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JAN 1 3 1999

ASSISTANT ADMINISTRATOR
FOR SATELLITE &
INFORMATION SERVICES

JAN 8 1999

MEMORANDUM FOR: Robert S. Winokur
Assistant Administrator for Satellite and Information Services

FROM: John J. Kelly, Jr.

SUBJECT: National Weather Service's Operational Requirements for Future Geostationary Operational Environmental Satellites (GOES)

The attached Operational Requirements Document (ORD) outlines our validated requirements for future GOES satellites. These requirements should be used in the development of the future GOES spacecraft and sensors. Operational needs evolve with time and are influenced by budgetary and programmatic considerations. Consequently, we view this ORD as an initial operational requirement baseline, which should enable you to begin initial sensor design and cost studies. Over the next several years, we would like to work with you in accomplishing system definition studies. Once definition activities are completed, we will be postured to develop a validated statement of requirements to govern the satellite procurement.

The ORD contains many validated requirements; the following are our top priorities:

1. Operation of sensors through eclipse and "keep-out-zones."

2. Resolution of imaging conflict among climatic, synoptic, and mesoscale requirements.

3. Improved time and space resolution for the imager sensor.

4. Improved space coverage of the sounder sensor.

Attachment

THE ASSISTANT ADMINISTRATOR
FOR WEATHER SERVICES

OPERATIONAL REQUIREMENTS DOCUMENT

FOR

THE EVOLUTION OF FUTURE NOAA

OPERATIONAL GEOSTATIONARY SATELLITES

January 1999

Operational Requirements Document
for
The Evolution of Future NOAA
Operational Geostationary Satellites

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OPERATIONAL REQUIREMENTS DOCUMENT
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OPERATIONAL GEOSTATIONARY SATELLITES

1. General Description of Operational Capability.

This Operational Requirements Document (ORD) establishes the National Weather Service's (NWS) requirements for the Geostationary Operational Environmental Satellite (GOES) observational data, i.e., imager, sounder and data collection, in the next generation system (2010 time frame). These requirements were developed with a total system view and include both spacecraft and ground processing needs. Table 1 contains a summary of key requirements.

The NWS requires observations of the space environment and continuous high temporal and spatial resolution observations of the Western Hemisphere from a geostationary satellite orbit. NWS realizes an intermediate geostationary satellite system may be required to bridge the time frame between the GOES I-M series and the next generation satellite system. Within this document requirements for such a bridge system are identified as near-term needs. All requirements were derived subject to the following constraints:

- o - No impact on the GOES I-M nor the intermediate system acquisition program
- o - Not be system driven, i.e., based on operational needs
- o - Support operational services or products

This document does not address the needs and functional requirements related to the following:

- o - Climate and Global Change
- o - Search and Rescue
- o - Processing and communication of data and/or products derived from those data
- o - Archiving of GOES data and/or products
- o - Coastal and Oceanic Programs

Satellite development and acquisition activities proceed in an evolutionary and time phased manner. The requirements in this document form an initial operational baseline and should facilitate instrument design and cost studies. NWS plans to work with NESDIS in completing system definition and cost benefit studies. These studies will allow development of a final validated statement of requirements to govern system procurement.

For the purposes of this ORD, the terms "threshold" and "goal" mean:

a. Threshold - The minimum acceptable requirement.

b. Goal - A requirement which, if met, would greatly enhance the utility of the data.

GOES REQUIREMENTS SUMMARY
TABLE 1

NWS GOES Requirements			Current	Threshold	Goal
Operate sensors through eclipse and keep-out-zones			No	Yes	Yes
Resolve climatic, synoptic, and mesoscale imaging conflict			No	Yes	Yes
Improve temporal and spatial resolution of imager	spatial	vis	1 km	0.5 km	0.2 km
		IR	4 km	2 km	0.5 km
	temporal		Full disk every 3 hours CONUS every 15 minutes	Full disk every 15 minutes CONUS every 5 minutes	Full disk every 15 minutes CONUS every 1 minute
Improve spatial coverage of sounder			3000 x 3000 km per hour	12000 x 12000 km per hour	Full disk per hour
Number of imager channels			5	8	19
Navigation - daytime			6 km	0.5 km	0.2 km
Backup			2 weeks, if stored on orbit Otherwise 6-9 months	2 hours - imagery 2 days - products	As seamless as possible
Sounder observational accuracy	temperature		2° K per 3-5 km	1°K per 1 km	0.5°K per 1 km
	humidity		± 20%	±10%	± 5%
Improve sounder resolution			10 km	10 km	2 km
Recover time after maneuvers			2-3 hours	1 hour	5 minutes
Growth (power & weight)			None	5 %	25 %
Lightning Mapper			No	No	Instantaneous view of hemispheric events

Microwave Sounder	No	No	Footprint : 20 km
			Coverage: hemispheric hourly
			Temperature Profiles: 15 layers
			Water Vapor Profiles: 2 layers (minimum)
			Total Precipitable Water: 3 mm rms
			Atmospheric Winds: 3 Layers (minimum)
			Rainfall Rate: 0 to greater than 20 mm/hr
Low light imager	No	No	Expand imaging capability to include dusk and dawn time frames

The requirements are separated into imaging and sounding requirements, but this is not intended to dictate development of separate imaging and sounding instruments.

2. Mission.

The National Weather Service provides weather, hydrologic, and climate forecasts and warnings for the United States, its territories, adjacent waters and ocean area, for the protection of life and property and the enhancement of the national economy. NWS data and products form a national information database and infrastructure which can be used by other governmental agencies, the private sector, the public, and the global community.

GOES is one of the complementary observing systems needed to fulfill this mission. In some cases, (e.g., over oceans and data sparse areas in the central and southern hemispheres and the Caribbean region), GOES is the only source of real time data.

3. Top Priority Requirements.

The current GOES-I/M series of satellites cannot meet the requirements for climatic, synoptic and mesoscale imaging, and sounding data to support global forecasts and local warnings. Thus the NWS top priorities are: (**1) operation during eclipse and keep-out-zone**

periods, (2) meet simultaneous global, climatic, synoptic and mesoscale imaging data needs, (3) improve temporal and spatial resolution of imager data, and (4) improve sounder spatial coverage.

