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# Satellite Activities of NOAA 1970

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration

compiled by
NATIONAL ENVIRONMENTAL SATELLITE SERVICE

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# National Oceanic and Atmospheric Administration
# TIROS Satellites and Satellite Meteorology

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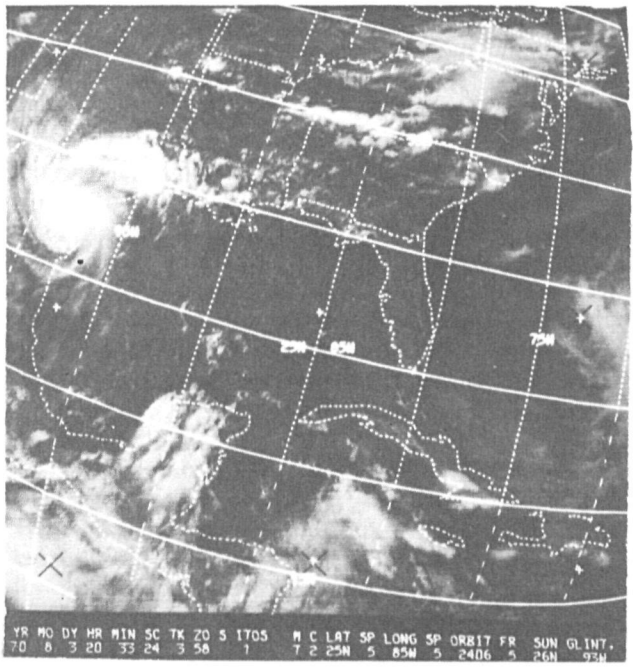
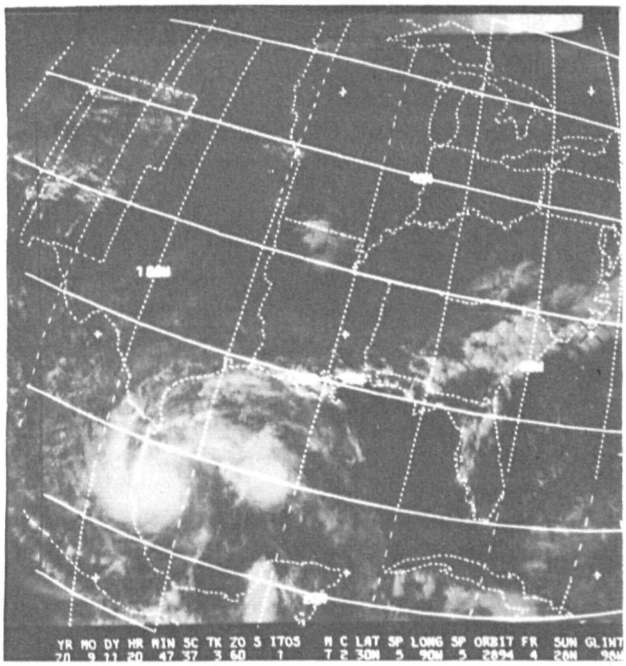



**Hurricanes Celia and Ella as observed by ITOS 1. Celia was photographed over southern Texas on August 30, 1970. Ella was photographed over the northeastern shore of Mexico on September 11, 1970.**

## National Oceanic and Atmospheric Administration

The National Oceanic and Atmospheric Administration (NOAA) was created within the U.S. Department of Commerce on October 3, 1970, pursuant to Presidential Reorganization Plan No. 4 of 1970. The NOAA is composed of organizational entities from the Department of Commerce, the Department of the Interior, the Department of Transportation, the National Science Foundation, and the Department of Defense. The Environmental Science Services Administration (ESSA) of the Department of Commerce was abolished and its major units were incorporated into the NOAA. Current NOAA organizational elements and the organizations from which they were derived are shown below:

| *NOAA organizational elements* | *From* |
|---|---|
| National Weather Service. | ESSA Weather Bureau. |
| National Marine Fisheries Service. | Bureau of Commercial Fisheries and the Marine Sport Fish Research Program, both from Department of the Interior. |
| Environmental Research Laboratories. | ESSA Research Laboratories. |
| National Ocean Survey | ESSA Coast and Geodetic Survey, and the U.S. Lake Survey from the U.S. Army Corps of Engineers. |
| National Environmental Satellite Service. | ESSA National Environmental Satellite Center. |
| Environmental Data Service. | ESSA Environmental Data Service, and the National Oceanographic Data Service from the U.S. Navy. |
| Office of Sea Grant | National Sea Grant Program of the National Science Foundation. |
| Data Buoy Project Office | National Data Buoy Project of the Coast Guard, Department of Transportation. |
| National Oceanographic Instrumentation Center. | Same name, U.S. Navy. |
| Marine Minerals Technology. | Same name, Department of the Interior. |

*Extracted from "Aeronautics and Space Report of the President," transmitted to Congress, January 1971.

The NOAA mission is to explore, map, and chart the global oceans, their basins, their geophysical forces and fields, and their biological and mineral resources.

***Highlights of 1970.***—On January 23, 1970, an Improved Tiros Operational Satellite, I–TOS 1, was successfully launched by NASA. This satellite is the operational prototype of the second generation of polar-orbiting operational environmental satellites. I–TOS 1 meets major National Operational Meteorological Satellite System (NOMSS) objectives in that it has the capability to obtain nighttime observations, temperature measurements of cloud tops and the earth's surface, and is equipped with a solar proton monitor.

ESSA–2, the first Automatic Picture Transmission (APT) spacecraft of the Tiros Operational Satellite system was retired after almost 5 years of continuous service. This spacecraft was launched February 28, 1966, and was deactivated October 16, 1970, after 1,691 days in orbit.

The improved Satellite Infrared Spectrometer (SIRS–B) on Nimbus 4, launched April 8, 1970, obtains measurements of atmospheric water vapor content and vertical temperature profiles. SIRS–B also provides a more dense network of observations than did the earlier SIRS–A carried on Nimbus 3.

NOAA–1, designated I–TOS A prior to launch, was placed in orbit on December 11. This is the first operational satellite of the ITOS system.

Intensive, realtime operational experiments to use Applications Technology Satellite (ATS) pictures were conducted by the National Environmental Satellite Service, the National Severe Weather Warning Center, Kansas City, and the National Hurricane Center, Miami. The purpose was to test the utility of near-continuous cloud cover observations for severe weather warnings, and for hurricane surveillance, advisory, and warning operations.

NOAA and NASA initiated procurement for the Geostationary Operational Environmental Satellite (GOES) system. NASA will produce the operational prototype spacecraft in its Synchronous Meteorological Satellite (SMS) project.

Solar proton data, obtained in near real-time from the I–TOS 1 satellite, were used to support the Apollo 13 mission in the critical hours prior to reentry.

The National Marine Fisheries Service started investigations on the uses of aerospace sensors for charting the oceanic environment of marine life, and for locating and tracking fish stocks.

NOAA National Weather Service has furnished support, under the World Meteorological Organization Voluntary Assistance Program, for the installation in foreign countries of 10 ground stations for receiving data directly from U.S. environmental satellites.

**National Weather Service**

The National Weather Service (NWS) is involved in the aeronautics and space program in two ways. NWS furnishes weather support to the space program through its Space Operations Support Division and to civil and military aviation through its forecasting services and research programs. The NWS also is involved in determining the usefulness of space technology for its data gathering and dissemination systems, and the usefulness of space-acquired data for weather analysis and forecasting. During 1970 the National Weather Service has expanded its operational use of space technology using satellite-acquired data in its routine analysis and forecasting procedures, and satellite telemetry systems to relay information expeditiously. The NWS also provides meteorological guidance and support for space test facilities and operations.

