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Remapping GOES Imager Instrument Data for South American Operations, Implementing the XGOHI System

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ABSTRACT

Operational weather forecasting depends critically on the Geostationary Operational Environmental Satellite (GOES) system. The GOES constellation consists of an eastern satellite stationed at 75°W longitude, a western satellite stationed at 135°W longitude, and an Extended GOES High Inclination (XGOHI) satellite stationed at 60°W plus in-orbit spares. Currently, GOES-12 occupies the eastern slot while GOES-11 occupies the western slot. National Oceanic and Atmospheric Administration (NOAA) replaced GOES-10 with GOES-11 as the operational GOES-W satellite in June of 2006. GOES-10 is still functioning well, but has exhausted its north-south station-keeping fuel. GOES-10 completed its eastward drift from longitude 135°W to 60°W in early December 2006 where it will continue to operate as an XGOHI satellite to provide coverage over South America. GOES-10 also served as a backup for the eastern satellite while GOES-12 was temporarily out of service following an in-orbit anomaly in December 2007. Other GOES satellites may also be operated as XGOHI missions when they exhaust their station-keeping fuel, extending their lifetimes and enhancing the return on the public investment in the GOES system. XGOHI is helping protect lives and property in Central and South America by significantly improving satellite detection of severe storms, precipitation, atmospheric motions, volcanic ash clouds, fires and other natural hazards. Without GOES-10 data, and when GOES-East is in a rapid-scan operations mode, large regions of South America only receive GOES imagery every three hours. XGOHI is part of the implementation of the Global Earth Observation System of Systems (GEOSS)-Americas initiative. Repositioning GOES-10 for better satellite coverage over the southern part of the Western Hemisphere was one of the first major activities to take place under GEOSS-Americas.

Implementation of Image Motion Compensation (IMC) via ground processing through resampling is an integral part of the high-inclination mission operations concept. On-board IMC enables the Imager to capture images that are in a "perfect GOES projection" for a fixed point in orbit. GOES operational spacecraft were nominally designed to operate within a 0.5° inclination limit. Their on-board IMC dynamic range saturates at about 2°, limiting the useful lifetimes of GOES spacecraft in that older spacecrafts (with lower fuel reserves) cannot be maintained within the 0.5° inclination limit. To support XGOHI, the GOES ground system was enhanced to accommodate an on-ground IMC implementation operating on IMC OFF data received from the GOES-10 spacecraft.

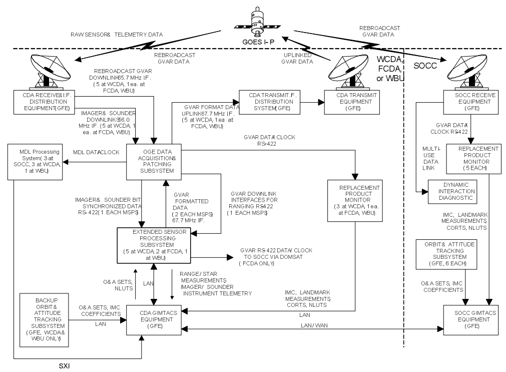
GOES-10 began operating as an XGOHI mission with IMC applied on-ground in early October 2007 shortly after its orbital inclination passed the 2° saturation point. GOES VARiable (GVAR) format adaptations for XGOHI are transparent to the users since spare words are used for XGOHI specific parameters within GVAR. Several resampling methods have been implemented for XGOHI and may be configured according to the needs of the user community. A resampling impact study has been conducted by the Advanced Satellite Products Branch (ASPB) and the Cooperative Institute for Meteorological Satellite Studies (CIMSS) at Space Science and Engineering Center (SSEC) at University of Wisconsin. As of October 2007, XGOHI infrastructure is operational at Wallops Command and Data Acquisition Station (WCDAS) and the Wallops Backup Unit (WBU) at Goddard in Maryland.

INTRODUCTION

The Operations Ground Equipment (OGE) for the Geostationary Operational Environmental Satellite (GOES) spacecraft consists of components located at the National Oceanic and Atmospheric Administration (NOAA) Command and Data Acquisition (CDA) stations (CDAS) at Wallops Island, Virginia and the Satellite Operations Control Center (SOCC) in Suitland, Maryland. The Extended Sensor Processing System (ESPS) is the functional element of the OGE responsible for the real-time ingest and processing of the GOES sensor data producing the GOES Variable (GVAR) data stream. The ESPS also provides input to the orbit and attitude determination function, contained in the Orbit and Attitude Tracking Subsystem (OATS), by performing range measurements, processing Imager and Sounder star sense data, and extracting periodic Image Motion Compensation (IMC) and servo error data for transmission to OATS. The ESPS ingests raw imager and sounder data from the spacecraft via the OGE Data Acquisition and Patching Subsystem (ODAPS) and performs the functions necessary to generate a GVAR-formatted data stream for real-time transmission through the ODAPS back to the GOES spacecraft. The spacecraft, in turn, relays that data to the primary user receiver stations. The block diagram shows the ESPS in relation to the rest of the GOES ground system.

