simple to blow up the images (fig. 8). By examining the IR image one can see from the brightness that the tops of these mature cells are very high.

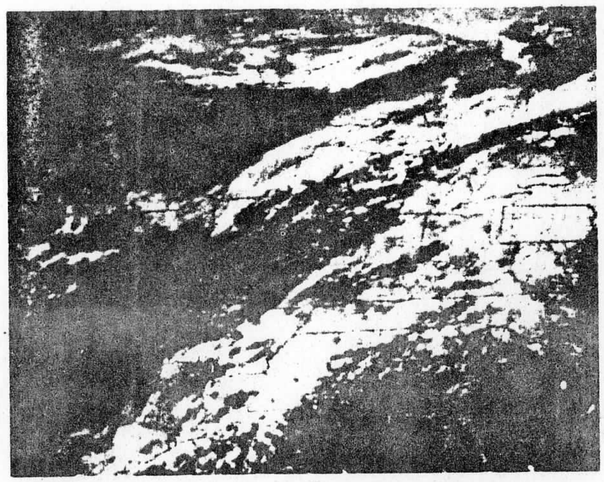


Figure 4. GOES visible image for 1700Z, June 7, 1978, with a 6:1 reduced resolution and a superimposed map for the Eastern and Central U.S. A frontal cloud band can be seen over the upper Midwest.

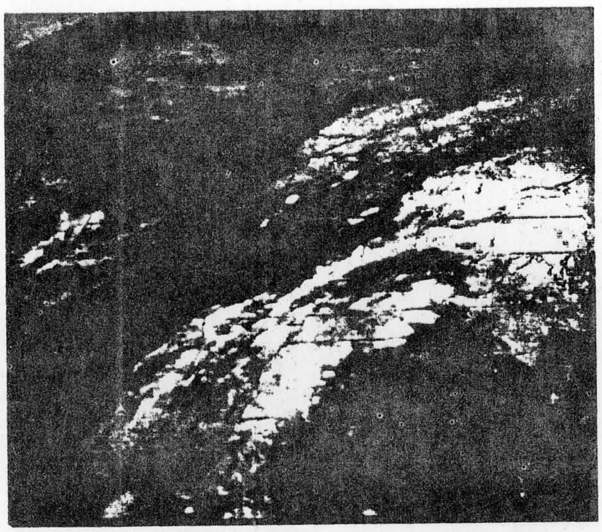


Figure 5. Same as figure 4, except the IR picture for 1700Z is shown.

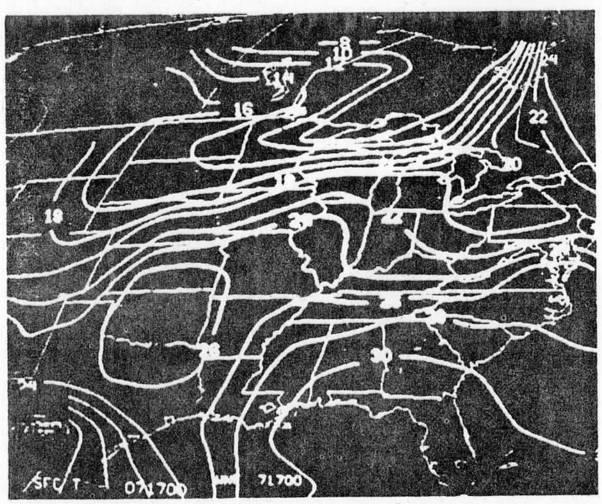


Figure 6. Surface temperature (in °C) for 1700Z, June 7, 1977. The scale of the map and analysis are the same as for figures 4 & 5.

Figure 7. GOES visible satellite picture for 2000Z, May 20, 1977. Surface streamlines and a map for the Texas, Oklahoma, and Arkansas area are overlaid. Resolution is 2 to 1 reduced.

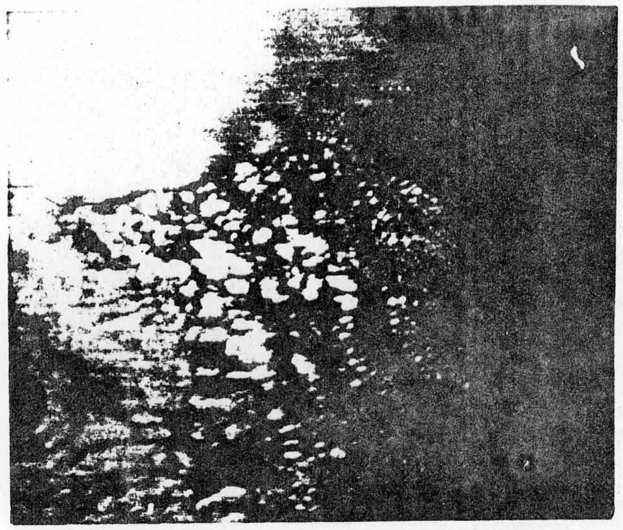


Figure 8. A full resolution visible GOES-1 image for 2000Z, May 20, 1977. The picture is centered along the eastern Texas-Oklahoma border.