***Collection and Relay of Data by Satellites.***—The Applications Technology Satellite ATS–1 has been used experimentally for the past 2 years to collect river stage and rainfall measurements from untended automatic stations and to relay these data to a central point for analysis. This successful experiment will become operational with the planned 1972 launch of the prototype GOES. These data will be used routinely in the preparation of flood forecasts, and for research into many water resources problems. The telemetry system will aso be used to broadcast timely warnings of flood conditions. As the system develops, other hydrological sensor equipment will be added to the GOES data collection and relay system.

The ATS–3 satellite transponder is in use in a continuing operational experiment, testing an inexpensive shipboard data transmitter as part of the design of system for rapid collection of weather data from ships at sea.

***Snow Mapping by Satellite.***—Studies performed under contract for the National Environmental Satellite Service (NESS) and NWS have materially aided in providing a better understanding of the benefits and limitations of visual photographic mapping by satellite of snow-covered areas. Timely data on the areal extent and water equivalent of snowfields are required by hydrologists in the preparation of river and water supply forecasts for the nation. NWS River Forecast Centers are receiving satellite products for application to these operational problems.

***Remote Sensing of the Water Equivalent of Snow.***—Techniques are being tested for remote measurement of the water equivalent of snow cover from sensors aboard aircraft. Sensing techniques are based on the changes in attenuation of natural earth-emitted gamma

radiation due to variations in the water equivalent of snow. The results of the first year of research are promising for future application of the method to operational river forecasting.

Cloud pictures collected routinely from the ATS satellites by NOAA's Wallops Station command and Data Acquisition Station are processed for retransmission by the ATS transponders to local Automatic Picture Transmission (APT) ground stations at Honolulu and San Francisco where they are used in the daily operations of the forecast offices.

Special receivers for ATS pictures were established at the National Severe Storm Forecast Center (NSSFC) at Kansas City and the National Hurricane Center (NHC) in Miami. The installations are complete, with high quality photographic recorders, special receiving equipment, and a complete photographic laboratory. In addition to photographic prints, 16-mm. movie loops are produced, by which the evolution and motion of the storms can be observed and studied. This represents a breakthrough for the field forecasters. It enabled the NHC to program reconnaissance flights more efficiently and the NSSFC to evaluate the radar weather data more effectively.

***Digitized Cloud Mosaics.***—Digitized mosaics of satellite cloud pictures are transmitted routinely from the National Meteorological Center to NWS forecast offices throughout the United States. The mosaics, now prepared and transmitted once a day, will be replaced with mosaics prepared and transmitted on an orbit-to-orbit basis (approximately once every 2 hours).

***Automatic Picture Transmission.***—Early in 1968 the National Weather Service began the transmission of raw APT signals in an existing central facsimile network. The APT data acquired at Wallops Station, Va., San Francisco, Calif., and Kunia, Hawaii, are transmitted to stations on the network within minutes after receipt from the satellite. Transmission of infrared nighttime imagery was added in November 1970. This operational network has been expanded to include a large number of Air Force and Navy installations in the conterminous United States. The number of APT stations needed for Government weather stations has decreased materially as a result of this network operation.

Under the voluntary assistance program the Weather Service has provided technical assistance and advice for installation of complete APT systems in 10 underdeveloped countries. More installations are planned.

***Nimbus 4 Satellite Infrared Spectrometer.***—The SIRS–B spectrometer, an improved version of the SIRS–A used on Nimbus 3, is furnishing global vertical temperature and moisture profiles daily. These data are used as experimental operational input to the numerical (computer) weather analysis programs, and are being evaluated for their accuracy. Availability of these data globally in realtime conceivably could lead not only to improvement in the computer forecasts but also to economic savings from reprogramming of the current ground-based upper-air observation network.

***Services to Aviation.***—Specialized weather information is provided to pilots, controllers, and aircraft operators to promote efficiency in aviation activities. This information is in the form of observations, forecasts, warnings, and pilot briefings.

## National Marine Fisheries Service

The National Marine Fisheries Service (NMFS) plays a major role in the development and utilization of national fisheries resources. The NMFS mission is to discover, describe, develop, and conserve the living resources of the oceans, particularly those that affect the economy and food supplies of the United States. To this end the NMFS conducts biological and ecological research on fish and marine organisms, analyzes the economics of fishery operations and marketing, develops methods for improving catches, and conducts a voluntary grading and inspection program of fishery catches. The NMFS and the U.S. Coast Guard conduct joint enforcement and surveillance operations in territorial waters of the United States and on the high seas. Twenty-nine vessels, 30 laboratories, and 50 offices across the Nation are used to carry out the NMFS mission.

***Aerospace Program for Remote Sensing.***—Since the ocean environment determines the activity and movement of fishes and other marine life, it is necessary to study this environment in as much detail as possible. In the past such measurements were, of necessity, limited to those that could be acquired by ships and shore stations. Remote sensors, developed concurrently with aerospace technology, have great potential as means for acquiring detailed, timely measurements over large areas of the ocean. The NMFS signed an agreement with NASA on August 21, 1970, that initiated a program to assess the value of remote sensing to their mission. This is the National Marine Fisheries Aerospace Remote Sensing Program at NASA's Mississippi Test Facility. Sensors mounted on aircraft will be tested to determine their utility for measuring patterns of ocean surface temperature and for locating fish stocks. Instruments to be tested include low-light-level image intensifiers, lasers, aerial cameras, and spectrometers. As tests proceed, existing instruments may be modified

and new instruments may be developed. In addition, observations of oceanic patterns over large areas will be studied by using measurements obtained from spacecraft sensors. The NASA is cooperating with and advising the NMFS in the development of instrumentation and sensor systems to gather data from spacecraft during the proposed Earth Resources Technology Satellite (ERTS) and Skylab programs. The NMFS has also started studies of the surface temperature patterns of the oceans using infrared data obtained by NOAA's Environmental Survey Satellites. These studies are part of a general program being developed by NMFS to relate space-acquired oceanic data to the NMFS mission requirement for assessing and monitoring living marine resources. The NMFS requirements for ocean surface data closely matches the requirements of the NWS and of the National Ocean Survey in that the data required in common are ocean surface temperatures, sea state (wave conditions), winds, sea currents, storm locations, salinity, and other phenomena.

## Environmental Research Laboratories

The Environmental Research Laboratories (ERL), with headquarters in Boulder, Colo., conduct the fundamental investigations needed to improve man's understanding of the physical environment. Ten laboratories conduct research in the various scientific disciplines required in support of NOAA missions.

***Office of the Director.***—Two geophysical studies were conducted in support of systems design for geostationary satellites for aeronautical communications. One was to determine the effects of ionospheric irregularities in polar regions on S-band (1,700 MegaHertz) radio signals passing through the ionosphere. Transmissions received at Gilmore Creek, Alaska, from ESSA 8 and I–TOS 1 at both 1,700 MHz and 137 MHz were used to detect these effects (known as scintillations). Comparisons showed that scintillations at the higher frequency are considerably smaller than those at the lower frequencies usually used for satellite communications.

The second study was to determine what effects polar region solar proton events have on satellite signals. Although such events, known as polar cap absorption (PCA), are rare, they can absorb radio signals transmitted through the ionosphere. Such absorption can be considerable and can last many hours. Calculations of the effects of PCA on 137 MHz transmissions at the elevation angles to be used with geostationary satellites established the probable amount of such absorption and its geographical extent. Analysis of PCA events over the past 15 years also established the probability of occurrence of various amounts of such absorption.

