Analysis of attitude errors in GRACE data and their impact on monthly gravity field solutions

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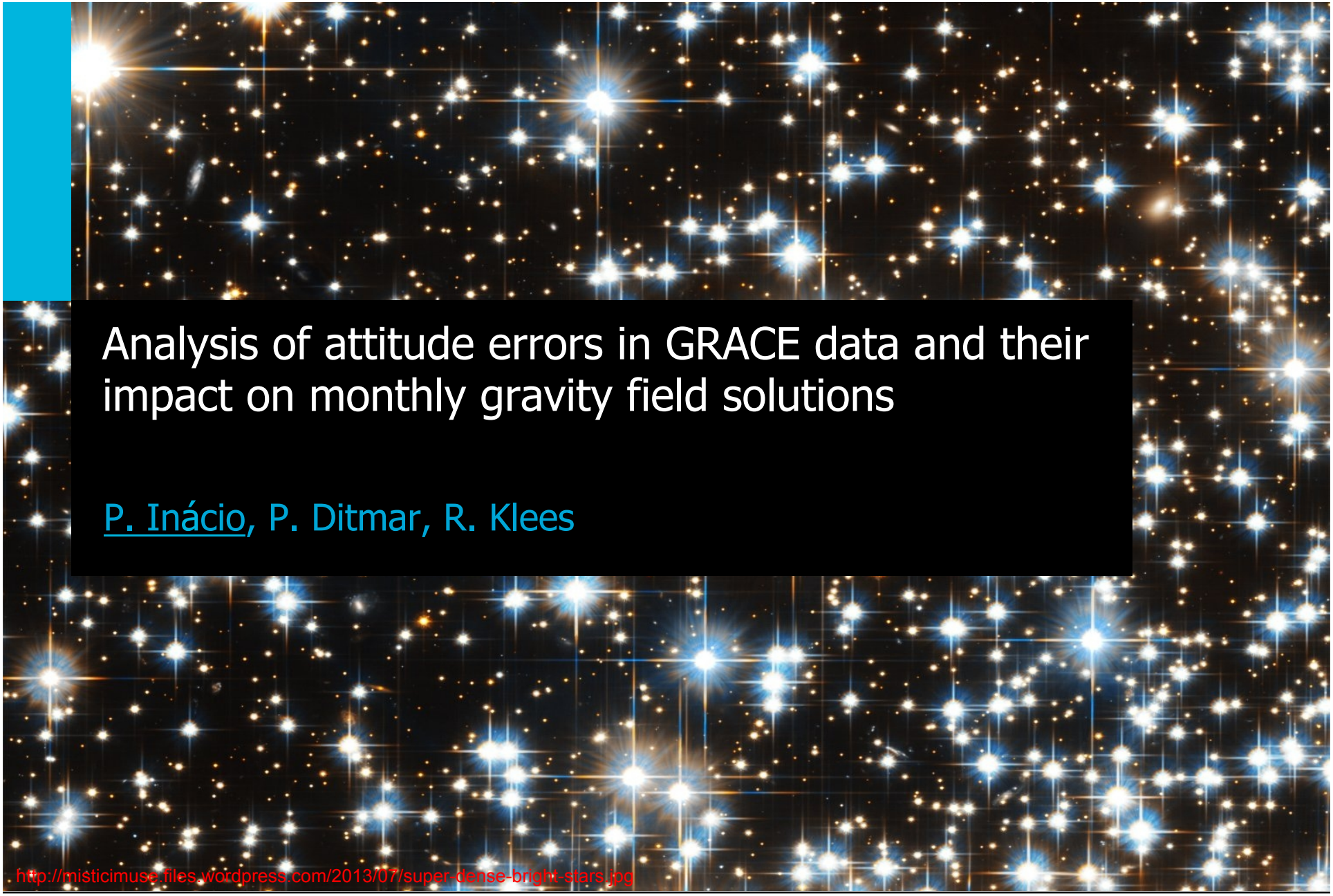


http://misticimuse.files.wordpress.com/2013/07/super-dense-bright-stars.jpg

Overview

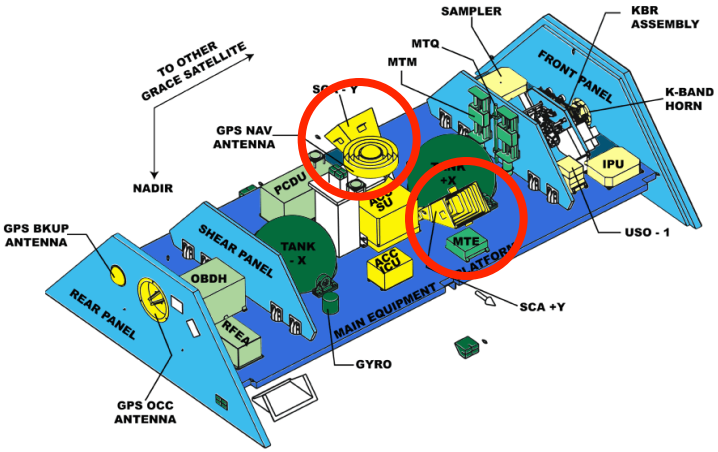
- Background
- SCA errors and their modeling
- SCA error propagation
- Conclusions

