

The GGM03 Mean Earth Gravity Model from GRACE

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Next Generation Models

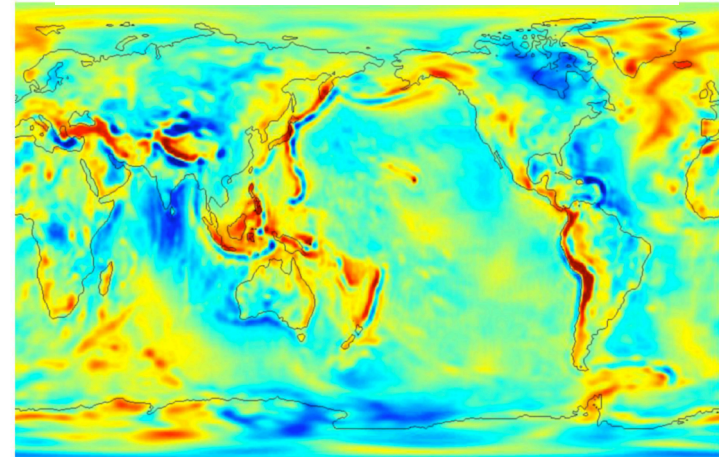
- **GGM03S**

- Four full years of GRACE data to help average annual variations
 - Jan 03 - Dec 06 (only Jan 04 missing)
- Improved background models and processing methods (RL04)
- Complete to degree/order 180

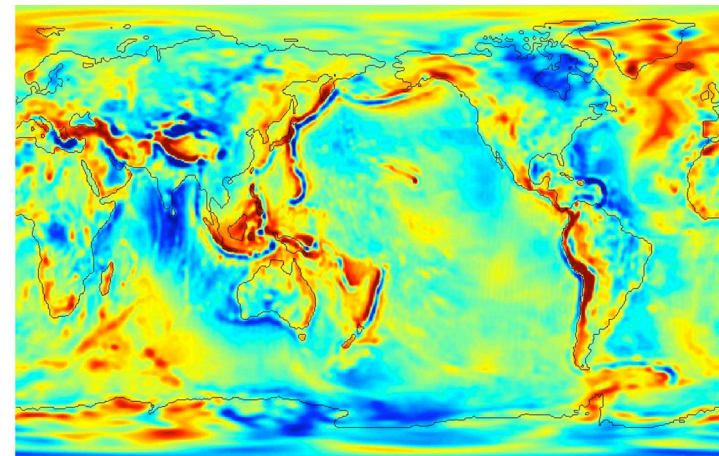
- **GGM03C**

- Rigorous combination of GGM03S with full degree/order 360 information equations from surface gravity and altimetric mean sea surface (with complete covariance)
- Ensures smooth blending from GRACE to surface information

GGM02S (13 months)



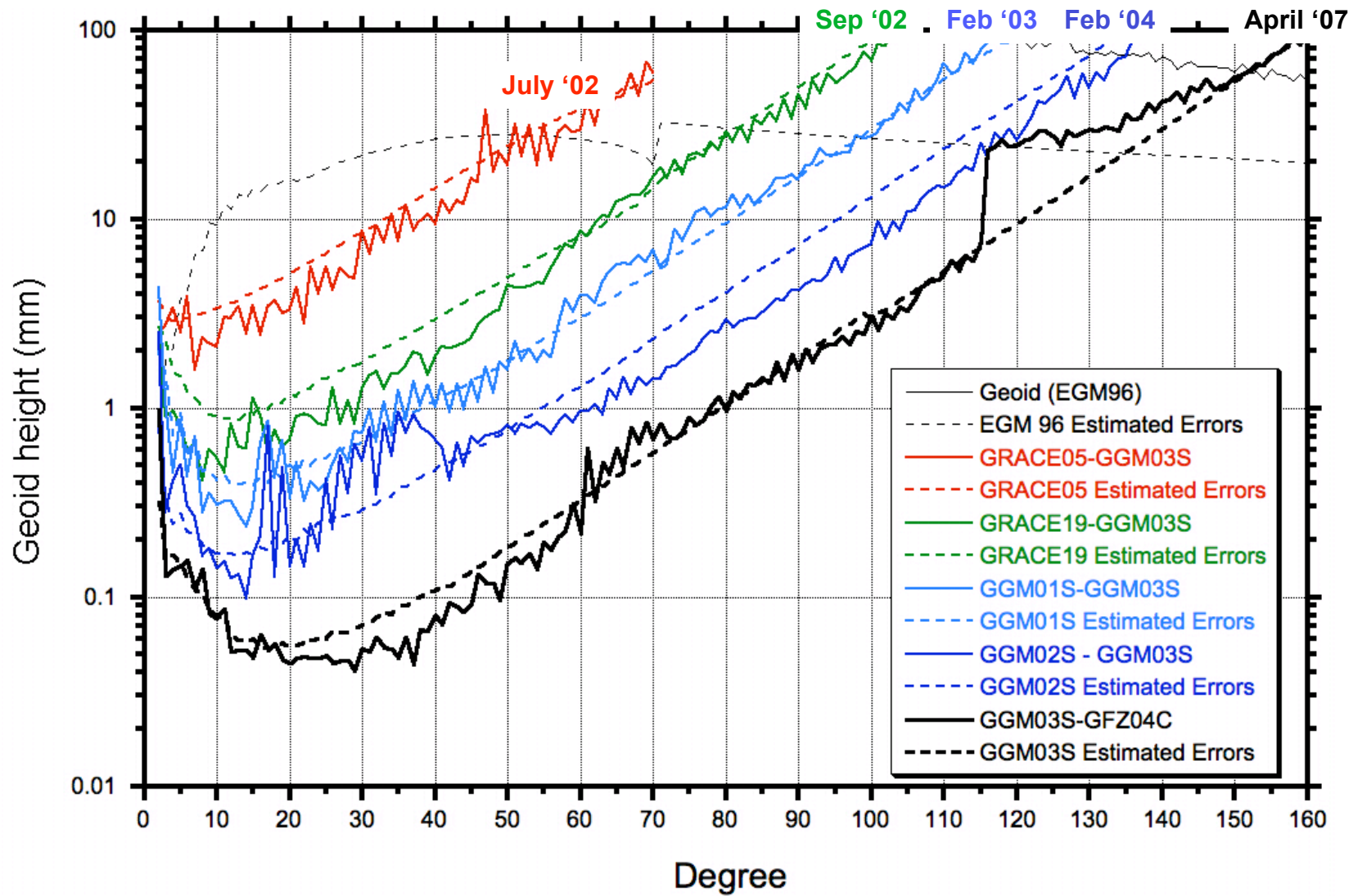
GGM03S (47 months)



