EGSIEM

Title: WP3 Integration of complimentary data

Presenter: Matthias Weigelt

Affiliation: UL

EGSIEM Kick Off Meeting
University of Bern
January 13. – 14. 2015

Horizon2020

Objective

Pre-processing of all necessary supplementary data

- Reference frame and SLR (also NRT) – Tasks 3.1-3.4

- Validation with GNSS site displacements and ocean bottom pressure data – Tasks 3.5-3.6

- Lake and river levels from Hydroweb data – Task 3.7
- GIA for separating hydrological trends – Task 3.8
- Historical flood situations – Task 3.9

Task 3.1-3.4
Reference Frame

Presenter: Rolf Dach / Krzysztof Sosnica
Affiliation: UBERN

What is CODE?

- CODE: Center for Orbit Determination in Europe
- Joint venture between:
  - Astronomical Institute, University of Bern
  - Federal Office of Topography swisstopo
  - Federal Agency for Cartography and Geodesy
  - Institut für Astronomische und Physikalische Geodäsie; Technische Univeristät München

CODE-activities

- IGS analysis center since 21 June 1992
- Use of Bernese GNSS Software package
- Combined GPS/GLONASS processing
- IGS processing lines:
  - Final: latency of 2 weeks; as accurate as possible
  - Rapid: same quality; but available after 18 hours

The regular rapid product meets the requirements of the NRT service of the EGISEM project.

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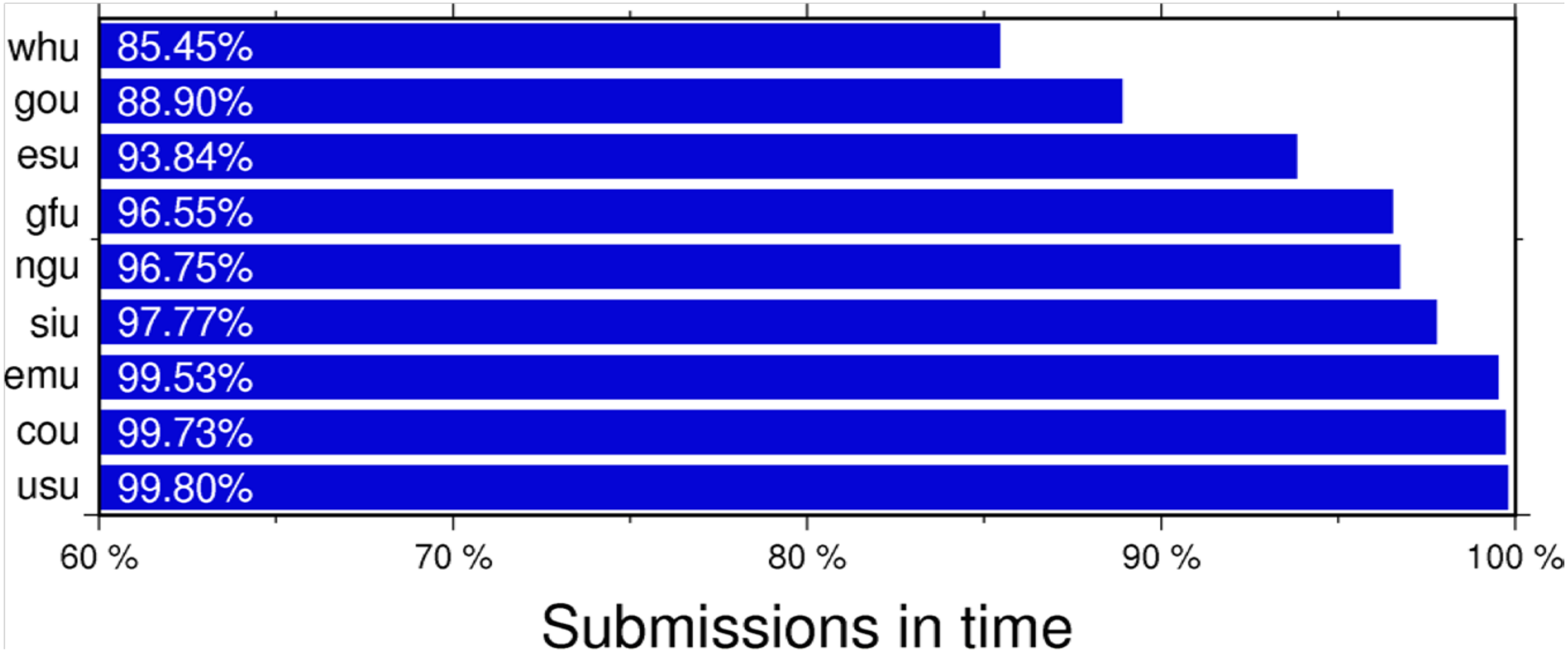
CODE processing for the IGS

- Some numbers on the CODE processing:

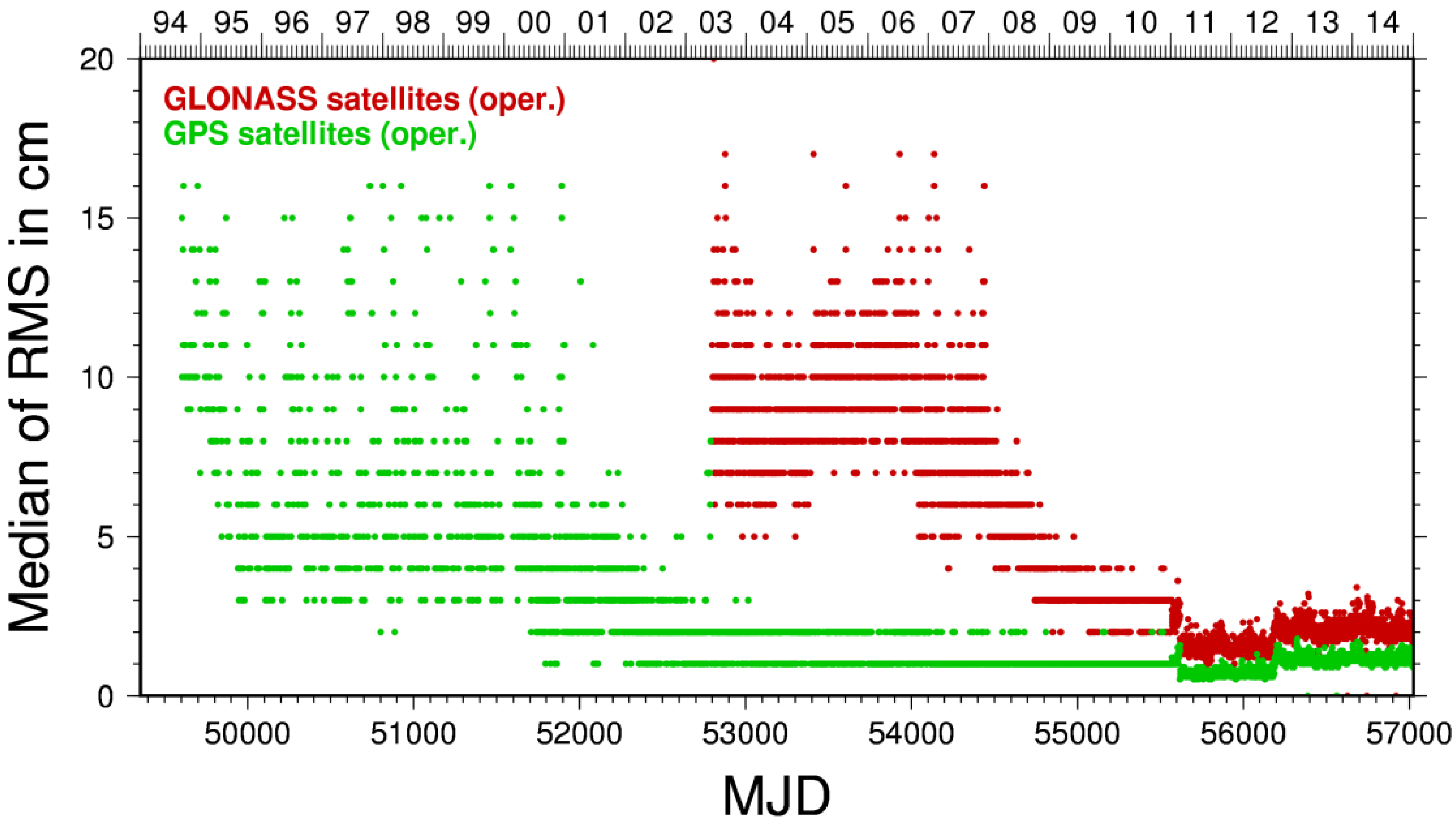
	Ultra-rapid	Rapid	Final
Number of stations	90	120	250
Number of satellites	56 (32GPS+24GLONASS)		
Number of observations	740,000	930,000	1,600,000
Number of parameters	14,000	16,500	25,000
Computing time	<1 hour	2 hours	5 hours
Cumulated CPU-time	6 hours	10 hours	35 hours

Reliability of submissions to the IGS ultra-rapid in 2014

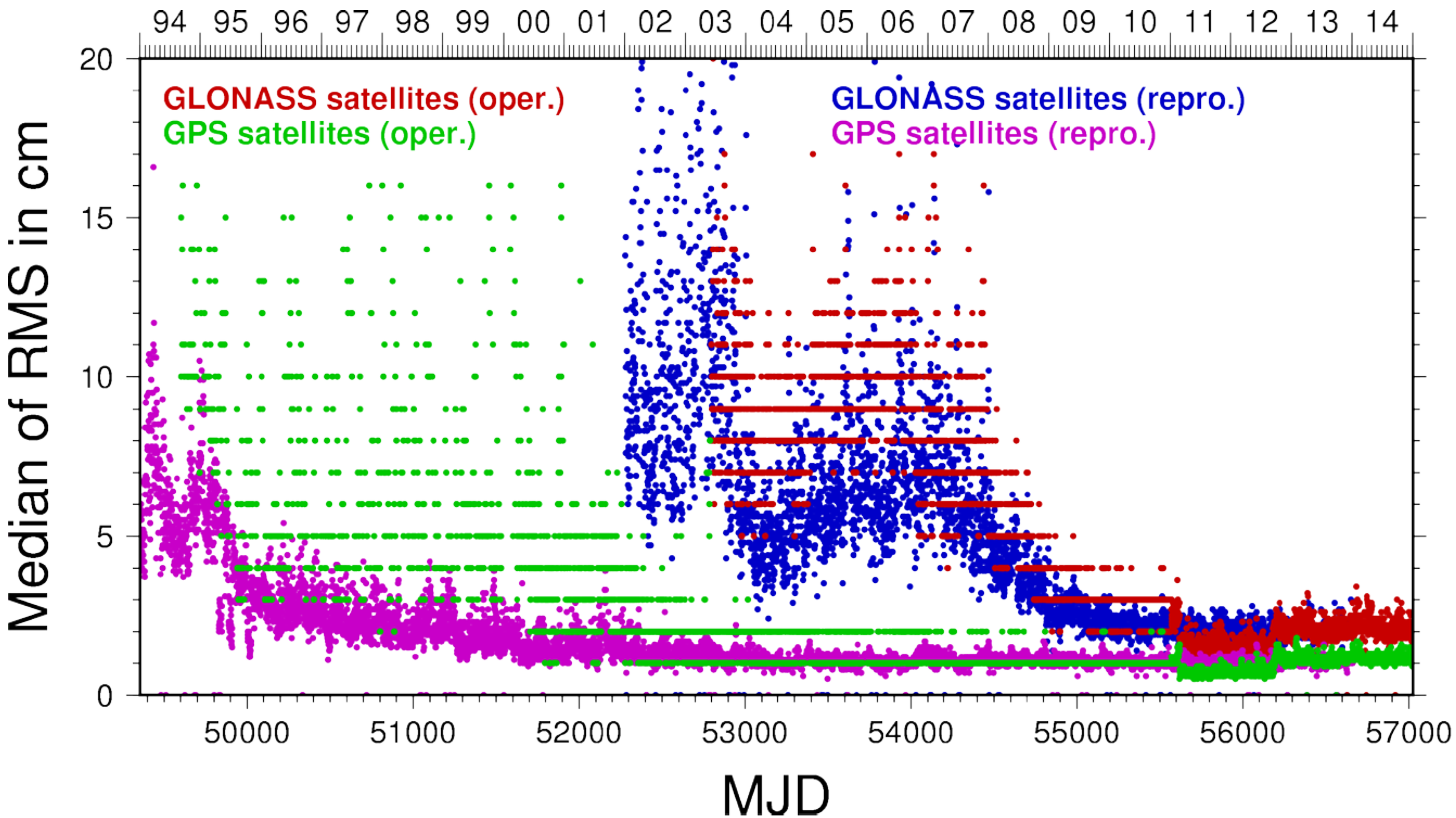
	COD	EMR	ESA	GFZ	GOP	NGS	SIO	USN	WUH
In time	1474	1471	1387	1427	1314	1430	1445	1475	1263
Late	4	7	91	51	164	48	33	3	215



