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GOES High-Inclination Mission GVAR Impact Study

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I. Introduction

The GOES-10 satellite will be replaced by GOES-11 as the operational GOES-W satellite in mid-2006. The GOES-10 satellite is still functioning well, but has exhausted its station-keeping fuel. GOES-10 will be drifted east to its new station at 60°W longitude where it will continue to operate in a high-inclination mission to provide coverage over South America and off the west coast of Africa where hurricanes are born. Other satellites may also be operated in high-inclination missions when they exhaust their station-keeping fuel, extending their operational lifetimes and mitigating the risk to NOAA that the GOES-R generation is deployed late.

This report begins (Sec. II) with a description of the operations concept for the high-inclination mission. Implementation of Image Motion Compensation (IMC) on the ground through resampling is an integral part of the high-inclination mission operations concept. The objective of the on-ground IMC implementation is to provide the same level of Image Navigation and Registration (INR) performance that is achieved normally. Resampling is not new to meteorological satellite systems. It has been employed on Meteosat[1] and Meteosat Second Generation (MSG)[2] for many years and resampling is also part of the Japanese MTSAT program.

GOES Imager and Sounder data is distributed to the user community through the GOES Variable (GVAR) telemetry[3]. Assessing the need for GVAR adaptations is the main purpose of this GVAR impact study. Additional information will need to be included in the GVAR telemetry to document the state of the system and the processing performed on the data. Sec. III surveys the structure of the GVAR telemetry. Sec. IV describes the recommended adaptations to GVAR, including what additional information should be packaged within the spare space available.

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[1] Blancke, B., J. Carr, E. Lairy, F. Pomport, B. Pourcelot, "The Aerospatiale Meteosat Image Processing System (AMIPS)", First International Symposium on Scientific Imagery and Image Processing, L'Association Aéronautique et Astronautique de France, April 1995. This article describes the first implementation of higher-order resampling for Meteosat.
[2] Blancke, B., J. Carr, F. Pomport, D. Rombaut, B. Pourcelot and M. Mangolini, "The MSG Image Quality Ground Support Equipment", 1997 Meteorological Satellite Data Users' Conference, EUMETSAT, Brussels, Belgium, September 1997. This article describes the first implementation of resampling for MSG.
[3] NOAA/NESDIS DRL 504-02, "OGE Interface Specification, Section 3 - GVAR Transmission Format", DCN 1 Version, June 2000. The document is online at http://www.osd.noaa.gov/gvar/gvardownload.htm.

II. High-Inclination Mission Operations Concept

Normally, the GOES Imager is operated in fixed-grid mode, meaning that IMC is applied in space to control the Imager scan mirror to compensate for image distortion caused by deviations of the orbit and attitude from their reference values. In fixed-grid mode, the relationship between GVAR line and pixel[4] coordinates and latitude and longitude is standard and invariant. Users benefit in that they do not need to navigate images using a complicated description of the orbit and attitude. Instead, users navigate images as if the satellite were on the equator at a fixed longitude and oriented towards the Earth with all attitude angles zero[5]. In addition, the image geometry is stable; movie loops will show clouds moving but the land fixed. Normally, the Sounder is operated in dynamic-gridding mode, meaning that no IMC has been applied (IMC is disabled) to control its pointing. Each sounding is navigated by the Sensor Processing System (SPS)[6], with the navigation reported in GVAR.

IMC Dynamic Range

IMC dynamic range is limited to ±8000 μrad in its high range[7]. This dynamic range must be sufficient to correct instrument pointing for deviations in attitude and orbit from their reference values, or the satellite cannot operate in fixed-grid mode. The attitude corrections should not be very different from those in a low inclination orbit; however, the orbit corrections will be larger, because they are proportional to the orbital inclination. Figure II-1 shows a reasonable allocation between attitude and orbit for the full dynamic range. The orbit correction and inclination are in proportion 1:5.6 (ratio of the radius of the Earth to the orbital altitude), implying that inclinations >2.25° saturate the allocation for orbit. In practice, some dynamic range margin should be reserved; therefore, 2° inclination is about the limit for instrument operations in fixed-grid mode. For the purposes at hand, a high-inclination mission is understood as one where the inclination exceeds 2° and routine operations in fixed-grid mode are no longer possible.

System Architecture

Users of the Imager are accustomed to fixed-grid mode; whereas, users of the Sounder are accustomed to dynamic-gridding mode. In fixed-grid mode, there is an invariant relationship between the GVAR line and pixel coordinates and geographic latitude and longitude. Because of this invariance, movie loops may be made that show cloud motion rather than ground motion. The utility of the Imager data would be significantly degraded if dynamic gridding were required. To avoid this situation, changes in the ground segment are envisioned that will permit Imager fixed-gridding during the high-inclination mission; specifically, the MSPS will be extended to allow IMC to be applied

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[4] "Lines" refer to image row numbers and "pixels" to image column numbers.

[5] In principle, nonzero reference values for orbit latitude and attitude angles can be specified, but this is never done in practice.

[6] The latest version of the SPS is referred to as the Modernized Sensor Processing System (MSPS).

[7] NOAA/NESDIS DRL 101-08, "GOES I-M DataBook", Revision 1, August 1996. The document is online at http://rsd.gsfc.nasa.gov/goes/text/goes.databook.html.

on the ground through resampling. Resampling would be driven by the Orbit and Attitude (O&A) data already sent to MSPS by the Orbit and Attitude Tracking System (OATS). Figure II-2 shows a how the Extended MSPS (henceforth, ESPS), which includes resampling, fits within the overall system architecture. Distribution of GVAR through a DOMSAT link is also shown. Because DOMSAT inclination is tightly controlled, the GVAR broadcast would available to users with fixed antennas. They would otherwise be required to use more expensive tracking antennas to receive the broadcast of GVAR through the high-inclination GOES satellite. While DOMSAT broadcast of GVAR is relevant to users, it is irrelevant for the structural definition of GVAR so long as the GVAR bandwidth does not change.

