Progress in Marine Geoid Modeling

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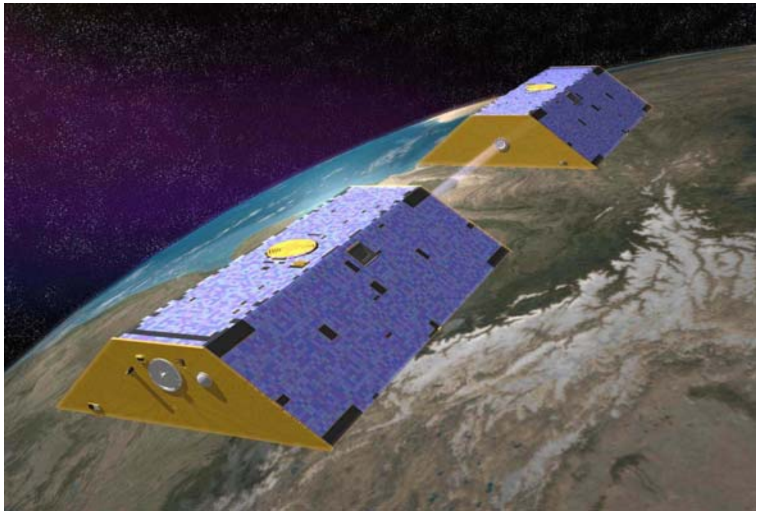
GRACE Mission Status

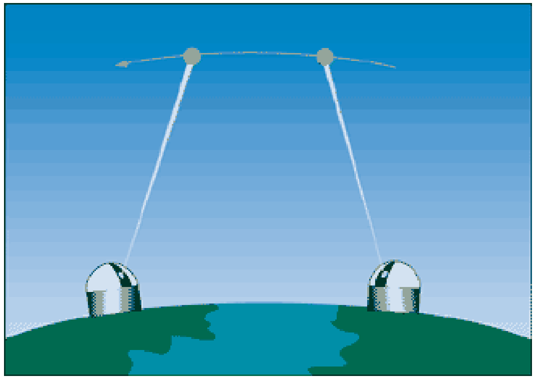
- **Mission Accomplishments:**
  - 2007 William T. Pecora Award (US DoI/NASA/USGS)
  - Gravity Models
    - Mean fields (GGM03S, EIGEN-GL05S/C, ITG-GRACE03S and others)
    - Time variable fields (75 monthly solutions through September 2008)
  - Time variable effects in gravity field are stimulating mass flux studies in Hydrology, Oceanography, Glaciology and Solid Earth Sciences
- **NASA 2007 Senior Review and DLR approved mission extension and funding through 2009**
  - Extension to 2011 approved by NASA "in-principle"
  - Discussions underway at DLR
- **Flight Segment**
  - Nearly 100 % of scientific measurements for nearly seven years have been collected and analyzed
  - Instrument performance continues to meet mission requirements



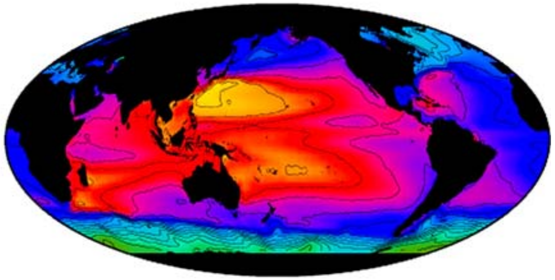
Orbit
Launched: March 17, 2002
Nearly 7 years in orbit
Initial Altitude: 500 km
Current Altitude: ~460 km (-10 m/day)
Inclination: 89 deg
Eccentricity: ~0.001
Separation Distance: ~220 km
Nominal Mission : 5 years
Non-Repeat Ground Track, Earth Pointed, 3-Axis Stable
Predicted Lifetime until 2013

Gravity Model Evaluation
(limited to degree/order 360)

- Orbit determination tests
  - Laser ranging to geodetic satellites and using models consistent with RL04 processing (IERS2003 standards, ITRF2005, RL04 Atmosphere-Ocean Dealiasing)
  - GRACE K-band range-rate
- Marine geoid tests
  - Test consistency of inferred ocean circulation from (DOT - geoid) (up to d/o 120)
  - Tests consistency of short-wavelength geoid with mean sea surface from altimetry (up to d/o 360)



Satellite Laser Ranging (SLR)

