Chapter 15

Weather/Environmental Satellites

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Timely knowledge of weather conditions is of extreme importance in the planning and execution of military operations. Real-time night and day observations of current weather conditions provide the operational commander with greater flexibility in the use of resources for imminent or ongoing military operations. The military has firmly established the importance of meteorological data from satellites in the effective and efficient conduct of military operations. Satellite-based remote sensors provide situational awareness of environmental conditions to areas that otherwise would not be accessible via aircraft or other terrestrial means. The purpose of this chapter is to describe in detail the current fleet of Defense Meteorological Satellite Program (DMSP) satellites and their capabilities. This chapter will also describe other civil and foreign weather satellites and look ahead to the future of the weather satellite program, the National Polar-Orbiting Operational Environmental Satellite System.

Why Do We Need Weather/Environmental Satellites?

Weather and environmental satellites are capable of providing joint force commanders with essential data required for accurate, dependable weather forecasting in support of air, land, and maritime operations. Cloud cover data are needed to determine weather conditions in data-denied and data-sparse regions and to forecast target-area weather, theater weather, en-route weather (including refueling areas), and recovery weather. Surface and upper-level wind data are used to support all aspects of military operations, such as assessing radioactive fallout conditions; nuclear, biological, and chemical weapon effects; movement of weather systems; and predicting winds for weapons delivery.

Precipitation information (type and rate) is required to forecast soil moisture, soil trafficability, river stages, and flooding conditions that could impact land-based force deployment/employment. Ocean tides information is vital to naval operations for the safe passage in and out of ports and river entrances and for the landing of amphibious craft. Sea ice conditions can have a significant impact on surface/subsurface ship operations. The location of open water areas or areas of thin ice is crucial to submarine surfacing operations, submarine missile launch, and penetration by air-dropped sonobuoys, which are used for detecting submarines. Knowledge of the location and size of icebergs is also imperative for the safe navigation of surface ships and submarines. This information could provide an important advantage over adversaries in submarine and antisubmarine warfare. Most of this information is currently acquired through the use of the Defense Meteorological Satellite Program.

Defense Meteorological Satellite Program

The DMSP mission is to provide an enduring and survivable capability to collect and disseminate global visible and infrared cloud data and other specialized meteorological, oceanographic, and solar-geophysical data in support of worldwide DOD operations.[1] It was designed to provide the military with a dedicated weather observing system. Under peacetime conditions, weather data is also available from civil weather satellites, such as geostationary operational environmental satellites (GOES) and polar operational environmental satellites (POES). The National Oceanic and Atmospheric Administration (NOAA) operates these systems. While such systems provide useful information, the DMSP has specialized meteorological capabilities to meet specific military requirements. Through DMSP satellites, military weather forecasters can detect developing patterns of weather and track existing weather systems over remote areas. The DMSP accomplishes its mission through a system of space- and ground-based assets categorized into three segments: the space segment; the command, control, and communications segment; and the user segment.

Space Segment

The space segment consists of the expendable launch vehicle, the spacecraft (vehicle), and the individual sensor payloads. Previously, the DMSP satellite was launched on the Titan II launch vehicle from Vandenberg AFB, California. The last DMSP satellite, *DMSP Flight 17* (*DMSP F17*), was launched on a Delta IV-M. The next DMSP launch will be aboard an Atlas V launch vehicle. This satellite has been designated as *DMSP F18*. Details about the capabilities of these launch vehicles can be found in chapter 20 of this handbook. In addition to *DMSP F18*, there are two satellites remaining in the DMSP series: Flights 19 and 20. The launch dates of the remaining DMSP satellites will be determined by the status of the current satellites in orbit.[2] As these satellites begin to reach the end of their operational lifetime, new satellites will be launched to replace them.

The launch weight of the satellite is 2,720 pounds, with a final on-orbit weight of 2,552 pounds (including the 772-pound sensor payload).[3] The satellite is injected into a near-circular, sun-synchronous, 450 nautical mile (nm), near-polar orbit with a period of 101.6 minutes and an inclination of 98.75 degrees.[4] As discussed in chapter 6, a sun-synchronous orbit is one in which the orbital plane rotates eastward around the earth at the same rate at which the earth orbits the sun. This enables the satellite to orbit a location on the earth's surface at roughly the same local time each day. For example, if a satellite flies over New York City at 9:30 a.m. eastern time, then roughly three hours later it will fly over San Francisco at 9:30 a.m. Pacific time. Later that day it will fly over Beijing at 9:30 a.m. Beijing time.[5]

The space-based portion of DMSP nominally consists of two satellites, both of which orbit the earth a little over 14 times a day. Each satellite is capable of crossing any point on the earth twice a day.[6] The on-orbit satellites operational at the end of December 2000 were designated as the Block 5D-2 as shown in figure 15-1.

