GRACE Mission Status and Current Results

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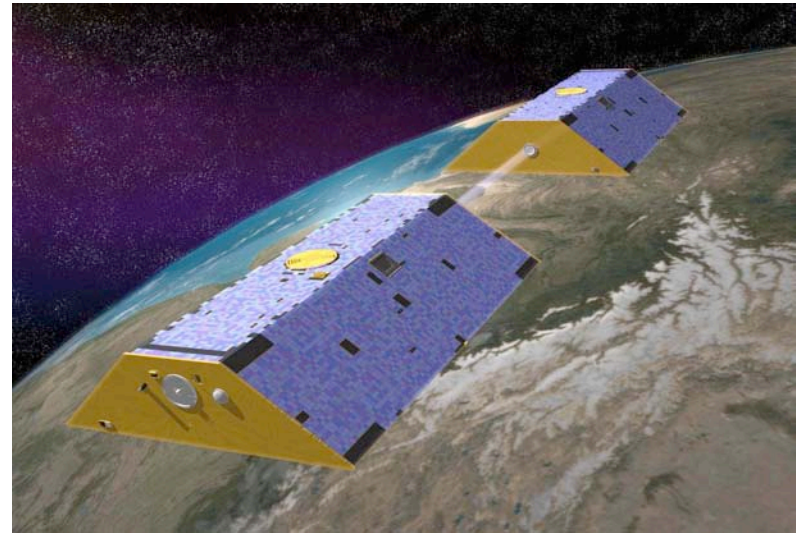
GRACE Mission Status

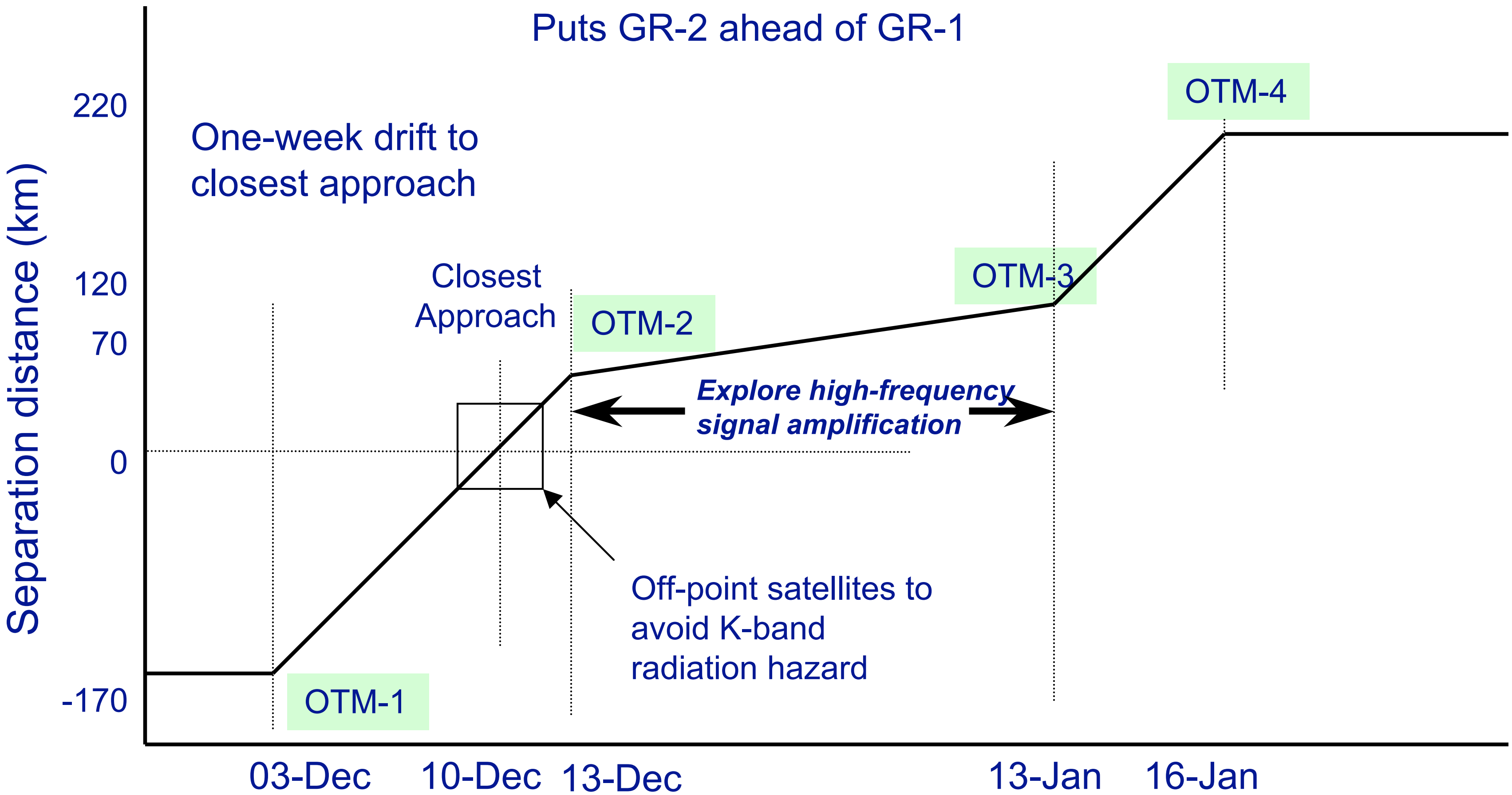
- **Mission Accomplishments**
  - Second generation gravity models available
    - Mean field (GGM02, EIGEN-CG03C)
    - Over 40 monthly solutions
  - Orders of magnitude improvement in gravity field determination is invigorating mass balance studies in Hydrology, Oceanography, Glaciology and Solid Earth Sciences
- **NASA 2005 Senior Review rated GRACE Science "Compelling" and has approved a mission extension through 2009**
- **Flight Segment**
  - Nearly 100 % of scientific measurements during 4-years has been collected and analyzed
  - Payload performance meeting mission expectations
  - Satellite switch (performed Dec 2005)
  - GPS Occultation capability validated