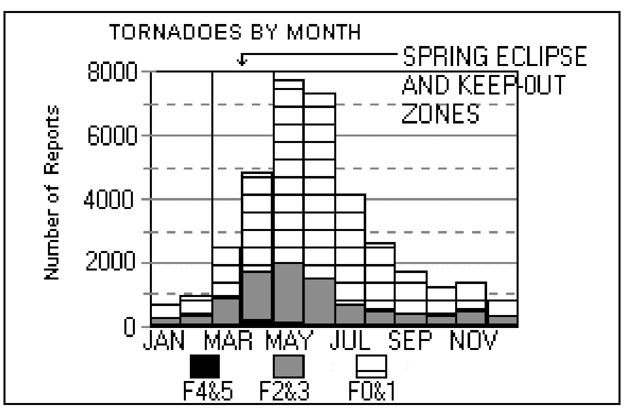
REQUIREMENT: Operation during eclipse and keep-out-zone periods.

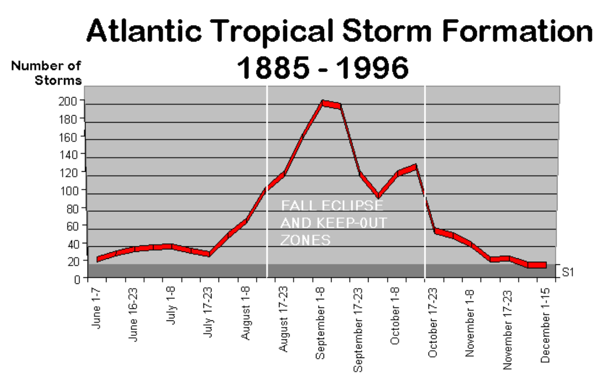
BENEFIT: Provides continuous coverage during the current GOES-I/M satellites extended outages during the spring and fall eclipse and keep-out-zone periods. These outages occur when sunlight enters the imager and sounder sensors. This has introduced a term known as keep-out-zones, which occur before and after the eclipse periods. The combined impact is a 3 to 4 hour loss of data for 10 to 12 days before and after eclipse (around the spring and fall equinox). Figures 1 & 2 show the spring and fall eclipse and keep-out zone periods for the tornado and hurricane seasons. During the spinner era, the outage during eclipse was on the order of about an hour. For GOES-I/M, the outage is on the order of 3 hours, resulting in a significant loss of data.

Figure 1. Spring Eclipse and keep-out-zones superimposed on the tornado season.

Figure 2. Fall Eclipse and keep-out-zones superimposed on the hurricane season.

REQUIREMENT: Meet simultaneous global/climatic/synoptic and meso- scale imaging needs.





BENEFIT: Imaging and high density winds below the equator will be available during mesoscale imaging. The current lack of these winds degrades performance of global forecast models by as much as 10%.

REQUIREMENT: Improve temporal resolution of the imager data:

a) Full disk imager data every 15 minutes.

b) Multispectral image data over the CONUS every 5 minutes. For severe weather activity, updated satellite imager data every 30 seconds covering more than a 1000 x 1000 km area is also required. The actual time and space demands on any particular day for severe storm monitoring could vary according to weather conditions.

BENEFIT:

a) Allows synoptic scale changes to be monitored and satellite derived wind production over the southern hemisphere, resulting in improved regional and global model performance.

b) Allows the monitoring of rapidly changing mesoscale events, which could increase the lead time for watches and warnings by up to 50% in areas with insufficient radar coverage.

REQUIREMENT: Improve spatial resolution of the imager data.

a) The threshold spatial resolution for visible band data are 0.5 km (with 0.2 km as a goal) for near-term and long-term requirements.

b) The spatial resolution requirement for all IR bands is 2 km (with a goal of 0.25 km). All IR bands are required to have a common spatial resolution to support the multi-channel products.

BENEFIT:

Visible:

a) Improve forecasters' ability to identify severe thunderstorms resulting in improved warning lead time, especially in areas with limited radar coverage (Adler et al., 1983;Purdom, 1982: Adler et al., 1985; Weaver et al., 1995).

b) Improve forecasters' ability to make quantitative precipitation estimates (QPEs) and quantitative precipitation forecasts (QPFs).

IR:

1) Improved nighttime detection of severe thunderstorm signatures resulting in improved warning lead time (10%).

2) Improved detection of fog at night resulting in improved aviation, public, and marine forecasts.

3) Improved detection of cloud top temperature gradients resulting in improved QPEs/QPFs.

Because forecasters must infer information from the IR bands at night, similar to that which is inferred from the visible band during the day, the goal is for the IR band spatial resolution to be the same as the visible band resolution.

The NWS has a goal of higher resolution IR data, but its feasibility has been limited by optical and cost restraints.

REQUIREMENT: Improve spatial coverage of the sounder. Within each hour, requirements are for soundings over an area of 12000 x 12000 km as a threshold, with a goal to cover the full disk.

BENEFIT: Allows for generation of the satellite cloud product hourly over the CONUS plus oceanic coverage for assimilation into numerical models.

4. Additional Requirements.

EXPERIMENTAL SENSORS

REQUIREMENT: Future geostationary satellites should also have the capability to fly experimental sensors to support atmospheric research and development activities which are key to improving operational forecasting.

BENEFITS: (1) acquire new types of observations, (2) develop new technical capabilities, and (3) better understand the science.

4.a. IMAGING REQUIREMENTS

REQUIREMENT: Data format must allow integration of future GOES imager data with data from the WSR-88D, ASOS, the lightning detection network, ACARS, and other automated aircraft reports, in AWIPS and for use in numerical weather prediction models.
BENEFIT: These integrated data sources will be used for cloud cover determination, global wind measurements, precipitation and snow cover estimates, and hurricane, thunderstorm, and winter storm tracking.

