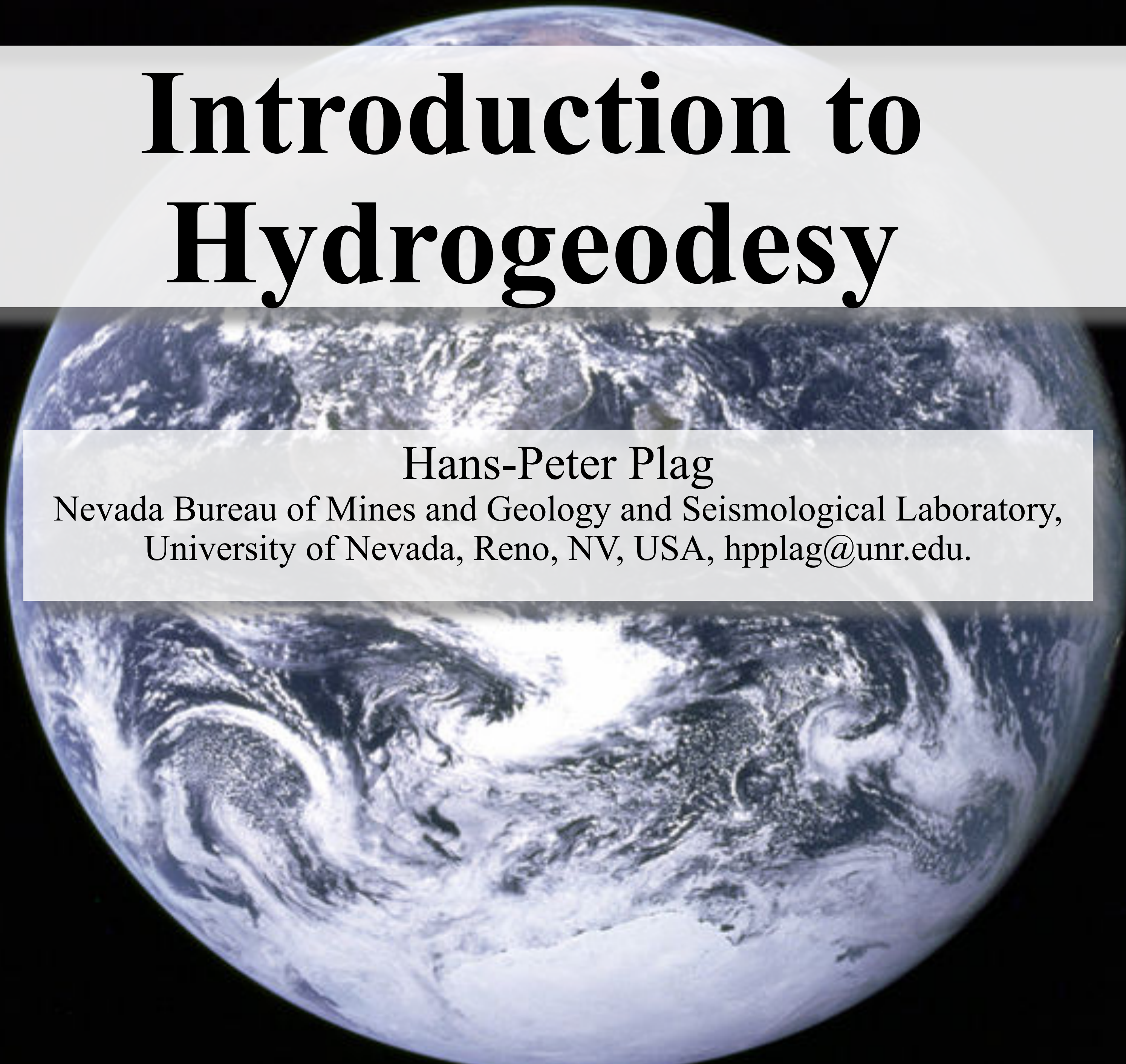
Introduction to Hydrogeodesy

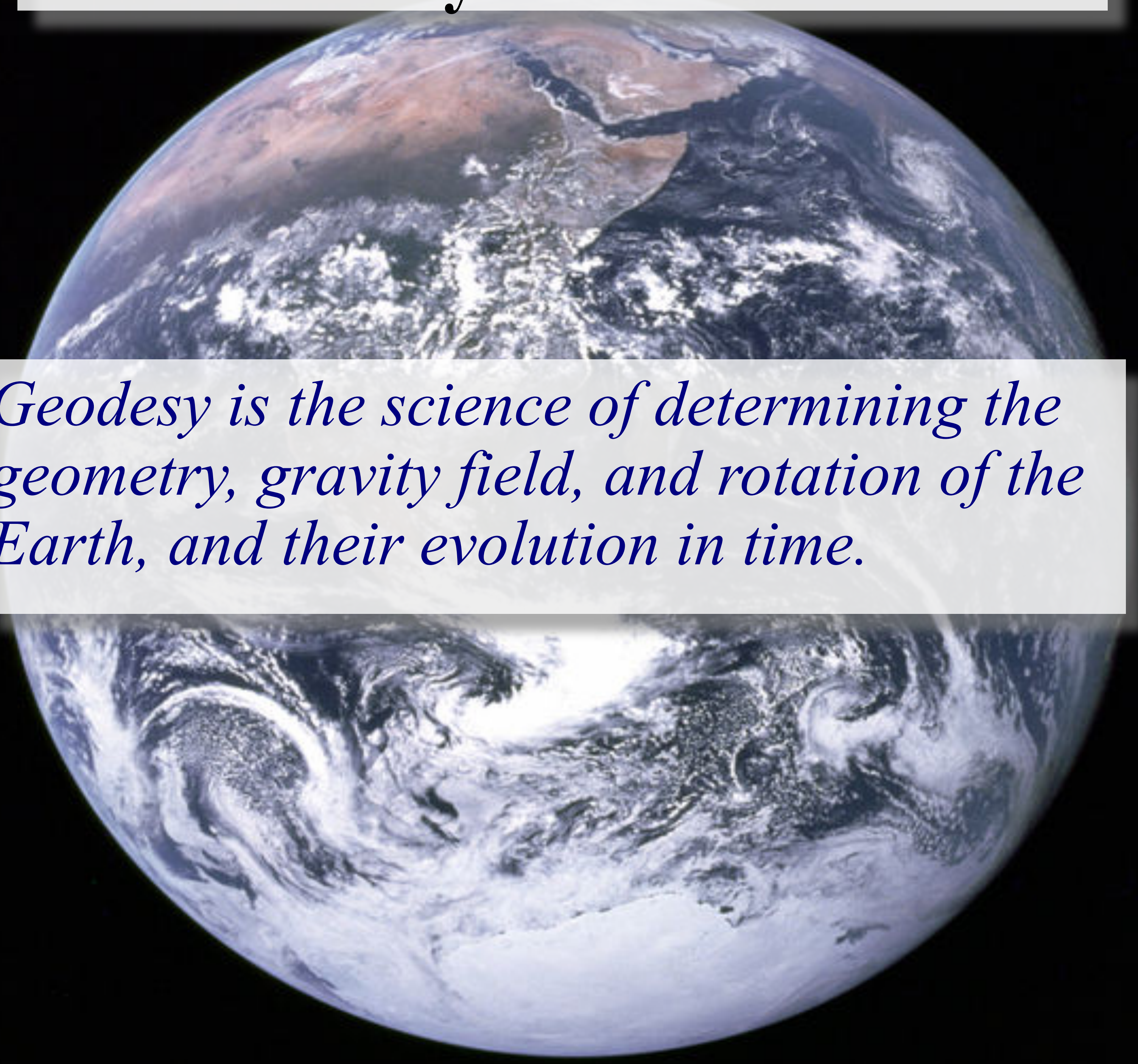
Hans-Peter Plag
Nevada Bureau of Mines and Geology and Seismological Laboratory,
University of Nevada, Reno, NV, USA, hpplag@unr.edu.



