

# EIGEN-5C

## A new global combined high-resolution GRACE-based gravity field model of the GFZ-GRGS cooperation

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## Background

Global gravity field models can be derived from the combination of satellite data and surface gravity data.

At GFZ Potsdam and GRGS Toulouse, such global gravity models are routinely produced in the framework of the EIGEN\* processing activities.

## Scope of this presentation

We present the latest combined gravity field model: EIGEN-5C

In particular, this presentation shall give:

- information about the currently used data sets,
- a brief overview about the applied combination strategy,
- results of the comparison to previous EIGEN- and other models.

\* EIGEN = European Improved Gravity model of the Earth by New techniques

# Overview over the GFZ/CNES combined gravity field models released during the last years

		EIGEN-CG01C	EIGEN-CG03C	EIGEN-GL04C	EIGEN-5C
<b>Released:</b>		May 2004	March 2005	March 2006	April 2008
<b>Resolution:</b>		360 x 360	360 x 360	360 x 360	360 x 360
<b><u>Main differences:</u></b>					
<b>Satellite data</b>	<b>CHAMP</b>	33 months: 10/2000 - 06/2003		./.	
	<b>GRACE</b>	200 days: 04/2002 - 11/2003	16 months: 02/2003 - 07/2004	30 months: 02/2003 – 07/2005	54 months: 08/2002-01/2007
	<b>LAGEOS</b>	./.	./.	24 months: 02/2003 – 02/2005	14 years: 1993 - 2006
<b>Ocean data (direct altimetry)</b>		CLS01 sea surface heights		GFZ mean sea surface heights	
<b>Maximum degree of the the full normal matrix</b>		140	140	179	280
<b>Overlapping range [deg] between satellite and terrestrial data:</b>		70 ... 109	70 ...120	70 ...115	70 ... 150
<b>Terrestrial data: Grid size for the full normal equations</b>		1° x 1°	1° x 1°	30' x 30'	30' x 30'
<b>Remarks:</b>				including the latest <b>ArcGP</b> data (Forsberg 2006)	
				New data of <b>Europe</b> and <b>Australia</b>	

## Basic principle of the generation of the combined EIGEN models:

The combination of the satellite and surface data is done by the **combination of normal equations**, which are obtained from observation equations for the spherical harmonic coefficients.

## GRACE and LAGEOS satellite data used for EIGEN-5C/S

Satellite-only part: based on a joint data processing at GFZ and CNES/GRGS:

### GRACE GPS-SST and K-band range-rate data:

CNES: ~ 4 years: August 2002 ... October 2006

GFZ: 4 years: February 2003 ... January 2007

### LAGEOS-1/2:

CNES: 5 years: January 2002 ... December 2006

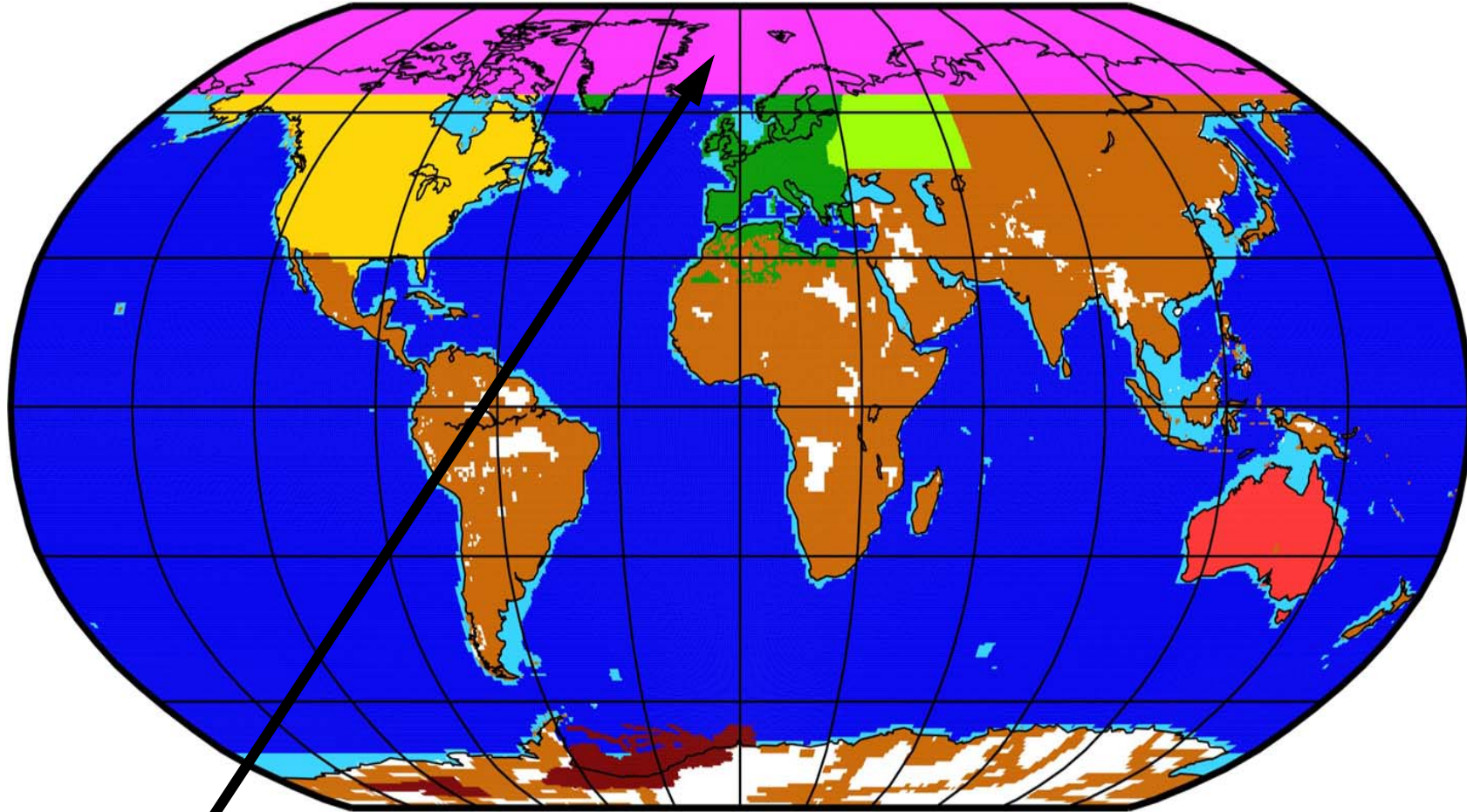
GFZ: 6 years: January 2001 ... December 2006

### Processing Standards:

#### GRACE GFZ Level-2 Processing Standards Release 4

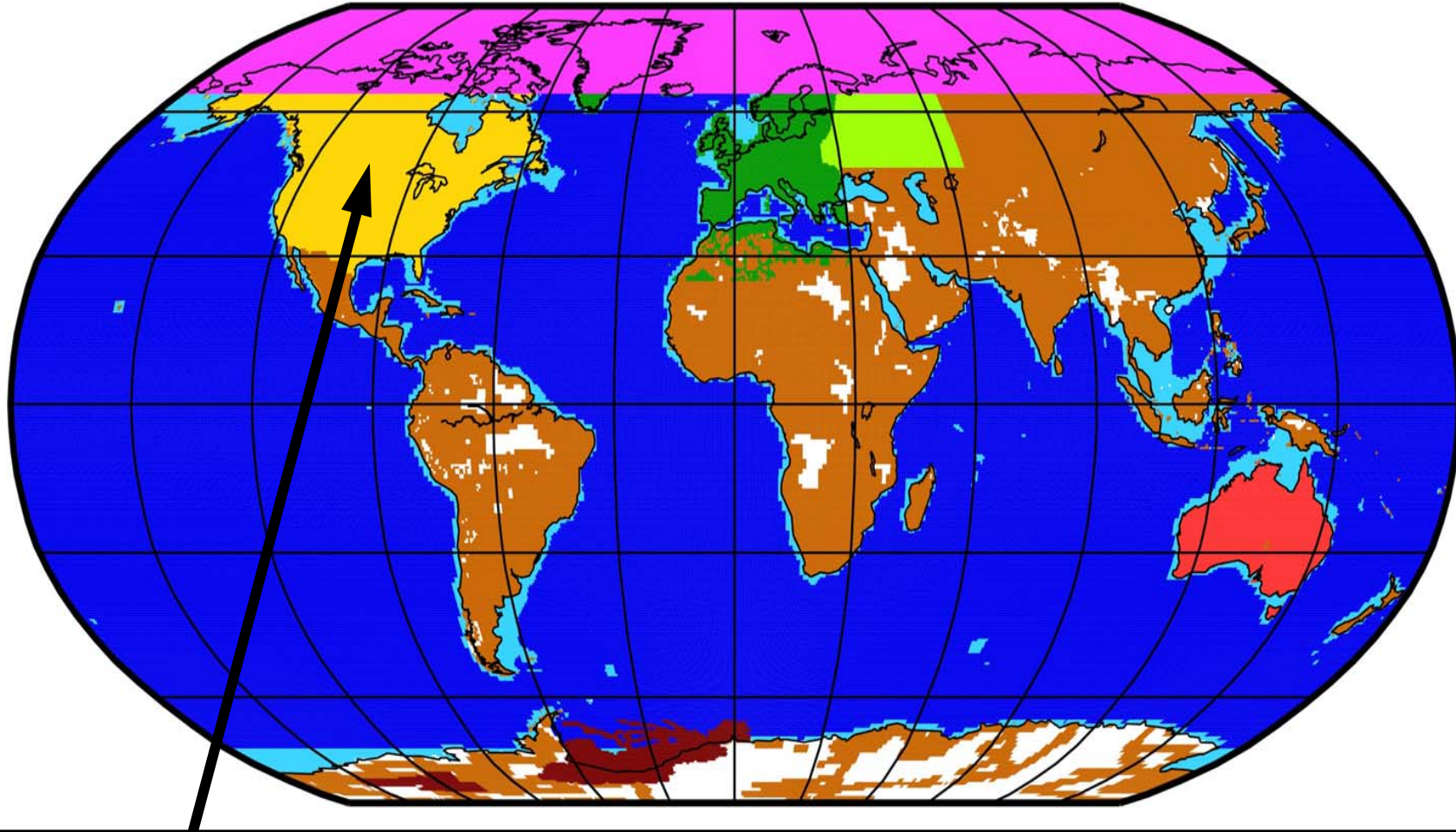
(GRACE GFZ Level-2 Proc. Standards Doc. - RL 0004 GR-GFZ-STD-001)