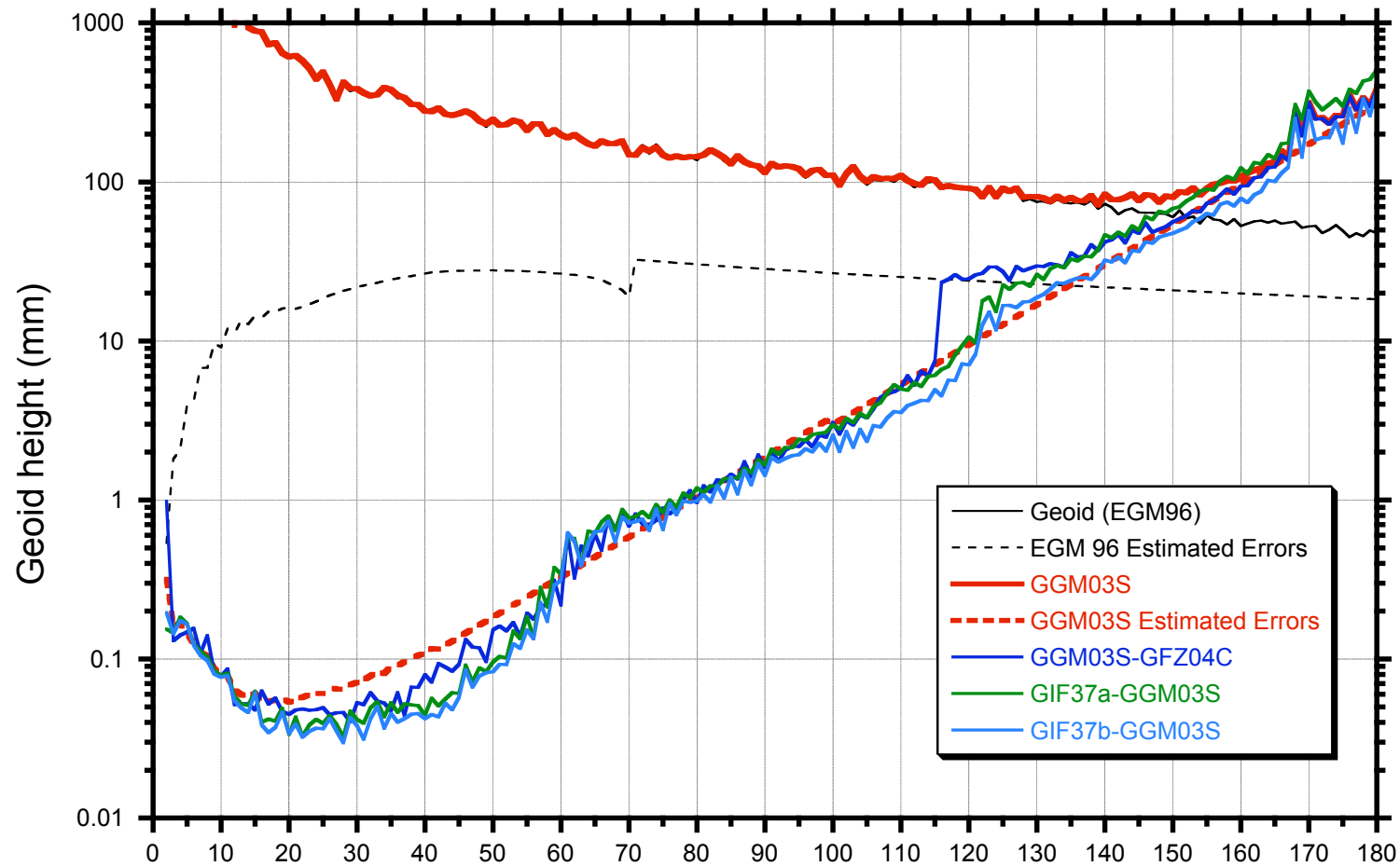
-60 -40 -20 0 20 40 60

Gravity Anomalies (mgal)

