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REPORT ON NOAA'S GOES SATELLITE PROGRAM

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1. INTRODUCTION

NOAA plans to launch GOES-R, the first of its next generation, in the 2012 timeframe. A major difference between the GOES-R series and the current generation of GOES satellites will be a significantly higher data rate. The current GOES imager and sounder have a combined data rate of 2.6 mbps for raw data and 2.1 mbps for the rebroadcast of processed data. Present plans call for an Advanced Baseline Imager (ABI) with 12 or more bands whose more frequent scanning and finer resolution will have data rates of about 24 mbps for raw data and 8 mbps for processed data. Experience with the increased number of channels on EUMETSAT's Spinning Enhanced Visible and InfraRed Imager (SEVIRI) will be an important contribution to the success of geostationary imagers, as shown in Schmetz, et al., 2002. GOES-R will also carry a Hyperspectral Environmental Suite (HES), an advanced Interferometer-class sounder based on technology in NASA's Geosynchronous Imaging Fourier Transform Imager Spectrometer (GIFTS). HES is expected to have a data rate of about 64 mbps.

Data rate increases of nearly 40 times today's rates move data distribution challenges to a new plane. Issues arise relative to data distribution policy, user requirements, sensor design, communications engineering, ground system design, maximization of existing radio frequency (RF) allocations, compressing data into fewer bits, and cost. After describing the current GOES system as a basis for comparison, discussion turns to issues for data distribution.

2. THE GOES I-M SERIES

The present GOES constellation consists of two operational satellites, GOES-8 (I) at 75°W and GOES-10 (K) at135°W; two fully capable on-orbit spares, GOES-11 (L) and GOES-12 (M); and an earlier satellite, GOES-9 (J). The five satellites in the GOES I through M series were produced by Space Systems/Loral. NOAA describes each satellite with a letter (e.g., I, J, etc.). Once it is successfully inserted into geostationary orbit, it is redesignated with a number (e.g., 8, 9, etc.).

Instrumentation on the GOES-8 through 12 consists of an Imager, a Sounder, and a Space Environmental Monitor (SEM) suite, along with a Data Collection System (DCS), weather facsimile (WEFAX) transponders, and Search and Rescue (SAR) receivers. The Imager is a five channel imaging radiometer, with Images formed by scanning an array of detector footprints across the Earth from East to West, then back from West to East, from the top of the image to the bottom. An excellent description of both the Imager and Sounder can be found in Menzel and Purdom (1994). The visible channel consists of eight detectors mounted in a north-south line, each having a horizontal resolution of one km at nadir. Each scan covers an eight km swath. There are four infrared channels centered at 3.9, 6.7, 10.7, and 12.0 micrometers. On GOES-12, the

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12.0 micrometer channel was replaced with a 13.3 micrometer channel. Three of the IR channels consist of two four km detectors also mounted in a north-south line. The two detectors cover eight km each scan. One channel on each satellite, the 6.7 micrometer channel on GOES 8 through 11, and the 13.3 micrometer channel on GOES-12, has one detector at eight km resolution. Thus, each scan produces eight lines of visible, two lines of IR in three channels and one line in one IR channel.

The Sounder instrument is a 19 channel discrete-filter radiometer that senses emitted radiances to measure the vertical distribution of temperature, moisture, cloud top temperatures, and ozone in the atmosphere. In addition to the one visible channel, there are seven longwave, five midwave, and six shortwave IR channels, all with horizontal resolution of 8.6 km at nadir. The Sounder stares at each field of view on the Earth for 0.1 to 0.4 seconds (the choice is commandable) and measures radiances in all 19 channels.

GOES-12 was launched July 23, 2001 and reached geostationary orbit on August 12, 2001. It has redesigned and more robust instrument mirror motors and carries the same instrument complement as GOES-8, 9, 10, and 11, with two exceptions. The Imager on GOES-12 will have its 12.0 micrometer channel replaced by a 13.3 micrometer channel to better determine the heights of mid-level steering winds and more accurately measure atmospheric and cloud optical properties. Also, the 6.7 micrometer channel resolution will be improved from eight km to four km. GOES-12 carries the first Solar X-Ray Imager (SXI) instrument, designed to provide images of the Sun in four X-Ray energy bands at intervals as frequently as once every few minutes. SXI data will provide the first continuous operational series of Solar X-Ray images and is expected to provide extremely valuable data during and after Solar Maximum.

