IAF-01-B.2.06

AVStar High Temporal and Spatial Resolution Imaging from Geostationary Orbit

M.A. LeCompte
AstroVision International, Incorporated
Woodmont Road, Suite 210
Bethesda, MD 20814

52ND International Astronautical Congress
1-5 Oct 2001/Toulouse, France
for permission to copy or republish, contact the International Astronautical Federation3-5 Rue Mario-Nikis, 75015 Paris, France

---

AVSTAR HIGH TEMPORAL AND SPATIAL RESOLUTION IMAGING FROM GEOSTATIONARY ORBIT

M.A. LeCompte
AstroVision International, Incorporated
Woodmont Road, Suite 210
Bethesda, MD 20814
mlecompte@astrovision.com

Abstract

Earth Imaging from Geostationary Earth Orbit (GEO) allows frequent sampling of the environment within an observable hemisphere. GEO Meteorological Satellites, have exploited this advantage for over three decades. Visual imaging from these satellites could be characterized as low in spatial and temporal resolution. The absence of 'true color', and high spatial and temporal resolution is partly due to the need to optimize the METSAT's ability to perform 24-hour multi-spectral coverage of hemispheric cloud cover. Furthermore, providing coverage in a variety of spectral bands, at nadir spatial resolution of 1-4 km, provides a flood of data which must be transmitted over limited telemetry bandwidth. The new US NOAA GOES-Next series can resample limited areas at higher rates, however, high resampling rates sacrifice full hemispheric coverage, and the mode cannot be used. Transient phenomena occurring at the smallest temporal scales, with significant environmental impact are unobserved. The full benefit of GEO based imaging is not realized. AstroVision International's AVStar Earth monitoring system is designed to overcome current limitations of GEO Earth coverage by providing ' real time' monitoring of changes to the Earth's atmospheric, land and marine environment at unprecedented spatial resolution. AstroVision's AVStar-1 is scheduled for launch in late 2003. This initial capabilities of the first of a globe girdling constellation of five satellites will be discussed and the potential benefits to society, science, commerce and education will be reviewed.

Introduction:

. The AVStar commercial Earth monitoring satellite systems being developed by AstroVision International, Inc. (AVII) of Bethesda Maryland will deliver live, 'true-eye' color views of the Earth from Geostationary Earth Orbit (GEO) at unprecedented temporal and spatial resolution for that altitude. Eventually, five GEO AVStars, spaced at equal longitudinal intervals around the globe will continuously monitor over 80% of the Earth at sub-kilometer spatial resolution providing information for news, weather, scientific and educational applications. Data from the AVStar system will be immediate and relevant at a local user level, by significantly improving severe weather detection and warning capability, while becoming an important tool to mitigate the effects of natural disasters and catastrophic events. The commercial basis for AstroVision's venture is the fundamental recognition that a continuous source of new and unique information is the 'Holy Grail' of the 'Information Age'.

The first satellite, AVStar-1, is to be launched to its initial GEO location over the equator at 90° West Longitude in late 2003. AVStar-1 will monitor North and South America awaiting the launch of the upgraded AVStar-2, which will include an expanded suite of sensors and will replace AVStar-1 at that location a year later. The initial satellite will then be moved to provide coverage to the mid-Pacific Ocean from 160° West Longitude. Subsequent AVStar launches will occur at approximately six-month intervals thereafter until each of the full system of five satellites is operational.

While the Earth's environment has been monitored from GEO for more than three decades, the full advantage of that position has yet to be realized. The AVStar system will be the first designed to fully exploit the advantages of its GEO location.

Environmental Monitoring from Geostationary Orbit

The advantages of monitoring the Earth with instruments on satellites in GEO have been recognized as early as Clarke's 1945 seminal observations identifying the unique properties of that orbital altitude[1]. From a circular orbit at 35,765-km altitude a satellite's speed matches the Earth's 24-hour rotation. For Earth-based observers with a direct line of sight, a satellite in GEO appears to be fixed at a point above the horizon. This makes GEO satellites ideal stations for 'point-to-point' long-range communications relay.

