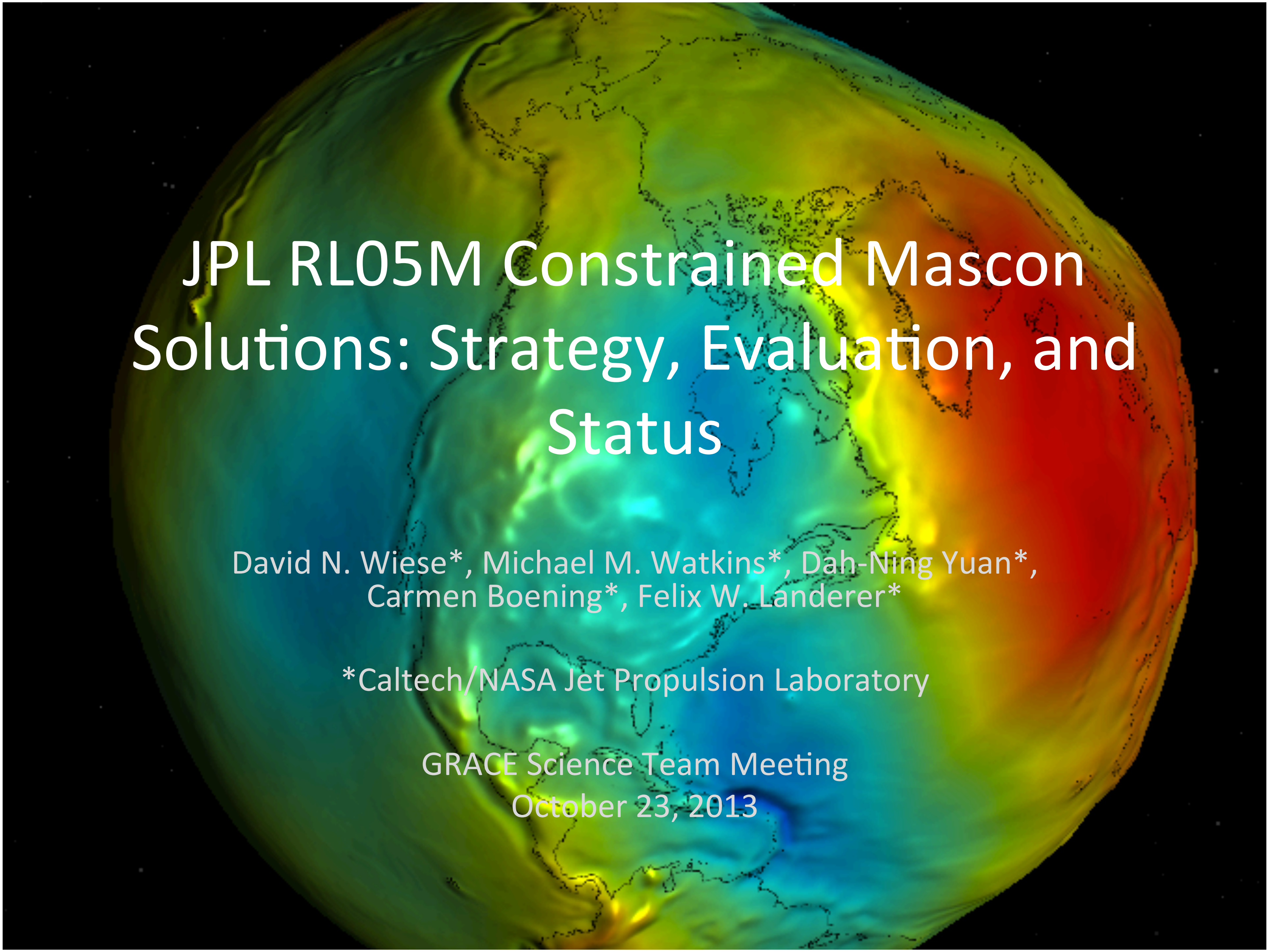

JPL RL05M Constrained Mascon Solutions: Strategy, Evaluation, and Status

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Mascons vs. Harmonics

Unconstrained Spherical Harmonics

Apriori Covariance = 0

Solve for parameters: C_{lm} and S_{lm} coefficients out to degree 60 or 90

$$\left(H^T W H + \bar{P}_0^{-1}\right)\hat{x}_0 = H^T W y + \bar{P}_0^{-1}\bar{x}_0$$

H = partials of observations with respect to state

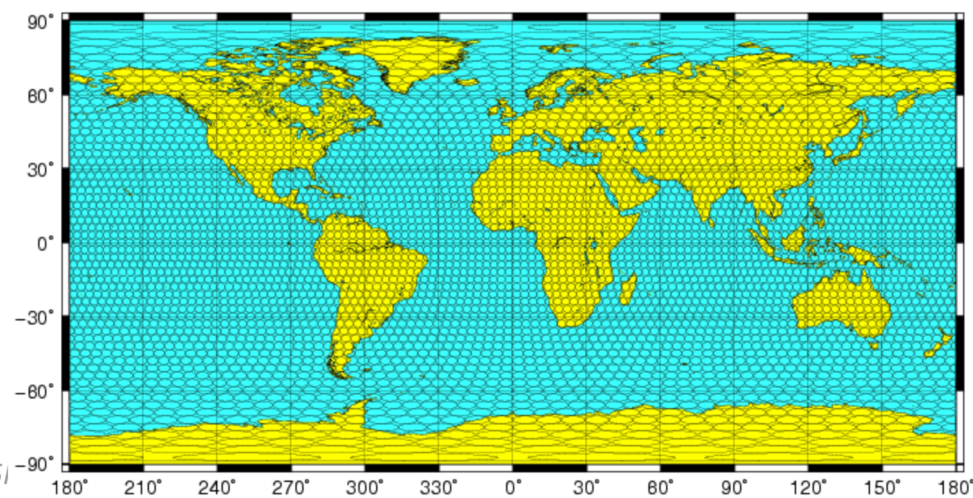
W = weighting for observations

y = observations

$$\bar{P}_0 = \begin{bmatrix} \sigma_i^2 & \rho_{ij}\sigma_i\sigma_j & \cdots \\ \rho_{ij}\sigma_i\sigma_j & \sigma_j^2 & \\ \vdots & & \ddots \end{bmatrix}$$

Apriori state estimate: Set equal to zero to be purposefully conservative in our approach

Solve for parameters: 4,551 equal-area 3-degree spherical cap mass concentration blocks distributed over the Earth



Apriori Covariance = Based on variability of each mascon as given by reliable external data (geophysical models or observations)