Progress in Mean Gravity Models



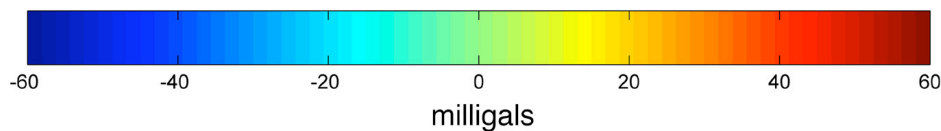
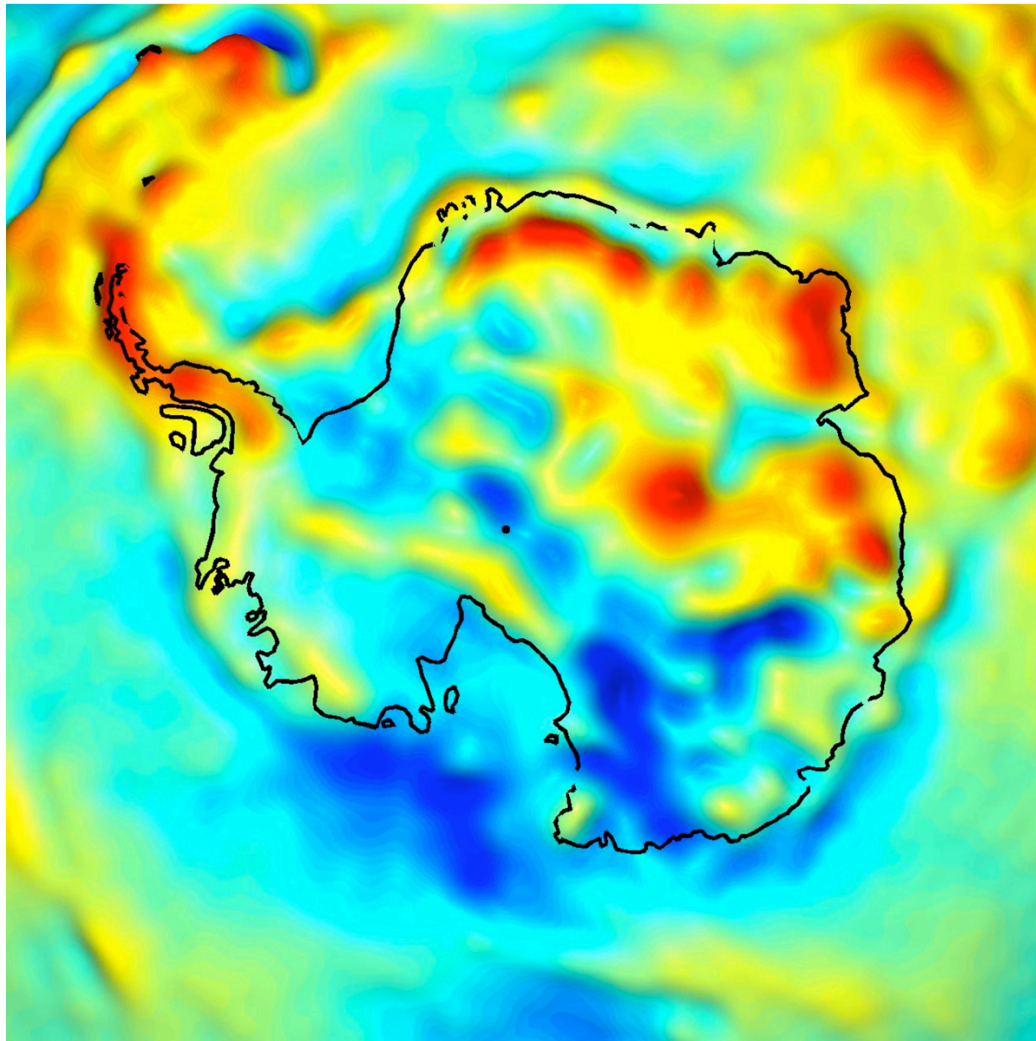
GGM03S Error 'Calibration'



GIF37a and GIF37b are subset-solutions (2003-2004 & 2005-2006)

GFZ04C is EIGEN-GL04C

GGM03S over Antarctica



Gravity anomalies from GGM03S to degree/order 140 (~140 km resolution)

Can probably be pushed to degree/order 160

High accuracy geoid can be used to remove biases in aerial gravity surveys in this region

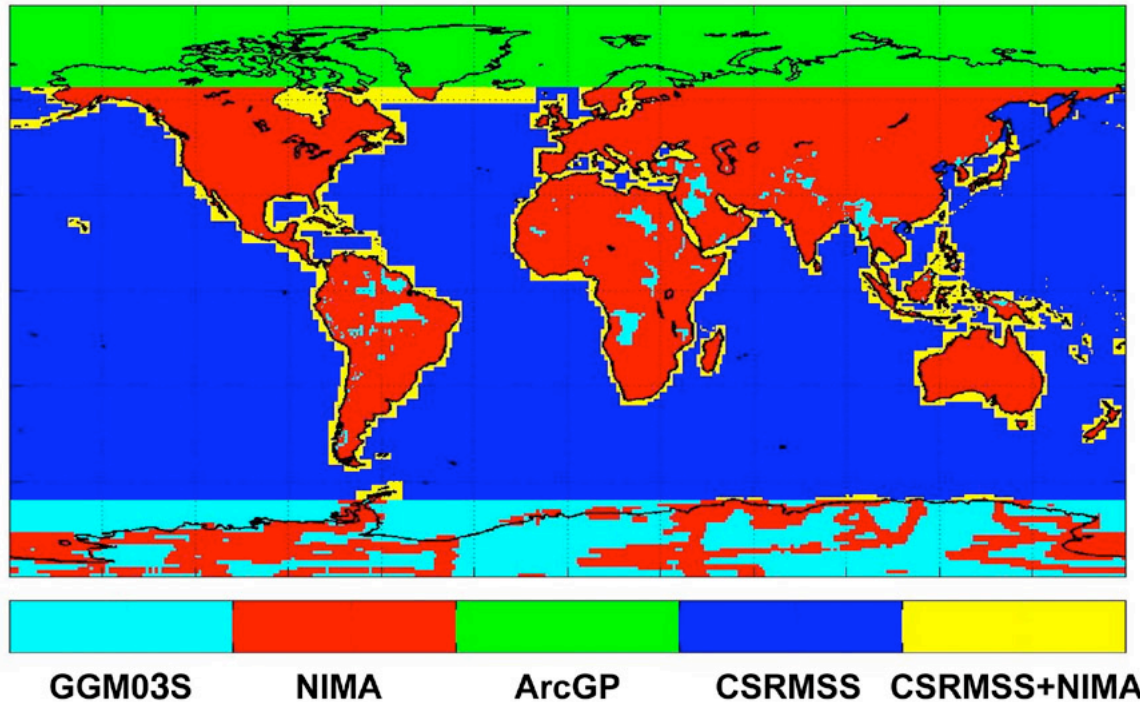
Scale is +/- 60 mgal.

GGM03C Processing Strategy

- Combine altimetry derived sea surface data over water, gravity and other types of data over land, with very precise GRACE data
 - Inhomogeneous data types combined using optimal weighting approach
 - Allows a seamless transition between satellite and surface data
 - Allow for mixed data types (e.g., deviation of the vertical, gravity, sea surface heights, gradients, point-by-point data weighting and non-uniform distribution)
 - Ingest gravity observations directly (can include biases or other parameters)
 - Produces a solution with full covariance matrix, complete to spherical harmonic degree/order 360 (or higher) involving ~130,000 parameters (68 GB)
 - Ready for simultaneous GRACE/GOCE/surface combination
- New out-of-core parallel processing algorithm developed to enable solution of large problem with reasonable computational resources
 - In-core solution would require 160 GB of memory (104 processors)
 - Required ~4 days of wall clock time to compute using two IBM P5 575 nodes (16 Power5 1.9 GHz processors) and only 32 GB of memory

