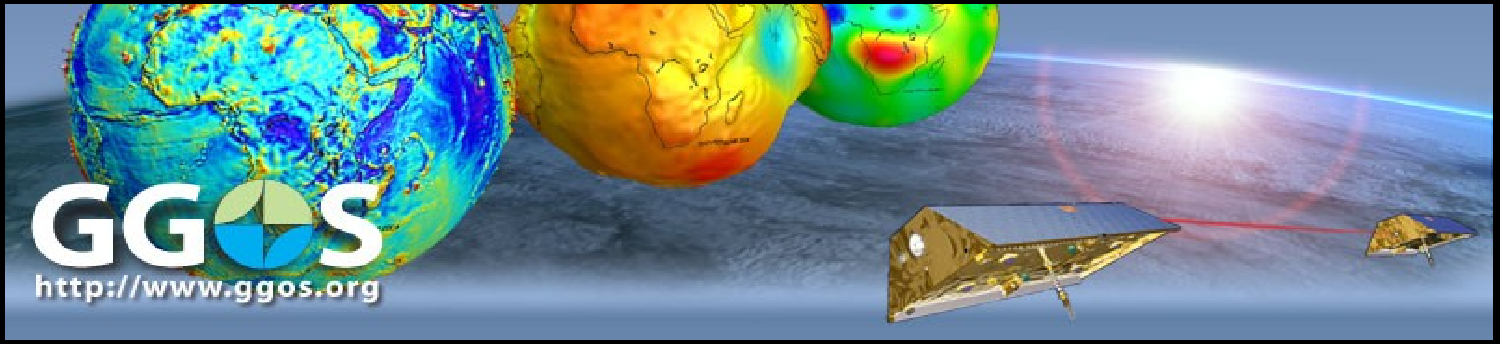

Improving spatial and temporal resolution through combined geodetic observations

Hans-Peter Plag

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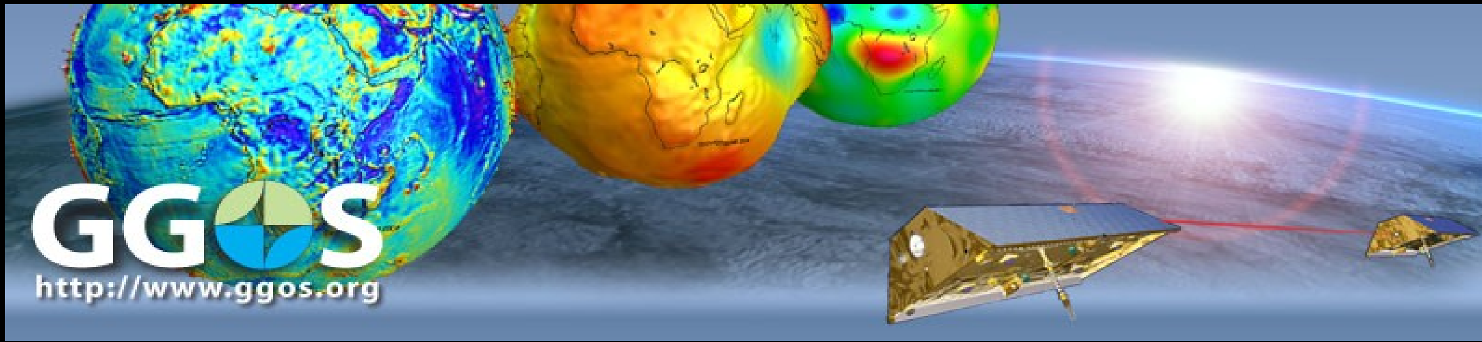


Improving spatial and temporal resolution through combined geodetic observations

Introduction (geodesy and the water cycle)

Inversion versus assimilation (or separation versus simulation)

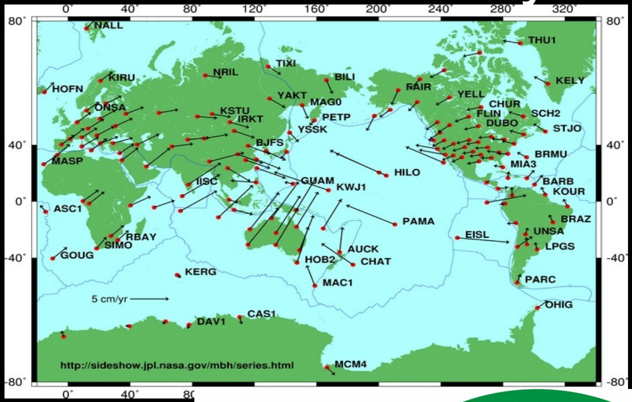
Resolution of (forward) models (the inherently global nature of geodesy)