Constrained Spherical Cap Mascons

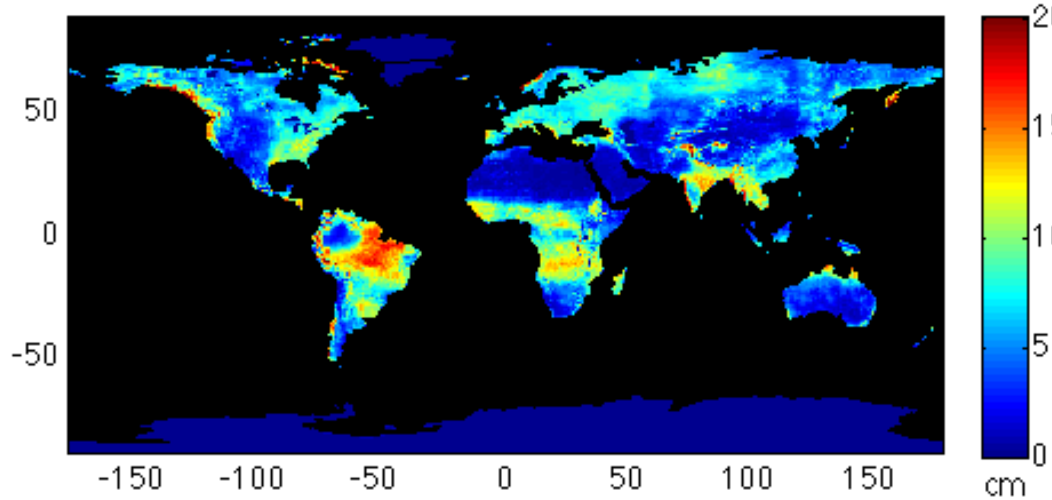
Apriori covariance: diagonals

$$\bar{P}_0 = \begin{bmatrix} \sigma_i^2 & \rho_{ij}\sigma_i\sigma_j & \cdots \\ \rho_{ij}\sigma_i\sigma_j & \sigma_j^2 & \\ \vdots & & \ddots \end{bmatrix}$$

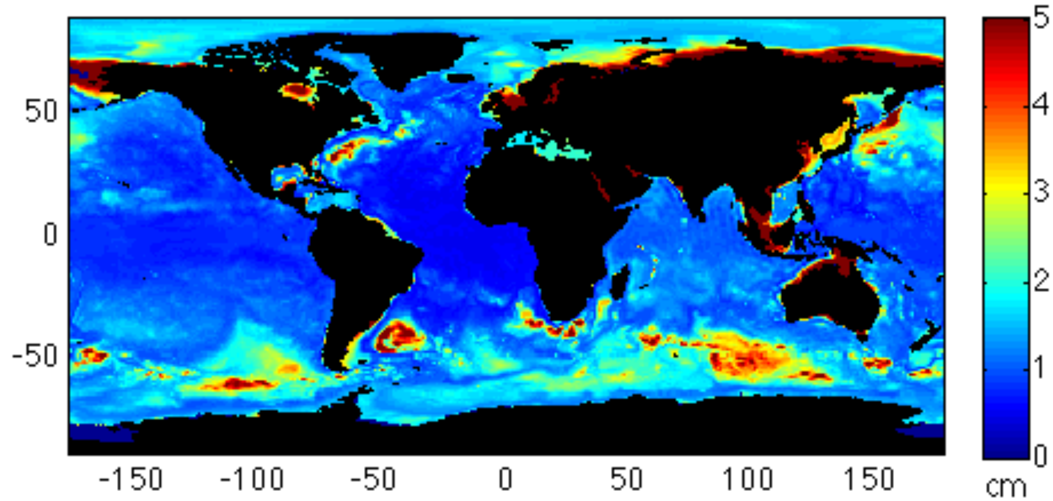
$$\sigma_i = W_m RMS_k \sqrt{\cos\theta}$$

- W_m – Monthly weight on $\bar{P}_0$
- RMS_k (6 regions):
  - Land (GLDAS-NOAH)
  - Ocean (ECCO2/OMCT)
  - Ice (Empirical 2-step)
    - Greenland, Antarctica, Baffin, Ellesmere, Iceland, Alaska, Patagonia
  - Inland Seas (*Crétaux et al.,* 2011)
    - Altimetry
  - Earthquakes (*Han et al.,* 2013)
    - Sumatra, Dec 2004
    - Maule, Feb 2010
    - Tohoku, Mar 2011
    - Indian Ocean, Apr 2012
  - GIA (*Paulson et al.*, 2007)

