HASLER CODE 914

NASA CR-166663

A STUDY OF THE ECONOMIC BENEFITS OF METEOROLOGICAL SATELLITE DATA

(NASA-CR-166663) A STUDY OF THE ECONOMIC BENEFITS OF METEOROLOGICAL SATELLITE DATA Final Report (Wisconsin Univ. - Madison.) 260 p HC A12/MF A01 CSCL 04B

N81-25631

Unclas
G3/47 28186

David Suchman
Brian A. Auvine
Barry H. Hinton

Space Science and Engineering Center
The University of Wisconsin-Madison
Madison, WI 53706

September 1980

Final Report on NASA Contract NAS5-23706

Abstract

The clients of a meteorological consulting firm, not initially receiving satellite data, were studied to determine the effects of weather forecasts on their operations. Specifically, we intended to show whether, satellite data aided the forecasters, and produced savings for the clients. We determined what weather conditions triggered certain operational decisions for 131 clients responding to our questiontionnaires, representing governmental bodies, gas and electric utilities, fuel oil dealers, commodities dealers, marine and construction interests. Then, using actual forecasts over a two year period, we calculated the monetary losses incurred as a result of incorrect forecasts for over 50 of these clients. 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.

Beginning with the third year of the study, the meteorological consulting firm was given the means to receive real-time satellite data, and incorporated it into their forecast procedures. In addition to just viewing the GOES-TAP images, they were able to loop, enhance and navigate them, track clouds, determine cloud heights, and combine the satellite images with conventional data. Through their McIDAS (Man Computer Interactive

Data Access System) they could also plot, and analyze surface and upper air data.

After a year, we repeated the process of calculating monetary losses as a result of incorrect forecasts. This time the forecasts were prepared with the aid of satellite data. Unfortunately, because the weather events during that year were so benign, we were not able to arrive at figures comparable to those for the control period.

The significance of the value of satellite data varied with the type of operation involved:

Marine clients - The satellite data was extremely valuable in identifying and tracking convective systems and determining their characteristics;

Storm forecasting - The satellite data aided in locating and tracking storms, especially in oceanic areas;

Temperature and Weather forecasting - Here, the satellite had the least impact, though it was some help in temperature forecasts in regions of cloud cover; and

Commodities - It was essential for analyzing South American weather.

The satellite data was of most use when it could be looped to show evolving cloud patterns, and enhanced to show brightness differences. The grids that are supplied with the GOES-TAP images were often inaccurate; when the images were looped, they were very distracting. The economic value of the satellite data to the consulting firm was at a minimum, several hundred dollars per month (the cost of maintaining the GOES-TAP line, an additional data source was not in their plans prior to the experiment).

Our main conclusions are as follows:

(1) Satellite data, while most useful in data poor areas, serves to fine tune forecasts in data rich areas. It consequently has a resulting significant economic benefit because, as previously stated, even one improved forecast per client per year can save each client thousands of dollars. Multiply this by several hundred clients and the dollar savings are sizeable.

(2) The great educational value which experience with satellite data gives undoubtedly leads to improved forecasts.

(3) This study lays the important foundation for future work in this area. More studies of this type should be undertaken for longer periods of time to smooth out the unreliability of the weather.

(4) Any type of future satellite data delivery system should take into account the needs and facilities of the user community to make it most useful.

Finally, we have shown that it is possible, using real data in actual situations, to determine the economic impact of a new tool and the ways it can be used to bring about greater public benefits.

TABLE OF CONTENTS

1. Introduction

a. Background

The purpose of this report is to document a four year research program carried out by the University of Wisconsin Space Science and Engineering Center aimed at exploring the economic benefits of meteorological satellite data to a variety of users of weather information.

Historically, weather forecasting received its first big technical advance with the invention of the telegraph which made rapid collection of weather data possible. Later, the critical dependence of air transportation upon weather factors in the first half of the twentieth century brought about a significant increase in the weather data collected and reported by government agencies. During this same period the public became accustomed to general weather forecasts produced by the Weather Bureau, but largely dispensed by the privately controlled media--both printed and electronic.

By mid century, radiosonde networks were established for more adequate upper air coverage. The last half of the century--from the 60's onward--has been marked by the development of earth satellites and remote sensing methods suitable for weather satellites. Meteorological satellites and the data they produce have changed greatly from the TIROS of the 1960's to the sophisticated GOES, NIMBUS, and NOAA satellites of today. Over a period of only 15 years, the technical capabilities of these systems have increased and improved to such an extent that data processing and utilization techniques simply have not kept pace.

The volume of the data involved in storing and editing satellite images dwarfs that coming from conventional sources, often cramping available space and time allowances. In addition much remains to be learned about how best to obtain useful information from these images once they are made available for viewing and manipulation. While many advances have been made in these problem areas, these techniques are not yet generally available to the forecaster. This is caused in part because the maintenance of a weather satellite system entails considerable expense.

There are however other factors which account for the slow acceptance of this new technology. 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. Although meteorological satellites have evolved greatly, adequate utilization techniques are still being developed. Lacking a demonstration of the value of direct application of satellite data, very few private firms were willing to invest the capital required, or to undertake the additional operating expense to acquire more than twice daily GOES images transmitted over the FAX lines when this program began. This situation is gradually changing. Up to now private forecast operations have been labor intensive. However, the decreasing relative cost of hardware will soon make investment in computing equipment feasible. Since the same equipment might be used to reduce the labor of processing and charting conventional data as well as satellite based data, the adoption of high technology is probably imminent.

Before this can happen however, there must be some way of assessing at least tentatively the possible benefits of such system versus its prospective cost. The problems encountered in arriving at an objective and reliable assessment of the effectiveness of the meteorological satellite programs and of their value to the nation are many, and very difficult to handle. For example: Satellite data, radar, surface observations, rawinsonde data, aircraft observations, and so forth are all melded to produce a forecast. Hence, the value of the contribution of any single data source is extremely difficult to isolate. Furthermore, the parameters which are featured in the general purpose forecast may not be the ones important to a specific economic activity. To accommodate such needs, special purpose forecasts have been developed: bog temperatures for cranberry growers, winds aloft and significant weather for aviation, marine forecasts plus several others, a few of which are discussed by Hussay and Heacock (1978) in the context of satellite data.

Despite these problems, we found a convenient way to approach the problem of forecast value or utility by studying the relationship of a private meteorological forecasting service and its clients. These firms have arisen because 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). Meteorological information specially tailored to the needs of both the public and private sectors of the economy has now become increasingly in demand. As industrial and business operations generally become more efficient, well-planned, and technical in nature, small environmental changes have become of obvious importance to the overall success of an operation (see World Meteorological Organization, 1968; Maunder, 1970; and Taylor, 1970). Because these needs are not always fully met by the general or special forecasts available to the public, and because managers and planners perceive a monetary value in specialized information, meteorological consulting firms have been established. (Some larger firms have also engaged in in-house forecasting.)

The clients, or end users, of these 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 expected the clients to be more aware of the quality of service they received, and to be more motivated to cooperate in a research program whose ultimate outcome might improve these forecasts. These factors encouraged us to focus 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 had been made of satellite data by the cooperating firm prior to this study, we have taken advantage of the possibility of a before- and after-the-introduction-of-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 and other data that are eventually combined in a given forecast.

b. Consulting firm operations

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 are not, or 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, and radio and television programing, as well as short- and long-term forecasting for various business and industrial operations.

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. Teletypewriter 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 channels. Radar information can be obtained even more frequently (up to every 5 minutes) from certain NWS stations in the United States by means of a dial-up facsimile system.

The flow of weather information can be briefly represented as in Fig. 1. This report primarily considers the change in economic benefit to the user/client group (bottom box in the figure) due to the use of newer satellite based technology for part of the data collection (top box in the chart). For reasons to be considered in more detail below, we have concentrated on the information path through the consulting firm and will not extensively consider the impact of public, or media forecasts (see Fig. 1).

At present 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. The American Meteorological Society has a Certified Consulting Meteorologist

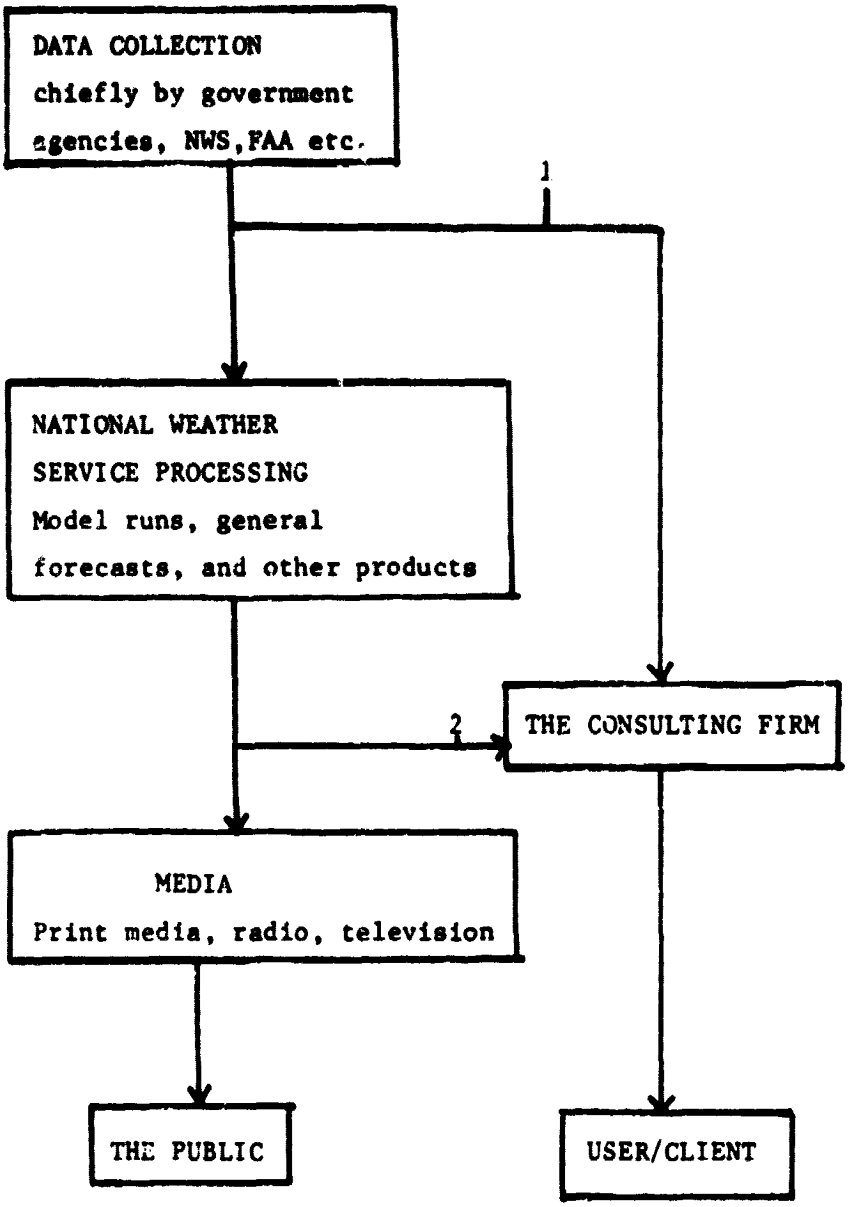


FIGURE 1.
Data from current weather observations gathered by government agencies, is available to the consulting firm in near "real time" by telecommunications (denoted by 1 above.) Similarly, 2 indicates rapid availability of maps, charts, and text pertaining to operationally processed data and forecasts by telecommunication.

(CCM) program consisting of certain professional and ethical standards to which a member must adhere; many consulting meteorologists operate with this certification. There are, however, other competent meteorologists in consulting who are not CCMs simply because they have not felt the need to go through the process of applying for certification.

c. Purpose and initial plan of program

In our program we proposed to bypass the economic effects of the actual weather, and examine the effects of the forecasts, and thereby the effects of satellite technology, on the accuracy and timeliness of the forecasts. The value of any meteorological service is very difficult to pin down. David Atlas (1975) described the problem well:

> Another difficulty, when discussing atmospheric science and its value, is that so little has been done to appraise the value of present and potential atmospheric science applications. Changnon and others have suggested the need for socio-economic studies of such potential benefits. The importance of such studies cannot be overemphasized, nor should their hazards be minimized....

The last statement needs to be elaborated. Most past cost-effectiveness and socio-economic studies fall into the category that Atlas calls "what if" studies. An assumption is made, and the consequences of that assumption are then calculated and reported. Obviously, at best, these studies are only as good as their beginning hypothesis. Again, Atlas states:

> .....Unless accompanied by realistic appraisals of what capabilities are realistic to expect, "what if" studies may merely give the impression that we are more confident of reaching the capability than we have any right to be. Again, we are raising premature expectations.

In order to determine the value of meteorological satellite data in a realistic way we planned the following program in five steps:

1. Find an established private weather service with a variety of clients, in which meteorological satellite data has not been used, but for whose services it would be valuable.
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.

Prior analogous studies have centered on the consequences of alternate decisions (e.g., Thompson, 1972); we have used actual forecasts, outcomes, and consequences to examine some clients who are 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.

In summary, we chose a "before and after" approach. A private consulting firm and its clients are suitable for this approach because they form a relatively closed system, because at the start of the program they were making little explicit use of satellite data, because with their active cooperation we could learn how the data were used. Further as suppliers of the data, we could control the data to some degree. Access to the firm's forecast records was expected to give detailed information on forecast accuracy and timing. As noted above, public forecasts already incorporate satellite data to some degree, but it seemed unlikely that we could effect a change of NWS operations that would materially affect the fraction of satellite data in the mixture to the degree that this would be possible with a cooperating private firm. In the case of the private forecaster, locations of forecast areas, the timing of the forecasts, the forecast parameters and the detail or resolution of the forecast are designed to meet the need of specific identifiable economic activities. These forecasts are subject to more definite verification than general public forecasts. Finally, it was thought that with the help of the consulting firm the cooperation of the client firms could be secured in order to obtain information on the costs and other consequences of various forecast and weather situations.

The initial problems we expected to encounter were many and varied: How can the weather of one season be compared with that of another? How do we find an impartial means of selecting a firm to whom we will supply satellite data? How do we gain confidential information from the beneficiaries of the data? How do we quantify "economic benefits?" The solution to these problems, plus the other problems we faced and their solutions will now be discussed. These will be followed by our results, general observations and a discussion of the program.

2. Program Formulation

a. Selection of cooperating consulting firm

One of the earliest hurdles of this study was the selection of a meteorological consulting firm which would be most suitable for our needs. The selection had to be totally impartial because we, a government funded facility, would be working with a firm in the private sector. We also had to avoid giving the chosen firm any undue competitive advantage. A fair balance had to be struck between the benefits to be received from the use of (and experience with) the satellite system, and the expenditures of time and manpower for participation in the study.

Prior to contacting any potential participant, a list of criteria for selection, based on the needs of the program, was drawn up (see Appendix A) to provide an objective basis for selection. The program needed an established and well respected consulting firm with a large and varied clientele. We wanted to work with a firm that offered services of high quality, and we preferred a firm with at least one Certified Consulting Meteorologist on its staff. In addition, we looked for a complete willingness to cooperate in the many facets of the program. The assessment of these criteria could be made only by personal visits and inspection of the interested firms.

From a directory of currently active consulting firms supplied by the American Meteorological Society, the most promising companies were contacted. The letter of contact included a description of the program plus the selection criteria described above. These letters were then followed up by phone calls. The two most promising firms were then chosen for a visit. It was agreed that all information gained from these visits was strictly confidential.

To help insure the impartiality of the selection process, additional precautions were taken. First, a list of the type of information of interest to us was sent to the two interested firms so they could best prepare for our visit (see Appendix A). Second, a detailed list of questions to be asked on both visits was prepared in advance (see Appendix A). These questions were to be our guidelines for the visit. In addition, each visit was to be made by two staff members to minimize personal bias. One staff member made both interview trips so that a more direct comparison between the firms could be made.

The actual interview paralleled the list of previously prepared questions. The areas discussed were: staff organization and procedures; the nature of in-house quality control; the current and future plans for satellite data usage; actual forecast operations; hardware in use; and reasons for participation in this program. After the visit, each interviewer also recorded his subjective impressions of the operation of the consultant, based upon what he was able to view.

When all the questionnaires were completed and analyzed, the selection was made on the basis of the previously described criteria. Weather Services Corporation of Bedford, Massachusetts met all the needs of the program, and this choice was strengthened by the individual evaluations and subjective impressions formed by the visiting team members. The crucial selection factors were items 2, 4, 6 and 7 on the criteria list in Appendix A.

Weather Service Corporation (WSC) is a highly respected meteorological consultant firm with more than 30 years of experience. They employ more than 20 professional meteorologists and four technicians; three staff members are certified Consulting Meteorologists. Their members are active on the National Board of Industrial Meteorologists and in local and national activities of the

American Meteorological Society. Their forecasts and verifications are archived for research as well as quality control. The hardware and techniques they use employ the latest advances in the field of meteorology. Most important, they expressed a strong interest in the study, had a strong desire to incorporate satellite data into their operations, and gave every impression that they would be cooperative partners in the study.

The clients of WSC number more than 300 from Maine to Georgia. Many are potentially affected by weather originating in oceanic regions where conventional meteorological data are sparse. At the time of our interview, they included: (1) one hundred forty-seven state, county and municipal governments, shopping centers, universities and some private industries interested in snow and ice removal and other emergency weather warnings (e.g., floods, high winds, heavy rains); (2) thirty-three gas utilities interested in temperature forecasts as well as emergency warnings; (3) eleven electric utilities interested in temperature, humidity and cloud cover forecasts as well as emergency storm warnings; (4) fifty-nine fuel oil companies which need temperature and heavy snow information; (5) nine commodities clients who use current, long range, and world-wide climate data; and (6) an assortment of construction, blasting, marine and aviation clients. Media clients served by a subsidiary of WSC were not included in this study, to preclude advertising of the satellite data.

At Weather Services Corporation, 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 h. 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 teletypewriter 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. In addition to the above forecasting areas, Weather Services also has a world wide climatology group, a marine forecasting group, plus a media subsidiary.

Once the selection was official we entered into an agreement with WSC (see letters in Appendix B) which outlined restrictions and responsibilities of both parties. To summarize, SSEC was to develop the means by which WSC would receive satellite data, and would train WSC personnel to use it. WSC would document its forecasts and verifications, and would permit SSEC to contact all WSC clients.

In addition, WSC was restricted from referring to this study in any advertising or promotion to gain new clients, and would not display any reproductions obtained directly from our data installation in any communications medium during the period of this study. All records and discussions pertaining to this project would be kept confidential unless otherwise decided by both parties. The selection of Weather Services Corporation in no way constituted an endorsement of that firm over any other consultant.

b. Initial problems

The initial plan for the program was to have the Man-Computer Interactive Data Access System (McIDAS) system built and installed by September 1977. (This was the means chosen to supply them with satellite data.) This date continued to be pushed back, and the system was delayed a full year. The reasons for this were twofold. First, due to a manpower drainage to other programs, intensive work on the system did not begin as soon as it should have. This program was given a rather low priority on SSEC's list of tasks to be accomplished, and hence, much of the engineering work that was expected to be finished early in the year never was. The second problem was that since this system differed in various ways from our McIDAS, certain of the components presented time consuming unforeseen delays.

The second hurdle we had to overcome was presented by the private meteorological firm that we interviewed, but did not select. Their feeling was that since we were working with a private firm, we were giving them an unfair competitive advantage, and it was excess government interference in the free enterprise system. These feelings were not at all expressed when there was a chance of their participating in this program. In restrospect, these fears have proven to be unfounded: our involvement with WSC has caused minimal changes in either their operations or their clientele.

As a consequence, SSEC and the University of Wisconsin were threatened with legal action to halt the program. We and the University's legal staff spent many hours rebutting their allegations. When the initial threats did not produce the desired results, they were then directed at NASA. This led to a period of uncertainty as to the future of the program, and all work was halted. Eventually, we received reassurances from NASA that our efforts were to be supported.

c. Program operation

The program, lasting four years was originally planned as follows:

Year 1, 1976-77: Develop the methodology for the program, find consulting firm and contact clients, develop and build hardware.

Year 2, 1977-78: Control year - complete hardware/install.

Year 3-4, 1978-80: Experiment period.

As it turned out, we were able to gather control statistics from the first two years, and that is what will be referred to as the control period. Due to the delays discussed elsewhere, the McIDAS system was completed and installed at the beginning of the third year, almost a year behind schedule (September, 1978). It was never reliable enough during that third year for statistical purposes, so although it was functioning sporadically, the forecasts during that period were not documented. The experiment period began in May, 1979 when McIDAS operations became more reliable and continued until April 1980. The program operation was terminated early as a means of saving money, and because the April-May period would add little to our results.

In addition, because WSC did not keep complete records on the down-time of McIDAS, we therefore had to assume that satellite data was available to them, unless specifically told otherwise.

3. Methodology

a. Approaches

There are several different ways in which this economic impact study could have been approached theoretically. One which could be rejected almost immediately would involve working with two different consulting firms, one having a satellite data system, the other not. Comparing the operations of these two firms over a suitable length of time should reveal a difference in forecast accuracy. In addition to the practical problems of getting two firms to cooperate, there are two other obvious obstacles. The operations of any two firms in this field would vary significantly in terms of the size and abilities of the staff and their general forecasting procedures. These differences somehow would have to be "subtracted out" in order to detect a variation due to the use of satellite data. Second, the client groups served by the respective firms would differ substantially in nature and location. To account for such diverse factors in any systematic way would be impossible.

Another approach which initially seems more attractive would involve only one firm. After installation of satellite data hardware, the firm would be responsible for generating two forecasts for every client in every situation; one with knowledge of the satellite data relevant to the forecast, the other without. Differences between the two sets of forecasts over a long period would indicate variations due solely to satellite data input.

Unfortunately, this method is not as feasible as it seems. First, the burden of producing two forecasts for every client would cause a significant and probably unacceptable, disruption in the operations of the firm.

Second, it would be extremely difficult to set up such a procedure in a scientifically valid way. If two different staff members produced the two different forecasts, one would have to account for differences in personal forecast abilities. If the same person did the two forecasts (one without looking at the satellite data, then another revised forecast after seeing satellite data), the first forecast might affect the way he interprets the satellite data. It is also doubtful that later updates or new forecasts could be made without recollection of satellite data.

The methodology chosen for this study was a variation of the one-firm approach just described. The forecast and client operations of a single firm were studied for a control period of two years to obtain base statistics about the forecast and the clients. During this phase researchers became familiar with clients' operations and their particular vulnerability to the forecasts, and examined the records of the consulting firm's forecast and their verification to determine the economic impact each year of service had on clients.

This whole procedure was then repeated after the satellite data hardware was installed and debugged, providing a one-year period in which to study the effects of the new data. It was hoped that comparison of this set of data with that from the previous years would illustrate any relevant differences due to the use of satellite data, provided certain extraneous influences were removed. One of these influences stems from the variation in weather from one year to the next. For example, in a year with twice as many snowstorms as usual the total economic benefits due to correct forecasting may be significantly increased. In comparing successive seasons, reference to a climatological mean to normalize the data or provide for a similar sampling of storms from both seasons was necessary.

Concerning the consulting firm operations, it was important that there be little change in personnel, or operational procedure (other than that associated with the use of satellite data) over the three year study period. WSC is a stable and well established firm and fulfilled this requirement very well. The regular forecasting staff remained essentially the same over the three year period.

Similarly, substantial changes in the clients serviced over the period of the experiment could adversely affect our results. By "changes" we mean either that the client ceased being a customer of the consulting service altogether, or that the client modified forecast requirements in such a way that older forecasts could not be quantitatively compared with newer forecasts for the calculation of benefits. Changes affecting the clients' operations only and not creating associated changes in the forecast information received (inflation, or acquisition of new equipment, for instance) were not considered after our initial survey in 1977. Since in this experiment we wished ideally to consider only one variable, that of having and not having satellite data, all our results are essentially "normalized" to the situation prevailing at the beginning of this project.

For the most part our desire for a stable client base was fulfilled. For one of the two main client groups (utilities), only two clients (out of 10) dropped their service, while in the other (snow and ice) four clients out of twenty-six (15%) dropped. Though two of these latter drops were large state wide clients, this still left several similar clients in the study for the complete period. Finally there was one marine client whom we might have used for analysis had they remained a client. Overall, however we consider that these client changes did not seriously affect the quality of our data sample.

Finally, it was important that the satellite data system installed not produce a major disruption or reorganization in the procedures used by the consulting firm; otherwise, the study might measure the effect of the changed forecast procedures and not of the introduction of the satellite data. This is a difficult goal to achieve. On the one hand, the means must be provided to make the satellite data as useful as possible. For example, combinations of contoured conventional data with satellite images will facilitate the integration of the satellite information into the total forecast product.

On the other hand, the convenience of having conventional data at one's fingertips in a new and useful format may, in itself, have an effect on forecast accuracy. To minimize this problem it was necessary to scrutinize the capability of the equipment given to the consulting firm to assure that nothing really "new" was being made available to the forecaster except the satellite data itself. Since SSEC would be installing a computer with both satellite and conventional data displays, it was highly desirable that the participating consulting firm have some in-house computer capabilities prior to the beginning of the second phase of the experiment. WSC, the chosen firm, did have PDP-11 computer facilities allowing the display of conventional data.

b. Defining economic benefits

There are many different economic benefits accruing to the clients of meteorological consulting firms, but not all of them are tangible. An attempt will be made here to describe and classify such benefits, especially those with which this study is concerned.

1. Direct and immediate benefit to the client

Forecasts to a client may be improved in one of three ways: by making possible a more accurate forecast; by improving on the frequency and timeliness of the forecast (including updates and emergency warnings); and by allowing the inclusion of more detail or aerial coverage in current forecasts. These improvements may benefit a client in a variety of ways. The most easily measured benefits are those which a client realizes from a single forecast or group of forecasts (for, say, a single storm); the client can point to a specific gain coming directly to him (as opposed to the community of users the client may serve or operate in) over a short period of time (a period of days). Examining in detail the operations of a client, one can ascribe a fairly exact monetary value to some of these benefits. Examples include savings in payroll size, in deployment of equipment costs, and in the use of materials. A major goal of this study was the accurate measurement of this sort of economic value.

Other direct and immediate benefits are not so easily quantified because they involve factors of convenience or efficiency. For instance, it may be of great psychological value to a foreman of a snow and ice crew to know that no storms are expected over the weekend or overnight, since he can, with peace of mind, use his time without the worry of making special plans for handling a plowing situation outside of regular hours. Should a storm occur unexpectedly anyway, he still may be able to handle the situation through last minute efforts in a way no more wasteful of money than he would have used had he known earlier about the storm. But the unpleasant strain placed on him in such a situation is something he would rather avoid by paying for a weather service. In the final analysis, such convenience may have economic ramifications by improving worker morale, efficiency, and turnover rate, and by decreasing the number of errors made in scheduling.

Assigning an exact dollar value to such complex factors, however, was not a central objective of this study.

2. Direct and long term benefits

There are some advantages to a client subscribing to a weather service which, while accruing directly to the client, can only be seen as a gradual occurrence or as the net result of a long *series* of forecasts. Again, as with short term benefits, some of these advantages can be measured; others cannot. An example of the former case would be a fuel oil dealer who finds that accurate degree-day forecasting allows him to make fewer refuelings per customer over a winter season. While this kind of benefit could possibly be quantified by examination of seasonal statistics, there certainly would be difficulties in determining how satellite data was contributing to the overall success or failure of the forecasting.

Other long term benefits are more ambiguous. Through improved forecasting, equipment wear and maintenance may be less over a season, but not in any readily quantifiable amount. The increased accuracy of a forecasting service may encourage a client after a long period of doubt to increase his reliance on the forecast in ways that will ultimately save money, but unless this decision can be specifically connected with satellite data input, it has little meaning to this study.