## Surface data sets for EIGEN-5C



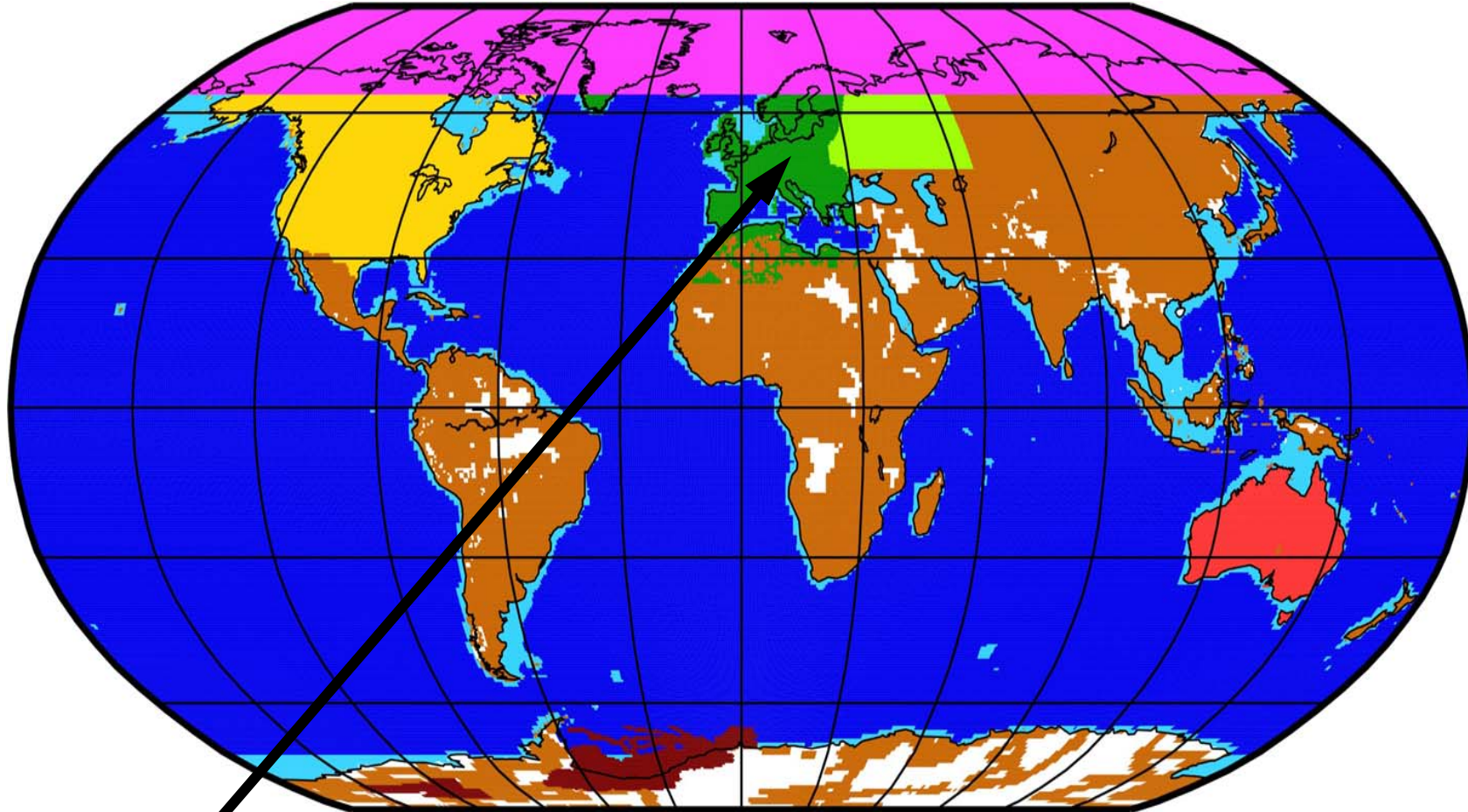
Arctic Gravity Project (ArcGP, resolution 5' x 5')  
Gravity anomalies for regions of latitude > 64°  
(Forsberg, Kenyon 2004 & 2006)

## Surface data sets for EIGEN-5C



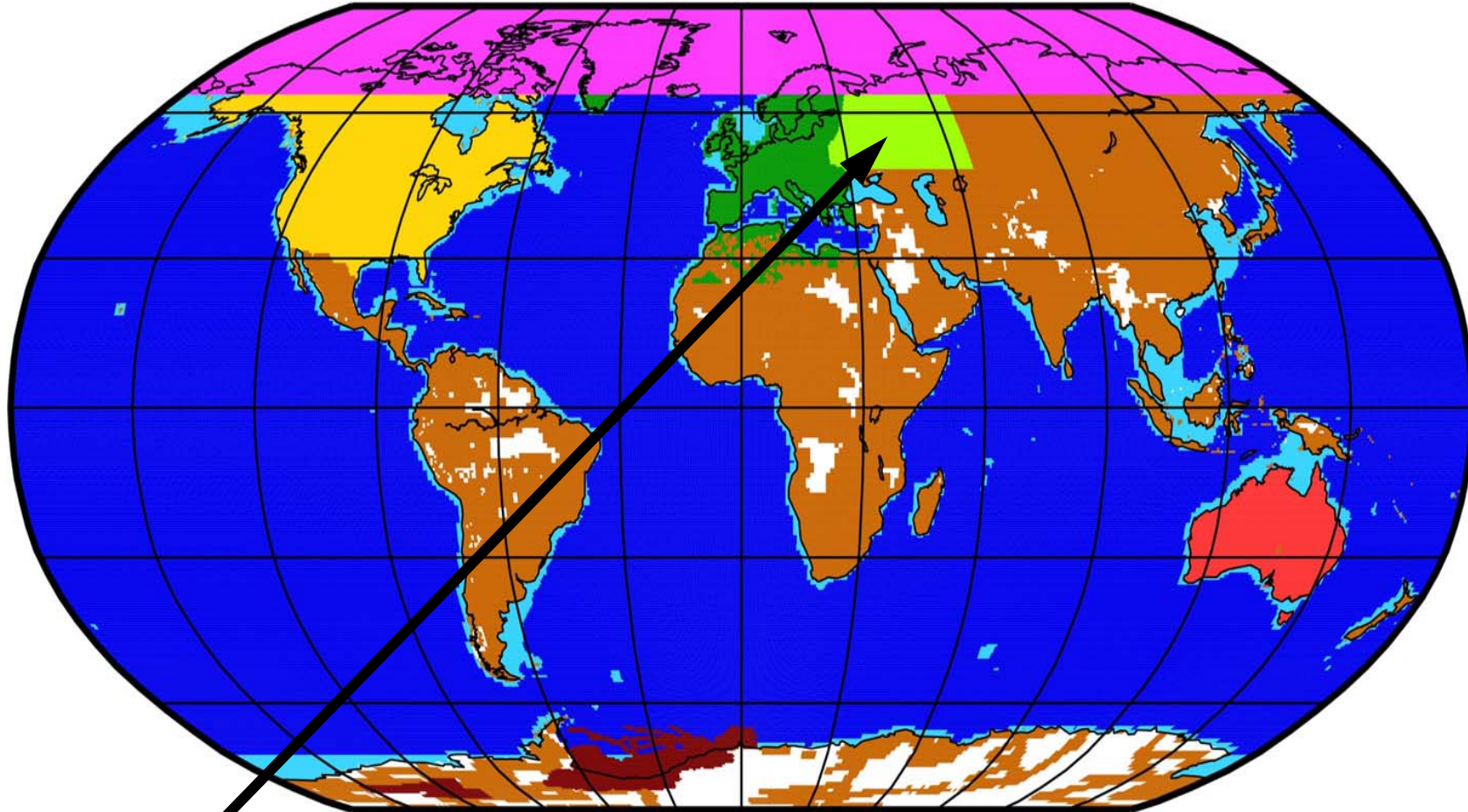
**Gravity anomalies of North America (resolution 2' x 2')**  
**(M. Véronneau 2003, National Ressources Canada, personal communication)**

## Surface data sets for EIGEN-5C



Gravity anomalies of Europe (resolution 15' x 15')  
(H. Denker, IfE Hannover, 2007, personal communication)