Monthly RMS of GLDAS-NOAH, 2003-2010



Monthly RMS of max(ECCO2, ECCO2-OMCT), 2004-2007



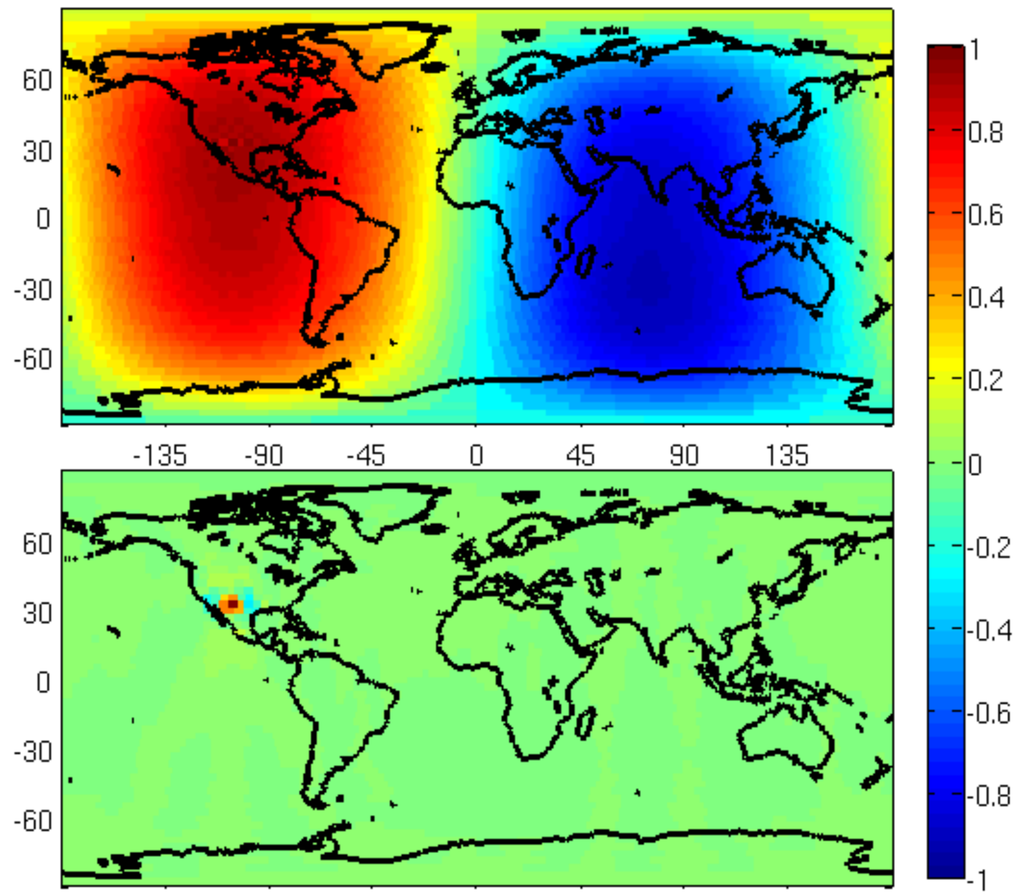
Apriori covariance: off-diagonals

$$\bar{P}_0 = \begin{bmatrix} \sigma_i^2 & \rho_{ij}\sigma_i\sigma_j & \cdots \\ \rho_{ij}\sigma_i\sigma_j & \sigma_j^2 & \\ \vdots & & \ddots \end{bmatrix}$$

- Our approach: use models
  - Land (GLDAS) (500 km cutoff)
  - Ocean (ECCO2) (750 km cutoff)
  - Ice (zero)
  - Inland Seas (altimetry/GLDAS)
  - Earthquakes (*Han et al.,* 2013)
    - Sumatra, Dec 2004
    - Maule, Feb 2010
    - Tohoku, Mar 2011
    - Indian Ocean, Apr 2012
- Impose zero correlation between land/ocean, specify L/O mascons as either land or ocean based on maximum correlation
- Use *Qi and Sun* (2006) to find "nearest correlation matrix" to guarantee positive definite

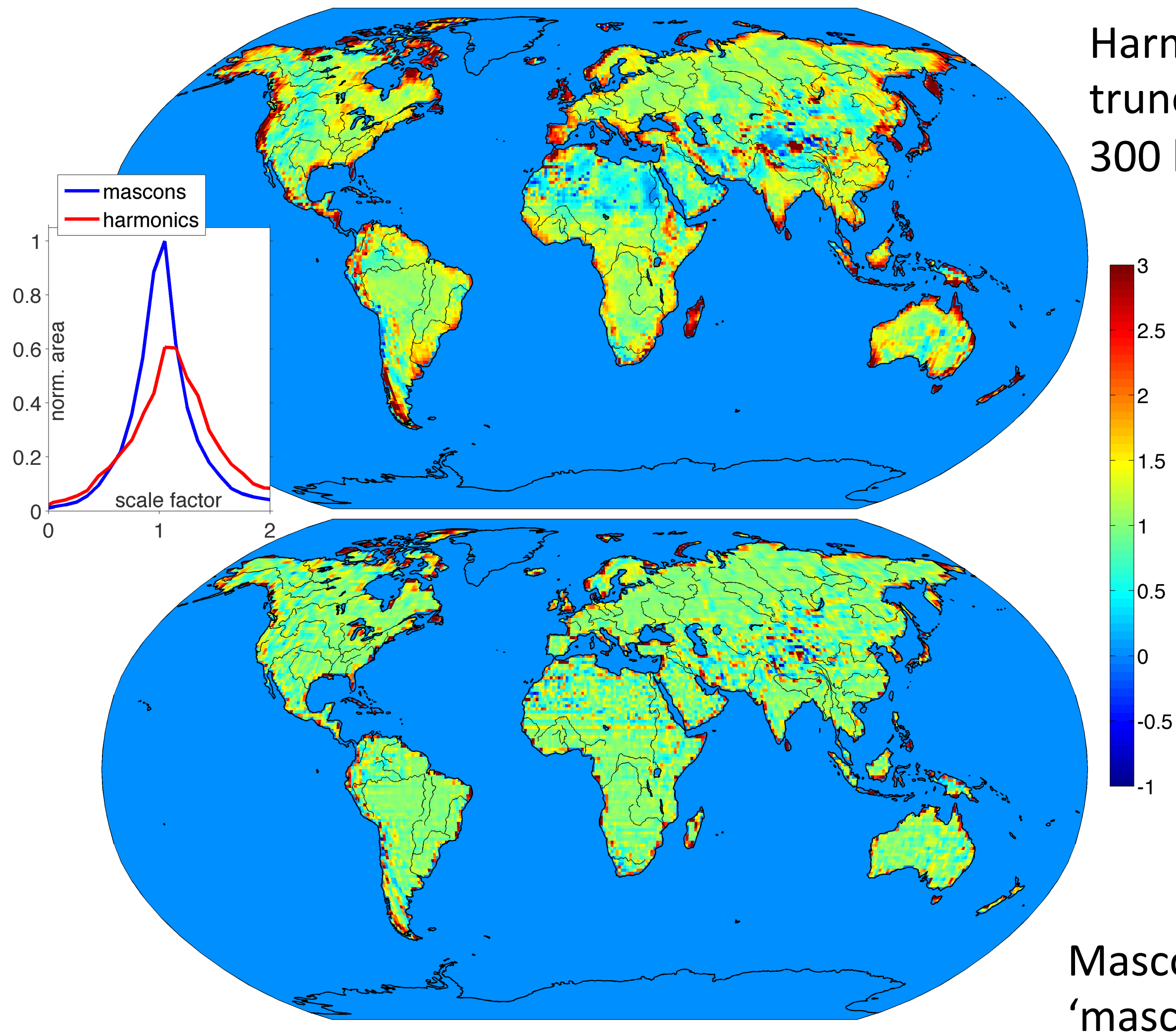
Posteriori correlations for a particular mascon in the Southwest United States

