CSR: GRACE and GRACE-FO Level-2 Overview

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GRACE/GRACE-FO Science Team Meeting (Virtual)

CSR GRACE RL07 re-processing

- GRACE v05 data for the entire mission is being reprocessed with latest standards and processing improvements
  - *Reporting on **2004 to 2016** (few missing months)*
- GRACE-FO v05 L1B data will be also processed with the same standards as GRACE RL07
- The signal definition of RL07 GRACE(-FO) solutions has ***not*** changed from RL06
  - The GSM-2 products will continue to represent primarily the Hydrology, Solid Earth, Ocean Mass and Cryospheric variability; as well as errors in the background models of tides, non-tidal ocean variability, and atmospheric pressure variations.

Force Model Changes for RL07

Model	RL06	RL07
Mean Gravity	**GGM05C** (360)	**GIF63** (360)
3rd Body Pert	DE 430	DE 430
Body Tides	IERS-2010	IERS-2010
Ocean Tides	**GOT4.8** Major + Mm and Mf (Egbert and Ray) + Mtm and MSqm (FES 2004) + SCEQ (d/o 180)	**GOT5.6** major & minor tides + variable sea water density + FES22 long period tides + SCEQ (d/o 180)
Pole Tide (Solid+Ocean)	IERS-2010 (linear mean-pole)	IERS-2010 (linear mean-pole)
Atmosphere + non-tidal Oceans	AOD1B **RL06**	AOD1B **RL07**

Data and Parameterization Changes for RL07

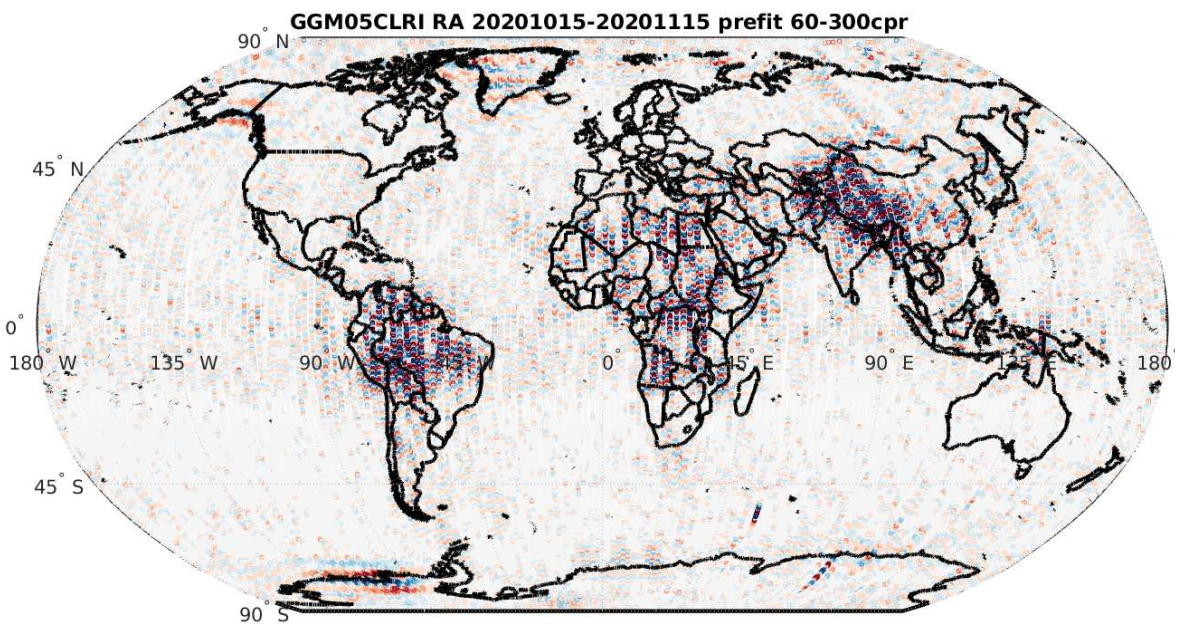
Changes	RL06	RL07
Level - 1 data	**V03** for SCA1B and KBR1B **V02** for everything else	**V05** for all L1B data
GPS Observations	**Double Difference Phase**	**Undifferenced Phase and Range (30s)**
ACC – bias parametrization	along-track: 1/day linear cross-track : 8/day linear radial : 1/day linear	along-track: 1/day linear cross-track : 8/day linear radial : 1/day linear
ACC – scale parametrization	Full matrix - 1 per arc	Full matrix - 1 per arc
Observation Noise	**White noise (diagonal covariance matrix)**	**Colored noise (full covariance matrix)**
Solution Strategy	Estimating non-gravity and some gravity parameters separately	Estimating non-gravity and some gravity parameters separately

Updates and Improvements (Mean Field: GIF63)

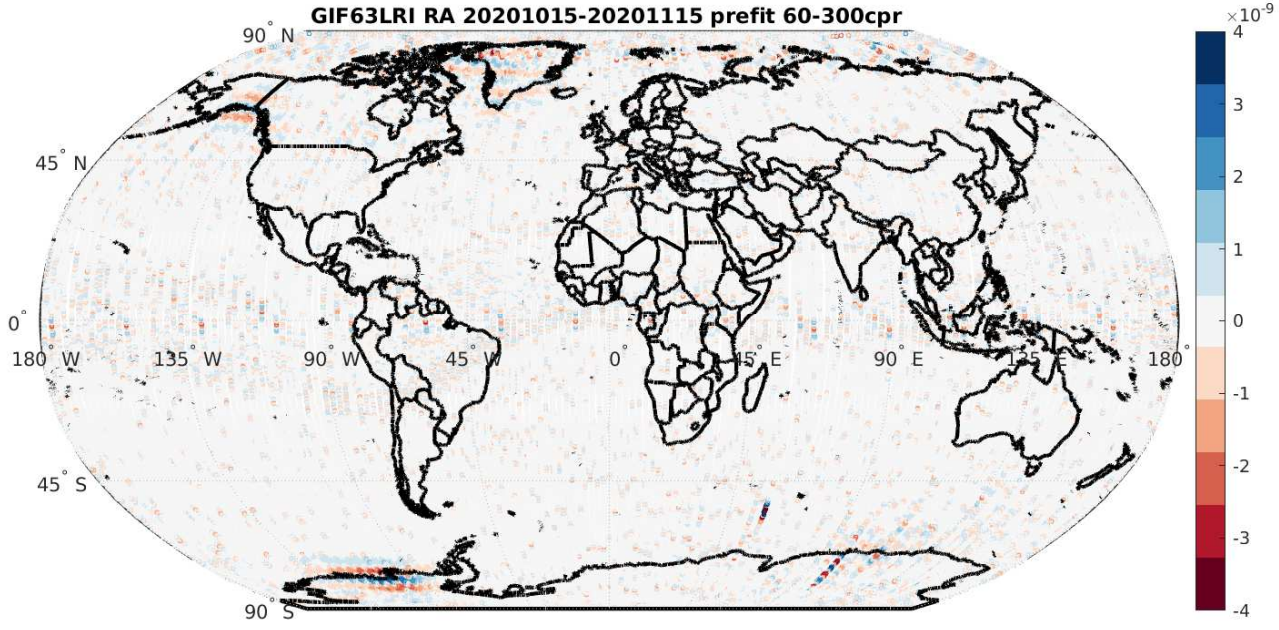
GIF63 is an intermediate mean field (d/o 360) developed at CSR for use in RL07 processing