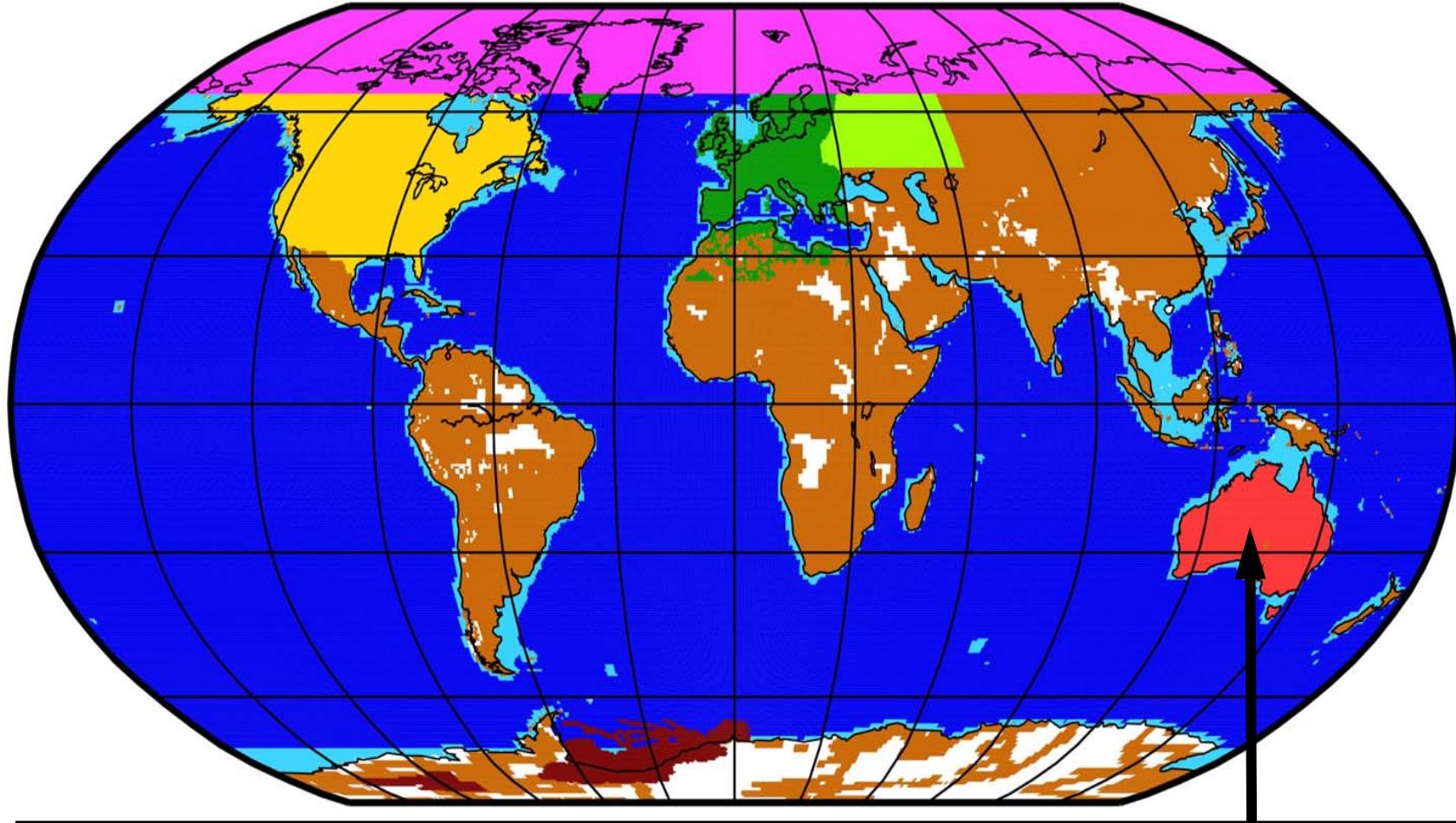
## Surface data sets for EIGEN-5C



**Gravity anomalies of East Europe (resolution 30' x 30')**  
(H. Denker, IfE Hannover 2007, personal communication)

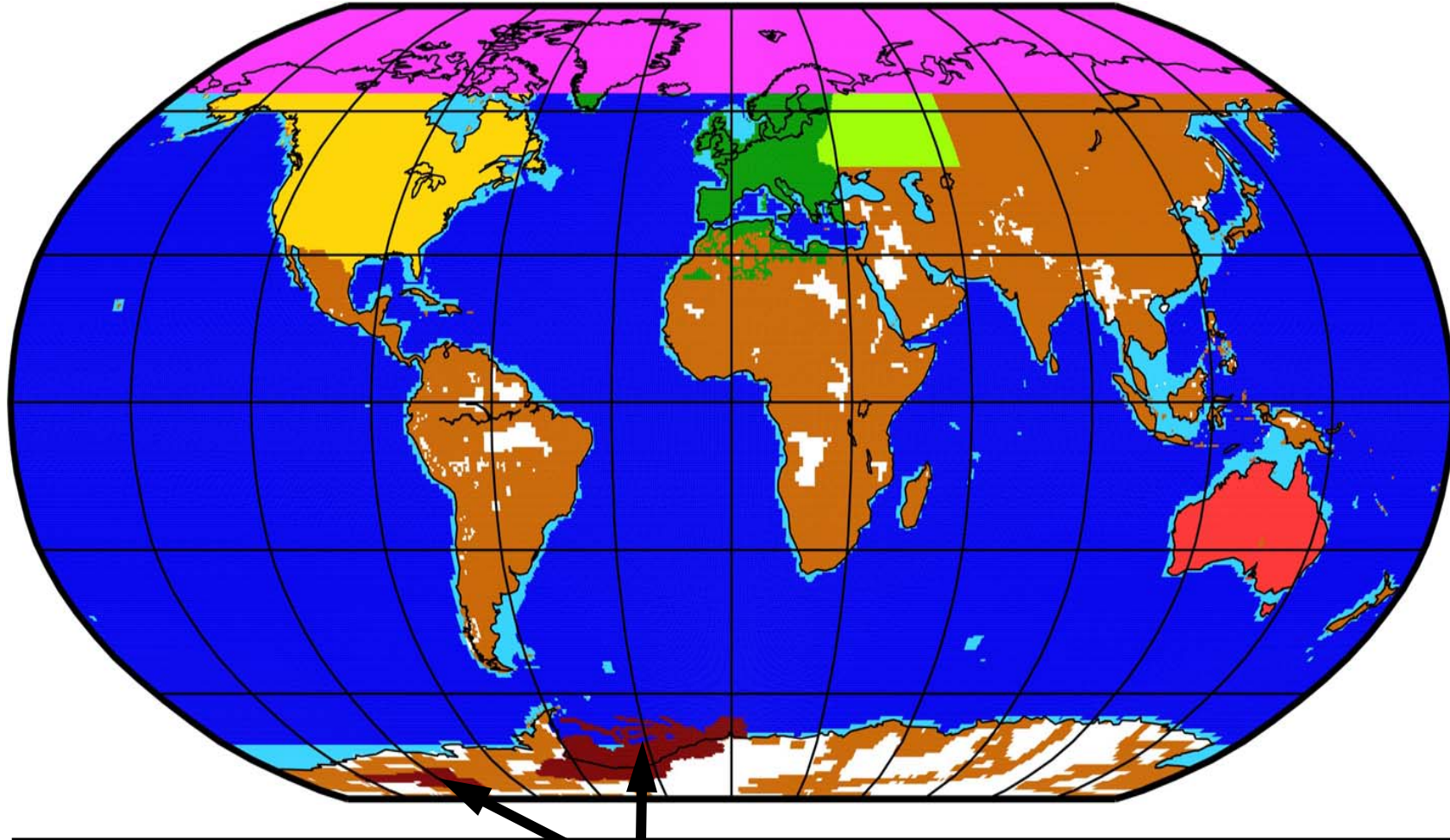


## Surface data sets for EIGEN-5C



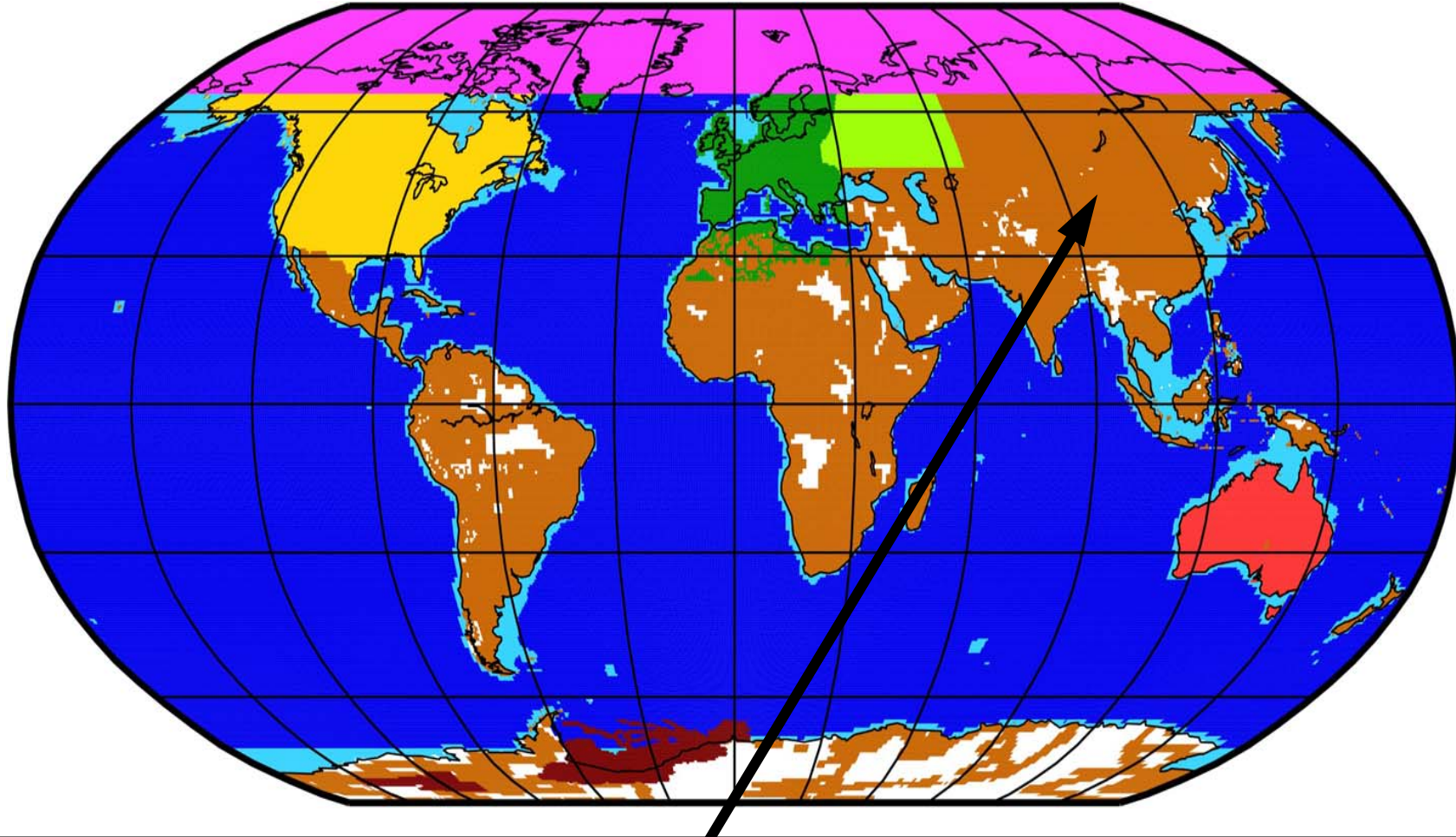
Gravity Anomaly data of the Australian Region (point data, resolution higher than 5' x 5')  
(A. Murray, Geosciences Australia, 2001)

## Surface data sets for EIGEN-5C



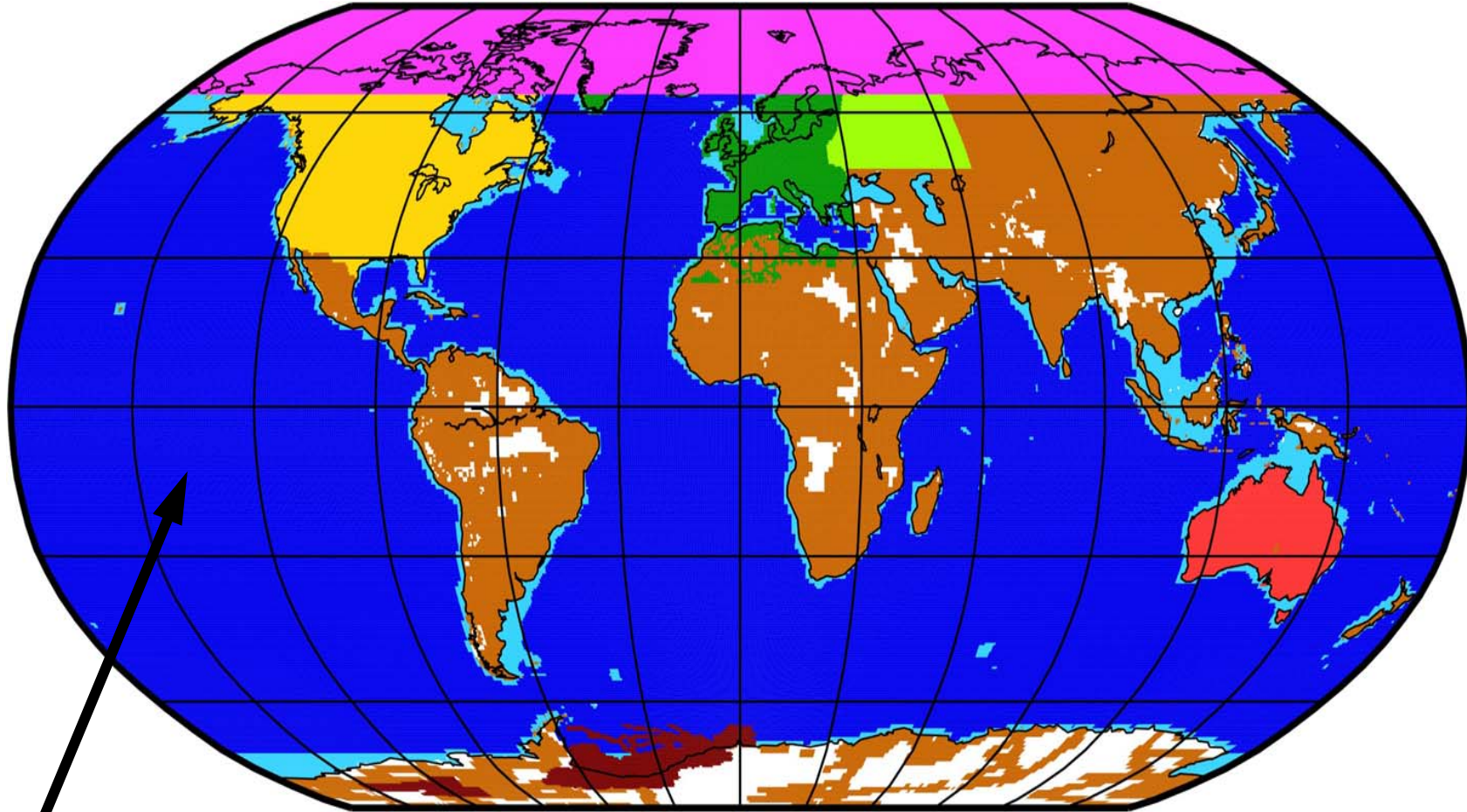
**LDO and AWI gravity anomalies (point data, resolution higher than 5' x 5')**  
**2 small areas over Antarctica and adjacent sea ice.**  
**(LDO: Bell et al., 1999; AWI: Studinger 1988)**

## Surface data sets for EIGEN-5C



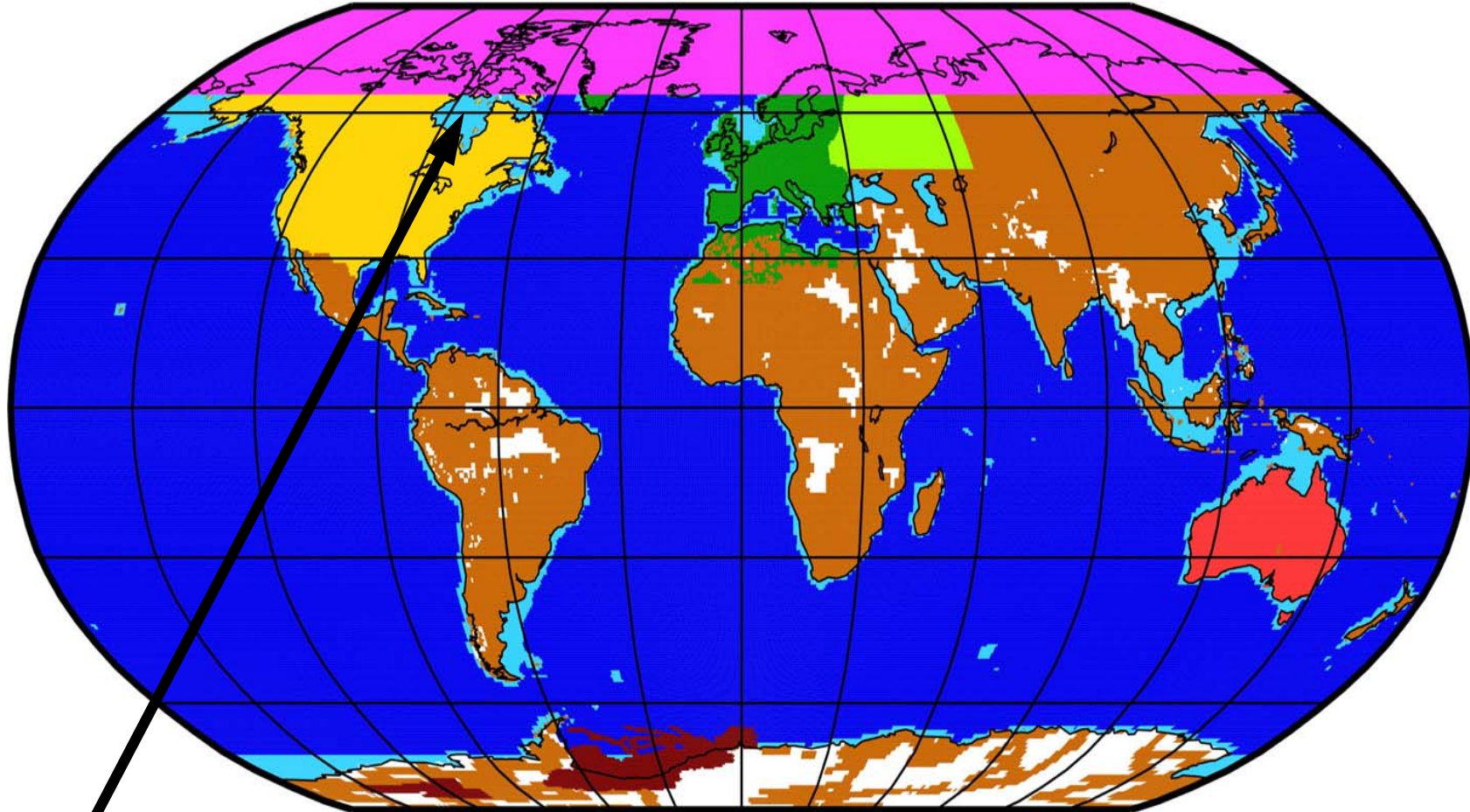
NGA terrestrial gravity anomalies  
(resolution 30' x 30')

