SECTION 2

STUDY SUMMARY

2.1 GENERAL

The GOES spacecraft are operational environmental observatories with potential for significant improvement. Their principal value is the ability to monitor rapidly changing conditions with multi-spectral imagery. Future GOES imagers could be endowed with the remote sensing capabilities for measuring of the rapid and unpredictable processes on the face of the Earth, especially for variations in the Earth's chaotic feedback systems.

For improved weather forecasting operations, NOAA has already identified the need to upgrade the GOES capabilities for a next-generation GOES-R Imager (circa 2008 AD), with approximately double the data-gathering capabilities (channels and resolution and coverage rate) of the current GOES Imagers. These improvements will enhance the standard operational weather products: winds, cloud cover and water vapor.

For improved understanding of chaotic processes and the diurnal cycle, an advanced GOES imager must also have the multi-spectral spectral bands used by low earth orbit (LEO) imagers, with on-orbit calibration for all bands. A synergy between GEO and LEO radiometry would enable earth system scientists to fuse the remote sensing data from all the space-borne platforms. These additional radiometric capabilities are designed to observe important physical processes that vary rapidly and unpredicably: smoke, fires, precipitation, ozone, volcanic ash, cloud phase and height, and surface temperature.

We believe the technology now exists to develop an imaging system that can meet future weather reporting and earth system science needs. Due to the level of technological challenge and risk involved, developing such an advanced imager as part of the operational GOES program would be a significant undertaking. GOES-8, the first satellite in the current operational series, required years of pre-launch re-engineering and over one year of on-orbit characterization and software corrections to develop adequate pointing and radiometric performance. That experience made it clear that the next generation geo-imager for use in the future GOES spacecraft should be more carefully designed and tested. We believe a modern software-assisted design could be developed by 2000 AD, and be prototyped with a flight model by 2005 AD to minimize the risk and expense to an operational series in 2008 AD.

To meet this need, we propose a design for a comprehensive geosynchronous atmospheric imager. This imager is envisioned to fly on a GOES-N class spacecraft, within the volume, weight and power constraints of a platform similar to GOES-N while delivering 100 times more data and radiometric quality than the GOES-N imager. The higher data rate probably requires its own ground station, which could serve as a systems prototype for NOAA’s next generation of operational satellites. For operational compatibility, our proposed advanced GOES imaging system contains the GOES-R requirements as a subset, and the GOES-N imager capabilities (and the sounder's imaging channels) as a further subset.

An operational GOES wideband imager would be a state-of-the-art geo-observatory, providing continuous weather and climate data well into the next century.

2.2 SCIENTIFIC OBJECTIVES AND REQUIREMENTS

Let's define two key words: objectives and requirements. “Objectives” are general functions to be accomplished -- they are the reasons for carrying out a mission. “Requirements” are detailed specifications or benchmarks for measuring how well those objectives are being met. In a radiometric mission, the requirements are not simple pass/fail scores. Instead, the requirements mark the point at which the overall objectives begin to suffer significantly. During mission planning, detailed requirements are adjusted to the real constraints of engineering, cost and schedule while still meeting the general objectives. Now, let's discuss the objectives, requirements and outstanding issues for a GOES high performance imager.

2.2.1 GOES Imager Science Objectives

The main operational objective of an advanced GOES imager is to meet the National Weather Service’s future requirements for geosynchronous observations, anticipating a new operational instrument by the GOES-R era, circa 2008 AD. In the next decade, the NWS will meld satellite image data with other real-time field data, such as the national weather radars. This requires rapid image updates with non-conflicting global and local imaging. Higher spatial resolution, lower radiometric noise, and more accurate ground-registration are needed to improve the analysis of clouds, winds, and water vapor across the visible and infrared spectral bands. The satellite must be easy to operate, and should provide useful images on demand, all day, every day.

The main earth science objective is to help measure fluctuations and trends in weather and climate. Geosynchronous orbit provides continuous observations of the rapidly changing cloud and water vapor patterns that are needed to monitor the diurnal cycle between overpasses by the polar orbiting environmental satellites (POES). At the start of the next decade, there is an opportunity for synergy with the advanced imagers in low earth orbit. An advanced GOES imager will be the prototype for a long series of imaging observatories of general use to weather and climate studies for decades. Scientific feedback from the weather and climate users must be built into the prototype flight, and the affected agencies should support post-launch science testing to assure long-term usefulness to the agencies' strategic objectives.