Motivation

- No detailed investigation of star camera (SCA) errors
- Unknown source of observed errors in mid-frequency range 1-10mHz (Ditmar et.al., 2012)
- Clear indications that SCA errors play a role in gravity field determination
  - Horvath et.al., 2011
  - Bandikova et.al.,2012
  - New VKB and QSA products in L1B RL02

Background

Star cameras (SCA) on board GRACE

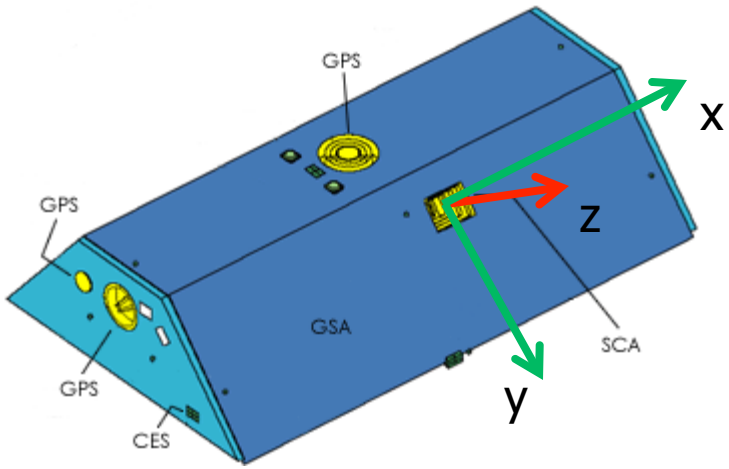


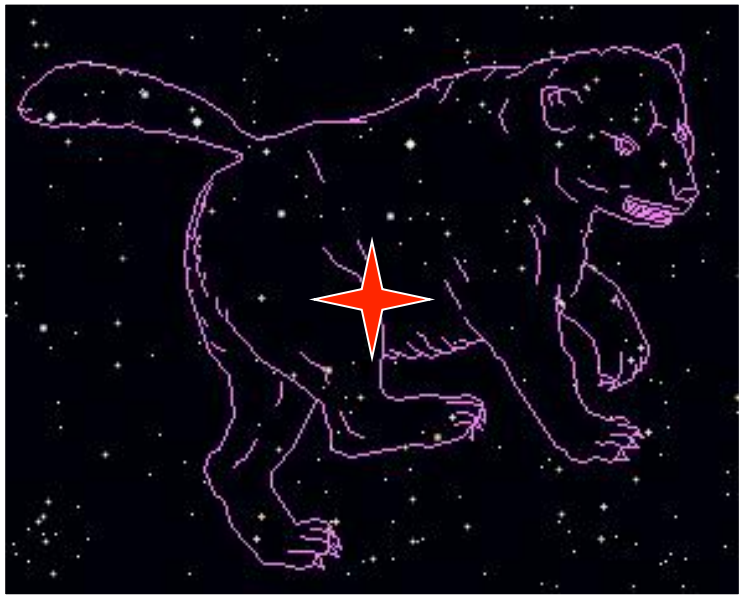
- Optical camera + star catalog + processor
- Measure attitude w.r.t. celestial reference frame
- Two SCAs in each satellite
- Two SCAs provide redundancy and improve accuracy

http://earthobservatory.nasa.gov/Features/GRACE/page5.php

Background

What do SCAs measure?





http://earthobservatory.nasa.gov/Features/GRACE/page5.php
http://starryskies.com/The_sky/constellations/ursa?major.html

Background

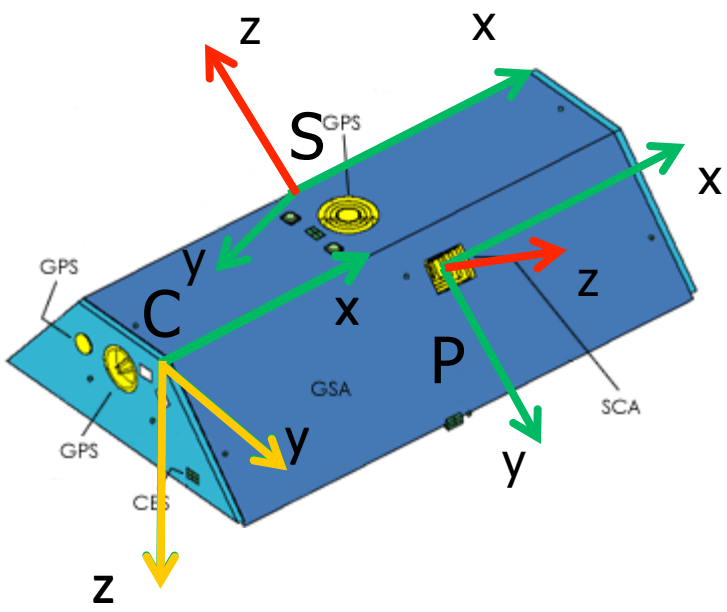
How do SCA errors propagate?

