Geodetic Monitoring of the Global Water Cycle: Potential and Status

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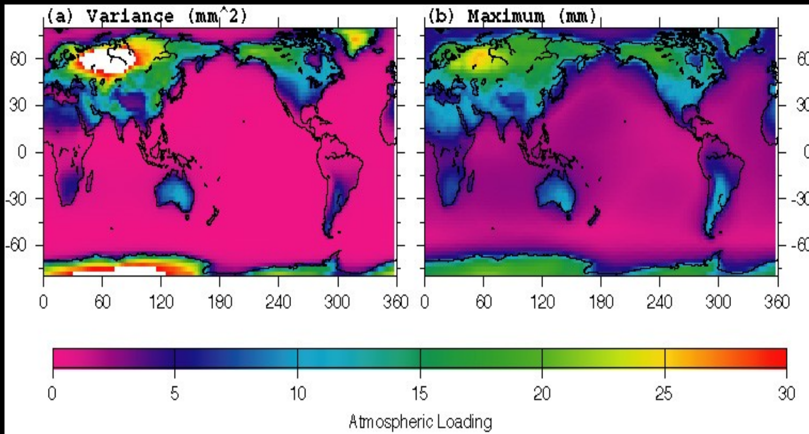
Geodetic Monitoring of the Global Water Cycle: Potential and Status

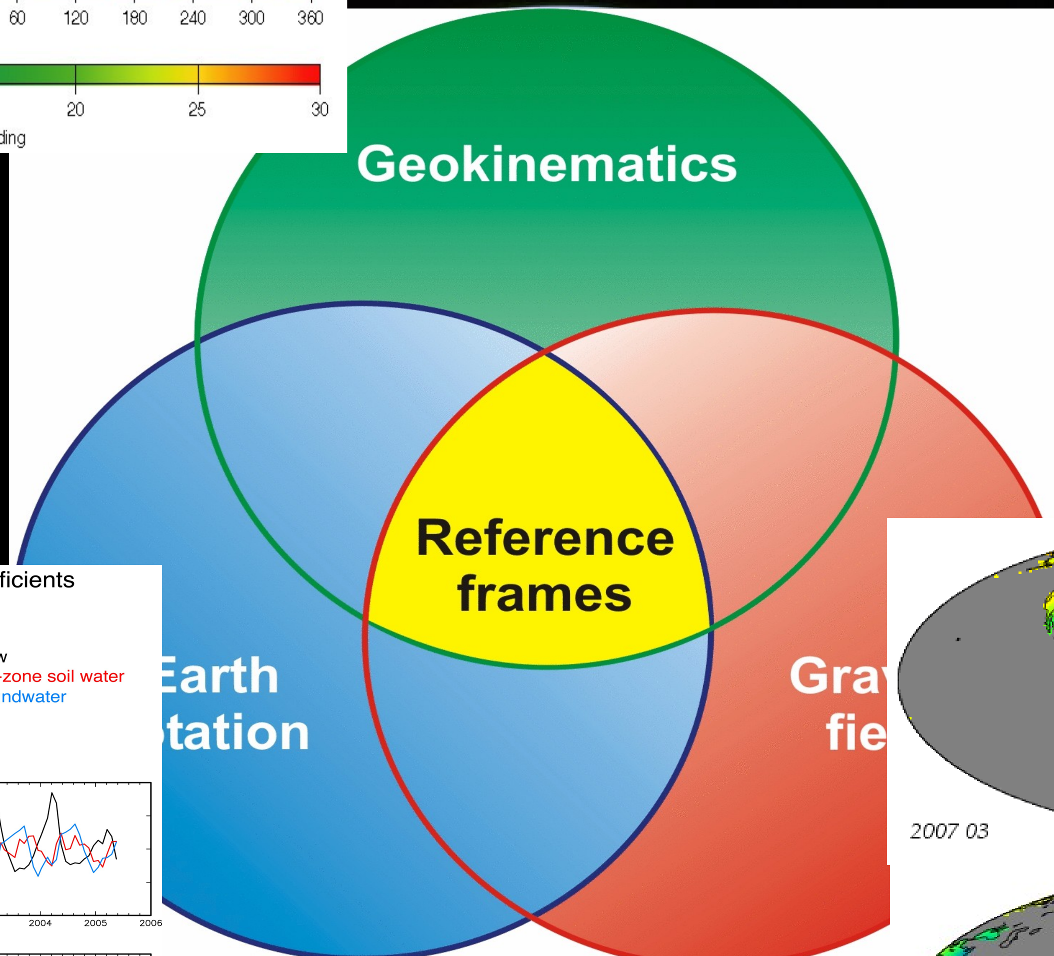
- Introduction
- Mass Relocations and Geodesy
- Global Geodetic Observing System (GGOS) and Observations
- Approach to Modeling/Analysis and Challenges
- Conclusions and Status

Introduction



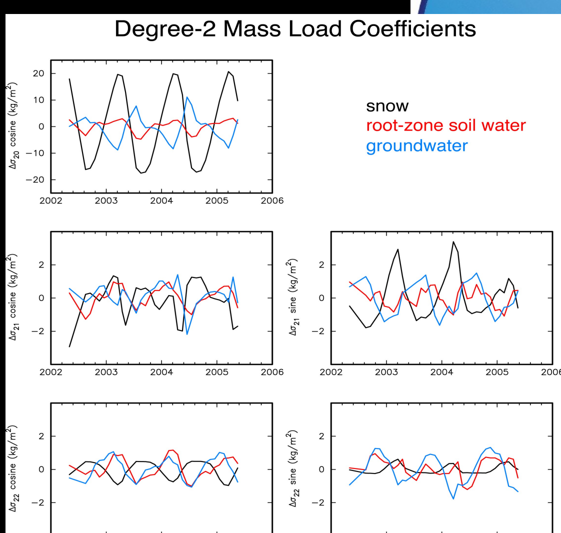
The 'three pillars of geodesy':

