GOES-8/9 data ingest and public file service at NASA-GSFC

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ABSTRACT

Desktop computers have evolved to the point where they can process GOES variable-length (GVAR) data blocks at 1 Gbyte/hour, despite the complexity of the data stream and the varied demands of realtime users. Because of the lack of off-the-shelf GVAR processing packages before the launch of GOES-I in 1994, we assembled a custom Open System at NASA-GSFC to automatically ingest, process and disseminate full-resolution GOES-8 and GOES-9 imagery 24 hours per day. This data service is now widely used by the Internet community. The hardware-software package described here can be copied freely. Similar systems are now available from commercial vendors.

Keywords: goes, gvar, ingest

1. DATA FLOW - OVERVIEW

Figure 1 sketches the GOES data ingest and distribution architecture at NASA-GSFC. The GOES-8 and GOES-9 "data product" broadcasts are captured by two antennas at NASA-GSFC, and converted to GVAR data blocks (bit-packed scanlines) using custom cards in a SUN workstation. After a GOES Imager scan ends, the GVAR blocks are converted using a home-grown software package to parse the complicated GVAR format into full-resolution images and sounding files in standard formats. Calibrated and navigated GOES images for the last 24 hours are offered to the public in TIFF format, accessible to everyone with World Wide Web (WWW) browsers[1] or anonymous FTP[2]. An archive of historically interesting images and technical notes is also maintained by the GOES Project Scientist[3], providing an attractive and informative[4] public interface.

For the scientific analysis of large GOES datasets, the Interactive Image Spread Sheet (IISS)[5] is used on well-equipped workstations from Silicon Graphics Inc. (SGI) at the Goddard Laboratory for Atmospheres (GLA)[6]. For automated analysis of large amounts of data, custom IDL scripts are employed[7]. For smaller analyses and custom visualization in the GOES Project scrapbooks[8] and in the Remote Sensing Datasets (RSD) program[9], Macintosh personal computers are employed. Digital image animations are piped to a rack of television video equipment. High-quality dye sublimation printers are used for hardcopy. The ensemble of computers and visualization equipment scattered throughout the earth sciences building at NASA-GSFC is facilitated with FDDI and ethernet LANs that have very good connectivity to the Internet "cloud" of casual browsers and scientific users.
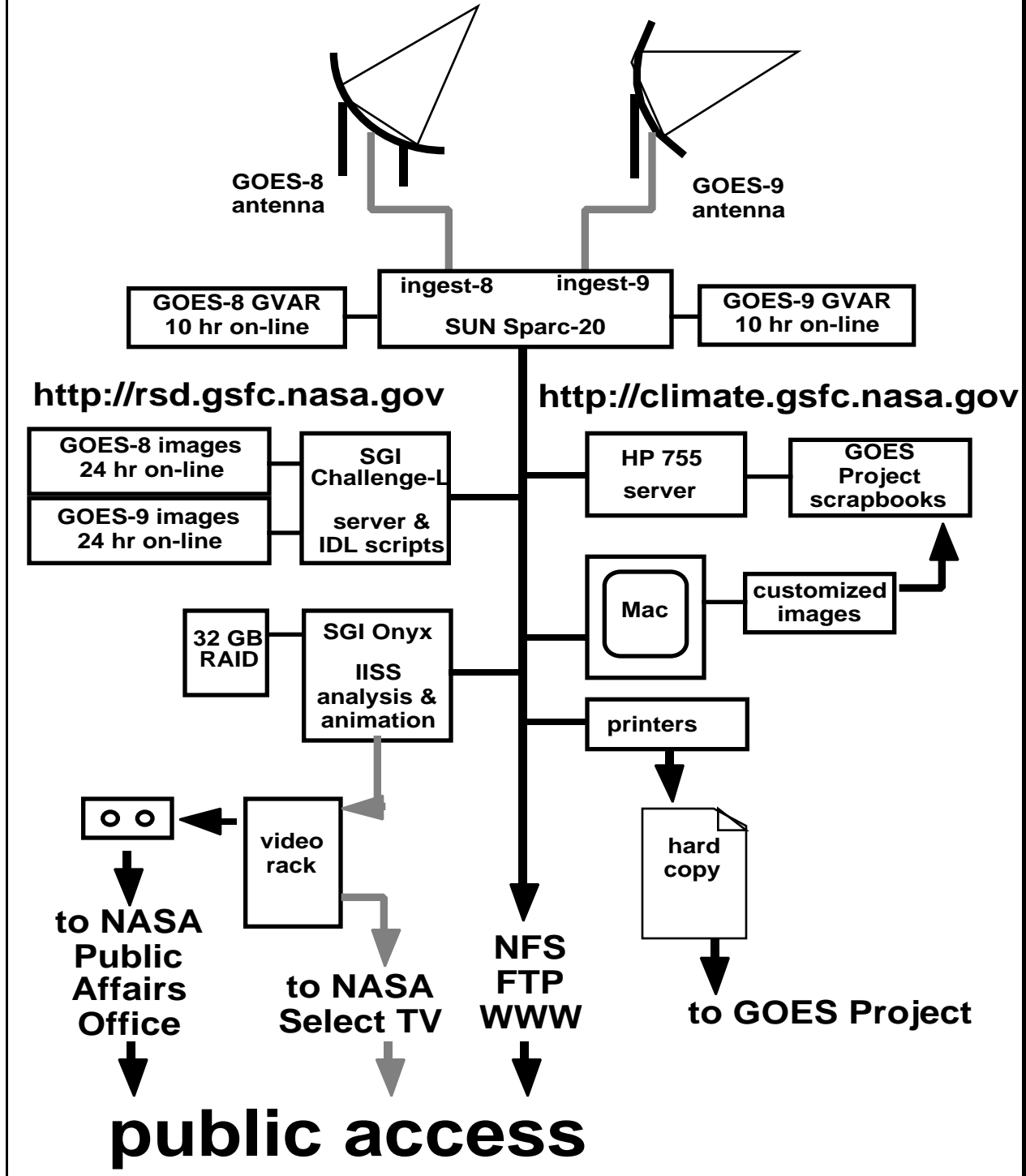
GOES Ingest at NASA-GSFC

