The GOCE Calibration and Monitoring Facility (CMF)

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3rd GOCE User Workshop, ESA ESRIN, November 6-8, 2006
q The Calibration and Monitoring Facility: What, Why, Who
q Situation of the CMF within the Ground Segment
q Definition of the Toolboxes: how they work, what they produce
q Monitoring Functions: EGG, In-flight Cal, SSTI and DFACS monitoring

q Conclusions
The CMF: A top level view

- The CMF ...
  - Is responsible for the monitoring of the GOCE space segment (platform + payload)
  - Verifies the quality of the PDS calibration products
  - Evaluates the reliability of alternative calibrations
  - Supports corrective actions to improve the nominal (PDS) calibration

- The CMF belongs to the GOCE ground segment

- Following an Open Tender, the CMF was awarded to a consortium lead by DEIMOS Space
Within the CMF, DEIMOS Space is prime contractor, having as main subcontractor ACS and with SRON and IAPG for the specification of algorithms.
CMF Mission Management Core Ground Segment
The CMF as a facility in the Ground Segment

Core Ground Segment:

- **Flight Operation Segment (FOS)** in charge of mission planning, command and control of the platform
- **Payload Data Ground Segment (PDGS)** in charge of the generation, monitoring, distribution and archive of the L0 and L1b data. These tasks are dealt with the PDS, LTA, MUS and PMF facilities
- **High Level Processing Facility (HPF)** is in charge of the generation of L2 to be submitted to PDGS

Mission Management:

- **Reference Planning Facility (RPF)**: in charge of some planning activities (e.g. DFACS 10Hz recording) plus on-ground and on-board configuration parameters
- **Calibration and Monitoring (CMF)** in charge of assessing the quality of the L1b products and calibration. The CMF ingests mainly data from PDS (a part of PDGS) although it processes also L2 products provided by HPF
The CMF facility exploded (1/2)
The CMF facility exploded (2/2)

- **I/F Infrastructure**, which interfaces with external facilities for ingestion of products and distribution of CMF products. It is also responsible of the inventory and archiving of input products and CMF products.

- **Monitoring Infrastructure**, which provides the means for the routine and interactive monitoring. It triggers the different toolboxes and publishes the outputs in a Web Sever (or by e-mail).

- **Toolboxes**, which are the MATLAB functions that encompass the actual monitoring of nominal and calibration products.

- **In-flight CFI**, in charge of a parallel/alternative calibration of the space segment (ESA provided).

- Interface with **IPF1 Stand-alone**, which shall be used for testing purposes, and for generating specific products for the In-flight CFI as well.

- Interface with **E2E Simulator**, to be used for simulating specific cases.

- **The Operator**, who shall be responsible of the CMF operations.

- **The users**, who will make use of the CMF Toolboxes.
The CMF I/F Infrastructure has been built reusing PDS facilities and adding a new specific module (Archive and Inventory API’s) in order to integrate I/F Infrastructure with the SW Infrastructure.

The DGF facility implements the CMF interface with external entities, allowing data transfer via network or media.

The CMF Storage, as well as in the PDS, is composed by two main facilities namely the SDF (a DBMS acting as online archive) and the ARF.

A dedicated API has been implemented to allow the Monitoring Infrastructure to access the CMF Archive and Inventory:

- to perform a query on CMF I/F database in order to retrieve the information about the data stored in it,
- to download files from CMF I/F archive system into user directory,
- to upload files into CMF I/F inventory and archive system.

The CMF I/F Infrastructure is highly configurable and plug-in based.
The kernel of a toolbox is based on Matlab code aimed for evaluating the status and behavior of the GOCE payload and platform.

When designing the toolboxes the focus is put on quick problem detection more than on complex algorithms.

Problems detected automatically by the system can be analyzed in more detail by the CMF Users using the interactive execution of toolboxes.

When designing or implementing a toolbox one of the main objectives is to keep as much as possible decoupled the algorithm from the input/output handling.

Toolboxes are configured by means of a dedicated HMI:

- Input products and triggering conditions
- Algorithm configuration parameters (e.g. thresholds)
- Output products or Reports

In addition to the specific report generated by Toolboxes, there are a number of “generic” reports to assess the overall system behaviour.
The configuration of a Toolbox: I/O
How a Toolbox is run

Toolbox Selection

Toolbox Name: SST_ORB_TE

Configuration File

Version: 3
Location: User

SW

Version: 1
Location: User

Execution Type

Interactivity: Interactive

Sub-mode

Stop: 2007-07-16T23:41:50.000000

File Type | Level | File Class
----------|-------|---------
SST NOM 1b | main | CONS
EGG NOM 1b | secondary | CONS

Output File Class: CONS

Ok  Cancel  Start Matlab  Help
Toolboxes and the execution type

- **Manual (or interactive):** Launch the toolbox, ingest the necessary data, but without running the associated algorithm.

- **Semi-automatic:** Similar to the manual type, executing the algorithm but leaving the Matlab session open (we can interact too with the outputs).