***Atmospheric Physics and Chemistry Laboratory (Boulder).***—In a program to study inadvertent weather modification caused by jet contrail "clouds," infrared radiometers carried aboard a NASA 990 aircraft were used to obtain thermal measurements. Immediately beneath the contrails, a decrease of about 7 percent in net incoming radiation was observed at the earth's surface. However, these effects were found to decrease rapidly as one moved 50 miles on either side of the jet corridor. A recent pilot program was conducted with a stratospheric jet aircraft carrying a down-looking spectrometer to measure atmospheric effects of infrared radiant emission from vapor trails. This experiment, conducted at 65,000 feet, showed essentially no effect at altitude and no effect at the earth's surface. These measurements are expected to be important in evaluating the effect of increasing jet aircraft traffic on local and worldwide climate.

Possibilities for eliminating the hazard to manned spacecraft launches caused by lightning discharges are being studied. One approach is to predict the possibility of natural electrical discharges, using measurements of electric field conditions in the launch area just prior to launch. The other approach is to discharge potential lightning by artificial means just prior to launch of a vehicle; this should greatly reduce the possibility of hazardous discharges during launch. Small rockets were launched into thunderclouds to test this idea. The rockets did trigger discharges, and aircraft measurements obtained in the cloud shortly after the rocket firings indicated a significant reduction in electrical field strengths.

***Air Resources Laboratory (Washington, D.C.).***—The laboratory and the FAA conducted studies on the effects of the sonic boom produced by supersonic aircraft. A study was done at Pendleton, Oreg., on the effect of sonic boom on the space-time variability of atmospheric parameters. A significant small-scale space variability in overpressure was detected.

A quantitative study was conducted on the geometry and intensity of wing tip vortices produced by heavy aircraft such as the 747 and C–5A flying at low altitudes. These measurements, gathered by sophisticated meteorological instruments mounted on low-flying aircraft, were used by the FAA for establishing regulations to guarantee safe distances between aircraft in flight.

***ERL Research Flight Facility (Miami, Fla.).***—The facility provided and operated aircraft in support of weather modification experiments, hurricane surveillance, and experiments requiring collection of data.

During the solar eclipse of March 7 RFF aircraft seeded stratiform clouds with dry ice in the vicinity of Langley AFB. The seeding was done to dissipate the cloud so the NASA facility could photograph the eclipse.

During the period April 15–May 31, RFF participated, with other research groups, in an experiment over south Florida using pyrotechnics to seed cumulus cloud with silver iodide. The objectives of the experiment were to repeat the single-cloud seeding experiment of May 1968 to obtain a statistically significant cloud sample (30 clouds) and to use massive silver iodide pyrotechnic seedings of individual cumulus clouds. The latter part of the experiment was to permit recognition and documentation of any changes in mesoscale structure and precipitation resulting from seeding.

Extensive reconnaissance and research was conducted on cyclogenesis on the Atlantic coast of the northeastern United States during the fall and winter of 1969. The main objective was to provide real-time data to the operational forecaster in an attempt to improve forecasts of coastal storms.

*Aeronomy Laboratory (Boulder).*—This laboratory studies the physical and chemical processes of the ionosphere, upper atmosphere, and exosphere of the earth and other planets.

One accomplishment of 1970 was the first completely successful rocket flight of an atomic-oxygen sensor for the upper atmosphere. Atomic oxygen is an important constituent of the atmosphere at altitudes above the stratopause; prior to the development of this new rocket-borne sensor, measurements of its concentration have not been obtainable. The new measurements will permit a definitive choice of a theory of the production and loss of atomic oxygen, thus promoting our understanding of the interaction between the upper and lower atmosphere.

A continuing extensive program of laboratory measurements of atmospheric ion-molecule reaction rates has resulted in major advances in understanding the importance of water vapor in the lower ionosphere and the role of carbon dioxide in the ionospheres of Mars and Venus.

Experimental studies in upper-atmosphere plasma physics are continuing. Under investigation is the structure of radio-frequency fields within the nonuniform plasma sheaths that surround spacecraft reentering the atmosphere.

*Earth Sciences Laboratory (Boulder).*—ESL conducts research in geomagnetism, seismology, geodesy, and related technologies.

Hydromagnetic wave emissions at 0.33 Hz were observed at the Dodge satellite as it drifted across the geomagnetic field line connecting Byrd (Antartica) and Great Whale River (Canada). These data are being used in studies of rapid variations in the geomagnetic field, and to test current theories on the origin of such emissions. The use of satellite observations will be increased as a result of the successful detection described above.

*Space Disturbances Laboratory (Boulder).*—This laboratory conducts research on solar-terrestrial physics, and develops techniques for accurate forecasting of solar disturbances, and their effects on the earth environment. SDL is the national and international focal point for current information on the solar-terrestrial environment; SDL disseminates this information and current forecasts to a wide variety of users.

Studies of solar physics are conducted to gain understanding of solar energy release mechanisms with the aim of improving forecasts of the times and locations of solar flares that can produce geophysical disturbances. Recent findings include:

—Analyses of high resolution magnetograms show that the magnetic field of the solar surface can be resolved into small elements with strengths of about 20 gauss.

—Periodic brightenings on the solar disc of hydrogen alpha mottles, with a period of about 5 minutes and phase coherence over regions 30,000 KM broad have been identified with solar acoustic-gravity waves.

—It has been found that energetic ultraviolet (EUV) radiation and hard X-ray bursts from solar flares are correlated. The energy of electrons required to produce hard X-rays appears sufficiently strong to account for the EUV, through ionization and subsequent radiative recombination in the lower chromosphere.

—The intensity variations of white light emission in some large flares were found to be well correlated with a strong flux of EUV at 10 to 1030 Angstroms, and that the flux increase in white light is approximately equal to that in the EUV range. This correlation is of interest since the occurrence of white-light flares seems to be directly connected with collisions between two sunspot groups.

Studies continue on the interactions between the magnetosphere and the solar wind, the transfer of energy from the solar wind into the earth's magnetosphere, and the behavior and transport of this energy within the magnetosphere ionosphere and upper atmosphere. Satellite measurements appear to confirm current theories on magnetosphere shock wave formation.

Experimental ground-based observation of interplanetary scintillations at 11.4-meter wavelengths

yielded daily information from September 1969 through April 1970. This information on the velocity and small scale structure of the solar wind complements the suprathermal observations obtained by particle detectors aboard scientific satellites. These measurement techniques can be used to detect and fix the location of an interplanetary magnetic field sector boundary between the sun and the earth; such information could be used to predict when the boundary will sweep past the earth. If such observations became available routinely, they would be of great use in forecasting magnetic and ionospheric activity.

The SDL cooperated with a Canadian research group at York University in flying photometric sensors on two Black Brant III rockets. The start of an infrared aurora was measured by this instrumentation, yielding valuable information on the energy characteristics of a unique excited state of the oxygen molecule. This newly observed phenomenon suggests the existence of a source, other than particle precipitation, for infrared emissions. Auroral studies using rocket sensors are being planned with the University of Bergen and four launches are planned.

Data from the solar proton monitor aboard the I–TOS 1 were available for operational use during the Apollo 13 mission. Real-time data from this instrument are becoming available for routine use in space environment monitoring and forecasting. Solar proton and magnetic data, now available continuously from the ATS–1 and Pioneer satellites are particularly useful to the Space Disturbances Forecast Center for early detection and real-time analysis of solar proton events.

SDL assumed operation of the solar proton alert network (SPAN), under a contract with NASA. The SPAN network consists of four ground-based solar observation stations spaced to permit continuous observation of the sun with radio and optical telescopes. Data from this network are used to detect solar proton events. With the inclusion of this activity, the SDL has become a world data center for ground-observed solar data.

A new spectrohelioscope built and installed at SDL in 1970 permits routine observations of sunspot and plage magnetic polarities. This instrument has made possible the collection of a data base adequate for routine sunspot forecasting. It is now possible to predict the location of about 80 percent of all flares.

SDL is involved in determining specifications for a beacon to be flown on NASA's ATS F for use in studies of the magnetosphere and ionospheric electron densities. Signals from the beacon will be received by scientific groups in other nations; SDL is coordinating international scientific activities on the use of the signals.

