A STUDY OF THE ECONOMIC BENEFITS OF METEOROLOGICAL SATELLITE DATA

THIRD ANNUAL REPORT

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

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I. INTRODUCTION

Work during much of the past year proceeded at a slower pace than the two previous years. Our efforts can be divided into three periods: Sept. - Nov. when McIDAS was installed, training and debugging occurred; Dec. - April--the picture quality and selection of McIDAS was poor and McIDAS was basically idle; May - present--the analog disk was repaired, the new satellite line was installed, and the use of, and usefulness of the satellite data increased dramatically. At this writing, the system is operating very smoothly, and has had a marked impact on WSC forecast operations.

On a parallel front, work has been completed on the two control years, and case study work has begun on the experimental year.

In a broader sense, the objective of this program is to determine the economic value of meteorological satellite data to a sample of users in both the public and private sectors. Specifically this has entailed:

1. Finding an established private weather service with a variety of clients in which meteorological satellite data had not yet been used;
2. Establishing and documenting the current weather service supplied to the clients and determining a quantitative measure of the value of that service;
3. Developing, 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. Installing and activating the meteorological satellite data

capability in the operator's place of business;

5. After a suitable period, establishing a quantitative measure of the value of the augmented service.

With the completion of this third year of work, (1) thru (4) of the above objectives have been substantially met. Only (5) remains to be completed as data from the last year becomes available. This report concentrates on the results from the second control year, a year in which the satellite data system, McIDAS-2, had not yet been integrated into daily forecasting. The two control years will be the basis of comparison with the results from the fourth year--a period in which McIDAS has been incorporated into the routine forecast operations.

Since the specific methodology of the experiment has been adequately described in the First and Second Annual Reports, we will not repeat that information here; the reader is referred to those documents for further detail. Also of use might be the appendix of this report which contains the text of a paper to be published in the October 1979 Bulletin of the American Meteorological Society (The Economic Effects of Private Meteorological Forecasting). This material should be helpful to anyone wishing a summary of the kinds of clients we have been working with and some of the preliminary results we have obtained from the control period data. In particular we describe how various clients' use the forecast and what economic effects the forecast can have if it is in error.

In the remaining year we will use this information as a basis of comparison with forecasting that has been able to draw on meteorological satellite data.

II. McIDAS SYSTEM, HARDWARE AND SOFTWARE

At the writing of the Second Annual Report the McIDAS system had been installed at Weather Services Corp. and the first hardware and software problems encountered. It was clear that limited local service was necessary to augment occasional visits by SSEC engineers. CompuServ of Boston, Mass. was retained and has successfully handled thirteen calls.

Three trips were made by SSEC personnel to WSC Boston in calendar year 1979 to implement important hardware changes. The final system configuration is as described in the second annual report. The system changes made in the last year either improved performance or reliability.

Changes made include:

1. New software installed in terminal processor (change made to bring system up to current revision)
2. Complete change and update of analog disc electronics (made to improve picture quality and reliability)
3. Auto-answer modem installed (allows diagnostic and program reload access by SSEC without WSC assistance)
4. Direct GOES-TAP line installed

The serious problems experienced with the system have been associated with the analog disc. The repair and modification efforts have paid off in that since the trip of 14, 15 June 1979 no disc problems have occurred.

At the writing of this report the customer controlled switching system for the GOES tap has arrived in Bedford. This is the last expected hardware change to the system. It will permit Weather Services to control the GOES line without intervention by NESS personnel in Washington.

In summary, the general system reliability has become excellent, certain hardware systems presented problems that have been corrected and are not expected to reoccur.

III. INSTALLATION OF THE McIDAS SYSTEM AND ON SITE TRAINING

The McIDAS-2 system construction was completed in August 1978 and after a period of several weeks of testing in Madison, McIDAS was shipped to Bedford at the end of the month. Soon thereafter, an engineer and a programmer were sent to install the system at Weather Services. This task was completed in a week, following which David Suchman and Brian Auvine arrived to complete the introduction of McIDAS into the consulting firm's routine operations. Specifically our intentions were to train the staff in the effective use of the system, to correct hard and softwear deficiencies, and to see how well the staff would adapt to McIDAS in terms of the objectives of this program.

Training of the staff involved group demonstrations followed by individual sessions with as many people as possible over a week long period. Several of the forecasters were already familiar with McIDAS from previous training sessions in Madison (see Second Annual Report) and were therefore in a position to help the rest of the staff on the use of the system after our departure.

Our second objective, correcting hard- and softwear deficiencies proved to be the most difficult. The system hardware, especially during the first weeks of operation, had numerous problems including analog disk faults, difficulties in cursor manipulation and bad connections between various system elements. Rather than sending someone out from Wisconsin everytime there was a problem, we decided to hire a local computer maintenance firm (CompuServ) to provide the backup for correction of the smaller, more easily handled equipment failures. This scheme proved to be helpful in providing quick solutions in several situations, although in the case of serious failings (of the analog disk, for example), it has still been necessary either to return the component to Wisconsin for repair or to send an engineer to Bedford.

Softwear changes were more easily manageable. The quality of the incoming image data was highly variable and the IR brightnesses proved to be uncalibrated, and thus not usable for cloud height calculations. The navigation routines did, however, give reliable alignments of the pictures and the graphics and other system softwear were in need of only minor adjustments. The latter changes could all be done remotely from Madison via a telephone computer link.

Our overall evaluation was that the system was potentially capable of fulfilling the goals of this project. It was, of course, still unknown to what extent the forecasters would actually incorporate the satellite data into their routine. Personal reaction from the staff appeared to be initially favorable, although one possible problem lay in the fact that the forecasters were kept busy meeting forecast deadlines and it might be difficult for them to find time to do the necessary ingest and navigation of the satellite data when a significant storm threatened. This has not proved to be a serious obstacle. A more serious problem, recently remedied, was that the fax line data received was controlled by the Boston NWS office and they did not always choose to bring in pictures covering the area of interest to WSC. The solution was to pay for the rental of a private line for WSC, allowing the consulting firm to control the resolution and geographical area to be brought in (completed in early June). Finally, a log was set up in which forecasters noted their use of McIDAS data in particular storm situations; this record allows us a means of finding and documenting case study days when satellite data proved useful. An example of the log (not complete) is shown in Table I. In all the situations listed, satellite data was useful in preparation of the forecast or providing special warnings to WSC clients. In addition, McIDAS proved helpful in providing insight into the mechanics of the atmosphere such as the formation of tropical disturbances or long wave features.

During much of the past year, the lack of high quality images and the inability of WSC personnel to determine the sectors they received caused McIDAS to lay idle much of the time. With that, interest also waned. But with changes in the analog disk, and the installation of their own satellite line, the use and usefulness of McIDAS and satellite data has increased dramatically over the past three months.

In summary, the installation and training period proved helpful in determining and correcting actual and potential problems and making possible effective use of the system toward the objectives of this program.

Table I - Log of Forecasts In Which McIDAS Satellite Data Proved Useful.

