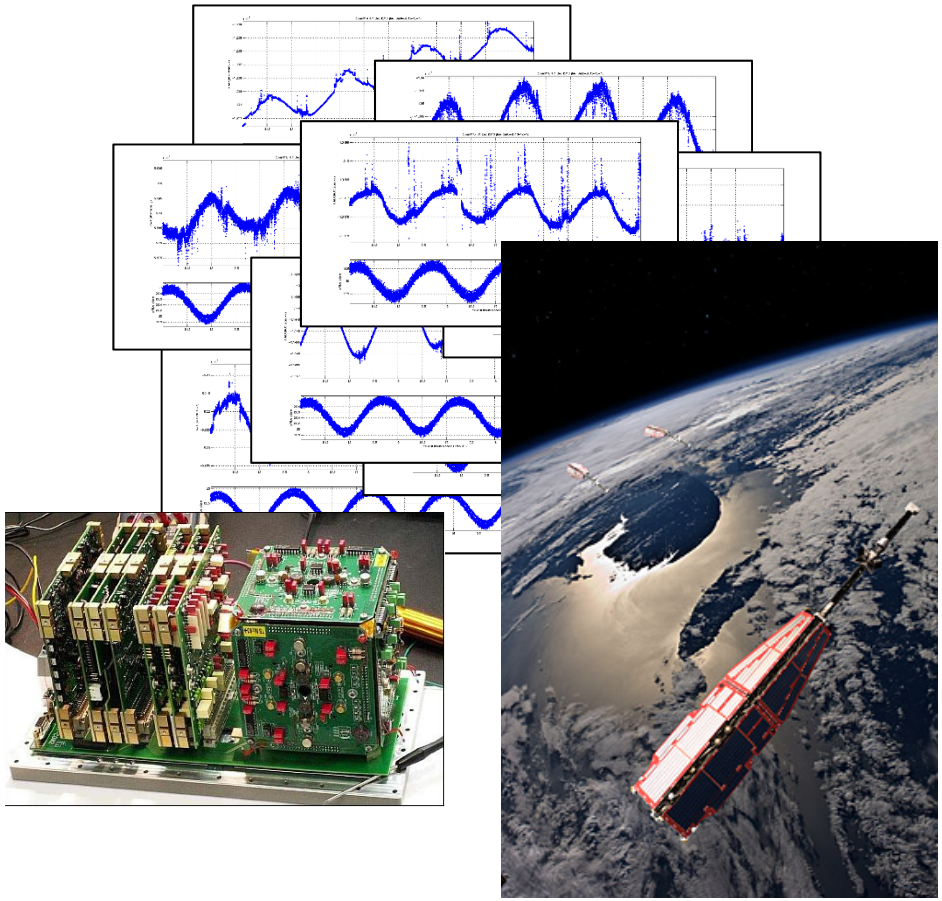
Reduction of temperature dependence in Swarm ACC data by means of modelled nongravitational forces



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Motivation: Swarm ACC data show temperature dependence