- **Automatic (or Batch):** Do everything without the interaction of the user.
Batch vs. Interactive runs

Batch uses a scheduler, and a broadcasting system.

Interactive shows Matlab console.
A typical (user-defined) report for a toolbox

Toolbox that did the report

Overview

List of contents: click & go

Hereby the plots (and everything else)
and hereby a product made with a toolbox

**QI:** What happened, broadly speaking, in this run?

These are the datasets (or "CMF products")
The Electrostatic Gravity Gradiometer (EGG) is the key instrument of GOCE for measuring gravity gradients. It is based on 6 accelerometers (or “proof masses”) distributed in three perpendicular axes. Each axis contains two devices within a nominal distance of 0.5 m. The measurements are located in 3D using GPS signals.
EGG toolboxes (1/3)

q EGG toolboxes use a combination of EGG, DFACS and / or STR signals. There is also cross-talk between some toolboxes

q **EGG_ANM_TB**: Anomalous behavior. This function checks the EGG voltages and DFACS linear accelerations against fixed thresholds. Besides saturation detection, mean, standard deviation and a power spectral density are evaluated for those products

q **EGG_OAO_TB**: Check for outliers and offsets. Here the EGG signatures are assumed properly represented by a trigonometric fit. Anything “too far” from the mean value is flagged as outlier. Offsets are looked for in those outlier regions where the residues (signal vs. fit) show a significant departure from the mean residue

q **EGG_CON_TB**: Consistency checks between accelerometers. Here the redundant voltages and accelerations from EGG and DFACS are compared for consistency accelerometer-by-accelerometer. Other tests consist of checking (against a threshold) the different accelerations measured by accelerometers on an axis-by-axis basis
EGG toolboxes (2/3)

- **EGG_COR_TB**: Correlation with H/K data. The EGG voltages from the accelerometers are correlated with the temperature changes. Note that the changes in the temperature are considered only important if its first derivative crosses an a-priori threshold.

- **EGG_GGT_TB**: Checks if the measured gravity tensor has a trace = zero (as it shall happen in theory). Furthermore, a power spectral density of the trace is evaluated to see its stability along the mission.

- **EGG_GAP_TB**: Geolocation of the data gaps. The function reads the datagaps available on the EGG_NOM product. With the time-tag and some generic tools (e.g., a predicted orbit file), the datagaps are geolocated and projected into a geographical map for further study.

- **In flight Calibration**: verification/validation of the measured calibration elements (quadratic factors, scale factors, misalignments and coupling).

- **EGG_K2F_TB**: Validation of Quadratic Factors. This function evaluates the K2 factors derived with DFACS accelerations, against thresholds. The PDS initial values are declared valid or invalid afterwards.
q **EGG_K2F2_TBG**: Validation of Quadratic Factors after adjustment. After verifying the absence of anomalies, gaps, outliers and offsets in the linear accelerations for DFACS used for the K2 determination, it compares the re-measured values with the expected improvements of the K2 after the first measurement and adjustment. In addition, the gravity tensor trace is also re-calculated.

q **EGG_ICM_TBG**: Inverse Calibration Matrix Validation (GOCE “shaking”). It checks if the Inverse Calibration Matrix elements are within limits. Then, it compares the GGT trace from the IPF1 Nominal Stand-Alone processor after the ICM application with the trace before the ICM application and with the trace expected.
An alternative in-flight calibration is performed by a SW developed by ESA.

The In-flight alternative SW will be outside the CMF system:
- the CMF provides the necessary inputs,
- and gets the output produced.

The CMF analyses the Inverse Calibration Matrix coming from both the PDS and the alternative SW.

Based on the analysis performed, a selected Inverse Calibration Matrix is sent to the PDS.
The Satellite to Satellite Tracker Instrument (SSTI) is intended to locate EGG data with high precision. It is essentially a GPS receiver.

Main products include: {CA-L1 P-L1 P-L2} pseudorange and {L1 L2} carrier phase (for L1= 1575.42 MHz, L2=1227.60 MHz)

Secondary products include: GOCE Position, velocity, clock correction both on-board (NAV) and on-ground (PVT) types.
SSTI toolboxes (1/2)

- **SST_GAP_TB**: Consistency among raw pseudorange and code and the receiver signal status SSTI product. Temporal gaps are flagged if consecutive times define intervals > 1 s. Eventually, this function produces azimuth / elevation maps for all the GPS (at GRF reference).

- **SST_MWU_TB**: The Melbourne-Wubbena linear combination is used to check the existence of cycle slips and outliers (looking for jumps above thresholds with consecutive measurements). MW is calculated with IFB corrected phases and raw pseudorange.

- **SST_CNS_TB**: A ionosphere-free linear combination is made with IFB corrected phases and ICB corrected code. An “LP” combination is build so that residues, mean values, etc. are calculated. Residues (mean subtracted) are evaluated as a function of the GPS azimuth / elevation.