Zero apriori correlation



After introducing apriori correlations

Scale Factors

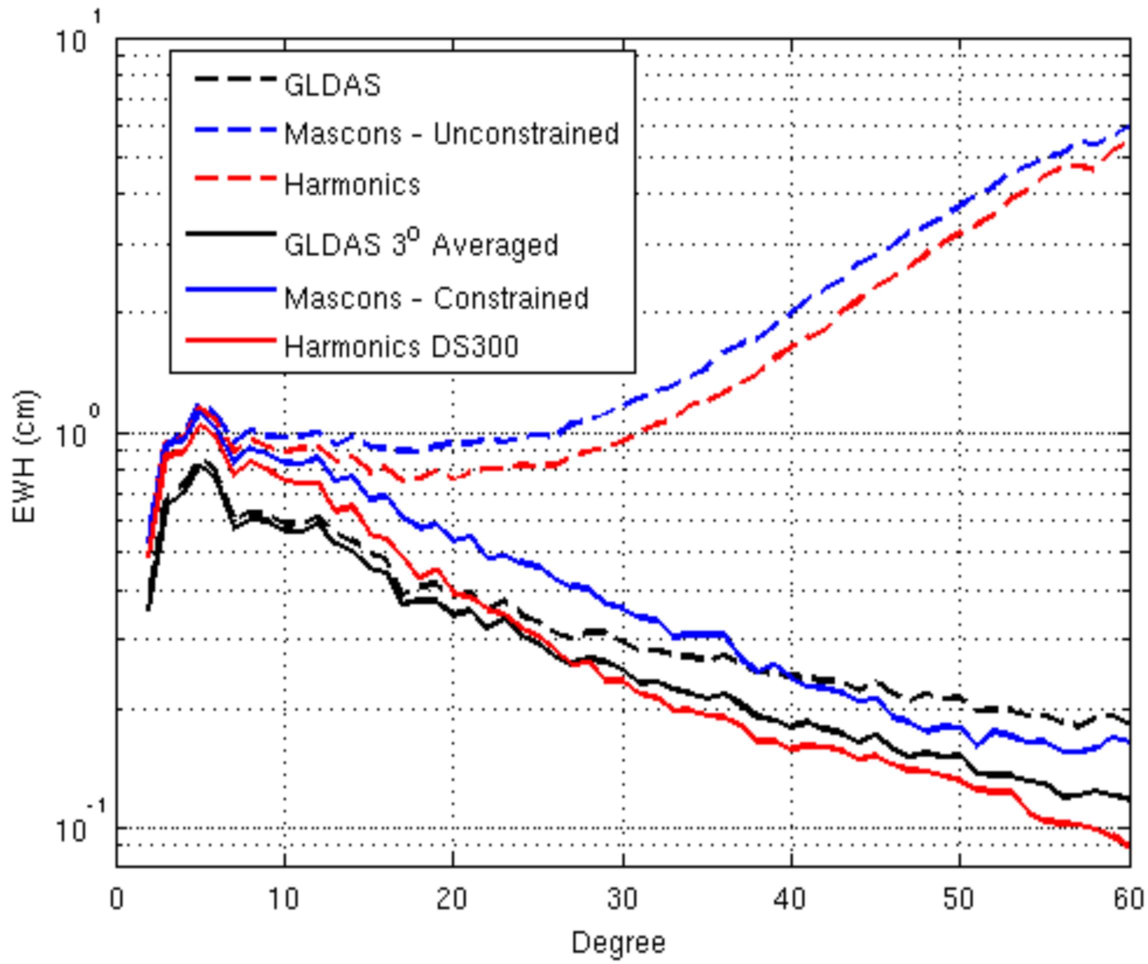


Harmonics, degree 60 truncation, destriping, 300 km smoothing

Mascons, 3-degree 'mascon-averaging'

Solution Evaluation

Harmonic Comparison



Plots are constructed using average of monthly solutions from 2004-2010

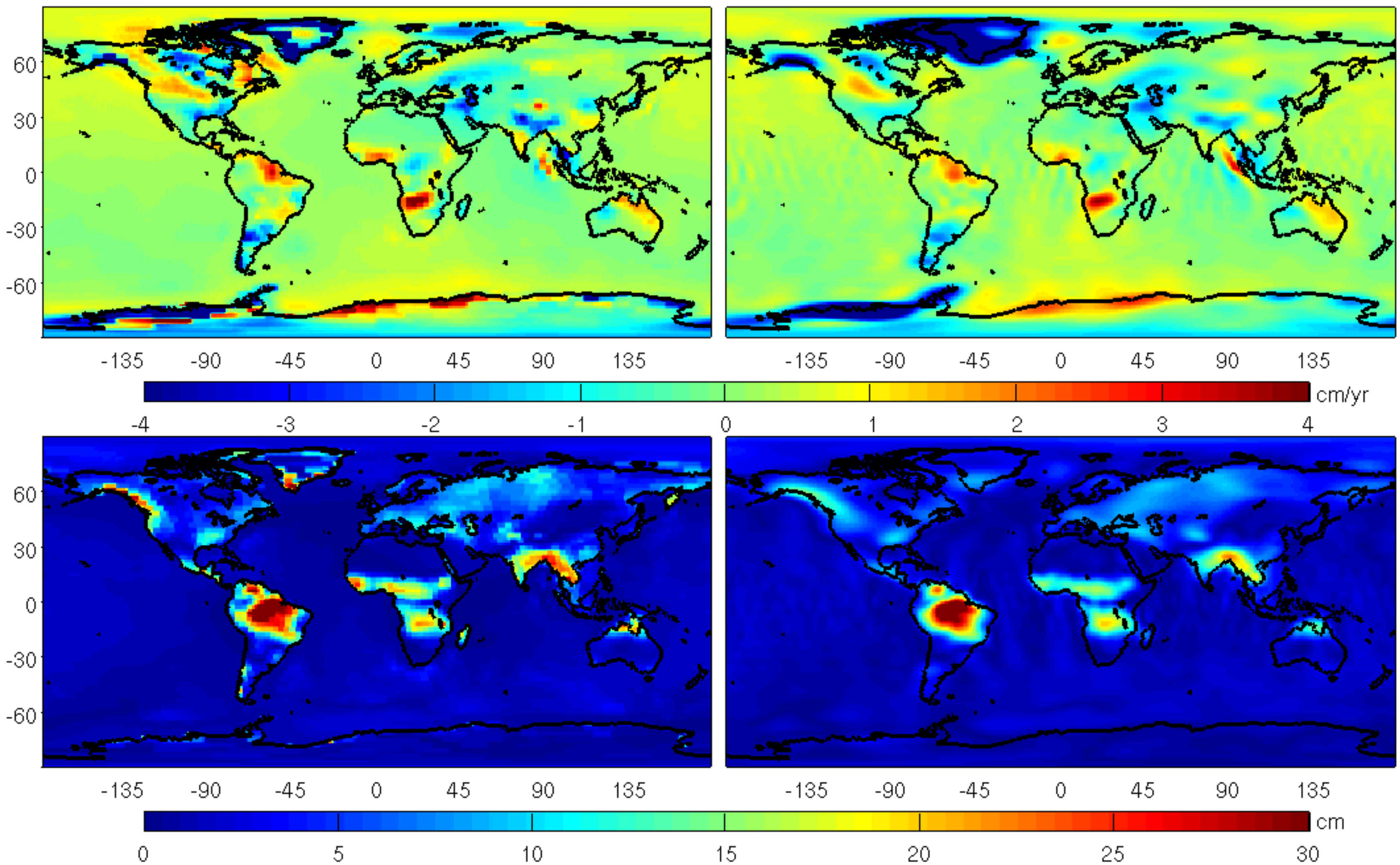
Trend and Annual (2003-2012)