Introduction to Hydrogeodesy

- Geodesy - the Science
- The “Three Pillars” of Geodesy
- Reference Frames
- Hydrogeodesy
- The Hydrogeodesy Pillars: Examples
- Societal Benefits
- Available Products
- Results and Critical Issues
- The Globale Framework

Geodesy - The Science



Geodesy is the science of determining the geometry, gravity field, and rotation of the Earth, and their evolution in time.

Geodesy - The Science

Measuring position and motion requires a coordinate system.

Geodesy - The Science

Measuring position and motion requires a coordinate system.

Assigning coordinates to points and objects on Earth, and to describe Earth's motion in space, we need to measure Earth's shape, gravity field, and rotation.

Geodesy - The Science

Measuring position and motion requires a coordinate system.

Assigning coordinates to points and objects on Earth, and to describe Earth's motion in space, we need to measure Earth's shape, gravity field, and rotation.

For this purpose, two reference systems are intrinsic in geodesy:
- International Celestial Reference System (ICRS)
- International Terrestrial Reference System (ITRS)
and these are connected through Earth Rotation.

Geodesy - The Science

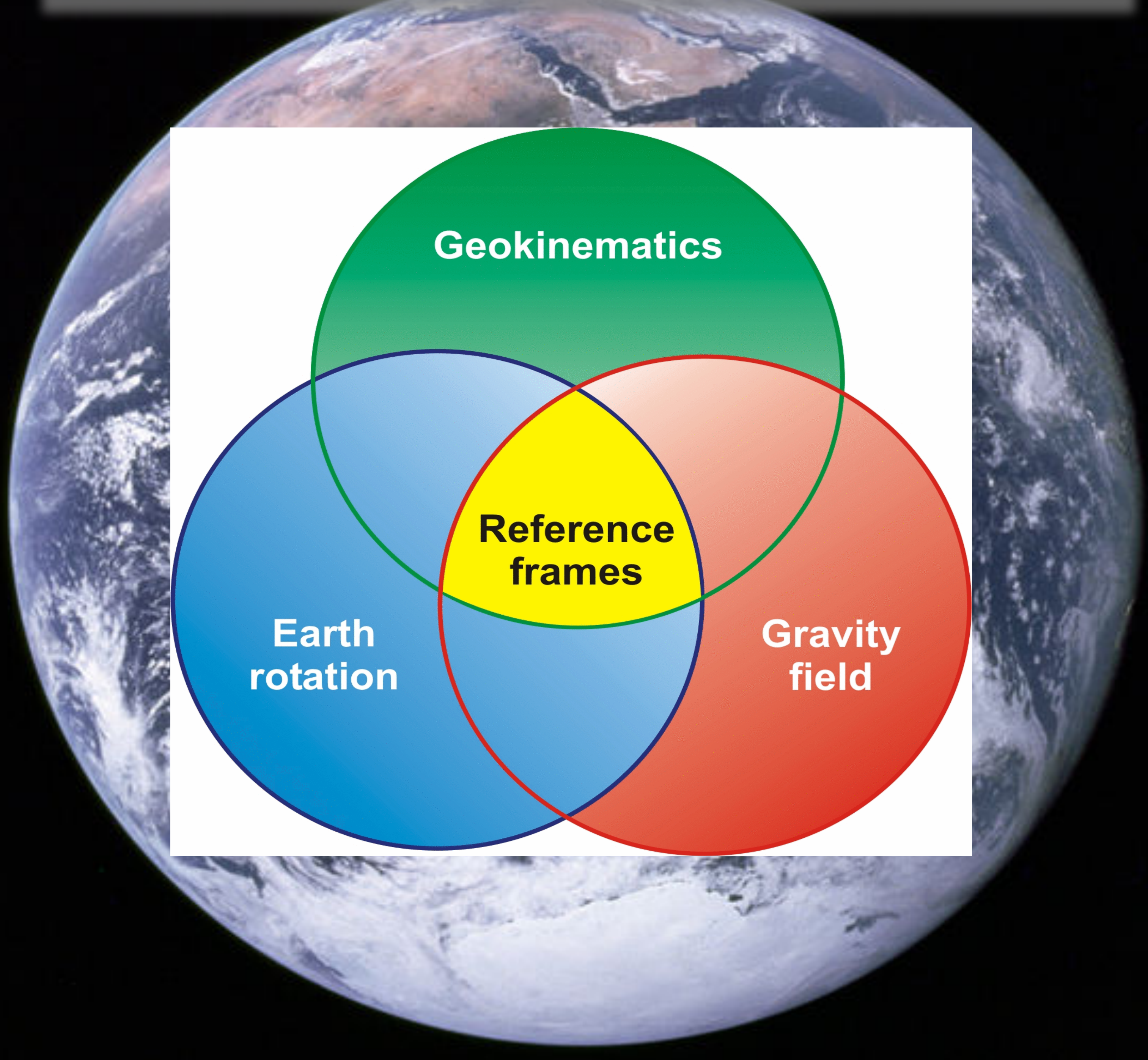
Measuring position and motion requires a coordinate system.