3. Indirect benefits

Indirect benefits are those that accrue to the clients' customers or to the community which they serve. There are many possible examples of this type of benefit. Time is saved by motorists going to work on roads that have been quickly cleared of an early morning snow; lives may be saved and accidents prevented in the same situation. Consumers of agricultural products will save money where prices have been lowered by wise commodities purchasing based on the latest weather information. Certainly there is also an economic value to the better service a utility customer may get through prompt emergency repairs. Although all these benefits could be linked to the improved use of satellite data, quantifying them would be a formidable job, requiring massive public interviewing plus an ability to translate intangibles (e.g., time) into money. For this study, then, these benefits were generally beyond our powers of quantitative analysis. It should be noted that many of those benefits which were calculated were also indirect benefits to the public. This was particularly true where tax money was saved by municipal departments (i.e., the majority of snow and ice forecast clients).

In summary, this study concentrates on quantifiable short term benefits of direct economic value to the client. This is not to say that other types of benefits do not accrue from the use of satellite data, but only that such benefits cannot be reliably determined.

Two final comments: There was a certain degree of difficulty in the assignment of an effect to any one cause in a process as complicated as the interaction between a weather forecast and a business decision. In many cases the forecast was only one item among many affecting the decision, for example, to increase energy production or buy commodities. Attention in this study had to concentrate on those decision-making processes where the weather information had a clearly defined role.

Second, we measured only those benefits the client, itself, chose to capitalize on. It was often apparent that a client could have put a forecast to better use than its procedures would then allow. However, our purpose was to measure what was actually being done by a cross section of different enterprises, not to specify what could have been done under ideal conditions.

c. Methods of measuring economic gain

Since one of our goals was to understand the operations of each client to see how each eventually would be affected by satellite data, it was first necessary to group clients according to the type of operation they performed. It is important to keep in mind that such groupings do not imply that the clients in each group were by any means homogeneous in their use of and response to the forecast, but only that they all received the same type of forecast product. Grouping the clients was done merely with the expectation that certain similarities in operation could form the basis of useful generalizations later in the study. Six general groupings were decided upon: snow and ice, electric utilities, gas utilities, fuel oil dealers, commodities dealers and construction clients. In addition, we considered a number of miscellaneous clients (whose unique operations received separate analysis), and a small group of clients concerned with blasting. We decided not to include the latter group in this study. This decision hinged on the fact that blasting operations rely on accurate sounding information to determine how far from the blasting site the noise will penetrate and on other weather data for safety considerations. Though both of these were valuable uses of the forecast products, neither was economically quantifiable. The remaining client groups will be dealt with more thoroughly in Section 6.

There are three main approaches possible for measuring economic gain: a study of overall group characteristics and operations; individual studies of a particular client over time; and case studies of particular weather events in relation to a client or set of clients.

The first approach is the most desirable because it allows a larger, more widely applicable picture to emerge but requires not only a good cross section of clients from a particular specialty (i.e. in sufficient numbers and variety), but also an adequate number of weather events over the experimental period to insure statistically valid generalizations. While we cannot claim to have met the former criteria completely, the statistics presented for the individual clients in each main group were drawn from a sample sufficient to indicate at least the magnitude of the forecasting benefits involved. We have, however, been reticent to provide means or generalized statements about these clients as a group. The second criteria proved to be more formidable in terms of the original objectives of the project and will be discussed later.

At times case studies proved interesting as well, particularly in situations where the weather events were unusual and complex, as in the case of severe weather affecting utility maintenance. These are presented where appropriate.

In summary, we have relied chiefly on the analysis of individual clients over time, grouped by type of operation and presented together to show the variation within the group. Where the method would have been infeasible, we have used case studies to illustrate the nature of the benefits involved.

d. Use of questionnaires

Questionnaires provide an attractive means of gathering data. They are cheaper than personal visits, and allow the respondent time to carefully think out and research his answers. It would be very difficult to accurately obtain the same quantity of information by phone, so telephone interviews were not considered as a primary means of gathering data. Consequently the use of questionnaires, supplemented by personal contacts where necessary, was chosen as the only practical means of obtaining the vast amount of information required.

The main purpose of the questionnaires was to provide written documentation on the operations of individual clients of Weather Services Corporation, and to ascertain, through the structured questions, the general economic impact of weather forecasts on their operations. This method presupposes that only a discrete number of weather conditions affect each client. If the reactions to and impact of each weather condition were known, we could determine the impact of each situation as it arises during the course of the study without re-contacting the client.

We allowed for several obvious limitations in constructing our questionnaires. Recognizing that we were totally dependent upon the good will and cooperation of the clients, we tried to keep the questions short and to the point, to avoid wasting the respondents' time and trying their patience, and to gather only directly useful information. Because this requires some prior knowledge of each client's operations, we used an "iterative approach."

Except for those clients primarily concerned with snow and ice control or removal, each client was first mailed a one page, two question form and a letter explaining the program. The questions were:

1. In what specific operations do you use weather forecasts from Weather Services Corporation as an aid?
2. If you were asked to place an economic value on the weather forecast you receive, what factors would go into your calculations? (Monetary values are not currently needed, but we're interested in specifics about manpower, equipment, materials, etc.)

Because it was December, and because we wanted responses from "snow and ice" clients for the current season, we attempted to accelerate development of a more specific set of questions for this group. Thus preliminary snow/ice questions were drafted and sent to a sample group. To gain more insight into the impact of the forecast on snow/ice removal, and to ascertain the utility of our questions, we personally visited several "snow and ice" clients to discuss the questions, responses and our general understanding of their operations. Most of our questions elicited the desired responses, so this questionnaire was distributed to the client group as a whole.

For other large client groups the returned preliminary questionnaires, supplemented by phone conversations, provided much of the informational basis for more specific questionnaires. Helpful information was also obtained from the collaborating consulting firm in the form of promotional material, and from trade journal publications based on their own "product research and development" efforts. The final questionnaires were constructed after extensive evaluation by project staff members and distribution to similar clients in our local area for their comments. When necessary, all completed questionnaires were supplemented by phone calls.

The basic information that these questionnaires obtained included:

1. Size and scope of weather sensitive operations;
2. Circumstances under which weather information was expected to have a differential impact on operations, and variables most important to these situations (how often, when or how far in advance information on these was needed);
3. Responses or possible outcomes of these weather sensitive situations, and the effect of received weather information on actual responses or outcome; how the decisions were made;
4. Variable costs or expenses, their sources and quantitative relation to both the chosen response and actual weather conditions.

The questionnaires, in many situations, had to be followed up by phone calls for a variety of reasons--misunderstanding of questions, reluctance to put facts into writing which the client considered unpleasant, and a need to translate figures given in one format to some format that we would find useful. In general, however, the questionnaire approach proved satisfactory.

Smaller groups, such as construction companies and commodities dealers, require detailed study and consideration because they do not constitute a statistically valid sample size. The same applied to the one-of-a-kind clients, such as off-shore operations. For some of these, the questionnaire that gathered background information was also the basis for more detailed case studies.

For all clients, the questionnaires gave us documented information on how each client uses the weather forecast in a variety of situations, and how the accuracy of the forecast affected operations financially. In most cases the answers were used to predict what a client's response would be to a given forecast so that we could calculate an economic impact without having to contact the client about his response in every forecast situation. The questionnaire also gave us enough information to judge what weather situations would offer potentially interesting case studies. By checking through weather records for forecasts which were likely to have affected the client significantly we could follow up to determine the history of the event from the client's point of view. During the course of this study, these answers were applied to a variety of weather situations and along with the forecasts clients received and their verification, were the basis of our calculated benefits.

e. Forecast verification

An important stage in the process of analysis for both the first and second phases of this study was the verification of the forecasts made by Weather Services Corporation. If satellite data did in fact improve their forecast, and if this improvement had an impact on the clients, this could best be proven by showing that forecast errors in the control period were "significantly greater" than those in the experiment period. Verification is a notoriously difficult problem, but in this study there were several factors which made the problem much easier to solve. We should point out first that the verification we were attempting was designed only to catch those errors which had a significant economic effect on the clients, where the individual client was located.

Second, clients, in many cases, could supply the necessary verification data themselves. Utilities, for instance, kept their own observations of temperature and related power requirements. Using such client observations and regular National Weather Service data, Weather Services Corporation was able to construct maps and tables which were sufficient to provide the verification needed in all cases. Table 1 contains a listing of the verifications we used, and which were supplied by WSC.

A related problem in this study was that of obtaining the climatological statistics necessary to normalize the data for all phases of the study, so that the same basis of comparison was used in analysis. Not a great deal of data was available for this task. With the end of the federally supported State Climatologist System, high density data from many eastern states were sparse. If we had attempted to determine accurately the climatology for each client location, we would have faced an insurmountable

TABLE 1

Forecast forms and other data obtained from Weather Services Corporation

A. Snow and Ice

1. Time of predicted onset on storm
2. Amount of frozen precipitation predicted, temperature and wind.
3. Updates
4. Base maps for prediction and verification
5. Location of client vs. location of prediction and verification
6. Base maps for State and Turnpike systems

B. Gas Utilities

1. EHDD forecasts and updates--up to six days in advance
2. Verifications
3. Location of prediction and verification
4. Same for Weather alerts (cold temperatures, rain, wind, frost)
5. Base maps

C. Electric Utilities

1. Load Forecast (temperature, humidity, cloud cover, wind), updates
2. Verification
3. Location of prediction and verification
4. Same for weather alerts (cold temperatures, rain, wind, frost, severe weather, lightning)
5. Base maps

D. Fuel Oil

1. Total degree days for season
2. Daily DD forecasts--up to three days and updates
3. Weekly (or daily) verifications
4. Storm warnings (snow and ice) and updates

5. Location for prediction and verification

E. Marine Forecasting

1. Forecast sheets

F. Construction

1. Rain, wind, high and low temperatures, snow prediction and updates

2. Verification

G. Automobile Association

1. Temperatures in November and December (10 degree or below)

2. Rain and temperatures rising into the 40's

3. Verification

H. Commodities

1. Forecast sheets

problem. However, because we were attempting only to compare data from the two periods, an absolute error in the averages to which we referred was not of major significance. It was important only that the statistics from the two periods be compared to the <u>same</u> base statistic. The available monthly and annual statistical summaries contained the gross kind of averages necessary to accomplish this aim.

4. The McIDAS System

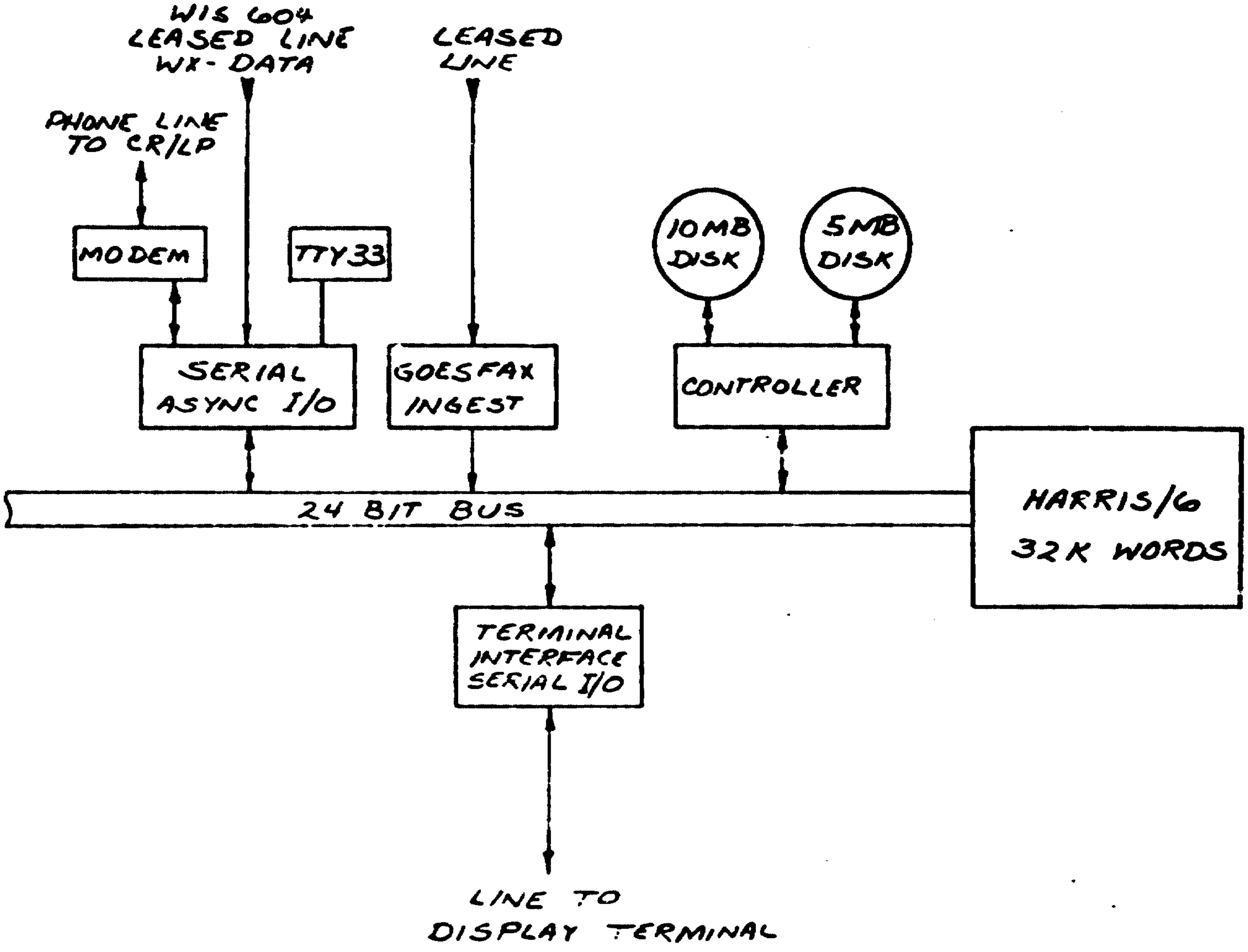
a. McIDAS hardware

1. General

The satellite image processing system 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--a general purpose scientific computer with digital disc storage and a display terminal consisting of a terminal controller, high resolution color monitor, alphanumeric CRT and keyboard, joystick pair and hard copy printer. Figures 2 and 3 detail the functional blocks of the computer system and the display terminal.

2. Processing section

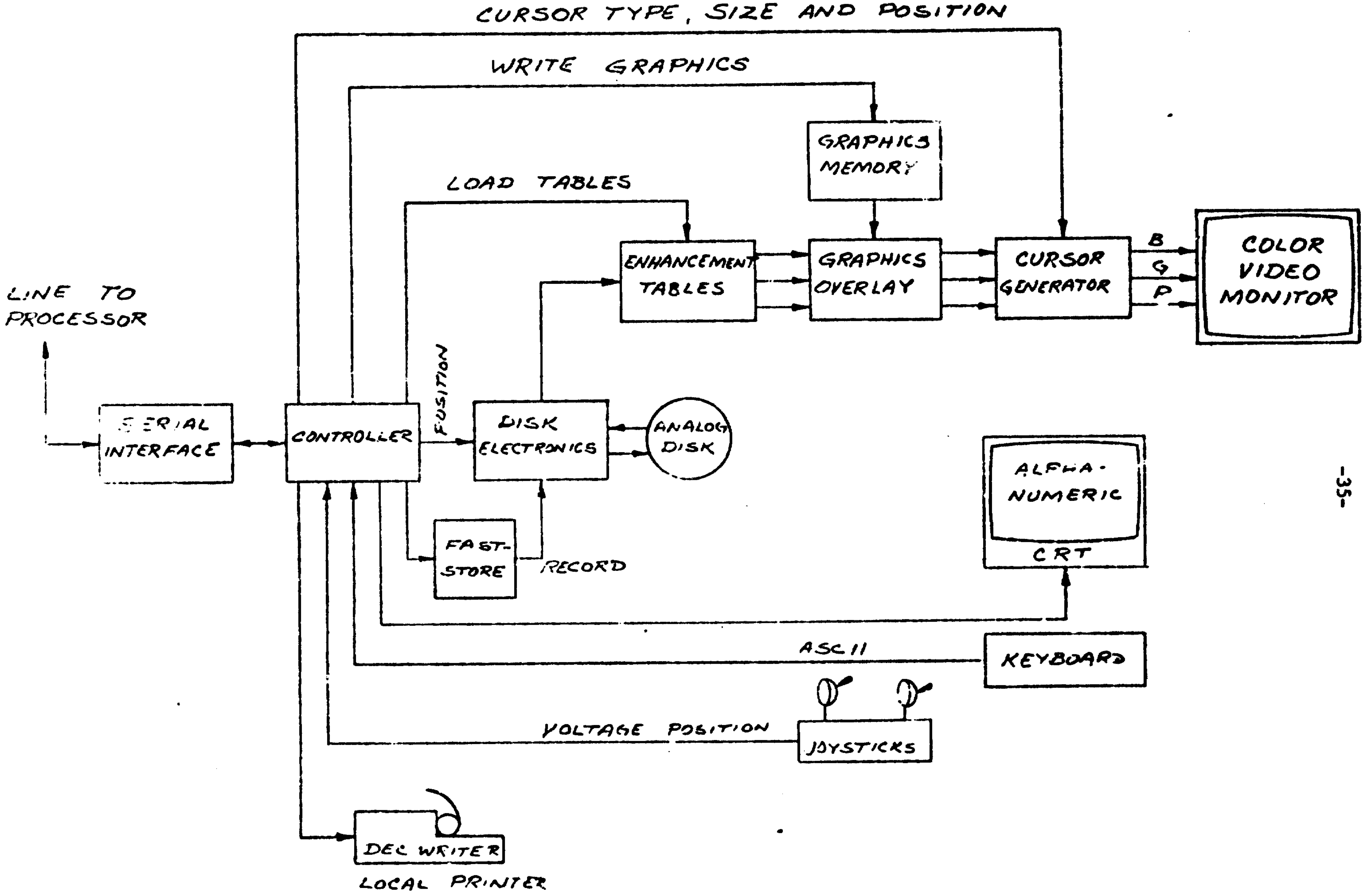
The McIDAS System is built around the Harris Slash 6 general purpose digital computer. This computer contains some 32 K words of 24 bit main memory and is configured with 15 megabytes of digital disc storage. In addition to the digital disc, the computer is connected to three data interfaces. Low speed asynchronous communications is supported by the asynchronous interface. The asynchronous interface connects to the Teletype control terminal, the FAA WB604 Data Service supplying conventional weather data (surface and upper air) and a modem permitting the system connection to the remote card reader/line printer at the University of Wisconsin for remote software maintenance. Satellite data, in a form of sectorized GOES images, are received off the leased telephone line and brought into the system via the GOES-FAX ingest. Connection to the display terminal is accomplished via the terminal interface serial I/O controller. This controller permits high rate communications between the display terminal and the computer.



PROCESSOR

FIG. 2

ORIGINAL PAGE IS
OF POOR QUALITY



DISPLAY TERMINAL

FIG. 3

3. Display terminal

The display terminal consists of a terminal controller and the visible human interfaces; color monitor, alphanumeric CRT and keyboard, joysticks and hard copy printer. The terminal controller contains the microcomputer that handles communications with the Harris computer, controls the image and graphic displays, including the enhancement functions, and supports the joystick and cursor generation. The color monitor is used to display graphics and image information. Image information is held on the 100 frame analog disc. Graphics information is contained in two 640 pixel by 512 line one bit graphic planes. The dual joysticks are used as a generalized analog input device but are usually used to control the cursor displayed on the color monitor. In this mode, one joystick acts as a coarse position control and the other a fine position control.

b. McIDAS application software

1. General

The bulk of the application software sued in this program is a subset of SSEC's McIDAS system software. It was necessary to cull out a subset of the software due to the limited disc space available.

2. Types of programs

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

a. Image handling. This group includes those for ingesting satellite images, loading a display frame from digital areas, frame selection and setting up frame loops.

b. Enhancement. This group of programs controls the enhancement function permitting either gray scale or color enhancements of the images contained on the analog disc. Table values may be determined by a set of key-ins or may be controlled by the joysticks.

c. Navigation. Navigation programs are used to align the satellite image sequences, thus allowing calibration of the images in latitude and longitude coordinates for tracking clouds.

d. Wind measurements. This function is implemented in one program called WINDCO. WINDCO permits generation of wind vectors from displacement of clouds and measurement of cloud height from the infrared temperature.

e. Conventional data. These programs automatically ingest data from the WB604 data line and archive it in the system data base. The data base may be queried via a set of key-in commands which permit generation of plots, lists, tables and maps of the station data, upper air data and ship data. The output functions are applicable to some or all of the following parameters: temperature, dew point, pressure, wind, cloud amount and type, advection, divergence, vorticity, mixing ratio and time differences in temperature, dew point, wind, potential temperature, equivalent potential temperature and pressure. These may be viewed independently as charts or overlayed over satellite images to aid analysis.

c. Design changes over system life

This section will detail design changes made to the hardware and software system, either to correct deficiencies or to enhance system operation.

1. Computer memory expansion

Very early in the program, it became clear that additional memory was needed in the Harris computer to permit faster execution times. At 32 K words, the system was memory bound. An additional 16 K word memory board was purchased for the system and installed, increasing the system's operating efficiency.

2. Terminal software

Minor deficiencies in the terminal controller were noted and corrected by installation of new terminal firmware.

3. Auto-Answer Modem

The existing modem on the remote card reader/line printer port required activation by Weather Services Corporation's personnel in order to be able to perform remote programming of the system. The manual 300 Baud modem originally installed was replaced with a 1200 Baud auto-answer modem. This permitted remote maintenance without intervention by Weather Services personnel to initiate or terminate the calls. Automatic termination of the calls permitted a significant savings in phone charges between UW SSEC and Weather Services Corporation.

4. Direct GOES TAP

As originally installed, the GOES-TAP connection supplying sectorized satellite data to the system was paralleled off the National Weather Service Forecast Office in Boston, Massachusetts. Selection of the sectors received on a Tap from the Satellite Field Service Station at NESS can be made only from one location. As an auxiliary Tap off the National Weather Service Forecast Offices GOES-TAP line, Weather Services Corporation had no control, nor any knowledge of what sectors would be received from the line. This difficulty was eliminated by installation of a direct leased line to NESS in Washington, D. C. Additional hardware for control of the GOES TAP was installed to permit selection of sectors without intervention of personnel at NESS. With this change, WSC personnel had complete control over the satellite pictures received off the GOES-TAP line.

5. 80 Megabyte disc

In November of 1979, a minor problem with the Harris computer escalated into a loss of important segments of the operating software for the McIDAS system at Weather Services Corporation, including backup discs. Lacking a tape drive, the only method available for reprogramming the system was lost. Space Science and Engineering no longer used the same type of disc drives installed at Weather Services. In order to restore the system, an 80 megabyte disc and controller were removed from operation at SSEC and installed at Weather Services. The necessary software was transported and installed successfully on the system permitting Weather Services to resume operation. The additional capability of the 80 megabyte disc permitted faster execution of many functions and permitted storage of more and larger satellite images.

6. Analog disc

Throughout the life of the system, nearly all of the serious problems with the system were due to malfunctions of the analog disc. These problems are reviewed in the next section. Although the present device is the same unit that was installed in the original installation, extensive modifications were made in an attempt to improve its performance. The only functional change was the reduction in frame space from 200 to 100 total. All other modifications to the analog disc were made to correct various deficiencies and to increase system reliability.

d. Major problems

The McIDAS system installed at Weather Services Corporation had a number of serious problems but nearly all were concentrated in two basic areas. The first and most serious, as well as most numerous set of problems, was due to the analog disc. The second source of problems was due to the lack of a tape drive on the system.

Analog discs can provide satisfactory performance as a display device if certain conditions are met. The most important consideration is that a well-engineered product must be used. The analog disc used on this system is manufactured by Davis-Smith Corporation. The disc was not supplied as a complete disc subsystem but rather as a kit. The kit contained the necessary mechanical elements to build an analog disc but lacked any electronics, and the mechanical portions were designed for low cost rather than performance or reliability. In order to complete the disc subsystem, bits and pieces of other technology and some original designs were applied to come up with a one-of-a-kind disc. However, no amount of reengineering could make up for the basic deficiencies of the device. In retrospect, additional funds should have been used to buy a better quality disc, even after the original installation, in light of the high maintenance costs that were incurred in support of the analog disc.

The lack of a tape drive on this system made software maintenance of the system extremely difficult and also presented problems in hardware maintenance when computer diagnostics were necessary for isolation of problems. The tape drive was deleted from the original system for cost considerations and because of our desire tc limit potential system modifications by WSC personnel. If the system had a tape drive, many problems could have been averted. All reprogramming of the system required transporting of mechanically sensitive digital discs to Weather Services Corporation or required use of the remote card reader/line printer interface. The remote card reader/line printer interface is adequate for small reprogramming tasks but is useless for major software efforts. Normally, diagnostics for the Harris computer are on tape. Lacking a tape drive, diagnostics had to be run from disc. This is not a particularly desirable situation as a common problem area in computers is with the disc itself. While software problems were not a major factor at this installation, the lack of a tape drive was definitely felt.

As a general note on system problems, it should be pointed out that most portions of the system performed admirably. Most of the hardware of this system was installed and required no further attention throughout the system life. This is instructive as it should be clear with with the correction of the system's chronic deficiencies, extremely reliable hardware and software would result.

e. Maintenance procedures

All maintenance of the Weather Services Corporation McIDAS system was carried out under the direction of Gary Banta, a UW SSEC engineer. Two maintenance organizations located in Boston, Massachusetts, were used to provide local maintenance for the McIDAS system.

The general maintenance procedure was as follows. Should a problem be noted by the operating personnel at Weather Services, a call was placed to Gary Banta at SSEC. The purpose of this centralized control over the maintenance was to insure, that first of all, the Center, having basic responsibility for maintenance, was aware of all system maintenance problems and that the problem was not merely an operator problem. Most problems were either correctable over the telephone or were no problem at all. Some problems required the assistance of SSEC programmers utilizing the remote card reader/line printer interface to make some minor software modification. If there was indeed a hardware problem, a decision was made as to the appropriate authority. If the problem was with the Harris system, as it was about four times over the system life, Harris Corporation was called in to repair the hardware. If the problem was in any of the non-Harris hardware, a determination was made as to whether the problem was of sufficient severity to require onsite attention by one of SSEC's engineers. If the problem did not require direct action by one of SSEC's engineers, a local maintenance organization, Compu-Serve, was used. This maintenance procedure worked quite well over the system life. Had the two major deficiencies, that is the analog disc and the tape drive, been corrected--either at the initial design or early in the program--this procedure would have worked quite well. However, the severity of the problems, particularly with the analog disc, resulted in numerous trips by SSEC personnel to Weather Services Corporation in Bedford, Massachussets, for problem correction.

f. Installation and training

Well before the completion of the McIDAS system itself, a trip was made to Bedford to inspect the proposed facilities for housing the computer system. It was decided to located 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 were 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 was providing hardware maintenance) inspected the facility and approved it.

Of major importance to the success of this project was the training of Weather Services personnel on McIDAS. If the system was to have an impact on forecasting, the staff must not only know how to use McIDAS, but must hav a positive attitude toward the potential help that satellite imagery could have on weather prediction. With these aims in mind we had two forecasters here at SSEC for a one-week period in October of 1977. 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 throroughly 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 expected these two people to have gained sufficient familiarity with McIDAS to be useful in helping us undertake a similar training process at Weather Services itself.

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 software deficiencies, and to see how well the staff would adapt to McIDAS in terms of the objective 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. The two forecasters previously trained were in a position to continue this training after we left and help oversee the use of the system.

The training of the staff was made somewhat more difficult because of the nature of McIDAS software which was designed as a research and development oriented system as opposed to a routine forecasting applications system. Thus the manual with its organization of commands into a set of two letter key-ins was not a particularly easy system to memorize. The command structure, unlike others designed for the inexperienced, did not prompt the user or provide simplified means to accomplish routine tasks. While the manual was not impossible to use, it proved to be inconvenient and time consuming. It was partly this situation that necessitated the the expenditure of considerable time on training in the first place.