JPL RL05M Constrained Mascons

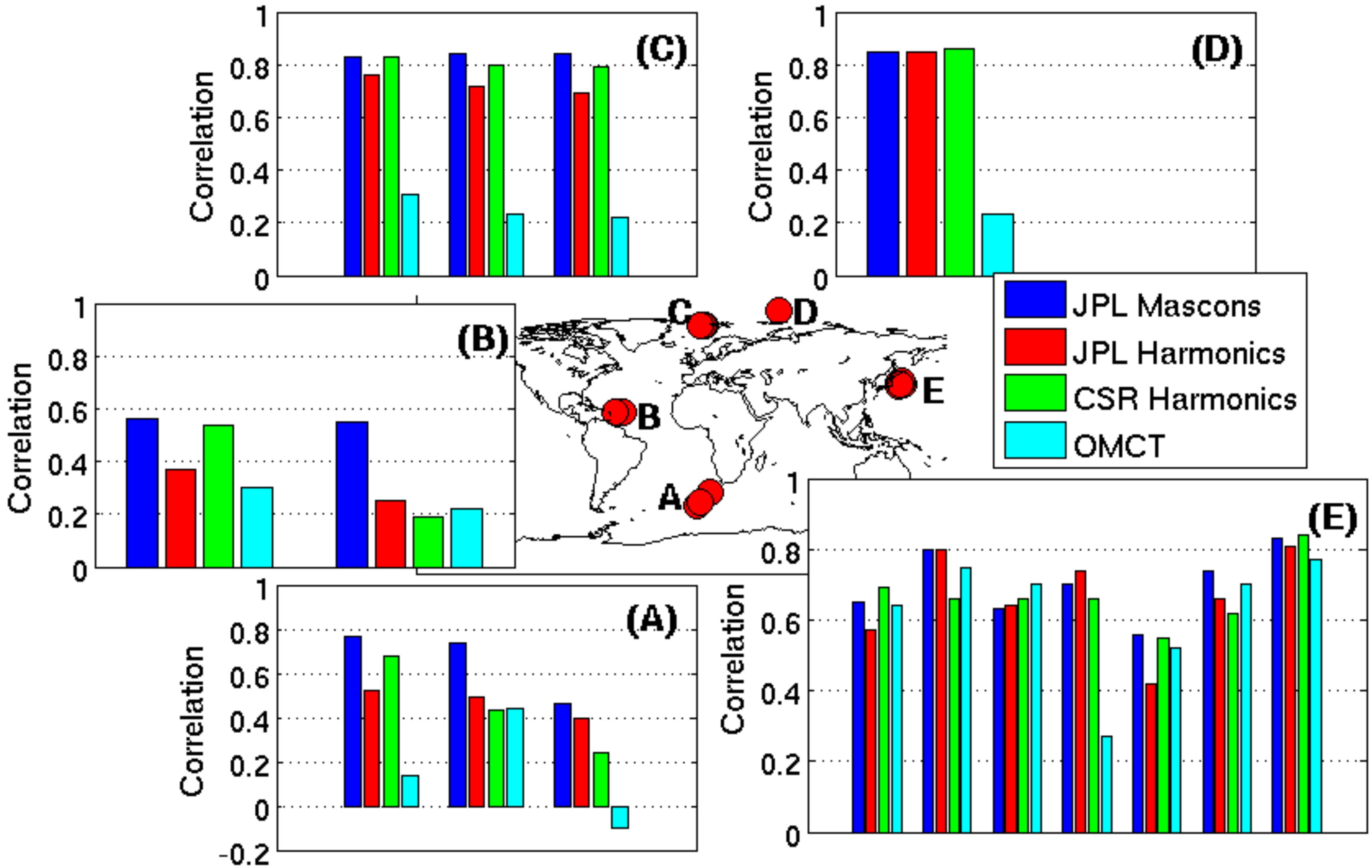
JPL RL05 Harmonics destriped & 300km smoothed