The DMSP spacecraft are three-axis stabilized, Earth-oriented vehicles. Using a hands-off, precision attitude-control system, the spacecraft are capable of maintaining a 0.01 degree pointing accuracy in all three axes.[7] This pointing accuracy is required to avoid optical distortion in the primary sensor, the operational linescan system, which will be explained in detail in a later section. The vehicles carry redundant onboard computers in both the spacecraft body and primary sensor. This redundancy has

Figure 15-1. DMSP deployed. (USAF image)

reduced the possibility of a single-point failure and increased the mean on-orbit lifetime of the spacecraft to three to four years. However, in some cases, for example *DMSP F13*, which was launched in 1995, the operational lifetime exceeded expectations by almost 10 years.[8]

The latest version of DMSP satellites is the Block 5D-3. Block 5D-3 satellites consist of the same major component subsystems as the Block 5D-2 satellites. However, 5D-3 satellites have increased payload capacity, increased power capability, improved on-orbit autonomy (60 days), and a design-life duration of five years. The first launch of a 5D-3 satellite (*DMSP F16*) occurred on 18 October 2003.[9] Although *DMSP F15*, launched in December 1999, featured the new 5D-3 satellite bus, it carried the legacy 5D-2 sensors. The 5D-3 designation has been reserved for DMSP Flights 16–20. The latest 5D-3 satellite is *DMSP F17*, launched on 4 November 2006.

Each satellite carries an operational linescan system (OLS) as the primary sensor. Up to 12 additional mission sensors can be carried on board the satellites. The combination of the OLS and the other mission sensors results in an existing capability for the DMSP to satisfy many of DOD's meteorological requirements. While each of the sensors provides valuable mission data, only the OLS and the special sensor microwave imager (SSMI) will be addressed in detail. A brief description of the other sensors will follow.

Operational Linescan System. The OLS is the primary sensor on board the satellite for providing visual and infrared imagery. The OLS, built by Westinghouse Corporation, is a sophisticated cloud imager consisting of an oscillating-scan radiometer, data processor, and storage system.[10] It is designed to gather, process, and output data in real time to tactical sites and store (on four recorders) both day and night visual data and infrared spectrum imagery. An example of an OLS image is shown in figure 15-2. The recorders on 5D-3 satellites have been upgraded from digital tape recorders to a reliable solid-state design. The OLS scanning radiometer (in reality, a Cassegrainian telescope) oscillates at six cycles per second and scans a 1,600 nm–wide swath with little or no distortion at the edges.[11]

Figure 15-2. Operational linescan system image. (NOAA photo)

Imagery collected by an OLS is formatted into three data types:

1. The thermal detector collects thermal fine-resolution data continuously day and night.
2. Light (visual) fine data is gathered during daylight only. Fine-resolution data has a nominal linear resolution of 0.3 nm. However, satellite contact duration (typically 10 minutes) limits the vast quantity of fine-resolution data which can be stored for subsequent transmission to the ground. As a solution, the capability exists on board the spacecraft to digitally average or “smooth” the fine data into a 1.5 nm–resolution format.[12]
3. Data smoothing permits global coverage in both the thermal smooth (TS) and visual light smooth (LS) modes. Nighttime collection of visual imagery can be accomplished in the LS mode by using a low-resolution photo multiplier tube (PMT). The PMT is effective under one-quarter or better moonlight conditions.[13] The OLS also has the capability to combine fine-resolution data, interleaved with “smooth,” for real-time downlink to remote ground terminals.

The capacity for on-orbit storage of fine-resolution data for subsequent transmission to the ground is limited to 40 minutes. This is less than half of the satellite’s 101-minute single-orbit period. The stored data is transmitted down to a ground station at a 4:1 ratio during a single satellite contact. Smoothing the fine-resolution data inputs permits global coverage in an LS or TS mode. Up to 400 minutes of smoothed recorded data can be played back at a 40:1 ratio during typical ground station contact.

The OLS data-management unit has a capability for acquiring, processing, recording, and outputting data from up to 12 other mission sensors. One of the most significant of these sensors is the SSMI.