2.2.2 GOES Imager Science Requirements

The National Weather Service requirements are drawn from their draft document for the GOES-R Imager, circa 1995, and summarized in Figure 2.1. The NWS calls for doubling the GOES-8 scan rates, the horizontal resolution, and the earth-location accuracy for local, continental and global scales. A few new spectral bands are required to distinguish clouds, snow and upper air water vapor, with noise values at the current GOES-8 level or better. The GOES-R satellite must operate continuously through eclipse and local midnight, when the sun shines into the telescope. Images of storm sectors must be easily selected and delivered to match the 5-minute refresh rate of the other real-time weather sources such as the Doppler radars.

The radiometric requirements on a GOES imager for earth system studies are to emulate the MODIS and polar weather satellite bands in the atmospheric windows in order to capture the diurnal cycle of clouds and water vapor, which are not well observed by the polar orbiters. To accomplish this, the satellite must be well calibrated against internal, terrestrial, lunar and solar targets, and it must cross-reference the polar orbiter imagers, such as the MODIS instrument on AM-1 and PM-1. For long-term analysis, and archive of radiances and data products must be readily available in standard formats on the national network. The earth system requirements for space-time resolution are similar to the operational weather requirements for GOES-R, and so they are not repeated in Figure 2.1.

FIGURE 2.1 GOES Imager Science Requirements

- National Weather Service requirements (GOES-R markup 95)
  - rates: 1 min. 1000x1000 km, 3 min. CONUS, and 15 minute global
  - resolution: 0.5 km vis & 2 km infrared
  - earth location: ± 1 km
  - 8 spectral bands: 0.6, 1.6, 3.7, 6.7, 7.3, 11, 12, 13 microns
  - Signal/Noise 250/1 vis., NEDT 0.3 K infrared
  - operate through eclipse and local midnight
  - selectable sectors, data delivery in 3 minutes

- Earth System Science requirements
  - emulate MODIS and POES bands in all atmospheric windows
  - diurnal cycle, full-disk; cloud phase, wind, and water vapor layers
  - generous calibration: internal, terrestrial, lunar, solar
  - cross-references with polar-orbiting satellites
  - standardized radiance data and products in servers on the network

2.2.3 GOES Imager Spectral Objectives

The spectral objective for an advanced GOES imager is to observe in all the broad band atmospheric windows from the solar-reflected visible to the thermal-dominated infrared, as shown in Figure 2.2. Because all of the spectrum is used, this design objective will provide a general-purpose platform for monitoring weather and climate change in the next century.

In Figure 2.2, the broad band windows are split into two of three narrower bands to provide accurate differential measurements of water vapor and surface conditions. In addition, many bands are placed on strong water vapor absorption features, either to probe water vapor vertically (in the 6-to-8 micron band), or to provide a dark background for observing cirrus clouds in reflection (in the 1.3 micron band).

The spectral bands illustrated in Figure 2.2 have been identified in previous EOS studies as useful for measuring rapidly varying atmospheric and surface conditions:

- cloud height/amount, and cloud phase (ice or water), and cloud-tracked winds
- clouds over snow fields
- aerosols and volcanic ash
- water vapor in layers and water vapor tracked winds
- surface temperature, vegetation, and fires

These scientific products are indicated with icons in Figure 2.2.

