Assessment of GRACE mission performance and the RL05 gravity fields

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Work described in this paper would not have been possible without the world-class supercomputing facilities at the Texas Advanced Computations Center (TACC)

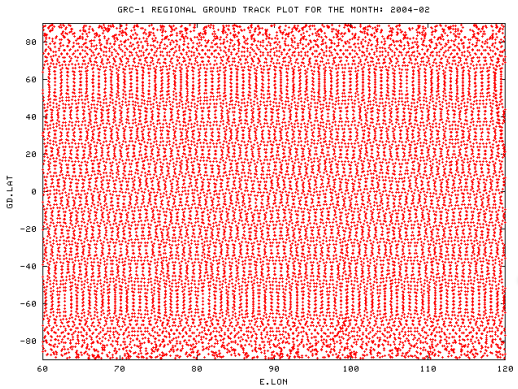
Available GRACE RL05 Products

- Monthly global Earth gravity field models delivered as coefficients of the spherical harmonic expansion of the geopotential (the "GSM-2" products)

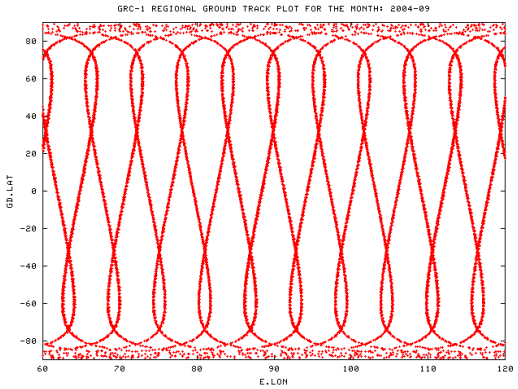
- UTCSR has provided 60x60 GSM-2 data products from Jan 2003 through Sep 2012.
  - Level-2 and Level-1B data products delivered for each new month as they becomes available
  - JPL and GFZ products go to higher degrees for selected months
  - Catch up on 2002 early next year, after re-processed Level-1B data becomes available.

- Error estimates for the CSR products are not yet delivered – Subject of this paper