Our second objective, correcting hard- and software 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. Software changes were more easily manageable. The quality of the incoming image data was highly variable and the IR brightness 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 software were in need of only minor adjustments.

g. System incorporation into forecasting procedures

Initially, personal reaction from the staff to the capabilities of the McIDAS system seemed favorable. Between intention and actual use, however, there were a number of barriers. One of these has already been mentioned: the awkwardness of the command structure. This factor may have discouraged the more inexperienced staff from using the system.

Another problem lay in the fact that the staff was often busy keeping forecast deadlines and did not always have time to ingest and navigate the current satellite image. Ideally there would have been a regular operator whose job was to ingest and display all pictures. In practice this problem was minimized by designating certain staff as operators during their slow periods.

A third general problem area was found in the actual performance of the system. Particularly during the first six months, McIDAS had a fair number of hardware problems which included both poor image production or actual down time. In addition it was not until June, 1979, that a private facsimile line was rented. Prior to this, WSC was dependent for its images on the National Weather Service Boston Office which did not always select an image appropriate to WSC's needs. Together, these two situations tended to discourage system use because of unreliability and inability to establish a routine for obtaining and using the information.

In general, all these problems were of minimal importance during the last year of system operation, there having been nearly a whole year previous during which bugs in operation had been greatly reduced. System performance had improved, the staff had become more familiar with the command structure, and the staff had to a large degree incorporated picture ingestion into their routine. A more subtle problem has to do with how well this new information was being incorporated into actual forecasting decisions, a factor that would intimately affect how much the satellite data proved beneficial to the accuracy of the forecast. We will deal with this question in our later discussion of the actual outcome of the experiment.

5. Climatological Work

In order to compare both forecast skill and resultant economic effects 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 cases for which snow near or above the threshold for plowing might have been reasonably forecast. Similarly, for heating degree days, we are interested in cases above the threshold for the use of supplemental gas or electric supplies. If there are five plowable storms one year, 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.

Theoretically, this normalization can be done in two different ways. One of these would be to simply compare the actual monthly temperature or snowfall with the 30 year mean, or with those from the other years. Higher snowfalls, for example, implys an increased probability of storms that could result in dollar losses, in comparison with a year of lower snowfall. If there were an exact relationship between the difference in means and the frequency of possible dollar loss situations, then normalization would be relatively simple. There would still be the problem that not all storms are equally difficult to forecast correctly, thereby making a year of exceptionally difficult storms more error prone. This error factor is minor, however, in comparison to the problems that arise by only using the mean value for a season with several large storms or temperature excesses. A season with the same mean but a multitude of smaller events, will have a greater vulnerability to loss. Thus a comparison of means only gives an approximate indication of the effect of weather on possible economic loss. We have nonetheless presented these comparisons to illustrate the unusual fluctuations occurring over the period of this study.

A second method of normalization fares better in regard to our data, especially the temperature forecasts. This scheme entails an actual count of potential loss situations. For temperature forecasting, for example, a potential loss occurs every time the threshold temperature (see Section 6b) is exceeded or is forecast to be exceeded (if there is no threshold then every day is a potential loss day). With snow forecasting, such a determination is more difficult. If the forecast calls for flurries, should this be considered a potential loss situation? Complicating this picture is the fact that there is a double threshold for losses, one for sanding and salting and another for plowing. A simple total of the number of actual snowstorms or the number of storm forecasts does not therefore give a complete indication of the proper normalization, but again we have included these figures here to point out the magnitude of the fluctuations in climate over the period.

We should also note that normalizations are most meaningful when there are a large number of cases (i.e. snowstorms, temperatures above threshold) from which the statistics are being drawn. A small and unrepresentative sample of weather events, such as we have been faced with does not produce reliable results capable of accurate normalization.

We have acquired several series of NOAA publications for verification of forecasts and as source material for normalization statistics. We have calculated for each city or location, the monthly recorded snowfall, its distribution by storm as well as 30 year means of the monthly snowfall and storm amount. Using these, monthly departures for both the control and experiment period have been obtained. We have generated the standard deviations from the individual year's 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. These include both 30 or 40 year means and standard deviations of monthly average temperatures as well monthly average departures from these long term means for both the control and experiment periods. We have similar statistics for daily maximum, daily minimum and daily average temperatures. The 30 year base was used for T_{max} and T_{min}, a 40 year base for T_{ave}. The T_{ave} departure has also been obtained as a percent of the standard deviation of the 40 years in the base period. Finally, departures and standard deviations are available from a minimum 20 year base of heating degree days and a minimum 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, are listed by station name and climatological division, for each state or geographical region. Included are 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 precipitation 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, as well as 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, this publication summerizes 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.

Tables 2 and 3 show the stations for which our calculations have been made.

a. Snow and ice

Figures 4a and 5a show the ten year mean annual snowfall for the eastern United States. The amounts increase from 3"-6" over North Carolina to about 20" over Maryland and about 55" over eastern New England. Some typical 30 year means and standard deviations are:

	Snow Amount		No. of Storms		
	Mean	σ	>1"	>3"	>6"
Boston, MA	42.7"	14.8"	9.7	4.7	1.9
Springfield, MA	47.9"	16.7"	10.7	5.9	2.6
Bridgeport, CT	27.4"	13.3"	6.9	2.9	1.0
New York, NY	24.3"	13.7"	7.1	3.0	1.1
Philadelphia, PA	20.5"	11.2"	5.6	2.5	0.9
Pittsburgh, PA	45.9"	15.7"	12.4	4.5	1.5
Baltimore, MD	21.5"	13.6"	5.3	2.9	1.0
Washington, DC	16.8"	10.5"	4.5	2.0	0.8
Richmond, VA	14.0"	10.3"	3.7	1.9	0.8
Raleigh, NC	7.0"	5.7"	2.3	0.9	0.3

Unfortunately, for our study, during the control seasons of 1976-7, and 1977-8, the northern stations had unusually heavy snows (see Figs. 4b, c) while during the experimental season of 1979-80, these areas (especially New England) had one of the least snowy winters on record (see Fig. 4d). To the south, the reverse was more generally true (see Figs. 5b-d).

Table 2

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 CT
Bridgeport CT
Concord NH
Boston MA
Avoca PA
Atlanta GA
Allentown PA
Albany NY
Providence RI
Worcester MA
Syracuse NY

Table 3

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 CT
Bridgeport CT
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 CT
Yorktown Hts NY
Bedford MA
Brockton MA
Holyoke MA
Peabody MA
Pittsburg (APT) PA
Springfield MA
Taunton MA
Walpole MA
Norfolk VA

WEATHER SERVICES CORPORATION
Bedford, Massachusetts 01730

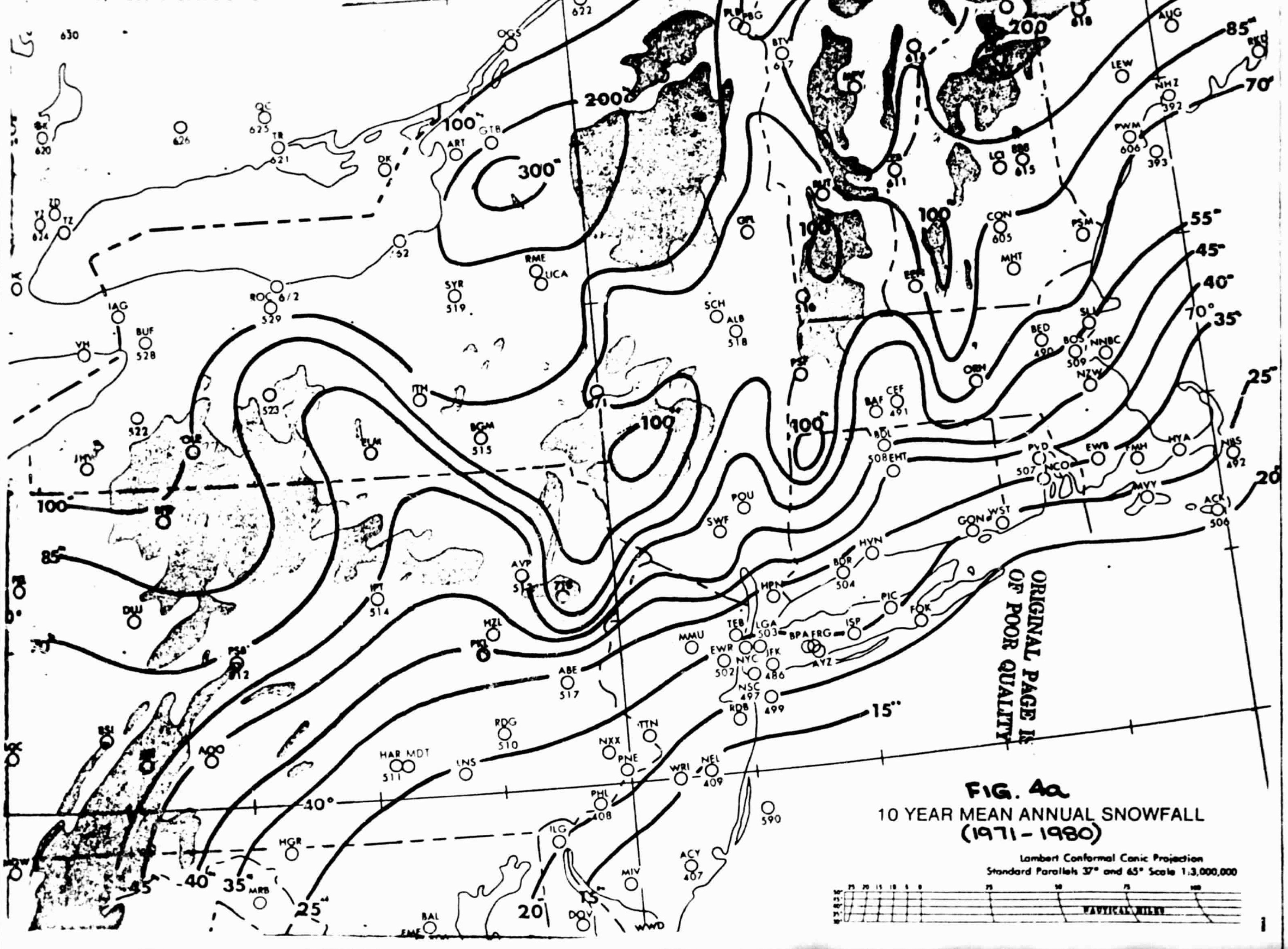


FIG. 4a
10 YEAR MEAN ANNUAL SNOWFALL
(1971 - 1980)

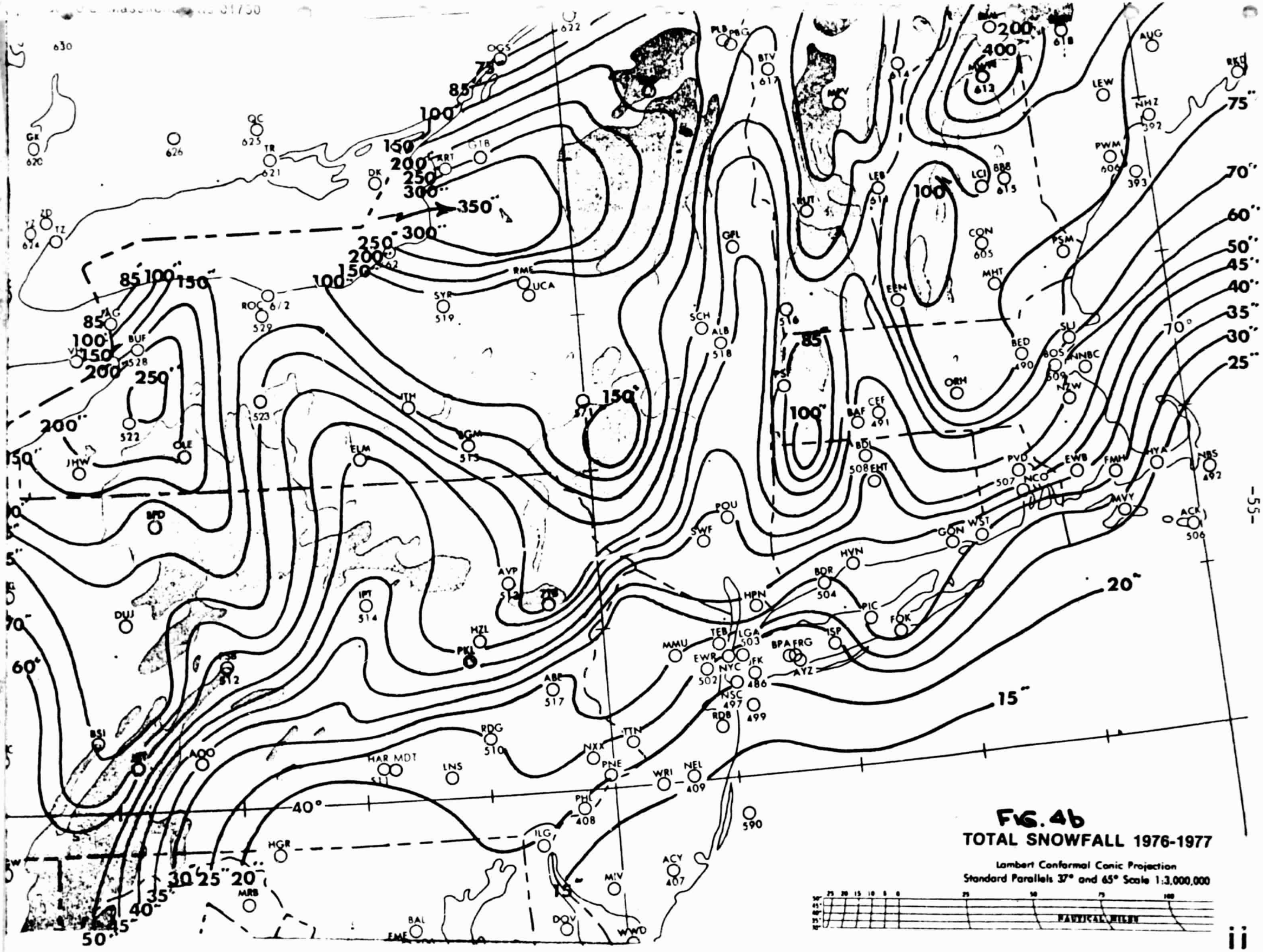


FIG. 4b

TOTAL SNOWFALL 1976-1977

WEATHER SERVICES CORPORATION
Bedford, Massachusetts 01730

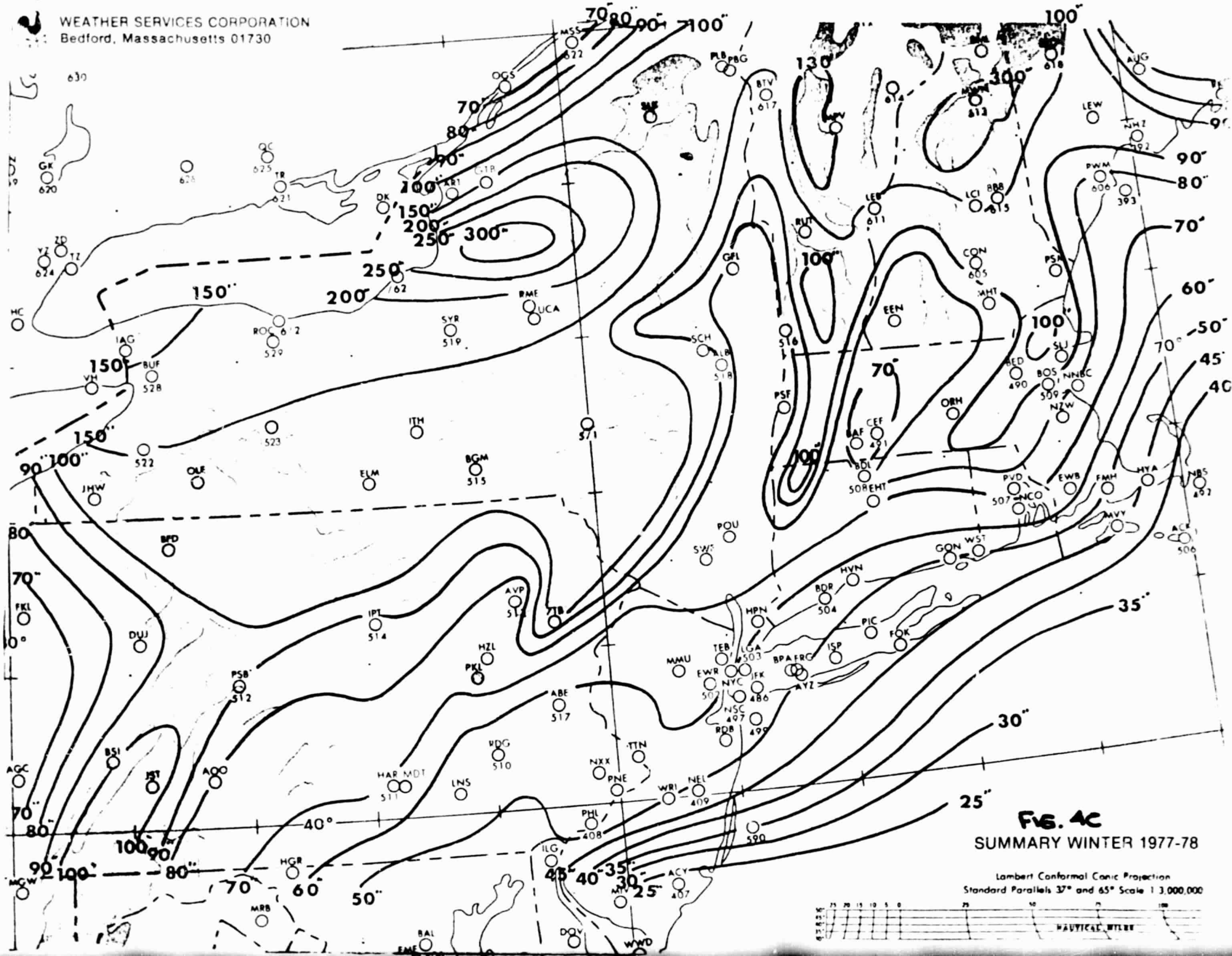
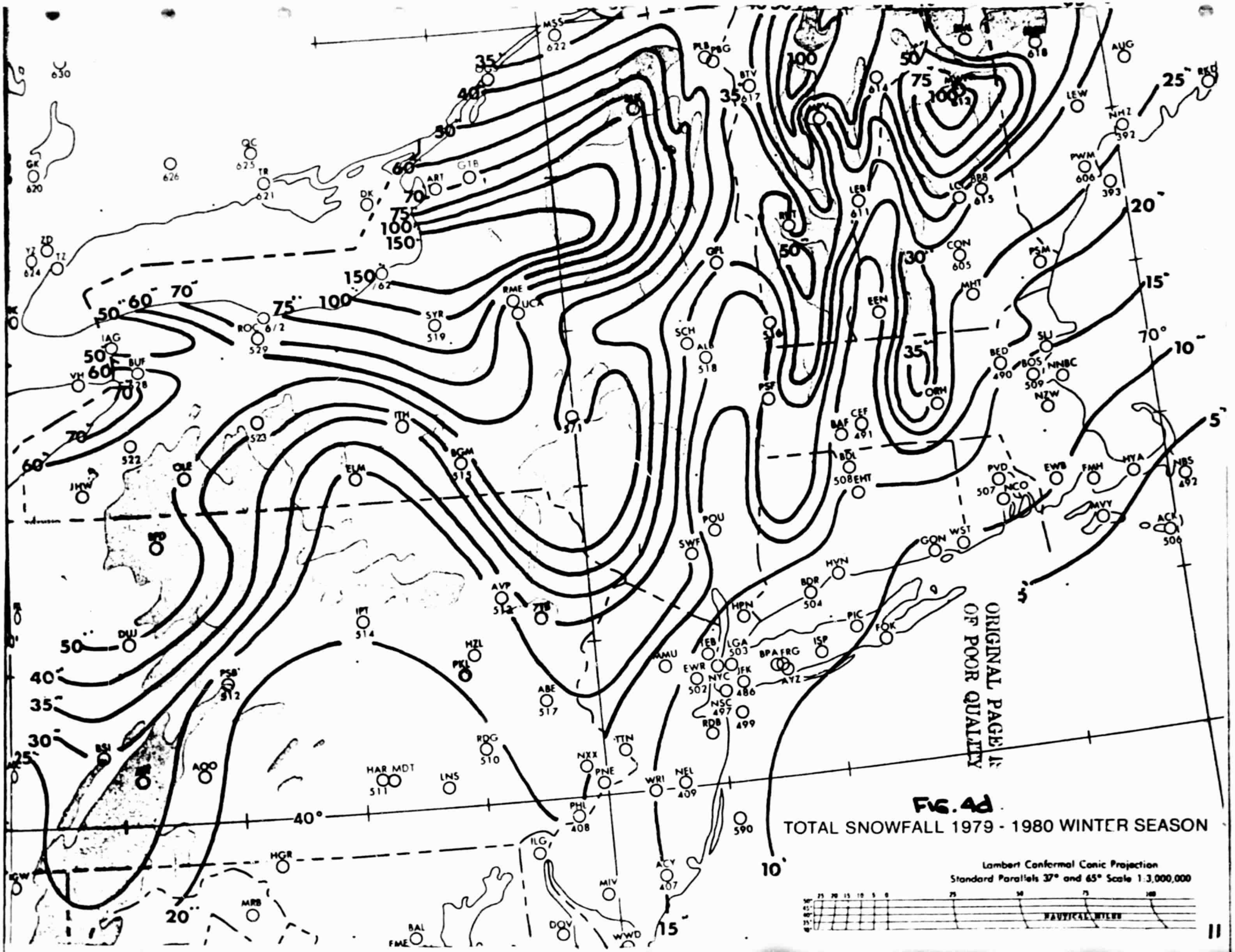


FIG. 4C
SUMMARY WINTER 1977-78



ORIGINAL PAGE IS OF POOR QUALITY

FIG. 4d

TOTAL SNOWFALL 1979 - 1980 WINTER SEASON

Wea...
Bedford, Massachusetts 01730

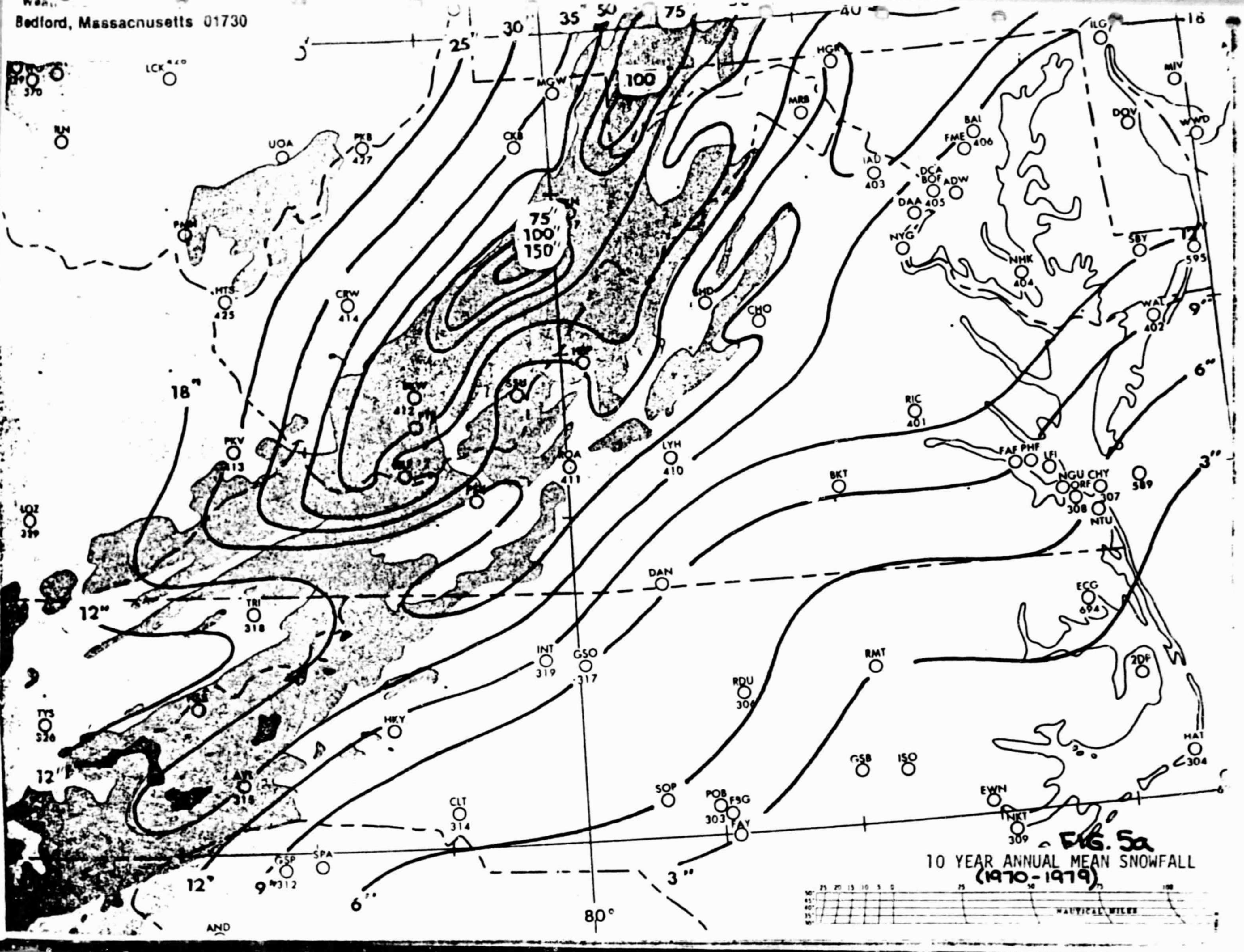


FIG. 5a
10 YEAR ANNUAL MEAN SNOWFALL
(1970-1979)