Physical **nongravitational (NG) signal**

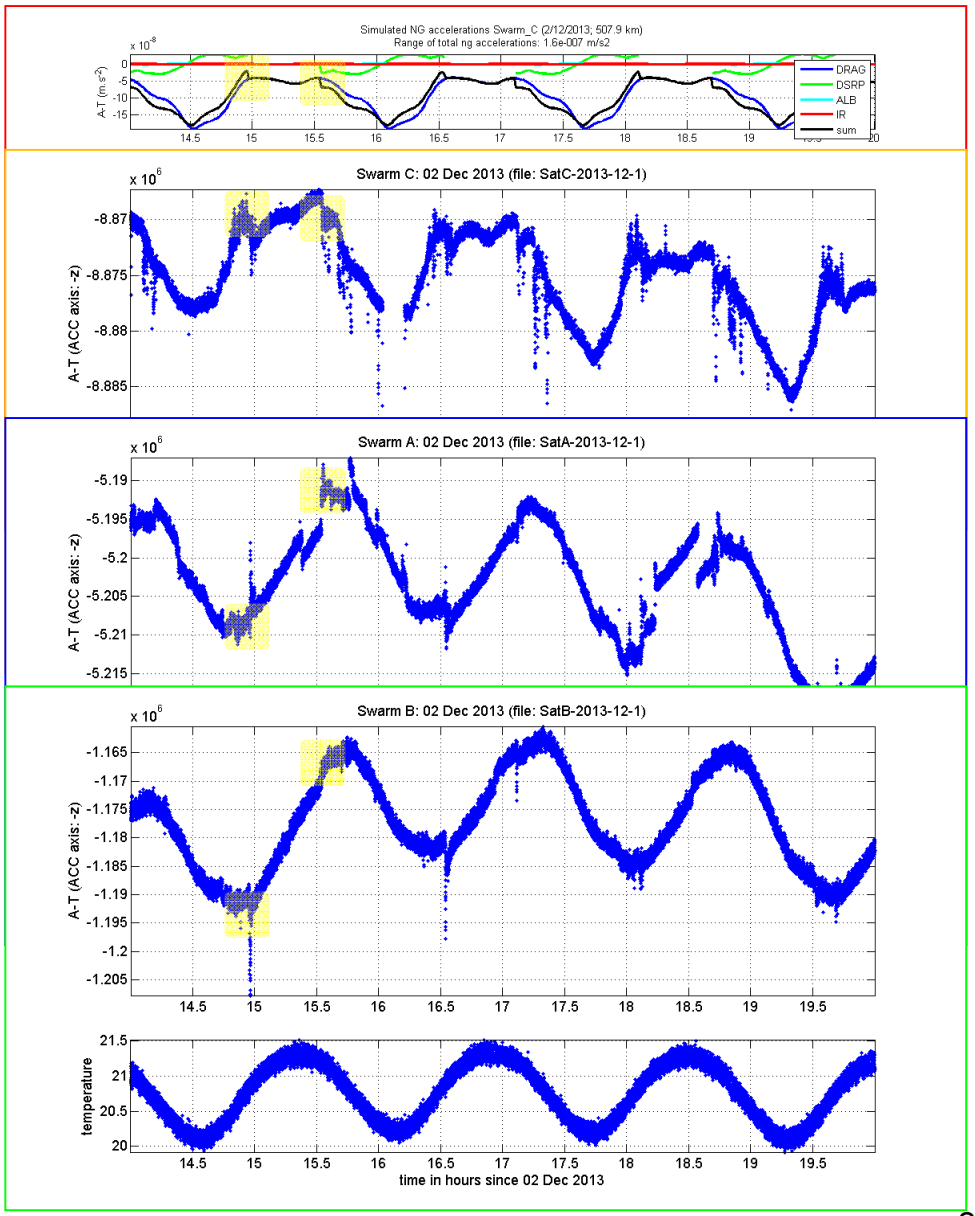
- sum of atmospheric drag + radiation
- characteristic steps at crossing the Earth shadow boundary (terminator)

