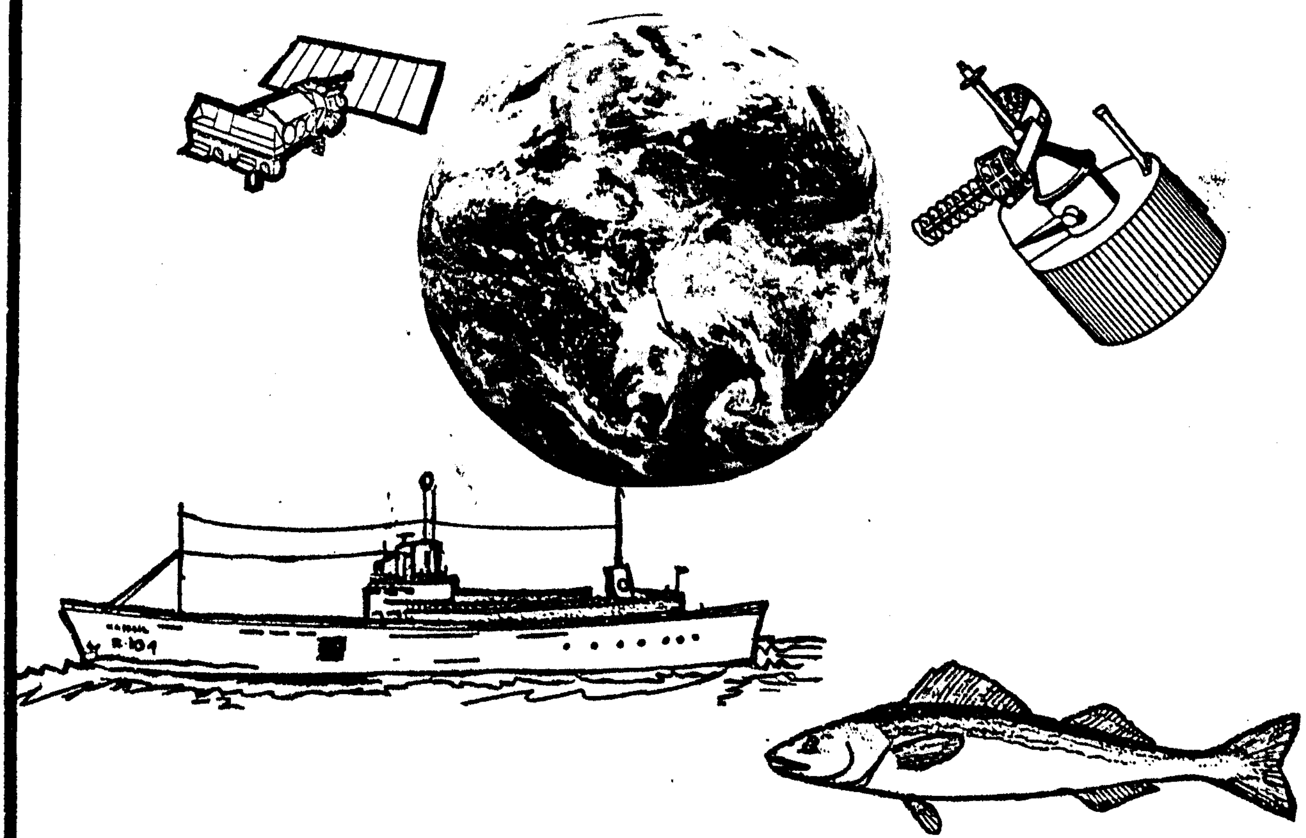
THE ECONOMIC BENEFITS OF OPERATIONAL ENVIRONMENTAL SATELLITES



by

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Abstract

Satellite observations of the atmosphere on a global scale began 23 years ago. In the intervening period, satellite sensors and operational techniques for the use of the data has evolved to a high degree of proficiency. This paper identifies and attempts to quantify, to the extent possible, many of the current benefits and uses being derived from the United States' Operational Environmental Satellite System.

The initial paper on this subject was published by W. John Hussey and E. L. Heacock in April 1978 and presented at the Fourth Annual Convention of the Eastern Economic Association in Washington, D.C. Subsequently, there has been considerable interest in the evolving benefits of environmental satellites and the primary benefits discussed in the 1978 paper have been updated and included in this paper. In addition, many other unique uses of environmental satellite data are discussed in this paper.

The benefits discussed herein are evidence that the operational environmental satellite has earned its place as an irreplaceable weather and ocean observing tool. These satellites are making major contributions towards the saving of lives and property from natural disasters and improving the efficiency of many sectors of our national economy.

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National Oceanic and Atmospheric Administration
TIROS Satellites and Satellite Meteorology

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1. Operational Environmental Satellite Program Mission Objectives

The Nation's operational environmental satellites are operated by the National Oceanic and Atmospheric Administration's (NOAA) National Environmental, Satellite, Data, and Information Service (NESDIS). The mission objectives of this operational satellite program include:

I. Monitoring the atmosphere regularly and reliably on a global basis, day and night, with direct readout to local ground stations around the globe within radio range of the satellites.

II. Sounding the atmosphere regularly on a global basis and providing quantitative data for numerical weather prediction services.

III. Continuous monitoring of environmental features in the western hemisphere, and the collection and relay of environmental data from remote platforms such as buoys, ships, automatic stations, aircraft, and balloons.

IV. Applying environmental satellite data for the purpose of improving environmental services.

2. Geostationary Satellite System

NOAA's Geostationary Operational Environmental Satellite (GOES) system includes two satellites, the ground data acquisition station, and a centralized data distribution system. The first satellite in this system, NASA's Synchronous Meteorological Satellite (SMS-1), a prototype for GOES, was launched May 17, 1974. The latest in the SMS/GOES series, GOES-5, is the seventh operational geostationary spacecraft to be operated by NESDIS. The next GOES satellite, GOES-F, is scheduled to be launched from Cape Canaveral in April 1983. Two additional GOES spacecraft are being built by the Hughes Aircraft Company. These have been designated GOES G and H and are scheduled to be launched in 1986. The next generation geostationary environmental spacecraft called GOES NEXT is in the preliminary planning stages. It is scheduled to be available for launch in mid-1989 to ensure continuity of geostationary coverage. The GOES NEXT series is planned to cover a 12 year period beginning in 1989.

The operational system consists of two satellites; GOES West located over the equator at 135^{o} West longitude and GOES East located at 75^{o} West longitude. GOES West observes North America and the Pacific Ocean to west of Hawaii and GOES East observes North and South America and most of the Atlantic Ocean. These geostationary spacecraft are in circular orbits at an altitude of approximately 35,800 km. (22,240 miles).

The primary instrument carried by GOES satellites is called the Visible Infrared Spin-Scan Radiometer (VISSR) Atmospheric Sounder (VAS). This instrument, first carried into space on GOES-4, provides the traditional visual and infrared imagery of cloud cover and the earth's surface. In addition, VAS provides measurement of infrared radiation which can be used, with known atmospheric properties, to calculate atmospheric temperature profiles over selected geographic areas. It can also produce images in multiple IR spectral bands instead of the single band produced by the VISSR. This new capability is called multispectral imaging and has proven very useful in depicting the amount, distribution and movement of water vapor at various levels.

The VAS provides a full disc view of the earth every 30 minutes. More frequent images can be obtained at the sacrifice of spatial coverage. The visible channel provides high resolution (about 1 km) daytime images. The infrared channel provides lower resolution (about 8 km) day and night images. The GOES images are processed through the NESDIS Central Data Distribution Facility, either as a full disc image or a sector of this full disc image. These products are routed to Satellite Field Services Stations (SFSS) for analysis with further routing to National Weather Service Forecast Offices and other users.

The SFSS's are located at Washington, D.C.; Miami, Florida; Kansas City, Missouri; San Francisco, California; Honolulu, Hawaii; Anchorage, Alaska and Slidell, Louisiana. Each SFSS provides regional analysis, interpretation, and distribution of the VAS images to meet a wide variety of environmental needs. A most important service is the near-continuous viewing of the development and movement of severe weather systems such as hurricanes and thunderstorms. An extension of the GOES image distribution service is the "GOES-TAP" system. Established by NESDIS in 1975, "GOES-TAP" allows Federal, state, and local agencies, television stations, universities, and private industry to receive an inventory of GOES satellite images directly from the nearest SFSS. In addition, the GOES satellites broadcast environmental products to remote locations using the Weather Facsimile (WEFAX) System.

The GOES satellites also carry a Data Collection System (DCS) which collects and relays environmental data obtained by remotely located sensing platforms such as river and rain gauges, seismometers, tide gauges, buoys, ships, aircraft, and automatic weather stations. Each operational GOES spacecraft can accommodate data from more than 10,000 platforms each six hours. Data are normally transmitted in a self-timed mode or upon interrogation by the satellite. Data may also be transmitted under emergency conditions in which the platform transmitter is triggered whenever an observed parameter exceeds a predetermined threshold value. About 3,600 + platforms now provide environmental data to users in the United

States and Canada. The geostationary satellite DCS provides a near-instantaneous source of information for many applications such as river level and flood monitoring and forest-fire index measurements.

Also included in the GOES instrument complement is a Space Environment Monitor (SEM) which provides measurements of solar activity for detecting solar flares, the intensity of the solar wind, and the strength and direction of the earth's magnetic field. The SEM data which is included in the satellite telemetry data stream is received at the NOAA Space Environment Services Center (SESC) in Boulder, Colorado. These data are separated out of the telemetry stream and processed in the SESC data base. When significant solar events are detected, the SESC issues warnings to a number of users throughout the United States. Routine forecasts of solar activity and its implications such as interference with high frequency radio transmissions, are also distributed by SESC.