Trend

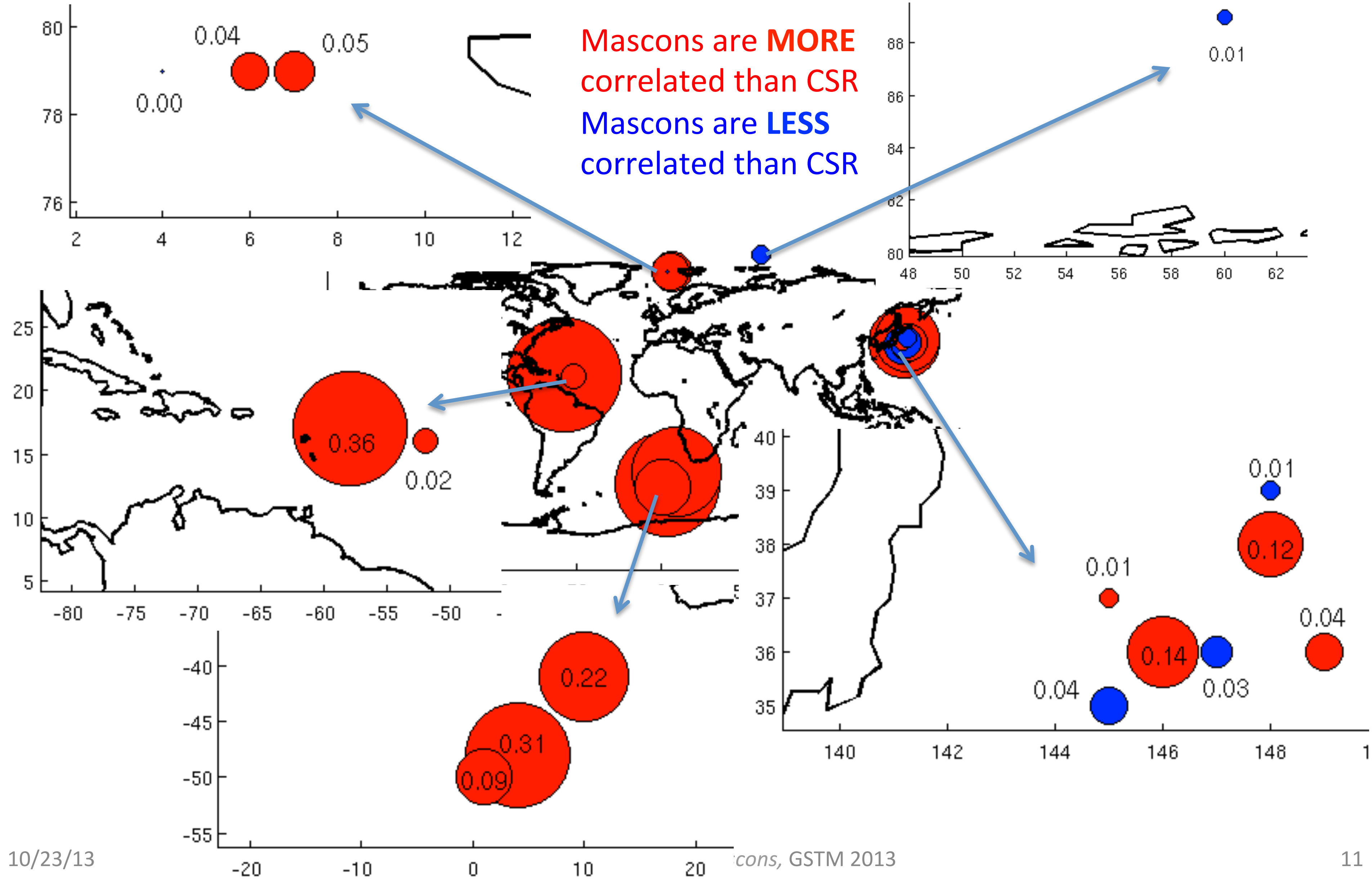
Annual



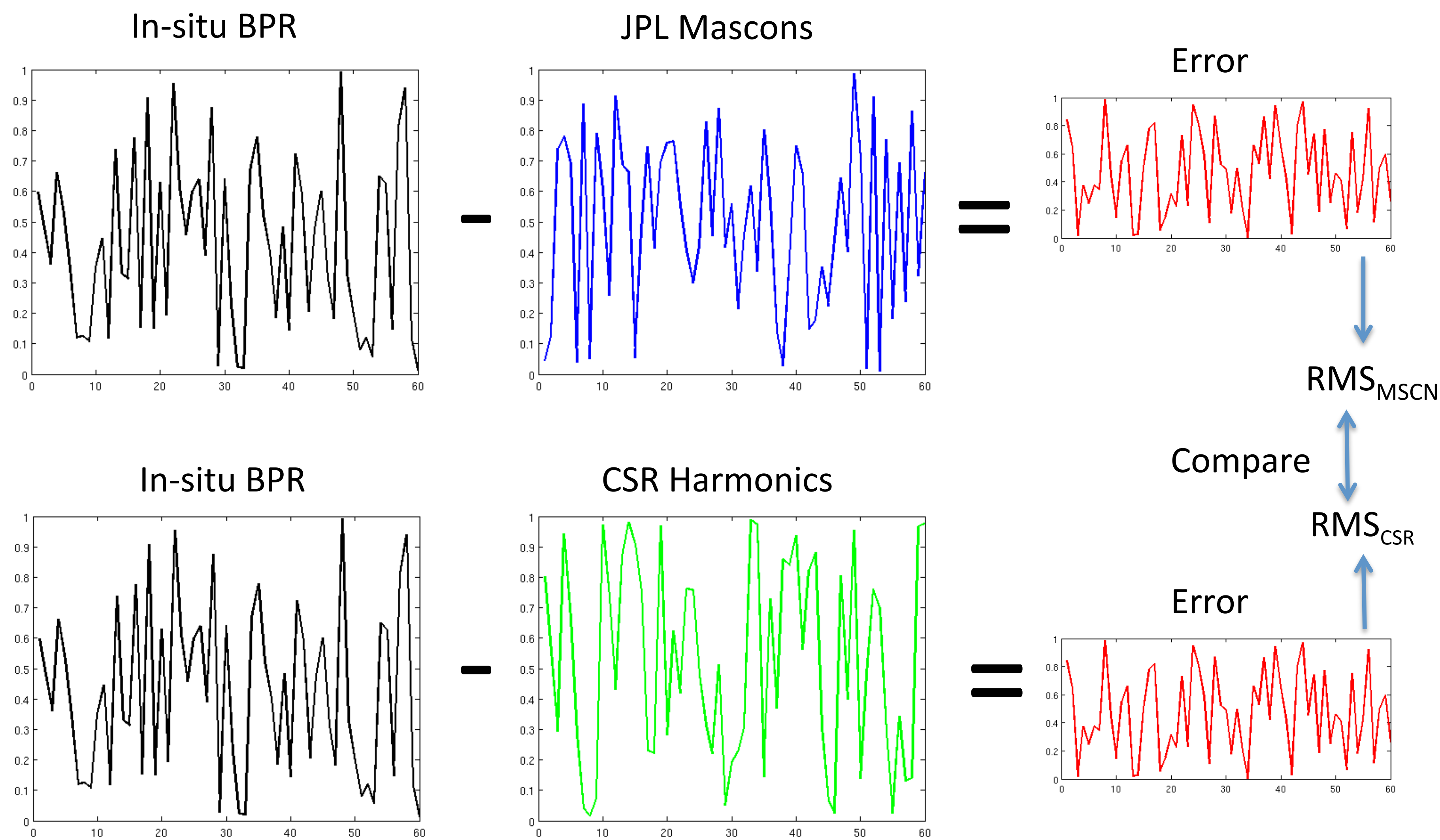
Correlation with in-situ BPRs



Correlation with in-situ BPRs



Correlation with in-situ BPRs

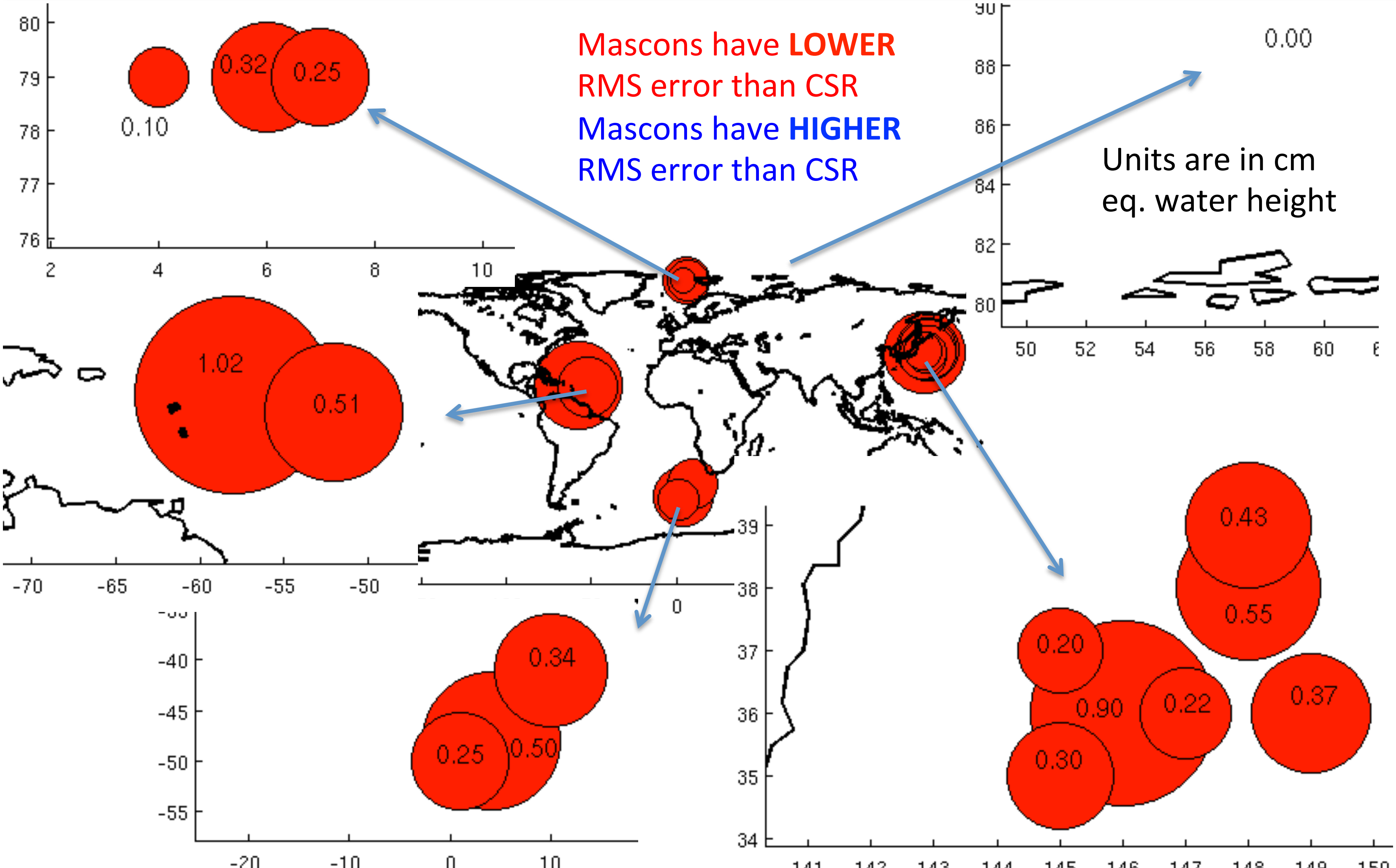


In-Situ Ocean BPR Comparison

Mascons have **LOWER** RMS error than CSR

Mascons have **HIGHER** RMS error than CSR

