NOAA Technical Memorandum NESDIS 19

A SUGGESTED HURRICANE OPERATIONAL SCENARIO FOR GOES I-M

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U.S. DEPARTMENT OF COMMERCE

National Oceanic and Atmospheric Administration

National Environmental Satellite, Data, and Information Service

NOAA TECHNICAL MEMORANDUMS

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NESDIS 4 Publications and Final Reports on Contracts and Grants, 1983. Nancy Everson, April 1984. (PB84 192301)

NESDIS 5 A Tropical Cyclone Precipitation Estimation Technique Using Geostationary Satellite Data. Leroy E. Spayd Jr. and Roderick A. Scofield, July 1984. (PB84 226703)

NESIDS 6 The Advantages of Sounding with the Smaller Detectors of the VISSR Atmospheric Sounder. W. Paul Menzel, Thomas H. Achtor, Christopher M. Hayden and William L. Smith, July 1984. (PB851518/AS)

NESDIS 7 Surface Soil Moisture Measurements of the White Sands, New Mexico. G.R. Smith, September 1984. (PB85 135754)

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A SUGGESTED HURRICANE OPERATIONAL SCENARIO FOR GOES I-M

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I. INTRODUCTION

Improvements in tropical cyclone forecasts require optimum use of remote sensing capabilities, because conventional data sources cannot provide the necessary spatial and temporal data density over tropical and subtropical oceanic regions. In 1989, the first of a new series of geostationary weather satellites, GOES I-M, will be launched with the new capability for simultaneous imaging and sounding. Careful scheduling of the GOES I-M will enable measurements of both the wind and mass fields over the entire tropical cyclone activity area. These data will help the tropical cyclone forecasters at the National Hurricane Center (NHC) in their tasks of detection, tracking, analysis, and prediction. This document briefly describes the GOES I-M imager and sounder, surveys the data needs for hurricane forecasting, discusses how geostationary satellite observations help to meet them, and proposes a GOES I-M schedule of observations and hurricane relevant derived products.

II. GOES I-M CAPABILITIES

The Goes I-M spacecraft will be a three axis, body stabilized platform with separate imaging and sounding instruments. Unlike the present GOES where the VAS (VISSR Atmospheric Sounder) is time shared to perform the imaging and sounding functions, the GOES I-M imager and sounder operate completely independent of each other. The GOES I-M radiometers offer improved sensitivity, scan flexibility, pointing accuracy, signal quantization, and spatial resolution when compared to the current VAS. These characteristics are briefly summarized below (see Juarez and Koenig, 1986 for additional details).

The imager on GOES I-M is capable of multispectral observations at intervals less than a minute and can scan the full disk in under 30 minutes. The image frame can be interrupted for a priority image over an area of intensifying weather. The resolution will range from 1 km to 8 km depending on spectral selection. The sensitivity in the thermal bands will be better than 0.25 degrees

Kelvin at nominal scene temperatures. The pointing accuracy will be within 2 km, a considerable improvement over the current 10 to 20 km (Juarez and Koenig, 1986). These capabilities offer the opportunity for better atmospheric monitoring and wind field depiction through tracking clouds and moisture features in sequences of images.

The GOES I-M sounder is a nineteen channel filter radiometer that has a small instantaneous geometric field of view (8 km), a high sampling rate providing rapid areal coverage (soundings over the contiguous United States require roughly 40 minutes and soundings over a 1000x1000 km area require about ten minutes), and an increased thermal sensitivity for each field of view (better than the sounding requirement of .25 mW/ster/m**2/cm^{-1}). While the vertical resolution of the soundings has not been significantly changed from the VAS, the improved calibration of these radiances with an external blackbody is expected to yield high quality soundings of temperature and moisture.

