Improved GRACE preprocessing methodologies: impact on monthly gravity field solutions

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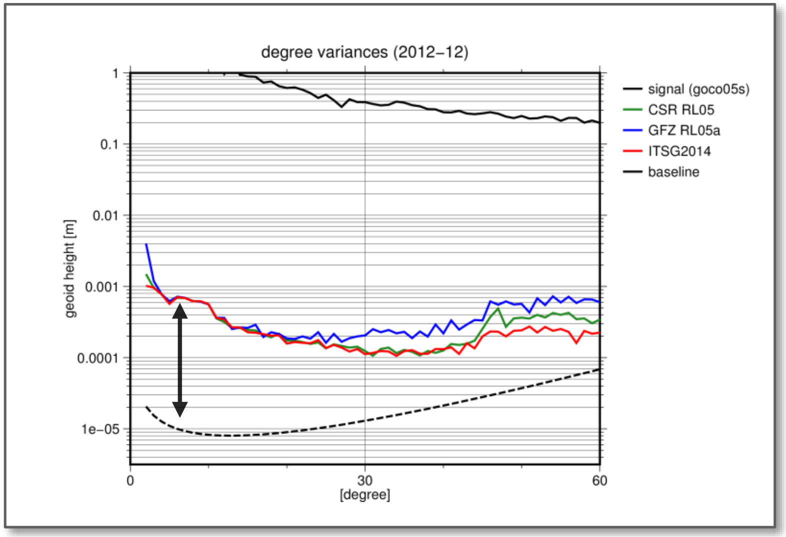
Outline

- Motivation
- GRACE Preprocessing
  - GRACE sensor fusion
  - Accelerometer simulation & calibration
- Impact on monthly gravity field solutions – Examples
- Conclusions

Motivation

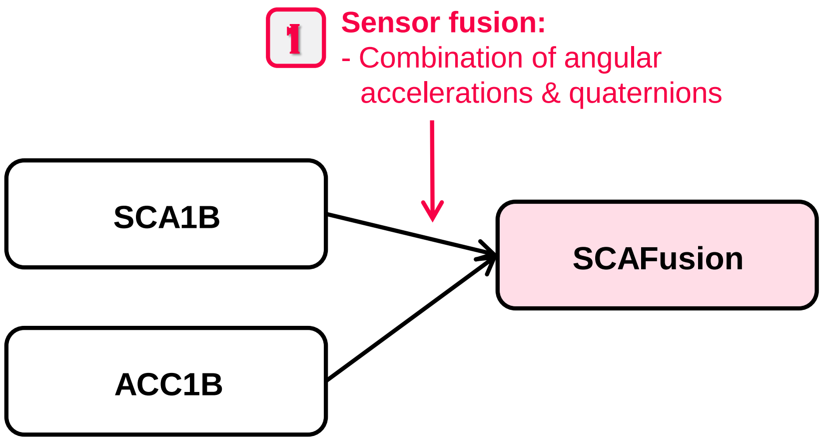


- Offset between present error level and GRACE baseline accuracy.
- **Potential contributors:**
  - Unmodeled errors in Level-1b alignment data products
  - Outlier
  - …

Our focus:

- Preprocessing
  (outlier detection, gap filling, calibration)
- Improved attitude determination

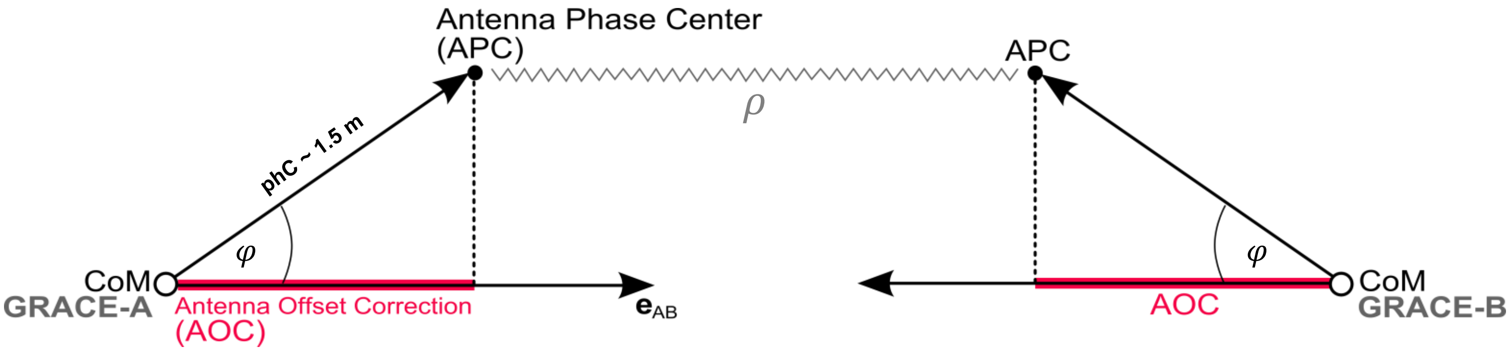
GRACE Preprocessing



K-band ranging (KBR)

- Essential requirement:
  - Precise inter-satellite pointing

- Geometric correction:
  - KBR ↔ inter-satellite pointing ↔ Antenna Offset Correction (AOC)

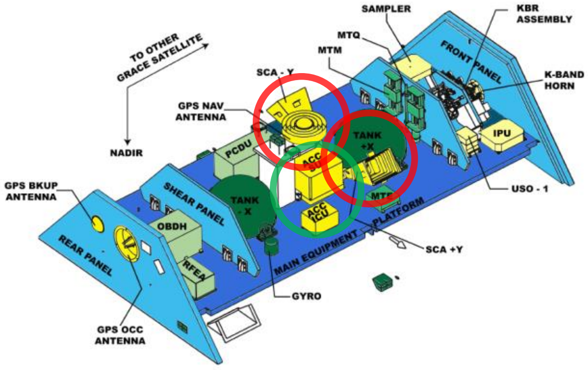


GRACE sensor fusion

Combination of Level-1b star camera (SCA1B) & accelerometer (ACC1B) data:

- In a least squares approach (LSA)
- Optimal weighting by VCE

- Combined estimation in the time domain
- No cut-off frequency used



Quaternion rates ↔ angular accelerations:

- $\dot{\omega}(\mathbf{q}, \dot{\mathbf{q}}) := 2\mathbf{W}(\mathbf{q})\ddot{\mathbf{q}}$