Figure II-1. IMC Dynamic Range Allocations

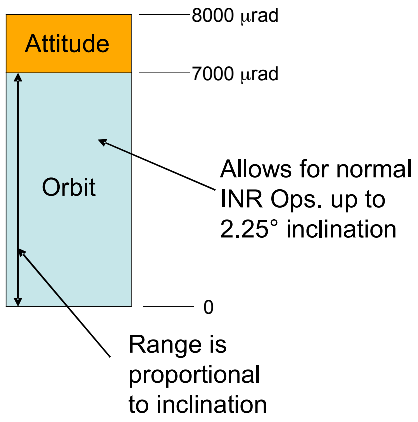
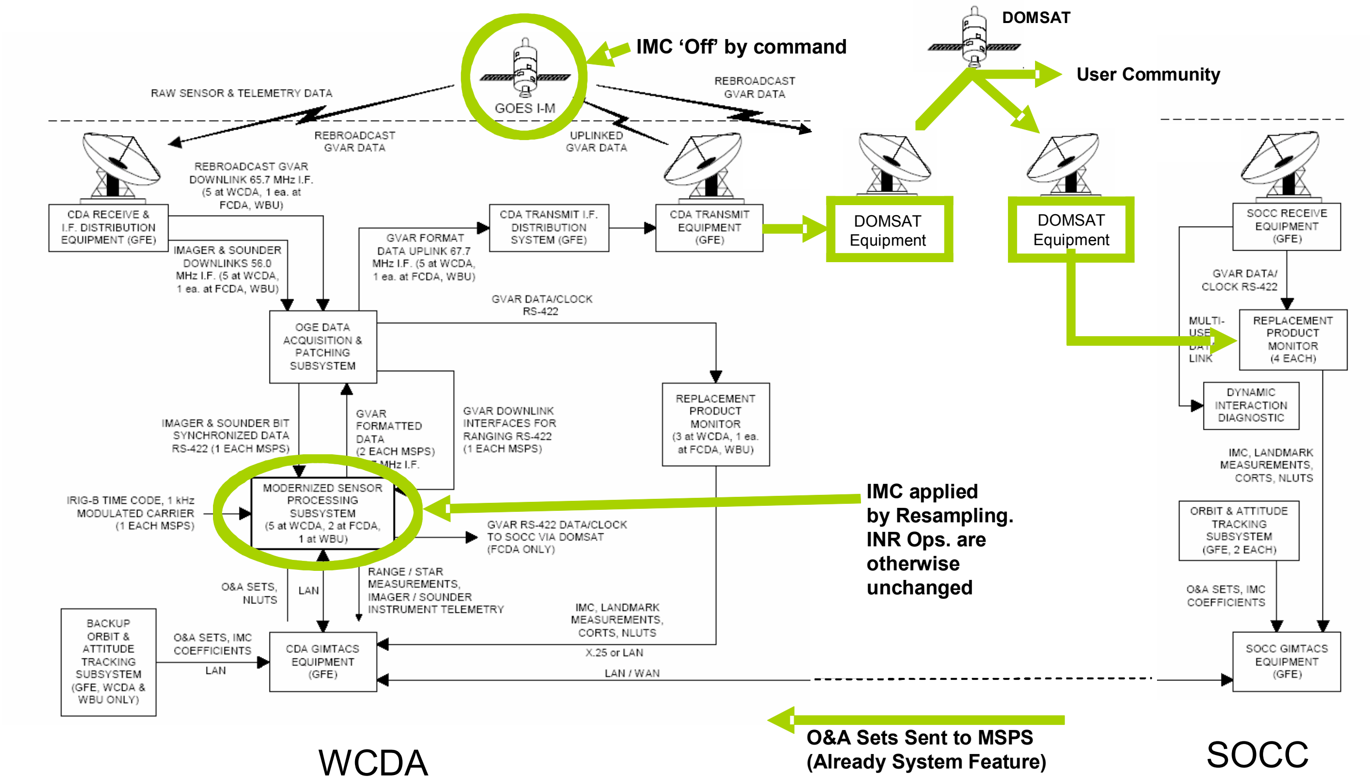


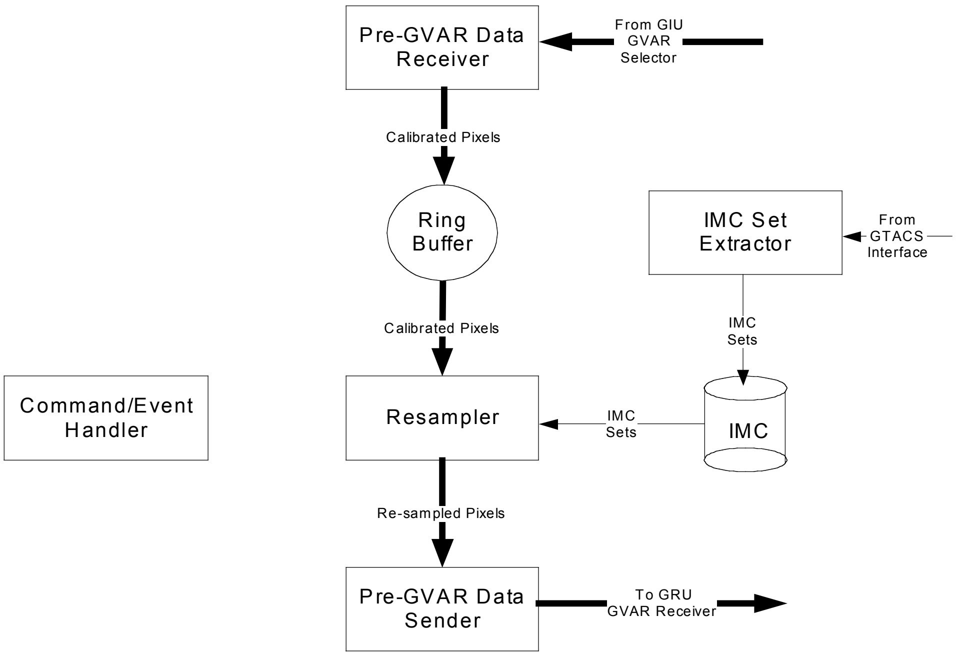
Figure II-2. High-Inclination Mission Architecture