Reversing the observer's perspective to view the Earth from a GEO satellite reveals other advantages. The Earth itself has no apparent motion, and the same area of the Earth's surface is continuously in view, 24 hours a day. From GEO altitude, an observer's line-of-sight horizon on the Earth's spherical surface subtends an angle about 81° as measured from the satellite's nadir point. Therefore GEO provides a view of nearly an entire hemisphere of the Earth making it very useful for wide area radio broadcast to the horizon. Furthermore, with the same area always in view from GEO, the only changes apparent in the scene will be due to processes occurring on the surface or in the atmospheric above it. (although, within about 5° of the horizon, the curvature of the Earth reduces the practical utility of the view). Furthermore, any event occurring within that vast geographical area can be viewed, recorded and concurrently reported by line-of sight broadcast to anywhere within the observable hemisphere.

Thus systems in GEO are able to monitor environmental changes due to either natural processes or human activity, as they are occurring. The GEO location allows observations over areas and time periods that encompass the complete range of environmental changes, including the most severe and rapidly evolving weather, and the largest scale extra-tropical cyclonic disturbances. Observations can be made of the most transient phenomena such as volcanic eruptions, lightning activity and even meteoritic events, as well as more slowly evolving events like flooding, biomass burning, and land cover changes due to seasonal and climatic effects. These observations have significant societal and commercial value in a variety of applications.

The most obvious drawback to placing sensors in GEO, is the low spatial resolution that must be endured to achieve hemisphere scale coverage at even moderate sampling frequencies with telemetry rates typically limited to a few megabits per second. The parameters that must be traded to determine the temporal and spatial coverage possible for a satellite based imaging system are telemetry data capacity (including frequency and bandwidth considerations), spatial and temporal resolution and area coverage. For practical purposes, current GEO environmental monitoring satellite design is not determined by a requirement to observe all the terrestrial processes that occur and would be visible from GEO. but rather is driven by specific phenomena attributes that are traditionally judged to be most important for making synoptic meteorological predictions. These include observations of cloud cover, and measurements of atmospheric water vapor content and temperatures. Moreover, until recently, predictive models required the input of measurements made over relatively coarse temporal (hourly samples) and spatial (kilometer or larger) sampling grids. The temporal and spatial capabilities of initial and current generations of GEO satellite data are well suited to that relatively benign requirement.

Current GEO Systems Capabilities and Limitations

The first meteorological observations from GEO were made with a panchromatic (black and white) scanning imaging system

---

carried aboard the first United States (US) Applications Technology Satellite (ATS-1) launched by the National Aeronautics and Space Administration (NASA) December 6, 1966. The experimental scanning type imaging systems flown on the ATS series (which included a short-lived color capability on ATS-3) led to two prototype NASA Synchronous Meteorological Satellites (SMS) launched in 1974 and 1975. SMS-2 was followed by the first Geostationary Operational Environmental Satellite (GOES) launched in 1975, developed by NASA and, with all subsequent GOES systems, operated by the US National Oceanic and Atmospheric Administration (NOAA).

Every meteorological satellite placed in GEO since ATS-1 has employed some form of visible or infrared scanning imaging system.

In a scanning system, the instrument's optically sensitive element is periodically and repetitively moved in discrete horizontal and vertical steps across a scene until the complete scene has been digitally recorded as an image. The full disk defined by the GEO horizon subtends about 17.4° or about 0.3 radians. At the satellite's equatorial nadir point, a one-kilometer wide picture element subtends 28 microradians. A full disk scene is thus comprised of nearly 11,000 such elements at its widest point. (Satellites are not perfectly stable platforms so the actual area viewed must be larger than 17.4° to allow for drift and jitter). With optical elements sized to view no more than a few kilometers at any one moment and each step requiring about 50 microseconds for photon integration, it may require a large fraction of an hour to build one complete image of the Earth's full disk.

For fixed telemetry band-width, spatial resolution performance of a single imaging system can be traded with sampling frequency to maintain a constant information flow-volume. Higher resolution can be achieved by replacing a single scanning optical element with a linear cluster of silicon optically sensitive elements, (for visible wavelengths, known as 'charge coupled devices' or more commonly as 'CCD arrays'). This latter approach incrementally increases the momentary data 'through-put' while reducing the total time required to scan the entire scene. Finally, some of the latest GEO MET-SATs can limit the extent of the scan coverage to enable more frequent sampling of areas smaller than the full disk area.