Types of Observation and Accuracy

REQUIREMENT: Following is a list of imager channels required on future GOES satellite and their applications:

Visible: Daytime cloud imaging, snow and ice cover, severe thunderstorm detection, cloud drift winds, precipitation estimates, fog, flash floods, winter storms

Near IR: Daytime automated discrimination of clouds from snow for estimating total cloud cover, discrimination of water clouds from ice clouds (in aviation), detection of smouldering fires

Shortwave IR: Nighttime detection of low clouds and fog detection when used with the IR and "dirty" IR windows; identification of fires; daytime detection of cloud over snow, fog

IR water vapor (500 mb): Broad scale mid-tropospheric patterns, mid-tropospheric water vapor drift winds (used for numerical model initialization and hurricane track prediction)

IR water vapor (300 mb): Upper-tropospheric water vapor-drift winds (used for numerical model initialization), broad scale patterns corresponding with jet stream cores

IR window: Continuous day and night detection of cloud cover and cloud top heights, low-level water vapor, fog, when used with the "dirty" IR window, precipitation estimates, surface temperatures, hurricanes, winter storms

IR "dirty" window: Low-level water vapor when used with IR window, volcanic ash

IR carbon dioxide: Used with the IR window to estimate cloud parameters above 12,000 feet to complement ASOS and provide cloud information to forecasters and numerical models; parameters include sky cover, heights of cloud tops, and cloud opacity

Sulfuric acid: Detection of sulfuric acid aerosols, for tracking volcanic clouds

Cloud ice/droplet: Determination of cloud ice/droplets

Cloud particles size: Determination of cloud particle size

Cloud top: Better determination of cloud top heights

BENEFITS:

The visible, long and short wave IR windows, the IR dirty window, and the IR water vapor (300 mb) are essential tools for forecast operations at present-day NWS forecast offices and National Centers. Their applications are well documented in the literature (Ellrod, 1995; Menzel and Purdom, 1994; Veldon, 1996; Veldon et al., 1997; Velson, Olander, and Wanzong, 1997; Weaver et al., 1995). Listed below are expected benefits of additional channels required for future operations:

IR water vapor (500 mb): More accurate observation of mid-tropospheric winds leading to improved forecasts of hurricane tracks and winter storm tracks.

IR CO_2 Channel: More accurate cloud heights resulting in improved performance of global, hurricane, and mesoscale numerical models.

Sulfuric acid: Improved detection and tracking of volcanic ash clouds resulting in improved warning for aviation operations.

Cloud ice/droplet detection: Improved forecasts of aircraft icing and QPE.

Cloud size particles: Improved forecast of aircraft icing and QPE.

Navigation and Related Needs

REQUIREMENT: Satellite navigation (earth location) threshold accuracy is required to be 0.5 km at SSP, with a goal of 0.2 km.

BENEFIT: Better navigated imagery allows the forecasters to accurately locate cloud features and phenomena and allows the data to be merged with other data sources, resulting in improved forecasts and warnings (public, aviation, and marine).

Band-to-Band Coregistration

REQUIREMENT: The center of the fields-of-view (FOV) from each of the IR bands should be coregistered to the center of the corresponding FOV's from each of the other IR bands, within ±15% of the IR SSP spatial resolution requirement. The mean[1] FOV

[1] Mean FOV center positions must be used for the visible band, because the visible band has higher spatial resolution

center positions from the visible band should be coregistered to the corresponding FOV center positions from each IR band, within ±25% of the IR SSP spatial resolution requirement.

BENEFIT: Allows the combination of differing channels to produce other image products to aid in the forecasting of special events, e.g., arrival/dissipation of fog, tracking of volcanic ash. In order to produce the combined products, the data from the different channels need to be accurately coregistered.

Individual bands have unique attributes; however, the combination of two or more bands is often required for accurate measurement of a particular atmospheric/Earth parameter. The required windows permit functional combinations for derived products. For example, the IR and "dirty" IR windows can be combined to determine low level moisture and sea surface temperatures. The shortwave IR observations provide supplemental information for nighttime sea surface temperatures. Combining the shortwave IR with the IR window permits the nighttime detection of fog and low clouds. The need to combine bands requires each band looks at the same FOV, as much as diffraction allows.

<u>Pixel-to-Pixel Registration Within Frame</u>

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than any channel in the IR.

REQUIREMENT: The requirement for the relative position accuracy for pixel location within an image with respect to other pixels within the image is stated for 1) line-to-line/element-to-element position accuracy and 2) the entire image. For adjacent scan lines of the detector system[2], the north/south position accuracy should be 0.43 km (at SSP) or 0.1 FOV (3σ), whichever is larger, with similar east/west, element-to-element position accuracies along each scan line. Over the entire image, the deviation in the location of the center of any pixel relative to the center of any other pixel should not exceed 1.3 km relative to the SSP (3σ) for a typical 3000 x 5000 km image, expanding linearly to 5.3 km relative to the SSP (3σ) for a full disk size image. Meeting this requirement may be technically challenging.

BENEFITS: The pixel-to-pixel registration within an image are important to 1) provide distortion-free (no jitter) sequences of images for animation, 2) derive improved cloud drift winds, 3) more accurately estimate storm growth, decay, and movement, and 4) estimate cloud height by using shadows and stereographic techniques.

Image-to-Image Registration

REQUIREMENT: The visible band image-to-image registration should be returned to those proposed in 1983, viz. 0.5 km or less at SSP (where improvement to spatial resolution is possible) over consecutive images during a 60-minute period.

BENEFIT: Allows for more accurate cloud feature tracking for the production of cloud drift winds.

For periods 60 minutes or less, when monitoring the development of severe storms is critical, image-to-image registration is of the utmost importance. On the global scale, imagery over a 60-minute period is required to produce accurate cloud drift winds at least eight times daily, if not more frequently. The following example illustrates the need for accurate registration: a registration error of 2 km between successive 30-minute images yields a cloud track wind measurement with a 1.1 m/sec error.

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[2] This portion of the requirement is specified in terms of either adjacent north-to-south arrays or adjacent single east/west elements along any scan line. For example, with the current system, eight visible detectors are in a north-to-south- array with their relative positions fixed. Thus, the requirement is only valid between adjacent northern (detector 1, which scans lines 9, 17, 25, etc.) and southern (detector 8, which scans lines 8, 16, 24, etc.) scan lines.

More accurate monitoring (location and development) of severe storms from improved cloud drift wind tracer derivation can be realized by the utilization of 15-minute image sequences for global applications, and 5-minute sequences for mesoscale events.

Timeliness

REQUIREMENT: Product delivery (timeliness) must be done in real time to capture rapidly changing, relatively short term events, (e.g., severe weather, thunderstorms, and flash floods). The usefulness of the current imaging is greatly diminished if the imaging is not available for analysis by the forecaster before the start of the next image (i.e., 5-minute data should be distributed to the forecaster within 1 minute of the observation). Real time data stream and real time capability are needed to support data access at all direct access facilities. Because the forecast value of imagery diminishes with time, the imager data must be available in real-time. It should be emphasized that for short time interval observations, the data must be distributed to the user within the length of the observational repeat cycle.