ESPS Resampling Architecture

The MSPS consists of two units – the GOES Ingest Unit (GIU) and the GOES Ranging Unit (GRU) – communicating with each other over an Ethernet LAN[8]. In one approach to building the ESPS, a third unit – the Image Correction Unit (ICU) – would logically sit between the GIU and GRU. The ICU would implement the resampling and communicate with the GIU and GRU over the LAN as well. Figure II-3 shows a block diagram for the ICU. The three units – GIU, GRU, and ICU – would together comprise the ESPS. Most of the effort would be in building the ICU; however, some modifications of the GIU, at least, would be required to interface with the ICU and to control and monitor its functioning.

Figure II-3. Image Correction Unit (ICU) Block Diagram



There are several resampling methods that can be considered. The simplest is Nearest-Neighbor (NN) resampling, whereby the nearest real pixel value to the resampled pixel is used as the resampled pixel value. In general, the locations of resampled pixels will map to non-integer line and pixel numbers in the raw images; therefore, NN resampling introduces geometric quantization noise of $\pm 1/2$ pixel. NN resampling was used in the Meteosat ground processing until the mid-1990's. The NN geometric quantization error tends to be spatially correlated and this led to the phenomenon of "plates" of pixels shifting in whole pixel steps when Meteosat movie loops are were made. ESA/EUMETSAT upgraded the Meteosat resampling to implement bicubic resampling

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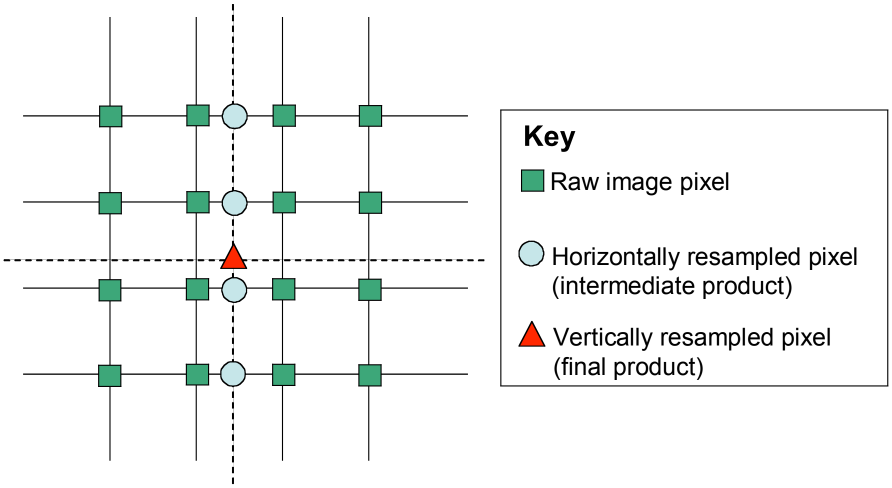
[8] NOAA-GOES/OSD-2004-0057R0UD0, "Modernized Sensor Processing System Software Operation and Maintenance Manual" DCN 0, September 2004.

to eliminate this artifact. Bicubic resampling is only one example of a high-order resampling method. Fundamentally, all such high-order resampling methods are convolutions of raw image pixels with resampling kernel functions. Following the Landsat model[9], there is first a horizontal resampling step and then a vertical resampling step as shown in Figure II-4. Resampling is, therefore, a Digital Signal Processing (DSP) algorithm. The kernel functions have an impact on the resampled image Modulation Transfer Function (MTF) and Signal-to-Noise Ratio (SNR). The kernel design can accomplish a desired modification of the MTF and SNR[10], or the kernel can be designed so as to minimize the impact of resampling on MTF and SNR[11]. The ESPS design is envisioned to allow for flexibility in the resampling kernel used (from NN to, 4-point bicubic, and up to 32-point kernels). The selection of horizontal and vertical resampling kernels can be done independently of the implementation of resampling in the ESPS.

Figure II-4. Resampling Process. A column of intermediate pixels is first created in a horizontal resampling step, and then the final resampled product pixel is created with a vertical resampling step. Each resampled pixel is created from a convolution of the input (either raw or intermediate) pixels with a resampling kernel.



Earth Coverage

Earth coverage is impacted by the higher inclination in two ways. First, coverage is lost at the extreme northern and southern limbs, as pixel slip over the horizon, depending on the orbital phase with respect to the nodal crossing. This is unavoidable and cannot be corrected for. More practically, as limb data is of little use, the prime coverage zone (within about 60° Earth Central Angle (ECA)) will oscillate north-south over the course