3. Polar Orbiting Satellite System

NOAA's operational polar orbiting satellite system is called the TIROS-N/NOAA series and consists of two satellites and the ground data acquisition and processing systems. The first spacecraft in this series called TIROS-N was launched on October 13, 1978. There are two polar orbiting satellites currently in operation providing global coverage at different times of the day. NOAA-6 is in a morning orbit (0734 local equator-crossing time descending) and NOAA-7 is in an afternoon orbit (1453 local equator-crossing time ascending). These satellites are in sun-synchronous orbits at altitudes of 808 km and 847 km, respectively. The orbital period is 102 min. which equates to 14.2 orbits per day.

The next TIROS-N/NOAA satellite, NOAA-E, is scheduled to be launched from Vandenberg AFB, California in March 1983. Three additional NOAA spacecraft are being built by RCA Astro-Electronics These have been designated NOAA F, G, and D and are scheduled to be launched in 1984, 1985, and 1986/87 respectively. Three other polar orbiting spacecraft, NOAA H, I, and J are in the planning stages.

The TIROS-N/NOAA series utilizes four primary instrument subsystems. These are:

1. Advanced Very High Resolution Radiometer (AVHRR)
2. TIROS Operational Vertical Sounder (TOVS)
3. Data Collection System (DCS)
4. Space Environment Monitor (SEM)

The AVHRR provides visible and IR image data for real-time transmission to direct readout users and for storage on the spacraft tape recorders for later playback. The AVHRR consists of five channels which provide data on daytime cloud cover, snow and ice coverage, nighttime cloud cover and sea surface temperatures. The direct readout High Resolution Picture Transmission (HRPT) has a resolution of 1 km in all spectral channels. The Automatic Picture Transmission (APT) provides an undistorted resolution of 4 km. There are over 800 APT receiving stations and 76 HRPT receiving stations located in approximately 123 countries throughout the world.

Also available is on-board recording of the 4 km resolution data which provides Global Area Coverage (GAC). Selected on-board recording of the 1 km resolution data is available as Local Area Coverage (LAC). The recorded data is played back to the NOAA Command and Data Acquisition (CDA) stations located near Fairbanks, Alaska and Wallops, Virginia. The data are subsequently transmitted via a domestic communications satellite to the NOAA central data processing facility in Suitland, Maryland.

The TIROS Operational Vertical Sounder (TOVS) includes three complementary sounding instruments. These are:

1. High Resolution Infrared Radiation Sounder (HIRS/2)
2. Stratospheric Sounding Unit (SSU)
3. Microwave Sounding Unit (MSU)

The HIRS/2 provides data which permits calculation of temperature profiles from the surface to 0.1 mb ($\sim$215,000 ft.), the water vapor content of the atmosphere and the total ozone content. Data from the TOVS instruments are also broadcast via the direct readout transmission links. The SSU instrument is provided by the United Kingdom.

The Data Collection System (DCS) is provided by France. It is called the ARGOS Data Collection and Platform Location System. The ARGOS system provides a means to locate and collect data from moving platforms. The platform data are stored and relayed to the Suitland center where it is separated and relayed to the CNES Toulouse Space Center in France. There, the data are processed, earth located and relayed to the ultimate user.

The TIROS Space Environment Monitor (SEM) includes three detectors which measure solar proton flux, alpha particle and electron flux density, energy spectrum and total particulate energy distribution at spacecraft altitude. The data from the SEM are stripped out of the spacecraft telemetry stream and transmitted to NOAA's Space Environment Services Center (SESC) in Boulder, Colorado. These data are used to monitor the state of solar activity which has a significant effect on terrestrial communications, electrical power distribution, etc.

II. Activities Benefiting From Operational Environmental Satellite Programs

Following is a synopsis of several specific examples of the economic benefits and also intangible benefits, such as lives saved, which are derived directly from operational environmental satellite data or from a combination of satellite and "conventional" weather data. It should be recognized that many of these benefits are possible because of the operational nature of the environmental satellites. In other words, users can depend on the availability of these data today, tomorrow, and in future years. Therefore, users can afford to invest in special data handling and processing equipment, software, and techniques with confidence that these satellites will be available to provide the data they require year after year.

1. Ocean Current Navigation for Fuel Savings

Use of the swift Gulf Stream currents to increase northbound steaming speed is an old idea, but utilizing that idea has not been easy. The swiftness and great variability of the Gulf Stream position creates many uncertainties and hazards to navigation. Much of the uncertainty is created by eddies and meandering of the Stream. Meanders can be 250 miles across and the stream axis can move as much as 60 miles in a week.

A 1975 Gulf Stream Navigation Experiment conducted jointly by the EXXON Company and the National Oceanic and Atmospheric Administration (NOAA) showed that significant fuel savings can be realized by using timely satellite analyses of the Gulf Stream position for oil tankers navigating along the eastern seaboard. An improved NOAA satellite capability, operationally available with the launch of NOAA-2 in 1972, was infrared measurement of sea-surface temperatures. Enhanced infrared images representing sea-surface temperature differences clearly delineated the warm Gulf Stream in contrast to the colder shelf water. The joint EXXON/NOAA experiment was conducted to test whether using satellite-derived Gulf Stream analyses could improve navigation enough to realize significant fuel savings. NOAA analyzed the satellite infrared images of the Gulf Stream's western boundary called the "Western Wall"; and estimated the axis of maximum current velocities relative to the Western Wall. EXXON arranged for radio broadcast of the information to their tankers at sea.

Eleven EXXON tankers, steaming from the Gulf of Mexico to east coast ports and returning, participated in the experiment. Five were instructed to follow the usual navigational practices, which used or avoided the Gulf Stream in a relatively random manner. The other six were to use the NOAA satellite analyses for their navigation. In other words, the tankers were to transit within the Gulf Stream northward and avoid the Gulf Stream on their southbound journey.

The seven month study showed a very definite fuel savings for the six vessels using the NOAA data. EXXON, assuming a total of 15 tankers navigating by satellite data, projected savings amounting to 31,500 barrels of fuel oil. Using a 1975 cost of $11.50 per barrel, the EXXON study reported a potential annual fuel savings of around $360,000 for their company alone. Assuming a 1982 cost of $30.00 for a barrel of fuel oil, the estimated annual savings would be around $945,000 for 15 tankers navigating the Gulf Stream effectively. Use of satellite derived Gulf Stream position data is now standard navigating procedure for all ships of the EXXON fleet. Applications of this information by all coastal traffic of the U.S. merchant marine is possible and could result in significant savings of U.S. fuel resources. The analyses are made available by automatic telecopier and radio broadcasts.

A similar product is available for Gulf of Mexico navigation. A clockwise flow of warm water from the Yucatan Straits, around the Gulf, and out through the Florida Straits is quite strong. The coastward edge of the warm water in this "Loop Current" is marked by a thermal gradient which is great enough in the cold winter months to be discerned in the satellite infrared imagery. The NOAA Miami Satellite Field Services Station produces a Loop Current Bulletin (November to May) which aids ships in the Gulf of Mexico to use the Loop Current for assistance in a manner similar to the use of the Gulf Stream described above. These analyses are also available by automatic telecopier.

The Crowley Towing and Transportation Company of Jacksonville, Florida operates 60 vessels in the West Indies and Gulf of Mexico and has stated that accurate knowledge of the Gulf Stream and Loop Currents is vital to their operations. An on-going fuel conservation program has been enhanced by this satellite information with fuel savings of 20-40% obtainable when their 9000 Hp tugs are able to reduce engine rpm by 18%, with only small reduction in speed. They are experiencing up to $2000 per steaming day savings on their line haul tugs. Other Crowley barge sailings returning north from Cuba via the Santaren Channel utilizing the Gulf Stream to the utmost, are improving their average speed from 9.5 to 12.0 knots which on a bi-weekly basis saves 8 hours per voyage. This totals 192 hours per year or 8 days per year at an average equipment operating cost of $15,000 per day.

2. Commercial Fishing Industry

The NOAA Satellite Field Services Station at San Francisco has produced charts derived primarily from the polar orbiting satellites' Very High Resolution Radiometer (VHRR) infrared imagery depicting the location of thermal boundaries or "fronts" as part of an operational sea surface temperature analysis. It has been well documented by marine biologists and fishermen that certain species of fish are temperature-sensitive. Albacore (blue fin tuna) and coho (silver) salmon, the principal commercial fish found along the west coast, tend to congregate in nutrient rich waters in the vicinity of thermal fronts. Albacore are found in temperatures ranging from 16°C - 20°C, while salmon prefer temperatures of 11°C - 13°C.

Since 1975, the National Environmental Satellite, Data, and Information Service (NESDIS) has been issuing Sea Surface Temperature (SST) Frontal Charts from the SFSS in San Francisco to aid fishermen in locating these "productive" areas. In 1981 the SFSS began producing a sea-surface thermal analysis incorporating satellite-observed thermal features. Geographically, the area originally covered by the charts extended from 34°N to 49°N and from the coast to 128°W. Since 1981, only one area has been charted and that extends from 28°N to 40°N and west to 136°W. It is known that the food chain is often concentrated along these fronts, usually as a result of the seasonal upwelling process that takes place along the west coast of the United States. Charts produced when skies are cloud-free, have greatly assisted commercial albacore and salmon fishermen in locating fish productive areas. Results were so encouraging that the program was expanded to cover most of the West Coast.

The IR images, received up to four times daily, are enhanced using computerized tables to assist in the identification of the thermal gradients. The changes in temperature are represented by changes in the tones of gray in the enhanced satellite image. The frontal postions are analyzed directly on the image and then transferred to a marine navigational base chart. These analyses are produced twice a week. The latest chart is transmitted twice daily by radio facsimile from Point Reyes, California, and by automatic telephone telecopier.

Satellite images are also transmitted twice per day to the Seattle Ocean Services Unit of the National Weather Service. This unit produces a satellite derived thermal boundary and sea surface temperature analysis extending from 40°N to 52°N which is distributed to Pacific Northwest fishermen via a telecopier system, mailing list, and direct telephone briefings.

