

Status GFZ RL05 and RL05a GRACE L2 Products

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RL05 Processing Status

- 121 monthly fields from 01/2003 - 07/2013 available
- 01-12/2002 ready to process (L1B already available)
- Maximum d/o: 90x90
- Level-2 products: GSM, GAA, GAB, GAC, GAD
- weekly solutions (30x30): 5.1.2003-28.7.2013

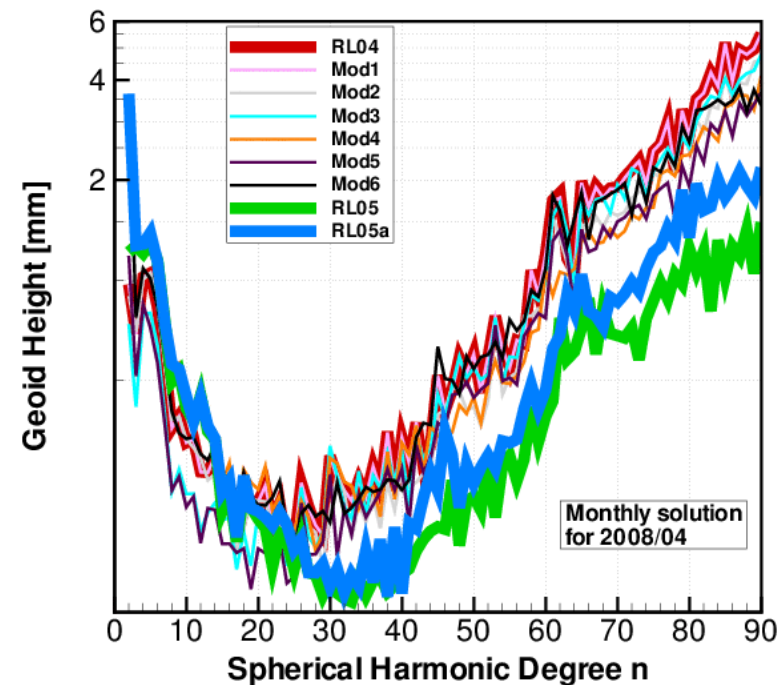
GFZ RL05	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2002												
2003												
2004												
2005												
2006												
2007												
2008												
2009												
2010												
2011												
2012												
2013												

Modifications from RL04 to RL05 (1)

- Reprocessed Level-1B data (RL02)
- Changes in the force models:
 - EIGEN-6C incl. time-variable part till d/o 50x50
Note: RL05 contains no drift rates for C_{20} , C_{30} , C_{40} , C_{21} , S_{21}
 - EOT11a
 - AOD1B RL05 (new OMCT model, same (RL04) atmosphere)
Note: AOD1B RL05 Product Description Document available at ISDC/PO.DAAC
- Changes in the reference frame:
 - reprocessed GPS constellation (orbits & clocks) based on IGS08 realization of ITRF2008
 - frame transformation according to IERS2010

Modifications from RL04 to RL05 (2)

- Changes in the observation model:
 - 1-hourly ACC biases in all 3 directions, no longer scale factors
 - GFZ derived phase center corrections for GRACE GPS-SST obs.
 - modified relative weighting of KRR and GPS-SST
- Changes in the gravity field parameter solution procedure
 - Arc specific parameters such as initial orbit state vectors, K-band parameters, ACC biases fixed before solving gravity field parameters
 - Reason: significant noise reduction on top of all other modifications (see bold green calibrated errors)



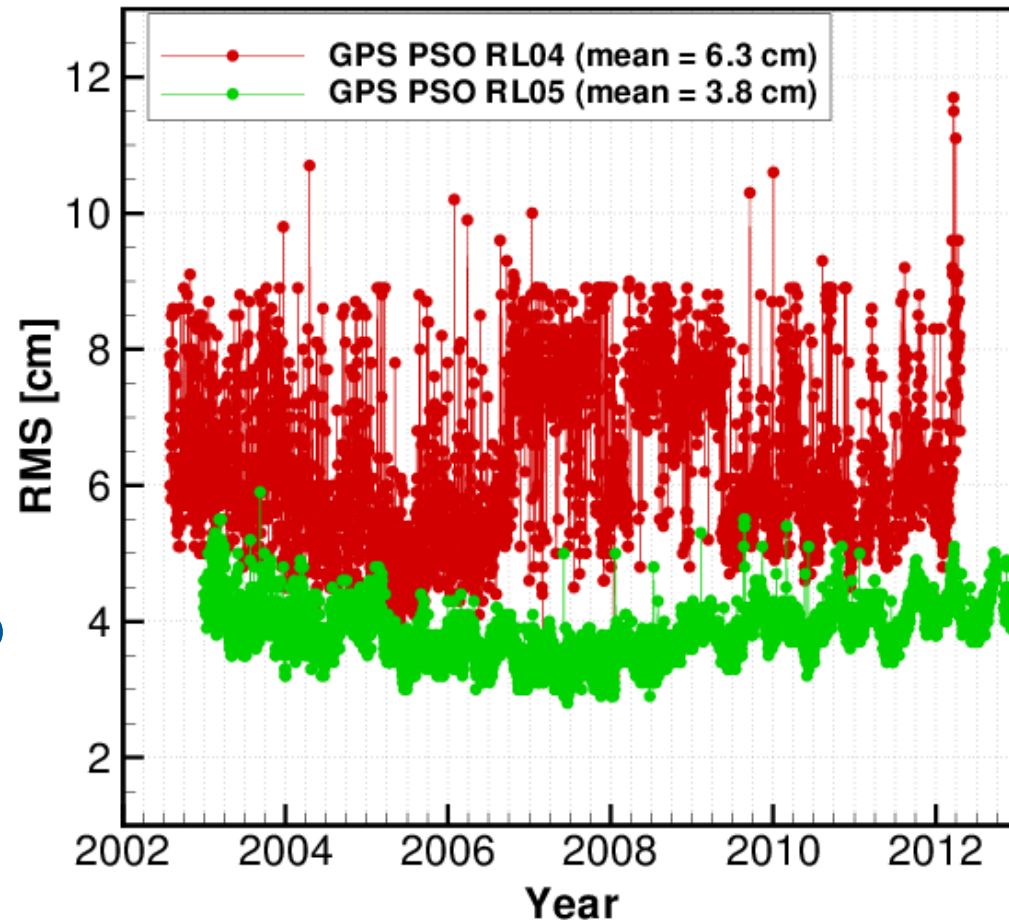
RL05 Pros and Cons

GPS Constellation

Updated GPS orbits and clocks for RL05:

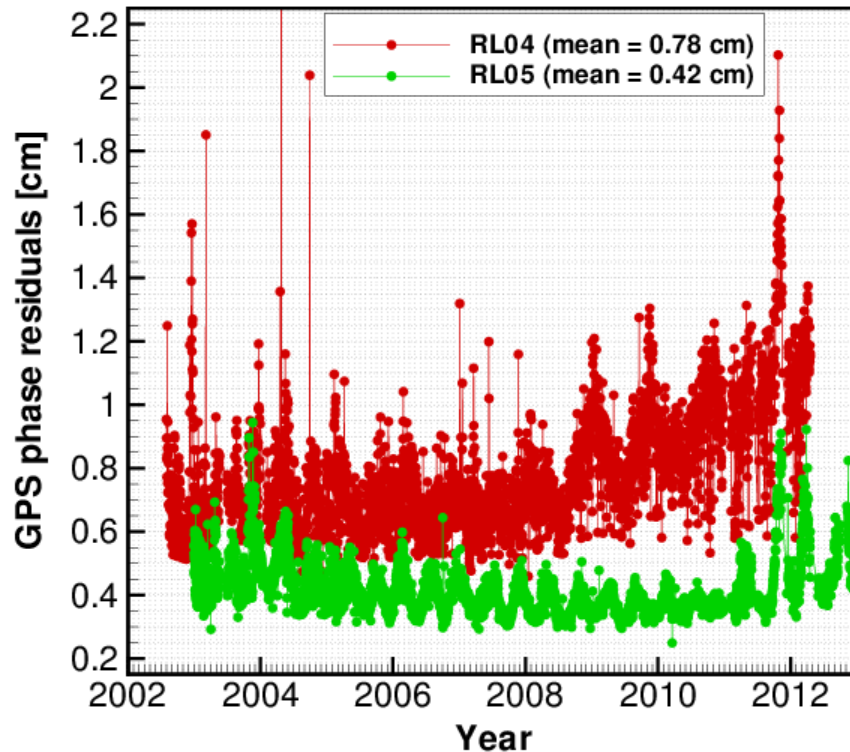
- absolute PCVs
- phase windup corr.
- GPS attitude model

→ clear reduction of 3D RMS wrt. IGS orbits

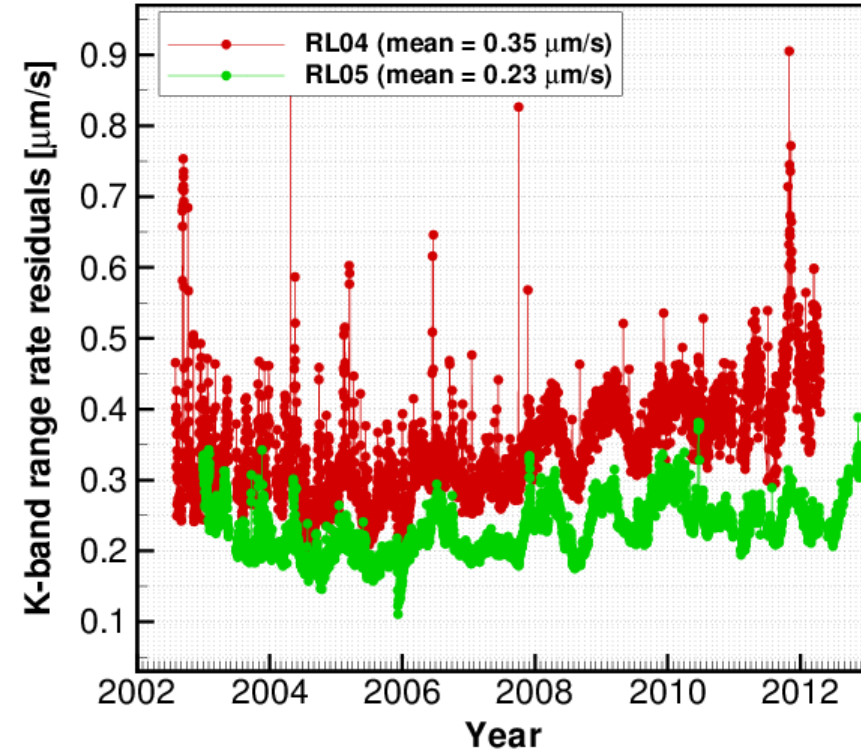


Pre-fit Residuals

GPS phase (49%)



K-band range rate (32%)