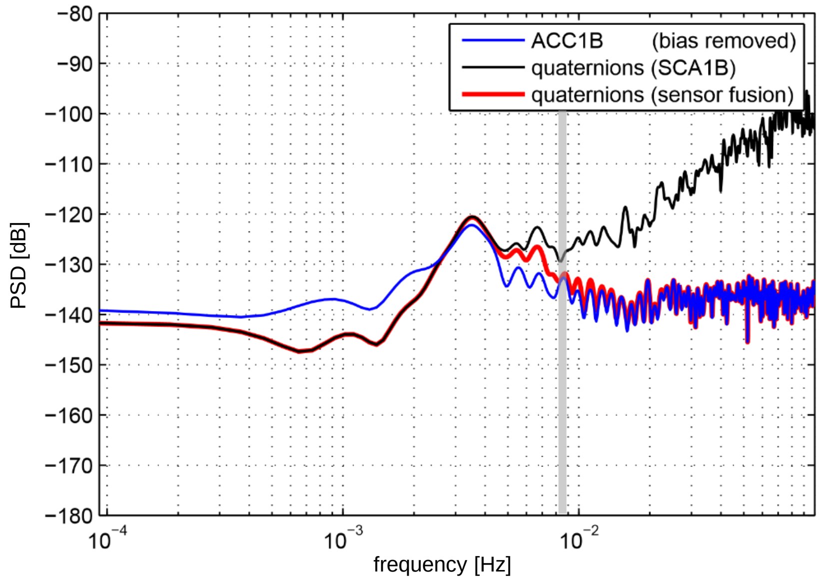
angular accelerations ($\dot{\omega}$)

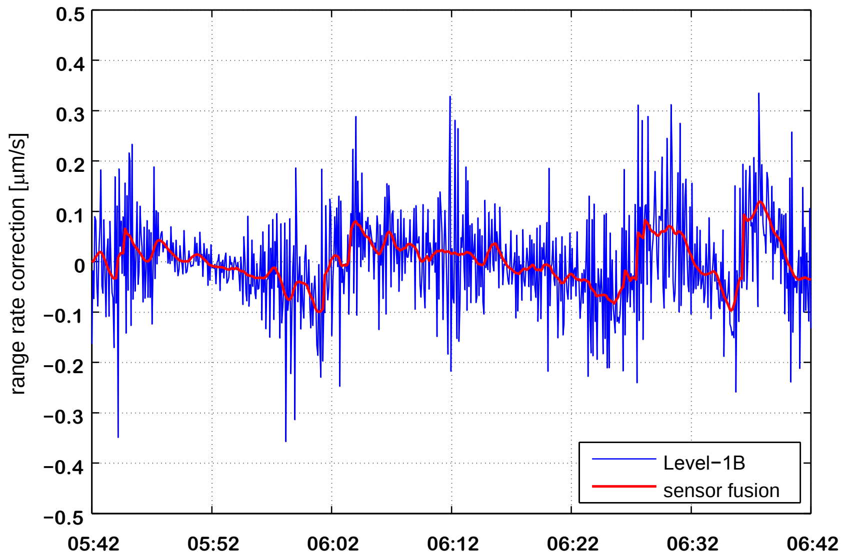
Quaternion rate matrix ($\mathbf{W}(\mathbf{q})$)

2nd derivative of the unit quaternion ($\ddot{\mathbf{q}}$)