SDL participates, under NASA contract, in the International Satellite for Ionospheric Studies (ISIS) program. The satellite data acquisition station at Boulder receives data from ISIS 1, and Alouette 1 and 2, and reduces the data to ionograms for dissemination to participating scientific groups.

Other ongoing programs of SDL include analysis of data from the Interplanetary Monitoring Platform (IMP) and Orbiting Geophysical Observatory (OGO) satellites, and support to NASA for the Apollo Telescope Mount program.

## National Ocean Survey

The National Ocean Survey (NOS) continues to make steady progress in support of the aeronautical and space programs of the United States. The basic programs of the NOS in this area include the operational use of satellites for geodesy and precise navigation, research to determine the feasibility for using satellite techniques to perform assigned tasks, and operational aerial photography for charting. In addition, NOS provides seismic and geomagnetic support to space facilities and activities.

***Geometric Satellite Triangulation.***—Data acquisition for the worldwide satellite triangulation network was completed during mid-November 1970. This program designed to establish a world data system connecting all of the continental data systems is based on the strictly geometric technique of photographing sun-reflective satellites against the star background. It began with the launch of PAGEOS in June 1966 as an integral part of the National Geodetic Satellite Program (NGSP), and will serve as the primary geometric framework for other phases of the program.

Forty-five stations in 23 countries have been established through the joint efforts of NASA, the U.S. Departments of Commerce and Defense, and the 23 host countries. This national program, under the technical direction of NOS will provide a unified three-dimensional framework encircling the earth and connecting all major land masses of the world within the extremely close tolerances in all three positional components.

NASA has overall management responsibility for the NGSP; they designed and launched the PAGEOS satellite and furnised orbital elements for computation of observation predictions. The Topographic Command (TOPOCOM) of the U.S. Army Corps of Engineers, has the primary responsibility for logistics. They furnished four field observation teams and equipment. NOS has the technical responsibility for data acquisition, reduction, analysis, and intial publication of results. NOS provided for personnel training and furnished operation manuals and up to 10 field observation teams at a time.

International cooperation has been generous and substantial, indicating the interest in and the recog-

nized need for an accurate, three-dimensional worldwide geodetic control network. The following nations participated by permitting the establishment of from one to seven camera stations within the country or its territories: Argentina, Australia, Brazil, Chad, Chile, Denmark, Ecuador, Ethiopia, Federal Republic of Germany, Iran, Italy, Japan, Mascarene Islands, Mexico, New Zealand, Norway, the Philippines, Portugal, Senegal, South Africa, Surinam, Thailand, the United Kingdom, and the United States.

During the program, the Federal Republic of Germany furnished two camera teams and two observation systems. The United Kingdom supplied a field team. The Republic of South Africa, Australia, and Mexico furnished observation teams during operations in their countries. In addition, Australia provided complete logistic support for two stations at their Antarctic bases.

To scale the satellite triangulation properly, at least four base lines spaced around the world were essential to meet NGSP accuracy requirements. In the U.S. work continued on the measurement of a precise geodimeter traverse network with connections to two of the worldwide network stations and to several of the supplemental network stations. Geodetic organizations in Norway, Sweden, Denmark, Federal Republic of Germany, Austria, Italy, Australia, Nigeria, and France cooperated by measuring the required scale lines.

The PAGEOS and Echo II satellites were utilized as observational targets for all data acquisition. Of the almost 10,000 simultaneous photographic observations scheduled during the program, almost 1,500 were successful, resulting in about 3,000 useful plates. Photogrammetric processing during 1970 included 192 new plates measured, 427 old plates remeasured to conform to new criteria, and 256 plates processed through anaylsis and computation. To date in the program, a total of 1,550 plates has been measured and processed through analysis and computation. New computer programed data reduction and analysis methods have been introduced to provide a final accuracy of at least one part per million in terms of earth dimensions.

The measuring and processing of photographic plates will continue as planned, with completion of data processing scheduled to occur during 1972.

Many developments and improvements in methods and equipment were adopted during the period 1967 to 1970. Precise transfer of epoch time was accomplished at first by use of portable crystal clocks and later replaced by portable cesium clocks. Transponders aboard geostationary satellites of the ATS type were utilized for time transfer to remote islands in the Atlantic and Pacific Oceans. A time reset capability using polar-orbiting doppler satellites was developed and successfully used at stations in the Antarctic. As Loran C chains became synchronized and available, they were used to provide time reset capabilities without the necessity for carrying portable clocks from station to station.

As data acquisition for the world net drew to a close in the fall of 1970, NOS continued the Cooperative Program of Satellite Triangulation Densification in North America which was established in 1963. TOPOCOM and Canadian interests furnished airlifts and observer personnel. The United Kingdom is continuing support by providing two observation teams.

Observations were conducted from July through September 1970 at five stations in the southern United States. Currently, field teams are on station in Alaska, Canada, and Greenland. Current plans call for the completion of the field work during 1972 and the computations during 1974.

***Photogrammetric Applications.***—In the area of aerial photography technical and theoretical assistance was provided in support of the NASA Apollo Program. A metric camera experiment was designed to determine geometric as well as gravimetric conditions on the moon.

NOS operates two aircraft to conduct aerial photographic missions required for NOAA progams. One aircraft is a Government-owned, twin-turboprop; the other is a leased, twin-engine aircraft. Both are manned by specially trained NOAA pilots and aerial photographers.

The aerial metric photography, in which panchromatic, infrared, and color film is used, supports aeronautical and nautical charting programs, seaward boundary surveys, and coastal inundation mapping. Photogrammetry is also used in surveys of areas devastated by earthquakes and hurricanes, surveys of estuarine and ocean currents, and for monitoring crustal movements in areas of high seismicity.

***Seismological Activities.***—Expansion of the Tsunami Warning System continued. The eventual goal is a network of 30 seismograph stations and 84 tsunami detectors (tide gage and wave sensors). It is planned that elements in the network will eventually telemeter actual recordings to an analysis center in Hawaii via a geostationary satellite. Automatic transmission—by triggering or on query from the satellite—automatic signal identification, and on-line earthquake hypocenter and tsunami arrival-time computations are being planned.

***Geomagnetism.***—NOS continued its long-term cooperation with NASA in the development of geophysical instrumentation for space applications. A controlled magnetic environment test chamber, the NOS Fredericksburg Geomagnetic Center, is used in this

work. NOS also provided facilities and technical assistance to the U.S. Naval Oceanographic Office for testing and calibrating instrumentation employed on Project Magnet, a worldwide, airborne geomagnetic survey.

In a joint effort with NASA, NOS is using computers to process geomagnetic analog records from some 50 worldwide magnetic observatories and geomagnetic data collected by satellite and space probes. These cooperative efforts have been in progress for the past 7 years.

NOS published a Technical Report (C. & G.S. 38) containing a description of a Fortran II computer program for deriving magnetic values at points near and above the earth's surface. The mathematical model is the International Geomagnetic Reference Field for 1965; this model is used as a common base by scientists around the world in studies of the earth's main magnetic field and in studies of related atmospheric, ionospheric, and outer space parameters. The report also includes tables of total magnetic intensity and annual change data on a worldwide grid, and small scale world charts of total magnetic intensity.

The 1970 issue of the *World Magnetic Charts* was published; for the first time analytical methods were used to describe secular change patterns as well as distribution of the magnetic field. Among other important uses, these charts provide basic magnetic data for worldwide nautical and aeronautical charts.

***Use of Navigation Satellites.***—Five NOAA survey vessels are equipped with satellite navigation systems to provide the accuracy in position fixing necessary for deep sea surveys.