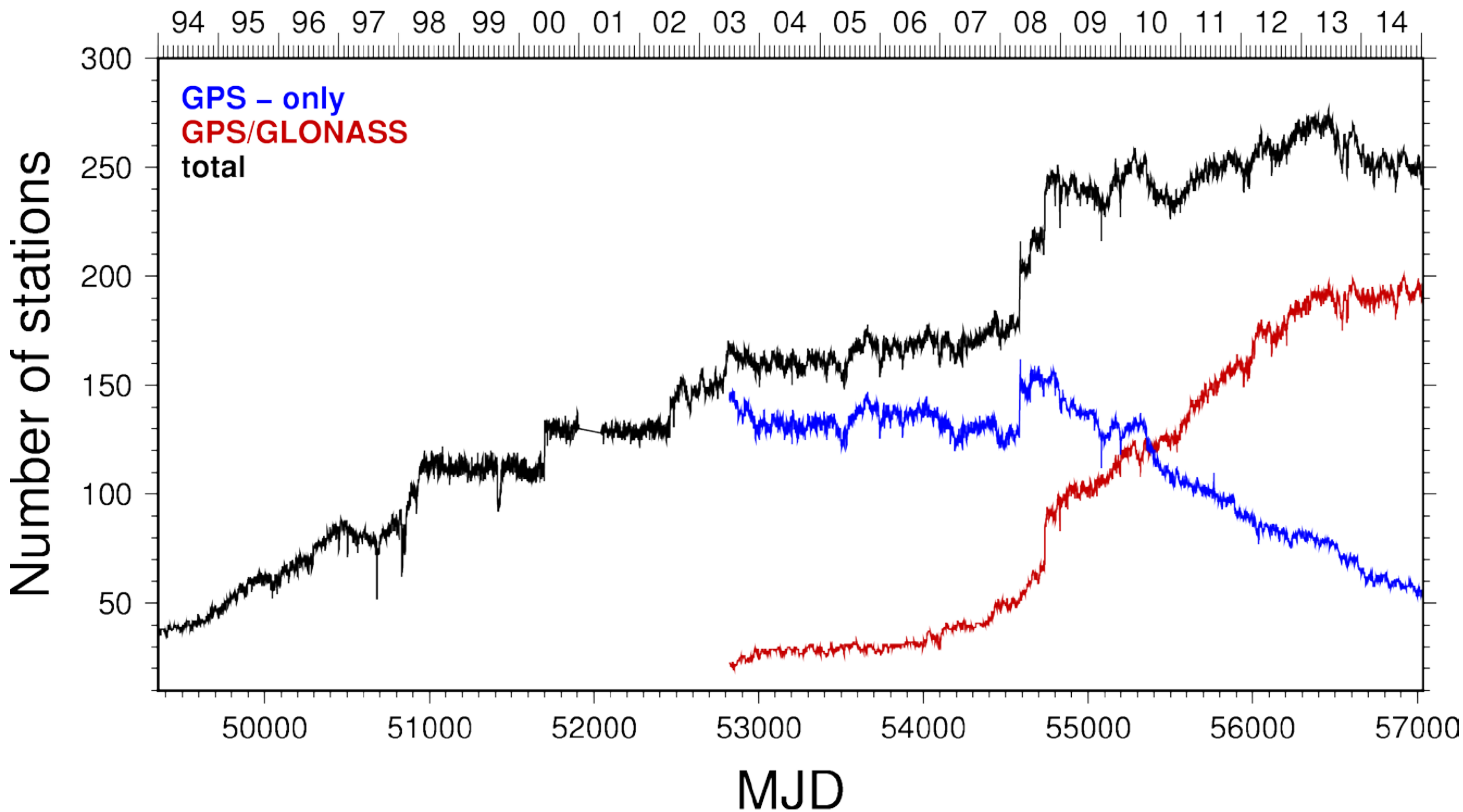
GNSS Orbit performance



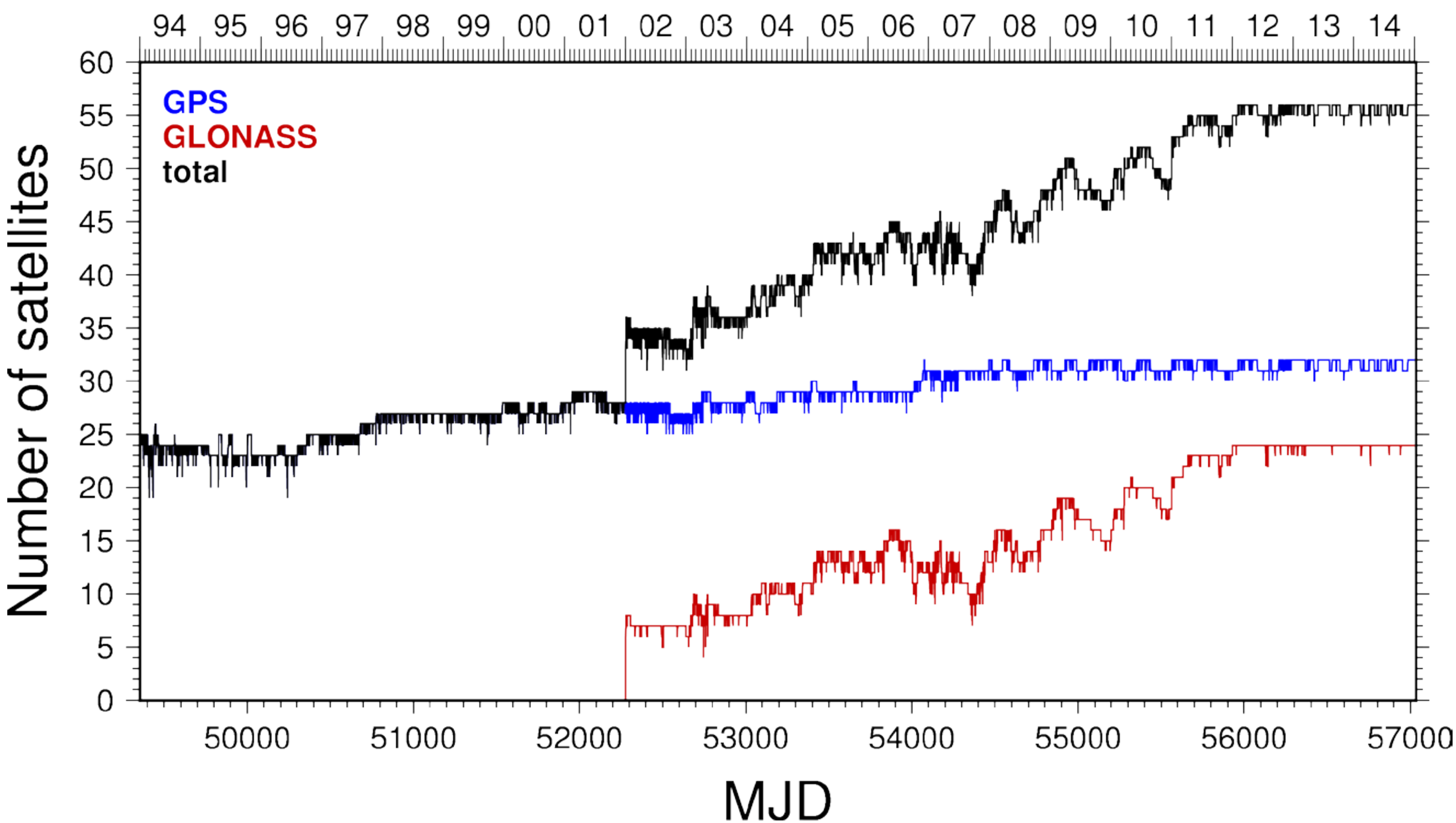
GNSS Orbit performance



Number of stations in operational CODE processing (final)



Number of satellites in CODE solution (reprocessing series 2)



IGS-repro2 from CODE

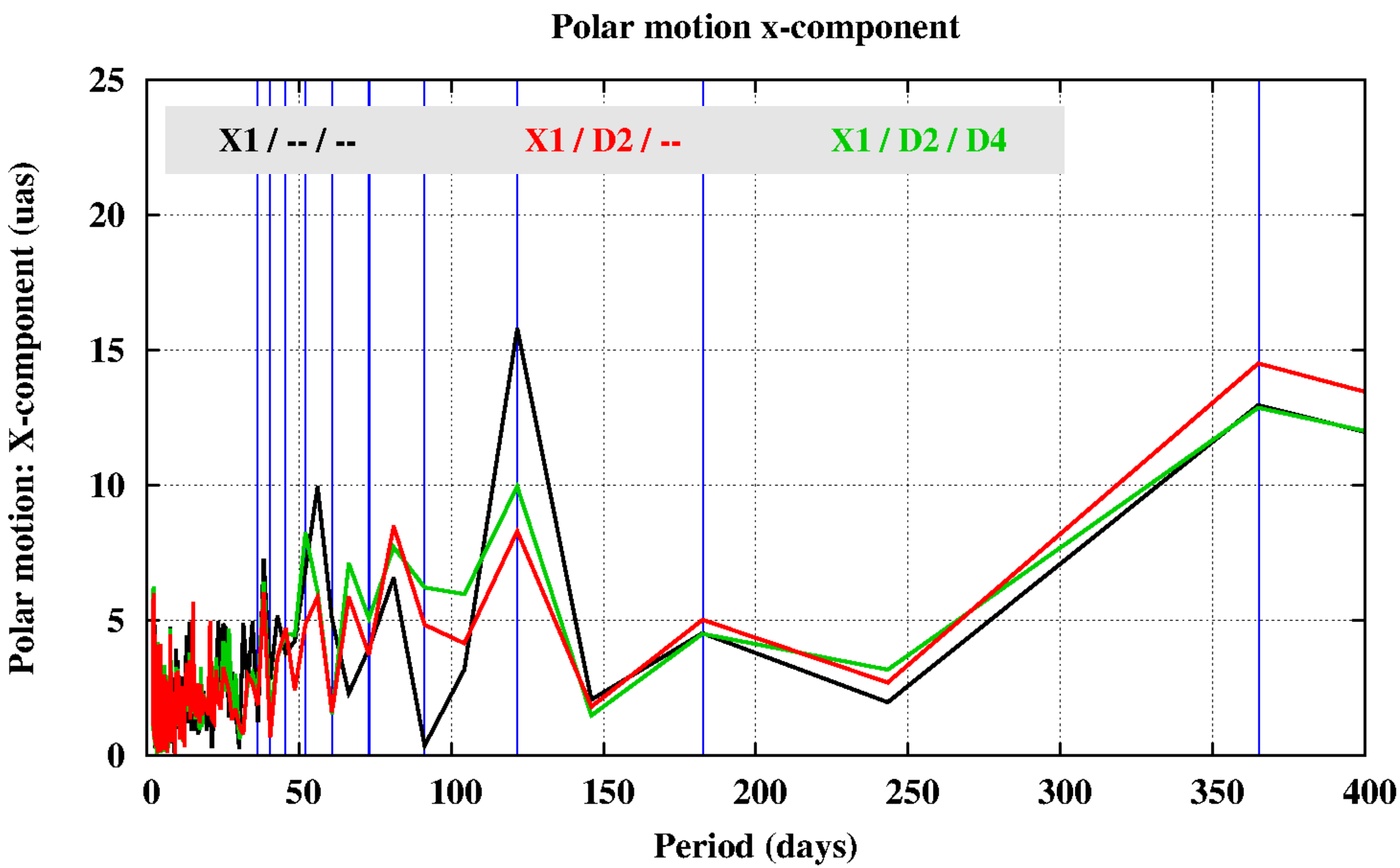
Most recent reprocessing effort at CODE:

- GPS orbits since 1994
- GLONASS orbits since 2002
- Computed during 2013/2014 based on the CODE processing strategy from Summer 2013
- Computed at TU München (according to the work distribution at CODE)

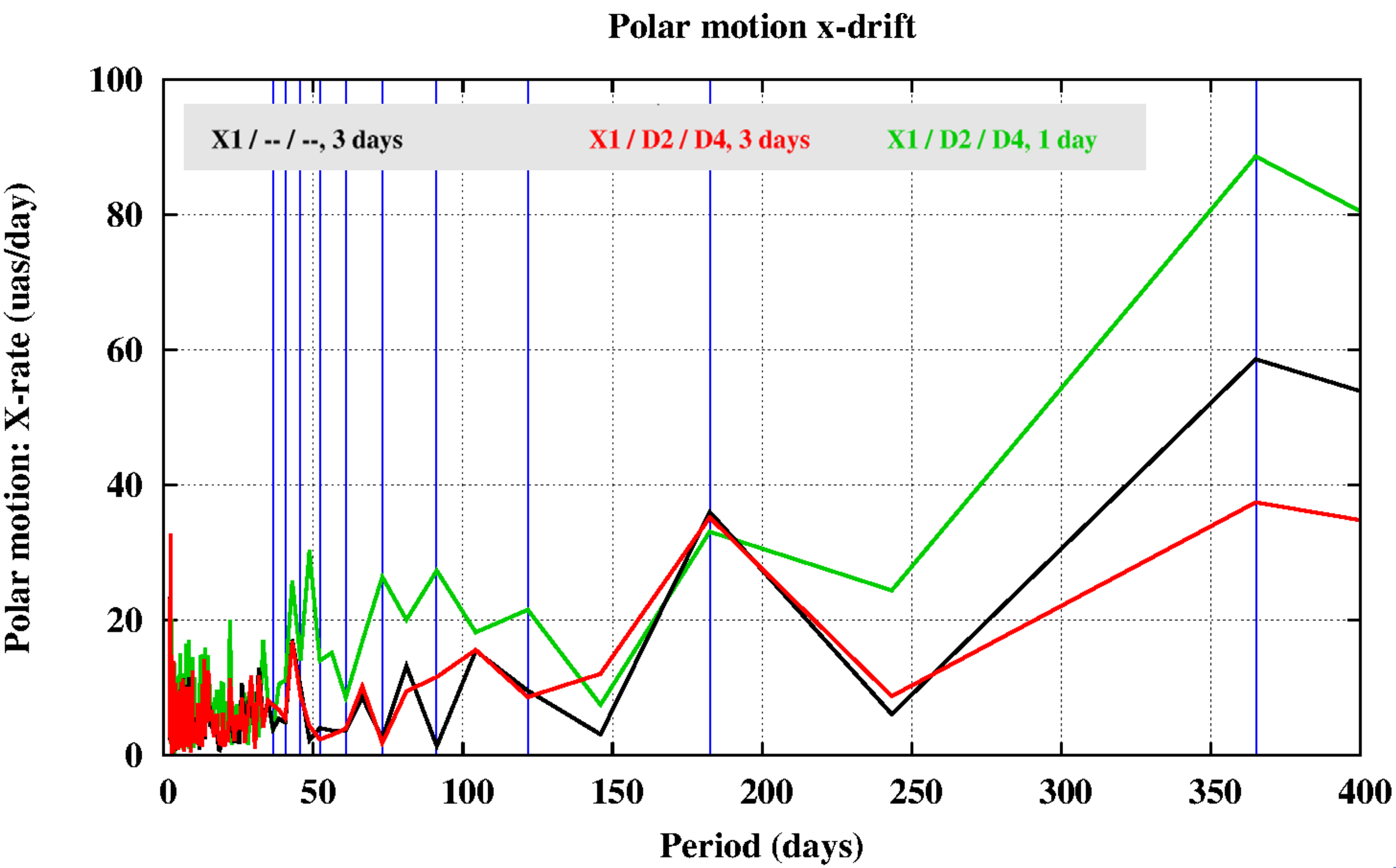
Extended GNSS orbit model

- During 2014 we have updated the empirical solar radiation pressure orbit model for GNSS satellites:
- $$D(u) = D_o + D_{2c}\cos 2u + D_{2s}\sin 2u + D_{4c}\cos 4u + D_{4s}\sin 4u$$
  $$Y(u) = Y_o$$
  $$B(u) = B_o + B_{1c}\cos u + B_{1s}\sin u$$
- See D. Arnold et al., 2015 for more details

Influence on ERPs



Influence on ERPs



GPS or GPS+GLONASS?

- All LEOs are flying GPS-only receivers so far.

- In WP 3.2 SLR reprocessing
  For GNSS-SLR space ties GLONASS may be relevant: The two GPS satellites equipped with SLR reflectors are meanwhile out of service; but a few SLR stations are tracking the full GLONASS constellation.