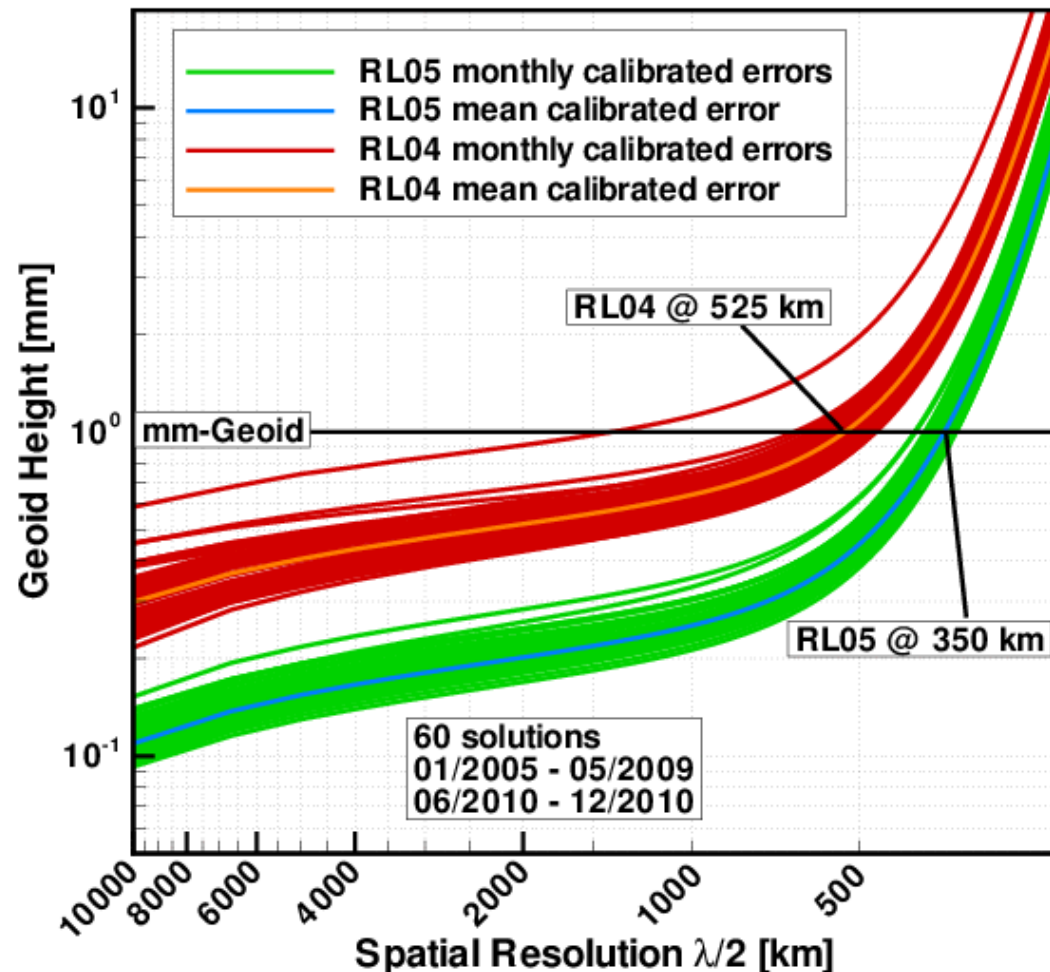


- RL05 residuals significantly decreased & less scattered
- RL05 revealed some systematic structure in GPS residuals
- structure of KRR residuals correlated with inter-satellite distance

Cumulated Errors

RL05 features

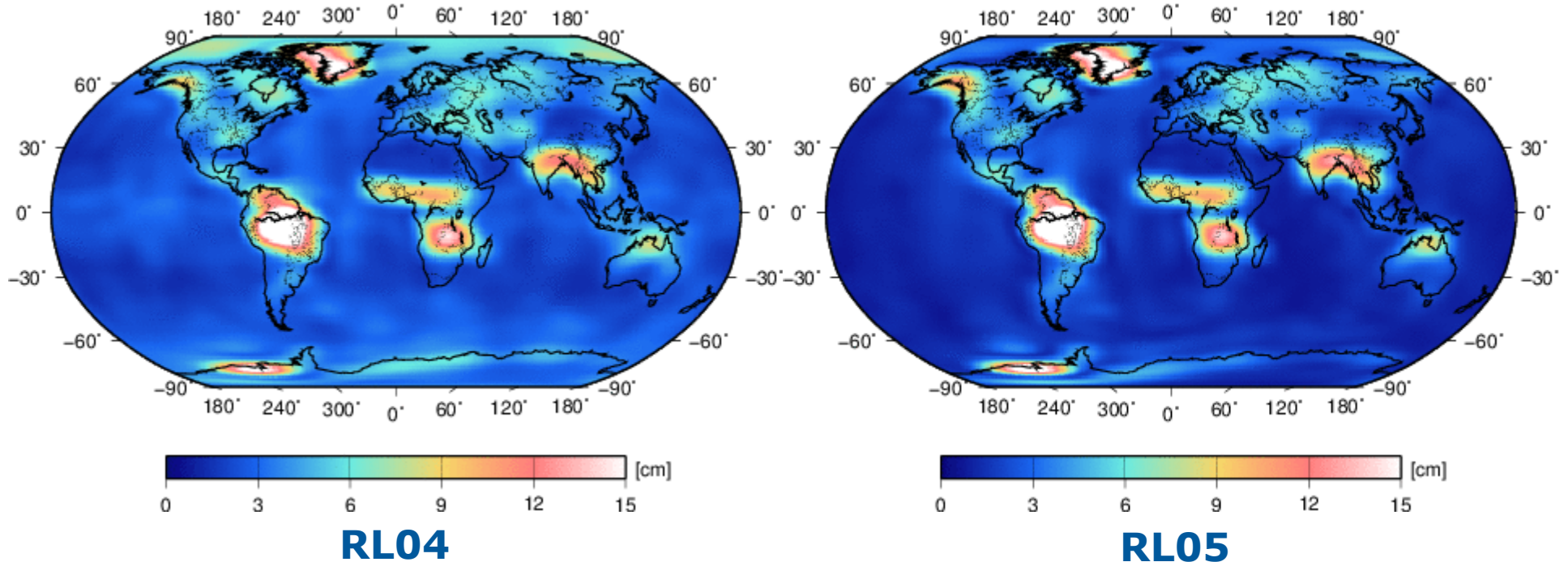
- increased spatial resolution
- less difference in accuracy from month to month
- no more extremely large errors



RMS Variability

RMS variability of EWH grids over 6 years (2005-2010):

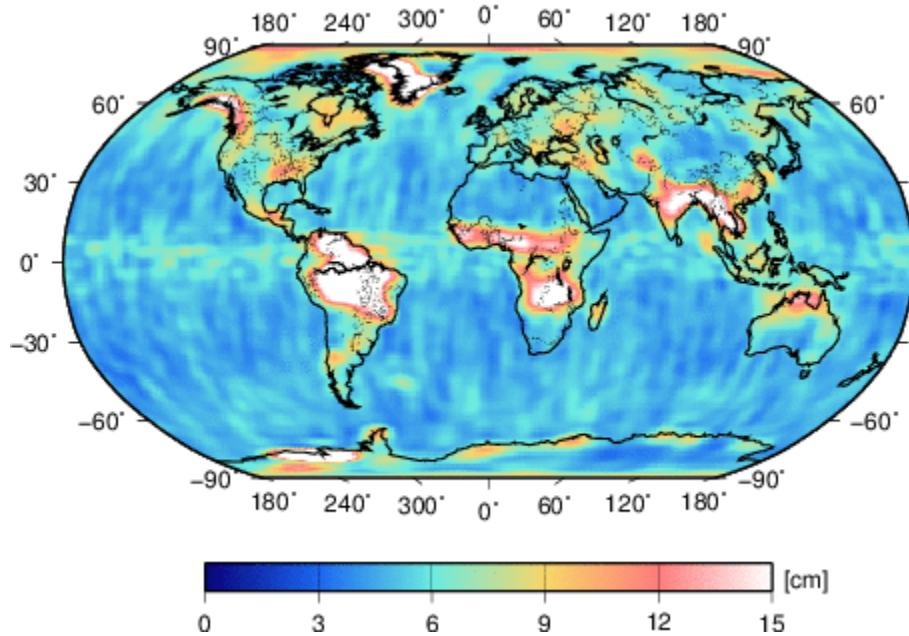
DDK1 filter ($\sim 530\text{km}$)



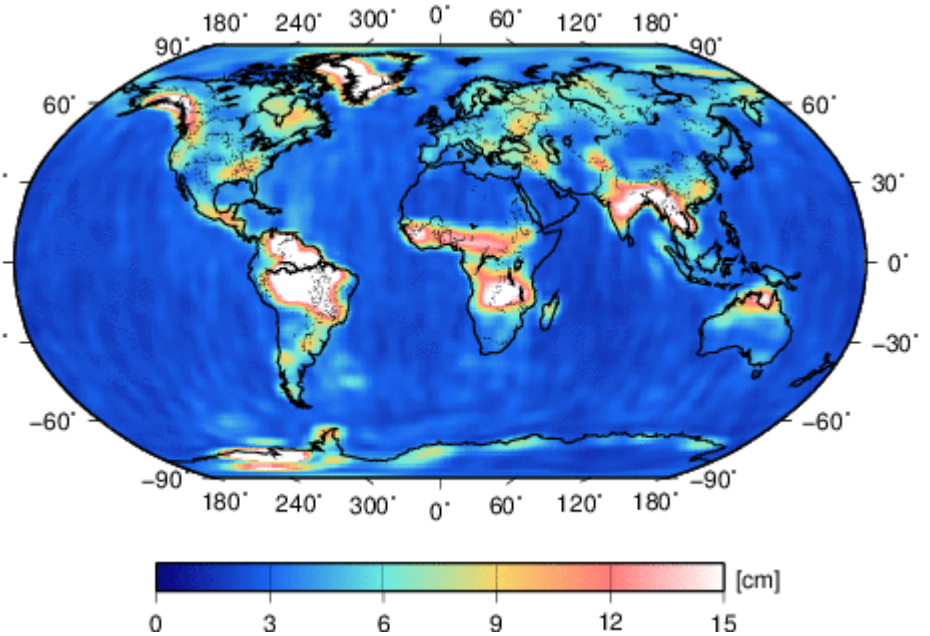
RMS Variability

RMS variability of EWH grids over 6 years (2005-2010):

DDK3 filter ($\sim 240\text{km}$)