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?**

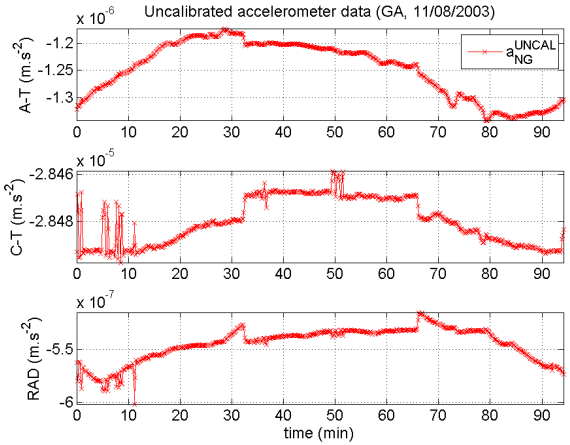


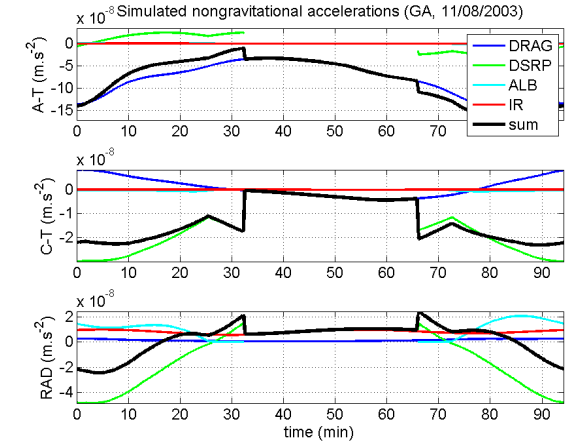
NG signal measured by ACC's of previous missions

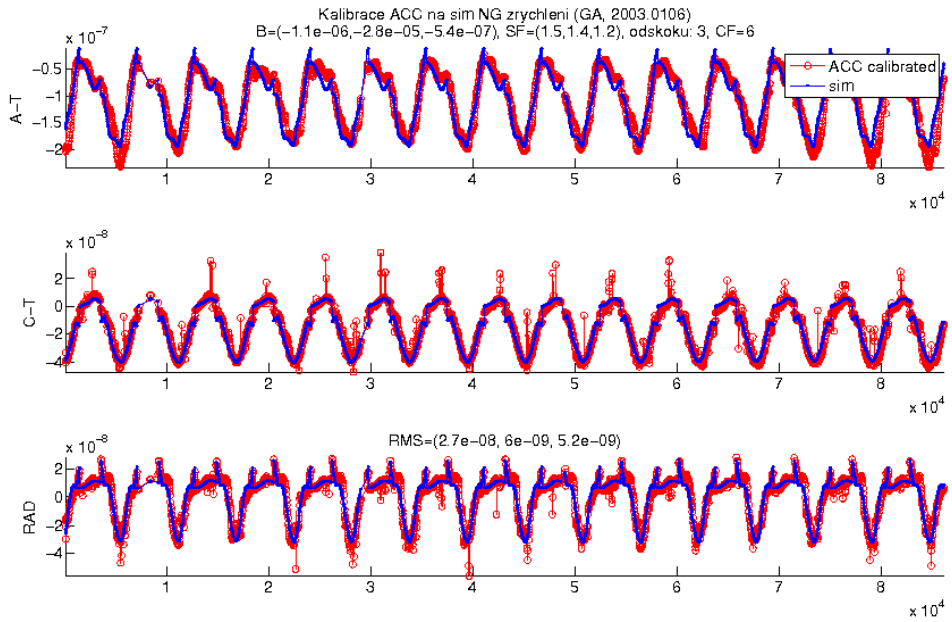
- Space ACC aboard Champ, Grace A/B, Goce
- NG signal of **Grace A/B** is **most similar to Swarm** (shape, mass, altitude→ similar drag & radiation)

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

$$\mathbf{UNCAL} = \mathbf{B} + \mathbf{S}\times\mathbf{SIM} + \mathbf{Q}\times\mathbf{T(t+F)} + \mathbf{G}\times(t-t_0) + \varepsilon$$

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

- **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–t_0)..trend; ε..noise
- **CAL**..calibrated ACC signal
  - ➢ pair of equations for each linear ACC channel (A-T; C-T; RAD)