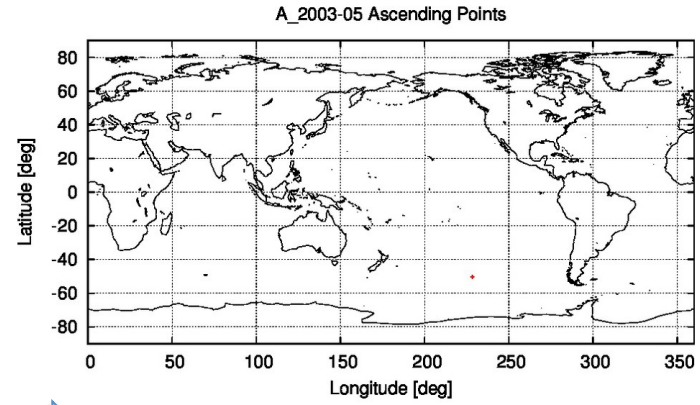
Data Quality Factors: 2003 to present

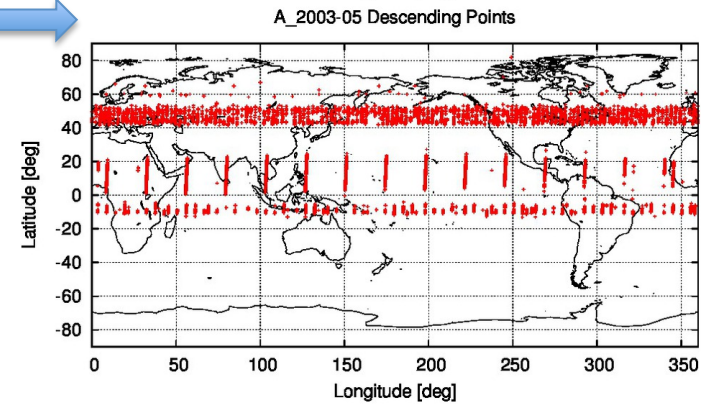


Ground Track

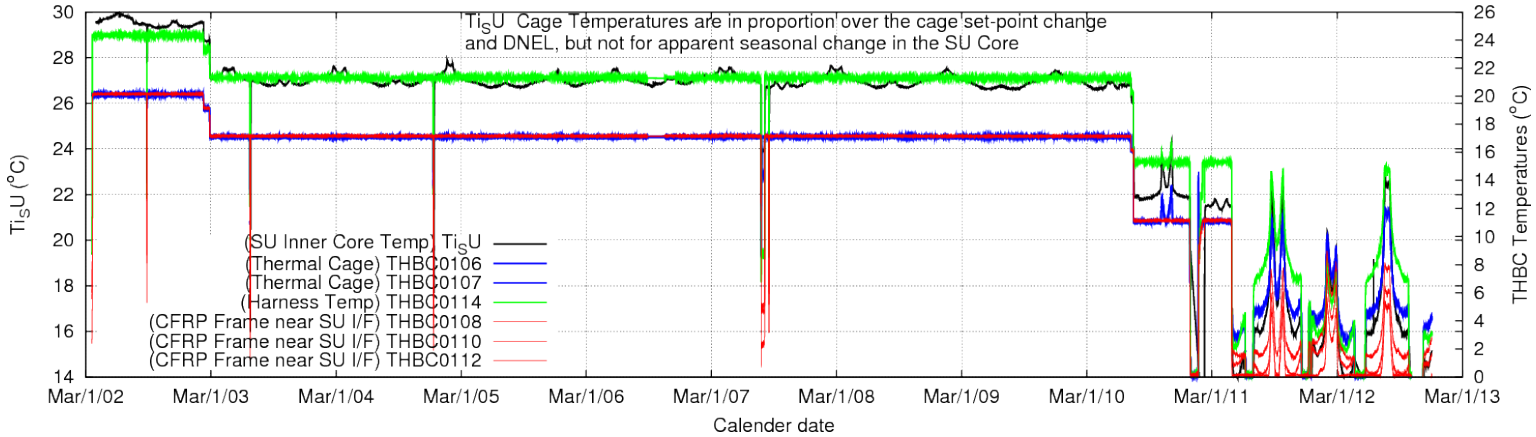


Dual Star Camera Outage





Thermal Control



Data Quality Factors (contd…)

- A fourth factor (star camera data rate) will become relevant once the 2002 data products are available

- Error in each monthly field is determined by the "state" of the GRACE flight segment with respect to each factor:
  - Ground Track: Repeat or Not-Repeat
  - Star Camera Outage: Dual-camera outages or No dual-camera outages
  - Thermal Control: Good Thermal Control or No Thermal Control
  - Star Camera Data Rate (2002 to Feb 2003): Dual-1-Hz or not-Dual-1-Hz

- A catalog with month-by-month data quality factors will be made available to the users at the GRACE website: http://www.csr.utexas.edu/grace/RL05.html