Special Sensor Microwave Imager. The SSMI is a seven-channel, passive microwave radiometer sensing radiation at 19, 22, 37, and 85 GHz. It detects the horizontal and vertical polarizations at 19, 37, and 85 GHz. The microwave brightness temperatures are converted to environmental parameters such as sea surface wind speeds, rain rates, cloud water, liquid water, solid moisture, ice edge, and ice age. The SSMI data are processed at centralized weather facilities and some tactical sites. The data are collected in a swath width of almost 760 nm. The resolution is 13.6 nm at the lower three frequencies and 7.8 nm at 85 GHz.[14]

Other Sensors. Other DMSP sensors include:

- Microwave temperature sounder (SSM/T-1): A passive microwave sensor used to obtain radiometric measurements at seven frequencies. The data provides atmospheric temperature profiles for pressure levels between the earth’s surface to 30 km.[15]
- Microwave water-vapor profiler (SSM/T-2): A passive microwave sensor used to obtain water-vapor mass in seven layers and relative humidity at six levels. It provides data on contrail formation as well as location of weather systems with high water-vapor content with no associated clouds.[16]
- Microwave imager/sounder (SSMIS) (Block 5D-3 only): Also a passive microwave sensor. However, it combines the capabilities of the SSMI, SSM/T-1, and SSM/T-2 for the Block 5D-3 satellite. It is capable of scanning a swath width of 920 nm with resolutions ranging from 6.7 to 27 nm.[17]

- Ionospheric plasma drift and scintillation monitor (SSI/ES): A suite of four sensors that measures ion and electron temperatures, densities, and plasma irregularities characterizing the high-latitude space environment.[18]
- Enhanced ionospheric plasma drift and scintillation monitor (SSI/ES-2): This sensor is an upgrade to the SSI/ES. Data supports high frequency (HF) and ultrahigh frequency (UHF) communications and provides atmospheric drag calculations for low Earth orbit satellites.[19]
- Plasma monitor system (SSI/ES-3) (Block 5D-3 only): This sensor is an upgrade to the SSI/ES-2 and performs the same mission.
- Precipitating electron and ion spectrometer (SSJ/4): Detects and analyzes electrons and ions that precipitate into the ionosphere, producing the auroral displays. The sensor supports those missions which require knowledge of the state of the polar ionosphere such as communications, surveillance, and detection systems (for example, the over-the-horizon [OTH] radar) that propagate energy off or through the ionosphere.[20]
- Precipitating particle spectrometer (SSJ/5) (launched on *DMSP F16*): A follow-on to the SSJ/4 with a new detector design capable of providing a greater detailed analysis of the ionosphere.[21]
- Gamma ray detector (SSB/X): An array-based system that detects the location, intensity, and spectrum of x-rays emitted from the earth's atmosphere.[22]
- Gamma ray detector (SSB/X-2): An upgraded SSB/X with the additional capability to detect gamma ray bursts.
- Triaxial fluxgate magnetometer (SSM): Provides information on geomagnetic fluctuations that affect HF communications.[23]
- Ultraviolet limb imager (SSULI) (Block 5D-3 only): Uses the ultraviolet spectrum to provide additional data for users of HF communications, satellite drag and vehicle reentry issues, and OTH radar.[24]
- Ultraviolet spectrographic imager (SSUSI) (Block 5D-3 only): Gives the 5D-3 satellite the ability to obtain photometric observations of the nightglow and nightside aurora.[25]
- Laser threat warning sensor (SSF): An operational, static Earth-viewing, laser threat warning sensor.[26] Currently in prototype on the 5D-2 satellites, the operational version was launched on *DMSP F16* and *DMSP F17*.

The newer Block 5D-3 satellites include upgraded instruments, solid-state data recorders, and a UHF downlink which will enable data to be sent directly to tactical users sometime in the future.

Command, Control, and Communications Segment

The command, control, and communications (C3) segment (fig. 15-3) makes use of ground station sites to command and control DMSP satellites. The sites include the Fairchild Satellite Operations Center at Fairchild AFB, Washington; the Hawaii Tracking Station; the Thule Tracking Station in Greenland; and the New Hampshire Tracking Station. These sites collect environmental data collected by the DMSP constellation, which is then routed to the DMSP user community. Through its communications links, the control segment provides all functions necessary to maintain the state of health of the DMSP satellites and to recover the payload data acquired during satellite orbit. Although real-time, primary-sensor payload data are available to deployed tactical terminals worldwide, access to stored data is obtained only when the DMSP satellite is within the field of view (FOV) of a DMSP-compatible ground station. Once the stored data has been transmitted to one of the four ground stations (Thule, Fairbanks, Hawaii, and New Hampshire), that data is usually relayed to the Air Force Weather Agency (AFWA) and the Fleet Numerical Meteorological and Oceanographic Center (FNMOC) for processing via two domestic communications satellites (DOMSAT).[27]