The sounder coverage over the data sparse oceans attempts to describe the synoptic situation in which the tropical disturbance is forming. Since GOES I-M possesses only visible and infrared observing capabilities, clouds will often obscure the scene. In the absence of a microwave sensor, sounding and derived meteorological parameters must be obtained by hunting for holes in and around the clouds. Therefore, the increased spatial resolution available on GOES I-M is very important. When clear fields of view are determined, the geostationary temperature profiles and the associated thicknesses have compared very well with radiosonde values (Velden et al., 1984).

III. CURRENT USE OF GOES PRODUCTS IN HURRICANE FORECASTING

GOES satellites have been an important part of the hurricane warning system for over a decade. Though the GOES alone cannot meet the needs of operations, they are recognized as being an indispensable tool for hurricane forecasting. The following paragraphs are intended to familiarize the reader with hurricane forecasting and the present use of GOES series products.

What makes hurricane forecasting unique? Hurricane forecasting is a subtle problem, since the significant flow is weaker and mass gradients are far smaller than in the mid-latitudes. Thus, the remote sensing of a tropical disturbance is difficult due to a poor signal to noise ratio for the necessary observations. Although hurricanes develop and move more slowly than mid-latitude storms, the deadlines are nonetheless very tight for some of the operational tasks such as numerical and statistical model runs, forecast preparation, and forecast dissemination.

The hurricane forecaster has several basic tasks: (1) detection, (2) tracking, (3) analysis, (4) prediction, and (5) warning. Each of these tasks will be described in succession, with emphasis on the role of satellites in the GOES series.

Detection of incipient tropical cyclones is the primary responsibility of the hurricane forecaster on most days of the six month hurricane season. Well over fifty areas of disturbed weather occur each season in the tropics or subtropics, and these must be monitored for signs of development. Although aircraft are used to confirm cyclogenesis, the decision to commit them to flight is made primarily from imagery from the GOES satellites. Visible loops of one or two hour duration serve to identify low level circulations forming within a cloud mass. Infrared loops are generally less useful because of their lower resolution (8 km versus 1 km) of low level features, but they are still essential for nighttime usage. Soundings are less useful because profile retrieval is restricted to cloud free fields of view, and tropical disturbances are usually accompanied by widespread cirrus clouds.

Once a tropical cyclone forms, it must be located accurately and frequently, so its motion can be estimated. For hurricanes nearing land, aircraft reconnaissance and land-based radar are used extensively, but limited resources require that many hurricanes at sea are tracked using satellite information alone. Visible images at one kilometer resolution usually provide enough information to locate the circulation center. A well developed eye is readily detected during daylight. However, in difficult cases of a weak or moderate cyclone, cirrus often obscures all low cloud features and hurricane center locations are less accurate. Finding the center is even more difficult at night, as the eight kilometer resolution infrared imagery often cannot discern the small low cloud features which can help locate the center. Failure to recognize the hurricane signature at night has led to severe positioning and forecast errors. Figures 1-2 shows a few examples. The increased infrared resolution of GOES I-M is expected to help with nighttime tracking.

The maximum winds and area of damaging winds must also be monitored as part of the tracking responsibility. In the absence of reconnaissance aircraft, intensity must be estimated from satellite images. The systematic subjective Dvorak technique will likely remain the standard until a sounder with high resolution and cloud penetration capability is launched. Intensity is estimated from single images every three to six hours, with emphasis on using the enhanced infrared.

Large scale analyses (and output from the National Meteorological Center (NMC) global models) are used to forecast the future path of the tropical cyclone, which is mainly determined by the synoptic scale tropospheric flow. Because most of the analysis domain is over water and conventional observations are lacking, satellite information is essential. Winds are emphasized over heights because of the weaker wind-pressure constraint at low latitudes, with mid-level (700-400 mb) winds being particularly valuable. The goal is to define a wind every few hundred kilometers at three levels (low, middle, high) covering the entire tropics and subtropics at least every 12 hours. In the presence of tropical disturbances, improved spatial and temporal resolution is necessary (e.g., winds at five levels every three to six hours). Water vapor imagery plays an important role in the qualitative analysis in several ways; it is the source of mid- to upper-level tracers, it helps to identify situations which constrain or accelerate tropical cyclone development, and it is a means of level assignment for cloud drift winds from infrared imagery. The 7.3 micron band is especially useful as it is the only reliable source of mid-level winds.