BENEFIT: More timely data allows for more timely and accurate warnings and forecasts.

Simultaneity

REQUIREMENT: Data from all imager bands obtained for any specific point on the earth must be coincident within 5 seconds.

BENEFIT: Allows the forecasters to accurately earth locate data from multiple channels, thus provide accurately located warnings and forecasts.

The bands selected for the imager provide the capability to monitor various atmospheric and cloud parameters, often requiring the combined information from two or more bands for the most accurate assessment. The continual motion of the atmosphere requires simultaneous or near-simultaneous data collection from all bands if accuracy is to be maintained. For example, a cloud moving at 40 m/sec wind will move across a 4-km space in 100 seconds. Information from all bands for a given area must be acquired in a small fraction of 100 seconds. Specifically, if not sensed simultaneously, the time required to obtain coincident data covering any 4-km x 4-km area from all bands should not require more than 5 seconds.

Image Smearing

REQUIREMENT: The output should reach 99.5% of its true radiance value within the shortest distance possible of the pixel locations. This is currently believed to be within 3 FOVs for scanning systems.

BENEFIT: The control of cloud smearing will permit sharply defined cloud edges: 1) for better image interpretation (e.g., arc cloud line characteristics); 2) for improved target selection for cloud drift wind measurements and stereo cloud height determination; and 3) for optimization of cloud clearing techniques for derived products (e.g., SSTs and stability). The current specification for GOES I-M is for the output to be within 1% of the difference between the initial and final values within 3 FOVs.

Recovery Time After Routine Maneuvers

REQUIREMENT: Recovery from maneuver should be within 1 hour (threshold, with a goal of 5 minutes) to minimize the disruption to the sequence of images. Maneuvers should be scheduled to minimize data continuity gaps during Critical Weather Events. The time for GOES I-M to return to normal operations may take up to 9 hours. This excessive delay is unacceptable for a forecast operation that requires and depends upon satellite data input. A realistic improvement would be to minimize the recovery time to less than 1 hour. Improvements to as short as one image time period (5 minutes for severe weather operations) is the ultimate goal, especially for simple maneuvers. Maneuvers' scheduling should permit great flexibility in order to prevent outages during severe weather events.

BENEFIT: Minimizes impacts to the forecasting and modeling operations.

Performance around Local Midnight

REQUIREMENT: Spacecraft performance around local midnight needs to approach the daytime performance.

BENEFIT: Minimizes the loss of data and thus the impacts to forecasting and modeling operations.

Many specifications for the GOES I-M series were relaxed around local midnight, usually for a period of ±4 hours. Unfortunately, the needs of forecasters do not diminish during this time. Severe thunderstorms, tornadoes, and flash floods often occur around local midnight; sometimes they develop, intensify, and move over data sparse regions.

Additionally, satellite derived winds are still required for forecast operations during these hours of the day, and the production are approaching the time when the winds will be available on an hourly basis. It would be very advantageous for forecast operations if the aforementioned time window around local midnight were similar to the performance of daylight operations. Thus, no performance degradation will be accepted.

Loss of Data during Eclipse

REQUIREMENT: Data from at least the IR window are required during an eclipse period to provide continuous view during the spring severe weather and hurricane seasons.

BENEFIT: Minimizes the impact to forecasting and modeling operations.

A loss of data during a satellite eclipse period seriously impacts operational forecasting. For example, rapidly developing storms, such as hurricanes (e.g., Andrew and Hugo) and flash floods (e.g., the Superstorm of March 1993), have formed or intensified during the eclipse period over data sparse regions, such as the Gulf of Mexico, and moved inland. The poor forecast services could be traced primarily to the loss of satellite information. Even though continuous multispectral data are desirable, the minimum requirement[3] during eclipse is for full global coverage, with no “Keep Out Zones” from the IR window.

Visible Calibration

REQUIREMENT: On board calibration of the visible sensor is a requirement to the limits technology permits, and cost is acceptable.

BENEFIT: Quantitative information about the Earth's surface, clouds, and atmospheric properties can be determined from satellite-acquired visible data and are important to climate measurements. Such parameters include cloud measurements, radiation budgets, vegetation estimates, snow cover, and aerosol

[3] This minimum requirement is stated to lessen the impact of this requirement on spacecraft weight, power limits, fuel requirements, and additional cost.

monitoring. Accurate calibration of the visible band is required, both pre- and post- launch, if these variables are to be monitored in an improved manner.

Though pre-launch techniques are standardized, no method has been established for an onboard, absolute calibration.

IR Calibration

REQUIREMENT: On board calibration must provide brightness temperatures for the IR channels within 0.2°K relative precision; absolute accuracy must be within 1°K.

BENEFIT: Allows for more accurate temperature measurements of the top of the clouds in the different channels, thus alerts to the forecasters, when certain thresholds are crossed (e.g., cold tops collapsing, signaling the possibility of tornadic formation), have more validity, thereby improving severe weather warnings and forecasts.

4.b. SOUNDING REQUIREMENTS

NWS (1983) noted the need for obtaining highly accurate observations in a large number of bands throughout the entire infrared spectrum. These capabilities are now practical. These types of multispectral data are needed to: (1) obtain more accurate vertical profiles of temperatures and moisture, (2) accurately estimate cloud top heights, (3) monitor the concentration and distribution of various trace gases which can affect climatic change, and (4) obtain a cleaner window to extract better estimates of sea surface temperatures. An instrument with similar capabilities is already planned for polar-orbit space flight on Earth Observing System in 2000. These capabilities were shown to be technically and experimentally feasible for the last of the GOES I-M series, but financial constraints did not allow these capabilities to be placed on the system.

Type of Observation and Sounding Accuracy

REQUIREMENT: At least one temperature and humidity sounding should be obtained in adjacent 10 x 10 km areas (single FOV pixel soundings to enhance mesoscale sounding capabilities) in clear areas. As technology advances, it is anticipated that there will be additional future requirements for microwave sounding capability for measurements within areas of extensive cloud cover.

BENEFIT: Allows the monitoring of rapidly changing precondition situations, particularly threshold values, for forecasting severe weather conditions.