Each GOES satellite views almost a third of the Earth's surface: GOES-East monitors North and South America and most of the Atlantic Ocean, GOES-West monitors North America and the Pacific Ocean basin. GOES-12 or GOES-East is positioned at 75° W longitude and the equator, while GOES-11 or GOES-West is positioned at 135° W longitude and the equator. GOES-E and GOES-W together produce a full-face picture of the Earth, day and night. Coverage extends approximately from 20° W longitude to 165° E longitude. The main mission is carried out by the primary instruments, the Imager and the Sounder. The Imager is a multi-channel instrument that senses radiant energy and reflected solar energy from the Earth's surface and atmosphere. The Sounder provides data to determine the vertical temperature and moisture profile of the atmosphere, surface and cloud top temperatures, and ozone distribution.

Now GOES-East and GOES-West have been joined by GOES-10 which is operated at 60°W as a high-inclination mission to provide coverage over South America. Continuous operation of GOES-10 in a high inclination mode using a new ground-based motion compensation capability is dramatically improving the quantity and quality of data available to Latin/South American partners for improving weather forecasts, improving coverage of natural disasters, and improving energy and water resource management. Other GOES satellites may also be operated in high-inclination missions when they exhaust their station-keeping fuel, extending their lifetimes and potentially mitigating the risk if there are delays in the implementation of other GOES satellites.

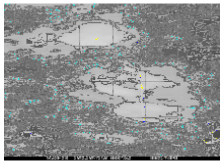


HIGH INCLINATION MISSION OPERATIONS CONCEPT

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 with on-board IMC. Resampling is not new to meteorological satellite systems. It has been employed on the European geostationary METEOrological SATellite (METEOSAT) and METEOSAT Second Generation (MSG) for many years and resampling is also part of the Japanese Multi-functional Transport Satellite (MTSAT) program.

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 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. 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.

During one orbit, the satellite position drifts north and south of the equator depending on time of day relative to the nodal crossing as shown in the figure to the right. The resulting images would appear to "wobble" without any compensation. On-ground IMC compensates for this wobble for the Imager through resampling. The Sounder data are not resampled as the Sounder is normally operated in dynamic-gridding mode.

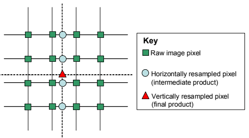


The figure to the left shows two extremes of coverage during an orbital cycle when the inclination is 3°. Coverage is lost at the top and bottom when the earth appears to nod towards and away from the satellite; however, South America remains within the area of prime coverage: Earth Central Angle (ECA) < 60°. Landmark sites for operational navigation are shown as red dots.

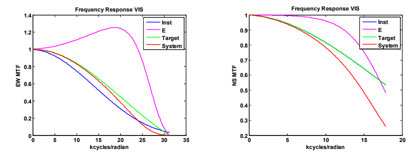
XGOHI GVAR includes several adaptations to document the resampling processing (Table). Spare Block 0 words have been harvested for this purpose.

When resampling is "on", the kernel suite ID informs the users about the resampling method in effect for each channel. The interested user will find information on each defined suite ID on the GEOSS-Americas website: http://www.ssd.noaa.gov/PS/SATS/GOES/TEN/. XGOHI GVAR includes time-tag correction coefficients for users who care about precise time keeping. This is necessary because the resampled data in GVAR Blocks 1 to 10 that follow each Block 0 are constructed from multiple scan lines. Time-tag imprecision can be reduced from as much as a minute without correction to less than five seconds when the time-tag correction coefficients are used as described in the XGOHI GVAR documentation found on the GEOSS-Americas website. Many users will not need to be concerned with any of the XGOHI GVAR adaptations and may continue to use GVAR from XGOHI interchangeably with GVAR from an non-XGOHI satellite.

The ESPS allows the flexibility to select the resampling order from Nearest-Neighbor (NN) to 4-point bicubic and up to 32-point kernels. The horizontal and vertical resampling kernels can be selected independently for each channel as shown in the figure to the right.



A resampling kernel has been defined so as to provide a familiar product to the user community. Resampling for those channels of most interest for fire applications (IR2 and IR4) has been optimized for point-like fire scenes. Resampling for IR5 has been similarly designed because it is often used in conjunction with IR4. Resampling for VIS and IR3 has been optimized for meteorological scenes with power-law Power Spectral Density (PSD) functions. All kernels have been designed using a Wiener Filter methodology that attempts to match the resampled image to the output of the system to that of an instrument with a given "Target" Modulation Transfer Function (MTF). Kernel ID=00 selects the Imager itself for the target except in the East-West direction for VIS and IR2 where over-sampling encourages some sharpening. Sensor noise limits our ability to achieve the target.