Orbit

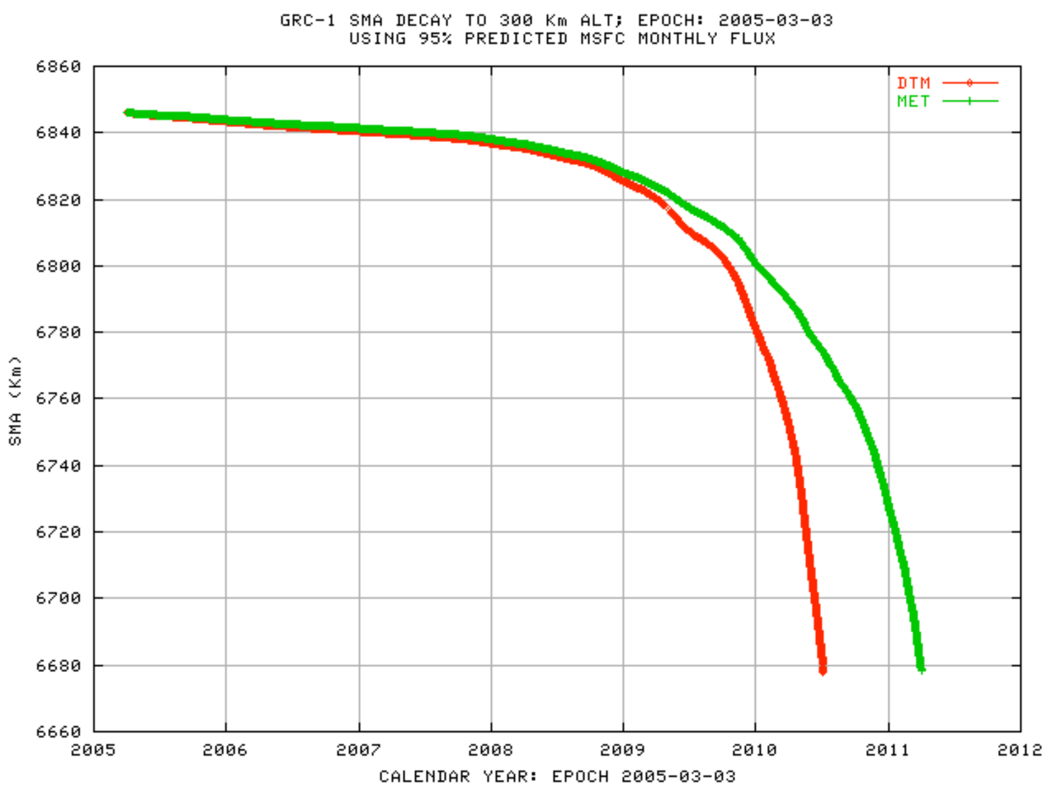
Launched: March 17, 2002
  4 years in orbit
Initial Altitude: 500 km
  Current Altitude: ~465 km (-30 m/day)
Inclination: 89 deg
Eccentricity: ~0.001
Separation Distance: ~220 km
Nominal Mission : 5 years
Non-Repeat Ground Track, Earth Pointed, 3-Axis Stable
Predicted Lifetime through 2010

Satellite Switch



Nominal data collection at all times except for 2-3 days

GRACE Mission Lifetime

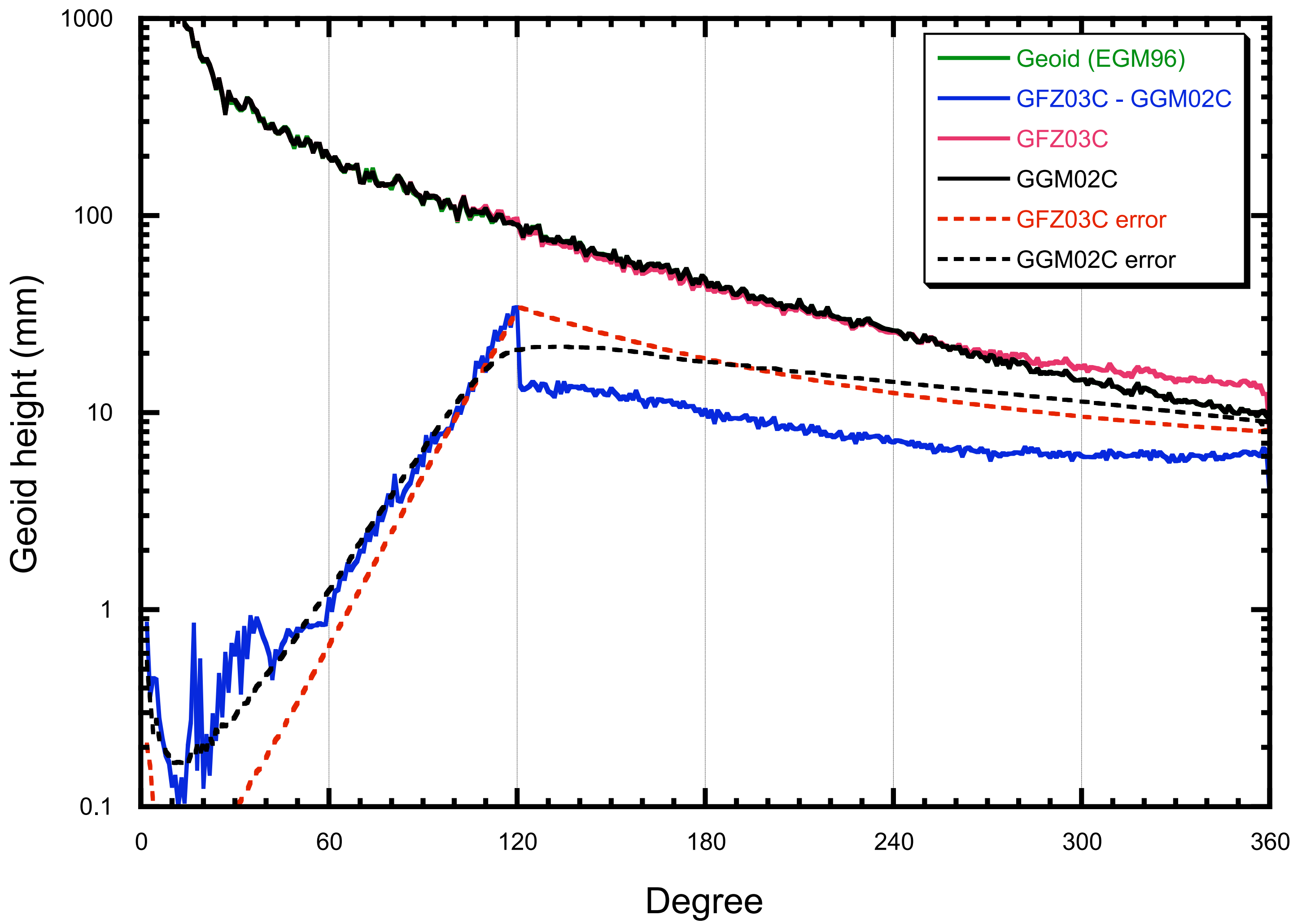


- Resources
  - Battery Cycles
    - > 13 years
  - Orbit Decay
    - > 8 years
  - Cold-gas Fuel
    - > 10 years
  - Thruster Actuations
    - 8-16 years
- Critical units
  - MWA+USO (GRACE-1)
  - ICU (GRACE-1)
  - SU (both)