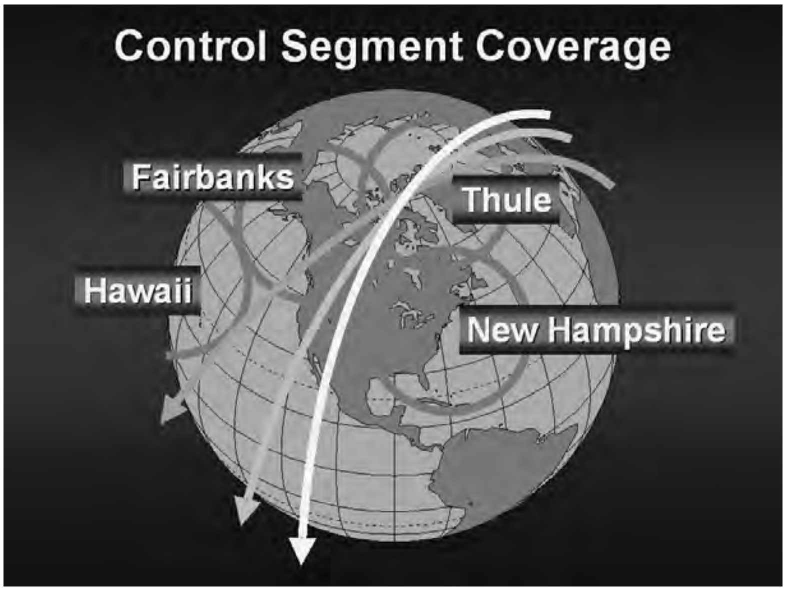

Figure 15-3. DMSP control segment coverage. (*Reprinted from* Air University, *Space Primer***,** unpublished book, 2003, 13-5.)

The Multipurpose Satellite Operations Center (MPSOC), manned by the 6th Space Operations Squadron (6 SOPS) at Offutt AFB, Nebraska (colocated with the AFWA), was the primary center for DMSP operations. As part of the merger of the DMSP with its civilian counterpart, NOAA, the MPSOC was closed during May 1998. NOAA assumed all functions related to command and control of the DMSP constellation at their Satellite Operations Control Center at Suitland, Maryland, on 29 May 1998.[28] The Space and Missile Systems Center at Los Angeles AFB, California, is currently responsible for managing the actual Defense Meteorological Satellite Program.[29]

The 6 SOPS was officially inactivated on 11 June 1998 because its operational mission was assumed by NOAA. Subsequently, the 6 SOPS Air Force Reserve Unit was activated at Schriever AFB, Colorado, and provides a "hot backup" capability for the MPSOC and takes 10 to 15 percent of the satellite contacts per week.

The Air Force Satellite Control Network, using its Automated Remote Tracking Station (ARTS), can be used for routine telemetry, tracking, and commanding (TT&C) functions. Only three of the stations (Thule ARTS, New Hampshire ARTS, and Hawaii ARTS) currently have the necessary hardware and software enhancements to retrieve DMSP mission data. Additionally, the NOAA site at Fairbanks, Alaska, supports DMSP data retrieval.[30]

User Segment

While the C3 segment meets the ongoing needs of the DMSP satellites, the DMSP user community is serviced by centralized and tactical components of the user segment. The user segment consists of Earth-based processing and communications functions required to receive, process, and distribute global weather data to support Air Force, Army, Navy, and Marine Corps requirements. Vans and shipboard terminals, using direct readout of real-time infrared and visible spectrum images from the DMSP satellites, also form a part of this segment.

AFWA and FNMOC are the centralized components of the user segment. Products provided by AFWA include aviation, terminal, and target forecasts; weather warnings and advisories; automated flight plans; and exercise/special mission support. AFWA recovers the stored mission data from the C3 segment, processes it, combines it with data from other sources (GOES, POES, etc.), generates weather and space environmental products, and provides operational support to their respective customers. AFWA is the lead DOD organization for the overall processing and distribution of centralized meteorological mission sensor data in support of worldwide military activity.[31]

FNMOC, located in Monterey, California, receives DMSP data to provide operational products and forecasts to the Navy. Specifically, FNMOC provides naval forces with analyses and forecasts of oceanographic and marine weather parameters at any global location, to include ocean surface and subsurface temperatures and other meteorological conditions. AFWA and FNMOC also provide support to other elements of DOD and many government agencies.[32]

The tactical components of the DMSP user segment are the fixed and mobile land- and ship-based tactical terminals operated by the Air Force, Navy, and Marine Corps. These terminals recover direct readouts of real-time visible and infrared cloud-cover data from the DMSP satellites as well as SSMI data.[33]

Tactical terminals (TACTERM) have been a part of the DMSP since the early 1970s. These TACTERMs have the capability to receive, process, decrypt (when necessary), display, and distribute the data from any DOD or NOAA meteorological satellite. They also receive localized information from the satellite, with the satellite transmitting the information it is currently observing down to the tactical user. Soft-copy data (terminal display) is available in real time while hard-copy data is available within 10 minutes. Imagery resolution can be both fine (0.3 nm) and smooth (1.5 nm).