- optimal combination of reprocessed GRACE (d/o 2-150) & GOCE mission data (d/o 120-220), and pseudo-surface gravity “data” (XGM19, past d/o 220)

GGM05C

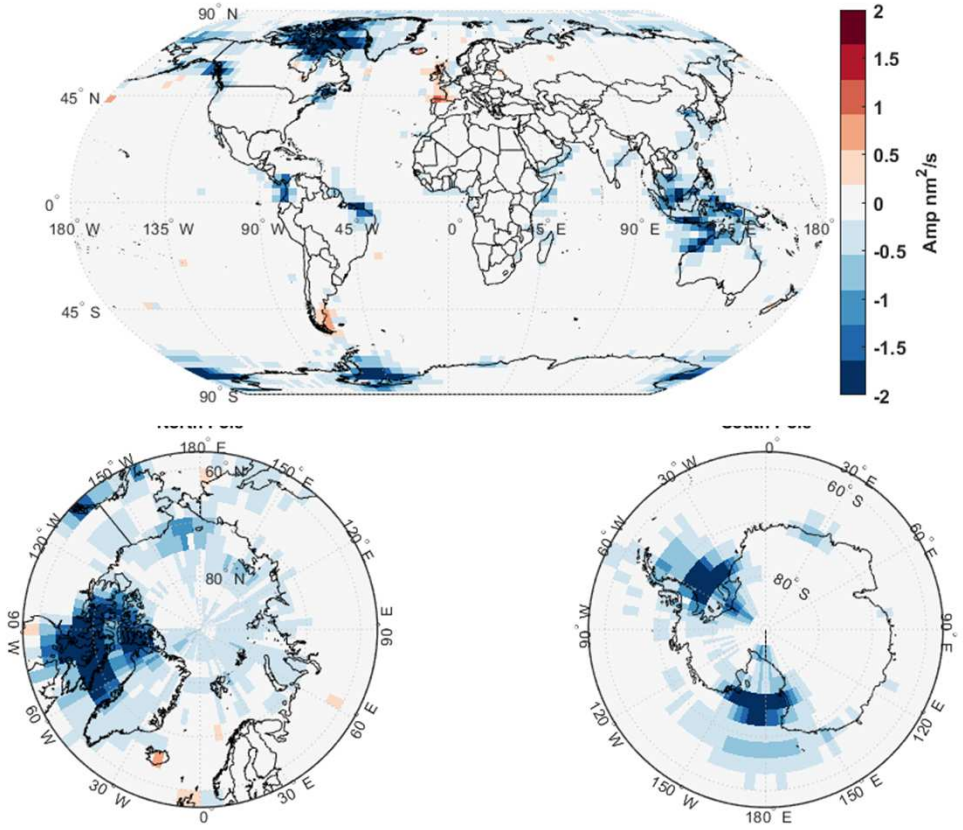


GIF63



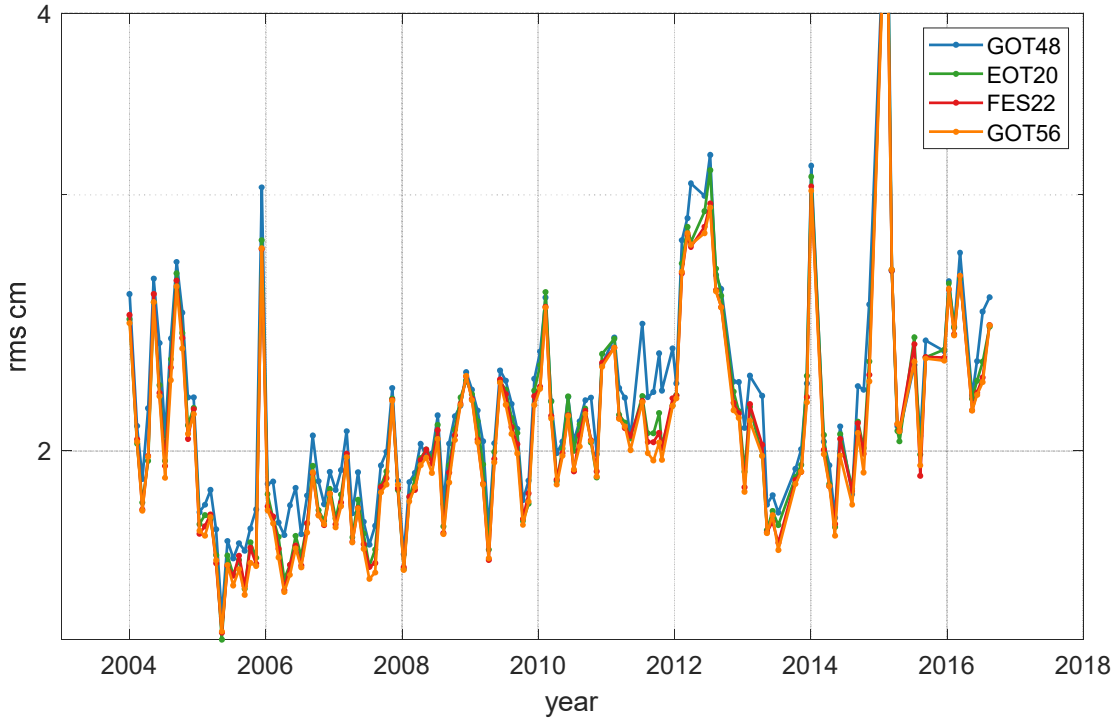
LRI residuals (band-limited to 60-300 cycles per revolution) show **improvement** for GIF63 due to **change in how GRACE and GOCE data were blended**

Updates and Improvements (Ocean Tides)



Variance Reduction (GOT5.6 – GOT4.8)

GOT5.6 shows a consistent improvement over GOT4.8
(blue = GOT5.6 better & red = GOT4.8 better)