GOES-8 antenna

GOES-9 antenna

ingest-8   ingest-9

| GOES-8 GVAR 10 hr on-line | SUN Sparc-20 | GOES-9 GVAR 10 hr on-line |

http://rsd.gsfc.nasa.gov

http://climate.gsfc.nasa.gov

| GOES-8 images 24 hr on-line | SGI Challenge-L server & IDL scripts |
| GOES-9 images 24 hr on-line | |

| HP 755 server | GOES Project scrapbooks |

| 32 GB RAID | SGI Onyx IISS analysis & animation |

Mac

customized images

printers

video rack

hard copy

to NASA Public Affairs Office

to NASA Select TV

NFS FTP WWW

to GOES Project

public access

Figure 1: Hardware used to ingest GOES-8/9 data at NASA-GSFC for the GOES Project and for public service for schools, broadcast TV, and the Internet.

2. S-BAND FRONT END

The radio frequency (RF) front end for GOES GVAR reception begins with two 16-foot parabolic antennas with F/D ratios 3.5. One antenna is an old solid dish on a manually operated altitude-azimuth mount, normally fixed on GOES-EAST at 75W. The other dish is lightweight mesh on a motorized polar mount, purchased from Antenna Technology Communications, Inc. (ACTI). The newer antenna has a remote control for slewing to GOES-9 check-out station at 90W, and for fine-pointing in any weather at the operational station at 135W, low on the western horizon. Both dishes are mounted on top of the main earth sciences building at NASA Goddard Space Flight Center (GSFC) in Greenbelt, MD. The 5-story building is located on a hill near the watershed between the Patuxent and Potomac River basins, with a wide horizon in all directions, as shown in Figure 2.

Figure 2: GOES steerable 5-meter S-band antenna on rooftop at NASA-GSFC.

The wide horizon is a source of potential interference from the many government and military communications facilities in the Washington-Baltimore-Annapolis region. Consequently, we use 5 meter dishes, where 3- to 4-meter dishes are normally sufficient collecting area for the GVAR broadcasts. The large dishes have about the central 70% of their areas illuminated with feeds that have a F/D ratio of 3.9, instead of a dish-filling 3.5, with the aim of using the edge of the dishes as a "dark band" to minimize potential interference.

Nevertheless, bursts of interference occur occasionally, especially near dawn in mid-winter, presumably when the leafless trees allow greater visibility to the military radars on the horizon. The episodes of interference are visible as bursts of narrow-band spikes, observed with a power spectrum analyzer tuned within ±20 MHz of the GVAR downlink frequency at 1685.7 MHz.