## Surface data sets used for EIGEN-5C



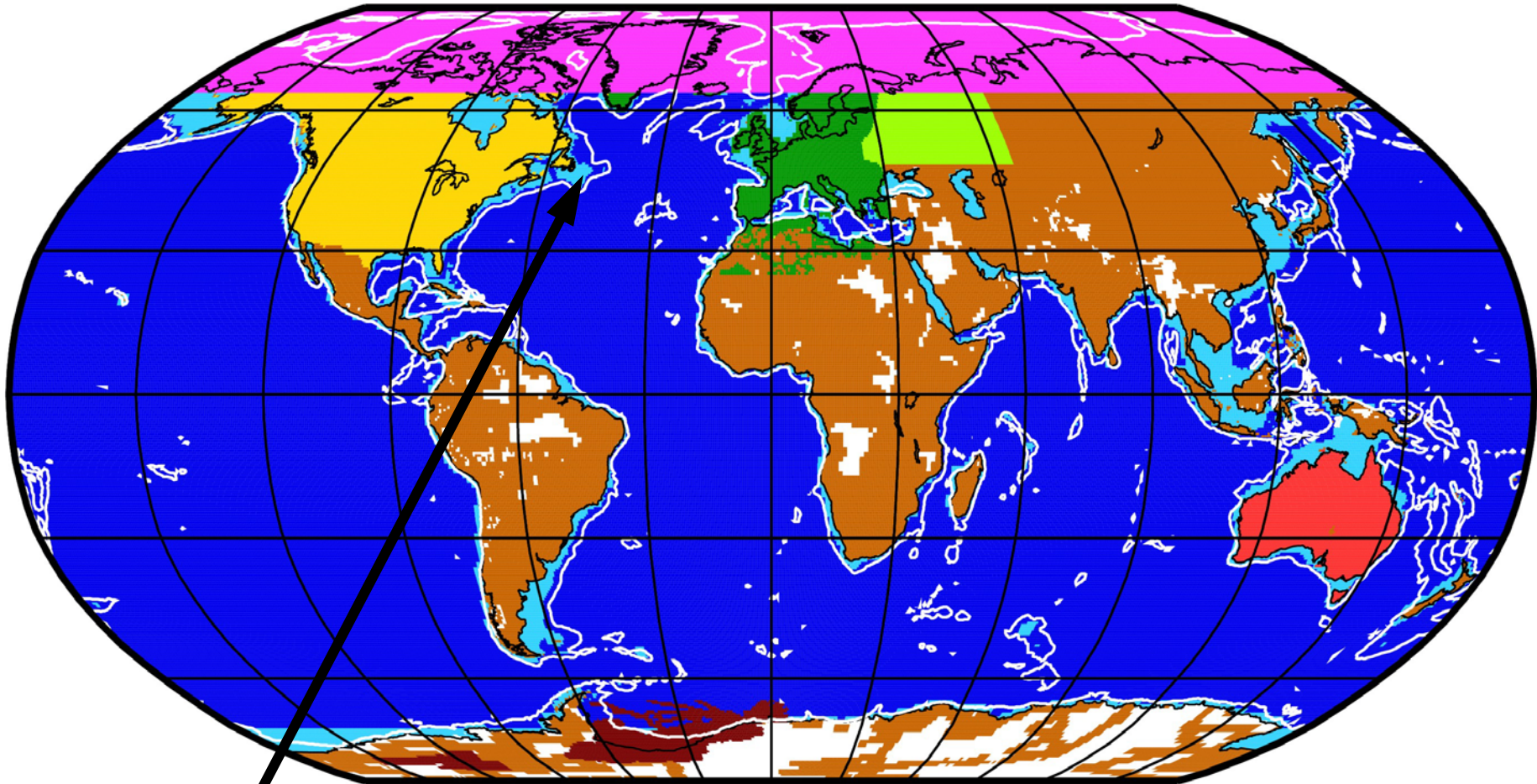
Geoid undulations over the oceans:  
GFZ Mean Sea Surface Heights (resolution 2' x 2') minus ECCO-SSTop.  
(GFZ: T. Schöne and S. Esselborn 2005, personal communication;  
ECCO: Stammer et al., 2002),

## Surface data sets used for EIGEN-5C



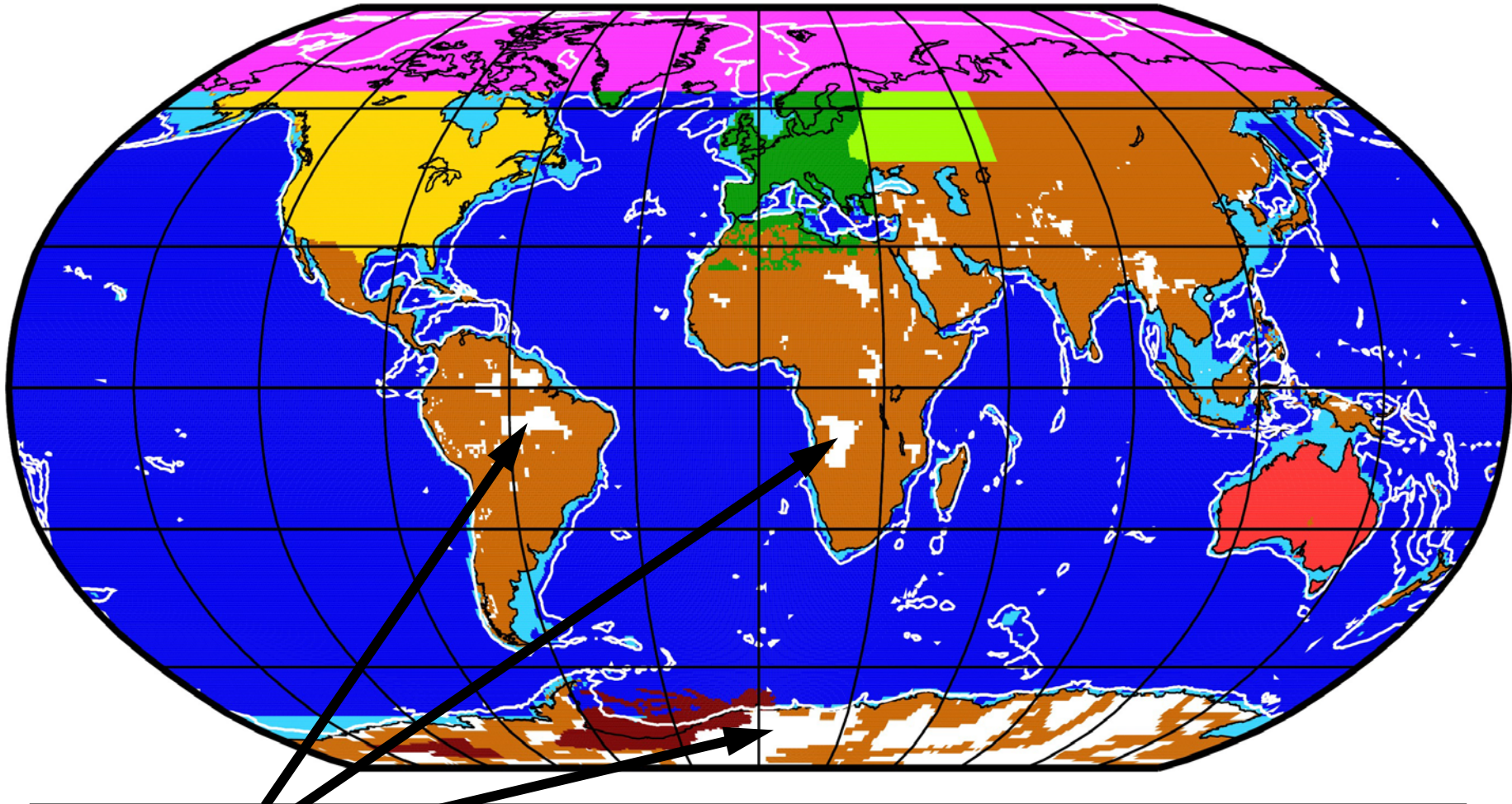
**NGA altimetric gravity anomalies for regions in the oceans (and adjacent seas) which are not covered by the GFZ-geoid, resolution 30' x 30'**

## Surface data sets used for EIGEN-5C



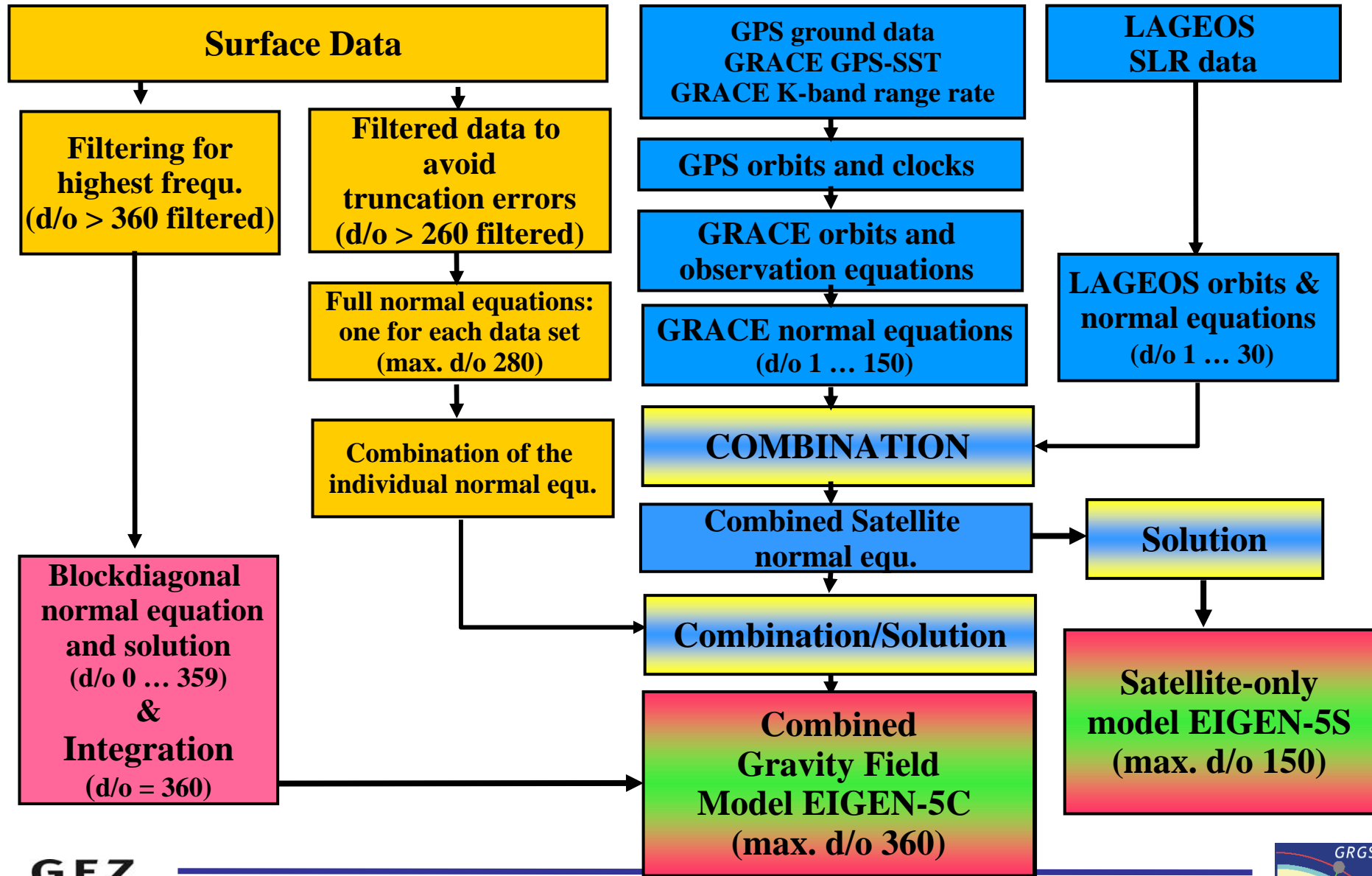
NGA ship-borne gravity anomalies over water  
depths less than 2000 m (white contourline resolution  $1^\circ \times 1^\circ$ )