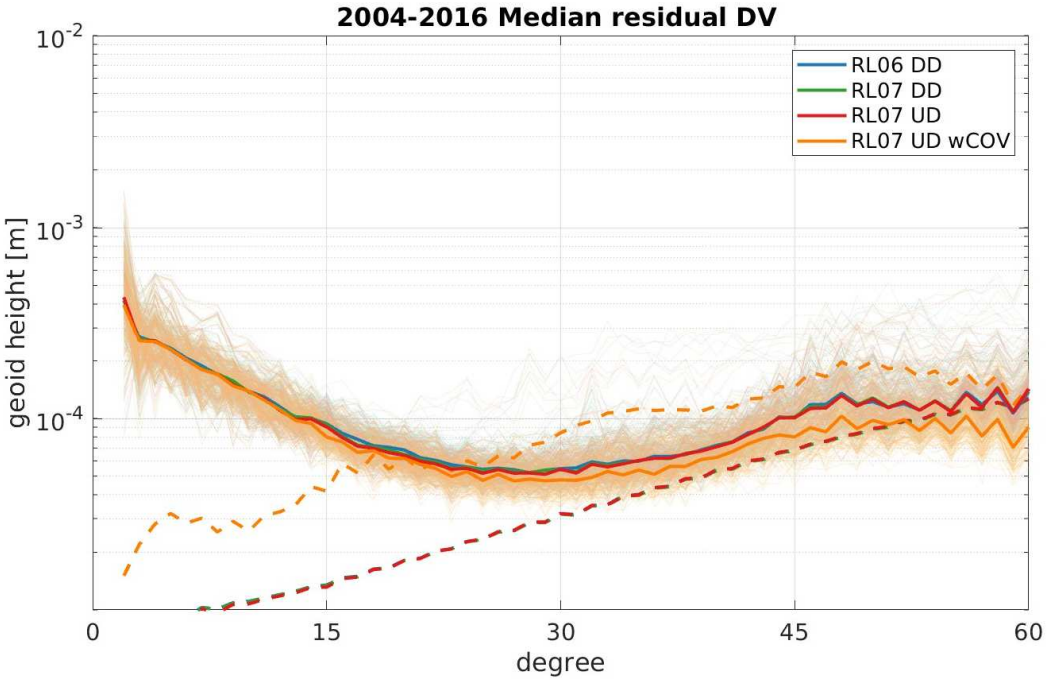
Residual Ocean Mass Error RMS

Gravity field estimation using GOT5.6 shows a consistent improvement over GOT4.8 (and EOT20 and FES22)

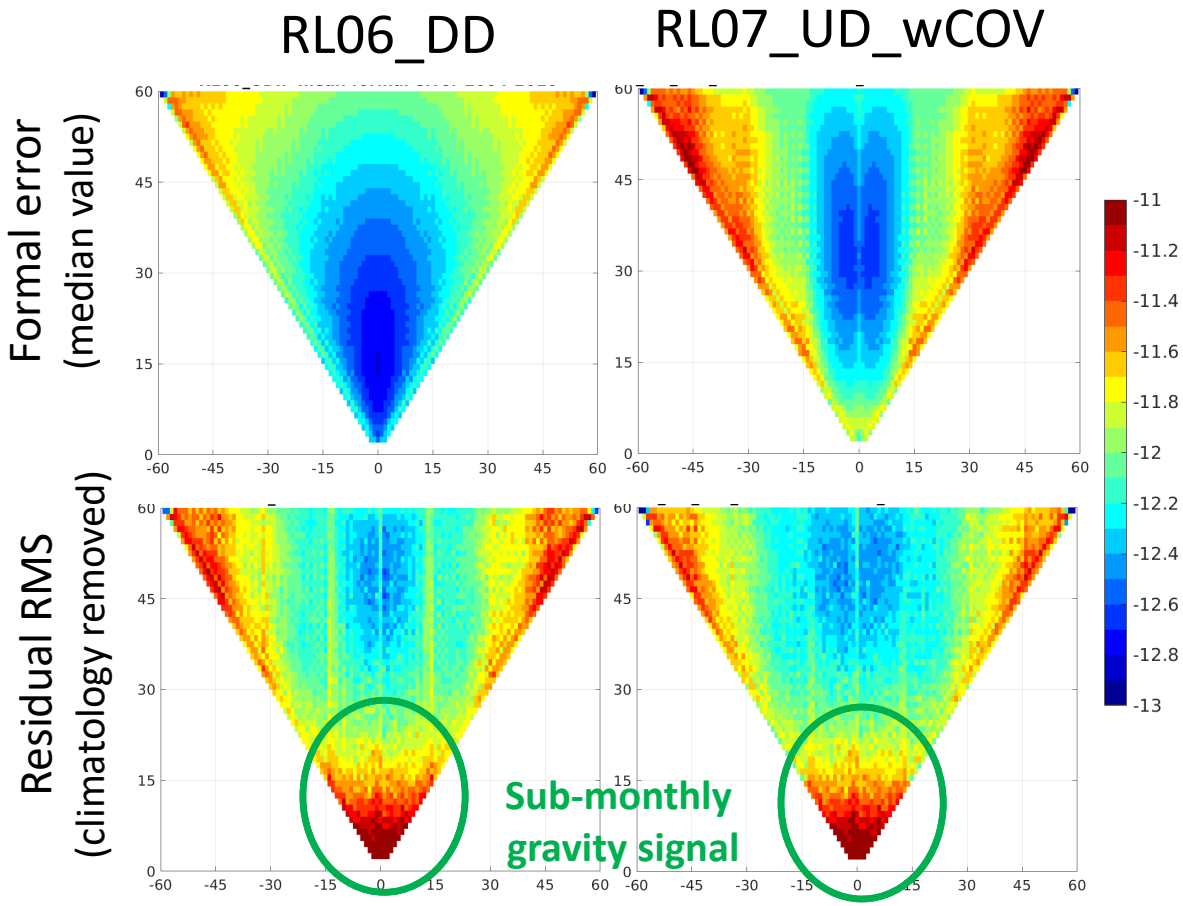
Updates and Improvements
(White noise vs Colored noise Covariance)

Colored noise vs white noise assumption for KBR obs

- full covariance instead of diagonal covariance
- Post-fit residuals are used to estimate the covariance



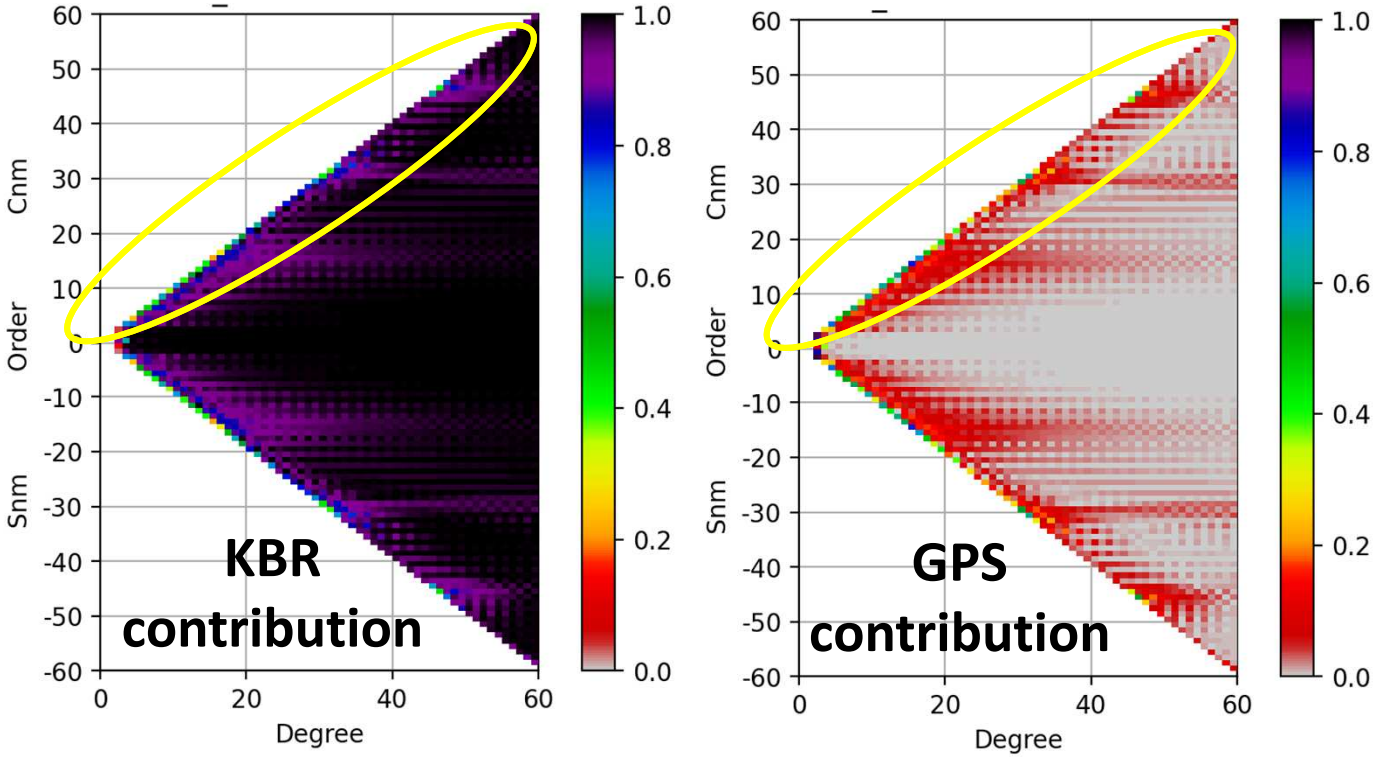
Residual DDV for colored noise case shows consistent improvement at mid and high degrees