Bedford, Massachusetts 01730

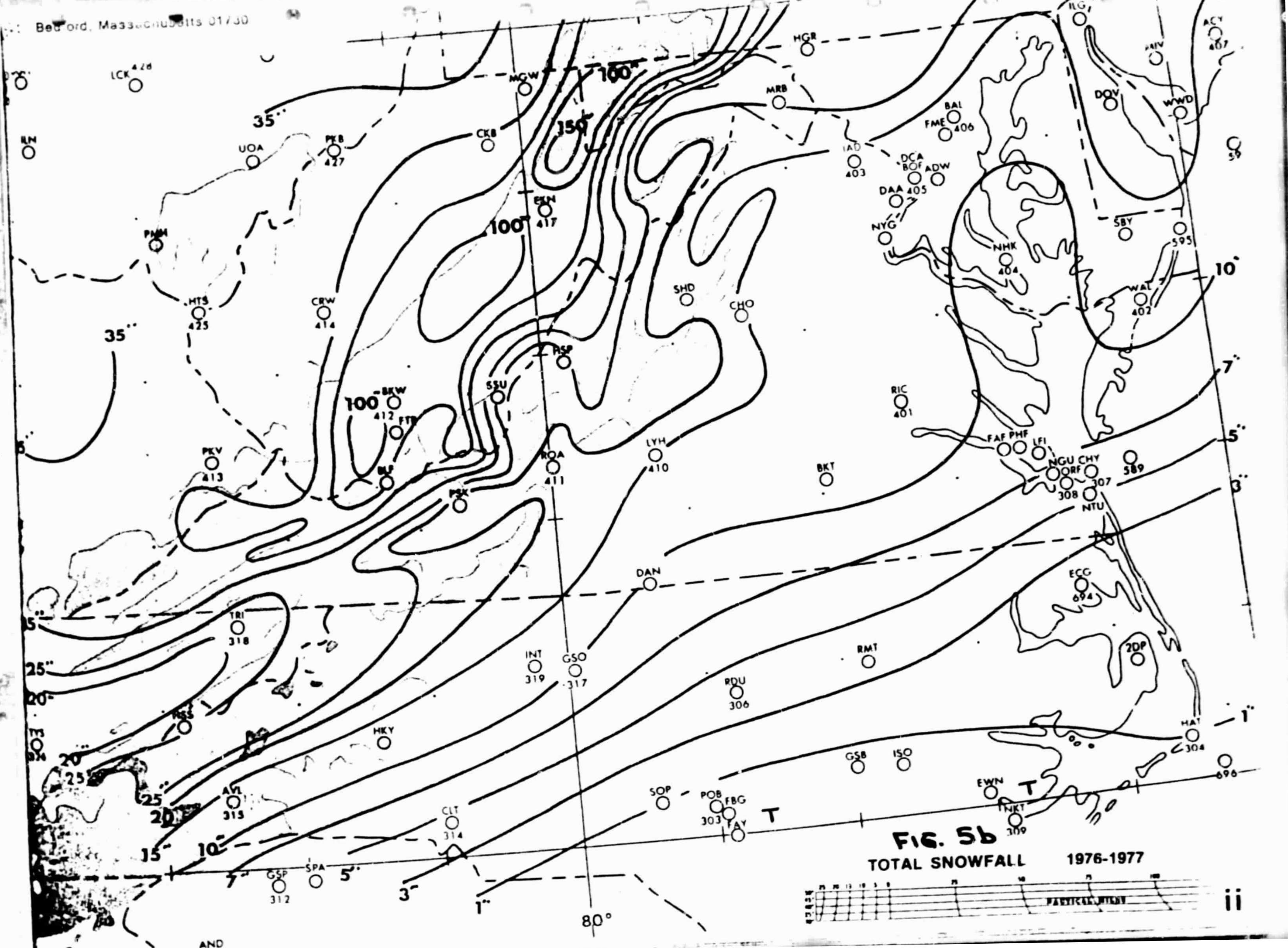


FIG. 5b
TOTAL SNOWFALL 1976-1977

Bedford, Massachusetts 01730

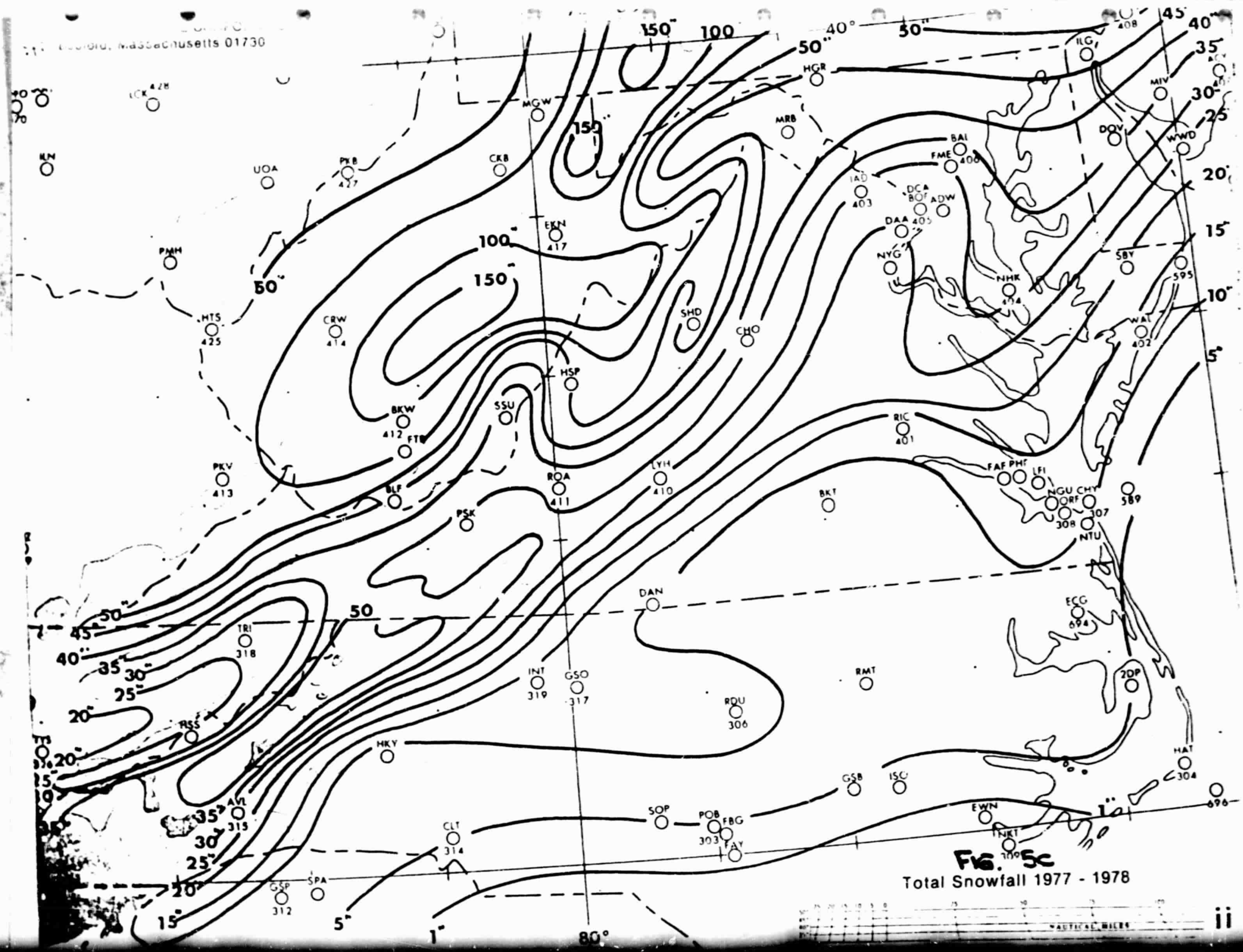
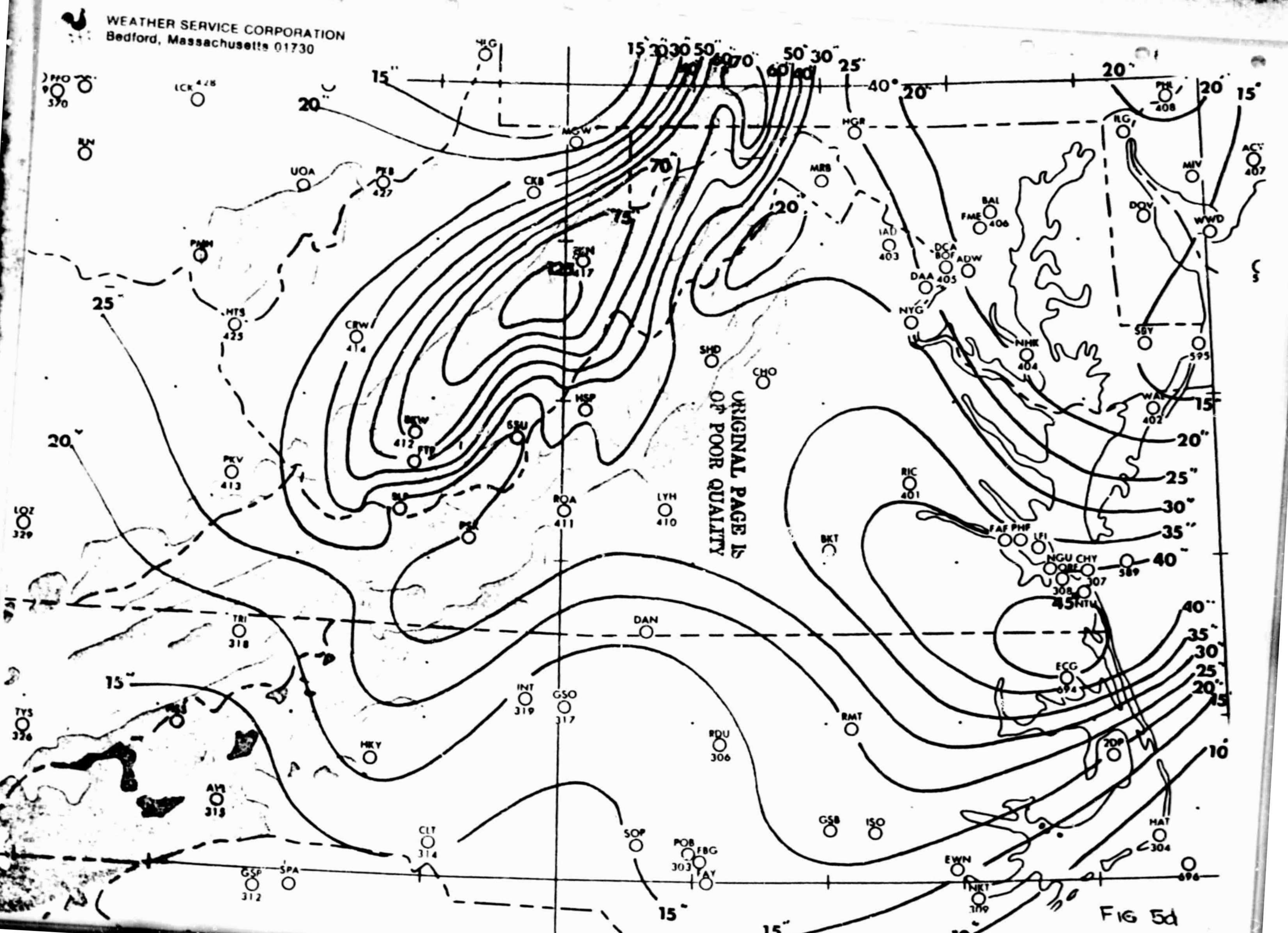


Fig. 5c

Total Snowfall 1977 - 1978



ORIGINAL PAGE IS OF POOR QUALITY

FIG 5d

Total Snowfall

To be more specific, for the same cities:

	Snow Amount			No. of Storms					
				Control			Expt.		
	Control	Expt.	Diff.	>1"	>3"	>6"	>1"	>3"	>6"
Boston, MA	71.8"	12.7"	-59.1"	11	5.5	4	3	2	0
Springfield, MA	59.7"	14.0"	-45.7"	14	8	4	5	2	1
Bridgeport, CT	40.0"	9.6"	-30.4"	10.5	4	1	3	1	0
New York, NY	35.6"	11.0"	-24.6"	8.5	3	1.5	5	1	0
Philadelphia, PA	36.8"	20.9"	-15.9"	8	4.5	1.5	5	3	0
Pittsburgh, PA	55.8"	24.1"	-31.7"	15.5	5	1.5	7	3	0
Baltimore, MD	22.7"	14.6"	-8.1"	4.5	2	0.5	5	2	0
Washington, DC	16.9"	20.1"	+3.2"	4	2.5	0	6	2	1
Richmond, VA	12.6"	38.6"	+26.0"	4.5	1	0	6	3	2
Raleigh, NC	7.1"	18.3"	+11.2"	2.5	1	0	4	2	1

Complete statistics can be found in Appendix C. To put some of the above into perspective, for the control period, the snow at Boston was +1.966 σ, Philadelphia, +1.46 σ and greater than one standard deviation above normal for much of the northeast. By contrast, during 1978-80, the snow at Boston was -2.03 σ, Bridgeport, -1.34 σ, Worcester, -2.65 σ, Avoca, PA, -1.46 σ, Pittsburgh, -1.39 σ, Hartford, -2.56 σ, and more than one standard deviation below normal for much of the remainder of the northeast. By contrast, during 1979-80, at Richmond it was +2.39, Raleigh, +1.98, and at Norfolk, +5.48 σ.

Even more telling are the scarcity of snowfalls during the experimental period; some New England clients had no plowable storms during 1979-80. Therefore, it would be fruitless to try and normalize the data for snowfall during the period of the program. The amounts vary so greatly, that our only recourse is to view our results in the context of the weather seasons, and not try to compare them directly.

b. Temperature and heating-, cooling-degree days

For the electric utilities (all located in the Northeast) in the summer season when peak load forecasting is critical, the temperature statistics reveal no great deviations from normal. In 1977, cooling degree days and temperatures were near average or slightly above, while 1978 and 1979 were below average from one-half to two degrees for all clients. This makes the experimental period on the whole somewhat cooler (by about 0.5°) than the control period. See Appendix C, for more information on these temperatures as they relate to specific clients and stations.

The gas utilities experienced an extremely cold winter season in 1976-77 especially in the South where temperatures averaged up to 7 degrees (more than two standard deviations) below normal. The season 1977-78 was somewhat warmer but still one to three degrees below average. The last season, 1979-80, was substantially above normal by 3 to 4 degrees. In comparison to the control period winters, this represents a change in average temperature of 6 to 8 degrees and accounts for the drastic drop in the number of critical forecasting days.

6. Client Groups Surveyed

Once a group of clients was selected for analysis, we tried to keep in touch with them when interesting weather situations arose. Some were more willing than others to discuss problems caused by bad weather or forecasts. During the time that satellite data was incorporated into WSC's forecast procedures, the WSC forecasters maintained a log of situations where the satellite data had a strong bearing on their forecasts; it appears as Table 4. The log is not intended to be a complete catalogue, but more as a sample: the number of entries was not regulated and varied with the forecaster and with the situation. We have hoped to use this log as the basis for case studies during the experiment period. Unfortunately (for this project) the area under study had no major weather events which involved participating clients. This will be discussed further in Section 8. Therefore, what follows are the seasonal averages of losses due to incorrect forecasts for both the control and experiment periods.

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 on 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.

These clients formed the basis for our first questionnaire, a process which began in December 1976. Since this was the largest and most varied client group (147 subscribers), and because an early start seemed advisable,

Table 4 - 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/GUS FRONT VISIBLE NEAR 25N/94.SW. ADVISED THAT MOVEMEN 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 CONVECTIC 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.

Table 4 (cont)

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.

Table 4 .ont)

DATE	AREA/CLIENT	ACTION TAKEN
-79-		
10-10	ALL NEW ENGLAND SNOW/ICE	BASED ENDING TIMES OF SNOW ON TIMING SUGGESTED BY SAT LOOP.
10-23	CHARLOTTE, RALEIGH PORTSMOUTH, IBM-GAITHERSBURG	RAIN/WIND FORECAST ISSUED BASED ON LOOP
-80-		
1-24	NY YORK THRWUAY	MOVED SQUALL BANDS ACCORDING TO POSITION AND MOTION SUGGESTED BY LOOP.
1-27	MID-ATLANTIC AND SOUTHERN UTILITIES	RAISED FORECASTED MIN TEMPS DUE TO CLOUD
1-28	ALL UTILITIES IN N. & S. CAROLINA	RAISED FORECASTED MIN TEMPS DUE LINGERING CLOUD COVER
1-29	SAME AS FOR 1-28	SAME REASON AS FOR 1-28
2-4	N.Y. STATE AND NEW ENGLAND CLIENTS	TEMPS AND GENERAL WEATHER FORECASTS
2-5	SAME AS 2-4	SAME AS FOR 2-4
2-5	MINNEASPOLIS AND KANSAS CITY RADIO	ENDING OF SNOW BASED ON LOOPS

DAILY USE OF SOUTH AMERICA PORTION OF EASTERN FULL DISC BY COMMODITIES GROUP FROM 1-1 TO CURRENT DATE. GRAPHICS VERY HELPFUL ON NUMEROUS OCCASIONS MAINLY AS ONGOING MONITORING OF A GENERAL FORECAST.

we contacted this group first. Also, the winter season had already begun--a time when we could expect these clients to be most aware of their problems and operations.

The makeup of the snow and ice client group when the program began, can be summarized as follows: Almost all (138 of 147) are government departments in an area ranging from Maine to North Carolina; of these, most (121) are cities ranging from a few thousand to several hundred thousand population. Over half of these cities, however, have populations of less than 30,000. In addition to the cities, there are four state highway divisions, six turnpike authorities, and seven county bodies. The non-governmental bodies among the snow and ice clients are either universities, shopping centers or private corporations, all of whom have large parking areas to clear.

The questionnaire design effort was followed up by a visit to a number of clients of different types. On the basis of the information so obtained, we were satisfied that the questionnaire was sufficient for our purposes. Questionnaires were mailed in early January 1977. As replies were received, each client was contacted personally by phone for a few additional questions and possible clarification.

Of the 147 subscribers in our sample, we received a total of 70 complete replies (48%). 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 cover 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 a 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. The others did not use the forecast in a way that we can calculate its economic impact.

A sample questionnaire is included in Appendix D. (For reasons of confidentiality, no client names are included on any of the samples.) The example given is from a city of about 25,000 population. As the questionnaire shows, we were interested not only in how forecast situations were related to decision-making, but also in general characteristics of the entire operation, such as budget size, cost for an average plowing or sanding situation, the size of the highway system, and so forth.

The replies to the questionnaires indicated that 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 vary from as little as 1 1/2 inches to as much as 4 inches. Hence, a city that plows at 4 inches will have one course of action for any forecast less than 4 inches and a different one for 4 inches or more. In most cases a forecast of 4 inches produces the same action as one of 10 inches. The exception is when outside contractors are called in, usually at a 6 or 8 inch forecast. Contractors often require 2-4 h notice and must be paid for a minimum amount of time (usually 4 h) 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 h after it was forecast can thus cost thousands of extra dollars.

There are a few other significant points. First, for about 1/4 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 1/5 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 falls, 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 indirect, 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 fall of the snow or ice at the beginning of the 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 5 shows this variation for three governmental bodies, and also shows possible monetary losses. 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; and 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

TABLE 5. Monetary losses due to incorrect snow forecasts.

Forecast	Outcome	Cost
City A		
<4″	no snow	$44/h + $750 (mobilization and demobilization)
<4″	later than forecast	$44/h
>4″	no snow	$132/h + $750 (mobilization and demobilization)
>4″	later than forecast	$132/h
>4″	<4″	$88/h
		Four-hour minimum, 1.5 for overtime, 2 for holidays.
City B		
no snow	plowable	$150/h extra
>2″	no snow	$200/h + $150 (mobilization and demobilization)
>2″	later than forecast	$200/h (standby)
>2″	<2″	$1 000/h + $100 (mobilization and demobilization)
		If during regular hours (8 a.m. to 4:30 p.m.) costs are ⅓ less and mobilization cost = 0
State C		
<2″	no snow	$27 050/h + $9 800 (mobilization and demobilization)
>2″	no snow	$27 050/h + $15 200 (mobilization and demobilization)
>2″	later than forecast	$27 050/h
>2″	<2″	$5 800 (mobilization and demobilization)
		1.5 for overtime

ORIGINAL PAGE IS
OF POOR QUALITY

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 <4 inches of snow would cause the sand and salt trucks to be mobilized ($750) and the crew to wait ($44/h), 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.

Similarly, forecasts and outcomes for >4 inches cause plow mobilization ($750) and possible waiting time for the crew ($132/h). The case of a forecast >4 inches and an outcome of <4 inches is a hybrid: the losses are the result of paying for a plow crew when only a sand and salt crew was needed ($132/h - $44/h = $88/h). 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/h) on standby until precipitation begins, at which time their full crew ($1000/h) is put on their payroll. State C puts its full crew out for any amount of frozen precipitation, with the only difference being in mobilization costs.

Appendix E 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 6a and b, and are chosen to illustrate our calculation procedure. The December 29 storm (see Table 6a) is an illustration of a gross underforecast which did not result in calculable direct losses--though 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 did not reach plowable amounts (3 inches) during the evening, plows were mobilized unnecessarily ($3300), contractors were called in at a forecast accumulation >6 inches 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 h x $250/h = $2500). Total loss was $12,800 or close to 9% of the total seasonal snow budget.

Table 7 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

Table 6a
Sample Snow Forecast

Forecasts

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".

Actual Conditions

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

Total accumulation: 12"-16".

Table 6b
Sample Snow Forecast

Forecasts

Jan. 13	9:30 A.M.	light snow 1"-3" beginning 1 A.M.
	2:00 P.M.	snow beginning 3-6 A.M.
		1"-3" by afternoon
		55% chance of 4"+
Jan. 14	9:30 A.M.	snow redeveloping 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 6-9 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"

Table 7

Actual Snow Forecast and Outcome

Forecast	10:10 A.M.	3"-6"	beginning 7-9 P.M.
	3:00 P.M.	3"-6"	beginning 3-5 P.M.
	9:40 P.M.	as above	
Next Day	5:30 A.M.	1"-2"	

Actual Conditions

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

Plows mobilized at 5 P.M. and stayed until 5:30 A.M. update.

Plowing criteria: 3"

extra cost was $23,450 calculated from

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

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

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 rather 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 inches and the actual accumulation is 15 inches. The 6 inch 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 the clients for the control seasons. Mean snowfall for these clients ranges from over 100 inches to as low as 5 inches. The results for the 1976-77, and 1977-78 are summarized in Table 8, with the specifics for each client given in Table 9.

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 comment relevant only for particular clients. There are a few clients for whom some forecasts were

TABLE 8: SNOW/ICE CLIENT RESULTS:
CONTROL SEASONS

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		36.7	9.3	4.2	19.3%	$57,200	$315,000
TURNPIKE AUTHORITIES		41.8	13.1	5.8	15.6%	$9,523	$348,000
SOUTHERN CITIES		24	4	1	13.2%	$2,440	$45,000
NORTHERN CITIES Pop >60,000		45.1	16.1	7.8	13.0%	$19,992	$273,000
NORTHERN CITIES Pop <60,000		45.4	14.5	7.1	15.5%	$4,841	$91,300
RANGE	MAX.	64	24	12	37.5%	$108,000	$853,000
	MIN.	17	2	0	2%	$300	$10,000

CLIENT	BUDGET	NO. OF STORMS	NO. OF FORECASTS	LOSS (NO.)	COMMENTS
Southern City	$310K (75-76)	76-77: >1":7 >3":2	76-77: 29 96.6% cor.	76-77: $300(1) 0.1%	Does Not Plow! $500/hr Overtime
		77-78: >1":3 >3":2	77-78: 31 64.5% cor.	77-78: $11K(11) 3.5%	
		79-80: >1":6 >3":3;>6":2	79-80: 18 83.3% cor.	79-80: $2524(3)	
Northern City <60,000	N/A	76-77: >1":16 >3":4;>6":1	76-77: 54 75.9% cor.	76-77: $7431(13)	Delay, plow: $1000/hr
		77-78: >1":15 >3":7;>6":4	77-78: 59 76.3% cor.	77-78: $11K(14)	
		79-80: >1":6 >3":3,>6":1	79-80: 30 83.3% cor.	79-80: $517(5)	
Northern City >60,000	$729K (75-76)	76-77: >1":15 >3":8;>6":3	76-77: 52 76.9% cor.	76-77: $12.5K(12) 1.7%	<4 hrs warning Adds 25%
		77-78: >1":14 >3":6;>6":4	77-78: 60 78.3% cor.	77-78: $13K(12) 1.8%	
		79-80: >1":4 >3":2;>6":1	79-80: 29 82.8% cor.	79-80: $1250(5)	
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%	
		79-80: >1":5 >3":3	79-80: 23 95.7% cor.	79-80: $3300(1)	
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)	
		79-80 >1":5;>3":2	79-80: 21 85.7% cor.	79-80: $3100(3)	
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.)	
		79-80: >1":3 >3":1	79-80 23 100% cor.	79-80: 0	

Table 9. Snow and Ice Results by Individual Client

ORIGINAL PAGE IS
OF POOR QUALITY

CLIENT	BUDGET	NO. OF STORMS	NO. OF FORECASTS	LOSS (NO.)	COMMENTS
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 Overtime
		77-78: >1":16 >3":7;>6":2	77-78: 42 85.7% cor.	77-78: $17,044(6)	
		79-80: >1":9 >3":3;>6":1	79-80: 26 96.2% cor.	79-80: $1400(1)	
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%	
		79-80: >1":5 >3":4	79-80: 21 95.2% cor.	79-80: $1000(1)	
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 Delay in Plowing $500/hr
		77-78: >1":12 >3":8;>6":3	77-78: 37 78.4% cor.	77-78: $19,417(8) 7.3%	
		79-80: >1":5 >3":2	79-80: 23 91.3% cor.	79-80: $20,050(2)	
State District	$3,413,000 (75-76) 8 District Total	76-77: >1":5 >3":2;>6":0	76-77: 32 78.1% cor.	76-77: $80.4K(7) 18.8%	Big Storm, up to $10,350/hr standby 6" storm: $30,000/hr 2" storm: $1600/hr: Sand and Salt
		77-78: >1":8 >3":5;>6":2	77-78: Data Incomplete	77-78: Inc.	
		79-80: >1":6 >3":2;>6":1	79-80: 20 80.0% cor.	79-80: $37,060(4)	
State District	"	76-77: >1":5 >3":2;>6":0	76-77: 36 83.3% cor.	76-77: $82K(6) 19.2%	"
		77-78: >1":9 >3":5,>6":2	77-78: Data Incomplete	77-78: Inc.	
		79-80: >1":5 >3":2	79-80: 24 83.3% cor.	79-80: $59,660(4)	
Turnpike District	$2,243,485 (75-76)	76-77: >1":19 >3":5;>6":0	76-77: 55 96.3%	76-77: $4789(2)	No monetary cost for forecast less than 2". Only cost is for overtime: Up to $1300/hr/district
		77-78: >1":19 >3":8;>6":2	77-78: 37 83.8%	77-78: $36,714(6)	
		79-80: >1":7 >3":3	79-80; 28 92.9%	79-80: $17,220(2)	

Table 9. (cont)

CLIENT	BUDGET	NO. OF STORMS	NO. OF FORECASTS	LOSS (NO.)	COMMENTS
Turnpike District	$2,243,485 (75-76)	76-77: >1":7 >3":3;>6":0	76-77: 36 86.1% cor.	76-77: $10.7K(5)	
		77-78: >1":12 >3":8;>6":3	77-78: 28 100% cor.	77-78: 0	Worst Consequence of Bad Forecast: Close Turnpike
		79-80: >1":5 >3":3	79-80: 20 95% cor.	79-80: $6020(1)	Accuracy: 80% (75-76) (126 fcsts)
Turnpike District	"	76-77: >1":14 >3":5;>6":1	76-77: 47 85.1% cor.	76-77: $12.8K(7)	
		77-78: >1":18 >3":8;>6":2	77-78: 37 91.9% cor.	77-78: $13,169(3)	
		79-80: >1":5 >3":3;>6":1	79-80: 23 95.7% cor.	79-80: $4052(1)	
Northern City <60,000	$193K	76-77: >1":17 >3":10;>6":5	76-77: 48 93.7% cor.	76-77: $6100(3) 3.2%	Plow, Overtime: $700/hr MOB: $300 Contractor: $320/hr
		77-78: >1":14 >3":10;>6":5	77-78: 39 92.3% cor.	77-78: $12,486(3) 6.5%	
		79-80: >1":6 >3":2	79-80: 23 95.7% cor	79-80: $300(1)	
Northern City <60,000	$70K (76-77)	76-77: >1":11 >3":4	76-77: 39 79.5% cor.	76-77: $8064(8) (11.4%)	Mobilization: $800 4 hr notice to call back crews
		77-78: >1":12; >3":5,>6":2	77-78: 37 83.8% cor.	77-78: $8280(6) (11.8%)	
		79-80: >1":3 >3":1	79-80: 23 87% cor.	79-80: $3960(3)	
Northern City <60,000	$10K (75-76)	76-77: >1":12 >2":3	76-77: 34 85.3% cor.	76-77: $2720(5) (27%)	Plow: at night $180/hr (x 4 hour minimum)
		77-78: >1":12 >2":5;>6":3	77-78: 37 78.4% cor.	77-78: $4136(8) (41.3%)	
		79-80: >1":5 >3":1	79-80: 23 91.3% cor.	79-80: $944(2)	
Northern City <60,000	$45K (75-76)	76-77: >1":12 >2":3	76-77: 36 88.9% cor.	76-77: $3270(4) (7.2%)	Plow: $340/hr Overtime MOB. on fcst
		77-78: >1":12 >2":5;>6":3	77-78: 40 82.5% cor.	77-78: $4310(7) (9.6%)	
		79-80: >1":5 >3":1	79-80: 23 87% cor.	79-80: $3130 (3)	

Table 9. (cont)

CLIENT	BUDGET	NO. OF STORMS	NO. OF FORECASTS	LOSS (NO.)	COMMENTS
Northern City <60,000	$113K (75-76)	76-77: >1":10 >3":3	76-77: 39 92.3% cor.	76-77: $7125(3) (6.3%)	MOB: $775 Delay: $480/hr
		77-78: >1":11 >2":8;>6":3	77-78: 41 95.1% cor.	77-78: $7975(2) (7.1%)	
		79-80: >1":5 >3":2	79-80: 24 91.7% cor.	79-80: $5880(2)	
Northern City <60,000	$120K (75-76)	76-77: >1":23 >3":11;>6":5	76-77: 48 83.3% cor.	76-77: $1202(8) (1%)	Contractors >4" $1000/hr
		77-78: >1":17 >2":12;>6":5	77-78: 54 87% cor.	77-78: $3897(7) (3.2%)	
		79-80: >1":5 >3":3	79-80: 26 84.6% cor.	79-80: $518(4)	
Northern City >60,000	$420K (75-76)	76-77: >1":24 >3":10;>6":3	76-77: 44 93.2% cor.	76-77: $35K(3) (8.45%)	Contractor: $2600/hr x 4 hrs minimum Hold over: $1800/hr
		77-78: >1":13 >2":10;>6":5	77-78: 43 88.4% cor.	77-78: $43K(5) (10.2%)	
		79-80: >1":5 >3":2	79-80: 29 82.8% cor.	79-80: $15,500(5)	
Northern City >60,000	$450K (75-76)	76-77: >1":20 >3":6;>6":3	76-77: 44 95.4% cor.	76-77: $24K(2) (5.3%)	Late, plow: $3000/hr Contractor (6") $2400/hr
		77-78: >1":15 >3":7;>6":4	77-78: 43 79% cor.	77-78: $68K(9) (15.1%)	
		79-80: >1":3;>3":2	79-80: 24 79.2% cor.	79-80: $28,080(5)	
Northern City <60,000	$59K (75-76)	76-77: >1":17 >3":10;>6":5	76-77: 45 73.3% cor.	76-77: $3566(12) (6%)	Plow fcst. wrong: $1200; timing <u>not</u> impt.
		77-78: >1":15 >3":8;>6":5	77-78: 51 82.4% cor.	77-78: $2366(9) (4%)	
		79-80: >1":3 >3":1	79-80: 29 79.3% cor.	79-80: $2242(6)	
Southern City	$30K (75-76)	76-77: >1":5 None Plowable	76-77: 24 100% cor.	76-77: None	MOB: $150 Plow approx. $100/hr
		77-78: >1":8 >3":1;>6":1	77-78: 27 81.5% cor.	77-78: $2912(5) (9.7%)	
		79-80: >1":5 >3":5;>6":3	79-80: 19 89.5% cor.	79-80: $1756(2)	

Table 9. (cont)

CLIENT	BUDGET	NO. OF STORMS	NO. OF FORECASTS	LOSS (NO.)	COMMENTS
Southern City	$10K (75-76)	76-77: >1":2	76-77: 19 84.2% cor.	76-77: $306(3) (3%)	Plow at 1.5"; Delay Overtime: $210/hr (3 hr min.)
		77-78: > 1":3 > 3",2	77-78: 24 83.3% cor.	77-78: $2383(4) all storms incorrectly forecast (24%)	
		79-80: >1":4 >3":2; >6":1	79-80: 17 94.1% cor.	79-80: $194(1)	
Southern City	$25K (75-76)	76-77: >1":2	76-77: 17 88.2% cor.	76-77: $720(2) (2.9%)	Plow M.B: $1200
		77-78: >1":1 >3":1	77-78: 22 95.5% cor.	77-78: $1880(1) only snow, misforecast (7.5%)	
		79-80: >1":3 >3":2; >6":1	79-80: 17 82.4% cor.	79-80: $7360(3)	

Table 9. (cont)

lost for part of a season, and hence, no calculations were made for that year. All dollar figures are based on data obtained in 1976.