Assigning coordinates to points and objects on Earth, and to describe Earth's motion in space, we need to measure Earth's shape, gravity field, and rotation.

For this purpose, two reference systems are intrinsic in geodesy:
- International Celestial Reference System (ICRS)
- International Terrestrial Reference System (ITRS)
and these are connected through Earth Rotation.

The two reference systems are realized through reference frames:
- International Celestial Reference Frame (ICRF)
- International Terrestrial Reference Frame (ITRF)
and the connections is provided by the
- Earth Orientation Parameters (EOPs).

Geodesy - The Science



Geodesy - The Science

Historically, geodesy was limited to determining the shape of the Earth, its gravity field, and its rotation, and (recently also) their changes over time.

Geodesy - The Science

Historically, geodesy was limited to determining the shape of the Earth, its gravity field, and its rotation, and (recently also) their changes over time.

Over the last few decades, the scope of geodesy has extended to include the causes of the observed changes, i.e., the dynamics of and mass transport within the Earth system.

Geodesy - The Science

Historically, geodesy was limited to determining the shape of the Earth, its gravity field, and its rotation, and (recently also) their changes over time.

Over the last few decades, the scope of geodesy has extended to include the causes of the observed changes, i.e., the dynamics of and mass transport within the Earth system.

Today, geodesy contributes to the understanding of the Earth system as well as the development, functioning, and security of society.

Geodesy - The Science

Historically, geodesy was limited to determining the shape of the Earth, its gravity field, and its rotation, and (recently also) their changes over time.

Over the last few decades, the scope of geodesy has extended to include the causes of the observed changes, i.e., the dynamics of and mass transport within the Earth system.

Today, geodesy contributes to the understanding of the Earth system as well as the development, functioning, and security of society.

To a large extent, geodesy is a "service science".

Geodesy - The Science

Historically, geodesy was limited to determining the shape of the Earth, its gravity field, and its rotation, and (recently also) their changes over time.

Over the last few decades, the scope of geodesy has extended to include the causes of the observed changes, i.e., the dynamics of and mass transport within the Earth system.

Today, geodesy contributes to the understanding of the Earth system as well as the development, functioning, and security of society.

To a large extent, geodesy is a "service science".

In the past, the main "customers" of geodesy came from the surveying and mapping profession.

Geodesy - The Science

Historically, geodesy was limited to determining the shape of the Earth, its gravity field, and its rotation, and (recently also) their changes over time.

Over the last few decades, the scope of geodesy has extended to include the causes of the observed changes, i.e., the dynamics of and mass transport within the Earth system.

Today, geodesy contributes to the understanding of the Earth system as well as the development, functioning, and security of society.

To a large extent, geodesy is a "service science".

In the past, the main "customers" of geodesy came from the surveying and mapping profession.

Today geodesy serves all Earth science, including the geophysical, oceanographic, atmospheric, and environmental science communities.

Geodesy - The Science

Ultimately, all geodetic observations are affected by the same physical Earth system processes.

Geodesy - The Science

Ultimately, all geodetic observations are affected by the same physical Earth system processes.

Geodesy provides a unique framework for monitoring and ultimately understanding the Earth system as a whole.

Geodesy - The Science

Ultimately, all geodetic observations are affected by the same physical Earth system processes.

Geodesy provides a unique framework for monitoring and ultimately understanding the Earth system as a whole.

Modern space-geodetic techniques are well suited for observing phenomena on global to local scales, and thus are an important complement to traditional in situ observation systems.

Geodesy - The Science

Ultimately, all geodetic observations are affected by the same physical Earth system processes.

Geodesy provides a unique framework for monitoring and ultimately understanding the Earth system as a whole.

Modern space-geodetic techniques are well suited for observing phenomena on global to local scales, and thus are an important complement to traditional in situ observation systems.

The rapid development of space-geodetic techniques enables auxiliary applications utilizing atmospheric disturbances of the geodetic signals:

- troposphere

- hydrosphere and cryosphere

- ionosphere

- magnetic field

Transition from limiting noise to promising signal

Geodesy - The Science

With this development, geodesy faces several challenges

Geodesy - The Science

With this development, geodesy faces several challenges

(1) inter-disciplinarity is required in order to contribute to collaborative solutions to problems, to allow for an optimal assimilation of a wide spectrum of observations into inter-disciplinary models, and to enable to interpretation and separability of the various signals;

Geodesy - The Science

With this development, geodesy faces several challenges

(1) inter-disciplinarity is required in order to contribute to collaborative solutions to problems, to allow for an optimal assimilation of a wide spectrum of observations into inter-disciplinary models, and to enable to interpretation and separability of the various signals;

(2) development of a framework for a four-dimensional geodesy is required, in which temporal variations in the shape of the Earth and its gravity field are fully accounted for, and an accuracy level for geometric and gravimetric quantities of much better than 10^{-9} (approaching 10^{-10} to 10^{-12}) is achieved;