Forecasts are issued every six hours in the form of predicted position and intensities for the next 72 hours. Though the satellite data are not used directly, the forecasts are heavily dependent on tracking to obtain accurate initial motion estimates and wind analyses to depict the current large scale flow in which the tropical cyclone is embedded.

Warnings are the core of hurricane forecasting. A threatening hurricane or tropical storm generates greater media attention than any other weather event and requires preparation, decisions, and actions which can involve over a million people. The nature, extent, and seriousness of the threat must be communicated quickly and evoke an appropriate response. Here is where the satellite images, with suitable enhancements and graphic annotation, are extremely valuable. The GOES schedule must be able to support loops of half hourly (or hourly) imagery over relatively large areas at all times of the day or night for optimum effectiveness in warning dissemination. It is also essential that the display devices in the field offices allow access by the news media without interfering with the detection, tracking, and analyses functions also in progress. Finally, it is crucial that adequate numbers of trained personnel are on site and ready to interpret the satellite information and to explain it to the awaiting public.

IV. GOES I-M OBSERVATIONS DURING HURRICANES

The hurricane scenario for GOES I-M satisfies the traditional requirements for full disk imaging every three hours and regional scale imaging every half hour. In addition, it attempts to schedule sufficient hurricane imaging and sounding so that the needs of the hurricane forecaster are met. Table 1 shows the six hour duty cycle that either GOES East or GOES West could use, depending on whether the storm is in the Pacific or the Atlantic basin. It is assumed that there will be a two GOES operation at roughly 75W and 135W (positioning of the satellites closer together would increase the stereo coverage, but reduce the overall coverage). Figure 3 displays the same information in graphical form.

1. Imager

The imager is scheduled for two 15 minute scans of the northern hemisphere, a full disk, and two 15 minute scans of the southern hemisphere to enable determination of global winds. Currently, global winds are produced from half hour interval image loops. It has been suggested that reducing the time interval to 15 minutes will greatly improve the depiction of both atmospheric flow in and around the jet for land-based severe weather and low level circulation associated with tropical cyclones.

Hourly coverage of the northern hemisphere (to 20S) is incorporated in the schedule to enable continuous hour interval loops throughout the day. The NHC uses these loops for routine hurricane monitoring.

The next activity is rapid scan imaging over the hurricane area. This imaging occurs at 7.5 minute intervals for 45 minutes. Rodgers et al. (1979) showed that up to ten times as many low level winds were derived from 7.5 interval images as from those at 30 minute intervals. The higher temporal resolution also increased the number of traceable upper tropospheric cloud elements. Thus, these short interval images make it possible to produce better wind data between 200 and 1100 km from the tropical cyclone center which will help define the extent of the low-level circulation and improve the initial fields necessary for numerical forecasts. Attempts will be made to synchronize some of the rapid scan imaging from both GOES so that stereo coverage is possible. Hasler (1981) showed that the three dimensional cloud geometry available from stereo imagery improves the altitude assignment for the cloud motion winds and reveals changes in the structure in the central dense overcast region as a function of time. These measurements can provide new insight to the storm intensification or dissipation.

Table 1. GOES-NEXT Hurricane Schedule

Time	Imager	Sounder
0-1	full disk 15(s), 15(s)[a]	US[f] eye, eye[g]
1-2	15[b], 7.5, 7.5 7.5, 7.5, 7.5, 7.5[c]	US eye, eye
2-3	15, 15 15, 15[d]	hurricane[h] eye, eye
3-4	full disk 15, 15	US eye, eye
4-5	15, 7.5, 7.5 7.5, 7.5, 7.5, 7.5	US eye, eye
5-6	15, 15 15, 15[e]	hurricane eye, eye

a full disk followed by two southern hemisphere (south of 20N) images for global winds production every six hours (see footnote e also)