GNSS satellite clock estimation

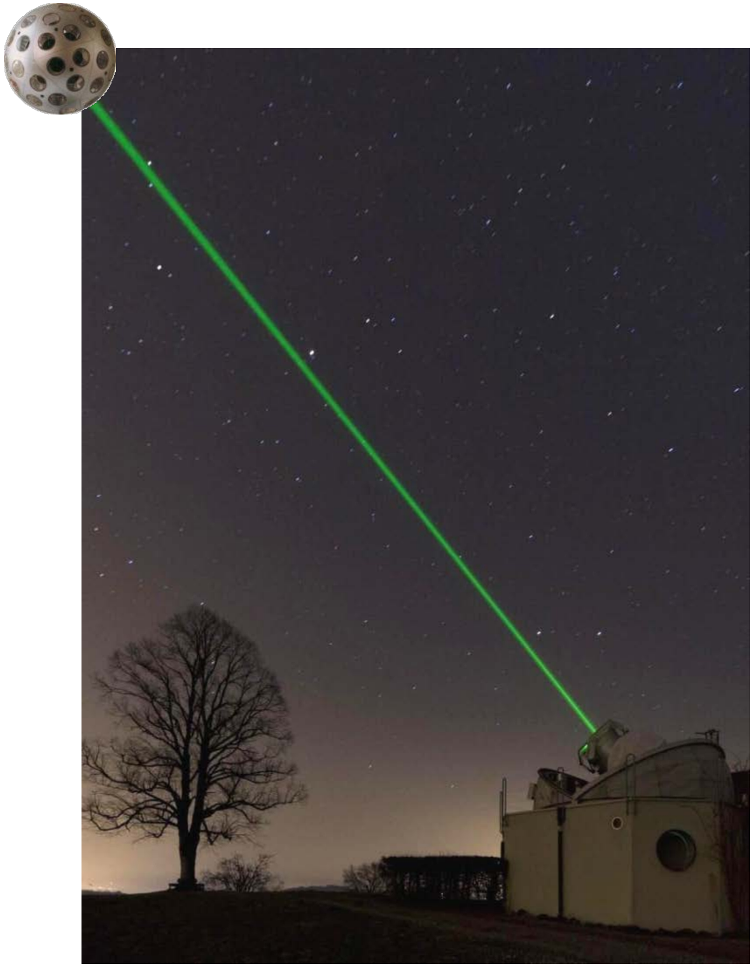
- GNSS-geometry is derived on double-difference level what corresponds to a GNSS solution with pre-eliminated clock parameters.
- Strong back-substitution step with a 300-sec. sampling
- Phase-based interpolation to 30-sec. based on the regular IGS observation files
- Further densification to 5-sec. based on IGS real-time network with a 1Hz data sampling (unclear when this gives satisfied completeness)

LEO trajectories

- Because all products have been computed fully consistent with a well-defined setup, the LEO trajectories can be computed following the PPP approach.
- LEO trajectories will be fully consistent to the reference frame realized with the GNSS/SLR ground station network.
- Gravitiy field components obtained from SLR are expected to be consistent with thoses from LEOs.

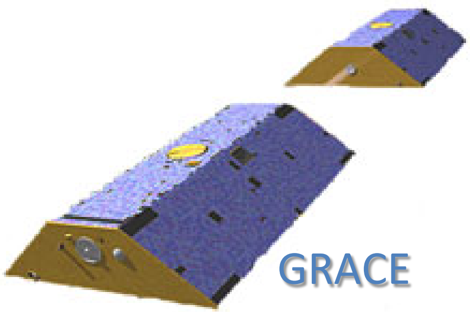
Satellite Laser Ranging (SLR)

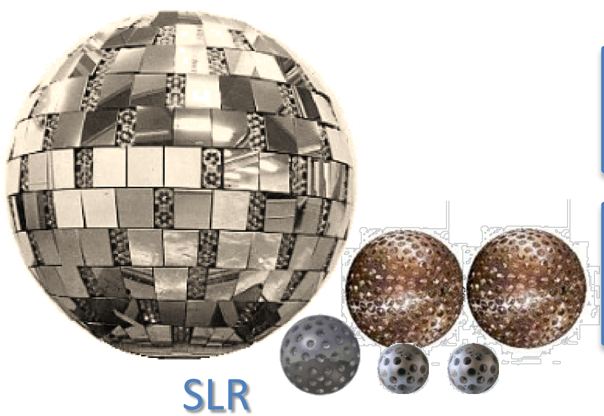
- SLR provides very accurate distance measurements (at a few mm-level) between ground stations and satellites.
- SLR geodetic satellites have a minimized area-to-mass ratio. They orbit the Earth at higher altitudes that the satellite gravity missions (e.g., GRACE, GOCE).
- Up to now, SLR observations were mostly used for deriving low-degree gravity field coefficients (degree 2) or zonal harmonics.
- Tesseral and sectorial harmonics up to degree 10 of monthly gravity field models can also be very well derived from SLR observations using a combination of long and short arcs.



SLR station in Zimmerwald, Switzerland

SLR gravity field solutions in Bernese GNSS Software

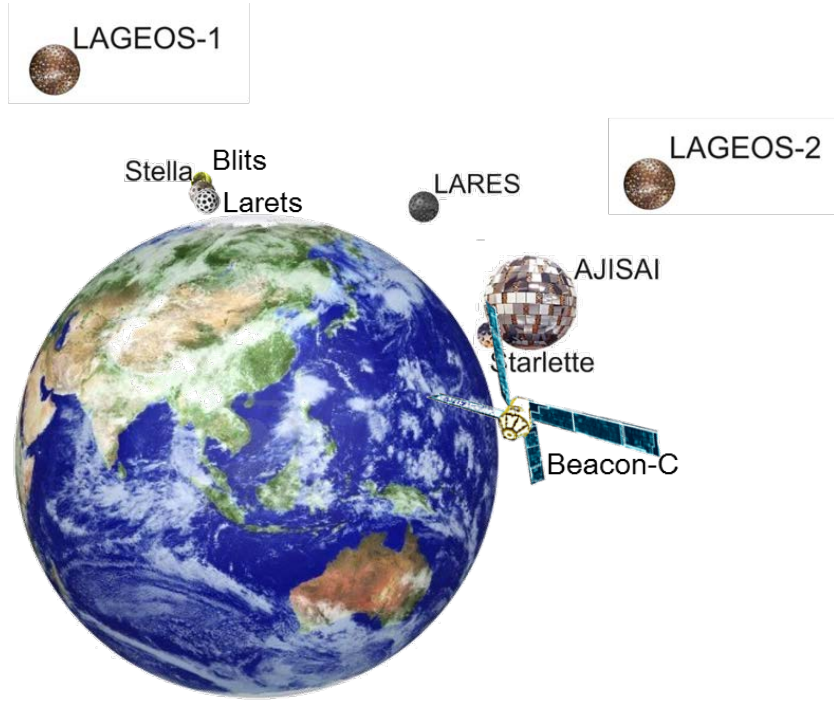




GRACE	SLR
Kinematic orbit solutions + K-band range and range rates	Dynamic approach
Microwave observations	Laser observations
Differential technique using (pseudo)ranges between satellites	Undifferentiated (direct) ranges between ground stations and satellites
~1M observations per month	~40k observations per month
High-rate observations	Normal points every 30 s (Starlette, Stella, AJISAI, LARES, Larets, BLITS) or every 120 s (LAGEOS)
Continuous observations	Noncontinuous observations limited by the station-satellite visibility
Homogeneous quality of observations	Quality of observations dependent on SLR stations (different frequencies and laser systems: 10Hz/kHz used)
Homogeneous distribution of observations	Most of tracking stations in the northern hemisphere
No weather dependency	Weather dependency on observations, + the Blue-Sky effect
Low and high-degree coefficients can be resolved	Typically only low-degree coefficients can be resolved
Reasonably small correlations between estimated parameters	Strong correlations between some harmonics resulting in the lumped coefficients
No direct link to reference frame	Directly connected to the terrestrial reference frame
Very low altitude of satellites ~380 km	Different altitudes, typically above 800 km
The same inclination for both GRACE satellites	Different inclinations
Strong S_2 aliasing with orbits	Strong S_2 aliasing only for some satellites (e.g., Stella, Larets, Blits)
Very sensitive to non-gravitational forces (atmospheric drag, albedo, solar radiation)	Sensitivity to non-gravitational forces substantially reduced
Sensitive to ionosphere activity	No ionosphere delay of the signal
Active satellites, expensive maintenance	Passive, low-cost satellites
Limited life-time	Unlimited life-time

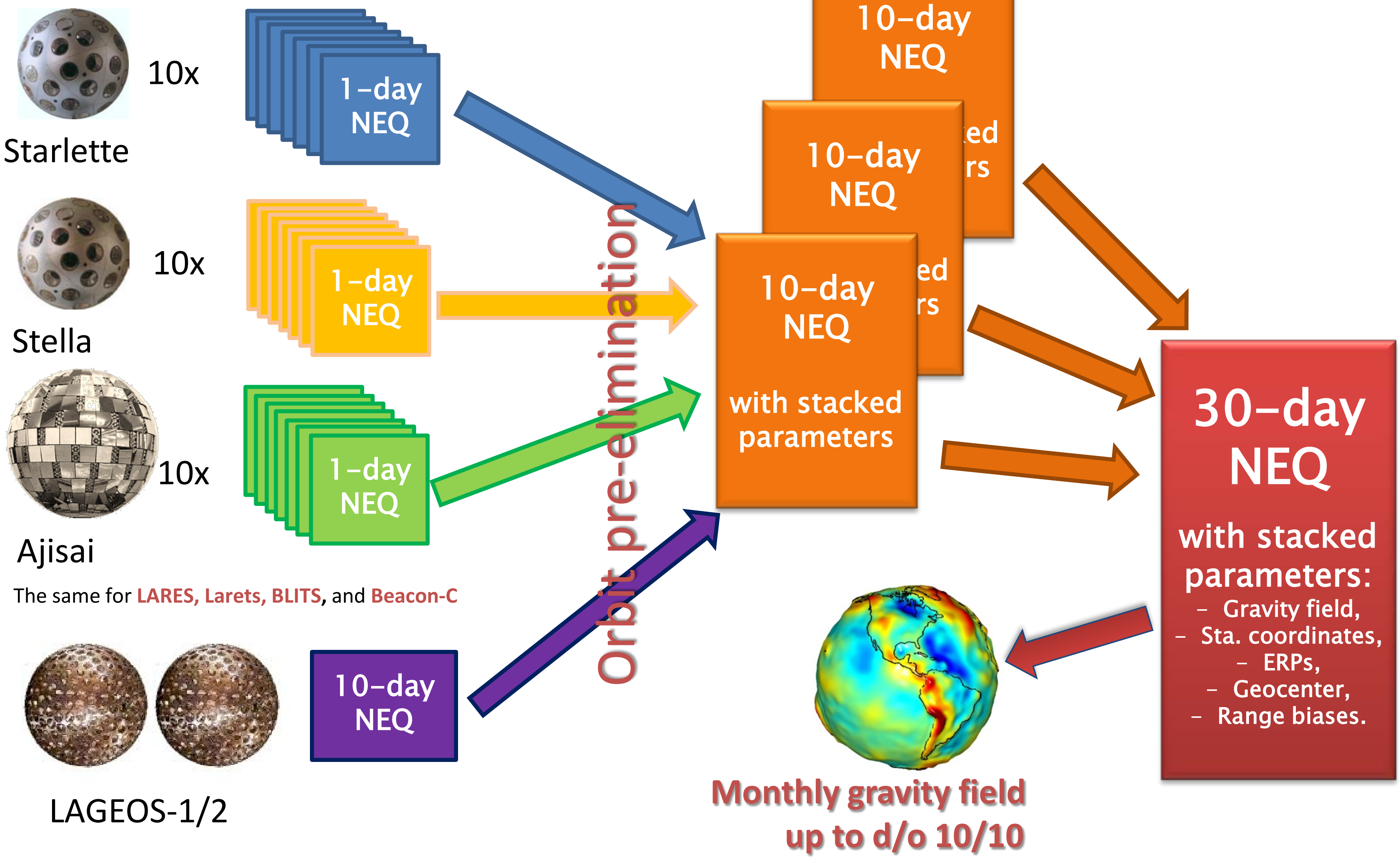
SLR gravity field solutions in Bernese GNSS Software

		SLR solutions
Estimated parameters		LAGEOS-1/2, Starlette, Stella, AJISAI, LARES, Blits, Larets, Beacon-C
Orbits	Osculating elements	$a, e, i, \Omega, \omega, u_0$ (LAGEOS: 1 set per 10 days, LEO: 1 set per 1 day)
	Dynamical parameters	LAGEOS-1/2 : S_0, S_S, S_C (1 set per 10 days) Sta/Ste/AJI : C_D, S_C, S_S, W_C, W_S (1 set per day)
	Pseudo-stochastic pulses	LAGEOS-1/2 : no pulses Sta/Ste/AJI : once-per-revolution in along-track only
Earth rotation parameters		X_P, Y_P, UT1-UTC (Piecewise linear, 1 set per day)
Geocenter coordinates		1 set per 30 days
Earth gravity field		**Estimated up to d/o 10/10** (1 set per 30 days)
Station coordinates		1 set per 30 days
Other parameters		Range biases for all stations (LEO) and for selected stations (LAGEOS)

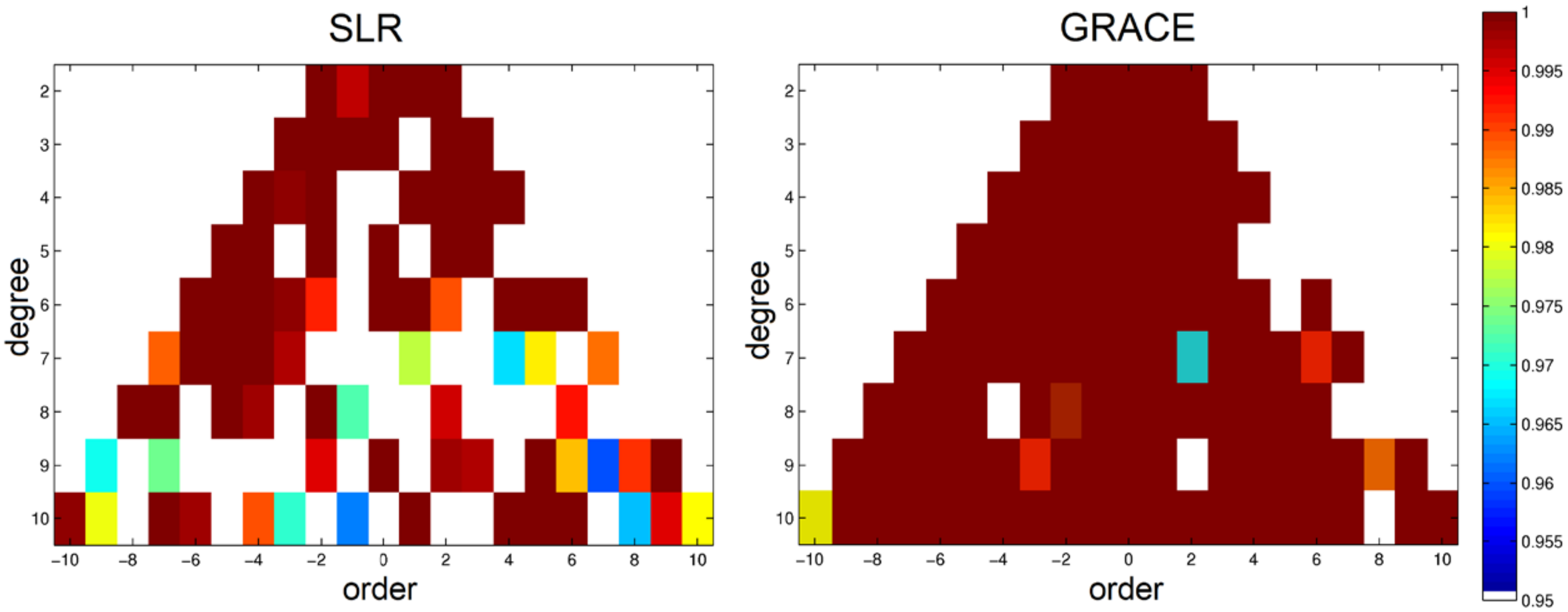


- Up to 9 SLR satellites with different altitudes and different inclinations are used.
- For LAGEOS-1/2: 10-day arcs are generated, for low orbiting satellites: 1-day arcs.
- Different weighting of observations is applied: from 8mm for LAGEOS-1/2 to 50mm for Beacon-C.