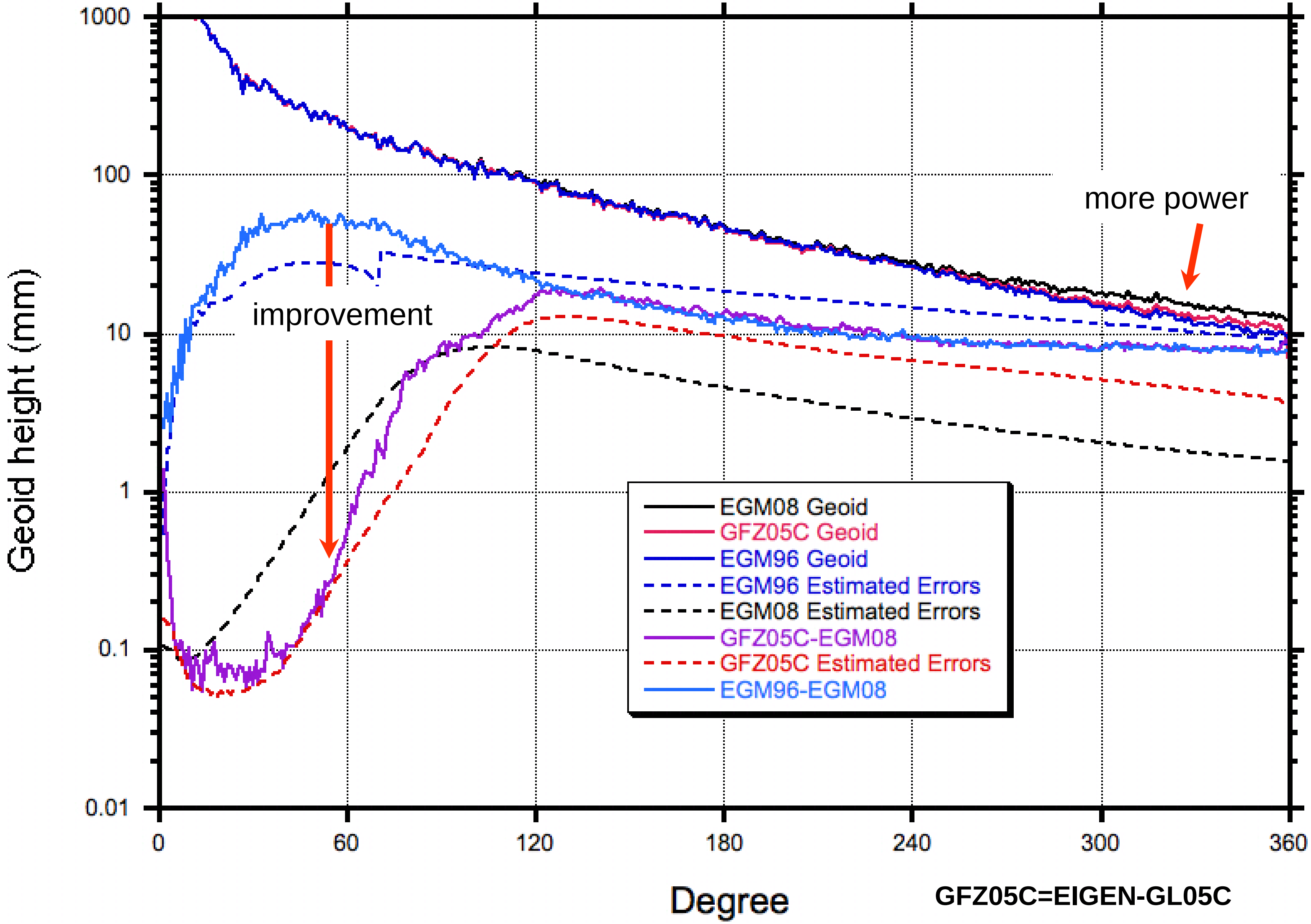


Dynamic Ocean Topography (DOT)

Geoid Models

- EGM96 (360x360, Lemoine et al., 1998)
  - Pre-GRACE model
- EIGEN-GL04C (360x360, Förste et al., 2008)
- EGM2008 (2190x2159, Pavlis et al., 2008)
  - Only 360x360 part tested here
- EIGEN-GL05C (360x360, Förste et al., 2008)
- GGM03S (180x180, Tapley et al., 2007)
  - Satellite-only model

Progress from EGM96



GFZ05C=EIGEN-GL05C

Geodetic Orbit Fits (1)

Satellite laser ranging fits to 6 geodetic satellites
(units are cm)

Satellite	EGM96	EGM08	GGM03S	GFZ05C
LAGEOS-1	1.5	1.5	1.5	1.4
LAGEOS-2	1.3	1.4	1.3	1.3
Ajisai	5.9	5.3	5.0	5.0
Starlette	5.1	4.8	3.4	3.3
Stella	9.0	3.0	2.8	2.6
BEC	11.1	9.4	9.1	9.0

Average laser ranging residual RMS from one year (2003) of 3-day orbit fits without adjusting once-per-revolution (1-cpr) empirical accelerations

Fits may be dominated by longer wavelength gravity model errors, particularly secular perturbations and long-period resonances, as well as non-gravitational effects

RL04 background models used (including AOD1B)

Geodetic Orbit Fits (2)

Satellite laser ranging fits to 6 geodetic satellites
(units are cm)

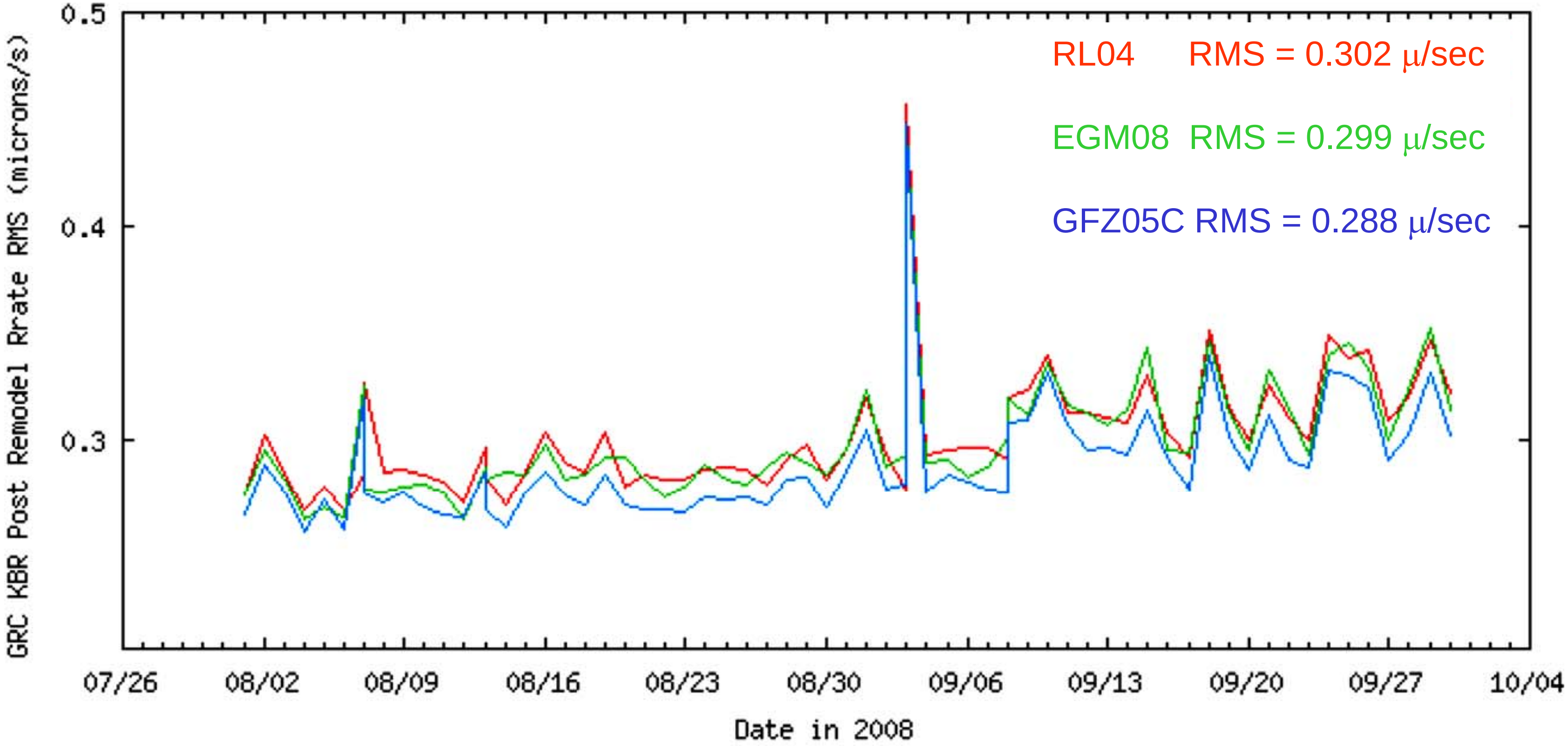
Satellite	EGM96	EGM08	GGM03S	GFZ05C
LAGEOS-1	1.05	0.97	0.97	0.96
LAGEOS-2	0.96	0.85	0.85	0.84
Ajisai	5.6	4.4	4.4	4.8
Starlette	3.7	1.8	1.8	1.7
Stella	6.5	1.6	1.6	1.6
BEC	9.1	7.6	7.5	7.5