GRACE sensor fusion

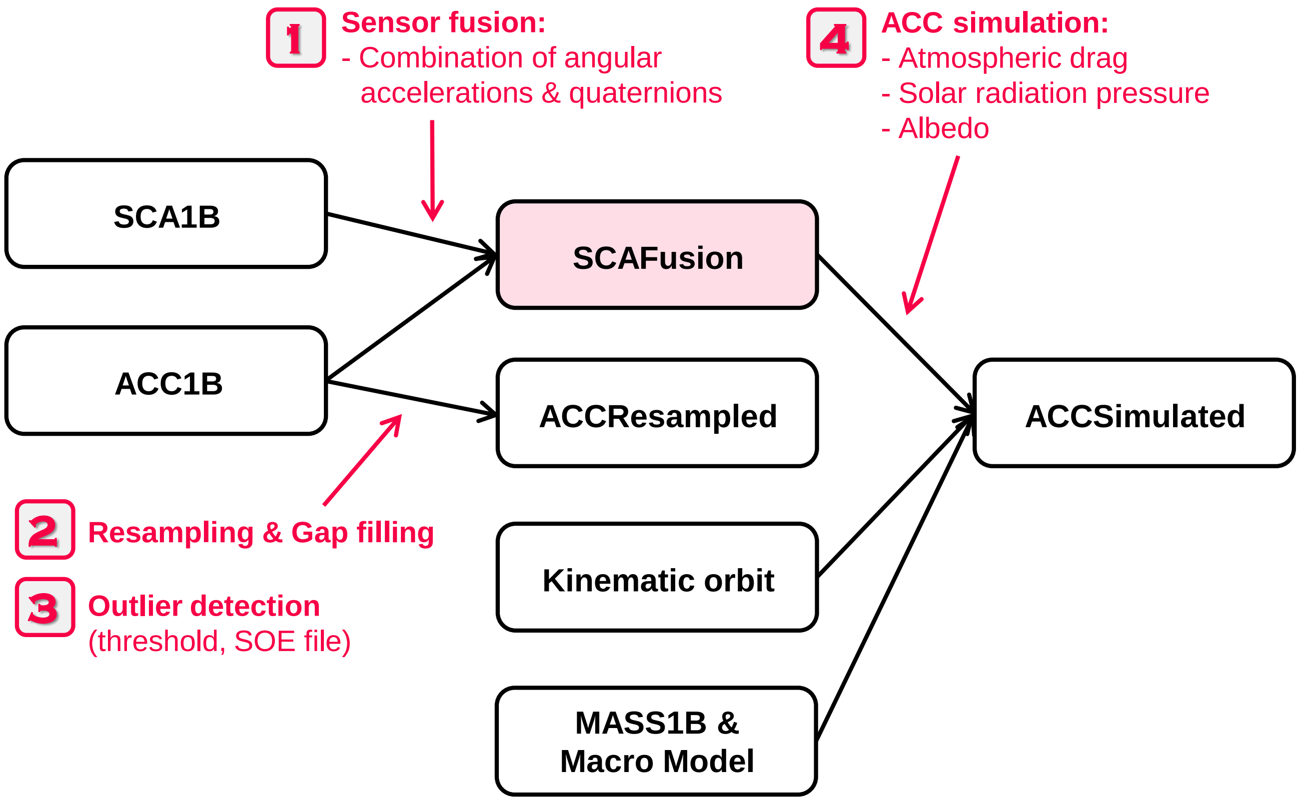
Angular accelerations & AOCs



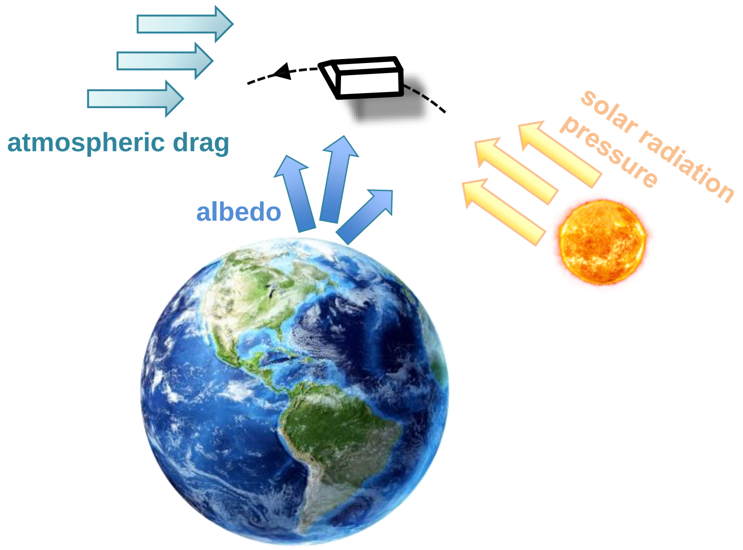


- Angular accelerations contribute to high frequencies
- High frequent noise of the attitude data can be decreased significantly!
- Smoothed Antenna Offset Corrections (AOCs) & RPY-angles

GRACE Preprocessing



Accelerometer Simulation



Modelling of non-conservative forces:

- Atmospheric drag (DTM2013)
- Solar radiation pressure
- Earth radiation pressure (CERES data)
- Thruster firings

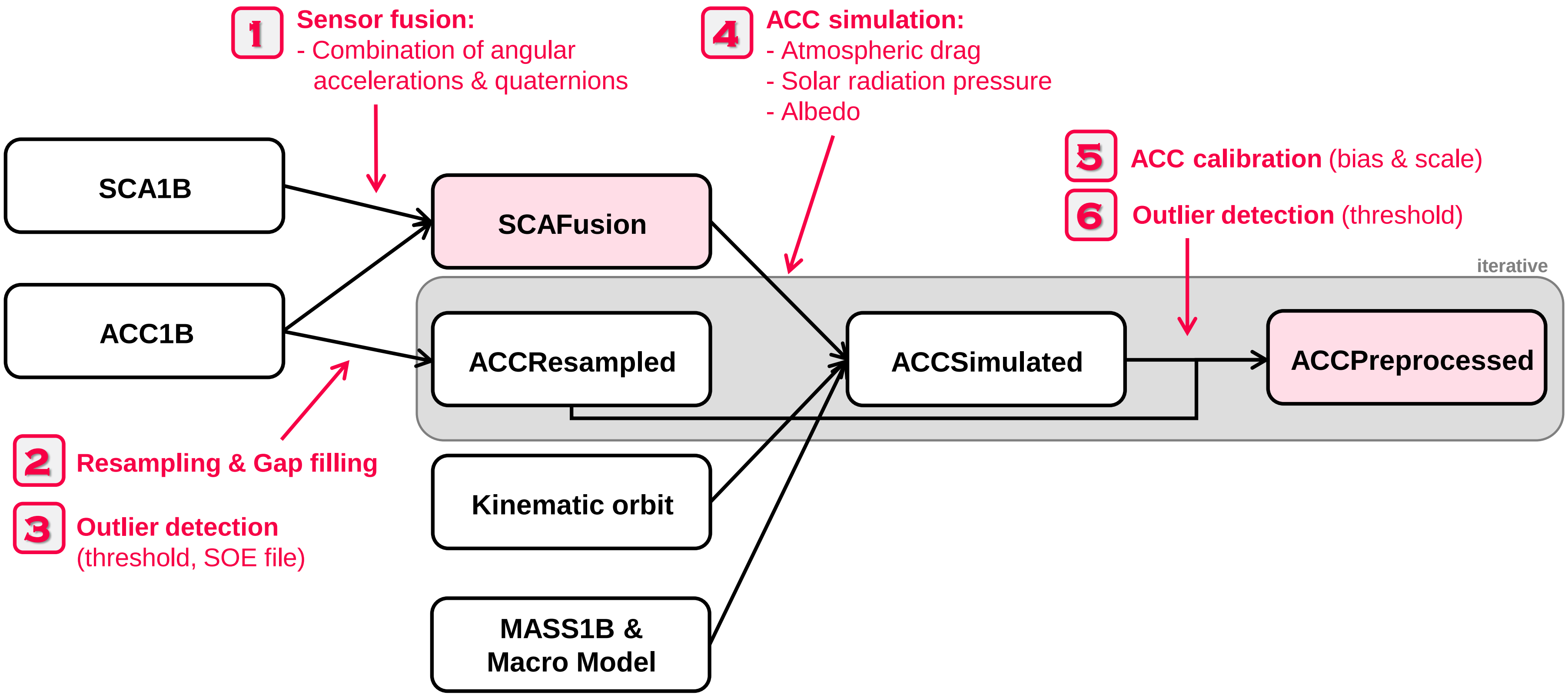
Input:

- Orbit & attitude information
- GRACE macro model & satellite mass

Output:

- Linear accelerations in x/y/z-direction

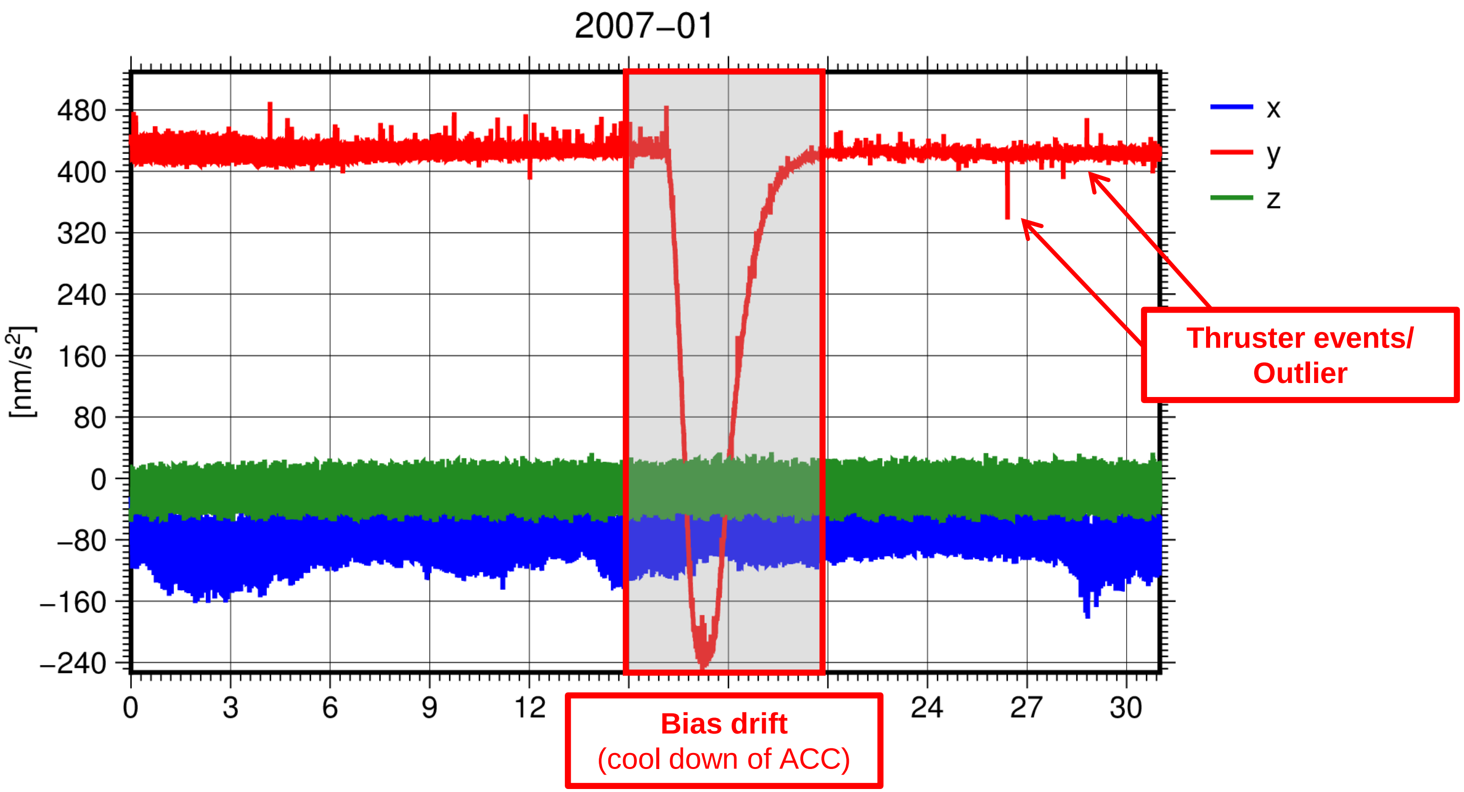
GRACE Preprocessing



Accelerometer Calibration

GRACE-A Level-1b accelerometer data:

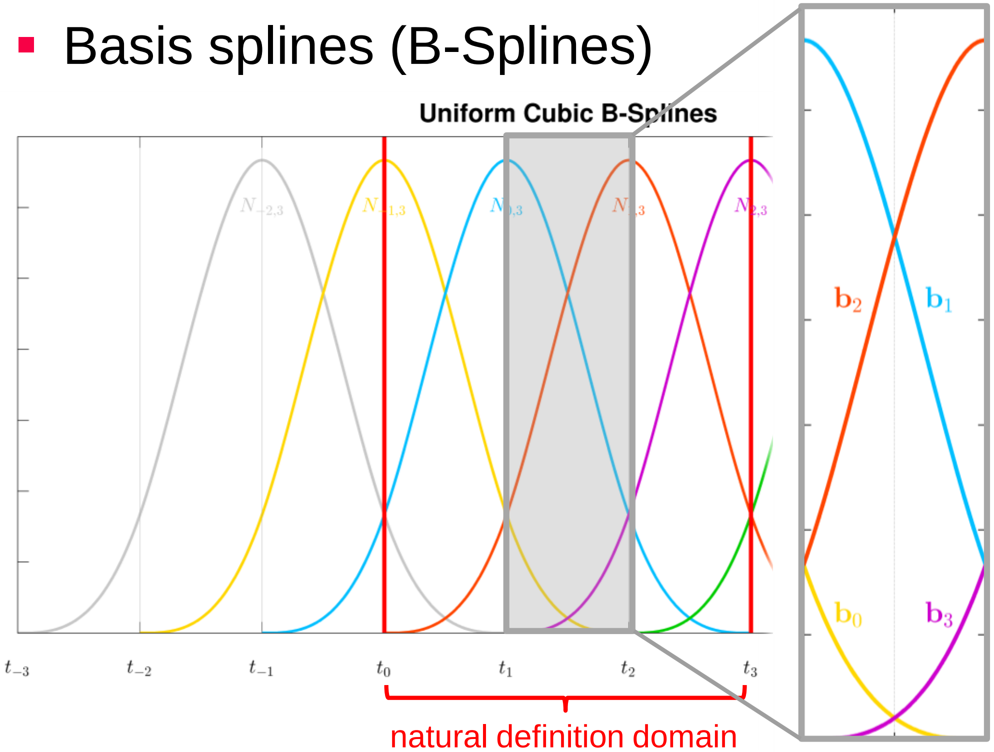
- Calibrated according to TN-02



Accelerometer Calibration

Estimation of accelerometer bias (& scale):

