CHAPTER 6

SATELLITE SURVEILLANCE OF TROPICAL AND SUBTROPICAL CYCLONES

6.1. Satellites.

6.1.1. Geostationary Operational Environmental Satellite (GOES). Using modern 3-axis stabilization for orbit control, GOES-13 at 75°W and GOES-11 at 135°W support the operational two-GOES constellation. Independent imager and sounder instruments eliminate the need to time share, yielding an increase in spatial coverage of image and sounder data at more frequent scanning intervals. The GOES also provides higher resolution and additional spectral channels than its predecessor, affording the hydrometeorological community improvements in detection, monitoring, and analysis of developing tropical cyclones. From 135°W and 75°W, routine GOES satellite data coverage is extensive, stretching from the central Pacific through the Americas to the eastern Atlantic, including the vital breeding grounds for tropical cyclones.

Routinely, each GOES schedule provides two views of the CONUS (GOES-11 view is termed PACUS) every 15 minutes. More frequent interval scans can be employed to support NOAA's warning programs, including the tracking of tropical and subtropical cyclones. Government agencies and the private sector have access to digital data transmissions directly from NOAAPORT, from NOAA's Environmental Satellite Processing Center (ESPC), or directly from GOES.

The current series of GOES satellites provide satellite data generated from full resolution imager and sounder data. Imagery at 1, 4, and 8 km resolution is available for daytime and nighttime applications. The increased resolution of the satellite imagery is a vast improvement from previous satellites. Visible data are available at 1 km, "shortwave" infrared (channel 2 data) as well as the infrared channels 4 and 5 are available at 4 km resolution, and water vapor (channel 3) is available at 8 km resolution on GOES-11 and 4 km resolution on GOES-13. Channel 2 data are valuable for the detection of low clouds, fog, stratus, and surface hot spots; channel 5 data, available on GOES-11, in combination with data from channels 2 and/or 4 are useful for detecting volcanic ash in the atmosphere. On GOES-13, channel 6 is a 13.3 μm band at 8 km that is useful in the detection of CO_2. Channel 6 improves the measurement of the height of clouds, derived winds and volcanic ash, thus improving computer model forecasts and ash warnings to the aviation community. The digital data may be enhanced to emphasize different features as desired. A suite of digital data and environmental products is available to users in the National Weather Service (NWS); the National Environmental Satellite, Data, and Information Service (NESDIS); other Federal agencies; the academic community; and many private agencies, both national and international. These data are made available through NOAAPORT, from ESPC, the Internet, and other means such as local networks.

6.1.1.1. GOES-13. GOES-13, launched May 24, 2006, supports the GOES-East station at 75°W and serves NOAA operations, to include the NHC, other Federal agencies, and the private sector. Various imager channels at higher resolutions are being utilized to monitor the intensification and movement of tropical cyclones over the Atlantic Ocean and a portion of the East Pacific. In particular, greater detail in the imagery facilitates tropical cyclone

monitoring and analysis, and the use of the GOES imager channel 2 has vastly improved the detection of low-level circulation centers at night to assist in storm positioning. Retrievals from the GOES sounder are being incorporated into NCEP's numerical models to improve model output. In addition, sounder data are being exploited to generate derived product imagery such as total precipitable water, atmospheric stability indices, surface temperatures and cloud heights.

During the 1996 hurricane season, NESDIS instituted a specialized GOES-East sounder schedule consisting of four sectors covering distinct areas of the Atlantic Ocean. Of the four sounder sectors, the CONUS sector is scanned every hour and covers the northern Gulf of Mexico and the east coast of the United States. During routine scanning operations, of the other 3 sounder sectors (the Gulf of Mexico, North Atlantic, and the East Caribbean) the Gulf of Mexico sector is designated as the “primary OCONUS” (off CONUS) sector and is scanned 4 times in a 6 hour period, while the other two sectors are only scanned once in every 6 hour period. Event driven, this “primary OCONUS” sounder sector can be changed by the NHC. The "primary" OCONUS sector provides frequent scans over the area of interest to generate vertical profiles of temperature and moisture, and additional derived environmental products such as atmospheric winds.