b coverage of the northern hemisphere (to 20S) is scheduled every hour for regular interval loops throughout the day

c rapid scan imaging over hurricane covering a 4200x4200 km area (to be synchronized with other GOES for stereo coverage when possible)

d 15 minute interval imaging to monitor convergence/divergence

e two 15-minute images of northern hemisphere (to 20S) followed by full disk for global winds every six hours

f US sounding coverage takes 40 minutes for continued NSSFC support; in a landfalling hurricane situation, US coverage will be replaced by hurricane coverage to provide hourly sounding updates (US coverage must then be accomplished from the other GOES)

g attempts for eye sounding in 1000x1000 km area takes five minutes

h hurricane sounding coverage of 3000x3000 km area takes 40 minutes and is used for model initialization every six hours and for monitoring major thermal and moisture gradients (including SST, 500-700 mb moisture) every three hours

Fifteen minute imaging over the northern hemisphere follows. This allows simultaneous support of all the national weather centers through the monitoring of cloud and water vapor motions over the continent as well as over the oceans.

The next three hours are a repeat of the previous three without the southern hemisphere wind coverage.

2. Sounder

Sounding coverage over the hurricane region (3000x3000 km) takes about 40 minutes and is scheduled to occur every three hours. The profile retrievals from this coverage can be used for model initializations every six hours and for monitoring the major atmospheric thermal and moisture gradients. The soundings are synchronized with the rapid scan imaging from the imager so that wind fields and retrievals are available nearly simultaneously. In addition, the radiances observed in the infrared window channels will provide sea surface temperatures (SST) in cloud free areas.

Reduced sounding coverage in the near environment of the hurricane is scheduled to occur twice every hour. Sounding in the 1000x1000 km area surrounding the hurricane center (which takes five minutes) occupies the last ten minutes of each hour. Attempts to sound in the eye of the hurricane are possible during this part of the schedule.

In between the three hourly hurricane sounding coverage, the sounder is programmed to scan the contiguous United States for the first forty minutes of each hour. This enables continued support for the National Severe Storm Forecast Center (NSSFC). In a landfalling situation US coverage would be replaced by hurricane coverage to provide hourly sounding updates (US sounding coverage would then be accomplished from the other GOES).

3. GOES I-M Products

GOES East or West will be programmed to cover a 60 degree latitude by 60 degree longitude box in the region of interest. Dual basin coverage in the Atlantic and the Pacific is planned (from Africa to the International Dateline). In this region, multispectral images, soundings, and winds will be generated. Table 2 summarizes the GOES I-M products for hurricane surveillance.

The multispectral images include visible (at 1 km resolution), the shortwave (3.9 micron), longwave (10.7 micron), and more opaque (12.0 micron) infrared windows (at 4 km resolution), and mid-level water vapor (6.7 micron at 8 km resolution). These will be available at 15 minute intervals unless rapid scan imaging is producing them at 7.5 minute intervals.

Some of the radiance fields sensed by the sounder will also be used in time sequence to track moisture features in the mid-tropospheric levels. The time interval for these loops will be approximately one hour. In particular, the 7.2 micron radiance field shows promise in this application.

Wind measurements are the most important satellite product for hurricane forecasting. Analysis of the satellite derived deep layer mean wind field provides information about the steering current for prediction of hurricane movement. High and low level cloud drift and mid-level water vapor drift winds