DATE	CLIENT	TYPE OF WEATHER/ACTION TAKEN
6/13	CITY OF CHARLOTTE, NC	THUNDERSTORM ADVISORY ISSUED
7/5	DUKE POWER	THUNDERSTORM NEAR ATHENS, GA., ADVISED OF POSITION AND MOVEMENT.
7/9	BROWN AND ROOT	ADVISED OF INCREASING CONVECTION AND POSSIBLE CIRCULATION OVER SW GULF OF MEXICO.
7/10	BROWN AND ROOT	BRIEFED ON STRONG TROPICAL DEPRESSION OVER CENTRAL GULF OF MEXICO
7/11	BROWN AND ROOT	CLUSTER OF STRONG THUNDERSTORMS WITH ARC CLOUD/GUST FRONT VISIBLE NEAR 25N/94.8W. ADVISED THAT MOVEMENT WAS TOWARDS THE WORK SITE AT 624 WEST CAMERON.
7/16	BROWN AND ROOT	ADVISED OF DEVELOPING THUNDERSTORMS OFF THE MISSISSIPPI DELTA MOVING TOWARD WORK SITE AT 57 SOUTH PASS.
7/17	SOUTH CAROLINA ELECTRIC AND GAS	THUNDERSTORMS DEVELOPING OFF-SHORE BUILDING WESTWARD TOWARD CHARLESTON.
7/18	BROWN AND ROOT	THUNDERSTORM CELL DEVELOPING OFF LOUISIANA COAST MOVING TOWARDS THE WORK SITE AT 624 WEST CAMERON.
7/23	ALL MEDIA CLIENTS	USEFUL IN DETERMINING EXTENT OF THUNDERSTORMS IN NORTHEAST AND MIDDLE ATLANTIC STATES. *
7/25	BROWN AND ROOT	HELPFUL IN DETERMINING LOCATION OF HEAVY CONVECTION OVER GULF OF MEXICO. *
7/29	K C M O RADIO	EXTENT AND MOVEMENT OF CONVECTION IN THE KANSAS CITY AREA.
7/30	ALL MARINE ACCOUNTS	LOOP OF TROPICAL WAVE NEAR 15N/43W GAVE BETTER INFORMATION AS TO STRENGTH OF THIS WAVE THAN ANY OTHER SOURCE OF INFORMATION.
8/3	BRONW AND ROOT	ADVISED OF SQUALL AREA AND ITS MOVEMENT OVER THE SOUTHWESTERN GULF OF MEXICO.
8/6	BROWN AND ROOT	ADVISED OF RAPID DEVELOPING THUNDERSTORMS OFF THE LOUISIANA COAST NEAR 3 WORK SITES.

DATE	CLIENT	TYPE OF WEATHER/ACTION TAKEN
8-9	BROWN & ROOT	DOWNPLAYED TROPICAL WAVE IN BAY OF CAMPECHE
8-10	ALL NORTHEAST CLIENTS	DEVELOPMENT OF STORM SYSTEM OVER GRT LAKES AND ASSOCIATED TSTMS AND MOTION
8-11	ALL NORTHEAST CLIENTS	DEVELOPMENT OF FRONTAL WAVE AND ASSOCIATED WEATHER PROBLEMS
8-18	KCMO AND WDGY	MONITORED THUNDERSTORMS
8-18	BOSTON RED SOX	RAIN ADVISORIES FOR BALLGAME
8-19	THE CAROLINA UTILITIES	POSITION, GROWTH, AND MOVEMENT OF THUNDERSTORMS
8-21	PHILADELPHIA ELECTRIC/ PP&L	REVISED GENERAL WEATHER FORECAST
8-23	SOUTH CAROLINA ELEC AND GAS	USED SATELLITE LOOPS EXCLUSIVELY FOR TSTM MAPS
8-23	WDGY	BASED ON LOOPS, HELD CLOUD IN FORECAST LONGER THAN OUR EARLIER FCSTS AND LONGER THAN BUREAU FCST
8-30	ALL NEW ENGLND CLIENTS	BASED ON GRAPHICS AND SAT LOOPS (ALONG WITH THE CONVENTIONAL DATA) ISSUED SEVERE TSTM ALERTS 2 HRS BEFORE SELS ISSUED SEVERE TSTM BOX
8-31	CAROLINA POWER & LIGHT	LOOPS SHOWED HRCN DAVID TURNING SHARPLY NNW INTO DOMINICAN REPUBLIC. BASED ON THIS, SENT FORECAST TO CAR POWER & LIGHT SHOWING DAVID THREATENING THE SE U.S. EARLY THE FOLLOWING WEEK
9-4	THE CAROLINA UTILITIES	MOVED DAVID ON SHORE AT SAVANNAH DURING THE LATE AFTERNOON/EARLY EVENING PERIOD.

IV. CLIENT GROUP RESULTS

A. Snow & Ice

Most of the relevant information, including the details of our calculation procedure are contained in the preprint (p. 32, Appendix). A final summary of the results is in Table II with the specifics of each client shown in Table III. In the latter the second column shows an annual snow/ice budget; the third includes the number of measurable snowfalls by amount; the next column includes the number of forecast situations, and the percentage of forecasts not producing a loss. That does not mean that the forecasts were judged in an absolute sense, but only by their effect on the client's operation. This is followed by the number of cases producing a calculable monetary loss, the monetary loss, and the percentage loss relative to the annual budget. The final column includes any figures relevant only for particular clients. There are a few clients for whom some forecasts were lost for part of a season, and hence, no calculations were made for that year.

Though, for the most part, the number of measurable snowfalls averaged out to be about the same for the two control years, the number of plowable snowfalls increased by one-third, with many unusually heavy seasonal totals. Correspondingly, the number of storms producing monetary losses increased by 10% during the second year with resulting losses increasing substantially (62%). We have found, that in general, the greater the seasonal snowfall, the greater the potential economic loss, and that is borne out by these statistics. Another factor affecting the increased costs was that an abnormally large number of storms either occurred at night or on weekends resulting in premium wages being paid to workers on standby, etc.

The results for the experimental period will be calculated the same way as those for the control years, and will then be related to them considering the varying climatologies. Although costs for salaries and materials have increased by about 10%/year, all of our results reflect costs based on 1977 figures.

FINAL
SNOW/ICE CLIENT RESULTS

CLIENT TYPE		No. of Forecast Days	No. of Snow Days	Plowable Storms	Per Cent of Forecasts Producing Loss	Mean Annual Loss Due to Incorrect Forecast	Mean Annual Snow/Ice Budget
STATE HIGHWAY AUTHORITIES		38.1	7.8	3.9	17.4%	$60,775	$450,000
TURNPIKE AUTHORITIES		38.7	13.2	6.3	15.8%	$11,200	$313,000
SOUTHERN CITIES		24.1	3.9	1	13.2%	$2450	$45,000
NORTHERN CITIES Pop >60,000		44.8	16.8	7.9	13.4%	$18,200	$270,000
NORTHERN CITIES Pop <60,000		44.4	14.6	7	15.0%	$5300	$98,600
RANGE	MAX.	64	24	12	37.5%	$108,000	$853,000
	MIN.	17	2	0	0%		$10,000