The focus of current and past Earth observation from GEO has been the monitoring of cloud-cover at visible and infrared wavelengths. This emphasis has defined the required attributes of virtually all GEO based instrumentation (excepting that highly classified monitoring done for national security purposes).

Clouds in typical weather systems may move at 10-100 km/hour with maximum velocities found in hurricanes, cyclones, and typhoons on rare occasions exceeding 400km/hr. Thus wind driven cloud movements may correspond to shifts of up to 50-200 picture elements (pixels) between successive images of tropical storms at a full disk resampling rate of twice per hour and spatial resolution of 1 km. This is a large fraction of almost any organized storm system, which frequently measure from 500 to 1,500 pixels in extent. Furthermore, the most severe convective weather systems evolve at speeds that rival the resampling rate of many GEO weather sensors obviating the use of current satellite imagery for providing measurements of detailed cloud dynamics. Perhaps most important, the opportunity is missed to provide timely, local warning and damage mitigation information for the destructive phenomena associated with severe convective systems, such as tornadoes, hail, and microbursts. Recognizing that clouds may move up to 7 'kilometer-sized' pixels in a minute, the need for higher sampling rates becomes evident.

It was, to some extent, to remedy this very shortcoming, that the most recent generation of US NOAA GOES MET-SATs (GOES-Next) introduced the capability to selectively limit the area scanned at any point in the hemispheric field of regard, allowing more rapid resampling of regions of particular interest. In practice, this capability allows the two operational GOES platforms (GOES-East and GOES-West at 75° and 135° West Longitudes respectively) to sample a scene in one of three modes[2]:

1. *Routine Operations*: provides coverage of the 48 contiguous United States (CONUS) with four (4) samples/hour, the northern hemisphere nearly two times per hour and South America sampled about once 45 minutes. The full disk is observed once every three hours. This is the usual mode in which the GOES are operated.

1. *Rapid Scan Operations (RSO)*: provides coverage of the Continental United States (CONUS) with eight (8) samples/hour, the northern hemisphere with coverage about once per hour and South America sampled about once an hour. The full disk is observed once every three hours. GOES is rarely operated in the RSO.

1. *Super Rapid Scan Operations (SRSO)*: allows scenes approximately 1,500-km square to be resampled once per minute. As the area observed is increased, the sampling rate decrease (an area the size of CONUS requires about 5 minutes to scan), however, SRSO sacrifices coverage of all other areas and hence has been used only in test operations. The few opportunities to demonstrate SRSO have resulted in dramatic animations of thunderstorms and hurricanes more than proving the worth of observations at the higher sampling rates.

However, with SRSO mode unavailable for practical operations, even the more modern GOES scan imaging system, is unable to provide data that is sufficiently **current** or with **adequate resampling frequency**, to totally exploit the full potential of their GEO location. A scanning system requires a finite time to create an image, so its data cannot be truly live and refresh rates will be fundamentally limited by the time required to complete a scan.

For the most violent weather processes this time lag can be an important limitation of scanning systems. Furthermore, observations of significant, but very transient phenomena that occur in sub-minute time scales, (lightning and meteors) are missed entirely.

Clouds are efficient diffuse mirrors of solar radiation and therefore naturally appear white with variations in brightness seen as shades of gray. Color, enhancing the contrast and visibility of the Earth's surface background, may actually detract from cloud contrast-visibility in a scene. This is one reason why, although virtually all GEO MET-SATs are capable of multispectral observations, they do not image the Earth in color. Adding color at the same spatial resolution as a pixel Instantaneous Field of View (IFOV) triples the digital volume of an image, which burdens otherwise limited data telemetry bandwidth.

