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-10 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-10 view is termed PACUS) every 30 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, "near 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-10 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-10, in combination with data from channels 2 and/or 4 are useful for detecting volcanic ash in the atmosphere. On GOES-12, channel 5 is replaced by a new 13.3 micron channel 6 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 3.9 micron channel to the GOES imager 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, and surface and cloud temperatures.

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 Carribean) 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 Mesoscale Meteorological Studies (CIMSS), University of Wisconsin.

6.1.1.2. GOES-10. GOES-10, a clone of GOES-8, was launched on April 24, 1997, and supports the GOES-West station at 135°W. The spacecraft carries the same specified imager and sounder instruments as GOES-8 and GOES-9. Due to failure of GOES-9 described below, GOES-10 was declared operational in July 1998 and was moved to 135°W. The routine scanning mode of GOES-10 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.

6.1.1.3. GOES-9. GOES-9, launched May 23, 1995, was replaced by GOES-10 as the operational satellite located at 135°W due to its imminent failure. While the satellite has some momentum wheel problems, *GOES-9 is currently stationed over the West Pacific at 155° East, and being used operationally for weather surveillance. This operation is the result of an agreement between NOAA and the Japanese Meteorological Agency (JMA) to ensure the continuity of weather satellite operations when GMS-5 was taken out of operation in mid-2003. JMA is scheduled to launch MTSAT-1R in late 2004 to replace GOES-9.*

6.1.1.4. GOES-11. GOES-11 was launched on May 3, 2000. GOES-11 is also a clone of GOES-8 and carries the same imager and instrumentation capabilities as GOES-8 and GOES-10. GOES-11 is stored on orbit until required to replace either of the older operational satellites.