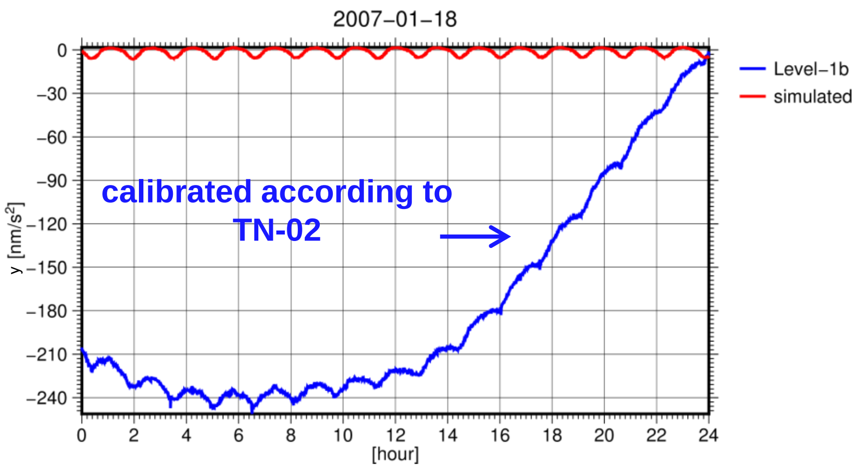
- $acc_{sim} = bias + scale \times acc_{1b}$
- Polynomial
- Basis splines (B-Splines)

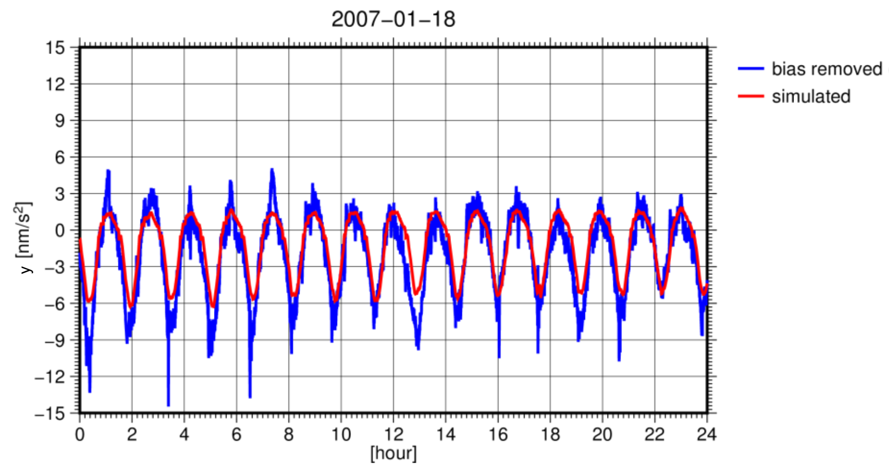


$$N_i(x) = \begin{cases} b_0 = (1/6)(-x^3 + 3x^2 - 3x + 1) & if\ x \in [t_i, t_{i+1}[\\ b_1 = (1/6)(3x^3 - 6x^2 + 4) & if\ x \in [t_{i+1}, t_{i+2}[\\ b_2 = (1/6)(-3x^3 + 3x^2 + 3x + 1) & if\ x \in [t_{i+2}, t_{i+3}[\\ b_3 = (1/6)(x^3) & if\ x \in [t_{i+3}, t_{i+4}[\\ 0 & otherwise \end{cases}$$

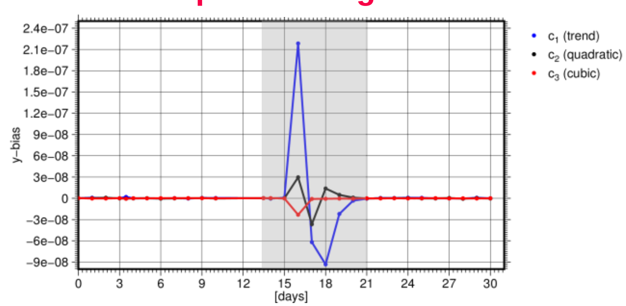
Accelerometer Calibration

GRACE-A simulated vs. calibrated data (w/o thruster):





B-spline of degree 3



Accelerometer Calibration

Polynomial vs. Uniform Cubic B-Splines (UCBS):

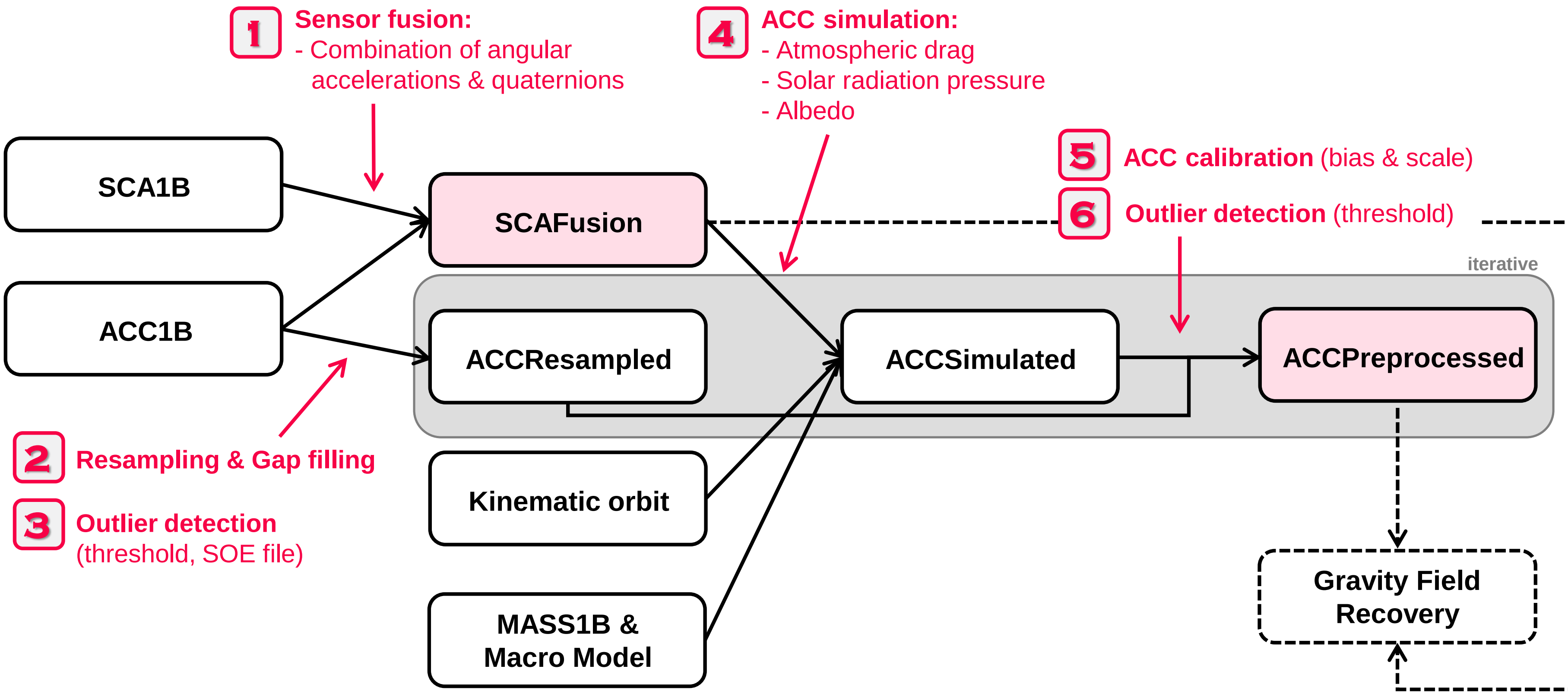
	Polynomial	UCBS
	degree d	degree d, knot intervals n
Parameter	3 (d+1)	3 (d+n)