6.1.1.2. GOES-11. GOES-11 was launched on May 3, 2000, and supports the GOES-West station at 135°W. The routine scanning mode of GOES-11 provides coverage of the Northern and Southern Hemisphere eastern Pacific Ocean as well as the western United States. The GOES-West satellite also supports the missions of both the NHC and the CPHC, and provides coverage of developing tropical cyclones over the East and Central Pacific. The DOD and other Federal agencies are also supported.

During the 2008 Central Pacific hurricane season, NESDIS instituted a specialized GOES-West sounder schedule consisting of additional Hawaii sectors. During routine operation, the GOES-West sounder scans two Hawaii and four North Pacific sectors. To aid in the surveillance and input of additional sounder data into hurricane models, the Central Pacific Hurricane Sector (CPHC) can request an alternate GOES-West sounder schedule that replaces two North Pacific sectors with two Hawaii sectors, allowing for four Hawaii sector scans and two North Pacific sector scans in a six-hour period.

6.1.1.3. GOES-12. GOES-12 was launched on July 23, 2001, and was operating as the GOES-East satellite until April 14, 2010. On April 26, 2010, GOES-12 began to be moved to its new station at 60° West, and is operating at that location in support of GEOSS in the Americas providing imager and sounder coverage to South America and surrounding areas. GOES-12 provides one imager scan every 15 minutes for the full South American continent, and a sounder scan every four hours. Data from GOES-12 is not processed at NESDIS.

6.1.1.4. GOES-N Series. The GOES-N Series will be used to continue and enhance the environmental monitoring and communications functions of the GOES-I thru M (GOES-8 thru 12) series of NOAA operational spacecraft. GOES-13, the first in the GOES-N series, was designed with a different spacecraft bus than the previous GOES series, and contains larger power cells. This design results in the increased accuracy in navigation and instrument radiometrics, and the operation of the imager and sounder through the satellite “eclipse” season.

GOES-O and GOES-P were also procured as part of the GOES-N series contract. GOES-O was launched on June 27, 2009 and renamed GOES-14; GOES-P was launched on March 4, 2010 and was renamed GOES-15.

6.1.1.5. GOES-14. GOES-14 was launched on June 27, 2009. GOES-14 is the spare GOES located at 105° West and is ready to back-up GOES-13 or GOES-11.

6.1.1.6. GOES-15. GOES-15 was launched on March 4, 2010, and is undergoing Post Launch Testing at 90° West. GOES-15 is the last of the GOES N series of satellites and will be used as standby.

6.1.2. EUMETSAT Meteosat Geostationary Satellites. Meteosat-9, launched December 21, 2005, and stationed at the Prime Meridian (0º), replaced Meteosat-8, which is stationed at 9.5º East, on April 11, 2007. It provides vital coverage of developing tropical waves off the African Coast and eastern Atlantic Ocean. Conventionally, the full disk IR, visible (VIS), and water vapor imagery have a 3 km resolution whereas a specialized VIS sector provides a maximum 1 km resolution. This visible sector has a limited scan, and will shift from the West Indian Ocean to the East Atlantic Ocean from 14:00 UTC to 01:00 UTC every day during hurricane season. This shift will ensure interests monitoring for tropical activity in the North Indian Ocean (Meteo-France) as well as the East Atlantic (TPC) will be satisfied. The digital data are transmitted to NESDIS and NCEP at the NOAA Science Center (NSC) in Camp Springs, MD, every 15 minutes. They are also available to the TPC and the Storm Prediction Center (SPC) through an encrypted DOMestic SATellite (DOMSAT) relay and through direct transmission from ESPC. Meteosat-7, launched September 2, 1997, provides coverage for the monitoring of Indian Ocean tropical cyclone formation and development while stationed at 57° East, with Meteosat-6 at 67° East in standby status.