3. THE GOES-N SERIES

For the next series, referred to as the GOES-N series, instruments and spacecraft are being manufactured under separate contracts, each structured for two firm orders with two separate options for a third and a fourth, i.e., as a 2+1+1 procurement. Imager and Sounder instruments are under development by ITT Aerospace/Communications. Solar X-Ray Imagers are being produced by Lockheed-Martin Advanced Technology Laboratories. Boeing Space Systems (formerly Hughes Space and Communications) is manufacturing the spacecraft. The first satellite, GOES-N, will be ready for launch by early 2004. Imagers and Sounders will be essentially the same as for the GOES I-M series. Imager channels remain the same as those on GOES-M, with an improvement in horizontal resolution from eight km to four km in the 13.3 micrometer channel beginning with GOES-O. Sounder instruments will be the same filter-wheel based sounders. For SXI, current plans are to always have at least one operational unit in orbit. Shortly before GOES-N is launched, analog WEFAX signals will be replaced by the digital Low Rate Information Transmission (LRIT) system. More information can be found in McClinton and Dittberner, 2001. Satellites in the GOES-N series also have additional space, power, and data capacity for experimental sensors. Current candidates under consideration are instruments such as a Coastal Zone Remote Sensor, a Geostationary Lightning Mapper, and a Volcanic Ash Mapper.

4. THE GOES-R SERIES

In the 2012 time frame, a crucial part of the GOES-R architecture will be the challenge of a much greater data rate, especially for data distribution. This topic is the focus of this paper. A number of issues have been identified leading to engineering studies to quantify the cost behaviour of various aspects with respect to the ultimate data rate. The current state of the effort and quantitative evaluations is outlined below.

4.1 *Requirements*

A number of studies are underway to help design the follow-on series of GOES sensors and satellites. An important review of user requirements along with an analysis of potential benefits has been underway for more than two years. The first of a sequence of User Workshops was held in Boulder in September 2000. A description of this “Initial GOES-R+ User Workshop” 2000 can be found in Gurka and Dittberner, 2001a. A larger open GOES Users’ Conference was held in May 2001 in Boulder, Colorado (see Gurka and Dittberner, 2001b), 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 from 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. A summary is found in another paper at this conference (Gurka, et al, 2002). A more formal report is in final review and will be posted on the web at: http://www.osd.noaa.gov. The next workshop is planned for October 2003 in Boulder, Colorado. In late 2001, NESDIS initiated development of an updated GOES requirements process that involves all NOAA line offices and major areas of concern (weather, climate, oceans, fisheries, research, and space weather), reaches out to other Federal agencies as well, and considers private and international needs.

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. 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.

4.2 *Advanced Baseline Imager*

One of the strongest messages coming out of the conference was that a minimum of twelve spectral channels on the imager are required to meet the needs of a wide cross section of the user community. These channels should include the following: a) 0.64μ for daytime detection of clouds; b) 0.86μ for daytime detection of clouds, aerosols, vegetation and ocean properties; c) 1.375μ for daytime detection of thin cirrus; d) 1.6μ for distinguishing clouds from snow and water cloud from ice cloud (daytime only) e) 3.9μ for detection of fires, and nighttime detection of low clouds and fog; f) 6.15μ for detecting upper tropospheric moisture and determining upper level flow; g) 7.0μ for detecting mid tropospheric moisture and determining mid level flow; h) 8.5μ determining cloud phase, detecting sulfuric acid aerosols and determining surface properties; i) 10.35μ for determination of cloud particle size and surface properties; j) 11.2μ for detection of clouds, generating cloud drift winds, and determination of low level water vapor. k) 12.3μ for detection of volcanic ash, low level water vapor, and sea surface temperatures; and l) 13.3μ 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 0.47μ and the 9.6μ. The 0.47μ channel would be valuable for generating true color images, and for detecting aerosols and haze in determining slant range visibility for aircraft operations. The 9.6μ channel would be important for detecting ozone and for the detection of clear air turbulence. Beyond these channels, providing they would not result in major additional sensor complexity or expense, a 4.57µ channel would be useful for improved determination of precipitable water and a 14.2µ 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 0.64µ 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 .86µ channel match the 0.5k resolution of the 0.64µ channel. Also, the visible channels should be calibrated on-board. This will allow for calibration changes to be tracked more precisely and rapidly than via a vicarious method.

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.

4.3 *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. 2002), 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 2-3 deg. 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 recurring 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 2010 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 would: 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, and possibly methane and other trace gases.

4.4 *GOES-R Data Dissemination*

Initial science requirements from early NESDIS planning led to GOES-R imager and sounder concepts having estimated processed high resolution data rates of 8 Mbps and 64 Mbps, respectively, for global distribution. “Global distribution” in this context refers to broadcasts from a geo satellite over the entire surface of the Earth that can see the satellite. Data compression studies on reducing the sounder data rate are underway and until completed, a nominal compression of a factor of four is used, bringing the rate for processed sounder data down to 16 Mbps. The combined initial estimated imager and sounder raw data rates are estimated at about 90 Mbps. Based on these requirements the imager may have around 12 bands with faster scanning and finer resolution. The sounder was conceptualised as a fast scanning Michelson Interferometer. A grating spectrometer implementation is also under study. Follow-on NESDIS requirements gathering, still underway, may lead to higher data rates, at least for the raw data. At this stage of development, communication system technology assessments have used the data rates based on these early requirements (See Table 1). These data rates are significantly more than the 2.6 Mbps raw and 2.1 Mbps of the current GOES satellite series.