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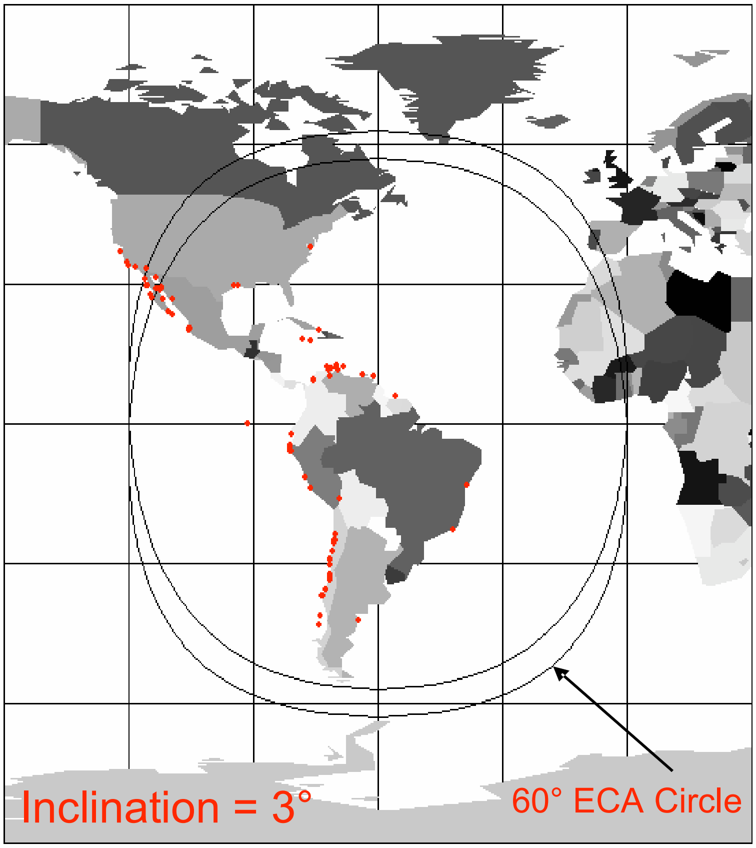
[9] Carr, J., "Data Processing and Reprocessing" in *Manual of Remote Sensing*, F.C. Billingsley (ed.), American Society of Photogrammetry, Second Edition, 1983.

[10] Carr, J. and D. Rombaut "Optimal Deconvolution and Resampling", First International Symposium on Scientific Imagery and Image Processing, L' Association Aeronautique et Astronautique de France, April 1995.

[11] A truncated Shannon (or *sinc*-function) kernel will approach achieving this purpose when the spatial frequency content of the raw image is band-limited.

of a day. Full-time (*i.e.*, 24-hour-a-day) coverage of a latitude range equal to the inclination is thereby lost at the northern and southern extremes of the prime coverage zone. This effect is present at low inclination too, but it is obviously less important. Figure II-5 shows the two extreme coverage circles for ECA < 60° when then orbital inclination is 3°. The second effect pertains to targeting of frames that are not Full-Disk (FD) frames. Obviously, FD frames will continue to be fully covered (noting as above, the slippage of pixels over the northern/southern horizons with the emergence of new pixels from behind the Earth near the opposite pole), but other frames (*e.g.*, CONUS or storm tracking frames) will need to be targeted or over-scanned to achieve the desired coverage. In the case that a frame is over-scanned, some data will be lost to trimming required to form a rectangular resampled image frame. On the other hand, without over-scanning, there will likely be a need to insert "fill" pixels into the resampled frames because of a lack of data from which to construct certain resampled pixels (note that one needs to cover the desired frame with some margin to allow for the width of the resampling kernel). If over-scanning is employed, there will be a mismatch between the number of pixels input into the ESPS and the number of pixels output in GVAR. In general, one would expect fewer pixels on output because of over-scanning. Idle blocks may be inserted to fill time in GVAR, but the opposite problem of needing to force more pixels through GVAR, if it occurs, would need to be managed through insertion of idle time in the scan schedule. Such considerations, of course, only apply to non-FD frames.

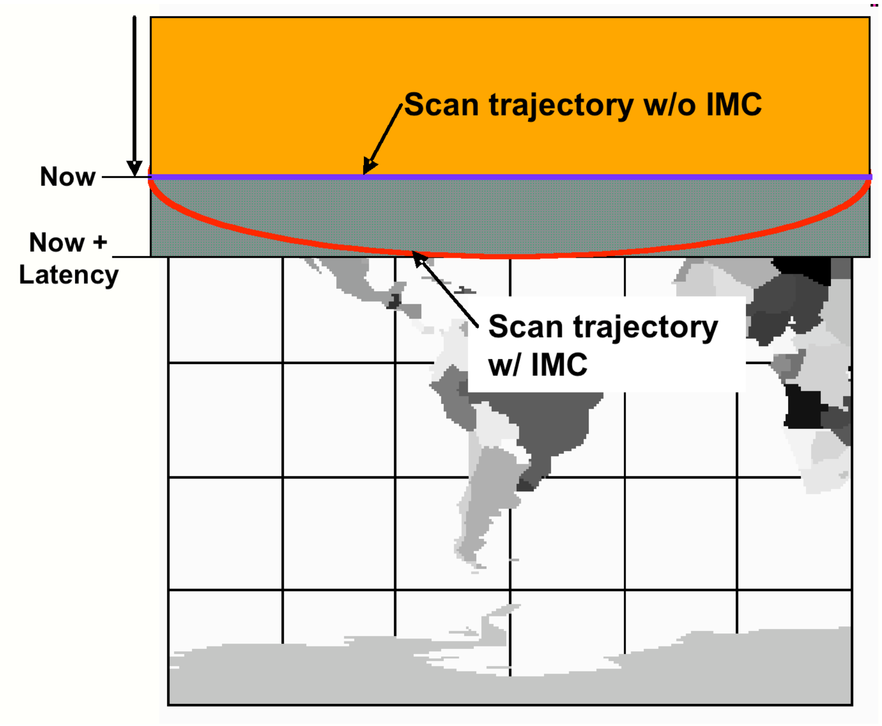
Figure II-5. Earth Coverage at 3° Inclination



Data Latency

Additional latency in data delivery will necessarily be introduced in the high-inclination mission. Figure II-6 illustrates how latency is added as a result of the need to "look into the future" to construct an entire resampled scan line. There will also be latency added by the resampling process proper, but this should be much smaller than the latency added by the need to wait to acquire all the necessary pixels.

Figure II-6. Pixel Acquisition Latency. The raw data is acquired along the blue trajectory with IMC disabled, but the resampled line needs to follow the red trajectory that would have been followed were IMC enabled onboard the spacecraft. The ESPS must wait until all necessary pixels are acquired to complete the resampled line.