In December 1995, EUMETSAT, the program administrator, began encrypting digital Meteosat data 24 hours per day to regulate use within Europe. Based on international data policy agreements, U.S. non-government users are allowed access via a domestic satellite to non-encrypted Meteosat data 4 times per day at synoptic times; at other times, the data are encrypted. Hence, if quarter-hourly transmissions are required to support operational requirements, it is necessary for users to register with EUMETSAT to acquire decryption devices for installation at their local site (NOAA/DOD and other U.S. government agencies are registered).

6.1.3. MTSAT-1R. The Multifunctional Transport Satellite-1 Replacement (MTSAT-1R) was launched for the Japanese Meteorological Agency (JMA) on February 26, 2005. MTSAT-1R is located at 140° East, covering the West Pacific Ocean, East Asia, and the East Indian Ocean. MTSAT-1R is similar to GOES as it carries a 5-channel imager (one visible channel at 1 km plus four IR channels at 5 km, to include a new low-light IR channel). MTSAT-1R provides imagery for the Northern Hemisphere every 30 minutes, and JMA makes the data available to 27 countries and territories in the region. Data from MTSAT-1R is available to CONUS users via the DOMSAT or directly from ESPC and available to Pacific OCONUS users directly via downlinks in Hawaii and Guam.

6.1.4. MTSAT-2. MTSAT-2, launched February 18, 2006, is scheduled to replace MTSAT-1R on July 1, 2010. MTSAT-2 carries the same 5 channel imager with data downlink through the High Resolution Picture Transmission (HRPT) service. NOAA will continue to obtain the HRPT through the current downlink and corresponding DOMSAT uplink in Keana Point, Hawaii. MTSAT-2 is stationed at 145° East, and provides coverage for the monitoring of tropical cyclone formation and development for the West Pacific Ocean, East Asia, and the East Indian Ocean. The transportation and communication functions of MTSAT-1R will continue to be utilized after July 1, 2010, when MTSAT-1R becomes secondary.

6.1.5. COMS. The Communication, Ocean and Meteorology Satellite (COMS) is the first operational weather and ocean satellite from The Republic of Korea. COMS was developed by the Korean Astronomical Research Institute (KARI) through contract with EADS Astrium, and carries a 5 channel imager similar to the image on board MTSAT-1R and GOES. The Korean Meteorological Administration (KMA) will operate COMS through its National Meteorological Satellite Center (NSMC) with coverage of the West Pacific and East Indian oceans. COMS's launch occurred on June 26, 2010, and is slated to operate at 128.2° East.

6.1.6. Initial Joint Polar System (IJPS). Two primary operational polar orbiting satellites, NOAA's NOAA-19 and EUMETSAT's Metop-A, provide image coverage four times a day over a respective area in 6 spectral channels (however only 5 channels can be supported at one time; channel switching is used to support the 6th channel). These satellites cross the U.S. twice per day at 12-hour intervals for each geographical area near the Equatorial crossing times listed in Table 6-2. NOAA-19 and Metop-A provide the same capabilities as previous NOAA satellites, except that the Advanced Microwave Sounding Unit–B (AMSU-B) sensor flown aboard NOAA-17 and previous polar orbiters has been replaced by the Microwave Humidity Sounder (MHS) on NOAA-19. Data are available via direct readout—high-resolution picture transmission (HRPT) or automatic picture transmission (APT)—or via central processing. Data from the Advanced Very High Resolution Radiometer (AVHRR) on NOAA-19 and the corresponding Visible Infrared Imaging Radiometer (VIIRS) on board Metop-A are available on a limited basis through the GOES distribution system (Figure 6-1). The Air Force Weather Agency (AFWA), Offutt AFB, NE, receives global data from the Advanced Scatterometer (ASCAT) on board Metop-A direct from central readout sites on a pass-by-pass basis. The Command and Data Acquisition (CDA) stations at Fairbanks, AK, and Wallops, VA, acquire recorded global area coverage data sub-sampled to a 4 km spatial resolution, and then route the data to NESDIS computer facilities in Suitland, MD, where the data are processed and distributed to the NOAA, the DOD, and private communities. Ground equipment installed at various NWS regions including Kansas City, Miami (TPC), and Monterey enable direct readout and data processing of 1.1 km resolution AVHRR and VIIRS data from NOAA-19 and Metop-A. The high resolution polar data and products generated at NHC complement other satellite data sources to support tropical mission objectives.