An effort is underway to construct a list of users that could benefit from receipt of high data rate GOES data. So far, it is estimated that there are about 1000 current users of the GOES Variable format data (GVAR), and approximately one or two dozen numerical prediction centers around the world that may benefit.

A set of principles guides the current effort:

1. Dissemination of GOES data should be done in a manner that achieves the best balance between the goals of maximizing the usefulness of the information and minimizing the cost to the U.S. government and the American public.

2. GOES information should be made available in a manner that facilitates worldwide cooperation and promotes the exchange of meteorological and related information.

3. GOES data should be made available in a manner that provides at least the same level of service experienced by present GOES users.

4. GOES data are critical to meteorological operations and the protection of life and property.

5. Continue some form of wide area distribution within the footprint of GOES satellites. Figure 1 shows the current broadcast area from the 2 GOES satellites located at 75 degrees West and 135 degrees West. Reception is thought to be generally possible out to areas where the elevation angle is between 0 to 5 degrees.

Table 1. Nominal data rates used for engineering analyses to date

GOES-R Initial Data Rates	Raw Data Rate	Processed Data Rate for Global Distribution
Imager (ABI)	24 Mbps	8 Mbps
Sounder (HES)	64 Mbps	64Mbps (Assumed to be 16 Mbps with Compression)

4.5 *Data Compression*

NESDIS is also undertaking data compression studies on the future sounder data to see if significant data reduction of interferogram or radiance data is feasible. Such an approach may or may not be different from compressing imagery data. Presently, the GOES-R sounder with 64 Mbps is the larger data rate source of the two main sensors. To explore these issues, a sounder data compression group has been assembled from the University of Wisconsin, NESDIS, NASA-GSFC, and the Aerospace Corporation to undertake compression studies of interferometer-type sounder data. The group has been working since early January 2002. Efforts are focusing on such approaches as Wavelet transforms, Modulated Lapped transforms, and Principal Components. There are three (3) separate teams pursuing compression. The teams have been using simulated data from the spectrometer-based Atmospheric InfraRed Sounder (AIRS) instrument now flying on NASA's Aqua satellite (launched May 4, 2002). Both lossless and lossy compression are being explored. It is because of this effort and an anticipation of success that a compression factor of four in being used in these concept studies.

5. SUMMARY AND CONCLUSIONS

With GOES-R, there is a new level of challenges driven by the possibility that data rates will be substantially higher than those experienced by today's users. Issues surrounding dissemination of GOES-R data in the 2012 time frame have been identified. They include the high cost of distributing the new high data rates; relative distribution roles for GOES-R satellite global broadcasts, use of commercial communication satellites for global broadcasting, other government services, dedicated land lines, or combinations of the above; identification of international users sites thought to benefit from GOES-R data and products.

The international systems of operational geostationary environmental satellites are critical to weather forecast operations, in both the public and private sector. Improvements in the GOES-R Series will rapidly accelerate advances in the understanding of weather systems and in our ability to provide effective forecasts. Future improvements to geostationary satellite capabilities, better in terms of spatial, spectral, and temporal resolution, also have the potential for improvements in the performance of numerical predictions of significant weather events. Participants of the GOES Users' Conferences provide strong endorsements for the improved capabilities of the Imager and Sounder on the GOES-R Series. We are reaching a point where the volume of data being considered for gathering in the future will be costly to distribute globally.

6. REFERENCES

Aune, R.M., W.P. Menzel, J. Thom, G.M. Bayler, A. Huang, and P. Antonelli, 2000: Preliminary findings from the geostationary interferometer observing system simulation experiments (OSSE). NOAA/NESDIS Tech. Rep. 95, 18 pp.

Broderick H.,C . Watkins and A. Gruber, 1981: Statistical and synoptic evaluations of TIROS-N and NOAA-6 retrievals. NOAA Tech. Report NESS 86, Washington, D.C.

Gurka, J., and G. Dittberner, 2001a: The next generation GOES instruments: status and potential impact, Proceedings, AMS 5th Symposium on Integrated Observing Systems, Albuquerque, NM, January 15 - 19, 2001, 5pp.

Gurka, J., and G. Dittberner, 2001b: Recommendations from the GOES Users' Conference, Preprints, AMS 11th Conference on Satellite Meteorology and Oceanography, Madison, Wisconsin, October 15 - 19, 2001, 4pp.