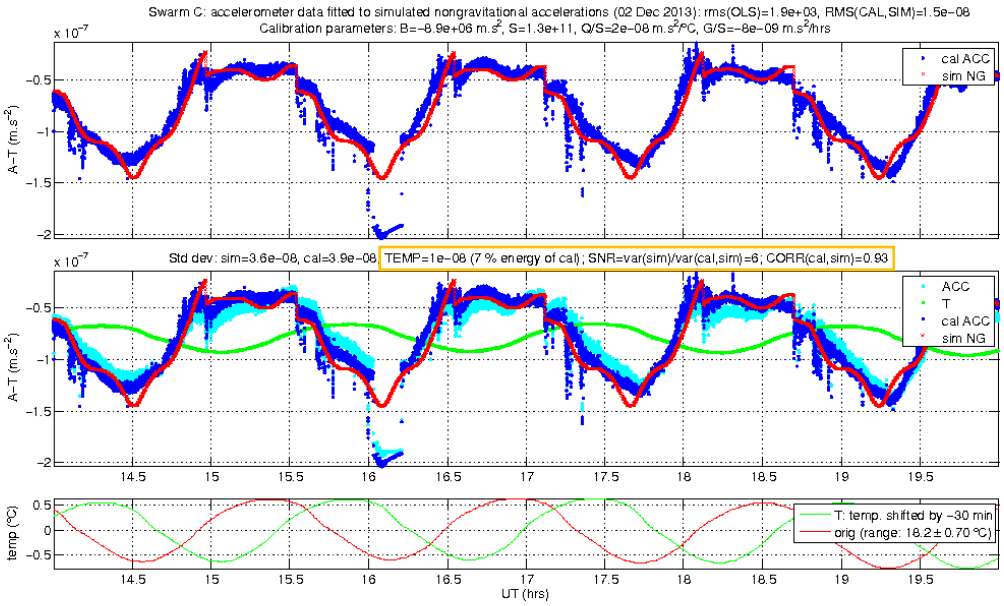
Swarm C (2 Dec 2013)

- **T(t+F)**: **F**=-30 min
- **SNR**=6 (match CAL&SIM)
- **CORR**=0.93
- **TER**=7% (energy temp. T vs. energy SIM)

<u>If CORR & SNR good:</u>

→ waveform of CAL validated by SIM

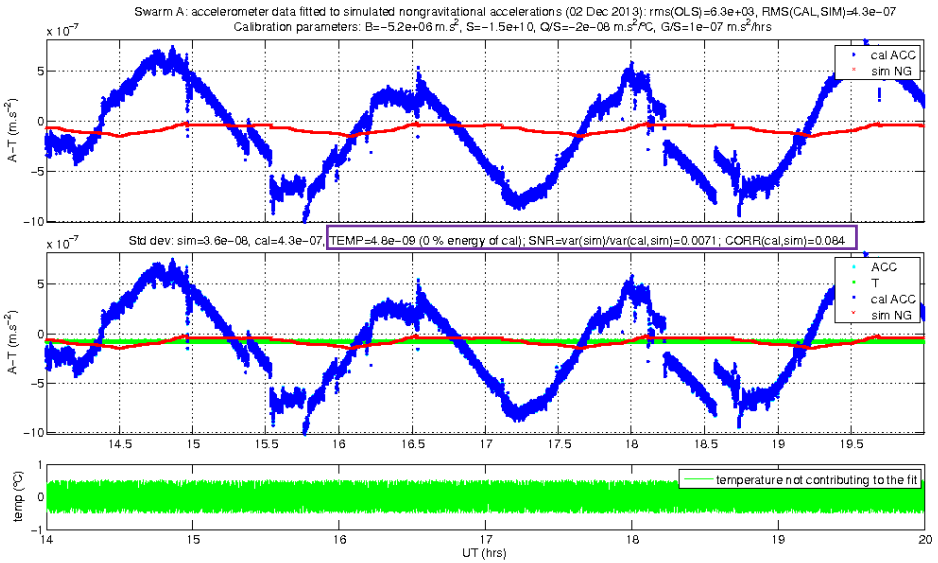
→ TER quantifies T contribution



Reduction of temperature signal from ACC data (Swarm A)