An example of how the fishing community has received this product is indicated in a quote from the Summary of Pacific Input to the Eastland Fisheries Survey prepared by the Pacific Marine Fisheries Commission as their input to the nationwide Eastland Fisheries Survey, a report to Congress dated May 1977. This report states (underscore added):

> "Commercial salmon and albacore trollers emphasized that the federal government should not be involved in developing new equipment and methods for locating fish with one exception. They support the use of satellite pictures which display temperature gradients and indicate that the federal government should continue to use existing satellites to provide this information. Present methods for developing and providing advisories are adequate and existing advisories for the albacore fleet should continue. More emphasis should be placed on provision of practical information such as water temperature, weather, and currents...."

The commercial fishermen are beset with a number of problems which include changing and more stringent regulations and increasing fuel costs. By delineating those areas which are often fish-productive through the use of infrared satellite imagery, a fisheries management tool is available whereby commercial fishing can become more efficient and thus more cost effective. Fishermen can disperse over larger areas when productive frontal locations are known thus helping to avoid overfishing small areas.

During the initial experiment in 1975, it was estimated that approximately 200 salmon and albacore fishing vessels were able to save $580,000 in fuel costs as a result of using satellite data. The albacore fishery has the most direct benefit from the satellite data since they are very temperature oriented. The salmon industry benefits to a lesser extent. Mr. Fred Jurick formerly of the NOAA Sea Grant Program, Marine Advisory-Extension Service at Humbolt State University in Arcata, California was a pioneer in the use of satellite data to directly support fishermen. Mr. Jurick correlated catches of albacore and salmon ranging from $2,000 to $14,000 directly to the use of the satellite derived thermal front charts. One commercial salmon troller stated that he caught an extra $10,000 to $12,000 of fish (which was about one-third of his total seasonal catch) as a direct result of using the thermal front charts.

If one uses the figures provided by the National Marine Fisheries Service, and places a modest savings of 10% on the fuel bill for each of 1000 fishing vessels in operation off the West Coast, the annual fuel savings for the fleet is $440,000. If one then adds a "catch advantage" of $2000 worth of fish per vessel (approximately 2 ton of albacore) due to time saved and improved location of the fish, one has an annual benefit of $2,440,000 to the fishing industry on the West Coast. This figure is conservative since there are more than 1000 vessels fishing off the West Coast.

In Alaska, the weekly Sea Surface Temperature (SST) charts are distributed by the Anchorage Satellite Field Services Station to approximately 200 users of which 65% are commercial fishermen/processors, 15% are Federal and state agencies, 10% are oil industry and 10% are research organizations. These SST charts provide guidance to commercial fishermen and fisheries researchers concerning the expected arrival of commercial species to Alaskan waters: herring (SST 4°C); red salmon (SST 7°C) in Bristol Bay; silver salmon (SST 11-13°C) in Southeast Alaska; and pink salmon (SST 11°C) near Kodiak Island thus saving travel time, labor and fuel costs. This information is being used for local fish inventory and migration studies and fish harvest forecasting.

NOAA sea surface temperature and ice condition charts derived from polar-orbiting satellite data have saved an Alaskan herring processing plant an estimated $7000-$8000 per day in wages and fuel costs. Using these data, the company determines where it should send its floating processing plant for herring runs. Multiplied by 8-10 processors over a month's time, the savings are subtantial. Commercial fishing for silver salmon around southeast Alaska has also been enhanced by the location of the 11°C isotherm. Catch increased from 50 to 200 salmon a day; again trolling costs (fuel, equipment and time) are significantly reduced.

Other Alaskan users are the king crab fishermen in the southern Bering Sea and Bristol Bay. In 1980, the king crab fishermen lost more than $3 million in crab pots due to untimely ice formation. These fishermen now use the satellite derived ice charts to determine when to retrieve their pots prior to ice formation.

On the East Coast, the swordfish is one of the few temperature-sensitive fish in the Atlantic. Swordfish prefer areas with temperatures ranging from 13° to 25°C. The East Coast fishermen supplement satellite derived data with information on water depth and the migration routes of the swordfish. The president of the Swordfishermens' Association stated: "Receiving these charts has resulted in a tremendous savings of time. We used to spend up to five days looking for the fish, and now we can go right to the place where the fish are located. When you figure that most boats will use from 20 to 50 gallons of fuel an hour, you can recognize the savings involved. There are about 500 vessels in the swordfish fishing fleet."

For completeness and comparative purposes, the dollar value of all pelagic and benthic fish species caught in the major fishing regions within U.S. waters in 1981 are shown in the following table. Note that 62% of the dollar value of these species were caught in Alaskan and Californian waters. It is interesting to note that satellite data support to the fishing industry is utilized to a greater extent in Alaska and California than in any other major U.S. fishing area.

Value of All Pelagic and Benthic Fish Species Caught in 1981

	Dollar Value	Percent
Alaska	$ 639,797,000	43
California	275,196,000	19
Maine	196,854,000	13
Louisiana	193,549,000	13
Texas	174,787,000	12
	$1,480,183,000	100

Internationally, NOAA satellite-derived sea surface temperature data are used to aid commercial tuna fishing by the Portugese near the Azores and by a consortium of New Zealand companies and the Star-Kist Tuna Company fishing around northern New Zealand.

3. Agriculture Industry

A. Gèneral

A study published in 1973 by the Space Science and Engineering Center of the University of Wisconsin showed that improved weather information and forecasting could provide large economic benefits to the agriculture industry. The purpose of the study was to determine the value of improved weather information and weather forecasting to farmers and agricultural processing industries in the United States. The study, funded by NASA, was undertaken to identify the production and processing operations that could be improved with accurate and timely information on changing weather patterns. Estimates were then made of the potential savings that could be realized with accurate information about the prevailing weather and short term fore-casts for up to 12 hours. Improved weather information was defined to mean that a satellite observation not more than one hour old was available and was the basis for a current weather description and an accurate 12-hour forecast.

The growing, marketing, and processing operations of the twenty most valuable crops in the United States in 1971 were studied to determine those operations that are sensitive to short-term weather forecasting. Agricultural extension specialists, research scientists, growers, and representatives of processing industries were consulted. Statistics from the U.S.D.A. Crop Reporting Board show that the value for farm crops produced in the United States was more than 26 billion dollars in 1971. The total value for crops surveyed in this report exceeds 24 billion dollars and represents more than 92 percent of total U.S. crop value.

A detailed study was made of the operations in the production and processing of vegetable crops to obtain precise estimates of the value of improved weather information. Vegetable processing industries of the North Central Region (Wisconsin and Minnesota) were contacted through the Wisconsin Canners and Freezers Association and a special weathercasting subcommittee was established. Meetings were held with industry personnel representing six large processors in these states to determine aspects of their operations that could be improved with more precise weather information and to develop procedures for estimating the value of this information. The company representatives utilized their field and processing plant records to determine losses resulting from unfavorable weather and to provide estimates of the savings that could have been realized with accurate short-term weather information. The entire agricultural process was considered in the survey from soil preparation and pesticide spraying operations to the harvesting of crops and the delivery of field products to consumers or food processors.

This survey of agricultural crops has indicated that improved weather information would have saved crop growers and processors $74,000,000 in 1971. Short-term forecasts from satellite data are of particular value for crops which yield perishable products and which require very precise production practices in order to insure marketability. The annual weather related loss in agriculture in the U.S. is estimated to be $12 billion. It is estimated that protectable losses through improved 3-5 day weather forecasts average about $5 billion per year. Regional agricultural advisories issued by the National Weather Service (NWS) are responsible for saving approximately $400 million per year in the NWS Western Region alone. These regional savings include:

- Raisin crop drying - harvest vs. cover - California
  ($800 million/year potential loss)

- Water removal from ripe cherries using helicopters
  ($124 million/year protectable loss)

- Grape harvest - Monterey County, California
  ($79 million/year bonus)

- Frost protection - Arizona
  ($500/acre savings)

- Planting impact in Washington State
  ($70 million/year savings)

- Weed and pest control - cost to re-spray due to rain washoff
  ($8-$10/acre)

In 1980, specially enhanced AVHRR data were used in a novel way to solve an agricultural problem in California. A local bee breeder, with the intention of relocating and expanding his operations, asked the San Francisco SFSS for help in determining the warmest daytime areas during the months of January through March. Warmer daytime temperatures increase bee activity. TIROS-N/NOAA-6 AVHRR IR images over the three-month period were enhanced to accentuate afternoon ground temperatures. Persistent warm areas were then located in the desirable counties, and these data were superimposed on maps detailing favorable bee habitats. Once an optimum correlation was made, the bee breeder contacted the land owners for possible rental space for the beehives.

B. Citrus Industry

When frost is expected in Florida on cold winter nights, the NOAA Satellite Field Services Station (SFSS) in Miami, Florida, provides specially enhanced GOES infrared images and interpretations to the National Weather Service which has responsibility for fruit frost forecasting. This capability was first successfully demonstrated in January 1976 and became an operational program during the winter of 1976-1977.

The enhanced satellite images show surface temperatures which are critical to freeze predictions. These ground temperatures, derived from images taken every 30 minutes over the entire southern citrus belt, are accurate within $\pm$ 1°C. Thus, the movement southward of the cold winter air and associated "freeze line" can be monitored and tracked every half hour. The Weather Service provides the observations and forecasted movement of the cold air to the citrus growers as soon as it is available.

The Florida citrus grower must decide whether or not to protect his crop upon receiving a forecast for temperatures below about 28°F. These protective actions usually include the firing of diesel heaters and/or the use of electrically operated wind machines. The grower must decide when to call in work crews, when to activate heaters and/or wind machines and how many heaters must be used. All of these decisions affect their operating costs and losses incurred from inadequate protection.