Geodesy - The Science

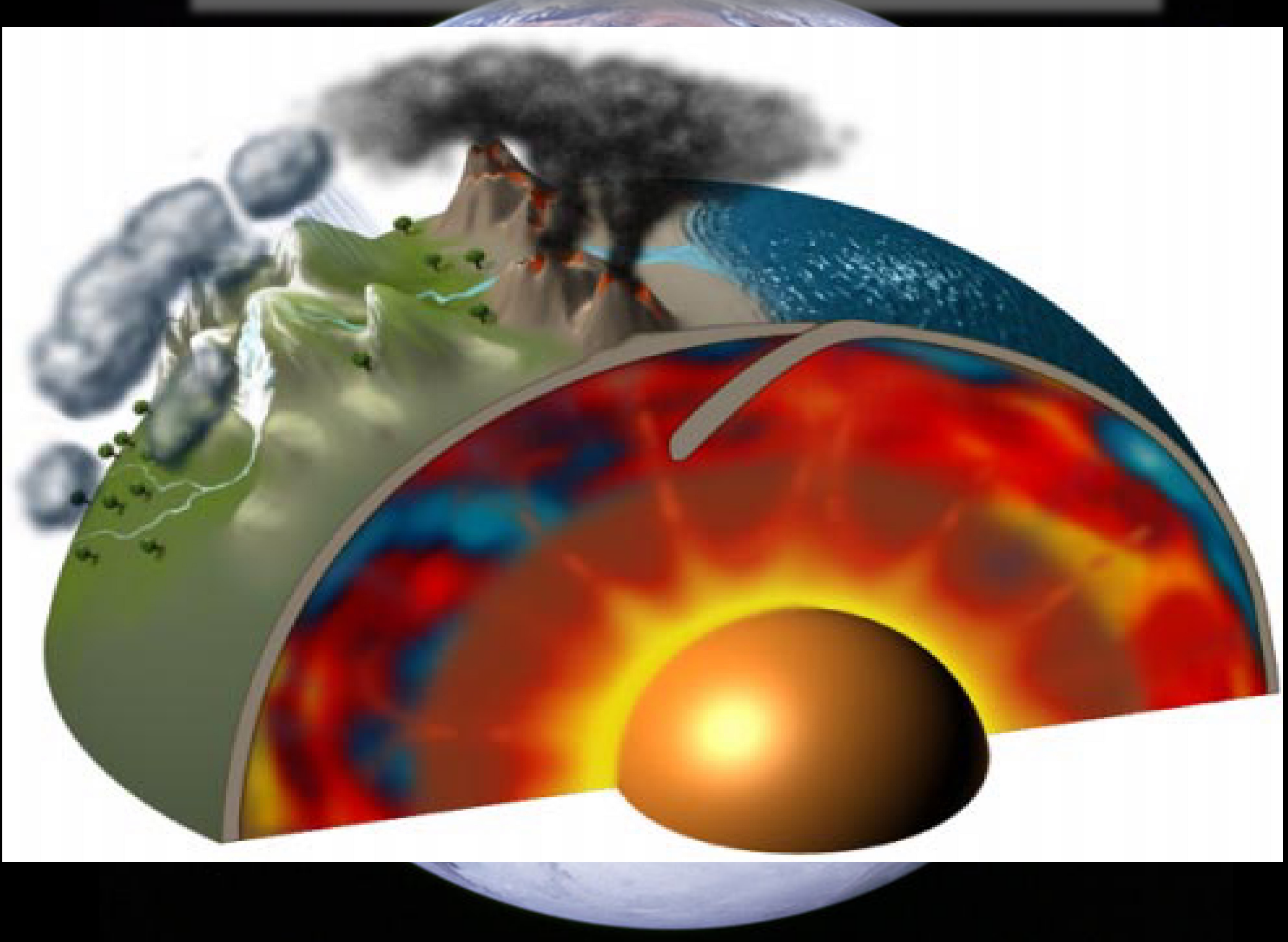
With this development, geodesy faces several challenges

(1) inter-disciplinarity is required in order to contribute to collaborative solutions to problems, to allow for an optimal assimilation of a wide spectrum of observations into inter-disciplinary models, and to enable to interpretation and separability of the various signals;

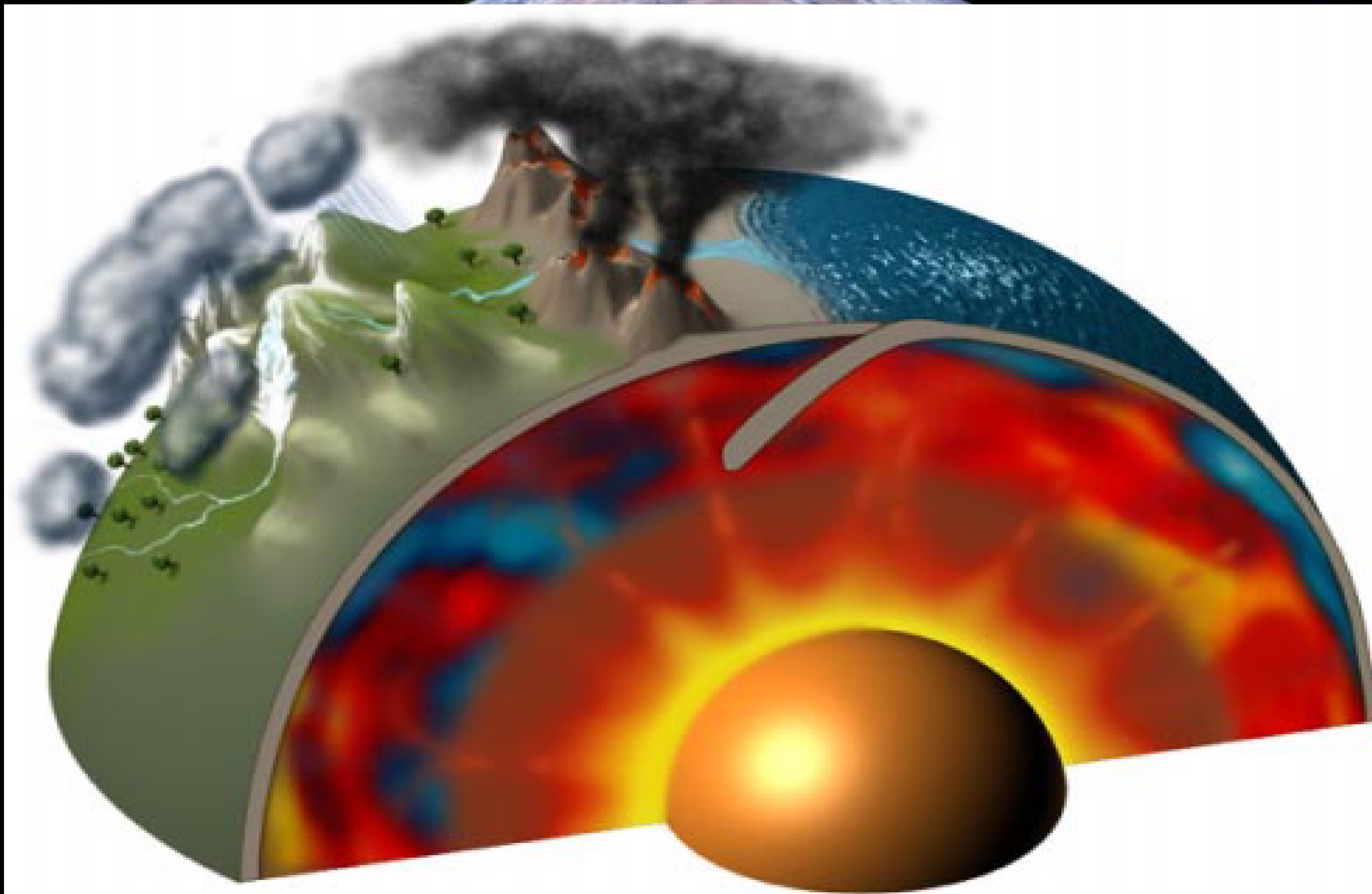
(2) development of a framework for a four-dimensional geodesy is required, in which temporal variations in the shape of the Earth and its gravity field are fully accounted for, and an accuracy level for geometric and gravimetric quantities of much better than 10^{-9} (approaching 10^{-10} to 10^{-12}) is achieved;

