EGSIEM

Title: WP5 (NRT and Regional Service)

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Horizon2020

WP5 Background

- Nominal time delay of the GRACE Level-1 instrument data is 11 days and of the derived monthly global Level-2 gravity field products is 60 days.
- This makes the application of GRACE for monitoring of e.g. hydrological extremes (floods or droughts) difficult.
- In essence the present products only allow for
  - a confirmation after the occurrence of an event, and
  - an estimation of the severity/magnitude of the event
- Much more interesting from a hydrological user or SAR acquisition planning point of view is a near real-time (NRT) mass transport product.

WP5 Objectives

- **Establish a NRT and Regional Service** (Project Partners GFZ, TUG, UL) that aims
  - to **reduce the time delay of necessary input data** from currently 60 days to less than 5 days,
  - to **increase the time resolution** from one month to one day, and
  - to **improve the quality** by providing regional solutions based on alternative representations of the gravity field, e.g. space-localizing radial base functions.
- The performance of the **NRT service will be tested using historical hydrological extreme events** (from T3.9).
- An **operational test run of the service at DLR/ZKI** for half a year is foreseen in the final phase of the project.

WP5 NRT & Regional Service Timeline

- Input Requirements and Draft Concept have to be defined within M01-M03
- NRT and Regional Solutions have to be processed within M04-M27 by GFZ and TUG
- Concepts will be refined during this phase till M27
- Service installation will be divided into
  - **Implementation phase M04-M27** (based on standard data, background models and delays to test the overall concept and procedures for historical flooding events (from T3.9) and
  - **Operational phase M28-M33** (based on NRT requirements)

WP5 NRT & Regional Service Input Requirements

- **Instrument Data**
  - Implementation phase: Standard Level-1B data (JPL, 11 days delay)
  - Operational phase:
    - Standard: Q/L Level-1B data (JPL, 1 day delay)
    - Backup: Q/L Level-1B data (GFZ, 1 day delay)

- **Background models** as defined in WP2 are sufficient except short-term atmopheric and oceanic mass variations (based on ECMWF analysis data and OMCT (both available at GFZ))
  - Implementation phase: Standard RL05/RL06 AOD1B (GFZ, 7 days delay)
  - Operational phase: Faster available RL05/RL06 AOD1B (GFZ, 3-4 days delay)

WP5 NRT Gravity Processing Input Requirements

- **Auxiliary data**
  - IGS orbit products: from T3.4
  - IGS clock products: from T3.4
  - Earth rotation parameters: from T3.4
  - Kinematic Orbits: from T3.4

WP5 Output

- GFZ (Section 5.4) will derive for all areas of interest and all flooded regions area mean values (AMV) based on gridded equivalent water heights of gravity field time series derived in WPs 2 (monthly), 4 (combined) and 5 (NRT & Regional) and masks defined in WP3. Resulting AMVs will be used in WP6 e.g. for derivation of flooding indicators and will be visualised in WP7.

- Documents & Reports
  - 5.1a Draft Concept of NRT Service (M03)
  - 5.1b Final Concept of NRT Service (M27)
  - 5.2 NRT Service product report (M27)
  - 5.3 Operational NRT Service product report (M33)
  - 5.4 Regional solution product report (M27)
  - 5.5 NRT validation report (M36)

WP5 Validation of NRT Solutions

- WP5 NRT gravity field solutions are validated by UL (M19-M36) with
  - hydrological models (e.g. GLDAS, WGHM) and
  - GNSS loading time series (mass redistributions are converted to site displacements).
- Procedure will be automated to allow NRT validation

WP5 Validation of NRT Solutions (UL)

WP5 Validation of NRT solution

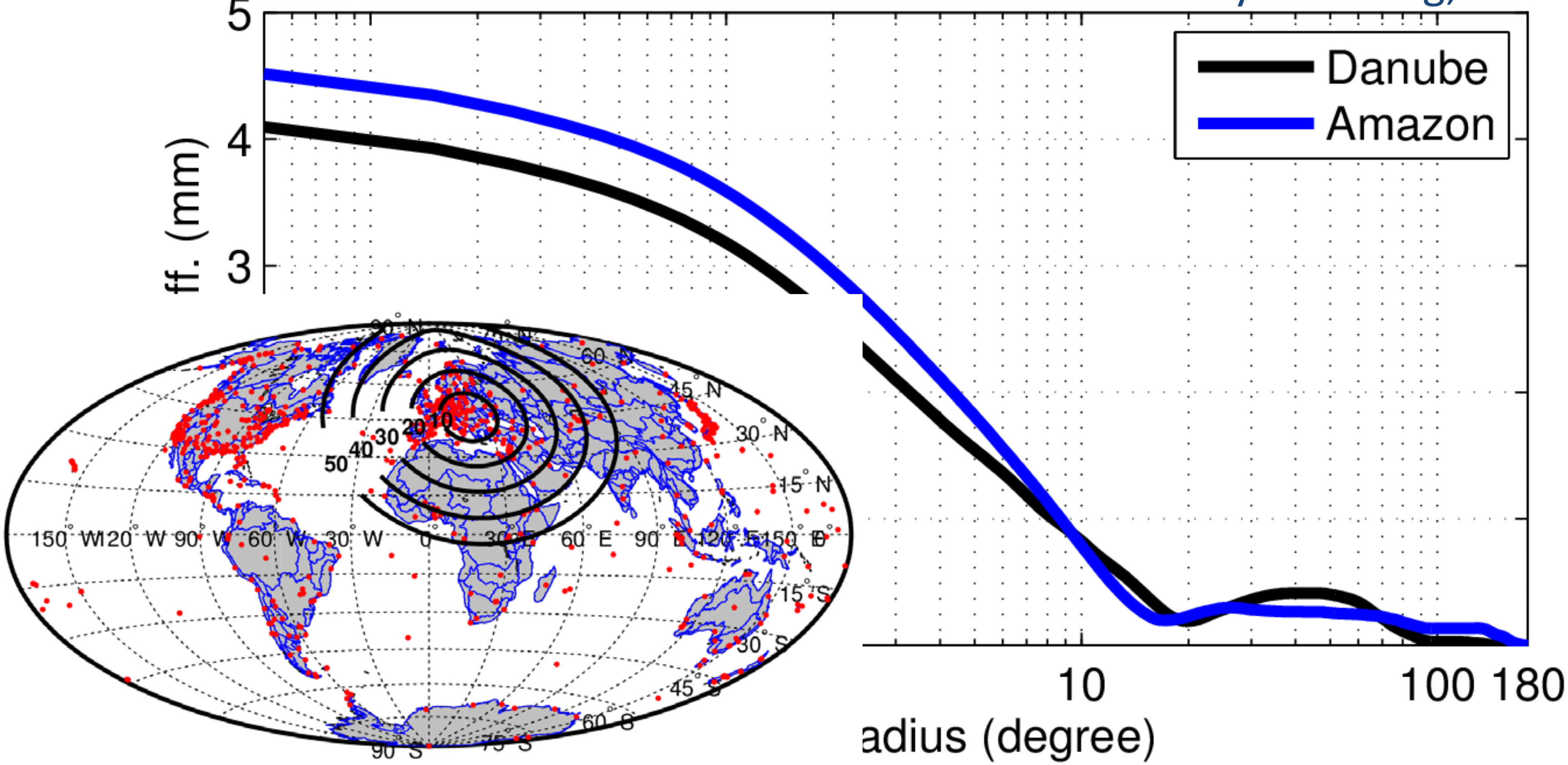
Method 1: comparison with GNSS displacements

- Gravity data:
  - SH coefficients → loading modeling via SH (Kusche and Schrama, 2005)
  - Regional (spatial) models → spatial modeling via Green's functions (Farrel 1972, van Dam et al. 2008)
- GNSS data:
  - NRT reference frame time series from WP3, T3.3. (~250 stations)
  - Other sources, e.g. Nevada Geodetic Laboratory Rapid solution
    - Latency: 1 day with 5 minute resolution -> daily averages - Consistency?
- Corrections:
  - GNSS senses atmospheric and ocean loading → restore the AOD1B product to the gravity data (or subtracting from GNSS)
  - Averaging procedure for AOD1B product?

