NOAA's Operational Satellite Service: C^3A

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What areas of the United States are threatened by severe thunderstorms or tornadoes during the next few hours? What is the best location for California's salmon and albacore fishing fleets to operate tomorrow? Is the latest tropical depression developing into a hurricane or dissipating? What routes should be taken by shipping fleets to minimize steaming time and save precious fuel? What winds aloft are being encountered by commercial airlines around the world? Will sufficient water be available for those U.S. farms which depend on irrigation next year? Answers to this list of questions and many more depend on data collected by one of the United States' unsung space heroes—the operational environmental satellites of the National Oceanic and Atmospheric Administration (NOAA).

All Americans are aware of the space exploits of the National Aeronautics and Space Administration (NASA) and most are aware that long-distance telephone, television and other communications are aided by satellites. Readers of *SIGNAL* are also aware that the Department of Defense (DOD) operates a number of satellites to ensure the nation's security and defense posture. Surprisingly few are conscious, however, that our daily lives are being increasingly affected by a different ongoing civilian space program which is operated by the National Oceanic and Atmospheric Administration.

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NOAA's National Environmental Satellite Service (NESS) is about to complete its second decade of providing services to the people of the United States and the world. Every issue of *SIGNAL* contains such common abbreviations as C^2, C^3 and C^3I. The NOAA satellite system can be thought of as C^3A where the abbreviation denotes command, control, communications and applications (of the data).

The timely, cost-effective and successful operation of this service is a tribute to one of the most smoothly functioning interagency relationships in the Federal Government. Under the provisions of the National Aeronautics and Space Act of 1958, NASA is responsible for and funds design and development of NOAA's spacecraft as well as supporting research and development in response to mission requirements specifications provided by NOAA/NESS. NASA also serves as NOAA's prime contractor for operational spacecraft and launchings under reimbursement from NOAA. NOAA, in turn, is responsible for C^3A once the spacecraft have been launched and checked out in orbit. Even this latter function, orbital check-out, is currently performed by NASA utilizing NESS facilities.

The present system consists of two basic types of satellites:

1. The Geostationary Operational Environmental Satellite (GOES); and
2. The polar orbit satellite series which carries the NOAA name, the latest series of which is the fourth-generation, television and infrared observation satellite (TIROS-N) series. Technical management of the industrial contracts for development and manufacture of both spacecraft series is the responsibility of project teams at NASA's Goddard Space Flight Center. The current production contract for the GOES spacecraft is with Hughes Aircraft Company, although satellites currently in orbit were produced by Ford Aerospace and Communications Corporation. All polar-orbiting spacecraft have been produced by RCA AE Division.

Once declared operational, command and control is performed by NESS's Satellite Operations Control Center (SOCC) located in Suitland, Maryland, through Command and Data Acquisition (CDA) stations located at Wallops Island, Virginia, for GOES and at Wallops and Gilmore Creek, Arkansas, for the NOAA satellites. Communications are via a mix of terrestrial leased lines, Domestic Communications Satellite System (Domsat) and the GOES satellites' own transponder system.

Applications of the System

The payloads of the satellites consist of remote sensing instruments for measurements of the earth's atmosphere, land and ocean surfaces, as well as the space environment; they also include a number of communications subsystems for reliably transmitting this sensor data to earth, for relaying data from remotely sited platforms to the central data facility and to broadcast data and analyses to weather stations around the globe.

Turning to the answers to the questions posed rhetorically in the introduction, the advent of the geostationary satellite has contributed heavily to the improved performance of the National Weather Service's (NWS) forecasting of severe storms since 1974. Once NOAA's NWS (which is the biggest single "customer" for NESS data) has forecast that conditions are conducive to severe storm development, one of NESS' two GOES satellites is programmed to shift from its normal two images of the earth per hour to four or more per hour. A computer derived "enlargement" of the endangered area is then passed via direct circuits to the NESS Satellite Field Services Station and the co-located NWS National Severe Storm Forecast Center (NSSFC) or National Hurricane Center where a close watch is kept on the development of these storms.