Average laser ranging residual RMS from one year (2003) of 3-day orbit fits with adjusting once-per-revolution (1-cpr) empirical accelerations

Empirical accelerations remove longer wavelength orbit errors, including secular perturbations, long-period resonances and some part of the non-gravitational effects

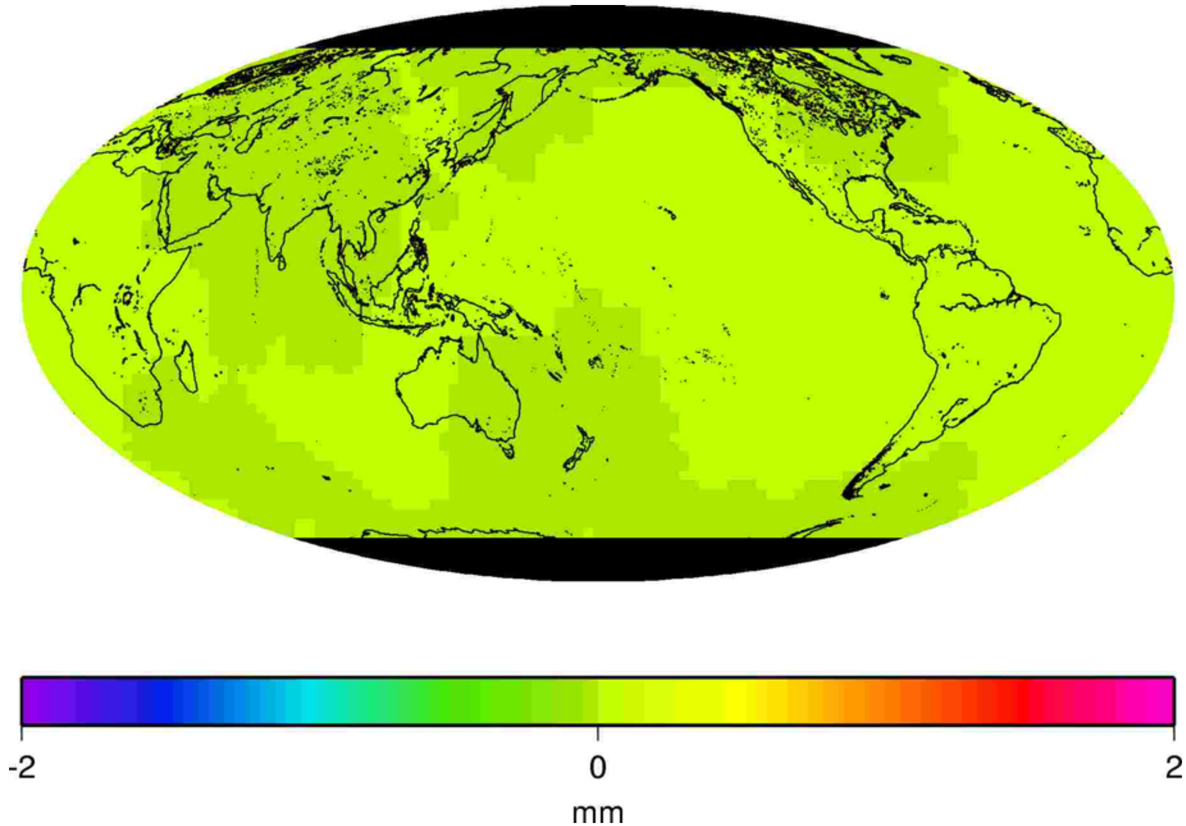
RL04 background models used (including AOD1B)

GRACE K-band Range-Rate Residual RMS per 1-day Arcs



Correlated Orbit Error

Mean geographically correlated orbit error for Jason/Topex orbit
(EGM08 vs EIGEN-GL05C)



Geographically correlated orbit error now dominated by time variable component
(tides, atmosphere, ocean, hydrology, ice loss, GIA)

Geostrophic Current Comparisons

Residuals of the geostrophic currents implied by the mean surface (CSRMSS98) minus various marine geoid models compared to the World Ocean Atlas 2001 (WOA01) data (Stephens et al., 2002) (relative to 4000 m, courtesy of V. Zlotnicki)

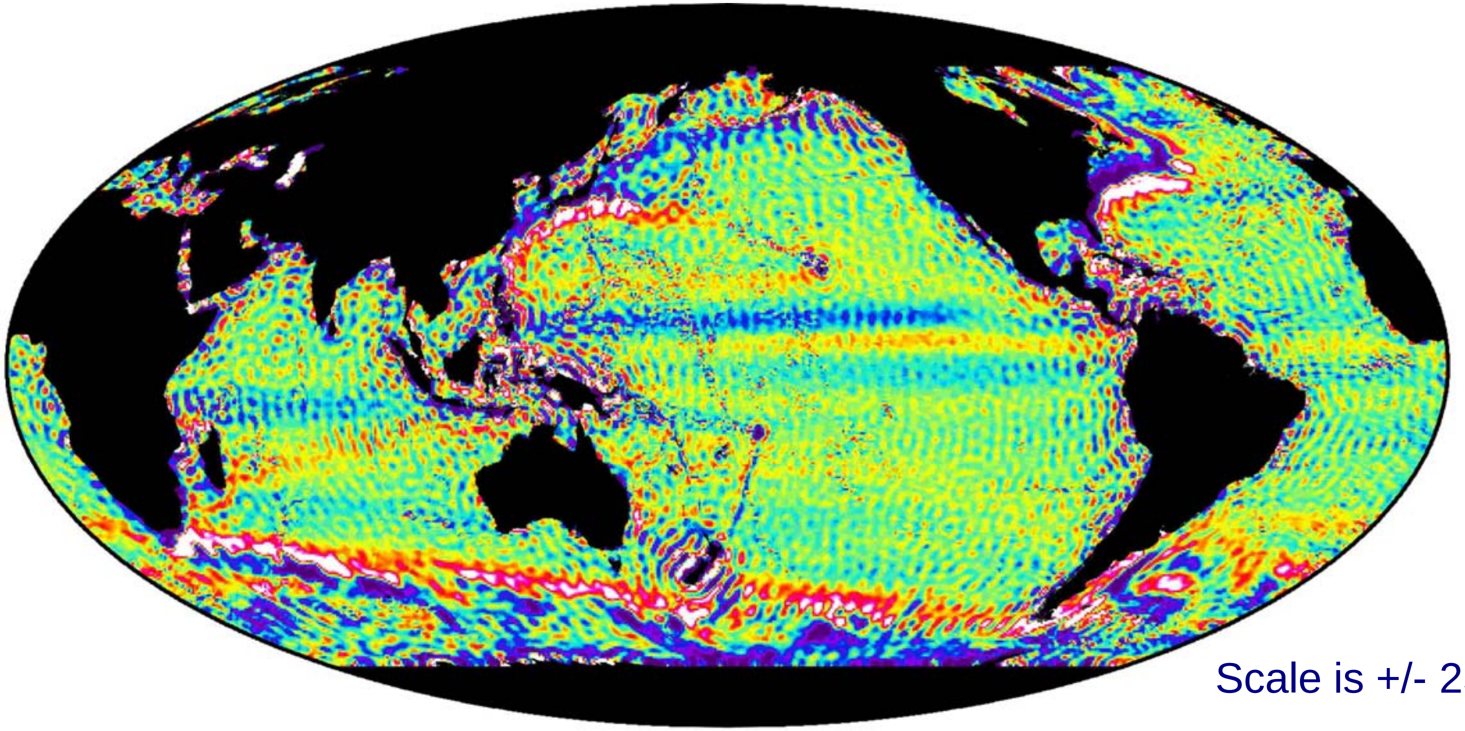
Model	Standard Deviation (cm/s)		Correlation	
	Zonal	Meridional	Zonal	Meridional
EGM96	8.18	7.00	0.352	0.288
GGM02C	3.04	3.23	0.914	0.482
EIGEN-GL04C	3.01	3.01	0.916	0.543
EIGEN-GL05C	3.24	3.10	0.903	0.513
GGM03S	2.91	2.97	0.921	0.550
EGM08	2.97	2.99	0.918	0.551