Data Sources and Coverage

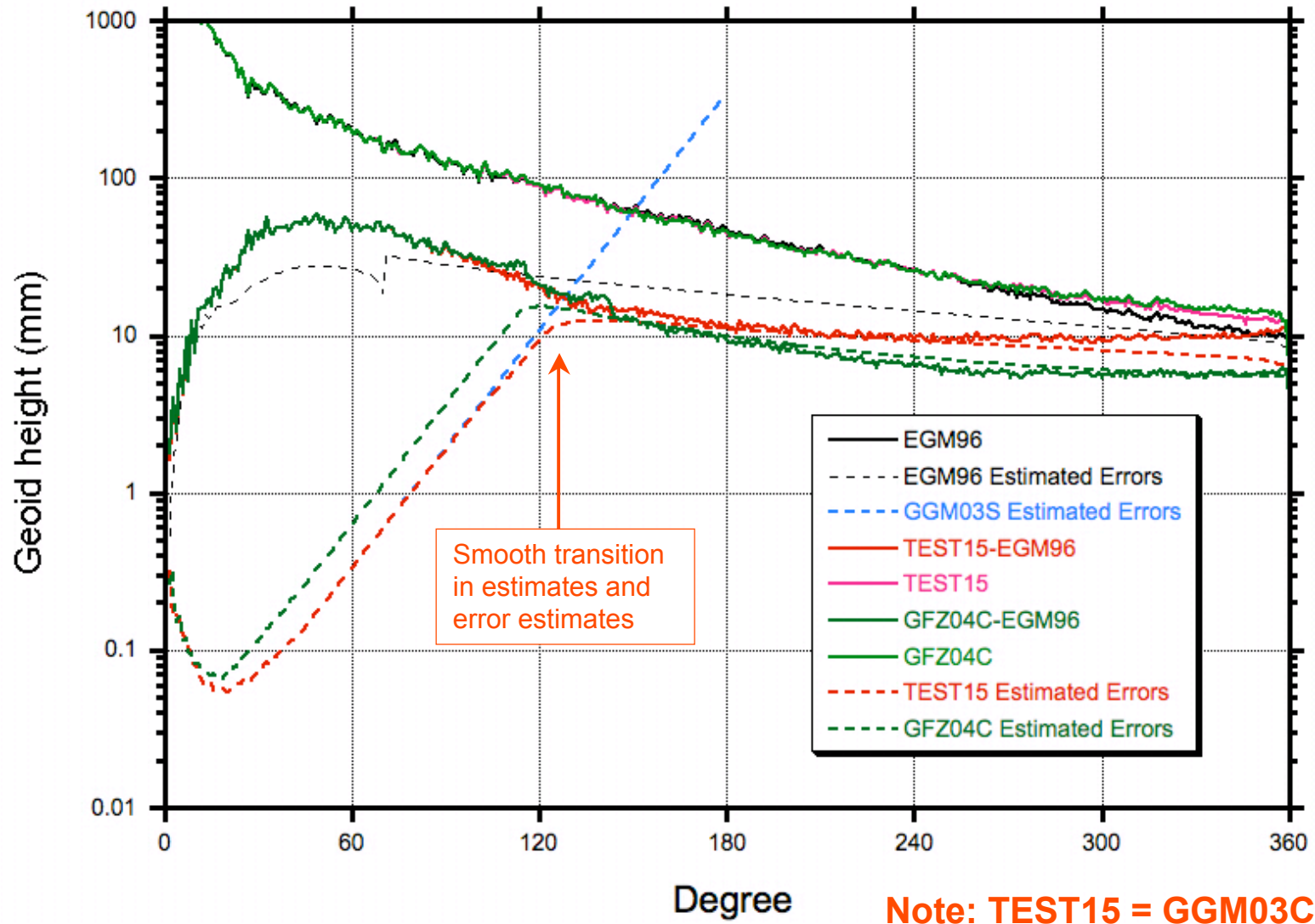
Data Sources and Coverage



- 1) Latest ArcGP gravity anomalies for latitude > 64 deg reduced to 0.5 deg
- 2) NIMA 0.5 deg gravity anomalies over land only
- 3) CSRMSS98 mean sea surface reduced to 0.5 deg meridional and zonal slopes
- 4) Coastal areas overlap NIMA and CSRMSS98
- 5) No topographic predictions used; missing areas filled in with GGM03S gravity model
- 6) GGM03S information equation, based on 4 years of GRACE data spanning 2003-2006, suitably calibrated