The vulnerability to interference is exacerbated by the front end design, which amplifies and conducts the entire S-band down a 150-foot coaxial cable to the RF receiver, instead of down-converting the S-band inside the feed to a standard low frequency carrier such as 70 MHz. The long coaxial cable can be an

antenna for high frequency interference. Considered time and effort has gone into shortening the run and optimizing the cable. Ideally, this design should be limited to less than 50 foot runs and be used in radio-quiet suburban areas, as it is at Colorado State University[10] using the front end supplied to them and to us by Western Engineering and Satellite Technology (WEST) of Melno Park, CA.

3. GVAR INGEST

Each antenna feeds a RF demodulator and bit-synch receiver also supplied by WEST. The output from each receiver is a clock-and-data bit stream that feeds a corresponding bit-handling S-bus card installed in one SUN SPARC-20 workstation. The cards are semi-generic bit-correlation engines supplied by Apogee Solutions (associated with the University of Hawaii). Apogee supplies proprietary C language software in the SUN workstation to locate the bit-synch pattern at the start of each GOES data block (scanline) using only a few percent of the SUN's CPU cycles. Apogee's ingestors are very efficient, each using about 5% of the CPU on the SPARC-20. Similar ingestors are also used at NASA Ames Research Center (ARC) in Palo Alto, CA, to ingest GOES-8/-9 images for the popular and completely automated "Explorer"[11] anonymous FTP site there. At NASA-ARC, these software-driven S-bus ingestors operate completely autonomously on two separate SPARC-5 stations. At NASA-GSFC, both S-bus cards run simultaneously inside one SPARC-20 station. The ingest is autonomous, automatically restarting each time the computer is rebooted by power outages.

There is an advantage to controlling the ingest process in high level software instead of PROM hardware. We have modified software several times to correct errors and to optimize throughput, and also to correct for problems in the SUN operating system (Solaris), which changes with each version. For example, the character-string version of the Solaris clock, which should be accurate to a millisecond, is only updated once every 4 minutes in Solaris 2.3 and 2.4. Because we use the date-time stamp from Solaris to label our raw GVAR datasets each time an image begins, we could not capture 1-minute interval images from GOES without a software work-around in the naming convention.

On the SUN, the GVAR data blocks are written into a UNIX disk file, named with a date-time-satellite stamp corresponding to the beginning of each new Imager frame. For example, the raw GVAR file named "9607041745G8w" was captured on the 4th of July 1996 at 1745 UTC by GOES-8. In this case, the suffix "w" is an character drawn sequentially from the alphabet, to ensure that rapid multiple image-starts will all have different names.

This ingest scheme generates several GVAR files per hour for processing and/or archiving to tape. Operational files are typically a few 100 MBytes each. We maintain a pool of raw GVAR data 10 hours deep for each GOES satellite, each on a 8-Gbyte disk pack. We have a UNIX script automatically delete the oldest files on each pack to maintain at least 500 MBytes of free space for the incoming GVAR data. The deep pool of recent GVAR data allows us to reprocess interesting events and to re-extract special features at full resolution and precision. The SUN disk packs are NFS-mounted to the workstations at NASA-GSFC, with as many as 6 stations drawing simultaneously on the raw GVAR data pool to create special-purpose imagery. The SUN has both FDDI and 10BaseT connections to facilitate GVAR data transfer at rates greater than the realtime flow (2.1 Mbits/sec from each satellite).

4. GVAR PARSING

NOAA's GVAR data format packs the GOES scanlines into long, variable-length blocks described in two thick books about the software in the GOES Operational Ground Equipment (OGE)[12]. There are copies of these OGE books on-line in several word-processing formats[13]. The demonically complex

