P5.2 SPECIFYING THE REQUIREMENTS FOR IMAGING AND SOUNDING CAPABILITIES ON THE GOES-R SERIES

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1. INTRODUCTION

After issuance of the U.S. National Weather Service (NWS) Operational Requirements Document for the next generation Geostationary Operational Environmental Satellite (GOES), in January 1999, a concept for an imager and sounder to satisfy most of the requirements was developed. The Advanced Baseline Imager (ABI) was initially planned to have 8 channels, with .5 km resolution in the visible channel and 2 km resolution in the infrared (IR) bands. Plans for the Hyperspectral Environmental Suite (HES) include an infrared atmospheric sounder, that will sample the atmosphere in approximately 1500 narrow spectral bands, much faster than today's sounders.

However, as feedback from the user community continued to surface through meetings, such as the "Initial GOES-R Series User Workshop", held in Boulder, CO in September of 2000, and the GOES Users' Conference, also held in Boulder, in May 2001, the planned capabilities of the GOES-R Series Imager and Sounder continued to evolve. User recommendations called for a minimum of 12 to 14 imager channels, with 1) calibrated visible channels to be used for cloud detection, aerosol detection, ocean color observations, and vegetative properties; and 2) a variety of IR channels to: detect clouds, determine land and ocean surface temperature, distinguish ice from water clouds, to distinguish clouds from snow cover, detect cloud properties (such as cloud particle size), detect volcanic ash clouds, detect fires, just to name a few examples.

For a sounder, participants of the GOES Users' Conference recommended it should:

1) provide an accurate three-dimensional picture of atmospheric water vapor; 2) determine atmospheric motions much better by discriminating more levels of motion and assigning heights more accurately; 3) distinguish between ice and water cloud and identify cloud particle size; 4) provide a field of view no greater than 4 km to provide better viewing between clouds and near cloud edges; 5) provide accurate land and sea surface temperatures and characteristics by accounting for the emissivity effects; 6) distinguish atmospheric constituents with improved certainty, including volcanic ash, ozone and methane; and 7) detect atmospheric inversions; 8) provide temperature and moisture profiles within clouds. A microwave sounder, probably on a separate spacecraft would be needed to meet the last requirement.

To ensure that these and other new instruments meet the needs of a wide cross section of the user community, the National Environmental Satellite Data and Information Service (NESDIS) has begun a task of enhancing and unifying the process used to identify, characterize, verify and validate environmental satellite observation requirements. The main components of this process include: 1) a comprehensive, NOAA-wide identification of NWS, Office of Atmospheric Research (OAR), the National Ocean Service (NOS), and the National Marine Fisheries Service (NMFS) satellite-based, platform-independent, mission requirements; 2) an extensive collection of requirements for both Short- and Long-term applications across the disciplines of atmosphere, land, ocean, cryosphere and space, including those documented by EUMETSAT and other international agencies; 3) an enhanced process of translating and documenting agency-level mission needs into system-level operational requirements and technology level acquisition requirements; and 4) extensive cost-benefit analysis and validation phases. These efforts will result in establishment of an efficient, cost effective process, which solicits, documents, analyzes and updates, from a cost benefit perspective, user requirements for application to the design of current and future satellite systems.

This paper will focus on the input provided by the participants of the GOES Uses' Conference, and how this input will fold into the new requirements gathering and validation process.

2. NATIONAL WEATHER SERVICE OPERATIONAL REQUIREMENTS DOCUMENT

The primary component of the GOES system is the instrument suite. The instrument requirements will continue to evolve and were based initially on the National Weather Service (NWS) requirements, documented in 1999 in the "Operational Requirements Document for the Evolution of Future NOAA Operational Geostationary Satellites". This document provided the foundation for conceptual designs for the

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next generation imager and sounder. The top priorities for the instrument capabilities include: 1) Continuous observations, including operations through eclipse and minimal loss of data for keep-out zones; 2) the capability of observing all scales of atmospheric phenomena simultaneously, from the global scale to the mesoscale; 3) improved spatial and temporal resolution in the imager; and 4) improved spatial coverage in the sounder.