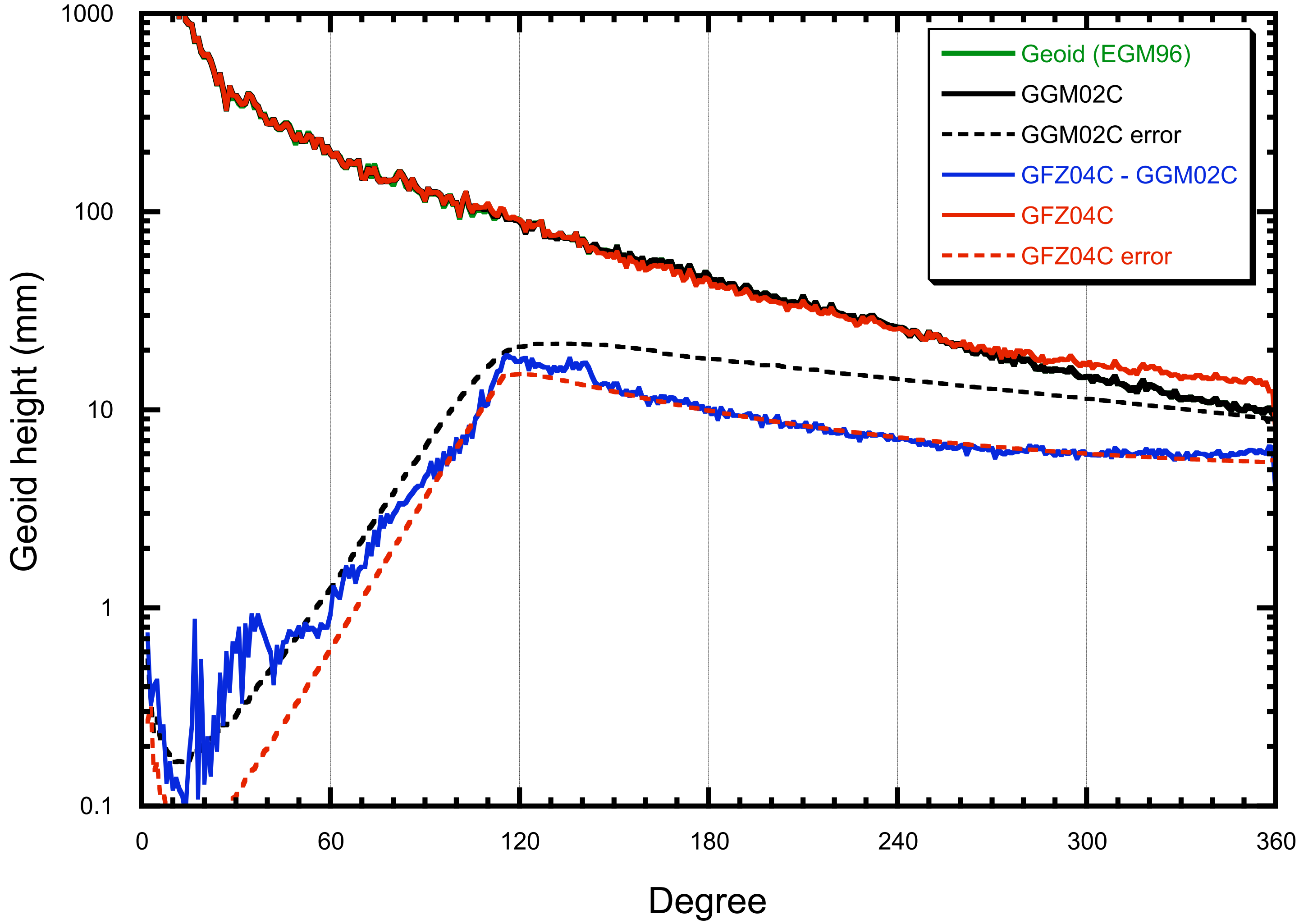
Marine Geoid Evaluation

- Evaluate available 360x360 geoid models for marine applications
  - EGM96
  - GGM02C (extended to 360x360 with EGM96)
    - GGM02C constrained to EGM96 at higher degrees to provide smooth extension from 200x200 to 360x360
  - TEST05
    - unpublished preliminary combination of GGM02S information with full 360x360 surface information
  - EIGEN-CG01C, -CG03C and -GL04C
    - “band limited combinations” of GRACE and surface information
- Look at correlation with ocean circulation and short-wavelength marine geoid errors
  - In particular, look for meridional ‘striations’ and other artifacts

Degree Variance Comparison (1)

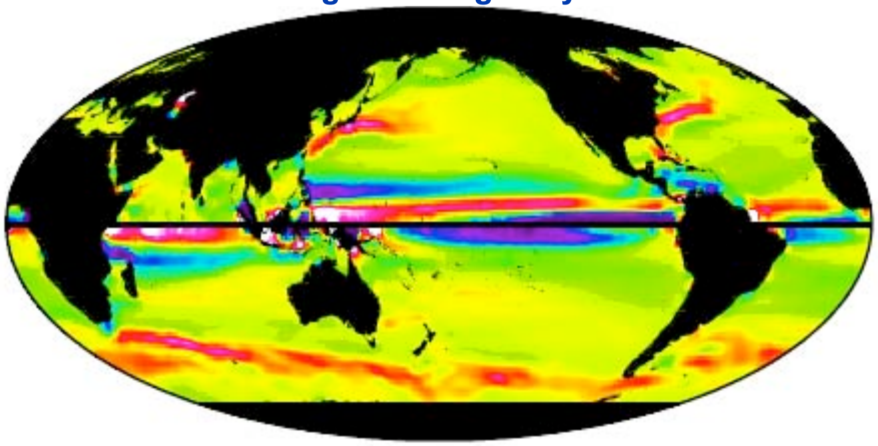


Degree Variance Comparison (2)



Zonal Circulation Improvements

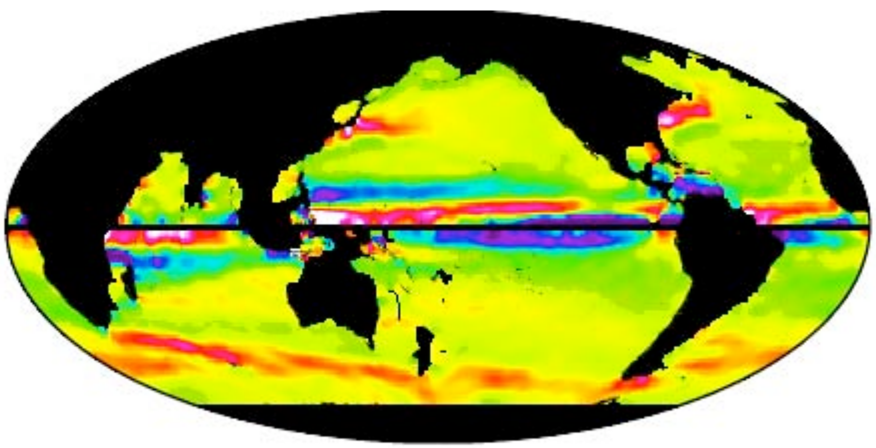
Using GRACE gravity model



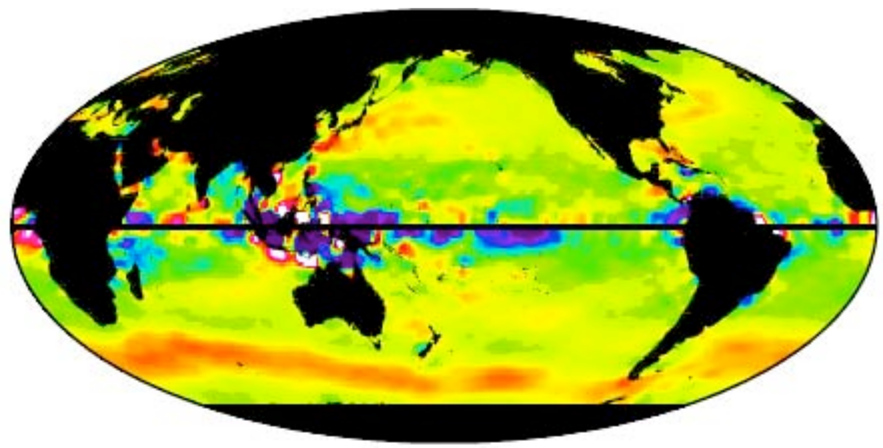
East-west currents are much more clearly seen with a GRACE gravity model than with previous models.