***Satellite Telemetry Applications.***—The Coast Survey Marine Observation System is a stable, moored, subsurface platform from which oceanographic and atmospheric measurements can be collected. A surface float with attached telemetry antenna provides the capability for telemetering data in real time via the ATS–3 satellite. The telemetry package was provided through a cooperative agreement with NASA. The power source is a radioisotope thermoelectric generator provided through a cooperative agreement with the U.S. Navy. One of the first applications planned for the platform is its use as a tsunami detection station in the mid-Pacific Ocean.

Plans are being made for development of a system for telemetering geomagnetic data in real time via satellite from a network of magnetic observatories to a central receiving station in College, Alaska.

## National Environmental Satellite Service

The National Environmental Satellite Service (NESS) plans and operates environmental satellite systems, gathers and analyzes satellite data, and develops new methods of using satellites to obtain environmental data. As environmental satellite technology matures, sensors will be added to measure additional atmospheric characteristics, and to provide data on solar, ionospheric, oceanographic, and other geophysical phenomena.

***Environmental Satellites.***—The operational environmental satellite system inaugurated the second generation operational spacecraft with the launch of the NASA-funded I–TOS 1 in January 1970. The Improved Tiros Operational Satellite (I–TOS) replaces both the Automatic Picture Transmission (APT) and Advanced Vidicon Camera System (AVCS) satellites of the first-generation Tiros Operational Satellite (TOS) system which have been used since 1966. NOAA 1 (I–TOS A), the first of the NOAA–funded second-generation satellites, was launched in December 1970.

The I–TOS satellites fulfill a major service objective—daily observation of global weather conditions, day and night.

***Operations of NOAA Satellites.***—At yearend, two of the first-generation TOS satellites—ESSA 8 (APT) and ESSA 9 (AVCS)—remain in operable condition: ESSA 8 is used regularly to supplement the direct readout service from I–TOS 1 and NOAA 1. ESSA 9 is held in standby status to supplement the global observing services of the I–TOS spacecraft if needed.

The I–TOS satellite provides both full global coverage and direct local readout services. Observations are provided twice daily at 12-hour intervals. In addition to vidicon camera systems of the type used in the earlier TOS satellites, the I–TOS satellite carries a two-channel scanning radiometer. This sensor provides daytime and nighttime (infrared) observations of the earth's cloud cover. In addition, the data from the infrared sensor can be converted to temperature; in cloudy areas this information provides a measure of cloud top height. In clear and partly cloudy areas, sea surface temperatures may be derived from the infrared observations for use by environmental service agencies.

Both global and direct readout services are provided by I–TOS. Observations by the vidicon camera system and/or the scanning radiometer are recorded as the satellite proceeds along its orbit. The stored data are transmitted to ground stations in Alaska and Virginia, relayed to a central processing unit at Suitland, Md., processed, and made available to environmental service agencies nationally and internationally.

Data from the APT camera and the scanning-radiometer are broadcast continuously for reception by simply equipped ground stations within a 2,000-mile range of the satellite. A given station can obtain observations from the satellite during a period centered

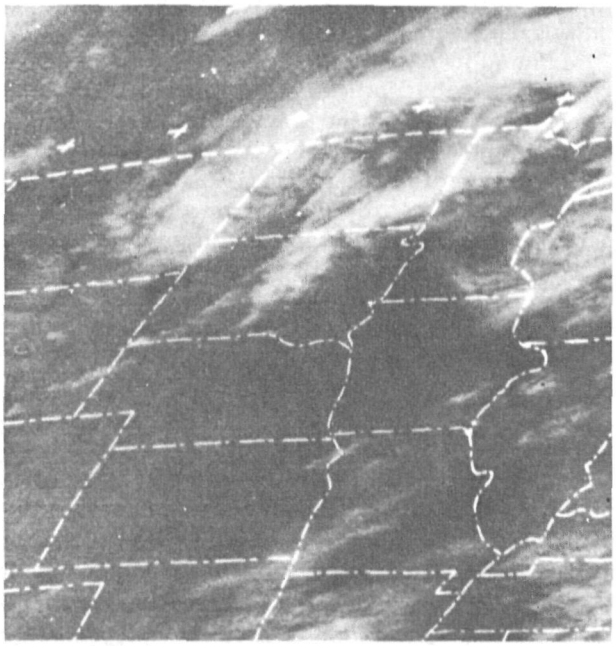
on 3 p.m., local standard time, and again around 3 a.m., local standard time. These data are acquired and used daily at some 500 locations in over 50 countries around the world. The pictures are used as a basis for local, area, and air-route forecasts, to illustrate television weather progams and newspaper weather reporting, and to support a variety of operations. In addition to the imaging and temperature sensors, the I–TOS carries a solar proton monitor (SPM) as part of its complement of operational instruments. This sensor provides a measure of the solar proton flux in the polar regions. These measurements are used in providing support to telecommunications agencies. Data from SPM were used to support Apollo 13 during critical hours before reentry.

***Applications Technology Satellites.***—NOAA has cooperated with NASA to continue the experimental operation of ATS–1 and ATS–3. During this past year, intensive operational experiments have been conducted in the application of geostationary satellite observations to severe storm advisory services and to hurricane surveillance, advisory, and warning services. Results of these experiments demonstrate the utility of near continuous observations to vital public warning and advisory services. For example:

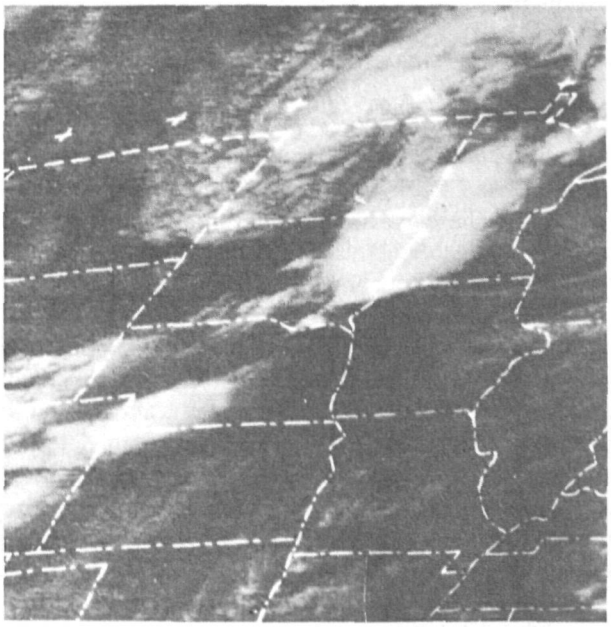
One—At the National Severe Storms Center, on July 14, 1970, a line of clouds of the type associated with the early stages of severe weather was observed in the ATS picture. These clouds were in an area known to have high potential for the development of severe weather, but were undetected in the conventional network at this time. This interpretation of the satellite pictures led to an early issuance of a severe weather watch for the area downstream from where the cloud line was located. It was some 4 hours later that radar detected the squall line. This early warning was of particular value to the public as 26 events of severe weather occurred in the forecast area later in the day.

Two—On August 13 and 14, 1970, a tropical disturbance moved across the Atlantic from off Africa to just north of Puerto Rico. As it moved toward the U.S. mainland, it was observed by both satellites and aircraft. This storm contained unusually strong easterly winds, which the aircraft measured, ranging between 50 and 70 miles per hour in local areas. Normally, whenever winds this strong are observed in a tropical disturbance, it is named and warnings are issued so that all interests in its path can take hurricane precautions. However, the satellite showed that this was not a rotating storm and, therefore, did not cause immediate danger. On the basis of these satellite observations the decision was made at the National Hurricane Center in Miami not to name the storm and not to forecast that it would become a hurricane. The storm subsequently broke up, reformed, broke up again, and finally passed into the U.S. mainland near Cape Hatteras without becoming a hurricane.