SLR gravity field solutions



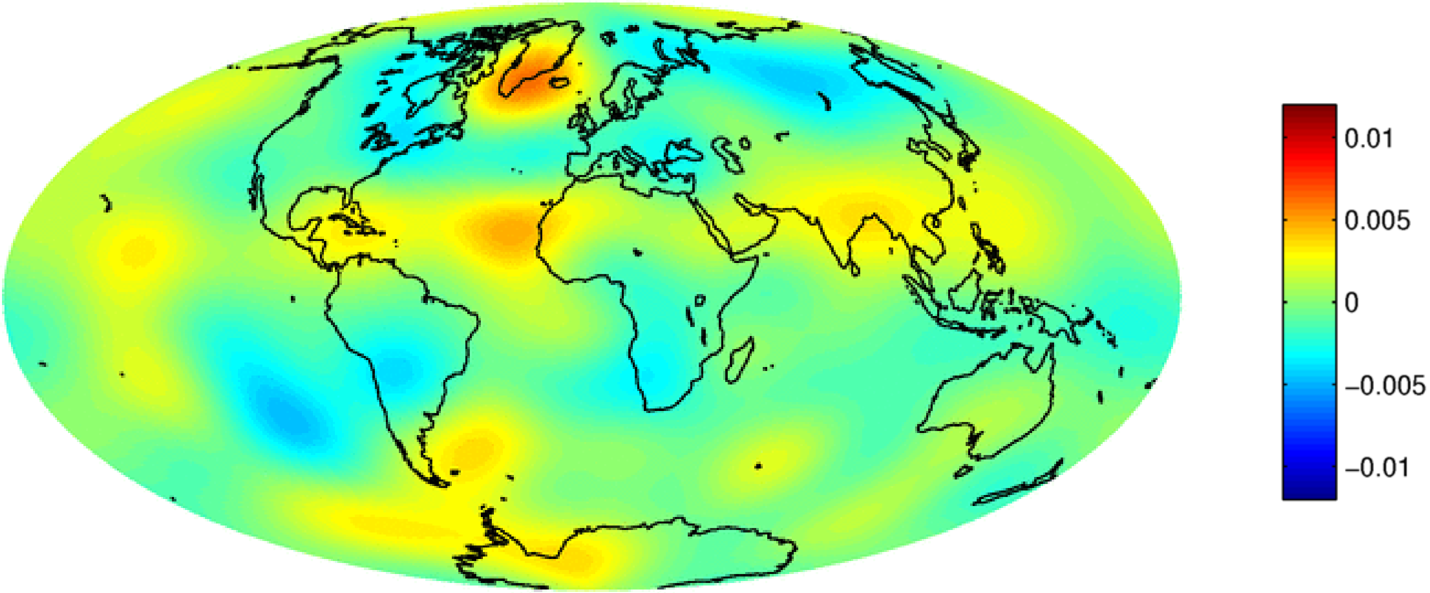
SLR gravity field solutions in Bernese GNSS Software



Associated cumulative distribution function showing the significance of the recovered annual for SLR solutions (left) and GRACE solutions (right).

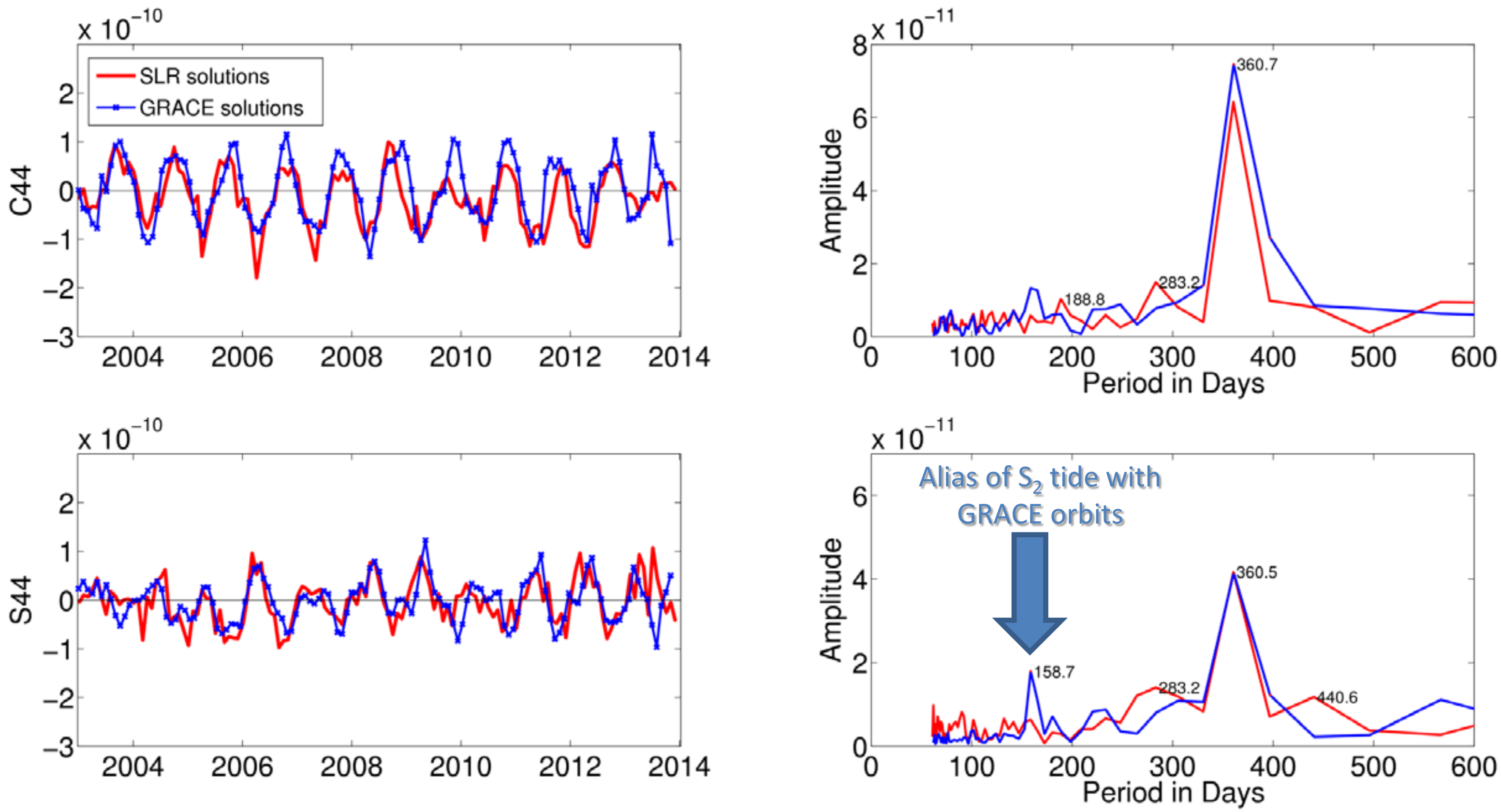
SLR gravity field solutions in Bernese GNSS Software

SLR can recover the largest gravity variations, e.g., in Amazon basin, Greenland, Africa, and South-East Asia. The spatial resolution is, however, limited.



Mean monthly gravity field variations up to d/o 10/10 derived from SLR-only (no filtering applied, scale in m)

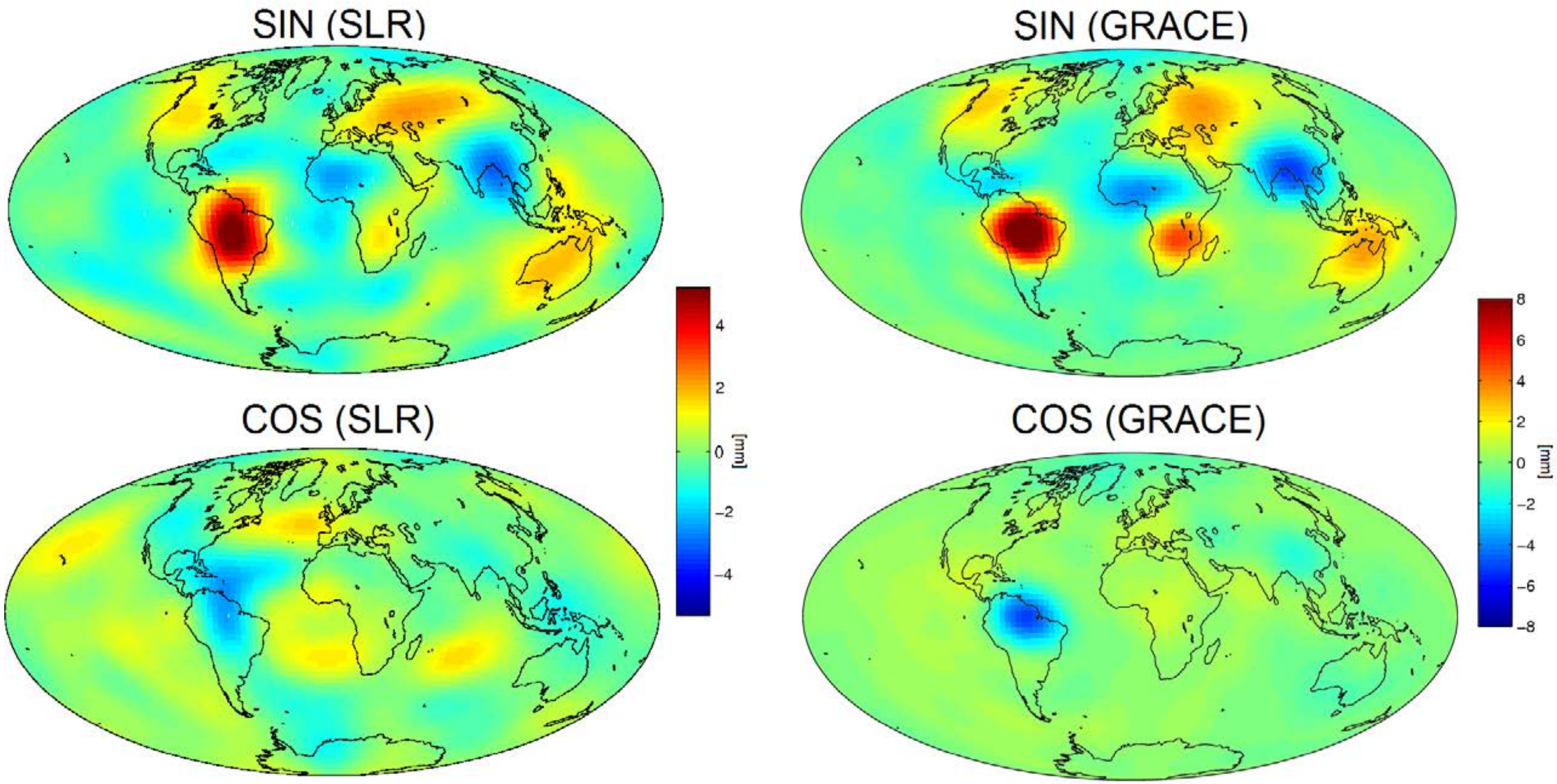
SLR gravity field solutions in Bernese GNSS Software



Coefficient C_{20}, describing Earth's oblateness, is strongly affected by the aliasing with the S_2 tide in the GRACE solutions, and thus, C_{20} is better determined by SLR. However, other GRACE-derived coefficients are also affected by S_2 alias.

SLR solutions are free from this modeling issue as they comprise observations to many satellites of different inclinations and altitudes, and thus, different period of orbit alias with S_2.

SLR gravity field solutions in Bernese GNSS Software

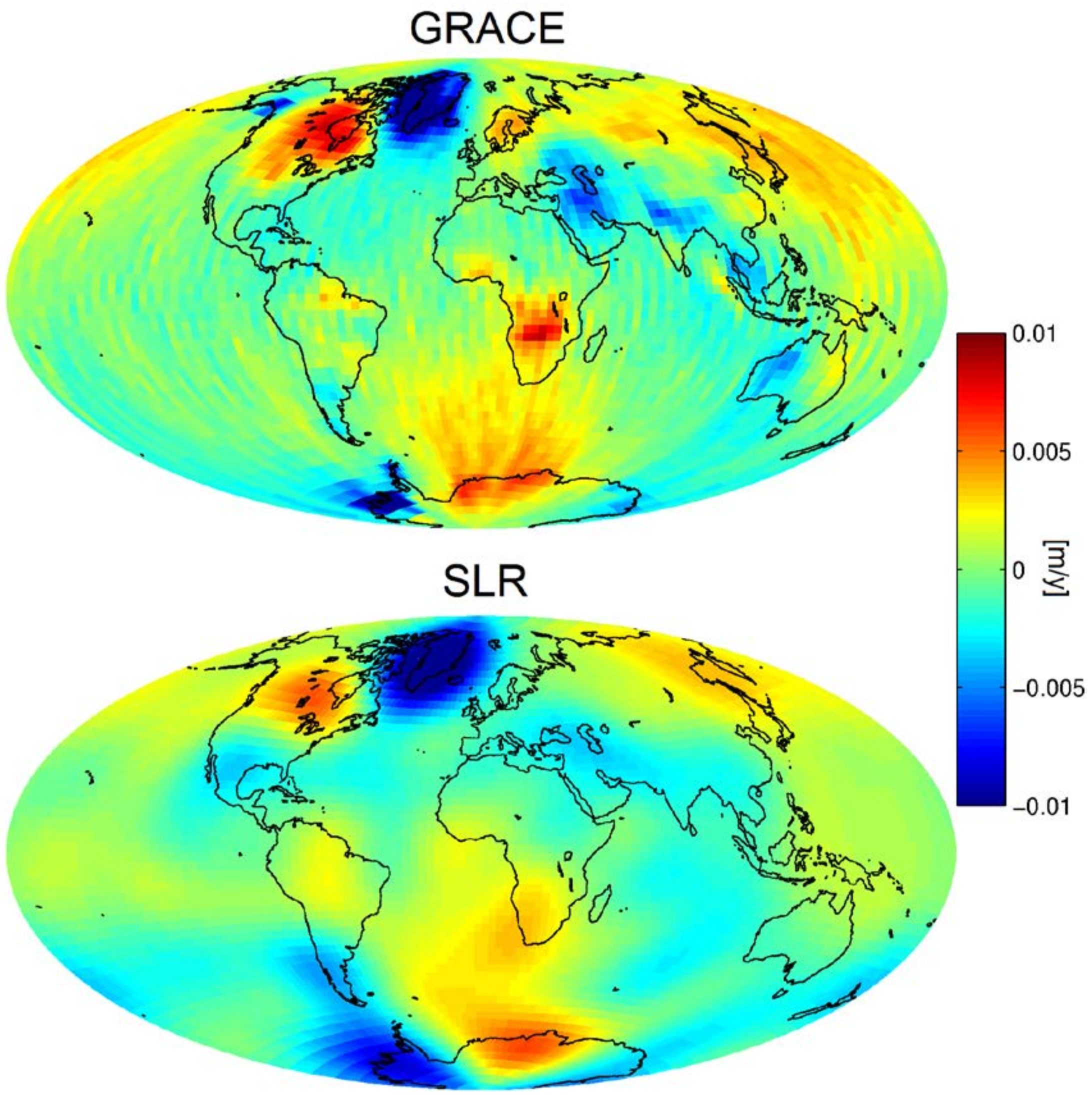


The annual variations of geoid height deformations can be well captured by SLR, however, the SLR-derived amplitudes of annual signal are typically smaller than the GRACE-derived values.

