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-12 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 or directly from GOES.

The current series of GOES satellites provide satellite data generated from full resolution, and 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-12. 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-12, channel 6 is a 13.3 μm band at 8 km that detects the presence of CO_2. Channel 6 improves the measurement of the height of clouds 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 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, RAMSDIS, the Internet, and other means such as local networks.

6.1.1.1. GOES-12. GOES-12, launched July 23, 2001, supports the GOES-East station at 75°W and serves NOAA operations, to include the TPC/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 now 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 TPC/NHC. The "primary" OCONUS sector provides frequent scans over the area of interest to generate experimental sounder winds (identifies steering currents) and provide moisture and temperature retrievals. Sounder winds are made available to TPC/NHC as a forecasting tool by the Cooperative Institute for Meteorological Satellite Studies (CIMSS), University of Wisconsin.

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 TPC/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 the alternate GOES-West sounder schedule that replaced 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-13. GOES-13 was launched on May 24, 2006. GOES-13 carries the same imager and instrumentation capabilities as GOES-12. GOES-13 is stored on orbit at 105°W until required to replace either of the older operational satellites.

6.1.1.4. GOES-10. GOES-10 was launched on April 25, 1997. GOES-10 was used as the primary GOES-West satellite until it was replaced by GOES-11 on June 21, 2006, due to the low fuel reserves on GOES-10. In 2007, NOAA signed an agreement with several countries in South America to use GOES-10 for operations. Since then, GOES-10 has been operating as the primary satellite covering South America and its adjacent waters. During an emergency outage of GOES-12 in December 2007, NOAA switched GOES-East operations to GOES-10. GOES-10 imager and sounder are similar to GOES-11, with a 5 channel imager with a 12 micron channel and 8 km water vapor channel, and a 19 channel imager at 10 km.

(NOTE: For GOES imager/sounding schedules go to http://www.ssd.noaa.gov/PS/SATS/)

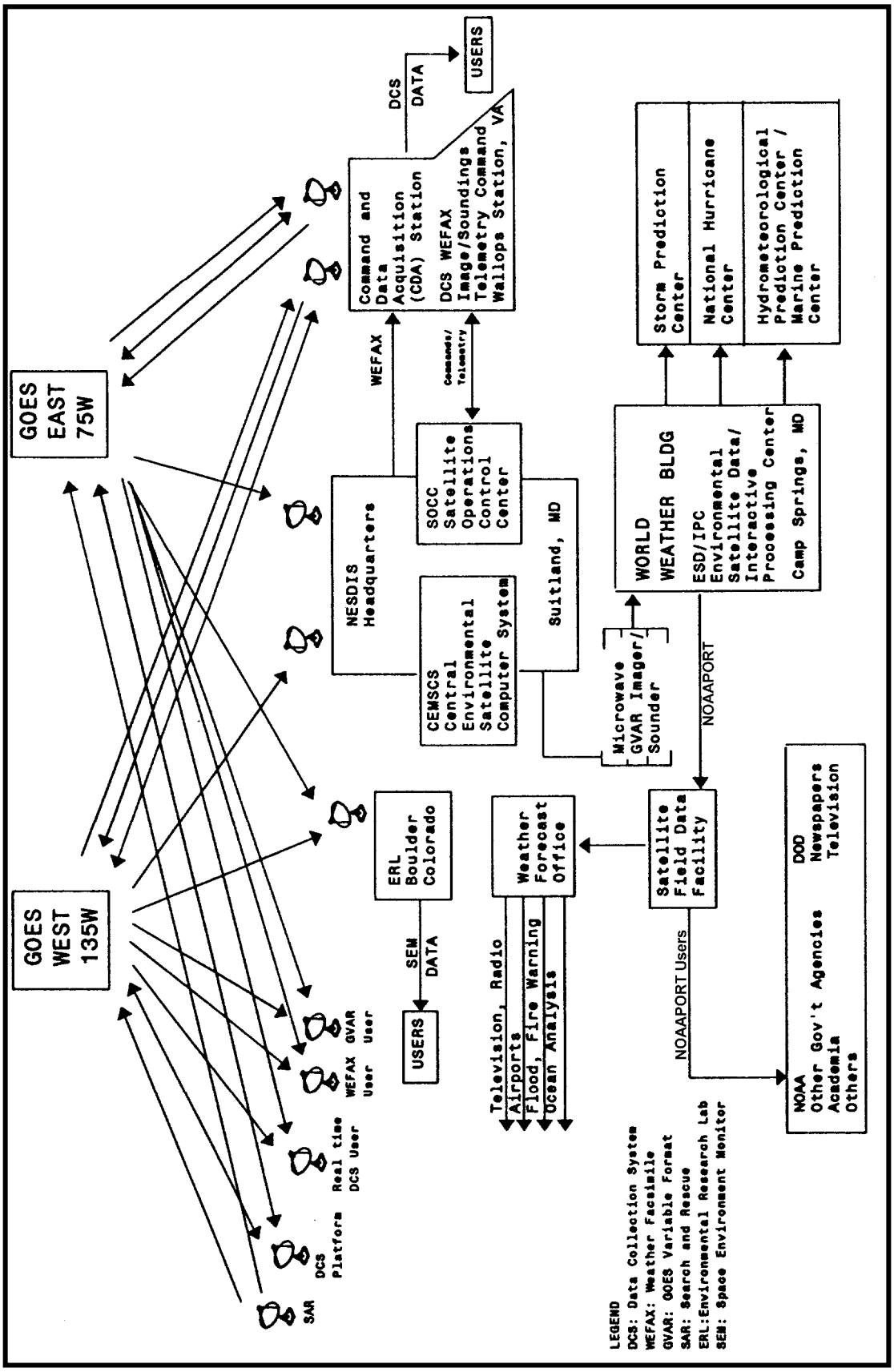

Figure 6-1. The GOES Satellite System

6.1.2. EUMETSAT Meteosat Geostationary Satellites. Meteosat-9, launched December 21, 2005, replaced Meteosat-8 on April 11, 2007, and 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 central processing at the NSC. Meteosat WEFAX data are also available and distributed via the GOES WEFAX system and through NOAAPORT as part of a northern hemisphere composite image.