THE “CURSE” OF INCREASING ACCURACY:
EVERYTHING MATTERS

Geodesy - The Science

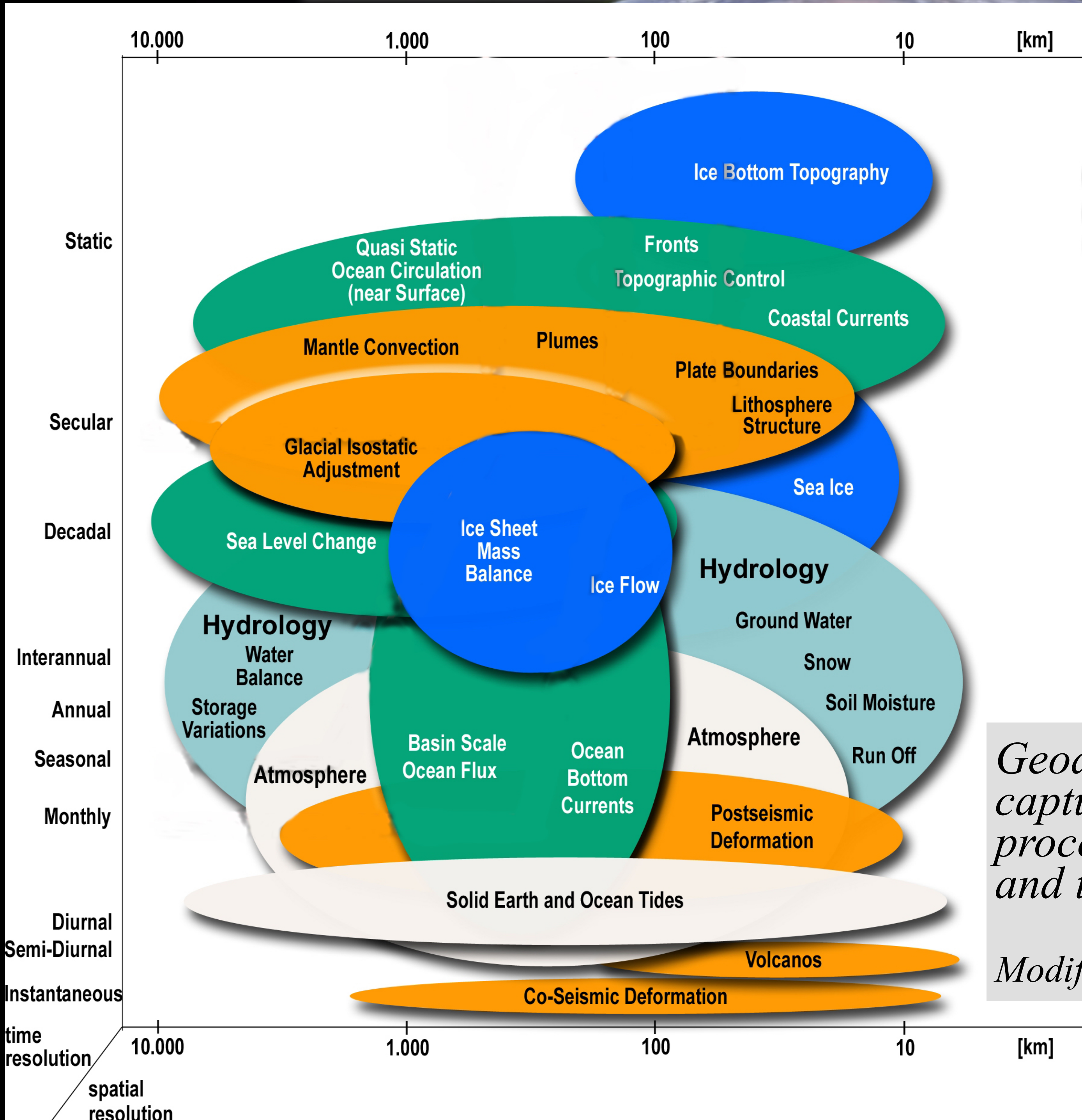


Geodesy - The Science



Solomon et al., 2002

Geodesy - The Science



Geodetic observation techniques capture signals of many processes overlapping in spatial and temporal scales.

Modified from Ilk et al. (2005).