Comparison is to degree/order 120, and 400 km smoothing has been applied.

(see Tapley et al., 2003, for additional information)

Short Wavelength Geoid Residuals EIGEN-GL04C

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.

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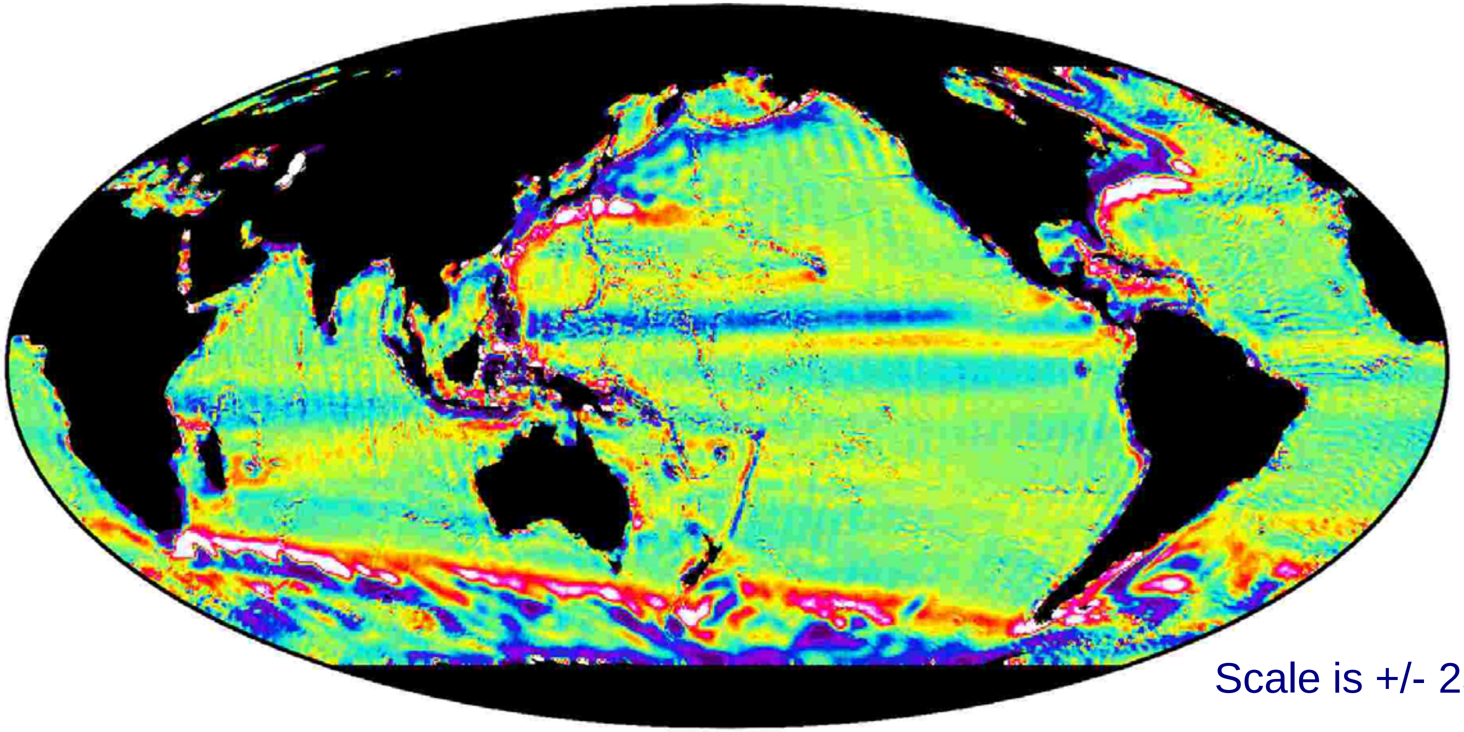
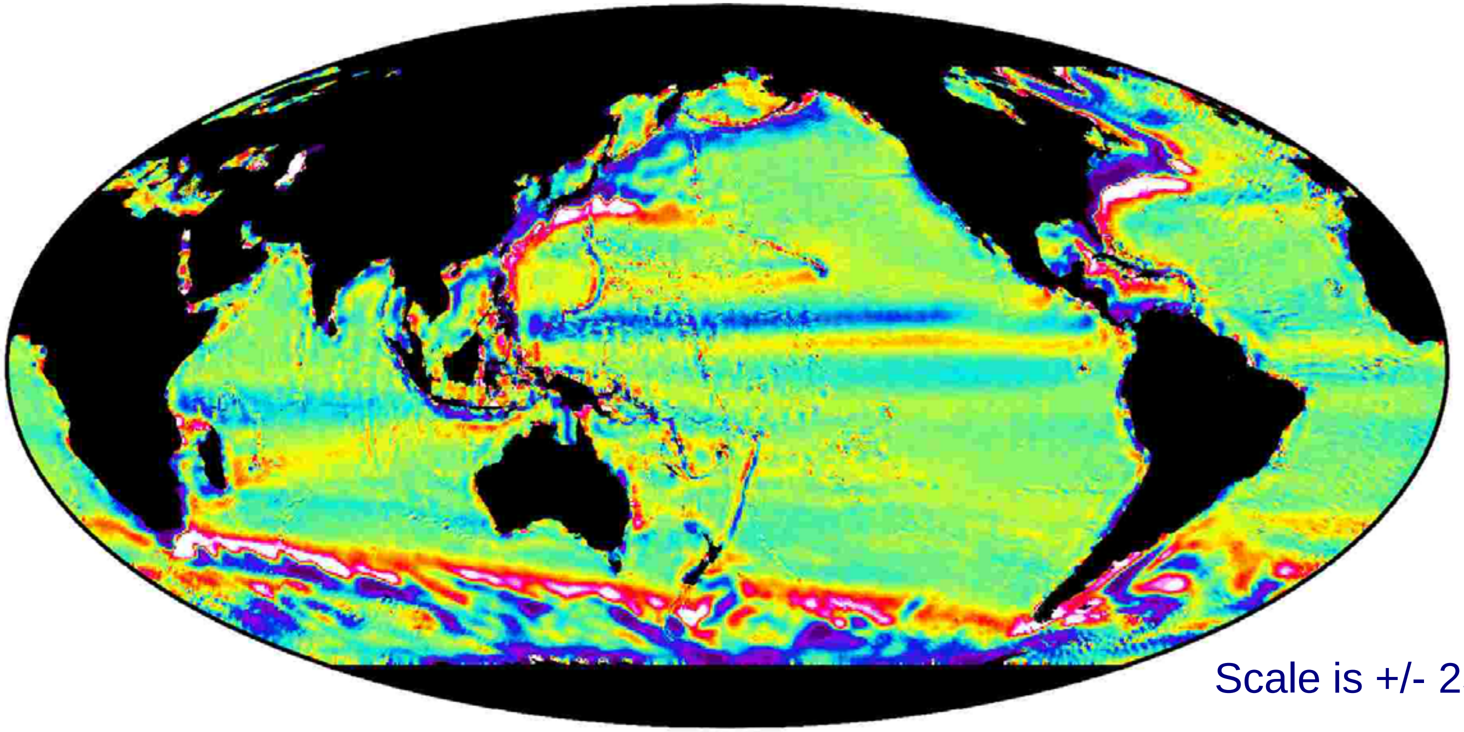