WP5 Validation of NRT solution

A note on regional (spatial) solutions
- or - how regional is GNSS loading?

courtesy Lin Wang, UL



WP5 Validation of NRT solutions

Method 2:

Terrestrial water storage changes from NRT solutions and hydrological models

Problem 1:

Model	Data source	Unit	Temporal resolution	Spatial Resolution (degree)	Latency
GLDAS-A (NOAH)	SM (4 layers)	Kg/m^2	Monthly	1×1	1-4 months
	SWE	Kg/m^2			
NCEP-R-2	SM (2 layers)	m^3/m^3	6-hourly	$1.875 \times (1.8889 - 1.9048)$	3-4 days
	SWE	Kg/m^2			
GLDAS-B (NOAH)	SM (4 layers)	Kg/m^2	3-hourly	1×1	1-4 months
	SWE	Kg/m^2			
MERRA-A	PRMC	m^3/m^3	Monthly	$2/3 \times 1/2$	1-2 months
	SNOMAS	Kg/m^2			
MERRA-B	PRMC	m^3/m^3	1-hourly	$2/3 \times 1/2$	1-2 months
	SNOMAS	Kg/m^2			

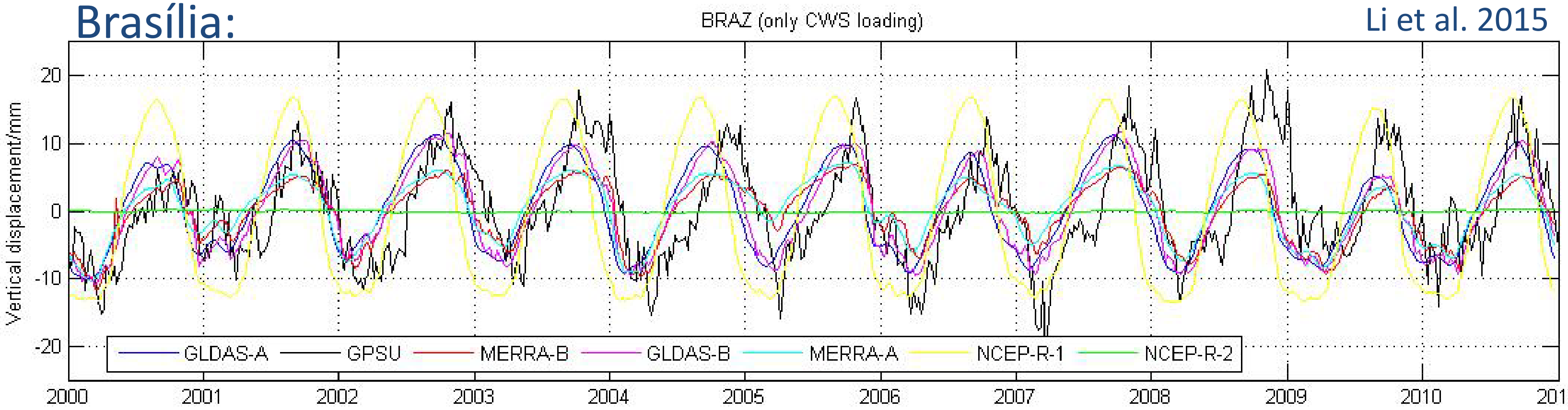
Li et al. 2015

WP5 Validation of NRT solutions

Problem 2: precision

Brasília:

Li et al. 2015



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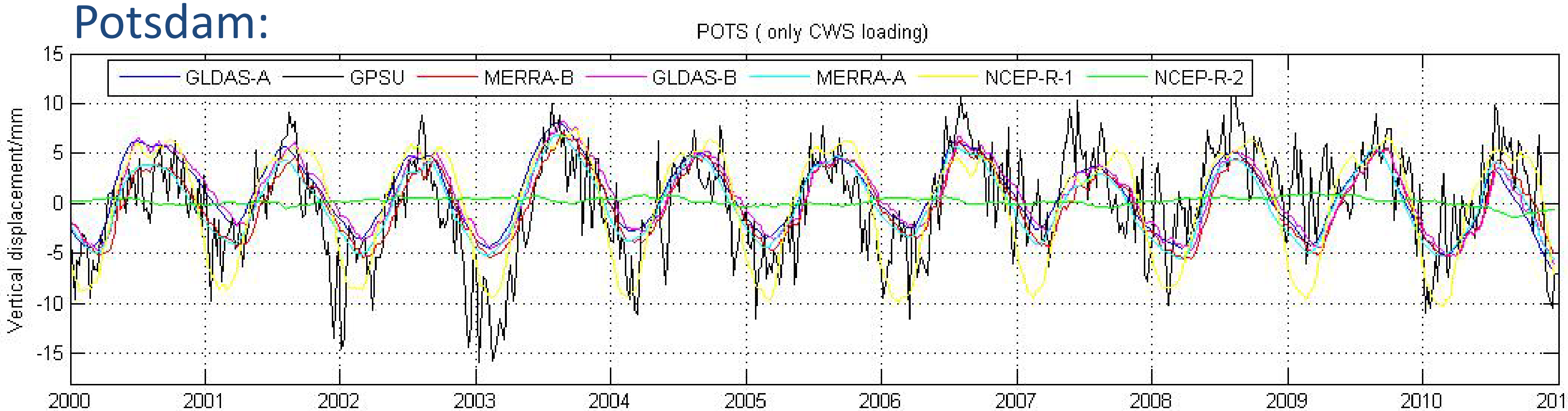
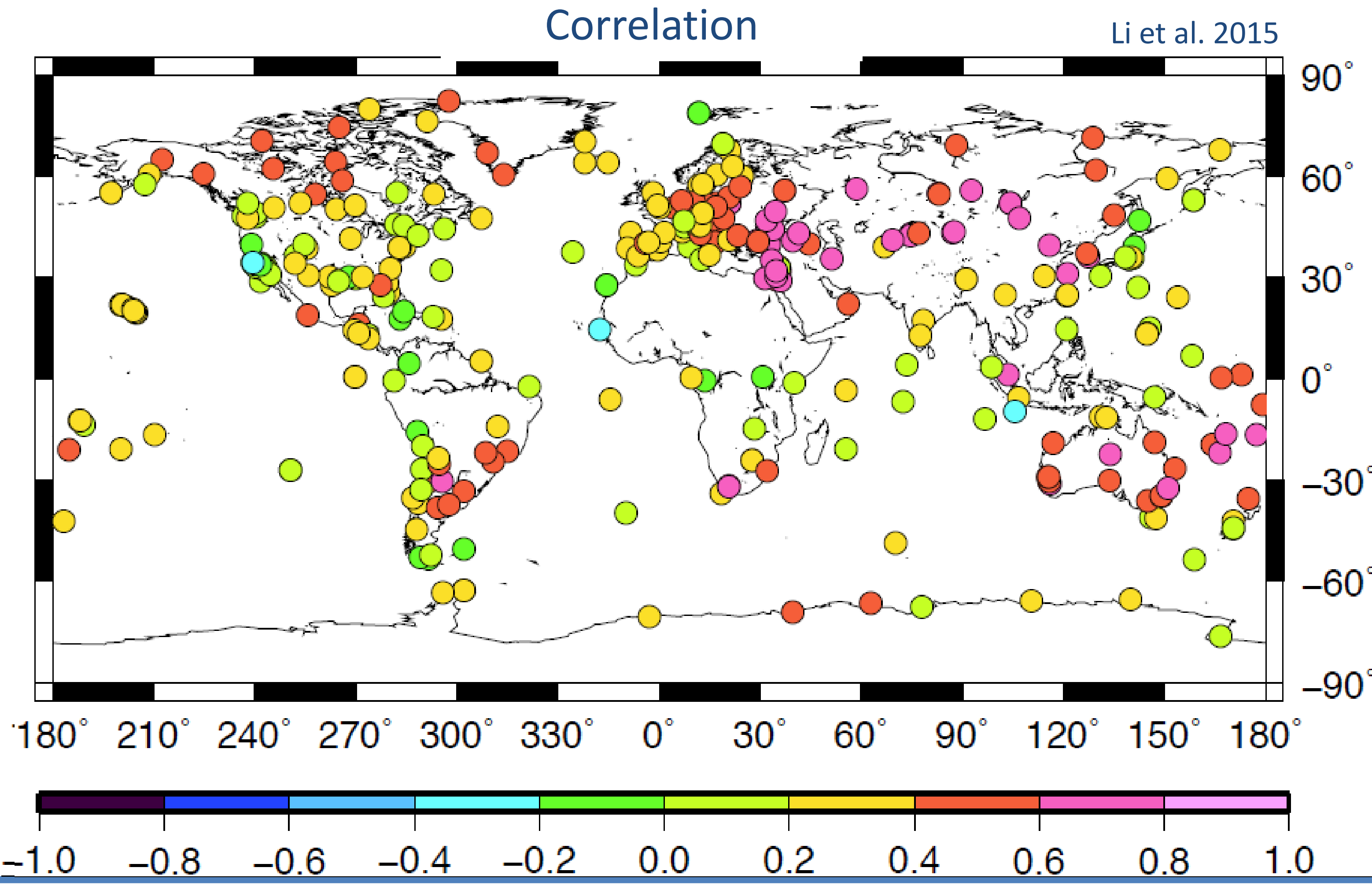