Since the launch of TIROS-I on April 1, 1960, satellites have played an extremely important role in tracking hurricanes and tropical storms. We are able to estimate quite reliably the strength of these storms, which is very important in making forecasts of where they are going to go and how severe the damage might be. The geostationary satellites now provide essentially continuous monitoring.

In support of California fishermen, the sea surface can be monitored in the infrared portion of the radiation spectrum to detect temperature differences, including those caused by the phenomenon called upwelling. It is known that the food that fish feed on (so-called phytoplankton) is concentrated in upwelling zones. The satellite senses differences in sea surface temperature, from which upwelling can be detected. This information is provided to the West Coast tuna and salmon fishing fleets. They sail directly to the location detected by satellite rather than searching in the blind. In this way, they often catch their fish much more rapidly and efficiently.

One of the more ingenious uses for satellite observations also is dependent upon infrared sensing. We can measure the location and approximate strength of the Gulf Stream, including large eddies or circular pools that develop along its edges. The Gulf Stream moves north-eastward with a speed of several miles per hour and very strongly affects commercial ship traffic. If a boat travels with the Stream in the region of the strongest current or on the correct side of the eddies, of course the vessel is going to move faster, get to its destination sooner and save fuel.

Conversely, if a ship is going in the other direction against the Stream, it will be slowed down dramatically, and operating costs will be increased significantly. Observations now are broadcast regularly to marine interests offshore, whereby they can know where the Stream and its eddies are. Shipping in high latitudes and the Great Lakes also is provided ice information derived from satellite images to safely extend the shipping season.

A new use of the geostationary satellites which employs their communications capability involves not only our GOES satellites, but also the Geostationary Meteorological Satellite (GMS—called Himawari) of Japan and the European METEOSAT—all of which have similar, compatible Data Collection Systems. Called Aircraft to Satellite Data-Relay (ASDAR), this application provides for special data systems to be installed on wide-body jet aircraft operated by several of the world's airlines, including at this time Pan Am, SAS, KLM, Singapore Airlines, Lufthansa and Quantas as well as the U.S. Air Force (USAF).

These black boxes use data generated by the aircraft's digital inertial guidance systems and other normal on-board sensing systems to generate enroute weather messages which are relayed by the geostationary satellites to the appropriate ground station operated by NESS, the Japan Meteorological Agency (JMA), or the European Space Agency (ESA), depending upon which satellite receives the data. It is then possible to get accurate measurements of the average winds, temperature and pressure height along the routes flown by these airplanes. Furthermore, because the data are relayed in near real time, ASDAR represents an important source of upper air data for medium-range weather forecasting.

In the western United States, satellite data are used to monitor snowpack by measuring the extent of the snow cover. This information, combined with the relatively sparse ground observations that are available to hydrologists, is used to give a much better estimate of the total amount of water stored up in the snowpack. Another role of the satellite is to assist in determining when this snowpack is going to start to melt, to aid in estimating the runoff. This is of use in two ways: in improving water management by controlling reservoir levels; and assisting in warning of flooding when there is rapid melting of snow.

Command, Control and Communications

The NESS satellite system normally requires two geostationary and two polar orbit spacecraft to provide the data base upon which its services are based. In addition to these four satellites, there are other spacecraft (particularly geostationary ones) which have suffered a degree of degradation requiring launch of replacements, but which are still capable of providing some back-up service. Thus the Saellite Operations Control Center (SOCC) must maintain a measure of control over these satellites as well. At times, the number of geostationary satellites being controlled has reached as high as five.

The polar orbiting TIROS-N series of satellites, unlike the geostationary spacecraft, are in communication with the ground stations only briefly on each orbit. Therefore, they require intensive command and control during overpasses to insure readout of their highly perishable data, to update programs in their on-board computers and to monitor and adjust on-board support subsystems, such as power supply and attitude control.