Challenges for large-scale geodesy and hydrology

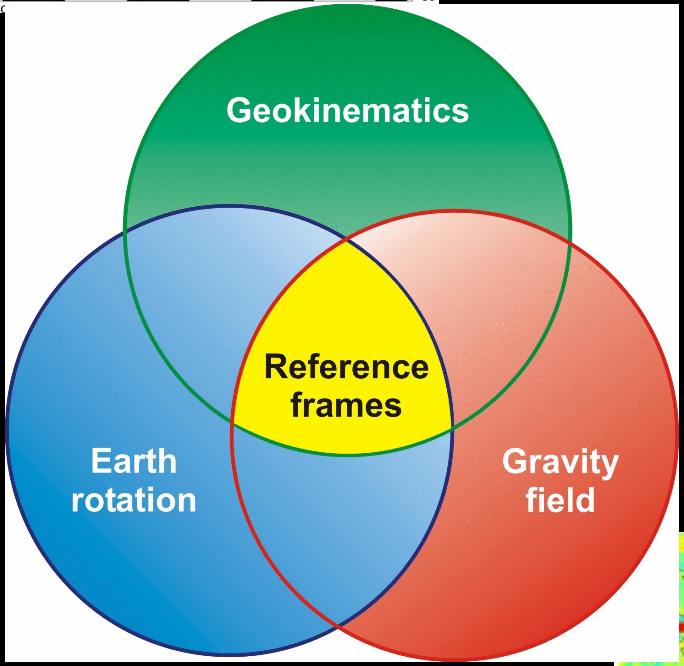
Local approaches and techniques

Conclusions

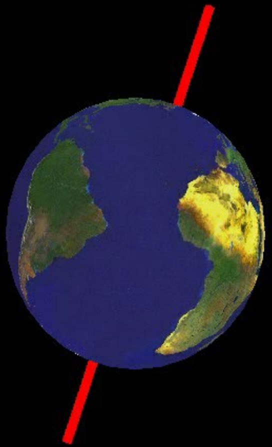
Geodesy and the Water Cycle

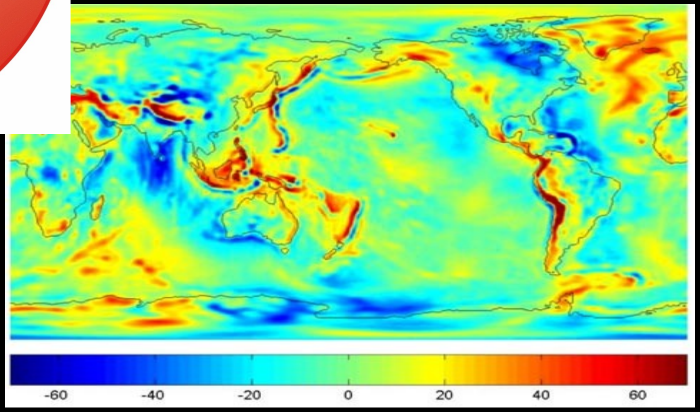


The 'three pillars of geodesy':
- Earth's Shape (Geokinematics)
- Earth's Gravity Field
- Earth Rotation

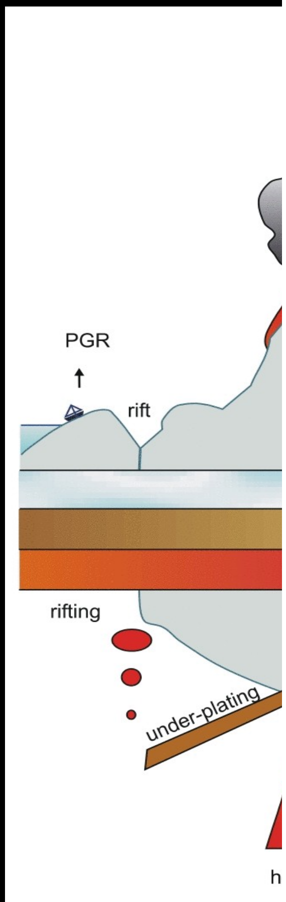


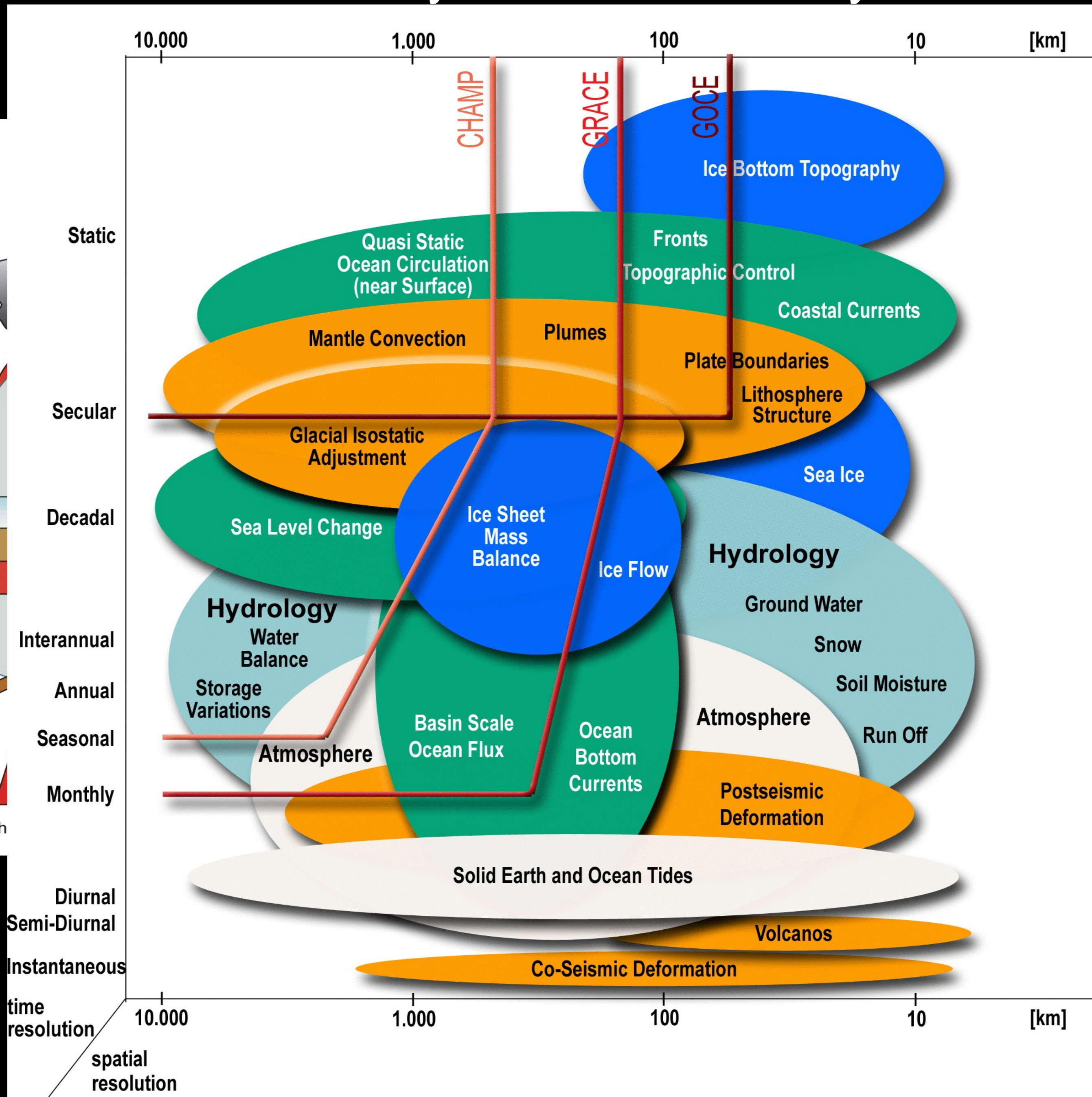
Output:
- Reference Frame
- Observations of the Shape,
- Gravitational Field and
- Rotation of the Earth