The Mark IV terminal is a transportable satellite terminal designed for worldwide tactical deployment in hostile environments. Mounted in a standard shelter, the Mark IV can be towed over virtually any terrain or transported on C-130 or larger aircraft. Once deployed, it can be set up and operational within eight to 10 hours.[34]

The DMSP satellite does not constantly transmit tactical data; it must be commanded to do so. Tactical users (shipboard or land-based) must make their requirements known to AFWA. AFWA coordinates with the NOAA Operations Center to command the satellite to transmit the tactical data during specific portions of its orbit. Not all mission sensor data is available to the tactical user, but information from the operational linescan system and special sensor microwave imager is available.

Another TACTERM, the Mark IVB, increases the ability to process DMSP, POES, and GOES satellite data, allowing for processing and displaying OLS and mission sensor data by the tactical user. It provides timely environmental databases and images from remotely sensed satellite observations to users and external communications/

processing systems. The Mark IVB is a stand-alone system consisting of a tracking antenna for polar orbiting satellites (to include DMSP) and a pointing antenna for geostationary satellites such as GOES. The system also has a processing area containing a console for operator/maintenance personnel to control and monitor the system and to perform routine maintenance.[35]

The AN/SMQ-10 and AN/SMQ-11 shipboard receiving terminals are complete satellite meteorological terminals that receive, process, and display real-time DMSP data. The data retrieved from the DMSP include the following: (1) high-resolution visible and infrared images of clouds; (2) atmospheric moisture and temperature profiles; (3) high-resolution ice-edge mapping in polar regions; (4) ocean wind velocity; and (5) ionospheric data.[36] The system is designed to be used aboard aircraft carriers and designated capital ships. The SMQ-11, an upgrade to the SMQ-10, is capable of receiving full-resolution DMSP OLS and SSMI data as well as data from other civilian satellites.

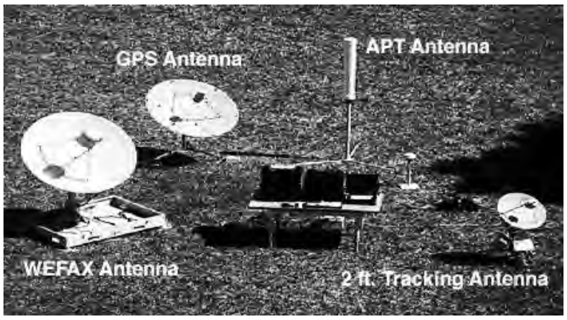

Figure 15-4. Small tactical terminal. (*Reprinted from* DMSP Overview, http://www.fas.org/spp/military/program/met/overview/dmsp35a.html [accessed 28 May 2009].)

A fully capable field system, the small tactical terminal (STT) is a lightweight, two-man portable, direct receiving, processing, and display system (fig. 15-4). The STT processes and stores data, generates meteorological soft- and hard-copy display products, and forwards imagery and data to other systems. It receives and automatically processes the DMSP real-time data smooth (RDS) and real-time data fine (RTD). (The basic terminal is only capable of processing smooth data [RDS].)[37]

The STT comes in four configurations: basic, enhanced, light-weight STT (LSTT), and the Joint Task Force Satellite Terminal (JTFST).[38] The basic STT can be upgraded to the enhanced configuration by adding an AN/TMQ-43 enhancement kit. The kit adds the capability to receive, process, and display RTD data from DMSP and high-resolution picture transmission (HRPT) data from NOAA satellites. The new LSTT can do everything the enhanced terminal can do but uses a smaller three-foot tracking dish. The four-foot dishes will be phased out as they need maintenance and replaced with three-foot dishes. The LSTT also has a smaller display system and can be carried in nine cases vice 12.

The STT receives data directly from the satellites in data streams consisting of visual and infrared imagery and mission sensor data. It receives and displays:

- Polar-orbiting automatic picture transmission (APT) imagery (basic configuration and above).
- HRPT imagery (enhanced, LSTT, JTFST).
- Weather facsimile (WEFAX) data (basic and above).
- High-resolution imagery transmitted by geostationary satellites (enhanced and above).[39]

The Army primarily uses the basic terminal, which receives only APT and WEFAX data, while the Air Force uses the enhanced, LSTT, and JTFST terminals.