In order to manage this widely diversified program, the NESS Office of Operations (O/O) utilizes an impressive melange of communications media and techniques ranging from low bandwidth analog signals to high data rate digital communications.

The C^3 for each of the two GOES satellites is outlined in Figure 1. Basic satellite to ground communication is performed at the Wallops Island, Virginia, Command and Data Acquisition (CDA) Station, utilizing the S-band links allocated to the Meteorological Satellite Service (i.e., 1670-1700 MHz space to earth and 2025-2120 MHz earth to space). The process begins when a command is transmitted to the spacecraft to start the on-board primary imaging sensor (Visible Infrared Spin Scan Radiometer—VISSR). The sensor generates a 28 megabit/second data stream during the approximately 30 milliseconds that the spinning satellite "views" the earth on each of its 100 revolutions per minute.

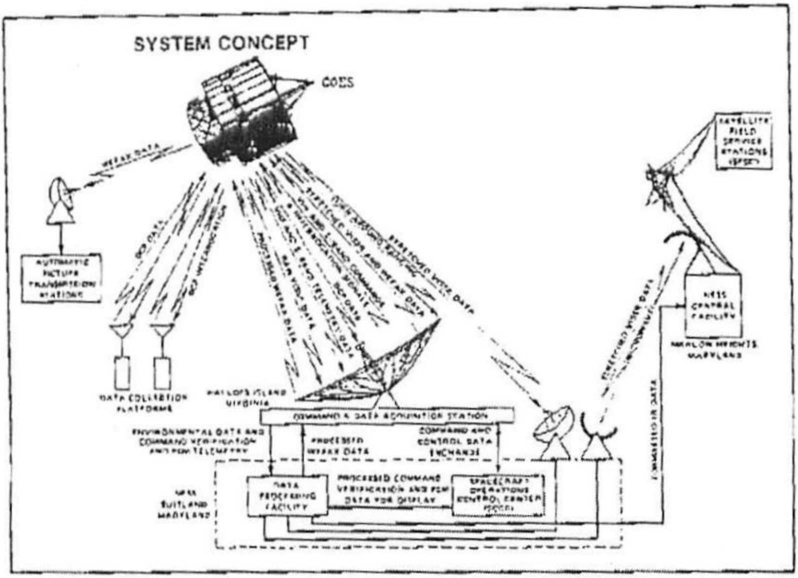

Figure 1. Command, Control and Communications System for One of the Geostationary Operational Environmental Satellites (GOES)

This burst of data is transmitted in real time to the ground where the data are buffered and retransmitted at 1.75 Mbs to the satellite during the 570 millisecond gaps between bursts of raw data. The spacecraft transponder then broadcasts this "stretched" data on the NESS facility at Suitland, Maryland (and to a number of users who have equipped themselves with appropriate receiving stations). At Suitland, selected portions of the data are diverted to the NOAA computer facility where quantitative processing takes place.

The full data stream also is forwarded via microwave to another NESS facility, where the images are broken down into several sectors, each having much lower total data content (varying resolution and geographic area such that the number of pixels is approximately equal in each output). The sectors are then transmitted at slow speed in analog facsimile format via leased telephone lines to NESS' Satellite Field Service Stations (SFSS) throughout the country. The sectors also are passed on to National Weather Service Forecast Offices, other government agencies and many users in the private sector.

Using the satellite data processed in Suitland, low resolution imagery also is formatted and sent (by telephone line) back to the CDA where it is transmitted to the geostationary satellites for broadcast to users having relatively unsophisticated receiving stations. This latter service is called WEFAX (for weather facsimile).

Telemetry plus data from the low data rate Space Environment Monitor (SEM) on board the GOES also are received at Wallops and sent to Suitland by land line where SOCC personnel monitor the spacecraft subsystems and generate appropriate commands which are sent to the CDA by land line to close the loop.