WP5 Validation of NRT solutions



WP5 NRT Gravity Field Products (GFZ)

Monitoring the Earth´s Gravity Field in NRT

- Daily mass variations of the atmosphere, ocean and continental hydrology are estimated in a Kalman filter approach
- Physically motivated constraints from external data are used to numerically stabilize the process
- Specific sensor characteristics (MWI range-rate low-low SST, GPS high-low SST) are taken into account
- Dedicated functional and stochastic model based on RBF has been developed

Functional & Stochastic Model

Grace observations
$$f(\rho, \dot{\rho}, \ddot{\rho}, |\delta \dot{\vec{r}}|) = \langle \nabla\phi(\vec{r}_A) - \nabla\phi(\vec{r}_B), \vec{e}_{\mathrm{LOS}} \rangle \qquad (1)$$

Reproducing kernels
$$f(P) = \iint_S \phi(Q)\ \langle \delta\nabla\,\mathrm{K}(P,Q), \vec{e}_{\mathrm{LOS}} \rangle\ \mathrm{d}S, \qquad (2)$$

Poisson's kernel
$$\mathrm{K}(P,Q) = \sum_{n=2}^{\infty} (2n+1) \left(\frac{R}{r_P}\right)^{n+1} P_n(\cos\psi), \qquad (3)$$
$$Q \in S, \quad P \in \Sigma$$

Adjustment
$$\left\| \sum_{i=1}^{M} f_i(P) - \sum_{j=1}^{N} \phi_j(Q) \langle \delta\nabla\,\mathrm{K}(P,Q), \vec{e}_{\mathrm{LOS}} \rangle \right\|_2 \longmapsto min. \qquad (4)$$

Adopted objective
$$\|vC^{-1}v\| + \|\phi D\phi\| \longmapsto min. \qquad (5)$$

Cov Regularization
$$\phi(Q) = (A^{\mathrm{T}}C^{-1}A + \alpha D)^{-1} A^{\mathrm{T}} C^{-1} f(P) \qquad (6)$$

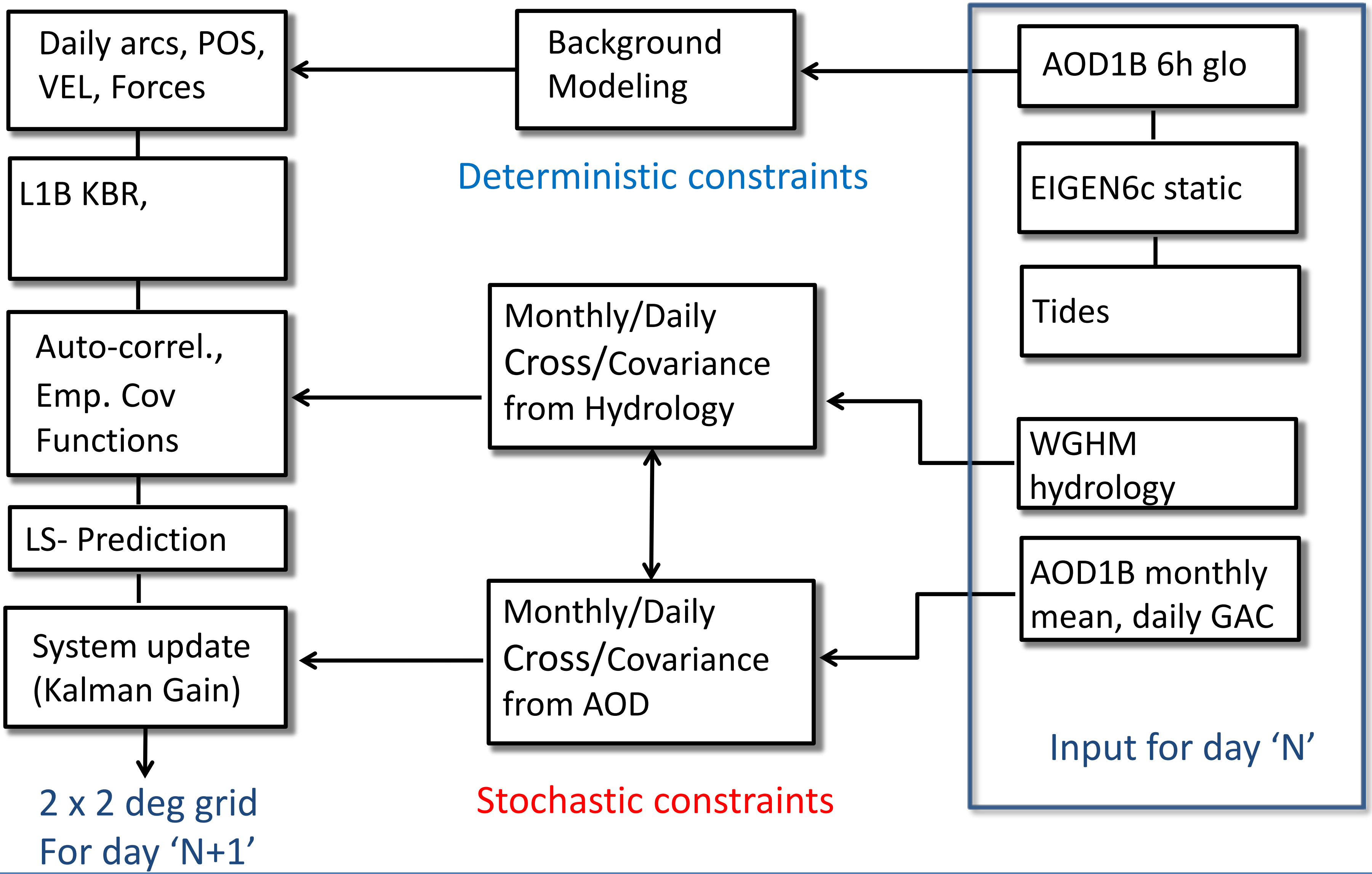
Kalman-Regularization
$$\phi(Q) = \text{Kalman- Filter} \qquad (7)$$