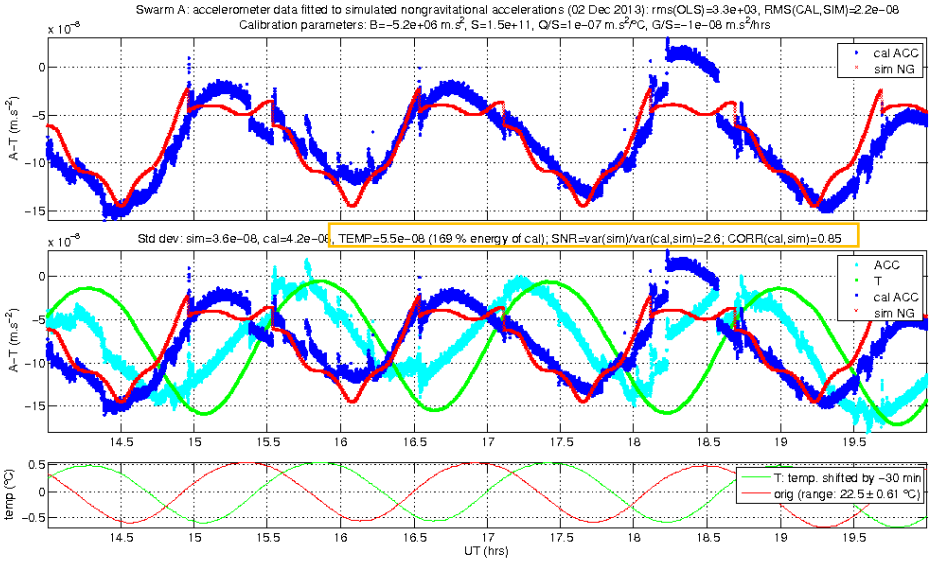
Swarm A (2 Dec 2013)

- no temperature in the fit
- **SNR**=0.071 (match CAL&SIM)
- **CORR**=0.084



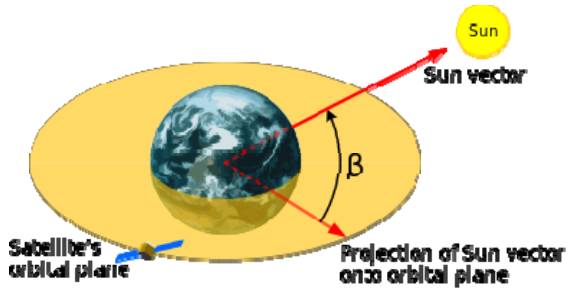
Swarm A (2 Dec 2013)

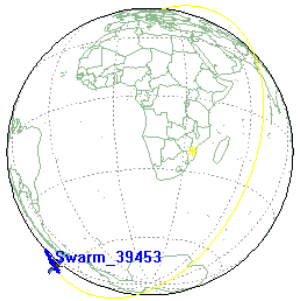
- temperature included
- **T(t+F)**: **F**=-30 min
- **SNR**=2.6
- **CORR**=0.85
- **TER**= 169% (energy temp. T vs. energy SIM)



Insolation of Swarm satellites

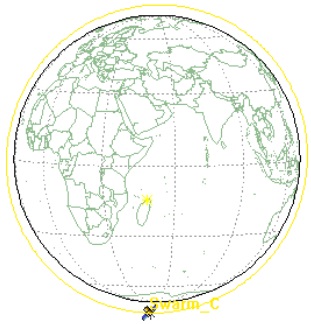
- Studied 3-month period: 12/2013–02/2014
- ß: angle between satellite's orbital plane and the Sun
- Different insolation regimes
  - ➢ **ß=27°**: Swarm enters Earth's shadow
  - ➢ **ß=0°**: orbital plane contains subsolar point (≈20 Dec)
    → no CT-component of direct solar radiation
  - ➢ **ß=–70°**: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