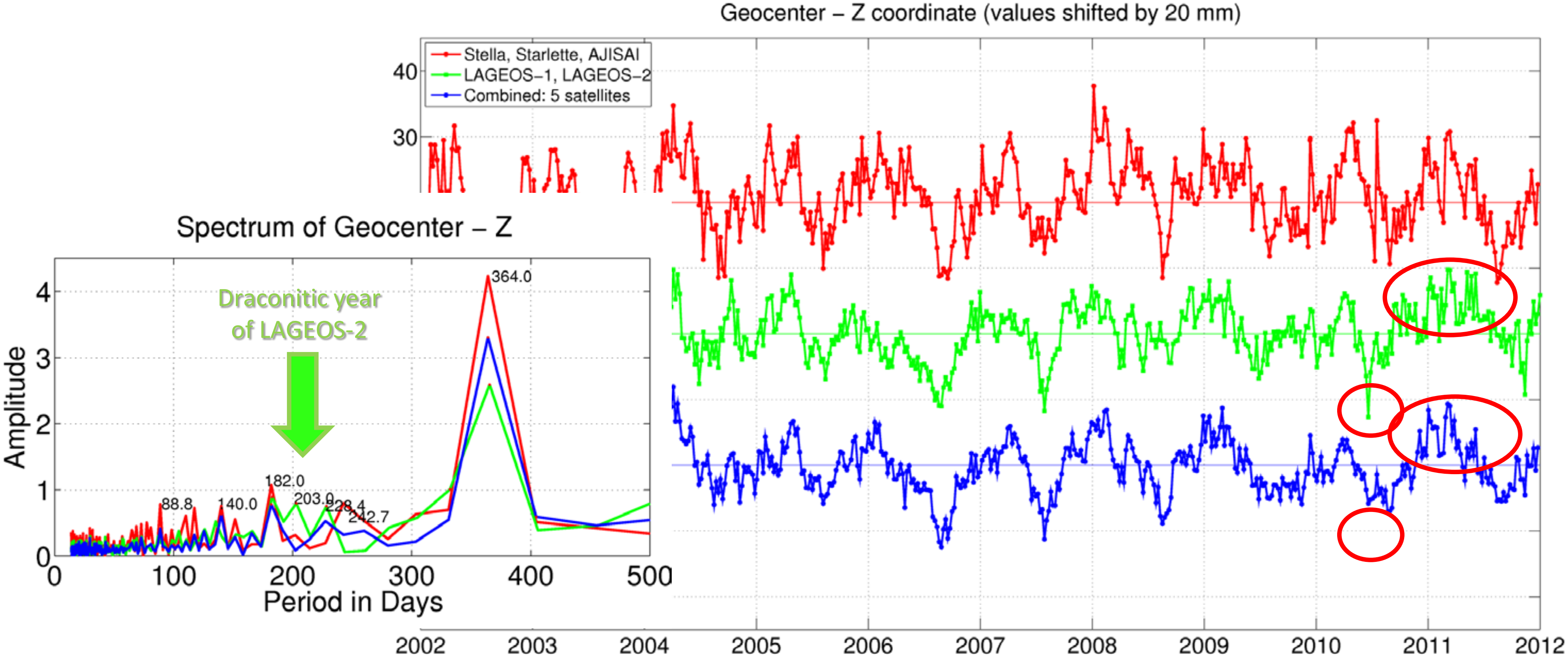
SLR gravity field solutions in Bernese GNSS Software

Secular changes of geoid deformations derived from SLR show a very high level of consistency with the GRACE-based results, however, with a lower spatial resolution.

The ice mass loss in Greenland, West Antarctica and Patagonia is well captured in the SLR solutions.



Geocenter coordinates



The geocenter coordinates are known to be well-determined from SLR observations to spherical geodetic satellites. The Z-component of geocenter coordinates is very sensitive to modeling deficiencies of the solar radiation pressure even in the SLR solutions.

A combined SLR solution with low- and high-orbiting SLR satellites removes the spurious variations in geocenter series related to harmonics of draconitic year (222 days for LAGEOS-2), and thus, improves the quality of SLR-derived geocenter.

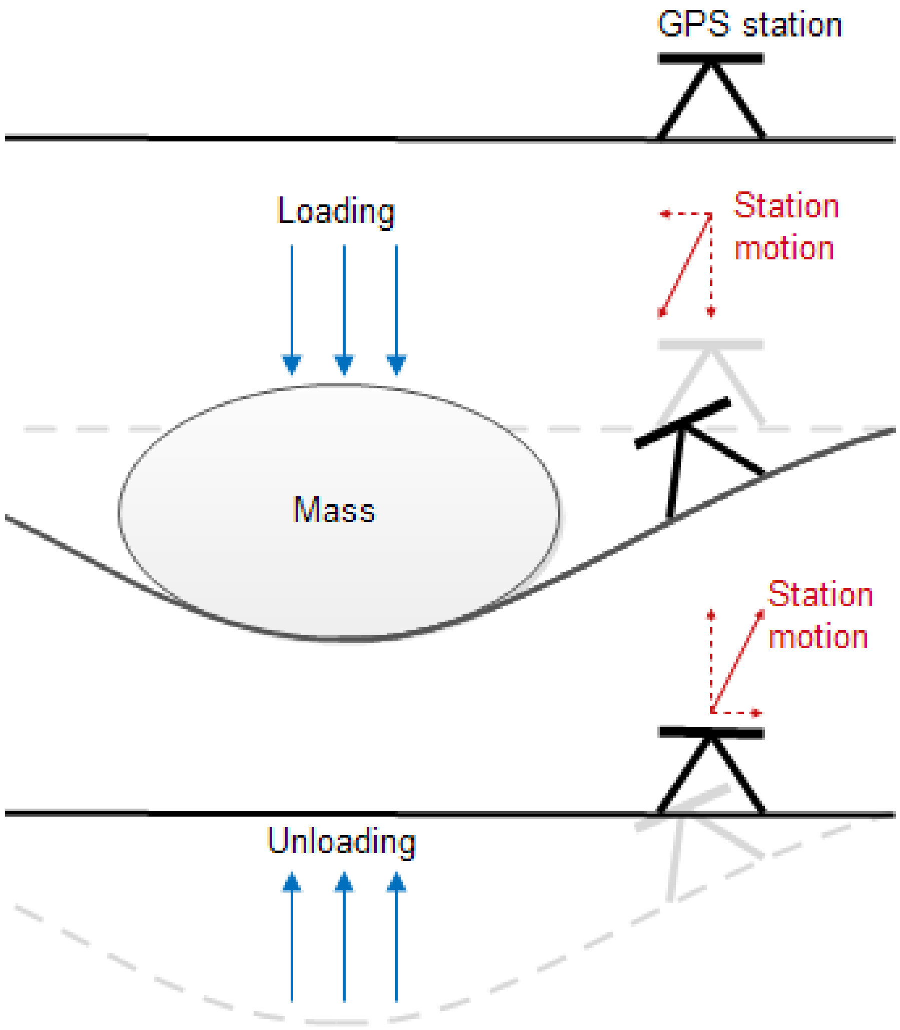
Task 3.5

Validation with GNSS site displacements

Presenter: Matthias Weigelt

Affiliation: UL

Principle of GNSS loading



SH to site displacement

$$du = R \sum_{l=0}^{\infty} \frac{h_l}{1+k_l} \sum_{m=0}^{l} \left(\bar{C}_{lm} \cos m\lambda + \bar{S}_{lm} \sin m\lambda \right) \bar{P}_{lm} \left(\sin \phi \right)$$

$$de = R \sum_{l=0}^{\infty} \frac{l_l}{1+k_l} \sum_{m=0}^{l} \frac{m}{\cos \phi} \left(-\bar{C}_{lm} \sin m\lambda + \bar{S}_{lm} \cos m\lambda \right) \bar{P}_{lm} \left(\sin \phi \right)$$

$$dn = R \sum_{l=0}^{\infty} \frac{l_l}{1+k_l} \sum_{m=0}^{l} \left(\bar{C}_{lm} \cos m\lambda + \bar{S}_{lm} \sin m\lambda \right) \frac{\partial \bar{P}_{lm} \left(\sin \phi \right)}{\partial \phi}$$

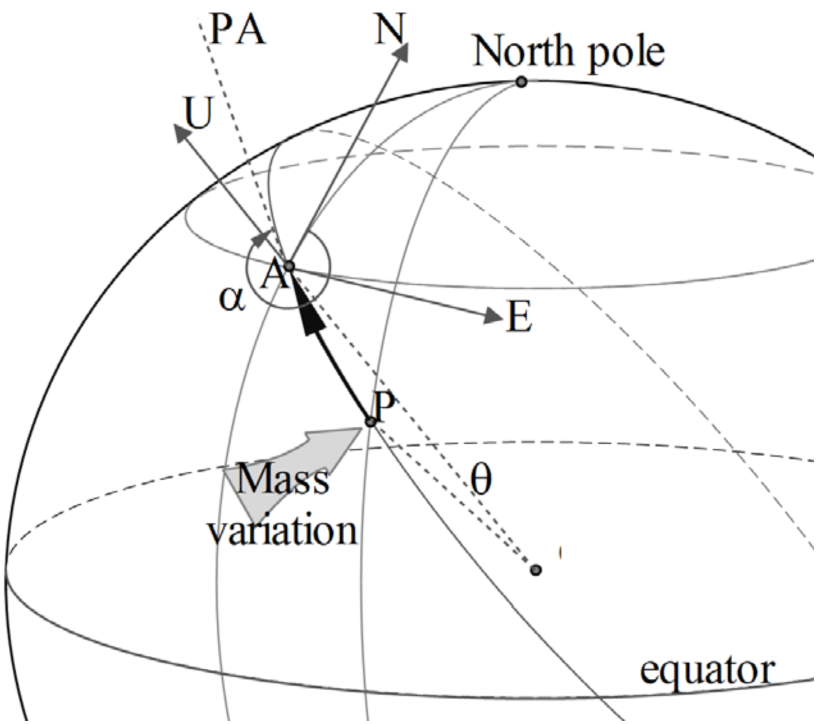
Grid to site displacements

Mass-loading Green's function [Farrel, 1972]

$$Gu(\theta) = \frac{a}{m_e} \sum_{n=0}^{\infty} h_n P_n(\cos\theta)$$

$$Gv(\theta) = \frac{a}{m_e} \sum_{n=1}^{\infty} l_n \frac{\partial P_n(\cos\theta)}{\partial \theta}$$

h and *l* are love numbers,
θ is angular distance
P_n are the Legendre polynomials.
a and m_e are radius and total mass of the Earth.

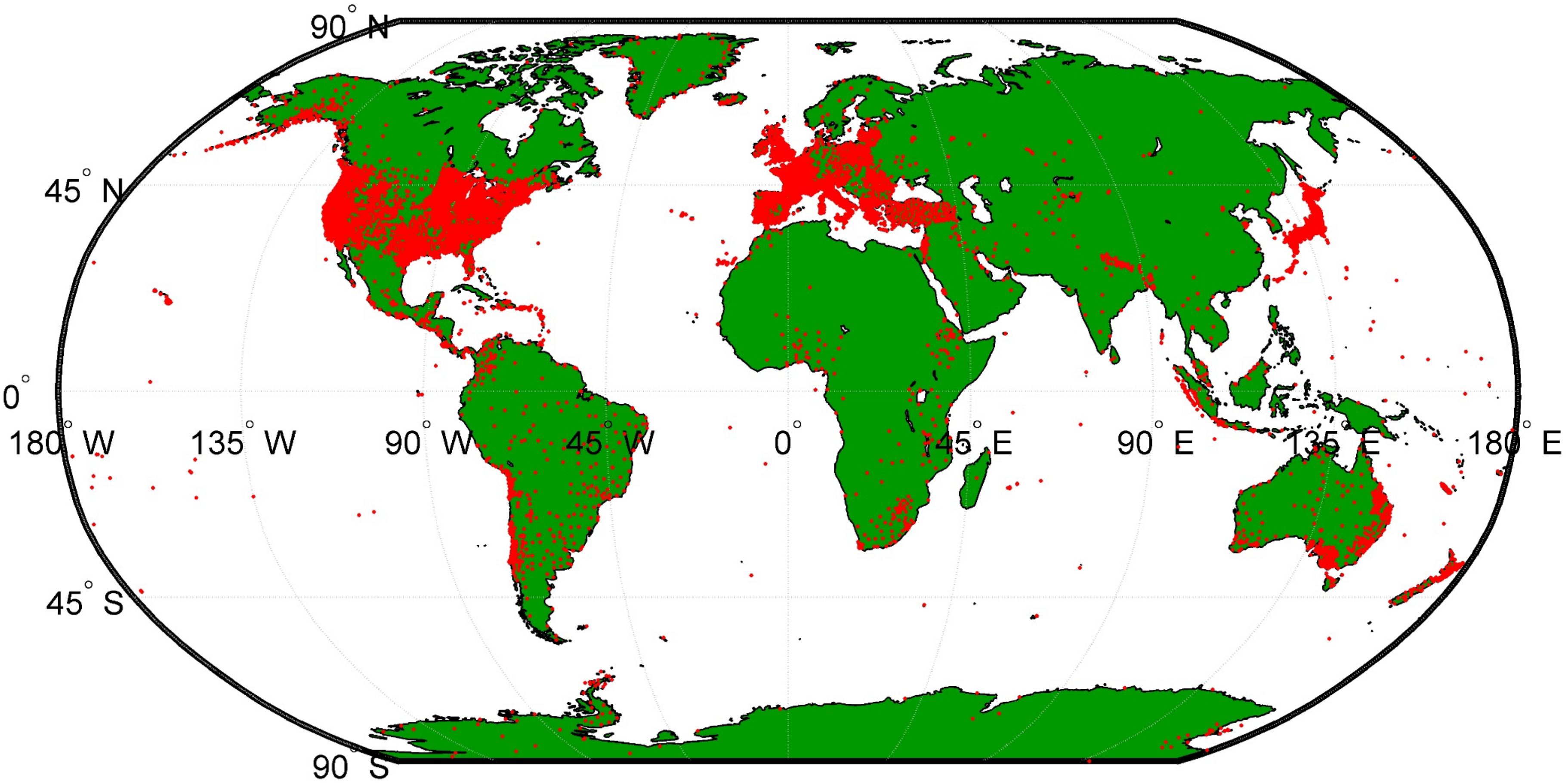


Surface displacements (U, V):