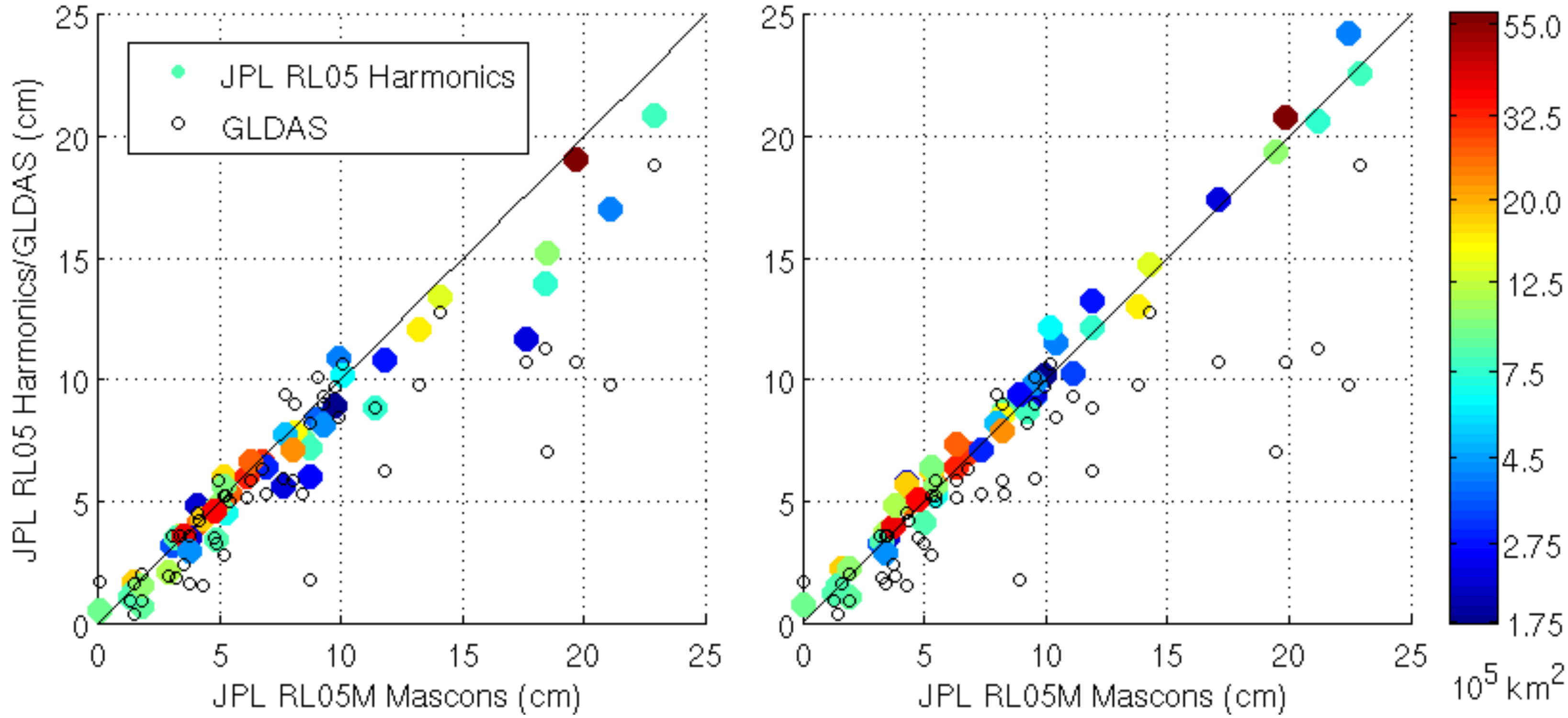
Units are in cm eq. water height



Wiese et al., *JPL RL05M M*

Hydrology Comparison

Annual Amplitudes (cm) for 50 largest hydrological basins 2003-2012



- JPL RL05M is NOT constrained to GLDAS
- Applying scale factors changes annual amplitude for harmonics by 31% compared with 8% for mascons