ß=27°

1 Dec 2013 09:34:00.000



ß=-70°

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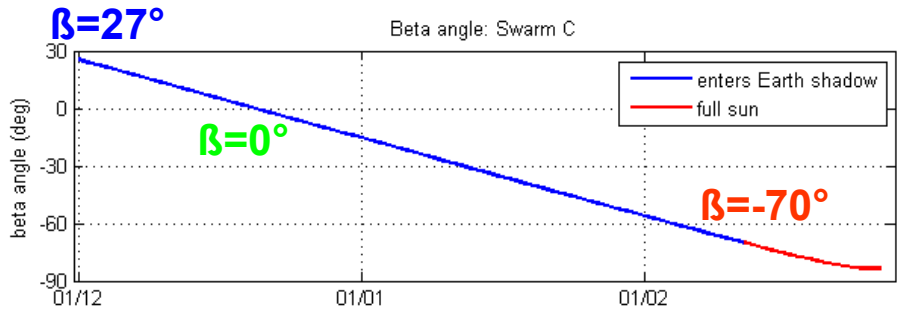
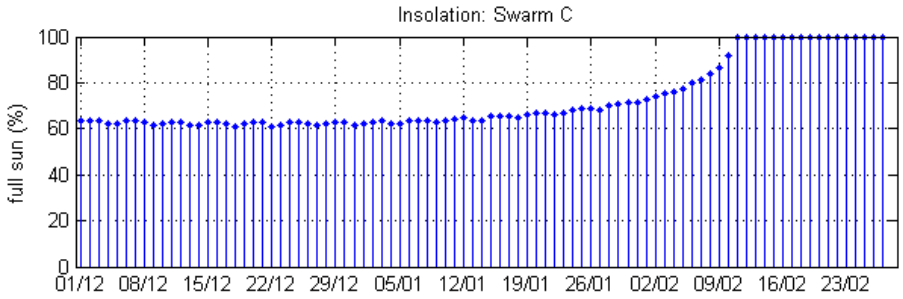


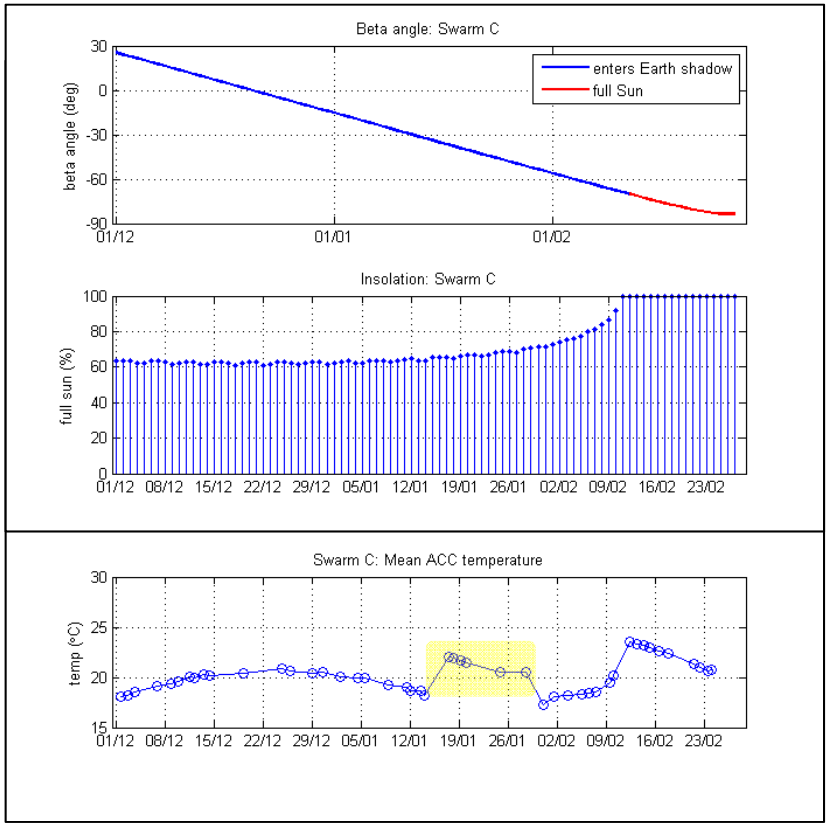


Longterm behaviour of calibration statistics: 12/2013–2/2014

- 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

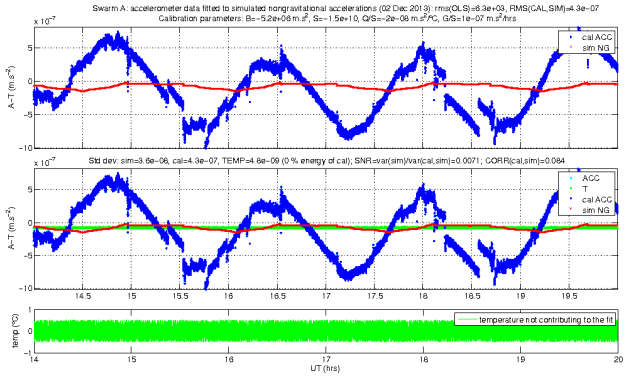
- Temperature on ACC
  - ➢**heaters switched on**: 16–30 Jan 2014