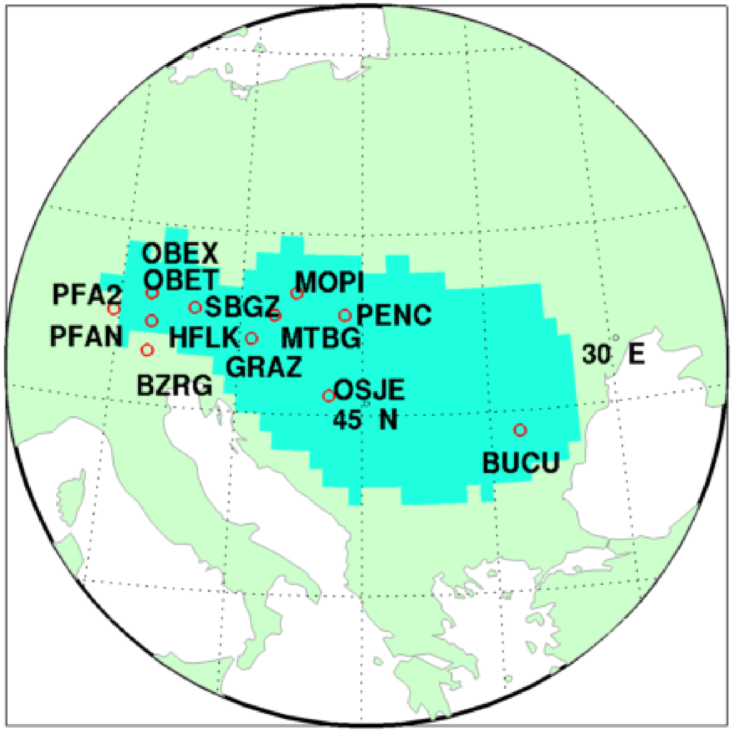
$$\begin{bmatrix} \delta U \\ \delta V \end{bmatrix} = \begin{bmatrix} Gu \\ Gv \end{bmatrix} \delta M$$

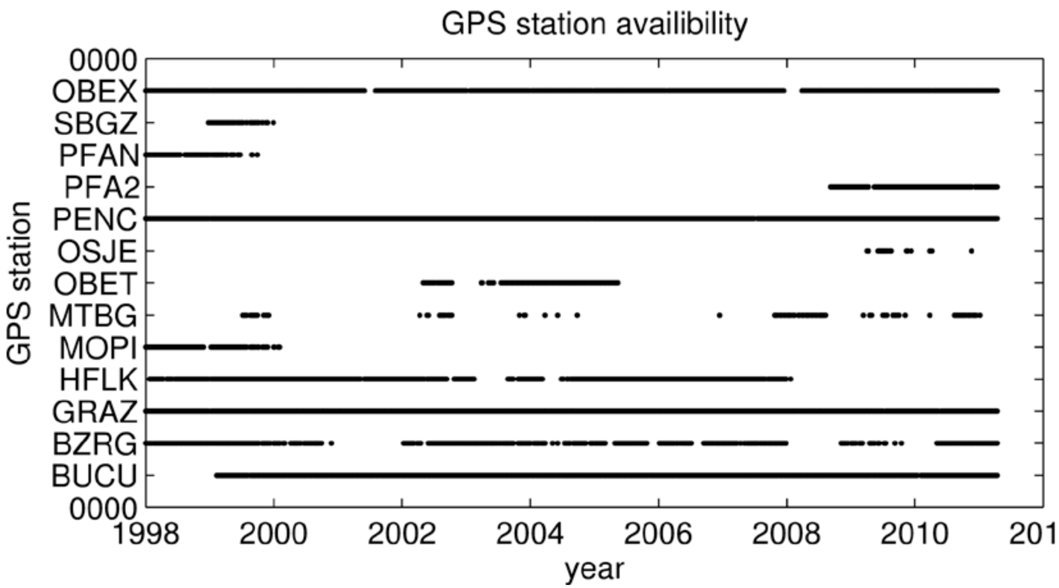
with M is the mass variation. V aligns to direction P→A .

Data availability: UNR station list (example)

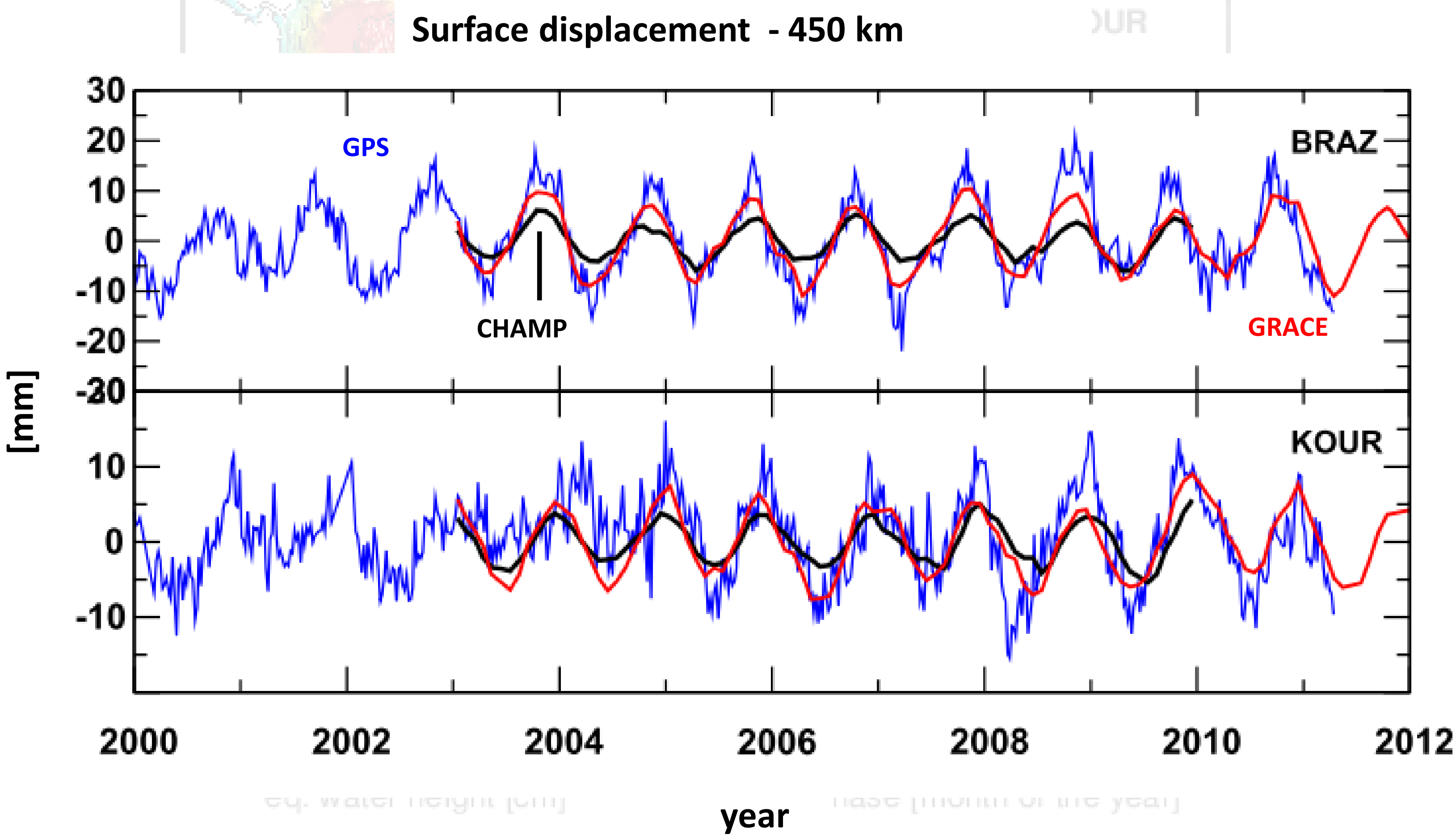


Data availability: Danube

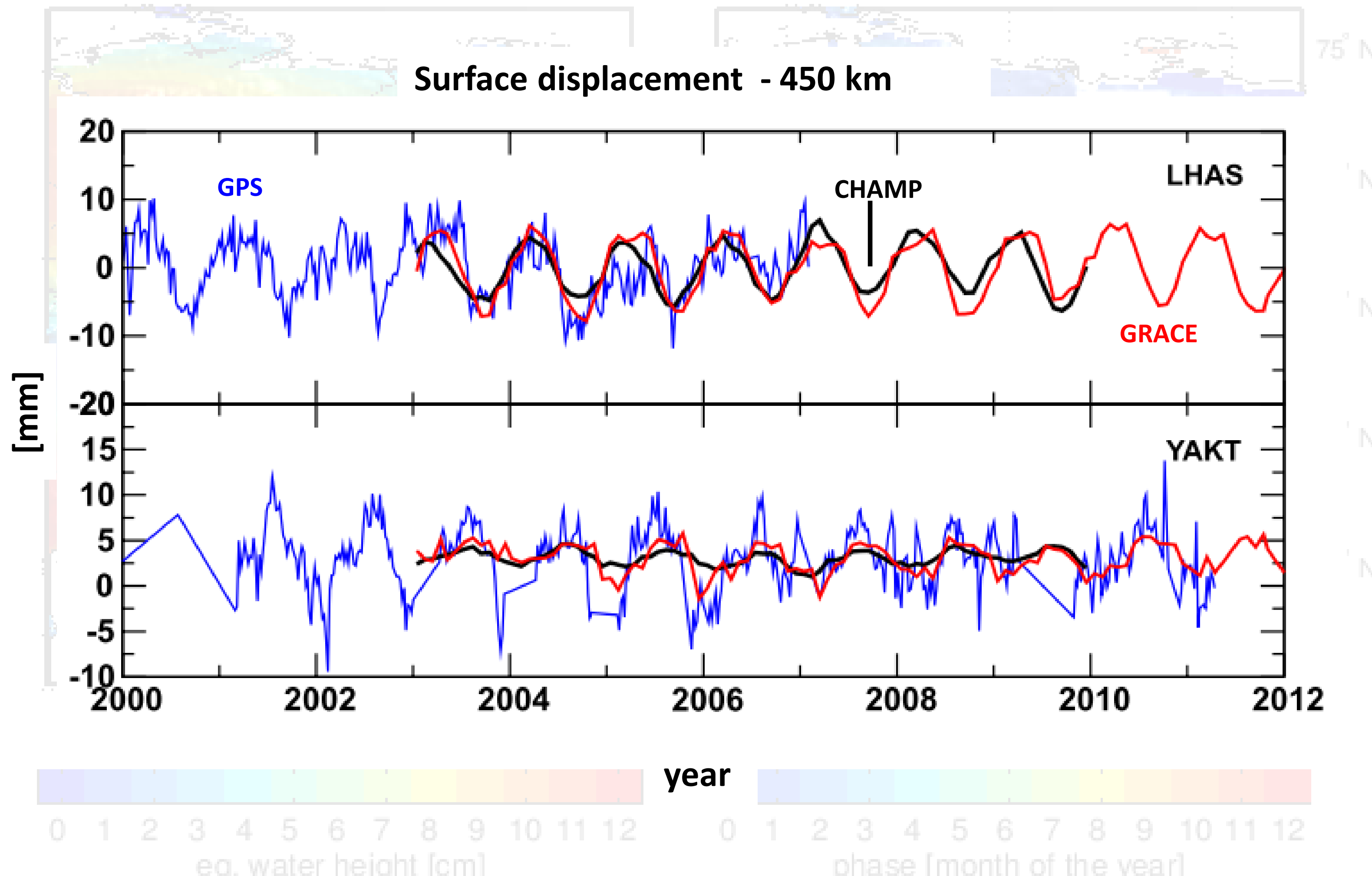




Loading analysis: Amazon



Loading analysis: East Asia



Task 3.6

Validation with Ocean Bottom Pressure

Presenter: Frank Flechtner

Affiliation: GFZ

Validation by Ocean Bottom Pressure

- To validate oceanic mass transport (M25-M36) we will use OBP data
- OBP is the sum of the mass of the atmosphere and ocean in a 'cylinder' above the seafloor.
- OBP data used
  - as available from OBP archives (AWI or PSMSL (Permanent Service for Mean Sea Level)
  - as simulated by the Ocean Model for Circulation and Tides (OMCT, used to generate AOD1B)

Validation by Ocean Bottom Pressure

- Necessary corrections to GRACE Level-2 products (GSM)
  - Degree-1 term to be added to GSM as approximated from GRACE GSM fields as demonstrated by Bergmann-Wolf et al. (2014)
  - Level-2 GAD product has to be added back to GSM
  - Continental leakage to be reduced e.g. according to Wahr et al. (1998) with a 300km Gauss filter
  - Filtering needed, e.g. with non-istropic smoothing and decorrelation filter DDK2/DDK3 (Kusche et al., 2009)
  - Synthesizing GRACE-derived ocean bottom pressure variations on a 1° by 1° grid

Validation by Ocean Bottom Pressure

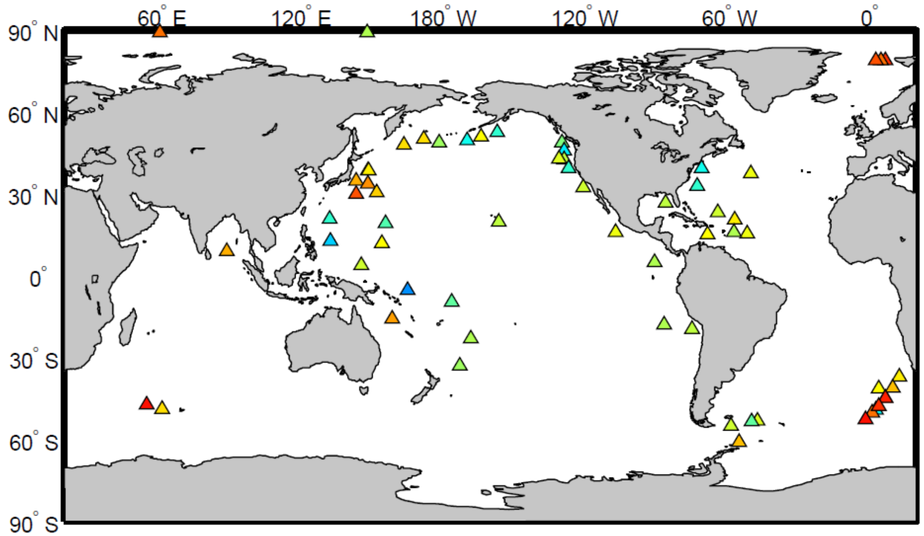
- Necessary corrections to in-situ OBP data
  - Mean, trend and annual signals has to be estimated with a least square fit and to be removed from the OBP time series
  - Provided (hourly) data are quality controlled, instrumental drift is removed by a quadratic fit and tides have been empirically removed
  - Daily averaged data are then 30days low pass filtered with a Butterworth filter of order 3 to estimate nearly monthly solutions which can be compared to the GRACE results