- **SST_CAL_TB**: Calibration parameters are considered here in terms of two corrections, namely ICB and IFB. The PDS raw code and phase are compared with the PDS IFB and ICB corrected products. For the IFB corrected – uncorrected shall be similar to the IFB correction available in SST_IFB_1b. A similar test “raw-corrected” is applied for testing the ICB values (nominal values are in AUX_ICB_1b).
SSTI toolboxes (1/2)

- SST_SNR_TB: Here the SSTI PDS values for SNR (known also as the log of “C/No”) are studied in terms of GPS-azimuth / elevation.

- SST_HKH_TB: Health of SSTI using SSTI (PDS) parameters like receiver status, data validity, channel status, etc. The parameters are transformed into binary counterparts, producing a diagnostic / report as a function of which bytes are equal to 1 or 0.

- SST_ORB_TB: This function tests the quality of the PDS orbital information comparing the on-board NAV orbit with the PVT on-ground and the L2 HPF GOCE orbit. The comparison is done in the ITRF (or ECEF) system as well as the IRF (or ECI) system. In addition, with the use of L2 quaternions, an attitude profile (Euler angles) is calculated. Warnings are raised if the differences are above user-defined thresholds.

- SST_CLK_TB: Quality of the receiver’s clock correction. This function calculates a receiver’s clock correction in order to compare it with the PDS PVT clock correction.
The SSTI toolboxes are based on SSTI data and, as with other instruments, some toolboxes use products from other sources (DFACS, ...)

There is also cross-talk between toolboxes
The Drag-Free Attitude Control System (DFACS) is a combination of instruments and sub-systems. Its aim is to keep GOCE in free-fall

**§ Xe-ion engine**: main system (also known as ITA) based on Xe ions. It has two main flows, one is constant and the other variable (total thrust $\approx 10$ mN) to better adapt to the atmospheric drag

**§ N2-cold (8) gas thrusters**: these thrusters ($\approx 0.6$ mN) switch on/off when necessary. They are identified also as the Gradio Calibration Device (GCD) because these can “shake” GOCE

**§ Star Trackers (3)**: They are in charge of attitude pointing ($\varepsilon \approx \text{arcsec}$) looking at stars (say 20-100 simultaneously)

**§ Digital Sun Sensor (DSS)**: It provides the Sun position ($\varepsilon \approx 0.02$ deg) with respect to the GOCE platform

**§ Coarse Earth Sun Sensor (CESS)**: This device is intended for coarse pointing, so that it is calculated a rough guess ($\varepsilon \approx 10$ deg) for the position of the Earth (nadir pointing) and the Sun respect to GOCE

**§ Magnetic field and magnetic torque measurements**
Contrary to, e.g., the SSTI, the DFACS functions do not have cross-talk. However, they also rely on data from other instruments (EGG, SSTI, …)

- **DFC_ANM_TB**: It checks the overall DFACS performance. Linear and angular accelerations and angular rates are compared against thresholds. To evaluate the goodness of the DFACS corrections, using the SSTI PVT solution an estimation of the instantaneous semi-major axis is made. This axis is monitored in time so that the stability of the orbit can be evaluated.

- **DFC_COM_TB**: Evaluates the change of the Center of Mass. Using AUX_NOM_1b data for the N2 and Xe thrusters, the change of mass is calculated. For Xe the change of mass is directly measured. However, for N2 is evaluated with look-up tables of the N2 density as a function of the tank temperature and pressure. The drift of COM is calculated subtracting consecutive calculations.

- **DFC_IPA_TB**: Checks the performance of the Xe-ion main engine. Here AUX_NOM_1b parameters like thrust, voltages, currents, etc. are compared against thresholds. Mean and standard deviations are also tested.
**DFC_STR_TB**: Here the star trackers, DSS and CESS instruments are monitored for evaluating the GOCE attitude performances. The STR variables (e.g. number of stars or presence of the moon within STR FOV) are checked against thresholds. DSS and CESS data are also checked to see if there are within the expected boundaries.

**DFC_GCD_TB**: It checks the behavior of each individual cold gas thruster respect the expected nominal values of thrust. The DFACS accelerations are transformed into forces. The EGG angular acceleration and angular rate are transformed into torque. Then, torque and force are related to thrust with a “mounting matrix” (an instrumental property).
It has been shown an overall description of the Calibration Monitoring Facility for GOCE.

The CMF main aim is to evaluate the performance of the payload.

The monitoring is based on (Matlab) toolboxes that rely on algorithms targeting quick and reasonable accurate evaluations.

There has been presented a brief description of the toolboxes for EEG, SSTI and DFACS instruments.

The system can run unattended, based on automatic execution of toolboxes and report publishing in a web server.

The CMF users are supported by the system for performing more detailed analysis (interactive execution of toolboxes).

It is also possible to monitor the long-term evolution (e.g., weekly, monthly) of selected GOCE parameters.

The system has been designed so that there is freedom for including new toolboxes if necessary.