Scale is +/- 25 cm.

Short Wavelength Geoid Residuals EGM08

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 Comparison

Calculate global RMS of the residual geoid after removing a model for the mean dynamic ocean topography (i.e. MSS - WOA01 DOT - geoid) at different wavelength filtering (shorter and longer than 300 km [λ/2]).

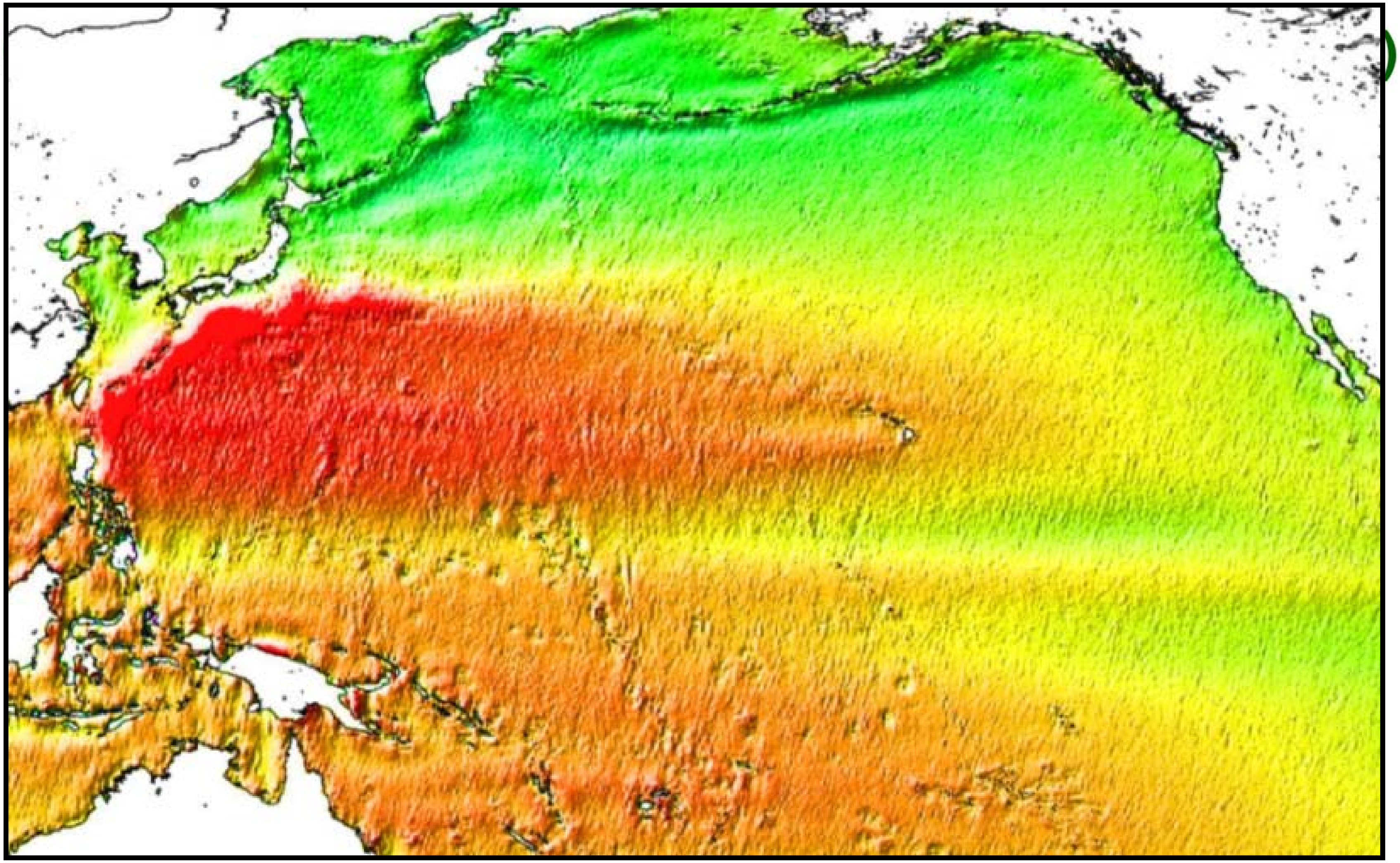
Model	**> 300 km**	**< 300 km**
EGM96	9.3	12.7
GGM02C (+EGM96)	8.2	12.7
EIGEN-GL04C	8.7	13.1
EIGEN-GL05C	7.8	12.6
EGM08	7.6	11.7

Units are cm

Computed along new T/P groundtrack to provide independent assessment.
Mean removed along each altimeter pass before computing the RMS.