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. Although no direct relationship exists between snow amount and economic loss, the greater the number of snowfalls, especially those which are plowable, the greater the potential for misforecasts which can cause monetary loss. 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.

To summarize, 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 t[illegible]. The majority of misforecasts were for light (up to 3 inches) snow that 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 underforecasts. The percentage of correct forecasts averaged about 85%, which, from our experience, is rather high.

The consultant's fees ranged from about $1,000 per snow season for many of the cities to over $10,000 for the larger units. In most cases, one forecast that 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 responded felt that the service was well worth the cost.

The same procedures used to calculate losses during the control period were applied to the 1979-80 snow season when satellite data were available. It should be reiterated that the experimental period was one of the least snowy years on record in the Northeast (e.g. it had the least snow in over 40 years at Albany, Providence, and Hartford), and among the snowiest on record in many stations in Virginia and North Carolina. In addition, during the course of this study, four of the snow/ice clients whose operations we concentrated on, dropped the service: one from each group except "southern cities."

The results for the 1979-80 season are summarized in Table 10, with a client breakdown given in Table 9. We assumed the same dollar amounts in all our calculations, though current costs are certainly much higher than they were in 1976. A comparison of Table 10 with Table 8 shows that during the experiment year:

1. The number of forecast days was reduced by between one fourth (in the south) to one half (in the north).
2. The number of days of 1" snow or more was as few as 25% of those during the control period in the north, but increased slightly for the southern clients. This figure represents the number of cases

TABLE 10: SNOW/ICE CLIENT RESULTS: EXPERIMENT YEAR

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		23.3	6.7	2.7	13.5%	$32,700	$315,000
TURNPIKE AUTHORITIES		23.0	5.4	3.0	6.0%	$9,670	$348,000
SOUTHERN CITIES		17.8	4.5	3.0	12.7%	$2,960	$45,000
NORTHERN CITIES Pop >60,000		24.6	4.0	1.9	12.4%	$7,460	$273,000
NORTHERN CITIES Pop <60,000		25.0	5.0	1.9	12.4%	$1,930	$91,300
RANGE	MAX	30	9	5	20.8%	$59,660	$853,000
	MIN.	17	3	1	0%	0	$10,000

where some action was taken (e.g. sanding or salting the streets).

3. The number of plowable storms averaged fewer than three (a reduction by over half) with the greatest number of snowfalls over three inches occurring in the south.
4. The percent of forecasts producing losses decreased everywhere with the most significant change in the large governmental bodies.
5. The monetary losses were either constant or reduced with the changes reflecting the decrease in snow. In the turnpike authority class, one very bad forecast greatly biased the average.

Thus, the only real conclusion we can draw is that the milder the snow season, the smaller the losses due to incorrect forecasts. Many of the forecast situations during the experimental year were for storms of less than one inch. These forecasts rarely have much of a monetary effect on the clients, and hence few situations existed this year where the satellite data could have had an impact. In order to more closely measure the impact of the satellite information we would need more data obtained from more representative seasons.

b. Electric utilities

Eleven large electric utilities from New England to North Carolina receive weather data from Weather Services Corp. Unlike many of the other client groups, most of the electric companies service large areas and have a clientele ranging over a million households. Hence, 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 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 a forecast cannot prevent disruption, it can allow the utilities to alert their own crews to catch trouble when it develops, to alert crews from nearby systems, and to restore power at the fastest rate possible. For routine maintenance, the utilities use the forecasts to make the most efficient use of their manpower. In addition to economic factors, accurate forecasts also have a benefit in the area of safety (such as the safety of crews during electrical storms) and personal comfort.

Load forecasting depends upon a number of meteorological variables: temperature, humidity, wind and cloud cover. Accurate forecasts enable the utilities to better cope with long periods of temperature extremes or, for example, by preparing reserve generators which are not economical to maintain during non-peak situations, and which take a long time to be put into operation. A more efficient use of available equipment could minimize down time and reduce "brown-outs."

Eleven utilities in all were contacted as part of this study, most of them located in the Northeast. A sample completed questionnaire is included in Appendix F. This company received forecasts every three hours for temperature, relative humidity, winds and weather for two days in advance, plus a third day outlook. If severe weather occurred, they were also notified. They are a summer peaking company whose major problems are brought about by heavy air conditioning use and rapid changes in cloud cover. In addition, all their maintenance operations are very sensitive to weather.

Eight out of eleven clients completed these questionnaires and were contacted with follow-up interviews. 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 are 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 (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 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 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. (By the summer of 1979, these costs had risen to from 50 to 80 mills/KW for combustion and 25 to 30 mills/KW 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. There 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 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 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 combustion turbines to cover a high temperature that was 5° in error was $6600/hr. Since the peak load period can generally occur anytime from 11 AM to 3 PM, this same cost could be incurred during other hours; however, since this client was not as vulnerable to extended periods of peak shaving only used this one hour value as an indication of the loss. Because of our conservative approach, actual losses could have been several times higher.

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

The results from these three utilities are summarized in Table 11 for the period 1977-79. The calculations for all years were carried out using the same method and cost factors. These calculated costs do not include person power (to run extra generators) which was a negligible part of the total. The months included in the analysis are consistent from year to year for each client, but vary between the clients themselves

TABLE 11

Electric Utility Results*

Company	Max Power Used (MW)	Mi^2 Serviced	Critical Point	Tolerance	Cost/deg	Period Analyzed
A	4,425	10,000	85°	4°	$2205	4/1 to 9/30
B	2,932	1,230	70 THI**	2°	$2200	4/1 to 9/30
C	5,760	2,475	None	3°	$2000	5/9 to 6/15, 7/1 to 9/30

	Total No. of Misforecasts/ Total Forecasts exceeding Critical Point			Overforecasts			Underforecasts		
	1977	1978	1979	1977	1978	1979	1977	1978	1979
A	12/22	4/35	5/30	10	3	1	2	1	4
B	49/103	70/100	42/90	36	34	28	13	36	14
C	56/101	53/100	53/101	28	31	26	28	22	27

Total Loss Due to Forecasts

				Normalized	
	1977	1978	1979	1978	1979
A	$67,813	$28,665	$11,585	-$11,406	-$13,074
B	$323,400	$492,800	$235,400	$502,219	$276,217
C	$1,113,500	$1,144,500	$1,037,000	$1,144,500	$1,037,000

* Based on 1977 data
** Temperature-humidity index

depending on the completeness of the data. Thus Client A and B were analyzed over a similar 7 month period from April to October while Client C could be followed only over approximately a four month period through May to September.

Comparing the clients with one another, one quickly sees that although costs per degree are about the same for all three clients, Client A has both a lower number of misforecasts and a lower dollar loss figure. This is primarily due to the fact that Client A has a relatively high critical point and tolerance level. Thus in 1977, only 22 forecasts were for temperatures equal to or exceeding 85°F and of these only twelve had errors greater than the tolerance value.

One would expect, looking at the number of misforecasts and cost/degree, that Clients B and C would have similar dollar losses. In fact, Client C has losses larger by a factor of about four. This is because Client C stated that they could incur peak load forecasting losses over a four hour period depending on forecast and actual temperatures given twice during this interval. Based on the information we had, we assumed Client A incurred losses only over a one hour period and Client B over two hours although these assumptions underestimate the actual dollar loss on exceptional days.

In addition, Clients B and C were, as previously mentioned, not compared over the same length of time. The longer data series used for B along with its lower tolerance tends to compensate for the more restrictive critical point. In any case, the dollar figures are most meaningful in their variations from year to year for the same client. Costs are not strictly comparable between clients as absolute values not only because of the differing times compared but also because of variations in the quality of the information upon which the calculations are based. The dollar figures nonetheless do give an indication of the order of magnitude of costs involved.

The total number of misforecasts is broken down into overforecasts, those times when predicted maxima exceeded the actual, and the opposite case, underforecasts. Overforecasts outnumber underforecasts by 57% to 43%, but we are doubtful that there is any statistical significance to this, especially since we can think of no practical reason for the predominance of overforecasting.

The final entries of Table 11 show the actual losses for the two control years and one experimental year plus the values of the last two years, normalized with respect to the first. This normalization was accomplished by comparing the number of times in each year 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 of the former, if forecast accuracy were to remain the same. Of course, this accuracy varies, and should account for most of the differences between the normalized values.

If this assumption is true, then one can make the following observations: for Client A there was a drastic improvement in accuracy after 1977 when normalized losses actually became negative. This sudden change is a little hard to explain unless one assumes that a different forecaster with greater skill or better techniques assumed the job after the first year (although WSC has no recollection that this happened). Clients B and C are more uniform; they both have greater normalized losses in 1978 and the best record of all in 1979, a 14% improvement over the first year for B, a 7% improvement for C.

Can this improvement be related to the introduction of satellite data? Unfortunately, no. There were few known instances when temperature forecasts for these utilities were altered because of satellite information. Forecast accuracy may have been helped in 1979 by the fact that there were fewer cases than average of heat wave or severe storm conditions, times when the forecast would be more crucial and data sources consulted more thoroughly.

Turning now to our case studies, one documented storm we have studied 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 delays in power restorations tend to compound themselves due to continuing storm conditions, (e.g. snow, wind, and drifting). 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 severity of this storm was a surprise, 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.

Both these case studies are for the control period. Our hopes for similar case studies in 1979 where we could perhaps have shown a concrete application of satellite data to an ice storm situation were foiled by the fact that there simply were no ice storms of note in the 1979-80 season affecting the region served by the utilities.

In summary, we have documented here in a quantitative way the effect of weather and weather forecasting on the electric utilities. While we cannot present the actual benefits of satellite data to such a user, one can easily see the areas where satellite information would be valuable. In summer, clues as to the location, movement, and severity of thunderstorms are often provided from satellite data, and in winter, the advantages pointed out under the snow and ice section pertain here.

Satellite data is less crucial to temperature forecasting (used in peak load determination), but even here changes in cloud cover can on occasion greatly alter the prediction. Especially with a looping capability, one can sometimes spot trends such as the movement of dry tongues or regions of subsidence before they are clearly apparent in other data sources. For the cases studied, however, these opportunities are found only infrequently.

c. Gas utilities

Weather Service Corporation provided forecast information to 33 gas utilities from Maine to Georgia. They ranged from among the largest utilities in the country (Con Edison, Philadelphia Gas) to small municipal systems (Lexington, NC Gas Dept.; Vermont Gas Sytems, Inc.). The weather forecasts were used in two major areas: (1) maintenance and service of the system, and (2) forecasting load requirements in order to make optimal use of the available gas supply.

Since most gas mains are underground, weather does not frequently interfere with equipment. Occasionally extreme cold, snow and other forms of precipitation interfere with routine maintenance, and heavy snow plus deep frost penetration require the call-up of emergency manpower. In emergency situations the forecast is used to minimize the time customers are without service, and to schedule available manpower efficiently. In routine maintenance, forecasts are used to call men into work when the weather permits. For example, if crews are called in and the weather is inclement, they would have to be directed to other tasks or paid even if they did not work; if they were not called in during good weather, needed repairs may have to be done on overtime shifts. No company was able to quantify these losses or relate them directly to forecast errors, however, due to complicated union rules or other work force scheduling arrangements. As a result we have not included case studies in this area.

Gas utilities are vulnerable to many of the same factors as the electric utilities with regard to peaking problems. In general, 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 has to 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 (in 1977 anywhere from $1.50/MCF to $3.50/MCF*) than pipeline gas and therefore unneeded use of these due to forecast error would have an economic effect. Sometimes, generation of unneeded gas could be stored for the next day thus eliminating financial loss. In other cases, a company might have a special contract whereby gas could be provided through storage or pipeline on a few hours notice. But in many cases such flexibility was not available and the loss due to excess gas generated could not be mitigated. Likewise, the failure to prepare for an actual peak load, would mean using either pipeline gas at penalty rates (up to 10 times more expensive), using more expansive storage gas that had eventually to 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 caused most

---

*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 in 1979 cost between $5 and $6 per MCF as opposed to $3.50 in 1976 and steam turbine costs have increased by 50% or more. Also, in at least one case, the client has laid an additional pipeline thereby changing his critical point by 10°.

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 could be done on short notice thus giving the gas company great flexibility. Where such an operation was in effect, it made calculation of monetary loss impossible unless one knew in exact detail the situation in regard to gas supply and allocation on a given day.

Of the 33 gas utilities contacted, complete responses were received from 21; three declined to participate. Many of the 21 also were contacted by phone to clarify some answers. A sample completed questionnaire is included in Appendix G. This utility (Company S) received forecasts up to three days in advance for average temperature, maximum and minimum temperature, degree-day, and effective heating degree-day (EHDD, which includes wind). In addition, temperature forecasts were given for every three hours, and wind data every twelve hours. When significant weather was expected, that too was included in the forecast. Company S explained that since every maintenance situation was different, it would be impossible to give exact monetary figures. On the other hand, it was apparent that when temperatures dropped to about 10° F, the exact accuracy of the forecast became crucial, with penalties of up to $5.00/million cubic feet for the gas that was "misused."

In studying this gas utility company we used the forecast EHDD along with their updates, matched them with actual conditions and determined how far Company S was from the optimal use of their gas supplies due to the weather forecast.

Of the 21 clients who returned questionnaires, 5 were usable for cost calculation. Another 7 were not used because of failure to provide sufficient information on their operations; 8 were clients using a flexible system of special contract, storage facilities, or priority allocation mentioned above; and one client dropped service after 2 years. Generally the 16 clients whose responses were not used were either smaller utilities with less gas flow, or the very large companies with ambiguous cut-off points for peak shaving.

To illustrate the operations of those clients which were used for calculation purposes, we will examine one forecast for a utility which receives forecasts for two cities within its service area. The critical point for this utility was 52 degree days (DD), arrived at by their send out and gas availability. (The critical point is reached if the weighted [by relative gas consumption] average temperature of the two cities equals or exceeds 52°). They could tolerate a 1° error and needed a lead time of four hours to adjust their operations. Table 12 shows the forecasts, updates and verifications; the 1200 LT forecast is the one used for verification. For city A, the error was 2°. Since they use 1875 thousand cubic feet/degree day (MDF/DD) and expensive gas is $3.50/MCF extra, the extra cost is 1875 x $3.50 = $6562.50 (considering the 1° tolerance). For city B, with a 5° error and a sendout of 625 MCF/DD, the cost for the gas was $8,750. In addition it cost them $40/HR x 24 hrs ($960) to run 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.

Table 12
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	City F
(2° error - 1° tolerance) x	(5° error - 1° tolerance) x
1875 MCF/DD = 1875 MCF.	625 MCF/DD = 2500 MCF.
1875 x $3.50/MCF extra	2500 x $3.50/MCF extra
= $6562.50	= $8750.00. +
	Manpower Costs: $40/hr x 24 hrs
	= $960.
	Total: $8750 + 960 = $9710.

Total Loss: $16,272.50

The results from our calculations are summarized in Table 13. Notice that the critical points for gas companies are in degree days. The 1978-79 season is not included because it was a transitional period in the use of the satellite data, as stated previously.

In general, the gas utilities here are smaller operators than the electric utilities previously surveyed, although their losses due to forecasting error can still mount up into the hundreds of thousands of dollars. Companies D and E are exceptions to this rule because they both have high (in degree days) critical points which are seldom reached. Even a slight lowering of these points would have resulted in substantially greater vulnerability to loss. It would appear that Client A would be the most prone to such losses but A is a Southern system with a high tolerance. Its losses are therefore less than the Northern Clients B and C. Company C in particular has a lower tolerance and a higher cost per degree, making its losses the largest in the table. We caution, however, that these figures should be considered only as estimates of the actual losses. Because of the complexity of the individual operators, these figures are not strictly comparable except when viewing one client's change over time.

As with electric utilities, overforecasts (i.e. prediction of higher temperatures than actual) predominated 61% to 39%. We do not know the reason for this bias.

The 1976 thru 1978 winter seasons were considerably below normal in temperature and unnormalized losses are correspondingly great. The 1979-80 season was much above normal. Taking these fluctuations into account, one can see that normalized (with respect to 1976-77) losses show worse

Table 13

Gas Utility Results

Company	Max Gas Used (MCF)	Mi^2 Serviced	Critical Point	Tolerance	Cost/deg.	Period Analyzed
A	144,000	1025	28	3°	$2500	11/1 to 2/28
B	260,000	1703	50	2°	$7000	11/1 to 2/28
C	206,000	666	52	1°	$8750	11/1 to 2/28
D	36,000	150	55	2°	$1995	11/1 to 2/28
E	91,878	225	55	2°	$3125	11/1 to 2/28

	Total # of Misforecasts/ Total # of Forecasts exceeding Critical Point			Overforecasts			Underforecasts		
	1976-1977	1977-1978	1979-1980	1976-1977	1977-1978	1979-1980	1976-1977	1977-1978	1979 1980
A	22/65	14/63	10/49	15	9	5	7	5	5
B	12/29	8/19	2/11	8	3	1	4	5	1
C	25/28	15/17	8/13	13	13	7	12	2	1
D	1/2	0/1	0/0	0	0	0	1	0	0
E	1/4	1/1	0/0	0	0	0	1	1	0

Total Loss Due to Forecast

				Normalized	
	1976-77	1977-78	1979-80	1977-78	1979-80
A	$122,500	$95,000	$50,000	$98,770	$80,154
B	$175,000	$133,000	$49,000	$193,345	$157,621
C	$354,375	$264,688	$85,313	$403,907	$275,157
D	$1,995	$0	$0	--	--
E	$9,375	$9,375	$0	--	--

forecasting errors in 1977-78 for clients B and C, and then noticeable improvement thereafter for all three clients (35%, 10%, and 22% for A, B, and C respectively, comparing 1976-77 to 1979-80). In all cases, this last season brought forward the best forecasting results.

We can say as with the electric utilities that satellite cloud cover information could be expected to improve temperature forecasts. Yet the staff of WSC could point to few specific situations when the satellite data helped their predictions. Thus we cannot ascribe any of this final improvement to the McIDAS system data.

d. Fuel oil dealers

Fuel oil dealers generally receive three distinguishable services from the weather consulting firm. One of these, calculated effective heating degree-days, is based on actual weather data and is used with the customer's empirical "K-factor" to estimate the rate of fuel consumption. By keeping track of cumulative effective degree-days since the last fill, the current status of a customer's fuel supply can be determined. The impact of satellite data on knowledge of actual (past) wind and temperature would be slight. However benefits might be expected in the other two services--predicted degree-days and storm warnings which are both used to make delivery schedules more efficient.

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. The uniformity of response to the principal questions indicated that this is an adequate sample. A representative completed questionnaire has been reproduced in Appendix H. The operation described is typical, though a bit larger than most.

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 (1976) rate of pay ranged mostly within a dollar of $6.50 per hour, but drivers often worked overtime at around $10.00 per hour. Within the heating season there are peaks in the demand for fuel delivery. Most firms handle this by the overtime mentioned above, but a few 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 carries almost seven days reserve ([265 gal - 180 gal]/12 gal/day = 7 days).

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 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 6a-c shows the predicted and actual EDD values for December 1976 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. These errors, however, are economically insignificant since the operators themselves use the latest information for planning.

The effect of improved precipitation information on actual oil delivery would usually be more important than improved degree day forecasts. Winter storm warnings play a major role in short range schedule changes. The oil dealers agreed that up to four inches of snow would 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'. This usually means overtime pay for drivers at 1.5 times normal wage rates. 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 which the forecast snow depth and the actual depth fall on the same side of the 4" mark.

If overtime is scheduled on the basis of a forecast which later proves incorrect, the loss arises because the overtime and premium rate were unnecessary. Similarly, if a storm occurs which was not forecast properly, drivers are unable to make deliveries at difficult "snow stops" and, in

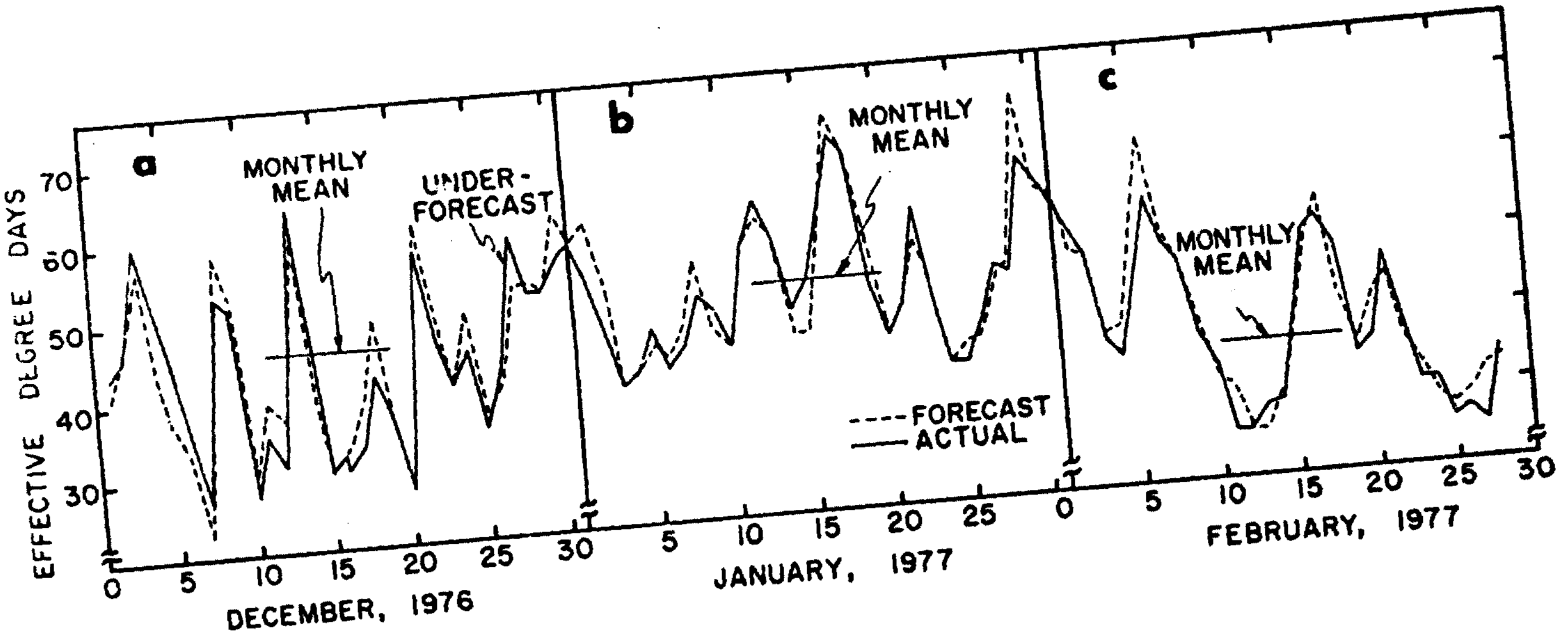


Fig. 6. Predicted and Actual EDD (Effective Degree Days).

an extreme case, have had to hand carry 5-gallon cans of fuel to customers. Snowy conditions also slow down deliveries to normal customers, which cause reserves to drop, and the risk of a run-out to increase.

Considering the factors important to the fuel oil dealers, there were only a small number of potentially significant weather events to monitor even in the severe winter of 1976-77. 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. Delivery efforts would already be backed up. For snows much greater than 4", the available response time was often too short. It simply takes more than two or three days to recover from a 10" snow.

Of the ten principal events examined for 1976-77, five forecasts exceeded the threshold criteria set forth above (namely, a 4" depth or greater). Only one of the ten precipitation forecasts had a large error with regard to amount. With respect to being on the same side of the 4" threehold, however, only five of the forecasts were good. The above results apply to three geographical areas and affect 16 of the 21 firms available for study.

For a December 1976 storm with an 11" snowfall, for example, an hour of overtime worked before the storm was worth a savings factor of four times as much as an hour of overtime worked after the storm according to one of the clients. 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. (7.5 drivers x \$10/hr/driver x 3 [= savings factor] x 6 or 8 hours) 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, 1977 storms.