Geometric correction of ranging measurements

$$\delta\lambda = 2||\mathbf{p}||\theta\delta\theta$$

Background

SCA combination



- 2 SCAs,
  - statistically optimal combination
  - isotropic accuracy in determined attitude
- 1 SCA,
  - full accuracy roll
  - worse accuracy pitch, yaw

➢ Sub-optimal SCA configuration for gravity field recovery

- pitch, yaw critical for KBR geometric correction
- roll much less important

http://earthobservatory.nasa.gov/Features/GRACE/page5.php

Research questions

- What errors are observed in SCA measurements?
- How can we model SCA errors?
- What is the impact of SCA errors on gravity field solutions?

Observed SCA errors

- Both SCAs measure the same,

$$\tilde{\mathbf{R}}^{C}_{I,P},\ \tilde{\mathbf{R}}^{C}_{I,S}$$

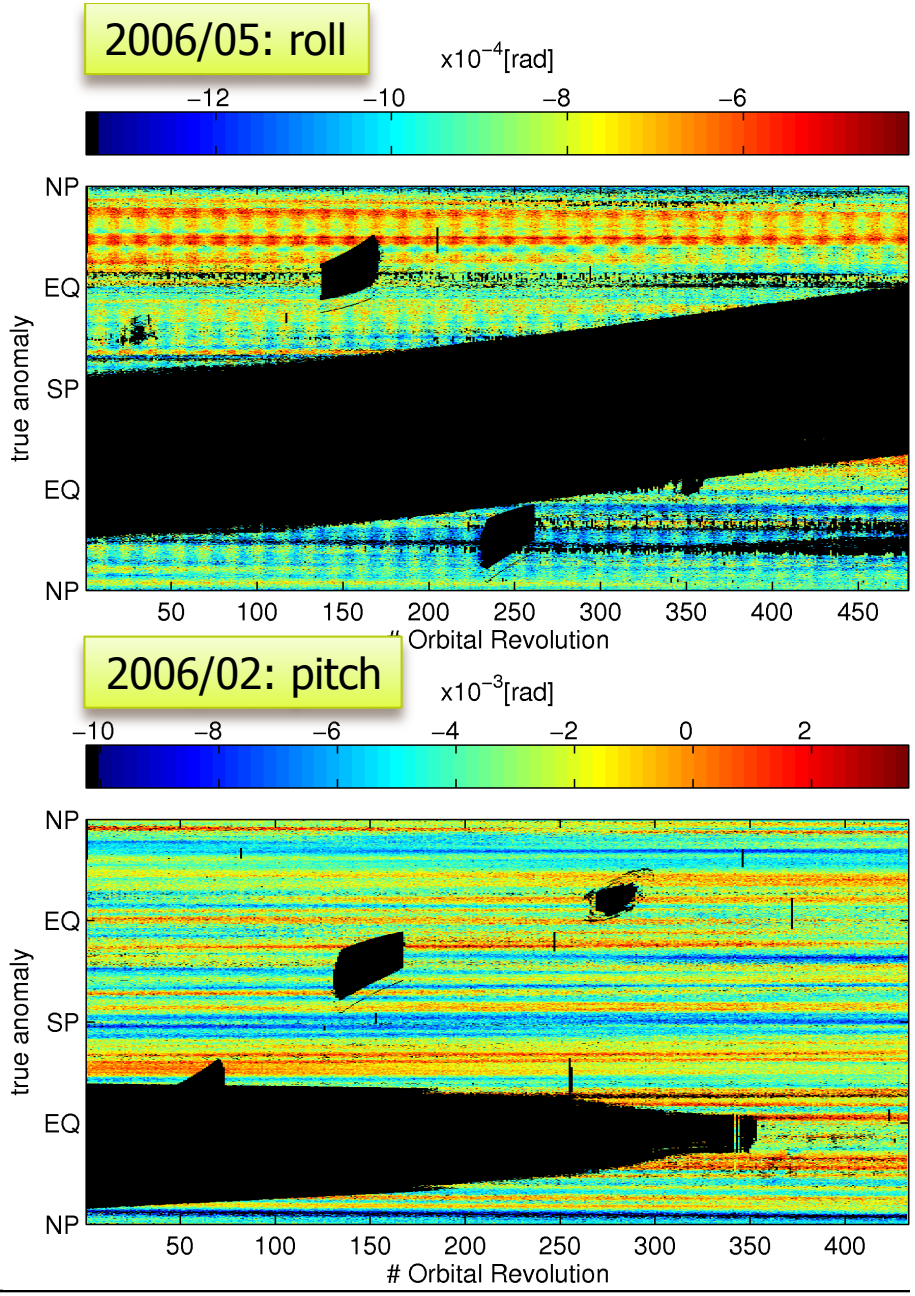
- Differential transformation,

$$\delta\mathbf{R} = \left(\tilde{\mathbf{R}}^{C}_{I,P}\right)^{-1}\ \tilde{\mathbf{R}}^{C}_{I,S}$$

$\times 10^{-4}$ [rad]	**GRACE-A**	
2006/02	**mean**	**std**
Roll	0,27	0,32
Pitch	1,87	2,09
Yaw	0,51	2,27
2006/05	**mean**	**std**
Roll	-0,01	0,31
Pitch	-1,30	2,39
Yaw	-0,36	2,30

Observed SCA errors

- 2D plot differencial transformation
  - Yaxis satellite's true anomaly
  - Xaxis number of revolutions
- SCA gaps in black,
  - sun/moon shines directly in SCA
  - outliers
- High correlation between SCA errors and satellite's true anomaly
- Pattern changes over time
  - thermal expansion
  - thermal sensitivity of SCAs
  - star catalog
  - ...