GVAR blocking and packing requires well-structured code to deal with the many variations of Imager and Sounder blocks.

```
Usage:gvar [OPTIONS] <RawGvarDataFile> [MoreRawGvarDataFiles]
VERBOSE      -h more verbose description of the following options
INSTRUMENT   -i <instrument>            default: none
                [none imager sounder iIcse
                 sIcse iSpacelookStats iNav sNav]
 FILETYPE    -f <file>                  default: none
                [none bin jpeg tiff tifftile tiffstrip ncdf]
 TIMESTAMP   -T <stamp>                 default: fromFilename
                [fromFilename framestart]
 START       -s <VISpixel,VISline>   default: from gvar
 END         -e <VISpixel,VISline>   default: from gvar
 AREA        -A <[+/-] Mbytes>       default: inactive
 LINKNAME    -l toggle link to latest   default: none
 CHANNEL     -c <channel>               default: all
                [all 1 2 .. ]
  WORDTYPE   -w <wordtype>              default: none
                [none char uchar short ushort int uint float double]
  UNITS      -u <units>                 default: counts
                [counts radiance
                 tstar tscene modeA    (for IR )
                 albedo albedo2]       (for VIS)
 GAIN        -g <gain> {y=((x-b)/g)^G}  default: 1.0
 BIAS        -b <bias>                  default: 0.0
 GAMMA       -G <gamma>                 default: 1.0
 XSCALE      -x <pixels>                default: 1.0
 YSCALE      -y <lines>                 default: 1.0
 DIRECTORY   -p <output_path>           default: ./
 HOURS       -H <start,end>             default: 0,23
                GMT hours
 MAP         -M <map>                   default: none
                 [none grid1 grid2 grid12 ]
 MAPVALUE    -m <counts>                default: 1023
 COMPRESS    -C <scheme|QUALITY>        default: none|75
                 for tiff:
                 [cittrle ccittfax3 ccittrlew lzw
                  next packbits thunderscan pixarfilm]
                 for jpeg: QUALITY [0 - 100]
SNOOZE       -S <directory>             default: off
DEBUG        -D <mode>                  default: none
                [none header lineDoc block0time SAD CRC]
COUNTER      -K toggle counter off      default: on
CMDFILE      -F <fileName>              default: none
XECUTE       -X <scriptName>            default: none
 Version @ Tue Sep 26 12:26:11 EDT 1995
```

Figure 3: The command-line options for the "gvar" parsing freeware application that converts NOAA's raw, packed GVAR scanline format into images in common scientific formats.

The GVAR parser used at NASA-GSFC was written in C++. It is portable software, having been compiled and tested on the SGI, HP, SUN and GNU's C++ compilers in mid-1995. The source code and make files are freeware. They can be downloaded from the public domain[14]. The "gvar" software offers

a large number of command-line options when you type the command "gvar", listed in Figure 3. Each option is explained in greater length by invoking the verbose form "gvar -h".

The "gvar" options listed in Figure 3 offer choice of instrument (Imager or Sounder), choice of output file type (binary, JPEG, TIFF, tiled TIFF, etc.), choice of the time and place ranges of observation (in instrument scan coordinates), and choice of channel selections. Channel output options include the computer word type (short or long, integer or floating point), physical units (radiance, brightness temperature, or albedo), intensity rescaling options for the output in the form $y=((x-b)/g)^G$ to reset gains and offsets, and horizontal and vertical rescaling. Either or both of NOAA's dot-maps containing geopolitical boundaries can be embossed in the images with a user-specified numerical value for the dots to make them stand out in the image. The "gvar" code offers several programmer conveniences, such as output path names, debug modes, running counts of blocks processed, and a link to other command files to be run after each raw GVAR block is process (such as the removal of old files or the creation of multi-spectral combinations of new images).

The "gvar" channel selection block can be repeated as many as 36 times within a single invocation of the application, each with its own output path. This means that it can create as many as 36 different sectors, each with it own image characteristics, while reading the raw GVAR data stream just once. The "gvar" parser can operate on one or more named raw GVAR files. It can also just "snooze" along, waiting for a new raw GVAR file to appear in the input directory path, allowing continuous automated processing.

The "gvar" parsing code does most of its work very efficiently using pointers and lookup tables. On modest RISC workstations (100 to 200 MHz CPUs), the "gvar" code processes local raw GVAR at rates limited by the SCSI disk bus -- about 10 times faster than the raw data comes from the satellite. Over a NFS-mounted FDDI network, a remotely running "gvar" parser can still process raw GVAR 4 times faster than the satellite downlink (2.1 Mbits/sec) while creating 36 sectors of calibrated, full resolution imagery in all channels of the GOES-8 Imager and Sounder.

5. DATA DISTRIBUTION

As each GOES Imager scan is completed, the "gvar" software immediately parses the stream of raw data, converting a large-area Imager scan into dozens of smaller megapixel sectors. Consequently, we maintain a realtime data pool of images that are no more than 30 minutes old.

These realtime images are written to a workstation dedicated to public file service of Remote Sensing Data (RSD) in the Mesoscale Processes[15] branch at NASA-GSFC-GLA (**http://rsd.gsfc.nasa.gov**). GOES images are written in TIFF format to preserve radiometric accuracy. The images remain on-line for 24 hours. The images are organized into 36 directories, one for each sector. Each realtime Imager sector contains a 1200x1000 pixel visible image and four corresponding 300x250 pixel infrared images, each in its own directory: vis, ir2, ir3, ir4, ir5.. Most sectors are supplied at full resolution (over-sampled by the satellite by a factor of 7/4ths in the east-west direction, making the earth appear oblate). The larger area sectors, such as full earth, Conterminous US (CONUS), Brazil, etc., are subsampled to round-earth infrared resolution.