Table 2. GOES-NEXT Products

Region:	Dual basin coverage in Atlantic and Pacific (Africa to the International Dateline)
	60° lat x 60° lon (programmable over area of interest)
Soundings:	$T(p)$, $T_D(p)$, $Z(p)$, $V(p)$, total precipitable water, total ozone, cloud top pressure at 40 km resolution with 110 km spacing every six hours (used in improved initial analysis of ten levels)
	Single fov sounding in eye of hurricane (when formed) every hour (if possible)
Winds:	Cloud drift (low, high) and H_2O drift (mid)
	Deep layer mean wind analysis every six hours
Images:	Visible (1 km), IR windows (4 km), and H_2O (8 km) imaging every 15 minutes (except when covering southern hemisphere every three hours)
	Rapid scan imaging over hurricane (in stereo, if two GOES can be synchronized) every three hours
	500-700 mb derived moisture image (10 km) every three hours
	SST image (4 km) twice daily using composites of three hourly SST estimates; visible images used for cloud filtering

can be calculated from image loops in the visible, infrared window, and the water vapor sensitive spectral bands. Level assignments to the tracers are made from water vapor brightness temperature determinations for mid and high winds and from infrared window brightness temperatures for low winds (Stewart et al., 1985). In addition thermal gradient winds can be derived from GOES sounding retrievals in clear areas. The resulting wind fields are high density and are readily converted to a deep layer mean wind, which closely approximates the steering current. Early testing of these satellite derived wind analyses in numerical models (e.g., the SANders BARotropic model) have shown considerable reductions in hurricane track prediction error (Velden and Goldenberg, 1987).

The water vapor imagery has been shown to be useful in depicting mid- to upper tropospheric structure and features in the tropical cyclone environment that are not always apparent in the usual infrared or visible images. During Hurricane Elena the 6.7 micron images provided timely information regarding the interaction of a mid- to upper-tropospheric trough with the hurricane (see Figure 4). That interaction appears to have caused a three day meander in the storm track, prolonging the hurricane threat and warranting massive evacuations during the Labor Day weekend of 1985. With the enhanced water vapor images from VAS, the synoptic features of Elena's environment were better described (Velden, 1987).

Several analyses techniques are currently used to estimate intensity of a tropical cyclone from visible and infrared imagery. These techniques are based on models of day to day changes in the cloud patterns associated with the storm and on correlations between the intensity and the temperature gradient between the eye and the surrounding cloud tops (Dvorak, 1984). The visible and infrared image loops generated from the GOES I-M schedules would enable these analyses to continue to be produced operationally.

Derived product images of sea surface temperature and 500 to 700 millibar moisture will be determined every three hours. The VAS derived product images (Smith et al., 1985) are composite images of cloud and sounding information. The sounding information is displayed only in clear conditions (where the infrared radiances are unaffected by cloud absorption) and the clouds are shown in the remainder of the image. The forecaster can use a time sequence of these images to monitor changes in atmospheric moisture and stability or sea surface temperature and at the same time monitor the cloud developments associated with these tendencies. These derived product images have been found to be extremely useful to depict atmospheric trends by forecasters at the national weather centers.

The geostationary sounder and imager are both capable of producing SST fields with good horizontal coverage (Bates and Smith, 1985). Unlike the polar orbiter, the GOES can wait for the clouds to move out of the field of view to make an SST determination. The detailed SST information is useful to the NHC for preparing large scale analyses and to forecast hurricane intensity. For the latter application, an early study indicates that hurricane wind speeds are bounded by the warmth of the underlying SST (Merrill, 1987).

The soundings will be possible at 10 km resolution in cloud free fields of view. Each retrieval will include determination of temperature, dewpoint, thickness, height, and thermal gradient wind at 20 mandatory levels between the surface and 100 mb. Total atmosphere column precipitable water vapor and ozone are also derived. In a cloudy fov, the cloud top pressure is determined; this assists in the level assignment of cloud drift winds. It is possible that radiances from several fovs will need to be averaged to enhance the quality of the sounding; the area of the averaged sounding will possibly be 40x40 km. Thickness fields in three layers are usually inspected for depiction of the synoptic situation: these are 1000-700 mb, 700-300 mb, and 300-100 mb. Thermal gradient winds are used in conjunction with the cloud and water vapor drift winds to delineate possible steering currents.

In favorable circumstances, soundings in the eye could provide a measure of the pressure differential at the storm center with respect to the storm environment and thus would be a direct measure of the storm intensity. Aircraft reconnaissance has been the primary source of storm intensity information for hurricanes which threaten land. The satellites could be used to supplement these data.