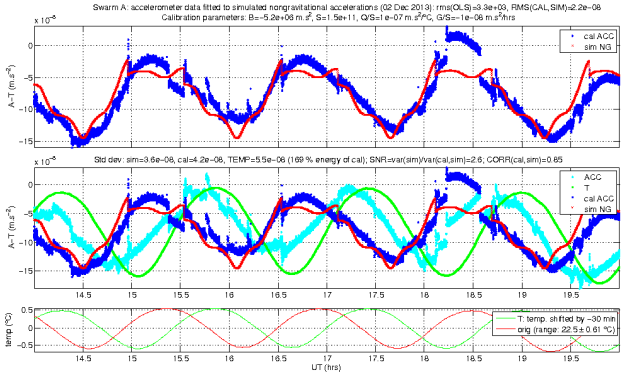
Longterm behaviour of calibration statistics: December 2013

	SA		SB		SC	
	no temp.	temp. incl.	no temp.	temp. incl.	no temp.	temp. incl.
CORR	0.23	0.85	0.3	0.86	0.8	0.88
SNR	0.09	3.0	0.12	3.0	3.0	5.6

- 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

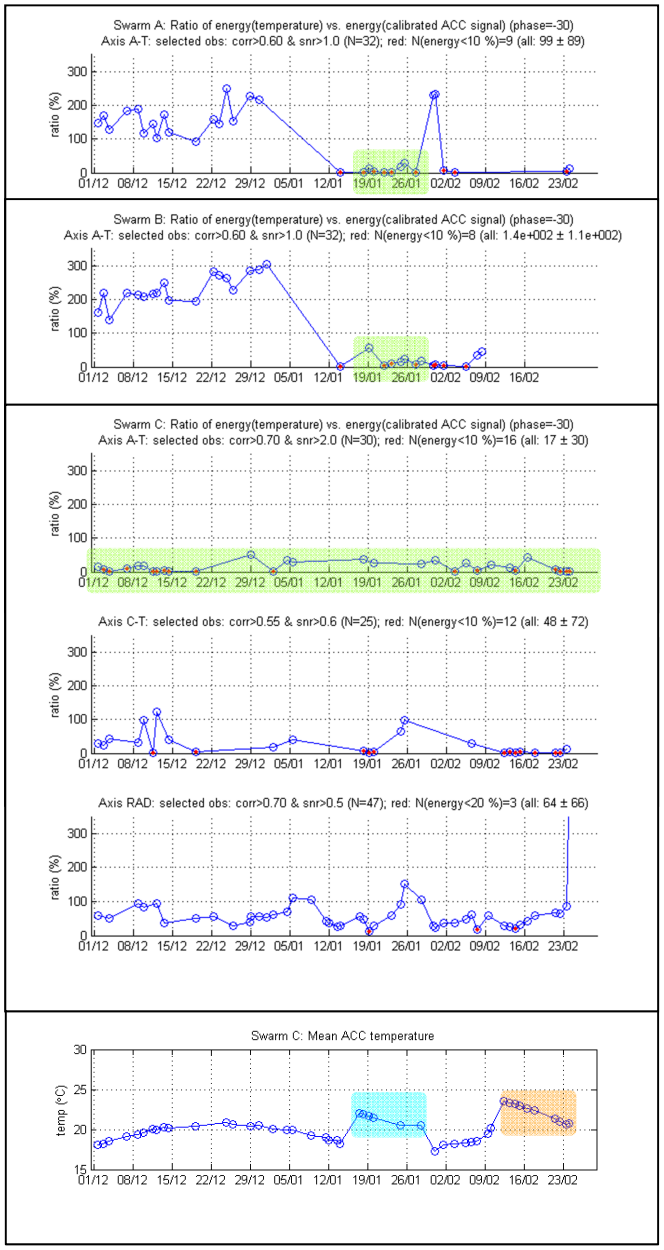
Heating ACC of Swarm A/B resulted in a considerable reduction in the temperature dependence!