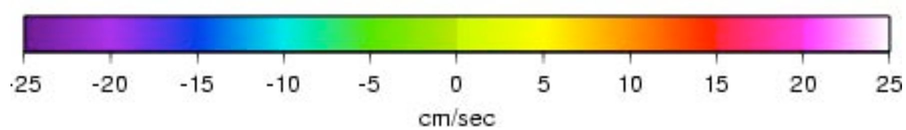
Previous gravity models needed altimeter data over the oceans to help determine the geoid; this GRACE model uses none

Using WOA01 Hydrography



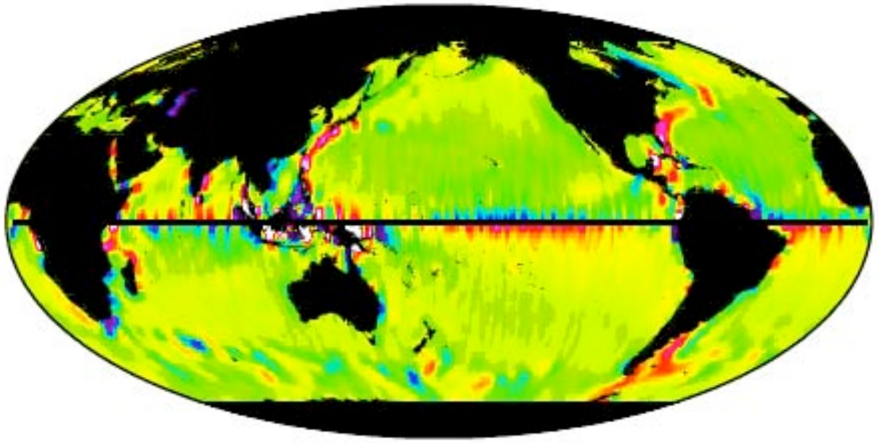
Using EGM96





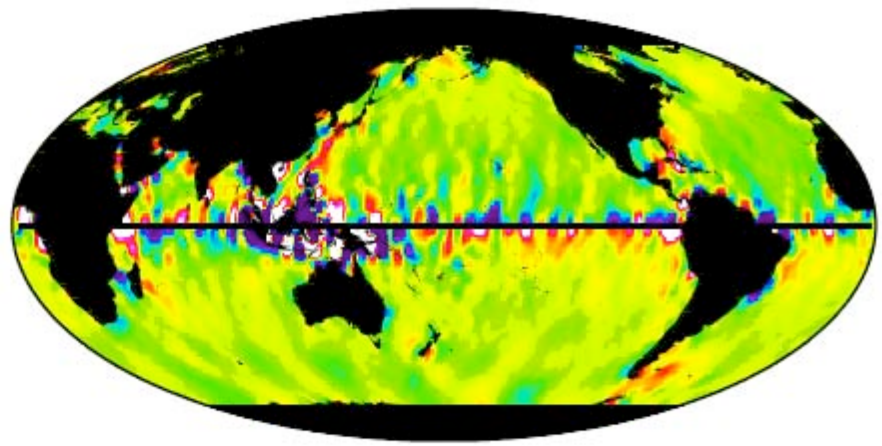
Meridional Circulation Improvements

Using GRACE gravity model

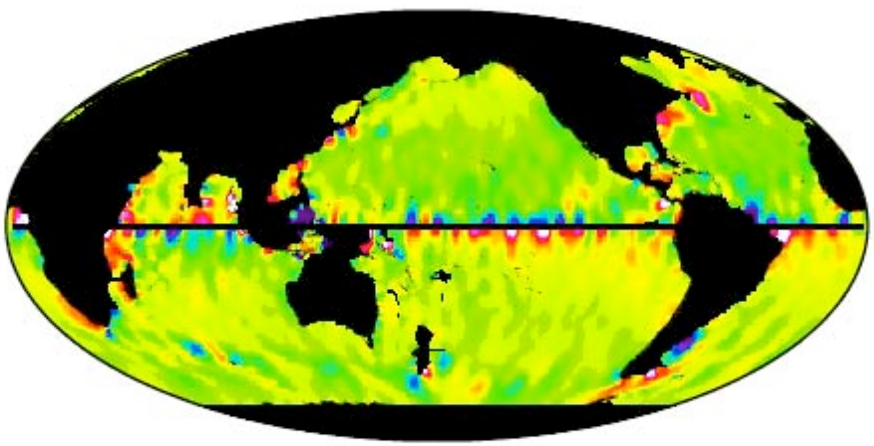


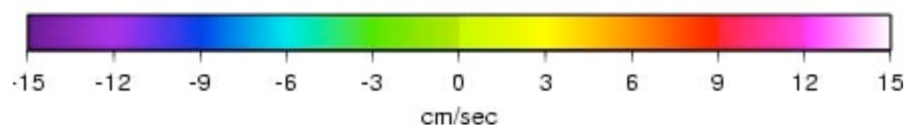
North-south currents are also much more clearly seen with a GRACE gravity model than with previous models.

Using EGM96



Using WOA01 Hydrography





Geostrophic Currents Comparison

Comparison of geostrophic currents computed from various geoid models 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. Comparisons at 400 km smoothing.

Model (400 km smoothing)	**Standard Deviation (cm/s)**		**Correlation**	
	Zonal	**Meridional**	**Zonal**	**Meridional**
EGM96	8.2	7.0	0.352	0.288
EIGEN-CG01C	3.2	3.8	0.905	0.398
EIGEN-CG03C	2.9	3.2	0.921	0.494
EIGEN-GL04C	3.0	3.0	0.915	0.542
GGM02S	2.9	3.4	0.919	0.464
GGM02C	3.0	3.2	0.914	0.481
TEST05	2.9	3.1	0.919	0.522

EIGEN-GL04C and TEST05 show significant improvement over others

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).

GGM02C extended to 360x360 using EGM96, so we would expect that the performance at short wavelengths is very similar.