While spectral resolution and radiometric sensitivity are required for a technical specification, it is expected NESDIS will provide this information based upon these general hydrometeorological requirements. It is considered essential that, for advanced geostationary sounding systems to play a significant role in the total observing systems available by the late 2010's, soundings must provide temperature and humidity accuracies (see Table 2) comparable with those achieved from conventional ground-based data platforms. Moreover, the need to define gradients between other types of observations requires that soundings be available from 10 x 10 km areas. The inclusion of surface and other ancillary data may be necessary to meet these accuracies. However, because these accuracies are required at all times of day, they should be achieved without the use of contemporaneous radiosonde data. In regions of low clouds and fog, soundings above cloud tops are necessary to monitor jet stream structure and vertical moisture gradients. While these additions represent a substantial increase in capability from existing GOES I-M specifications, scientific and technical studies completed since the 1983 NWS GOES-NEXT REQUIREMENT document support the view that these enhancements to a future geostationary system should be operationally feasible through the use of new detector technology in the form of a Michelson interferometer or grating spectrometer (Smith, 1991).

Table 2. Geostationary Sounding Requirements

ALTITUDE RANGE	OBSERVATIONAL ACCURACY (RMS ERROR)				VERTICAL RESOLUTION
	Temperature		Humidity		
	Threshold	Goal	Threshold	Goal	
Sfc-500 mb	± 1.0°K	± 0.5°K	± 10%	± 5%	300 - 500 m layers
500-300 mb	± 1.0°K	± 0.5°K	± 10%	± 5%	1-2 km layer
300-100 mb	± 1.0°K	± 0.5°K	± 20%	± 10%	1-2 km layer
100 mb and above	± 1.0°K	± 0.5°K	-----	----	2-3 km layer

To improve the nation's forecast and warning system more sophisticated numerical (objective) and conceptual (subjective) models will be needed on all scales of atmospheric motion to apply scientific theory to forecast operations. Through 1985 there was a steady increase in the number of forecast days where numerical models demonstrated skill in predicting 500-mb geopotential height fields. Following 1985, this increase in skill leveled off. The period of increased skill resulted from dramatic improvements in model resolution and physics, numerical analysis procedures, and satellite data assimilation methods. During this time, however, these gains were unaccompanied by gains in satellite observing or retrieval methods (Hollingsworth and Szejwach, 1989), and this stagnation of the upper air data base for model initialization has continued into the 1990s. This disturbing trend could continue into the next century if upgraded satellite sensors are not implemented.

The GOES sounder is beneficial to NWS operations because it provides spatially and temporally continuous measurements of temperature, water vapor, and wind. These elements are used to estimate atmospheric stability as well as horizontal and vertical motion fields. While the 2-3°C r.m.s. temperature errors of the filter wheel radiometer (the type of sounder on board GOES-7 and the GOES I-M series) may not initially appear too large, an analysis of individual situations reveals that temperature errors of 10°C are common under certain meteorological conditions. This problem is primarily due to the limited vertical resolution of the filter wheel radiometer and the tendency of temperature and water vapor fields to vary considerably over relatively short distances or small changes in elevation. Broderick et al. (1981) illustrates how soundings from radiometers with poor vertical resolution can easily miss meteorologically important features such as temperature inversions and dry/moist layers. Consequently, in areas where complementary data sources (e.g., radiosondes over continental areas in the northern hemisphere) are available, satellite-derived soundings have historically been less useful to operations. The availability of GOES-derived soundings with high vertical and temporal resolution would greatly enhance our ability to initialize the models with more realistic observational assessments of temperature, water vapor and wind.

For global and synoptic scale modeling, the improved high resolution temperature, water vapor, and wind measurements from geostationary satellites would help fill large spatial voids in the radiosonde network over the coastal oceans of the northern hemisphere and the entire southern hemisphere.

On the mesoscale, if skill in forecasting severe thunderstorms and tornadoes over the United States is to continue improving, an upgraded upper air data base will be required for initializing mid-latitude mesoscale models. While accurate vertical profiles of temperature, water vapor, and wind are already available over the United States and Canada from a reliable radiosonde network, hourly, high-resolution soundings from GOES would help fill the 12-hour time gaps between standard radiosonde observations. GOES soundings with high vertical and horizontal resolution would also help in the definition of mesoscale gradients of temperature or moisture between individual radiosonde stations. This improved definition of temperature and moisture fields would enable numerical models and forecasters to better identify areas of rapidly developing atmospheric instability responsible for vertical motion, convection, and precipitation development.

An important element in the development of deep convection is the amount of moisture below the convective cloud base available for conversion to buoyant energy. The bases of convective clouds are generally 1-2 km above the Earth's surface. Zehr (1986) used the Chesters, et al. (1983) split-window method of subtracting the VAS brightness temperatures of the 11.2 μm and 12.7 μm window channels from each other to estimate "low-level" water vapor fields over the central United States. The disappointing results indicated that the split-window technique came closer to giving an estimate of the integrated water vapor content through the entire depth of the atmosphere rather than the important lowest 1-2 km. It is likely this happened because the 12.7 μm "low-level moisture" channel detected moisture from too thick of a "bottom layer" (surface to 4 km). Therefore, a sounder which is capable of sensing moisture with 1-2 km vertical resolution is critical to estimating the all-important water vapor measurement from the lowest 1-2 km. Furthermore, for the purposes of mesoscale convective modeling, Smith et al. (1990), through an analysis of the thermal wind equation, derived accuracy and vertical resolution requirements for temperature and water vapor measurements, so that they would be thermodynamically compatible with hourly data from the central United States wind profiler network. The results of this analysis revealed that temperature and water vapor soundings must (1) be available hourly and (2) meet the accuracy and vertical resolution requirements stated in Table 2, if these soundings are to make a meaningful contribution to mesoscale numerical models. Consequently, the temporal requirement for hourly data must be met by geostationary, rather than polar orbiting satellites, and the accuracy/vertical resolution requirements must be met by a sounder with high spectral resolution.