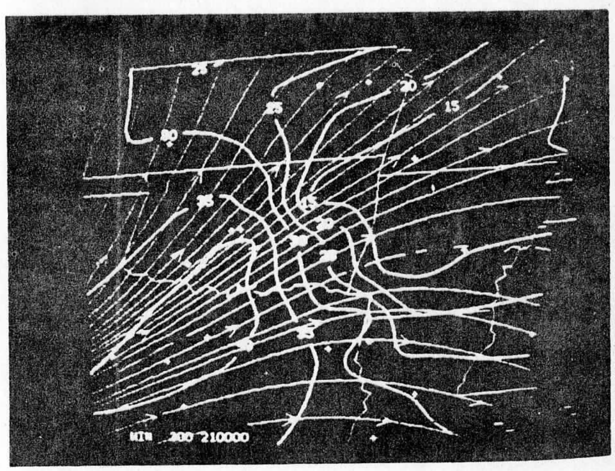


Figure 9. Map on same scale as figure 7 with 0000Z, May 21, 1977 300 mb streamlines and isotachs.

Using a simple program and a joy-stick positioned cursor box, temperatures for individual data points can be read out. It was found that many cold domes had temperatures below 210 K, indicative of very severe weather. By looking at an animated loop of pictures (usually available at 15 minute or more frequent intervals when severe weather is expected), one can spot the most rapidly developing cells and thereby track the line of the storm's maximum severity.

As mentioned above we have found it useful to superimpose conventional data on satellite images or on a satellite image projection. Figure 9 shows the 300 mb. streamlines and isotachs illustrating the location of the upper level wind maxima and divergence. Conventional and cloud drift winds can also be combined to produce a single, more complete analysis field.

Though we have mentioned, "tracking" and "extrapolating," we should point out that this task is carried out by a sophisticated set of software tools (WINDCO) which, gives u and v components of motion (in meters per second), plots the resulting vectors, and estimates the heights of target clouds automatically if requested, based on IR and, if available, visible brightnesses.

As illustrated by the above examples, an interactive computer is capable of increasing the accuracy of a prediction (as, for example, in predicting the amount of precipitation or the size of a temperature change) as well the precision of the timing of such events (i.e. the time of precipitation onset or temperature fall). While such improvements may not be crucial to the general public in a direct way, many business and industrial operations are seriously affected by even small errors in timing or accuracy. We can clarify this statement by looking at a few of those operations in detail.

Our first example, that of snow and ice control, is found to be a significant budget item for most northern cities and states in the U. S. Even in the South, a minor storm can cause great chaos. Many Southern cities spend large sums of money each year although annual snow accumulations are low.

Being overly prepared for a storm by calling out equipment and crews too early can result in unnecessary expenditures of money for "waiting" time or work (sanding and salting, plowing) that need not be done. On the other hand, failure to mobilize in time can prolong the clean up process, create traffic delays and accidents, and cause great public distress. Thus the time of arrival of frozen precipitation is (or should be) significant to any state or municipal street department; an error of even an hour results generally in thousands of dollars of direct cost.

Likewise every such department has a critical point at which plowing operations are readied. Usually this point is the reception of a forecast calling for between 2 to 4 inches of snow in the next few hours, the actual critical amount depending on the type of equipment and the quality of the snow removal effort in a particular city. A forecast of snow close to this threshold is of critical importance in determining the number of people and the type of equipment employed. Oddly enough, if the actual snow amount falls on the same side of the threshold value as the forecast, the actual error is relatively unimportant economically. For instance if 12 inches is forecast and only 6 inches of snow falls, a department would still have wanted to deploy its plowing crew, but if 6 inches are forecast and only 3 inches fall, a city with a 4 inch plowing criteria would be adversely affected. We should also note that not all such operations are run efficiently and with proper use of the forecast. Some groups out of mistrust, lack of communication, or ignorance, do not understand what they are being told in a forecast or will not admit they have made mistakes in their response.

An analogous situation holds for gas and electric utilities, each of which has its own critical point for peak load forecasting. Most utilities prepare for peak loads by scheduling more expensive supplemental power sources on the basis of some combination of temperature, humidity, cloud cover, or wind forecast during heavy use hours. Specifically, the forecast is first used to determine whether a certain value in degree days or other index is exceeded. Very cold temperatures and wind for gas utilities and very warm temperatures and high humidities for electric companies alert them to the possibility that power beyond their usual resources is needed. The amount of this excess then determines how many supplemental power sources will be needed. These decisions are usually made early in the day as there is a significant lag time before equipment can be readied. Again, errors in the forecast beyond the threshold value, especially in temperature, typically result in tens of thousands of dollars lost due to the unnecessarily high cost of the additional power generated. Another factor to be considered, especially in the case of electric utilities, is the system vulnerability to high winds, icing, and lightning. The timing and magnitude of the weather event are necessary to forestall system disruption.

What we have attempted to show in this paper is that modern technology has increased the demand for highly accurate and detailed meteorological forecasting. Even the most mundane weather events can have important economic consequences because our systems have become more sensitive to minor environmental changes. The interactive computer is certainly one means by which our present-day meteorological network can be made to provide the precision in forecasting demanded by today's society.

References

Hilyard, J. editor, 1977: Interactive Video Displays for Atmospheric Studies, Proceedings of a Workshop at the University of Wisconsin, Madison 14-16 June, 1977.