Data latency for the high-inclination mission will be driven by the orbital component of on-ground IMC because it consumes most of the dynamic range of the on-ground IMC. Figure II-7 shows the dynamic range for the orbit correction plotted over a quarter of an orbit for a 2° inclination. The worst-case forward look is approximately 225 VIS lines. Since the Imager acquires 8 VIS lines in about 1.1 s (for a FD), the latency contributed by the orbit correction will be approximately 31 s. This contribution will scale approximately linearly with the inclination.

The fact that a line in the resampled image will be curved when mapped into the raw image (as illustrated in Figure I-6) means that not all of the pixels in the resampled line will have time tags as close to each other as the pixels in a raw image line. The offset of the time tag relative to the nominal time tag varies along a resampled image line as shown in Figure II-8. The amplitude of the time-tag correction is approximately proportional to the inclination. In the example shown in Figure II-8, the error can be as large as 31 s. One might ask whether or not there is any consequence to an uncertainty in time tagging as large as 30 s. There are two avenues to explore, first, the impact to users, and second, the impact on OATS and navigation. These are discussed further in Sec. III.

Radiometric Impact

The radiometric impact of resampling has already been discussed in terms of SNR. The overall gain of the resampling process and the mixing of data from detectors with possibly different gains and offsets are other considerations. The overall gain of the resampling process is determined by the resampling kernel. The resampling gain should be set to unity to preserve the radiometric calibration of the instrument. This represents an important constraint on the kernel design. Gain equalization between detectors is important to remove image striping, which may be a problem for certain flight instruments but not for others. To mitigate striping, the existing SPS calibrates the IR detectors individually and can apply a Normalization Lookup Table (NLUT) to each of the VIS detectors. Each VIS NLUT is constructed so as to match the radiometric histogram of a detector to that of a reference detector. This represents a statistical equalization of the gain of each VIS detector, rather than a *bone fide* calibration.

The IR calibration and the VIS NLUT should be applied to each detector prior to resampling, even though resampling, as it mixes data from different detectors, will tend to equalize the gains. The VIS NLUT for each detector should, therefore, be developed from the raw, rather than the resampled, pixels.

Sounder

No resampling is envisioned for the Sounder, as users are accustomed to using Sounder data in the dynamic-gridding mode. No special adaptations for the Sounder or its GVAR are foreseen as part of the high-inclination mission.

Constraint on Frame Interrupts

It is, at least in principle, possible to operate the GOES I-M instruments so that higher priority frames interrupt low-priority frames; however, NOAA never operates the GOES I-M system in this way. In fact, when this feature was recently tested using the non-operational GOES-11, the Replacement Product Monitor (RPM) failed to properly return to landmarking the interrupted frame. Frame interrupts add great complexity to the resampling implementation, so operating the extended mission without frame interrupts is an assumed ground rule.

Figure II-7. Orbital Correction for 2° Inclination.

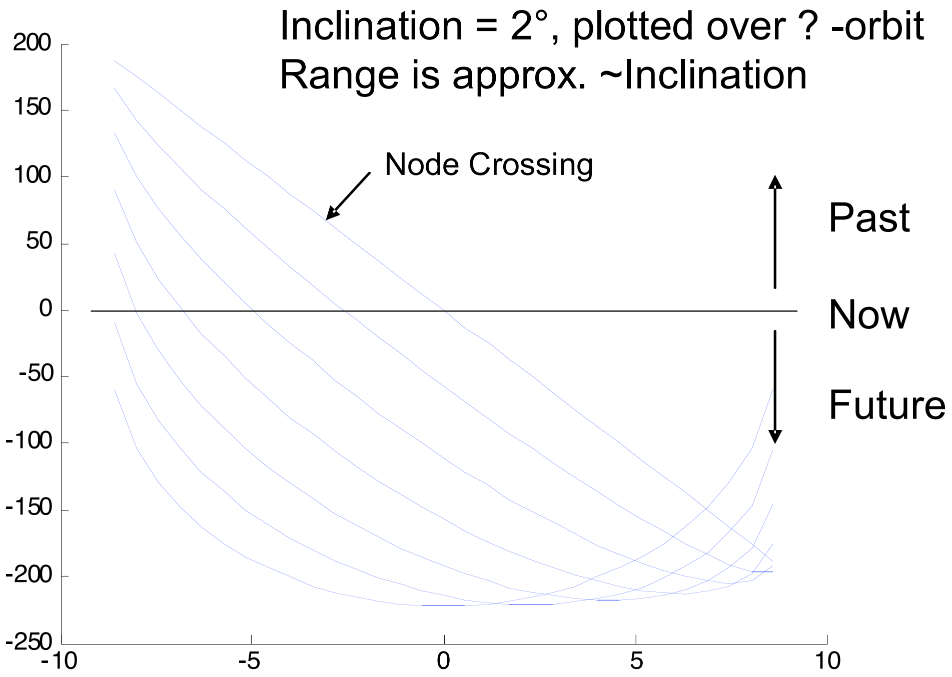
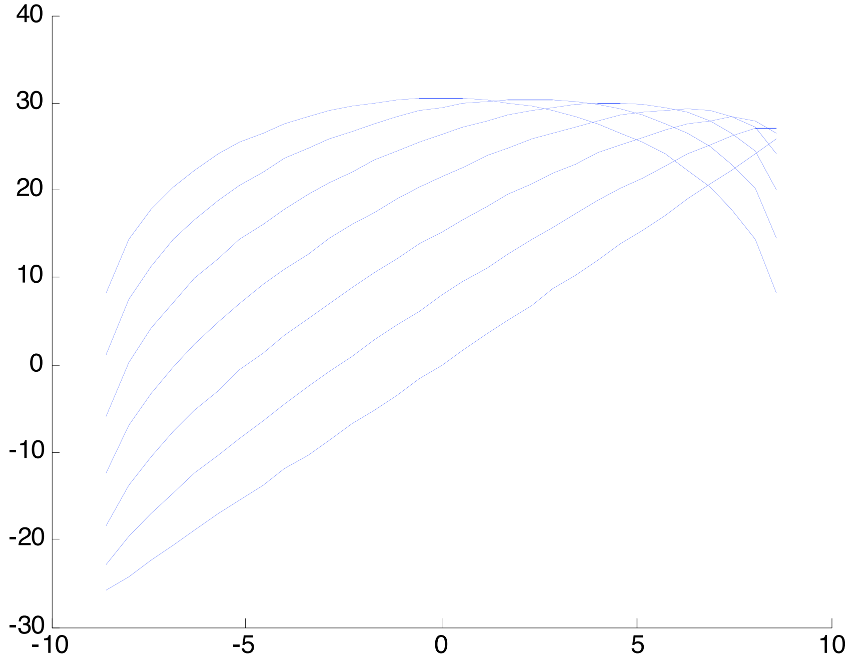