Basic Ideas of RBF Method

- Prediction step: (hydrologic) information is required for regions with strong variability.

  The stochastic information can be derived from available GRACE time-series (RL05), time-variable part of gravity field models (EIGEN-6Cx) and hydrology models (WGHM).
- Empirical (isotropic) covariance functions define the spatial and temporal correlation between neighboring grid points
- Kalman filter system evolves the a-priori values of the normal equation system
- For weekly/monthly inversion, regularization is obtained from the error covariance estimates from our Kalman process.
- Space/time stationary (ergodic) process characteristics have to be considered: not all regions are of same variability (e.g. climate zones down to basin scales), and signals show (residual) seasonality.

Processing Scheme Kalman Filter



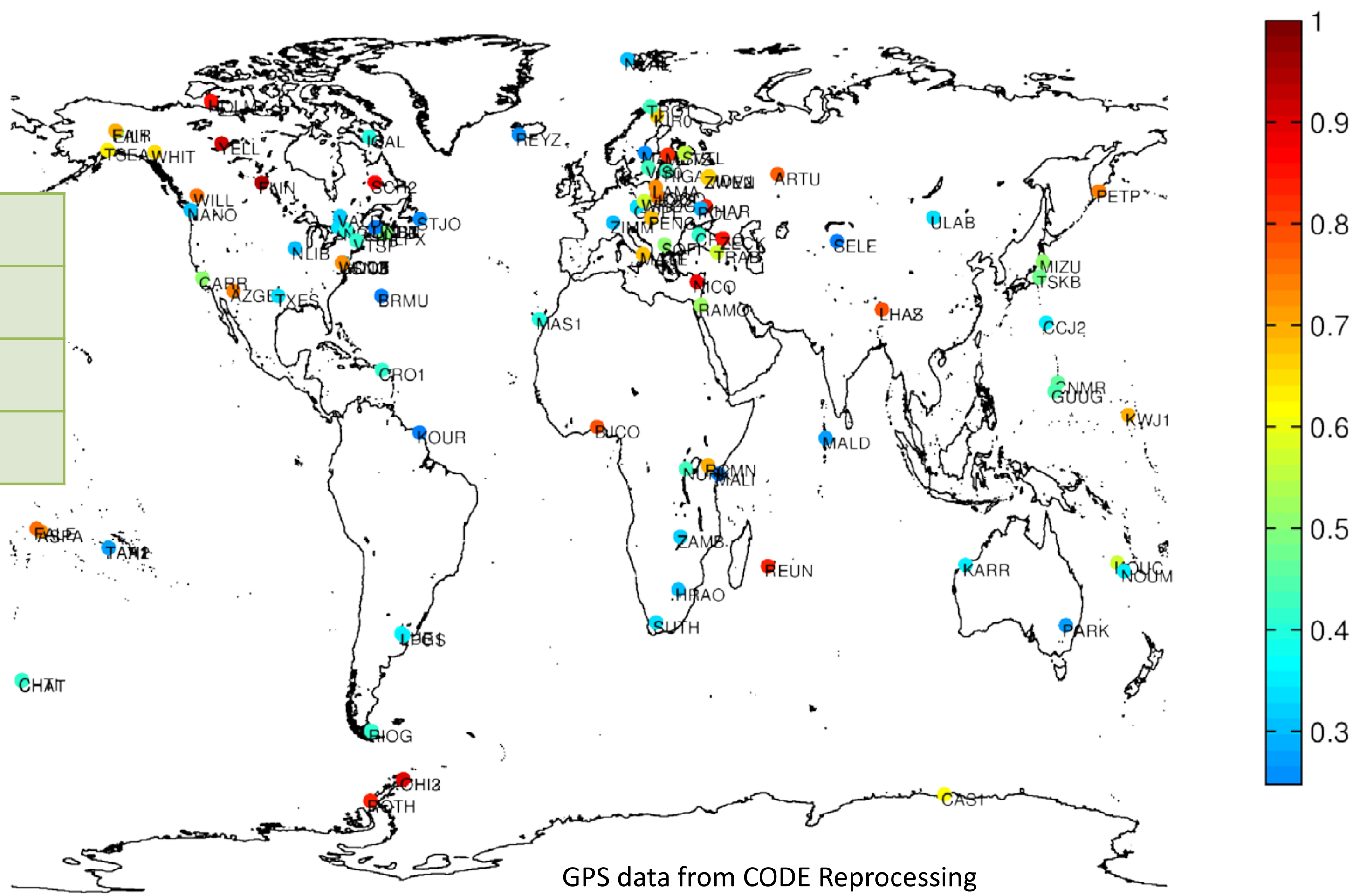
Known issues …

- Separation of signals (GAC residuals → aliasing)
- Ergodicity for the Prediction step, we thus need to remove trends and seasonal signal
  - Trends/seasonal are derived from GRACE solutions
- Biased solutions from regularization
  - accumulated solutions are regularized with the output of the Kalman filter process error covariance. KF delivers thus not only daily state vectors but also statistical moments.

- Infiltration of the dynamic orbit from time-variable background modeling
  - Using 'consolidated' GRACE derived time-variable result of previous month
  - Kinematic orbit from WP4 (independent, higher noise level)

Validation with GPS station network 2002-2012 (monthly)