V. CONCLUSION

The opportunity for improved support of the National Hurricane Center arises with the advent of GOES I-M. The satellite schedule suggested here makes the relevant data available in the appropriate time interval. The processing system that will convert the data into information must be designed so that winds and soundings can be processed within the hour. The forecasting and analysis team at the center must have sufficient training and familiarity with the satellite derived products to make correct meteorological inferences. The satellite will be ready in the fall of 1989; plans must be made to have the NHC processing system in place and to assure sufficient trained staffing is available.

VI. ACKNOWLEDGMENTS

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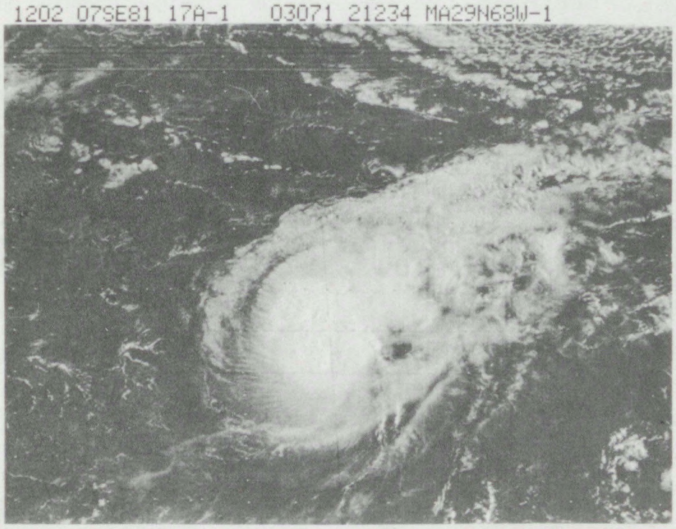

Fig. 1. Hurricane Floyd of 1981 (1202 UCT 7 September) presents a challenge for a satellite analyst wishing to pinpoint its center. Low level circulation features are obscured, and no eye is apparent. Aircraft reconnaissance reported a central pressure of 975 mb and maximum winds of 100 kt.