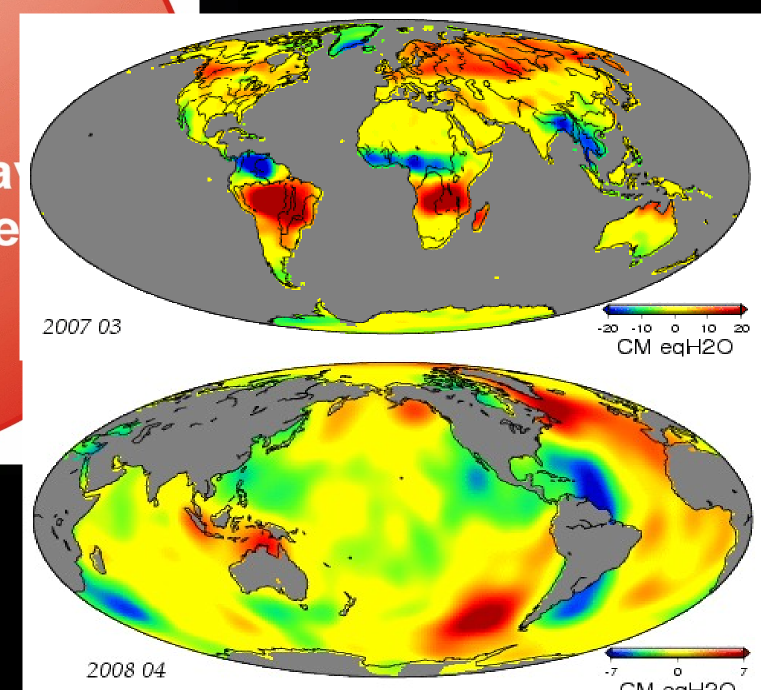
- Earth's Shape (Geokinematics)
- Earth's Gravity Field
  Earth Rotation



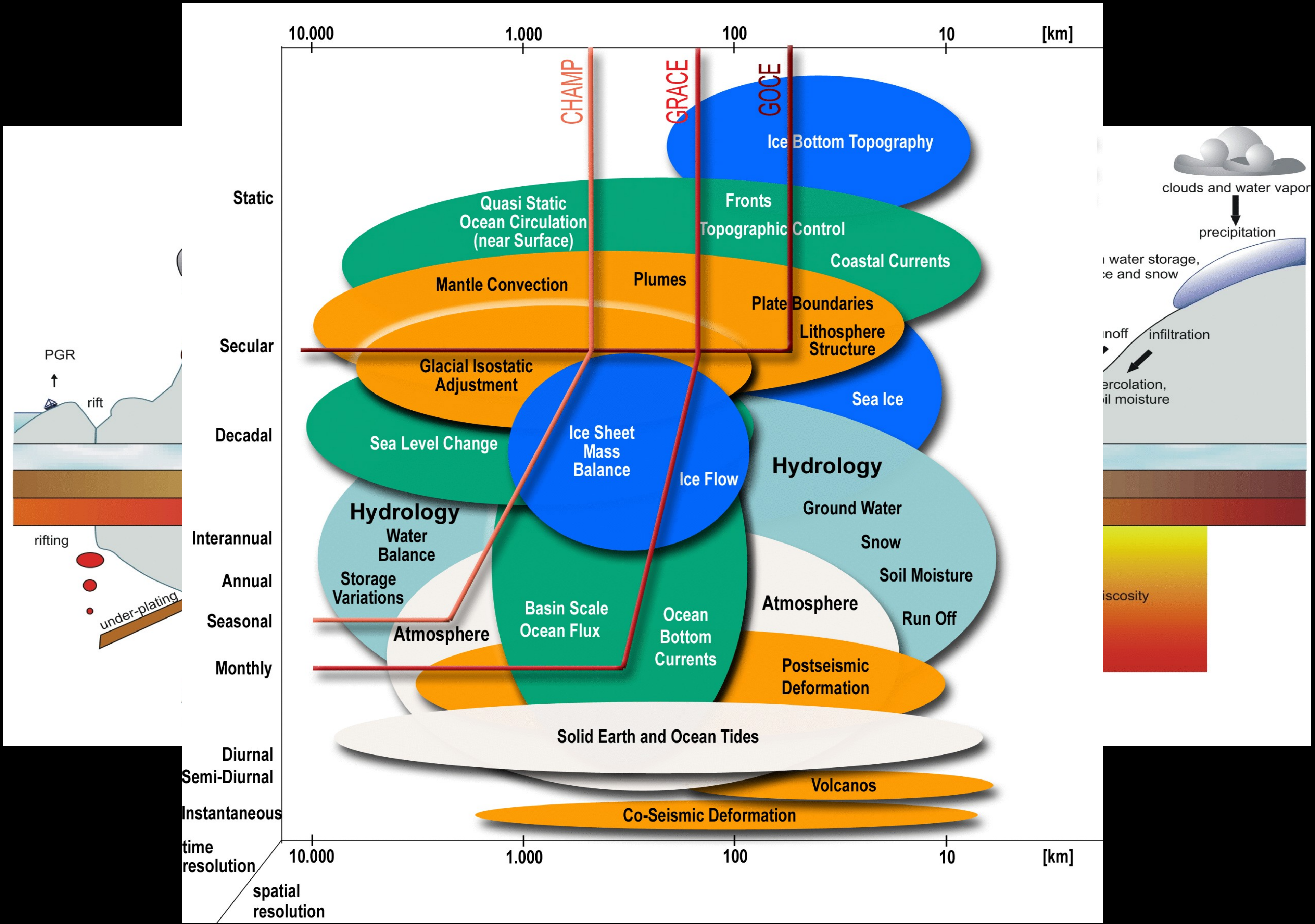
Output:

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





Mass Relocation and Geodesy



Mass Relocation and Geodesy

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

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

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

(Local) geodetic variables are inherently global and have memory ...

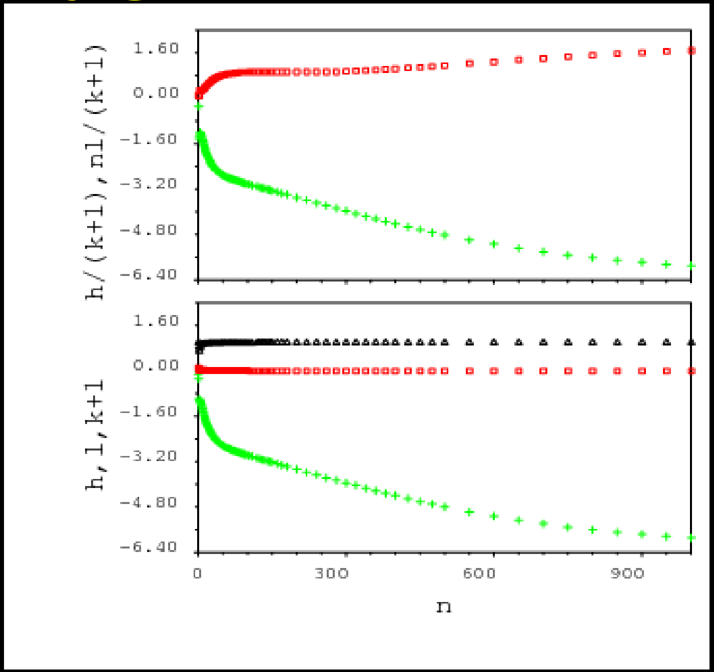
Unit load at North Pole,
SNREI Earth model:

$$u_r(a,\vartheta,\phi) = \frac{M_\circ a}{M}\sum_{n=0}^{\infty} h'_n P_n(\cos\vartheta)$$

$$u_\vartheta(a,\vartheta,\phi) = \frac{M_\circ a}{M}\sum_{n=0}^{\infty} \ell'_n \frac{\partial}{\partial\vartheta} P_n(\cos\vartheta)$$

$$u_\phi(a,\vartheta,\phi) = 0$$

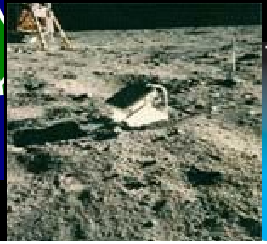
$$\varphi(a,\vartheta,\phi) = \frac{M_\circ G}{a}\sum_{n=0}^{\infty} (k'_n + 1) P_n(\cos\vartheta)$$

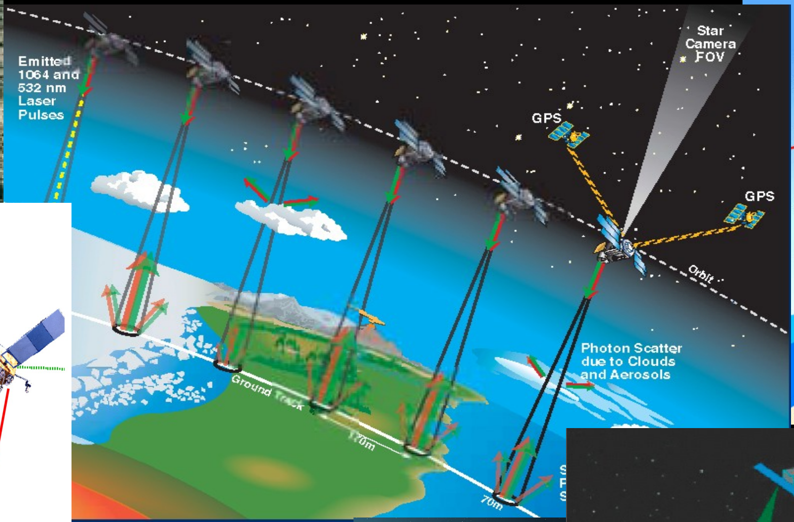


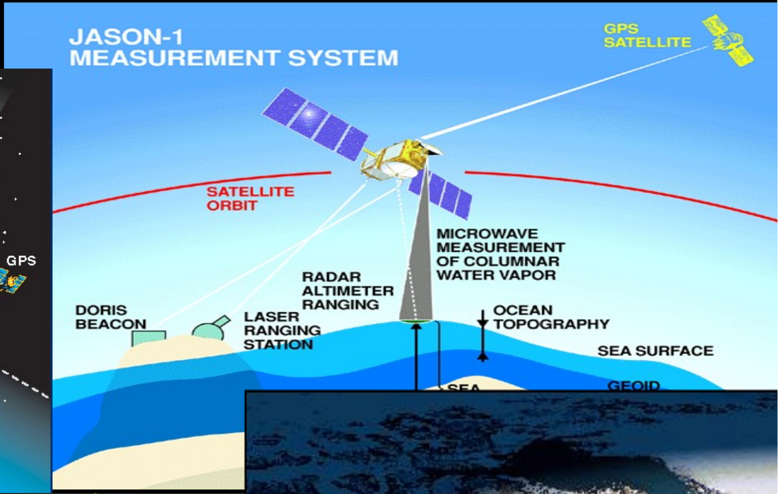
h: green
l: red
k: black

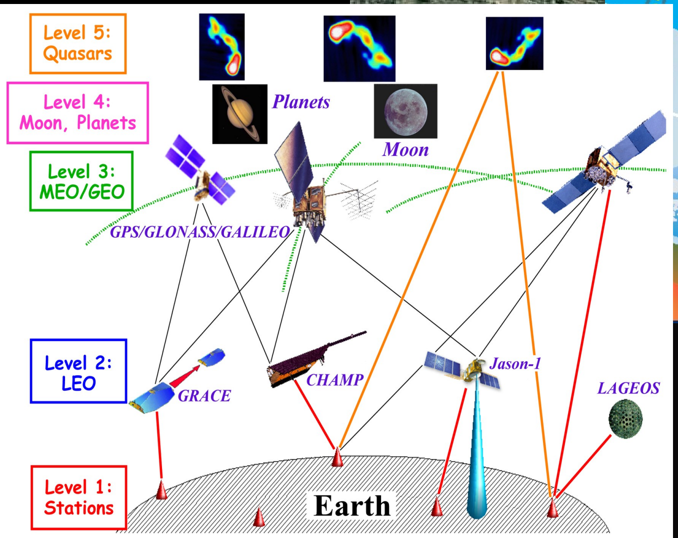
Small spatial scales:
Vertical displacement is most sensitive