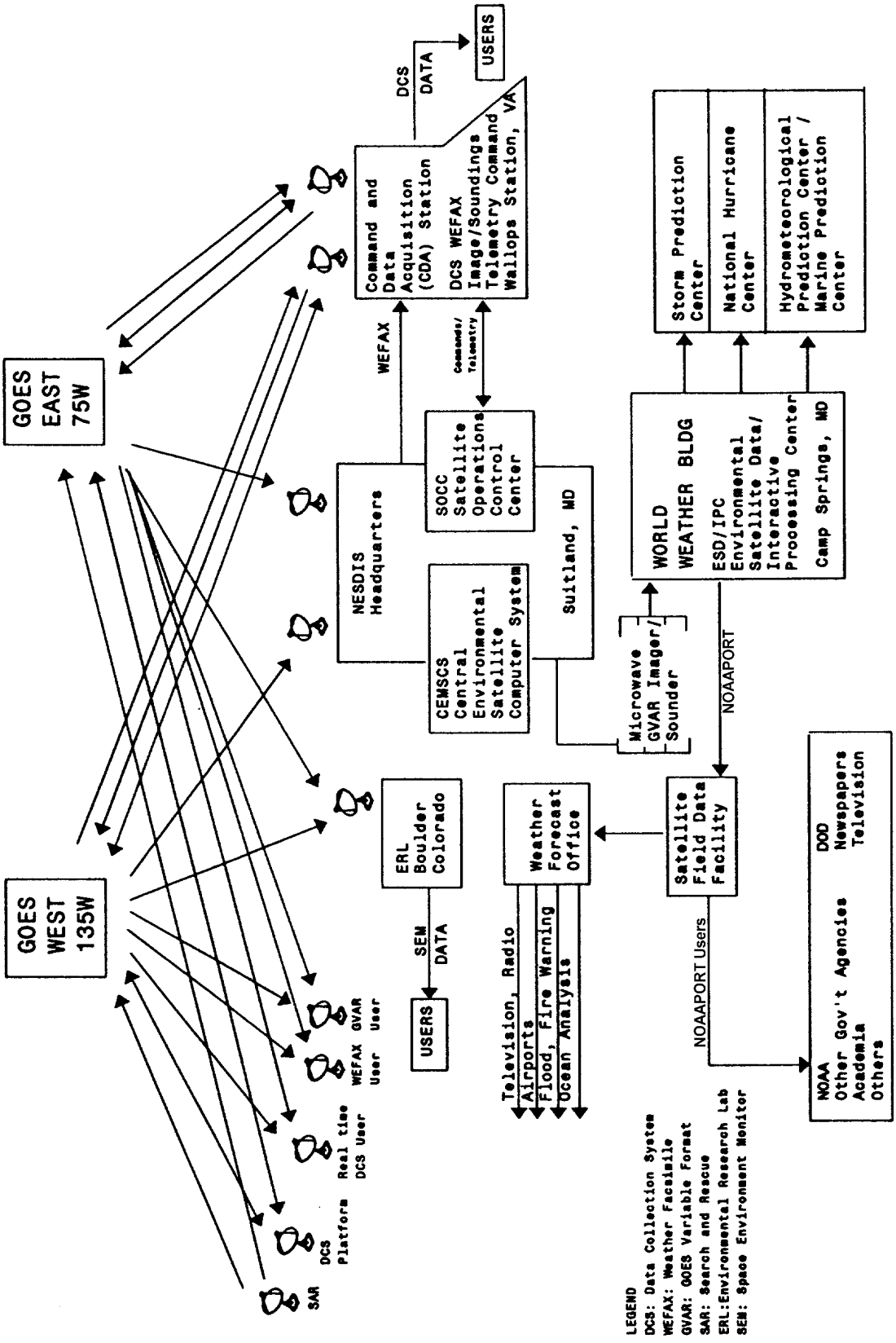

Figure 6-1. The GOES satellite system

6.1.1.5. GOES-8. GOES-8 was launched on April 13, 1994 and is stored on orbit as a secondary backup to GOES-9.

6.1.1.6 GOES-N. *GOES-N is scheduled to be launched in December 2004. GOES-N is a clone of GOES-12 and will carry the same imager and instrumentation capabilities as GOES-12.*

(NOTE: Sounding schedules can be obtained at http://www.ssd.noaa.gov/PS/SATS/eclipse.html)

6.1.2. EUMETSAT Meteosat Geostationary Satellites. *Meteosat-8, launched Aug 28, 2002, has replaced Meteosat-7* and provides vital coverage of developing tropical waves off the African Coast and western Atlantic Ocean. *Conventionally, the full disk IR, visible (VIS), and water vapor imagery have a 2 km resolution whereas specialized VIS sectors provide a maximum 1 km resolution.* The digital data are transmitted to NESDIS and NCEP at the NOAA Science Center (NSC) in Camp Springs, MD, every half hour. *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. National Oceanic and Atmospheric Administration (NOAA) Polar-Orbiting Satellites. Two primary operational NOAA polar orbiting satellites, NOAA-16 and NOAA-17, 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-16 and NOAA-17 provide the same capabilities as previous NOAA satellites, except for the addition of an Advanced Microwave Sounder Unit (AMSU). Data are available via direct readout--high resolution picture transmission (HRPT) or automatic picture transmission (APT)--or central processing. Data from the Advanced Very High Resolution Radiometer (AVHRR) 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, AL, and Wallops, VA, acquire recorded global area coverage data, 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 and Miami (TPC), enable direct readout and data processing of AVHRR data from NOAA-16 and NOAA-17. The high resolution polar data and products generated at TPC complement other satellite data sources to support tropical mission objectives.

6.1.3.1. NOAA-N. *NOAA-N is scheduled to be launched in September 2004. NOAA-N will have the same capabilities as NOAA-16 and NOAA-17.*

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 two additional satellite products issued by the centers and their alternates.

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. CPHC issues these discussions twice a day. They describe significant features from the latest surface analysis and significant weather areas for the central north and south Pacific from 140°W to 180°, and for the western north and south Pacific from 100°E to 180°. Plain Language is used.

6.2.2.2. Satellite Interpretation Message. CPHC issues these messages four times a day to describe synoptic features and significant weather areas in the vicinity of the Hawaiian Islands. FAA contractions are used.

6.2.3. Satellite Tropical Weather Discussion. The Miami and Honolulu WSFOs distribute satellite discussions for prescribed oceanic regions at the times indicated in Table 6-1. The Miami WSFO is responsible for the tropical regions of the Atlantic and Eastern Pacific; Honolulu WSFO monitors the tropical regions of the Central and Western Pacific. These satellite discussions describe significant weather in tropical regions including tropical storm activity over the Atlantic, Eastern Pacific, Central Pacific, and Western Pacific Oceans.