Table II Summary of Control Years for Snow and Ice Clients

CLIENT	BUDGET	NO. OF STORMS	NO. OF FORECASTS	LOSS (NO.)	COMMENTS
Northern City >60,000	$150K (75-76)	76-77: >1":17 >3":11 >6":5	76-77: 48 98% cor.	76-77: $12.8K(1) 8.5%	MOBILIZATION: $3300 Contractor (>4"): $1100/hr
		77-78: >1":21 >3":11 >6":7	77-78: 39 94.8% cor.	77-78: $9900(2) 6.6%	
Northern City >60,000	N/A	76-77: >1":20 >3":11 >6":5	76-77: Data Incomplete	(Inc.)	Plow MOB: $2500 Plow Cost $2800/hr
		77-78: >1":17 >3":11 >6":6	77-78: 35 68.6% cor.	77-78: $9350(11)	
Northern City >60,000	$121K (75-76)	76-77: >1":15 >3":5 >6":1	76-77: 35 97.1% cor.	76-77: $3200(1) 2.6%	Contractor: 3" on ground, expect >6": $800/hr 4 hr min.
		77-78: >1":12 >3":5 >6":2	77-78: Data Incomplete	(Inc.)	
State District	N/A	76-77: >1":13 >3":4 >6":1	76-77: 39 76.9% cor.	76-77: $8842(9)	Sand & Salt MOB: $800 Plow only, (4"): $571/hr (OT)
		77-78: >1":16 >3":7 >6":2	77-78: 42 85.7% cor.	77-78: $17,044(6)	
Turnpike District	$133K (75-76)	76-77: >1":8 >3":3 >6":1	76-77: 36 80.5% cor.	76-77: $7940(7) 6%	Contractor >4": $950/hr Plowable Delay $500/hr
		77-78: >1":12 >3":6 >6":2	77-78: 36 77.8% cor.	77-78: $10,545(8) 7.9%	
Turnpike District	$266K (75-76)	76-77: >1":10 >3":3 >6":0	76-77: 37 83.8% cor.	76-77: $11,250(6) 4.2%	Contractor >4", $475/hr Plowable Delay $500/hr
		77-78: >1":12 >3":8 >6":3	77-78: 37 78.4% cor.	77-78: $19,417(8) 7.3%	

Table III Complete Snow/Ice Client Results

CLIENT	BUDGET	NO. OF STORMS	NO. OF FORECASTS	LOSS (NO.)	COMMENTS
Southern City	$310K (75-76)	76-77: >1":7 >3":2 77-78: >1":3 >3":2	76-77: 29 96.6% cor. 77-78: 31 64.5% cor.	76-77: $300(1) 0.1% 77-78: $11K(11) 3.5%	Do Not Plow! $500/hr OT
Northern City <60,000	N/A	76-77: >1":16 >3":4 >6":1 77-78: >1":15 >3":7 >6":4	76-77: 54 75.9% cor. 77-78: 59 76.3% cor.	76-77: $7431(13) 77-78: $11K(14)	Delay, plow: $1000/hr
Northern City >60,000	$729K (75-76)	76-77: >1":15 >3":8 >6":3 77-78: >1":14 >3":6 >6":4	76-77: 52 76.9% cor. 77-78: 60 78.3% cor.	76-77: $12.5K(12) 1.7% 77-78: $13K(12) 1.8%	<4 hrs warning Adds 25%
State District	$5,225,700 (75-76) 8 District Total	76-77: >1":8 >3":3 77-78: >1":16 >3":5 >6":2	76-77: 47 85% cor. 77-78: 45 86.7% cor.	76-77: $60K(7) 9.2% 77-78: $108K(6) 16.5%	Per District: Crew Cost (Delay) $3375/hr; $5063 OT MOB. (OT) only $3375
State District	"	76-77: >1":6 >3":3 77-78: >1":14 >3":3 >6":2	76-77: 30 76.7% cor. 77-78: 34 88.2% cor.	76-77: $53K(7) 8.1% 77-78: $77K(4) 11.8%	ex. 4 hr unnec. mob. $25,000
Northern City <60,000	$150K (76-77)	76-77: >1":19 >3":6 >6":2 77-78: >1":11 >3":7 >6":4	76-77: 44 93.2% cor. 77-78: 41 80.5% cor.	76-77: $1275(3) 0.8% 77-78: $4725(8) 3.2%	Costs only during OT: $150/hr

CLIENT	BUDGET	NO. OF STORMS	NO. OF FORECASTS	LOSS (NO.)	COMMENTS
State District	$3,413,000 (75-76) 8 District Total	76-77: >1":5 >3":2 >6":0 77-78: >1":8 >3":5 >6":2	76-77: 32 78.1% cor. 77-78: Date Incomplete	76-77: $80.4K(7) 18.8% 77-78: Inc	Big Storm, up to $10,350/hr standby 6" storm: $30,000/hr 2" storm: $1600/hr: S & S
State District	"	76-77: >1":5 >3":2 >6":0 77-78 >1":9 >3":5 >6":2	76-77: 36 83.3% cor. 77-78: Data Incomplete	76-77: $82K(6) 19.2% 77-78: Inc	"
Turnpike District	$2,243,485 (75-76)	76-77: >1":19 >3":5 >6":0 77-78: >1":19 >3":8 >6":2	76-77: 55 96.3% cor. 77-78: 37 83.8% cor.	76-77: $4789(2) 77-78: $36,714(6)	No monetary cost for forecast less than 2" Only cost is for OT: Up to $1300/hr/district
Turnpike District	"	76-77: >1":7 >3":3 >6":0 77-78: >1":12 >3":8 >6":3	76-77: 36 86.1% cor. 77:78: 28 100% cor.	76-77: $10.7K(5) 77-78: 0	Danger: Close Tpk. Accuracy: 80% (75-76) (126 fcsts)
Turnpike District	"	76-77: >1":14 >3":5 >6":1 77-78: >1":18 >3":8 >6":2	76-77: 47 85.1% cor. 77-78: 37 91.9% cor.	76-77: $12.8K(7) 77-78: $13,169(3)	
Northern City <60,000	$193K	76-77: >1":17 >3":10 >6":5 77-78: >1":14 >3":10 >6":5	76-77: 48 93.7% cor. 77-78: 39 92.3% cor.	76-77: $6100(3) 3.2% 77-78: $12,486(3) 6.5%	Plow, OT: $700/hr MOB: $300 Contractor: $320/hr

CLIENT	BUDGET	NO. OF STORMS	NO. OF FORECASTS	LOSS (NO.)	COMMENTS
Northern City >60,000	$70K (76-77)	76-77: >1":11; >3":4 77-78: >1":12; >3":5 >6":2	76-77: 39 79.5% cor. 77-78: 37 83.8% cor.	76-77: $8064(8) (11.4%) 77-78: $8280(6) (11.8%)	Mobilization: $800 4 hr notice to call back crews
Turnpike District	$140K (75-76)	76-77: >1":13 >2":8 >6":0 77-78: >1":14 >2":10 >6":3	76-77: 40 62.5% cor. 77-78: 38 84.2% cor.	76-77: $13,974(15) (9.9%) 77-78: $5396(6) (3.9%)	Storm Delay ($305/hr OT)
Northern City <60,000	$10K (75-76)	76-77: >1":12 >2":3 77-78: >1":12 >2":5; >6":3	76-77: 34 85.3% cor. 77-78: 37 78.4% cor.	76-77: $2720(5) (27%) 77-78: $4136(8) (41.3%)	Plow: at night $180/hr (x 4 (min.))
Northern City <60,000	$45K (75-76)	76-77: >1":12 >2":3 77-78: >1":12 >2":5; >6":3	76-77: 36 88.9% cor. 77-78: 40 82.5% cor.	76-77: $3270(4) (7.2%) 77-78: $4310(7) (9.6%)	Plow: $340/hr OT MOB. on fcst
Northern City <60,000	$113K (75-76)	76-77: >1":10 >3":3 77-78: >1":11 >2":8; >6":3	76-77: 39 92.3% cor. 77-78: 41 95.1% cor.	76-77: $7125(3) (6.3%) 77-78: $7975(2) (7.1%)	MOB: $775 Delay: $480/hr
Northern City >60,000	$250K (75-76)	76-77: >1":19 >3":6, >6":3 77-78: >1":24 >2":11 >6":5	76-77: 64 92.2% cor. 77-78: 52 86.5% cor.	76-77: $3215(5) (1.2%) 77-78: $4095(7) (1.6%)	Large underforecast, add 25%