Formal errors (top row) for RL07 is a better representation of the real errors (bottom row)

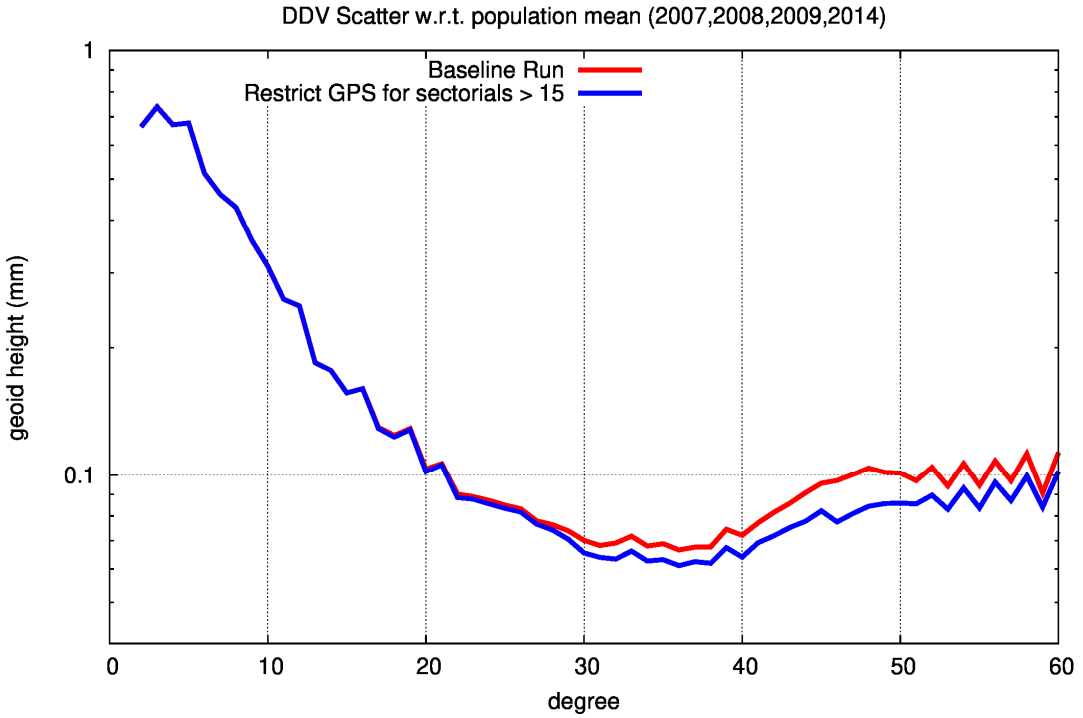
Updates and Improvements
(Limiting GPS Contribution from Sectorials above degree 14)

Motivation to limit GPS contribution to monthly solutions

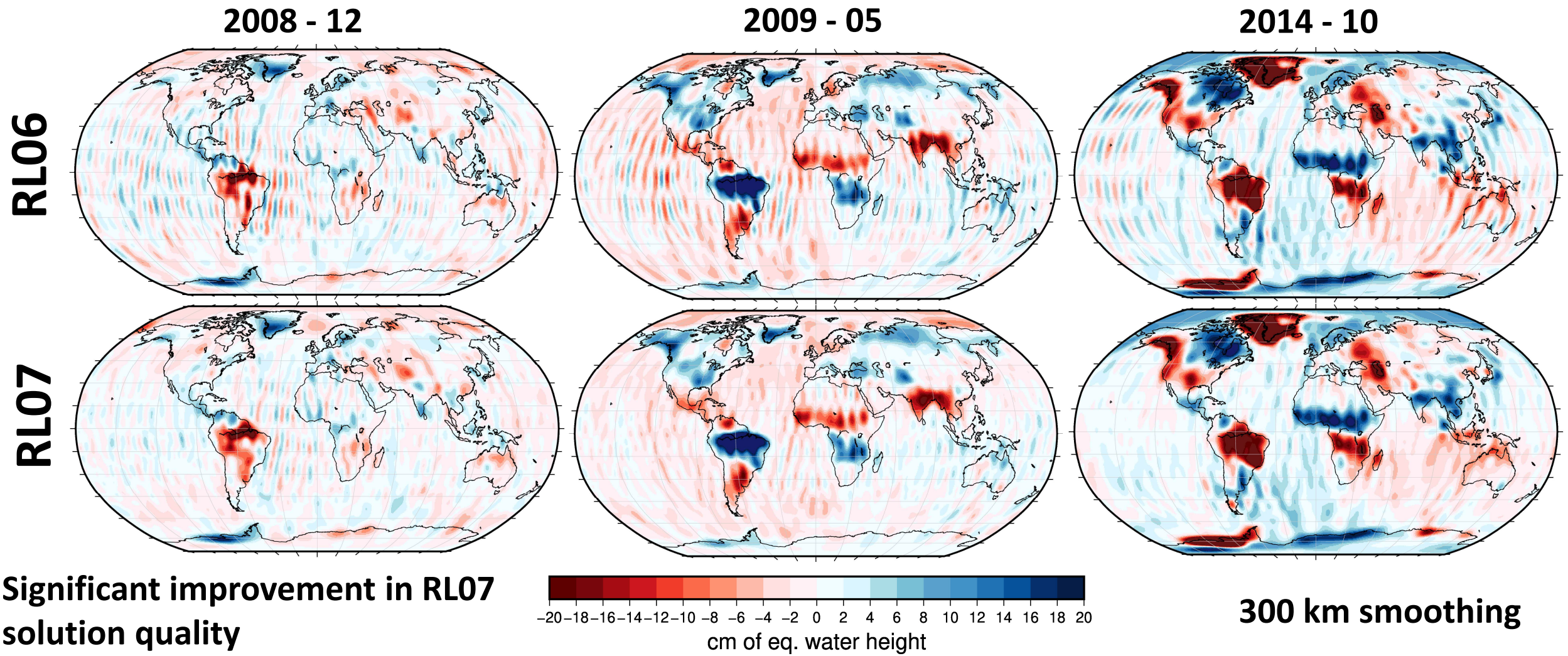


In a SHC solution for GRACE, KBR data contributes over 95% - 100% in the entire spectrum except at sectorials where GPS contributes 50% or higher (even above degree 14)

