

Swarm accelerometer data: temperature dependence and GPS-based calibration

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Swarm A/C: deep orbit resonance

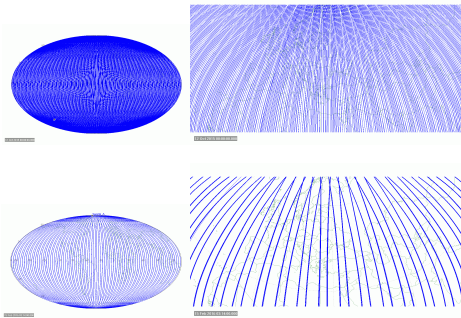
Passage through 46:3 resonance in Feb 2016

Upper figures: typical ground tracks in a month

Lower figures: **sparse coverage** due to deep orbital resonance (Feb 2016)

Next deep orbital resonances:

- 77:5 at 422.7 km in 2020
- 31:2 at 393.2 km well beyond 2020



Linear temperature correction (LTC)

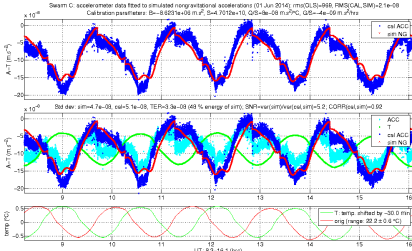
SIM-validation of accelerometer (ACC) data

Validation by means of simulated NG signal

$$\text{UNCAL} = \mathbf{B} + \mathbf{S} \times \text{SIM} + \mathbf{Q} \times \mathbf{T}(\mathbf{t} + \mathbf{F}) + \mathbf{G} \times (\mathbf{t} - \mathbf{t}_0) + \varepsilon$$

$$\text{CAL} = [\text{UNCAL} - \mathbf{B} - \mathbf{Q} \times \mathbf{T}(\mathbf{t} + \mathbf{F}) - \mathbf{G} \times (\mathbf{t} - \mathbf{t}_0)] / \mathbf{S}$$

- **UNCAL**..uncalibrated ACC data; **B**..bias;
- **S**..scale factor; **SIM**..modelled NG signal;
- **Q**..temperature factor; **T(t+F)**..temperature with phase shift **F**; **t**..time; **G**×(t−t₀)..trend; **ε**..noise
- **CAL**..calibrated ACC signal
- **Linear temperature correction: LTC=Q×T(t+F)**
- Local reference frame: along-track (A-T); cross-track (C-T); radial (RAD) directions

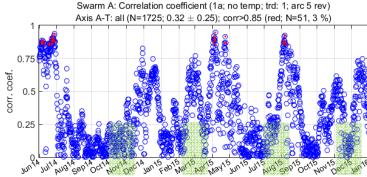


- **SIM-validated arcs** (blocks) are defined: good agreement of (un)corrected ACC waveform with physical nongravitational (NG) signal.
- Reasons for an arc not to be SIM-validated:
 - (1) arcs with substantial ACC anomalies (steps, jumps, spikes, ...)
 - (2) arcs with important temperature dependence (Swarm A/B, Swarm C less)

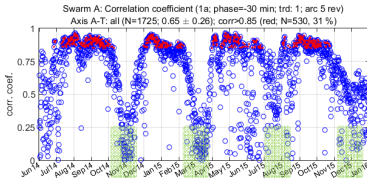
Effect of LTC on A-T component

- ACC data with no temperature correction do not correspond well to physical NG signal.
- Correlation of temperature corrected ACC data with NG is improved substantially.
- **Increase in #SIM-validated blocks by LTC.**

Swarm A – LTC off:



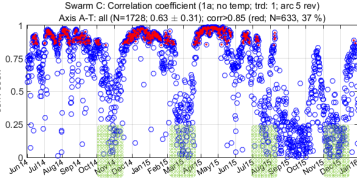
Swarm A – LTC on:



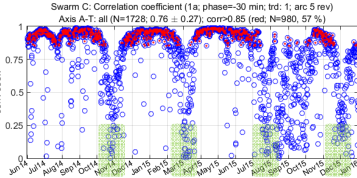
Anomalous periods in ACC data

- ESA: problematic 3-week period in Oct–Nov 2014: large number of steps, impossible to correct reliably; the net effect close zero.
- Originally, this issue concerned A-T data of Swarm C covering period Jun–Dec 2014
- Application of LTC to ACC data of Swarm A → both Swarm A and Swarm C experienced similar problems in the same periods!
- Taking 1.5 yr of ACC data for Swarm A/C → **correlation between the anomalous periods and the minima in AC component of the signal measured by ACC instrument.**

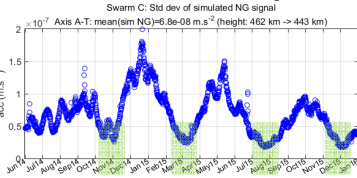
Swarm C – LTC off:



Swarm C – LTC on:



Swarm C – STD of sim NG signal:



GPS-based calibration of ACC data

Acceleration approach: ASU version

- GPS positions **r** with constant time step → numerical second derivative: $d^2\mathbf{r}/dt^2 \approx \mathbf{a}^{(\text{GPS})}$
- Newton's second law: $d^2\mathbf{r}/dt^2 = \mathbf{a}_{\text{geop}} + \text{other acc.}$
- $\mathbf{a}_{\text{geop}}(\mathbf{r}) \equiv \sum \mathbf{G} \times \nabla \text{SSH}(\mathbf{r}, \theta, \varphi) \dots$ geopotential

Assume the geopotential is known and define **GPS-based NG accelerations**

$$\mathbf{a}_{\text{NG}}^{(\text{GPS})} = \mathbf{a}^{(\text{GPS})} - (\mathbf{a}_{\text{geop}} + \mathbf{a}_{\text{LS}} + \mathbf{a}_{\text{TID}} + \mathbf{a}_{\text{REL}})$$

where **a_{LS}**, **a_{TID}**, **a_{REL}** ... lunisolar, tides, relativity

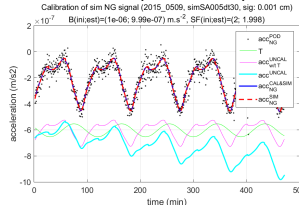
$$\mathbf{a}_{\text{NG}}^{(\text{GPS})} = \mathbf{B} + \mathbf{S} \cdot \mathbf{a}_{\text{ACC}}^{(\text{UNCAL})} + \varepsilon \quad (*)$$

Calibration parameters **B/S** for ACC are obtained by solving **linear system (*)**.

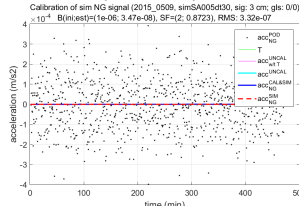
Problem: Numerical derivative amplifies noise in GPS positions. Solution: Generalized least squares (GLS) → linear transformation of (*)

Simulated data

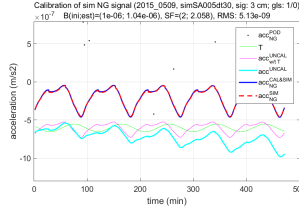
• GPS noise 0.01 mm (unrealistic):



• GPS noise 3 cm (≈realistic):

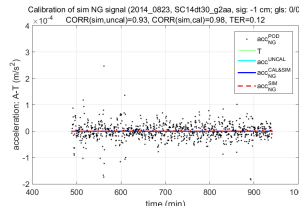


• Zooming to see the ACC/NG signal:

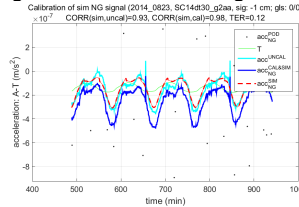


Real Swarm data

• GPS-based NG acceleration:



• Zooming to see the ACC/NG signal:



Acknowledgments

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