Protecting citrus groves is a very expensive operation, and needless heating can produce an exorbitant waste of fuel. There are approximately 750,000 citrus-bearing acres in Florida. On "cold" nights, an average of 6 hours of heating protection is needed at a cost of approximately $830,000 per hour for fuel. This amounts to a potential $5,000,000 cost per night for the state of Florida if smudge pots and other frost prevention devices are operated because of expected temperatures near the freezing mark. The cost to have labor on duty waiting for specific satellite aided fruit frost warnings before lighting smudge pots and operating frost prevention devices is about 42¢ per acre or $315,000 per hour. Thus, the net potential savings for timely and accurate satellite freeze line forecasting is $515,000 per hour.

It is estimated that 1 to 2 hours of heating protection per "cold" night could be saved as a result of the use of the frequent satellite imagery. Assuming a reduction of 1½ hours average heating protection, the savings could amount to $770,000 per cold night. During the winter of 1976-77, a total of 64 cold nights were experienced. During the winter of 1977-78, 54 cold nights were experienced in the state of Florida. The average number of cold nights in Florida each winter is 35 to 40. The enhanced satellite images are used routinely to observe the movement of the "freeze line" to warn citrus growers via NOAA Weather Radio and a telephone communications network via county agricultural agents. The satellite enables a greater amount of temperature information to be acquired more frequently and passed on to the citrus growers in a timely manner.

The NOAA Satellite Field Services Station (SFSS) at San Francisco prepares a daily satellite image interpretation narrative tailored to the needs of the National Weather Service (NWS) fruit frost forecasters. Frost sensitive agricultural products grown in California amount to $3.7 billion per year. Advisory committees have estimated that the frost forecasts provided by the NWS are responsible for saving between 5 and 20 percent. The fruit frost forecasters have estimated that the satellite contribution to this savings of harvests would be between 0.5 and 1.0 percent, or between $15 and $40 million annually.

C. <u>Hawaii Sugar Cane Industry</u>

The harvesting of sugar cane is a process which is very dependent upon local weather conditions and benefits greatly from satellite derived forecasts. The Waialua Sugar Company on the island of Oahu has been using satellite imagery provided by the NOAA Satellite Field Services Station in Honolulu, Hawaii, to plan their harvesting schedule.

When a cane field is ready for harvest (about 2 years after planting), it is first deliberately set on fire and burned; the remains are then gathered and hauled to the mill. Weather is an important factor in this complex operation. Convection and trade wind showers are the main weather hazards to the harvesting process. Burning must abide by State and Federal air pollution regulations. Tactical procedures for burning a particular field depend heavily on wind direction and speed. After burning, the remains must be harvested within 24-36 hours to avoid spoilage. Any significant rainfall during this critical period interferes with the movement of heavy harvesting vehicles in and out of the field. Typically, 50 to 100 acres are burned at one time, leaving burnt cane worth $250,000 lying in the field at the mercy of the weather.

The production manager of the Waialua Sugar Company, who is responsible for making the daily harvesting decisions, has said, "I look at the weather maps and listen to what they are saying on the broadcasts, but when I look at the satellite pictures, I can really see what's coming." Their company has about 15,000 acres under cultivation. Over a typical harvest season from September to December, the daily weather related decisions must be based on the most accurate information available if costly mistakes are to be avoided. The availability of satellite pictures helps reduce the odds in an operation where mistakes are measured in millions of dollars. The estimated savings of the Waialua Sugar Company alone as a result of using satellite data is $1,000,000 per year.

D. <u>Crop Monitoring</u>

The polar orbiting NOAA satellite's Advanced Very High Resolution Radiometer (AVHRR) Channel 1 and 2 data are used by a variety of national and international agencies for crop monitoring purposes. Some of these are:

a. U.S. Department of Agriculture Crop Commodity Assessment Division (CCAD) uses AVHRR data to monitor yields internationally including Russia, Australia, Argentina, India and Canada. Crop yields in these nations can have a direct impact on commodity prices in the United States. CCAD has been receiving about five AVHRR tapes daily from NOAA since May 1981. These are sent via air express from NOAA/NESDIS headquarters in Suitland, MD, to the Johnson Space Center (JSC) in Houston, TX. The data generally arrive at JSC for operational analysis by CCAD within 48 hours of a satellite overpass. Annual cost of the tapes to CCAD is as follows: 5 tapes daily x $72 per tape x 365 per year = $131,400 (annual cost). CCAD receives Landsat data for these same areas via the JSC-GSFC satellite (DOMSAT) link. In the past, Landsat-3 data arrived 6 weeks after overpass, but CCAD's only costs were for time on the link. In 1983, CCAD will receive the Landsat 4 data within 48 hours, but at a cost of almost $1000 per scene. Prior to 1981, CCAD used 15,000 Landsat scenes yearly. Users will obviously have to balance their budgetary resources, need for geographic coverage and need for the highest resolution data available to obtain the proper Landsat MSS vs. NOAA AVHRR mix.

b. The United Nation's Food and Agriculture Organization (FAO) uses NOAA AVHRR data in several projects some of which are listed below:

- The Sud area in Sudan - monitor agriculture develop ment activities in an area which experiences yearly flooding from the Nile.

- Kenya - country-wide agricultural land use assessment

- Zambia and Botswana - monitor grazing lands and large scale land use changes.

- Lake Chad area (Niger) - monitor agricultural activity surrounding the lake

4. Search and Rescue Operations

Satellite pictures provided by the National Environmental Satellite, Data, and Information Service (NESDIS) assist in search and rescue (SAR) planning throughout the United States inland SAR area. The satellite data are coordinated through the Air Force Rescue and Coordination Center (ARFCC) located at Scott Air Force Base, Illinois. The USAF Aerospace Rescue and Recovery Service provides coordination of air searches throughout the United States. Whan an aircraft is overdue, the AFRCC must obtain the routing of the aircraft, determine if weather might be a factor, check on the missing pilot's qualifications and have a knowledge of the performance capabilities of the missing aircraft.

Most search and rescue missions conducted over the enroute phase of flight have shown that missing general aviation aircraft encountered unexpected weather along their route. Pilots who obtained weather briefings prior to departure in which good VFR flight conditions were forecast, encountered narrow bands of unreported weather which can be seen on satellite imagery. If an aircraft is reported missing, areas of severe weather can be located with satellite imagery showing conditions at the time the pilot was in distress. These pictures assist in determining if certain preferred mountain routes were open or blocked by hazardous weather. The height of the cloud tops can be determined to see if the missing pilot could fly over the storm system or was faced with staying at lower altitudes and trying to get through the weather.

The statistics for missing general aviation aircraft that were lost on the enroute phase of flight over three years are discussed below. These are incidents in which the USAF Aerospace Rescue and Recovery Service (AARS) responded with search and rescue service. During the period 1975 through 1977, a total of 747 aircraft were lost. A total of 1,679 persons were aboard these aircraft of which 1,008 were killed and 671 survived. Based on the analysis of satellite imagery of the crash sites, the AARS and the California Wing of the Civil Air Patrol (CAP) believe that weather was a factor in more than 85% of these aircraft accidents. A ten-year study of aircraft accidents by the National Transportation Safety Board (NTSB) for the period 1964-1974 without analysis of satellite imagery, indicated that weather was a factor in only 25% of the accidents.

The California Wing of the CAP began utilizing satellite photos obtained from the NOAA Satellite Field Services Station in San Francisco for SAR in October 1974. By mid-1975, it was apparent that satellite data were a new timesaving aid in locating missing aircraft. During this test period, 58 search missions were conducted and only two searches exceeded 48 hours. During the previous year, 46 search missions were conducted and CAP pilots averaged more than a week searching for the crash sites. Search missions of 24 to 48 hours are now common as opposed to several days to two weeks without satellite data .

During the period 1975 through 1977, a reduction of 32% in total SAR flying hours was realized by the USAF ARRS and the CAP. However, at the same time, the number of SAR missions actually increased by 14%. Following the introduction of satellite data to SAR operations, for the first time in the history of rescue service, the number of flying hours actually decreased. The following table lists the number of CAP missions, hours flown, and average hours per mission for a seven year period.

Civil Air Patrol Mission Summary (1971-1977)

Year	Number of Missions	Hours Flown	Average Hours per Mission
1971	389	30909	79.5
1972	348	27391	78.7
1973	429	27284	63.6
1974	460	21773	47.3
1975	694	24500	35.3
1976	817	17064	21.6
1977	896	16004	17.9

Satellite support of search and rescue was introduced in 1974, tested in 1975, and has been used extensively since 1976. The mission summary table above shows a marked decrease in average hours flown per mission. Between 1974, immediately before the launch of the SMS satellite, and 1977, the average number of hours flown per search and rescue mission has decreased by 62%. With the average cost of $36 per hour for fuel, oil and maintenance (CAP manpower is entirely voluntary), these reductions result in an annual savings of $344,000 for CAP search and rescue operations. USAF ARRS C-130 SAR mission hours were reduced by 7000 hours for both 1976 and 1977. At $995 per hour, this results in an annual savings of $6,965,000 for C-130 time alone. Thus satellite data, available on an operational basis, has annually saved several million dollars in tangible benefits and has produced untold intangible benefits in reductions of human suffering and death through the faster location of missing aircraft.

5. Ice Monitoring

Shipping operations in the Arctic, Great Lakes, and St. Lawrence Seaway are obviously greatly affected by sea, lake, and river ice. The National Environmental Satellite, Data, and Information Service provides support during the ice season to the U.S. Coast Guard International Ice Patrol. The satellite ice analyses are also extremely valuable to ice reconnaissance aircraft in Canada as an aid in pre-flight planning and in locating areas of improved visibility. This has resulted in increased efficiency in the visual reconnaissance missions producing a savings of about 1500 aircraft flight hours and related cost reductions of about $5,000,000 annually.