For forecasting in the tropics, the requirement for a sounder with high spectral resolution is no less important than in the mid-latitudes. While the weak thermodynamic coupling between temperature and wind would place unrealistic demands for accuracy on the temperature sounder, multilevel wind estimates, which would be determined by tracking water vapor motion at six or more layers, would be very important for the proper initialization of future hurricane prediction models. The present geostationary sounders can provide only a sampling of this capability as the GOES-I/M sounders have only three water vapor channels. Multilevel wind profiles are generally unavailable from alternative data sources in the data-sparse tropics. A sounder with high vertical resolution for measuring water vapor appears to be the primary means by which this critical wind information could be made available for the hurricane models. It was shown by Velden (1996, 1997a,b) that water vapor motion winds from sounder channels was possible and could result in substantial improvements in model forecast errors.

The capability should be available to modify the sounder to allow single pixel soundings in the event that future technological advances support such an upgrade with a relatively minor change.

The absence of microwave sensing from geostationary sounding systems presents a major limitation. Temperature and moisture profiles derived solely from IR bands are not available over areas of extensive cloud cover. The addition of microwave to a geostationary system would make full-weather sounding capability possible for the first time on a geostationary platform. Therefore, geostationary microwave sensing should be considered a goal of the post GOES-N/O/P/Q era.

Spatial Resolution

REQUIREMENT: As a threshold, soundings should be produced for every 10 x 10-km area as clouds permit. The goal is to have soundings produced for every 2 x 2-km area.

BENEFITS: Allows the data to match the resolution of future models.

Profiles of temperature and moisture from the ground through at least 100 mb (as well as derived "image products") are needed in both clear and partly cloudy areas. As a minimum, soundings should be produced for every 10 x 10-km area.

For soundings the data need not be contiguous for any specific frame. Subsampling should be permitted to reduce the total number of observations within the 10 x 10-km area, thereby allowing longer dwell periods. As a suggestion, the subsampling could be accomplished either by making observations in a predetermined pattern (e.g., a checkerboard) and/or by using immediately previous imagery data to isolate totally cloud free or cloudy areas. In some cloudy regions, no data may be needed. The control of the subsampling would probably be best approached as a part of the ground functions of the total satellite system.

Navigation (Earth location)

REQUIREMENT: 1) As a threshold, the absolute navigation accuracy of the instrument must be better than 2.5 km at SSP. This applies for both normal and frequent scan modes. 2) Horizontally continuous images of products derived from the multispectral observations should be essentially contiguous at a distance of 5000 km from the SSP on the Earth in the viewing direction for all viewing directions.

BENEFIT: Allows for more accurately earth-located satellite derived soundings.

In their objective use, the future sounding data will be used in combination with data from a variety of different sources. For these sounding data to have their maximum impact relative to the other data types, the absolute locations of the observations must be known to a high degree of accuracy. As a minimum, the absolute navigation accuracy of the instrument must be less than 2.5 km at SSP. This applies for both normal and frequent scan modes.

Since significant weather events can occur at any time of the day, the amount of navigation degradation at local midnight and during maneuvers must be minimized. The allowable degradation during local midnight and during maneuvers should be made compatible with the imager.

The post GOES N/O/P/Q sounder must not only be able to produce vertical profiles of temperature and moisture at specific locations but also provide horizontally continuous images of products derived from the multispectral observations. As such, it must be possible to obtain adjacent sounding boxes which are approximately contiguous with respect to both latitude and longitude. To optimize observations over the United States, the boxes should be essentially contiguous at a distance of 5000 km from the SSP on the Earth in the viewing direction. This requirement must be met in all viewing directions.

Band-to-Band Registration

REQUIREMENT: Each of the spectral regions must view the same area of the Earth nearly simultaneously with the centroids of each spectral region to be within 10%. All measurements for a particular FOV should be made within 10 seconds to avoid clouds encroaching into more than 10% of the FOV.

BENEFIT: Allows the data to be accurately earth located from one spectral band to the next, thus producing a more accurate derived sounding.

Since the sounding process involves the combination of data from each of the individual spectral regions, it is vital that each of the spectral regions view as closely as possible the same area of the Earth nearly simultaneously. This becomes especially important as the area used to process individual soundings decreases, as will be necessary in defining strong gradient areas.

Pixel-to-Pixel Registration

REQUIREMENT: The relative positioning accuracy must be such that errors in positioning of adjacent observations should not exceed 1 km at SSP.

BENEFIT: Allows data to be accurately earth located from one spectral band to the next, thus producing a more accurate derived sounding.

Since a major use of the sounding data will be in providing information contained in the gradients of the observations, the relative navigation may be more critical than the absolute location accuracy. Accordingly, regular and accurate horizontal locating of observations pixel-to-pixel are essential to reduce gradient calculating errors.

Image-to-Image Registration

REQUIREMENT: The frame-to-frame registration of individual pixels must be within 2.5 km (at SSP). This is necessary to assure pixels are stationary and do not "jitter" between successive images.

BENEFIT: Allows data to be accurately earth located from one spectral band to the next, thus producing a more accurate derived sounding.

Timeliness

REQUIREMENT: The maximum time delay between radiant energy reaching the sensor and providing earth located calibrated radiance data ready for transmission to the forecasters should be 30 seconds. The final data products must be distributed to the field within the length of the observational repeat cycle.

BENEFIT: Allows for more timely tracking of changing events.

Data transmission systems must be responsive enough to provide timely data in situations of rapidly changing atmospheric conditions. The high resolution sounder data will be used in frequently updated (at least hourly) analyses and short range forecasts and warnings. The frequently updated analyses will provide forecasters a continuous record of changes in the detailed atmospheric structure. Since the majority of the other data used in these analyses will be available in real time (with analyses provided to the field within approximately 30 minutes of the nominal observation times), the value of the future geostationary soundings to the analyses will critically depend on rapid data delivery and processing.

The need for timely access and processing of the radiance data dictates the transmission of the sounder data must be independent from that of the imager, both in terms of data streams and transmission processing. The maximum time delay between radiant energy reaching the sensor and providing earth located calibrated radiance data ready for transmission to the users should be 30 seconds. The final data products must be distributed to the field within the length of the observational repeat cycle. In no case should the maximum delay exceed 15 minutes beyond the time of data collection completion.

4.c. SPACE ENVIRONMENT REQUIREMENTS

The Space Environment Center (SEC) requirements will be stated as in situ or solar observation requirements, and thus will be in a different format from above. Up until this point the requirements have been stated as if viewing the imagery or sounding at the subpoint of the satellite on the earth.