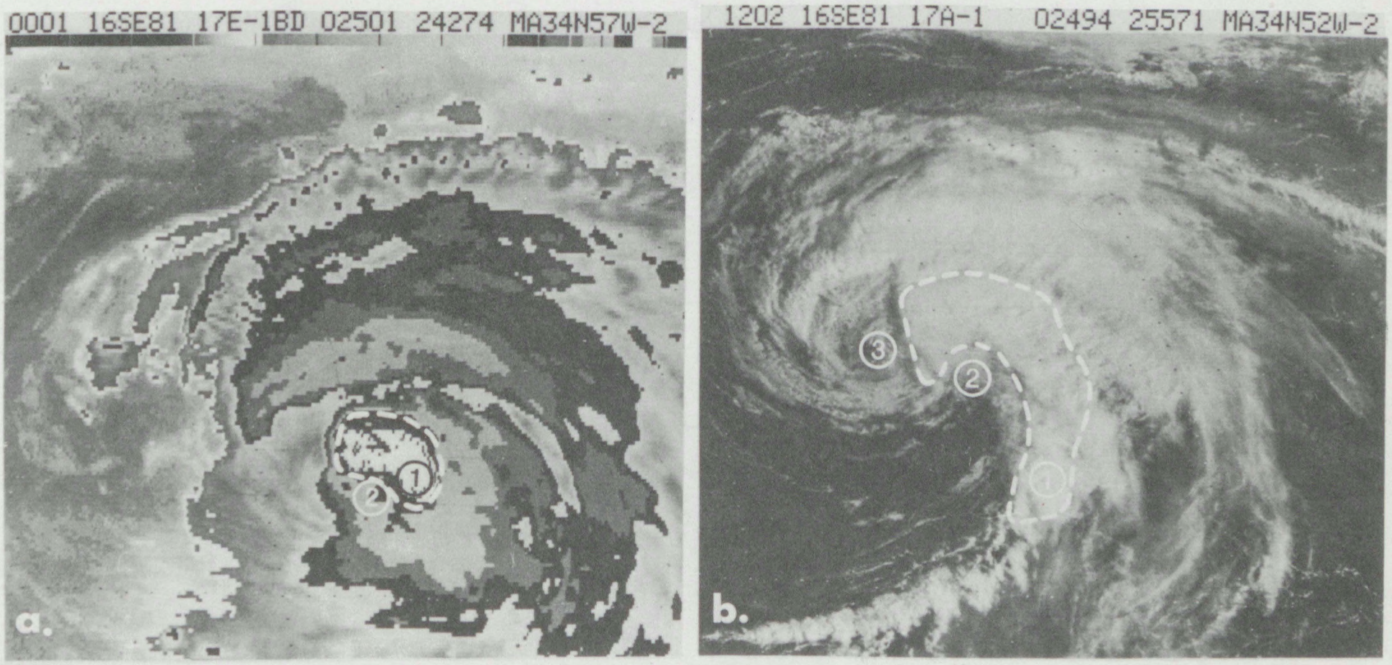

Fig. 2. Hurricane Harvey of 1981 furnishes an example of the difficulties of nighttime hurricane tracking. Infrared image a) at 0001 UCT 16 September shows a curved cold cloud feature (1) which defines a center (2). During the night, the hurricanes circulation becomes tilted in the vertical due to environmental shear, and the visible image b) at 1202 UCT 16 September shows two "centers"; high clouds (1) (cold in infrared) define a false center (2), while the actual low-level center (3) is well to the west.

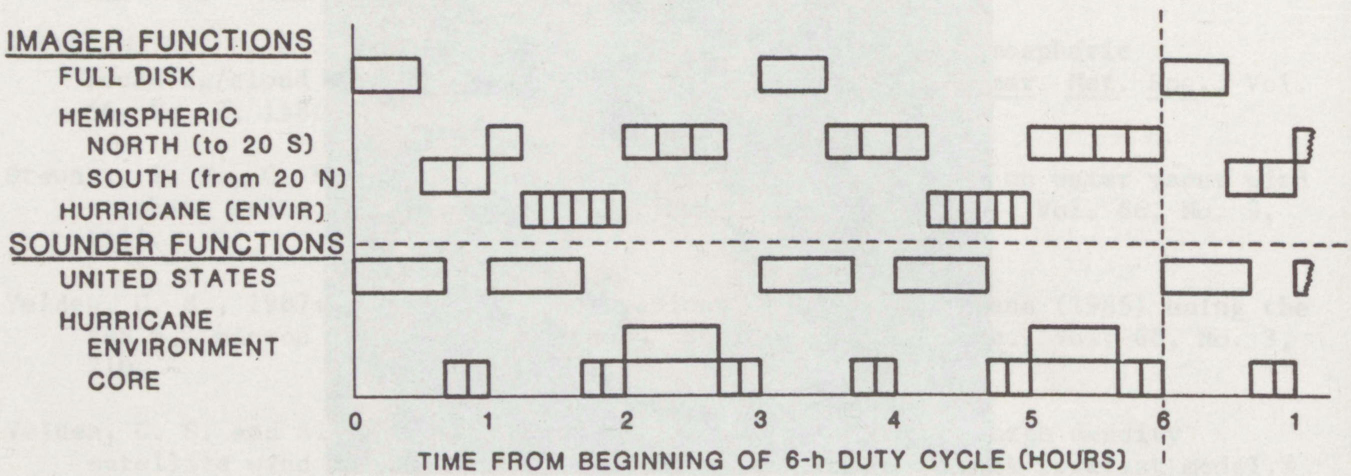

Fig. 3. Imager and sounder functions during a six-hour hurricane duty cycle.