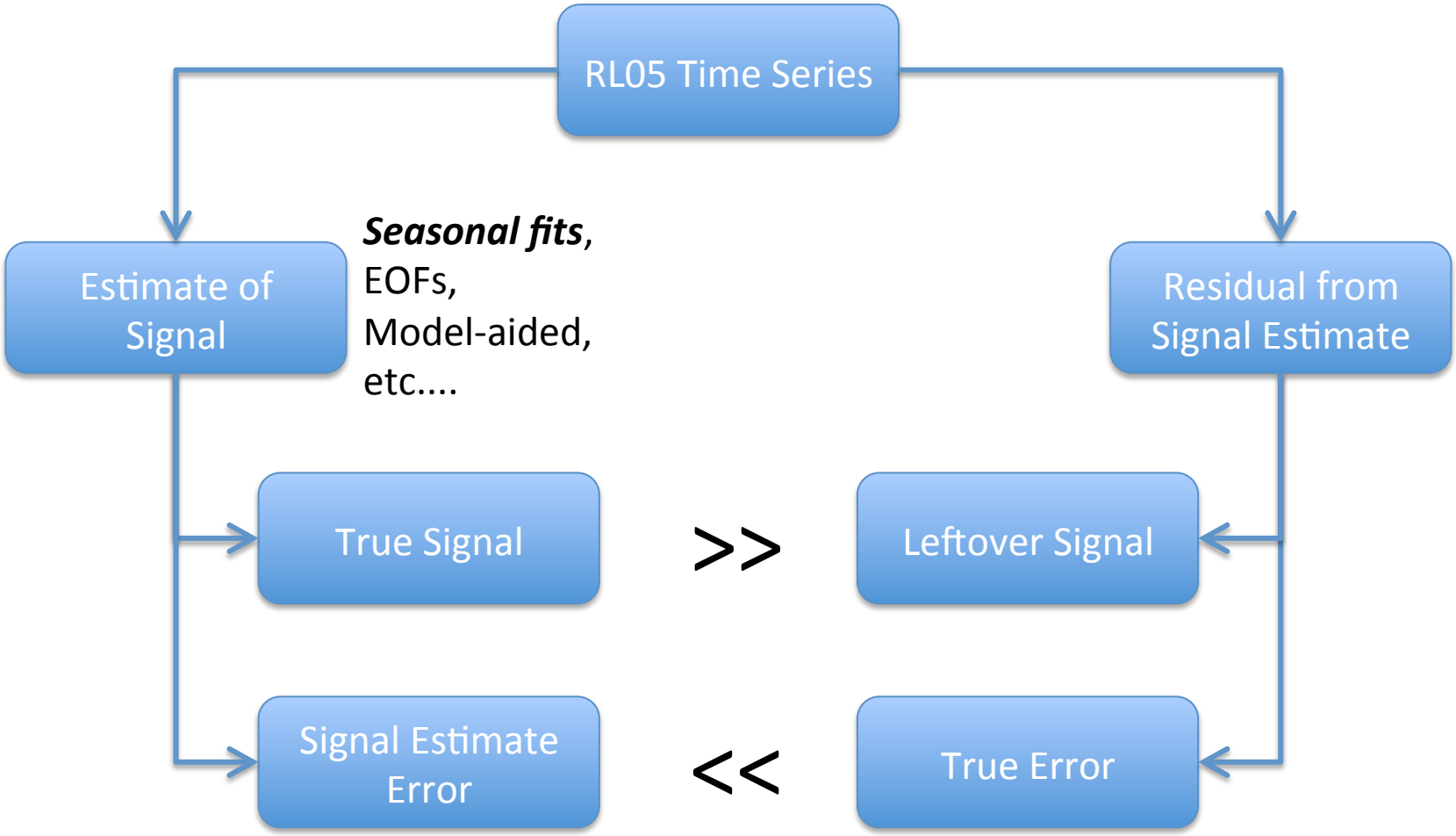
Data Quality Factors (contd…)

- General Observations (in ascending order of size of error):
  - **Dual Camera** Outage: Does not significantly affect spectral (degree) error estimates
    - Changes nature of East-West bands of errors in the selected months with dual-camera outage.
    - Localized effects.
  - **Ground Track Density**: Actual error variation over time is smaller than variation of the formal errors.
    - Exacerbates errors due to bad data arcs
  - **Thermal Control**: Largest reason (so far) for error variation over time