6.1.7. Non-NOAA Satellites. NOAA uses dedicated ground support systems to ingest and process data from select Non-NOAA satellite systems for use in operational forecasting and tropical cyclone analysis. These include data from the NASA Earth Observing System (EOS) satellites: Terra, Aqua, and Aura; CORIOLIS from the Department of Defense; Jason-2 from the joint NOAA, NASA, CNES, and EUMETSAT; and Envisat from ESA. These satellites employ

multiple infrared and microwave radiometers as well as active scatterometers to assess environmental features on the ocean surface. NOAA considers these datasets non-operational, and obtains the data on a best effort basis.

6.1.8. Oceansat-2. Oceansat-2 is an Indian satellite, launched September 23, 2009, by the Indian Space Research Organisation (ISRO). Oceansat-2 is designed to study surface winds and ocean surface strata as well as other oceanic and atmospheric properties. Oceansat-2 is currently completing calibration and validation phase for certification. Oceansat-2 carries two payloads for ocean related studies, Ocean Colour Monitor (OCM) and Ku-band pencil-beam Scanning Scatterometer (SCAT). SCAT will be used to determine ocean surface level wind vectors through estimation of radar backscatter. SCAT will provide valuable ocean surface wind vector data for monitoring tropical cyclone formation and development, especially since the loss of QuikScat on November 23, 2009.