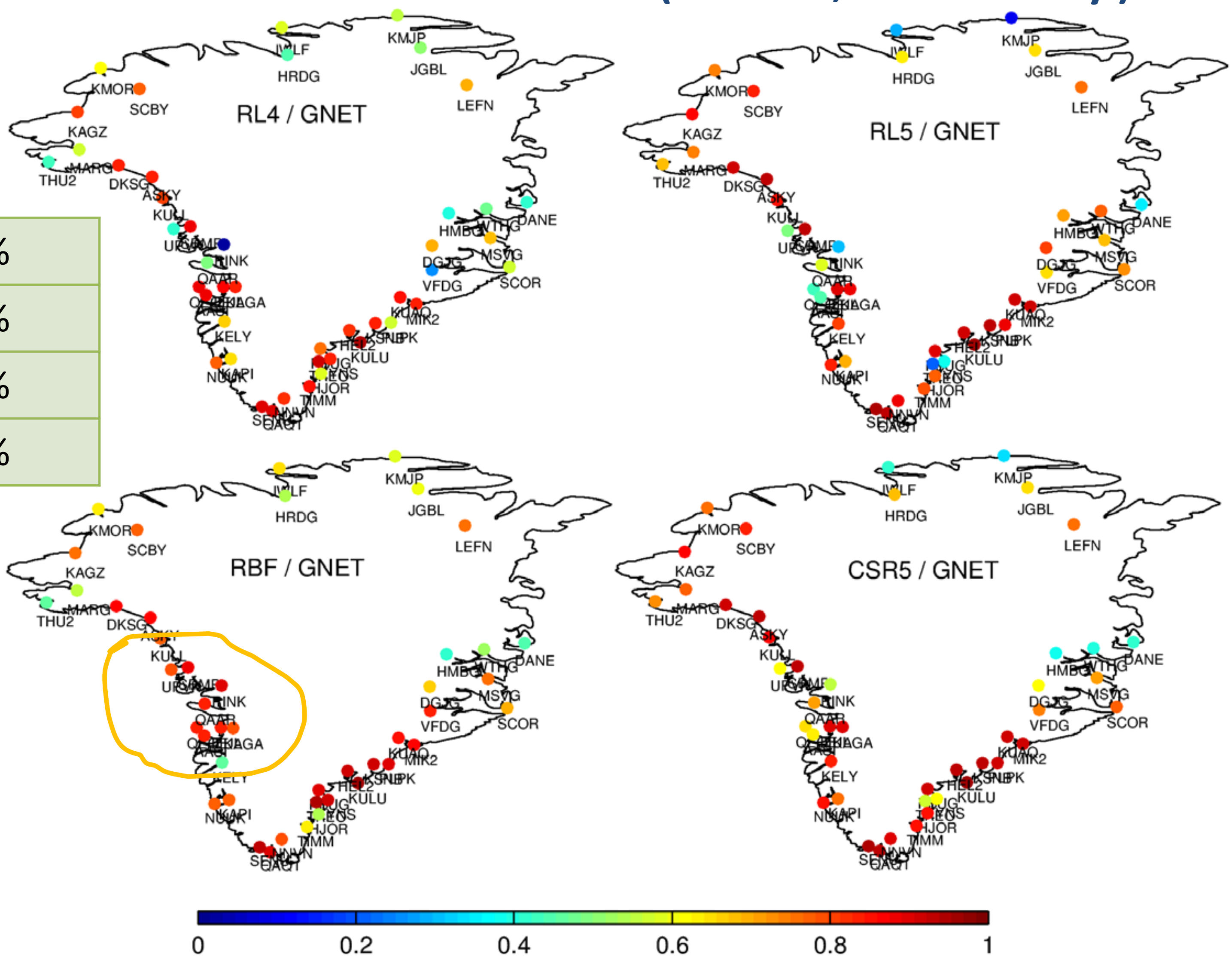
RL04	36.4 %
RL05	40.1%
RBF	39.4%
CSR05	40.5%



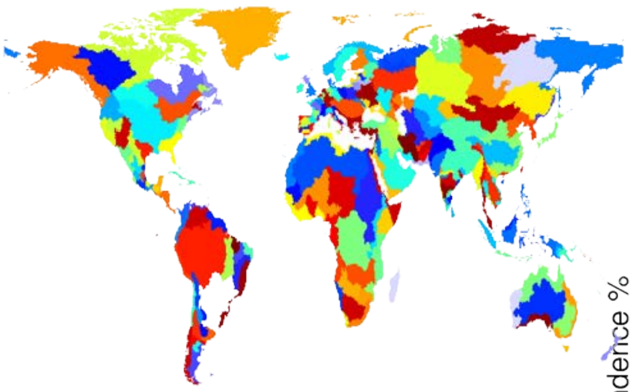
GPS data from CODE Reprocessing
(**Steigenberger, P.; Hugentobler, U.; Lutz, S.; Dach, R.**:
CODE contribution to the first IGS reprocessing campaign;
Technical Report 1/2011, IAPG/TUM, 2011)

Greenland GPS Network (GNET, monthly)

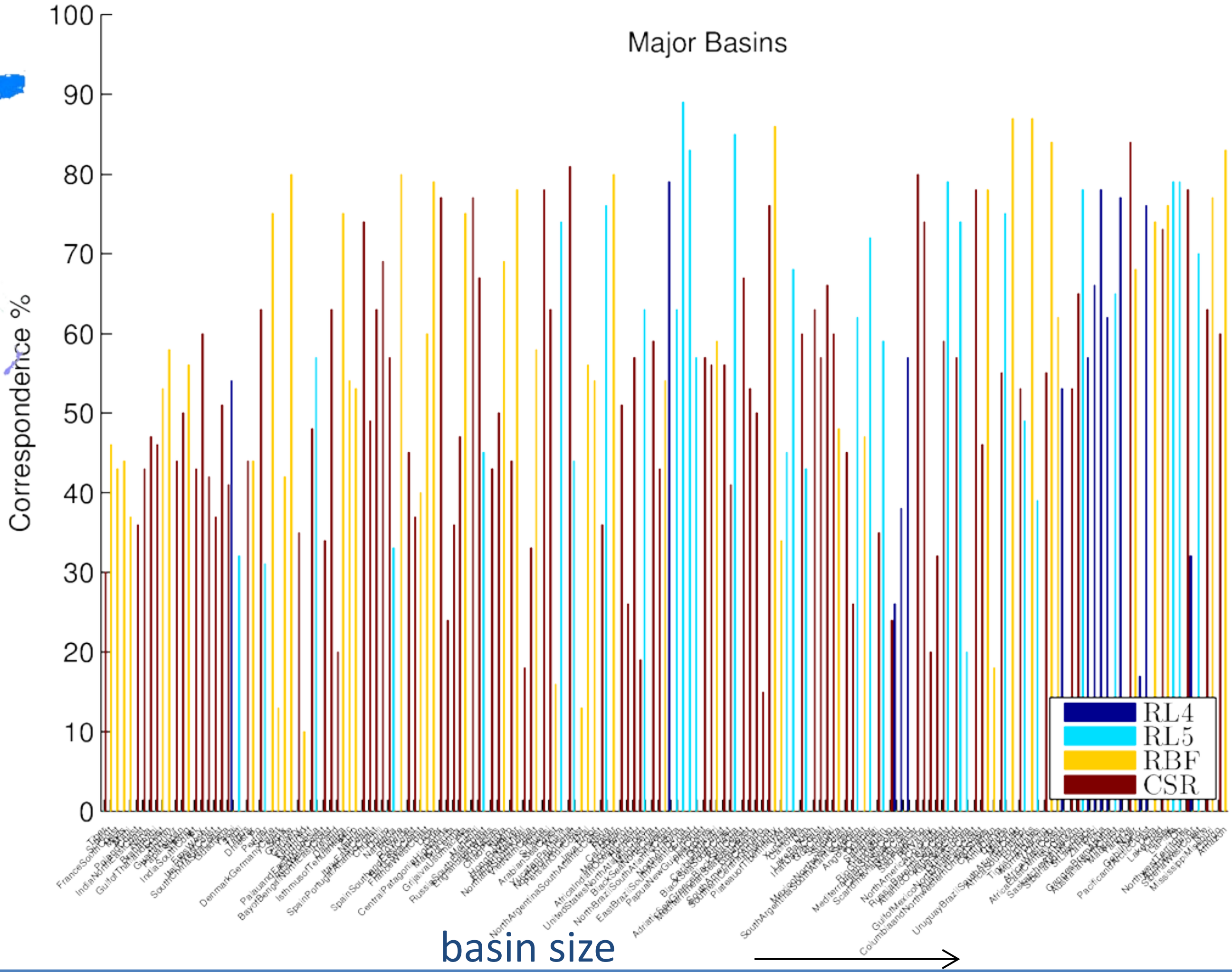
RL04	34.9%
RL05	36.7%
RBF	38.3%
CSR05	38.7%