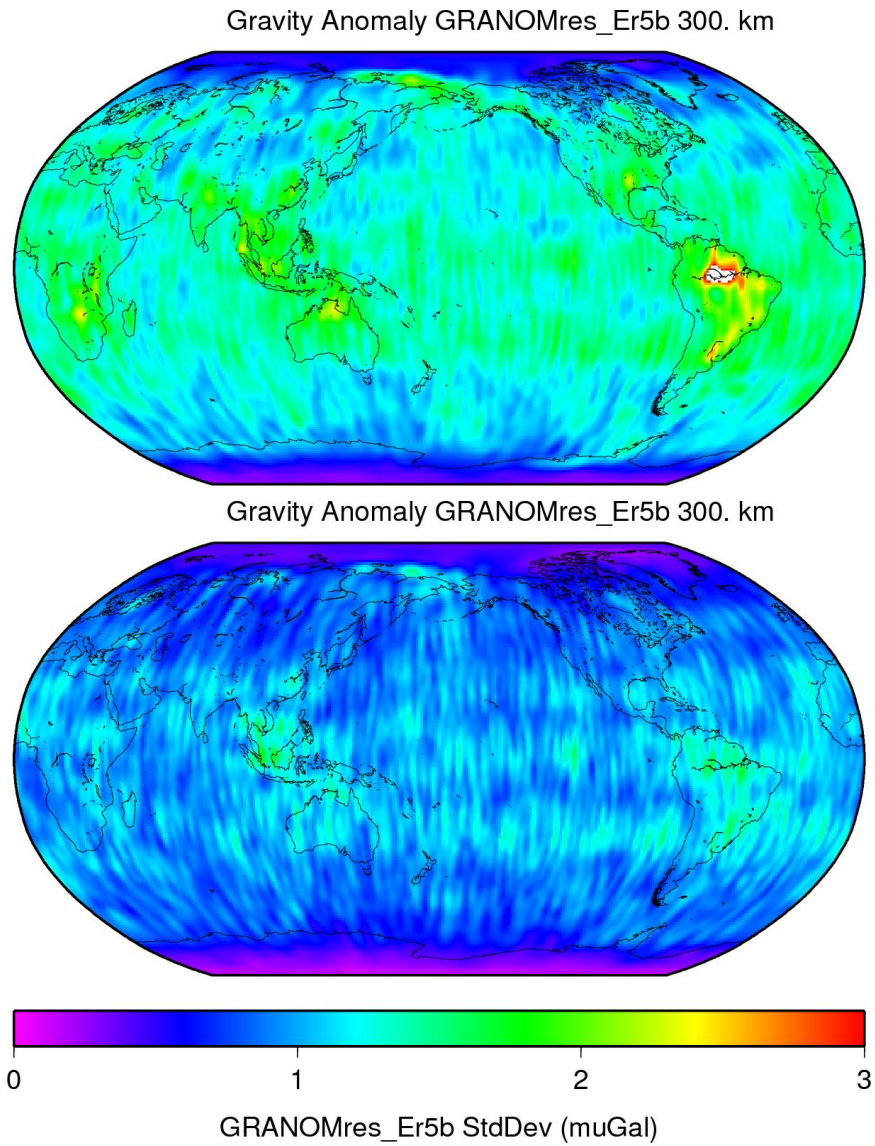
  - **Note:** Another major factor was the effect of "bad-data" arcs – Short stretches of data (minutes to hours) that were identifiably wrong, but for unknown reasons.
    - These were eliminated from RL05 with very careful data editing.
  - **Another Note**: Level-1B data has generally equally improved for all mission periods

- Leads us to:
  - BEST MONTHS: 61 months from March 2003 through Feb 2009
    - Good thermal control
    - Excludes the months with poor tracks
  - WORST MONTHS: All months from April 2011 to present (and onwards)
    - No thermal control
    - Effects of poor tracks are secondary to effects of poor thermal control