SOLAR MEASUREMENTS

REQUIREMENT: Hard and soft X-ray emission from the integrated solar disk, with a refresh of a 3 second cadance.

BENEFIT: Allows the addition of the hard X-rays to the current soft X-ray capability.

This equates to adding four channels in the 0.003 to 0.28 ηm range. The products are the determination of solar flares and their magnitude; radio communication conditions; inputs for the solar activity models; prediction of energetic proton events 1-3 hours in advance; forecasts that affect all space-based systems and satellites; and the enhanced ability to predict geomagnetic storms.

REQUIREMENT: Extreme ultraviolet (EUV) emission from the integrated solar disk, with the ability to measure bands between 5 and 120 ηm, at a refresh of 1 minute cadence.

BENEFIT: Allows for measurement of the solar contribution to changes in ionospheric and thermospheric densities; improved height resolution in calculation of thermospheric heating and ionization rates; and critical components in the modeling of the ionosphere and thermosphere.

REQUIREMENT: X-ray and EUV images of the sun, with measurement of 5 arcseconds per pixel at 1 minute cadence in the X-ray bands between 0.6 and 6 ηm and EUV bands between 10 and 31 ηm.

BENEFIT: Provides the location of coronal holes, solar flares, and active region morphology for predicting geomagnetic disturbances; provides corona emission information off the limb for 3-day warnings of increases in solar activity; and provides transition region coronal hole information for details of active region morphology and solar flare predictions.

REQUIREMENT: White-light radiation reflected by material ejected from the solar surface (Solar Coronograph), at ±30 solar radii FOV and 1 minute cadence.

BENEFIT: Allows the measurement of the direction and speed of the Coronal Mass Ejections (CMEs) responsible for geomagnetic storms, and major diagnostic for geomagnetic storm forecasting.

REQUIREMENT: Near-full disk vector magnetograms of solar chromosphere and photosphere (Vector Magnetograph), at arcsecond resolution of 5 minute cadence.

BENEFIT: Measures the potential of active region to produce solar flares, and increases lead time on solar forecasts.

REQUIREMENT: Ultraviolet spectra of total disk-integrated solar irradiance (UV Spectrometer), with Spectra from 120 to 400 ηm at 1 ηm resolution and 1 hour cadence.

BENEFIT: Allows the measurement of the solar contributions to ozone density and variability.

REQUIREMENT: Total solar irradiance of the integrated solar disk, with an integrated solar flux from 200 to 2000 ηm and a calibration stability of 0.1% at 24 hour cadence.

BENEFIT: Allows the measurement of the total solar irradiance, which will be used in global climate models to assess the magnitude of the solar contribution to global warming.

REQUIREMENT: Solar H-alpha (Hα)images, at 0.05 ηm at 1 arcsecond pixel resolution and a 1 hour cadence.

BENEFIT: Allows the identification of solar chromospheric features such as sunspots, filaments, plage, and network components on the solar disk and prominences on the solar limb, which are key components of a solar forecast and solar flare prediction.

REQUIREMENT: Ultraviolet images of Earth dayglow and nightglow emissions, using images of the entire Earth at UV wavelengths, with 100 x 100-km resolution at 5-minute cadence.

BENEFIT: Allows for the production of ionospheric and thermospheric densities from the column abundance of thermospheric O relative to N; total electron content of the ionosphere; and location and intensity of the auroral oval.

SOLAR AND MAGNETOSPHERIC ENERGETIC PARTICLES

REQUIREMENT: Solar Energetic Particles, with measurement of protons from 4 MeV to ~1000 Mev, alphas from 4 MeV to ~100 MeV, CNO from 50 MeV to > 2 GeV, and Fe from 100 MeV to > 4GeV, at 30 second resolution with multiple look directions in > 5 energy channels with large aperture (> 1 ster).

BENEFIT: Allows the alert of solar energetic particle events; specify single-event upset environment; specify cosmic radiation environment; detect polar cap absorption (ionospheric modification); and specify radiation-damage environment.

REQUIREMENT: Magnetospheric Energetic Particles, with measurements of electrons at 30 keV to > 4 MeV and protons at 30 keV to 4 MeV, at 10 second resolution with multiple look directions in > 5 energy channels with large aperture (>1 ster).

BENEFIT: Allows for the specification of spacecraft surface-charging environment; the specification of deep-dielectric charging environment; and alerts of rapid changes in particle environment.

MAGNETIC FIELD

REQUIREMENT: Magnitude, direction and fluctuations of Earth's magnetic field (MAG), with 0.5 second samples at 0.1 ηT resolution at ± 400 ηT range.

BENEFIT: Allows for the measurement of megnetopause crossing; solar wind shocks impacting Earth; geomagnetic storms and substorms; and geometry of field controls particle dynamics.

MAGNETOSPHERE

REQUIREMENT: Magnetospheric low-energy plasma, with measurements of electrons and protons from < 10eV to 30 keV at 10 second resolution and multiple look directions at > 5 energy channels.

BENEFIT: Allows for the specification of spacecraft surface-charging environment; location of the plasmapause; locations of the magnetopause; and level of in situ surface charging.

IONOSPHERE

REQUIREMENT: Measure of the phase-change in GPS signature as the GPS signal passes through the ionosphere to GOES, with a total line-of-sight electron concentration as the GPS satellites pass behind the Earth's limb, at 5-second cadence.

BENEFIT: Provides vertical profiles of electron density for use in ionospheric specification models.

4.d. <u>DATA COLLECTION PLATFORMS/SYSTEM (DCP/DCS)</u>

REQUIREMENT: The DCP/DCS communications capability requirement is for operational data collection of river gauges, rain gauges, ocean buoys, etc. for the real-time transmission for at least 200 gauges under each radar umbrella, and room to accommodate additional numbers.

Should a GOES DCP/DCS capability fail, immediate backup capability is required.

BENEFIT: Provides real-time remotely sensed data for use in the forecast and warning system.

4.e. EMERGENCY MANAGER'S WEATHER INFORMATION NETWORK (EMWIN)

REQUIREMENT: EMWIN is required for providing Emergency Manager's and the Federal Emergency Management Agency with a relative inexpensive and light weight method of receiving digital data for their operational needs.

Because of the importance of the data and products, immediate backup capability is required.

BENEFIT: Provides Emergency Manager's with updated forecast and warnings for their areas and satellite imagery from a single source.