Research question

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Observed SCA errors

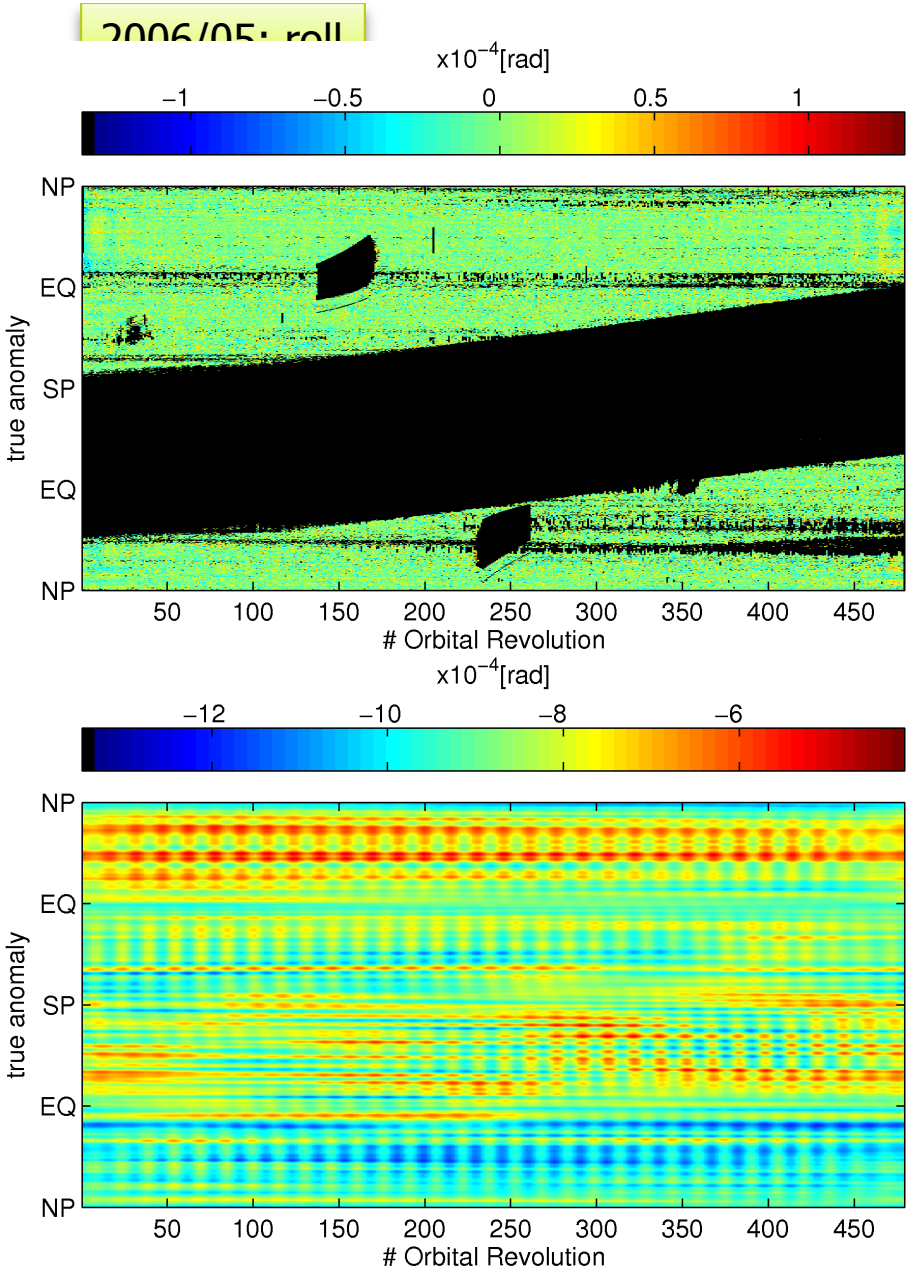
- Two types of errors
  - deterministic
  - stochastic
- Distinct in the frequency domain
- Deterministic component,
  - IDFT model,

$$y_i = \frac{1}{N} \sum_j Y_j \cdot e^{\frac{2\pi i j}{N}}$$

  - J-most energetic frequencies (J=300)
  - Regularized LS solution,

$$\hat{\mathbf{x}} = \left(\mathbf{A}^T\mathbf{A} + k\mathbf{A}_g^T\mathbf{A}_g\right)^{-1}\left(\mathbf{A}^T\mathbf{y}\right)$$