In the nearly 45 years since the first Russian Sputniks and almost 35 years after the first environmental monitoring ATS satellite in GEO, observations of the Earth from space at visible wavelengths remain less complete in some ways than that done during the exploration of the moon and planets. There are, as yet, insufficient means to observe or study all the processes that occur on or near the Earth's surface and influence life on the planet. The history of science confirms that the human eye is an extremely effective research tool, and instruments that might duplicate its spectral, spatial, temporal and radiometric attributes would provide enormously useful information. Planetary exploration missions place special emphasis on the importance of including an electro-optical surrogate human 'eye' in virtually every expedition. The fact that instruments currently monitoring the Earth's environment are far less capable than a human eye in some critical faculties ensures there will be gaps in our ability to observe certain critical phenomena. Coverage of the Earth, at visible wavelengths, including color during the day, and with sufficient sensitivity to observe at night is typically performed from spacecraft in low Earth orbit (LEO) where continuous monitoring and a full disk perspective are unavailable. (ATS-3 and the Apollo missions have provide the majority of the examples of color Earth images beyond LEO.).

Without solar illumination, it is difficult to observe clouds at night at visible wavelengths. Instruments with different characteristics are required (such an instrument is carried by the US military's polar orbiting Defense Meteorology Satellite Program (DMSP) spacecraft. Infrared scanning imaging systems which measure scene temperatures now perform the night imaging function for GEO satellites, albeit at coarser temporal and spatial resolution.

As described above, a major consequence of the scanning imager design used in GEO MET-SATs, is the inability to observe the occurrence of many known phenomena that significantly impact human lives. The improved understanding of these phenomena that GEO observations would yield are impossible with current systems. Moreover, it is believed that severe weather cloud dynamics may have correlated, recognizable and predictable behavior that provides an advance signal of the onset and locale of the most destructive phenomena.

The anticipated benefits to global society and the commercial value of observing these phenomena spurred the design and development of AstroVision International's AVStar commercial remote sensing system, using alternative technologies that fulfill the potential of Earth environmental monitoring from GEO.

AVStar System Description

Whatever their insufficiency, GEO MET-SATs have proven that GEO platforms are a source of valuable environmental news and weather information, in addition to their obvious scientific and educational applications. The full utility and commercial market for live, high-frequency, hemispheric scale environmental monitoring from GEO has been estimated (by AVII supported market studies) to be sufficient to support development of a totally commercial, global remote sensing system in GEO. The AVStar Earth monitoring system is designed to provide live hemispheric coverage from a suite of cameras aboard each of 5 satellites spaced at roughly equal longitudinal intervals around the globe.

Development of the AVStar commercial GEO Earth monitoring system was facilitated by exploiting enabling technologies developed for interplanetary class exploration. In particular, the launch energy and endurance requirements, of planetary science missions put a premium on the use of small, highly stable spacecraft with high reliability and long life. These spacecraft are much less expensive then the larger MET-SATs currently in use. The fact that small satellites may be launched to GEO as a secondary payloads results in further savings.

The requirements for interplanetary instruments are equally stringent in ways that make them ideal for GEO Earth monitoring from a small platform. Volume, mass and power requirements have motivated electronics miniaturization and the use of advanced technology optical elements that mimic the attributes of the human eye. During the last two decades, the use of Megapixel CCD FPA technology has become common in planetary space missions. Megapixel CCD FPAs can form a color image of a large two-dimensional area in microseconds. The exposure times can be varied allowing a vary wide dynamic range that includes solar to lunar levels of illumination. The advantage inherent in upgrading planetary-type cameras to incorporate recently developed multi-megapixel CCD arrays is an obvious and natural evolution of CCD technology. The result is digital cameras able to instantaneously image a very large area at reasonable spatial resolution with resampling rates exceeding a frame per second

AVStar imaging instruments are primarily designed to monitor a wide variety of phenomena, with relatively equal emphasis on surface and atmospheric processes. AVStar imaging system performance requirements were determined by the spectral, radiometric, spatial and temporal attributes required to sense specific phenomena. Radiometric characterization of the AVStar first generation instruments will allow only 'first order'

---

estimates of image radiometry with subsequent systems subjected to a more rigorous calibration.