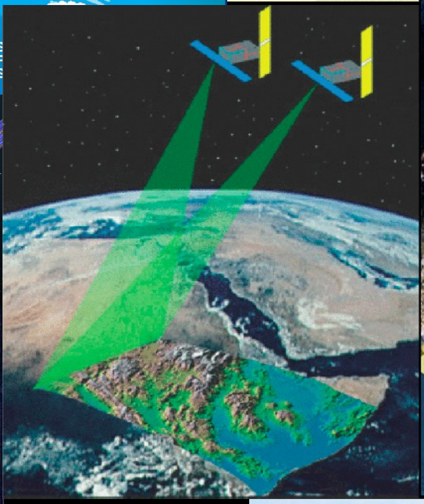
The Global Geodetic Observing System

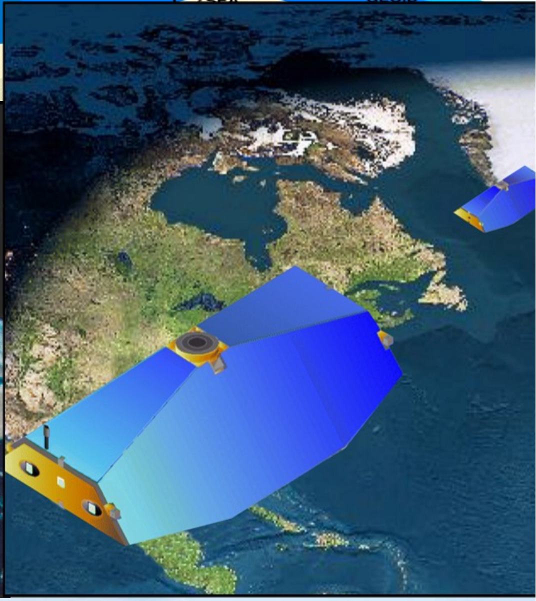


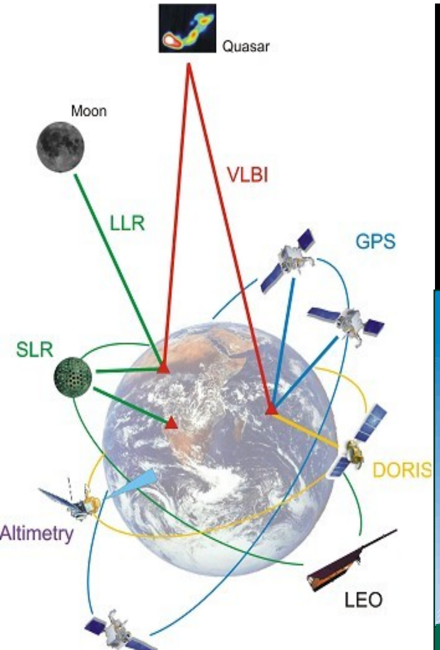


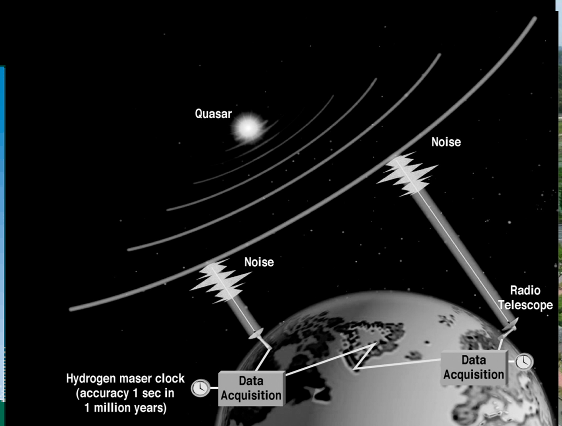




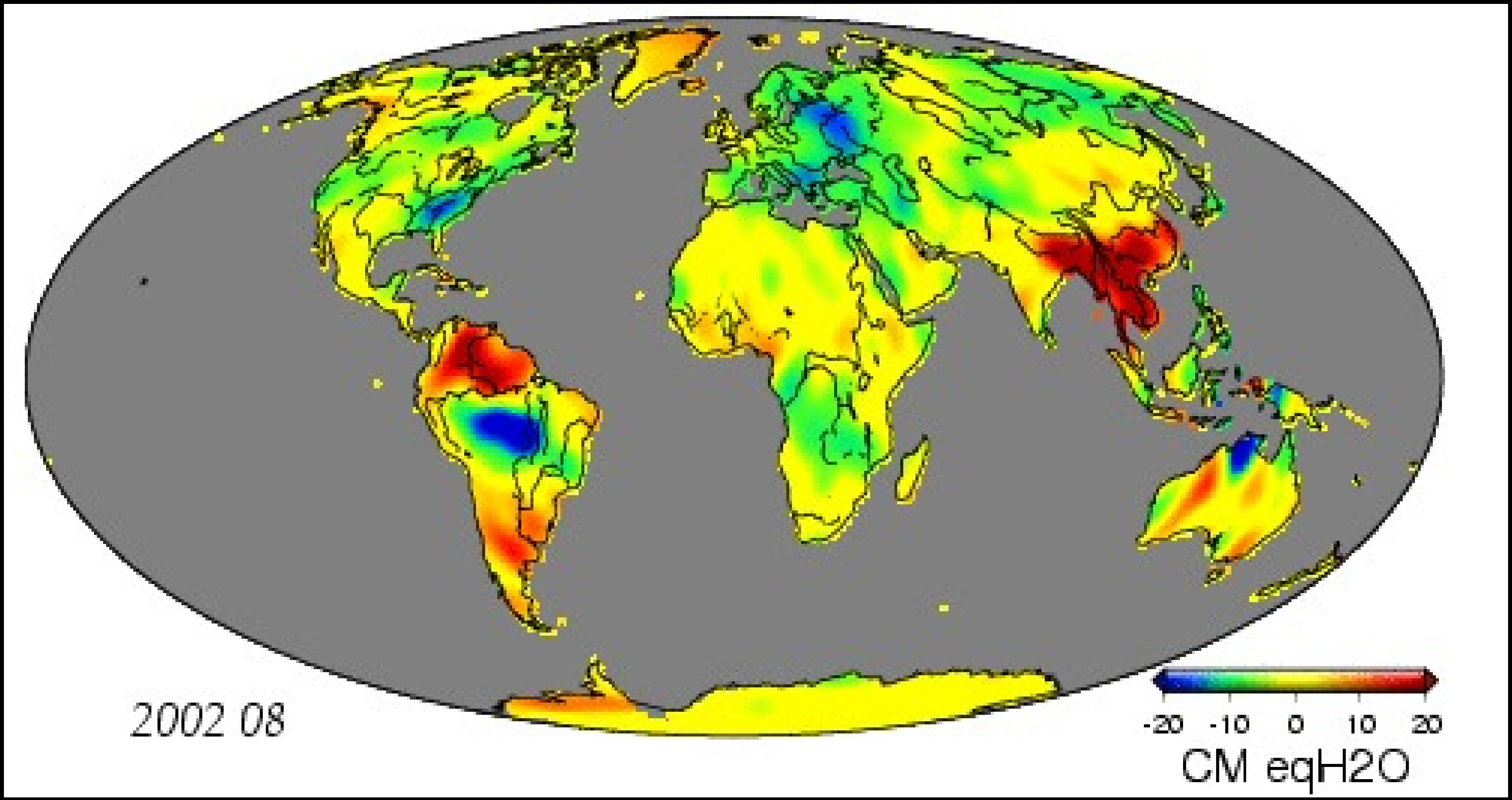






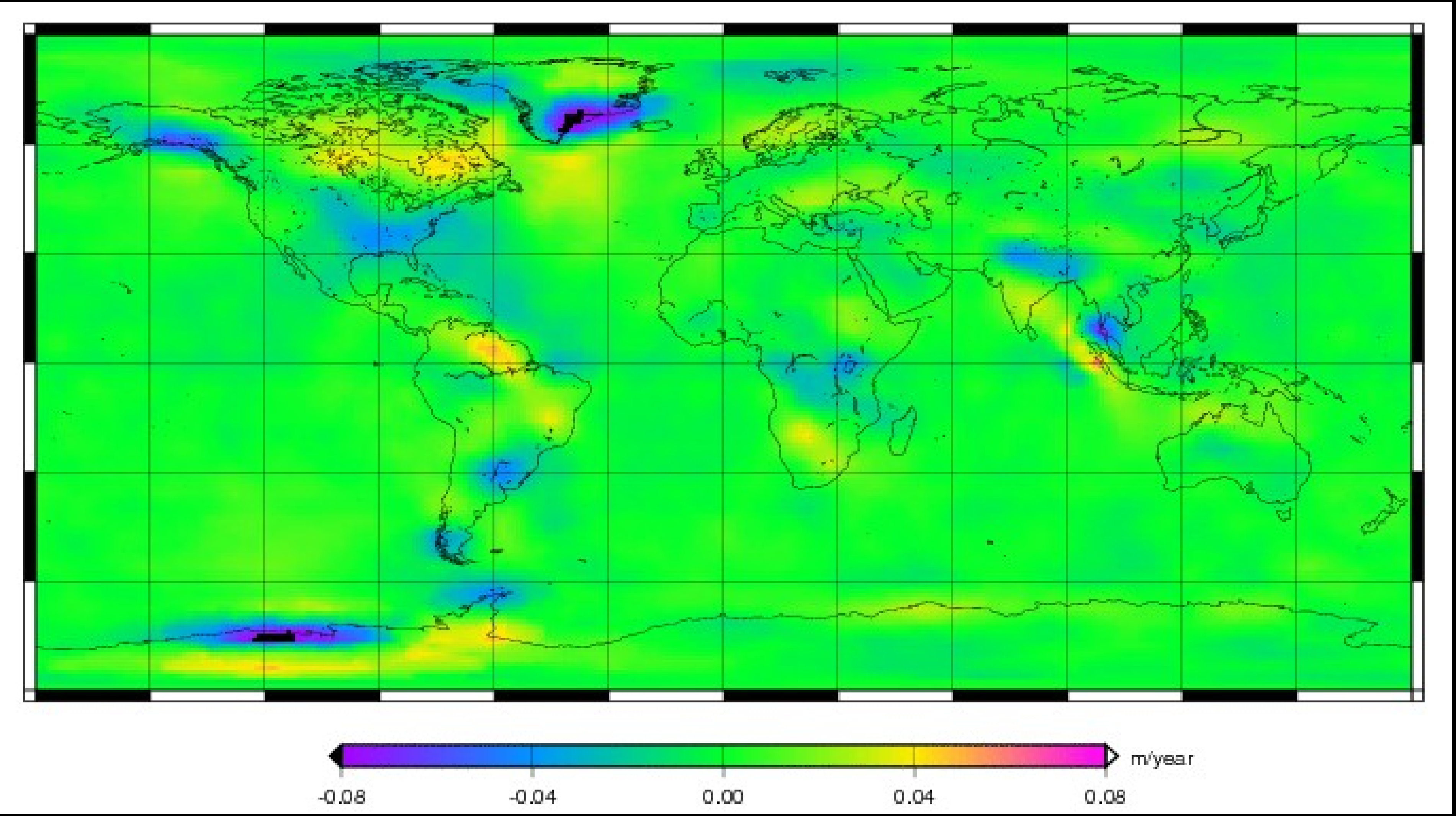


Observations



http://grace.jpl.nasa.gov/information/

Observations



JPL MASCON, secular trends 2003-2007, Watkins, 2008

Approach and Challenges

- Spatial resolution
- Temporal resolution
- Aliasing (spatial and temporal)
- Correlation of fingerprints from different processes
  (biases in separated contributions)
- Modeling of 'known' contributions

Approach and Challenges

'Trail and Error': compare model predictions to observations and modify model until a satisfactory agreement is achieved.

'Inversion': take geodetic observation and estimate (water cycle) model parameter in a LSQ-fit or by other estimation procedures

'Simulation': propagate a model (physical, empirical, hybrid) over time by integration, Kalman filter, or other methods