Unfortunately, as noted in other sections of this report, during the with-satellite data year of this study, the winter was so mild and nearly devoid even of threats of heavy snow (>4") that a meaningful comparison and valid conclusions are not possible.

e. Marine forecasting

One client firm was engaged in offshore exploration. General marine forecasting is an attractive application for satellite data, since one of the significant problems in marine forecasting is lack of conventional data.

The forecasts were intended for operations about 200 miles offshore, conducted from a 175 foot research vessel. The ship towed cables bearing sensitive instruments for geophysical sounding. After two weeks at sea, the ship would normally return to port, change crew and return to station.

Wind, waves and unusual weather were of interest. The cable-instrument assembly, valued at one-half million dollars, could easily be damaged by unfavorable weather. Consequently, weather forecasts were important in planning the orderly conduct of exploration (decisions to deploy or retrieve the equipment). Since the vessel is comparatively small it had to return to port in severe weather. This required a 15 to 20 hour warning to insure against damage or loss of the ship, a multimillion dollar investment, and harm to the lives of the crew.

If a storm occurred but was not forecast, or if it were more severe than forecast, the direct economic loss would include the cost of damage and lost time for repairs, multiplied by the ship operating costs and wage rates. If a storm were forecast (wind or waves) but was late, was less severe than forecast, or did not occur at all, direct economic loss would be quantifiable as lost time multiplied by wage rates, plus the cost of maintaining the scientific crew and operating the ship on station ($9K per day). There would be an additional cost for fuel, if the ship leaves station unnecessarily to avoid the expected storm. According to the client it was not possible to calculate the indirect economic impact of the lost time; such lost time affected the competitive position relative to other companies. (In the opinion of this client, indirect dollar benefits and losses of this kind were far larger than direct costs or benefits.) While our program was in progress, this client discontinued its forecasts from Weather Services, and hence it was not possible to complete the study of the benefits of satellite data.

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

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

The client did not maintain an independent log of verifications. The critical parameters were, according to the client, wind speed, and to a lesser extent, direction. For the Cape May to Providence leg, winds blowing out of the west to northwest were less effective in setting up short "choppy" waves which were much more important than swell. This is the reason the client was much more interested in the "winds" part of the forecast than the "seas" portion. Except for the obvious effect on visibility, general weather was of no consequence.

According to the client, one of the shortcomings of present forecasts was the tendency to a large spread in forecast values. 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.

The range of greatest interest was roughly speeds over 20 kt. It is possible that satellite data could have materially improved the shorter range portion of the forecasts and brought about a reduction of the spread of values, making the forecasts more useful to the client.

The obvious, direct economic loss to the barge operator was the wages of the crew during periods when prohibitive conditions were forecast, but did not prevail. However, there was a further economic value of the time lost. If none were lost, more loads could have been transported, hence more revenue generated. Therefore, the lost time should also have been multiplied by a significant fraction of the rate at which transport generated a net economic value (revenue less operating costs excluding those attributable to lost time itself), and the result added to lost wages. None of these calculations were in fact possible due to the absence of a ship log for verification.

The third marine client was added after our research was in progress. This client chose not to provide detailed information. The enterprises requiring marine forecasts were off-shore construction projects. The usefulness of satellite data to this company can be judged from the log in Table 4. Though we cannot quantify its impact, the log illustrates that satellite images are useful for precisely locating small scale intense systems like gust fronts and thunderstorms for very short range forecasts.

f. Commodity clients

Among the weather service clients are nine commodity dealers. We were able to obtain some information from seven, and detailed questionnaire responses from four of these. In addition we were able to acquire still more understanding of this group through two on-site visits.

Futures trading is a major preoccupation of these firms. In contrast to speculators whose intention is to turn a quick profit, client firms trade mainly to guarantee supplies and to protect themselves from unexpectedly large fluctuations in raw material prices (although they do occasionally take advantage of a singular opportunity).

This client group carries on mainly three kinds of activity: First, they may produce and merchandise brand name products to consumers through wholesalers and retailers. Secondly, they may produce a bulk, or unpackaged commodity which is made into consumer goods, or packaged, and merchandised by another firm. Sometimes the "other firm" may be a functionally independent branch of the same company. Typical commodities of this kind could be vegetable oil, sugar, or flour. The third activity is dealing in raw commodities, like soybeans, wheat or coffee beans. The intention is to obtain these from producers and make them available to producers after providing necessary storage, transportation or other service.

In order to clarify the economic benefits of weather information, both actual and forecast, for these firms, we must point out that the impact may be quite different for each of the activities mentioned above. In general, for consumer products, retail prices are determined by many factors unrelated to the cost of the raw materials (e.g. advertising, labor, shipping). In addition, prices obtained for consumer products do not necessarily vary in a one-to-one correspondence with these costs. Sometimes the price is relatively inflexible. Thus, even though the costs of the raw product may be a minor component of the total cost, it can be a major factor in the spread between prices and total cost. For this reason, the firms may use the futures market to assure themselves of a future supply of a commodity at a known price.

The cost of a raw commodity is a more significant factor in the case of the bulk processing activity. This is because other cost components such as advertising, labor, and transportation tend to be less significant, and because the product is a commodity indistinguishable from the competitor's product which must sell at a price determined by supply and demand in the market place. (In the case of finished products a portion of the cost increase can sometimes be passed on, because the product differs from the competition and consumers will continue to buy because of taste preference, brand loyalty, habit, or other factors.) To keep customers supplied and facilities running near peak efficiency, bulk processors must continue to buy, process and sell even if the cost price spread is unfavorable.

Commodities futures prices on which the above activities depend are very sensitive, experiencing short and long-term fluctuations in response to several types of information such as news of changing monetary policies, foreign trade considerations, the diplomatic climate and others. Commodities whose production is concentrated in small regions subjecting a significant fraction of the entire production to destruction by a single weather event such as a drought, hail or untimely freeze, are extremely sensitive to weather information on the futures market. In order to operate effectively in the commodities markets a variety of valid up-to-date information is needed, including weather information.

After studying the material obtained from the cooperating clients, we concluded that in most day-to-day operations of these companies, the effect of weather information could not be accurately quantified because it is diluted by the other considerations mentioned above. Weather plays a somewhat stronger role in advance planning for production, processing, and promotion, according to those we interviewed, but still could not be objectively quantified. With the information at hand, a direct economic benefit could be substantiated best in the futures market under suitable circumstances. Such circumstances occurred about the time our research program was beginning when a destructive freeze damaged the Florida citrus crop and also when the Brazilian coffee crop experienced severe freezing conditions. Certain traders, who had advance warnings of either of these and acted on the information, made substantial profits.

In view of the small number of such situations arising, as well as the unique circumstances associated with each, it was not possible to do a before and after satellite data comparison. Although quantitative results were not obtained, Weather Services Corporation found satellite data especially useful for forecasting temperature falls in the citrus belt, and rainfall in the soybean areas of Brazil.

Brazil affects the U.S. economy through corn and wheat markets, but especially through soybean markets. 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.

In the past offical estimates of Brazilian production have proved erroneous. Soybean Digest (July/August 1978) noted 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. For this reason, commodities clients desire independent data on Brazilian weather. Weather Services Corporation has found GOES-E images very useful for providing these data.

g. Other clients

1. Construction

Only three clients are included in this category. All are involved in concrete pouring and paving operations in the New England or mid-Atlantic region. A questionnaire was first prepared on the basis of preliminary information from these three companies. The answers to these questions were supplemented by detailed interviews by phone to gain better insight into the operations.

One of these clients felt the weather forecast had little value to his operation and in fact discontinued the service during the course of this study. The other two clients used the forecast for operations planning, especially optimal deployment of their crews. Factors affecting these decisions were heavy all-day rain, strong gusty winds, extreme temperatures, and snow--any of which could lead to the cancellation of part or all daily operations.

These clients, upon detailed questioning, were unable to link specific forecasts to amounts of economic loss partly because they had contingency plans for use of crews which though inconvenient, prevented total waste from occurring (e.g. indoor educational activities) and partly because they were unwilling to take the time to trace down the possible losses from given situations. This admittedly would be difficult to do since labor deployed and reaction to situations varied depending on type of construction project, its current state of vulnerability, and other variables which could only be obtained from back records. Even if such information had been provided, it would have been difficult to generalize over a whole season, not to mention year-to-year comparisons.

2. A state automobile association

Several phone interviews were conducted with this single client to learn if significant economic benefits were likely to arise in connection with this study. Conversation revealed that up to 90 employees could be called in for overtime in two types of situations: rain with temperatures rising from the 30's to the 40's (causing motor condensation), and temperatures of 10° or below in November and December (causing engine starting problems). Since the association was responsible for servicing members' cars, a large staff was needed to handle early morning service requests. In addition, this association was affiliated with about 100 branches, all of whom were advised by a main office about upcoming demands due to the weather situation. A director of the association estimated that the forecast caused overpreparation in 15 to 20% of the overtime cases.

A compilation of forecasts possibly having economic effects was sent to this client. The club was unable to correlate these forecasts with their payroll costs. Since workers with different salaries were 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. Thus, this client was not used for detailed analysis.

7. Some general observations about user clients

Although 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 that can be handled at the last minute should a weather emergency arise, but these people would rather have a greater lead time for 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 upsetting 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 knowledgeably 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.

It is also unfortunate that some members of the user community, mainly governmental bodies and large utilities, are pressured in their selection of, or use of consulting firms. Some of the clients we dealt with were forced into choosing the consulting firm with the lowest bid for the service. Unfortunately, the people who are responsible for the selection of the service rarely have any practical contact with its products. Their primary concern appears to be economy rather than quality. If they were surprised by a snowstorm or hit by power outage due to unforeseen overloaded circuits, then they would realize that meteorological forecasts are a science rather than a commodity.

8. Discussion

In the preceding sections, a summary of statistics and observations describing the benefits received by a variety of clients from private meteorological forecasts has been presented. In spite of this emphasis, the problems and potential of satellite data use has been the constant focus of this study. Even though we cannot present precise dollar benefits resulting from satellite data use, we can draw a number of conclusions about how satellite data can be used for greatest economic benefit.

Perhaps the most telling part of our study lies in the type and amount of use to which the McIDAS system, and satellite data was put. Before this subject is discussed in detail, some additional background information is necessary.

Weather Services had one McIDAS terminal which was located in the room where the storm and marine forecasts are made. Most of the personnel work in other parts of the building on scheduled forecasts or agricultural work. In these rooms are the facsimile maps, clip boards on to which forecasts are placed and terminals to their own computer system. Hence, in order for most of the forecasters to use the satellite data they had to make a special effort to go to the room in which the terminal was located. In addition, if McIDAS were being used to prepare a marine forecast, for example, a forecaster wanting to check on the movement of showers had to wait his turn. This situation tended to discourage the use of McIDAS by some of the forecasters. The terminal could not have been placed anywhere else due to space and logistical considerations.

A second important point is that McIDAS was designed as a research tool, and up to the time of this study was never used for operational forecasting. While we at SSEC were not forecasters, and hence were not totally familiar with all the tools used by operational forecasters, the Weather Services personnel had little familiarity either with interactive video computer systems like McIDAS, or with satellite data. Hence, the design of the system was probably not ideal in the sense of applying our resources most efficiently for forecasting. Where we erred was mostly towards excess-including much software which was rarely used.

In an earlier section, the problems with the analog disk were discussed. Being the prime source of system unreliability, the inclusion of an analog disk affected system use. Aside from causing the system to be down, the primary problem caused by the analog disk was the skipping of frames during looping. This caused disruption in the satellite use and frustration among some of the forecasters. During times of unreliability, the effort involved in setting up a long satellite loop was often not viewed as worth the effort, given the probability that the looping capability would malfunction. In retrospect, however, the forecasters at Weather Services knowing the problems involved would still have chosen an analog disk with one hundred frames over a digital disk with only ten or twelve frames. The capability of setting up long loops was felt to be too useful to be sacrificed.

Although the McIDAS system presented all of the above difficulties, it was used and used effectively. As mentioned previously, our means of keeping track of the satellite data usage was the log adjacent to the computer terminal (see Fig. 4). Forecasters were supposed to make entries when McIDAS made a difference in their forecasts. Unfortunately, because entering information into the log was not always utmost on the minds of

WSC personnel, we have a good indication of the type of uses McIDAS was put to rather than the actual amount of use.

As stated earlier, the WSC operations are in four general areas: marine, storm, general operations, and commodities. What follows are subjective appraisals of the usefulness of McIDAS and satellite data for each of these operations:

(1) Marine - one would expect any data source to be helpful for these forecasts which encompass large data void regions. The marine forecasters used McIDAS extensively, especially for the satellite data over the Gulf of Mexico. They were able to see cloud growth, the early formations of potential tropical systems and movement over the Gulf plus location and strength of rain producing systems. The satellite images were invaluable for forecasts affecting drilling, marine construction and other marine activities. In addition, the satellite data was extremely useful in preparing forecasts for hurricanes of which there were two significant ones during the forecast year. The forecasters did not find the tropical weather advisories issued from Miami to be helpful, and felt that their problem was the lack of adequate satellite data access. In fact, the WSC forecasters were able to produce accurate and timely forecasts and were able to give adequate warnings to their clients because of their ability to identify, track and predict movement of tropical systems from the satellite loops. They would not have been able to do so without the McIDAS system.

(2) Storm - this group includes forecasts for snow and ice, heavy rain, high winds and thunderstorms. Their use of McIDAS was

heavy, though somewhat less than the marine group and was split in half between the satellite pictures and the graphics. The satellite pictures were used to locate and track storms, especially off the coast, as well as fields of clouds and thunderstorms. The graphics were used in the traditional way (i.e. height fields, streamlines, temperature, etc.) The computer system streamlined their procedures and enabled them to do types of analyses which were ordinarily too time consuming. Its impact on the actual forecasts was not concrete enough to be measured.

(3) General Operations - these consist mainly of temperature and weather forecasts. Operations used the system about a third of the time, usually using only the graphics. When the satellite pictures were used, it was to aid in the forecasting of low temperatures by locating and tracking cloud layers.

(4) Commodities - their use of the system was the lightest of the four, only relying on satellite pictures of South America. These were used to track cold frontal penetrations into the coffee growing regions of Brazil as well as to catch moisture inflow into South America's soybean growing regions.

The four features of the McIDAS system which had the most frequent use were graphics, the real-time satellite capability, looping of satellite images and color enhancement. The ability to get real-time satellite images enabled them to locate various cloud features; getting images several hours old over the facsimile circuit had much more limited use. The ability to loop the current satellite pictures seemed to be the most useful feature by far. Many of the forecasters had little experience with satellite loops prior to this program, and these loops greatly aided their understanding of various weather phenomena according to their own reports. In a practical sense, the loops helped the forecasters track clouds, cloud shields and storms. The average loop of half hour pictures ranged from 4 to 12 images and often contained only the infrared images because they could cover longer time periods. The visible images were also used (for fog tracking, for example) but rarely was the full resolution of these iamges employed. McIDAS was of greater use in getting a general overview of the motion of the synoptic weather patterns, rather than in identifying and tracking small scale features. Color enhancement was used along with the cloud loops to note intensification of thunderstorms, the development of tropical features and to get a feeling for the relative changes in cloud-top temperature (although the IR brightnesses were not calibrated). All of these were not readily available from other sources.

The Weather Services McIDAS system contained a variety of features which were seldom used. These included most of WINDCO, for the determination of cloud winds (the motions of clouds were mainly viewed but not measured) cloud height determination, the statistics packages (for obtaining cloud areas and brightness frequency distributions) the plotting of conventional data on satellite images, plus many of the plotting routines.

In addition to the frame skipping caused by the analog disk malfunction, the biggest problems were associated with the grids that came with the images. The grids were often highly inaccurate, inconsistent and visually very distracting. When a satellite loop contained these inaccurate and moving grids (a frequent occurrence), the loops were difficult to use even though

WSC had the capability to navigate their own images. This undoubtedly lessened the frequency with which the loops were employed.

We asked the following question of WSC staff: knowing what you now know, how could the McIDAS system have been designed to best meet your needs? The following are some answers:

(1) WSC would have been better served by more terminals, placed in the various locations where the forecasts were being prepared;

(2) It would have been useful to have an operator whose task was to injest and navigate images and set up loops;

(3) McIDAS could have been designed with less and much simpler software--about 1/4 of its software was routinely used; and

(4) If money were no object, they would have preferred a system with its own receiving antenna. In that way they could receive whatever images they needed, and these images would be <u>ungridded</u>.

Two possible measures of the economic value of McIDAS and the satellite data were (1) the interest of WSC in buying McIDAS at the conclusion of the study, and (2) the continuation of their access to satellite data. Meteorological consulting is a highly competative field. The financial foundation for these firms is usually the business from a large contingent of small clients who pay small fees for services which are hopefully renewed yearly. The major resource of consultants is manpower rather than equipment, and hence, most of their expenditures are spent on salaries. It should also be noted that WSC has already invested heavily in their own computer system. It was felt that no matter now good the equipment, the most WSC could afford to invest was in the neighborhood of $20,000. This is far less than the cost of McIDAS which in any case was not the ideal system for their needs. Hence, their decision not to buy McIDAS.

When the computer system was removed, WSC decided to let the contract for the GOES-TAP lapse. But, many of the forecasters had become accustomed to the access of real-time satellite imagery, especially in the areas of tropical weather and commodities forecasts for South America. Thus, the GOES-TAP line has been restored, and a device to produce hard copy images has been purchased. Therefore, WSC views the value of satellite data to them to be at least the several hundred dollars per month this new service costs.

A final question we posed was: knowing what you do now, would you have participated in this program? The answers were not unanimous. Some felt that the rewards were not worth their inconvenience and expenditure. Others felt that it was well worth the effort, if only for the educational value. When asked what the economic benefits of the satellite data were, one reply was: "I don't know whether you can quantify the effects, but it certainly did help us, and in turn, our clients."

9. Summary and Conclusions

Five years ago, we stated in our proposal "...we propose to determine the impact that the addition of satellite data has on a particular segment of the public by introducing this data to a consulting firm and determining the value to their clients of the augmented weather service." We acknowledged the myriad potential difficulties ranging from governmental involvement with private industry to the fact that the type of study we proposed had not been performed before. We accomplished what we had set out to do, although some of our specific plans were thwarted by unforseen circumstances.

Regarding the use of the satellite itself, we gleaned a number of conclusions. As one would intuitively expect, satellite data is especially helpful in data-poor areas (e.g. the oceans), and in detecting the formation and movement of storms, and other cloud systems. Temperature forecasting, except in cases where it is directly affected by cloud cover, remained relatively unaffected. Satellite data is most useful when it is relatively recent (real-time), enhanced to bring out cloud brightness variations, and in loops to show relative motion. There is also an indirect benefit to satellite data: exposure to a satellite view of cloud systems illustrates and clarifies many meteorological concepts. Thus, satellite data has an educational value which undoubtedly results in better forecasting.

There is one additional point to be made about the usefulness of satellite data. Even if one makes allowances for the quietness of the weather over the last year of the study, and even if one considers that the forecasters did not make perfect use of the system, there were nonetheless relatively few times when the satellite data proved essential in preparing <u>routine</u> forecasts for temperature and weather. For those who had hopes that this data <u>in its present form</u> would revolutionize or even substantially modify forecasting in general, the results are disappointing. While satellite data proved extremely useful for data poor areas, the simple fact is, that in the vast majority of cases, satellite data served to fine-tune forecasts produced for data-rich regions. This does not mean that the satellite data is without great economic benefit even in data rich areas. As we have shown in our client studies, even one improved forecast per client per year can result in thousands of dollars saved. Multiplied by many clients even a few improved forecasts per year can mount into the millions of dollars. These figures are hypothetical but the principle is not: even minor improvements in the state of the forecasting art can, in today's economy, result in significant benefits. This prospect has caused WSC to invest several hundred dollars per month in retaining its satellite link.

Our results probably would have been more convincing were it not for the various problems encountered during the program. The most significant of these problems in terms of its effects on our final results was, of course, the unusual weather conditions that prevailed during the period of our study. Instead of fluctuating in an interval reasonably close to mean values, temperatures and snowfall alike gravitated to the extremes. A year of record snow was followed by one with nearly none. Winter temperatures 5 or 10 degrees below normal preceded unseasonably warm ones. Worst of all, the final year, the year in which the benefits of the satellite data were to be examined, produced virtually no winter storms over a large part of the study area. We were thus deprived of both the opportunity to document significant case studies and to apply statistical techniques to smooth out the yearly variations.

Though the obstinacy of the weather had by far the greatest influence on our results, there were several other problems which diverted energy or interest that could have been used more constructively. Certainly, the occasional malfunctioning of the McIDAS system was chief among these. Computer down time shortly after installation was considerable, and intermittant analogue disk problems thereafter disrupted use and tempered enthusiasm for the system. Even under ideal circumstances, it can be difficult to introduce new technical aides into an established routine: this resistance was compounded by the initial system failures and no doubt decreased the opportunities for the beneficial use of the satellite data.

We are happy to note that there were areas which could have had serious problems but which did not. Among these were the relative stability of the client base, the good cooperation beyond the call of duty by the personnel at Weather Services, and the stability of the staff at SSEC. The deterioration of the world energy situation during the course of this study did not seriously affect our gathering of information and statistics although the operations of some utility clients did change drastically between 1976 and 1978. On the whole, the energy crisis worked to our advantage by increasing interest in our efforts.

Overall, the problems we had, while serious, did not prove debilitating. We did, after all, introduce a satellite system successfully into a firm which had previously not had such capabilities. Generally, forecasters there achieved greater awareness of the usefulness of the satellite and made an effort to take practical advantage of the new technology. This, in itself, is quite important. That effort was quite sufficient to enable us to assess the impact of the satellite data on both the forecasting operations and the forecast itself. Had there been no system problems and had the weather cooperated fully, the impact of the data might have been greater in magnitude, (i.e. number of forecasts altered, dollars saved) but would have on the whole shown the same patterns of usefulness (which we have outlined in Section 8).

Perhaps the most interesting results to come out of the study are in a sense by-products of our major goals. In order to consider the effects of the satellite data on the user client, we had to know the details of WSC's and the clients' operations. These facts have been presented in detail because they are interesting in their own right. No other study has shown, in as wide-ranging terms, the actual impact of private meteorological forecasts based on actual forecast/verification data. Consequently, this study lays the foundation for future economic impact studies based upon actual conditions.

Although the methodology has been tested, there is definitely room, and in fact, a need for future studies of this type. We hope some lessons can be learned from our experience. Chief among these would be the need for a longer experimental period to obtain statistics. A year or even two is subject to fluctuations that can provide a very poor data base on which to work. Ideally the experiment should be open ended--continuing as long as necessary until a balanced sampling of different storm and forecasting situations has been obtained. More practically speaking, a three to five year experimental period (not including any control period) would substantially decrease the likelihood of obtaining an abnormal sample, especially one that was lacking in potential case studies.

We have also learned that for the purposes of this study a much simpler satellite data system could have been used. A video system displaying real time, navigated and concurrent IR and visible pictures with a looping capability would have ultimately been received more enthusiastically by the forecaster and would have also been easier to install and maintain. This option would be more feasible if the national satellite data dissemination service did not grid its images (or at least gridded them accurately) and allowed the reception of visible and IR image pairs. The current GOES-TAP images are not set up for an interactive-video computer system with looping capabilities, and is not flexible enough for a firm who forecasts in varied geographical areas. These lessons should be heeded when future national forecasting systems are designed.

Regardless of the alternatives chosen, planners and proposers should not overlook the necessity of including input from the forecaster in the design of any satellite (or any other data) dissemination or processing system of the future. These are the people who will determine how much the benefits of the meteorological satellite will filter down to the wider public. If their needs are met, we can be confident that the considerable economic benefits of this data will be realized.

To conclude, meteorological satellite data produces a positive economic effect when included in forecasts; in certain situations, it is invaluable. It is the only data source in some vital weather producing regions, and its educational value is great. To be put to better use, however, it must be available to a wider variety of potential users in a more flexible, usable form.

10. Personnel

Over the four years of the program, the bulk of the scientific work was performed by Mr. Brian Auvine, Dr. Barry Hinton and Dr. David Suchman, who also served as program manager. Additional scientific contributions were made by Prof. Roger Miller of the economics department and Mr. David Floyd. Mr. Thomas O. Haig played a large role in early program planning.

The computer system construction was initially managed by Robert Norton, and later by Gary Banta who oversaw system maintenance. Hardware support was supplied by Chris Davis, Robert Oehlkers, Doyle Ford, Juris Afanasjevs, and Eldon Grindey; software was constructed by John Benson, Ralph Dedecker and Gary Chatters. Ruth Lieberman, Russell Dengel and Tim Browning helped compile the climatological statistics. Secretarial support was provided by Angela Crowell and the late Barbara Mueller.

References

Atlas, D., 1975: Selling atmospheric science. Bull. Amer. Meteor. Soc., 56, 688-689.

Barnett, C. V., 1973: Weather and the short-term forecasting of electricity demand. Weather Forecasting for Agriculture and Industry, A Symposium, edited by J. A. Taylor, pp. 209-223, Associated University Press, Univ. Coll. of Wales, Aberystwyth.

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.

Hussay, W. J., and E. L. Heacock, 1978: The economic benefits of environmental satellites; presented at the Fourth Annual Convention of the Eastern Economic Association, April 27, 1978, Washington, D.C., 32 pp.

Maunder, W. J., 1970: The Value of Weather. Methuen & Co. Ltd., London, England, 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.

Taylor, J. A., 1970: Weather Economics. Pergammon Press, Elmsford, N. Y., 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, Calif., 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 Bull., 18, 181-186.

ACKNOWLEDGMENTS

We greatly appreciate the cooperation of all the industries, utilities and governmental bodies that were contacted during this study. All of the personnel at Weather Services Corp. went out of their way to help us under very trying circumstances, especially James Serna, Robert Rice, Peter Leavitt, John Murphy and John Wallace. Parts of section 4 of this report were written by Gary Banta. Angela Crowell typed the manuscript.

LIST OF TABLES

LIST OF FIGURES

APPENDIX A: THE SELECTION PROCESS

i) Criteria for selection

ii) Information to be Obtained from Consulting Firm

iii) Interview Questionnaires

i) CRITERIA FOR SELECTION OF A CONSULTING FIRM

Essential

1. The firm should not be using real time satellite data in any significant way (though should have some knowledge about it) to date, although it should otherwise be a technologically advanced company (make full utilization of "conventional" data).

2. Firm's clients should be a large and stable group containing a mix of public, industrial, and agricultural users (e.g. agriculture, construction, commodity forecasts, municipal services, transport, recreation, utilities).

3. Firm's clients should be located preferably in a region near a meteorologically data sparse area (East Coast), or at least in a relatively meteorologically active region (Midwest).

4. The firm or its clients should have available records over a 5 year period detailing charges for services, use to which service was put, and ultimate outcome of use. In addition, there must be ready access from both consultant and clients of financial data for performing cost/effectiveness analysis.

5. The firm should be providing several types of services to its clients (e.g. short term forecasts, long term forecasts, emergency warnings, current weather data).

Preferable

6. The firm should preferably have at least one certified consulting meteorologist on its staff.

7. We prefer a firm that has internal quality control--ongoing evaluations of effectiveness of service, documented information on loss of accounts, etc.

Additional Criteria

8. It would be an asset if the firm provided the same service to more than one customer.

9. Firm's staff should be large enough to allow the availability of at least one liaison person who would be available to work with us when needed.

10. A large part of data processing and predicting should be done in-house.

11. Firm must be willing to pay the major portion of the cost of hardware to obtain this data.

ii) THE FOLLOWING INFORMATION SHOULD BE OBTAINED FROM THE CONSULTING FIRM

1. A list of clients who have received services for a year or more. This list should indicate the type of client (i.e. industrial, public, etc.) where this is not obvious, the length of time the firm has been a client, the type and frequency of forecast product(s) received, and the client's location. In addition, we should find out if the firm has a record of the accuracy of their services (outcome of the forecast) or whether such information would be available from the client. Would the various clients be amenable to giving out financial information as to the value of the forecast product to them (and whether this information exists) and the nature of the operation toward which the product was applied?