Information products will be developed from a standard instrumentation package. All imaging systems will use multi-megapixel CCD focal plane arrays (FPA) capable of variable exposure times and sampling a full scene approximately once every second. The basic camera suite for the first two satellites will include:

- One wide, 18° circular field-of-view Red-Green-Blue (RGB) camera system providing modest 5.5-km nadir spatial resolution color images of the Earth's full disk; and

- Two identical narrow, 1.64° square field-of-view steerable RGB camera systems providing 500-meter nadir resolution. One of these high-resolution systems will be tasked to point toward and track events of particular interest (e.g. hurricanes), while the second will perform regular scans of either CONUS or the Earth's full disk to provide periodic high-resolution updates over these larger areas. A mosaic of the full disk, comprised of about 140 high-resolution narrow field camera images can be created in less than three minutes, while a mosaic of CONUS can be created in about 15 seconds.

- One steerable panchromatic 'low-light' imaging system for night observations having the same 'field-of-view' and spatial resolution as the narrow field RGB systems. This camera's primary purpose is to record night urban illumination and transient light sources such as lightning and meteorite activity, but it will also be sufficiently sensitive to detect lunar illuminated clouds at night.

- One multispectral camera system identical to the low-light camera except the FPA will include a layer containing ten (10) adjacent narrow band-pass filters. Each scene recorded will be divided into ten 1.64° x .164° spectral regions. The full scene can be sampled at each spectral band by steering the camera system through ten discrete 0.164° steps on an axis orthogonal to the filter long dimension. The ten spectral bands range from the near ultraviolet (NUV) at about 0.35-nm. to the near infrared, (NIR) at about 0.94-nm.

In addition to these five systems, the second satellite will carry a lightning detection system that will operate both day and night and a multi-band thermal imager to measure surface and cloud temperatures and water vapor content. While a separate low light system is carried specifically for night observations, the exposure times for all the systems are variable and should provide all systems with some night imaging capability.

Among the spectral bands sensed by the AVStar multispectral system, NUV and blue wavelength information is not currently obtained from GEO, and may be important for atmospheric aerosol and ozone measurements with practical application to climate studies and volcanic plume tracking for air traffic threat mitigation. NUV wavelengths are not well suited to monitoring surface processes (due to low intensity of solar illumination, and atmospheric ozone absorption), but blue wavelengths allow the determination of true surface color containing valuable information for the marine agriculture industry. Infrared image information in a variety of useful bands is already provided around the clock from meteorology satellites, in LEO and GEO.

Improved temporal and spatial resolution visible and infrared Earth coverage would be helpful to better serve existing markets for weather satellite imagery, and a source of high quality data products for new emerging markets for climate information products. For example, the telecast image quality from all cameras is superior to, but compatible with, high definition television (HDTV) standards and particularly suitable to serve the needs of the broadcast and cable television media.

Observable Phenomena

Phenomena observable from AVStar systems that are not currently well observed by GEO systems includes a variety of natural terrestrial, celestial and human activities: Amplifying references or satellite observation example are cited,

Terrestrial Events:

- Cloud Spatial Structural Scales and Motion Especially rapidly evolving storm systems.(GOES SRSO)
- Volcanic Eruptions and Plumes: Typically occurring about weekly around the globe[3]. Explosive eruptions may eject material at near sonic velocities causing large plumes to quickly expand and become visible from GEO within seconds. At stratospheric altitudes, the plume will be carried by prevailing winds at up to 200-kph. AVStar monitoring may be the first and best coverage available for major daylight volcanic eruptions; especially in remote areas. Volcanic plume detection and tracking may be a great boon to air traffic safety. (GOES)
- Biomass Burning and burn scars can be detected and climatic impact monitored[4]
- Flooding: measuring cloud precipitable water content and post-flood impact analysis.(GOES)
- Lightning: Observed from space, both cloud-to-ground and intra-cloud lightning are detectable. Flash rates of the latter, not easily observed by ground systems, have been correlated with the advent of severe weather[5, 6] .GEO-based detection is a means to provide advance warning of destructive severe weather outbreaks.(DMSP)
- Urban Illumination; a means of monitoring urban sprawl and environmental impact[7,8]
- Snow and Ice Detection
- Meteors (declassified US Defense Department documents reveal satellite sensors detected 136 meteoritic atmospheric impacts over 17 years with an explosive yield in excess of 1 kiloton[9]
- Terrestrial-Color Spatial and Temporal Variability

Celestial Events:

- bi-monthly limb transits of the Moon[10] (with the lunar surface observed at about 5-km resolution by AVStar narrow field cameras) (GOES)
- Solar Eclipses with the Moon's shadow moving at about 1,500-km/hr across the face of the Earth. (GOES)

In addition to live coverage of geophysical phenomena AVStar cameras will also be able to observe features related or due to human activities on the planet. These include:

- Space Shuttle launch and re-entry (GOES)
- Maritime wakes due to the movement of large maritime vessels[11]
- Industrial smoke plumes and aircraft contrails (GOES)
- Large explosions (GOES and METEOSAT)

Data Visualizations

During the past four years, AstroVision has worked with NASA's Commercial Remote Sensing Program Office at Stennis Space Center in Mississippi to create visualizations of AVStar-1 image products and Earth coverage. These simulated products, based on imagery from the NOAA GOES satellite series are dynamic animations processed to include a natural 'true-eye' color Earth surface background and to demonstrate the higher spatial resolution and sampling rates possible with AVStar coverage.

AstroVision has exploited the recent advent of computer models able to simulate the "true-eye" color of the Earth. AVII worked with ARC Science Simulations, of Loveland, Colorado, using their **"Face of the Earth" model** to add color to existing GOES

---

visible images by creating an overlay of the GOES "white" cloud layer on a model "true-eye" color Earth. Such purely synthetic models can not reproduce actual day-to-day changes in surface color and so do not obviate the need for "true-eye" color observations and are certainly not a substitute for live Earth coverage. High spatial resolution is simulated by extrapolating from the nearly 2-to-1 over-sampling in the horizontal scan direction of GOES imagery.

AVStar narrow field camera high temporal coverage was simulated by interpolating from GOES SRSO image sequences at one-minute image intervals.

Unfortunately, these colorful animations cannot be included in a static, black-and-white print format of this paper.

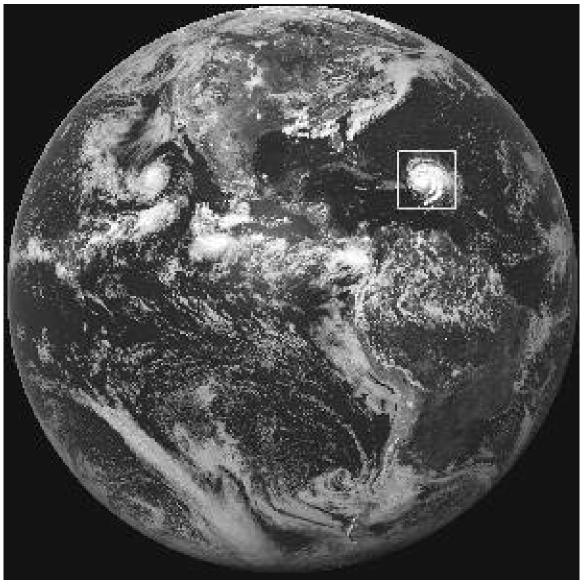

Figure 1. AVStar Wide Field Camera view of Earth's full disk from 90° West longitude.

The view of the Earth from AVStar-1's GEO position at 90° West longitude is shown in figure 1, a 'gray-scale' mosaic of the Earth's full disk recorded by GOES 8 and 9 on August 2, 1996. Luis is inserted near Puerto Rico interior to the narrow field camera coverage white outline.

The field of view of the two narrow field cameras is depicted in figure 2 from an image of Hurricane Luis recorded by GOES-9 September 6, 1995.

Project Status

The United States Department of Commerce licenses domestic US companies planning to engage in space based remote sensing of Earth for commercial purposes. AstroVision International was granted its initial license for one Earth monitoring satellite at 90° West Longitude in 1995. A recent (2000) amendment to that original license authorized AVII to operate two satellites with significantly enhanced capability at 90° and 160° West Longitude.