- Stochastic error
  - ARMA model fitted to LS residuals



Research question

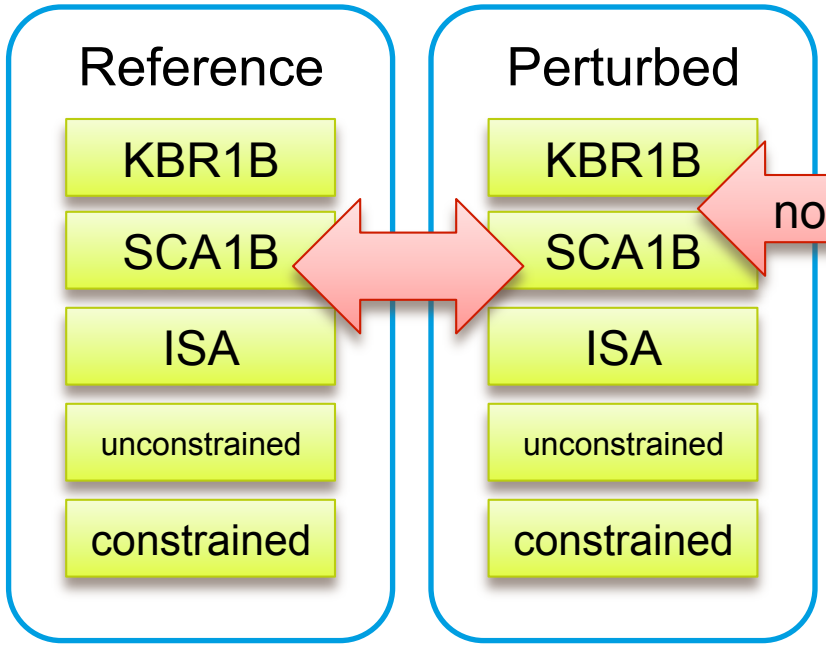
What errors are observed in SCA measurements?

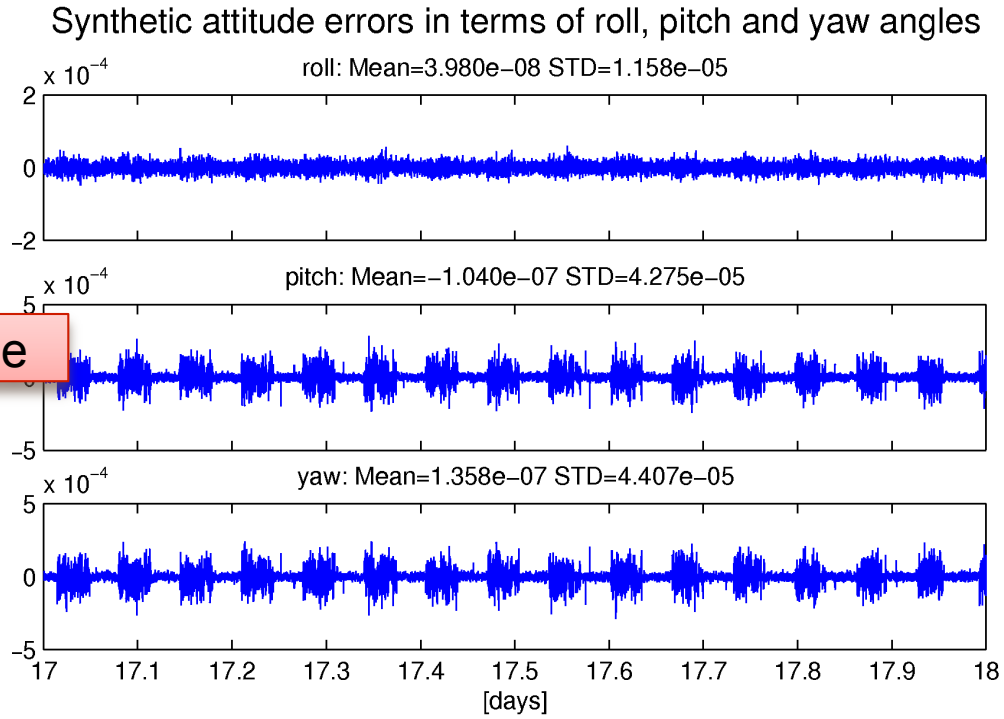
How can we model SCA errors?

What is the impact of SCA errors on gravity field solutions?