Figure 2 depicts the TIROS-N/NOAA C^3 operation. A significant difference in the modus operandi is necessitated by the fact that the two NOAA satellites are low earth orbiters (LEO) and hence communication with the spacecraft is only possible while it is within range of one of the two NESS CDA stations. Wideband data acquired at Wallops and Gilmore Creek by playing back on-board tape recorders is relayed to Suitland via domestic communications satellites of RCA American Communications, Inc. Spacecraft orbits beyond the range of Wallops and Gilmore Creek are received in Lannion, France, and relayed to Suitland via the eastern GOES spacecraft.

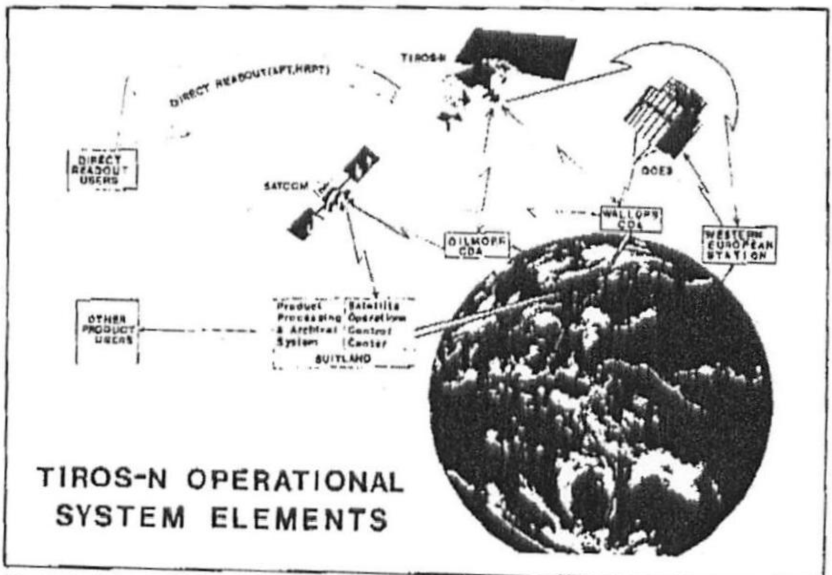

Figure 2. Schematic Representation of the Space and Terrestrial Communications Network used to Command, Control and Acquire Data from the TIROS-N Series of Polar-Orbiting Environmental Satellites

The data from the LEO, while it includes imagery, is much more heavily employed in quantitative applications such as the determination of sea surface and atmospheric temperatures. As a result, virtually all of the raw data remain in Suitland where they are processed in the NOAA IBM 360/195 computers to produce quantitative products used by NOAA's National Weather Service, the DOD and many other nations as part of the input to numerical weather forecasting.

Commands for the TIROS-N/NOAA spacecraft are generated in Suitland (at SOCC) and transmitted to the satellites via the CDAs during contact times. When necessary, they can be stored on-board the spacecraft for execution at a predetermined time. In addition to the worldwide data recorded on-board and acquired as described above, all of the sensor data are broadcast in real time from the satellite permitting reception by users equipped with suitable ground stations in all parts of the world. Indeed, the number of stations receiving data from the TIROS-N satellites' direct broadcast services is now nearing 1,000 in over 100 countries.

Summary

The NOAA satellite system is probably the least well-known of any U.S. space system. But it is the only civil program which is fully operational with a continuing commitment to provide necessary space remote sensing services to the people of the United States and the world. The necessary resources to fulfill this commitment constitute one of the most far-flung and comprehensive space systems outside the DOD yet represent a cost of less than one 5000th of the Federal Budget. As a civilian managed and operated system, it can concentrate its vital efforts on the "A" in C^3A: Applications of space remotely sensed environmental data for guarding, maintaining and improving the quality of life on planet Earth.