## Surface data sets used for EIGEN-5C



Data gaps filled with the satellite-only model EIGEN-5S

## Processing scheme for Satellite and Surface Data





# Combination scheme of EIGEN-5C

contribution to the solution, full normal matrix:



kept separately and bound together with the surface data using constraints\*\*):



kept separately (reduced from the full normal matrix):



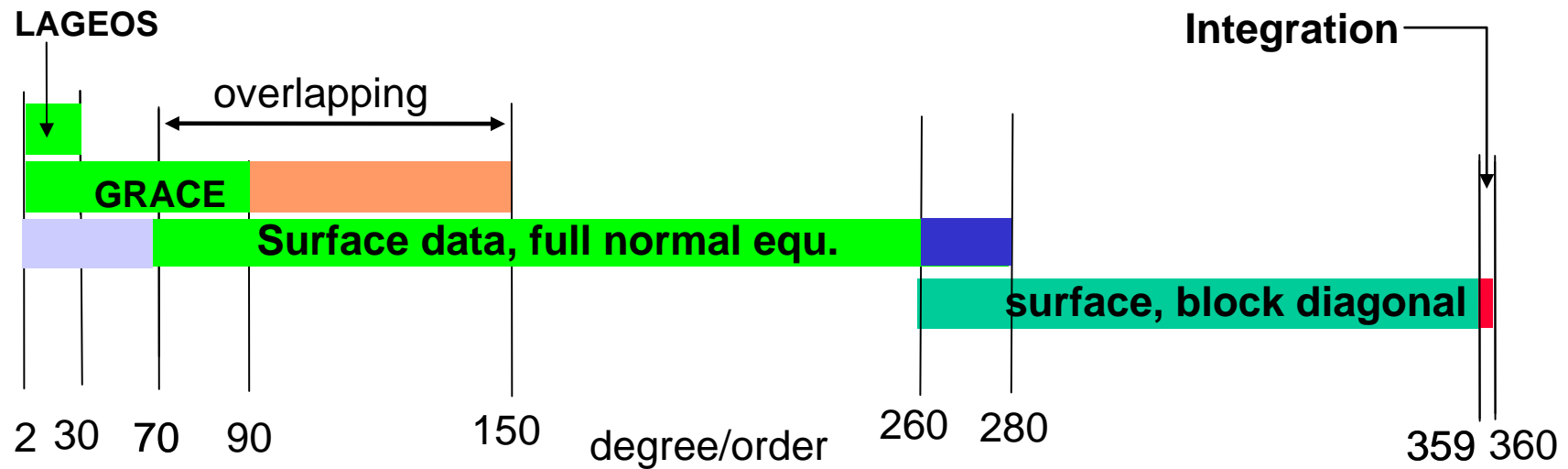
not used (low-pass filtered in order to avoid truncation errors) :



contribution to the solution, block diagonal matrix:



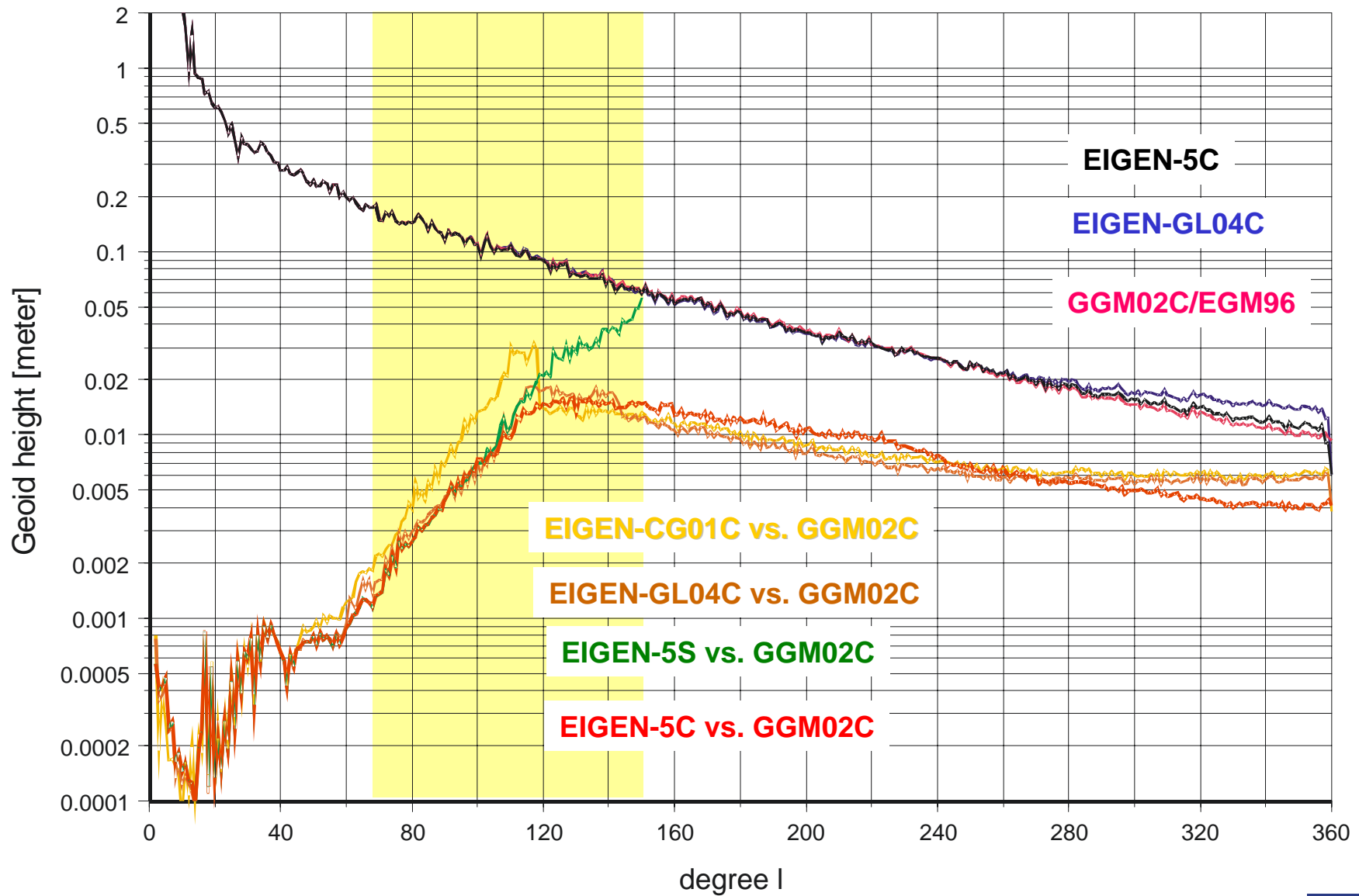
contribution to the solution, numerical integration:



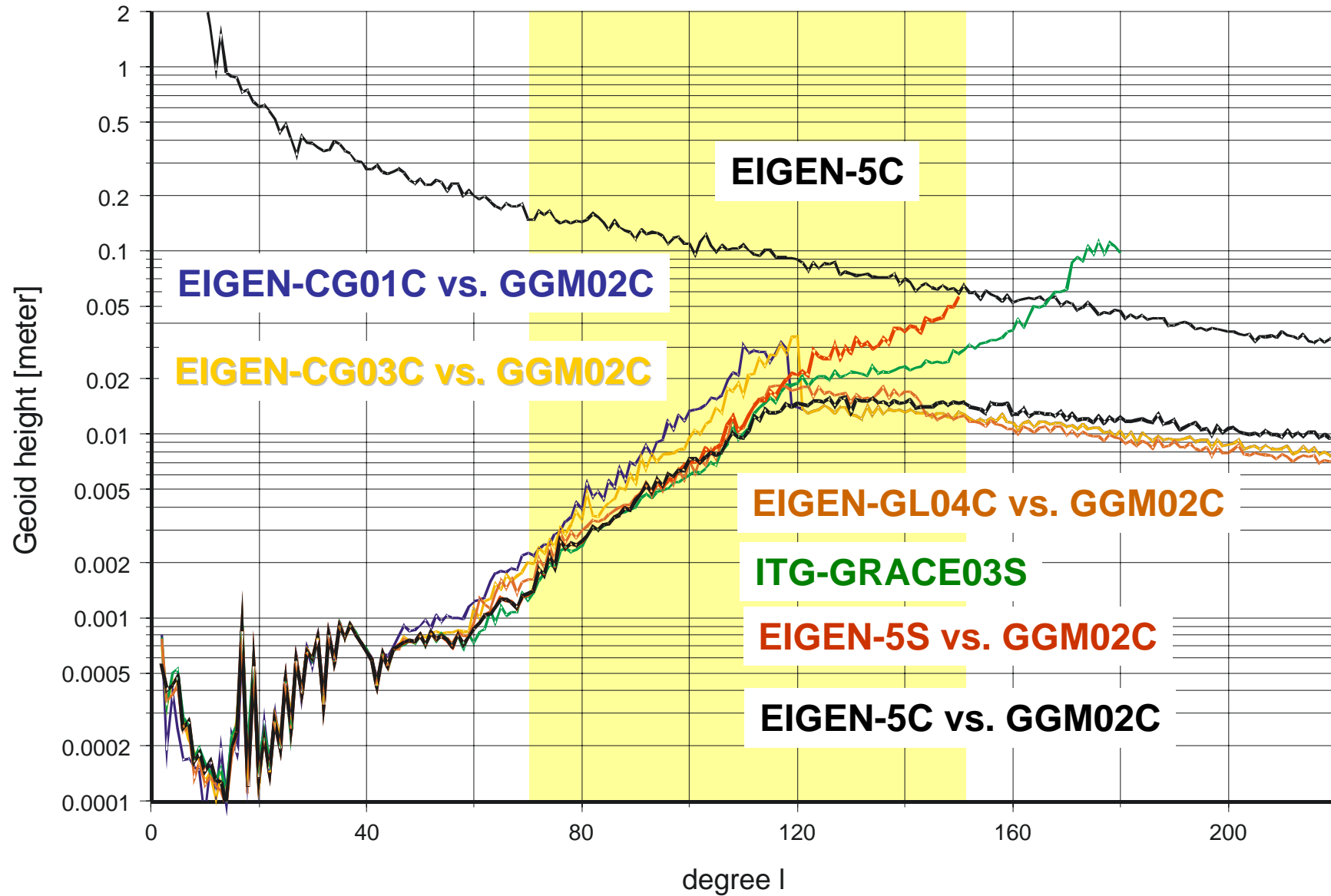
\*\*\*) constraints (pseudo observations), applied between degree 90 and 150:

$$C/S_{n,m, \text{Surface}} - C/S_{n,m, \text{GRACE} + \text{LAG.}} = 0 \pm \sigma \quad \sigma = 0.8696 \cdot 10^{-10} \cdot e^{\frac{l-90}{11.8}}$$

