Reduction of temperature dependence in Swarm ACC data by means of modelled nongravitational forces

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Motivation: Swarm ACC data show temperature dependence

Physical **nongravitational (NG) signal**
- sum of atmospheric drag + radiation
- characteristic steps at crossing the Earth shadow boundary (terminator)

**ACC data of Swarm C**
- waveform of NG signal can be recognized, especially terminator crossings (in yellow)

**ACC data of Swarm A/B**
- very large temperature dependence
- temperature variation dominates
- terminator crossings discernible by signal perturbations
- **Is it possible to obtain NG signal?**
NG signal measured by ACC’s of previous missions

- Space ACC aboard Champ, Grace A/B, Goce
- NG signal of Grace A/B is most similar to Swarm (shape, mass, altitude→ similar drag & radiation)

General experience with ACC of previous missions
- Level 1B ACC data need calibration
- Modelled NG signal is smoothed version of ACC data
- Shown graphs are typical for agreement between waveforms of ACC data and modelled NG signal
Approximate calibration of ACC data on modelled NG signal

\[
\text{UNCAL} = B + S \times \text{SIM} + Q \times T(t+F) + G \times (t-t_0) + \epsilon
\]

\[
\text{CAL} = [\text{UNCAL} - B - Q \times T(t+F) - G \times (t-t_0)]/S
\]

- \text{UNCAL}..uncalibrated ACC data; \text{B}..bias; \text{S}..scale factor; \text{SIM}..modelled NG signal;
- \text{Q}..temperature factor; \text{T}(t+F)..temperature with phase shift \text{F}; t..time; \text{G} \times (t-t_0)..trend; \epsilon..noise
- \text{CAL}..calibrated ACC signal
  - pair of equations for each linear ACC channel (A-T; C-T; RAD)

Swarm C (2 Dec 2013)
- \text{T}(t+F): F=-30 \text{ min}
- \text{SNR}=6 (match CAL&SIM)
- \text{CORR}=0.93
- \text{TER}=7\% (energy temp. \text{T} vs. energy SIM)

If CORR & SNR good:
  → waveform of CAL validated by SIM
  → TER quantifies \text{T} contribution
Reduction of temperature signal from ACC data (Swarm A)

Swarm A (2 Dec 2013)
- no temperature in the fit
- SNR = 0.071 (match CAL & SIM)
- CORR = 0.084

Swarm A (2 Dec 2013)
- temperature included
  - $T(t+F)$: $F = -30$ min
  - SNR = 2.6
  - CORR = 0.85
  - TER = 169% (energy temp. $T$ vs. energy SIM)
Insolation of Swarm satellites

- Studied 3-month period: 12/2013–02/2014
- \( \beta \): angle between satellite's orbital plane and the Sun
- Different insolation regimes
  - \( \beta = 27^\circ \): Swarm enters Earth’s shadow
  - \( \beta = 0^\circ \): orbital plane contains subsolar point (≈20 Dec)
    - no CT-component of direct solar radiation
  - \( \beta = -70^\circ \): Swarm satellites are in full sun (≥11 Feb)

- Studied 3-month period: 12/2013–02/2014
- 52 orbital segments for each satellite
- Segment: 6-hrs long (≈ 4 revolutions)
- Phase of temperature: F=-30 min (≈ 1/3 orbit)
- Results mainly for A-T component of ACC
  - similar calibration results for C-T and RAD

- Insolation:
  - entering shadow: 1 Dec 2013 – 10 Feb 2014
  - full sun: 11 Feb – 28 Feb 2014

- Temperature on ACC
  - heaters switched on: 16–30 Jan 2014
Longterm behaviour of calibration statistics: December 2013

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- Studied 3-month period: 12/2013–02/2014
- In **Dec 2013**: ACC data of **Swarm A/B** display **large temperature dependence**
- Results shown in figures for Swarm A (2 Dec 2013) are confirmed by overall statistics.
- Temperature is **not** in the fit for Swarm A/B → **very low CORR and SNR**
- Temperature is taken into account for Swarm A/B → **acceptable values of CORR and SNR**
- **Temperature is not dominant for Swarm C** during the whole studied period
Heaters aboard Swarm A/B help to reduce temp. dependence

Onboard ACC heaters switched on: 16–30 Jan 2014

TER = temperature-energy-ratio = energy(T)/energy(SIM)
- TER=0 %..temperature T not contributing to CAL
- TER=100 %..temperature has the same power as SIM

On average, TER=17 % for ACC data of Swarm C (A-T)
→ i.e. small, but not negligible contribution of temperature

Heating ACC of Swarm A/B resulted in a considerable reduction in the temperature dependence!
→ TER for ACC of Swarm A/B dropped to Swarm C values

After 11 Feb 2014, another cause of ACC temperature increase is that satellites are in full sun
- Insolation has 4.5-month half-period
→ TBD: optimum combination of heating ACC & insolation
Beta angle zero: no solar radiation in C-T component of ACC

$\beta=0^\circ$
- subsolar point is in orbital plane
- no cross-track component of direct solar radiation
- around 20 Dec 2013

Figs: ACC data (C-T)

Swarm A
- SNR=11 (match CAL&SIM)
- CORR=0.96
- TER= 16% (energy T vs. SIM)

Swarm B
- SNR=7.5 (match CAL&SIM)
- CORR=0.94
- TER= 1% (energy T vs. SIM)
Summary

- ACC data of Swarm A/B satellites display large temperature dependence.
- ACC data of Swarm C have small, still not negligible temperature dependence.

- Using modelled NG forces, this temperature dependence can be reduced from ACC data:
  - after temperature reduction, waveform of ACC data is validated using NG models;
  - such validated ACC data can enter the Level-2 calibration algorithm.

- Procedure of reducing the temperature is applicable to all three linear ACC channels.

- Using ACC heaters aboard Swarm A/B reduced considerably temperature dependence.

- Temperature dependence of Swarm ACC data is linked to the satellites’ insolation.
  - Possible study: optimum combination of heating ACC & insolation conditions

- Validation model can be improved (dependence on mean temperature, etc.).

Thank you for your attention