An operational version of these stationary satellites, the Geostationary Operational Environmental Satellite (GOES) is being developed in NASA's Syn-



**The thin line across the NW tip of Nebraska developed into a squall line 5 hours after this ATS-3 picture, taken at 1656 GMT, July 14, 1970.**



**Squall line over Nebraska and South Dakota, as seen in enlargement of ATS-3 photograph, taken about 2156 GMT, July 14, 1970.**

chronous Meteorological Satellite (SMS) program. Launch of the first GOES prototype, SMS–A, is planned for mid-1972.

*Nimbus IV.*—This NASA research and development satellite, launched April 8, 1970, carried an improved version (SIRS–B) of the Satellite Infrared Spectrometer (SIRS–A) first flown in 1969 on Nimbus III. SIRS–A provided measurements along the satellite track from which atmospheric temperature profiles could be derived. The SIRS–B provides measurements along and to either side of the satellite track, from which both atmospheric temperature profiles and atmospheric water vapor content can be calculated. Temperature soundings obtained routinely from SIRS–B are used daily in the numerical upper air analyses and forecasts prepared by the NWS. The SIRS soundings are now being disseminated for use by other national and international environmental service agencies.

*Environmental Service Products.*—The NESS has continued the daily production and distribution of global and sectional cloud cover mosaics for use by environmental service agencies. Production of the average brightness and minimum brightness charts has continued also. These show 5-, 10-, 30-, and 90-day average cloud cover conditions, and the extent of snow and ice fields, respectively.

During the past year, techniques have been developed for deriving sea surface temperature analyses, and depictions of vertical and horizontal cloud distribution from the I–TOS infrared measurements. Production and evaluation of these new environmental service products have begun on a trial basis.

*Operational Applications.*—Meteorologists continue to find the satellite photographs particularly useful for detecting and tracking weather systems over about 80 percent of the earth where conventional observations are not available. This worldwide weather surveillance continues to contribute to more reliable and timely environmental service—forecasts, advisories, warnings—to maritime operations and to communities located within and around the ocean basins. For example, the 45 named tropical cyclones that occurred in the Northern Hemisphere in 1970 were all detected and tracked by satellites. Advisories concerning these storms and a larger number of unnamed tropical storms in both hemispheres, were sent to U.S. installations and foreign meteorological services worldwide.

Winds derived routinely from cloud motions observed by ATS 1 and 3 are used daily in numerical weather analyses produced by the National Weather Service and by U.S. military weather services.

Solar proton observations are used by the Space Disturbance Forecast Center in Boulder to support telecommunications and space activities. The data also are distributed to other space environment service agencies.

*Research and Development Programs of the National Environmental Satellite Service.*—The NESS devotes its research and development efforts toward applications studies to increase the utility of satellite observations to environmental services and development of techniques and sensors for measuring environmental variables from a satellite platform.

Major emphasis during this past year has been placed on studies to develop and refine techniques for extracting and using quantitative data from satellite observations for weather, oceanography, and hydrology service programs.

Some progress has been made toward automating methods for extracting winds from cloud motions observed by ATS 1 and 3.

Techniques for deriving temperature and geopotential height fields from SIRS data have been refined to eliminate dependence on the short-term statistical history of conventional observations.

Techniques currently available for remote sensing of the earth's surface are ineffective when the earth is cloud-covered. Microwave technology shows some promise of reducing or removing this restriction. Basic microwave physics has been examined and microwave observations obtained from the NASA aircraft program have been analysed during 1970 as part of a program to evaluate the utility of microwave sensors for acquiring data to meet NOAA requirements.

Major effort has been devoted to the design and development of the Vertical Temperature Profile Radiometer (VTPR) and the Infrared Temperature Profile Radiometer (ITPR). The VTPR is scheduled to begin operation on I–TOS in 1972. The ITPR, an advanced version of the VTPR type atmospheric temperature sounder, has completed aircraft tests and is scheduled to fly on a NASA Nimbus satellite in 1972. A team of United States and British scientists, under the leadership of NESS, has begun preliminary studies to specify the next generation atmospheric sounder for operational use in the latter half of the 1970's.

*International Cooperation.*—Worldwide direct readout service via APT continued during 1970 and direct nighttime observations from the scanning radiometer were added. Some 50 countries own and operate ground stations to receive these satellite observations. Weather facsimile experiment transmissions through ATS 1 and 3 have continued on a semioperational basis providing APT ground stations with a variety of satellite products.

The NESS provided training and study facilities for

WMO and AID Fellows from Turkey, Japan, Korea, Indonesia, Chile, Argentina, the Philippines, India, Poland, Vietnam, and Pakistan.

***International Cooperation Plans.***—The United States is cooperating with countries engaged in space activities, as well as with other countries of the world, in the application of satellites to meteorology. This cooperation presently manifests itself in two major international programs, the Global Atmospheric Research Program (GARP) and the World Weather Watch (WWW).

During March 1970, a planning conference on GARP was held in Brussels, Belgium, to review plans and to ascertain the possible national contributions to the experiments. Environmental data from satellites will play a major role in the data requirements for the experiments. At this conference the United States reported that present plans call for one geostationary environmental satellite to be launched in mid to late 1972, and possibly another by mid-1973. In addition to the plans for geostationary satellites, the program for the polar orbiting ITOS operational meteorological satellites will be continued.

The WWW plan for 1972–75 calls for two or three near-polar orbiting meteorological satellites in continuous operation during the period. The plan also includes four geostationary satellites to provide for reasonably complete near-global cloud coverage, and for wind determinations in the tropics from cloud displacement measurements. The United States has indicated that it will support this requirement in a fashion similar to that proposed for GARP. The plan also states that at least some of the near-polar orbiting satellites should be equipped with local direct readout of cloud images. The United States is the only country so far that has supported this requirement by equipping its satellites with direct readout sensors. The United States has assisted WMO members in the installation of direct readout stations in their countries, through support under the WMO Voluntary Assistance Program. Support for 10 direct readout stations has been provided to date. Internationally, this has been a very important program since it offers to developing countries the opportunity to obtain almost instantaneous information on the meteorological conditions affecting the climate of the country for a relatively small expenditure of equipment and personnel resources.

***Washington-Moscow Data Exchange.***—The United States and the U.S.S.R. have continued the exchange of satellite information over the Washington-Moscow data circuit throughout 1970. The Soviet Union has provided television and infrared information from four identical Meteor satellites (Nos. 3, 4, 5, 6), all launched this year. The primary application of data received from Moscow at the World Weather Center, Washington, has been for research purposes. The United States has transmitted to Moscow satellite photographs and cloud analyses derived from data from ESSA 8 and 9, and the Improved-TOS satellites; these data are used routinely in the analyses made at the World Weather Center, Moscow. Representatives from the two countries met in Washington in March to discuss the joint operation of the circuit. Emerging from this meeting were agreements on high-speed data exchange and a change of circuit routing within Europe to improve reception of information.

## Environmental Data Service

The Environmental Data Service collects, processes, archives, publishes, and issues environmental data gathered on a global scale. The Service maintains data centers for geodetic, geomagnetic, seismological, meteorological, aeronomic, and oceanographic information, providing a single source of environmental data readily available to specialized and general user groups. It provides administrative support for the corresponding World Data Centers–A, which receive data from cooperative investigations and other international sources. It also sponsors and conducts research and development activities to improve these functions, and coordinates the international exchange of atmospheric and space data. These functions are exercised through the data centers and related research and information activities described below.