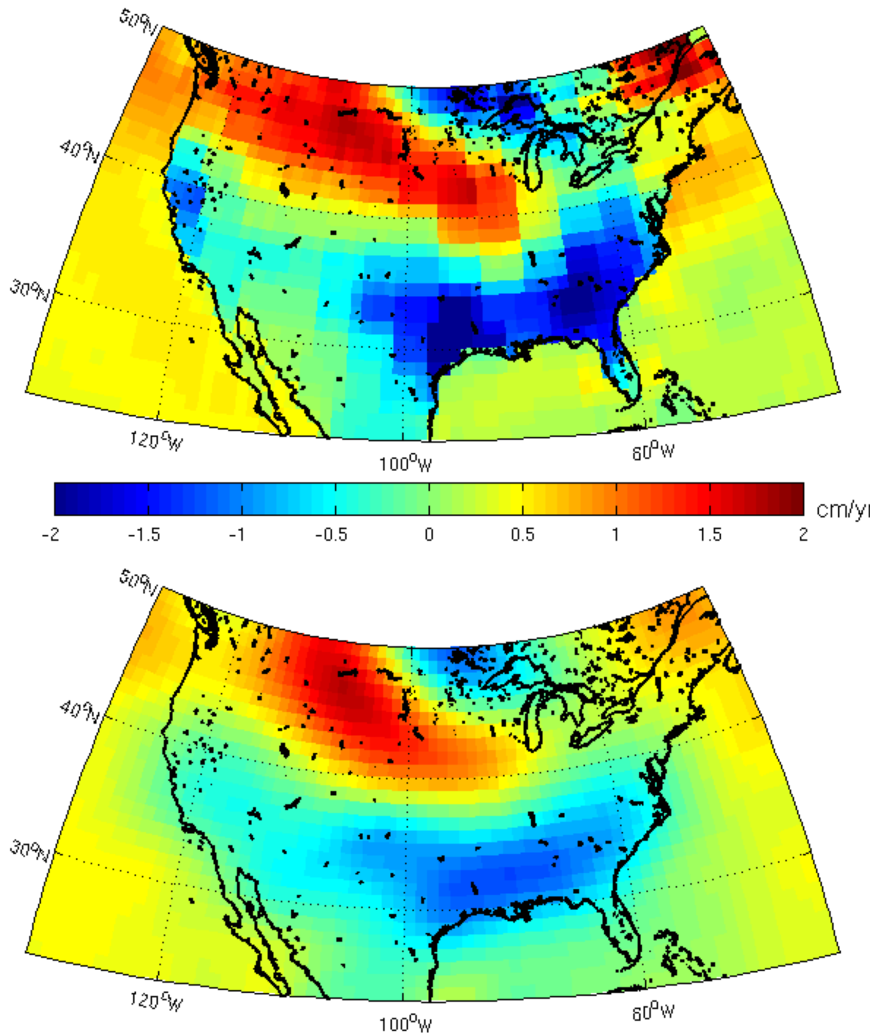
- Level of agreement indicates skill in:
  - 1) Mascon solution
  - 2) Process of deriving scale factors and applying them
  - 3) Spatial distribution of mass in GLDAS

Hydrology Comparison

2003-2012 Trend for Continental United States

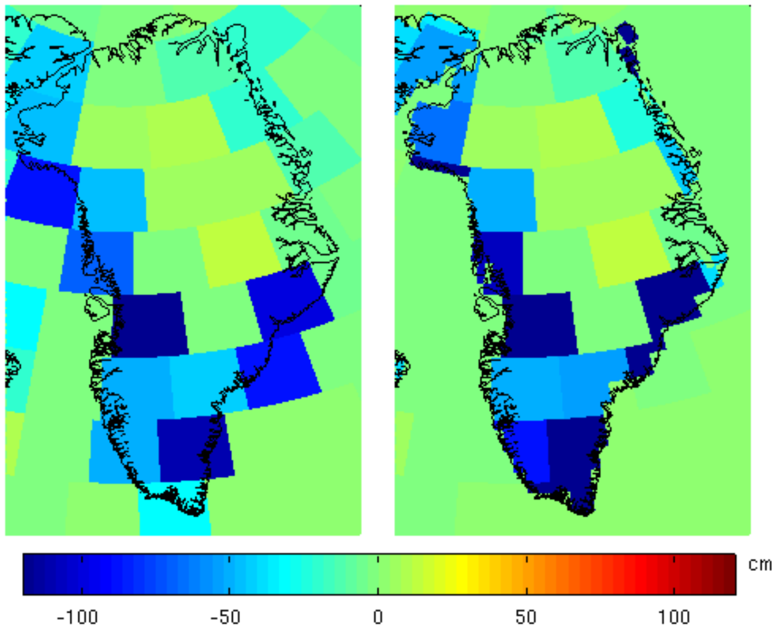
JPL RL05M Mascons

JPL RL05 Harmonics, Destriped, 300 km Smoothed



*Application of scale factors is not suitable for studying long term (trend) signals since the models do not represent these signals well (*Landerer and Swenson,* 2012)

Ice Sheet Mass Balance



Redistribute mass on land/ocean boundaries

Study	Timeframe	Antarctica Trend (Gt/yr)		Greenland Trend (Gt/yr)	
		Study	JPL RL05M	Study	JPL RL05M
Barletta et al. [2013]	Jan 2003 - Nov 2011	-83 ± 38	-107 ± 49	-234 ± 20	-258 ± 29
Jacob et al. [2012]	Jan 2003 - Dec 2010	-165 ± 72	-102 ± 49	-222 ± 9	-244 ± 29
Luthcke et al. [2013]	Dec 2003 - Dec 2010	-81 ± 26	-104 ± 49	-230 ± 12	-246 ± 29
Sasgen et al. [2012]	Oct 2003 - Oct 2009	---	---	-238 ± 29	-238 ± 29
Sasgen et al. [2013]	Jan 2003 – Sep 2012	-114 ± 23	-106 ± 49	---	---
Schrama & Wouters [2011]	Mar 2003 - Feb 2010	---	---	-201 ± 19	-236 ± 29
Shepherd et al. [2012]	Jan 2003 - Dec 2010	-81 ± 33	-102 ± 49	-230 ± 27	-244 ± 29
Velicogna & Wahr [2013]	Jan 2003 - Nov 2012	-83 ± 49	-105 ± 49	-258 ± 41	-275 ± 29

Summary

- JPL RL05M is a constrained mascon product
  - Better agreement with BPRs than harmonic solutions in most regions
    - Most improvement in low latitude/small signal areas
  - Good agreement for large hydrology basins after applying scale factors
  - Better suited to study trends in smaller basins due to less reliance on scaling
  - Reduces the reliance on scale factors to restore signal in mass estimates by ~25%
  - Ice sheet mass balance results agree within formal uncertainties
    - Mascon solutions estimate slightly larger rates of mass loss than most published estimates
  - Solution does not require post-processing
- Targeted release date: AGU 2013
  - Standard Level 2 GSM format
  - Gridded product on Tellus
- User Notes
  - Do NOT smooth, destripe, or filter the solutions in any way
  - Use high degree/order expansion for accurate analysis (n=719)
    - n=120 is good for general analysis
  - Apply scale factors to restore power due to 'mascon averaging'