Figure II-8. Time Tag Offset across a Resampled Image Line for 2° Inclination. Note that the time-tag offset reaches a maximum value equal to the orbital component of the latency. (1.1 sec. per scan is assumed, representative of a FD).



III. GVAR Overview

The GVAR transmission sequence consists of twelve distinct blocks, starting with a Block 0, followed by Blocks 1 to 10, and terminated with a variable number of Block 11s. The data from each Imager scan are packaged into Blocks 1 to 10. Block 0 documents the Imager scan data. The Sounder data, as well as instrument telemetry and other data, is packaged into Block 11s.

A GVAR block has 10,032 bits of synchronization code and 720 bits of block header at its beginning, and 16 bits for a Cyclical Redundancy Check (CRC) at its end. The data section in between has a fixed length of 64,320 bits (8,040 bytes) for Block 0 and Block 11, and a variable length of no less than 21,440 bits (2,680 bytes) for Blocks 1 to 10, depending on the Imager frame width.

The header of a block contains the block ID, product ID and version, block size and word size, data format, block sequence number in the GVAR sequence, a range word, the transmission time of the block, and a few flags. To increase the chances of error-free recovery, the same 240 bits of header data are repeated three times for a total of 720 block-header bits.

The Imager documentation block is Block 0, which contains the following data segments: 278 bytes of instrument and scan status, 1,348 bytes of instrument orbit and attitude data (in the form of an IMC set), 680 bytes of scan reference data, 3,080 bytes of grid data, 918 bytes of scan reference and calibration data, and 1,736 bytes of factory parameters.

The ICU will use the IMC set to direct the image resampling, so as to correct the geometric distortion caused by attitude errors and the high-inclination orbit. The ICU also needs the time tags of the start and finish for each line to interpolate the acquisition time of pixels, and hence to calculate the geometric correction to apply from the IMC set.

The Imager IR data are packaged in Blocks 1 and 2. Block 1 carries the data of the long-wave detectors (channels 4 and 5/6), while Block 2 carries the remaining detectors (channels 2 and 3)[12]. Blocks 3 to 10 contain the Imager VIS data, one block for each detector line. All these data blocks have the same two-partition record format. The first partition contains 16 bytes of line documentation and the second partition contains the detector data.

The transmission of 10 Imager blocks may be followed by a number of Block 11s, depending on which data are pending as well as a priority order of the data. Sounder data, if pending, takes tenth priority among 21 different Block 11 types.

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[12] GOES-12/13 replaces channel 5 at 4km resolution with channel 6 at 8 km resolution and improves the resolution of channel 3 to 4 km. GOES-14/15 will improve the resolution of channel 6 to 4 km. The GVAR for each GOES adapts to these changes.

IV. GVAR Modifications

Providing a GVAR product for the high-inclination mission that may be transparently used in place of the normal GVAR is the prime objective. However, GVAR should be modified to document the system configuration and provide additional data related to the resampling process that may be of interest to some users. The objective can be achieved if none of the existing GVAR telemetry variables have their locations changed; although, some of their meanings may change slightly by necessity (discussed below). Additional information will be added in "spare" locations in the GVAR format. Block 0, which documents the Imager data in Blocks 1 through 10 that follow, is the natural location for much of this additional information. There are 180 identifiable spare bytes in Block 0 (see Table IV-1).

Table IV-1. Inventory of Spare Locations in Block 0 of GVAR.

Block 0 Word[13] Number	**Bytes**
194	1
251 – 277	27
283 – 294	12
1680 – 1690	11
2303 – 2305	3
5383 – 5385	3
6290 – 6303	14
7267 – 7366	100
8031 – 8039	9
Total Spare Bytes	180

System Configuration

The system configuration data in GVAR should document whether or not the Imager data has been resampled. This could be represented by an additional GVAR flag that may be set to either to zero (not resampled) or one (resampled). There is already an indication as to whether or not the instrument is operated in fixed-grid or dynamic-gridding mode in the GVAR (the most significant bit of Block 0 word 4, mnemonic ISCAN, is set to one to indicate fixed-grid mode). Block 0 is a natural location for the additional resampling flag, which would require at most one byte. When resampling is enabled, the gridding mode indicated in GVAR should be set to indicate "fixed grid" even though IMC would be disabled on-board. This will inform the users that their normal Earth Location User Guide (ELUG)[14] software configured for fixed-grid mode can navigate the images. Information about the ELUG projection (most importantly, the reference longitude) defining the fixed grid is already contained in GVAR.

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[13] One GVAR "word" is the same as a byte.

[14] NOAA/NESDIS 504-11, "Earth Location User's Guide", Revision 1, March 1998. The online document is at http://rsd.gsfc.nasa.gov/goes/text/ELUG0398.pdf.