3. THE GOES USERS' CONFERENCE

Although GOES is a NOAA-led program, GOES-R has strong potential for supporting other federal agency missions, and NOAA must consider these requirements as well. In an effort to gather input from a broad cross section of the user community, the GOES Users' conference was held from May 22 through 24, 2001 in Boulder Colorado, with close to 200 participants from government, the private sector, academia and the international community. It was organized by the National Oceanic and Atmospheric Administration (NOAA) with cooperation of the National Aeronautics and Space Administration (NASA), the American Meteorological Society (AMS), the National Weather Association, the World Meteorological Organization, and the National Institute of Standards and Technology.

The goals of the conference were: (1) to inform GOES users of plans for the next generation (GOES R Series) capabilities; (2) to provide information on the potential applications; (3) to determine user needs for new products, data distribution, and data archiving; (4) to assess potential user and societal benefits of GOES capabilities; and (5) to develop methods to improve communication between the National Environmental Satellite, Data, and Information Service (NESDIS) and the GOES user community. Sessions included: Planned and Potential Sensors for U.S. Geostationary Satellites; User Requirements, Applications, and Potential Benefits from Future GOES; Future International Geostationary Satellites; and Communications, Ancillary Services and Training Issues. The third day of the conference consisted of facilitated breakout sessions in which the user community was asked to provide input to ten questions on their future needs for products, services, data distribution, archiving, training and potential benefits of the next generation GOES to their operations and to society technology-level acquisition requirements; and 4) extensive cost benefit analysis and validation phases. These efforts will result in establishment of an efficient, cost effective process which solicits, documents, analyzes and updates, from a cost benefit perspective, user requirements for application to the design of current and future satellite systems.

4. ADVANCED BASELINE IMAGER

One of the strongest messages coming out of the Conference was that a minimum of twelve spectral channels on the imager will be required to meet the needs of a wide cross section of the user community. These channels should include the following: a) 0.64µm for daytime detection of clouds; b) 0.86µm for daytime detection of clouds, aerosols, vegetation and ocean properties; c) 1.375µm for daytime detection of thin cirrus; d) 1.6µm for distinguishing clouds from snow and water cloud from ice cloud (daytime only) e) 3.9µm for detection of fires, and nighttime detection of low clouds and fog; f) 6.15µm for detecting upper tropospheric moisture and determining upper level flow; g) 7.0µm for detecting mid tropospheric moisture and determining mid level flow; h) 8.5µm determining cloud phase, detecting sulfuric acid aerosols and determining surface properties; i)10.35µm for determination of cloud particle size and surface properties; j) 11.2µm for detection of clouds, generating cloud drift winds, and determination of low level water vapor; k) 12.3µm for detection of volcanic ash, low level water vapor, and sea surface temperatures; and l) 13.3µm for determining cloud-top parameters and determining cloud heights for improved quality cloud drift winds.

In addition to these channels, which are considered absolutely essential, there was a strong recommendation for at least two additional channels: the 0.47µm and the 9.6µm . The 0.47µm channel would be valuable for generating true color images, and for detecting aerosols and haze in determining slant range visibility for aircraft operations. The 9.6µm channel would be important for detecting ozone and for the detection and forecasting of clear air turbulence. Beyond these channels, providing they would not result in major additional sensor complexity or expense, a 4.57µm channel would be useful for improved determination of precipitable water and a 14.2µm channel would be valuable for more accurate cloud top heights. However, these products will also be generated by the hyperspectral sounder on the GOES-R series.

The participants strongly endorsed plans for improved spatial and temporal resolution. Current plans call for 0.5 km spatial resolution (at satellite subpoint) for the 0.64µm channel and 2 km resolution for all other channels. Since there will be more quantitative applications for both the visible and IR channels, there was a recommendation that the resolution of the .86µm channel match the 0.5k resolution of the 0.64µm channel. Also, the visible channels should be calibrated on-board.

Participants voiced the need for improved temporal resolution to meet the need for simultaneous global, synoptic and mesoscale imaging needs. The ABI should be capable of providing full disk images every 5 minutes and a 1000km X 1000km area every 30 seconds.