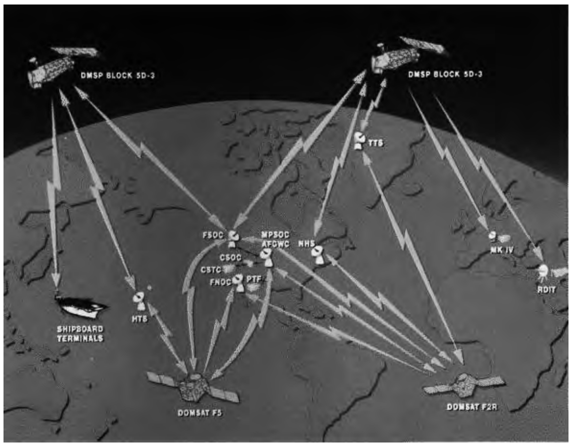

Figure 15-5. DMSP space, C3, and user segments. (*Reprinted from* DMSP Overview, http://www.fas.org/spp/military/program/met/overview/dmsp03.html [accessed 28 May 2009].)

DMSP Summary

The DMSP satisfies DOD's requirements for an enduring and survivable capability to collect and disseminate global visible and infrared cloud data to support worldwide DOD operations. Additionally, the DMSP collects and disseminates other specialized meteorological, terrestrial, oceanographic, and solar-geophysical data. The nominal two-satellite constellation provides worldwide data in a timely manner to the AFWA and FNMOC. Real-time regional data are also provided to deployed fixed and transportable (ground- or ship-based) tactical terminals. Figure 15-5 provides a graphical depiction of all three segments of DMSP.

NOAA Polar Operational Environmental Satellites

The POES satellite system is similar to the DMSP with regard to orbit type (sun-synchronous) and environmental monitoring capabilities. POES, however, is geared more toward civil applications, including weather analysis and forecasting, climate research and prediction, global sea surface temperature measurements, volcanic eruption monitoring, and forest fire detection, to name a few. These capabilities support aviation safety (i.e., volcanic ash detection and weather forecasting), support maritime and shipping safety through ice monitoring and prediction, and support search-and-rescue missions worldwide.[40]

The current NOAA POES constellation consists of four satellites: *NOAA-15*, launched 13 May 1998; *NOAA-16*, launched 21 September 2000; *NOAA-17*, launched 24 June 2002 (fig. 15-6); and *NOAA-18*, launched on 20 May 2005. All four of these satellites carry improved sensor suites, as compared to their predecessors, including the advanced microwave sounding units (AMSU-A), which provide more accurate temperature and water vapor profile information for weather forecasting.[41] They also carry the advanced very high resolution radiometer (AVHRR), which provides imagery data to scientific, commercial, and educational groups worldwide.[42] Finally, each of these satellites is equipped with the search and rescue satellite-aided tracking (SARSAT) system. The SARSAT system consists of the search and rescue repeater, which receives and retransmits position information from emergency beacons on three frequencies (121.5 MHz, 243 MHz, and 406 MHz) to ground stations. It also has a search and rescue processor which receives 406 MHz transmissions, provides measurements of the frequency and time, then retransmits the data in real time, and stores it aboard for later transmission.[43] It has the ability to store and continuously download received data for up to 48 hours to ensure that ground stations are able to pick up the signal and plan and conduct search and rescue missions. As of April 2008, 22,058 people worldwide have been rescued using this system.[44]

Figure 15-6. *NOAA-17*. (NASA image)

NOAA typically flies its satellites in pairs so that the two satellites are in complementary orbits. This means that the first satellite in the orbit would cross a certain point on the earth at a particular local time each day—mid-morning, for example. The second satellite would complement the first by crossing that same point on the earth at a later local time that same day, in this case mid-afternoon. This allows analysts to study the change in the weather pattern from the mid-morning to the mid-afternoon and facilitates among other things the creation of forecasts.

NASA Earth Observing System

The Earth observing system (EOS) of satellites was developed by NASA as part of the US Global Change Research Program to "monitor, understand, and ultimately predict the nature of global changes and the mechanisms that cause them."[45] The *Terra* satellite, formerly known as the *EOS AM-1*, was launched on 18 December 1999.[46] The *Terra* was the first in the EOS program series. It was launched from the US Air Force Western Space and Missile Center, Vandenberg AFB, into a 705 km (438-mile) sun-synchronous orbit with a morning (1030 local time) sun-shadow crossing time. *Terra* was designed with an operational lifetime of five years.[47]

The *Terra* spacecraft provides detailed measurements of clouds, aerosols, and the earth's radiative energy balance, together with measurements of the land surface and its interaction with the atmosphere through exchanges of energy, carbon, and water. These interactive processes present scientific questions of the highest priority in the understanding of global climate change.