CLIENT	BUDGET	NO. OF STORMS	NO. OF FORECASTS	LOSS (NO.)	COMMENTS
Northern City <60,000	$120K (75-76)	76-77: >1":23 >3":11 >6":5 77-78: >1":17 >2":12 >6":5	76-77: 48 83.3% cor. 77-78: 54 87% cor.	76-77: $1202(8) (1%) 77-78: $3897(7) (3.2%)	Contractors >4" $1000/hr
Northern City >60,000	$420K (75-76)	76-77: >1":24 >3":10 >6":3 77-78: >1":13 >2":10 >6":5	76-77: 44 93.2% cor. 77-78: 43 88.4% cor.	76-77: $35K(3) (8.45%) 77-78: $43K(5) (10.2%)	Contractor: $2600/hr x 4 hrs minimum Hold over: $1800/hr
Northern City >60,000	$450K (75-76)	76-77: >1":20 >3":6 >6":3 77-78: >1":15 >3":7 >6":4	76-77: 44 95.4% cor. 77-78: 43 79% cor.	76-77: $24K(2) (5.3%) 77-78: $68K(9) (15.1%)	Late, plow: $3000/hr Contractor (6") $2400/hr
Northern City <60,000	$59K (75-76)	76-77: >1":17 >3":10 >6":5 77-78: >1":15 >3":8 >6":5	76-77: 45 73.3% cor. 77-78: 51 82.4% cor.	76-77: $3566(12) (6%) 77-78: $2366(9) (4%)	Plow fcst. wrong: $1200/hr-timing not impt.
Southern City	$30K (75-76)	76-77: >1":5 None Plowable 77-78: >1":8 >3":1; >6":1	76-77: 24 100% cor. 77-78: 27 81.5% cor.	76-77: None 77-78: $2912(5) (9.7%)	MOB: $150 Plow ~$100/hr
Southern City	$10K (75-76)	76-77: >1":2 77-78: >1":3; >3":2	76-77: 19 84.2% cor. 77-78: 24 83.3% cor.	76-77: $306(3) (3%) 77-78: $2383(4) all storms incorrectly forecast (24%)	Plow at 1.5"; delay OT: $210/hr (+3 hr min.)

CLIENT	BUDGET	NO. OF STORMS	NO. OF FORECASTS	LOSS (NO.)	COMMENTS
Southern City	$25K (75-76)	76-77: >1":2	76-77: 17 88.2% cor.	76-77: $720(2) (2.9%)	Plow MOB: $1200
		77-78: >1":1 >3":1	77-78: 22 95.5% cor.	77-78: $1880(1) only snow, misforecast (7.5%)	

B. Electric and Gas Utilities

Presented in Table IV and V are the cost calculations for the electric and gas clients respectively. For purposes of comparison, the figures for the previous season are listed alongside the new results. The calculations for both sets were carried out using the same method and cost factors, and cover the same months of the year (all or part of the winter months for gas clients, the summer for electric) (see Second Annual Report for a description of the method). In cases where data was missing for the 1978 or the 1977-78 season, the corresponding figures for 1977 or 1976-77 were adjusted so that the same time periods were being compared. Also, some additional data for the earlier season have been made available since the Second Annual Report was issued. These two factors account for the discrepancies between the cost results reported here and those given in the last report. Note that there is one less gas utility listed in Table B than in the Second Annual Report. Data for this client were not available as of this writing.

The last three columns of each table show the actual losses for the two control years plus the values of the last control year, normalized with respect to the first. This normalization was accomplished by comparing the number of times in each year that the critical point was exceeded. Since this number is either a function of temperature, or both temperature and humidity, such a comparison is used to eliminate the climatological variations between the two years with regard to the dollar losses presented here. Thus, if client X had 20 days in 1977 which exceeded the critical point and 10 days in 1978, one would expect that the losses in the latter year would be half that in the former, if forecast accuracy were to remain the same. Of course, this accuracy varies,

TABLE IV

Electric Utility Results

Company	Max Power Used (MW)	Mi^2 Serviced	Critical Point	Tolerence	Cost/deg.	Total No. of Misforecasts 1977	1978
A	4,425	10,000	85°	4°	$2205	12	5
B	2,932	1.230	70 THI	2°	$2200	49	70
C	5,760	2,475	None	3°	$2000	59	54

	Over forecasts 1977	1978	Under forecasts 1977	1978	Total loss due to forecasts 1977	1978	Normalized 1978
A	9	4	3	1	$66,150	$28,665	-$4410
B	36	34	13	36	$323,400	$492,800	$502,219
C	30	32	29	22	$1,197,500	$1,184,500	$1,184,500

Table V

Gas Utility Results

Company	Max Gas Used (MCF)	Mi^2 Serviced	Critical Point	Tolerance	Cost/deg.
A	144,000	1025	28	3°	$2500
B	260,000	1703	50	2°	$7000
C	206,000	666	52	1°	$8750
D	52,328	314	50	2°	$1540
F	91,878	225	55	2°	$3125

	Total No. of Misforecasts		Overforecasts		Underforecasts	
	1976-77	1977-78	1976-77	1977-78	1976-77	1977-78
A	9	5	3	3	6	2
B	12	9	4	5	8	4
C	25	14	12	3	13	11
D	7	4	2	3	5	1
F	1	1	1	1	0	0

Total loss due to forecasts

	1976-77	1977-78	Normalized 1977-78
A	$55,000	$22,500	$47,500
B	$175,000	$168,000	$195,776
C	$336,875	$238,394	$390,468
D	$30,800	$18,480	$29,827
F	$9,375	$9,375	$16,406

and should account for most of the differences between the normalized values and the results for the first control year. In Table IV, this comparison shows some surprising results: client A experienced a very small 1978 dollar loss compared with 1977, despite the fact that the critical point was exceeded much more frequently. This resulted in a negative number in the normalization column. The reason for the greatly increased accuracy in prediction for this second year is unknown.

Client B, on the other hand, was not so fortunate. Prediction accuracy was much worse in the second year leading to greater losses although the critical point was exceeded about the same number of times in both years. Client C shows no difference between the normalized and unnormalized values because it has no critical point. The difference between 1977 and 1978 results are very close.

For the gas clients, A & D have very similar results over the period, while clients B & C suffered from a lower degree of forecasting accuracy. The normalized results for client F are not particularly meaningful because of the very few times that the critical point was exceeded in both years and because data was missing for the month of December, making a complete comparison impossible.

Conversations with some of the utility clients this past year indicate that cost, and in some cases, procedure have changed since our original survey. For instance, LNG conversion to pipeline gas now costs between $5 and $6 per MCF as opposed to $3.50 in 1976 and steam turbine costs have also approximately doubled. Also, in at least one case, the client has laid an additional pipeline thereby changing his critical point by 10°. This study, in order to produce results which are comparable from year to year and from client to client will ignore these subsequent changes although our final report will detail how the clients we are studying have evolved over the period of this project.

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. We have discussed the nature of these normalization statistics and the information sources used to derive them in our previous annual reports. The necessary data and resultant parameters have now been extended to cover additional time periods for which they are available.