RL04

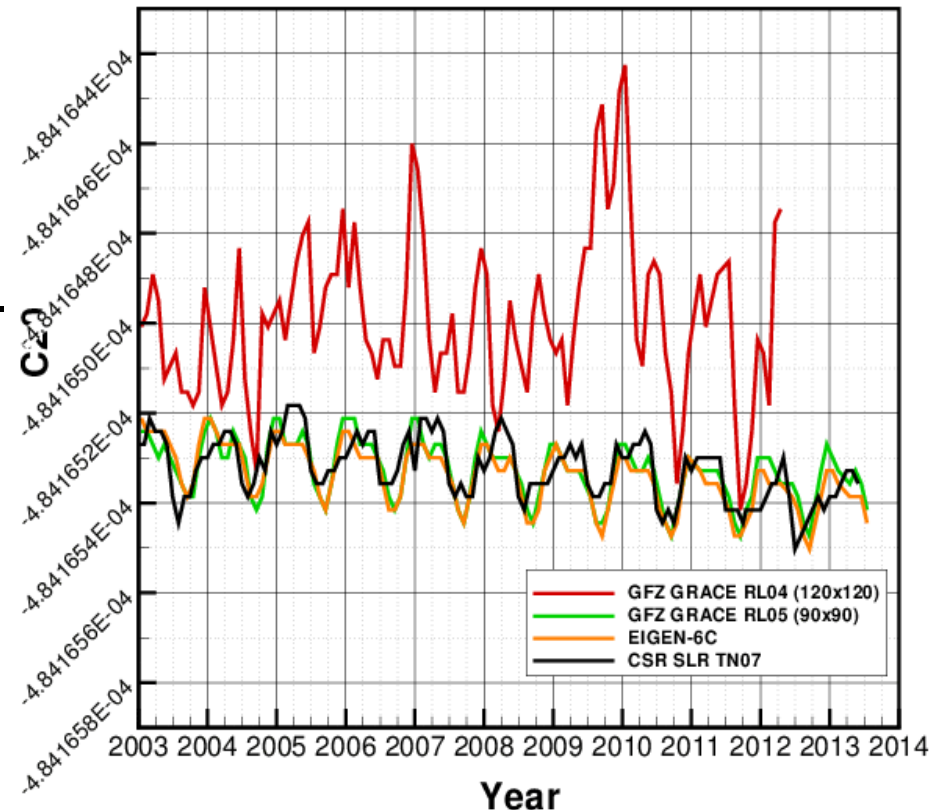


RL05

RL05 Problems

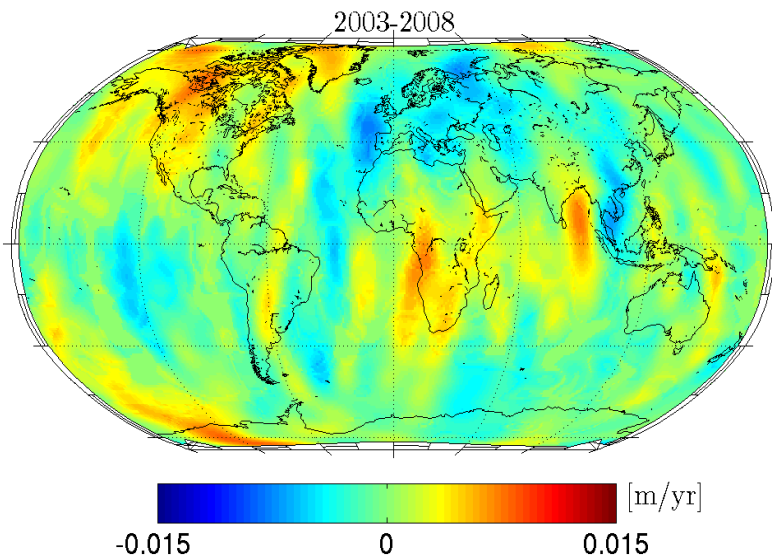
RL05 Facts

- Solved coefficients close to a-priori time variable model (Example C20)
- A-priori TV model based on GRACE data from 01/2003 - 06/2009 only
- Recent reality (e.g. accelerated ice mass loss in Greenland during recent years) differ from a-priori (trends, annual signals etc.)



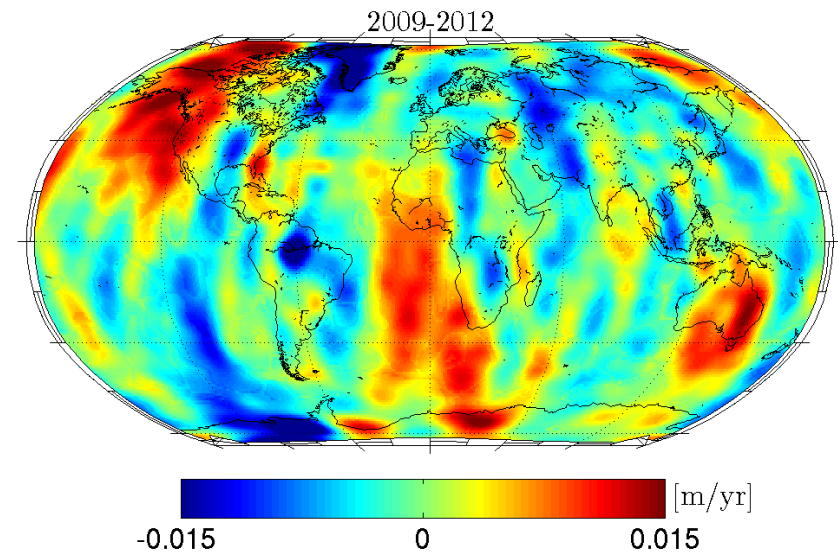
Trend CSR vs. GFZ for different Periods

CSR-GFZ
2003-2008



max+.009, min-.009, std+-.003, mean+.0004m/yr

CSR-GFZ
2009-2012



max+.018, min-.030, std+-.006, mean-.0001m/yr

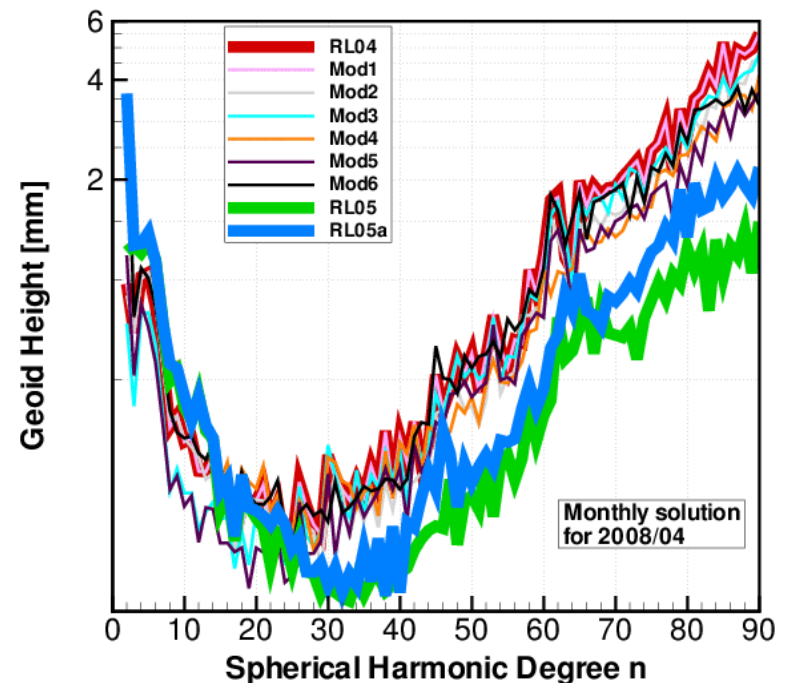
GFZ and CSR trends differ significantly starting ~2009!

**Solution:
RL05 alternative
(RL05a)**

RL05 alternative (RL05a)

Complete time series has been reprocessed **without fixing** the initial orbit state vectors (pos & vel), K-band parameters, ACC biases before solving gravity field coefficients: RL05a (alternative)

Effect: Noise increased
(from green to blue in 04/2008)



RL05a Formal and Calibrated Errors

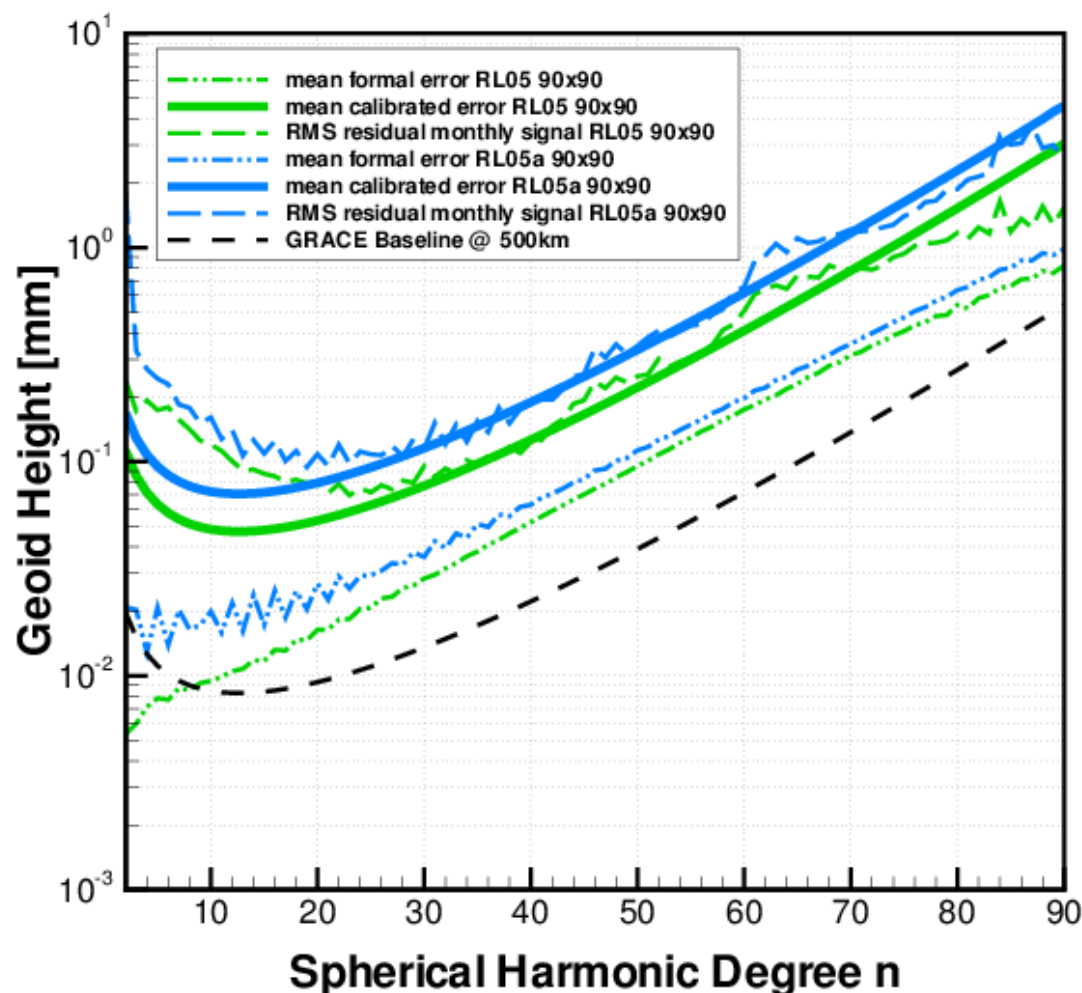
Formal and calibrated errors have increased, new model calibration factors due to higher noise in solutions

“baseline factors”:

RL05: 6

RL05a: 9

(RL04: 12)