The Canadian Centre for Remote Sensing (CCRS), Department of Energy, Mines and Resources has shown that imagery indicating the presence and extent of sea ice has been very useful and cost effective to geophysical survey ships engaged in seismic surveying off the north coast of Canada in the Arctic Ocean. AVHRR images are routinely received by the Atmospheric Environment Services Receiving Station at Downsview, Ontario.

Seismic operations for oil and gas exploration in the Bering Sea, Norton Sound, Chukchi and Beaufort Seas have relied heavily on satellite observations. Because of the competitive nature of this activity, information is proprietary, but exploratory companies involved indicate that the satellite data are used as a planning tool to lay out cruise tracks that save time and fuel and minimize damage by ice to non-ice reinforced ships and testing equipment. The presence of any floating ice makes seismic sounding impossible. In one instance, an area scheduled for survey was found to have free floating ice fragments. Advice was sought by a geophysical survey ship from the CCRS which redirected the ship to a nearby area (100 n.mi. away) where ice-free conditions were interpreted from the daily satellite imagery. As a result, the ship was able to acquire twice the amount of data normally gathered. In this instance, the single image saved $250,000.

In another other example, the ARCO Oil Company used NOAA satellite imagery in 1979 to monitor ice conditions near Alaska. ARCO was using a drilling ship designed for use in the Gulf of Mexico for exploratory ice drilling in the lower Cook Inlet. By using the satellite data, ARCO was able to save $45,000 in insurance premiums on this project. A more recent example of the use of satellite data to monitor ice conditions in support of offshore drilling operations occurred in January 1983. The ARCO Oil Company was using the "Gulf of Mexico" jack-up rig drilling an exploratory well north of Port Heiden in the Aleutians. Extremely cold temperatures and a strong north wind began moving the ice front towards the rig at 25-30 miles per day. NOAA satellite imagery and analyses of the ice were provided daily by the Anchorage SFSS to the Minerals Management Office, U.S. Coast Guard, ARCO and the media. The rig was eventually evacuated and towed to safety based almost entirely upon the real-time analysis of the polar satellite imagery. Satellite ice observations also play an important role in the Arctic regions for the U.S. Fish and Wildlife Service monitoring of marine mammals' (walrus, whales, seals and polar bears) migration patterns.

In the Great Lakes, satellite imagery is used to find navigable waters for shipping as long as possible into the winter season. The high resolution satellite images show small ice free areas which can be used by ships to continue operations longer than previously possible. It is estimated that the extension of the shipping season by this method results in a cost benefit of $1,000,000 per day for each day extended. Before the use of satellite data, the Great Lakes were closed to shipping for about 2 months each winter. In the winter of 1976-1977 which was exceptionally bad, the Lakes were closed to shipping for only 1 month and during the 1977-1978 winter, they were never completely closed. In this case, however, it is incorrect to attribute all of the savings to satellites alone, since the use of side-looking radar (SLR) on reconnaissance aircraft was introduced in the same time period. Nevertheless, satellites could contribute to annual savings of as much as $30 million.

Satellites are also used to provide early warning of river ice melting and break-up, which could cause ice jams and flooding. Hydrologists require timely information on the progress of river ice break-up during spring thaws. Ice jams often cause severe flooding and threaten hydroelectric plants, bridge piers, and ship navigation. As an example, in 1977, NOAA scientists closely monitored the Ottawa River in Canada using visible images from NOAA's polar orbiting satellites. They were able to view the day-to-day changes in break-up and melting of the ice.

6. Snow Cover Mapping

The use of satellite acquired data for mapping snow cover has proven valuable in water resource planning and flood forecasting. Snow covered area estimates from operational NOAA satellites have proven to be much faster and more economical than conventional aerial surveys. Snow and ice cover a significant portion of the earth's surface. For example:

1. Snow covers 30-50 percent of the land area.

2. Ice covers about 25 percent of the oceans.

3. Glaciers cover about 10 percent of the land area.

4. Permafrost covers 10 percent of the land area.

Frequent observations of the extent and characteristics of snow and ice are needed to assist many industries in their day-to-day operational requirements. Some operational requirements which are especially affected by snow are (1) flood warning systems, (2) municipal and regional water supply management, (3) irrigation systems management, (4) hydroelectric power management, (5) energy requirements, (6) transportation systems operations, and (7) food supply requirements.

For example, satellite snow cover analyses were used in 1976 while a storm was still in progress to determine that it would not be necessary to spill the Verde River reservoir system in Arizona as had been previously planned. Spilling of the reservoirs would have put water into the normally dry Salt River channel above Phoenix which causes road closings and local flooding in the Phoenix metropolitan area and results in the loss of valuable irrigation water. The dollar savings were considerable. In addition, continental snow cover has important climatic impacts on surface and air temperature, radiation balance, soil moisture, cloudiness and precipitation.

Mr. Donald R. Wiesnet, former hydrologist with the National Environmental Satellite, Data, and Information Service, has shown that satellites have made a significant contribution in snow cover mapping where the cost ratio between the satellite and conventional aerial survey is as much as 200 to 1 in favor of the satellite. For example, it takes about 40 hours of flying at $500 per hour to map 20 river basins in the Sierra Nevada mountains. Thus, it costs about $20,000 per aerial mapping operation which is done several times during the winter and spring, funds permitting. When cloud free conditions are available, this job can be accomplished using satellite data in about two man-days at a cost of $200. Thus, annual savings in mapping the Sierra Nevada basins alone could be as much as $1,000,000.

In the mountainous regions of the United States, millions of dollars are spent each year to measure snowpack at fixed locations for forecast purposes. In 1969, a panel of scientists from the National Academy of Sciences states, "The changing extent, surface temperature, thickness, water equivalent, and liquid water content of seasonal snowpack are necessary for engineering design and operation and planning of water projects large and small. In the mountain areas of the United States, millions of dollars are spent each year at fixed locations to measure snowpack for forecast purposes. Improved forecasts are estimated to be worth $10,000,000 to $100,000,000 per year to water users in the western United States alone." Operational environmental satellites can contribute greatly to improved hydrological forecasts.

Seventy percent of the runoff in the western United States is derived from melting snow. In a study funded by the National Science Foundation, it was found that increased cloud seeding in the upper Colorado River basin could result in snowpack augmentation with $12.8 million annual benefits.

NESDIS began operationally producing satellite snowcover maps for 30 selected western U.S. river basins in the spring 1974. The snowcover data are used in river runoff models, dam and reservoir release decisions, and are input to seasonal water supply forecasts to determine how much water is available for irrigation, hydroelectric power generation, municipal consumption, and recreation. About 600 river basin snow maps are produced annually; data are relayed to users via teletype, telecopier or through the mail. Agencies involved as subscribers to this satellite service include the U.S. Forest Service, Soil Conservation Service, Army Corps of Engineers, Bonneville Power Administration, National Weather Service, Bureau of Reclamation, Bureau of Land Management, and the U.S. Geological Survey.

In the late 1970's, the National Aeronautic and Space Administration (NASA) initiated a four year (1975-1979) effort to evaluate the usefulness of satellite snowcover information for water resource managers. The project was identified as the snowmapping Applications Systems Verification Transfer (ASVT) project. Volume VII of the project's final report addressed cost/benefit aspects of the snow study. It was found that:

a) The improvement in runoff prediction due to the addition of satellite information is 6-10%.

b) Benefit models developed for irrigation and hydroenergy uses revealed savings of $36.5 million yearly when satellite snowcover data were supplied for river basins throughout the western United States. The cost of such a satellite snowmapping program was determined to be $505K, thus yielding a benefit/cost ratio of 72:1.

7. Natural Disaster Warning

Environmental satellites have been very effective in providing data for improved natural disaster warnings. It is however, very difficult to correlate lives and dollars saved during a disaster directly to improved forecasts and warnings. NOAA satellites provide environmental data to forecasters and government officials regarding tornadoes, severe thunderstorms, hurricanes, tropical storms, flooding, severe winter storms and other less destructive environmental phenomena. Satellite data are transmitted around-the-clock, 7 days-per-week to the various National Centers for environmental warning including: the National Severe Storms Forecast Center (NSSFC) in Kansas City, Missouri; the National Hurricane Center (NHC) in Miami, Florida; the Eastern Pacific Hurricane Center in San Francisco, California; and the Central Pacific Hurricane Center in Honolulu, Hawaii.

A. Hurricane Warning

Satellite imagery is used extensively in monitoring tropical storms and hurricanes. Several years ago, aircraft reconnaissance was the primary method of finding and tracking dangerous tropical storms in the oceans. Increasing costs of petroleum, maintenance and manpower have caused a drastic cutback in tropical storm reconnaissance by the U.S. Air Force and NOAA. The satellite observations have practically replaced all storm reconnaissance except when a hurricane is approaching land. The cost of aerial reconnaissance is about $2,500 per hour and the average mission requires at least 10 hours. Thus, there is a potential savings of $25,000 per flight for every reconnaissance flight avoided by the use of satellite data. In addition, the satellite imagery has enabled the aircraft storm reconnaissance to be more efficient and cost effective in plotting flight tracks for data gathering due to improved navigational information about the location of tropical cyclones.

Since the inauguration of the operational satellite system, no tropical storm goes undetected, even in the most remote areas of the world. The GOES-E spacecraft acquires an image every 30 minutes around-the-clock of the North Atlantic Ocean, the Caribbean Sea and the Gulf of Mexico providing excellent tropical storm detection and monitoring capabilities. Hurricane reconnaissance aircraft no longer have to fly random search patterns over the vast tropical oceans to locate storms which may be developing there. Estimated savings from using satellite storm detection and monitoring in mid-ocean in place of expensive aircraft reconnaissance are about $1,800,000 annually.

The information listed below illustrates the magnitude of hurricane destruction in terms of dollars and fatalities.