# EIGEN-5C: Comparison of degree variances (1) (in terms of geoid heights)

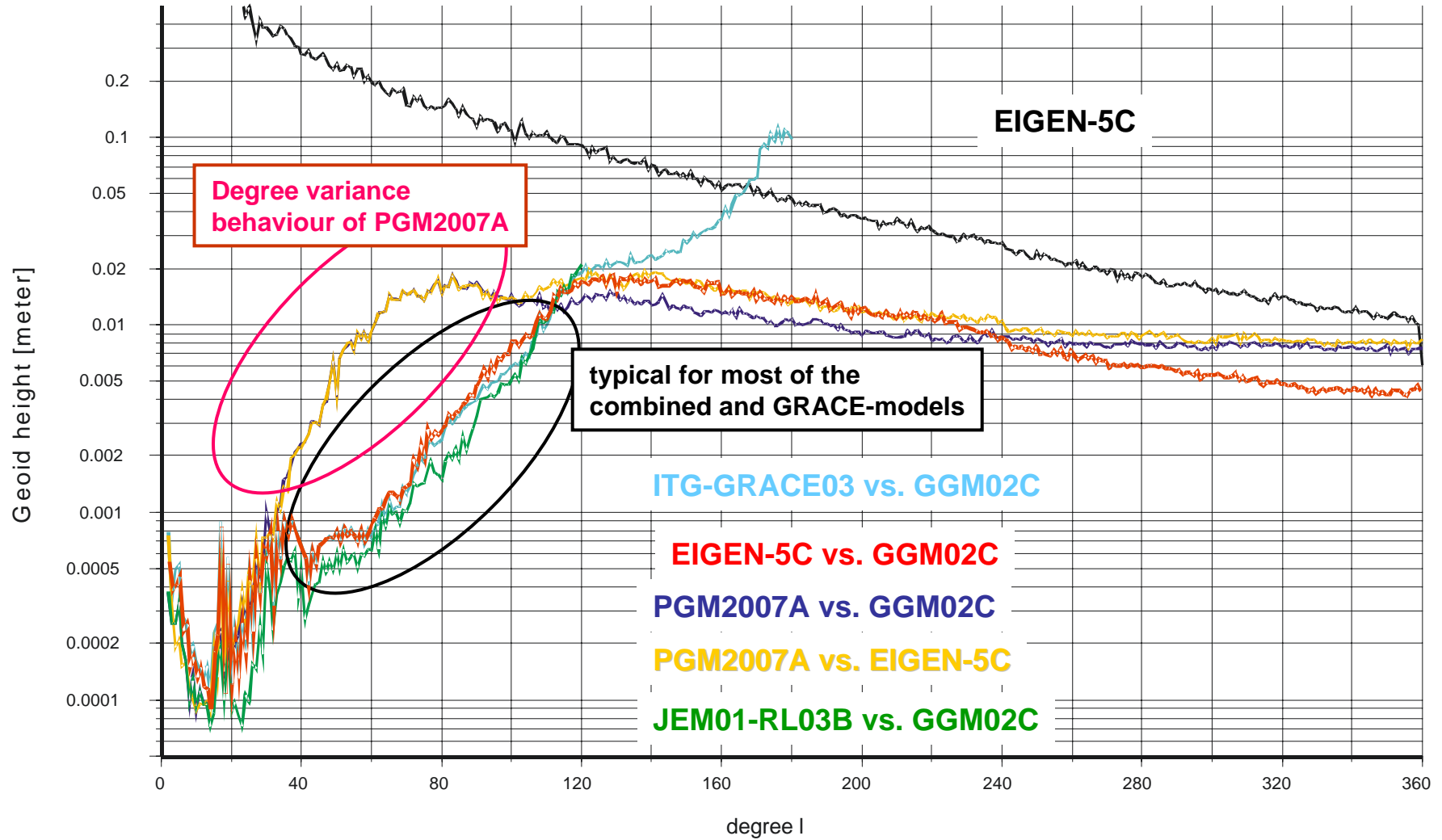


## EIGEN-5C: Comparison of degree variances (2) (in terms of geoid heights)

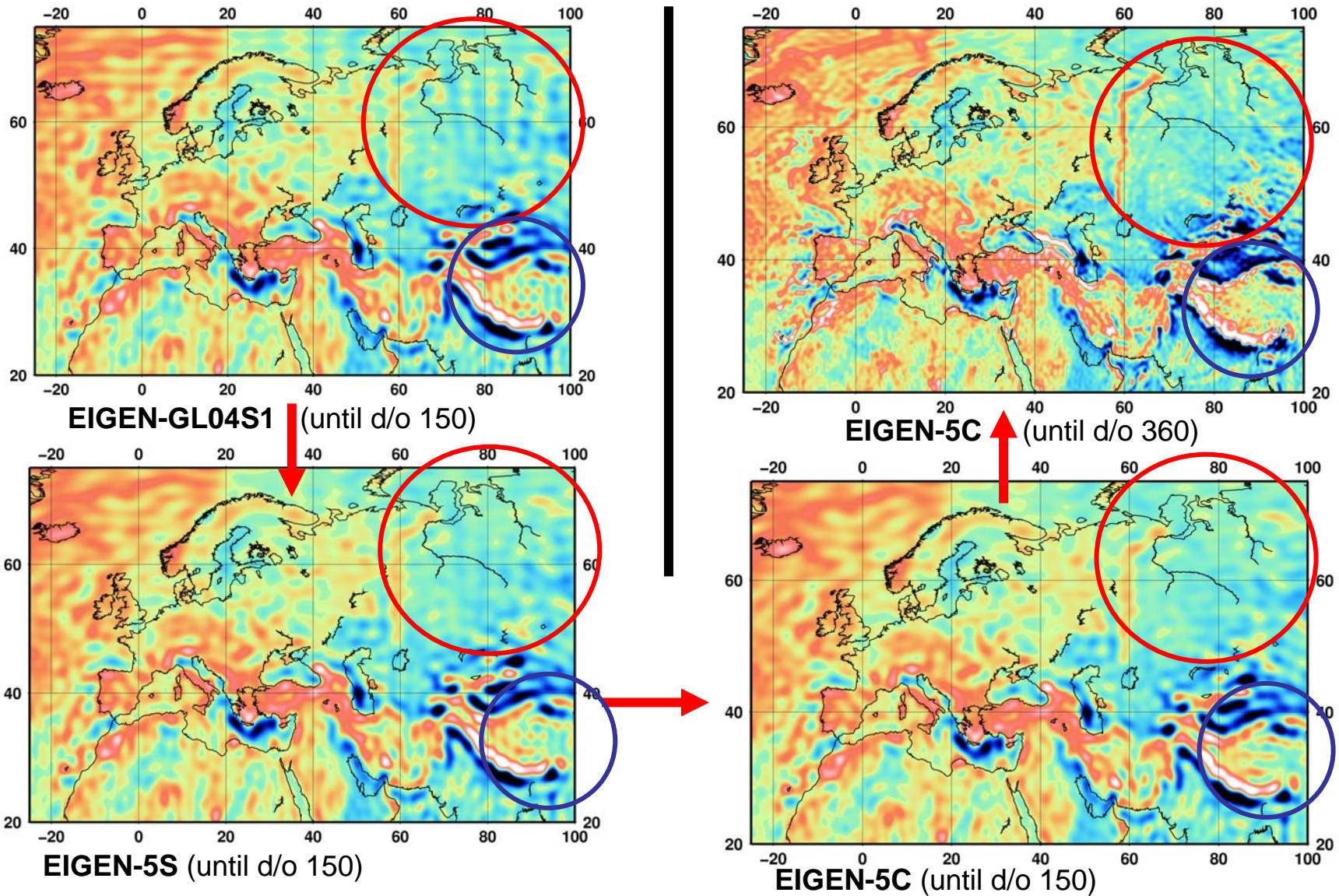


# EIGEN-5C: Comparison of degree variances (3) (in terms of geoid heights)

Including PGM2007A



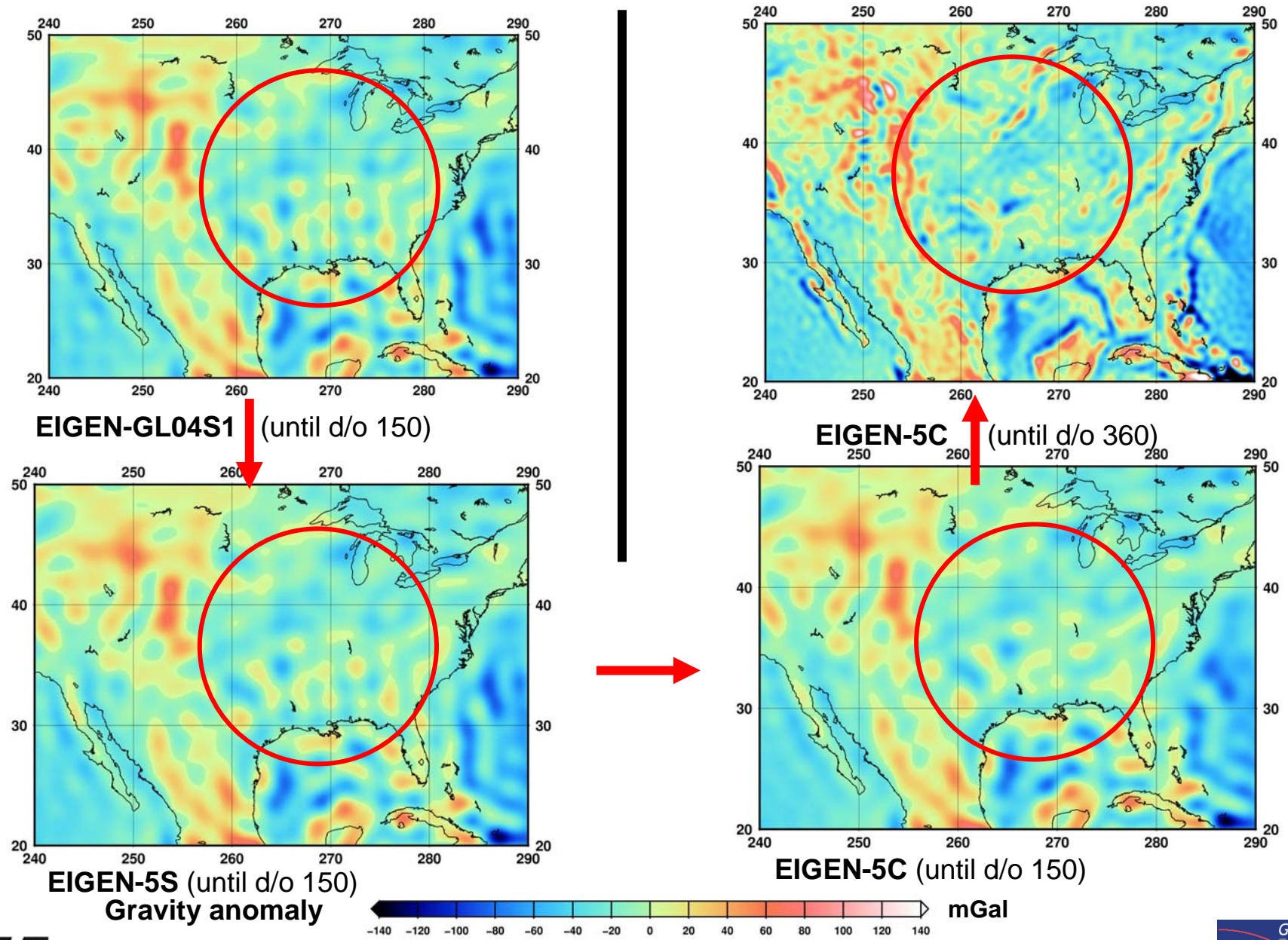
Quality improvement of EIGEN-5C: Reduction of stripes over continents - Europe/East Asia