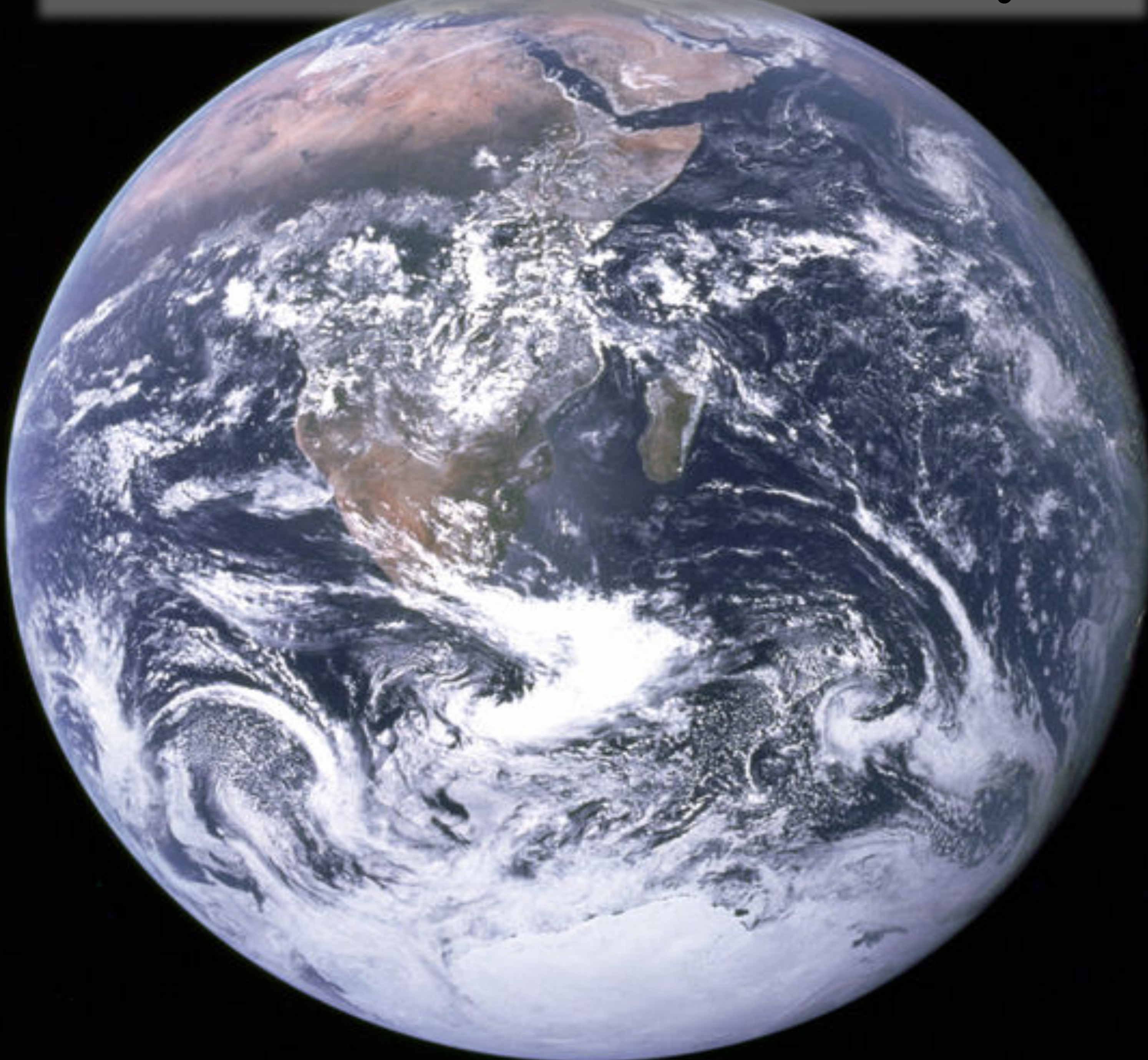
Geodesy - The Science

Science questions relevant to geodesy:
Convection: *nature of anomalies in seismic velocities*;
Plate tectonics: *location of and processes at plate boundaries*;
Ice sheets/glaciers: *ice load history, including present-day changes*;
Sea level: *quantification of different contributions*;
Rheology: *linear versus non-linear; transient versus steady-state; lateral heterogeneities*;
Core-mantle dynamics: *processes at core-mantle boundary*;
Hydrological cycle: *better quantification of fluxes; groundwater movements; land water storage*;
Solid Earth response to loading: *load history (continental water storage, ice loads, non-tidal ocean loading)*;
Rotational dynamics: *coupling of angular and linear momentum; free modes of ocean*;
Tides: *validation of ocean tidal models*;
Earthquakes: *strain/stress accumulation and earthquakes; physical processes*;
Earth structure: *structure and composition of the deep Earth and mantle dynamics*;