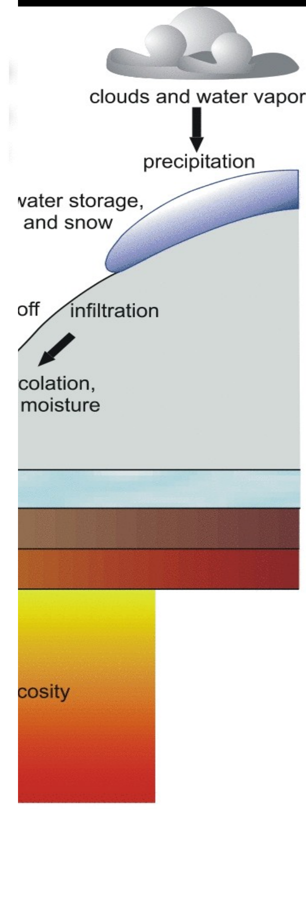




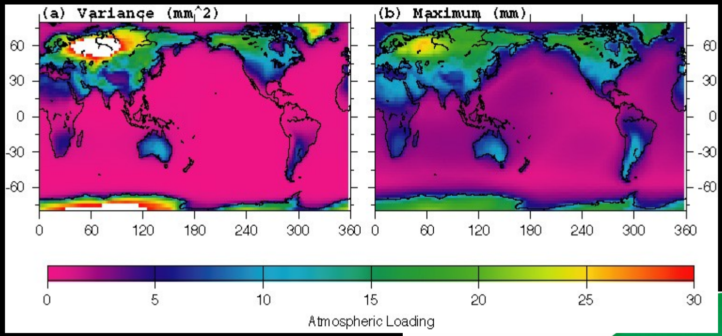
Geodesy and the Water Cycle





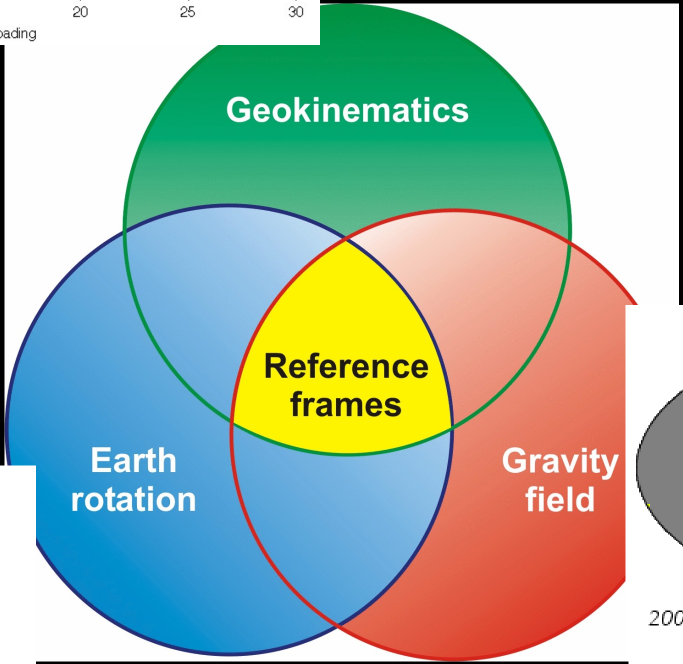


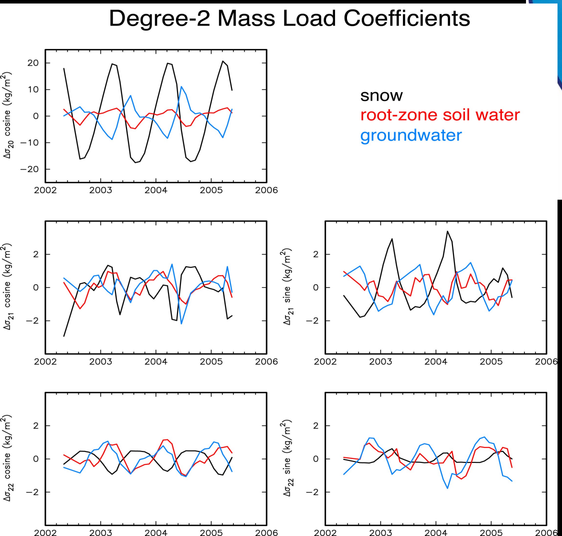
Geodesy and the Water Cycle

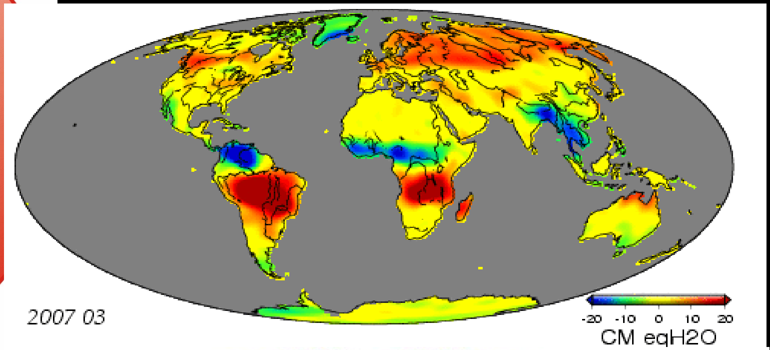


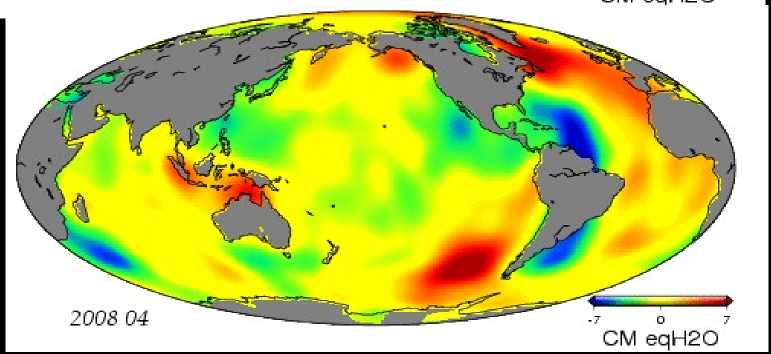
The 'three pillars of geodesy':

- Earth's Shape (Geokinematics)