(GGM02C extended above 200x200 by EGM96)

EGM2008 Complete



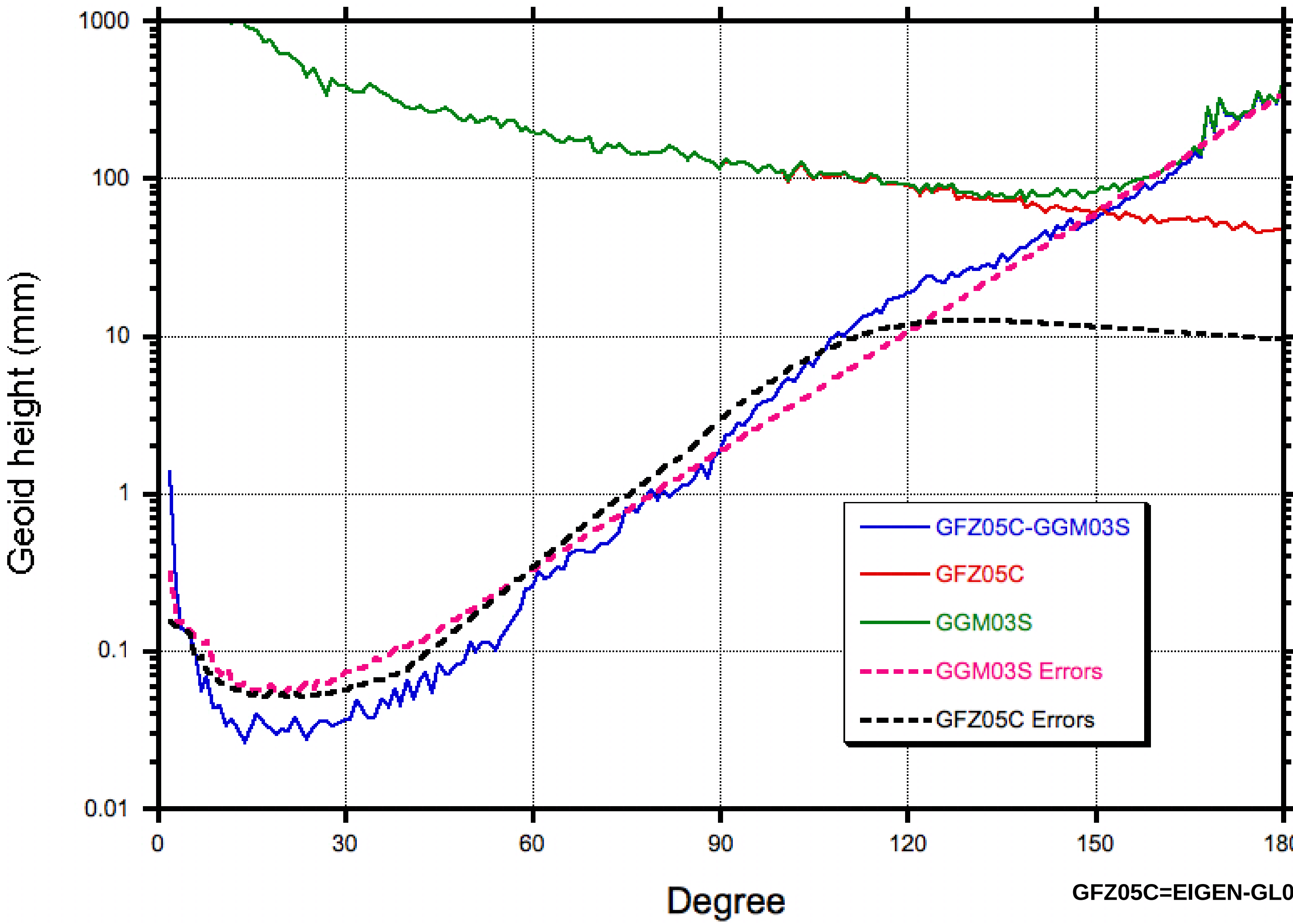
(from Pavlis et al., 2008)

Summary

- Newer global geoid models have more power at shorter wavelengths than EGM96
- Orbit fits show recent models performing similarly
  - Orbit errors/differences now dominated by time variable gravity
- EGM08 clearly performs well in the short-wavelength geoid tests
  - Best performance in the short-wavelength marine geoid
  - Provides smooth short-wavelength marine geoid residuals
  - Expansion to 2190x2159 provides considerably greater detail
- Looking forward to the contribution of GOCE to geoid accuracy at ~100 km resolution