Restricting the contribution of GPS to sectorials above degree 14 in SH solution helps reduce the striping in the solutions



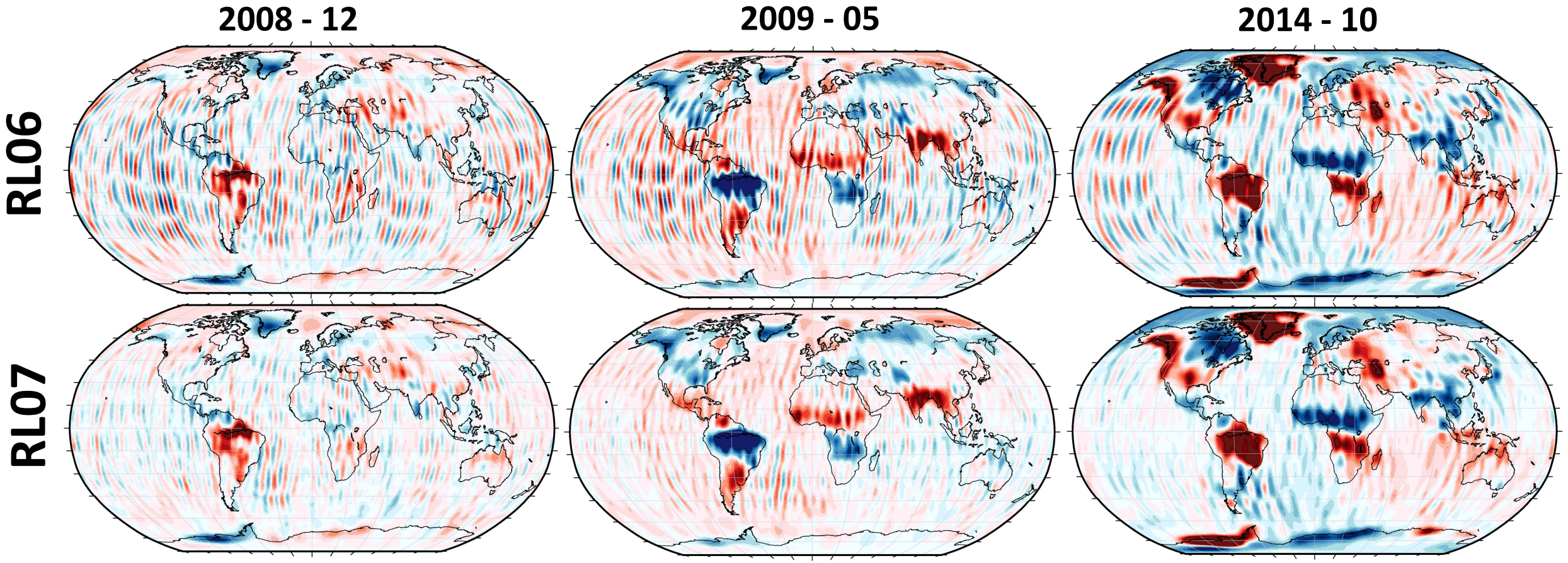
Results : RL06 vs RL07 e.w.h. maps (d/o 60)



Significant improvement in RL07 solution quality

300 km smoothing

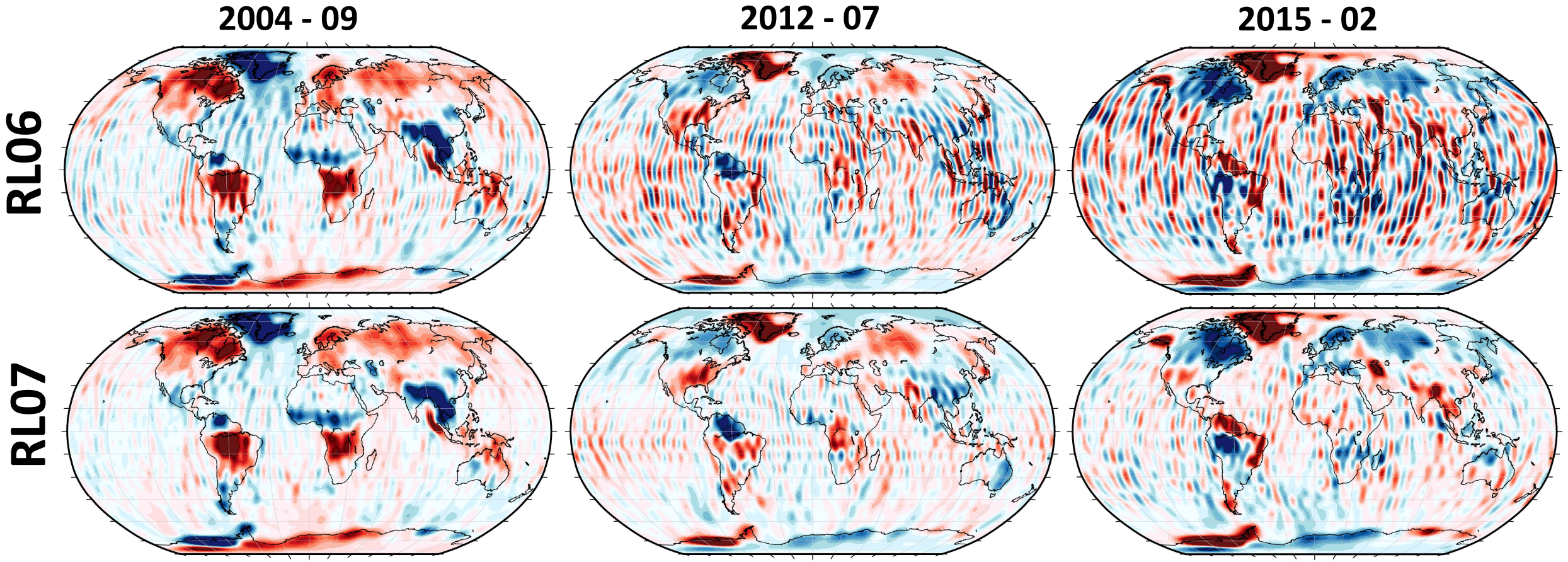
Results : RL06 vs RL07 e.w.h. maps (d/o 96)



Significant improvement in RL07 solution quality especially d/o 96

300 km smoothing

RL06 vs RL07 (months w/ repeat gr trk) - (d/o 60)