- Earth's Gravity Field
  Earth Rotation









Inversion Versus Assimilation
Separation Versus Simulation

Inversion:

Advantage:
- scientifically interesting

Problems:
- Base functions for inversion
- Effect of ocean
- Effect of networks, station distribution, temporal inhomogeneity (e.g., we have 1299 and 3825 stations in 2002 and 2008, resp.)
- Aliasing
- Separation of contributions/effects
- No predictive capability

Assimilation:

Advantages:
- Predictive capacity
- Insensitive to uneven data resolution

Problems:
- Assimilation kernels for geodetic observations
- Complexity of models

Inversion Versus Assimilation
Separation Versus Simulation

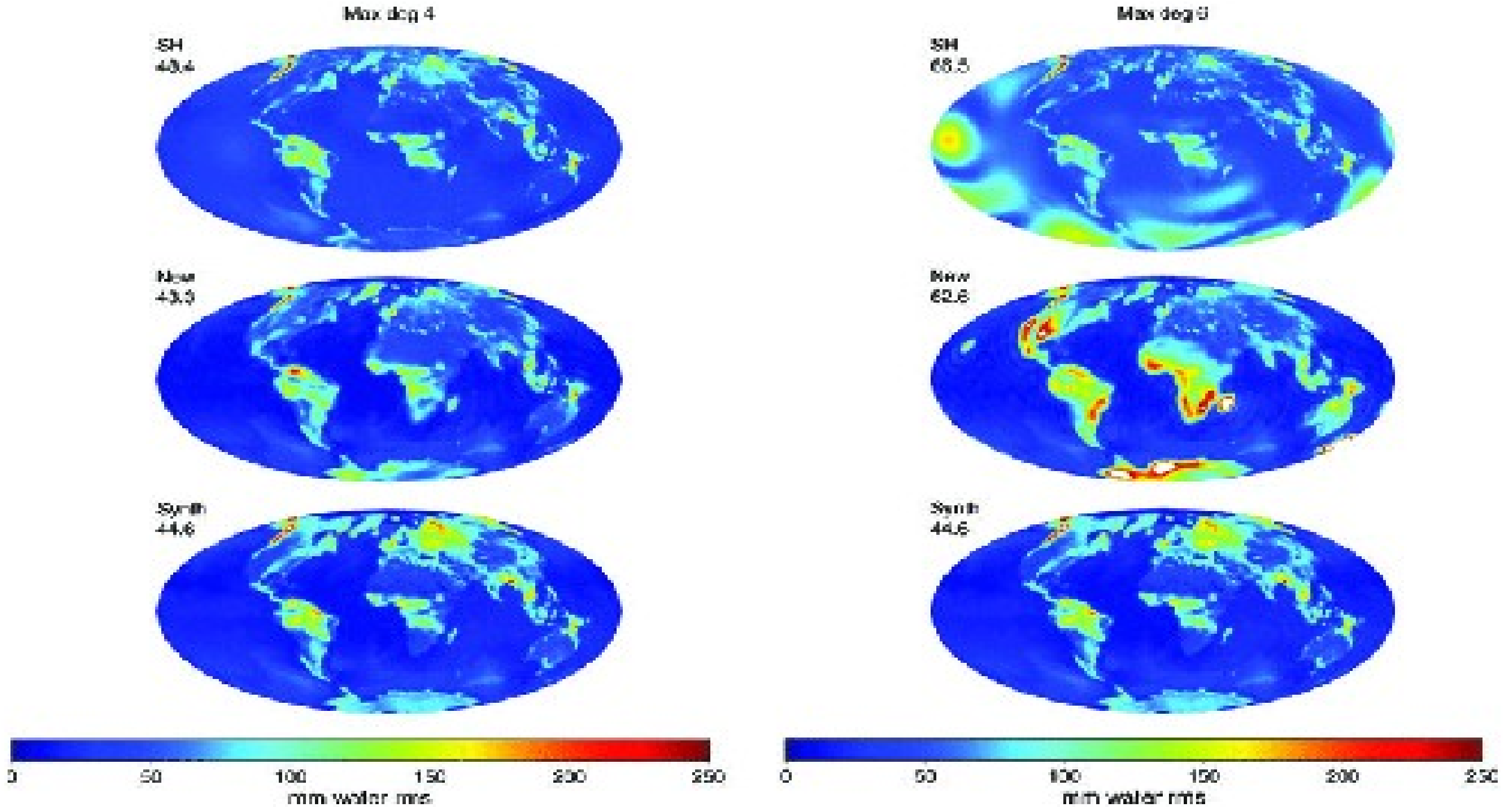
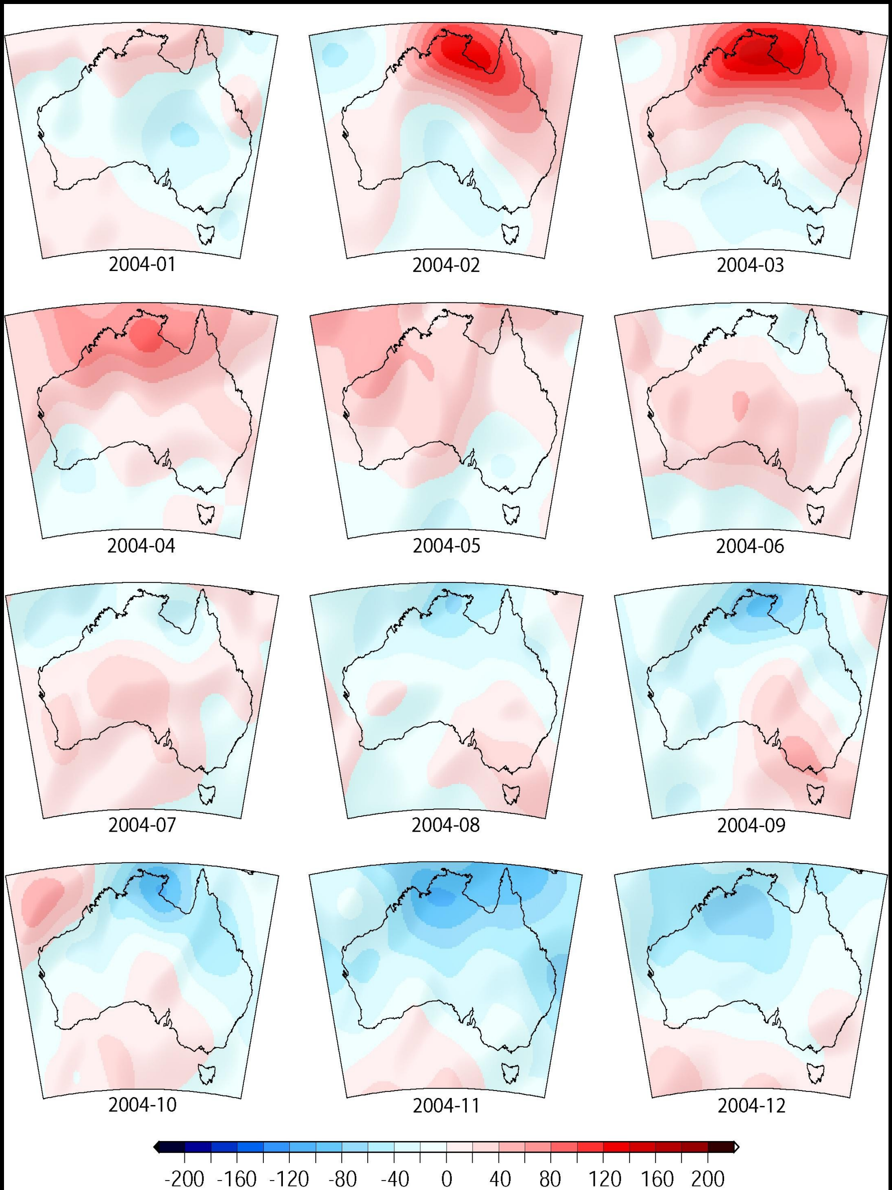