Signal and Noise

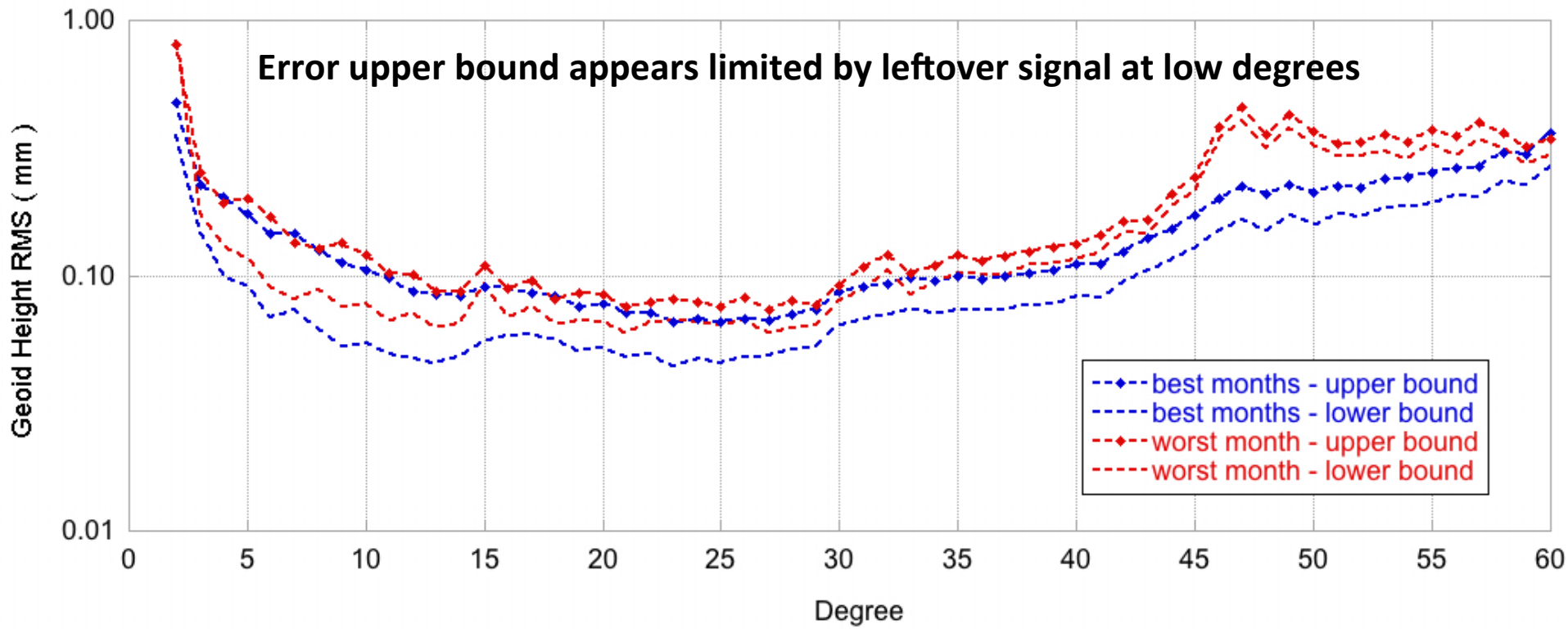


Residuals From Signal Estimates



- Seasonal fits
- Shown for the best months:
  - Top: Error Upper Bound derived with a more conservative approach, but retains more leftover signal
  - Bottom: Derived with a less conservative approach, has lesser leftover signal, but more signal estimate error (not shown)