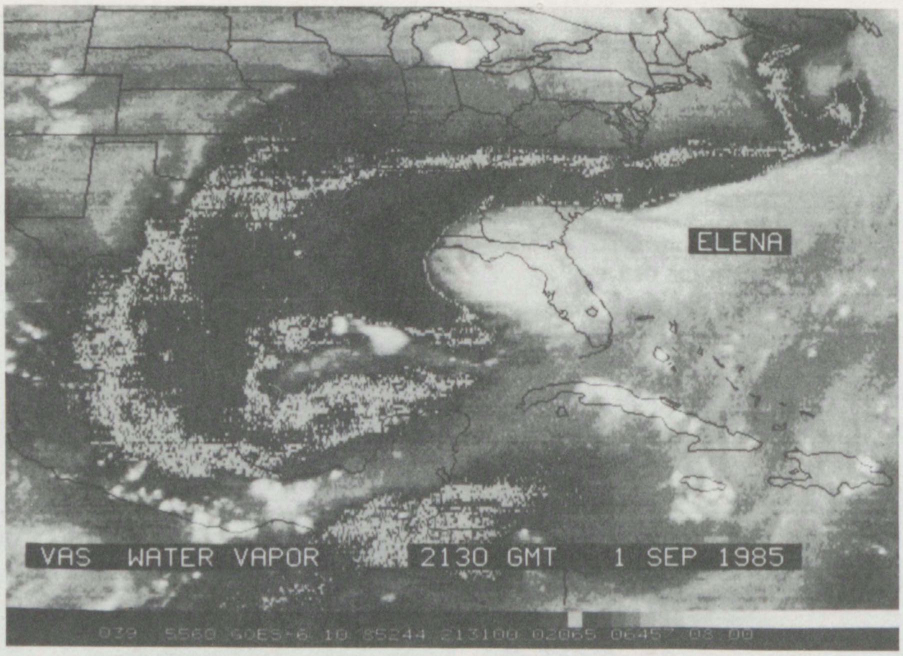

Fig. 4. GOES 6.7 micron image during Hurricane Elena of 1985. White areas are cloud, light gray areas are moist, and "speckled" and dark gray or black regions are dry. Dry trough blocked the passage of Elena for three days.

(Continued from inside front cover)

NESDIS 8 A Technique that Uses Satellite, Radar, and Conventional Data for Analyzing and Short-Range Forecasting of Precipitation from Extratropical Cyclones. Roderick A. Scofield and Leroy E. Spayd Jr., November 1984. (PB85 164994/AS)

NESDIS 9 Surface Cyclogenesis as Indicated by Satellite Imagery. Frank Smigielski and Gary Ellrod, March 1985. (PB85 191815/AS)

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NESDIS 13 Characteristics of Western Region Flash Flood Events in GOES Imagery and Conventional Data. Eric Fleming and Leroy Spayd Jr., May 1986. (PB86 209459/AS)

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NESDIS 15 An Experimental Technique for Producing Moisture Corrected Imagery from 1 Km Advanced Very High Resolution Radiometer (AVHRR) Data. Eileen Maturi, John Pritchard and Pablo Clemente-Colon, June 1986. (PB86 24535/AS)

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NESDIS 18 Tropical Cyclone Center Locations from Enhanced Infrared Satellite Imagery. J. Jixi, and V.F. Dorvak, May 1987. (PB87 213450/AS)

NESDIS 19 A Suggested Hurricane Operational Scenario for GOES I-M. W. Paul Menzel, Robert T. Merrill and William E. Shenk, July 1987. in press

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TECHNICAL SERVICE PUBLICATIONS—Reports containing data, observations, instructions, etc. A partial listing includes data serials; prediction and outlook periodicals; technical manuals, training papers, planning reports, and information serials; and miscellaneous technical publications.

TECHNICAL REPORTS—Journal quality with extensive details, mathematical developments, or data listings.

TECHNICAL MEMORANDUMS—Reports of preliminary, partial, or negative research or technology results, interim instructions, and the like.

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