GGM03C Solution

360x360 combination of GGM03S and surface information

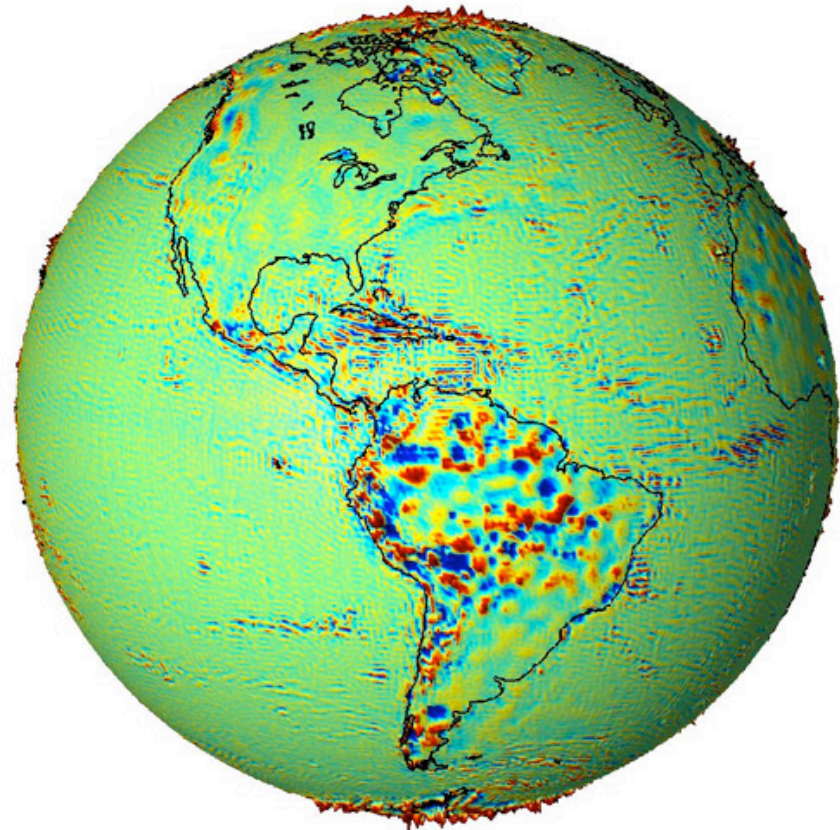
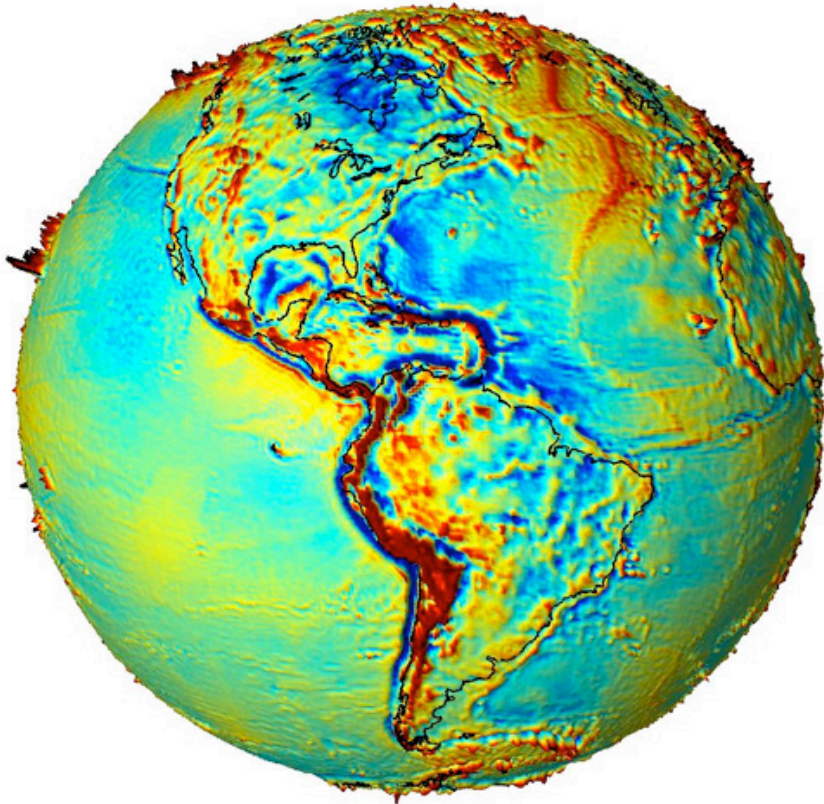


GGM03C-EGM96 (1)

North/South America

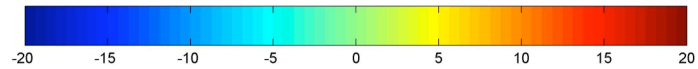
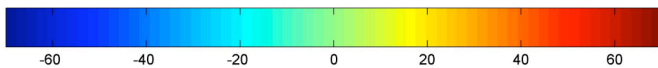
TEST15