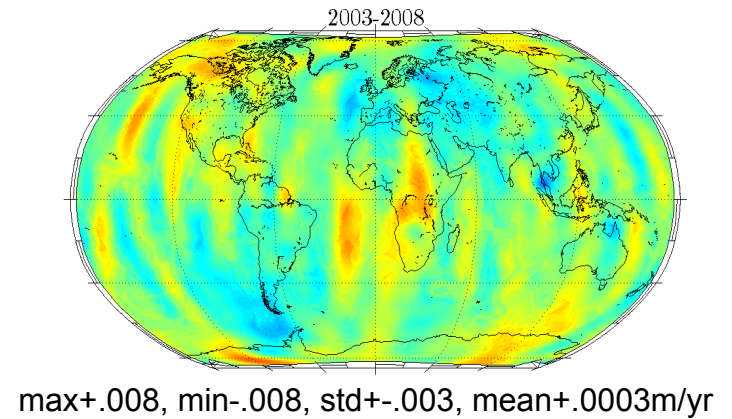
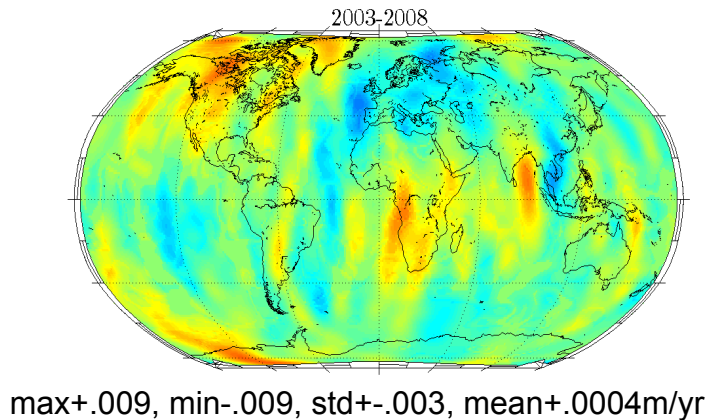


Trends CSR-GFZ: RL05 vs. RL05a

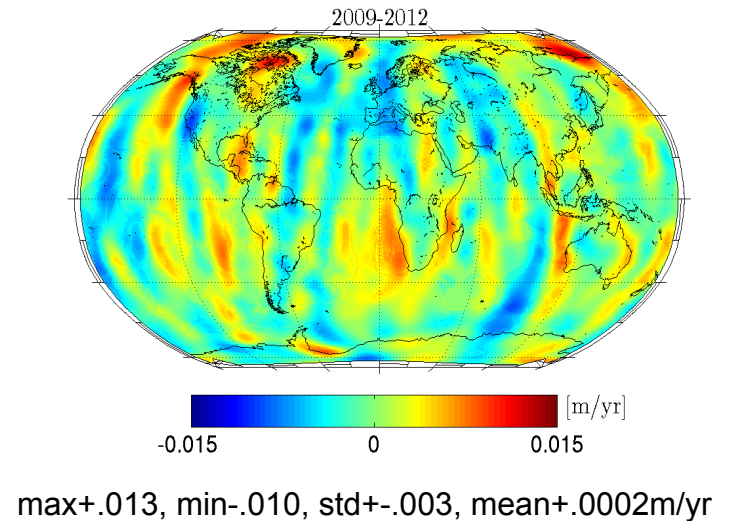
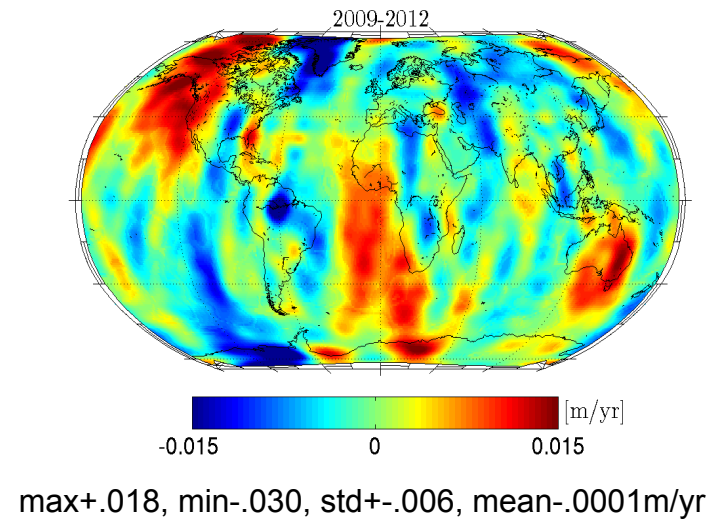
CSR-RL05

CSR-RL05a

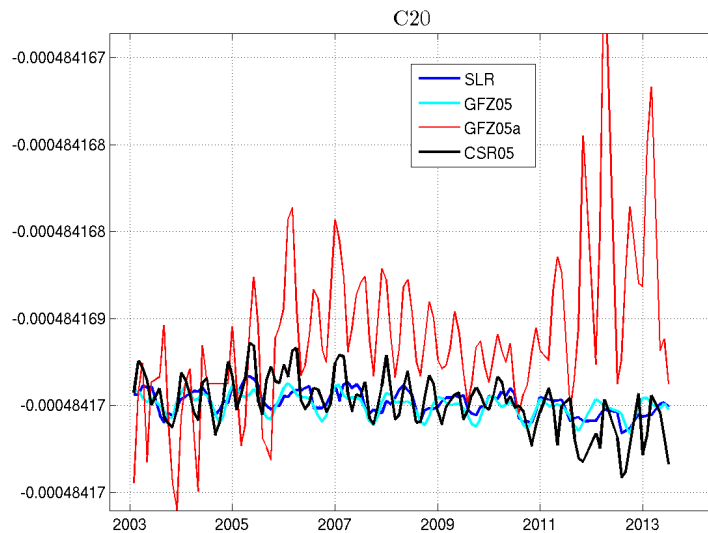
2003-2008



2009-2012



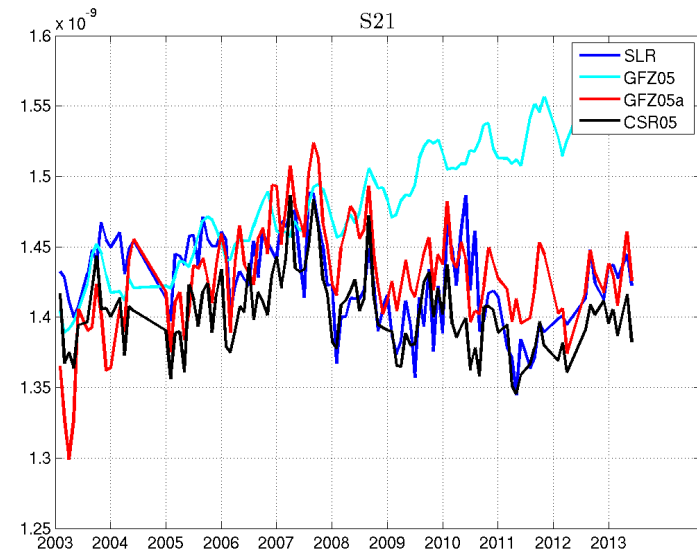
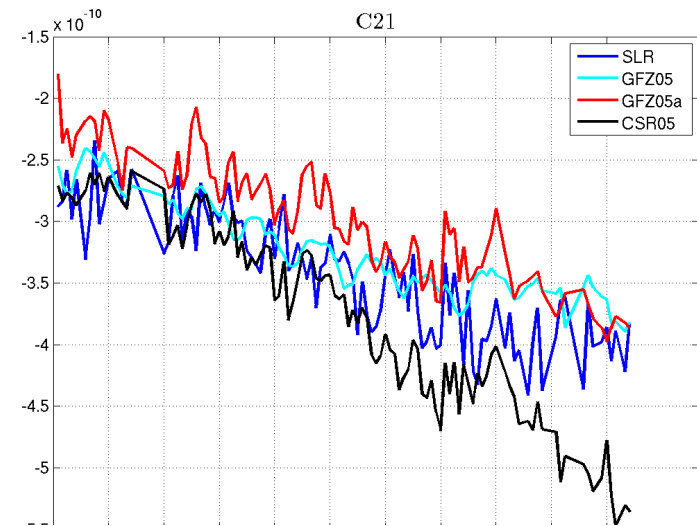
Degree 2



C20: RL05a now similar to RL04 and definitely to be exchanged by SLR

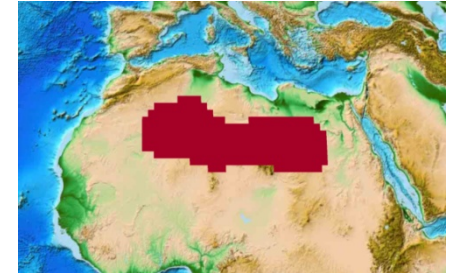
C21: GFZ RL05a biased wrt CSR, SLR to be further investigated

S21: Good agreement GFZ/CSR/SLR



Noise Sahara Basin

10% noise increase for mid/short wavelengths (see excl. C20). Still large improvement wrt RL04.

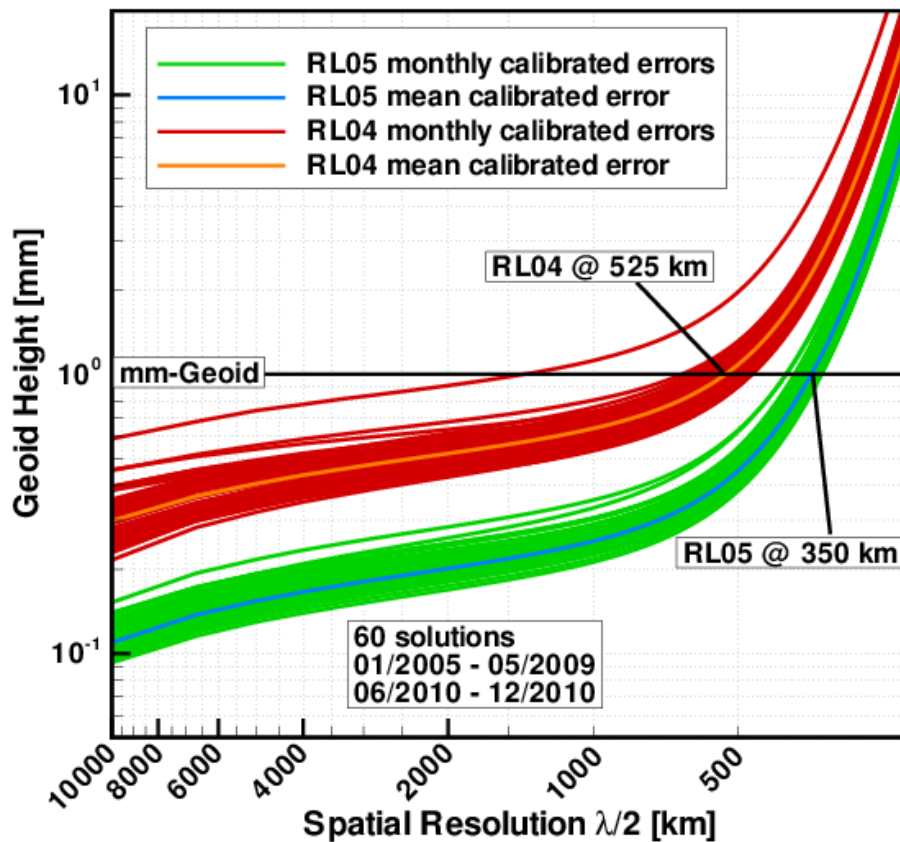


Sahara (incl. C20)	DDK1		DDK2		DDK3	
	wMean	wRMS	wMean	wRMS	wMean	wRMS
RL04	1.58	0.20	2.45	0.29	4.71	0.54
RL05	1.13	0.15	1.53	0.21	2.49	0.35
RL05a	1.64	0.29	2.09	0.35	3.13	0.44