Gravity anomaly

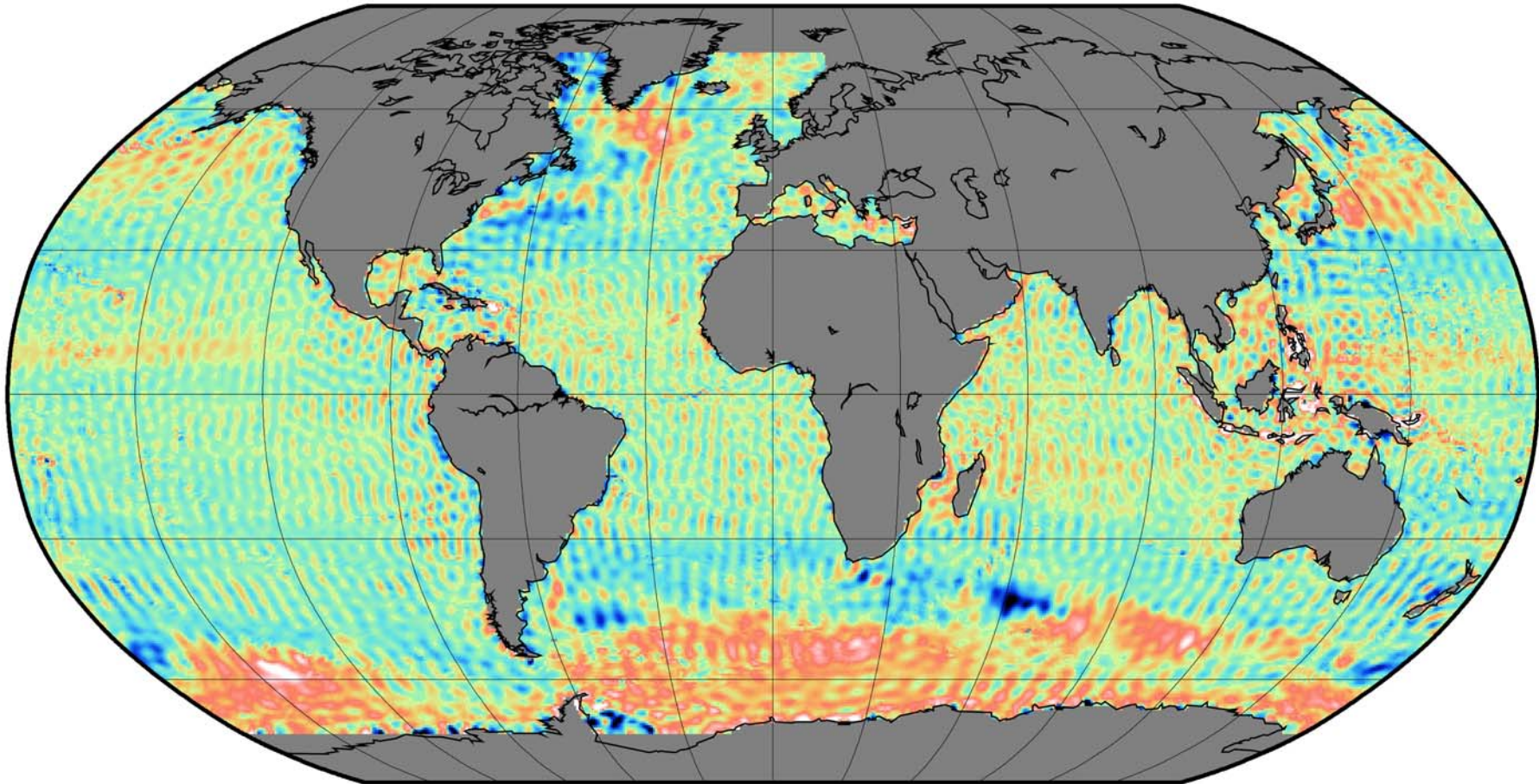


# Quality improvement of EIGEN-5C: Reduction of stripes over continents – North America



Testing for meridional stripes: Residual ocean geoid

**EIGEN-CG01C** – ( MSSH(GFZ) - DOT (ECCO) )



**EIGEN-CG01C vs. MSSH/ECCO**

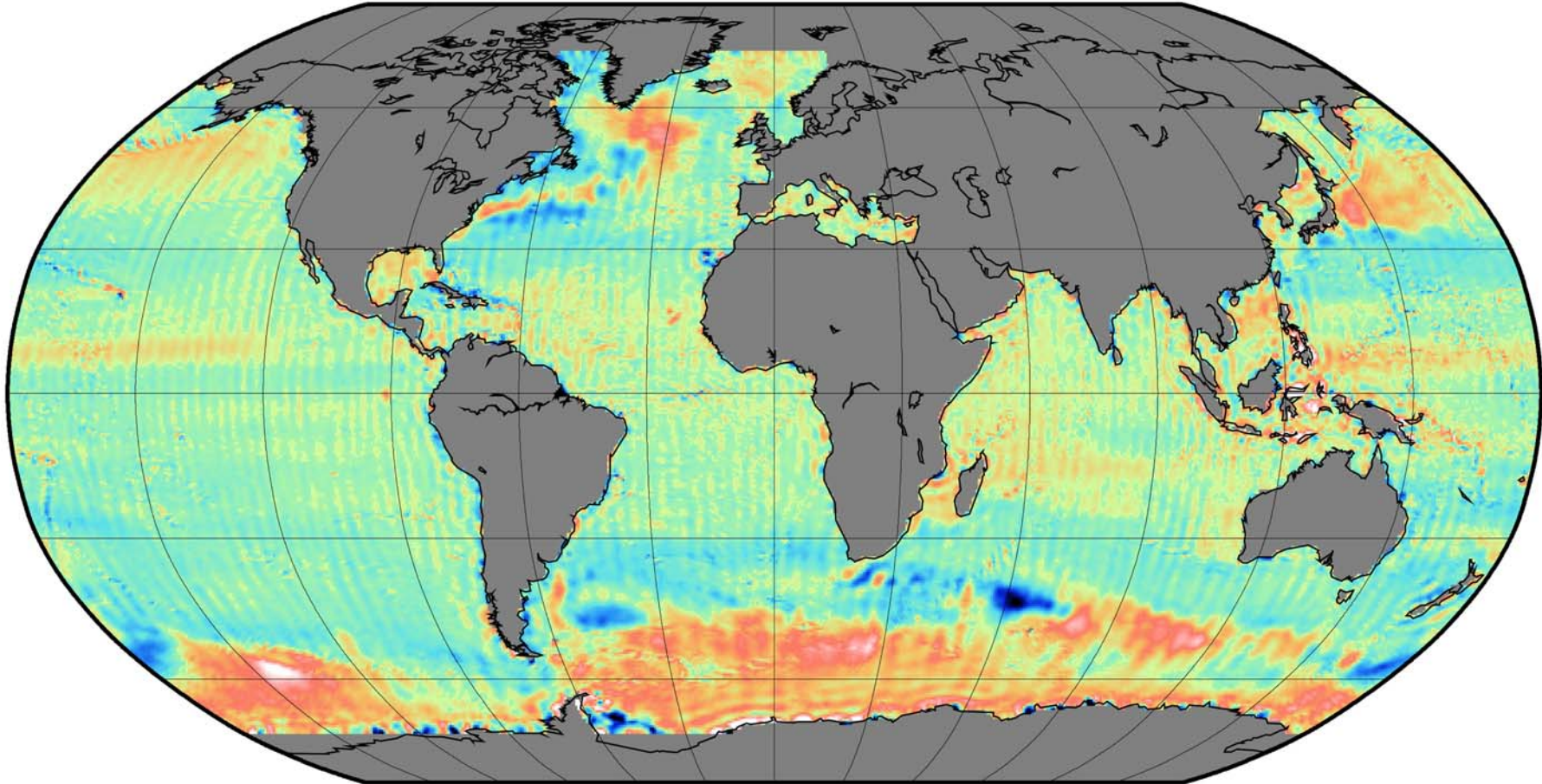
$\zeta$ ,  $0.5^\circ \times 0.5^\circ$

wrms about mean / min / max = 0.2478 / -2.374 / 3.012 meter



Testing for meridional stripes: Residual ocean geoid

**EIGEN-GGM02C – ( MSSH(GFZ) - DOT (ECCO) )**



GGM02C/EGM96 vs. MSSH/ECCO

$\zeta$ ,  $0.5^\circ \times 0.5^\circ$

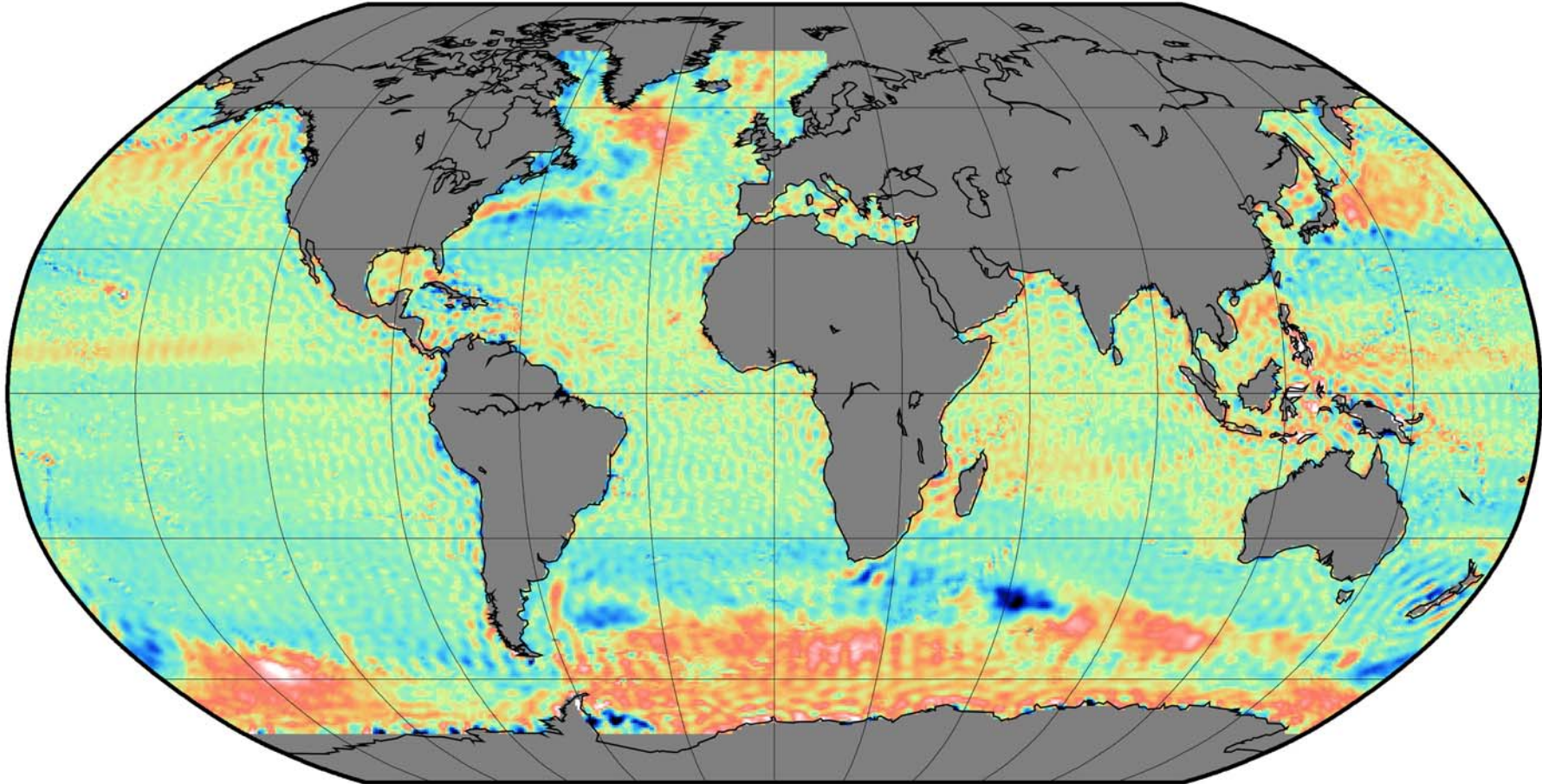
wrms about mean / min / max = 0.213 / -2.088 / 3.046 meter