5. HYPERSPECTRAL ENVIRONMENTAL SUITE

For geostationary soundings to provide a truly useful complement to other observing systems, they must yield continuous, reliable, high spectral resolution data in the following locations: (1) areas not observed by other data sources (e.g., over the coastal waters and open oceans), (2) near gradients of data when these gradients occur between observations derived from other sources of data, and (3) between temporal gaps of polar-orbiting satellite observations, providing complete observations of the diurnal cycle. This is true for the radiances, the soundings themselves, and the derived sounding product images. Future GOES sounders must be capable of covering much larger areas every hour to satisfy the observational needs over both the continental U.S. and the data-sparse ocean areas.

While NWS forecasters find the products from the present GOES Sounder to be valuable observational tools in the forecast process (Schmit et al. 2001), and continue to develop more operational uses for the data, the relatively coarse vertical resolution of the filter wheel sounder limits its value for some applications. The present generation of GOES sounder is limited to a 2 to 3 C accuracy over a 3 to 5 km layer. 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. The availability of GOES-derived soundings with improved vertical and temporal resolution would greatly enhance the ability to initialize numerical models with more realistic observational assessments of temperature, water vapor and wind (Aune et al. 2000).

The recurrent message from the conference participants, was that while the current filter wheel sounder provides valuable information for both numerical models and for subjective use in the forecast offices, future applications will require a much faster coverage rate for the sounder with much improved spectral and spatial resolution. For numerical applications in the 2012 time frame, models with much improved physics and a spatial resolution of 1 to 2 km, will demand detailed information on clouds, moisture and surface specifications as well as tendencies. In the seamless suite of products from the National Centers for Environmental Prediction (NCEP), with its essential climate, weather and water linkages, all model applications are essentially driven by the global model system, which in turn is driven by global observations, including observations from both polar and geostationary satellites. Improved spectral and spatial coverage of future GOES Sounders will be critical to meeting the National Weather Service's (NWS) future goals for numerical weather prediction, objective nowcasting and real time forecaster products.

The specific user recommendations for the HES follow:

1) Coverage rate should be much faster than the current sounder to eliminate the conflict between global and mesoscale observations. It should be able to scan an area close to full disk within one hour.

2) It should be capable of operating in a rapid scan mode, sacrificing areal coverage for greater temporal resolution over a limited area when needed.

3) It should have a field of view no larger than 4 km, to allow for more observations between clouds.

4) It should be able to detect temperature inversions, which are critical for severe weather forecasting.

5) Calibration information and algorithms to generate products should be made available to the user community.

6) Soundings are needed in cloudy areas. Conventional GOES clear air soundings should be supplemented either by a microwave sounder in geostationary orbit, or with GOES IR soundings above the clouds and polar microwave soundings.

7) Funding for research and development of new satellite products should be part of the satellite acquisition budget.

8) For developing new satellite products there should be improved collaboration between research and operations.

9) In operations there is a need for a blend of data and products from operational and research satellites.

If their recommendations are met, the user community expects that the HES will: 1) depict water vapor as never before by identifying small scale features of moisture vertically and horizontally in the atmosphere; 2) track atmospheric motions much better by discriminating more levels of motion and assigning heights more accurately; 3) characterize the life cycle of clouds and distinguish between ice and water cloud, and identify cloud particle sizes; 4) accurately measure surface temperatures (both land and sea) by accounting for emissivity effects; and 5) distinguish atmospheric constituents with improved certainty, including volcanic ash, ozone, methane and other trace gases.

6. NEW IMAGER AND SOUNDER PRODUCTS

With the expected improvements for the ABI and HES, the user community suggested the following new or improved products be developed for operational use: a) atmospheric aerosols; b) cloud phase; c) cloud particle size; d) surface properties; e) improved satellite derived winds; f) moisture flux; g) improved quantitative precipitation estimates; h) improved volcanic ash product; i) clear air turbulence threat areas; j) cloud emissivity; j) improved low cloud and fog product; k) cloud layers; l) probability of rainfall for each pixel; m) improved sea surface temperature product; n) true color product; o) cloud optical depth; p) sulfur dioxide concentration (precursor to volcanic eruption); q) aircraft icing threat; r) ocean color; s) under (ocean) surface features (i.e. coral reefs); t) improved sea ice products; u) improved vegetation index; v) ozone layers; and w) surface emissivity.