Error Spectrum

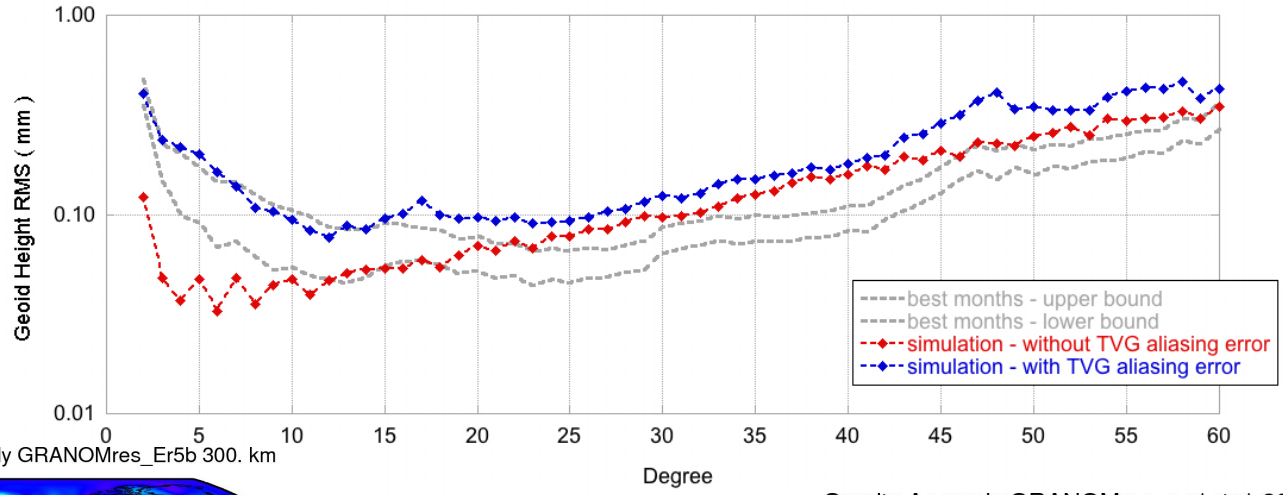


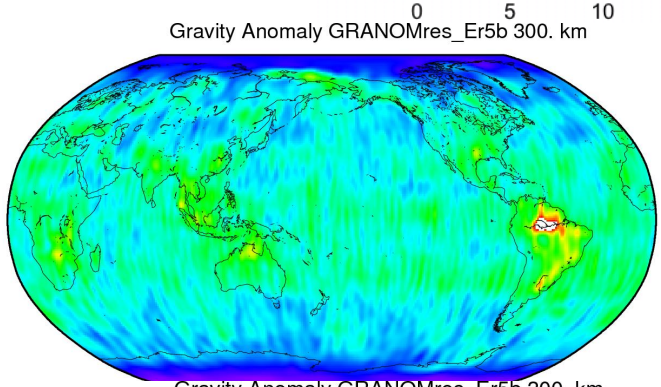
Can we simulate a GRACE mission error scenario that re-creates these errors?

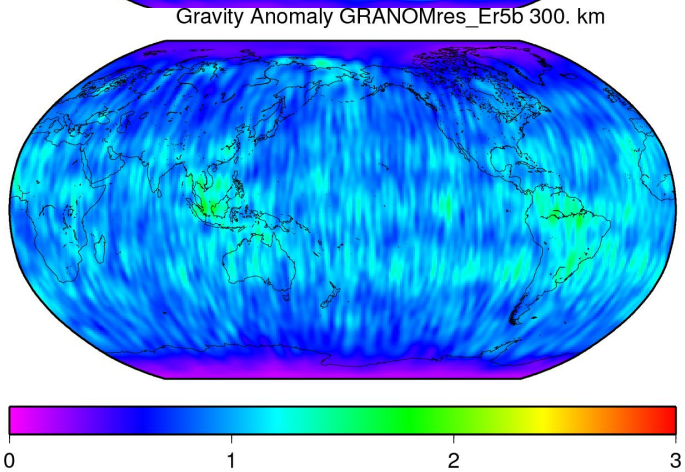
Reminder: Best Months: 61 months from Mar 2003 through Feb 2009

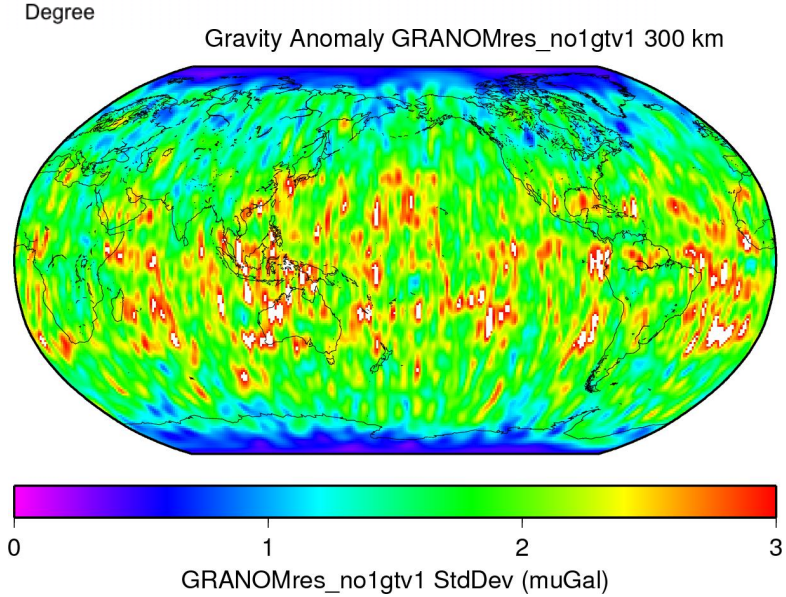
Worst Months: Since April 2011

Comparing to Simulation









Simulations were done for 2008 – among “best months”
Simulation errors shown above, compared to “best” month errors at left.