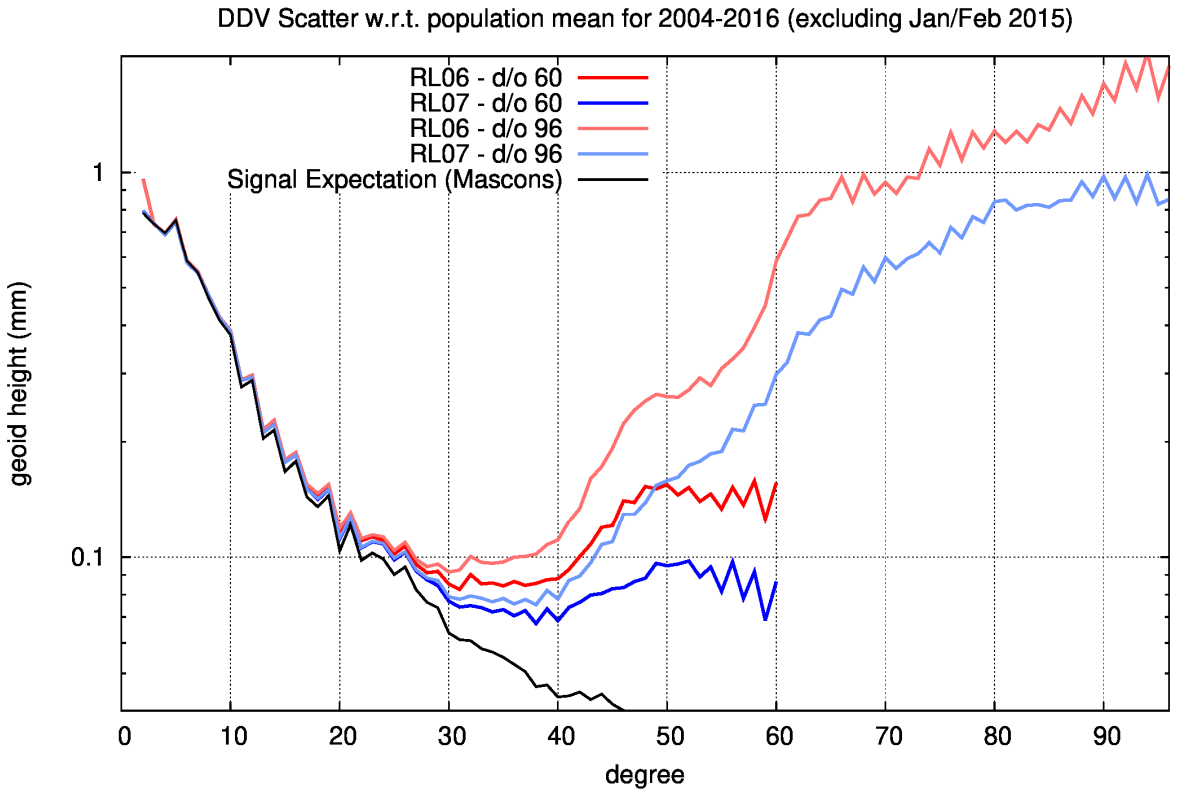


Months with repeat groundtrack see the most improvement in RL07

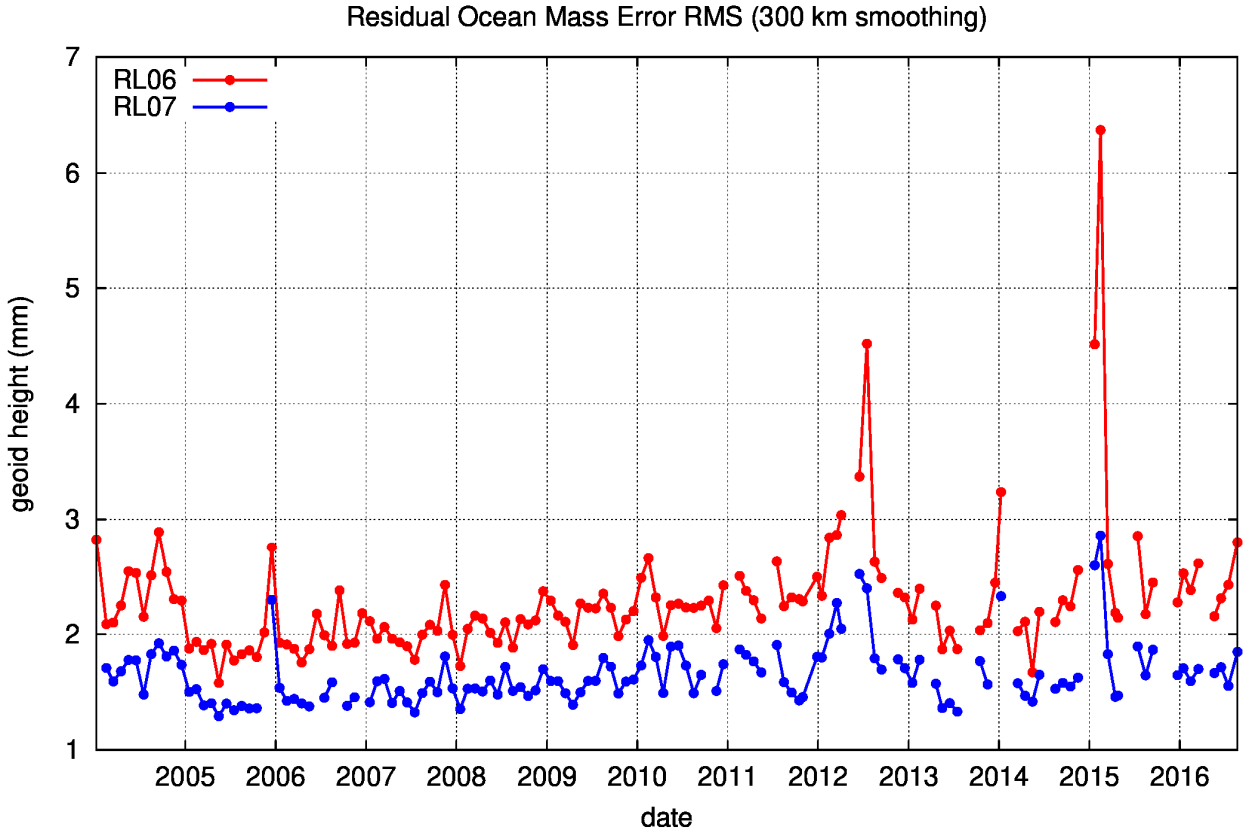
300 km smoothing

RL06 vs RL07 : DDV scatter and Ocean RMS Error

RL07 shows significant improvement v/s RL06

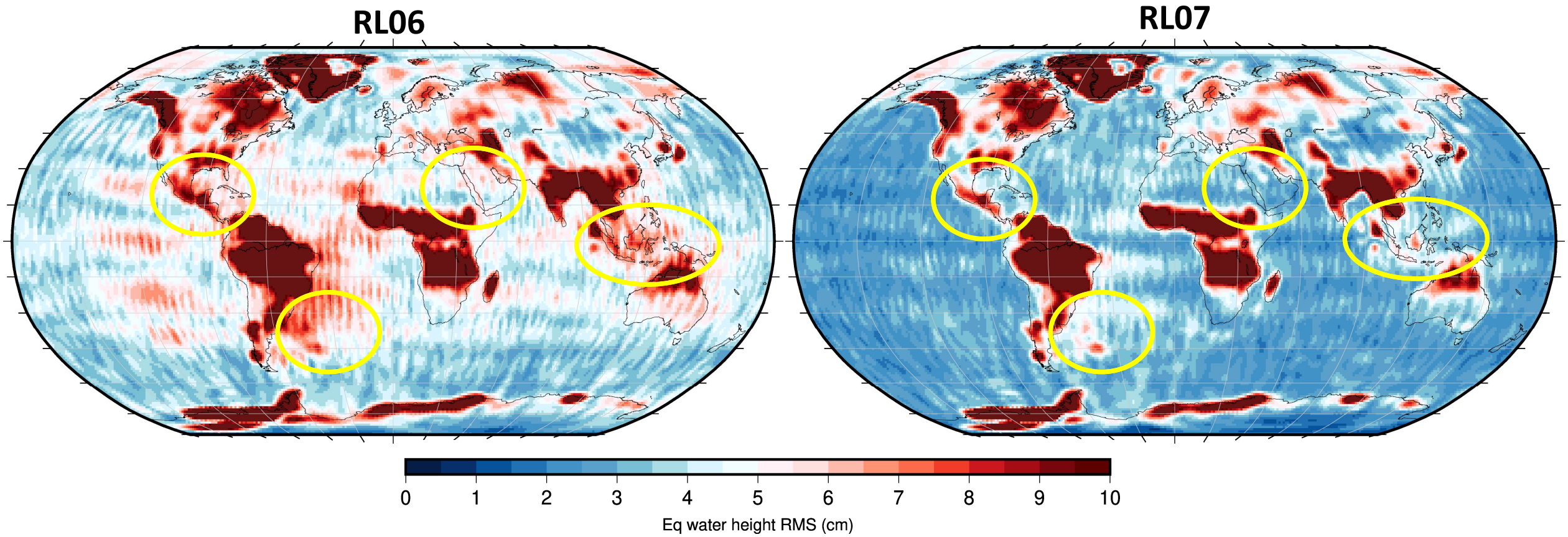


RL07 d/o 96 solutions have significantly lower errors than RL06 d/o 60 solutions below degree 50



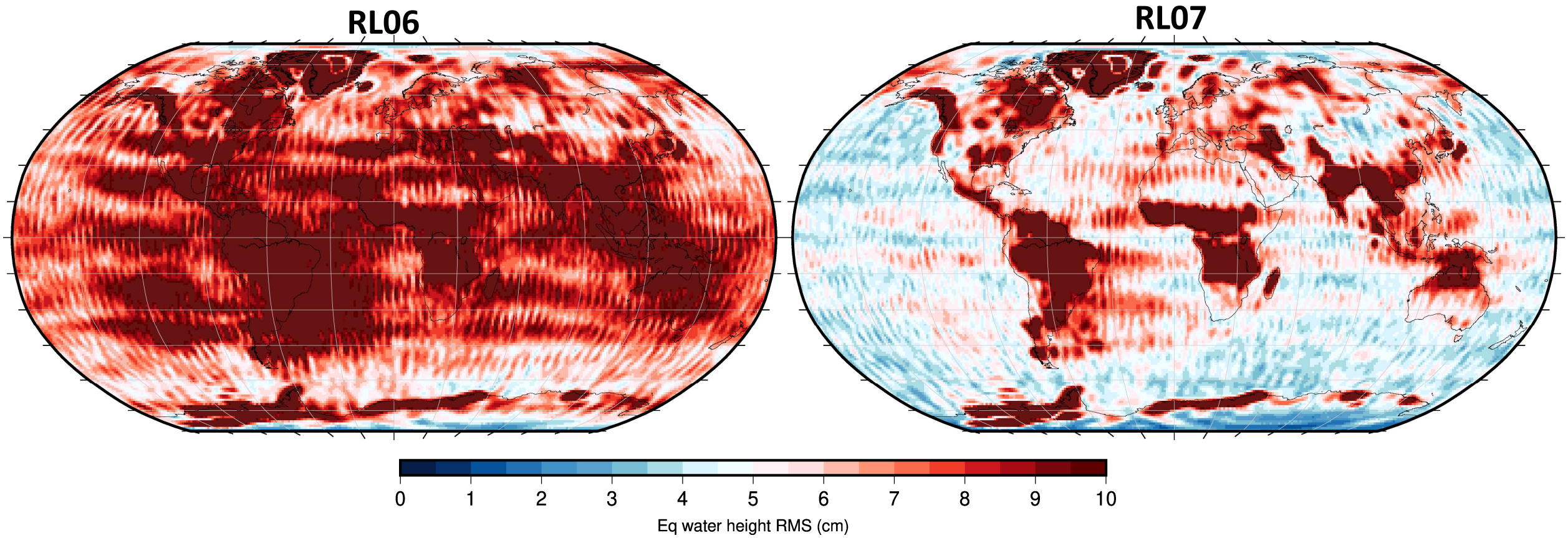
RL07 solutions show 25%+ improvement in global error over the Ocean compared to RL06 (@300km)