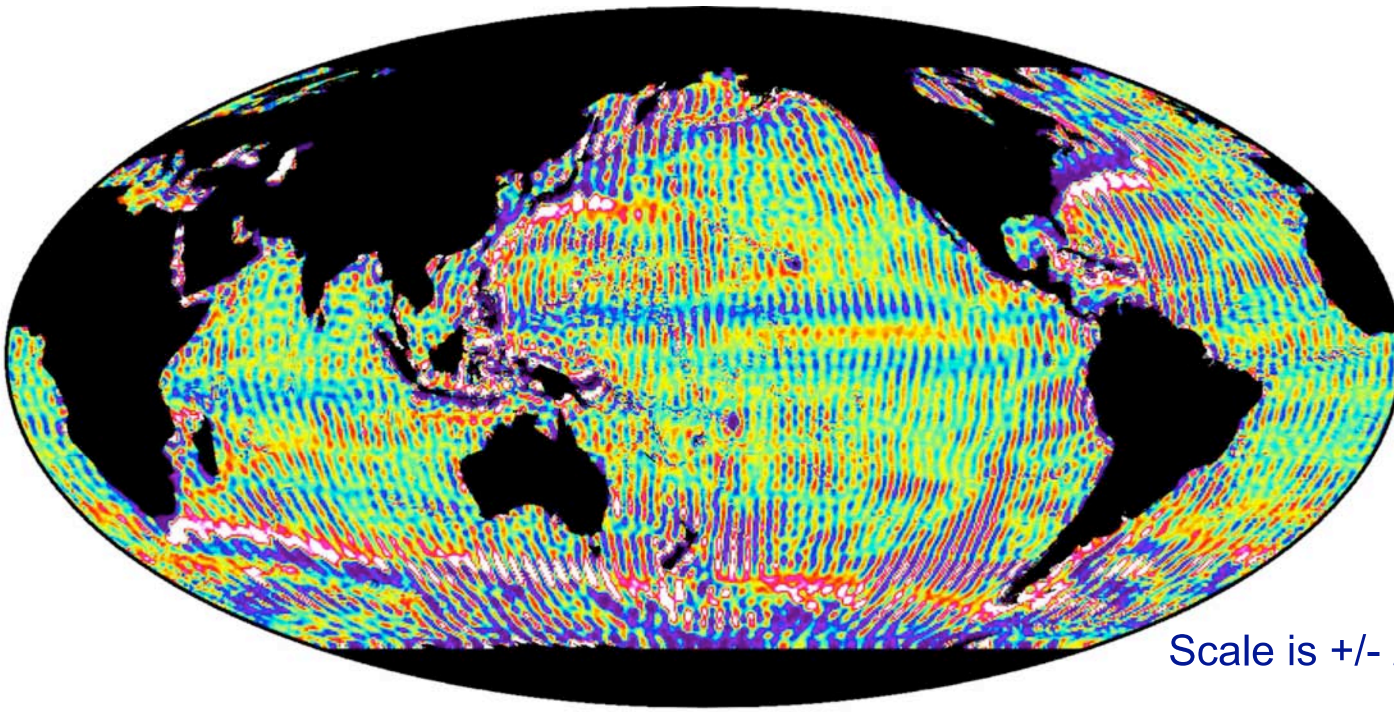
Units are cm

Model	> 300 km	< 300 km
EGM96	10.2	13.5
EIGEN-CG01C	10.6	14.4
EIGEN-CG03C	10.8	14.5
EIGEN-GL04C	9.0	13.9
GGM02C	8.5	13.6
TEST05	8.4	13.5

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

Short Wavelength Geoid Residuals EIGEN-CG03C

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

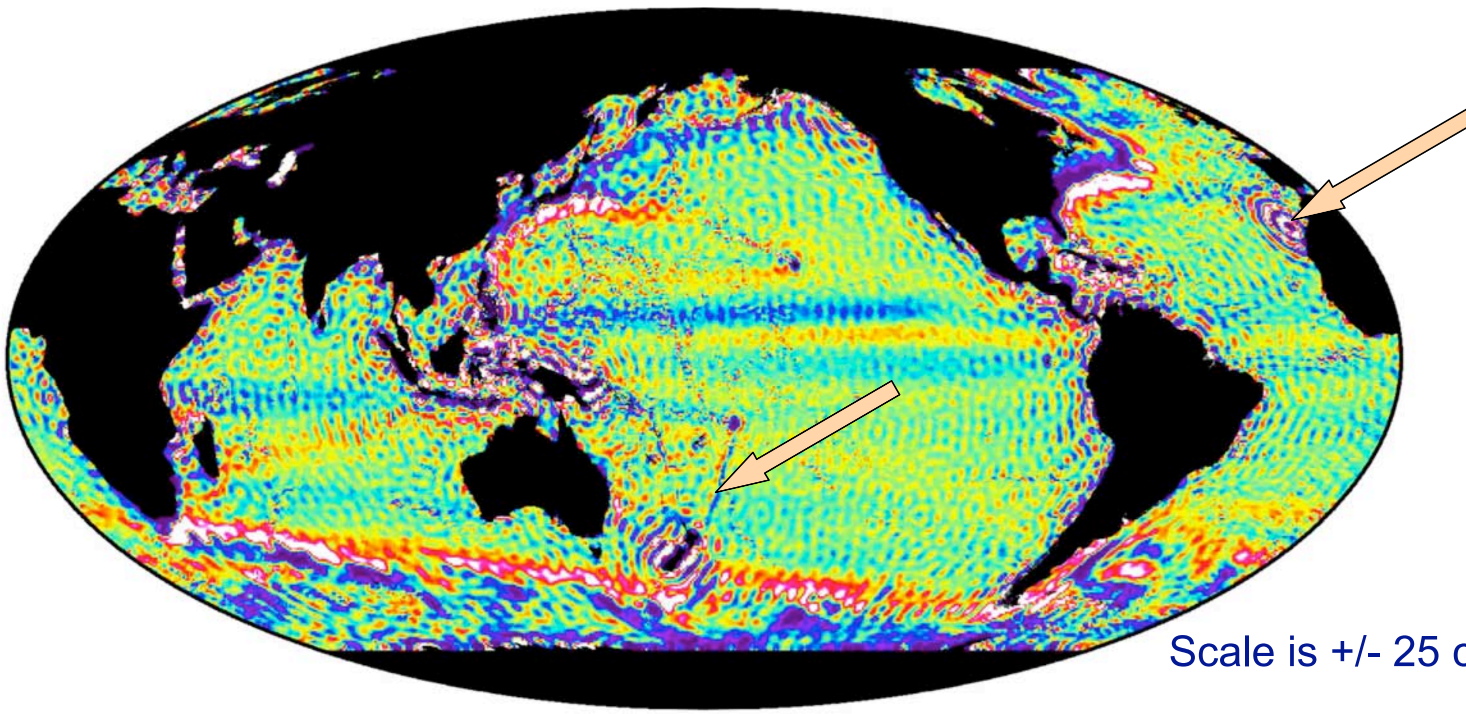


Scale is +/- 25 cm.

Strong meridional ‘striations’ present (EIGEN-CG01C very similar)