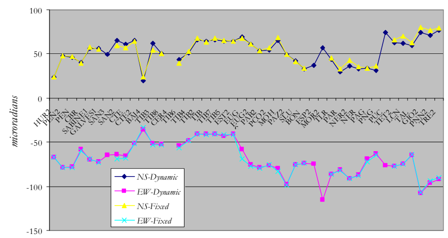


SYSTEM ARCHITECTURE

The core components of ESPS are the GOES Ingest Unit (GIU), GOES reSampling Unit (GSU) and the GOES Ranging Unit (GRU), which primarily function as a real-time front-end for the ESPS. The GIU and GRU perform data ingest, calibration, and GVAR output formatting functions for both the Imager and Sounder instruments, while the GSU provides on-ground image motion compensation for the imager sensor data. The GVAR formatted processed data is up-linked by the GRU to the satellite. Ranging is also accomplished in the GRU through timing comparison of up-linked and down-linked GVAR streams. The ESPS allows IMC to be applied on the ground through resampling within the GSU. Resampling is driven by the Orbit and Attitude (O&A) data sent to the ESPS by the Orbit and Attitude Tracking System (OATS).

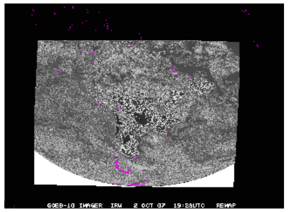
INR VERIFICATION

INR performance for an XGOHI satellite is no different than that of a non-XGOHI satellite. There is even a benefit in that residual VIS-IR and IR-IR channel-to-channel alignment errors that are present in non-XGOHI multi-spectral imagery can be compensated by resampling. A test was conducted to prove that INR performance would not be degraded by resampling. The ESPS was setup to resample recorded GOES-10 data and residual navigation error with respect to the fixed grid was measured with the Replacement Product Monitor (RPM). These results are indistinguishable from the navigation error measured with the RPM relative to a dynamic grid (measured minus predicted landmark coordinates before resampling).



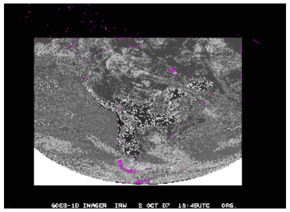
GOES-10 RESAMPLED DATA INDEPENDENT VERIFICATION

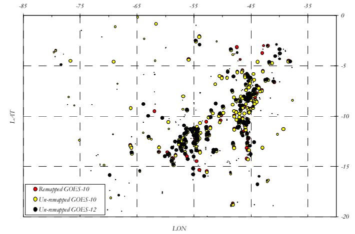
A resampling impact study was conducted by University of Wisconsin/Space and Science Engineering Center (SSEC) to investigate the effects of remapping on GOES products including fire pixels. The study included an analysis of XGOHI GVAR data, with comparisons of products produced by remapped and un-remapped GVAR data. Preliminary discussions indicated a need to focus on fire pixels and volcanic ash, though the study was not explicitly limited to these products. The study compared GOES-10 remapped data to GOES-10 un-remapped data as well as to GOES-12 un-remapped data.



GOES-10 un-remapped Imager data recorded on October 2nd 2007

GOES-10 remapped Imager data recorded on October 2nd 2007. As seen from the remapped image to the right, excellent navigation is achieved with remapped data.



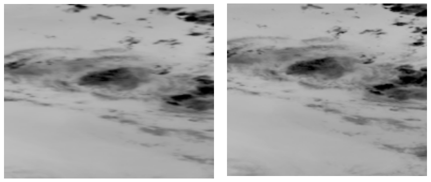


This figure shows the remapping impact on fires centered on Brazil by comparing remapped GOES-10 Imager data to un-remapped GOES-10 and un-remapped GOES-12 Imager data, respectively. As seen from this comparison, the majority of the fire signatures are preserved

IR3 CHANNEL WITH SHARPENING

Hot is bright and cold is dark

Remapped (sharpened) GOES-10 | **Un-remapped GOES-10**



CONCLUSIONS

We have investigated the implementation of Image Motion Compensation (IMC) on the ground through resampling with the objective to provide the same level of Image Navigation and Registration (INR) performance that is achieved with on-board IMC. As part of the XGOHI mission, the GOES ground system was modified to accommodate on-ground IMC through resampling GOES-10 data. As of October 2007, the XGOHI system has transitioned into operations at Wallops Command and Data Acquisition Station (WCDAS) and the Wallops Backup Unit (WBU) at Goddard in Maryland providing resampled GOES-10 GVAR data to the South American as well as other countries.

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