TEST15 - EGM96



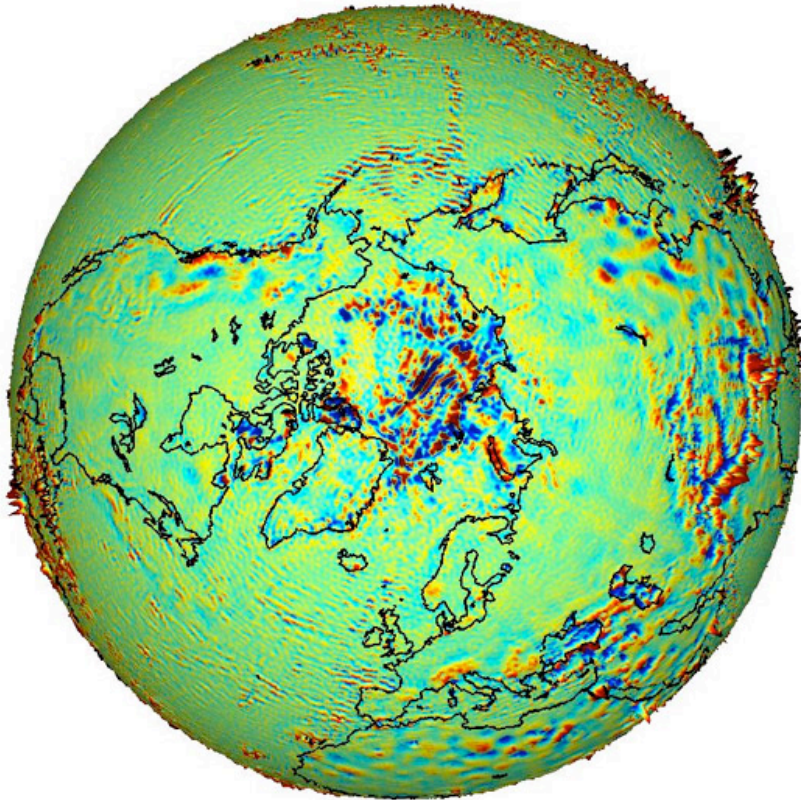
scale is +/- 70 mgal

scale is +/- 20 mgal

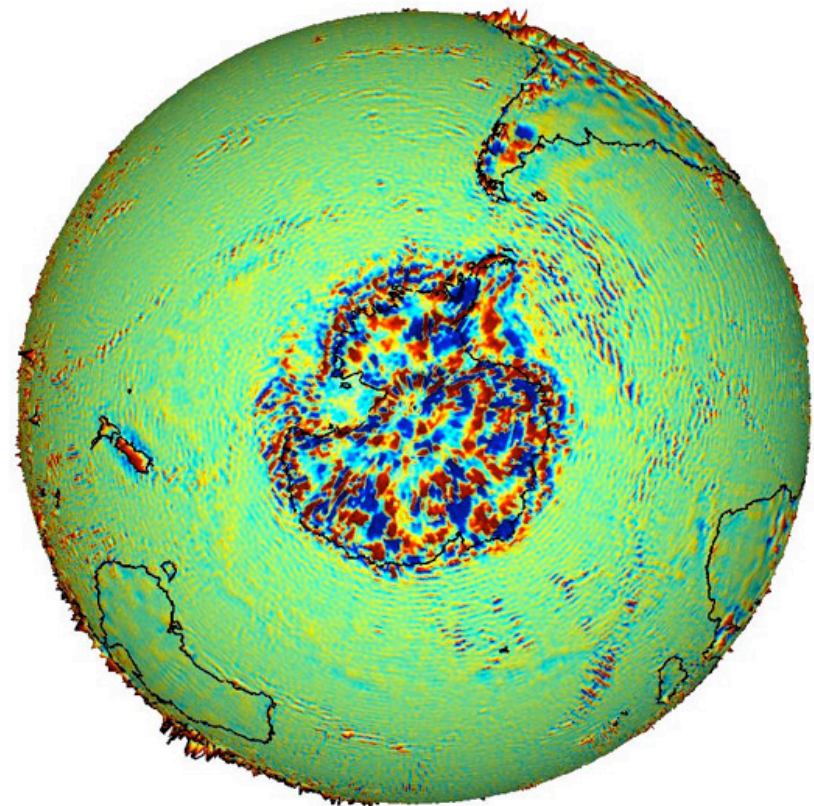


GGM03C - EGM96 (2)

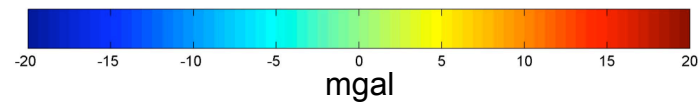
Arctic



Antarctica

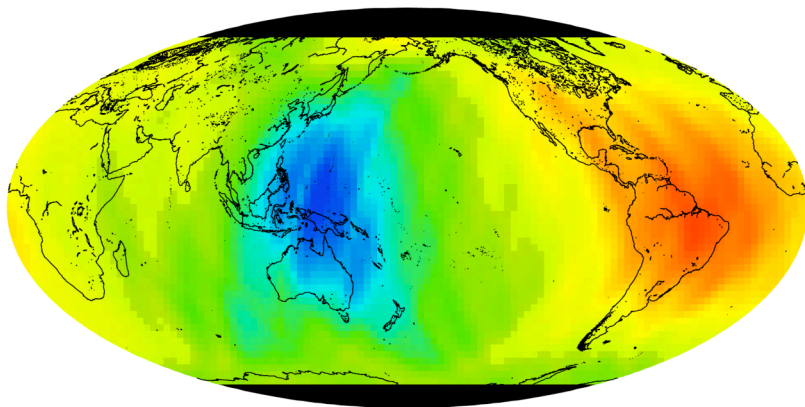


scale is +/- 20 mgal

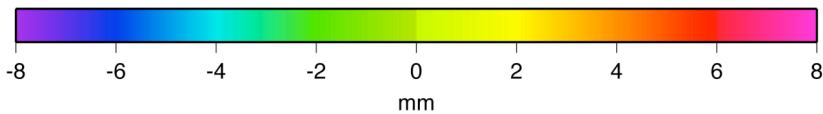


Orbit Tests

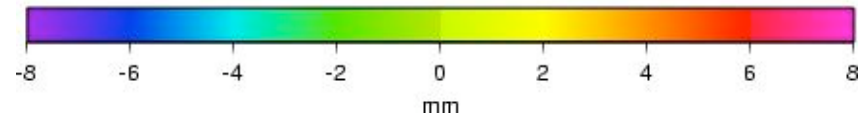
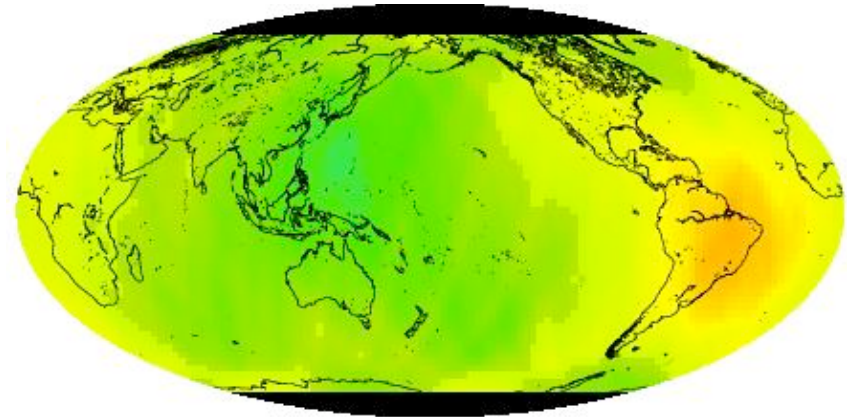
Correlated orbit differences for Jason-1 and Topex/Poseidon continues to decrease as gravity models improve



Dominated by 'Order-1' pattern



GGM02C vs
EIGEN-GL04C
(+/- 6 mm)



GIF22a vs
EIGEN-GL04C
(+/- 3 mm)

Marine Geoid Evaluation

Geostrophic Currents Comparison

Comparison of geostrophic currents computed from various geoid models (after 400 km smoothing) with the World Ocean Atlas 2001 (WOA01) data (Stephens et al. 2002) (relative to 4000 m, courtesy of V. Zlotnicki).