Figure 7. Spatial distribution of rms misfit between estimated surface loads and synthetic data, computed over the entire time-series, for estimates truncated at degree 4 (left-hand side) and 6 (right-hand side). The bottom plots show the variability of the synthetic data. Numbers indicate the overall rms of the misfit/data (in mm). The inversion data have JPL network geometry.

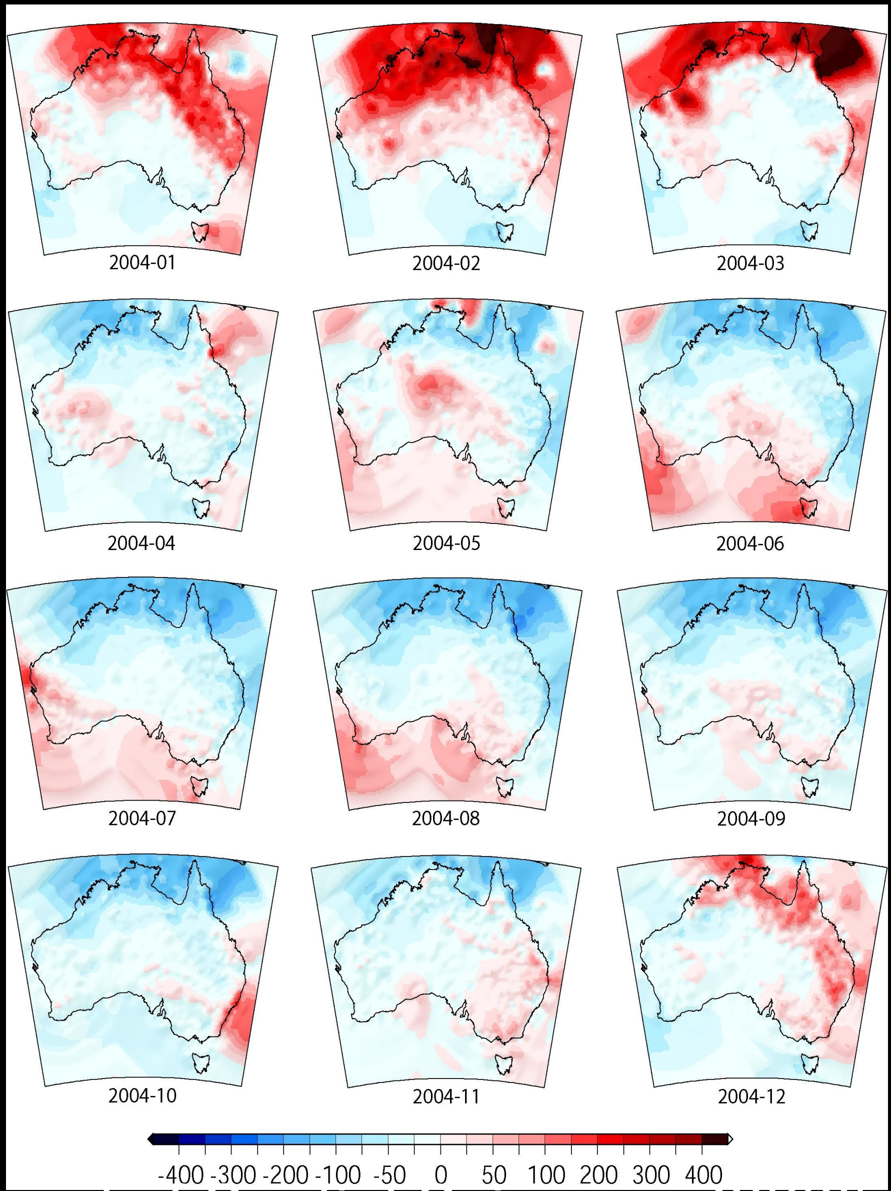
Clarke et al., 2007

Inversion Example: Terrestrial Water Storage

GRACE Mass variations

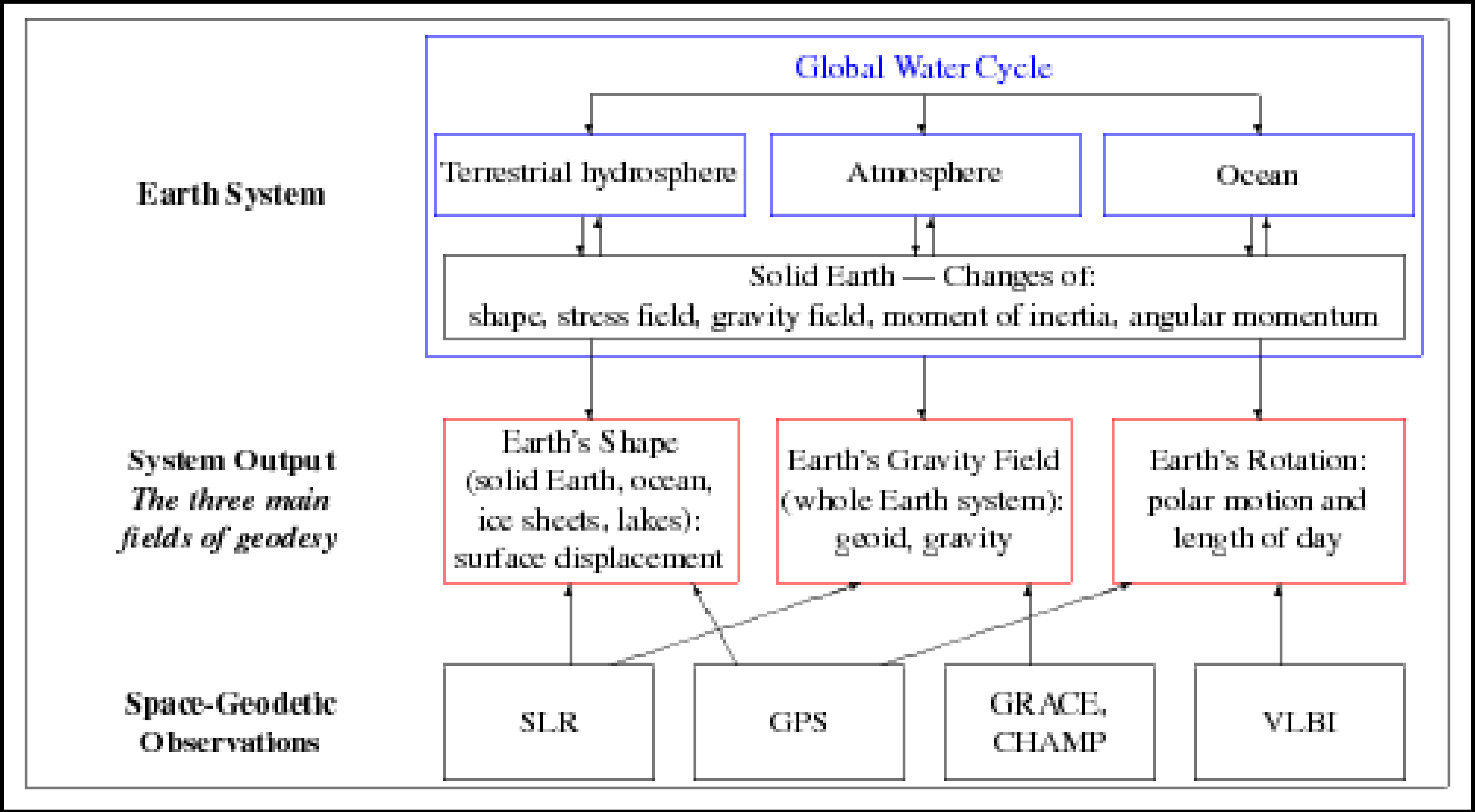


Rainfall from meteorology



Awange et al. (Journal of Spatial Sciences, 2008)

Resolution of Forward Models



- The 'three pillars' are inherently linked with each other.