Gurka, J., G. Dittberner, P. Taylor, and T. Schmit, 2002: The evolution of imaging and sounding capabilities for the GOES-R series, The 2002 EUMETSAT Meteorological Satellite Conference, Dublin, Ireland, September 2-6, 2002, 6pp.

McClinton, A. Jr., and G. Dittberner, 2001: GOES-N, The first of the next series - user community upgrades, Proceedings, AMS 17th Conference on Interactive Information Systems (IIPS) for Meteorology, Oceanography, and Hydrology, Albuquerque, NM, January 15 - 19, 2001, 2pp.

Menzel, P., and J. Purdom, 1994: Introducing GOES-I: The first of a new generation of Geostationary Operational Environmental Satellites, *Bull. Amer. Meteor. Soc.*, Vol. 75, No. 5, pp. 757-781.

Schmetz, J., P. Pili, S. Tjemkes, D. Just, J. Kerkmann, S. Rota, and A. Ratier, 2002: An introduction to Meteosat Second Generation (MSG), *Bull. Amer. Meteor. Soc*., Vol. 83, No. 7, pp 977-992.

Schmit, T.J., W.F. Feltz, W.P. Menzel, J. Jung, A.P. Noel, J.N. Heil, J.P. Nelson III, G.S. Wade, 2002: Validation and use of GOES sounder moisture information, *Weather and Forecasting*: Vol. 17, No. 1, pp. 139–154.

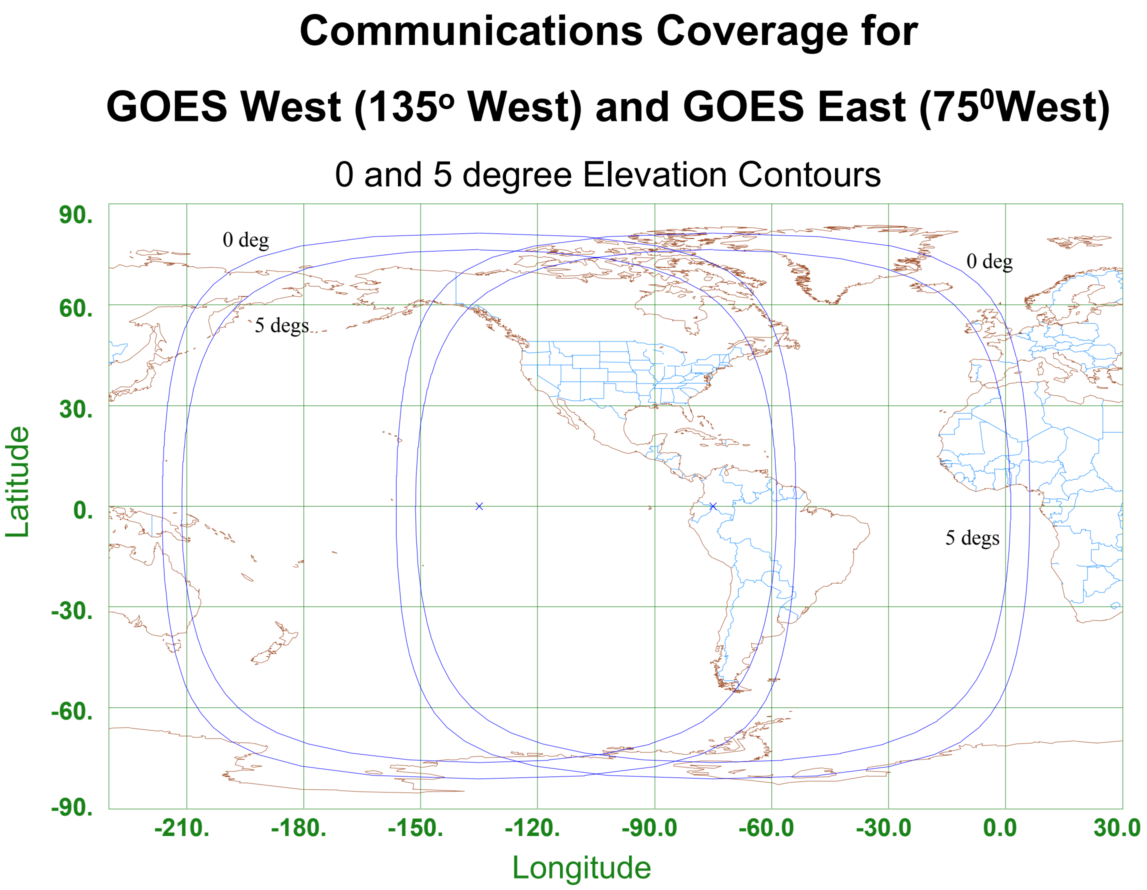

Figure 1. GOES Communications coverage areas. Elevation angles shown.