4.f. KEY PARAMETERS

The key parameters from the GOES satellites are images, sounding, in situ , solar observations, data collection platforms, and the broadcast of these data.

4.g. BACKUP CAPABILITY

Should a satellite fail, imagery products should be available within 2 hours for the imagery, 2 days for the sounder radiances and 2 days for derived products to cover as much of the coverage area of the failed satellite as possible, but no less than 60% of the areal coverage. Full areal coverage should be available within 2 weeks. The backup capability should meet the same product and timeliness issues as the original satellite. The benefit is to minimize the loss of data and thus minimize the impact on NWS products and services.

Should a natural or man-made catastrophic failure occur to the primary ground station operations, NWS needs to have the capability to start receiving all data within one scan time. For the imager this equates to 5 minutes. The benefit is to minimize the impact on NWS products and services.

4.h. AVAILABILITY REQUIREMENT

As stated above in the backup capability, the NWS needs to have near instantaneous coverage, more than 60% of the areal coverage, of a failed satellite within 2 hours of a failure for imagery and 2 days for products. Full areal coverage should be achieved within 2 weeks (time to move a satellite to its operating location).

Ground system operations should keep the loss of data to a minimum, one image (5 minutes), before the backup system is available on line.

The benefit of meeting requirement minimizes the impact on NWS products and services.

4.i. Lightning Mapper (LM)

REQUIREMENT: There is a need for an LM instrument with 10 km resolution (at SSP) with full disk coverage.
BENEFIT: Lightning data provides useful information for a number of forecast operations not available from radar or current satellite data. Ground-based lightning detection systems can detect cloud-to-ground strokes, but not the much more plentiful cloud-to-cloud flashes. Research data, though limited, indicate cloud-to-cloud lightning typically precedes the cloud-to-ground type in the life cycle of a thunderstorm. A lightning mapper would detect both cloud-to-cloud lightning and cloud-to-ground strokes. This dual capability makes such an instrument complementary to any ground-based system. A GOES LM would greatly aid forecast operations dealing with convection and would supplement data sources particularly in mountainous areas, where radar data are limited due to beam blockage.

4.j. Microwave Sounder/Imager

REQUIREMENT: Due to yet another possible conflict between synoptic and mesoscale forecasting, a microwave sounder/imager will need to scan the full disk at least once every hour. It will have to provide temperature and moisture sounding information, as well as derived products, such as rainfall rate. The field of view should be no more than 10 km at the satellite subpoint.

BENEFIT: There is a need to be able to provide soundings through clouds, which the IR sounder cannot do, and to be able to measure instantaneous rainfall rates. This is being done by the polar orbiting satellites, but the refresh time does not lend itself to be used in anything but the models. Microwave data from geostationary altitudes will provide better temporal resolution and could be used by the field forecasters. The microwave data will complement the IR sounder to enable the NWS to meet its mission in providing full coverage of all weather events.

4.k. Low-Light Imager

REQUIREMENT: There is a need for low-light imaging capability.

BENEFIT: One kilometer resolution, low-light visible imagery would allow forecasters to discern fog and important thunderstorm outflow boundaries earlier in the morning, as well as later into the evening hours, during severe and tornadic storm events.

4.l. GROWTH CAPABILITY

REQUIREMENT: There is a requirement for excess capacity to be incorporated to address growth. The recommended capacity is on the order of at least 25% of the payload mass capacity.

BENEFIT: Allows for new emerging technologies to fly in space sooner and allow for the evaluation and software development, before the sensor and data become operational on later satellites.

The need for growth capability on future geostationary satellites is a necessary requirement. Space provided for experimental instrumentation will benefit changing operational requirements and research. Promising new technologies (e.g. microwave) which appear feasible, but are not yet defined, would add weight to the overall system. New instruments and advanced current instruments need significant lead time to prove design and capabilities.

4.m. Availability.

REQUIREMENT: The data from the spacecraft need to be available 24 hours a day, with no break in service during orbit maneuver corrections and during eclipse seasons, and no break in service for keep out zones.

BENEFIT: Provides continuous data, particularly during severe weather events.

4.n. Continuity of Data.

REQUIREMENT: Continuity of data must be maintained at all times. There must not be any more than 2 weeks break in total continuity for any one satellite. A break of not less than 60%

normal areal coverage is acceptable as an initial condition, but must be rectified within 2 weeks. Thus keeping the impact to NWS products and services to a minimum. Imagery must be available within 2 hours and sounding radiances and derived products within 2 days, with 100% coverage within 2 weeks.

BENEFIT: Provides limited degradation to the product and services of the NWS for forecasts and warnings.

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LIST OF ACRONYMS

A - Albedo
ACARS - ARINC Communications Addressing and Reporting System
ADS - Angular Displacement Sensor
AIRS - Advanced Infrared Sounder
AMSU - Advanced Microwave Sounding Unit
ARINC - Aeronautical Radio Incorporated
ASOS - Automated Surface Observing System
AVHRR - Advanced Very High Resolution Radiometer
AWIPS - Advanced Weather Interactive Processing System
CDDF - Central Data Distribution Facility
cm-1 - inverse centimeter (1/cm)
DMSP - Defense Meteorological Satellite Program
EOS - Earth Observing System
FOV - Field of View
GOES - Geostationary Operational Environmental Satellite
IFOV - Instantaneous Field of View
IGFOV - Instantaneous Geometric Field of View
IR - Infrared
K - Kelvin
km - Kilometer
LM - Lightning Mapper
m2 - meter squared
m/sec - meter(s) per second
mb - millibar
min - minutes
MCC - Mesoscale Convective Complex
mW - milliwatts
NASA - National Aeronautical and Space Administration
NEDR - Noise Equivalent Change to Radiance
NEDT - Noise Equivalent Change to Temperature
NESDIS - National Environmental, Data, and Information Service
NHC - National Hurricane Center
NMC - Nation Meteorological Center
NOAA - National Oceanic and Atmospheric Administration
NWS - National Weather Service
POES - Polar-orbiting Operational Environmental Satellite
RMS - Root Mean Square
SEC - Space Environment Center
S/N - Signal to Noise
SSP - Satellite Subpoint
ster - steradian
WSR-88D - Weather Service Radar 88 Doppler
VAS - VISSR Atmospheric Sounder
VISSR - Visible Infrared Spin Scan Radiometer