Major hydrological basins (WGHM) 2002-2013 (monthly)

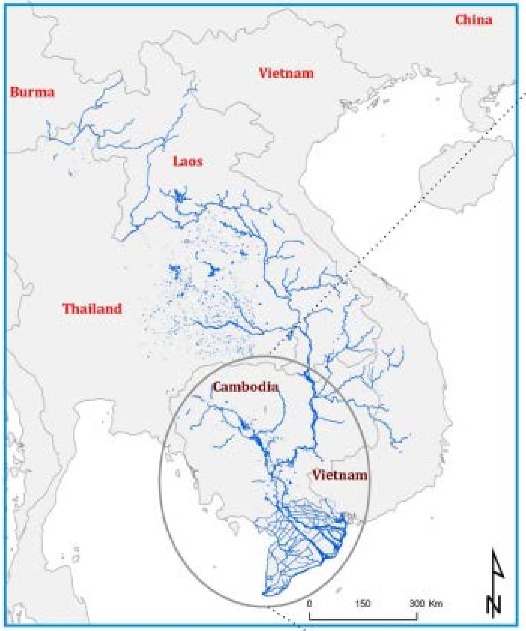


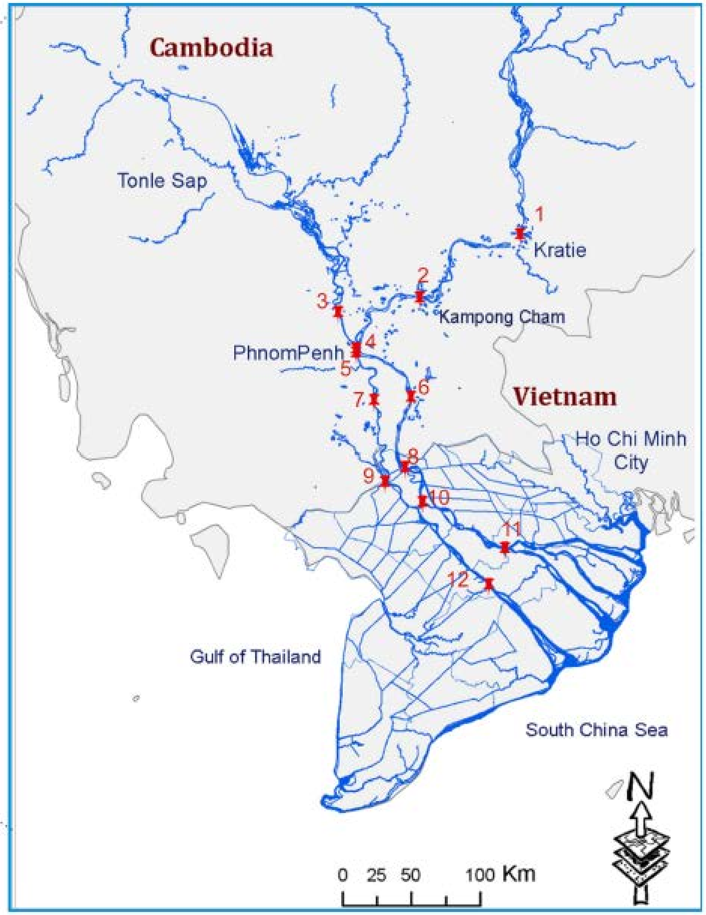
RL04	39.6%
RL05	49.3%
RBF	46.5%
CSR05	52.6%



Comparison: GRACE vs. “In situ Hydrology” (daily)

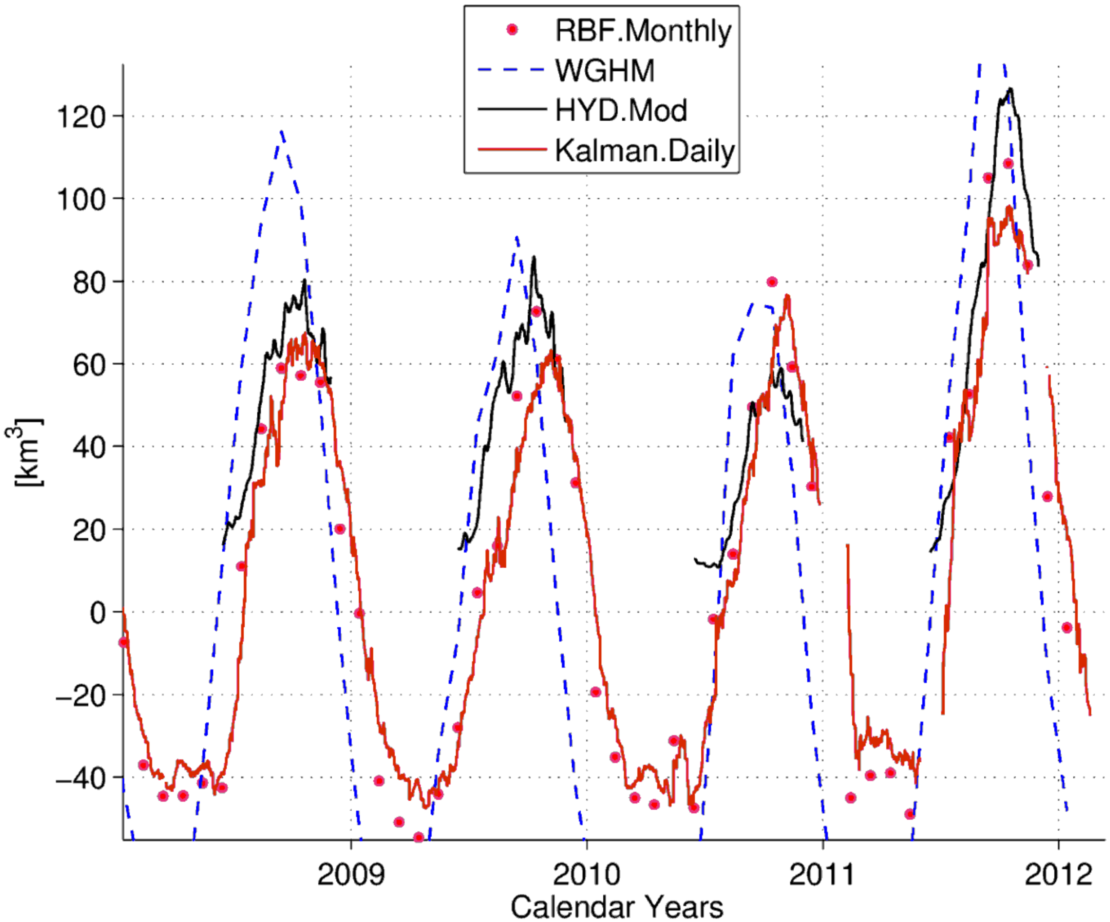
Lower Mekong





Comparing mass changes from GRACE with hydraulic simulations of the large scale annual inundation volume (red points: calibration).