***The National Climatic Center (NCC).***—This center is at Asheville, N.C., and archives meteorological surface and upper air data and NOAA satellite data. Raw and processed data from the National Weather Service and its cooperators, the U.S. Air Force's Air Weather Service, the Naval Weather Service, and foreign meteorological services are archived at the NCC. The NCC provides data retrieval services for a variety of users such as aviation and space activities, research, commerce, industry, and individuals. Data users can purchase, at production cost, copies of data in manuscript, microfilm, photographic, or magnetic tape form, and data summaries prepared to user specifications. Catalogs of satellite data are published periodically by EDS. The NCC also conducts a referral service for satellite data archived elsewhere, and provides information and advice about pertinent meteorological data. Accomplishments at the NCC relating to aeronautics and space activities during 1970 include:

1. Glossy 8×10 prints of individual frames of satellite cloud photography are now available from the NCC for interested users. Satellite photographs were previously available only in film strips.



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2. The first of four volumes on the Upper Air Climatology of the Southern Hemisphere was produced in cooperation with the Department of Defense and the National Center for Atmospheric Research.

3. In cooperation with the Naval Weather Service Command, the first of two volumes of an Upper Air Climatology of the Northern Hemisphere was published; the second volume is in process.

4. Data for the above six volumes are available from NCC on magnetic tape, microfilm, and microfiche. These data have been supplied to NASA for use in its space vehicle reentry studies.

5. Progress on the design of a Clear Air Turbulence Atlas was achieved through a contract. An extensive bibliography on the subject was compiled at NCC to supplement the contractor's listing, and is available on microfilm.

6. Climatological summaries were prepared for 41 selected airports in the United States in cooperation with the Federal Aviation Administration. These summaries contain several bivariate tables computed from observations taken when ceilings were below 200 feet or visibilities were less than one-half mile. These summaries were published by the FAA.

7. Cloud analyses transmitted on the national facsimile circuit are being coded and punched into cards for use by NASA in cloud cover studies.

8. The NCC has accepted responsibility for the receipt, processing, publication, and distribution of the High Altitude Meteorological Data received from the Meteorological Rocket Network, the EXAMET Net, and participating foreign countries. The data are published for the World Data Center–A for Meteorology and Nuclear Radiation.

In addition to the above, satellite data provide a particularly important contribution to the global Basic Data Sets which are being assembled by NCC for research in the Global Atmospheric Research Program. It will be the most complete collection of meteorological data possible for one winter month (Nov. 1969) and for one summer month (June 1970). ATS cloud and wind data and the SIRS data included are unique and otherwise unobtainable over large ocean areas.

***The Aeronomy and Space Data Center (ASDC) Boulder, Colo.***—ASDC has assumed responsibility for part of a new contract program between the NASA Manned Spacecraft Center and the NOAA Research Laboratories Space Disturbances Laboratory. Under this program 24-hour-a-day optical and radio monitoring data of solar conditions are gathered at three sites: Boulder, Colo., Carnarvon, Australia, and the Canary Islands. The solar films and solar radio noise data obtained are sent to the ASDC for processing, scaling, and archiving, after which they are made available to other scientists. The program produces a set of quality-controlled, highly homogeneous data, using the system developed by NASA in 1966 for the detection of hazardous solar particles. The solar patrol films, and reduced solar flare and radio noise data from these earlier observations, made in support of the Apollo and other space missions, have been transferred to this data center, and also are available to users. The Aeronomy and Space Data Center also archives solar-terrestrial data recorded by satellites and space probes. In addition, it publishes data monthly on several solar parameters (protons, X-rays, and solar wind) measured by satellites and space probes, in *Solar Geophysical Data*. This provides the international scientific and technical community with data valuable for understanding many solar-terrestrial relationships. Analyses of satellite and space probe experiments, included in data compilations for special events are published in the World Data Center–A *Upper Atmosphere Geophysics Report* series.

***The National Oceanographic Data Center.***—Oceanographic observations acquired by aircraft and satellite are still in an early stage of development. The National Oceanographic Data Center (NODC) has been conducting pilot projects for processing, storage, and retrieval of such data. It has acquired and begun digitization of a small number of air expendable bathythermograms to develop a processing system for the large number of observations anticipated. NODC has also undertaken a study to determine optimum techniques for storage and retrieval of sea surface temperature measurements acquired by airborne radiation thermometry.

***The Geomagnetic Data Center.***—This center furnishes hundreds of copies of observatory data annually to space researchers throughout the world. These data, primarily magnetograms (analog records) and indices derived from them, are furnished on microfilm, magnetic tape, and hard copy. They are used for correlation with data obtained from satellites and for interdisciplinary space studies.

***The EDS Laboratory for Environmental Data Research.***—This EDS Laboratory is investigating the uses of meteorological satellite data for climatological analysis:

1. Cloud climatology studies, in cooperation with NASA's Goddard Space Flight Center are designed to compute the mean monthly cloud cover over the Pacific Ocean. Frequency distribution of cloud cover amounts have been computed from the 8 years of satellite cloud cover analysis available, and maps of specific cloud amount frequency are ready for publication.

2. Climatological analyses, derived from satellite data, of cloud cover amounts in the Pacific Ocean are being compared to those in the Atlantic and Indian Oceans in an effort to understand oscillations

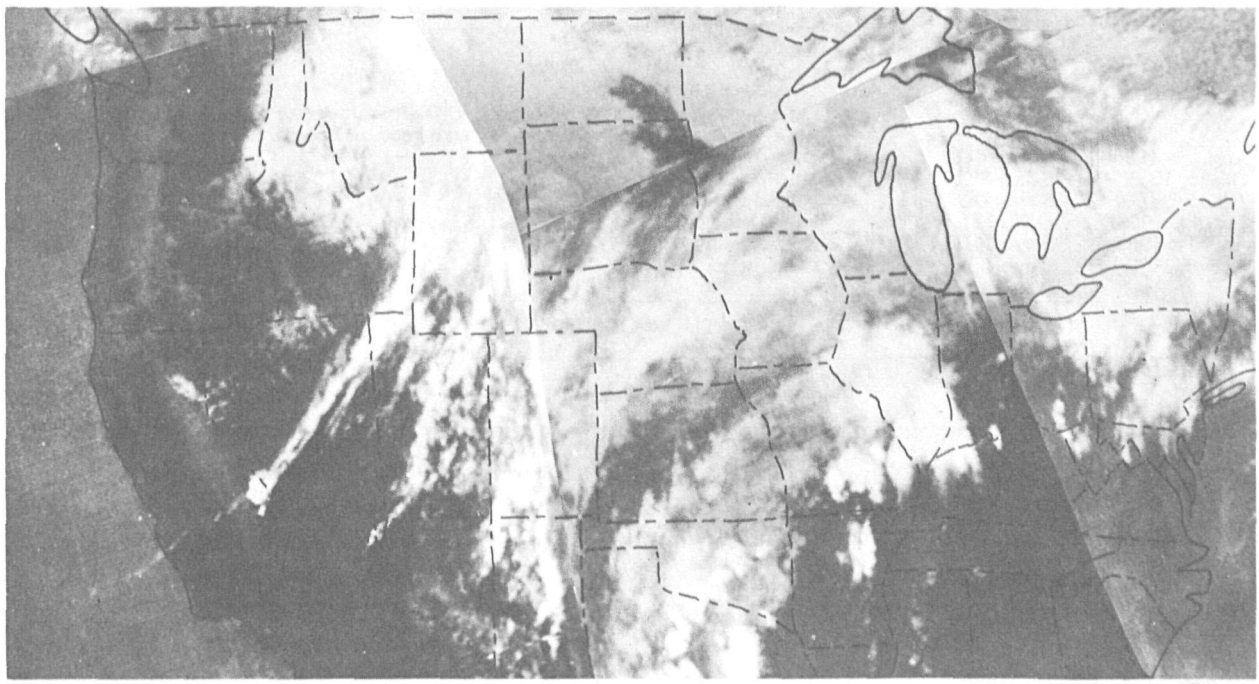
in the cloud cover.