Hurricane Fatalities and Damage (1900 - 1982)

Year(Period)	U.S. Fatalities	U.S. Damage ($ Millions)	
1900-1904	6000	N/A	adjusted to 1957-1959 construction costs
1905-1909	2200	N/A	
1910-1914	100	N/A	
1915-1919	983	541	
1920-1924	9	15	
1925-1929	2114	357	
1930-1934	80	164	
1935-1939	1026	850	
1940-1944	149	495	
1945-1949	67	480	
1950-1954	217	918	
1955-1959	675	1331	
1960-1964	173	1156	
1965	75	1420	unadjusted annual cost
1966	54	15	
1967	18	200	
1968	0	10	
1969	364	1455	
1970	11	454	
1971	14	213	
1972	121	3097	
1973	6	18	
1974	1	150	
1975	55	550	
1976	9	100	
1977	0	0	
1978	36	20	
1979	22	3050	
1980	3	300	
1981	0	25	
1982	1	280+*	

*Hurricane Iwa damage assessment was not completed at the time this paper was written. Hawaii had not been struck by a hurricane in 23 years.

The most damaging individual hurricanes by name and year are listed below:

Costliest United States Hurricanes of Record

Name	Year	U.S.Damage ($)
Frederic	1979	$2,300,000,000
Agnes	1972	2,100,000,000
Camille	1969	1,420,700,000
Betsy	1965	1,420,500,000
Diane	1955	831,700,000
Eloise	1975	550,000,000*
Carol	1954	461,000,000
Celia	1970	453,000,000
Carla	1961	408,000,000
Donna	1960	387,000,000
David	1979	320,000,000

*Includes $60,000,000 in Puerto Rico

The damage estimate of $2.3 billion makes Hurricane Frederic the costliest hurricane ever to hit the United States, exceeding the $2.1 billion cost estimated for Hurricane Agnes in 1972. Five deaths were attributed directly to Hurricane Frederic in the United States, only one of which occurred along the coastal region when a person was swept off a boat near Pensacola, Florida. The insurance industry estimated insured losses of $750-million for Hurricane Frederic. Approximately 250,000 persons were evacuated in advance of Frederic.

A 1975 NOAA Technical Memorandum entitled, A Statistical Study of Tropical Cyclone Positioning Errors with Economic Applications by C.J. Neumann noted that until 1974, the initial position error for storms within 500 n.mi. of the coast averaged 22 n.mi., and landfall forecasts were made from distances no more than 300n.mi. A positioning error is defined as the difference between the forecaster's assumed initial position of a storm and the actual position as determined from a postanalysis.

The issuance of hurricane warnings along a portion of the United States coastline is generally accomplished 18 to 24 hours prior to the expected arrival of the storm at the coast. This particular time interval has been found to be an optimized trade-off between the desire to provide maximum warning lead time and the ability to keep the size of the warning area within reasonable limits. With such a lead time, the length of the warning zone averages nearly 300 n.mi. Inasmuch as the swath of damaging winds is generally less than 100 n.mi., the public must expect a minimum overwarning area of about 200 n.mi.

The study includes an economic analysis of potential changes in the size of hurricane warning areas. It is estimated that protection costs (including losses due to temporarily curtailed production) for a typical 300 n.mi. Gulf of Mexico coastal hurricane warning zone total $25.1 million. A 10 n.mi. increase in positioning error will increase this economic loss by about $5 million per storm. A 10 n.mi. decrease in positioning error will decrease protection costs by about $2.75 million per storm. Since an average of about two hurricanes annually move inland on the continental U.S., using the above figures, $50 million is the average annual cost of protection. As a conservative estimate, a reduction of only 5% in the coastal warning area would mean an average annual savings of about $2,500,000 per year. Satellite observations play a major role in keeping the warning area to a minimum.

B. Global Tropical Storm Monitoring

NOAA polar orbiting satellites are used to monitor tropical storms worldwide in addition to those near or endangering the United States. The following table lists the number of named tropical cyclones monitored and tracked by NOAA satellites in three remote ocean areas of the world.

Satellite Monitored Named Tropical Cyclones

Year	West Pacific Ocean	South Pacific Ocean	Indian Ocean
1974	38	12	26
1975	27	8	33
1976	27	10	27
1977	21	10	23
1978	27	7	23
1979	27	6	20
1980	27	8	20
1981	28	12	19
1982	27	9	21

When these storms are detected and tracked by polar satellite, a Satellite Weather Bulletin is sent directly to the meteorological agency of the countries which could be affected by the storm. These bulletins are transmitted daily throughout the life of the tropical storm which averages 8-10 days. In the highly populated countries of southeast Asia, this satellite tropical storm warning service could save many lives if the capabilities to disseminate the warning to the general public were available. Unfortunately, in many cases, the populace does not receive the warnings due to the lack of adequate communications facilities and the death toll has not reflected the availability of these timely warnings.

C. Severe Thunderstorm and Tornado Warning

Satellite imagery is a primary data source for the National Severe Storm Forecasting Center (NSSFC) in Kansas City which has severe thunderstorm and tornado forecasting responsibility for the continental United States. In 1972, the NESDIS established a Satellite Field Service Station (SFSS) collocated with the NSSFC. The Kansas City SFSS has been instrumental in developing new techniques in applying satellite imagery to severe storm forecasting. The use of high resolution GOES visible and enhanced infrared imagery taken at frequent intervals (as often as every 15 minutes) has been extremely useful in monitoring the development of severe thunderstorms. This satellite capability has enabled NSSFC forecasters to pinpoint areas with a high probability of a tornado so as to reduce the area of warning. By reducing the area of warning, the "cry-WOLF!" attitude that sometimes exists toward tornado alerts will be lessened. The satellite has been instrumental in accurately defining the tornado watch areas which are provided to the news media and NWS forecast offices.

The following table lists the fatalities and property loss statistics for the period, 1972 through 1982.

TORNADO SUMMARY (1972-1982)
Property Loss Frequency*

Year	Number of Tornadoes	Fatalities	Category 5	Category 6	Category 7 and over
1972	741	27	100	28	1
1973	1102	87	219	67	9
1974	947	361	166	82	25
1975	920	60	189	31	11
1976	835	44	145	41	5
1977	852	43	173	40	6
1978	788	53	153	53	6
1979	852	84	169	62	11
1980	866	28	205	79	13
1981	782	24	144	43	12
1982	1028	64	N/A	N/A	N/A

*Number of times property losses were reported in storm damage Categories 5, 6, 7 and over.

Property Loss Category Definitions

Category 5	$50,000 - $500,000
Category 6	$500,000 - $5 million
Category 7	$5 million - $50 million
Category 8	$50 million - $500 million
Category 9	$500 million and over

The above losses are based on estimated values at the time of occurence.

As shown in the table above, the cost of damage has risen significantly in recent years due to more populated areas being hit by tornadoes and increased building costs due to inflation. Because tornadoes and severe thunderstorms are relatively small scale and short lived, it is difficult to prepare to protect property in a manner similar to that which is done with the larger scale and slower moving hurricanes. It is currently impossible to predict the exact time and locations these severe storms will arrive, but satellite images provide an indication of the development of the type of meteorological situations in which these storms occur. Unfortunately, satellite observations of tornadoes and severe thunderstorms can do little to aid in reducing the amount of property damage sustained. It is significant, however, that there has been a notable reduction in the average number of deaths since 1975.

Beginning in 1975, GOES data has been a significant and heavily used input to the NSSFC. It seems clear that there is a correlation between the lower number of lives lost since 1975 and the introduction of operational geostationary satellite data into the severe storm forecasting and warning process. Even excluding the April 3rd calamity of 1974, an average of 84 fatalities per year occurred between 1968 and 1974. The average number of deaths since satellite data has been extensively utilized is 50 fatalities per year.

The New Orleans SFSS plays an important role in reducing the element of surprise of severe weather sweeping in from the Gulf of Mexico and overtaking mariners, offshore oil workers and coastal residents. During this century alone, 21 hurricanes have come ashore from the Gulf killing hundreds of persons and causing billions of dollars in damage. In addition, scores of tropical storms and winter-time cyclones have hit the Gulf coast areas. Although not as severe as hurricanes, these storms cause extensive damage and threaten the lives of those individuals who use the Gulf for their livelihood and recreation.

With the advent of the energy crisis, emphasis has been placed on offshore oil drilling and production activity. The magnitude of this effort is reflected in the following statistics. There are 1,249 production platforms with heliports, approximately 240 drilling rigs on location, and 28,000 individuals working offshore. To support this vast and complex industry, approximately 700 helicopters (flying an average of 25,000 hours per month) transport 150,000 passengers each month from bases located along the Texas and Lousiana Gulf coast.

The New Orleans SFSS focuses on small-scale meteorological events in an area extending from 90 miles onshore to 200 miles offshore. Special attention is given to the thunderstorms and squall lines which develop rapidly throughout the Gulf with little advance warning. When these storms are detected, the SFSS issues advisories to National Weather Service Offices and other government agencies along the Gulf coast.

D. Flood Warning

Satellite data also have been valuable in providing early warning for floods. An example is the September 13, 1977 flood disaster in Kansas City. Information provided by the NESDIS SFSS in Kansas City to National Weather Service Forecast units prior to and during the Kansas City flood was timely and accurate. The early recognition of the precipitation boundary which had been left by the previous night's thunderstorm activity in northern Missouri identified a meteorological mechanism which had potential for initiating new thunderstorm development over an area where the ground was already saturated. This satellite information, when incorporated with other data, contributed to the NWS decision to issue a local forecast early in the day for heavy rain. Later satellite data provided information which was instrumental in the issuance of a severe thunderstorm watch which included the Kansas City metropolitan area. The satellite evaluation gave new information concerning the southward shift of the axis of thunderstorm development, and coupled with supporting evidence from the NWS radar, suggested the potential for heavy rain in the Kansas City area.