To first-order, the users will not care whether the Imager data distributed in GVAR has been resampled or the Imager is being operated normally (with IMC enabled in space). However, the users should be informed about the resampling processing applied. This information can be included by harvesting some of the spare words in GVAR. The IMC set created by OATS is already sent to SPS and included in the GVAR telemetry. This IMC set will drive the resampling process, so no additional information needs to be included to document the geometric transformation applied through resampling. It remains only to document the horizontal and vertical kernels in use. These kernels are continuous functions and would need to be quantized at subpixel resolution to tabulate them in the GVAR. This would be a very inefficient way to describe kernels, which may never change during the extended mission lifetime. For these reasons, it is recommended that the horizontal and vertical kernels be identified in GVAR by a code similar to the IMC set ID. The kernels tables corresponding with a given ID could then be obtainable through the NESDIS website or a Block 11. Block 0 would be a natural location for the resampling kernel IDs. A four-character ID string would require 4 bytes for each kernel.

Fill Values

In some cases, pixels within the resampled frame will not be able to be produced due to a lack of raw pixel input. GVAR already codes data drop-outs as zero, indicating “no data”. This convention should be preserved for indicating fill pixels.

Frame Definitions

Currently, GVAR reports the corners of the frame being scanned by the Imager in each Block 0. GVAR Block 0 words 157 – 158, mnemonic IWFPX, and words 159 – 160, mnemonic IEFPX, give respectively the westernmost and easternmost ELUG pixel numbers of the VIS frame. GVAR Block 0 words 161 – 162, mnemonic INFLN, and words 163 – 164, mnemonic ISFLN, give respectively the northernmost and southernmost ELUG line numbers of the VIS frame. With over-scanning and trimming, the frame actually being scanned is less important to the user than the resampled frame. These GVAR words should instead describe the resampled frame. The raw image frame actually scanned can be documented in spare GVAR words, requiring the harvest of 16 additional spare bytes in GVAR Block 0.

Time Tagging

Time tags for scan starts/stops (meaning the data following a Block 0 in this case) are included in GVAR. GVAR Block 0 words 31 – 38, mnemonic TCHED, and words 39 – 46, mnemonic TCTRL, give the time tags for the “current” header and trailer raw data blocks respectively in Binary Coded Decimal (BCD) format[15]. However, the scan represented in GVAR may actually be composed of data from the current and up to two lagging scans (so that VIS and IR detectors align – they are staggered in the focal plane). A pointer in each data block (word 15, mnemonic LLAG, in Blocks 1 through 10)

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[15] With 2 numeric characters per byte to encode a 16-digit time string: YYYYDDDHHMMSSmmm.

identifies which of the "current", "lagging"[16], or "old lagging"[17] time tags apply to the data in that block. The time tagging for resampled pixels along a resampled image line cannot simply be based on interpolation between the start/stop time tags for the line (see Figs. II-6 and II-8). A more precise means of time tagging resampled pixels is required if their time tags are to have a precision better than ~30 seconds.

Most operational weather applications would not need time tagging accurate to the second. However, it should be noted that latency, a concern for severe weather warnings, is uncertain so long as time tagging is uncertain. Since the GOES system delivers data normally with latency less than one minute, certainly time tagging needs to be more accurate than a minute or the latency would not be known with a precision commensurate with its value. Nonetheless, this argument still places a rather loose constraint on time tagging. There are a few applications, perhaps more in the research domain, which would require time tagging accurate to the second. One example is fusing Doppler radar and satellite image data[18].

While the sufficiency of time tagging accurate to the minute is unclear, there is a GVAR adaptation that will support more precise time tagging without burdening users insensitive to time-tag errors. Specifically, nominal scan start/stop time tags would be assigned to each scan line and reported as the usual time tags (see above) and time-tag correction coefficients would be placed in spare GVAR words so that users with precision time-tagging requirements could obtain them. Rational function approximation[19] is a particularly economical way to represent such corrections. Figure IV-1 shows residual time-tag errors in precision much less than a second after correction with a (4,2)-degree rational function[20]. The (4,2)-degree rational function requires 7 coefficients, occupying 28 of the spare bytes in Block 0 when represented as single precision floating point numbers.

Even though the error in time-tag precision may reduced below 1 sec, the error in the accuracy of the time tag remains somewhat larger. First, in deriving Fig. II-8 from the NS image shift shown in Fig. II-7, the assumption was made that time is a continuous function of the shift. In reality, time advances in nearly discrete steps every 8 VIS lines (one scan) and EW scanning also alternates in direction. Second, the meaning of a time tag for a resampled pixel is not precisely defined, as a resampled pixel is the weighted average of raw pixels, each with different time tags. Raw pixels may be mixed across two or more scans, depending on the size of the vertical resampling kernel; therefore, a nonsimultaneity of several seconds may exist among the raw pixels used to construct a

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[16] Block 0 words 47 – 54, mnemonic TLHED, and words 55 – 62, mnemonic TLTRL, are the lagging header and trailer time tags.

[17] Block 0 words 5571 – 5578, mnemonic TOHED, and words 5579 – 5586, mnemonic TOTRL, are the old-lagging header and trailer time tags.

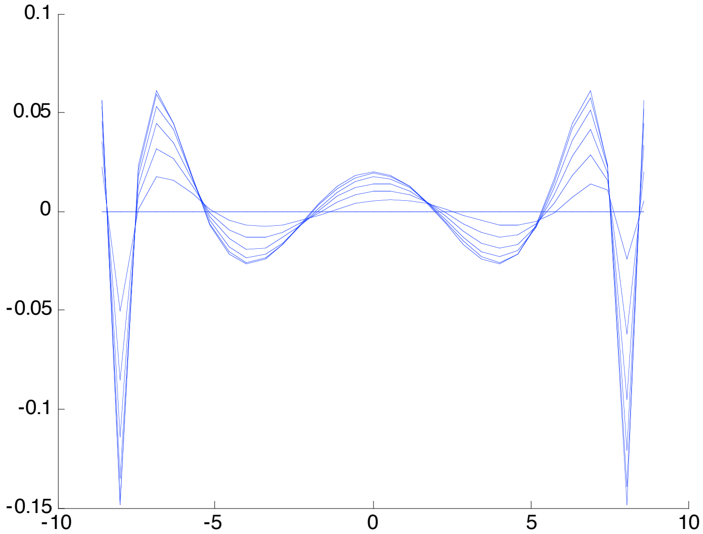
[18] Albers, C.S., J.A. McGinley, D.L. Birkenheuer, and J.R. Smart, "The Local Analysis and Prediction System (LAPS): Analyses of Clouds, Precipitation, and Temperature," Weather and Forecasting, 11, 273-287 (1996).