Dung et al.“Multi-objective automatic calibration of hydrodynamic models utilizing inundation maps and gauge data” (2011), *Hydrology and Earth System Sciences.*



Lower Mekong

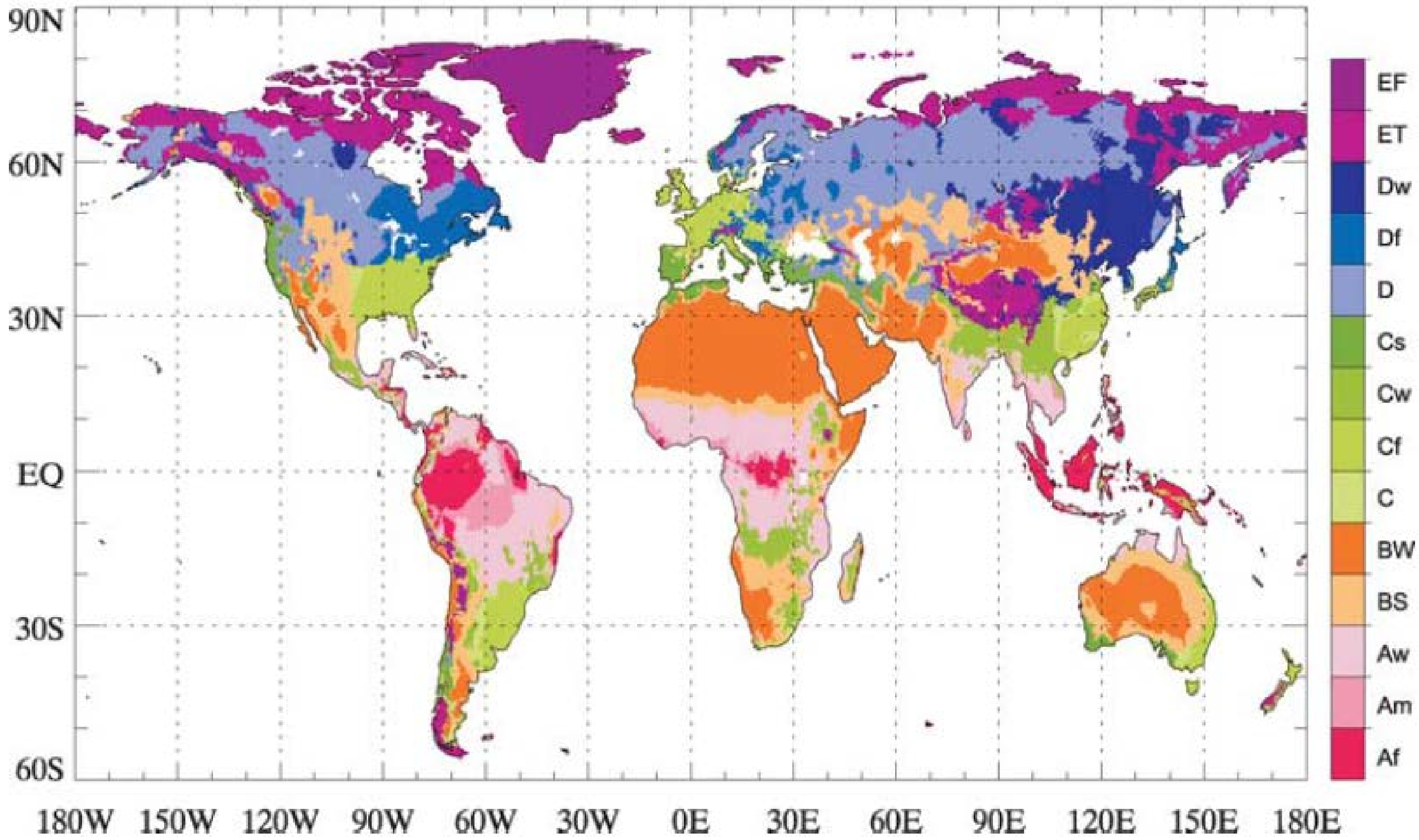
Rainfall periods 2008-2011

- Monthly and Daily solutions compared to specific hydraulic modeling of inundation Volumes in the lower Mekong
- The Kalman solutions follow the inundations from the hydraulic modeling better than monthly means and show the potential for hydrological monitoring

Why not modeling in spherical harmonics?

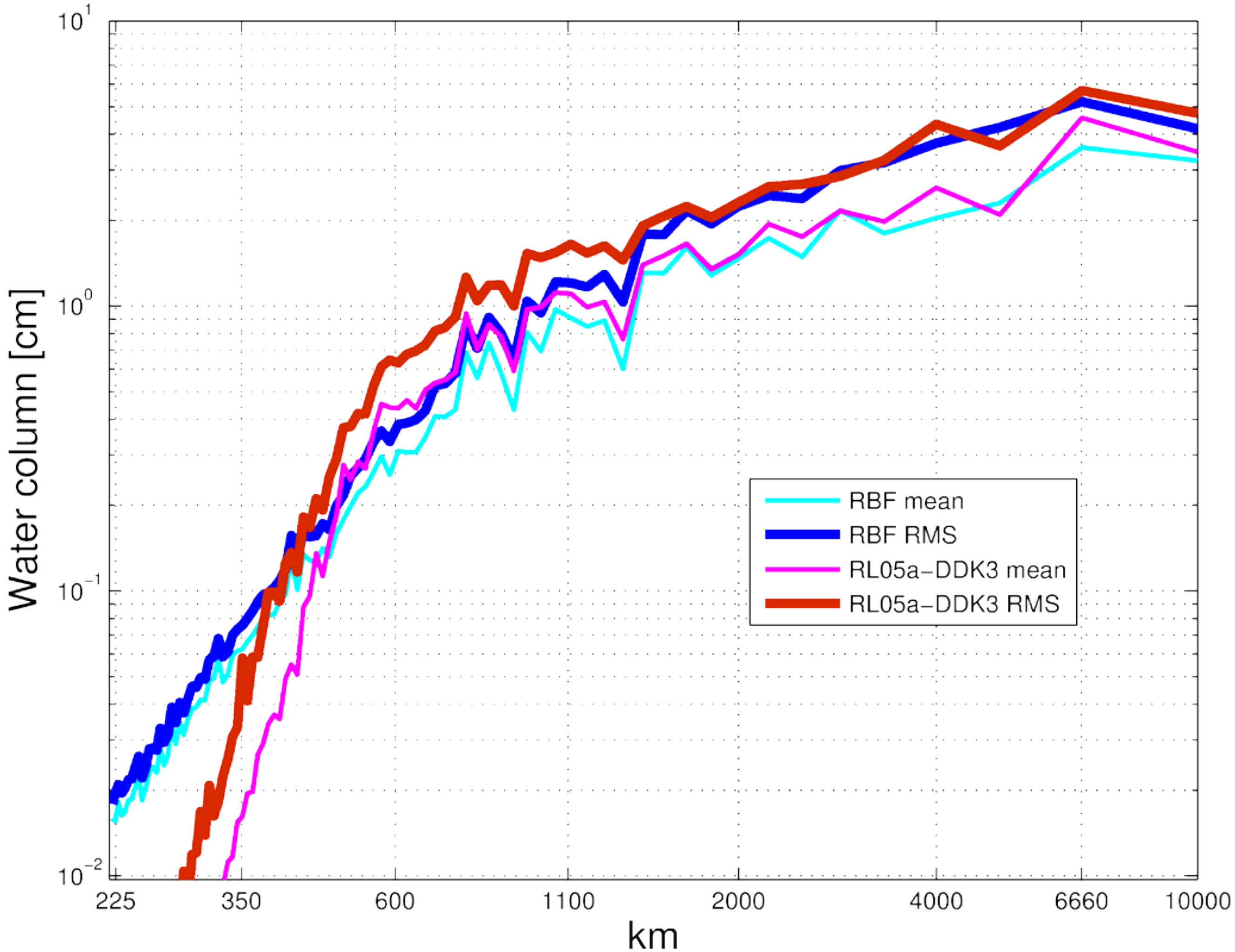
- ‘Tailored’ regional solutions feasible with
  - non-isotropic local COV functions using ‘ECO zones’
- Enhancements of regional solutions by
  - additional dense observation data (GPS station networks, absolute gravimetry, hydrologic gauges)
- No post filtering (user friendly)