Approach and Challenges

Inversion:
Advantage:
- scientifically interesting
Problems:
- Base/model functions for inversion
- Effect of ocean, atmosphere
- 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

Simulation/Assimilation:
Advantages:
- identification of emerging properties (complexity of system);
- Insensitive to uneven data resolution;
- some predictive capability;
Problems:
- Complexity of models
- Assimilation kernels for geodetic observations

Approach and Challenges

Two questions related to simulation/assimilation:

(1) What could be a framework for integrated model development?

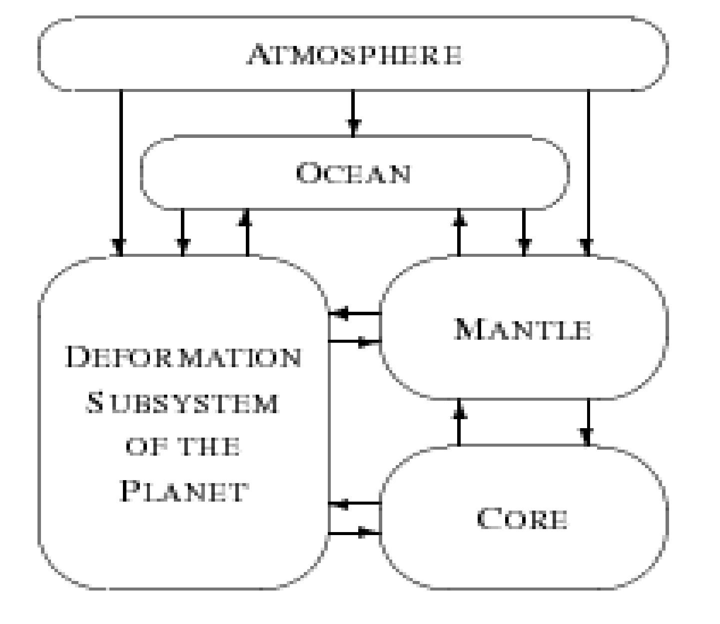
(2) How good are our forward models?

Answer to (1):

- Modular model of independent modules coupled by boundary conditions and volume forces;
- Calibrated and validated for GRACE time

Problems:

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



Answer to (2):

- More complex ...