Resolution of Forward Models

Basic "Loading" Theory:

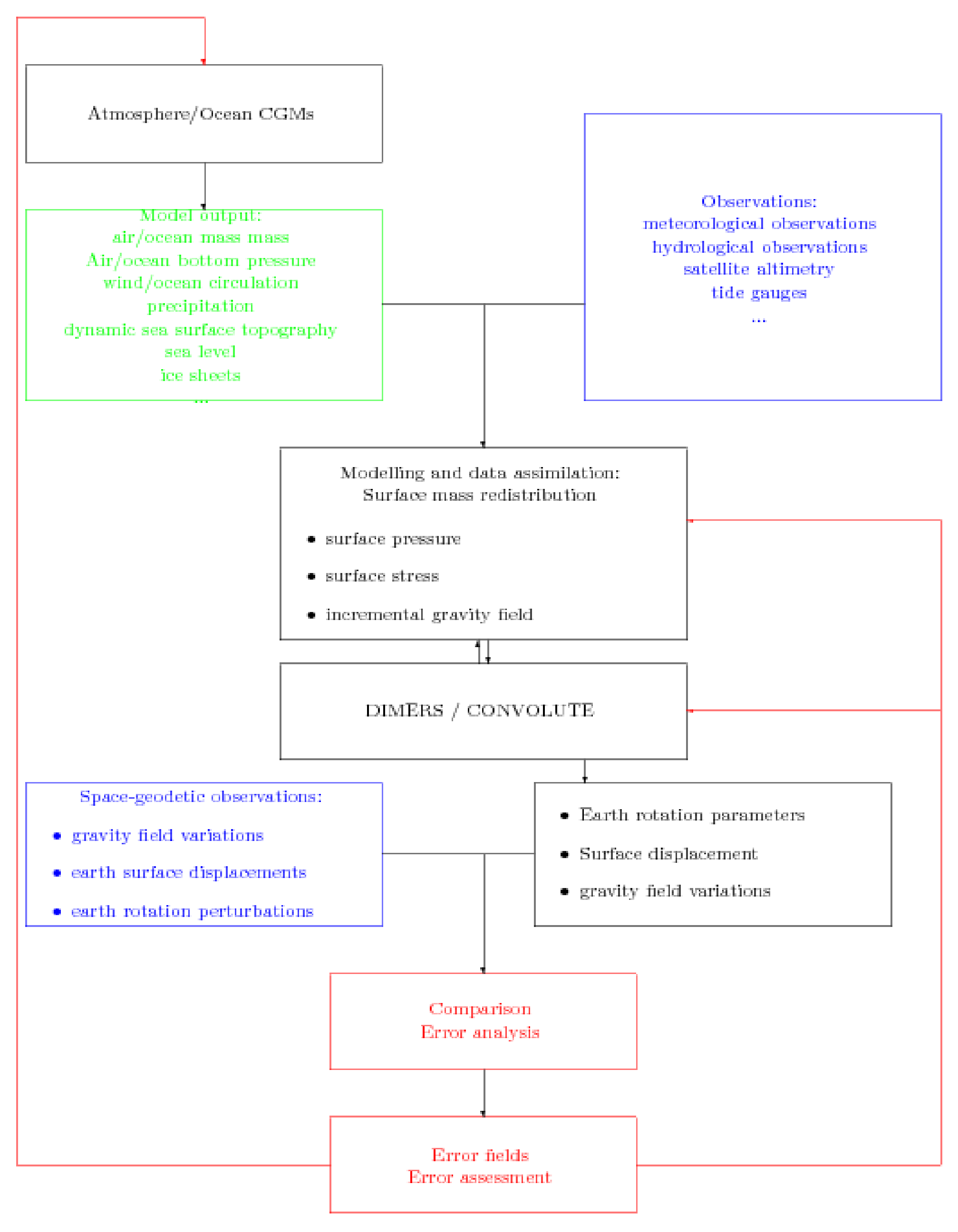
- Mostly used: Green's functions (boundary value problem)
- Basic assumption concerning the load: thin mass distribution.

$$\boldsymbol{u}(\boldsymbol{x},t) = \int_0^\infty \int_S \boldsymbol{G_u}(\boldsymbol{x},\boldsymbol{x}',\tau)L(\boldsymbol{x}',t-\tau)\mathrm{d}^2\boldsymbol{x}'\mathrm{d}\tau$$

$$\delta g(\boldsymbol{x},t) = \int_0^\infty \int_S G_g(\boldsymbol{x},\boldsymbol{x}',\tau)L(\boldsymbol{x}',t-\tau)\mathrm{d}^2\boldsymbol{x}'\mathrm{d}\tau$$

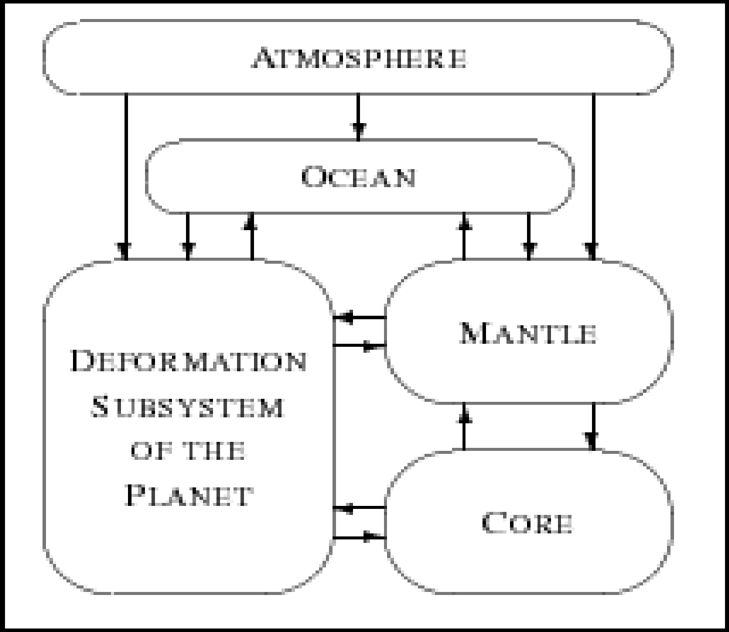
$$\delta\Theta = \int_0^\infty \int_S G_\Theta(\boldsymbol{x},\boldsymbol{x}',\tau)L(\boldsymbol{x}',t-\tau)\mathrm{d}^2\boldsymbol{x}'\mathrm{d}\tau$$

Resolution of Forward Models



We need:

Surface mass distribution (anomaly)
Surface pressure field (anomaly)
Surface stress field (wind, currents)



Resolution of Forward Models

Problems:

- Boundary value problem for deformation and gravity field
- Spatial resolution: << 1 degree;
  high demands in terms of computer resources
- Temporal resolution: << 1 day
- Long initialization times (order 100 years);
- Consistency of models and observations
- Mass conservation in the water cycle

Challenges for Large-Scale Geodesy and Hydrology

Synthesis/simulation instead of separation

Initial value problem for assimilation in time-domain models

Appropriate hydrological equations for regional to global scales

Developing the Global Geodetic Observing System into a Monitoring System for the Global Water Cycle

IGCP 565 Science Issues

- The development of an integrated dynamic model for the prediction of geodetic signals due to daily to interannual surface mass changes.
- (Inversion algorithms for combined geodetic observations for surface mass changes.)
- Assimilation of the observations in integrated predictive models of the hydrological cycle.
- Development of products relevant for regional water management.