Sahara (excl. C20)	DDK1		DDK2		DDK3	
	wMean	wRMS	wMean	wRMS	wMean	wRMS
RL04	1.52	0.18	2.43	0.30	4.72	0.55
RL05	1.19	0.16	1.55	0.21	2.50	0.34
RL05a	1.16	0.14	1.71	0.24	2.88	0.45

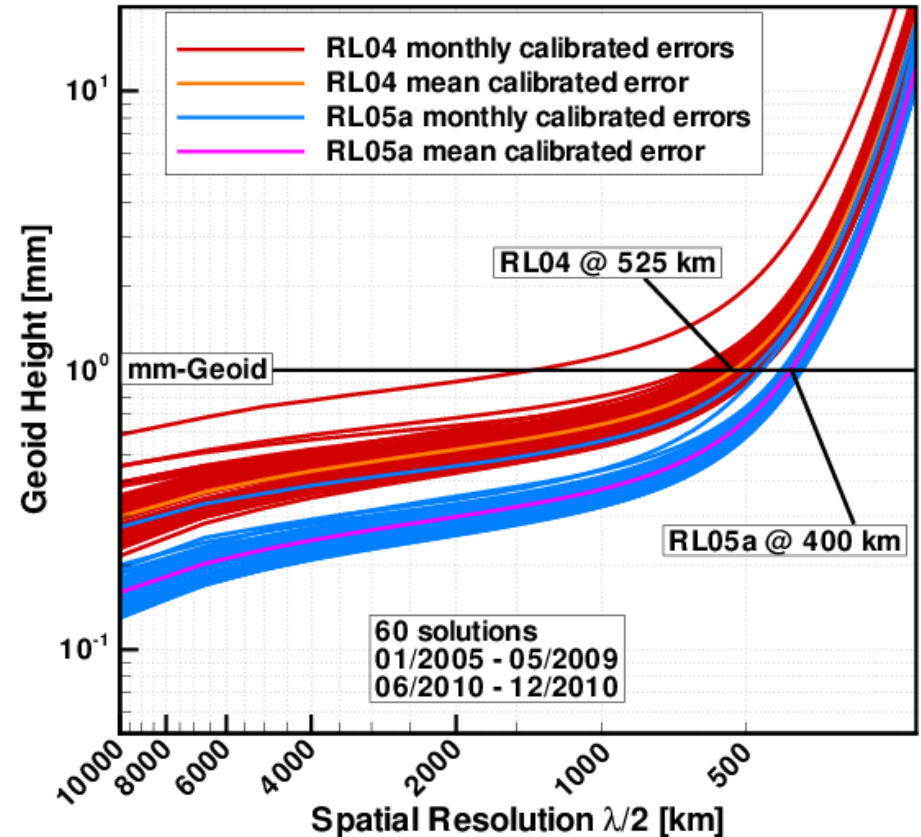
Accumulated Error

RL05



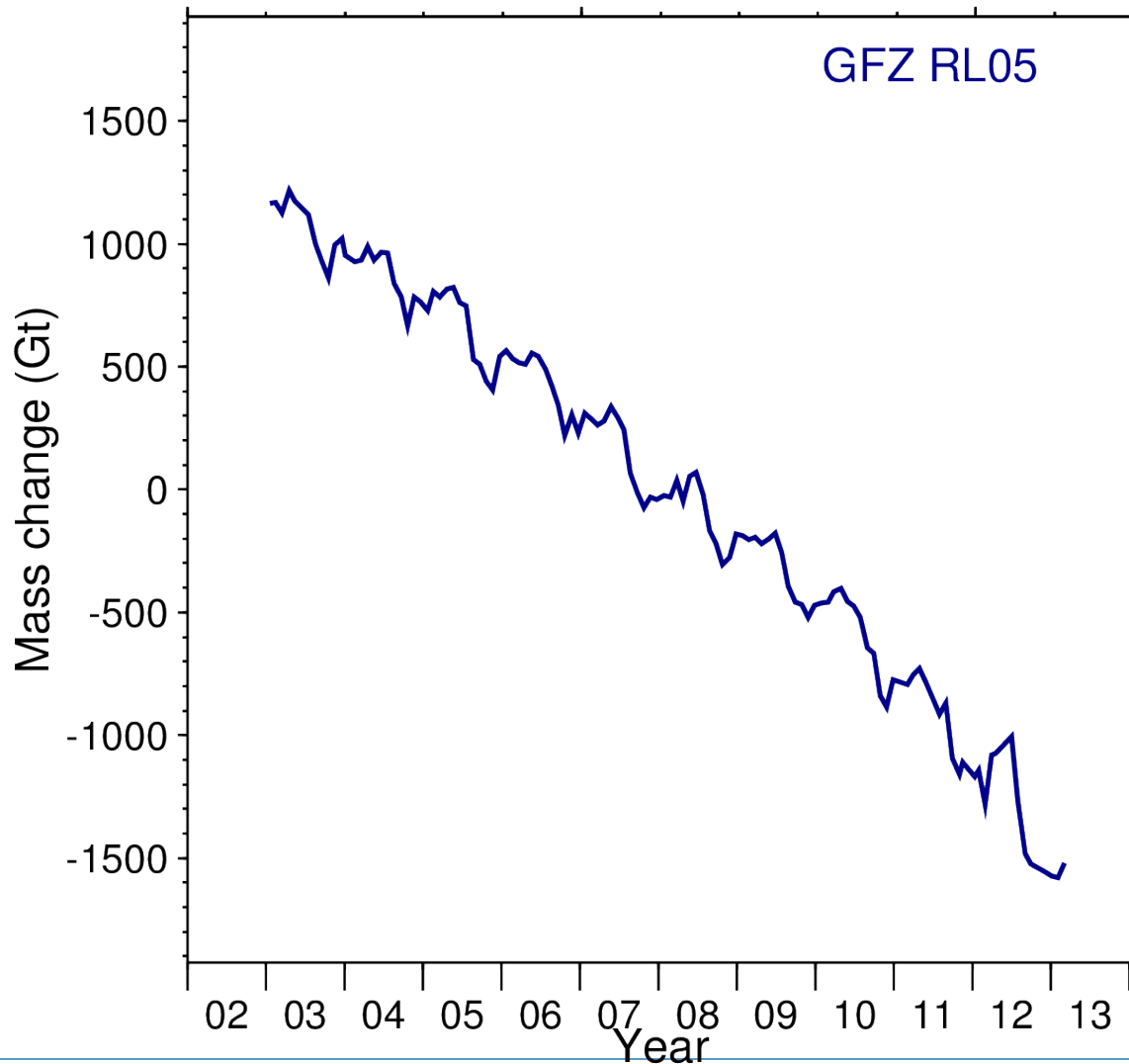
34% improvement

RL05a

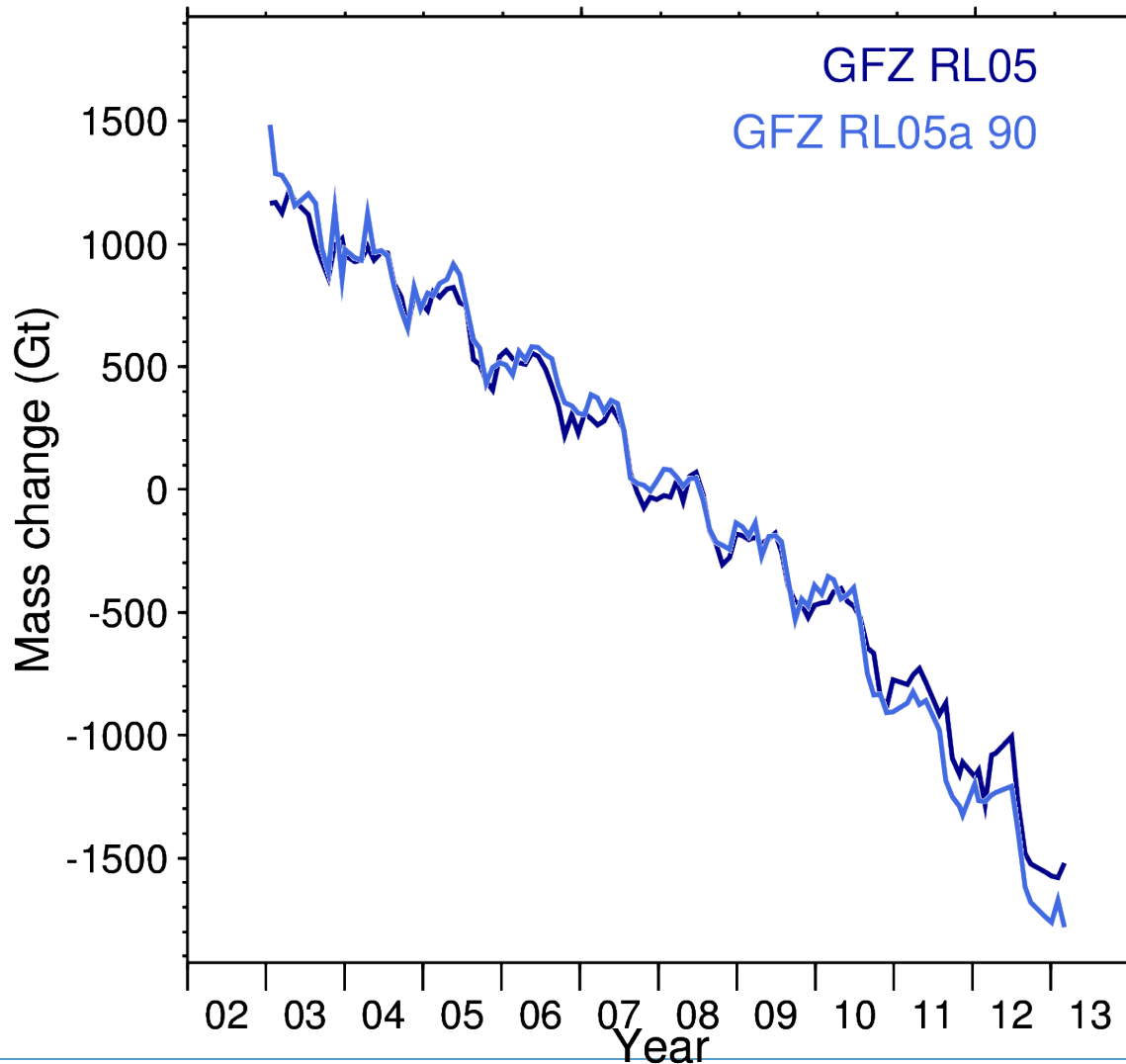


24% improvement (due to higher noise of single solut.)