In addition to realtime digital file service, the data stream can be run through a video rack to produce live video for NASA Select TV and broadcast quality BETA videotapes for immediate use by local broadcast meteorologists[16], some of whom routinely enhance the full-resolution images for broadcast and provide them, in turn, as "value added" to the Web[17]. More than once during the active 1995 hurricane season, we

would go home from an interesting day at the workstation terminals at NASA-GSFC to see our products on local or national broadcasts.

Sometimes the GOES ingestor at NASA-GSFC get personally involved in the weather it captures. For example, the GOES-8 ingest at NASA-GSFC captured the clouds containing the tornado in Fairfax VA on 24 June 1996 (Figure 4)[18] within a minute or two of the touchdown time officially estimated by the National Weather Service[19]. Shortly after taking this picture, the GOES ingestor at NASA-GSFC was knocked out by the enormous surges in the local power grid due to storm damage.
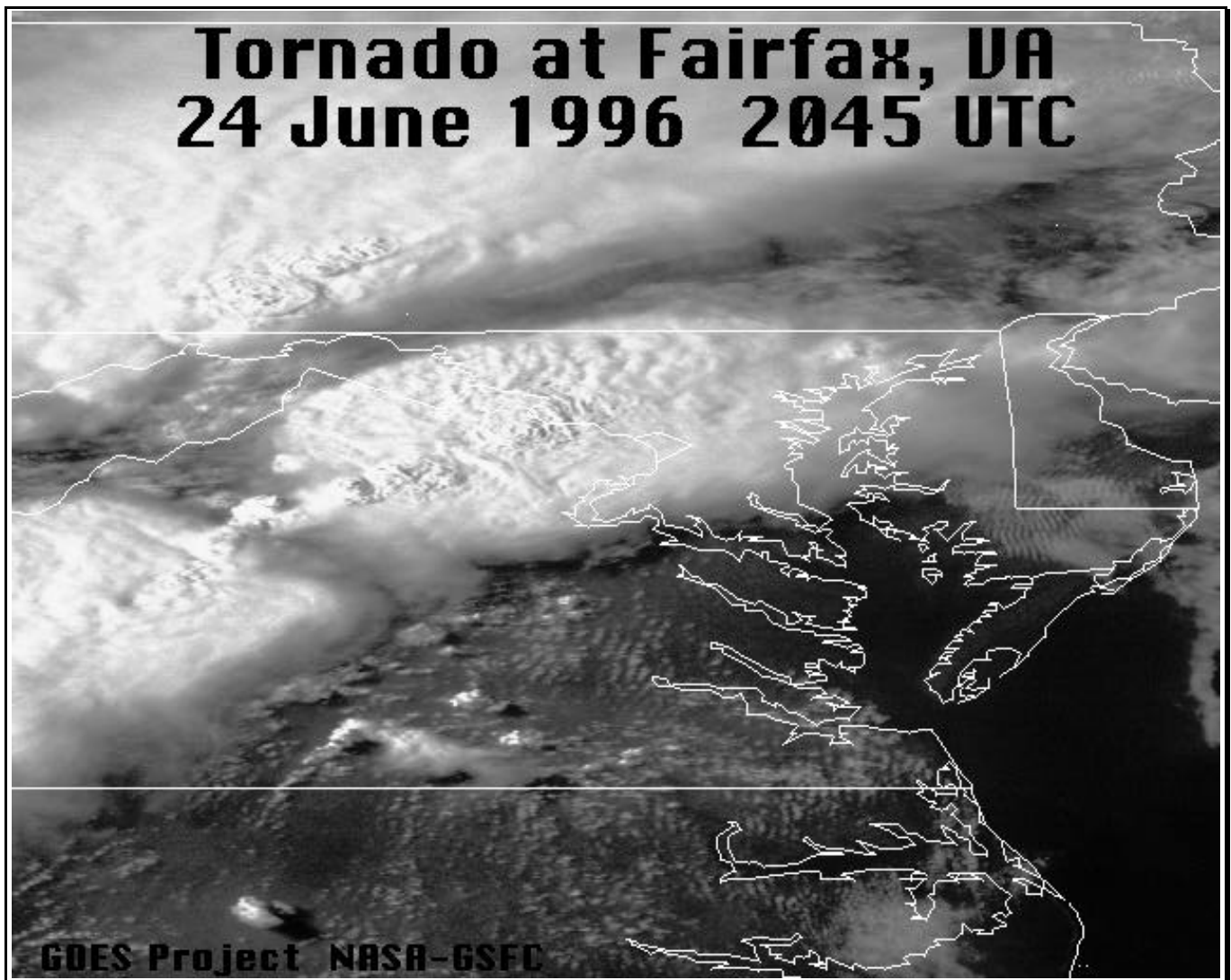
Figure 4: Enhanced GOES-8 image of Fairfax VA tornado, taken as the tornado was occurring, and just before the storm knocked out the GOES ingestor at NASA-GSFC in Greenbelt, MD.