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. SAB coordinates, as conditions warrant, four times per day with TPC and CPHC, relaying pertinent information on tropical cyclone development, including location, tracking, and intensity analysis. A Satellite Weather Bulletin for the Indian Ocean and West Pacific Ocean, providing current position and current intensity of tropical cyclones, is also disseminated four times per day at the times indicated in 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. Telephone numbers for the SAB are located in Appendix H.

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 locally at several direct readout sites. The USAF uses all available meteorological satellite data when providing fix and intensity information to NWS hurricane forecasters. The DOD will provide DMSP coverage of tropical and subtropical cyclones whenever possible.

6.4.1. North Atlantic and Eastern Pacific Surveillance. AFWA readouts will augment NESDIS surveillance for the North Atlantic and Eastern Pacific. AFWA will, resources permitting, transmit four daily electronic text bulletins, describing the location and intensity classification of the system, using format shown in Figure 6-2 to the TPC/NHC on organized disturbances evident at the tropical classification of one point five (T-1.5) or higher. AFWA will, resources permitting, provide gale wind radius analysis utilizing SSM/I data for all systems with maximum intensities greater than 50 kt.

6.4.2. Central Pacific Surveillance. AFWA will maintain the capability to provide surveillance support cited in para 6.4.1 to the CPHC. The 17 OWS/WXJ (JTWC Satellite Operations) will provide fix and intensity information to the CPHC on systems upon request.

Table 6-1. Communications headings for satellite tropical weather discussion summaries

WMO HEADING	TIME ISSUED	OCEANIC AREA	TYPE OF DATA
ACPA40 PHFO	2200 UTC	Central Pacific (north and south) from 180º to 140ºW	VIS/IR
ACPW40 PHFO	2200 UTC	Western Pacific (north and south) from 100ºE to 180º	VIS/IR
ATHW40 PHFO	0030, 0530, 1230, 1830 UTC	Vicinity of the Hawaiian Islands	VIS/IR
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
WWPN20 KWBC	0400, 1000, 1600, 2200 UTC	West Pacific Ocean	VIS/IR
WWPS20 KWBC	0400, 1000, 1600, 2200 UTC	South Pacific Ocean	VIS/IR
WWIO20 KWBC	0400, 1000, 1600, 2200 UTC	North Indian Ocean	VIS/IR
WWIO21 KWBC	0400, 1000, 1600, 2200 UTC	South Indian Ocean	VIS/IR

MESSAGE HEADING:
TPNT KGWC (Atlantic) or **TPPZ1 KGWC** (Eastern and Central Pacific)

A CYCLONE DESIGNATOR	A. Designator of tropical cyclone category including name/number. When a cloud system has not yet been designated by name/number enter TROPICAL DISTURBANCE. Sample entry: TROPICAL STORM AMY (15)
B DATE/TIME (Z) OF FIX	B. Date and nodal crossing time in Zulu; round time to nearest minute. Sample entry: 252303Z.
C LATITUDE OF POSITION	C. Latitude to nearest tenth of degree (N or S), followed by checksum. Sample entry: 29.9N/0
D LONGITUDE OF POSITION	D. Longitude to nearest tenth of degree followed by checksum. Sample entry: 56.7 W/8
E VIS/IR POSITION CODE NUMBER SSM/I CONFIDENCE NUMBER	E. Enter SSM/I Confidence Number and source of data (DMSP, NOAA, etc.). Spell out VIS/IR Position Code Number (PCN). Select MI Confidence Number and PCN number from code below: GEOGRAPHICAL GRIDDING: ONE: eye fix; THREE: well defined circulation center; FIVE: poorly defined circulation center EPHEMERIS GRIDDING: TWO: eye fix; FOUR: well defined circulation center; SIX: poorly defined circulation center Sample entry: MI4/DMSP/SIX
F DVORAK CLASSIFICATION	F. Dvorak classification for storm intensity as described in NOAA Technical Report NESDIS 11. Dvorak classification will be made a minimum of twice each day based on infrared and/or visual data. If a new Dvorak classification number cannot be derived, use the last reported number. Include in parentheses the date and nodal time of the data on which the Dvorak analysis is based. Sample entry: T 4.5/4.5/D1.0/25HRS (252305Z)
G REMARKS	G. Include information, as appropriate, on data type, eye characteristics, spiral rainbands, unexpected changes in storm movement, departures from Dvorak (modeled) intensities, etc.
H NADIR REFERENCE DISTANCE	H. Include crosstrack distance in degrees latitude between fix center and satellite nadir subtrack. Sample Entry: Center WAS 5.4 DEG EAST OF NADIR
I GALE WIND RADIUS ANALYSIS	I. Experimental gale wind (34kt) radius boundary utilizing image mapped SSM/I ocean surface wind speed algorithm estimates. Sample Entry: Gale Wind Radius Anal-Boundary Compass Points