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 8 times per day at synoptic times; at other times, the data are encrypted. Hence, if half-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 DOMestic SATellite (DOMSAT) or from the NOAA Science Center and available to Pacifiic OCONUS users directly via downlinks in Hawaii and Guam.

6.1.4. Initial Joint Polar System (IJPS). Two primary operational polar orbiting satellites, NOAA's NOAA-18 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 6-1. NOAA-18 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-18. 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-18 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 NOAA imagery data 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-18 and MetOp-A. The high resolution polar data and products generated at TPC complement other satellite data sources to support tropical mission objectives.

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. In addition to the satellite-related products listed in paragraphs 3.6.1, 3.6.2, and 3.6.3, there are additional satellite products issued by the centers and their alternates (see Table 6-1).

6.2.2.1. Satellite Tropical Weather Discussions. TPC/NHC issues these discussions four times a day. They describe significant features from the latest surface analysis 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. FAA contractions are used. 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 6-2). 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 Tropical Rainfall Potential (TRaP) 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 H.

Table 6-1. Communications Headings for Satellite Tropical Weather Discussion Summaries

WMO HEADING	TIME ISSUED	OCEANIC AREA	TYPE OF DATA
AXNT20 KNHC	0000, 0600, 1200, 1800 UTC	Atlantic Ocean South of 32°N to Equator.... Caribbean, Gulf of Mexico	VIS/IR
AXPZ20 KNHC	0135, 0735 1335, 1935 UTC	Eastern Pacific South of 32°N to the Equator.... east of 140° W	VIS/IR
ATHW40 PHFO	0030, 0530, 1230, 1830 UTC	Vicinity of the Hawaiian Islands	VIS/IR
ATPQ40 PGUM	0300, 1500 UTC	Over Micronesia, West North Pacific Equator to 25°N from 130°E to 180	VIS/IR

Table 6-2. Communications Headings for SAB Dvorak Analysis Products

WMO HEADING	TIME ISSUED	OCEANIC AREA	TYPE OF DATA
WWPN20 KNES	0330, 0930, 1530, 2130 UTC	North West Pacific	VIS/IR
WWPS20 KNES	0330, 0930, 1530, 2130 UTC	South Pacific	VIS/IR
WWIO20 KNES	0330, 0930, 1530, 2130 UTC	North Indian	VIS/IR
WWIO21 KNES	0330, 0930, 1530, 2130 UTC	South Indian	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 6-3 lists satellite capabilities for the current hurricane season.

Table 6-3. Satellite and Satellite Data Availability for the Current Hurricane Season

SATELLITE	TYPE OF DATA	LOCAL TIME	PRODUCTS
GOES-11 at 135°W GOES-13 (on-orbit storage at 105°W) GOES-12 at 75°W GOES-10 at 60ºW (supporting South America)	Multispectral Imager and Sounder 5 Channels for Imager 19 Channels for Sounder	GOES-12 and GOES-11: 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). GOES-10 is providing 15 minute imager data and hourly sounder data covering South America	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 6-3 (continued). Satellite and Satellite Data Availability for the Current Hurricane Season

SATELLITE	TYPE OF DATA	LOCAL TIME	PRODUCTS
METEOSAT-9 (replaced METEOSAT-8 on April 11, 2007)	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	Multi-band imager (Visible plus 4 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 derivation of intensity analysis. 5. Volcanic ash detection and analysis
TRMM (NASA Tropical Rainfall Measuring Mission)	85 and 37 GHz Microwave	Fluctuates from 30°N to 30°S	1. 15 km resolution microwave coverage of the tropics from 30°S to 30°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.

Table 6-3 (continued). Satellite and Satellite Data Availability for the Current Hurricane Season

MetOp-A NOAA-18	AVHRR; GAC and LAC (recorded); HRPT (direct); AMSU-A; AMSU-B (N-17); MHS (N-18); HIRS VIIRS 1 km global,	0931D[1]/2109A[2] 0138D/1337A	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.

[1] D - descending

[2] A - ascending

Table 6-3 (continued). Satellite and Satellite Data Availability for the Current Hurricane Season

DMSP F-13	OLS Imagery (recorded and direct), SSM/I, SSM/T-1	0633 D[1]/1833 A[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	OLS Imagery (recorded and direct), SSM/I, SSM/T-1 (inop), SSM/T-2	0543D/1743A	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	OLS Imagery (recorded and direct), SSM/I, SSM/T-1, SSM/T-2	0756D/1956A	3. SSM/T-1, SSM/T-2, SSM/I, and SSM/IS data transmitted to NESDIS and FNMOC from AFWA.
DMSP F-16	OLS Imagery (recorded and direct), SSM/IS	0809D/2009A	
DMSP F-17	OLS Imagery (recorded and direct), SSM/IS	0534D/1734A	
		Note: Times are accurate to +/- 5 minutes	

[1] D - descending

[2] A - ascending

6.6. Current Intensity and Tropical Classification Number. 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 6-4. The C.I. number is 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 6-4. 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

C.I. NUMBER	MAXIMUM WIND SPEED	T-NUMBER	MINIMUM SEA-LEVEL PRESSURE (Atlantic)	(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, Washington, D.C.