7. DATA DISTRIBUTION

The current GOES transmits data with a rate of 2.1 Mbits per second. The GOES-R series, with thousands of bands on the sounder, as well as more channels on the imager with higher spatial and temporal resolution, the data rates will increase to 20 to 80 Mbits per second, depending on the amount of data compression used. Options include land line distribution, commercial satellite distribution, or rebroadcast from the GOES. The current L band broadcast may have to be changed to an X band transmission (which has problems with rain fade and low angle reception). This would require completely new reception equipment. The current L band is also the only approved method of transmission while the satellite is moving into position from a storage location. The conference participants were asked to convey their needs for data distribution and provide suggestions for optimum methods of distribution.

Some recurring themes among the user responses include: 1) There is a wide spectrum of user needs with different tiers of data access. There should be a full range of methods of reception to accompany the broad range of data requirements. 2) Data distribution should be timely and have low cost and low data rate options available. 3) Data distribution options that should be considered include: a) commercial satellite broadcast; b) direct broadcast from GOES; c) Internet; d) dedicated land lines. e) data acquisition by users from a central location; and f) some combination of "a" through "e". 4) Re-use existing ground station assets and broadcast a subset of the ABI/HES data streams from decommissioned GOES satellites.

8. DATA AND PRODUCT ARCHIVE NEEDS

The breakout groups recommended that a full spectrum of GOES products, ranging from raw data to highly processed products be available in an archive for applications ranging from the nowcasting scale to the climate scale. The products should be stored in a user friendly format, allowing for easy remote access at minimal cost to the user. The user must also have access to metadata, including information on data and product quality trends due to variations in instrument or satellite performance. Users should be able to browse, select and submit requests for products via the internet. Potential options for product distribution to the users include: File Transfer Protocol (FTP) for electronic transfer, CD-ROMs, and DVDs. Turnaround for most data requests should be less than 1 day, while one week should be allowed for extremely large requests (i.e. years worth of data).

9. NEW DATA INTEGRATION

Participants of the workshop provided several recommendations on ways to minimize the time required for integrations of the GOES-R data stream into operations: 1) leverage data from relevant instruments on other satellites to better understand GOES-R capabilities (i.e. use the Atmospheric Infrared Sounder (AIRS) and the Geostationary Imaging Fourier Transform Spectrometer (GIFTS) data to prepare for HES; use the Moderate Resolution Imaging Spectroradiometer (MODIS) to simulate ABI data); 2) provide correctly formatted sample data sets to the user community at least one year prior to the GOES-R launch; 3) requirements for operational algorithms should be identified by the spring of 2002; 4) operational algorithms should be developed 3 to 5 years prior to launch; 5) establish a working group to develop plans to provide sample data sets and for development of new operational algorithms; 6) NOAA should invest in education, training, research, and product development to ensure optimal use of GOES-R products shortly after launch; 7) provide an extended scientific checkout period following the GOES-R launch to allow use of current data and to ease the transition to new data sets. 8) NOAA should have in place a fully operational infrastructure for reception, distribution, processing, and archiving, ready for use with test data sets prior to the GOES-R launch.

10. EDUCATION OF USER COMMUNITY

To ensure maximum return on the investment in the next generation GOES, the breakout groups at the GOES Users' Conference recommended a comprehensive education program for all levels of GOES users, including: forecasters, emergency managers, recreational users, academia, the media, industrial users, and commercial users. Education programs should be funded as part of the end-to-end GOES program budget.

Methods of education should include: 1) conferences and workshops; 2) web-based training; 3) teletraining; 4) CD-ROM or DVD based training; 5) brief segments on the Weather Channel; 6) educational packages appropriate for Congress, upper level management, and business leaders.