Local Approaches and Techniques

- In-situ gravity measurements
- Co-located GNSS observations
- InSAR

Gravity anomaly: $\delta g(t) = g(t) - g(t_0)$;

$$\delta g = \delta g_u + \delta g_m,$$

$$\delta g_u = -2ug/a = \beta u,$$

$g(t)$: gravity measured at time t;
t_0: arbitrary reference time;
δg_u: anomalies due to the vertical displacement $u(t) = h(t) - h(t_0)$ of the instrument through the unperturbed gravity field;
a: Earth's radius;
$\beta \approx -3.086\ \mathrm{nms}^{-2}/\mathrm{mm}$;
h: vertical position of the gravimeter.

δg_m: actual mass effect caused by concurrent mass redistribution.

Validation of method
Forward modeling of gravity/deformation as function of hydrology
Assimilation of observations in hydrological models

Summary/Conclusions

All geodetic observations are integral quantities on regional to global scale;
The "three pillars" are inherently linked to each other;

"Separation" of contributions is not unique;
Inversion has no predictive capability;

Increased predictive capability and spatial resolution through assimilation of geodetic observations in Earth system models;
Focus on Earth system model development;

On local scale, combination of displacement and gravity changes provide useful constraints for hydrology.

Developing the Global Geodetic Observing System into a Monitoring System for the Global Water Cycle

IGCP 565 Workshop 1

IUGS UNESCO IGCP

December 11, 2008, San Francisco (prior to GRACE Science Team meeting): Science of geodetic monitoring of the hydrological cycle

Workshop will:

- Review the state of the art in understanding the quantitative fluxes in the global water cycle;
- Consider the relation between geodetic observations and mass changes in the main reservoirs of the water cycle;
- Clarify the open science questions that the geodetic observations can help to reconcile;
- Report to the GRACE Science Team meeting.

Developing the Global Geodetic Observing System into a Monitoring System for the Global Water Cycle

Summary/Conclusions

The Global Geodetic Observing System has a great potential to contribute to monitoring of the global water cycle, including groundwater changes, on global to regional scales.

The IGCP 565 Project will exploit this potential for support of regional water management.

The IGCP 565 Project will focus on regional applications in Africa.

Developing the Global Geodetic Observing System into a Monitoring System for the Global Water Cycle

IGCP 565 Workshop 4

2011: Integration of geodetic observations and products in models of the hydrological cycle

- Workshop will focus on algorithms for assimilation of geodetic observations and products into models of components (terrestrial, atmosphere, ocean) the global water cycle.
- Assess the improvements in terms of accuracy, spatial and temporal resolution, and predictive capabilities of the models.

Developing the Global Geodetic Observing System into a Monitoring System for the Global Water Cycle

IGCP 565 Workshop 5

2012: Improving regional water management in Africa and Asia on the basis of geodetic water cycle monitoring

- Workshop will bring together representatives of regional water management authorities and representatives of the research and observation communities involved in the project activities.
- Assess the requirements of regional water management, in particular in developing countries, in terms of products derived from space-geodetic observations and the associated models.
- The goal is to define a set of products in terms of parameter, spatial and temporal resolution, accuracy, and latency, which can be made available in support of regional water management.

Over the last three decades, space-geodetic observations have increased in accuracy by about an order of magnitude every decade. Today, space-geodetic techniques allow the determination of positions with respect to a global reference frame with unprecedented accuracy. The techniques permit the measurement of changes in the geometry of the Earth's surface with an accuracy of millimeters over distances of several 1000 km. Moreover, geodetic imaging techniques increasingly gain importance, particularly when integrated with the traditional point-based approach of geodesy. Gravity satellite missions measure time-variable gravity with unprecedented accuracy, and the accuracy observations of time-variable Earth rotation has increased with a comparable speed. Based on these techniques, temporal changes in the Earth's shape, rotation and gravity field (the “three pillars” of geodesy) are provided with increasing accuracy and spatial and temporal resolution. Among others, these observations record the “fingerprints” of mass movements in ocean, atmosphere, ice sheets and terrestrial water storage. On time scales of months to decades, mass redistribution in the fluid envelop of the solid Earth in fact induces the most dominant persistent signals in geodetic observations.

Most importantly, the three pillars are linked through one unique Earth system. Changes in Earth's shape and rotation lead to gravity field changes, and changes in rotation and gravity field force changes in Earth's shape. Changes in these quantities induce mass redistribution particularly in ocean and atmosphere. Therefore, the traditional approach of geodetic analyses which aims at separation of the different contributions does not appear appropriate at a level where the interaction between atmosphere, ocean, terrestrial hydrosphere, and solid Earth are far above the accuracy level. Moreover, observations of the “three pillars” provide the basis for the realization of the reference system that is required in order to assign time-dependent coordinates to points and objects, and the accuracy of the reference frame is related to the accuracy to which time-dependent changes in the three pillars can be predicted. Predicting the geodetic signals cause by surfical mass relocation with an accuracy comparable to that of the observations requires a Earth system model taking into account these interactions. Analysing the geodetic observations jointly will allow for an exploration of the strengths of the individual techniques and a mitigation of their weaknesses. Combination of space-geodetic observations and in-situ observations helps to increase the spatial resolution.