According to Rummel et al., 2009

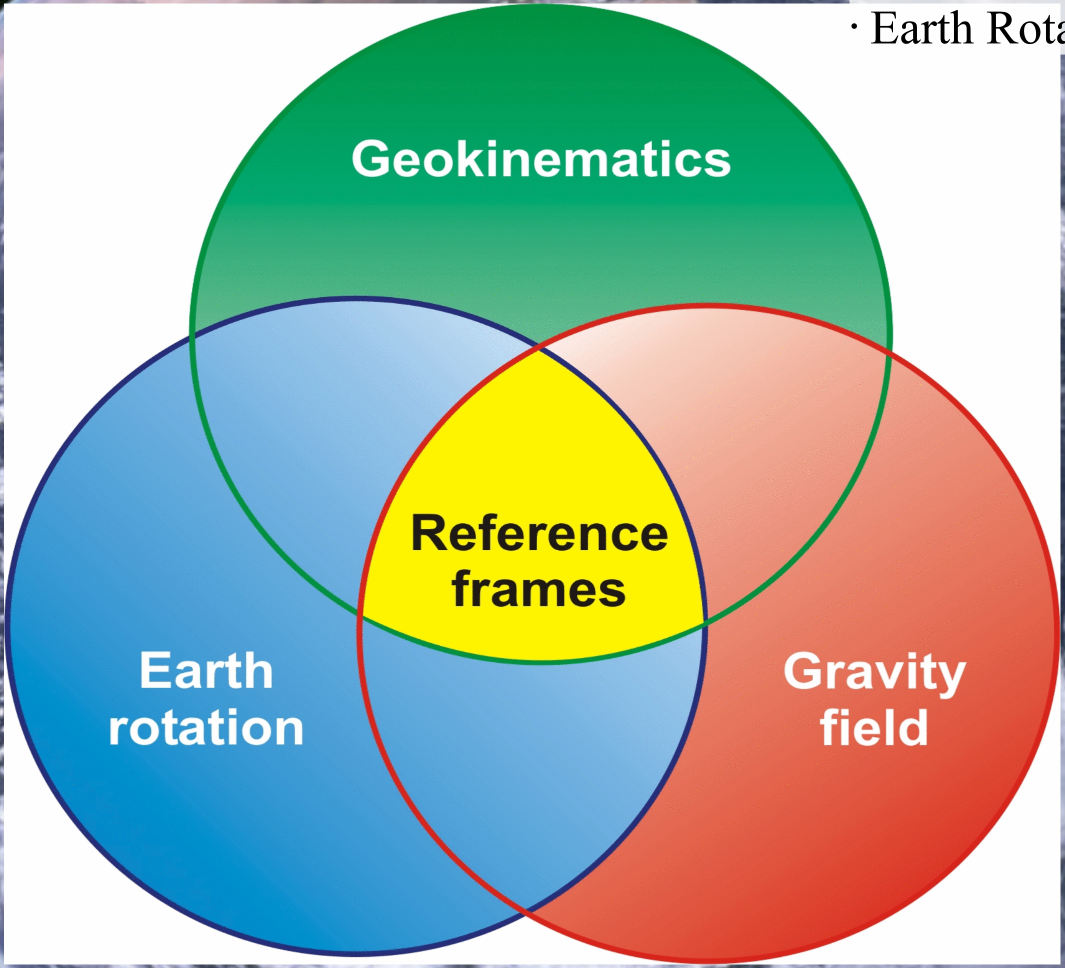
Geodesy - The Science

The Three Pillars of Geodesy



The Three Pillars of Geodesy

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

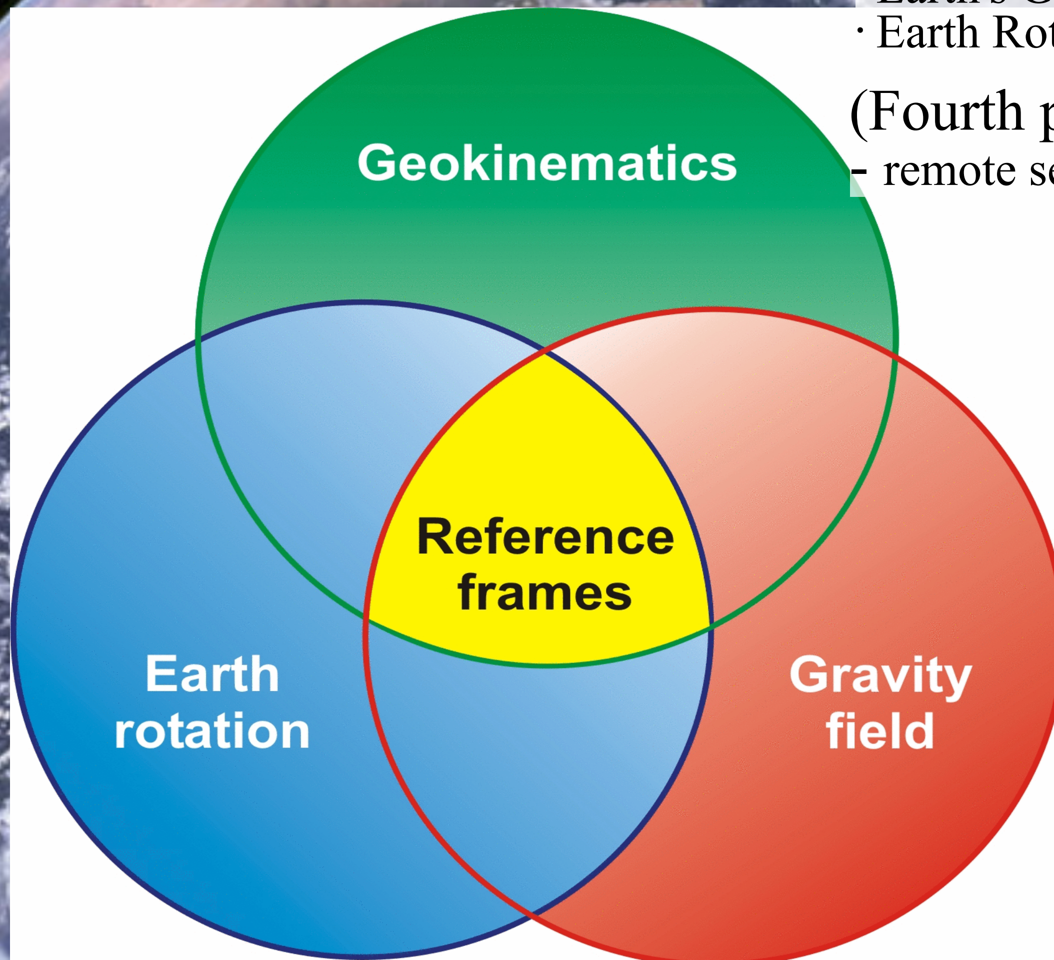


The Three Pillars of Geodesy

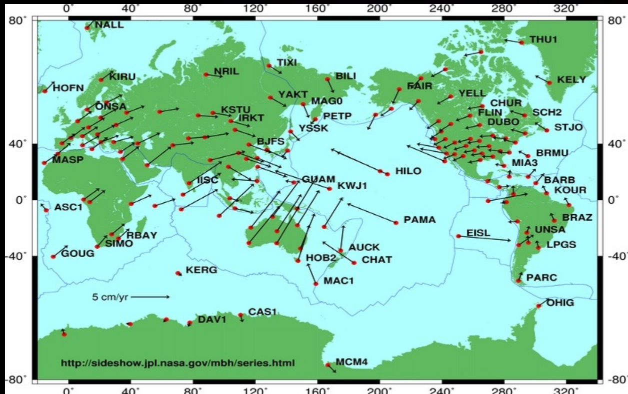
The 'three pillars of geodesy':