RL06 vs RL07 : Std. dev. over 13 years @ 200km



At 200 km smoothing, std. dev. over 2004-2016 is significantly reduced in RL07. Many signals hidden within the noise in RL06 are now clearly visible in RL07.

RL06 vs RL07 : Std. dev. over 13 years @ 100km



At 100km smoothing, signals in RL06 are overwhelmed by the noise in the solutions.

Std. dev @ 100 km for RL07 has a comparable SNR to std. dev @ 200 km for RL06

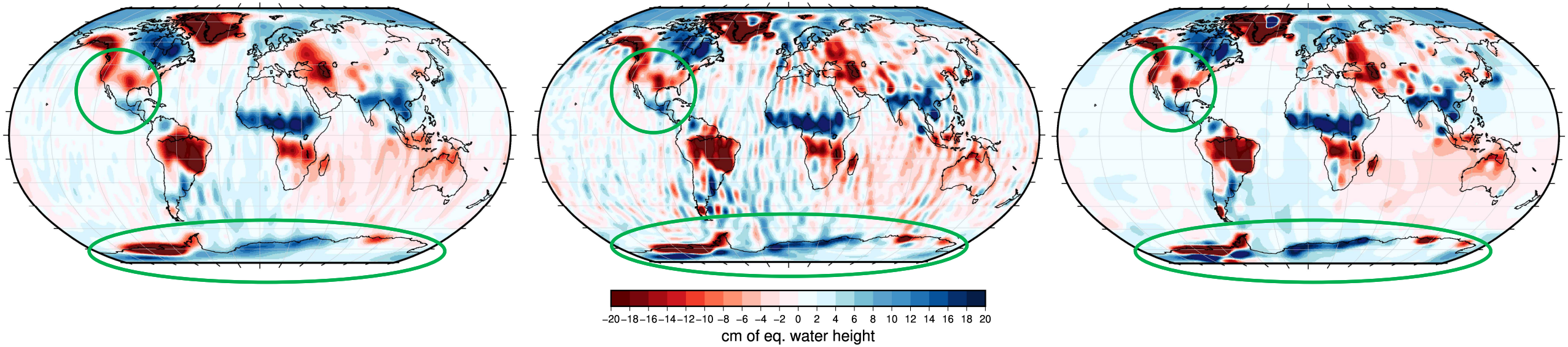
Total Variation (TV) Regularized Solutions from CSR