Error propagation

Forward simulation

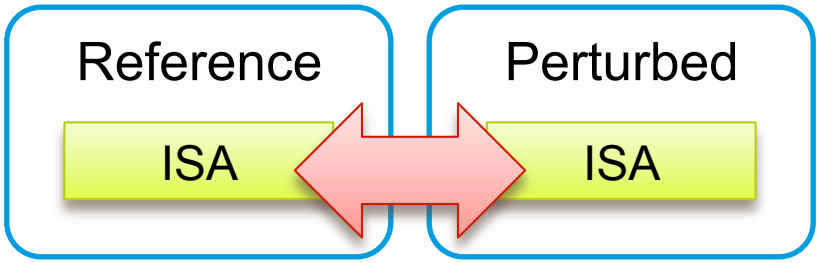


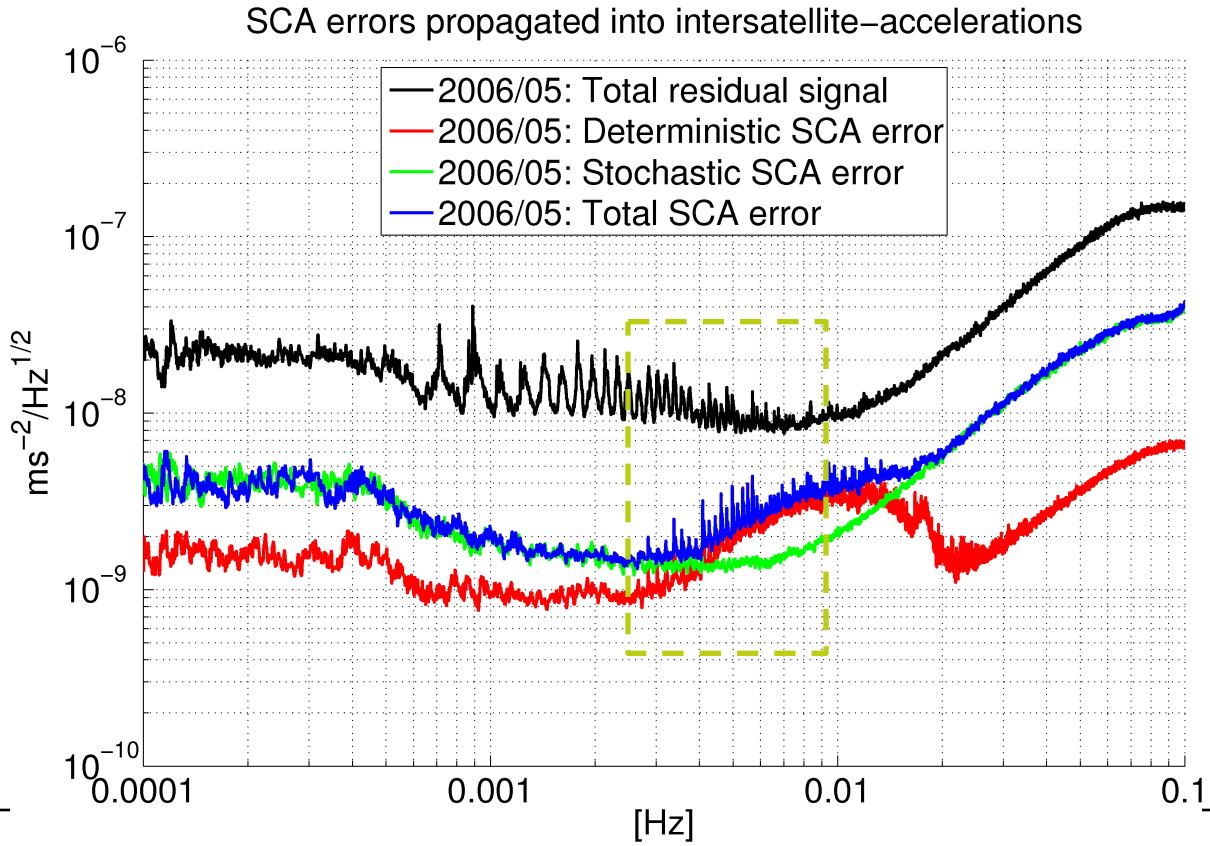


- Single SCA operation:
  - happens frequently
  - increased STD for pitch and yaw angles
  - full accuracy for roll