A thorough discussion of the results of the work awaits their application in the context of the interannual comparisons required to determine the value of satellite data. Consequently, we shall only list here the inventory of the most useful parameters obtained to date.

a. Temperature and heating-cooling degree days

For each of the 22 locations listed in Table VI, and beginning in calendar year 1977, we have both monthly and yearly departures from normals of the maximum, minimum and average temperatures. The normals, for monthly and yearly maximum, mimimum and average temperature were generated from 30-40 year samples. We have also calculated monthly and yearly heating and cooling degree days for the same period and their departures from normals based on 8-20 year samples.

b. Snowfall records

For each of 37 reporting stations in Table VII we have monthly recorded snowfall beginning in the winter of 1976-77, through the present. These have been referred to long term (17-40 yr) normals to generate monthly and seasonal departures from normal. A second characterization has been obtained in terms of the numbers of storms resulting in snowfall in the following categories: (1) Trace to 1 inch; (2) 1 inch to 3 inches; (3) 3 inches to 6 inches and (4) more than 6 inches. These distributions were obtained for each of the 37 locations of Table VII for the period of study.

Table VI

Stations With Temperature Records

- Trenton NJ
- Richmond VA
- Roanoke VA
- Philadelphia PA
- Portland MA
- Norfolk VA
- Milton MA (Bluehill)
- New York NY (LaGuardia)
- New York NY (J.F.K.)
- New York NY (Central Park)
- Buffalo NY
- Hartford CO
- Bridgeport CO
- Concord NH
- Boston MA
- Avoca PA
- Atlanta GA
- Allentown PA
- Albany NY
- Providence RI
- Worcester MA
- Syracuse NY

Table VII

Stations With Snow Records

Trenton NJ

Richmond VA

Roanoke VA

Philadelphia PA

Milton MA

New York NY (LaGuardia)

New York NY (J.F.K.)

Buffalo NY

Hartford CO

Bridgeport CO

Boston MA

Avoca PA

Albany NY

Providence RI

Worcester MA

Syracuse NY

Wilmington DE

Newark NJ

Baltimore MD

Lynchburg VA

Washington DC (National)

Washington DC (Dulles)

Charlotte NC

Raleigh NC

Amherst MA

New Haven CO

Yorktown Hts NY

Bedford MA

Brockton MA

Holyoke MA

Peabody MA

Pittsburg (APT) PA

Springfield MA

Taunton MA

Walpole MA

Norfolk VA

VI. 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. Tim Browning and Ms. Ruth Lieberman have assisted with the climatological statistics and other parts of the analysis. The engineering work was directed by Mr. Gary Banta while CompuServ and Harris personnel did on site computer maintenance at Weather Services.

We expect little change in personnel during the coming year.

VII. FINAL YEAR PLANS

The major thrust for the final year will be the tabulation and analysis of data from the experimental period. The experimental, or "with satellite data" year will run through June 1, 1980, which will give Weather Services Corp. a full year of operation with their own GOES-TAP line. As all of the background and methodology work is complete, these techniques can be applied to the experimental period data. In addition, during the season, we will also be continuing to perform case studies on situations where the satellite data was beneficial, as well as keeping an up-to-date account of how and when the satellite data is used.

Since the forecast forms (by company policy) are held for the entire weather season, we will not have access to the winter season forecasts before mid-June at the earliest. By then, we will have hopefully received all of the relevant climatological data, if there are no late season snowfalls. These two factors will probably delay the final report a few months from the contract ending date.

One final note: due to excess expenditures on the construction and maintainance of the McIDAS system, we expect to have a cost overrun in excess of $25,000.

VIII. SUMMARY

With one year remaining in this program, the control period statistics for the various Weather Services clients have been compiled and presented in this report.

McIDAS has been installed at Weather Services and is being used routinely for forecast preparation. Statistics for this experimental year, normalized for weather variability, will be compared with the control period. These results combined with case study documentation should lead to a successful conclusion of this study.

APPENDIX I: SOME ECONOMIC EFFECTS OF PRIVATE METEOROLOGICAL FORECASTING

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SOME ECONOMIC EFFECTS OF PRIVATE METEOROLOGICAL FORECASTING

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Abstract

The clients of a meteorological consulting firm were studied to determine the effects of weather forecasts on their operations. We determined what weather conditions triggered certain operational decisions in three groups of clients--governmental bodies, gas utilities, and electric utilities. Then, using actual forecasts over a two year period, we calculated the monetary losses incurred as a result of incorrect forecasts. The results generally show losses in the thousands of dollars for each erroneous forecast. Thus, if the weather service is able to prevent even one set of poor decisions based on a forecast, the cost of the service would be returned and in many cases greatly exceeded. Other effects of the clients' use of the forecast are discussed qualitatively. These include non-monetary gains to the clients and their customers through increased convenience, easier planning, and fewer breakdowns in service. At least some clients fail to realize these advantages through inefficient use of the forecast.

1. Introduction

Meteorological information specially tailored to the needs of both the public and private sectors of the economy has become increasingly in demand. As industrial and business operations generally become more efficient, well-planned, and technical in nature, the effect of small environmental changes has become of obvious importance to the overall success of an operation [see WMO (1968), Maunder (1970), and Taylor (1970)]. Many, if not most, jobs are sensitive to both weather and weather information either directly or indirectly. As business and governmental concerns become more aware of how weather affects their personnel, equipment, and timetables, they desire to control these effects as much as possible, [Collins (1956)]. At the same time, 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 technical information to meet the client's needs which, because of their highly detailed and specialized nature, cannot be met by the National Weather Service. Consulting meteorology covers many diverse areas: providing meteorological advice and information on instrumentation, weather modification, advertising and marketing, statistical analyses, surveys and field studies, data processing, legal matters, radio and television programming, as well as short and long term forecasting for various business and industrial operations. In this paper we concentrate on the effects of short term forecasting.

While other studies have centered on consequences of alternate decisions, [e.g. Thompson (1972)], we use actual forecasts, outcomes, and consequences, to examine some 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 effects of the consultation are more easily quantifiable. Forecasts are typically issued on a routine basis, thus 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). Such decisions, as, for example, those made by 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 and in some cases by the client users themselves. We hope to clarify the relationship between the service the consulting firm provided and the uses to which such information was put by the user in actual circumstances.

2. Consulting Firm Operations

The organization and facilities of meteorological consulting firms vary considerably [Myers and Cahir (1971), Wallace (1971), and Hallanger (1963)]. There is no minimum standard to which they must conform. Although the American Meteorological Society has a Certified Consulting Meteorologist (CCM) program 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 a person with no experience from setting up an operation in a 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 competence.

In the cooperating consulting firm, whose clients were contacted in this study, operational forecasting is divided into two areas: daily or routine forecasting and storm or emergency forecasting. Routine forecasts include information such as temperature, degree days, humidities, and cloud cover that is 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.

The level of service depends on how much the client is willing to pay. Reports are sent out by phone or teletype once a day or every few hours with updates as needed. These forecasts are usually tailored to the peculiarities of a client's needs. For example, areas prone to flooding, hills that ice up rapidly, or highly vulnerable power lines may be of particular concern to individual clients. 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.

The National Weather Service (NWS) and the Federal Aviation Administration are the consulting firm's basic sources of data. Facsimile machines reproduce NWS maps and analyses. Teletype circuits from the Federal Aviation Administration supply hourly surface and upper air synoptic data from most North American stations. Satellite data are becoming more widely used. Pictures in facsimile format from government transmission lines can provide satellite data as often as every half hour in the visible and infrared. Radar information can be obtained even more frequently (up to every five minute) 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 consulting firms by supplying instantaneous data recall and display; mapping; data storing; and calculating derived quantities such as streamlines, divergence, and degree days. Such systems are likely to become more widely used.