2014-10 RL07

350 km smoothing

200 km smoothing

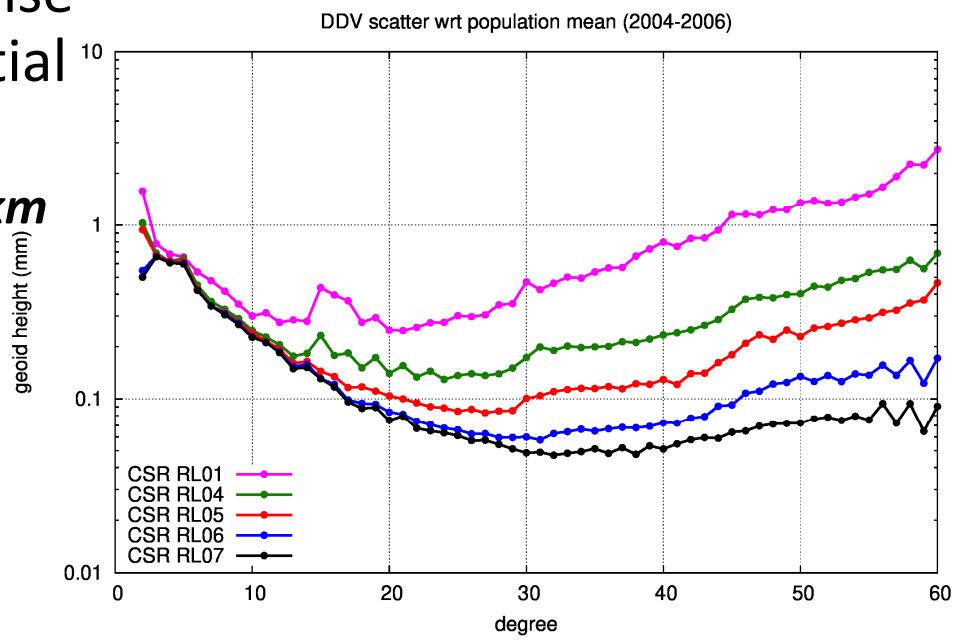
TV Regularized @ No smoothing



- CSR TV regularized solutions provide little or no signal attenuation while aggressively reducing stripes
  - ***signal amplitude preservation of smaller than 200km smoothing***
  - ***noise suppression of greater than 350km smoothing***
- For many applications, CSR TV regularized solutions should be used instead of filtering the SH solutions
- TV regularized solutions will be released as a part of regular monthly solution release bundles from CSR

Summary

- CSR RL07 solutions have significant reduction in noise compared to RL06 thus improving the realized spatial resolution
  - ***Noise in RL06 @ 200 km is comparable to RL07 @ 100 km***
  - ***Over 25% improvement in the noise over the oceans***
- CSR RL07 re-processing schedule:
  - GRACE (2004-2016) mostly complete
  - GRACE-FO + remaining GRACE by the Dec 2025
  - GGM07 mean field will be completed by March 2026
    - *GRACE + GRACE-FO (KBR+LRI) + GOCE + surface gravity*



- ***We recommend redesigning post-processing algorithms for use with CSR RL07 SH solutions because of reduced noise***
- We recommend the use of TV-regularized solutions from CSR instead of post-processing the RL07 SHC solutions for various application
  - These regularized solutions will be included as part of the regular scheduled releases

Thank You

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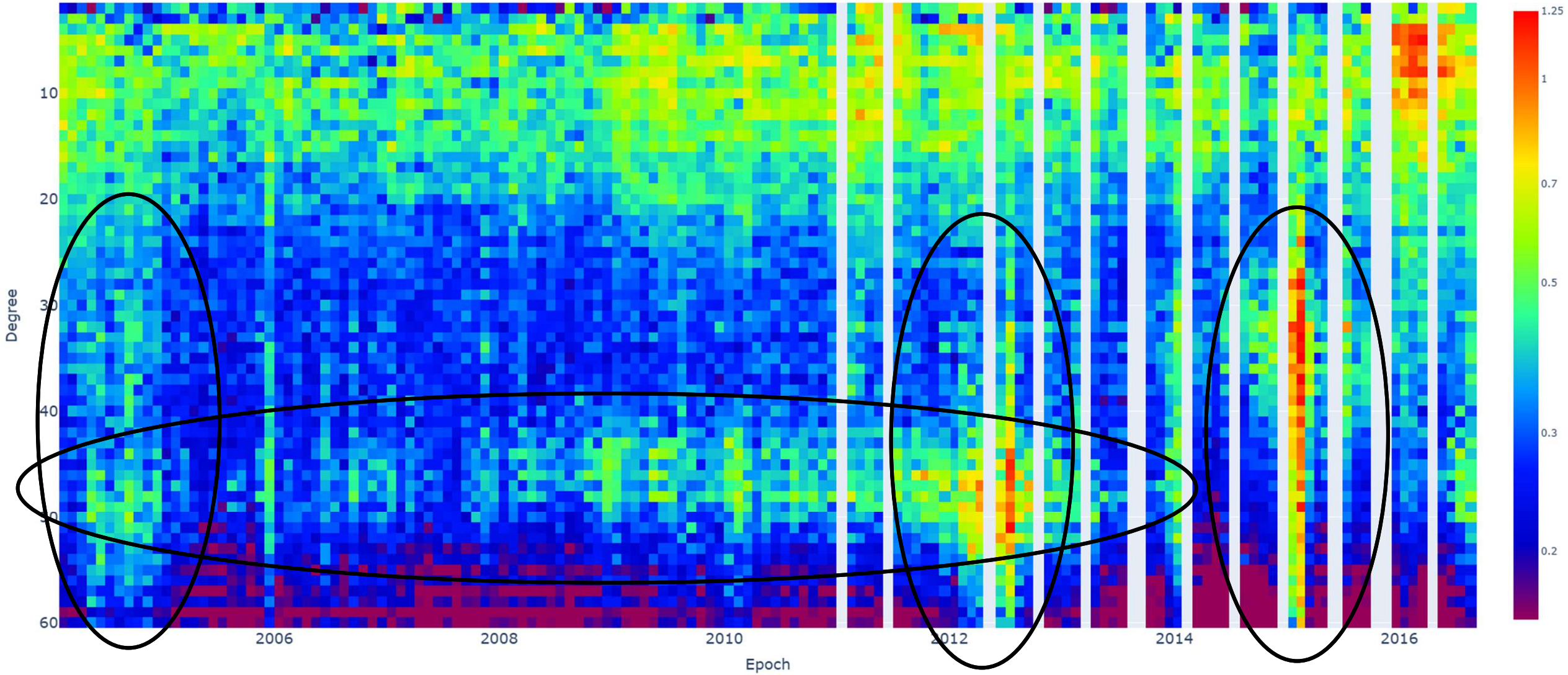
SUPPLEMENTARY INFORMATION

CSR RL06 : Global Residual DDV heatmap

RL06 Global EWH DDV (cm) w.r.t seasonal fit + trend and 300km gaussian smoothing



CSR RL07 : Global Residual DDV heatmap

RL07 Global EWH DDV (cm) w.r.t seasonal fit + trend and 300km gaussian smoothing