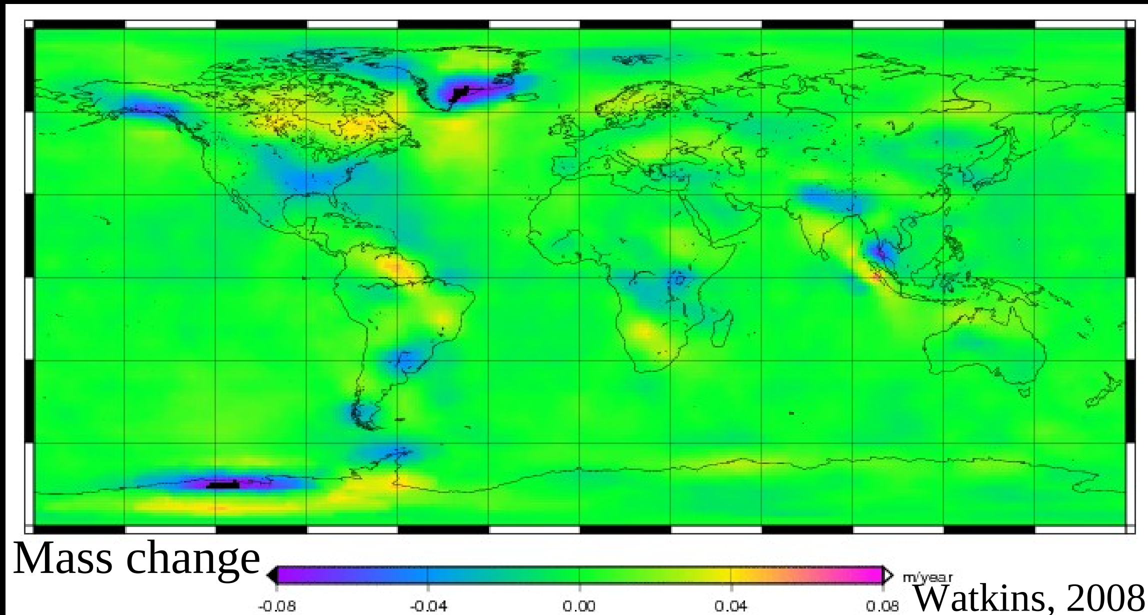
Approach and Challenges

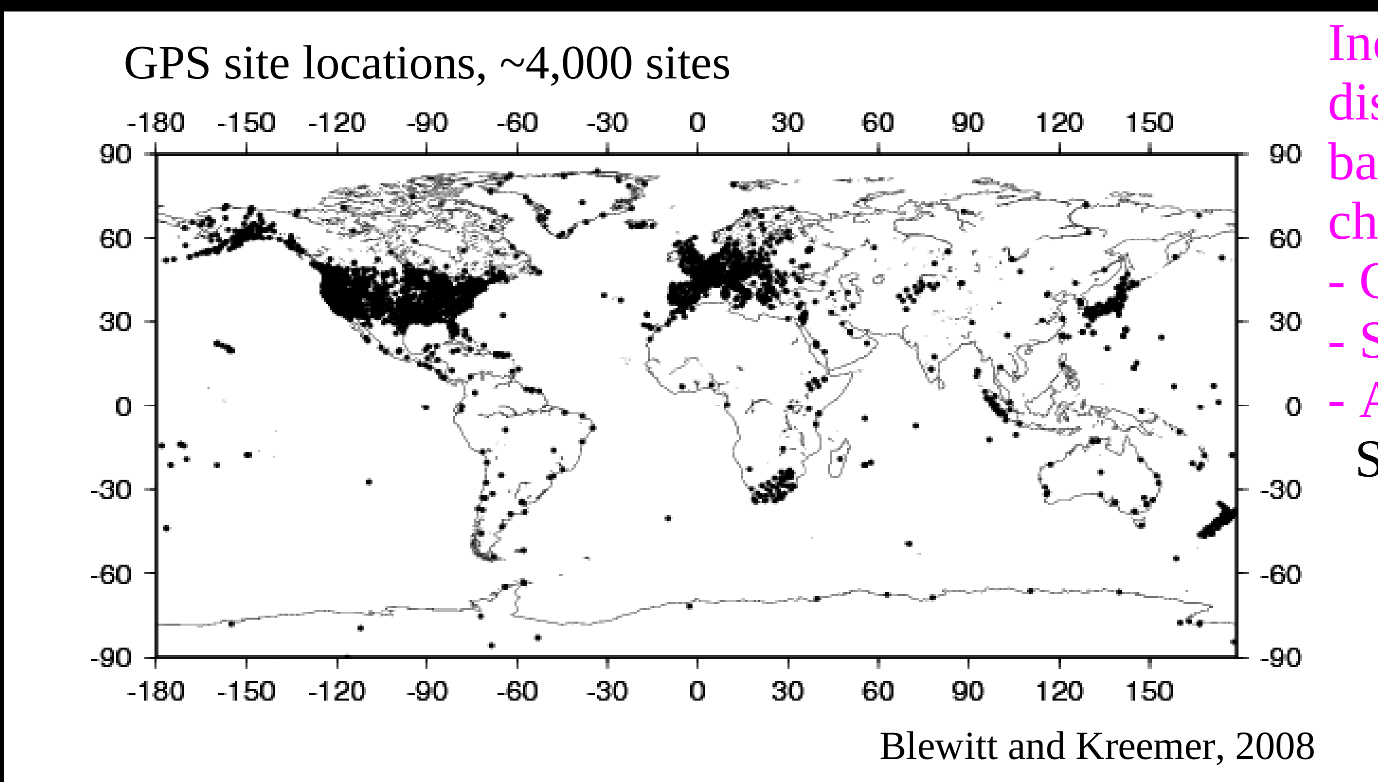
Some examples of problematic modules:

Module	Process	Status
atmosphere	loading	significant differences depending on pressure field, spatial resolution, ocean response
ocean	non-tidal loading	significant differences depending on ocean model
atmosphere	angular momentum	differences depending on meteorological model
cryosphere	Post-Mass Response	significant differences depending on ice history and Earth model
cryosphere	Co-Mass Response	significant differences depending on Earth model and approach

In most cases: Observation accuracy exceeds model accuracy

Approaches and Challenges





Spatial gaps hamper integration of gravity and displacements

Validation of response functions, mass change models, ice sheet dynamics models:

Increased observations (surface displacements, gravity, mass balance) in areas with large mass changes, in particular:

- Greenland;
- Svalbard;
- Antarctica and southern South America .

Conclusion

For higher spatial resolution, integration of gravity and displacements;

Observation accuracy exceeds model accuracy;

Large spatial gaps in displacements hamper full integration.