3. Collection and Analysis of Data

We chose a reputable consulting firm with a large and varied clientele who received regular operational forecasts and categorized over 400 of these clients into groups with similar needs and activities. These groups are 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.

Our next step was to contact most clients through a questionnaire specially designed for each group. First, some preliminary inquiries were put to the clients. Then, many of the questionnaires were reviewed by a person knowledgeable in the client's area. Questions were included to obtain a general description of client activities in terms of size, budget, manpower, equipment, and facilities and to determine the use of the consulting service's forecast. In particular we were interested in operational decisions directly affected by the weather forecasts and the process used to arrive at these decisions, the deadline for such actions, and the financial losses or benefits incurred by alternative options. We telephoned the clients and sent follow-up letters to explain the purposes of our research and our need for prompt replies. More than 50% of the questionnaires were returned. After a questionnaire was returned, it was usually followed up by a phone call to clarify answers or get further information. In some cases, personal visits were made to clients to get a first hand view of their operations. (For more details see Suchman et al., 1978).

In analyzing the great volume of data we collected we had to impose a number of limitations on the scope of this study. One of these was the assumption that the client always followed the general procedures described in the returned questionnaire, although this was not always the case. We were interested in obtaining a general model of the clients' actual operations with regard to the forecast, not an idealized model of what the client's method of operation should or could be.

We also decided only to measure those effects directly produced by the consultant's weather forecasts rather than trying to assess the relative merits of alternative courses of action. The impetus for this study (still in progress) was to eventually determine the benefits of satellite data to the cooperating consulting firm and its clients; the control statistics are presented here. Towards this end, we used as a standard reference the "perfect forecast," rather than a forecast produced by some other source (e.g. NWS). We assumed that if the client did not subscribe to the cooperating consulting service, he would have followed either the NWS forecast or that of another service. The former was not practical for comparison because the wording of local forecasts are not precise enough for verification. "A low in the low 20's" could be 21°, 22°, or 23°; "snow up to 2" in coastal areas and heavier amounts inland" could mean from 2.5" to 4" or more inland with exact accumulations unknown. Also, the NWS forecast does not give exact timing, and a few hours difference in the onset of snow can result in the saving/spending of thousands of dollars. Most of the clients felt that this feature alone was worth the cost of subscribing to the consulting service. Because of this choice of reference the effects of the forecasts all appear as losses relative to the perfect forecast, this in no way reflects on the consultants.

Finally, the effects measured were what we call "direct economic losses." These are specific monetary losses accruing directly to the client (not the client's customers or the general public) over a short period of time (usually days). Examples of these include payroll costs and money spent for equipment deployment and materials (e.g. sand, salt, fuel). There are other sorts of losses associated with incorrect forecasts, but these are difficult or impossible to quantify. For instance, the client's working conditions and reputation may be adversely affected by a incorrect forecast. The client's public may also experience similar losses which are again not easily measured in dollars, such as time wasted getting to or from work, vehicle accidents, and personal injury. These are very real effects of incorrect forecasts which may be comparable in dollars to the direct economic losses we have measured. Though these effects may be the most significant in the long run, we can only mention their presence where appropriate.

The client's responses to the forecast situations were determined from their answers to our questionnaire, and the consultant's forecasts. The costs for specific operations were then calculated. These costs were then compared with the clients' costs had the forecast been correct. The difference was the loss due to a poor forecast. Thus, for each year we tabulated the total forecast situations, correct and incorrect forecasts, and net loss. As stated above, only some effects of the firm's forecasts are included, and this paper does not intend to evaluate the actual worth of the consulting service. To give an additional perspective to our results, we do compare the "net loss" with total operation budget and the cost of the consulting service.

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.

4. Client Group Results

a. Road and Street Departments

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

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 1 1/2" 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 for 4" or more. 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. Contractors 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. Forecast amounts can therefore be translated into mobilization and personnel costs--what equipment should be mobilized and who should be put on alert.

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

There are a few other significant points. First, for about one fourth of the clients surveyed, the forecast of adverse weather has little economic impact. Many of these are small townships who use the forecast for information purposes only; 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 (usually under $1000 per season). Other clients, for example, those in high snow regions, are always mobilized for adverse weather or, at least, automatically mobilize prior to a weekend or holiday.

About one fifth of the respondents react to storms only when they are in progress. They 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. We also encountered many clients who seemed unpredictable; they either subscribed to other weather services or only occasionally listened to the consultant's forecast. These people preferred their own interpretations to those for which they paid. Finally, public officials are very reluctant to admit to misspending money or making mistakes; this makes the task of assessing the impact of weather forecasts even more difficult.

The "overforecast," a forecast predicting more snow or ice than actually fell, seems to cause the greatest quantifiable losses for snow and ice clients. In such cases, crews are called in and equipment mobilized unnecessarily. Given personnel salaries for sanding and salting, plowing mobilizations and road operations, and a knowledge of when and for how long crews would be called in, we were able to construct a fairly exact method for calculating the cost of all overforecasts.

The "underforecast" was not so amenable to analysis. Many of the "losses" here are <u>indirect</u>, as previously described, involving increased complaints, loss of reputation, delays and inconvenience to the public. Another more quantifiable loss is the increased amount of time necessary to clear or improve streets given a start in operations after the onset of precipitation. Most clients had no idea how much such situations affect their total time on the road; although one client thought it would result in about a 25% increase in time and therefore in cost. Unfortunately, this estimate is only approximate. In addition to the uncertainties inherent in speculation about what would have happened if the forecast had been otherwise, the actual difficulties imposed by a late start would depend significantly on the rate of snow or ice fall at the beginning of the

Table 1
Monetary Losses Due to Incorrect Snow Forecasts

City A

Forecast	Outcome	Cost
less than 4"	no snow	$44/hr. + $750 (mobilization and demobilization)
less than 4"	later than forecast	$44/hr.
greater than 4"	no snow	$132/hr. + $750 (mob. & demob.)
greater than 4"	later than forecast	$132/hr.
greater than 4"	less than 4"	$88/hr.

Four hour minimum, 1.5 for overtime, 2 for holidays.

City B

no snow	plowable	$150/hr. extra (standby)
greater than 2"	no snow	$200/hr. + $150 (mob. & demob.)
greater than 2"	later than forecast	$200/hr. (standby)
greater than 2"	less than 2"	$1000/hr. + $100 (mob. & demob.)

If during regular hours (8 AM to 4:30 PM) costs are 1/3 less & mob. cost = 0

State C

less than 2"	no snow	$27,050/hr. + $9,800 (mob. & demob.)
greater than 2"	no snow	$27,050/hr. + $15,200 (mob. & demob.)
greater than 2"	later than forecast	$27,050/hr.
greater than 2"	less than 2"	$5,800 (mob. & demob.)

1.5 for overtime

storm, the condition of the streets before the onset of precipitation, the speed with which crews could mobilize and be out on the streets, and the total effects of the storm including such factors as drifting or heavy icing that could magnify or minimize the effects of a slow start. Since it is almost impossible to obtain meaningful quantitative losses for the underforecast, in most cases we used only the overforecast for loss calculations; thus our total costs will underestimate the true losses to the clients due to imperfect forecasting.

Because different criteria are 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. Two of these are public works departments in moderate sized cities and the third is a state highway department. The dollar figures in the cost column are a combination of expenses for (a) mobilization and demobilization of sand and salt equipment; (b) the same except for plowing equipment; (c) payroll cost per hour for sand and salt crews; (d) the same except for plow crews. Plow crews are usually larger than sand and salt crews and thus involve greater expense. Mobilization is the process of readying the trucks for street work; this includes loading materials into the trucks and mounting plows.