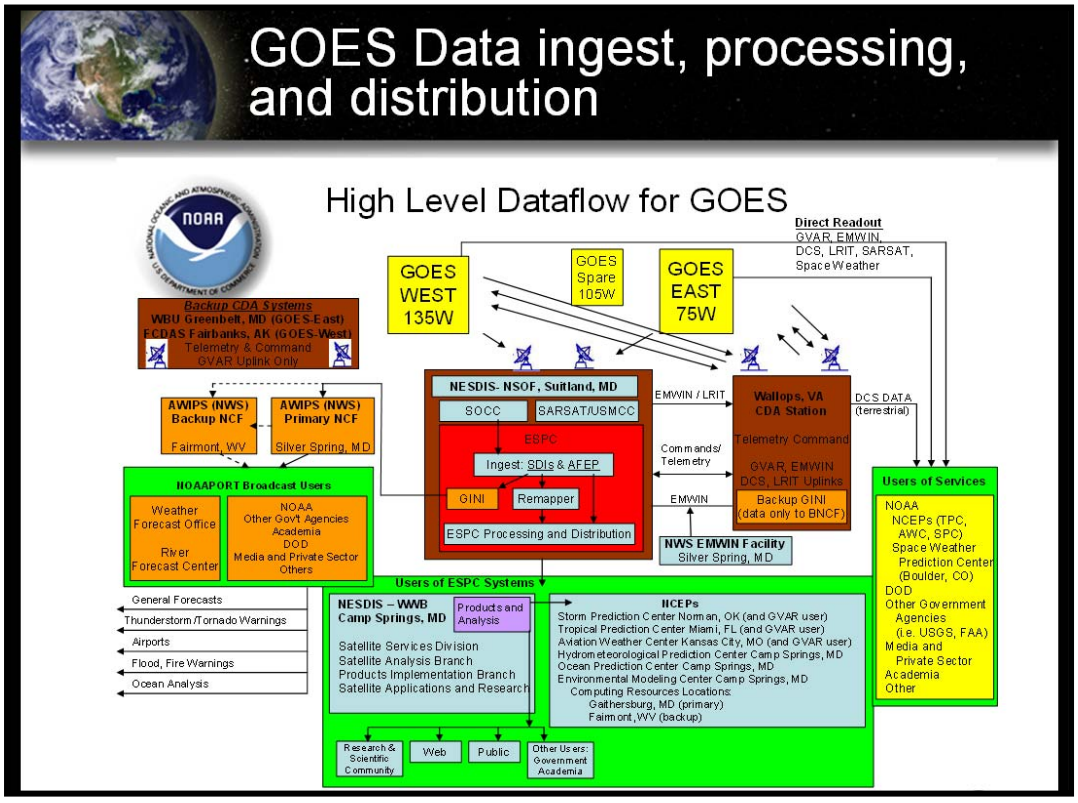

Figure 6-1. The GOES Satellite System

6.2. National Weather Service (NWS) Support.

6.2.1. Station Contacts. The GOES imagery is available in support of the surveillance of tropical and subtropical cyclones at specific NWS offices. Satellite meteorologists can be contacted at these offices; telephone numbers are in Appendix I.

6.2.2. Products. Satellite-related products are listed in Chapter 3, Table 3-5, "Summary of Products and their Associated WMO Header."

6.2.2.1. Tropical Weather Discussions. NHC issues these discussions four times a day based on satellite imagery, meteorological analysis, weather observations and radar. They describe significant features and significant weather areas for the Gulf of Mexico, the Caribbean, and between the equator and 32°N in both the Atlantic and eastern Pacific east of 140°W.

6.2.2.2. Satellite Interpretation Messages. CPHC issues these discussions four times a day to describe synoptic features and significant weather areas in the vicinity of the Hawaiian Islands. WFO Guam issues these discussions two times a day to describe synoptic features and significant weather over the Micronesian waters.

6.3 NESDIS Satellite Analysis Branch (SAB). The SAB operates 24 hours a day to provide satellite support to the HPC/OPC, TPC, CPHC, JTWC, and other worldwide users. In addition to providing high quality imagery from geostationary and polar-orbiting satellites and coordinating the execution of GOES Rapid Scan Operations (RSO) requests, SAB provides pertinent information on global tropical cyclone development, including location and intensity analysis based on the Dvorak technique (Table 6-1). For numerical model input and forecasting applications, data from high density cloud motion wind vectors, high density water vapor wind vectors, four layers of derived precipitable water from sounder moisture retrievals, and tropical rainfall estimates are provided to HPC and TPC. In addition, estimates of cumulative rainfall expected over coastal areas derived using the Ensemble Tropical Rainfall Potential (eTRaP) methodology are provided for tropical storms within 24 hours of landfall and posted to a web site in support of CPHC, HPC, TPC, forecast offices in U.S. territories, and international customers. Telephone numbers for the SAB are located in Appendix I.

Table 6-1. Communications Headings for SAB Dvorak Analysis Products

WMO HEADING	OCEANIC AREA	TYPE OF DATA
TXPN20-29 KNES	North West Pacific Ocean west of 180^{o}	VIS/IR
TXPS20-29 KNES	South Pacific Ocean east of 135 ^{o}E	VIS/IR
TXIO20-29 KNES	North Indian Ocean	VIS/IR
TXXS20-29 KNES	South Indian Ocean west of 135^{o}E	VIS/IR

6.4. Air Force Support and the Defense Meteorological Satellite Program (DMSP). Data covering the National Hurricane Operations Plan areas of interest are received centrally at the Air Force Weather Agency (AFWA) and distributed to the Air Force's Operational Weather Squadrons (OWS) and the Navy's Fleet Numerical Meteorology and Oceanography Center (FNMOC) at Monterey, CA. Satellite data covering the Central Pacific area are received at or shipped to the 17th OWS Meteorological Satellite Operations (SATOPS) Flight (17 OWS/WXJ), Joint Typhoon Warning Center, Pearl Harbor, HI. The 17 OWS/WXJ uses all available meteorological satellite data when providing fix and or intensity information to Central Pacific Hurricane Center forecasters.