The suite of instruments on the *Terra* spacecraft is highly synergistic, and measurements from each instrument directly address the primary mission objectives. For example, four of the five instruments will acquire simultaneous complementary observations of cloud properties and provide error-free Earth surface images. All instruments together will contribute to detecting environmental changes and thereby accelerate understanding of the total Earth system.[48]

The second EOS satellite, *Aqua* (formerly known as *EOS PM-1*), was launched on 4 May 2002. The primary mission of *Aqua* was to collect information about the earth's water cycle in all its forms (liquid, gaseous, and ice) as well as to measure the rate of flow of radiative energy, aerosols, vegetation cover on the land, oceanic organic matter, and air, land, and water temperatures.[49] It was designed for an operational life of six years.[50]

The *Aqua* satellite was the first mission in a six-satellite constellation of EOSs called the A-Train.[51] The purpose of the A-Train constellation was to provide near simultaneous measurements of aerosols, clouds, temperature, relative humidity, and other information by positioning the satellites such that each one passes over the same geographic area in succession (usually separated by a few minutes along the same orbit). This allows scientists to develop a clearer overall picture of the various elements affecting environmental conditions.[52] The other satellites comprising the A-Train constellation include the *Aura*, launched 15 July 2004, the French *PARASOL*, launched 18 December 2004, and the *CloudSat* and *Calipso*, both launched 28 April 2006.[53] The sixth satellite, the *Orbiting Carbon Observatory* (*OCO*), was launched 24 February 2009, but the fairing on the Taurus XL launch vehicle apparently failed to separate.[54]

Civil/Foreign Geostationary Weather Satellites

The average time it takes to get a DMSP product to its user is 15 to 45 minutes depending on satellite overpass and priority of the tasking. To help offset this time delay, civilian and foreign geostationary satellites are employed. Geostationary satellite systems such as NOAA's GOES and Europe's Meteorological Satellite (METEOSAT) offer a rapid refresh rate of cloud/weather data every 30 minutes. These satellites also offer a constant look angle resulting in high-quality "nightly news" pictures (fig. 15-7). Spatial resolution can be as good as 0.5 nm; however, resolution degrades the farther away you get from the nadir (center of the field of view).

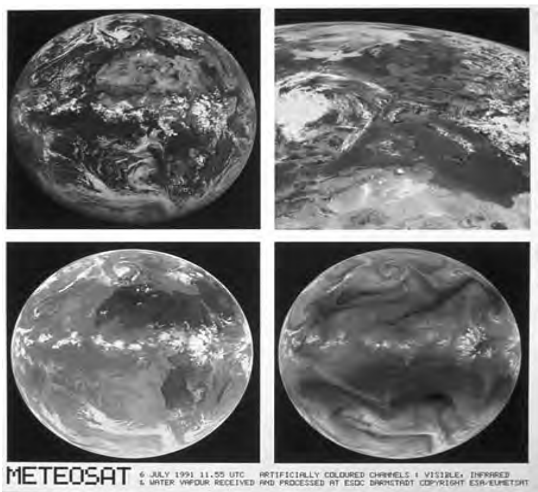

Figure 15-7. Geostationary METEOSAT scan. (European Space Agency photo)

Currently, NOAA operates two GOES satellites over the United States: (1) *GOES East* at 74.7° west longitude, and (2) *GOES West* at 134.9° west longitude.[55] The European Space Agency's METEOSAT series of satellites, which are similar to GOES, covers the Atlantic Ocean and European landmass. Spatial resolution of the METEOSAT is 2.5–5 km at nadir (located at 0° longitude).[56] An improved version called METEOSAT Second Generation (MSG) is capable of resolutions of 1 km. The most recent satellite, *MSG-2*, launched from Kourou, French Guiana, on 21 December 2005.[57]

Other international geostationary satellites include Japan's geostationary meteorological satellite (GMS) and the Indian National Satellite (INSAT) System. The GMS is based on an older GOES design and maintains similar capabilities. The GMS has since been replaced by Japan's Multifunctional Transport Satellite (MTSAT)-1R, which launched on 26 February 2005.[58] The MTSAT-1R is currently located in geostationary orbit at 140° east longitude.[59]

INSAT is operated by India; because of its imaging over the Indian landmass, India has chosen not to share INSAT data with the rest of the world. However, there is an agreement in place with the Indian government that allows INSAT data to be passed to the United States.[60] INSAT also provides a communications relay for India as a secondary mission. The most recent INSAT launch was *INSAT 4B*, which launched from Kourou, French Guiana, on 11 March 2007.[61]

The ability for weather satellites to image landmasses as well as clouds has opened the door for other types of civil/commercial imaging systems that further study the world environment. Primarily designed to aid in scientific studies of the earth's environment, such as rain forests, desert regions, and so forth, environmental satellites have also been used to gain wide-area imagery for military purposes.