An example of satellite contributions to international flood warnings occurred in August of 1977 when United States satellite assessments of snowpack were used as an indicator of flood potential in Pakistan. NOAA-5 VHRR coverage was especially programmed to include the Himalaya Mountains. Two large river basins in the Himalayas were monitored: the Indus River above Besham (162,100 km^2) and the Kobal River above Nowshera (88,600 km^2). A late snow melt in the Himalayas could have greatly increased the potential for flooding in Pakistan. Percent snowcover as derived from the satellite was compared with historical data and transmitted to the Pakistani Ambassador in Washington, D.C.

Satellite data is very beneficial in flash flood forecasting. During the period October 12-13, 1981 excessive rainfall occurred over Texas and Oklahoma. The primary ingredient for this episode was a dying tropical storm (Norma) which was moving out of Mexico.

Numerical forecast models, due to the scarcity of data over Mexico, were unable to forecast its movement. The first hint of this feature moving toward Texas came from satellite derived data. This information prompted the issuance of twenty Flash Flood Watches in various parts of Texas. As the system moved into Texas, triggering copious rains, Quantitative Precipitation Estimates based on satellite images were provided to numerous NWS offices. There were four major floods during 1982. Flooding in Fort Wayne, Indiana, New England, Louisiana and the central Mississippi valley claimed 150 lives and caused damage in excess of $2 billion.

8. Large Scale Weather Forecasting

NOAA operational environmental satellites contribute greatly to the National Weather Service's National Meteorological Center (NMC), the central weather analysis and prediction facility for the United States. At NMC, which is also a World Meteorological Center, observations from all over the globe including satellite data are collected, processed by computer, and used to produce maps of existing and predicted weather conditions. In a 24-hour period, the NMC receives about 42,000 approximately 50,000 satellite observations. Maximum benefits from satellite data are realized when this information is effectively used to bridge the gap in time and space between conventional meteorological observations. A synthesis of all types of meteorological data such as satellite, surface, upper air, radar, etc., results in a more complete and accurate understanding of atmospheric processes.

Dr. Robert M. White, former Administrator of NOAA, discussed the role of satellite data in large scale weather applications in an article in The Military Engineer (July-August 1973) entitled Environmental Satellites - A Progress Report. In this article, he wrote the following:

"The World Meteorological Center, Washington, D.C. (the other World Centers are in Moscow and Melbourne) uses photographs, temperature soundings, and wind measurements acquired by satellite to improve the accuracy of large scale weather analyses and forecast weather charts. These charts are communicated by facsimile circuits to civil and military weather stations in the United States and become part of the guidance material given to field stations for use in weather forecasting. Air Force and Navy weather centrals receive both direct and processed data for use in similar ways. Analysis centers, which provide special services to agricultural, hydrological, engineering, maritime, and other interests, use satellite data routinely in the preparation of their products. Several factors make satellite data unique in comparison with data acquired from other sources. A major characteristic is that, because of its vantage point above the atmosphere and its broad field of view, the satellite can provide information regularly for vast areas of the globe where data from other more conventional sources are sparse or unobtainable. This coverage of the large data gaps over oceans and remote land areas is one of the basic and most important contributions of satellites to improved weather forecasts. Also important is the immediacy of data transmitted directly from satellites to ground stations. Such data frequently are received and put into use some hours before routine data are received through normal communications channels. The third characteristic is the broad view of earth and atmospheric features that can be obtained only from satellite altitude. Large-scale weather systems can be seen in a single view, whereas the definition of atmospheric or sea surface conditions obtained from aircraft or groundbased observation is incomplete."

The environmental satellite is an excellent global observational platform and the United States freely contributes data from its satellites to the world meteorological community. Satellite data is an important part of the World Weather Watch Program of the United Nations' World Meteorological Organization. The direct readout systems (APT and HRPT) from the polar orbiting spacecraft and the WEFAX transmissions from the geostationary spacecraft are used by more than 123 countries around the world.

Thus, environmental satellites contribute significantly to large scale weather observation and forecasting. Deriving the actual cost benefits of such services is extremely difficult, if not an impossible task. This is because the only way of obtaining these benefits would be to compare the cost of information obtained via satellite with what it would cost to acquire comparable data via conventional means (e.g. surface observations, radiosonde, radar and meteorological buoys). Not only would the acquisition costs be prohibitive, but it would be physically impossible to obtain this large amount of diverse data in a timely manner. The value of satellite acquired observations to global scale forecasting is certainly several millions of dollars annually.

9. Miscellaneous Activities

There have been many uses of environmental satellite data some of which are significant and others which have no measurable economic benefit at present, but may have in the future. This section briefly discusses some of these activities related to the utilization of environmental satellite data.

A. Airline Fuel Savings

The NASA Lewis Research Center completed a 20 month study in 1981 regarding the value of improved upper air wind and temperature forecasts to the worldwide commercial airline industry. This study was discussed in a paper entitled Airline Flight Planning - The Weather Connection by Robert Steinberg in April 1981.

In his paper, Mr. Steinberg reviews the meteorological basis for the present method of airline flight planning and analyzes its impact on current flight operations. He suggests a new approach for developing a weather base for flight planning which has the potential of providing fuel savings of 2 or 3 percent on long distance flights.

Mr. Steinberg suggests that a meteorologist, using man-computer interactive techniques, could develop an accurate upper air nowcast (3-12 hours) using the NWS synoptic numerical forecast, satellite data, rawinsonde and pilot reports. Satellite data is the most timely and also provides information on the location of jet streams, which is very important. This nowcast would provide the basis for automated flight planning by the airline.

Mr. Steinberg estimates that an interactive system with satellite data input to provide upper air tuned forecasts, including manpower for a 24 hour operation would cost about $600,000 per year after a one time capital investment for equipment of about $1,000,000. An international carrier with a present fuel bill of one billion dollars could expect to save at least $20 million per year on trip fuel alone. When one considers the potential for optimizing reserve fuel requirements, the savings could even be considerably higher.

B. Game Bird Management

The Office of Migratory Bird Management of the U.S. Fish and Wildlife Service has used NOAA polar-orbiting VHRR pictures to help determine the reproductive success of several species of arctic nesting geese. The Wildlife Service is responsible for annually adjusting hunting regulations to conform with the estimated population of particular species of waterfowl. The waterfowl managers must know well before the hunting season what the supply of game birds will be, otherwise their existence could be threatened by over-harvesting.

The most important factors affecting the reproductive success of arctic nesting geese is the timely disappearance of snow, ice, and the availability of melt water to allow for the production and rearing of young. Late seasons or adverse weather conditions can result in the geese not nesting, reduced brood sizes, or failure to renest. Any of these adversely affects the population. Waterfowl managers, using NOAA's polar orbiting satellites, can monitor habitat snow and ice conditions in the remote arctic nesting areas in a timely and economical manner. The satellites provide visual and infrared images twice daily to help identify areas of catastrophic or outstanding goose production, permitting the wildlife service to establish appropriate hunting regulations.

C. Dust Storm Monitoring

Both the geostationary (GOES) spacecraft and the polar orbiting (NOAA) spacecraft have been used to monitor the development and dissemination of dust storms in the Plains States. For example, in February 1977, these operational satellites detected dust clouds originating in New Mexico and Colorado and tracked them across Kansas, Oklahoma, Mississippi, Alabama and Georgia out into the Atlantic Ocean. The major dust storm was considered among the worst since the "Dust Bowl" days of the 1930's.

Monitoring the development and movement of dust storms is important to the aviation industry, soil erosion and agriculture experts, scientists conducting solar energy research, pollution monitoring specialists, etc. Satellites can be used effectively by meteorologists to monitor major dust storms.

D. Locust Plague Control

Agricultural crops and rangeland resources estimated to be worth 30 billion dollars over some 30 million square kilometers in 60 countries with more than a fifth of the world's population are prone to the ravages by the Desert Locust, Schistocera gregaria. The primary factors which influence the growth and movement of the locust are the temperature and moisture content of the air and ground and the standing crop. These factors can be measured using NOAA environmental satellites and Landsat satellites. NOAA polar-orbiting satellite images have been used by the United Nations Food and Agriculture Organization (FAO) to monitor areas of probable rainfall in northern Africa countries such as Algeria, Somalia, India, and Pakistan. The NOAA satellite images are examined in detail with Landsat images of these areas, enabling U.N.FAO scientists to locate areas of emergent vegetation which is essential for desert locust development. The location coordinates of potentially dangerous areas are relayed to locust control teams in the countries involved. These teams then examine the area and determine if insecticide spraying is necessary to inhibit the development of migratory swarms.

Building further on the results obtained during the Desert Locust/Remote Sensing Pilot Project, carried out by FAO in Northwest Africa in 1976/77, techniques were developed and initially tested for quantitative rainfall monitoring over large areas using environmental satellite data, e.g., Meteosat and TIROS-N/NOAA, and vegetation biomass activity detection and monitoring with Landsat digital data. Vegetation monitoring for the entire desert locust region with Landsat 80 meter-resolution data (MSS Bands 5 (visible) and 7 (near infrared)) requires the processing of huge amounts of data at an extremely high cost. Analysis has shown that Landsat data often has excess resolution for FAO purposes and can be reduced by a factor of 35 and still used effectively.

With the launch of TIROS-N in October 1978 and NOAA-6 in June 1979, 5-channel AVHRR data (including the near infrared) at a resolution of 1.1 Km became operationally available for the first time. Previous NOAA polar orbiting satellites (the ITOS series) had sensors that imaged only in the visible and thermal infrared regions of the spectrum. FAO began exploring the use of AVHRR data in desert locust studies in the summer of 1980 with promising results. Locust breeding grounds in southern Algeria were successfully identified for the first time on AVHRR data of August 31 and September 10, 1981. The data were analyzed on the NASA/GSFC H.P.1000 interactive system. Ground confirmation was supplied through FAO headquarters in Rome.