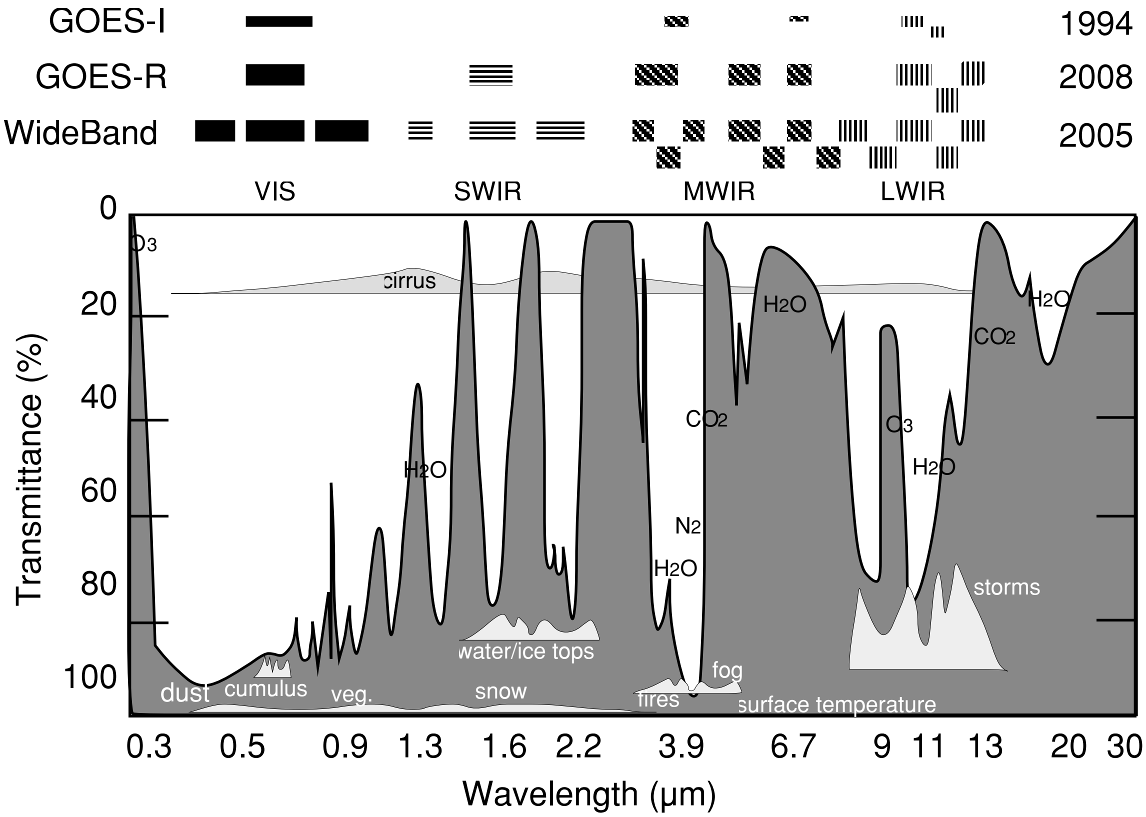

FIGURE 2.2 GOES Wideband Imager's Spectral Objectives

<u>2.2.4 GOES Wideband Spectral Requirements</u>

The GOES wideband imaging spectral requirements are tabulated in Figure 2.3. These detailed requirements are drawn from those written for GOES-R, MODIS, AVHRR, and the GOES-8 Imager and Sounder, particularly the bandpasses and signal/noise specifications. Noise levels are listed either as a fraction of a percent for a nominal scene albedo or as brightness temperature at a reference temperature, with the reference levels and maximum values listed. The FOV size for delivered pixels are from the NWS GOES-R requirements. The FOVs are consistent among channels that will be used differentially (e.g. the blue and yellow visible channels for aerosol measurement; the 4 and 11 micron channels for fog and fire detection).

The last two columns in Figure 2.3 indicate the principal purpose of the band and its the heritage with the other NOAA and ESE instruments (e.g. “M” stands for MODIS, and “ARMIS” indicates a band common to all five instruments). Most of the bands will be carried on the MODIS instruments on EOS AM-1 and PM-1 spacecraft. One exception are the channels in the midwave IR, 6-to-8 microns, which will observe the dynamics of water vapor in the troposphere with much better accuracy than on the current GOES imager or in the GOES-R proposal.