To assist image navigation, each directory has an image file named "MAP.TIFF" containing geopolitical outlines for the area. This map can be overlaid on the GOES images to provide subjective location of weather events. This map is based on the navigated locations of every pixel, derived from NOAA navigation software, which is available on-line[20]. The latitude-longitude locations of each pixel are also listed to the nearest 1/100th of a degree in a corresponding file named "goes.nav", and is described by the file named "readme.nav".

In addition to the realtime images, the GOES Project Scientist in the Climate and Radiation[21] branch at NASA-GSFC-GLA maintains a lively 2-year deep on-line scrapbooks of GOES-8[22] and GOES-9[23] images and other GOES technical information (**http://climate.gsfc.nasa.gov**). Internet users currently fetch about 500 MBytes/week of archived images from the project scrapbooks. The most popular items are a "hot stuff"[24] list containing the most recently enhanced GOES images, and two repositories of dramatically enhanced multi-spectral images[25] and movies[26].

For high-end analysis of technical quality and scientific content of the GOES-8 and GOES-9 datasets, we employ the Interactive Image Spread Sheet (IISS), developed at NASA-GSFC.. At GLA, the IISS resides on a SGI Onyx with 512 MBytes of RAM and 32 Gbytes of dual-striped RAID disk packs capable of full screen color animation at 30 frames per second, with output to broadcast video. This high-performance system allows us to roam and zoom through day-long animations of CONUS visible imagery at full resolution, to probe for small differences among the GOES Imager channels, and to navigate images from different aspects and sources into a common coordinate system.