Validation by Ocean Bottom Pressure

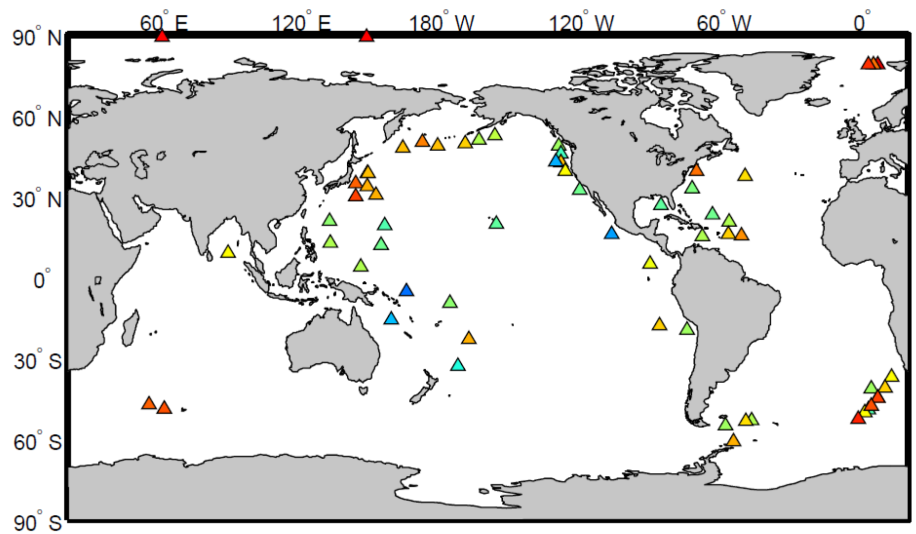
- Necessary corrections to OMCT output:
  - 6 hourly data are 30days low pass filtered with a Butterworth filter of order 3 to estimate nearly monthly solutions which can be compared to the GRACE results

- Following results show (as an example for EGSIEM) temporal correlations of in-situ (AWI) / modelled (OMCT) and RL04/RL05 GRACE determined OBP variations computed for time periods, where both data sets are available and time series were at least 6 months long

Validation by Ocean Bottom Pressure

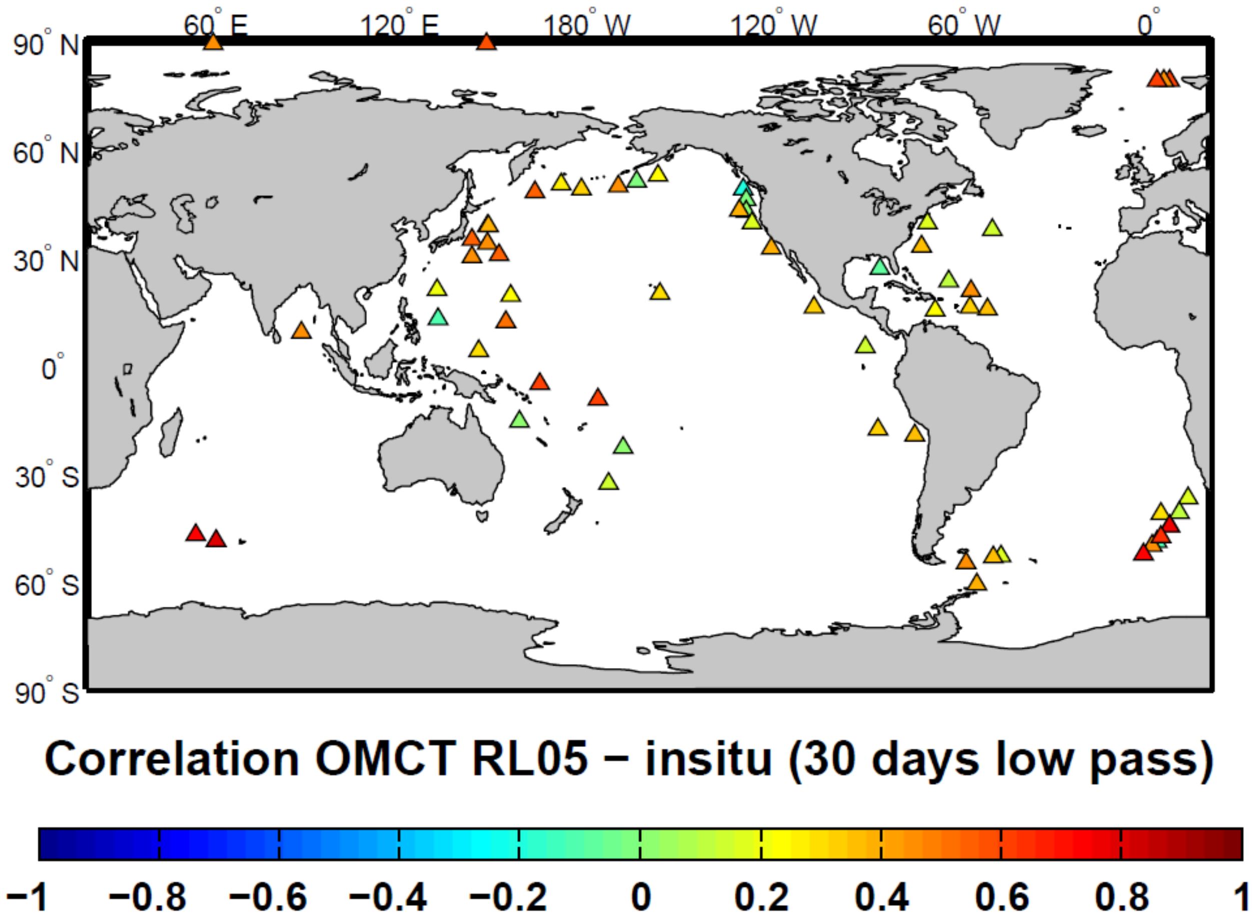


Correlation GFZ RL04 − insitu (30 days low pass)

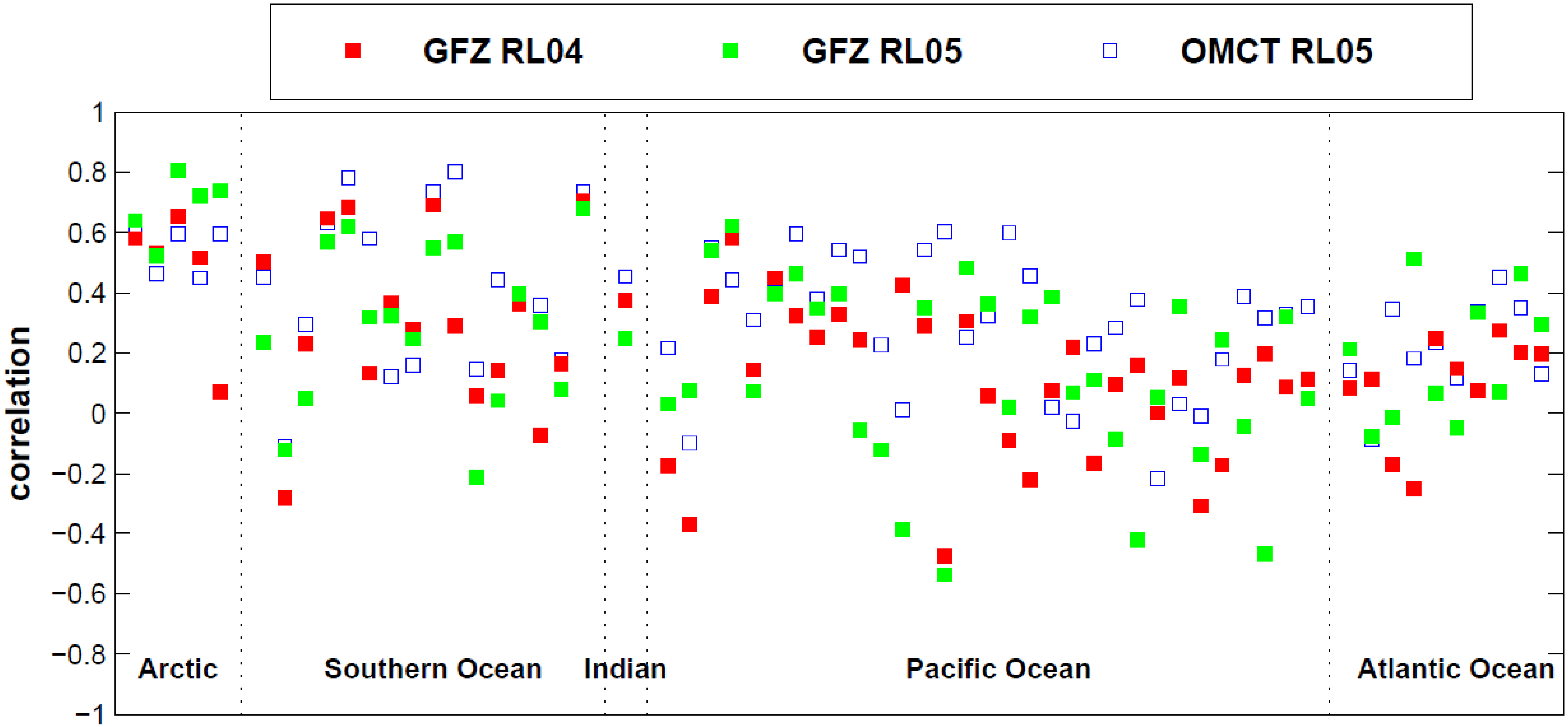


Correlation GFZ RL05 − insitu (30 days low pass)

Validation by Ocean Bottom Pressure



Validation by Ocean Bottom Pressure



Validation by Ocean Bottom Pressure

- The validation will be automized within 2015/16:
  - Upload GSM time series on input FTP directory by EGSIEM partner
  - Regular check if new time series is available
  - Run comparisons and provide results in terms of statistics (correlations, explained variance etc.) and figures

Task 3.7

Preparation of Hydroweb data

Presenter: Sean Bruinsma/Jean-Michel Lemoine

Affiliation: CNES

Hydroweb status in 2014

Back to LEGOS main site | Intranet

Hydrology from Space

Responsable Edition : Jean-François Cretaux *Webmaster : Marie-Claude Gennero*

Contacts	List of objets	Visualization	Validation

Lakes, Rivers and wetlands
Water levels from satellite altimetry

The altimetric water level data base

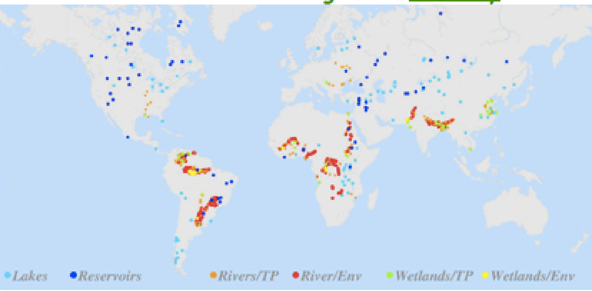
Our data base contains time series over water levels of large rivers, lakes and wetlands around the world. These time series are mainly based on altimetry data from Topex/Poseidon for rivers, but ERS-1 & 2, Envisat, Jason-1 and GFO data are also used for lakes. At present, water level time series of about 100 lakes (in Europe, Asia, Africa, North and South America) including Aral & Caspian seas are available. About 250 sites (called virtual stations) on large rivers are also available (see maps below).

Users of the data base can visualize the water level time series as well as Landsat images showing the geographic location of the site. Users can download the numerical values of the time series as well as associated errors.

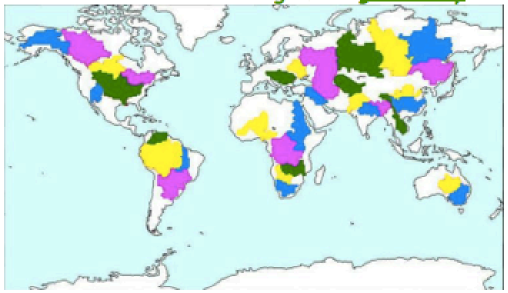
General information and data processing (click here)

Recent publications of GOHS/LEGOS, in space hydrology (click here)

Continental water storage from altimetry



Continental water storage from gravimetry



Hydroweb status in 2014

Products

- Water level of 20 rivers over more than 1400 stations:
  - -T/P, Jason-2 & Envisat
- Water level, surface & volumes for 100 lakes & levels for125 additional lakes by:
  - -T/P, Jason-1, Jason-2, GFO, ERS2, Envisat, Icesat
  - -Landsat, Cbers, Modis