11. NEW REQUIREMENTS GENERATION PROCESS

NESDIS has begun the task of enhancing the process used to identify, collect, assess, and allocate validated environmental satellite observation user requirements. The main characteristics of this process include collection of agency-based observation requirements and translation of these into system-based operational requirements, an efficient interface to the acquisition and budget, planning and programming management systems, and implementation of a requirements tracking tool to trace high level agency mission requirements through to technical system requirements.

The collection component first includes a comprehensive, NOAA-wide, identification of NWS, OAR, NOS, NMFS and the Office of Marine and Aviation Operations (OMAO) satellite-based, but orbit-independent, mission observation requirements. This collection includes those for both short and long term applications across the disciplines of atmosphere, land, ocean, solar, and space environment in the categories of mission critical (operations), mission optimal, and mission enhancing (research) requirements. Each individual agency's mission observations requirements list (MORL) will be integrated into the NOAA consolidated observations requirements list (CORL). Future plans also include a comprehensive identification of other U.S. federal and private agency needs which could be addressed with NOAA'S planned environmental satellites and identification of, international coordination of, and contributions to, global environmental satellite programs.

The NESDIS requirements management process will then assess these requirements against a suite of current and planned NOAA (GOES, POES, NPOESS) satellites, and other available satellite data streams from non-NOAA sources, for allocation to specific orbits and platforms. Evaluation of the level of requirement's fulfillment, cost benefit analyses and trade studies are used to determine the optimal selection of system(s) to address user needs.

The allocated requirements for a particular system are then translated into specific system operational requirements documents (ORDs) for use in generating, along with additional spacecraft and instrument trade studies and cost benefit analyses, the needed technical acquisition-level requirements documents (TRDs).

These efforts will result in establishment of an efficient, cost effective process which solicits, documents, analyzes and fulfills, from a cost benefit perspective, user requirements for application to both the use and operation of current NOAA environmental satellites and the design of future systems.

12. SUMMARY AND CONCLUSIONS

The first GOES Users' Conference was a major step forward for improving communication between NESDIS and the GOES User Community and for expanding the role of a broad cross section of GOES users in helping to define the future system capabilities. While it is only one step in the new requirements development process, it offered representatives from within NOAA, other federal agencies outside of NOAA, private industry and international partners to voice their needs and discuss the benefits of expanding the capabilities of the future GOES system. Participants strongly supported a continuation of the process promoting a two way dialogue between GOES users and those planning the development of the next generation GOES.

The participants strongly voiced the requirement for improvements in spectral, spatial, and temporal resolution in both the future Imager and Sounder. Observations should be relevant for all spatial scales, from the global to the mesoscale, for multi- discipline applications in meteorology, climatology, hydrology and oceanography. In order to meet the needs of a wide cross section of the user community, at least 12 imager channels will be required with .5 km resolution in the visible channels and 2 km resolution in the IR channels.

The Sounder should provide observations approaching radiosonde quality. It should: 1) provide an accurate three-dimensional picture of atmospheric water vapor; 2) determine atmospheric motions much better by discriminating more levels of motion and assigning heights more accurately; 3) distinguish between ice and water cloud and identify cloud particle size; 4) provide a field of view no greater than 4 km to provide better viewing between clouds and near cloud edges; 5) provide accurate land and sea surface temperatures and characteristics by accounting for emissivity effects; 6) distinguish atmospheric constituents with improved certainty, including volcanic ash, ozone, and methane; and 7) detect atmospheric inversions.

These improvements in the imager and sounder should lead to improved service to the user community, including: 1) improved quantitative precipitation forecasts; 2) reduced size of geographic areas affected by watches; 3) improved early detection of severe weather and flash floods; 4) improved forecasts of hail and hail size; 5) improved prediction of fog formation and dissipation; 6) improved forecasts of microburst potential; 7) improved forecasts of mesoscale convective systems; and 8) improved forecasts of hurricane intensity and motion.

GOES users and potential users will continue to refine the requirements for the GOES-R Series through a new requirements generation process, including the Second GOES Users' Conference (Oct. 1-3 in Boulder, CO).

13. ACKNOWLEDGMENTS

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