Trend Greenland (C20 replaced, cut-off degrees 2-60)

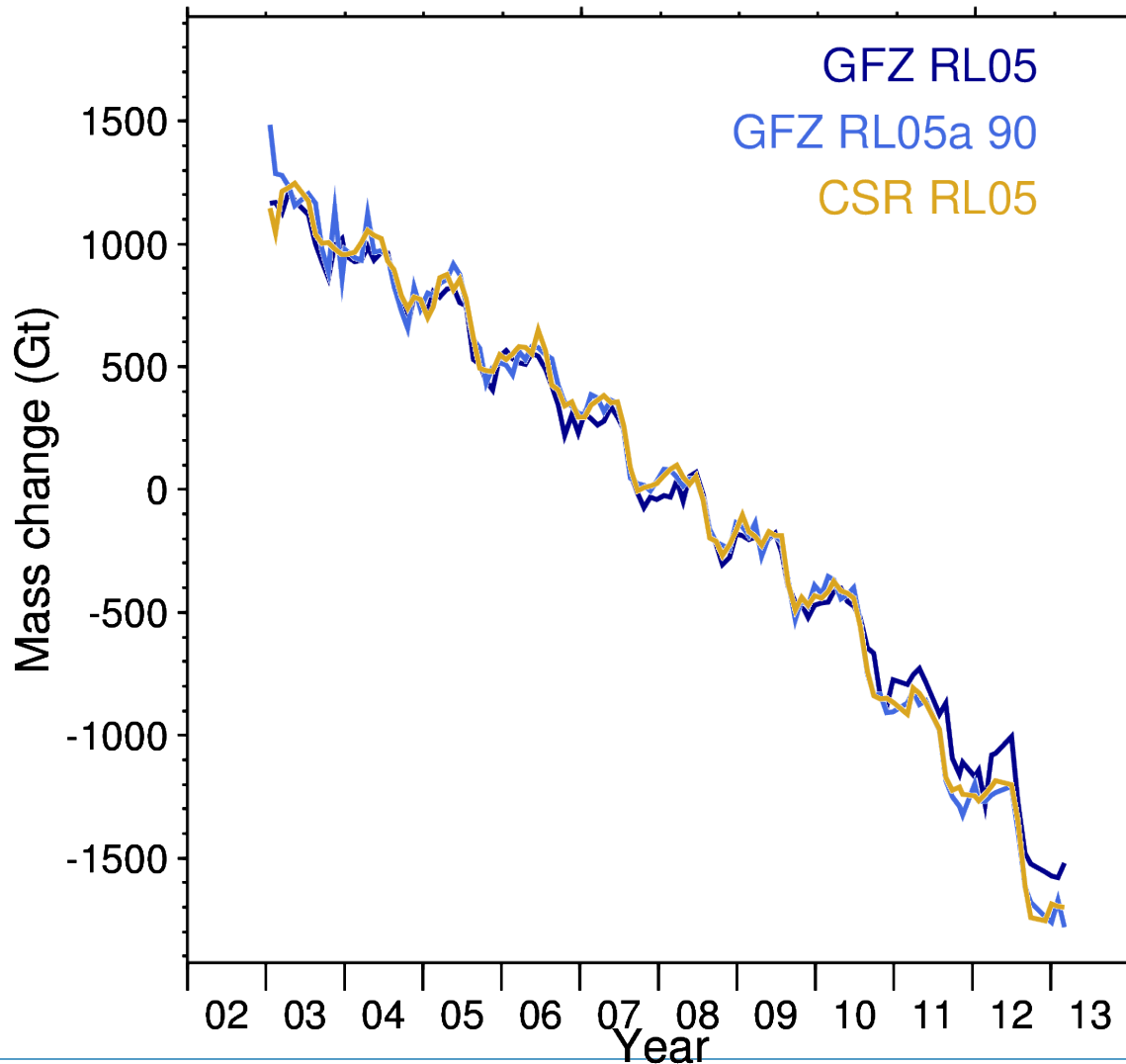


Trend Greenland (C20 replaced, cut-off degrees 2-60)



Trend changes after 2010
Higher noise (peaks)

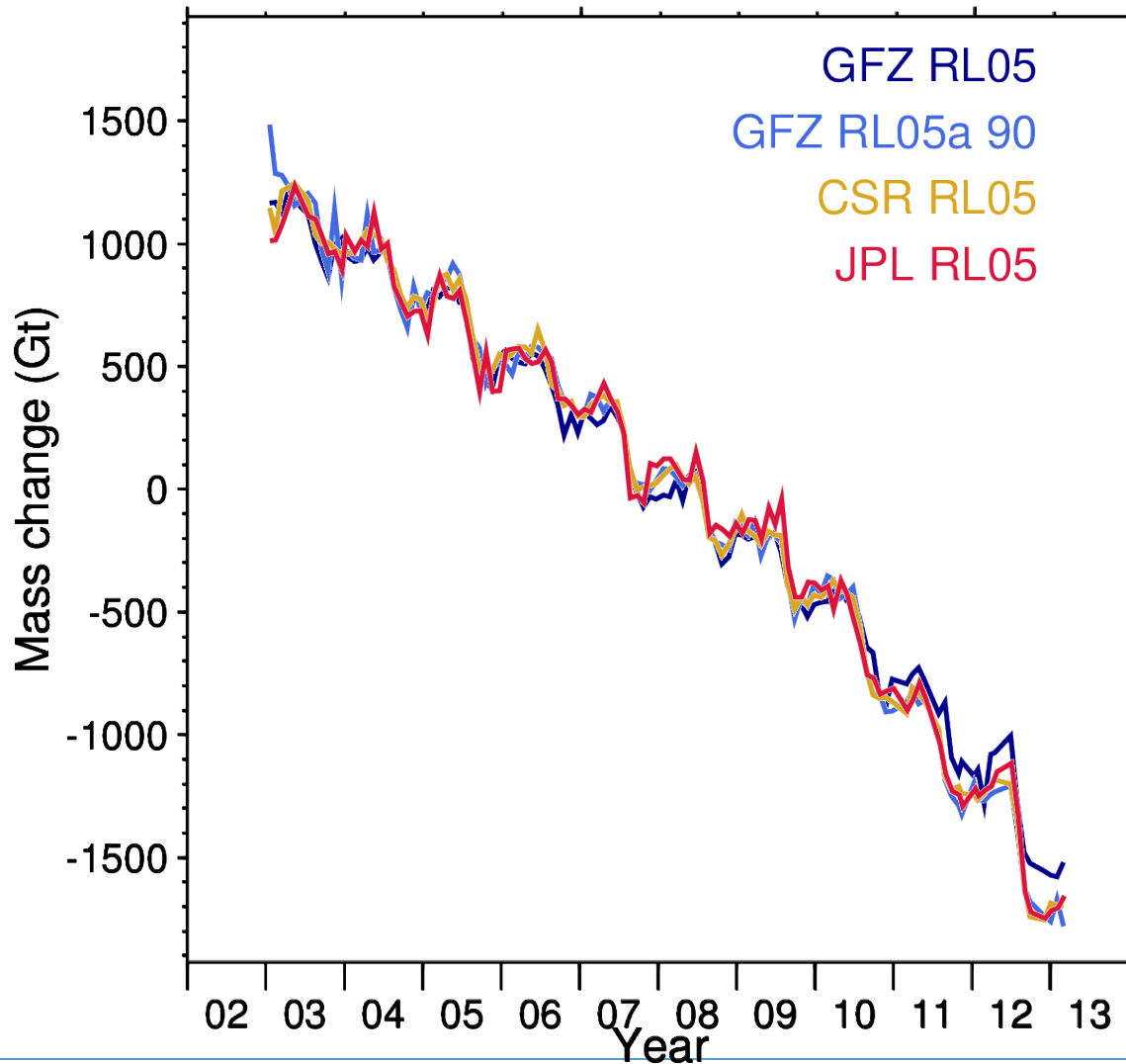
Trend Greenland (C20 replaced, cut-off degrees 2-60)



Trend changes after 2010
Higher noise (peaks)

RL05a close to CSR (n=60)
(except 2003)

Trend Greenland (C20 replaced, cut-off degrees 2-60)

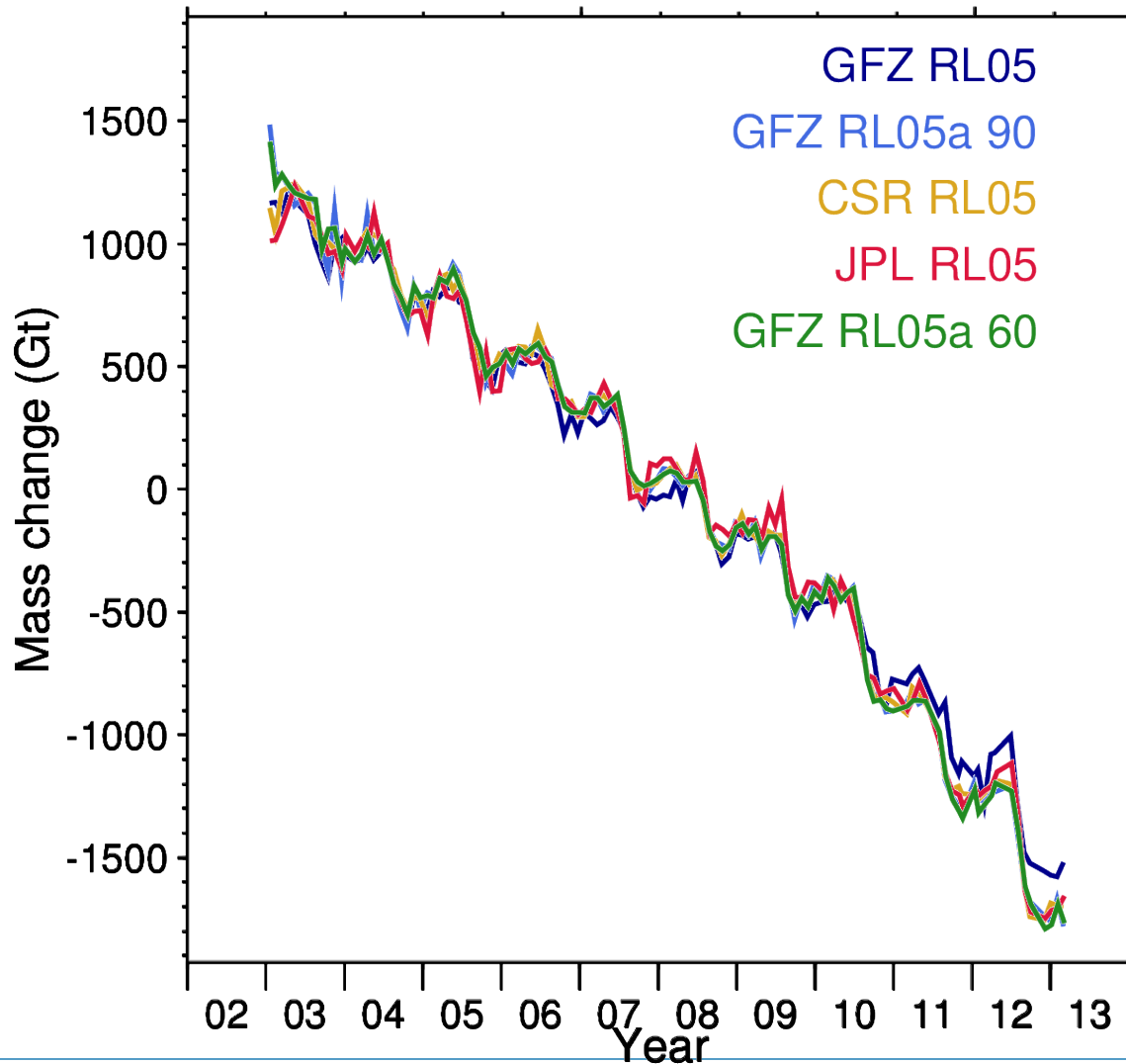


Trend changes after 2010
Higher noise (peaks)