6.4.1. Central Pacific Surveillance. The 17 OWS/WXJ (JTWC Satellite Operations) will provide, resources permitting, fix and intensity information to the CPHC on systems upon request.

6.5. Satellites and Satellite Data Availability for the Current Hurricane Season. Table 6-2 lists satellite capabilities for the current hurricane season.

6.6. Current Intensity and Tropical Classification Number using the Dvorak Technique. The current intensity (C.I.) number relates directly to the intensity of the storm. The empirical relationship between the C.I. number and a storm's wind speed is shown in Table 6-3. The C.I. number is the same as the tropical classification number (T-number) during the development stages of a tropical cyclone but is held higher than the T-number while a cyclone is weakening. This is done because a lag is often observed between the time a storm pattern indicates weakening has begun and the time when the storm's intensity decreases. An added benefit of this rule is the stability it adds to the analysis when short-period fluctuations in the cloud pattern occur. In practice, the C.I. number is not lowered until the T-number has shown weakening for 12 hours or more.

Table 6-2. Satellite and Satellite Data Availability for the Current Hurricane Season

SATELLITE	TYPE OF DATA	SCAN TIME	PRODUCTS
GOES-12 at 60ºW (supporting South America) GOES-11 at 135°W GOES-13 at 75°W GOES-14 (on-orbit storage at 105°W) GOES-15 (post-launch testing at 90°W)	Multispectral Imager and Sounder; 5 Channels for Imager; 19 Channels for Sounder (not operational for GOES-10)	GOES-12 is providing 15 minute imager data and hourly sounder data covering South America GOES-11 and GOES-13: Every 30 min, in Routine Scan Mode, provides 3 sectors with prescribed coverages: Northern Hemisphere (NH) or Extended NH; CONUS or PACUS; and Southern Hemisphere. Exception is transmission of full disk every 3 hours. (Available Rapid Scan Operations yield increased transmissions to 7.5 minute intervals to capture rapidly changing, dynamic weather events).	1. 1, 2, 4, and 8 km resolution visible standard sectors. 2. 4 km equivalent resolution IR sectors. 3. Equivalent and full resolution IR enhanced imagery. 4. Full disk IR every 3 hours. 5. 8 km water vapor sectors.(4 km on GOES-12) 6. Quantitative precipitation estimates; high density cloud and water vapor motion wind vectors; and experimental visible and sounder winds. 7. Operational moisture sounder data (precipitable water) in four levels for inclusion in NCEP numerical models. Other sounder products including gradient winds, vertical temperature and moisture profiles, mid-level winds, and derived product imagery (precipitable water, lifted index, and surface skin temperature). 8. Tropical storm monitoring and derivation of intensity analysis. 9. Volcanic ash monitoring and dissemination of Volcanic Ash Advisory Statements. 10. Daily northern hemisphere snow cover analysis. 11. Twice daily fire and smoke analysis over specific areas within CONUS.

Table 6-2 (continued). Satellite and Satellite Data Availability for the Current Hurricane Season