2. What type of internal quality control does the firm have in regard to effectiveness of service, documented information on the loss of accounts, etc.?

3. A description of the type of hardware being utilized by the firm, and their plans for future modification (NWS TTY circuits, fax machines, computers, software, etc.).

4. A description of their daily and weekly forecast operations. This could best be approached by considering the particular kinds of forecast products (e.g. emergency warnings, short term or long term forecasts) and describing how the firm goes about preparing this product--who does the forecasts and what information he relies upon. How do the forecasts differ from those produces by the NWS?

5. A detailed description of what is currently being done with satellite information (type of satellite information received and how this data is being included in the forecast). In addition, how much the forecasters know about it, how willing they would be to use it, and how much new training must be done.

6. An estimate of what sorts of satellite information, in what format and how frequent a reception of data would be most useful to the firm.

7. An estimate of what financial commitment the firm could make to rent or purchase such a system.

8. The number and professional expertise of the staff: we want to talk to as many staff members as possible; do they know about the program?

9. The name or designation of the person who would be the liaison with us in future work.

10. Why does the firm want to participate?

11. If possible, we would like to contact a few clients, get idea as to how cooperative they would be to participate, give financial data, talk, etc.

12. Accessibility of financial data from both clients and consulting firm.

iii) INTERVIEW QUESTIONNAIRE

STAFF ORGANIZATION AND PROCEDURES

1. Names of people on the staff, their duties and qualifications:

2. How many of these are part time? How many full time? How many hours are put in on an average working day?

3. What sort of professional contacts does the firm have with other meteorologists?

4. Who would be our liason person in the event we were to work with this firm? (Explain what we would expect from such a person).

5. Does the staff generally work alone or in pairs or in some other combination?

6. Pick out the names of two people on the staff and find out what their typical working day activities consist of (e.g. how many forecasts, what order of activities, what responsibilities).

7. Ask to see some typical operations in progress and summarize pertinent observations below:

(If possible, ask the observed staff the following questions)

a) What does the forecaster think of satellite data? Is it useful, and if so, how and when does he use it (be sure to ask when, in the process of forecasting, he decides to look at the satellite data)?

b) What would the forecaster do with an increased capability if he had it (describe the SSEC system).

8. Does the same forecaster always issue the same product? For how long? Are records kept for who does what?

QUALITY CONTROL

1. Does the firm archive its analyses and charts? How far back?

2. Is a record kept of the final product and the actual information conveyed to the client? How far back do these records go?

3. Does the firm keep a record of forecast accuracy or outcome?

4. Would the firm be willing to do any of the above for our records, if they are not doing so already?

5. Does the firm do any sort of quality control on a periodic or on-going basis (loss or gain in clients, effectiveness, speed, accuracy in various areas, etc.)? Describe the procedures used.

   a) Do you analyze these to improve service?

   b) Do you have specific procedures to review compliants by customers? How are they resolved?

6. Does the firm keep a record of fees charged to client which would be available for our inspection?

7. How are charges arrived at?--Flat rate? --Competitive market prices? --Time that goes into forecast?

8. If you invested in satellite data, would your fees change? How?

9. In what ways do clients benefit from your product? (ask it for clients we personally talk to)

10. How do you sell yourselves to a prospective client?

PRESENT AND FUTURE SATELLITE DATA USAGE

1. What satellite data is currently received?

    a) What form?

    b) How processed?

2. In what types of forecasts is it being used and how? For what clients?

3. How is satellite data incorporated into the forecast (beginning, middle, end)?

4. Is the firm currently anticipating any changes in the above procedures? If so, how? Would it try to gain satellite data anyway?

5. What is your knowledge of the types and uses of satellite data? What types of applications have you seen?

6. Does anyone in firm have experience with satellite data?

    a) Where?

    b) When?

    c) What application?

d) How does he feel about applications to your business?

7. Do you think satellite data would: produce better product? reduce cost? produce more salable product?

FORECAST OPERATIONS

TYPE OF FORECAST/FREQUENCY

NAMES OF STAFF WHO DO THIS

WHAT EQUIPMENT AND READY-MADE ANALYSES USED (i.e. fax charts)

WHAT IN-HOUSE ANALYSES PERFORMED

WHAT IS FINAL FORM OF SERVICE

HOW CONVEYED TO USER

HOURS SPENT IN PREPARATION

PEOPLE NEEDED IN PREPARATION

STEPS IN PREPARATION OF FORECAST

HOW DO FORECASTS DIFFER FROM/COMPARE WITH THOSE ISSUED BY THE NWS?

Daily and Weekly Forecast Operations (To be used as a guide--for each type of forecast)

1. Do you issue emergency warnings?

2. What are these?

3. Which clients receive each of the above?

4. Who is responsible for each?

5. What data are relied upon for each?

6. How or from whom are data obtained?

7. How are data processed or treated?

8. How is information assembled for forecast decisions?

9. Do you issue daily forecasts on regular basis?

10. Do you issue other regular short term forecasts?

11. Do you issue weekly forecasts regularly?

12. Do you issue longer range forecasts or outlooks?

HARDWARE DESCRIPTION GUIDE

This is best done by inspecting the equipment room itself and asking the use and function of each machine, what circuit it is wired to etc. Nevertheless a responsible person might be asked to list or recall the following:

(1) Teletypes

(2) Fax machines

(3) Radar Displays

(4) Your own private data sources (describe)

(5) Capabilities of the following:

computers

computer/calculators

plotters

software

(6) Do you use any advanced data storage and or display?

magnetic tapes

microfilm

CRT-terminal

(7) List any future modifications or additions to this equipment that are currently being planned.

(8) Assess the ease with which the hardware interface with our system.

GENERAL QUESTIONS

1. Why do you want to participate?

2. How much does your staff know about project?

3. What type of financial arrangement would you prefer for the hardware? Rental fee? Total monetary investment?

4. What type of turnover of forecasters do you have for a particular forecast product?

RATING OF SUBJECTIVE FACTORS

	Excellent	Good	Fair	Poor	Notes
1. Pleasantness of working conditions					
2. Congeniality of head of firm and liaison person					
3. Staff interrelationships (friendliness, frictions, etc.)					
4. Enthusiasm of firm for the proposal					
5. Efficiency of and enthusiasm for the work shown by the staff					
6. Potential adaptability for change					
7. Enthusiasm of staff for proposal					

What impressed you favorably about this visit?

What impressed you unfavorably about this visit?

How would you estimate the willingness of forecasters to use satellite data?

APPENDIX B: LETTERS OF AGREEMENT WITH WEATHER SERVICES CORPORATION

SPACE
SCIENCE AND
ENGINEERING
CENTER

1225 West Dayton Street
Madison, Wisconsin 53706

THE UNIVERSITY OF WISCONSIN

7 December 1976

Mr. John Wallace
Mr. Peter Leavitt
Weather Services Corporation
131 A Great Road
Bedford, MA 01730

Dear Mssrs. Wallace and Leavitt:

This letter is to confirm our intention of working with your firm in a study of the economic benefits of meteorological satellite data, a proposal that has been funded by NASA, and which we expect to continue for a period of four years, from September 1, 1976, to August 31, 1980. In the remainder of this letter we have noted our initial expectations in regard to the goals and methods of this program.

One facet of this study is to establish and document the current weather service you are supplying to your clients and to establish a quantitative measure of the value of that service. Toward this end, we will need a record of the forecast products that you have supplied to your selected clients and their verification.

We will develop, with input from your firm, and within program limitations, the facilities and techniques required to supply you with meteorological satellite data in a form most likely to increase the value of your service to your clients. We do not guarantee, however, that the data actually supplied to you will augment the value of your services. We will be responsible for all costs and manpower associated with the installation and maintenance of any project hardware and software.

After a suitable period we will establish a quantitative measure of the value of the augmented service, again using a record of your forecast products and their verification as well as other information.

As we do not wish to give your firm an undue competitive advantage over other firms through our involvement, we ask that you not refer to this study in any advertising or promotion to gain new clients, and that you not display products obtained directly from our data installation in any communications media during the period of this study. This prohibition should continue until the end of the study or 31 August 1980 whichever is earlier. In addition, we hope that you do not alter your fees as a result of the acquisition of our data during the course of this study. Of course, our involvement with Weather Services Corporation in no way constitutes an endorsement of your firm over other meteorological consulting firms.

We also understand that SSEC will not be involved or responsible in any way in the actual preparation or dissemination of individual forecast products to your clients. The decision to use any or all of the services we provide shall rest with you.

Finally, it is our intention to keep all records confidential which might affect the competitive position of your firm in relation to other firms, or which might affect the relationships between your clients and you. We will view all information obtained from either you or your clients in that light.

Whether or not you have any comments or additions to these points, we would appreciate receiving written acknowledgement of this letter. We look forward to working with you and expect that our cooperation will be fruitful and interesting for both of our organizations.

Sincerely yours,

David Suchman

David Suchman

DS/bm

WEATHER SERVICES CORPORATION
131A GREAT ROAD, BEDFORD, MASSACHUSETTS 01730 • TELEPHONE: (617) 275-8860

December 14, 1976

Mr. David Suchman
Space, Science and Engineering Center
1225 West Dayton Street
Madison, Wisconsin 53706

Dear David:

We were delighted to receive your letter of December 7, 1976, stating your intention of working with Weather Services Corporation in your study of the ecomomic benefits of meteorological satellite data.

We agree to all stipulations and limitations mentioned in your letter, and will strive our utmost to carry this experiment through to a successful conclusion.

Cordially yours,

John E. Wallace

John E. Wallace
President

JEW:ep

APPENDIX C: SNOW AND TEMPERATURE STATISTICS

Control Years: 1976-78

Experiment Years: 1979-80

SNOW STATISTICS (in inches)

Station	Years of Record	Annual Mean	Standard Deviation	Control Year Snow	Experiment Year Snow
Peabody, MA	8	52.7	17.0	78.8 (1.53$_\sigma$)	14.8 (2.23$_\sigma$)
Holyoke, MA	26	47.9	16.7	54 (0.37$_\sigma$)	13.0 (2.09$_\sigma$)
Walpole, MA	25	52.7	17.7	75.6 (1.29$_\sigma$)	15.2 (2.12$_\sigma$)
Bedford, MA	17	59.2	12.7	92.3 (2.60$_\sigma$)	15.7 (3.43$_\sigma$)
Raleigh, NC	32	7.0	5.7	7.1 (0.02$_\sigma$)	18.3 (1.98$_\sigma$)
Newark, NJ	34	27.7	16.1	45.0 (1.07$_\sigma$)	14.3 (0.83$_\sigma$)
Trenton, NJ	39	22.8	12.1	35.8 (1.07$_\sigma$)	18.8 (0.33$_\sigma$)
Wilmington, DE	28	19.5	12.3	31.7 (0.99$_\sigma$)	15.9 (0.29$_\sigma$)
Philadelphia, PA	33	20.5	11.2	36.8 (1.46$_\sigma$)	20.9 (0.04$_\sigma$)
Norfolk, VA	39	7.9	6.2	10.0 (0.33$_\sigma$)	41.9 (5.48$_\sigma$)
Pittsburg, PA	23	45.9	15.7	55.8 (0.63$_\sigma$)	24.1 (1.39$_\sigma$)
Baltimore, MD	26	21.5	13.6	22.7 (0.09$_\sigma$)	14.6 (0.51$_\sigma$)
Washington Nat'l	32	16.8	10.5	16.9 (0)	20.1 (0.31$_\sigma$)
Avoca, PA	21	50.0	16.8	65.0 (0.89$_\sigma$)	25.5 (1.45$_\sigma$)
Worcester, MA	20	72.7	17.4	80.2 (0.43$_\sigma$)	26.6 (2.65$_\sigma$)
Bridgeport, CT	28	27.4	13.3	40 (0.95$_\sigma$)	9.6 (1.34$_\sigma$)

Blue Hill, MA	39	63.5	23.3	87.6 (1.03_σ)	25.3 (2.42_σ)
Boston, MA	39	42.7	14.8	71.8 (1.97_σ)	12.7 (2.03_σ)
Hartford, CT	21	53.8	14.6	65.2 (0.78_σ)	16.4 (2.56_σ)
Richmond, VA	39	14.0	10.3	12.6 (0.14_σ)	38.6 (2.39_σ)
Charlotte, NC	35	5.8	5.6	4.5 (0.24_σ)	14.5 (1.55_σ)
Providence, RI	23	37.4	12.8	54.9 (1.37_σ)	12.2 (1.97_σ)
New York-JFK	17	24.3	13.7	35.6 (0.82_σ)	11.0 (0.97_σ)
New York-LaGuardia	32	25.6	14.2	32.8 (0.50_σ)	10.3 (1.08_σ)

Thirty-Year Temperature Means (1950-1979)

Station	J	F	M	A	M	J	J	A	S	O	N	D
Atlanta	43.4	45.8	52.5	61.7	69.7	76.4	78.2	78.2	72.7	62.8	51.6	44.5
Hartford	26.0	28.4	36.7	48.3	59.0	68.4	73.3	71.3	63.4	53.1	42.0	29.6
Bridgeport	29.5	30.8	37.9	48.3	58.4	68.0	73.6	72.4	65.4	55.4	44.6	33.3
Concord	20.5	22.9	32.0	44.0	55.1	64.9	69.7	59.5	48.9	37.6	24.9	24.9
Providence	29.1	30.5	37.8	48.1	58.0	67.5	73.1	71.7	64.0	54.2	43.9	32.7
Boston	29.2	30.5	37.7	47.9	58.0	67.8	73.3	71.9	64.5	55.1	44.8	33.2
Worcestor	23.5	25.6	33.4	45.1	55.9	65.2	70.2	68.4	60.7	51.1	39.8	27.8
Portland	21.6	23.5	31.8	42.7	52.7	62.3	68.2	66.9	58.8	49.0	38.5	26.0
Milton	26.0	27.3	34.5	45.3	55.7	64.8	70.4	68.9	61.5	52.1	41.4	29.7
Richmond	37.6	39.7	47.1	57.4	66.2	74.0	77.5	76.3	69.6	59.0	48.6	39.6
Norfolk	41.5	42.6	49.1	58.3	67.1	75.1	78.6	77.6	72.3	62.2	52.3	43.7
Trenton	32.2	33.8	41.1	51.9	62.0	71.2	75.8	74.2	67.0	56.8	46.1	35.5
NYC Central Pk	32.3	33.7	41.0	51.9	62.2	71.5	76.6	75.1	68.2	58.2	47.1	35.9
NYC Laguardia	32.6	33.7	40.9	51.6	61.6	71.4	76.6	75.2	68.6	58.5	47.5	36.2
NYC JFK	31.9	33.5	40.0	50.2	59.8	69.7	75.4	74.4	67.6	57.4	46.7	36.2
Albany	21.6	24.0	33.3	46.3	57.6	67.1	71.7	69.7	61.4	50.0	39.3	26.4
Syracuse	23.5	24.8	33.1	45.9	57.0	66.9	71.2	69.7	62.0	51.7	40.5	28.2
Buffalo	24.8	25.6	33.0	44.8	55.6	66.2	70.8	69.5	62.2	52.1	40.5	29.2
Philadelphia	32.4	34.1	41.7	52.6	62.9	72.0	76.6	74.9	68.0	57.2	46.1	35.6
Avoca	26.5	27.9	36.2	48.3	59.1	67.9	72.2	70.3	62.8	52.4	41.1	30.0
Allentown	28.0	29.9	38.1	49.6	60.1	69.4	73.9	72.0	64.5	53.8	42.5	31.4

Control Period Temperature Means and Deviance from 30-Year Mean (in Standard Deviations) (Sept 1976-Aug 1978)

Station		J	F	M	A	M	J	J	A	S	O	N	D
Atlanta	T	31.5	40.7	53.5	62.3	68.8	76.7	79.1	78.0	71.7	59.9	49.2	41.0
	#(σ)	-2.33	-1.15	1.87	0.26	-0.32	0.12	0.41	-0.11	0.44	-1.75	-0.85	-0.98
Hartford	T	21.2	24.9	39.0	49.6	61.8	68.6	73.2	71.4	63.3	51.0	41.3	26.5
	#(σ)	-1.00	-1.01	0.34	0.47	1.03	0.10	0.06	0.05	0.05	-0.74	-0.26	29.6
Bridgeport	T	25.3	27.6	38.8	48.0	58.6	65.8	72.9	74.6	66.6	55.3	48.9	31.7
	#(σ)	-1.08	-1.04	0.29	-0.11	0.08	-1.30	-0.41	1.1	0.55	-0.04	1.66	-0.48
Concord	T	14.0	17.1	32.4	42.9	57.9	64.1	69.4	68.4	57.9	46.0	35.6	18.5
	#(σ)	-1.44	-1.67	0.12	-1.14	0.88	-1.13	-0.07	0.72	-1.40	-0.95	1.03	-5.36
Providence	T	23.0	26.0	38.8	48.6	59.5	67.4	73.0	72.2	62.8	50.1	41.9	28.5
	#(σ)	-1.38	-1.41	0.29	0.18	0.60	0.05	-0.05	0.23	-0.48	-1.45	0.77	-1.11
Boston	T	25.9	29.0	40.4	50.1	60.9	67.9	73.5	72.5	64.7	53.9	45.0	31.6
	#(σ)	-0.83	-0.45	0.82	0.78	1.16	0.04	0.12	0.30	0.10	-0.48	0.08	-0.43
Worcester	T	18.6	22.5	34.9	44.1	59.4	63.4	68.8	68.4	59.3	47.8	37.9	24.0
	#(σ)	-1.02	-0.93	0.38	-0.34	0.52	-0.90	-0.78	0.0	-0.64	-1.14	0.03	-0.99
Portland	T	17.9	20.1	33.2	41.5	53.2	60.0	68.1	67.6	57.5	45.8	37.8	22.4
	#(σ)	-0.84	-0.94	0.45	-0.56	0.23	-1.26	NA	0.28	-0.62	-1.28	-0.30	-0.84
Milton	T	21.1	25.0	37.3	40.3	58.1	64.7	71.0	70.4	61.3	49.6	40.3	26.7
	#(σ)	-1.14	-0.69	+0.82	o.36	0.96	-o.05	0.35	0.71	-0.10	-0.92	-0.39	-0.81
Richmond	T	29.7	5.4	49.2	59.2	66.9	73.9	79.5	80.0	71.4	55.8	47.6	38.2
	#(σ)	-1.61	-1.18	0.49	0.69	0.29	-0.05	1.25	2.32	0.75	-1.07	-0.42	-0.42
Norfolk	T	33.1	39.1	50.1	59.6	66.9	74.2	73.5	80.8	73.7	59.2	50.3	42.5
	#(σ)	-1.65	-1.50	0.25	0.52	-0.09	-0.41	0.63	2.00	0.54	1.08	-0.77	-0.30
Trenton	T	25.1	30.4	43.6	52.5	62.6	70.6	75.2	75.4	67.5	53.4	44.3	32.5
	#(σ)	-1.61	-1.06	0.69	0.21	0.25	-0.33	-0.40	0.70	0.22	-1.22	-0.69	-0.27
NYC Central Pk	T	24.1	30.3	42.9	52.6	63.3	70.8	76.7	75.9	66.4	53.9	44.5	32.8
	#(σ)	-1.67	-1.19	0.52	0.26	0.41	-0.35	0.06	0.40	NA	-1.54	-1.04	-0.93
NYC LaGuardia	T	25.6	30.1	42.1	51.4	61.9	69.7	75.5	75.1	67.4	54.7	45.2	33.2
	#(σ)	1.79	-1.08	0.38	-0.08	0.11	-0.81	-0.60	-0.06	-0.57	-1.41	-0.81	-0.84
NYC JFK	T	25.6	29.5	41.2	50.8	60.6	69.1	74.8	75.4	66.2	53.3	44.0	32.3
	#(σ)	-1.75	-1.26	0.43	0.25	0.29	-0.35	-0.36	0.55	-0.56	-1.71	-1.03	-1.05
Albany	T	18.5	21.3	35.5	45.1	59.3	64.5	70.3	68.5	60.3	48.2	38.8	29.1
	#(σ)	-0.60	-0.76	1.51	-0.36	0.57	-1.30	NA	-0.50	NA	-0.90	-0.17	-0.61

Station		J	F	M	A	M	J	J	A	S	O	N	D
Syracuse	T	18.5	26.4	34.8	45.1	59.3	63.8	71.8	69.5	61.1	48.7	42.2	25.2
	#(σ)	-1.04	0.43	0.39	-0.25	-0.74	-1.48	0.29	-0.08	-0.34	-1.04	0.59	-0.77
Philadelphia	T	24.0	29.2	43.9	54.0	63.6	70.6	76.7	77.7	68.7	53.4	43.1	31.4
	#(σ)	-1.83	-1.37	0.61	0.48	0.27	-0.84	0.06	1.40	0.32	-1.22	-1.30	-1.08
Buffalo	T	17.1	19.7	39.0	45.7	58.9	64.8	71.2	69.2	61.4	46.7	38.8	25.0
	#(σ)	-1.67	-1.71	1.36	0.27	1.07	0.64	0.21	-0.12	-0.32	-1.60	-0.59	-0.30
Avoca	T	19.7	23.1	36.8	47.5	59.4	64.5	70.3	69.9	61.9	48.3	40.1	26.3
	#(σ)	-1.34	-1.24	0.14	-0.25	0.10	-1.54	-0.95	-0.19	-0.36	-1.31	-0.34	-0.93
Allentown	T	21.7	26.5	41.0	51.5	62.4	69.8	79.0	73.2	54.1	51.7	40.9	28.6
	#(σ)	-1.40	-1.47	0.81	0.66	0.69	0.20	0.06	0.60	0.26	-0.71	-1.30	-0.78

Experimental Period Temperature Means and Deviance from 30-Year Mean (in Standard Deviations) (May 1979-March 1980)

Station		J	F	M	A	M	J	J	A	S	O	N	D
Atlanta	T	44.9	41.9	52.1		70.1	75.7	78.3	80.1	72.9	62.4	54.3	46.7
	#(σ)	0.29	-0.88	-0.10		0.14	-0.28	0.27	1.10	0.00	-0.14	0.96	0.08
Hartford	T	27.6	24.3	35.2		64.1	69.0	74.6	60.8	61.6	50.7	45.5	33.6
	#(σ)	0.33	-1.18	-0.39		1.88	0.29	0.72	-0.23	-0.87	-0.85	0.37	1.00
Bridgeport	T	31.7	28.1	37.0		61.7	55.5	73.8	72.8	54.8	53.2	47.3	37.9
	#(σ)	0.57	-0.88	-0.29		1.27	0.82	0.12	0.20	-0.27	-0.82	1.04	1.38
Concord	T	22.4	19.1	31.8		56.3	63.8	71.2	67.5	59.8	49.4	42.2	29.4
	#(σ)	0.42	-1.09	-0.06		0.32	0.18	0.34	-0.09	0.26	-0.49	1.58	1.13
Providence	T	29.7	26.8	37.1		60.3	65.1	73.5	70.2	69.0	53.0	48.3	37.3
	#(σ)	0.14	-1.16	-0.20		0.92	-1.14	0.21	-0.68	0.50	-0.42	1.69	1.21
Boston	T	29.4	27.9	36.9		61.1	68.2	74.5	71.7	54.9	52.7	48.6	36.7
	#(σ)	0.05	-0.78	-0.24		1.24	0.17	0.71	-0.10	0.20	-0.96	1.46	0.95
Worcester	T	25.0	22.2	33.1		57.7	63.6	71.2	67.7	60.0	49.0	44.3	31.9
	#(σ)	0.31	-1.02	-0.08		0.62	-1.80	0.56	-0.31	0.32	-0.72	1.45	1.10
Portland	T	22.7	20.5	32.0		55.3	62.7	59.3	64.8	57.4	47.5	42.4	29.8
	#(σ)	0.25	-0.96	0.06		1.18	0.22	NA	-0.84	-0.66	-0.60	1.69	0.89
Milton	T	25.5	24.5	34.8		58.9	64.4	72.9	68.8	62.0	50.8	46.7	34.2
	#(σ)	0.14	-0.84	0.09		1.28	-0.19	1.48	-0.05	-0.25	-0.48	1.89	1.22
Richmond	T	38.8	36.0	47.4		56.1	70.8	76.9	77.8	71.0	58.3	53.3	42.3
	#(σ)	0.24	-1.02	0.07		0.37	1.54	-0.38	1.56	0.58	-0.23	1.96	0.81
Norfolk	T	40.3	39.7	46.5		66.7	70.4	77.1	78.5	72.8	60.4	56.4	44.9
	#(σ)	-0.24	-2.15	-0.65		-0.17	-2.15	-0.94	0.56	0.23	-0.64	1.57	0.30
Trenton	T	32.9	30.3	40.6		63.1	68.5	74.5	74.5	67.4	59.8	50.8	39.4
	#(σ)	-0.16	-1.09	-0.14		0.46	-1.49	-0.87	0.17	0.17	-0.72	1.80	1.07
NYC Central Pk	T	33.7	31.8	41.2		65.3	69.2	76.9	76.8	70.5	57.3	52.5	41.1
	#(σ)	0.33	-0.81	0.06		1.15	1.15	-0.18	0.85	NA	-0.32	2.16	1.56
NYC LaGuardia	T	32.7	30.7	40.2		65.0	68.9	77.1	75.5	68.2	56.0	50.2	39.0
	#(σ)	0.03	-0.90	-0.22		0.52	-1.19	0.27	0.19	-0.19	-0.43	0.94	0.78
NYC JFK	T	32.2	29.2	38.4		62.8	66.9	74.7	73.6	67.1	54.9	48.3	38.1
	#(σ)	0.08	-1.35	-0.57		1.10	-1.64	-0.42	-0.44	-0.20	-1.04	0.61	0.51
Albany	T	24.1	14.8	33.3		60.0	66.0	72.5	67.0	61.2	50.2	44.1	31.4
	#(σ)	0.49	-1.18	0.00		0.80	0.55	NA	-0.30	NA	-0.20	1.66	1.33
Syracuse	T	25.6	14.8	32.4		58.6	66.0	71.7	67.9	61.4	50.9	44.5	33.4
	#(σ)	0.44	-1.33	-0.16		0.51	-0.43	0.24	-0.69	-0.23	-0.28	1.38	1.33

Buffalo	T	25.8	21.2	31.8		56.9	66.5	71.3	67.5	61.9	50.7	43.5	33.4
	#(σ)	0.22	-1.28	-0.27		0.42	0.14	0.26	-0.83	-0.12	-0.41	1.21	1.07
Philadelphia	T	31.8	24.7	40.2		66.4	69.1	76.2	75.5	68.5	54.9	50.1	38.2
	#(σ)	-0.13	-1.23	-0.42		1.35	-1.53	-0.24	0.30	0.23	-0.74	1.73	0.67
Aroca	T	27.8	24.2	35.9		58.6	65.1	70.7	70.7	53.2	51.8	45.9	35.6
	#(σ)	0.26	-0.96	-0.07		-0.16	-1.27	-0.75	-0.19	0.16	-0.19	1.63	1.4
Allentown	T	30.7	27.3	38.6		62.1	68.0	73.2	72.8	65.3	52.5	47.8	36.2
	#(σ)	0.60	-0.75	0.14		0.69	-0.70	-0.41	-0.40	0.34	-0.44	2.03	1.34

Climatology for Gas and Electric Utility Clients

Electric Client*		1976(April-Sept)	1977(April-Sept)	1978(April-Sept)
A	$\Delta\bar{T}_{MAX}$	-0.4	-1.7	-1.8
	#($\sigma_{\Delta\bar{T}}$)	0.13	-0.27	-0.25
B	$\Delta\bar{T}_{MAX}$	0.3	-1.2	-0.5
	#($\sigma_{\Delta\bar{T}}$)	0.06	0.30	0.11
		(May-Sept)	(May-Sept)	(May-Sept)
C	$\Delta\bar{T}_{MAX}$	0.00	-0.9	-0.7
	#($\sigma_{\Delta\bar{T}}$)	0.05	0.31	0.02

Gas Client		1976-77(Nov-Feb)	1977-78(Nov-Feb)	1978-79(Nov-Feb)
A	$\Delta\bar{T}$	-5.5	-3.1	-1.0
	#($\sigma_{\Delta\bar{T}}$)	-1.44	-0.65	-0.13
B	$\Delta\bar{T}$	-4.9	-2.8	+1.1
	#($\sigma_{\Delta\bar{T}}$)	-1.37	-0.77	+0.41
C	$\Delta\bar{T}$	-4.0	-1.1	+1.5
	#($\sigma_{\Delta\bar{T}}$)	-1.10	-0.25	0.44
D	$\Delta\bar{T}$	-5.5	-3.1	-1.0
	#($\sigma_{\Delta\bar{T}}$)	-1.44	-0.65	-0.13
E	$\Delta\bar{T}$	-5.1	-2.5	1.2
	#($\sigma_{\Delta\bar{T}}$)	-0.97	-0.49	0.50

* $\Delta\bar{T}_{MAX}$ = Departure of maximum temperature mean from 30 year mean

#($\sigma_{\Delta\bar{T}}$) = Number of standard deviations that average temperature departs from 30 year mean

APPENDIX D: SAMPLE SNOW AND ICE QUESTIONNAIRE

FIRM: Street Department

The following are a list of general questions that we will use to try and assess the economic impact of the snow/ice forecasts you receive from Weather Services Corp. They are not intended to cover every possible situation, but if any major part of your operation is neglected by these questions, please indicate.