	d = 9	d = 3, n = 4
Parameter	**30**	**21**

Advantages of UCBS:

+ Oscillation effects can be reduced
+ Number of parameter not increased

GRACE Preprocessing



Gravity field recovery

Monthly solutions:

- Improved preprocessing, including:
  - Combination of star camera and accelerometer data (sensor fusion)
  - Re-estimation of KBR phase center during gravity field estimation

ITSG2014 release

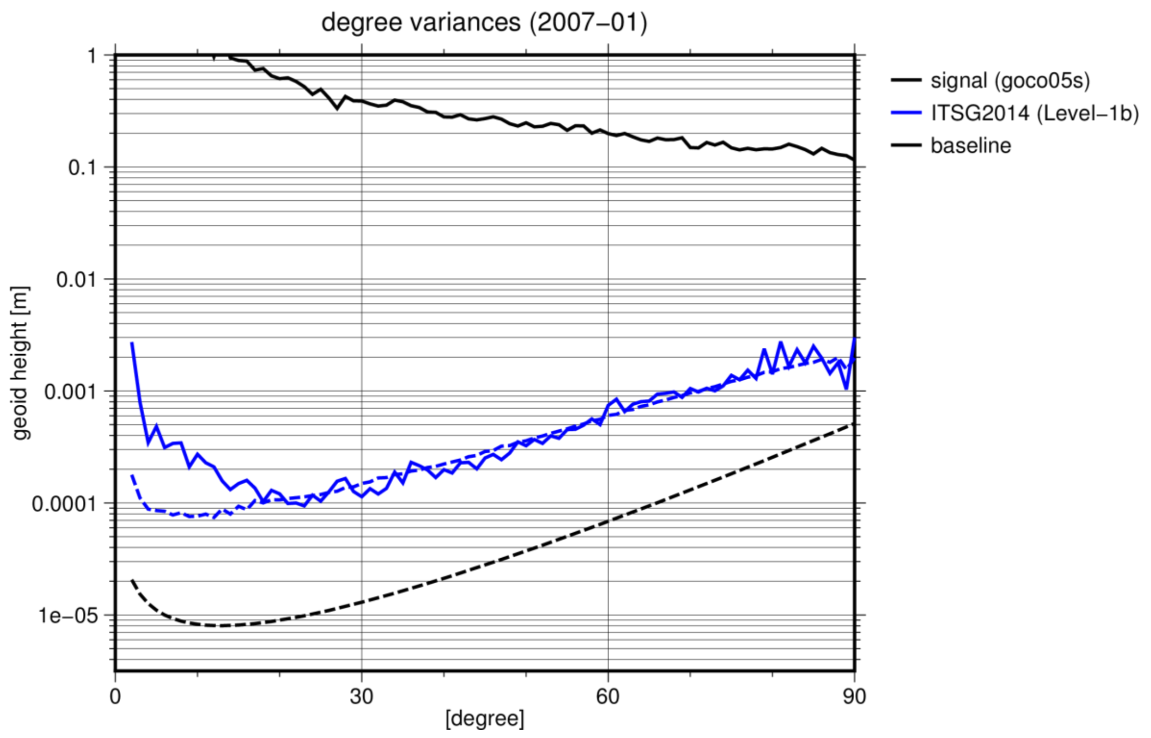
  - Automated & iterative outlier detection
  - Adapted modeling of accelerometer bias (B-splines)

- Comparison:
  - Official Level-1b vs. preprocessed data
  - With official GRACE Level-2 products