National Polar-Orbiting Operational Environmental Satellite System

On 10 May 1994, the White House issued Presidential Decision Directive/National Science and Technology Council-2 (PDD/NSTC-2), "Convergence of U.S. Polar-Orbiting Operational Environmental Satellite Systems." The purpose of the PDD was to establish "a single, converged, operational system [that] can reduce duplication of efforts in meeting common requirements while satisfying the unique requirements of the civil and national security communities."[62] The program resulting from that directive was designated as the National Polar-Orbiting Operational Environmental Satellite System (NPOESS).[63]

The tri-agency NPOESS Integrated Program Office (IPO) was created on 3 October 1994 to develop, manage, and operate NPOESS.[64] The NPOESS IPO includes representation from the Department of Defense, NASA, and the Department of Commerce, more specifically NOAA. The NPOESS IPO is located organizationally within NOAA and is based in Silver Spring, Maryland. NOAA has overall responsibility for the program, including C3 operations of the satellites. DOD is responsible for the major systems acquisition and support of the NPOESS satellite systems. NASA is responsible for developing and fielding new technologies that meet the operational requirements of NPOESS.[65] The three objectives of NPOESS include the following: (1) provide a single, national, polar-orbiting, remote-sensing capability to acquire, receive, and disseminate global and regional environmental data; (2) incorporate new technologies from NASA's Office of Earth Science (OES) program; and (3) encourage international cooperation.[66]

In an effort to meet the first objective, DOD's Defense Meteorological Satellite Program and NOAA's polar operational environmental satellites have been merged to be operated jointly by the NPOESS Integrated Program Office. The original plan was to launch a constellation of six NPOESS satellites to provide accurate and timely atmospheric, oceanic, terrestrial, climatic, and solar-geophysical data products that met the operational requirements of both the civilian and military users.[67] While these new satellites were being developed, the remaining DMSP and POES satellites currently in the inventory would continue to be launched to provide weather and environmental data. This planned "evolution" of capabilities from DMSP/POES to NPOESS was supposed to begin with the launch of the first NPOESS satellite, *NPOESS C1*, in 2008.[68] However, due to massive cost overruns in the acquisition of the new NPOESS satellites, major changes had to be made to the program. These changes included a reduction in satellites from six to four, a reduction in sensors to be carried aboard the satellites (to reduce costs), and a new projected launch date for *NPOESS C1* of 2013.[69] The projected launch dates for *NPOESS C2*, *C3*, and *C4* are 2016, 2020, and 2022, respectively.[70]

To meet the second objective, NASA, in conjunction with the NPOESS IPO, is working on the NPOESS Preparatory Project (NPP). The purpose of the NPP is twofold. First, the NPP will serve as a "bridge" between NASA EOS satellites (*Terra* and *Aqua*) and NPOESS by providing a platform to calibrate, validate, and verify the next generation of operational sensors scheduled to be flown aboard the NPOESS. The NPP will enable continuity by providing weather/environmental data after *Terra* and *Aqua* have reached the end of their operational lifetimes.[71] Second, the NPP will provide risk reduction for NPOESS through pseudo-operational demonstration and validation of instruments and algorithms prior to the first NPOESS flight in 2013.[72] The NPP satellite is currently scheduled to launch in June 2010.[73]

The third and final objective of encouraging international cooperation is being met via the incorporation of the European Meteorological Operational (MetOp) Satellite Program as part of the NPOESS constellation.[74] *MetOp-A* launched on 19 October 2006. The *MetOp-A* satellite is equipped with an array of sophisticated instrumentation, thus enabling a "major advance in global weather forecasting and climate monitoring capabilities."[75] The MetOp-A program was established by the European Space Agency and European Organization for the Exploitation of Meteorological Satellites (EUMETSAT). EUMETSAT has partnered with NOAA to provide free meteorological data to users worldwide free of charge.[76] *MetOp-A* is currently flying in a complementary orbit to *NOAA-18* (see previous section on NOAA POES for a description of complementary orbits). *MetOp-A* serves as the primary mid-morning weather-monitoring satellite, and *NOAA-18* is the primary mid-afternoon weather-monitoring satellite.[77]

Although there have been some delays in the acquisition process for NPOESS, the program is well on its way to being fielded as a fully operational system. The motives and reasoning for initiating this program are still valid. With continued cooperation among the US agencies within the NPOESS IPO as well as our European counterparts, the National Polar-Orbiting Operational Environmental Satellite System will carry on the legacy established by DMSP and POES by providing improved forecasts and warnings and long-term data continuity for climate monitoring and assessment in support of military and civilian users.[78]

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