SATELLITE	TYPE OF DATA	LOCAL TIME	PRODUCTS
METEOSAT-9 at 0° (Prime Meridian) METEOSAT-8 at 9.5°E METEOSAT-7 at 57°E	Multi-spectral Spin-Scan Radiometer (SEVIRI) and High Resolution Visible (HRV)	SEVIRI: Full disk image every 15 minutes. HRV: Sector scan to move with local noon.	1. 1 km resolution digital VIS imagery (HRV); 3 km resolution digital IR imagery (SEVIRI. 2. 3 km resolution VIS and IR WEFAX imagery. 3. 3 km water vapor imagery. 4. Tropical storm monitoring and derivation of intensity analysis. 5. Volcanic ash detection and analysis.
MTSAT-1R at 140°E MTSAT-2 at 145°E	Multi-band imager (Visible plus four IR channels)	Hourly Full disk and two Northern Hemisphere scans per hour, with special "quadrant" scans four per hour.	1. 1 km resolution digital VIS imagery 2. 5 km resolution digital IR imagery and water vapor 4. Tropical storm monitoring and intensity analysis. 5. Volcanic ash detection and analysis
TRMM (NASA Tropical Rainfall Measuring Mission)	85 and 37 GHz Microwave	Fluctuates from 35°N to 35°S	1. 15 km resolution microwave coverage of the tropics from 35°S to 35°N. 2. Microwave analysis of 85 and 37 GHz radiance composited passes. 3. Brightness temperature products of the 85 and 37 GHz horizontal and vertical polarization. Derived rain-rate products.
MetOp-A NOAA-19 NOAA-18 secondary NOAA-17 backup NOAA-16 secondary NOAA-15 secondary	AVHRR; GAC and LAC (recorded); HRPT (direct); AMSU-A; AMSU-B (N-17); MHS (N-19); HIRS VIIRS 1 km global	Local Crossing Times: 0931D[1]/2131A[2] 0156D/1343A	1. 1 km resolution HRPT and Local Area Coverage (LAC) data. 2. 4 km resolution APT and Global Area Coverage (GAC) data. 3. Mapped imagery. 4. Unmapped imagery (all data types) at DMSP sites. 5. Sea-surface temperature analysis. 6. Soundings. 7. Moisture profiles. 8. Remapped GAC sectors. 9. Sounding-derived products--total precipitable water, rain rate, and surface winds under sounding 10. Daily northern hemisphere snow cover analysis. 11. Twice daily fire and smoke analysis over specific areas within CONUS. 12. AMSU based tropical cyclone intensity estimates.

[1] D - descending
[2] A - ascending

Table 6-2 (continued). Satellite and Satellite Data Availability for the Current Hurricane Season

SATELLITE	TYPE OF DATA	SCAN TIME	PRODUCTS
DMSP F-13 Tactical	OLS Imagery (recorded and direct), SSM/I, SSM/T-1	0543D[1]/1743A[2]	1. 0.3 nm (regional) and 1.5 nm (global) resolution (visual and infrared) imagery available via stored data recovery through AFWA.
DMSP F-14 Tactical	OLS Imagery (recorded and direct), SSM/I, SSM/T-1 (inop), SSM/T-2	0424D/1557A	2. Regional coverage at 0.3 nm and 1.5 nm resolution (visual and infrared) imagery available from numerous DOD tactical terminals.
DMSP F-15 Secondary	OLS Imagery (recorded and direct), SSM/I, SSM/T-1, SSM/T-2	0841D/2041A	3. SSM/T-1, SSM/T-2, SSM/I, and SSM/IS data transmitted to NESDIS and FNMOC from AFWA.
DMSP F-16 Secondary	OLS Imagery (recorded and direct), SSM/IS	0732D/1905A	
DMSP F-17 Ops	OLS Imagery (recorded and direct), SSM/IS	0528D/1728A	
DMSP F-18 Ops	OLS Imagery (recorded and direct), SSM/IS	0801D/2001A Note: Times are accurate to +/- 5 minutes	

[1] D - descending
[2] A - ascending

Table 6-3. The Dvorak Technique: The Empirical Relationship* between the C.I. Number and the Maximum Wind Speed and the Relationship between the T-Number and the Minimum Sea-Level Pressure (SLP)

C.I. NUMBER	MAXIMUM WIND SPEED	T-NUMBER	MINIMUM SLP (Atlantic)	MINIMUM SLP (NW Pacific)
1	25 kt	1		
1.5	25	1.5		
2	30	2	1009 hPa	1000 hPa
2.5	35	2.5	1005	997
3	45	3	1000	991
3.5	55	3.5	994	984
4	65	4	987	976
4.5	77	4.5	979	966
5	90	5	970	954
5.5	102	5.5	960	941
6	115	6	948	927
6.5	127	6.5	935	914
7	140	7	921	898
7.5	155	7.5	906	879
8	170	8	890	858

*Dvorak, V, 1984: Tropical Cyclone Intensity Analysis Using Satellite Data. NOAA Tech Report NESDIS 11, Wash., D.C.