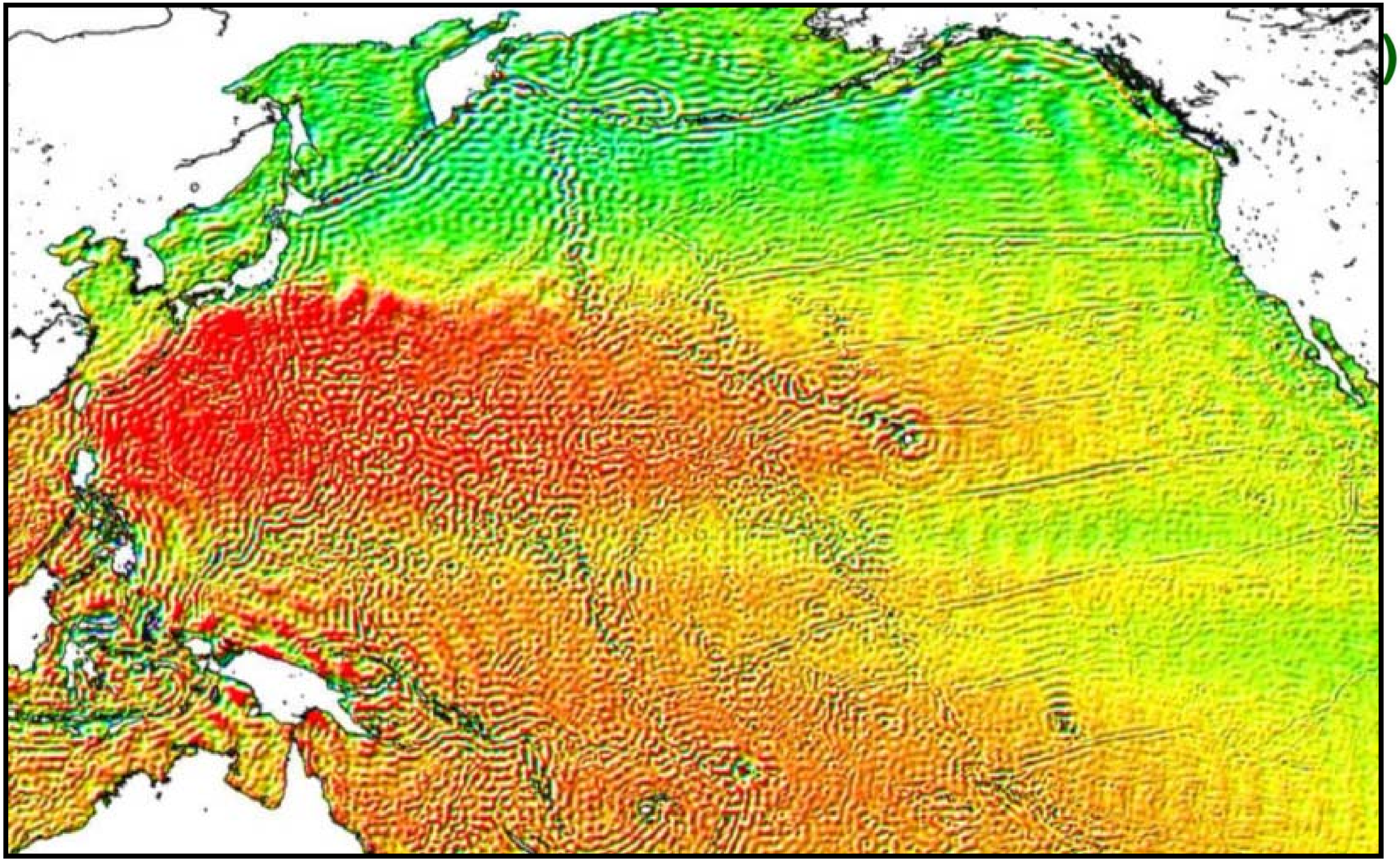
Backups

Estimated Error Comparisons



GFZ05C=EIGEN-GL05C

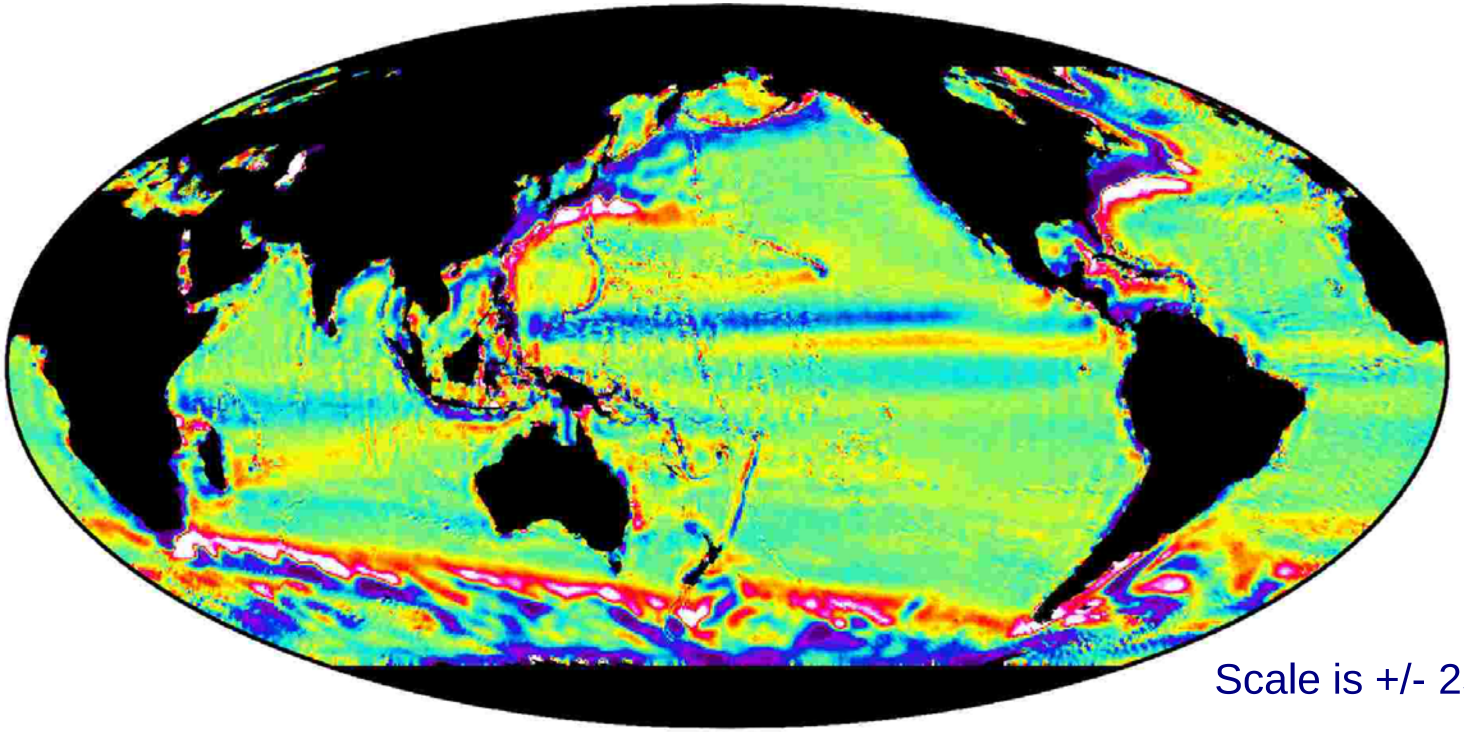
EIGEN-GL04c 360x360



(*from Pavlis et al., 2008*)