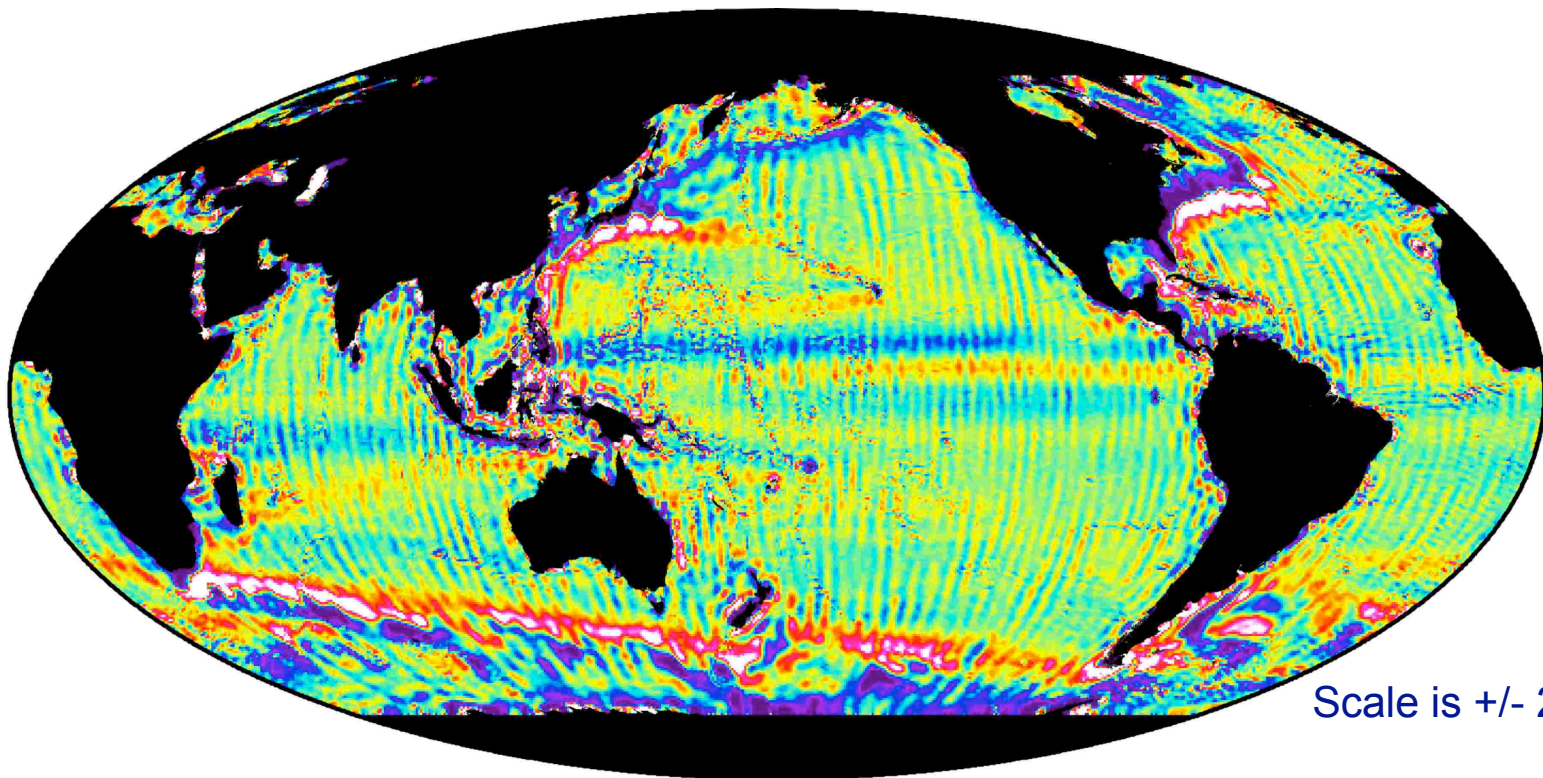
A higher correlation indicates a more accurate marine geoid model (caveats include: WOA smoothed to ~400 km, different averaging intervals for MSS, WOA and GRACE geoid, errors in WOA).

Model	Standard Deviation (cm/s)		Correlation	
	Zonal	Meridional	Zonal	Meridional
EGM96	8.18	7.00	0.352	0.288
EIGEN-GL04C	3.01	3.01	0.916	0.543
GGM03S	2.91	2.97	0.921	0.550
GGM03C	2.94	2.99	0.919	0.542

(Note: GGM03S includes no surface information)

Short Wavelength Geoid Residuals GGM02C

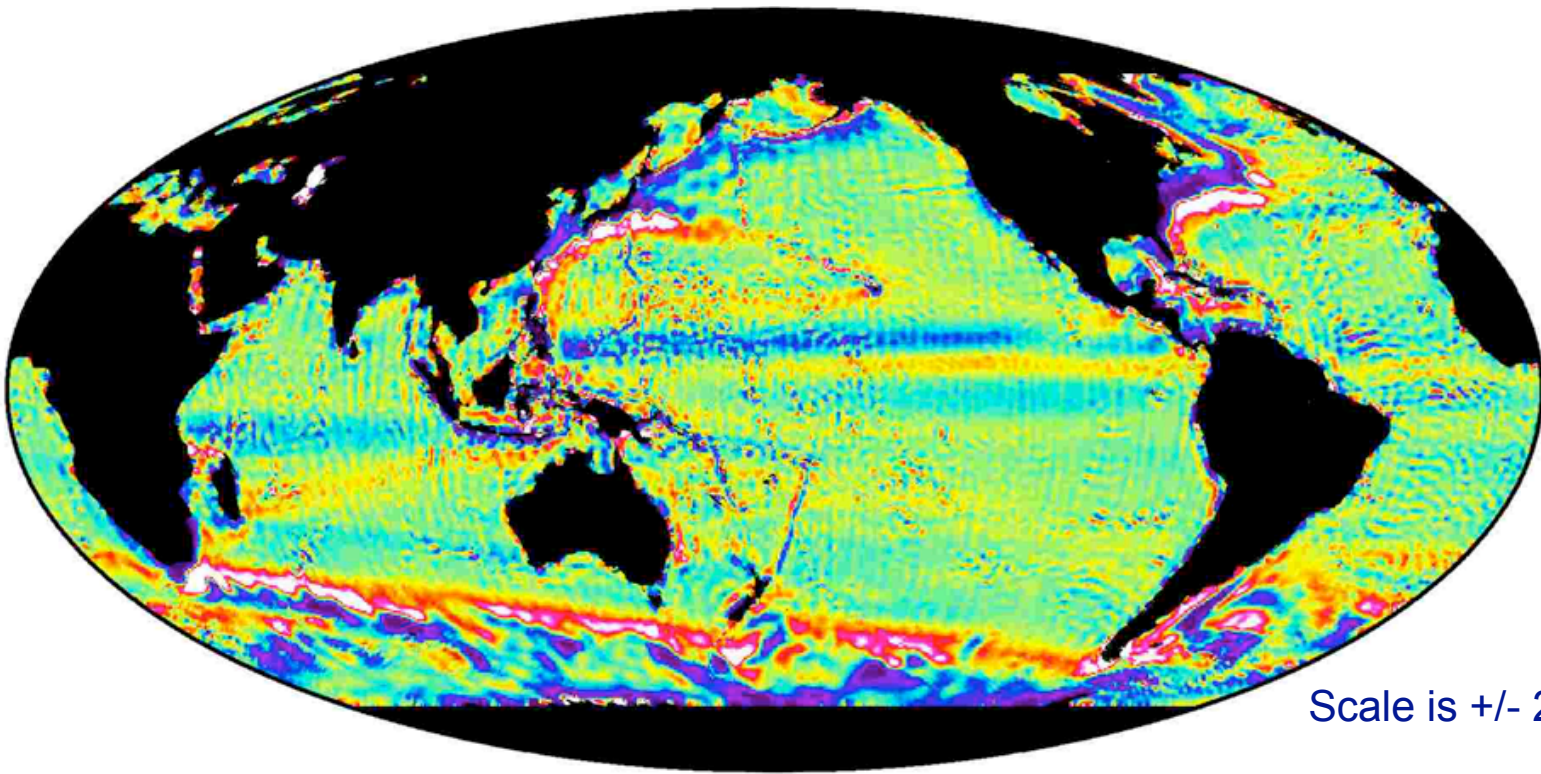
The residuals are the difference between a 'high-frequency DOT' defined as (GSFCMSS00 – geoid) and the same DOT smoothed to ~900 km