3. The influence of orographic effects on cloud cover was investigated with satellite cloud maps. It was found that the relative humidity at or near the surface is an important factor controlling the amount of orographically produced clouds.

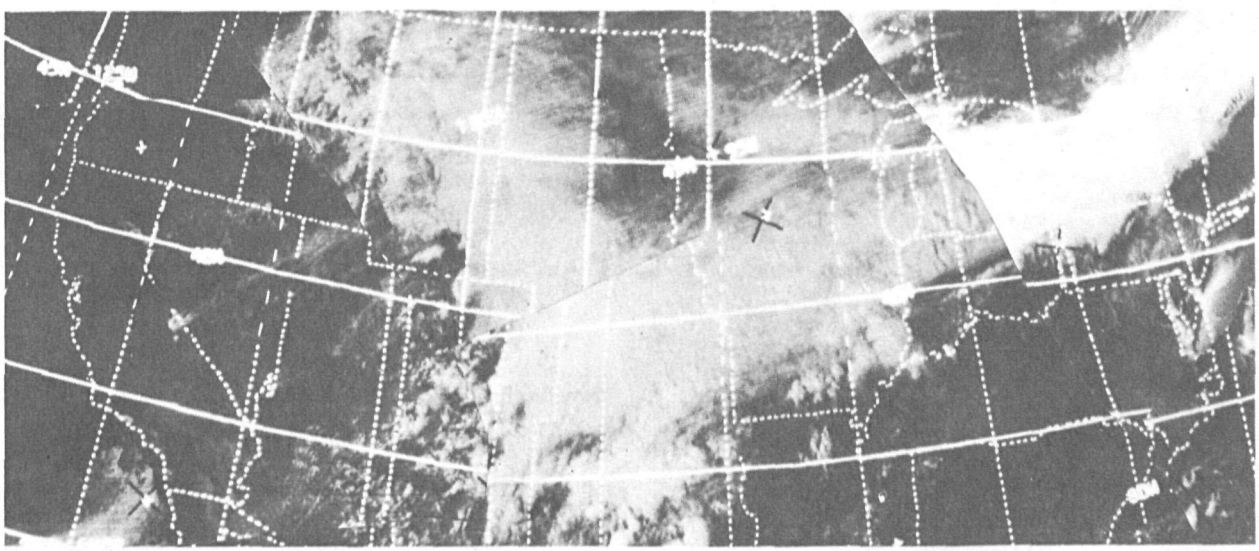
4. Estimates were made of the energy associated with the large scale buoyant lifting of air masses over tropical oceans, using cloud top height data derived from satellite measurements. The estimates based on satellite data were within 10 percent of those based on surface observations.

5. The relationship between the scales of satellite observed patterns and of sea-water temperature distributions derived from satellite data are currently being studied by EDS, NASA, and the Naval Oceanographic Office.

**Simultaneous ITOS 1 visual and infrared pictures are shown below. Infrared sensors detect temperature; visual sensors detect reflected sunlight.**



**Infrared Daytime 2038GMT Sept. 13, 1970**



**Visual Daytime 2038GMT Sept. 13, 1970**

# U.S. Applications Satellites 1958–1970

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## GEODESY

| Date | Name | Launch vehicle | Remarks |
|---|---|---|---|
| Oct. 31, 1962 | Anna 1B | Thor-Able Star | Used 3 independent measuring techniques: Doppler freq shift, flashing lights, and radio triangulation. |
| Jan. 11, 1964 | Secor I | Thor-Agena D | Uses radio triangulation and trilateration. |
| Oct. 10, 1964 | Beacon-Explorer XXII | Scout | Conducted reflecting-light geodetic measurements. |
| Mar. 9, 1965 | Secor III | Thor-Agena D | |
| Mar. 11, 1965 | Secor II | Thor-Able Star | |
| Apr. 3, 1965 | Secor IV | Atlas-Agena D | |
| Apr. 29, 1965 | Beacon-Explorer XXVII | Scout | |
| Aug. 10, 1965 | Secor V | Scout | |
| Nov. 6, 1965 | GEOS–I Explorer XXIX | Thor-Delta | |
| June 9, 1966 | Secor VI | Atlas-Agena D | |
| June 23, 1966 | Pageos I | Thor-Agena D | Spacecraft is a 100-foot-diameter balloon used as a photographic target to make geodetic measurements. |
| Aug. 19, 1966 | Secor VII | Atlas-Agena D | |
| Oct. 5, 1966 | Secor VIII | Atlas-Agena D | |
| June 29, 1967 | Secor IX | Thor-Burner II | |
| Jan. 11, 1968 | GEOS II | Thor-Delta | |
| Apr. 14, 1969 | Secor XIII | Thor-Agena D | |
| Apr. 8, 1970 | Topo I | Thor-Agena D | |

## WEATHER OBSERVATION

| Date | Name | Launch vehicle | Remarks |
|---|---|---|---|
| Apr. 1, 1960 | Tiros I | Thor-Able | First weather satellite providing cloud-cover photography. |
| Nov. 23, 1960 | Tiros II | Thor-Delta | |
| July 12, 1961 | Tiros III | Thor-Delta | |
| Feb. 8, 1962 | Tiros IV | Thor-Delta | |
| June 19, 1962 | Tiros V | Thor-Delta | |
| Sept. 18, 1962 | Tiros VI | Thor-Delta | |
| June 19, 1963 | Tiros VII | Thor-Delta | |
| Dec. 21, 1963 | Tiros VIII | Thor-Delta | First weather satellite designed to transmit continuously local cloud conditions to ground stations equipped with APT receivers. |
| Aug. 28, 1964 | Nimbus I | Thor-Agena B | Carried advanced videcon camera system, APT, and a high resolution infrared radiometer for night pictures. |
| Jan. 22, 1965 | Tiros IX | Thor-Delta | First weather satellite in a sun-synchronous orbit. |
| July 2, 1965 | Tiros X | Thor-Delta | |
| Feb. 3, 1966 | ESSA 1 | Thor-Delta | First operational weather satellite; carried 2 wide-angle TV camera systems. |
| Feb. 28, 1966 | ESSA 2 | Thor-Delta | Complemented ESSA I with 2 wide-angle APT cameras. |
| May 15, 1966 | Nimbus II | Thor-Agena B | |
| Oct. 2, 1966 | ESSA 3 | Thor-Delta | Odd-numbered ESSA spacecraft carry 2 advanced videcon camera systems. Even-numbered spacecraft carry 2 automatic picture transmission camera systems. |
| Dec. 6, 1966 | ATS–1 | Atlas-Agena D | Provided continuous black-and-white cloud-cover pictures from a synchronous orbit, using a Suomi camera system. |
| Jan. 26, 1967 | ESSA 4 | Thora-Delta | |
| Apr. 20, 1967 | ESSA 5 | Thor-Delta | |
| Nov. 5, 1967 | ATS–3 | Atlas-Agena | Provided continuous color cloud-cover pictures from a synchronous orbit, using 3 Suomi camera systems. |
| Nov. 10, 1967 | ESSA 6 | Thor-Delta | |
| Aug. 16, 1968 | ESSA 7 | Thor-Delta | |
| Dec. 15, 1968 | ESSA 8 | Thor-Delta | |
| Feb. 26, 1969 | ESSA 9 | Thor-Delta | |
| Apr. 14, 1969 | Nimbus III | Thor-Agena | Provided first vertical temperature profile on a global basis of the atmosphere from the spacecraft to the Earth's surface. |
| Jan. 23, 1970 | ITOS I (Tiros M) | Thor-Delta | Second generation operational meteorological satellite. |
| Apr. 8, 1970 | Nimbus IV | Thor-Agena | Fifth in a series of 7 advanced research and development weather satellites. |
| Dec. 11, 1970 | NOAA–1 (ITOS-A) | Thor-Delta | Second generation operational meteorological satellite |



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