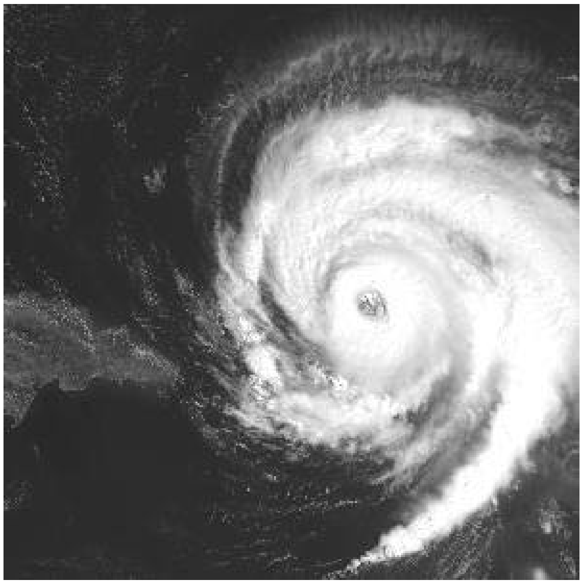

Figure 2. Narrow Field Camera area of regard with hurricane.

Also in 2000, the US Federal Communications Commission (FCC), which authorizes 'space-to-ground' telecommunications for Earth Exploration Satellites in the X-Band, has authorized AVII

---

the use of 160MHz of bandwidth between 8.075 and 8.375-Ghz. This corresponds to a data rate of 320-Mbps, sufficient for each AVStar to deliver uncompressed frame-per-second imagery of the Earth's day side from each of the three RGB cameras and data from the multispectral instrument..

In November of 2000, AVII selected Malin Space Science Systems to build imaging systems to be carried aboard the first two AVStars. In March of 2001, AVII selected Ball Aerospace of Boulder, CO, to build the initial two satellites. The design of these satellites will be based upon the Ball BCP-2000 bus.

Instruments and satellites are under construction with the launch of AVStar 1 scheduled for third quarter 2003. Earth coverage should become available within a month after launch.

AVStar data is being purchased by NASA to support the development of improved severe weather detection, tracking and warning under the auspices of its Earth Science Enterprise program during the first two years of AVStar operation. Ground station and image processing and distribution facilities are currently planned to be located in proximity to the John C. Stennis Space Center in Mississippi.

References:

1. Clarke, A.C., Wireless World, October 1945, pages 305-308
2. GOES I-M Data Book, Space Systems Loral, DRL 101-8, Revision 1, 31 August 1996.
3. Simkin, T., Terrestrial Volcanism in Space and Time, Annual Reviews of Earth and Planetary Science, 21, p. 427-452, 1993.
4. Levine, J.S., W.R. Coffer III, D.R. Cahoon, Jr., E.L. Winstead, Biomass Burning, A Driver for Global Change, Environmental Science and Technology, 29, no. 3, p. 121A-125A, 1995.
5. Boccippio, D.J., K.L.Cummins, H.J. Christian, S.J. Goodman, Combined Satellite and Surface- Based estimation of the intracloud-Cloud-to-Ground Lightning Ratio over the Continental United States, Monthly Weather Review, 19, 108-122, January 2001.
6. Christian, H.J., R.J. Blakeslee, and S.J. Goodman, The Detection of Lightning from Geostationary Orbit, J. of Geophysical Research, 94, no. D11, p. 13,329-13,337, 1989.
7. Beatty, J.K., Impacts Revealed, *Sky & Telescope*, February, 1994.
8. Elvidge, C.D., K.E. Baugh, E.A. Kihm, H.W. Kroehl and E.R. Davis, Mapping City Lights with Nighttime data from the DMSP Operational Line Scan System, Photogrammetric Engineering and Remote sensing, 63, pp 727-734, June 1997.
9. Sullivan, W.T. A 10-km Resolution Image of the Entire Night-time Earth Based on Cloud-Free Satellite Photographs of the 400 –1100-nm Band, J. Remote Sensing, 10, pp. 1-5, 1989.
10. Landecker, P.B., Lunar Surface as Viewed from GOES, Monthly Weather Review, 112, pp2122-2125, October, 1984.
11. Howard, W.E. and O.K. Garriott, Can You See Ships from Space?, Proceedings of the naval Institute, pp 89-94, December, 1989

Samples of observed from GEO platforms can be found at the NASA GOES project science web-site with url:

http://rsd.gsfc.nasa.gov/goes/