FIGURE 2.3 GOES WIDEBAND IMAGER SPECTRAL REQUIRMENTS

Band No.	Wavelen. µm	Bandpass µm	FOV km	Noise @ Ref.	Ref. Level	Max. Level	Heritage*	Purpose
1a	0.475	0.45-0.50	0.5	250/1	50%	100 %	M	aerosol
1	0.60	0.53-0.67	0.5	250/1	50%	100 %	ARMIS	cloud albedo. wind
2	0.80	0.75-0.85	0.5	200/1	50%	100 %	AM	vegetation
3	1.375	1.36-1.39	1	150/1	50%	100 %	M	cirrus cloud cover
4	1.65	1.57-1.73	1	250/1	50%	100 %	MR	cloud water, snow
5	2.22	2.10-2.35	1	200/1	50%	100 %	M	cloud ice
6	3.60	3.40-3.80	2	0.1 K	320 K	340 K	MS	low water vapor
7	3.95	3.85-4.05	2	0.1 K	320 K	340 K	ARMIS	sfc. & cloud temp.
8	4.15	4.10-4.20	2	0.2 K	320 K	340 K	MS	low air temp.
9	6.55	6.4-6.7	2	0.2 K	250 K	340 K	S	strat. water vapor
10	6.85	6.7-7.0	2	0.2 K	250 K	340 K	RMIS	high water vapor
11	7.15	7.0-7.3	2	0.2 K	250 K	340 K	RS	mid water vapor
12	7.45	7.3-7.6	2	0.2 K	250 K	340 K	MS	low water vapor & SO2
13	8.5	8.0-9.0	2	0.2 K	320 K	340 K	M	total water vapor
14	9.7	9.6-9.8	2	1.0 K	320 K	340 K	MS	ozone & SO2
15	11.0	10.2-11.7	2	0.2 K	320 K	340 K	ARMIS	sfc. & cloud temp
16	12.4	11.9-12.9	2	0.3 K	320 K	340 K	ARMIS	total water & ash
17	13.3	13.0-13.5	2	0.5 K	320 K	340 K	MRIS	mid cloud cover
*Heritage: A = AVHRR, R = GOES-R Imager, M = MODIS on AM-1, I = GOES-I Imager, S = GOES-I Sounder								

2.2.5 GOES Imager Radiometric Tolerances (TBD & TBR)

Radiometric tolerances assure the scientific value of image data, so that line-to-line and scene-to-scene differences are useful residual measurements of the true changes in intensity and location. These are still in the process of being defined (TBD) and refined (TBR).

Calibration for the sunlit channels is 5% absolute and 1% relative accuracy (TBR), whereas for the infrared channels, 1 K absolute and 0.2 K relative accuracy (TBR). Polarization requirements are based on MODIS, 5% absolute and 1% relative accuracy (TBR).

In the Phase B, we will develop more realistic values for calibration, polarization, image acuity, spectral purity, registration, navigation, and time-history (TBD).

2.2.6 Science Trades

Horizontal resolution is the strongest trade, since size and weight are strongly correlated with the size of the optics. Resolution will be marginal at the longest wavelengths because we selected a modest 30 cm telescope which will be diffraction limited (3 km Airy spot at 11 microns).

No ocean color bands or other narrow spectral bands are being required because of the difficulty in achieving MODIS-quality signal/noise in faint channels at geosynchronous orbit.

Although no low-gain shortwave IR band for fires was required, the dilution of the localized heat over the 2 km footprint should keep the 4 micron bands on-scale for most fires, considering the rapid dynamics of wild fires.

Low-light visible imaging is readily achievable, but it is not a NWS or ESE requirement.

2.2.7 Science Issues

The objectives and requirements are based in existing NWS and ESE plans, but the negotiations during the design phase require constant guidance and validation by the expected users of the data, particularly for the questions of radiometric tolerances and reasonable testing.

Our effort is a small, integrated study, where team effort is used make quick decisions constrained by real limits in quality, cost and schedule. The broad science issues that came up in our study included:

- The study scientist needs a science advisory group for resolving issues quickly.
- MODIS experience, equipment and support are needed to make design and testing practical on a small budget.
- Day-one algorithms, data products and data delivery need definition and pre-launch simulation in Phase B to assure useful feedback by weather and climate scientists.
- Is lossy data compression acceptable for distributing and archiving the enormous flow of imager data?
- Post-launch science must be supported by Announcements of Opportunity (AO's) organized by science management in the user agencies.

Ambitious radiometric tolerances carry with them the requirements to test and validate performance, which can be very difficult and expensive to do, before or after launch. Traceability is a serious issue. MODIS experience, equipment and procedures are needed to make high-quality radiometry practical on a small budget.