→ 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

ß=0°

- subsolar point is in orbital plane
- no cross-track component of direct solar radiation
- around 20 Dec 2013

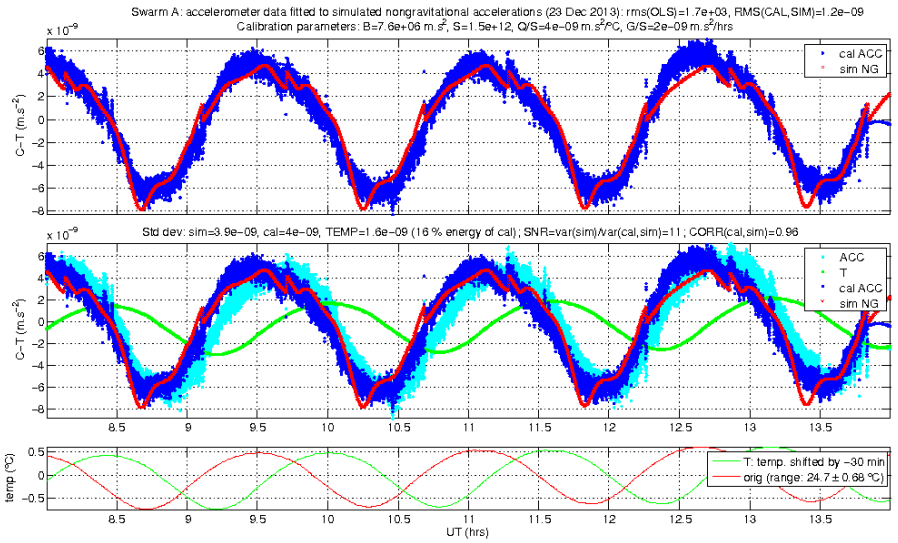
Figs: ACC data (C-T)

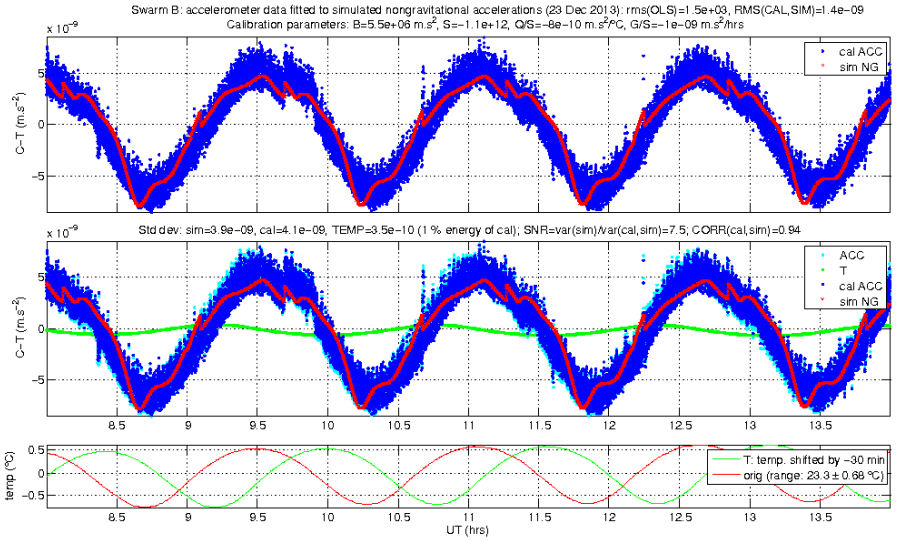
Swarm A

- 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