Every client has its own peculiar combination of costs. For instance, some clients incur no mobilization expense if the snow forecast is received during regular work hours because there are enough personnel to perform the mobilization as part of the normal daytime routine. Such factors along with overtime costs are noted in the table.

In general, mobilization is a one time cost (i.e. the entire cost is incurred once the decision to mobilize is made). Waiting time costs (c and d above) are hourly and rise proportionately to the length of the delay in precipitation onset or until the decision is made to demobilize. The decision to demobilize is usually made when a forecast update is received cancelling the snow alert.

Thus, for City A a forecast of less than 4" of snow would cause the sand and salt trucks to be mobilized ($750) and the crew to wait ($44/hr.), if necessary, from the time the snow was forecast to begin until the snow actually began or until the decision was made to demobilize. Mobilization costs in this case would only be counted as a loss if no snow fell; hourly crew costs would only be considered losses if the crew was required to wait for precipitation to begin.

Similiarly, forecasts and outcomes for over 4" cause plow mobilization ($750) and possible waiting time for the crew ($132/hr.). The case of a forecast greater than 4" and an outcome of less than 4" is a hybrid: the losses are the result of paying for a plow crew when only a sand and salt crew was needed ($132/hr. - $44/hr. = $88/hr.). This loss would be incurred for every hour the unneeded plow personnel were held over. For City A no mobilization loss would have occurred in this hybrid situation since the tasks involved are the same regardless of whether sanding or plowing is being planned. In other cities mobilization tasks vary between sand and salt and plowing preparations, and the difference in expense would therefore enter into the total loss.

City B estimates that it costs them about $150 per hour more to deal with an unexpected storm than one they are prepared for. They also have a skeleton crew ($200/hr.) on standby until precipitation begins at which time their full crew ($1000/hr.) is put on their payroll. State C puts it full crew out for any amount of frozen precipitation, with the only difference being in mobilization costs.

Appendix A illustrates the calculation procedure with a sample calculation for an overforecast storm in January, 1977. This overforecast produced an unnecessary expenditure of $13,000. In our study, however, most clients said they would prefer to be prepared for a storm and lose money if the storm does not develop than to be caught with their plows unmounted.

Finally, there is a situation in which an apparently incorrect forecast is really more than adequate. This would be in a case where a client receives a forecast for 6" and the actual accumulation is 15". The 6" forecast implies that the subscriber should put its entire plowing force into operation, and once this is done, total accumulation does not alter the procedure--the operation just takes longer.

Detailed analyses were performed on data for 26 clients in eight eastern states. Among the clients are six state or turnpike authorities and cities ranging in population from 10,000 to 300,000. Mean snowfall for these clients ranges from over 100" to as low as 5". The results for the 1976-77 and 1977-78 snow seasons are summarized in Table 2.

The economic losses due to incorrect forecasts varied from an average of under $5,000 for the smaller communities to over $60,000 for the larger subscribers. This represented 3%-15% of their annual snow budget. Half of the clients studied had received more than five poor forecasts that caused economic loss while only six subscribers had fewer than three. The majority of misforecasts were for light (up to 3") snow which never materialized. Though poor forecasts of plowable storms were infrequent, they caused considerable loss. The number of erroneous forecasts not causing direct losses averaged about four with most of these being under-

TABLE 2: SNOW/ICE CLIENT RESULTS

CLIENT TYPE	No. of Forecast Days	No. of Snow Days	Plowable Storms	Per Cent of Forecasts Producing Loss	Mean Annual Loss Due to Incorrect Forecast	Mean Annual Snow/Ice Budget
STATE HIGHWAY AUTHORITIES	37.6	10	3.9	17.8%	$64,100	$450,000
TURNPIKE AUTHORITIES	41.3	13.2	6.3	17.4%	$9550	$313,000
SOUTHERN CITIES	24	4	1	13.2%	$2440	$45,000
NORTHERN CITIES Pop >60,000	46.7	16.8	7.9	12.7%	$17,950	$270,000
NORTHERN CITIES Pop <60,000	45	14.6	7	15.2%	$4611	$98,600
MAX.	64	24	12	37.5%	$108,000	$853,000
RANGE MIN.	17	2	0	2%	$300	$10,000

forecasts. The percentage of correct forecasts averaged about 85%, which is rather high.

The consultant's fees ranged from about $1000 per snow season for many of the cities to over $10,000 for the larger units. In most cases, one forecast which prevents a client from unnecessarily calling in a contractor, mobilizing, or holding crews over at night pays for the service for the entire snow season. As the fee was usually less than 2% of total expenditures, the clients who reponded felt that the service was well worth the cost.

b. Electric Utilities

In general, both the electric utilities examined in this section and the gas utilities in the section following are more professional and less subjective in their use of the consulting firm's forecasts than the road and street departments discussed previously. From the utilities' point of view, the economic advantages of predictions tailored to their operations is both obvious and of sizable magnitude. For most utilities, the weather forecast is therefore incorporated into daily operations in a routine and well-defined way.

Electric utility clients were studied from two perspectives: the use of daily forecasting to predict and plan for peak loads, and the effect of snow, ice, and wind on the maintenance of the highly vulnerable power system. Load forecasting was studied with the help of daily forecast forms and verifications over the summer months when the utilities are most vulnerable to unexpected peak loads. The maintainance situations were done on a case study basis.

Peak load forecasting [see Barnett (1973)] refers to the necessity for electric utilities to predict the maximum power usage on any given day. During the summer months when power demand 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 when adequate warning is not received. These can be readied in a matter of minutes but are about twice as expensive to operate as steam generators. The economics of the situation are apparent; an overforecast 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.

There are a number of 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 and can tolerate unexpected fluctuations in temperature. This leeway can be as large as 10°, but usually it is from 2° to 4°. Leffler (1972) has found that utilities can tolerate forecast errors of under 3%.

Size of the System--Naturally very large systems covering population centers or even whole states are more greatly affected by temperature fluctuations than are small systems. 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 temperature/humidity above which a utility must schedule the use of its own turbines (i.e. the maximum available power is already being used). A forecast or actual weather near 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 the economic impact of a forecast on a given system. Such information was available from three systems in the eastern U.S. An example of such a calculation is given in Appendix B. The results for the 1977 summer season are presented in Table 3.

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 overforecasts are more common than underforecasts. The total losses for these companies were probably larger than average due to a summer which was slightly warmer than normal.

The northeastern snow storm of 22-24 March, 1977 provided an example of the effect of a forecast on maintenance. This storm, which produced up to 30" of snow over a two day period was not correctly forecast. 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 of hiring extra crews to service the area was in the hundreds of thousands of dollars. (One company estimated the cost to be $351,900). No forecast

Table 3
Electric Utility Results

Company	Total No. of Misforecasts	Over-forecasts	Under-forecasts	Cost/deg.	Max Power Used in Mega Watts	Mi^2 Serviced	Critical Pt	Tolerance	Total Loss due to forecasts
A	11	8	3	$2205	4,425	10,000	85°	4°	$55,125
B	38	29	9	$2200	2.932	1230	70 THI	2°	$281,600
C	43	23	20	$2000	5,760	2475	None	3°	$937,000

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. A company, adequately warned, would have had its crews on the road ready to work on outages. When caught unprepared, repair vehicles may not be able to reach the scene of trouble. One company reported up to 59,930 outages at the peak of the storm on the 22nd. 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. Restoring power quickly is highly desirable not only because of the inconvenience to the customer but also because storm conditions might worsen and totally prevent access to problem areas. The potential importance of the forecast in this process is obvious.