Example: 2007-01

degree variances

Level-1b



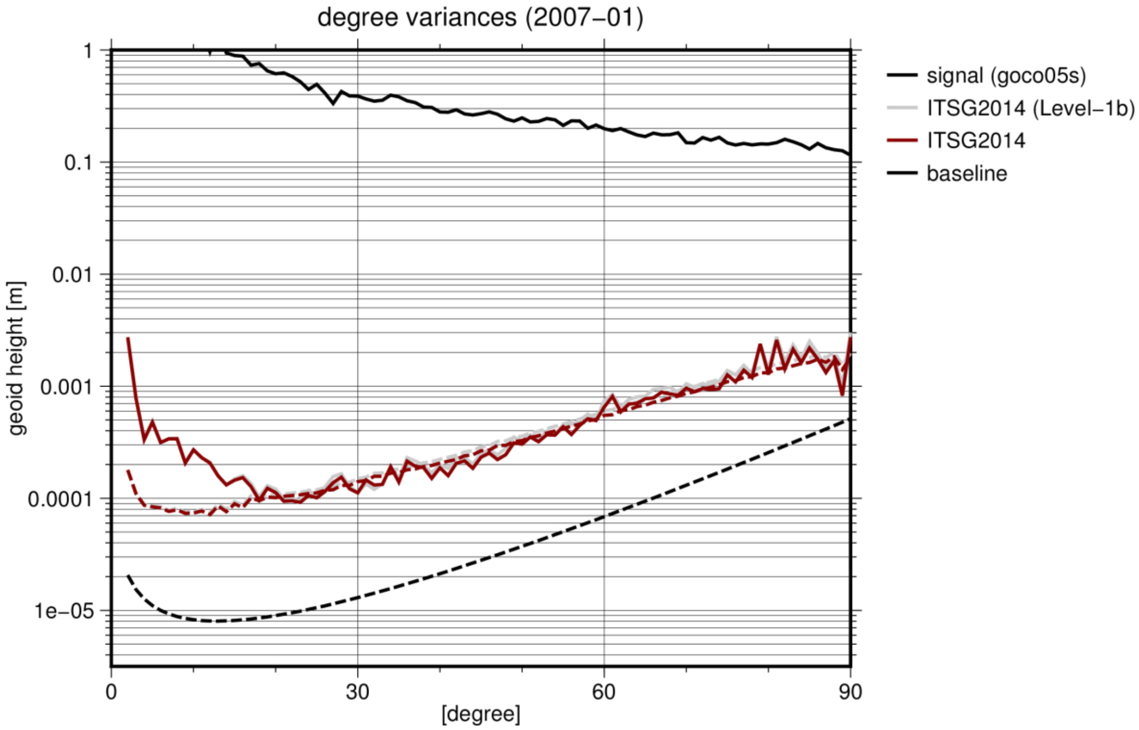
Example: 2007-01

degree variances

0 Level-1b

Preprocessing:

1 Sensor fusion



Example: 2007-01

degree variances

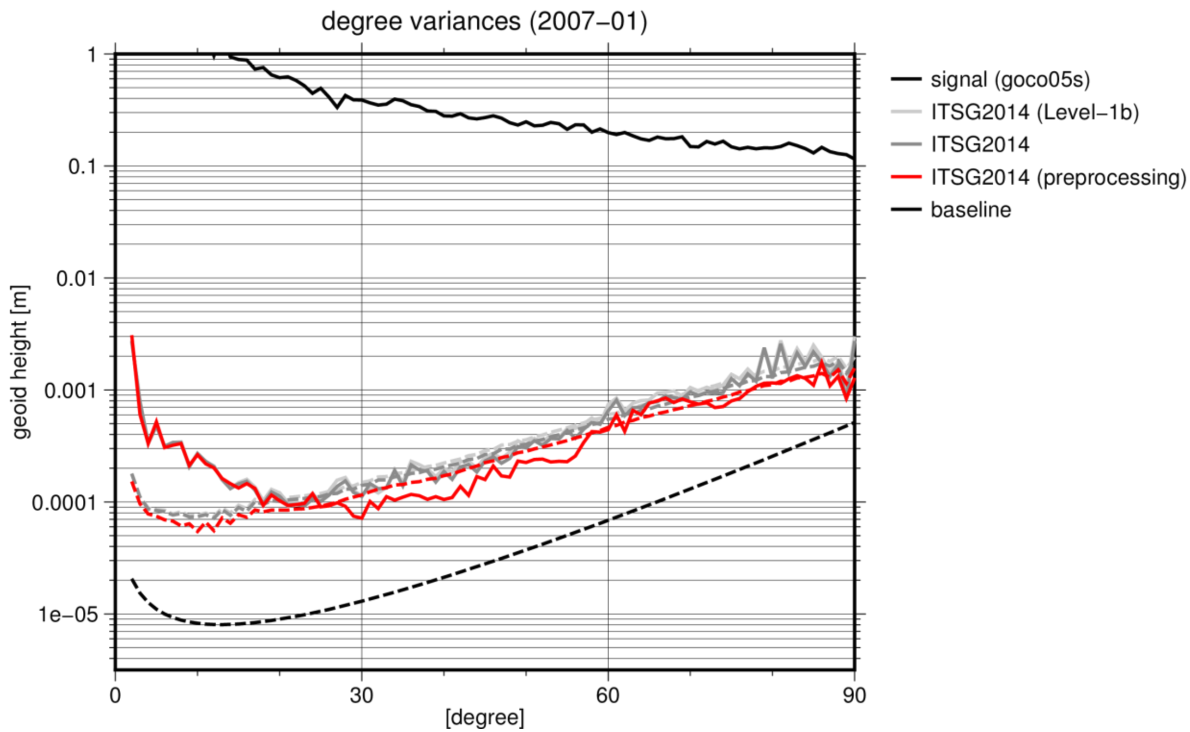
0 Level-1b

Preprocessing:

1 Sensor fusion

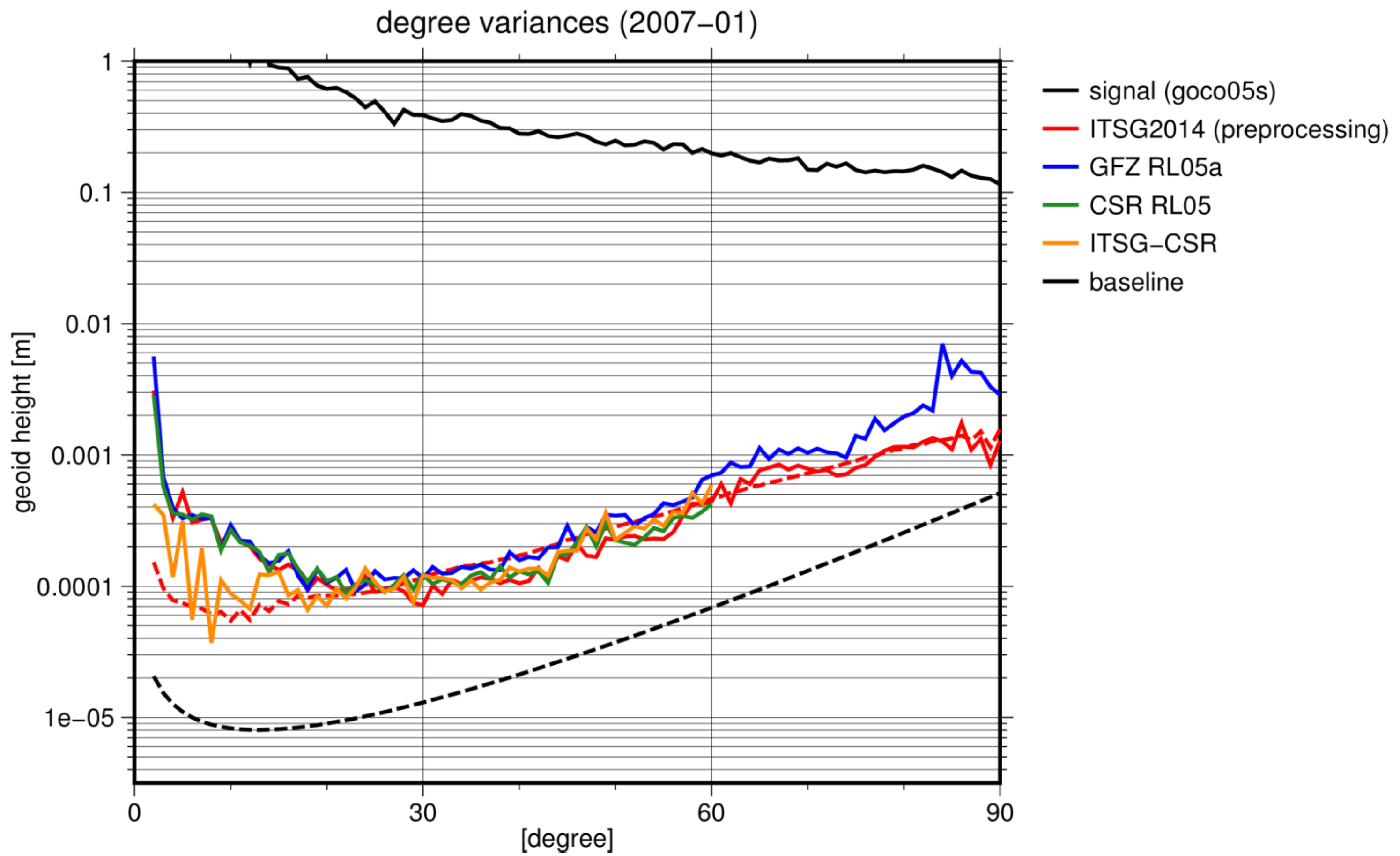
3 Data screening

4 5 6 ACC



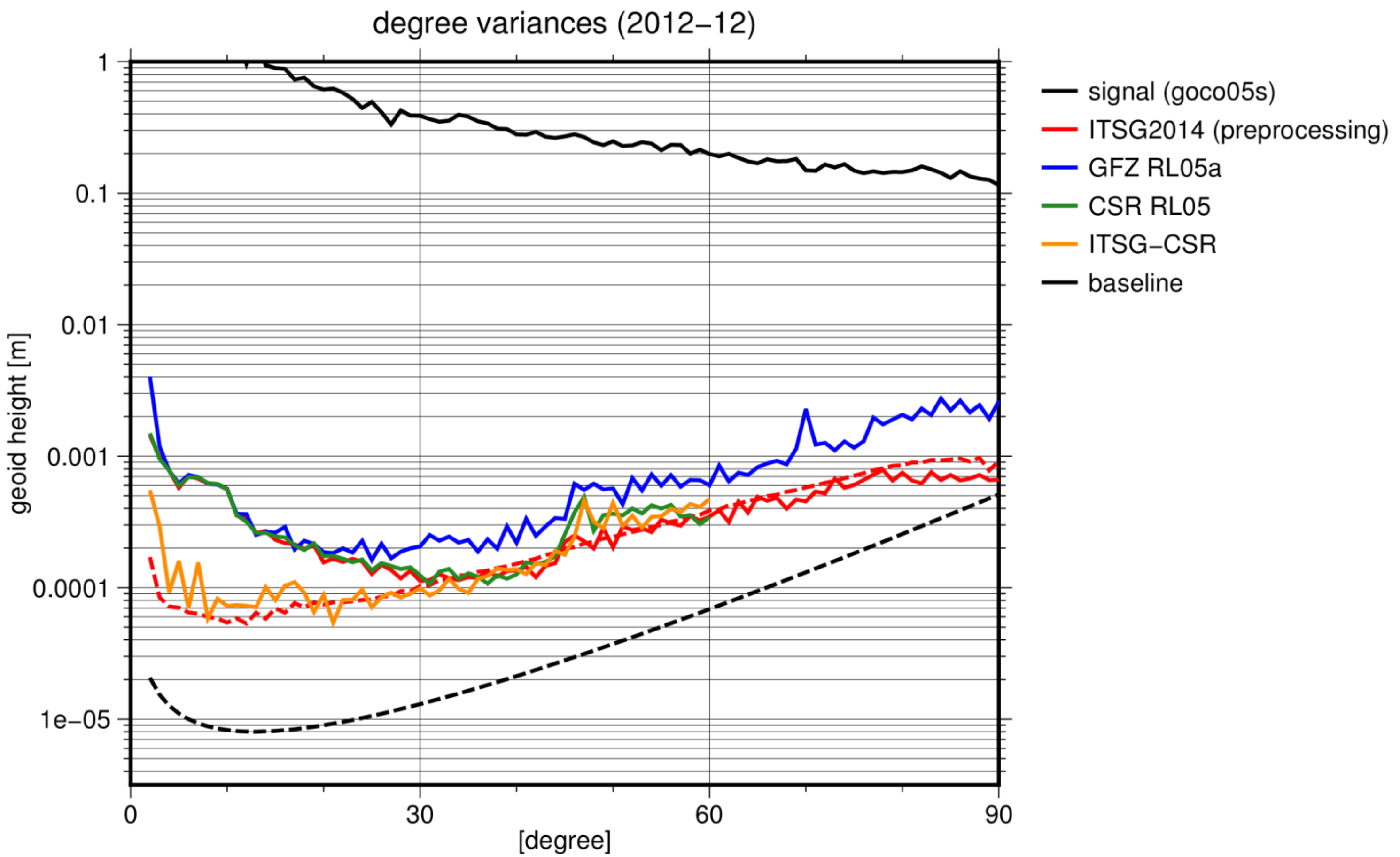
Example: 2007-01

Comparison to official processing centers



Example: 2012-12

Comparison to official processing centers



Conclusions

- Sensor fusion:
  - Combination of star camera and attitude data
  - High frequent noise within attitude data is decreased significantly
- Data screening:
  - Automated & iterative a-priori outlier detection (ACC)
- Accelerometer bias & scale:
  - Adapted modeling of accelerometer bias
  - Important for month with ACC temperature control problems
  - Accelerometer scale: further investigations needed
- Improved preprocessing methodologies contribute substantially to the overall accuracy. But other error sources and disturbances within the GRACE observations still have to be identified.

THANK YOU

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