‘ECO’ zones

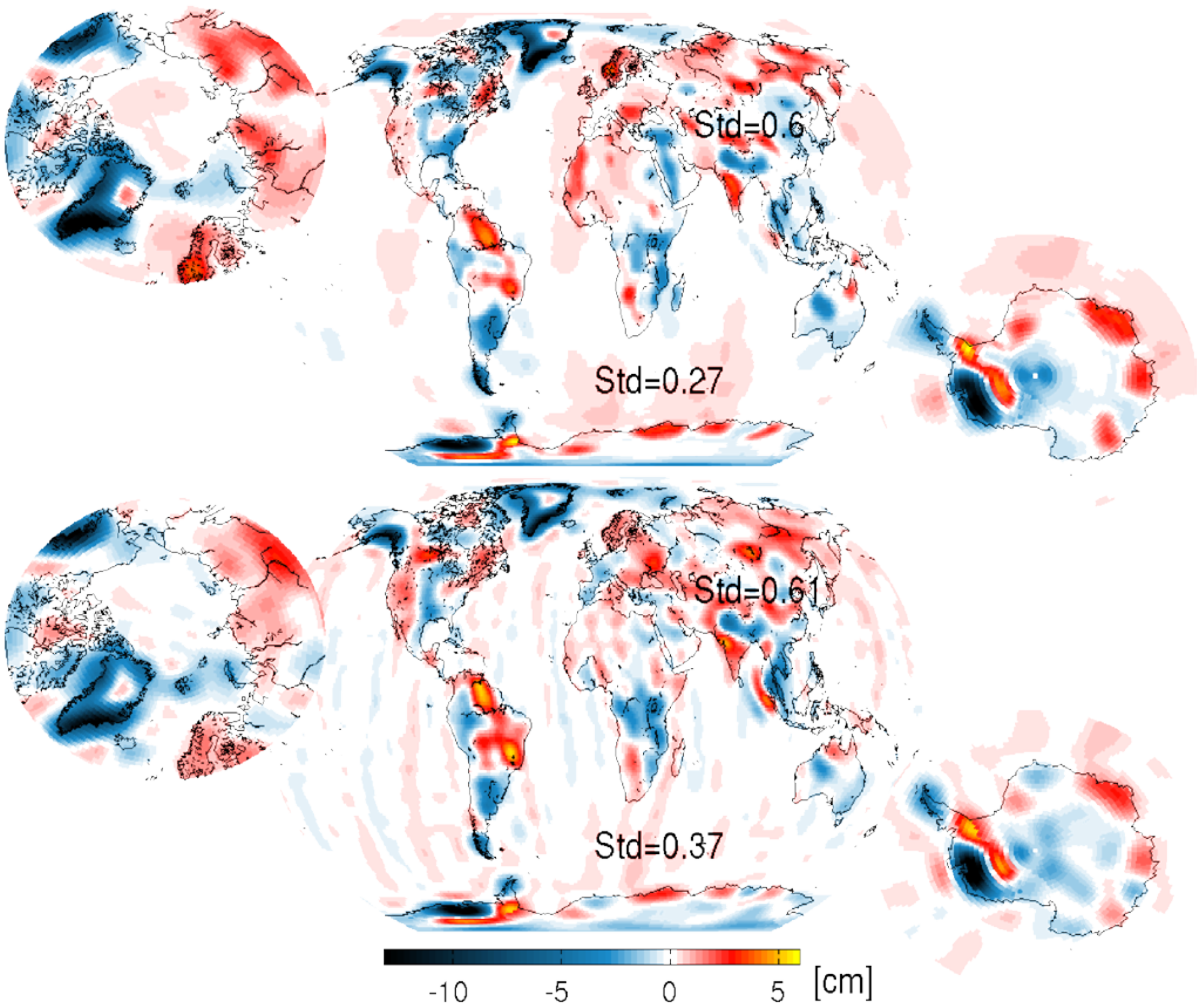


Climate Zones after Koeppen

Spectral densities (5yr)



Trend estimates (5yrs)



RBF

GFZ RL05a (DDK3)

Summary

- Validation against modeled hydrology, GPS uplift rates and in-situ inundation volumes confirms the RBF strategy
- Regional modeling can probably increase spatial resolution
- Kalman filter / regularization helps to reduce artefacts and noise level
- Full processing chain in a basic version soon available, optimization throughout the project

WP5 NRT Gravity Field Products (TUG)

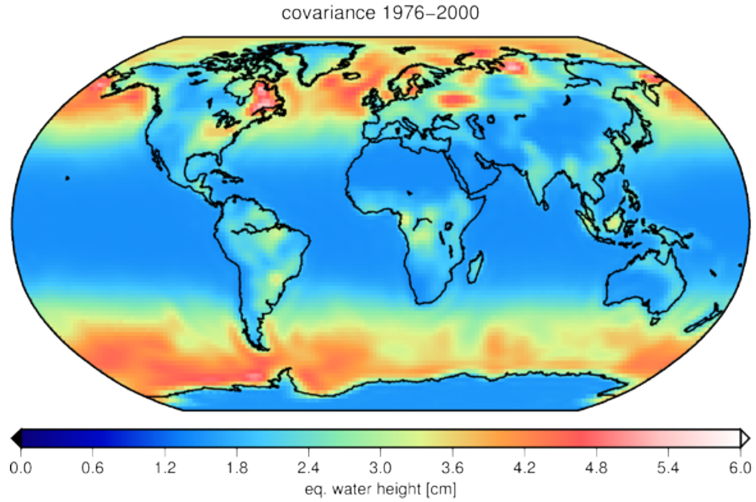
WP5 NRT Gravity Field Products (TUG Kalman Solutions)

- Idea: Gravity field does not change arbitrarily
  - prediction from previous day (Collocation)

$$\mathbf{x}_{i+1} = \mathbf{\Sigma}_{i+1,i}\mathbf{\Sigma}_{i,i}^{-1}\ \mathbf{x}_i$$

- Auto- and cross covariance estimated from geophysical models

- Combination with daily GRACE normals using a Kalman smoother



WP5 NRT Gravity Field Products (TUG Kalman Solutions)

- Gravity field represented as set of spherical harmonic coefficients from n=2 to n=40

- Geophysical models used to derive temporal correlations:
  - WGHM
  - ECMWF
  - OMCT

- Only stochastic behavior of models exploited
  - no bias towards model values

WP5 NRT Gravity Field Products (TUG Kalman Solutions)

- Kalman filter approach currently used in post processing
  - front-to-back filtering not applicable for NRT solutions

- Latest release: ITSG-Grace2014
  - daily solutions processed from 2003-02 to 2014-06
  - annual and secular variations as fallback (for days without data)

- Time series available at ICGEM or **itsg.tugraz.at/research/ITSG-Grace2014**