Testing for meridional stripes: Residual ocean geoid

**EIGEN-GL04C** – ( MSSH(GFZ) - DOT (ECCO) )



**EIGEN-GL04C vs. MSSH/ECCO**

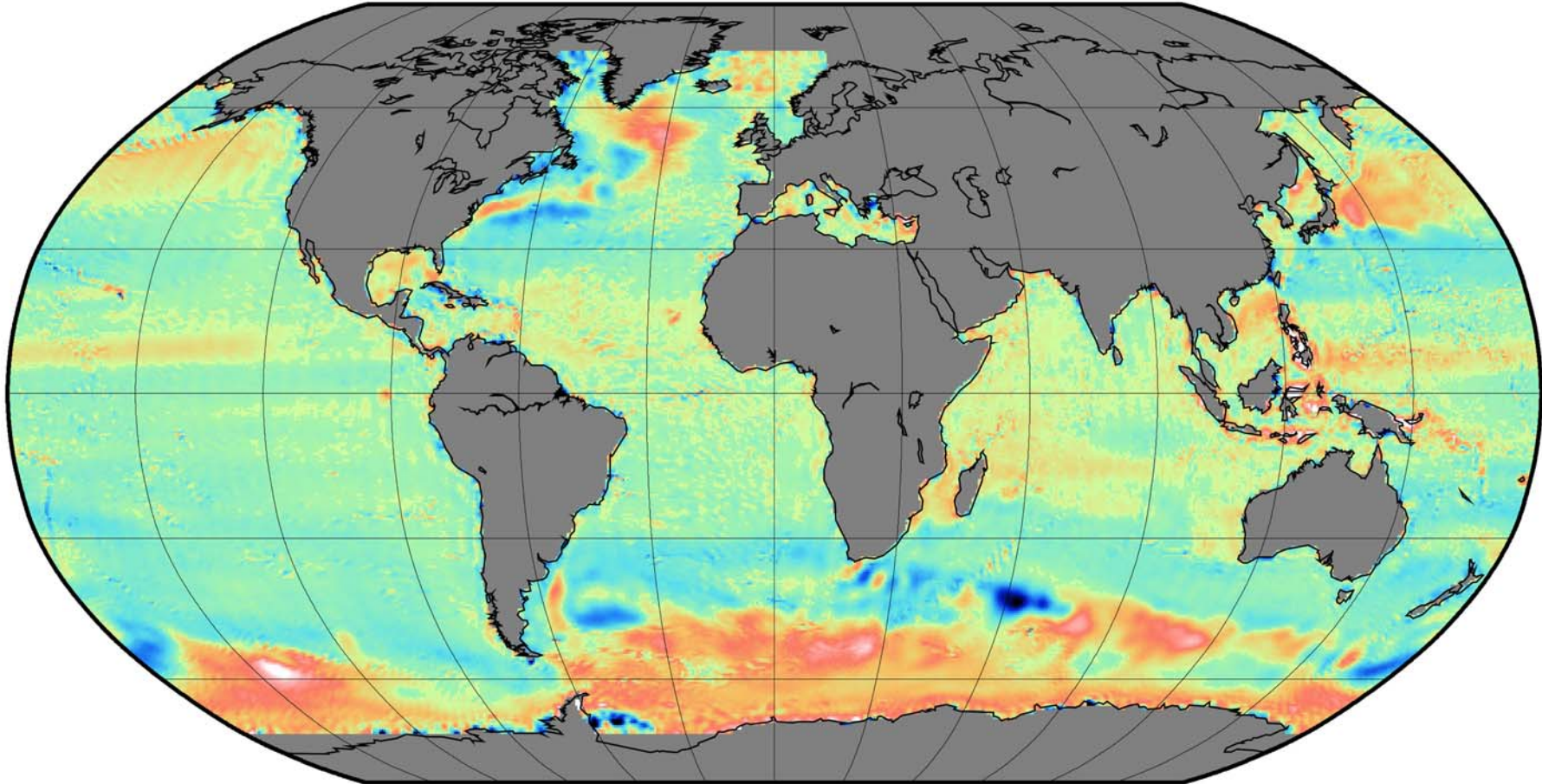
$\zeta$ ,  $0.5^\circ \times 0.5^\circ$

wrms about mean / min / max = 0.2277 / -2.012 / 2.706 meter



Testing for meridional stripes: Residual ocean geoid

**EIGEN-5C – ( MSSH(GFZ) - DOT (ECCO) )**



EIGEN-GL05C vs. MSSH/ECCO

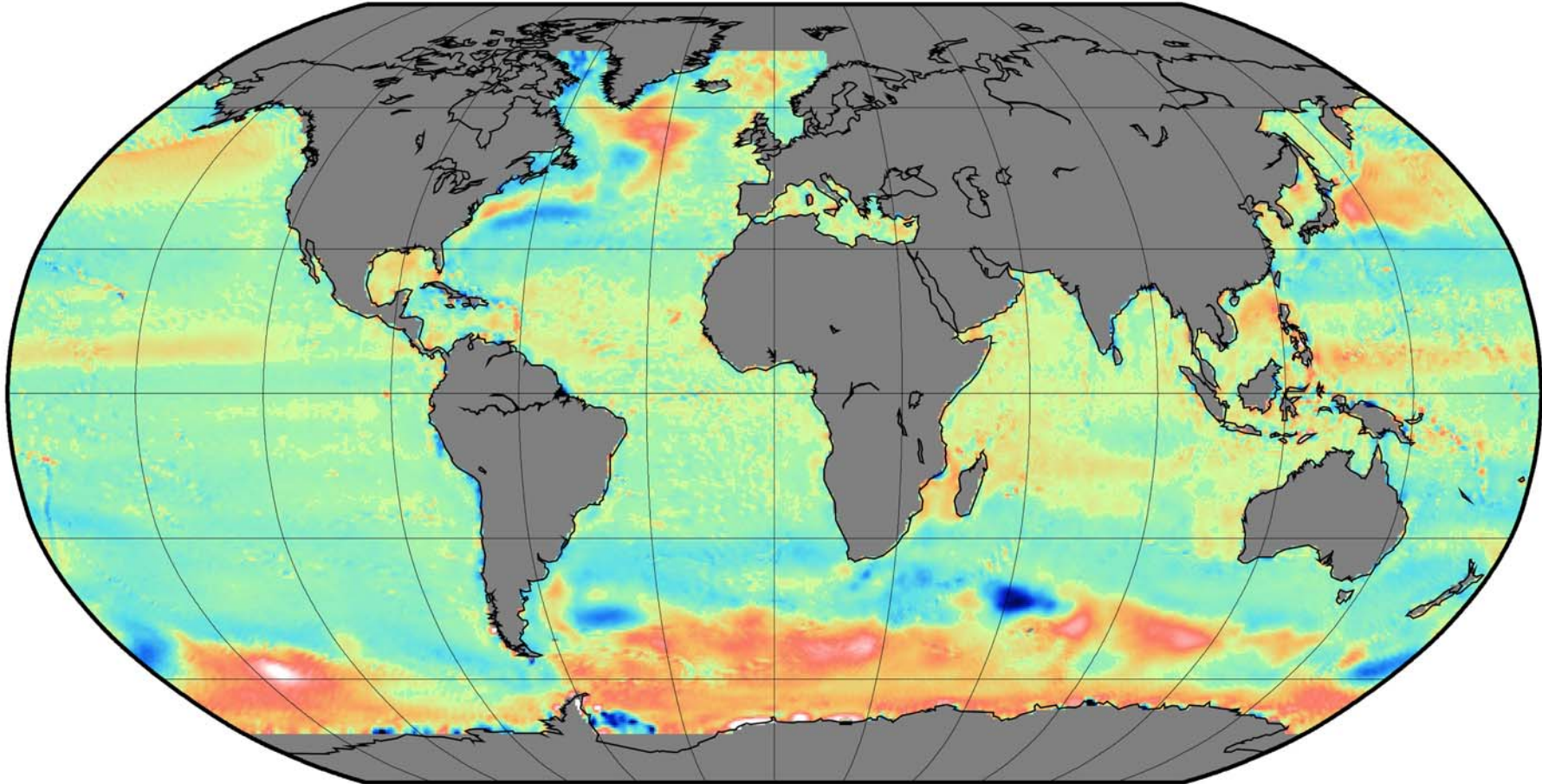
$\zeta$ ,  $0.5^\circ \times 0.5^\circ$

wrms about mean / min / max = 0.206 / -1.951 / 2.419 meter



Testing for meridional stripes: Residual ocean geoid

**PGM2007A** (till d/o 360) – ( MSSH(GFZ) - DOT (ECCO) )



PGM2007A/mean\_tide vs. MSSH/ECCO

$\zeta$ ,  $0.5^\circ \times 0.5^\circ$

wrms about mean / min / max = 0.1787 / -2.186 / 3.79 meter



## GPS/Leveling test

Comparison with geoid heights determined point-wise by GPS positioning and leveling:

- Root mean square (**cm**) about mean of GPS-Leveling minus model-derived geoid heights (number of points in brackets).

	EGM96	GGM02C/ EGM96*	EIGEN- CG01C	EIGEN- GL04C	EIGEN-5C	PGM2007A (till d/o 360)
Europe (186)	48	31	41	34	33	27
Germany (675)	29	17	22	18	15	14
Canada (1930)	36	26	25	25	25	23
USA (6169)	38	33	35	34	34	32
Australia (201)	30	25	26	24	24	24

**PGM2007A fits best  
for the most data sets**

\* GGM02C up to d/o 200; EGM96 degrees > 200

### Used GPS/Leveling data sets:

- **USA:** Milbert, 1998
- **Canada:** M. Véronneau, personal communication 2003, Natural Resources Canada
- **Europe/Germany:** Ihde et al., 2002
- **Australia:** G. Johnston, Geoscience Australia and W. Featherstone, Curtin University of Technology, personal communication 2007

# Orbit adjustment tests (1): CHAMP and GRACE

**SLR residuals (cm)** after an orbit determination based on GPS (CHAMP, GRACE) and K-Band Range-Rate (GRACE) data  
 The SLR data were not included for the orbit adjustment!

Data: **three 1.5 day arcs** per satellite,

Included SLR normal points: GRACE: **592** CHAMP: **358**

**best model**  
**worst model**

Satellite	truncation	GGM02C	ITG-GRACE03S	EIGEN-GL04C	EIGEN-5S	EIGEN-5C	PGM2007A	JEM1-RL03B
CHAMP	120 x 120	5.32	5.38	5.44	5.56	5.59	8.05	5.35
	150 x 150	5.19	5.30	5.41	5.58	5.57	7.85	-----
GRACE	120 x 120	5.50	5.39	5.25	5.16	5.16	6.21	5.55
	150 x 150	5.54	5.38	5.24	5.19	5.16	6.22	-----

Improvement  
 after the combination  
 with ground data

# Orbit adjustment tests (2)

Mean RMS: SLR and PRARE in cm, PRARE-Doppler and DORIS in mm/sec  
 All gravity fields truncated to 120x120,

best model  
 worst model

Satellite	Data #arcs	Data Typ	GGM02C	ITG-GR03S	EIGEN-GL04C	EIGEN-5S	EIGEN-5C	PGM2007A	JEM1-RL03B
GFZ-1	5x3 days	SLR	14.31	14.11	13.78	13.57	14.31	15.28	13.99
STELLA	5x3 days	SLR	3.24	3.01	2.97	2.96	2.97	3.23	3.13
STARLETTE	5x3 days		2.45	2.57	2.56	2.56	2.54	2.51	2.58
AJISAI	5x3 days		3.18	3.15	3.15	3.14	3.14	3.19	3.25
LAGEOS-1	5x6 days		1.13	1.13	1.13	1.13	1.13	1.14	1.14
LAGEOS-2	5x6 days		1.05	1.05	1.05	1.05	1.05	1.05	1.05
ERS-2	6x6 days	SLR	5.86	5.34	5.34	5.32	5.32	5.68	5.64
		PRARE	3.86	3.55	3.56	3.56	3.56	3.73	3.71
		PDO	0.371	0.344	0.346	0.345	0.344	0.360	0.358
ENVISAT	7x4...8 days	SLR	4.30	4.20	4.38	4.39	4.40	4.24	4.29
		DORIS	0.495	0.495	0.496	0.496	0.496	0.495	0.495
WESTPAC	5x6 days	SLR	4.21	3.98	3.97	3.97	3.96	4.07	4.08
JASON		SLR	1.89	1.87	1.88	1.87	1.87	1.90	1.88

## Summary

A new combined gravity field model **EIGEN-5C** has been obtained from the combination of GRACE & LAGEOS satellite data (= **EIGEN-5S** satellite-only model) and surface data.

The new **EIGEN-5C** model shows the following improvements compared to previously released models:

- better orbit fits for GRACE and SLR satellites
- smoother spectral behaviour
- better reduction of meridional stripes
- better fit in GPS/Leveling comparisons

The **EIGEN-5C/S** coefficients will become available for download in mid of May 2008 at the **ICGEM\*** data base at **GFZ Potsdam**:

<http://icgem.gfz-potsdam.de/ICGEM/ICGEM.html>

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\***ICGEM** = The **I**nternational **C**enter of **G**lobal **E**arth **M**odels at **GFZ Potsdam** is one of the six data centers of the **I**nternational **G**ravity **F**ield **S**ervice (**IGFS**) of the **IAG**