[19] Press, W.H., S.A. Teukolsky, W.T. Vetterling, B.P. Flannery, *Numerical Recipes in C*, Second Ed., Cambridge, 1992.

[20] Degrees (p,q) for the numerator polynomial P and denominator polynomial Q.

resampled pixel. Nonetheless, correcting the time tags as just described will improve the accuracy of time tagging; furthermore, there is little to be gained by more complicated or higher-order corrections that offer precision better than about 0.1 sec.

Figure IV-1. Residual Time-Tag Error in Precision after Correction. The residual error in precision is computed for each curve in Fig. II-8. These residual errors would scale in proportion with the inclination.



The uncorrected nominal time tags will probably be used by most users. This time tagging needs to appear "normal" to these users. Specifically, the stop time should follow the start time within the nominal period of time defined by the frame width and the fixed nominal scan rate, lagging and old-lagging time tags need to be correct, and time-tag pointers (LLAG) in Blocks 1 to 10 need to be properly assigned. The apparent bidirectionality of the scanning should also be preserved by proper alternation of the scan direction encoded in ISCAN bit 6.

Users sensitive to time-tag errors can evaluate the time-tag correction function using the correction coefficients included in Block 0 and apply the correction to the nominal time tags for pixels computed in the normal way. The correction coefficients will vary only slowly from scan-to-scan, so the same time-tag correction may be applied regardless of the pointing to current, lagging, or old-lagging nominal time tags.

The RPM is one special user of GVAR that is sensitive to time-tagging error. The RPM measures the location of landmarks in the images and sends this data to OATS along with its time tag. The OATS estimates the spacecraft orbit and attitude using, in part, this time-tagged landmark data. RPM time tags a landmark based on the time tag of the pixel where the landmark is nominally expected to be found (the center of the landmark "neighborhood", within which the RPM searches for a match between the image and a digital map). Errors in landmark time tagging will then map to navigation errors. It is difficult to assess the impact of landmark time tag errors, but they can be avoided by adapting the RPM to use the time-tag corrections inserted into GVAR.

The frame time given in GVAR indicates the time for the first scan[21], also in BCD format. This may be inappropriate for the resampled image because the first raw image scan line may be trimmed, or the first resampled image line might contain only fill values. The frame time for a resampled frame should instead be tied to the time tag of the first scan within the resampled frame. The special case where a "scan" of resampled pixels consists of entirely fill values will need to be handled by the ESPS. One solution would be to include such fill lines in the GVAR frame (rather than trimming them and redefining the frame with a smaller size) and to calculate their nominal time tags by extrapolation of the time tags for leading/trailing "scans" from non-fill lines. Time correction coefficients in this special case would be set so as to describe a correction of zero.

Finally, to document the start time of the frame as actually scanned in space, one 16-digit BCD time tag should be added to the GVAR, consuming a total of 8 spare bytes.

Resampling Impact Metrics

Resampling affects the data in ways that depend on scene content and the resampling kernels in use. Sophisticated users may be interested in metrics that characterize the impact of resampling on the image data. Some impacts, for example, the MTF, white noise reduction gain, or DC gain of the resampling filters, would depend only on the resampling kernels in use. Such metrics could be efficiently disseminated on a NOAA website. Other metrics will vary from scene to scene. These include histograms, means, variances, and entropy, before and after resampling. In addition, operators and users may wish to have statistics on latency, number of fill pixels, over-scanned pixels not used, and geometric error in the resampling implementation. Such data could be packaged in a new Block 11 type.

V. Conclusion

This GVAR impact study recommends adaptations of GVAR for the extended mission where image resampling will be employed to remap raw images to the fixed grid before dissemination via GVAR. The objective of providing an extend mission GVAR that may be transparently used by the existing user community is achieved by altering the nuance of meaning for several existing GVAR mnemonics; in particular:

- ISCAN bit 0 will indicate fixed-grid mode enabled, with IMC applied by resampling on the ground (in addition to its usual meaning of "IMC on" in space);

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[21] Block 0 words 71 – 78, mnemonic TINFS, for "normal" priority frames and Block 0 words 63 – 70, for "priority" frames. Block 0 ISCAN encodes the priority for the frame in bits 4 and 5.

- Frame line and pixel corner coordinates, IWFPX, IEFPX, INFLN, and ISFLN, will indicate the corners of the resampled frame rather than those of the frame as scanned in space; and

- Frame time tags TINFS (or TIPFS for "priority" frames) will designate the nominal time tag of the first line in the resampled image rather than the first line of the frame as scanned in space.

Additional information, for those users concerned about precise time tagging or the impact of resampling on the image data, would be provided in spare locations in each Block 0 and an additional Block 11 type. An inventory of the data to be added to GVAR Block 0 is given in Table V-1. Less than half of the available spares bytes need to be harvested for this purpose. Block 11 data would be limited to data appropriate for reporting on a frame-by-frame basis, including metrics quantifying the impact of resampling on the image data.

Many users will only need to use the nominal time tags reported in the usual GVAR locations TCHED and TCTRL (or their lagging and old-lagging counterparts). Other users can have more accurate time tagging by using the time correction coefficients included in each Block 0. The RPM is one such user. The RPM will need to be modified to evaluate the time-tag corrections.

Table V-1. Spare Block 0 Locations Harvested for Extended Mission Use.

Datum	**Bytes**
Resampling enable status flag	1
Horizontal resampling kernel ID	4
Vertical resampling kernel ID	4
Frame corner coordinates as scanned in space	4x4
Frame time tag as scanned in space	8
Time-tag correction coefficients	7x4
Total Bytes Harvested	61