DIR	DIST-NM	LAT	LONG
1. N	140	29.4N	88.2W
2. NE	130	28.9N	86.6W
3. E	80	27.0N	86.7W
4. SE	65	26.2N	87.4W
5. S	65	25.9N	88.2W
6. SW	65	26.3N	89.3W
7. W	80	27.0N	89.7W
8. NW	95	28.5N	89.2W

Figure 6-2. Center fix data form and message format (satellite)

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

Table 6-2. Satellite and satellite data availability for the current hurricane season

SATELLITE	TYPE OF DATA	LOCAL TIME	PRODUCTS
GOES-8 (on-orbit storage) GOES-9 at 155°E GOES-10 at 135°W GOES-11 *(on-orbit storage)* GOES-12 at 75°W	Multispectral Imager and Sounder 5 Channels for Imager 19 Channels for Sounder	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. Satellite and satellite data availability for the current hurricane season (continued)

SATELLITE	TYPE OF DATA	LOCAL TIME	PRODUCTS
METEOSAT-7	Multi-spectral Spin-Scan Radiometer	Full disk image every half hour	1. 2.5 km resolution digital VIS imagery; 5 km resolution digital IR imagery. 2. 5 km resolution VIS and IR WEFAX imagery. 3. 5 km water vapor imagery. 4. Tropical storm monitoring and derivation of intensity analysis.
METEOSAT-8	*Multi-spectral Spin-Scan Radiometer*	*Full disk image every 15 minutes.*	*1. 1 km resolution digital VIS imagery; 3 km resolution digital IR imagery.* *2. 3 km resolution VIS and IR WEFAX imagery.* *3. 3 km water vapor imagery.* *4. Tropical storm monitoring and derivation of intensity analysis.*

Table 6-2. Satellite and satellite data availability for the current hurricane season (continued)

SATELLITE	TYPE OF DATA	LOCAL TIME	PRODUCTS
NOAA-17 NOAA-16	AVHRR; GAC and LAC (recorded); HRPT (direct); AMSU; HIRS	0214D[1]/1414A[2] 1021D/2221A	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 6-2. Satellite and satellite data availability for the current hurricane season (continued)

SATELLITE	TYPE OF DATA	LOCAL TIME	PRODUCTS
DMSP F-12	OLS Imagery (direct only), SSM/I (non-functional), SSM/T-1 (non-functional), SSM/T-2 (direct only)	0615D/1815A	1. 0.3 nm (regional) and 1.5 nm (global) resolution (visual and infrared) imagery available via stored data recovery through AFWA. 2. Regional coverage at 0.3 nm and 1.5 nm resolution (visual and infrared) imagery available from numerous DOD tactical terminals. 3. SSM/T-1, SSM/T-2, SSM/I data transmitted to NESDIS and FNMOC from AFWA.
DMSP F-13	OLS Imagery (recorded and direct), SSM/I, SSM/T-1	0624D/1824A	
DMSP F-14	OLS Imagery (recorded and direct), SSM/I, SSM/T-1 (inop), SSM/T-2	0752D/1952A	
DMSP F-15	OLS Imagery (recorded and direct), SSM/I, SSM/T-1, SSM/T-2	0924D/2124A	
DMSP F-16	*OLS Imagery (recorded and direct), SSM/I, SSM/T-1, SSM/T-2*	*0754D/1954A* Note: Times are accurate to +/- 5 minutes	

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 6-3. 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 6-3. 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.