Error propagation

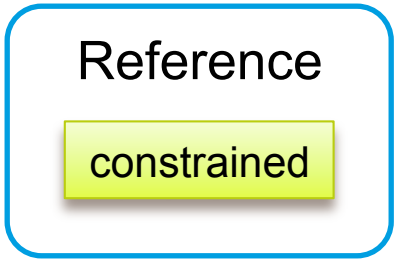
2006/05: Inter-satellite accelerations

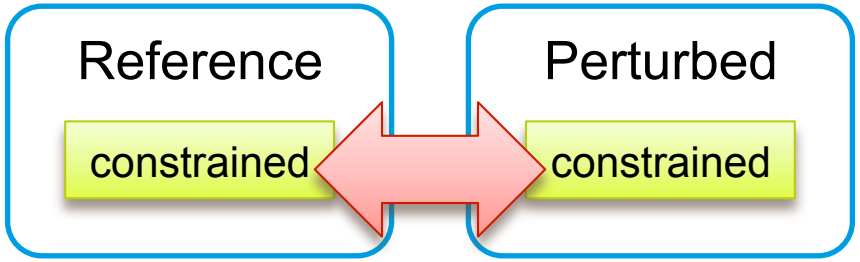


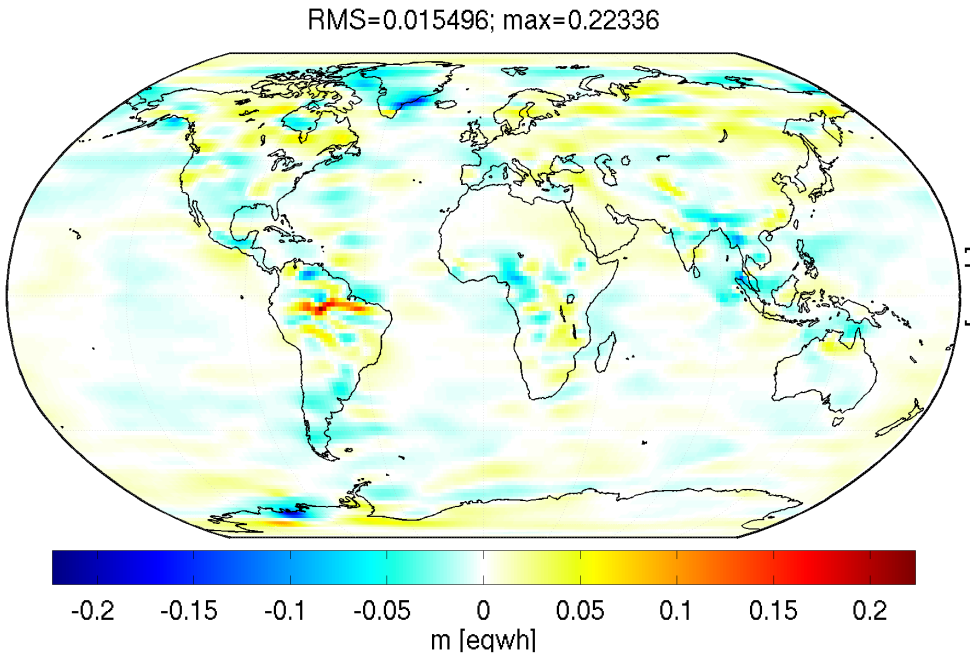


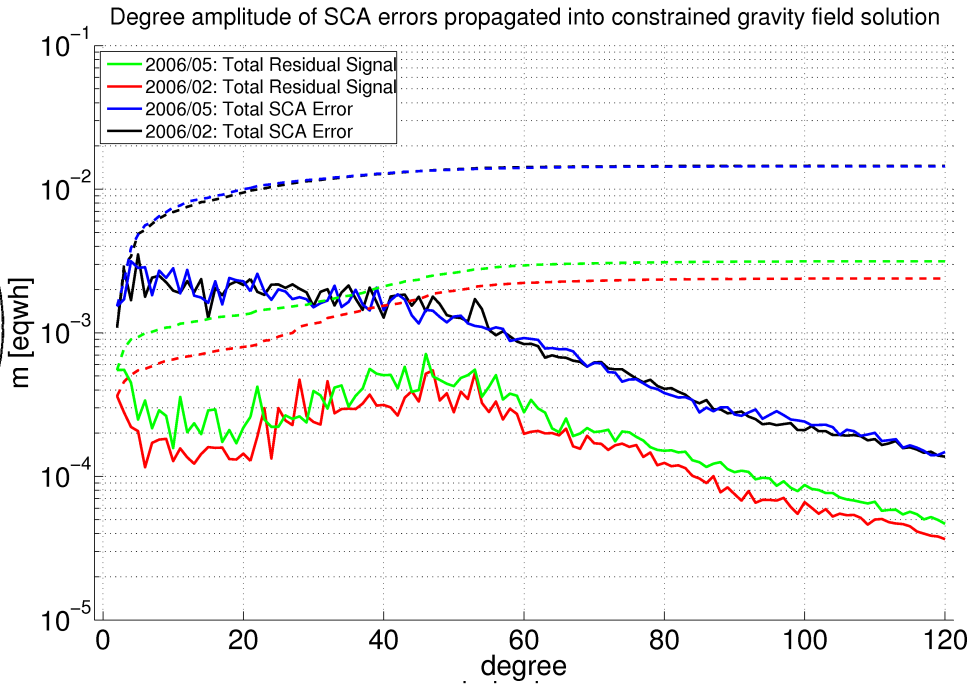
Error propagation

2006/05: Constrained gravity field solution



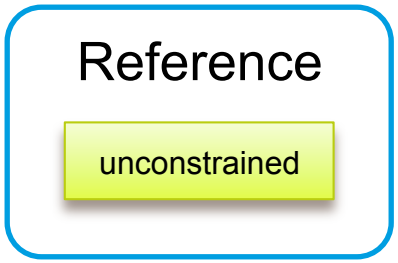


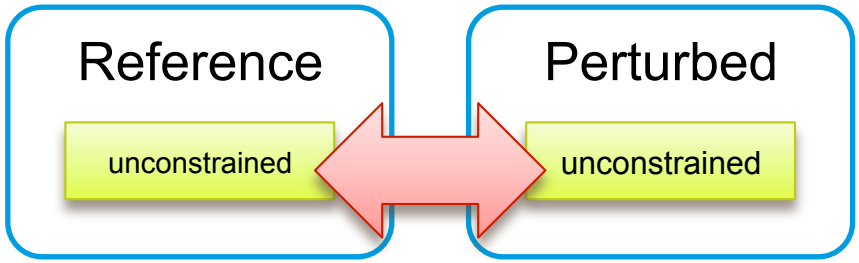


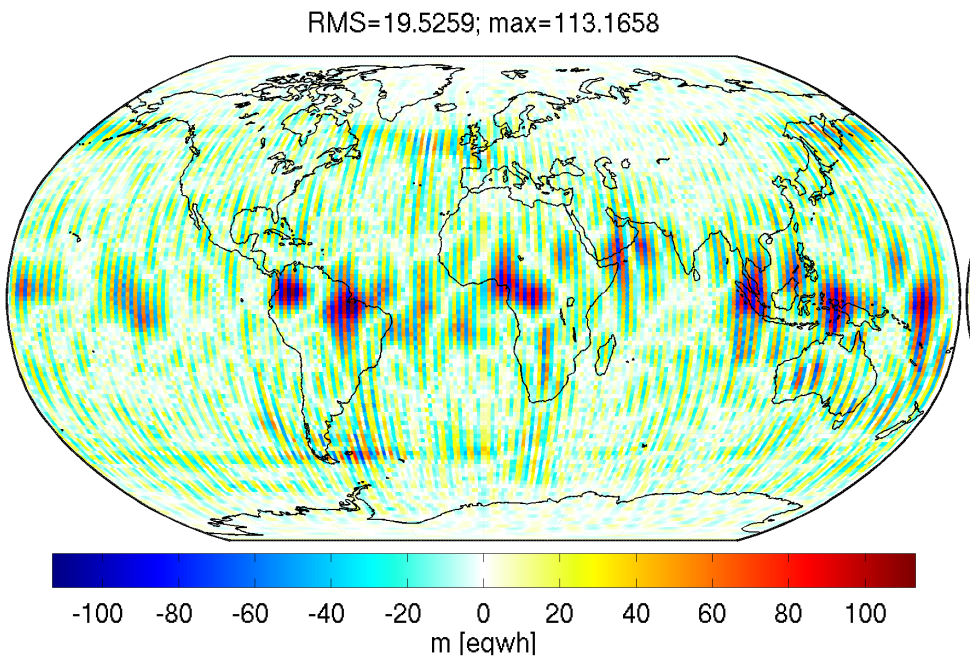


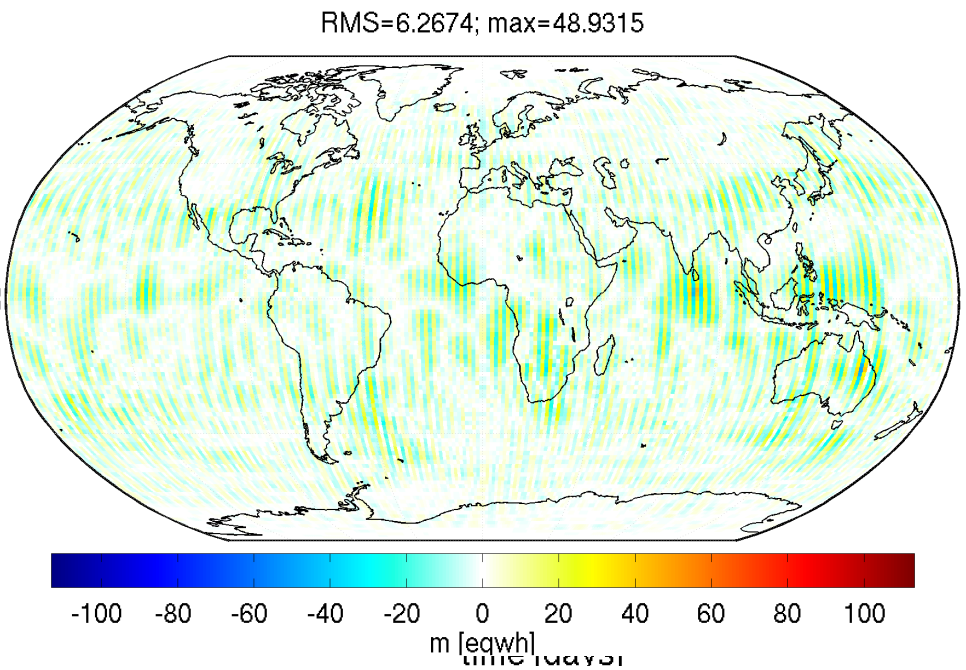
Error propagation

2006/02: Unconstrained gravity field solution









Conclusions

GRACE

- Deterministic and stochastic components observed in SCA errors
- High correlation between deterministic SCA errors and satellite's true anomaly
- Important source of error between 3-100mHz where mass transport signal is measured
- In case of a poor attitude control, SCA errors may become dominant
- Potential improvements by:
  - finding and removing time intervals when attitude control is poor
  - understanding and removing deterministic noise in attitude data

Conclusions

GRACE-FO

- GRACE-FO equipped with 3 SCAs
  - solves lack of redundancy
  - reduces stochastic errors by statistical averaging
  - **no obvious impact** on deterministic errors
- In GRACE, propagated SCA errors are close to KBR accuracy
- GRACE-FO equipped with laser ranging,
  - requires equal improvement to attitude determination accuracy
  - may lead to significant changes to satellite design