Most companies, given the option will choose to be overprepared rather than risk system damage. For example, during ice storms, crews are often deployed to remove potentially dangerous tree limbs, whether or not any outages are reported.

In general, the cost of the service to electric utilities ranges upwards from about $800/month, depending on the company's size and areal coverage. Enabling the company to correctly prepare for a single severe weather event will more than cover a year's service. One company last season spent $75,000 holding crews over for an ice storm that never materialized; however, being caught unprepared would have cost even more. With temperature forecasts resulting in a $2000 per degree cost within a critical region, the yearly costs can often be recovered by one improved forecast.

c. Gas Utilities

Gas utilities are vulnerable to many of the same problems as electric utilities, although maintenance problems are not nearly as extreme. The factors of threshold, system size, and tolerance apply here as they do for electric companies [see Ruskin (1967), Roth (1963)]. 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 stored gas. These sources are generally more expensive to use [anywhere from $1.50 per thousand cubic feet (MCF) to $3.50/MCF] than pipeline gas. and therefore unneeded use of these due to forecast error will have an economic effect. Sometimes the unneeded gas generated can be stored for the next day thus eliminating a portion of the 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 often 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 due to tight supplies. A sample calculation for a gas utility is given in Appendix C.

The results of our calculations based on 1976-77 data are summarized in Table 4. 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 gas companies 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 temperatures much below

Table 4
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

normal were reported all along the East coast. Because gas companies differ greatly in size, the cost per degree varies more widely than with the electric utilities. Unlike electric utilities, gas companies more often have incorrect forecasts turn out as overforecasts than underforecasts. The smaller losses for companies E and 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 and C), forecasting has significant impact on their yearly budget.

Gas utilities pay from $600 to $1000 per month for daily forecasts. As with the electric companies, a small improvement in forecast accuracy more than pays for the forecast service.

5. Some General Observations About User Clients

While a major motivation for subscribing to a weather service is financial, we should also mention some of the other reasons why 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 and crews can be alerted. 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 and the

National Weather Service in their planning. This approach is not necessarily bad if the client can knowledgably weigh the various sources of information. In practice, however, the user may be prone to plan according to the source he wants to believe having no objective way of choosing between them.

We found that a few subscribers did not really know what to do with the information they received from the consulting service. Sometimes the decision to subscribe was made at a higher level, and the people responsible for making operational decisions were not adequately briefed on the use or need for the service. In many cases, forecasts could be put to better advantage if the user knew more about the applications and limitations of the consultant's service. Also, the user's response to a forecast may often be influenced by outside factors such as the individual on duty at the time, the accuracy of recent forecasts, the timing of the forecast, and immediate budget considerations.

Finally, some clients feel that a subscription to a weather service looks good on their record regardless of how well the information is actually being used. They can assure the public or others who review their operation that they are using every possible performance aid. In addition, they have someone to blame for mistakes in decision-making.

6. Discussion

Although the illustrations presented 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 the fees paid by the subscribers for the services. In most cases, the fees were a minor part of the subscribers' operational costs. A few of the large clients have tried in-house forecasting but found the consultants to be more accurate and less expensive. The yearly expense of hiring a consulting service could usually be offset by the savings resulting from one accurate forecast the client would not have had without the service.

The cases discussed in this paper are just examples of how the varied clientele of one meteorological consulting firm benefit economically by using the forecast service. It is not intended to be more than that; all consultants operate differently--they disseminate different products that are received and processed in different manners than those described here. The end results for the clients, however, are the same; more efficient operation and more objective decision making.

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, oil 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 generally play an important role in organized economic decision making. In the race for viewer appeal, meteorological professionalism in the media is often of secondary importance.

In summary, private forecast services meet very important needs; they provide specific, localized, and interactive forecasts geared to the needs of their subscribers. They are most valuable when the subscriber is fully aware of what the information means and how it can be used. Finally, the accuracy and timeliness of these forecasts can have economic ramifications which can benefit the user directly and those served by the user, indirectly. These benefits depend upon the particular needs of the client and can vary from client to client within the same user group.

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APPENDIX A
SAMPLE SNOW CALCULATION

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.

Actual Conditions

January 14

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

Total accumulation: 1.5"-2"

Because the snow did not reach plowable amounts (3") during the evening, plows were mobilized unnecessarily ($3300); contractors were called in at a forecast accumulation >6" and paid the minimum four hours when they were not needed ($7000), and day crews were unnecessarily held over until the snow stopped at 2 A.M. (10 hours x $250/hr. = $2500). Total loss was $12,800 or close to 9% of the total seasonal snow budget.

APPENDIX B
SAMPLE ELECTRIC CALCULATION

Forecast

Given at 8 A.M.; 7/1/77 for 3 P.M. 7/1/77

Temperature = 81°, R. Humidity = 64%

Actual Weather

3 P.M. 7/1/77

Temperature = 86°, R. Humidity = 69%

Critical point at which extra turbines are added: 70 THI

Since both the forcast 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.

APPENDIX C
SAMPLE GAS CALCULATION

	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

This utility receives forecasts for two cities within its service area. The critical point is 52 degree days (DD), determined 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. The 1200 forecast is the one used for verification. For City W, 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 (considering 1° tolerance). For City F, with a 5° error and a sendout of 625 MCF/DD the cost for the gas is \$8750. 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 an adverse economic impact because it was not in the critical temperature range.

REFERENCES

Barnett, C. V., 1973: "Weather and the Short-term Forecasting of Electricity Demand." In Taylor, J. A. (ed.) Weather Forecasting for Agriculture and Industry, A Symposium. Assoc. University Press, 209-223.

Collins, G. F., 1956: A Severe Weather Service for Industry, Bull. Amer. Meteor. Soc., 37, 514-516.

Hallanger, N. L., 1963: The Business of Weather: Its Potentials and Uses, Bull. Amer. Meteor. Soc., 44, 63-67.

Leffler, L. G., 1972: "Electric load estimating experience at Public Service Electric and Gas Company." Paper presented at the Short-Range Load Forecasting in Electric Power Systems Conference, Saxtons River, Vermont, August 1, 1972.

Maunder, W. J., 1970: The Value of Weather. Methuen & Co. Ltd, 388 pp.

Myers, J. N. and J. J. Cahir, 1971: The Weather Business, Weatherwise, 24, 64-67.

Roth, R. J., 1963: Further Application of Weather Information, Bull. Amer. Meteor. Soc., 44, 72-74.

Ruskin, V. W., 1967: How to Forecast Gas Loads, Gas, 43, 54-57.

Suchman, D., B. Auvine and B. Hinton, 1978: A Study of the Economic Benefits of Meteorological Satellite Data. Second Annual Report on Contract NAS5-23706, 103 pp.

Taylor, J. A., 1970: Weather Economics, Pergammon Press, 126 pp.

Thompson, J. C., 1972: The Potential Economic Benefits of Improvements in Weather Forecasting, Final Report on Grant No. NGR 05-046-005. Department of Meteorology, California State University, San Jose, 80 pp.

Wallace, J. E., 1971: The uses of Private Weather Services, Bull. Amer. Meteor. Soc., 52, 548-550.

World Meteorological Organization, 1968: Economic Benefits of Meteorology, WMO Bulletin, 18, 181-186.