RL05a close to CSR (n=60)
(except 2003)

JPL also close to CSR and
GFZ. Higher noise (peaks)

Trend Greenland (C20 replaced, cut-off degrees 2-60)



Trend changes after 2010
Higher noise (peaks)

RL05a close to CSR
(except 2003)

JPL also close to CSR and
GFZ. Higher noise (peaks)

GFZa(n=60 solved) very
close to CSR (except
Jan/Feb 2003)

Trend Greenland (2003-2013)

2003-2013	Trend (Gt/yr)	Acc. (Gt/yr ²)	1- σ Trend (Gt/yr)	1- σ acc. (Gt/yr)
GFZ RL05	-252.4	-17.0	2.4	1.8
GFZ RL05a 60	-275.6	-25.8	2.8	2.1
GFZ RL05a 90	-273.4	-25.4	3.0	2.3
CSR RL05	-269.1	-27.2	2.5	1.9
JPL RL05	-263.1	-30.0	3.0	2.3

For whole time span very good agreement now for linear and quadratic terms

Trend Greenland (2003-2008)

2003-2008	Trend (Gt/yr)	Acc. (Gt/yr ²)	1- σ Trend (Gt/yr)	1- σ acc. (Gt/yr)
GFZ RL05	-214.3	-27.4	6.4	9.8
GFZ RL05a 60	-219.1	-6.1	7.1	10.9
GFZ RL05a 90	-219.7	-3.3	8.4	13.0
CSR RL05	-207.8	-27.1	6.1	9.4
JPL RL05	-201.0	-25.6	8.0	12.3

January / February 2003
IS USED:
Still disagreements for
2003-2008 results!

Trend Greenland (2003-2008)

2003-2008	Trend (Gt/yr)	Acc. (Gt/yr ²)	1-σ Trend (Gt/yr)	1-σ acc. (Gt/yr)
GFZ RL05	-214.3	-27.4	6.4	9.8
GFZ RL05a 60	-219.1	-6.1	7.1	10.9
GFZ RL05a 90	-219.7	-3.3	8.4	13.0
CSR RL05	-207.8	-27.1	6.1	9.4
JPL RL05	-201.0	-25.6	8.0	12.3

January / February 2003
IS USED:
Still disagreements for
2003-2008 results!

2003 (J-F excl.)-2	Trend (Gt/yr)	Acc. (Gt/yr ²)	1-σ Trend (Gt/yr)	1-σ acc. (Gt/yr)
GFZ RL05	-217.1	-28.5	6.0	9.7
GFZ RL05a 60	-217.0	-14.3	6.2	9.9
GFZ RL05a 90	-214.7	-17.5	7.4	11.9
CSR RL05	-214.1	-20.2	5.6	8.9
JPL RL05	-209.7	-12.9	7.8	12.4

January / February 2003
NOT USED:
Now good agreement for
2003-2008 results

Results: Trend Greenland (2009-2013)

2009-2013	Trend (Gt/yr)	Acc. (Gt/yr ²)	1- σ Trend (Gt/yr)	1- σ acc. (Gt/yr)
GFZ RL05	-315.6	-50.4	11.3	21.0
GFZ RL05a 60	-374.8	-53.0	13.1	24.4
GFZ RL05a 90	-374.1	-57.4	13.4	25.0
CSR RL05	-368.9	-52.2	12.8	23.8
JPL RL05	-377.0	-34.9	13.9	25.9

Very good agreement for recent years 2009-2013. Quadratic term JPL somewhat smaller.

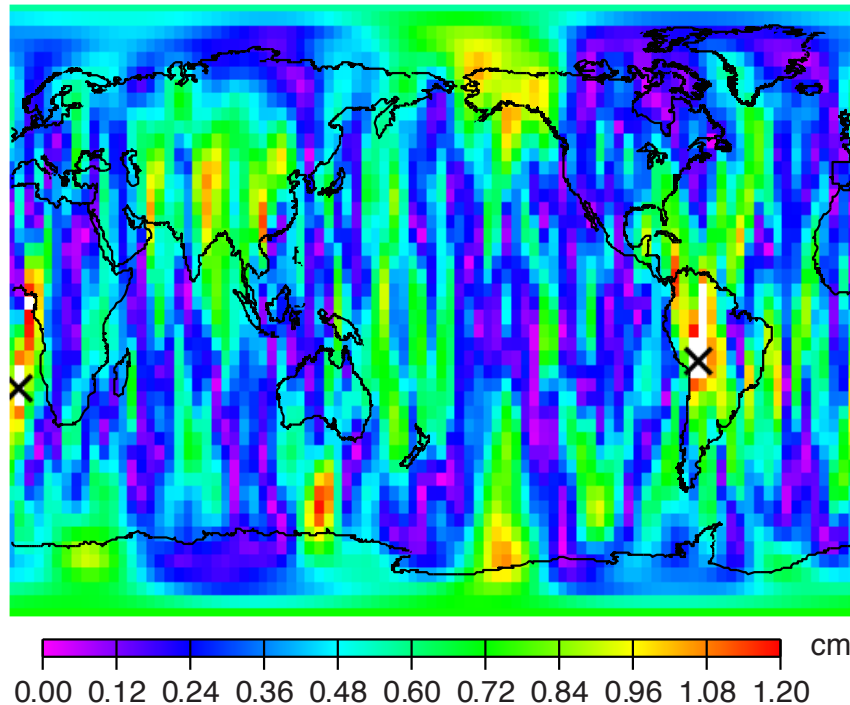
Annual Cycle CSR-GFZ (Courtesy: J. Wahr)