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

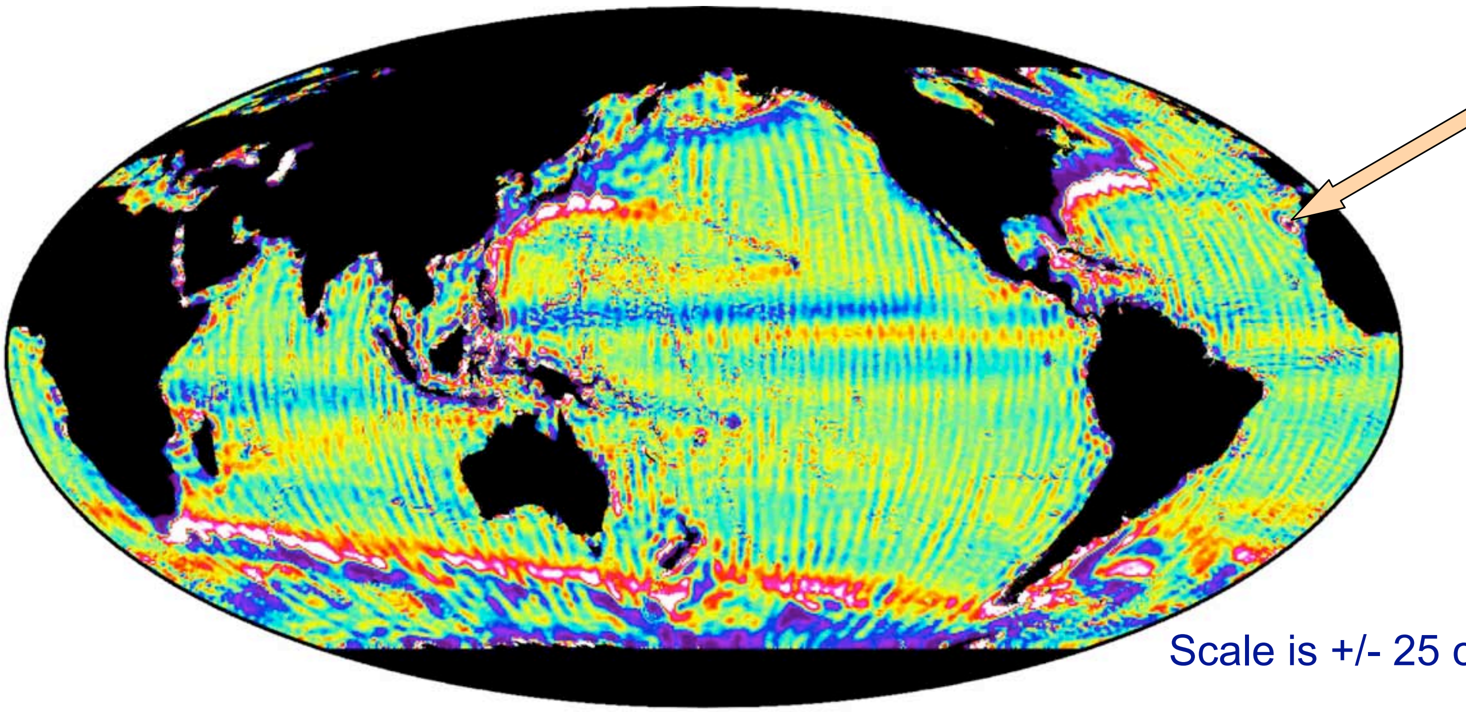


Scale is +/- 25 cm.

Meridional ‘striations’ greatly reduced, but other artifacts appearing (‘ringing’ around some land areas and artifact over Tonga/Kermadec trench)

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

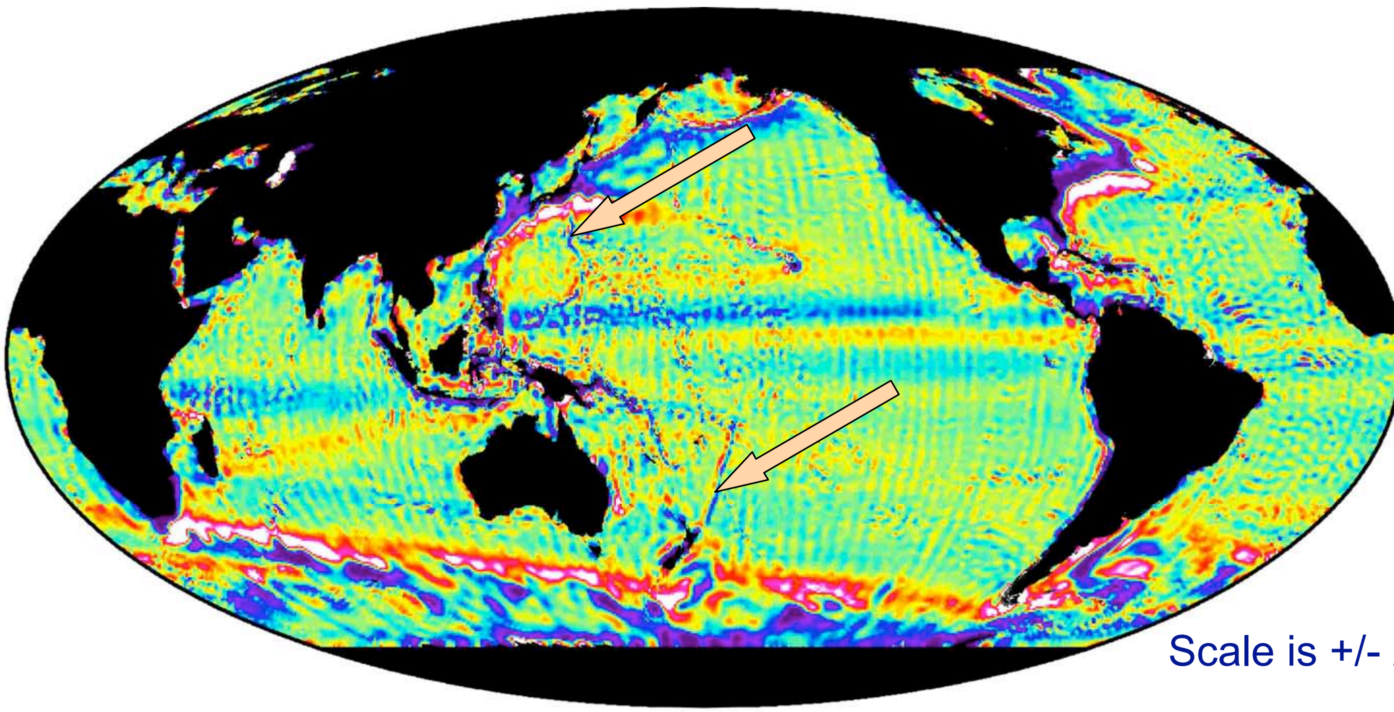


Scale is +/- 25 cm.

Meridional 'striations' clearly present. Some residual 'ringing' off northwestern coast of Africa likely from EGM96 contribution.

Short Wavelength Geoid Residuals TEST05

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

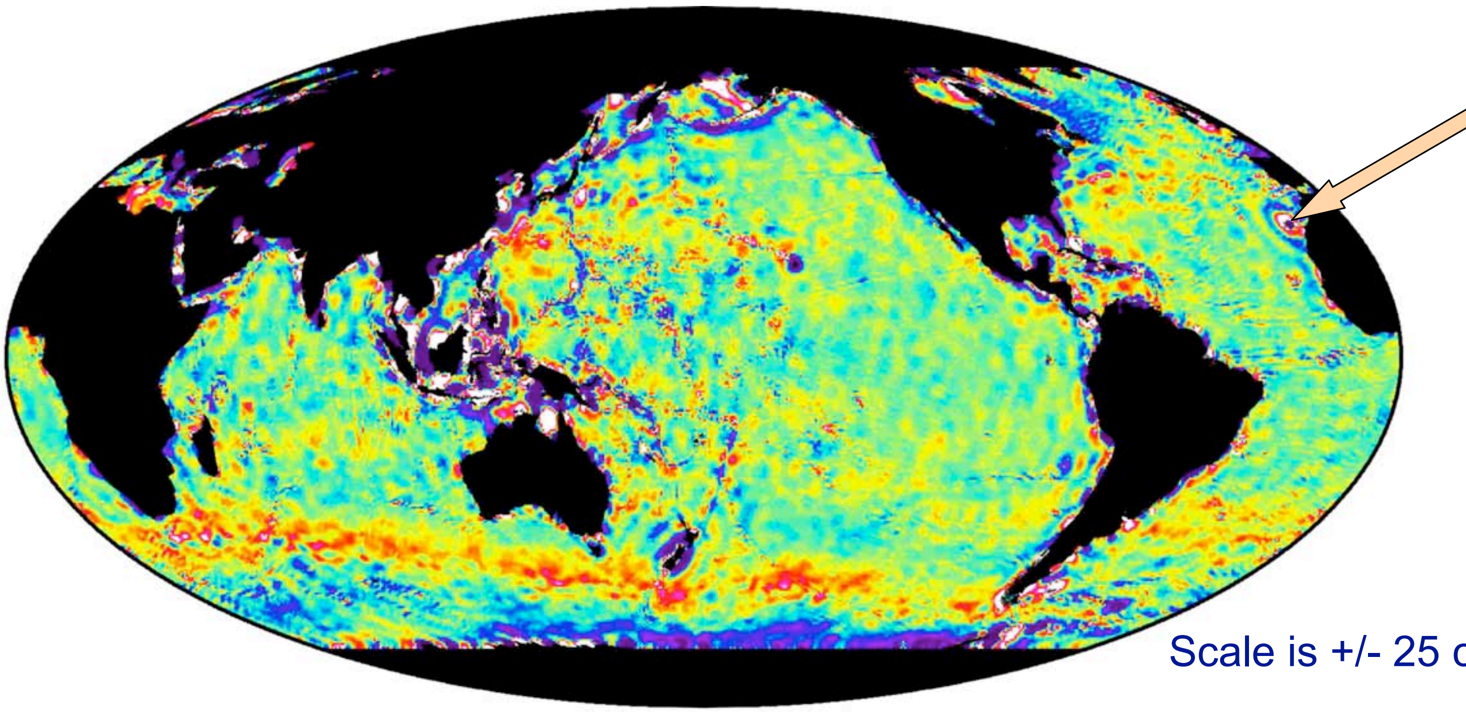


Scale is +/- 25 cm.