1. How much does it cost you (per hour) in snow/ice clearing operations for the followi

   a) salaries - Regular time for snow plowing based on a crew size of 41 men. $225 per hr. If the work was done on overtime, the cost would be increased to $340 per hr. If there was no plowing and work consisted merely of sand and salting, the cost would be approximately 20% of these figures.

   b) equipment: sanding - $10 per hr. per sander. The Village generally uses 4 sanders. Therefore, our cost would be $40 per hr.

   salting - $12 per hr. per salter. The Village generally uses 2 salt trucks. Therefore, our cost would be $24 per hour.

   plowing - $20 per hr. per truck. The Village generally uses 15 trucks. Therefore, our cost would be $300 per hr.

   c) materials (e.g. sand, salt)

   Salt - $22 per hr. using 2 trucks.

   Sand - $ 6 per hr. using 4 trucks.

2. What are your costs to mobilize your equipment for

   a) sanding - The sanding equipment is placed on our trucks at the beginning of the season and not taken off until the season is over. Therefore, there is no mobilization cost for each individual storm.

b) salting - The salting equipment is placed on our trucks at the beginning of the season and not taken off until the season is over. Therefore, there is no mobilization cost for each individual storm.

c) plowing - $90 per storm for mounting plows, if done during the regular work day.

Demobilize? - Approximately $50 to remove plows.

3. Are these costs (#1 or #2) affected by the amount and type of snow forecast? Please be specific.

The cost per hour for plowing snow would not be affected by the type or amount of snow. A large snowfall would naturally extend the number of hours that we would have to plow.

4. Are these costs (#1 or #2) affected by the time of day or day of the week? In what way? (Please be specific)

The only effect the time of day or the day of the week has on cost is on the overtime pay for our workers. Any snow removal done before 7 A.M. or after 4 P.M. on a weekday, or on weekends or holidays, would be paid at an overtime rate of 1.5% of regular pay.

5. Under what conditions do you <u>mobilize</u> for

   a) sanding - **Equipment on trucks during the entire season.**

   b) salting - **Equipment on trucks during entire season.**

   c) plowing - **Prediction of 3 or more inches of snow.**

6. When during the course of a storm do your crews actually do

   a) sanding - **We usually sand and salt during the very beginning of a storm and after plowing has been completed.**

   b) salting - **same as a)**

   c) plowing - **When there is 3 inches of snow on the ground and it appears that the storm will continue, we generally start to plow.**

7. Are your costs affected by the amount of snow received aside from having to keep your equipment in operation longer? How? (e.g. call in outside crews, call in backup crews, add more equipment)

   Under very severe conditions, we might attempt to hire outside equipment, but this has not been done in the last 5 or 6 years.

8. If a storm strikes earlier than forecast (or if it were not forecast) what additional costs do you incur? (per hour)

None.

9. If a storm strikes later than forecast (or is of less intensity than forecast) what additional costs do you incur? (per hour)

If the storm is less intense than forecast, we may be stuck with a larger work force than actually needed. For example, we might only call in a crew of approximately 10 for salting and sanding; whereas, a full scale plowing operation encompasses approximately 40 people. Therefore, the additional cost per hour could be in the order of $150 to $250 per hour.

NAME OF RESPONDENT:

DATE: January 25, 1977

FIRM: Street Department

1. **Number of Lane Miles of Road.**

148 miles plus 65 acres of municipal lots. Three lots (about 10 acres) are given high priority because they serve basis needs of the city.

2. **What was your total 1975-76 snow-ice budget?**

1974-75
1974-75

3. **What other services do you receive from WSC?**

Hurricane warnings. The forecast was used to get together a crew with front loaders to keep streets clear of limbs during the storm.

4. **How often do you mobilize unnecessarily?**

This happens occasionally. For example, with 4" on the ground and snow predicted to continue, crews were called in at 3 AM to have street clear by rush hour, but now stopped at 4 AM .
30 menXfour hoursXtime and one-halfX$5.50/hr = $990 lost.

5. **How long does it take you to mobilize?**

One hour or less. Plows are mounted if the forecast warrants during the normal work day (i.e. if forecast calls for snow during 'overtime hours'. Actual trigger for calling men in is police report of conditions for sanding and salting. Plowable accumulation initiates plowing. There is a tendency to leave plows on unless a period of good weather is definitely forecast.

6. **In what ways would you save money through an improved forecast?**

Savings in labor costs, especially in overtime (see question 4).

APPENDIX E: SAMPLE SNOW FORECASTS

Forecast A

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

OPERATIONAL WEATHER FORECAST

Multiple Listing Dec. 28 815 A

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 occnly moderate	20	NNE 10-15		2-4" ~~5-6~~
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 Ending	17	NW 15	30	
17	✓	3AM-6AM	P Cloudy	15		35	
18		6AM-9AM					
19		9AM-NOON					
20	✓	NOON-3PM	Turn to P Cldy	20		35	
21		3PM-6PM					
22		6PM-9PM					
23	✓	9PM-MID.	Fair	12		30	
24		REMARKS					

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

25	✓	REMARKS

P Cloudy Max 17
Min 10

01-

ORIGINAL PAGE IS
OF POOR QUALITY

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

OPERATIONAL WE[illegible]R FORECAST
Multiple Listing

Dec. 28 130

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- dofy	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	Bcmg 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 Ocnl S-	19	N5-10		T
15		REMARKS:					

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

		TOMORROW	GENERAL WEATHER	• TEMP.	WINDS	GUSTS	
16	✓	1AM-3AM	Ocnl 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	Bcmg Ocnl flurries	22	NW15	30	
23	✓	9PM-MID.	Bcmg P.C.	19	NW15	35	
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	
7		1AM-3AM					
8		3AM-6AM					
9		6AM-9AM					added
10	✓	9AM-NOON	S early Melt	22	N10-15		1-3
11		NOON-3PM					
12	✓	3PM-6PM	Bcmg Intmt S	22	N15		5-7
13	✓	6PM-9PM	Clearing ovnt 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	Clearing, few flurries	18	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, lows 5°

25		REMARKS:	P.C 18/5

OK

ORIGINAL PAGE IS
OF POOR QUALITY

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. SSW'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 6		Tot
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/K. 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.	Incr 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	= [illegible]	16	SE 5-10		T-<1
18	✓	6AM-9AM	= -	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[illegible] afternoon/midnight with about 40% 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 Intermittent S-	17	S-SW 5		½-¾"
10		9AM-NOON					
11	✓	NOON-3PM	M Cloudy few flurries	26	SW-SE 8		1" or le
12		3PM-6PM					
13	✓	6PM-9PM	Cloudy	25	SE-E 6		
14	✓	9PM-MID	Snow [illegible]	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-IP- 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 - pc	26	NW 14	18	
24		REMARKS	• Temperatures relate to the last hour of the 3-hour Forecast Period				

25 ☐ REMARKS Sun

pc to fair
Max 26-31 Wind NW 10-16

ORIGINAL PAGE IS
OF POOR QUALITY

WEATHER SERVICES CORPORATION
GREAT ROAD BEDFORD, MASSACHUSETTS 01730

OPERATIONAL WEATHER FORECAST
Multiple Listing

Jan. 14 130

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 flurries	25	SE 5-10		
12		3PM 6PM					
13	✓	6PM 9PM	Snow develop	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	✓	MID 3AM	S, overnight	28	NE 10-15		5-6"
17		3AM 6AM					
18	✓	6AM 9AM	S tapering off	29	NNE 15	25	6-8"
19	✓	9AM NOON	Becoming 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

Vbl Cloud

20/10

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

OPERATIONAL WEATHER FORECAST
Multiple Listing

Jan 14: 1015P

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, early intermit	18	N10	20	7-9
19	✓	9AM NOON	S ending	21	|	|	
20	✓	NOON 3PM	Becmg 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

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 F [illegible]N. 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.

ORIGINAL PAGE IS
OF POOR QUALITY

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 5-6 PM AND OCCASIONALALLY 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 MON 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 10-25 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 10-25 MPH, GUSTY TO 45 MPH DURING THE DAY, DIMINISHING SLOWLY AT NITE.

C-3

APPENDIX F: SAMPLE ELECTRIC UTILITY QUESTIONNAIRE

FIRM: Electric Utility

This questionnaire is designed to help us assess the economic impact of the weather forecasts that you receive from Weather Services Corporation on your company. The questions were designed along the lines of your responses to our last short questionnaire. Although all the questions may not pertain to your operations or may not be in the format you use, please answer all relevant questions in the best way you know how. Thank you.

General Questions:

1. How many households do you supply with electric power?

2. How many square miles do you service?

3. What is your client mix (based on power delivered)?

Residential 37.3 %

Commercial 27.6 %

Industrial 25.7 %

Other (Please describe) 9.4 %

4a) What is your maximum peak load?

3,844 MW

b) What fraction of peak load is normal load?

Load factor is approximately 0.6

5. What net fraction of the power that you distribute is purchased from another source? (exclusive of very short term exchanges)

Approximately 10% (1975 data)

6. Do you sell power to others? -- What net fraction of your normal production? (exclusive of very short term exchanges)_______________

Yes

Maintenance (when applicable)

1a) What sorts of weather events cause you to cancel *routine* maintenance or new construction?

Rain, snow etc. and cold weather of $10^{o}F$ or below.

For the following questions, also consider outside contractors if appropriate:

b) What is the minimum advance warning time necessary before such a cancellation that will minimize monetary loss?

On normal working days during scheduled working hours there is no penalty. At all other times, a twenty hour advance cancellation is required to avoid penalty.

c) What is a representative cost to you (in wages, equipment deployment) for failure to cancel in time?

Wages of $15/man plus fringe benefits. Number of men would depend on particular job. Equipment not normally deployed in advance.

d) Suppose that you cancel routine maintenance or construction unnecessarily due to the weather forecast. Do you incur any expenses which would have been avoided had the forecast proven correct? If so, how much?

No extra expense incurred if 20 hour advance notification given.

2a) What sorts of weather events cause you to call up extra crews or hold over crews to do *special emergency repair work* due to damage to the system?

Severe winds, gusting winds - branches and trees cause problems.
Lightning - fuse blowing etc.
Icing conditions - branch and tree problems. Sagging conductors etc.
Heavy rain - branches and trees - washing conditions that cause trees to lean or fall.

b) How far in advance of the occurrence of such a *forecast* event do you engage such crews? (Please include dependence of time of day, or day of week when appropriate.)

Forecasts are tempered by much judgement. Most weather emergencies are handled by local crews and by relocating system crews.

A hurricane, i.e., forecast to pass through the state, rather than on the fringes, would most likely require outside assistance. Additional outside crews would be requested from 4 to 6 hours prior to the predicted storm arrival.

Weekends would require greater advance notice as crew personnel are dispersed widely and require greater time to contact them for assembly.

c) What is the loss to you (in wages, cost of equipment deployment) per hour to engage most or all of your emergency manpower for a storm which is later than forecast or which never materializes at all?

Using premium rates, the cost of one three man line crew including wages, fringes, vehicle, room, meals etc. would be in the vicinity of $75 -$100/hour. This would be the cost of obtaining outside crews in advance. The number of crews requested would depend on an assessment of the path and severity of the forecasted storm; i.e., the last hurricane resulted in an initial request for 50 outside crews.

d) **If you fail to engage crews in time to handle emergency work when it is first needed due to a surprise storm, for instance, do you incur extra costs? If so, how much?**

- Failure to engage outside crews on time results in a slower restoration of service.

The penalties resulting are: criticism from public and governmental groups, loss of local crews for a longer period due to restoration activities and loss of revenue when service facilities are not in operation.

Load Forecasting (when applicable)

Summer

1. How far in advance do you use weather forecasts?

12 hours.

2. Is there a *minimum* lead time *after which* a weather forecast update is not useful? What is it?

Approximately 4 hours.

3a) What combination of weather and load conditions would require extra generators to be brought on-line beyond the spinning reserve, or the purchase of extra power from another source?

Severe storm alerts, i.e., hurricanes, ice storms. We will anticipate transmission line outages, tidal effects on seashore plants, etc.. Units will be brought on line as security measures for localized areas.

b) How much of a delay is there between the need for and start of extra power production beyond that available from the spinning reserve?

1. Jet units - 2 minutes
2. Gas turbines - 15 minutes
3. Steam - 2-6 hours after brief shutdown
   - 6-12 hours for cold unit

4. **Would additional personnel be required to maintain the extra power production capacity? How many people? What would be their average wage rate? What is the minimum number of hours for which they would have to be paid?**

It does not appear that there is a wage penalty here. There would always be enough personnel in the plant to get a unit on the line.

If additional personnel were required to operate the unit, they would be called in. Extra personnel would always be called in, as required, to meet the increased load no matter what the reason.

5. How much does a 1° change in wet bulb temperature affect your MW load in typical summer temperature ranges?

Not available.

6a) Is there a critical condition (temp, humidity, solar radiation) above which the *accuracy of the forecast* becomes crucial? How?

Temperature - variations of 10° F. or more from forecasts.
Humidity - at summer temperatures of approximately 75° F and an increase of humidity above 60% initiates critical conditions.
Solar radiation - generally has no wind influence and does not produce sustained load increase

b) In what way is this critical accuracy dependent upon the lead time of the forecast (12, 24, 36 hrs)?

12 hours or less.

7. How could a better forecast save you money in a peak load situation?

Peaking units or hydro would be used to shave sharp peaks if weather forecasts would specify temperatures and time of occurrence. This would eliminate the conservative attitude of scheduling units to cover possible longer periods of extreme temperature exposure.

8. How do rapid changes in cloud cover affect your load?

Approximately 2 to 6%

9. Do changes in cloud cover ever cause your load requirements to increase to the point where additional power generation capacity is necessary?

Yes.

Winter

1. Do you use weather forecasts as an aid for load forecasting in the winter?

   Yes.

2. How do the winter weather forecast formats differ from the summer formats?

   Formats are similar.

3. Do you experience "peak-load" problems in the winter? Under what circumstances?

   No.

COMMENTS: For information contact

NAME OF RESPONDE [redacted]

DATE March 10, 1977

APPENDIX G: SAMPLE GAS UTILITY QUESTIONNAIRE

FIRM: Gas Utility

This questionnaire is designed to help us assess the economic impact of the weather forecasts that you receive from Weather Services Corporation on your company. The questions were designed along the lines of your responses to our last short questionnaire. Although all the questions may not pertain to your operations or may not be in the format you use, please answer all relevant questions in the best way you know how. Thank you.

General Questions:

1. How many households do you supply with gas for space heating?

2. How many square miles do you service?

3. What is your client mix (based on cubic feet of gas distributed)?

Residential 39.4 %　　Commercial 18.7 %

Industrial 39.9 %　　Other (Please describe) 2.0 %

4. What is your average annual cumulative quantity (ACQ) of gas distributed?

5. What is your maximum daily quantity (MDQ) of gas distributed?

Maintenance (when applicable)

1a) What sorts of weather events cause you to cancel *routine* maintenance or new construction?

Snow
Extreme Cold

For the following questions, also consider outside contractors if appropriate:

b) What is the minimum advance warning time necessary before such a cancellation that will minimize monetary loss?

Two Hours

c) What is a representative cost to you (in wages, equipment deployment) for failure to cancel in time?

Indeterminate

d) Suppose that you cancel routine maintenance or construction unnecessarily due to the weather forecast. Do you incur any expenses which would have been avoided had the forecast proven correct? If so, how much?

None

2a) What sorts of weather events cause you to call up extra crews or hold over crews to do *special emergency repair work* due to damage to the system?

(1) 4" of snow accumulation
(2) Temperatures below 21°F average

b) How far in advance of the occurrence of such a *forecast* event do you engage such crews? (Please include dependence of time of day, or day of week when appropriate.)

Implement plan based on 7:30 a. m. forecast and 3:30 p. m. forecast.

c) What is the loss to you (in wages, cost of equipment deployment) per hour to engage most or all of your emergency manpower for a storm which is later than forecast or which never materializes at all?

Indeterminate

d) If you fail to engage crews in time to handle emergency work when it is first needed due to a surprise storm, for instance, do you incur extra costs? If so, how much?

Yes - Indeterminate

Load Forecasting (when applicable)

1. How far in advance do you use weather forecasts?

30 days

2. Is there a *minimum* lead time after which a weather forecast update is not useful? What is it?

Yes - Two Hours

3. How much does a change in Effective Heating Degree Day (per degree) affect your load in typical winter temperature ranges?

1,000 - 1,500 MCF per each DDD

4a) Is there a critical condition (low temperature, high wind velocities, etc.) where the accuracy of the Effective Heating Degree Day forecast becomes more crucial to your operations? Please be specific.

Critical temperature = 10°F (Avg.)

Critical wind velocity = 7 to 8 MPH

b) In what way is this critical accuracy dependent upon the lead time of the forecast (24, 48, 72 hrs)?

24 Hours

5a) At what point does an unexpected load become so large that you are forced to buy gas from another source?

At 55 DDD

b) What is the (additional) cost incurred per cu. ft.?

$5.00/MCF

c) How could you have saved money by an accurate forecast? *Please be specific.*

Could have curtailed and issued conservation requests.

6a) Suppose that the forecast mistakenly leads you to prepare for a load greater than that which you actually need. What additional cost do you incur, which would not have been present had the forecast been correct?

Additional cost may run as high as \$2.00 - \$3.00 p r MCF

b) How great an error has to be made in load forecasting for these costs to be incurred?

Average of 2° - 3° F

7a) At what point (if any) does an unexpected load become so large that you are forced to call up additional manpower?

At 55 DDD

b) What is the additional cost to you to do this over what your costs would have been had you *known in advance* what the exact load would be?

\$2.00 to \$3.00 per MCF

8. If the weather forecast compelled you to erroneously shut off (or not cut off) gas to an interruptible customer, are you hurt financially? In what way? Please be specific.

All gas under contract is on a take-or-pay proposition. If we cannot dump excess gas on interruptible customer once contracted for, we lose abaut $1.00 per MCF for all gas we are stuck with.

9. Do you use Weather Services for summer forecasting? Does this forecast format differ from winter forecasts?

Do not use weather service in summer

COMMENTS:

NAME OF

DATE March 9, 1977

APPENDIX H: SAMPLE FUEL OIL QUESTIONNAIRE

FIRM: FUEL OIL CO.

This questionnaire is designed to help us assess the economic impact of the weather forecasts you receive from Weather Services Corporation on your company. The questions were designed along the lines of your responses to our last short questionnaire. Although all the questions may not pertain to your operations or may not be in the format you use, please answer all relevant questions in the best way you know how. Thank you.

General Questions:

1. How many households do you supply with fuel oil for heating?

CONFIDENTIAL

2. What is your client mix (based on gallons of fuel oil delivered)?

Residential	90 %	Commercial	10 %
Industrial	— %	Other (please describe)	— %

3. What is your annual quantity of fuel oil distributed for 1976-1977?

10,000,000 gal

4. During the heating season how many drivers are normally engaged in keeping customers supplied? 16

How many employees/truck? 11 TRUCKS PER DAY 6 DAYS/WK

About how many deliveries does each driver make per day? 30

5. On the average how many hours per week does each driver normally spend delivering fuel oil to customers?

WINTER SEASON 48-50

SUMMER SEASON 40

6. How many total miles do your trucks drive per week?

1800 - 2000 MI/WK

7a. What is your average hourly wage paid to drivers?

CONFIDENTIAL

b. What is your hourly <u>overtime</u> rate paid to drivers?

TIME & A HALF

c. Is there a minimum number of hours guaranteed to drivers called up for overtime duty?

NORMALLY 10 HOURS EXCEPT EMERGENCY CALL WITH A 6 HOUR GUARANTEE

<u>Questions Relating to Degree Day Forecasts</u>:

1a. What is your <u>optimum</u> fuel oil drop per household?

200 GAL.

b. What is your <u>average</u> fuel oil drop per household?

185 - 190

2. How many days reserve of fuel do you aim to keep in a customer's tank just before refill?

4 - 5 DAYS.

3. Has any household that you service ever run out of fuel oil due to a bad weather forecast? In such an instance, what penalties did you incur?

No.

4. In planning to meet your optimum fuel oil drop per household, how do the following enter into your planning:

a. Cumulative degree days since the last drop

THIS IS THE MAIN. METHOD OF PREDICTING

b. Forecast degree days

Please explain.

WE USE THE FORCASTED DEGREE DAYS TO ESTIMATE THE NUMBER OF DELVS TO BE MADE & THE NUMBER OF TRUCKS & MANPOWER

5a. How far in advance do you set up your delivery schedule?

BASIC ROUTES 2 DAYS.

b. What would cause you to modify this present schedule?

WILL CALL ACCTS OR PREDICTED BAD WEATHER

c. What is the minimum forecast lead time that would affect your planning?

1 DAY

6. By how many degree days must a forecast be inaccurate before it costs you money? (degrees 10 DEGREE DAYS. FOR EXTENDED PERIOD between the inaccuracy of the forecast and monetary loss? If so, what is it?

POSSIBLE RUN OUT

7. Do you ever schedule (a) overtime for drivers presently on shift or (b) call up additional drivers because of a predicted number of 'degree days?' If you can, please give a recent example.

IF WEATHER IS PREDICTED TO BE COLD FOR EXTENDED PERIOD WE WILL SCHEDULE DRIVERS ON OVERTIME TO KEEP AHEAD OF THE ACCUM. DEGREE DAYS.

If the prediction proved to be incorrect, how might it cost you money?

BY SCHEDULING DRIVERS ON OVERTIME VS REGULAR TIME.

Emergency Storm Warnings

1a. Do you step up your delivery rate because of a forecast of light snow (less than 4")? If you can, please give a recent example.

No.

If such a prediction proved to be incorrect, how might the accelerated deliveries (which were not necessary) have cost you money?

In overtime wages ______________

Maintenance and materials ______________

1b. Do you step up your delivery rate because of a forecast of heavy snow (over 4")? If you can, please give a recent example.

YES. WE SCHEDULE TRUCKS ON OVER-TIME BASIS SO WE CAN PULL AHEAD

If such a prediction proved to be incorrect, how might the accelerated deliveries (which were not necessary) have cost you money?

In overtime wages ______4________

Maintenance and materials ______________

2. Has it recently happened that an unforecast storm, or one which arrived early, interfered with deliveries? How did it cost you money? Please be specific.

No - Forecasting is presently accurate.

3. How far in advance do you have to receive an emergency storm forecast [as in question (1)] in order to alter your delivery schedule?

4 DAYS.

We appreciate your cooperation. It sometimes happens that key information is not covered adequately by the questions, so please add anything you might think helpful to understand the impact of weather and weather forecasts on your business.

COMMENTS:

C

NAME OF RESPONDENT

DATE 4/11/77

APPENDIX I: SOME ECONOMIC EFFECTS OF PRIVATE METEOROLOGICAL FORECASTING

SOME ECONOMIC EFFECTS OF PRIVATE METEOROLOGICAL FORECASTING

David Suchman
Brian A. Auvine
Barry H. Hinton

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

June 1979

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
RANGE	MAX.	64	24	12	37.5%	$108,000	$853,000
	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
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

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)	Mi^2 Serviced	Critical Pt (DD)	Tolerance	Total Loss due to forecasts
A	22	7	15	$2500	144,000	1025	28	3°	$122,500
B	12	4	8	$7000	260,000	1703	50	2°	$175,000
C	25	12	13	$8750	206,000	666	52	1°	$336,875
D	7	2	5	$1540	52,328	314	50	2°	$30,800
E	1	1	0	$1995	36,000	150	55	2°	$1,995
F	1	1	0	$3125	91,878	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.

Acknowledgements

Data analysis was performed by David Floyd and Tim Browning, the manuscript was reviewed by Thomas O. Haig and Rosemary Stachel 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 Space Administration under contract NAS5-23706.

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

Forecast

	Temp.	Effective Degree Days
7:00 AM	15°	57
12:00 Noon	16	55
9:00 PM	19	53

Actual: 20°; 53 DD.

City F

Forecast

	Temp.	Effective Degree Days
7:00 AM	17°	55
12:00 Noon	18°	54
9:00 PM	22°	50

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, 105 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.

APPENDIX J:

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

ORIGINAL PAGE IS OF POOR QUALITY

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 [illegible], October 14, 1977 image with a [illegible] mb 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, 1978. The scale of the map and analysis are the same as for figures 4 & 5.

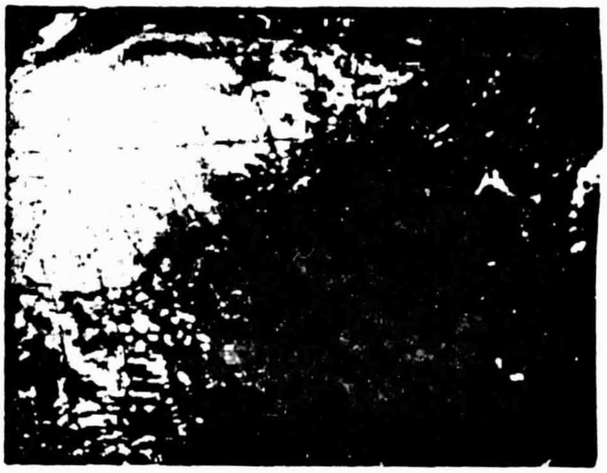


Figure 7. GOES visible satellite picture for 2000Z, May 20, 1977. Surface streamlines and a map for the Texas, Oklahoma, and Arkansas area are overlaid. Resolution is 8 to 1 reduced.

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

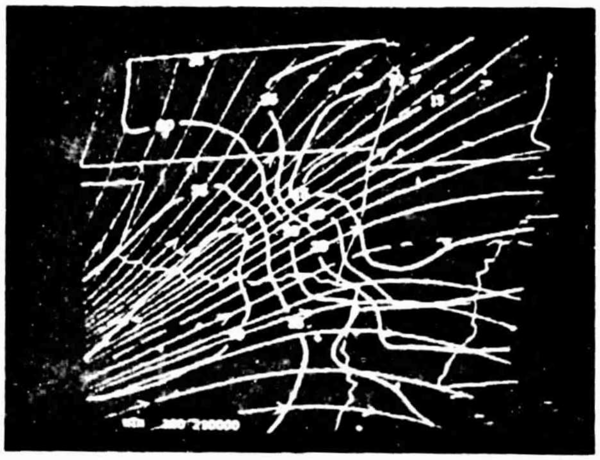


Figure 9. Map on same scale as figure 7 with 0000Z, May 21, 1977 300 mb streamlines and isotachs.

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.