Short Wavelength Geoid Residuals GIF38A

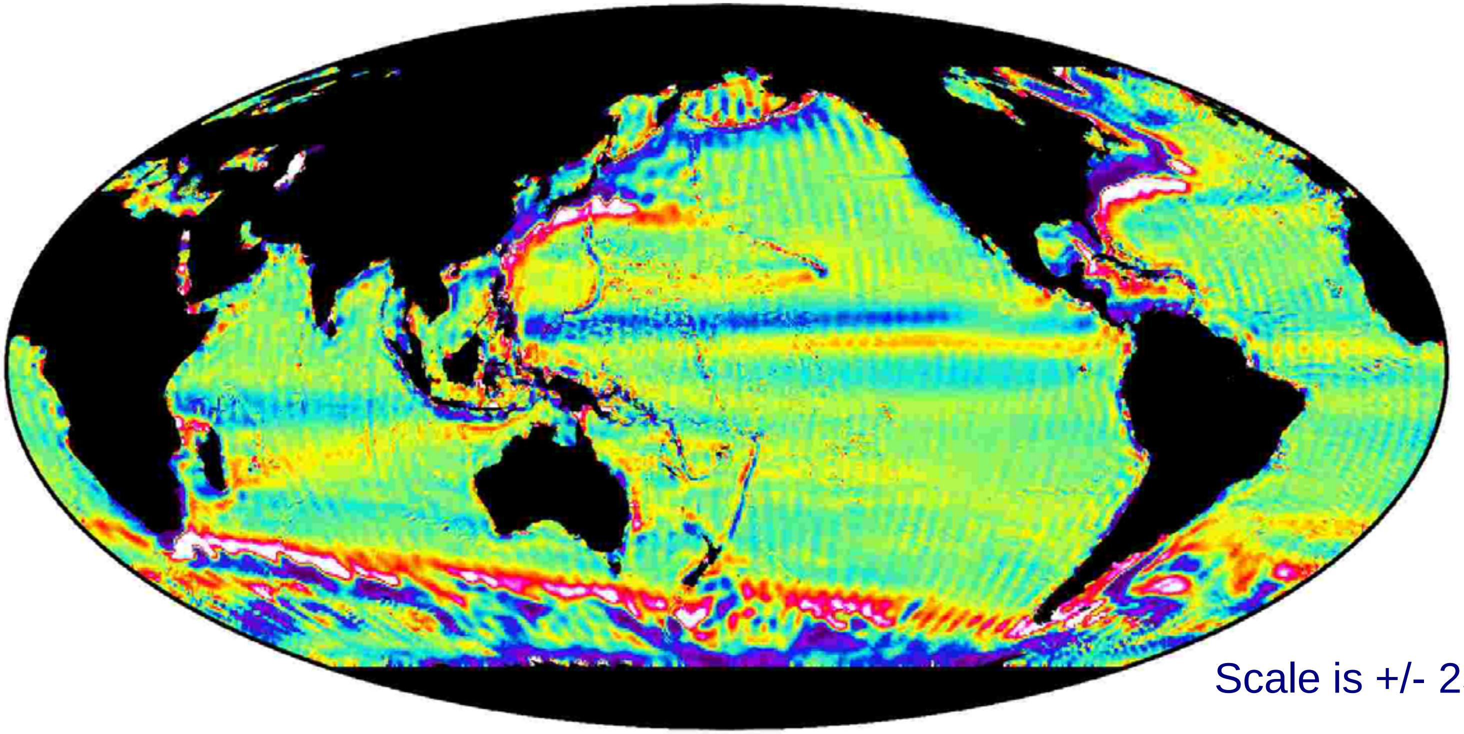
The residuals are the difference between a ‘high-frequency DOT’ defined as (GSFCMSS00 – geoid) and the same DOT smoothed to ~900 km



Scale is +/- 25 cm.

Short Wavelength Geoid Residuals GIF38B

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



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EIGEN-GL05C	7.8	12.6
EGM08	7.616	11.75
GIF38A	7.625	11.75
GIF38B	7.735	11.79

Units are cm

Computed along new T/P groundtrack to provide independent assessment.
Mean removed along each altimeter pass before computing the RMS.

(GGM02C extended above 200x200 by EGM96)

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EGM08	2.97	2.99	0.918	0.551

* GRACE-based component of EGM08

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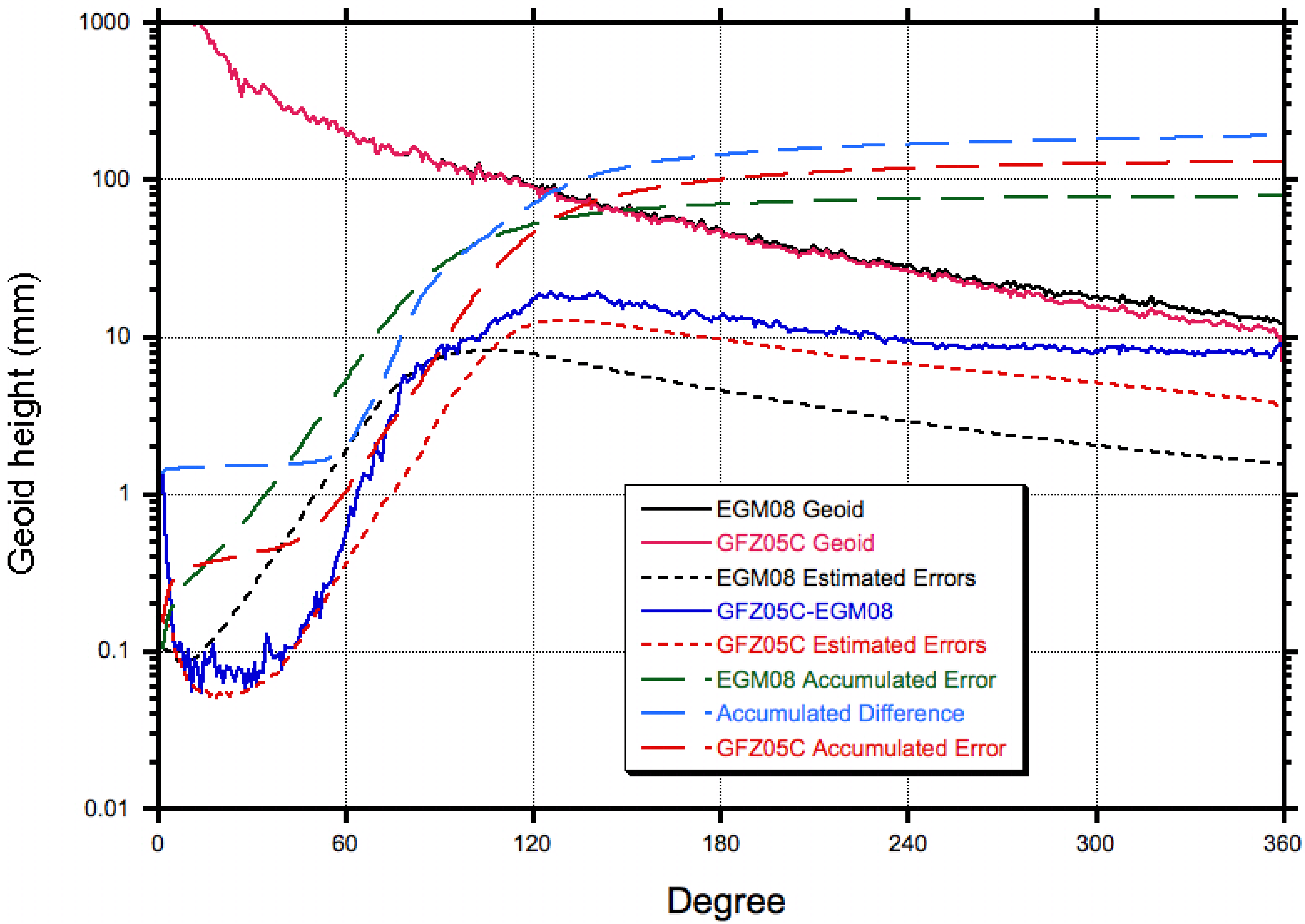
(see Tapley et al., 2003, for additional information)

Estimated Geoid Error



CSR