CSR – GFZ RL05

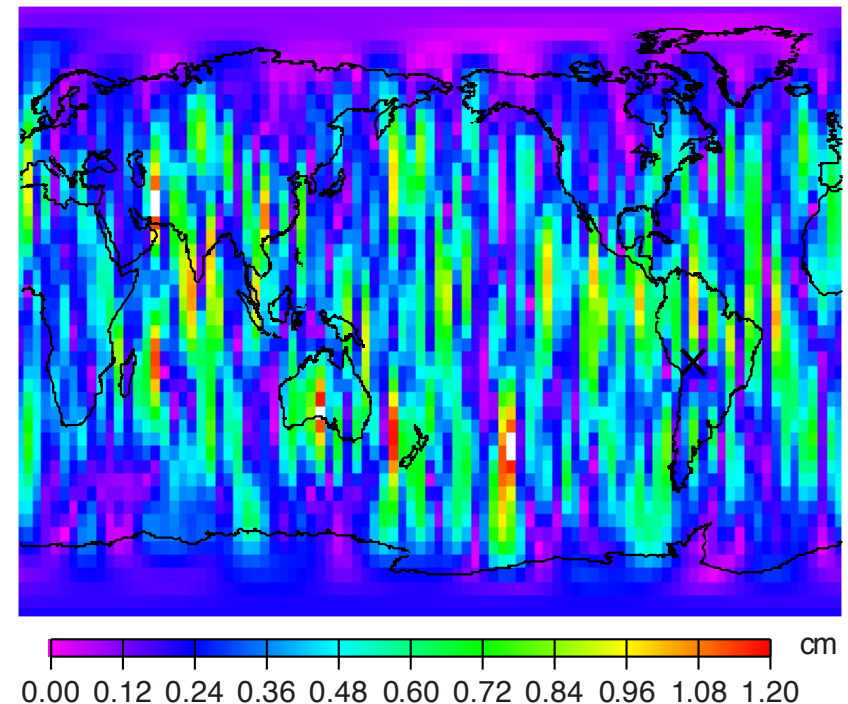
CSR – GFZ RL05a

90x90 fields, 500 km Gauss, w/o C20

Amp of Annual Cycle. CSR minus GFZ



Amp of Annual Cycle. CSR minus new (Oct 8, 2013) GFZ



Clear reduction of amplitude differences!
But also >1cm peaks still visible

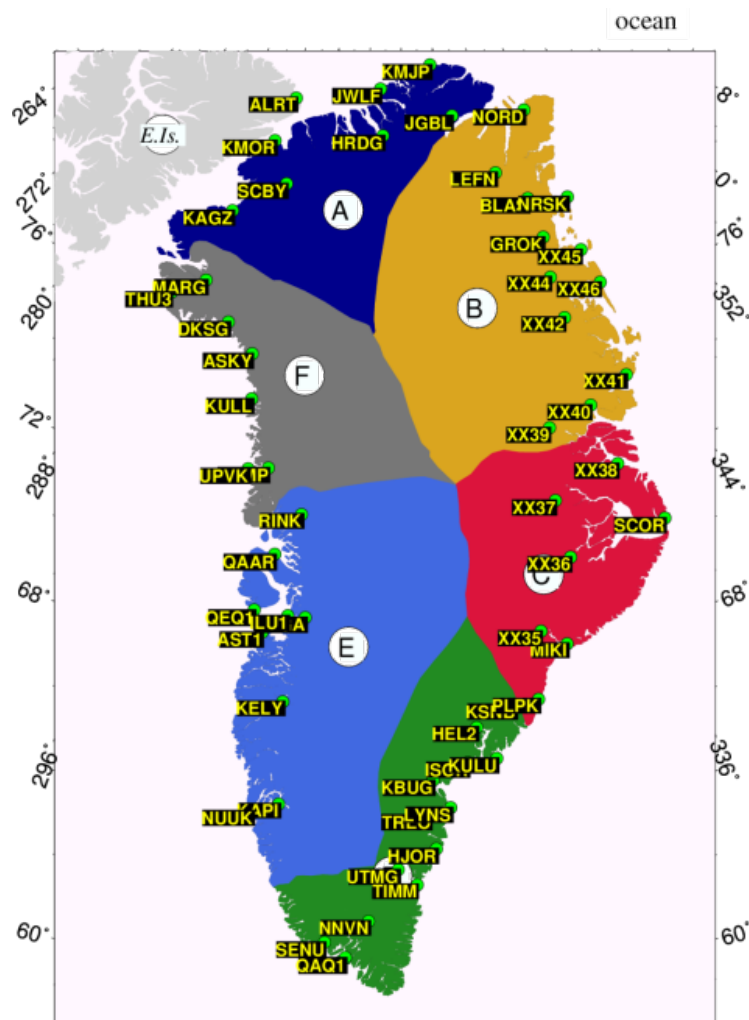
Comparison GRACE vs. GPS Greenland

Validation Greenland: Data/Method

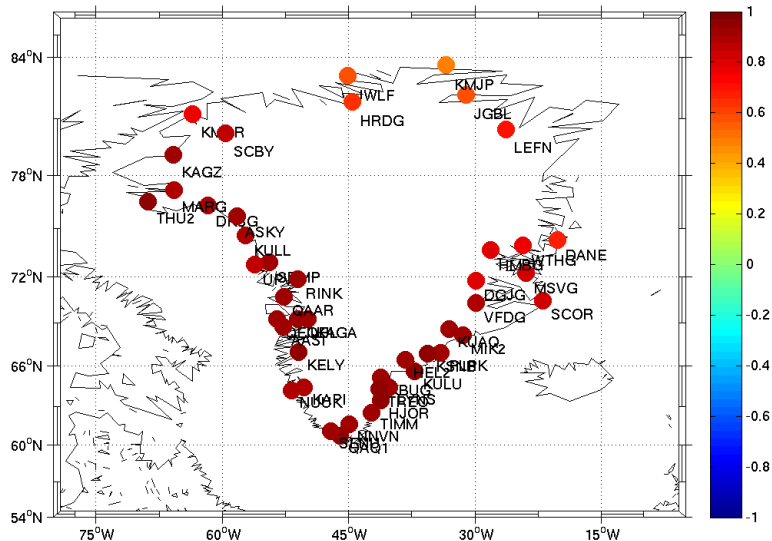
Received GPS data from 51 stations from Shfaqat Abbas Khan (DTU) covering the period 01/2002 to 12/2012.

Method: Direct comparison GPS vertical site displacements vs. GRACE point wise synthesis of GSMs

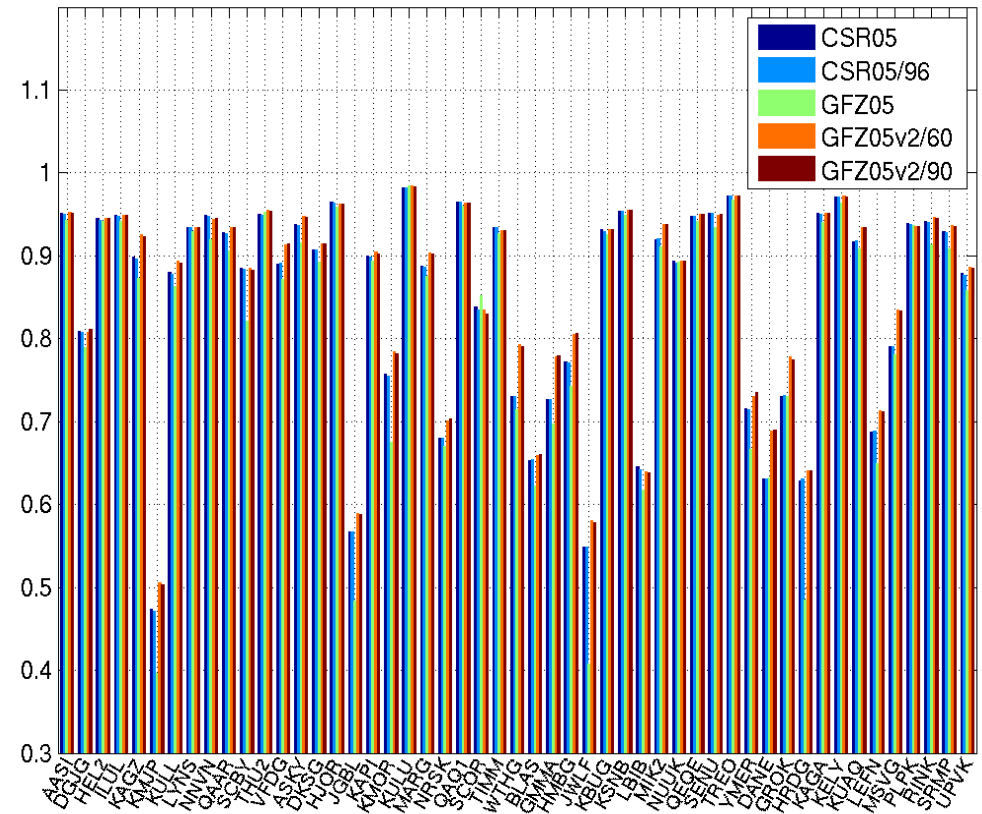
- No GIA correction (both the same)
- GAC re-added to GRACE
- Deg. 1 neglected (believed to play no role for (large) Greenland trends)



Validation Greenland: Correlation w/ Trend

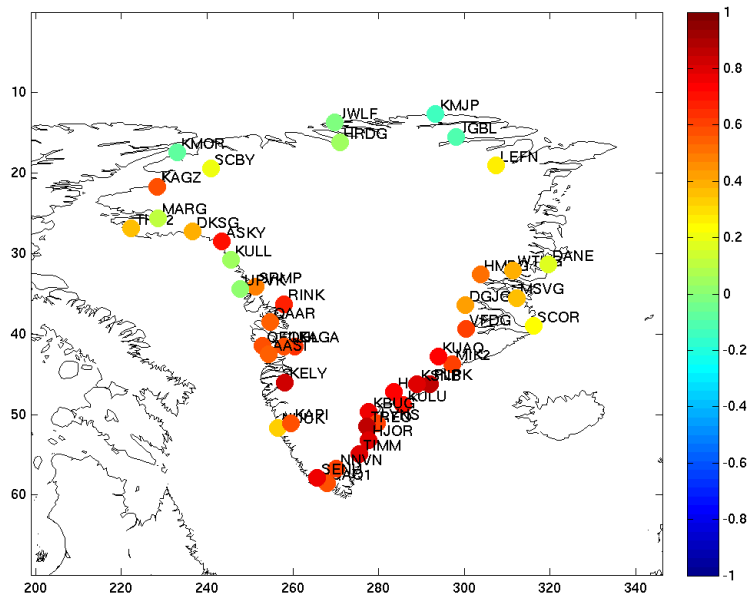


CSR60	0.8456
CSR96	0.8449
GFZ05	0.8223
GFZ05a/60	0.8580
GFZ05a/90	0.8576

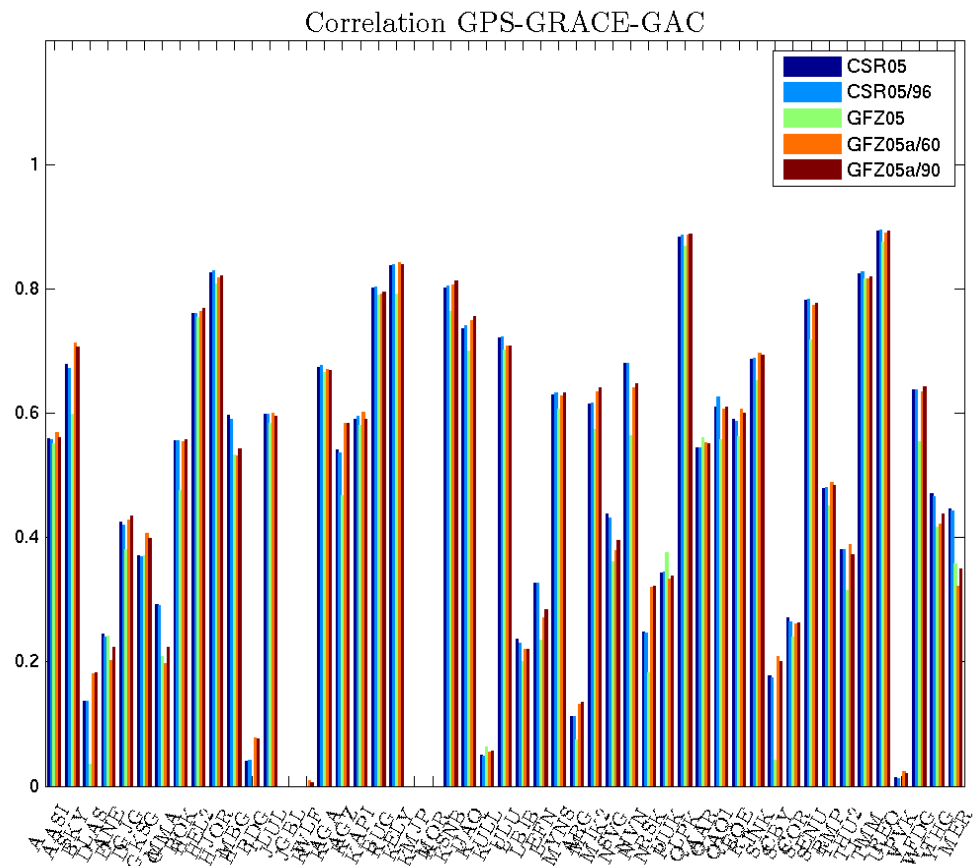


- Nearly all stations show positive and high correlations
- Little bit smaller correlations for Northern Greenland (Reason: small precipitation and melt annual signal in the North?)
- Clear improvement of GFZ RL05a vs. RL05 (deg90=deg60)

Validation Greenland: Correlation w/o Trend



CSR60	0.4650
CSR96	0.4647
GFZ05	0.4192
GFZ05a/60	0.4652
GFZ05a/90	0.4678



- Annual/Semi-annual signal in focus
- Clear average improvement for GFZ05a vs GFZ05 (deg 60 = deg90)
- Comparisons in the North again less good

Summary & Outlook (1)

- RL05 solution strategy (fixing of arc specific parameters before solving gravity field parameters) gave small noise but resulted also in
 - Trend differences (e.g. Greenland wrt CSR or JPL after 2009)
 - Annual amplitude differences wrt CSR
 - Smaller correlations wrt Greenland GPS site displacements
- Alternative RL05a (without fixing procedure) already available.
 - All tests show much better agreement with CSR, JPL and GPS
 - Still large improvement wrt RL04
 - Increased (~10%) noise wrt RL05
 - C20 to be substituted again
- RL05a January and February 2003 solutions seem to be outliers compared to CSR and JPL: to be further investigated

Summary & Outlook (2)

- GFZ RL05a monthly solutions have already been send to users (J. Wahr, B. Wouters, M. Horwarth, J. Kusche, U. Meyer) for validation: So far only positive feedback
- RL05a (also weekly) will be made available soon in the archives (see newsletters).
- Note: RL05 GAx products remain unaffected (no need to exchange these when using RL05a)