Swarm accelerometer data: temperature dependence and GPS-based calibration

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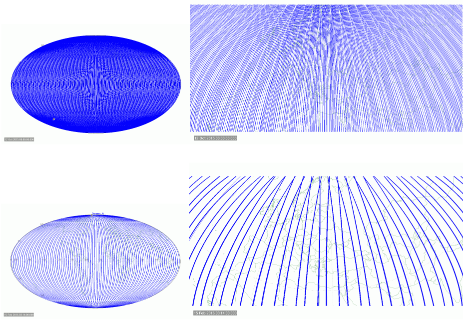
Swarm A/C: deep orbit resonance

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)

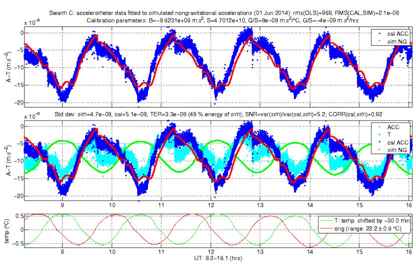
SIM-validation of accelerometer (ACC) data

Validation by means of simulated NG signal

UNCAL = **B** + **S**×**SIM** + **Q**×**T(t+F)** + **G**×(t–t_0) + ε

CAL= [**UNCAL** – **B** – **Q**×**T(t+F)** – **G**×(t–t_0)]/**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–t_0)..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

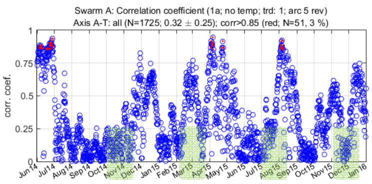


- SIM-validated arcs (blocks) are defined: good agreement of (un)corrected ACC waveform with physical nongravitational (NG) signal.
- Reasons for an arc not to be SIM-validated:
  (1) arcs with substantial ACC anomalies (steps, jumps, spikes, …)
  (2) arcs with important temperature dependence (Swarm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

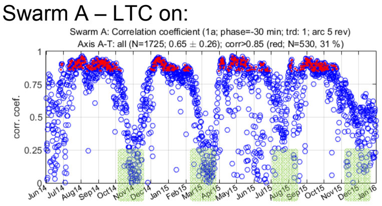
Effect of LTC on A-T component

- 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:



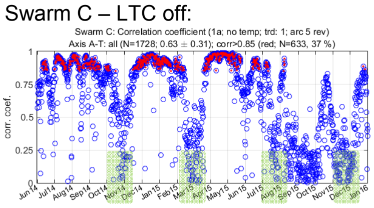
- Swarm A – LTC on:



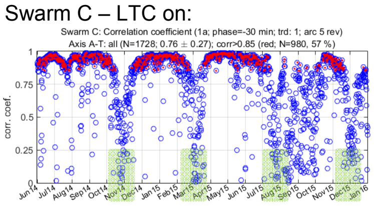
Anomalous periods in ACC data

- 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.

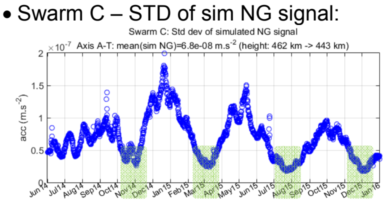
- Swarm C – LTC off:



- 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: $d^2\mathbf{r}/dt^2 \approx \mathbf{a}^{(GPS)}$

Newton's second law: $d^2\mathbf{r}/dt^2 = \mathbf{a}_{geop}$ + other acc.

$\mathbf{a}_{geop}(\mathbf{r}) \equiv \sum$ GC× ∇SSH(r,θ,φ) … geopotential

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

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

where $\mathbf{a}_{LS}$, $\mathbf{a}_{TID}$, $\mathbf{a}_{REL}$ … lunisolar, tides, relativity

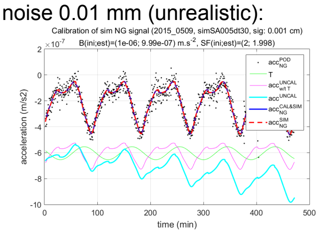
- $\mathbf{a}_{NG}^{(GPS)} = \mathbf{B} + \mathbf{S}.\mathbf{a}_{ACC}^{(UNCAL)} + \boldsymbol{\varepsilon}$ (∗)

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

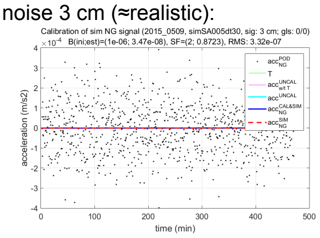
Problem: Numerical derivative amplifies noise in GPS positions. Solution: Generalized least squares (GLS) → linear transformation of (∗)

Simulated data

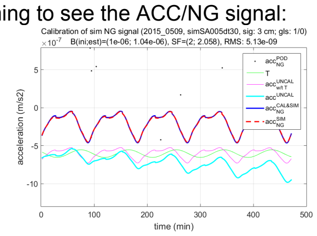
- GPS noise 0.01 mm (unrealistic):



- GPS noise 3 cm (≈realistic):

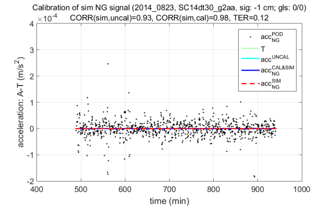


- Zooming to see the ACC/NG signal:

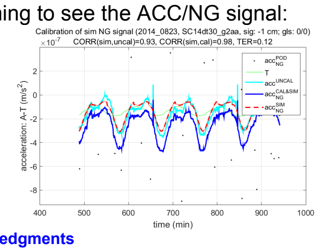


Real Swarm data

- GPS-based NG acceleration:



- Zooming to see the ACC/NG signal:



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