For example, Figure 5 shows a coordinated IISS probe among enhanced copies of the GOES-8 Imager channels examining the cloudtop temperatures to within a fraction of a degree over Hurricane Luis, with cell B2 equal to the difference in brightness temperatures between the 6.7 micron water vapor channel and the 11 micron window channel (cells A2 and B1, respectively). In this case, we were looking for signs of water vapor being injected into the stratosphere above the outflowing cirrus in the vigorously convective region that normally occurs northwest of the eye of a hurricane -- we did not find any.
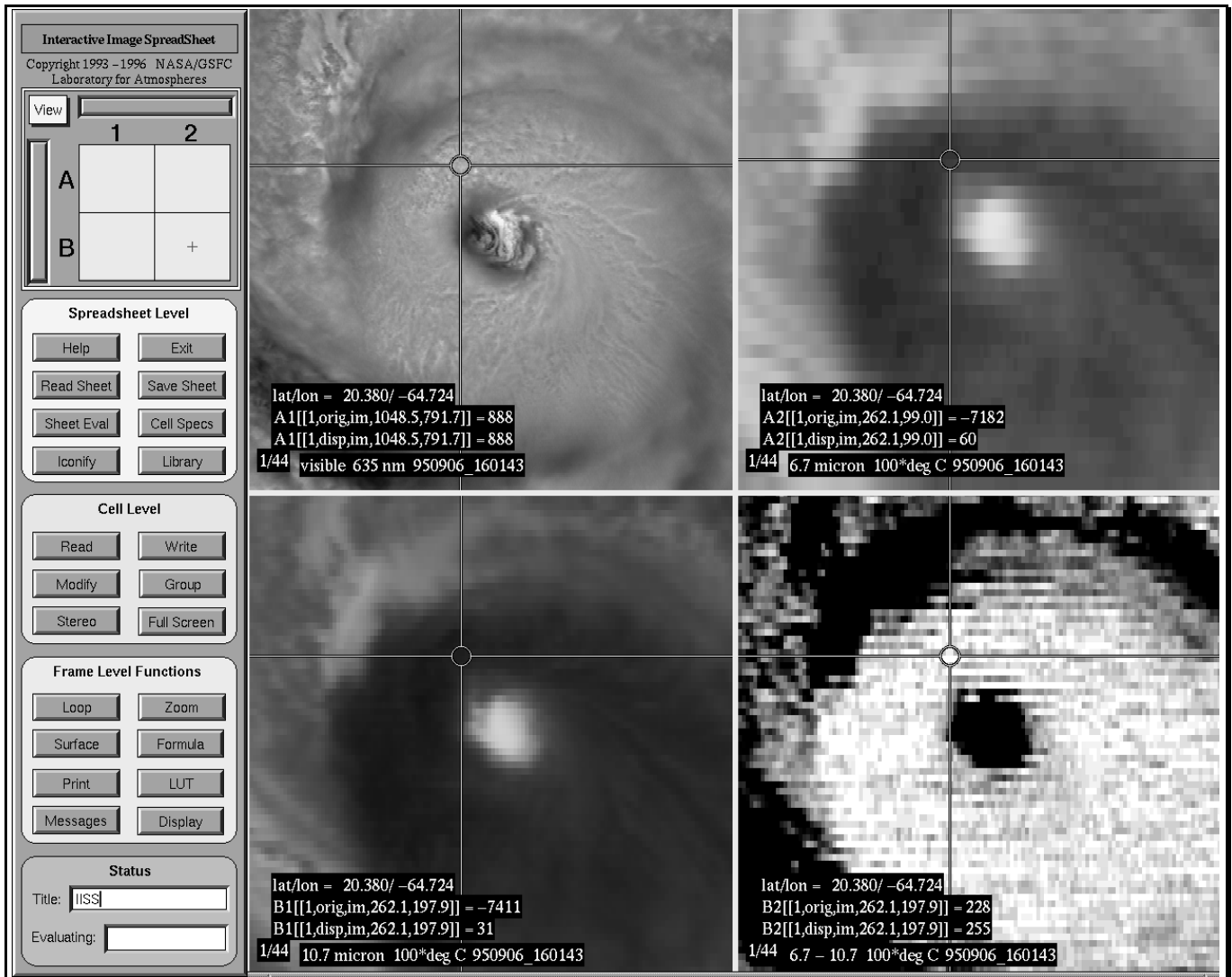
Figure 5: The IISS being used on Hurricane Luis to make a coordinated probe of cloudtop temperatures observed by the GOES-8 Imager channels.