Meridional ‘striations’ significantly reduced with new 360x360 surface information, but artifacts appear over Tonga/Kermadec trench and Mariana trench

Short Wavelength Geoid Residuals EGM96

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

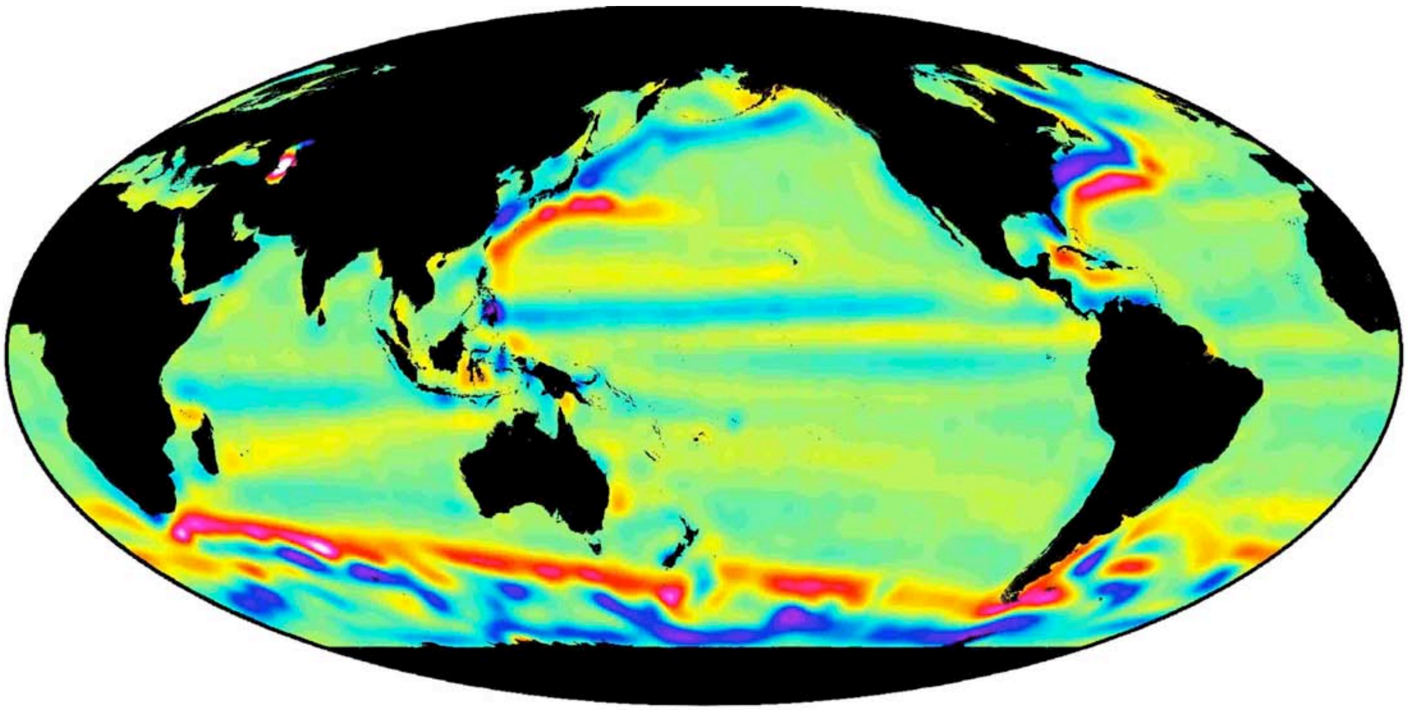


Scale is +/- 25 cm.

Loss of signal at Gulf Stream, Kuroshio current and equatorial currents indicates signal was aliased into EGM96 geoid

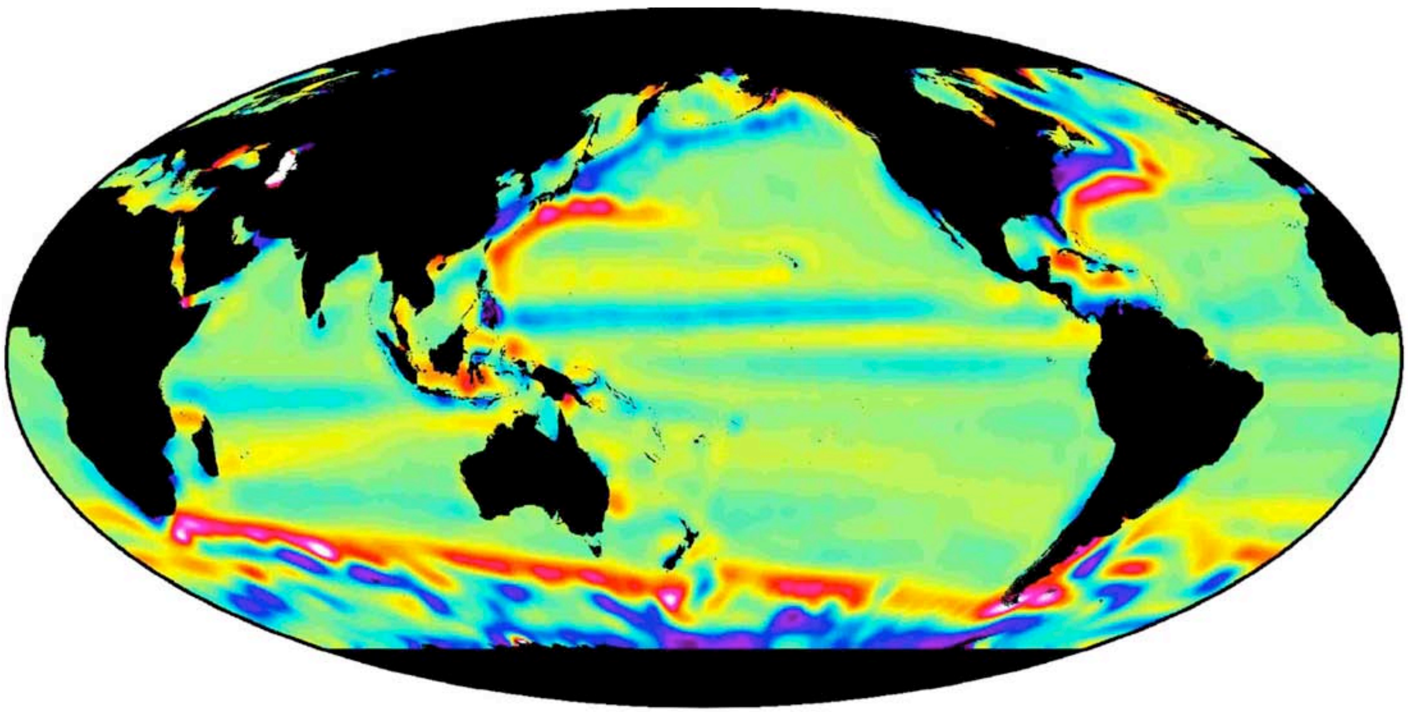
Smoothing Necessary for Best Results GGM02C