We need to improve/validate our forward models

We need to integrate the solid Earth into Earth system models

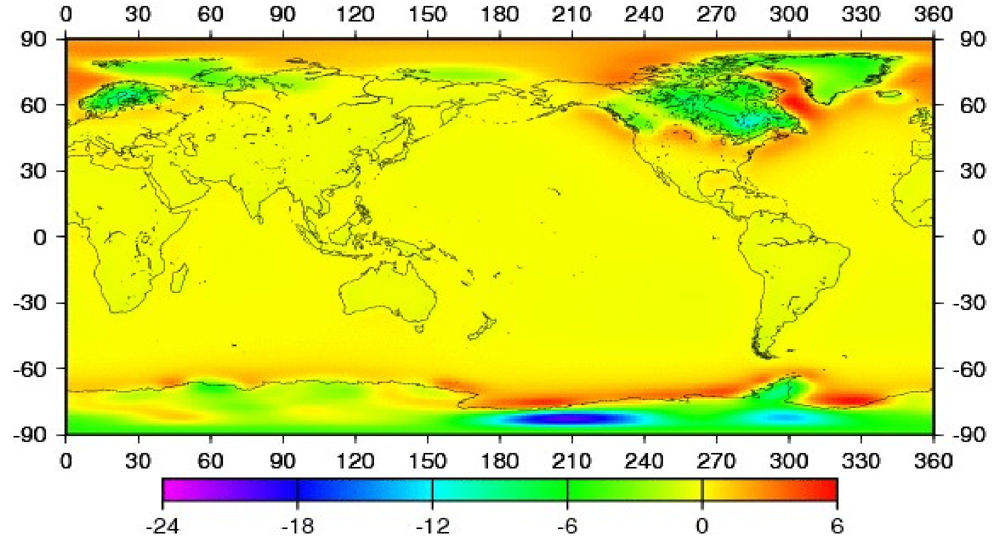
We need a major community effort focusing on solid Earth modeling comparable to the efforts on climate modeling

Complexity of Water Cycle (= Earth System) renders reductionist approach inappropriate

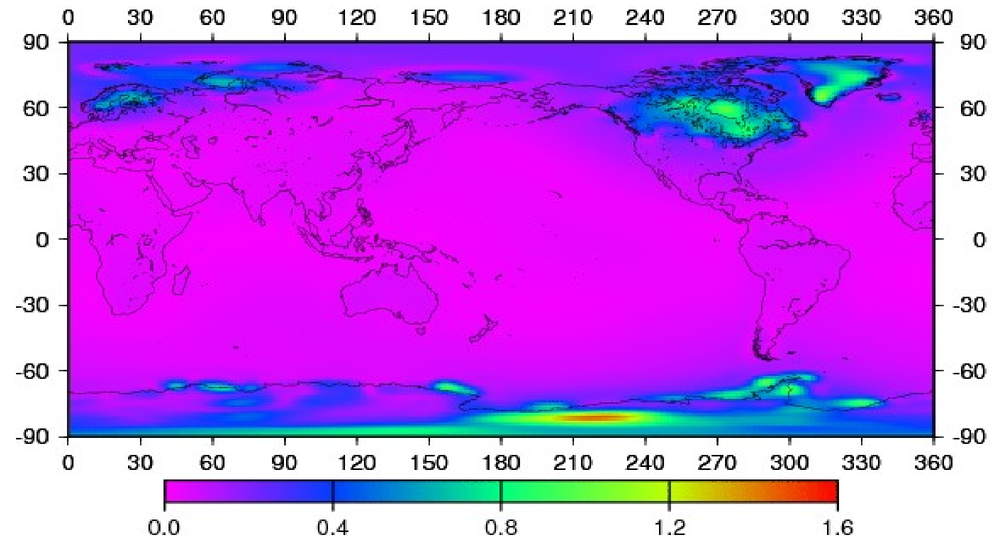
Emergence, based on observed characteristics: Earth observations are central

Approach and Challenges

Mean



Standard Deviation



Post-Mass Response (PMR):
- 14 Local Sea Level trend predictions
- 3 groups
- ICE-3G and ICE-5G
- 10 different mantle viscosities

(all values in mm/yr)

In areas with large signals, standard deviation ~ 10%

Approach and Challenges

Co-Mass Response (CMR):

Significant differences in predicted Local Sea Level Fingerprints

Response calculated with PMR models have much small spatial variability than models based on an elastic loading approach

For Greenland:

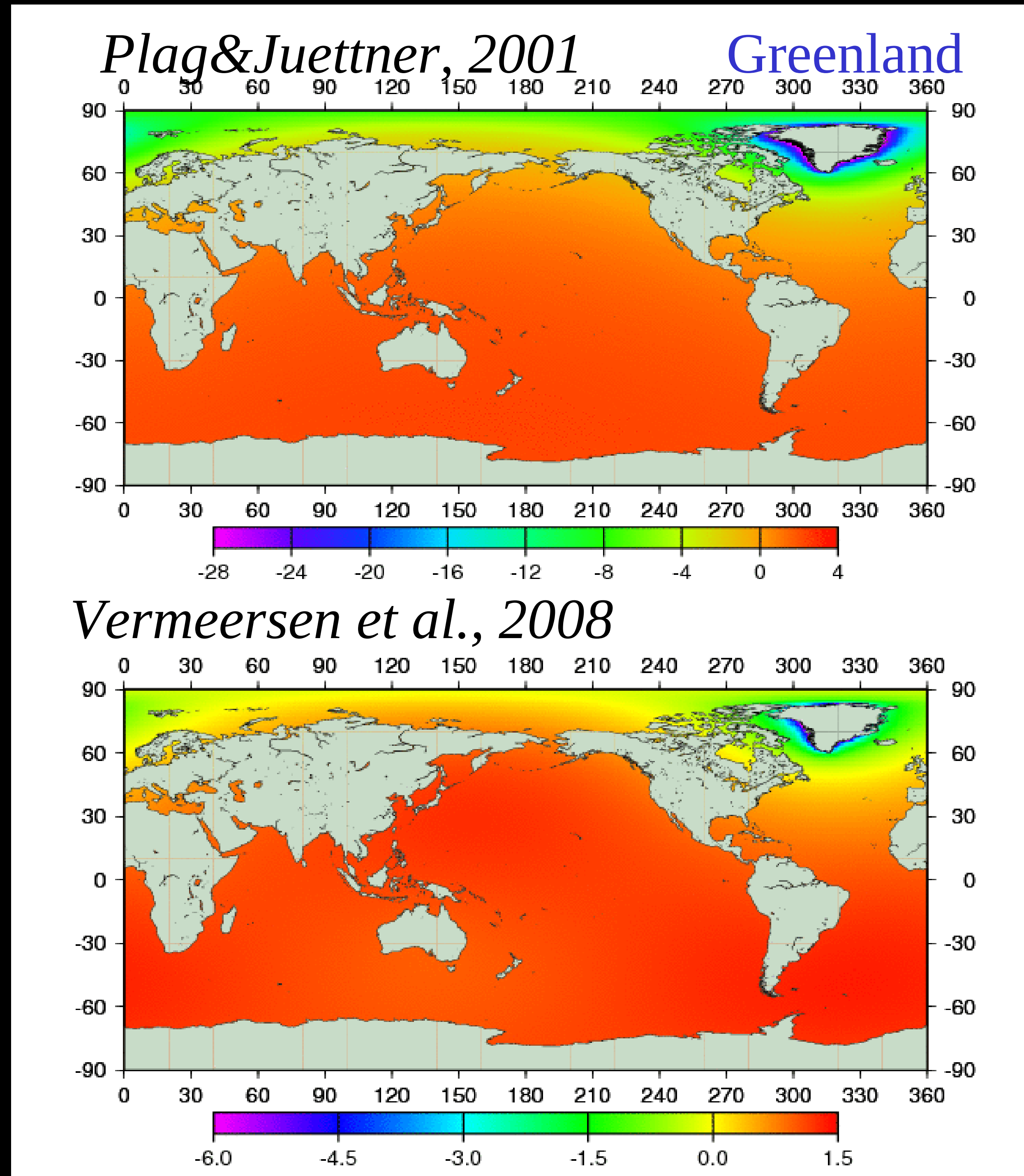
-6 to 1.4 versus

-25 to 3.0

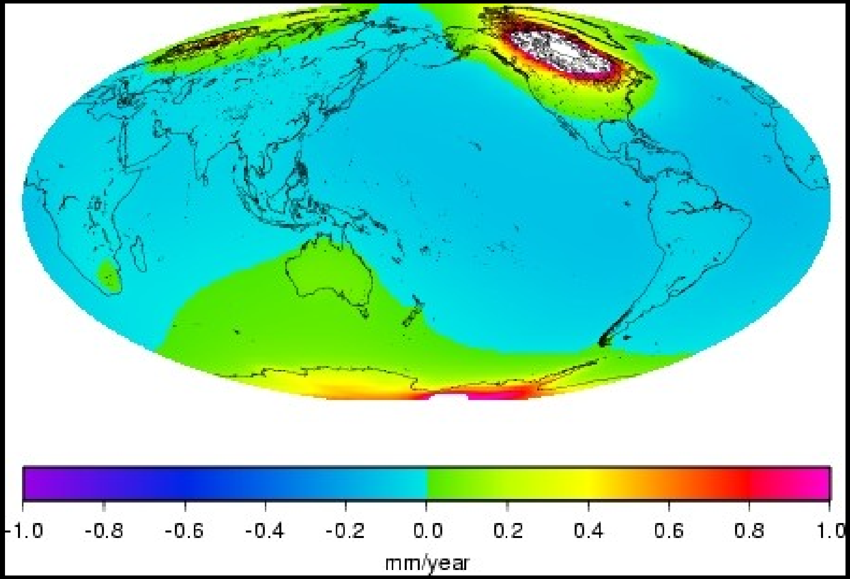
Both models are currently not validated!

Svalbard observations:

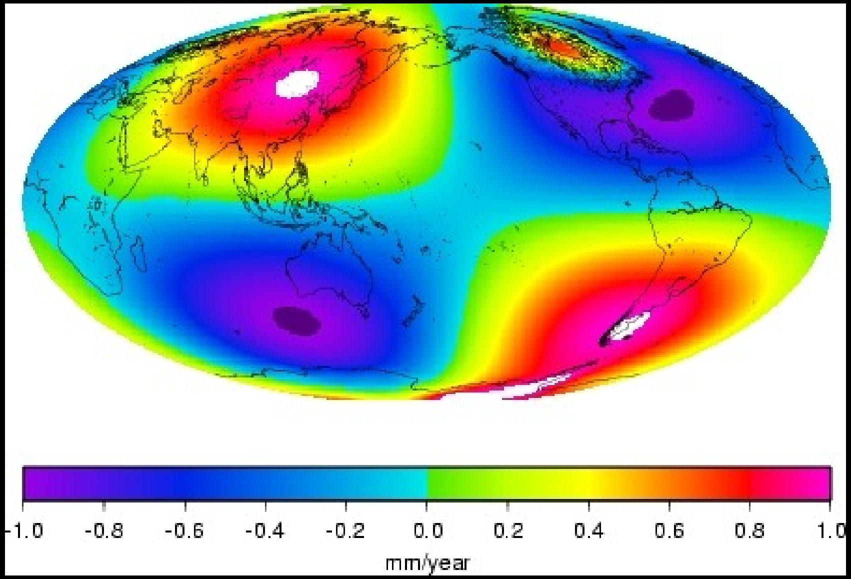
-60 close to ice load



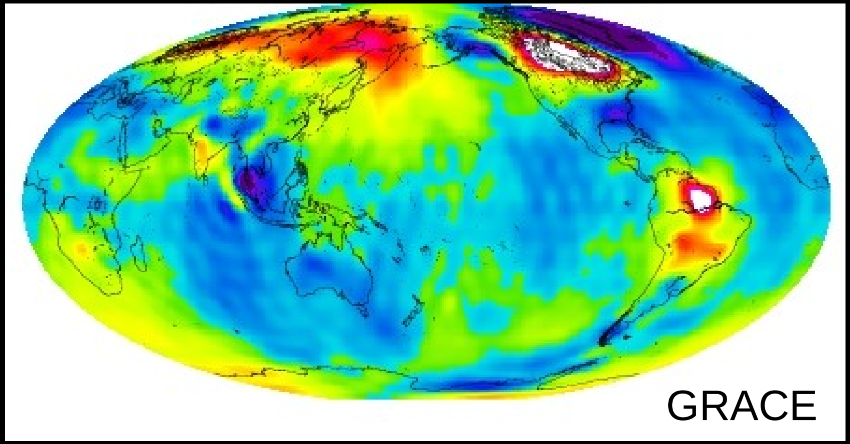
Approach and Challenges



Paulson et al., 2007



Peltier, 2004



Predicted geoid rates from different PGR models compared with observed rates from GRACE when no correction is applied

Chambers et al, 2009