Findings

- Simulation Model
  - Measurement Error – Suite of error "best-estimates" based on study of flight data
  - Time Variable Gravity Error –
    - Non-tidal Atmosphere & Ocean: AOD1B_RL04 – NCEP_IB
    - Ocean Tides: GOT 4.7 – FES2004

- Some amount of time-variable gravity aliasing error is essential to explaining the residual error upper bound at the lower harmonic degrees
  - This was generally not the case for RL04 – other "factors" could dominate
  - Have not yet found a system-level GRACE measurement error that can create the "fish-hook" in the error bounds
  - The Measurement Error model is perhaps too tuned to the expectations of RL04
  - The modeled "newer-older" de-aliasing error model suite explains the low-degree error spectrum well enough, but is too much at higher degrees (recall the 300 km smoothing)

Proposed Follow-Up

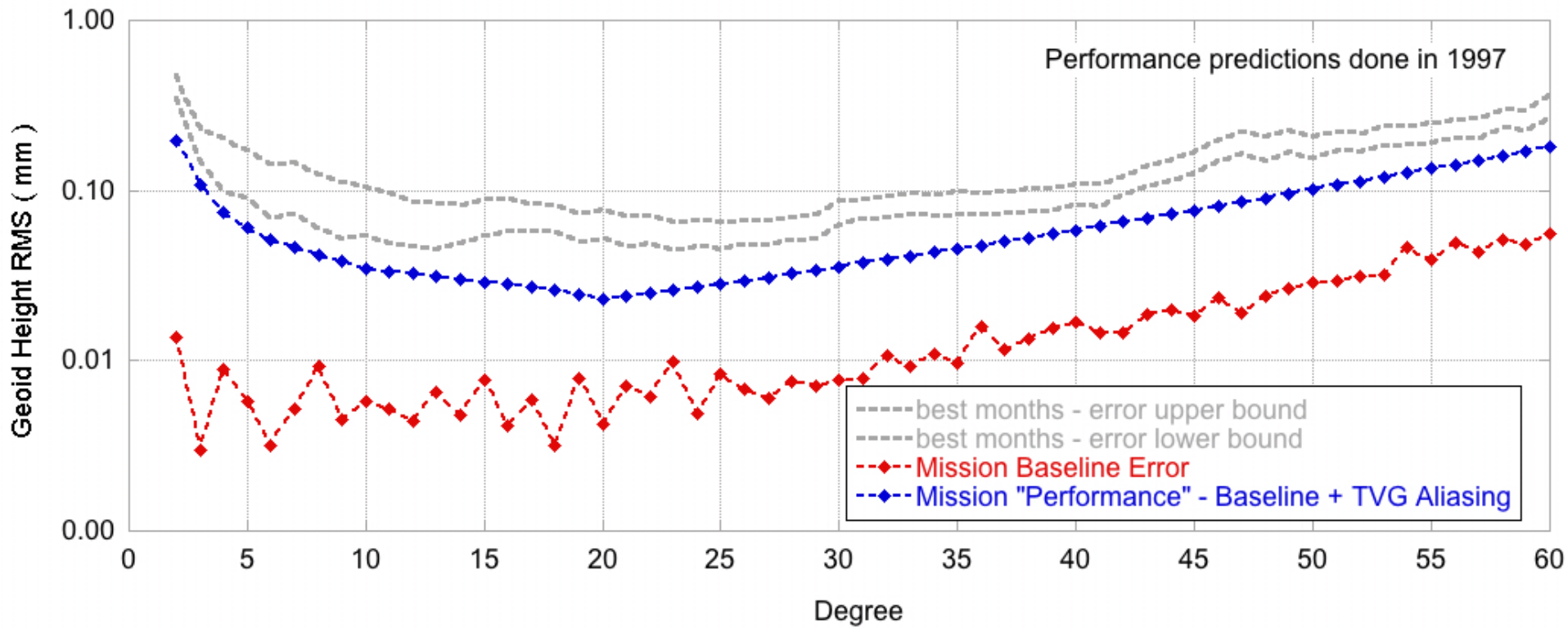
- Two (possibly three) tuned covariance matrices can be provided
  - The “best” months
  - The “worst” months
  - A third one for launch in 2002 through Feb 2003

- For each month, a catalog of the relevant factors will be provided, and suggested covariance matrix will be specified

- Small scale basin average time-series are susceptible to episodic additional errors, depending on specific place and time. There is no easy way yet to provide a universal specification of such error. Careful outlier detection may be needed, in addition.

- This framework does not account for subtle differences between solutions from different centers at the lowest degrees (particularly degree-2). That requires separate geodetic validation.

Looking Back…



Baseline Errors were used for flight system hardware specification
The “Performance Baseline” was used to communicate the role of model errors vis a vis system performance limitations

Thank you for your attention !!