Chambers and Zlotnicki (2004) showed that a
220 km (half-width) smoothing was sufficient



Smoothing Necessary for Best Results
EIGEN-GL04C

Very little difference after smoothing

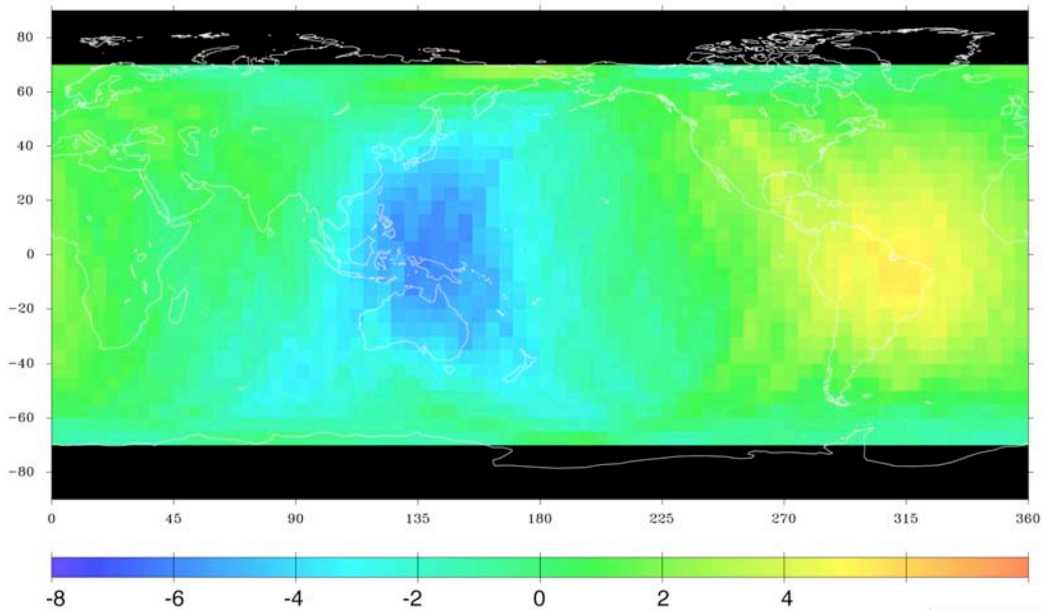


GGM02C vs EIGEN-GL04C for Jason-1 (1)

CSR (GGM02C vs EIGEN-GL04C)

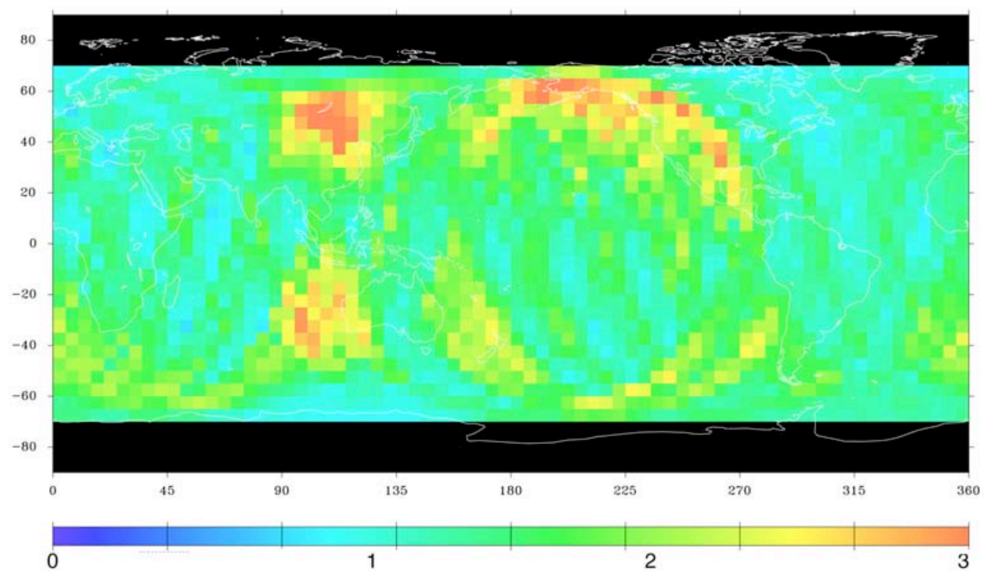
	Crossover (GGM)		Crossover (GL04)		Radial Diff		X	Y	Z
Cycle	Mean (mm)	RMS (mm)	Mean (mm)	RMS (mm)	RMS (mm)	Mean (mm)	Mean (mm)	Mean (mm)	Mean (mm)
1	-8	52.3	-6	52.4	3	0.1	-3	2	-2
2	-12	61.4	-11	61.4	3	0.1	-3	2	-1
3	-9	59.9	-8	59.8	3	0.0	-2	2	-1
4	-10	59.0	-8	58.6	3	0.1	-2	2	-1
5	-1	57.5	-1	57.0	3	0.1	-2	2	-1
6	2	57.2	3	57.2	3	0.0	-2	2	-1
8	0	59.7	1	59.6	3	0.0	-2	2	-1
9	2	57.5	2	57.4	3	0.0	-2	2	-1
10	-4	59.5	-4	59.2	3	0.1	-2	2	0
11	-9	60.0	-9	59.9	3	0.1	-2	2	-1
12	-3	55.9	-3	55.8	3	0.1	-3	2	-1
13	1	57.0	1	57.0	3	0.1	-2	2	-1
14	-7	56.2	-6	56.0	3	0.3	-2	2	-2
15	-3	53.8	-3	53.8	3	0.1	-2	2	0
16	-4	57.3	-2	57.2	3	0.1	-2	2	0
17	2	57.7	3	57.9	3	0.1	-2	2	0
18	-6	54.7	-6	54.9	3	0.1	-3	2	0
19	7	59.0	8	59.3	3	0.1	-2	2	0
20	8	55.9	8	55.8	3	0.1	-2	2	0
21	1	54.7	0	54.8	3	0.1	-2	2	0
22	-1	55.4	1	55.6	3	0.1	-2	2	-1
Mean	-3	57.2	-2	57.2	3	0.1	-2	2	-1

GGM02C vs EIGEN-GL04C for Jason-1 (2)



Mean radial orbit difference
(plot scale -8 to +8 mm)

RMS about mean of radial orbit
differences (plot scale: 0-3 mm)



Conclusions

- GRACE-based geoid models provide dramatic improvement in dynamic ocean topography determination
- All tested GRACE-based geoid models display some degree of meriodinal ‘striations’ or other artifacts
  - A modest amount of smoothing is sufficient to remove the undesired features (additional details at http://gracetellus.jpl.nasa.gov/dot.html)
  - Best geoids good to ~440 km resolution
- GGM02C and EIGEN-GL04C both perform well overall
  - TEST05 and EIGEN-GL04C demonstrate that ‘striations’ can be reduced but other artifacts have appeared
  - Combination of GRACE with surface information is still a challenge
- If publicly available and documented soon, EIGEN-GL04C is good candidate for both POD and marine geoid applications
  - Several mm-level geographically correlated orbit differences using GGM02C vs EIGEN-GL04C
  - Both appear to perform equally well wrt crossover RMS

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