E. Volcano Monitoring

Ash spewed out from erupting volcanos may remain in the atmosphere for many months posing a threat to commercial aircraft. The ash and dust may also affect the earth's radiation balance and surface temperature and in turn, crop and vegetation growth. The five channel AVHRR data have been used in recent studies to determine height of volcano plumes, plume dispersal, plume composition as well as to map the extent of lava flows and the distribution of volcanic ash and dust on the ground. Information gleaned from the satellite data is then passed to the Smithsonian Institute for inclusion in the SEAN (Scientific Event Alert Network) Bulletin published each month in order to pass needed information to scientists and government officials.

The AVHRR satellite data are analyzed on the H.P.1000 interactive system at the NASA/Goddard Space Flight Center. Information on the volcanic plume height is obtained by reducing the thermal data in channels 4 and 5. The extent of the lava flow can be mapped (while the lava is still hot) by using channel 3. The distribution and amount of dust covering the regional vegetation can be inferred using channels 1 and 2. The following volcanos have been studied extensively by NOAA/NESDIS during the past two years.

Location	Volcano	Dates
Mexico	El Chichon	March 29-April 4, 1982
Java	Galunggung	June 24-July 15, 1982
Soviet Union	Alaid	April 28-May 1, 1981
Iceland	Krafla	February 4, 1981
Iceland	Hekla	April 1981
U.S.A.	Mt. St. Helens	May 18, 1980

A team from the Australian Commonwealth Scientific and Industrial Research Organization (CSIRO) and the Western Australian Institute of Technology have developed a method of tracking volcanic clouds. The Australian team recognized that the volcanic ash would contain a large amount of silica that the infrared radiation band would detect. When the clouds begin to disperse, they consist of particles only a few microns across and they attain very high altitudes where they pose a threat to jet aircraft. The ash also merges with other clouds and becomes undetectable in the visible spectrum. The silicates in the ash provide a thermal emission pattern different from other clouds.

F. Metropolitan Planning

The heat emitted from metropolitan areas is measured by high-resolution infrared sensors aboard NOAA's polar-orbiting satellies. The sensing of urban "heat-islands" by environmental satellites is used by metropolitan planners to monitor population growth and industrial development as it occurs. Planners are able to monitor the urban growth by comparing greatly enlarged computer-enhanced satellite images with urban census maps. The satellite imagery supplements and in certain cases may be more cost effective than aerial photographs as a tool in determining the amount and direction of growth of a metropolitan area and for delineating boundaries for future census surveys.

The pattern of a city's heat can be quantified from satellite measurements and monitored annually or on a season by season basis. Even small urban areas can produce noticeable thermal anomalies or heat islands when compared to their surrounding rural environment. A NOAA-5 image of New Hampshire, Massachusetts, and Rhode Island acquired on May 23, 1978 was digitally enhanced by NOAA scientists to study urban heat islands. A total of 17 heat islands were detected ranging from Norwood, Mass. (pop. 32,000) to Boston, Mass. (pop. 625,000).

G. Hydroelectric Power Production

Temperature changes of 1°C or more at customer locations are reflected in electric power demand variations at the servicing hydroelectric facility within four to eight hours. The hydroelectric operator must regulate water flow or bring thermal power units on-line to compensate for these demand variations. Because it requires about four hours to make major water flow adjustments or to add thermal power, large hydroelectric operators invest substantial amounts in establishing well instrumented surface observation networks (temperature, wind, humidity, and precipitation) over their service regions. Observed data are used as the basis for specific area forecasts by the meteorologists supporting the hydroelectric operator.

In 1973, a major hydroelectric operator, the Tennessee Valley Authority, investigated the potential benefit of using satellite data every one or two hours to increase the density of surface temperature observations in order to improve the accuracy of their four to eight hour forecasts. It was concluded that operational efficiencies could be achieved that would result in savings "in excess of 1% of operating costs."

H. Forest Fire Prevention and Detection

The National Weather Service maintains Fire Weather Offices (FWO's) at 17 locations in the western United States: Billings, MT; Boise, ID; Wenatchee, WA: Eureka, CA: Fresno, CA; Los Angeles, CA: Medford, OR; Missoula, MT: Olympia, WA: Pendleton, OR; Portland, OR: Phoenix, AZ; Redding, CA; Reno, NV; Sacramento, CA; Salt Lake City, UT: and Salem, OR. The "official" fire weather season varies by FWO district, but can begin as early as April 1 and end as late as November 15. The FWO's release a daily Fire Load Index (defined on a scale from 1 to 100) for regions throughout the western United States. The higher the index number, the greater the number of manhours needed to contain a fire. With millions of acres to be monitored in the western region and limited resources to accomplish the task, the fire load index serves as the most important tool in determining how these resources will be distributed over the next day, week or even month. Poor weather forecasts can mean thousands of dollars lost when a misrepresentative Fire Load Index is distributed.

The NOAA Satellite Field Services Station (SFSS) in San Francisco, California, releases a daily Fire Weather Satellite Interpretation Message (SIM) to aid the FWO in deriving the proper Fire Load Index. The SIM's include information on rapidly developing thunderstorms, surface wind speed and direction, precipitation duration and type (layered or convective), cloud cover, variations in temperature and humidity, extent of surface inversions and amount of solar insolation.

Also of interest to fire weather forecasters is measuring the changes in plant biomass or chlorophyll density in forest plant life and cultivated fields. The plant biomass is directly related to its moisture level and thus to its susceptibility to burning. The Bureau of Land Management (BLM) and the EROS Data Center (EDC) are initiating a program to utilize NOAA AVHRR channels 1 and 2 data to determine fuel loading conditions in wildfire hazard areas. The AVHRR data are analyzed to make estimates of standing green biomass loading within previously Landsat-mapped wildfire fuel types. These estimates (high, medium, low) shall then be incorporated as part of the BLM Initial Attack Wildfire System data base. Initial spring 1982 test areas were located in southeastern Oregon, northwestern Arizona, and the Fairbanks region of Alaska. If the experiment is successful, this technique will be used operationally in fuel loading models beginning in 1984 for the entire western United States and Alaska.

A final application of NOAA AVHRR data is to monitor the actual outbreak of fires. The third channel on the AVHRR (3.5-3.9 um) is extremely sensitive to high heat sources. These data have been used to identify oil flares, mine smelts, factories, power plants, lava flows -- and wild fires. Some of these targets have been found to occupy an area that is less than 1 percent of the AVHRR pixel size, thus effectively giving "sub-pixel resolution" for high heat sources in this channel. The NOAA San Francisco SFSS ran a test in the summer of 1981 which involved locating "hot spots" on the channel 3 imagery and sending out precise locations to the Fire Weather Offices. As many as 30 fires were spotted on a single day. The overwhelming majority of fires detected on the data proved to be controlled timber or agricultural burns. However, in several cases the satellite data were used to give first notice of a fire. Field verification was supplied by the U.S. Forest Service, timber companies, and in several cases, the local police.

I. Bowhead Whale Monitoring

The NOAA Satellite Field Services Station (SFSS) in Anchorage, Alaska, supports several agencies with respect to the annual bowhead whale migration. Direct briefings and blowups of polar satellite visible imagery of the area from St. Lawrence Island to Prudhoe Bay are provided to National Marine Fisheries Service. Polar satellite imagery of the coastal sea ice is provided to the Bureau of Land Management Outer Continental Shelf Program. The imagery is used to determine where aircraft observers should fly to count and observe the whales. In addition, ice imagery is supplied to the nine Eskimo Whaling Commissioners of the Alaska Eskimo Whaling Commission who use the imagery as a management tool.

J. Water Quality Monitoring

The effectiveness of NOAA geostationary satellites in water quality monitoring was demonstrated in a recent study of Pyramid Lake. The lake, located northeast of Reno, Nevada, is the largest desert water body in North America with a surface area of 440 sq. km and a mean depth of 40 meters. During the summer of 1978 and 1980, the lake experienced massive precipitations of calcium carbonate (whitings). In each case the lake surface became entirely covered with calcium carbonate within two weeks of the onset of whiting, and it would take several months to regain its normal appearance. GOES data were used daily to map the entire whiting sequence: the growth, distribution pattern, intensity and finally cessation of the phenomenon. As more and more water is diverted for agricultural, industrial and municipal use in the western United States, lakes will become increasingly susceptible to such events. The NOAA satellites provide a timely source of data for monitoring such events.

K. Recreational Boating

Satellite data has been used as a major data source to brief sailboat cruising races for several years. The 1982 Newport to Bermuda Yacht Race was postponed 48 hours based on forecasts of a sub-tropical storm being monitored by NOAA satellites and conventional data. Unfortunately, one of the racers ignored the warnings and sailed on the original starting day. The yacht suffered considerable damage and one crew member was lost at sea in the storm. The satellite-based weather support was responsible for preventing considerable property damage and other loss of life in this particular sailboat race.

III. Summary

The use of operational environmental satellite data is well established in support of weather forecasting, especially severe storm forecasting and warning and large (global) scale forecasting. In addition, operational satellite data are used effectively in support of the following variety of activities:

- Ocean Current Navigation
- Ice Monitoring
- Citrus Industry
- Sugar Cane Industry
- Search and Rescue Operations
- Commercial Fishing Industry
- Agricultural Industry

Thus, operational environmental satellites have established their value and benefit to support many public warning functions and economic activities. To the tangible benefits must be added the intangible value of lives saved by improved natural disaster warnings to the public with respect to hurricanes, tornadoes, severe thunderstorms, and flooding. The advent of environmental satellites is the greatest significant advance in routine environmental monitoring that has been developed in history. The operational environmental satellite has earned its place as an irreplaceable weather and ocean observing tool in contributing towards the saving of lives and property from natural disasters and improving the efficiency of many sectors of our national economy.

The benefits discussed herein are evidence that the operational environmental satellite has earned its place as an irreplaceable weather and ocean observing tool. These satellites are making major cntributions towards the saving of lives and property from natural disasters and improving the efficiency of many sectors of our national economy.