Validation through comparisons with In Situ data

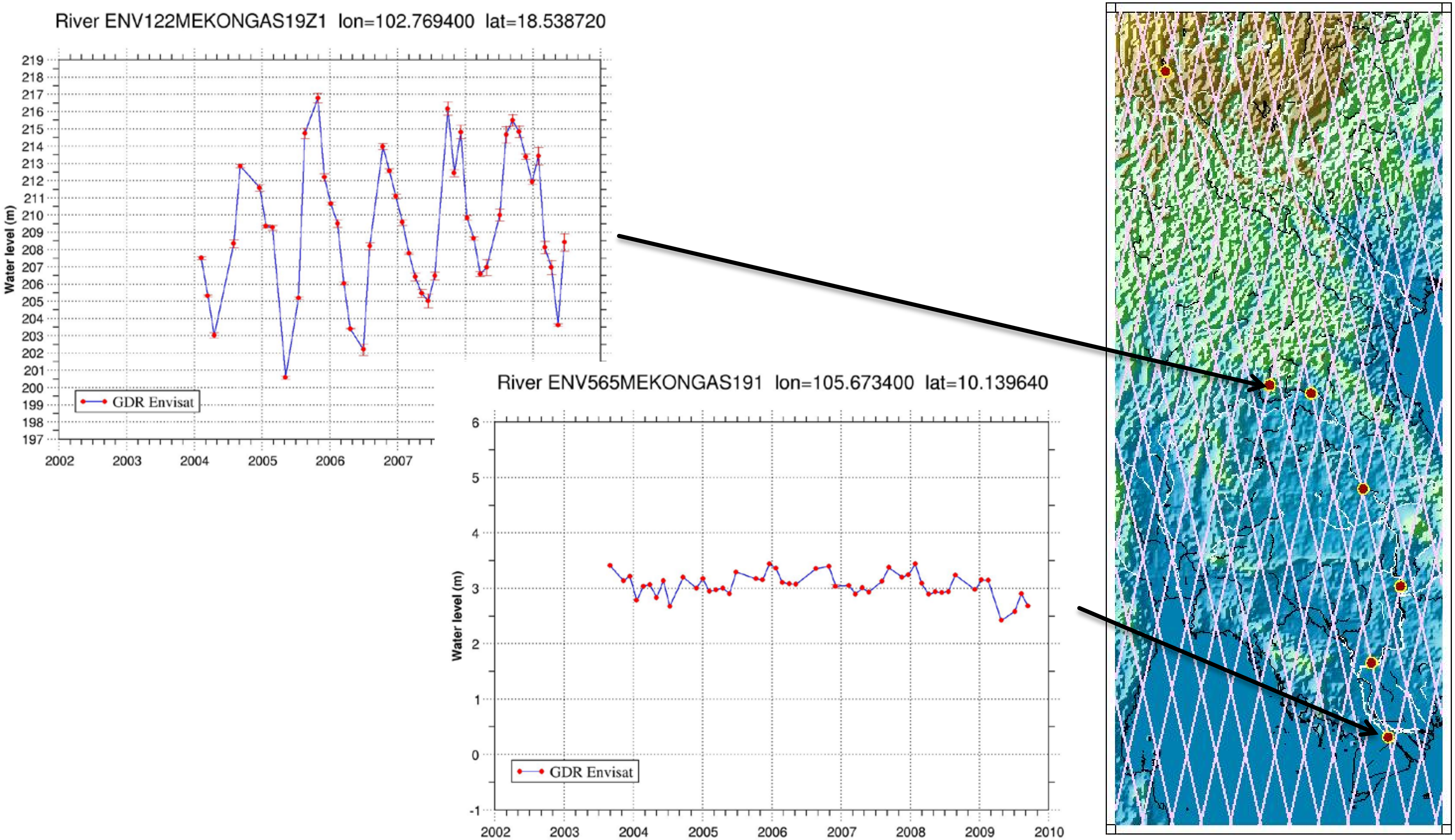
-10 cm to 80 cm for rivers

- 2 cm to 80 cm for lakes

Update of products on a 1-2 years basis

- data policy of CNES: free access to the users

Example: Mekong



What are the next steps?

- Milestone for Hydroweb Mid 2015: operational data service with near real time updating of the products and new web site (under finalization)

-Incorporation of new missions in the data processing system:

  -AltiKa, Cryosat 2, (2015)

  -Sentinel-2/3, Jason-3, Proba-V (2016)

  -Icesat-2 (2017)

  -Jason-CS (2018)

  -SWOT (2020)

⇩

Involvement of CNES (annual budget and manpower) is required and consolidated through the investment plan in the frame of the SWOT (NASA/CNES) mission preparation

Task 3.8
GIA for Hydrology

Presenter: Holger Steffen
Affiliation: LM

NKG and land uplift/GIA models

- NKG = Nordic Geodetic Commission
- Existing high-resolution land uplift model NKG2005LU will be substituted with a new one (test model recently circulated)
- NKG land uplift workshop in Reykjavik 2013 with a wish to support development of a GIA model for Fennoscandia
- Moral support to bring "modellers" of the NKG community together to work on such a model
- Participating modellers: Valentina Barletta (DK, USA), Matt Simpson (N), Maaria Nordman (FIN), Karin Kollo (EST), Per-Anders Olsson & Holger Steffen (S) + help by Glenn Milne
- Ice model support by Lev Tarasov

- GIA model shall explain the whole set of available observation data for Fennoscandia
- Model will also provide uncertainties

Suggested model set-up for first EGSIEM GIA correction

- Ice models:
  - Best GLAC for Fennoscandia/Barents Sea, ICE-6GC/GLAC/Gowan for North America, IJ05_R2 for Antarctica, Lecavalier et al. (2014) for Greenland, rest from RSES (Kurt Lambeck), but no Tibet
- Earth model:
  - Dedicated earth model for each region (e.g. VM2/VM5a), Maxwell rheology, using Wu (2004) 3D spherical FE model approach
  - Other model parameters (ice/water density, Earth radius, moments of inertia, π, etc.) as used in COST benchmark activity (see Spada et al. 2010)
- Observations:
  - New BIFROST 2015/16 release (currently in preparation with 100+ GPS stations)
  - EGSIEM GRACE result
  - Global RSL data (e.g. Barbados etc.) and Fennoscandian RSL data

Task 3.9

Compilation of historical flood situations

Presenter: Sandro Martinis

Affiliation: DLR

Outline

- Center for Satellite Based Crisis Information (ZKI)
- Compilation of historical flood situations
  - Existing flood/water masks
  - Acquisition of EO data
  - Reprocessing of flood/water masks

Center for Satellite-based Crisis Information (ZKI)

- Operational 24/7 service of DFD/DLR
- Rapid provision, processing and analysis of EO data
  - natural and environmental disasters
  - humanitarian relief activities
  - civil security issues
- Activities on national/international level
  - Copernicus Emergency Management Service
  - International Charter Space and Major Disasters
  - ZKI Service for Federal Agencies (ZKI-DE)

ISO 9001 DNV Certified Company

Copernicus The European Earth Observation Programme

International Charter Space & Major Disasters Charte Internationale Espace et Catastrophes Majeures

Federal Ministry of the Interior

ZKI Service for Federal Agencies (ZKI-DE)

Analysis Products in Support to the Emergency Management

Historical flood situations: Existing flood/water masks

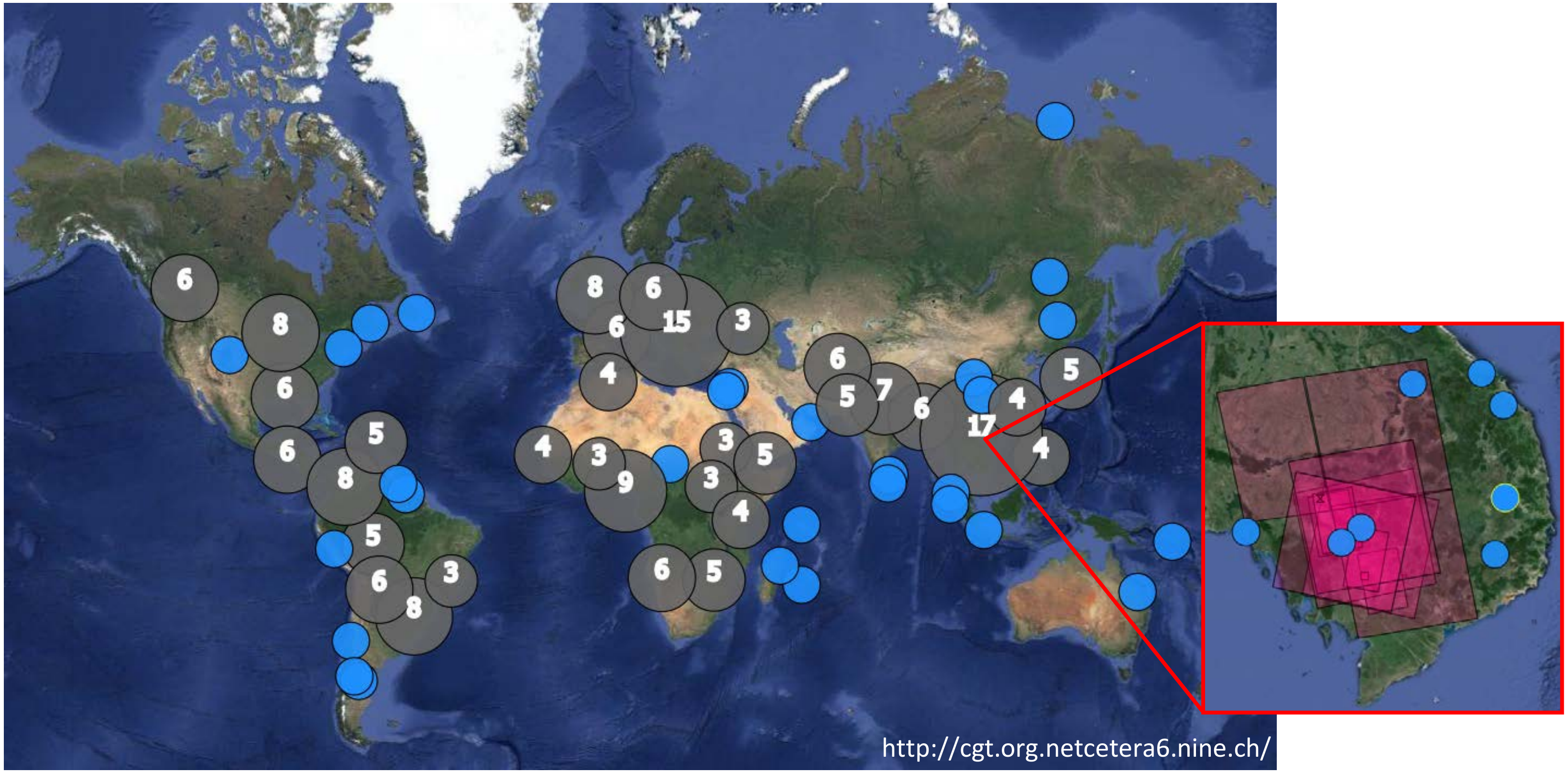
- Available historical flood/water masks at DLR based on
  - Past flood rapid mapping activities of ZKI in the context
    - ZKI-DE, Copernicus EMS (SAFER), International Charter

ZKI flood mapping activities since 2000 (In total: 51)

  - R&D acivities

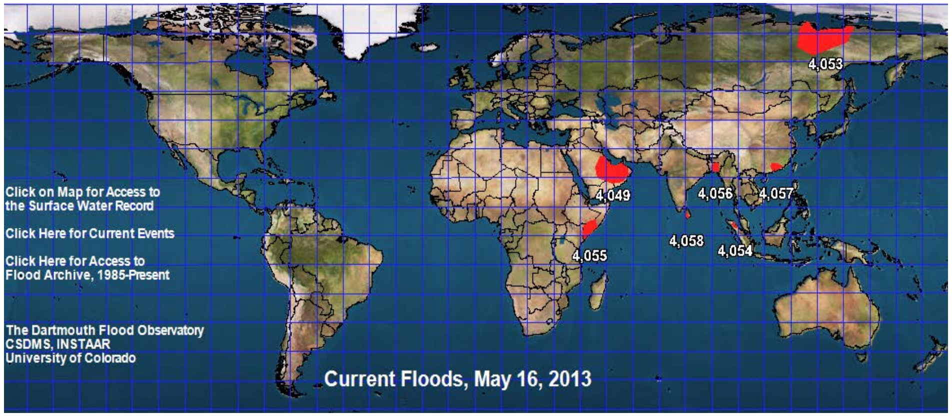
Historical flood situations: Existing flood/water masks

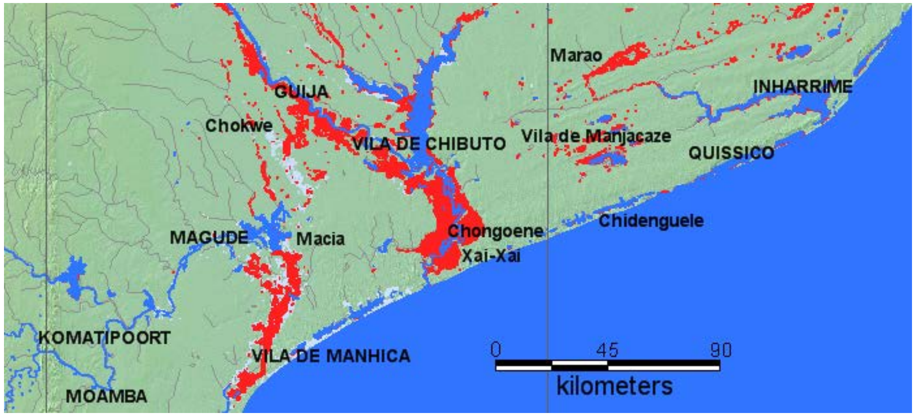
- Catalogue research of historical flood situations based on
  - International Charter Space and Major Disasters



Historical flood situations: Existing flood/water masks

- Catalogue research of flood situations based on
  - Dartmouth flood observatory
    - Global surface water record: Current and historical information
    - Global archive of large flood situations from 1985 to present
    - Provision of rapid response mapping for selected large-scale flood situations
    - Main data source: MODIS Aqua/Terra





Source: http://floodobservatory.colorado.edu

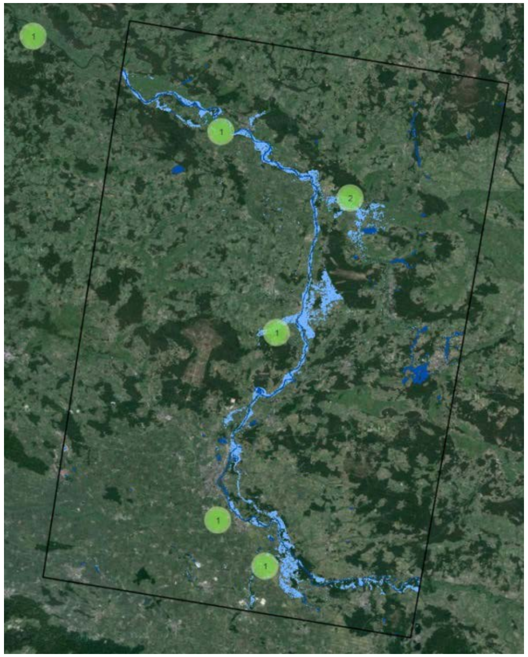
Historical flood situations: Acquisition of EO data

- Acquisition of archived EO data
  - Freely available (e.g. MODIS, Landsat, AVHRR, Sentinel)
  - Via GMES/Copernicus Space Component Data Access (GSCDA) → coordinated access to data procured from the Copernicus contributing missions
    - Optical data: e.g. Rapid-Eye, Spot, Envisat, DMC, etc
    - RADAR data: e.g. TerraSAR-X/TanDEM-X, Radarsat, Envisat, Sentinels, Cosmo-SkyMed
  - Via scientific data proposals

Historical flood situations: Reprocessing

- Semi-automatic flood detection tools (SAR & optical data)
- Automatic flood detection services
  - MODIS
    - Systematic country/continental scale flood mapping (250m)
    - High revisit interval
  - TerraSAR-X
    - Local to regional scale flood mapping (0.25-40m)
    - On-demand triggering in case of emergencies
  - Sentinel-1
    - Systematic regional scale flood mapping (5-40m)
    - Pre-programmed conflict-free operation mode

→ Interactive access via Browser/Web GIS



Web GIS interface: Germany 2013, TerraSAR-X

Thank you very much for your attention!