Scale is +/- 25 cm.

Short Wavelength Geoid Residuals GGM03C

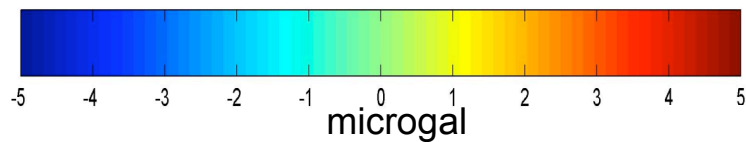
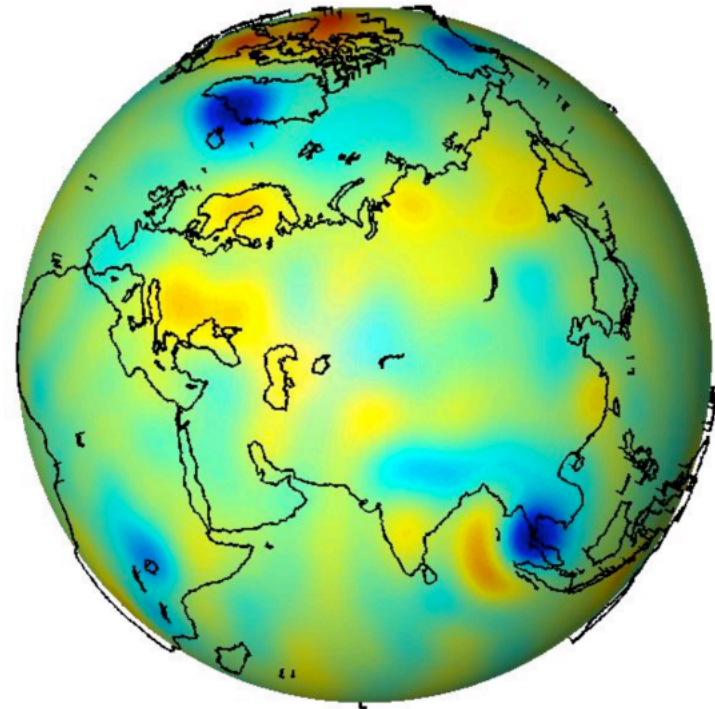
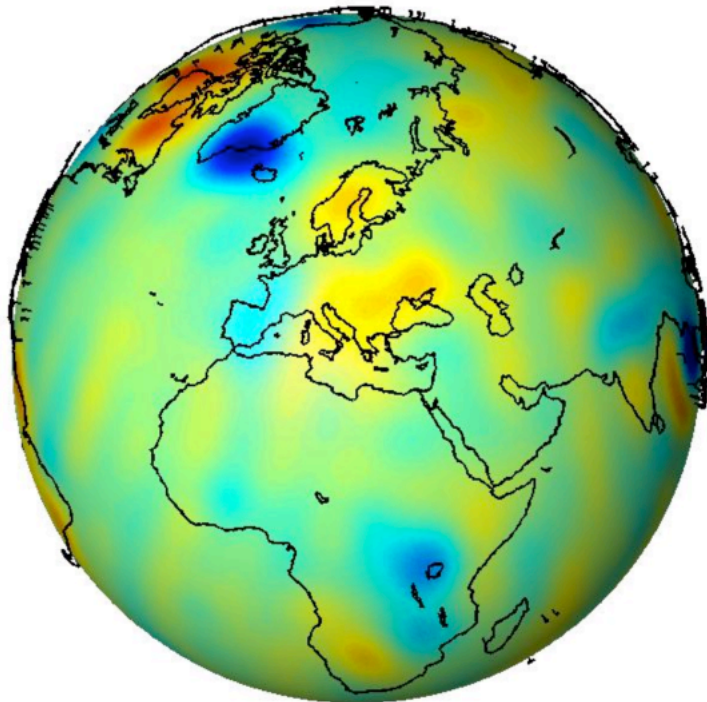
The residuals are the difference between a 'high-frequency DOT' defined as (GSFCMSS00 – geoid) and the same DOT smoothed to ~900 km



Scale is +/- 25 cm.

What Does 'Mean' mean?

Difference between two 2-year means (2003-2004 and 2005-2006) (to degree/order 30)



GRACE mean fields are epoch 2000.0, but only for J2-4 and C21/S21

Summary

- Third generation mean gravity solution GGM03S based on four years of GRACE Release-04 processing continues to refine details in gravity as seen from space
 - Further increases in resolution become progressively more difficult
- GGM03C solution rigorously combines full degree/order 360 surface information with GRACE
 - Some issues still to be resolved before final solution is ready
- Accuracy of GRACE mean fields also raises questions about definition of ‘mean’
 - Should higher degree/order secular terms be included?
 - How to handle ‘episodic’ changes (similar issue with TRF)?