Figure 6 presents another example of IISS analysis. In this case, GOES-8 and GOES-9 had simultaneously observed the eye of Hurricane Luis, and the two images are being navigated to a common latitude-longitude grid where the discrepancies in the apparent positions of cloudtops are being translated into stereoscopic height estimates. In this case, the unusual clouds within the eye are a secondary storm, a meso-vortex that occurs in the northwest quadrant of the eye, releasing energy and causing it to tilt. The animated version of Figure 6 is used to estimate wind speeds in the eye[27] for comparison to aircraft radar data that was taken by the National Hurricane Center (NHC) from a plane flying inside the eye of Hurricane Luis at the same time.
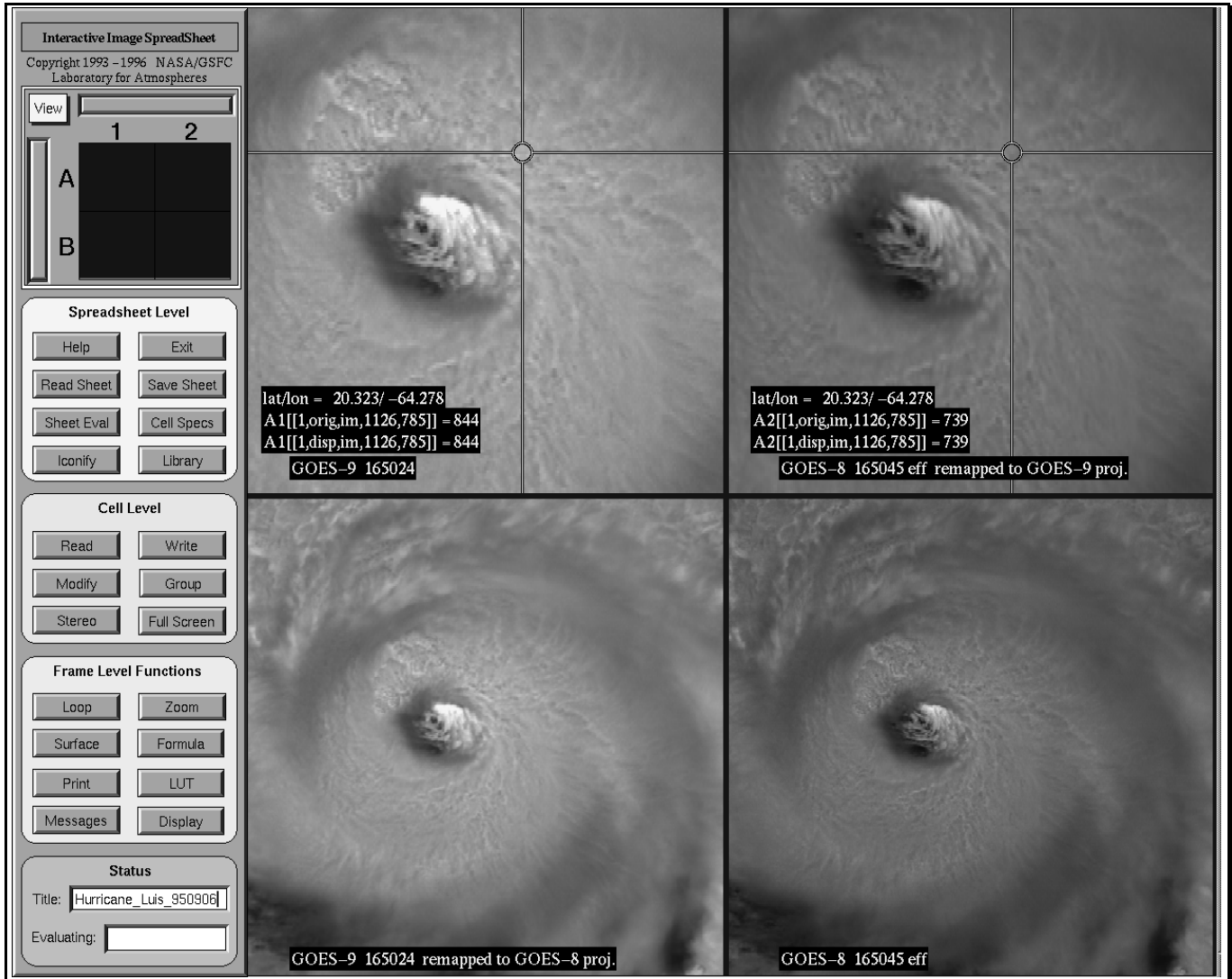
Figure 6: The IISS is used to map coordinated views of Hurricane Luis observed from GOES-8 and GOES-9 into the same coordinate system, to determine stereo cloud height and wind speed.

Finally, for NASA-funded science projects, we set up special GOES science data capture operations during field experiments. For example, we have provided GOES imagery over the internet to the 1995 stratospheric lightning chase[28] in Peru, enabling them to fly to the midnight locations of the most intense thunderstorms in the Amazon basin. On a more massive scale, we helped the Smoke/Sulfate Clouds and Radiation (SCAR)[29] experiment archive all the GOES-8 imagery of the Amazon basin during the summer of 1995, using FTP to move 20 Gbytes per day over FDDI into mass storage at NASA-GSFC. At the moment, we are providing daily images of Brazil to the Tropical Rainfall Measuring Mission (TRMM)[30] ground truth experiment, to help them calibrate their cloudtop/rainfall algorithm in preparation for the TRMM satellite launch in 1998. Finally, we are now routinely processing GOES Imagery in the California and Peru eastern Pacific Ocean basins to develop a reliable climatology of multi-layer, sub-resolution Marine Stratocumulus Clouds (MSC)[31].

6. SUMMARY

This GOES ingest system at NASA-GSFC automatically processes a significant flow of digital data with minimum customization with maximum openness and user software flexibility, assembled from "off the shelf" hardware components augmented by software. Multiple "gvar" processes can drink realtime data from the raw GVAR data pool using NFS over FDDI. The "gvar" image processing C++ software is efficient, self-explanatory, portable, and in the public domain. The Internet community gets free Web access to realtime images from GOES-8 and GOES-9, and to a rich scrapbook of interesting weather events ever since the launch of GOES-I in mid-1994. The science community gets free and easy access to full resolution, navigated and calibrated GOES data 24 hours per day, with special assistance from during NASA-supported field experiments. Similar systems are now available from commercial vendors[32] at modest cost, and other public servers have sprung up[33].

7. ACKNOWLEGEMENTS

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