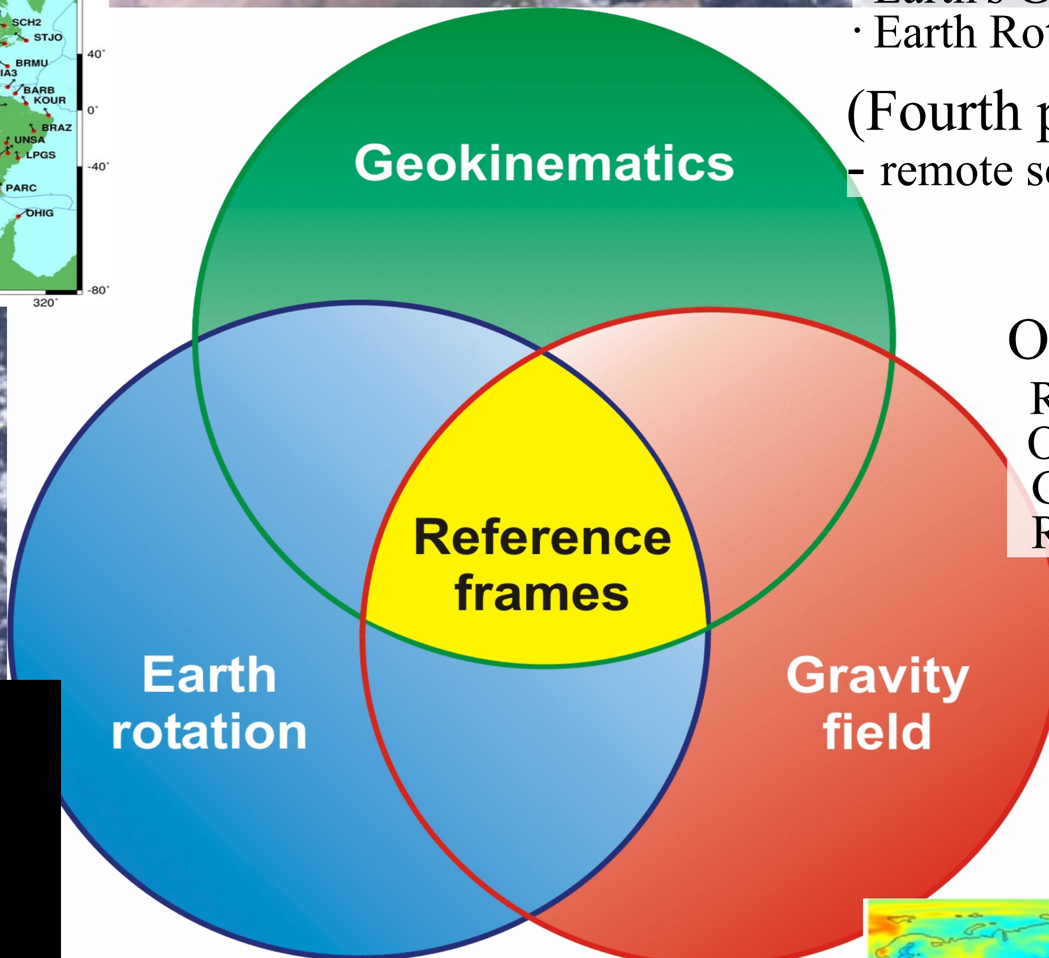
- Earth's Shape (Geokinematics)
- Earth's Gravity Field
- Earth Rotation

(Fourth pillar:
- remote sensing of the atmosphere)



The Three Pillars of Geodesy





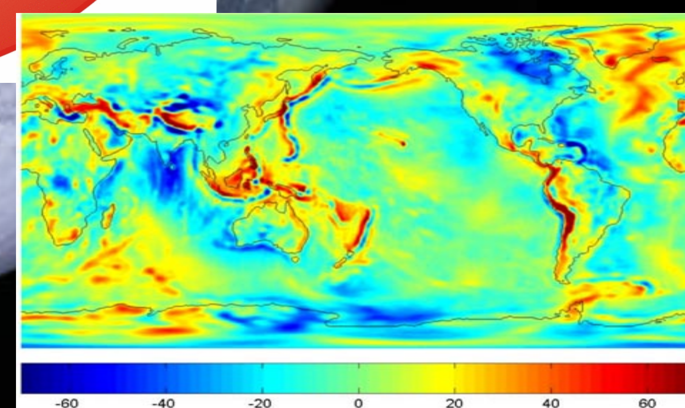
The 'three pillars of geodesy':

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

(Fourth pillar:
- remote sensing of the atmosphere)

Output:

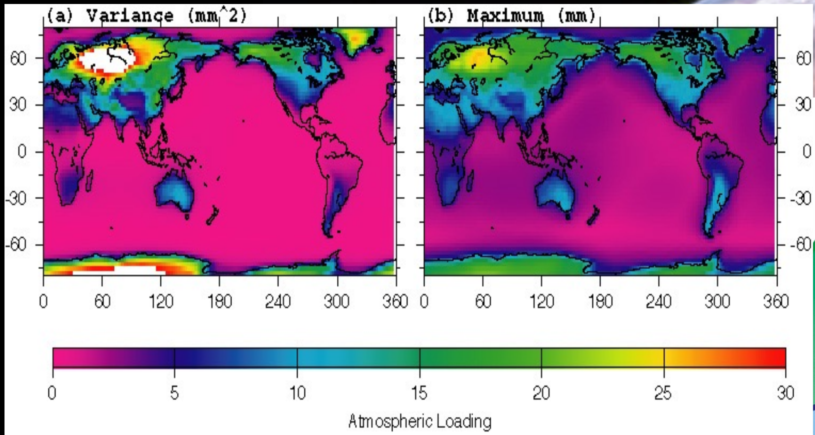
Reference Frame
Observations of the Shape, Gravitational Field and Rotation of the Earth

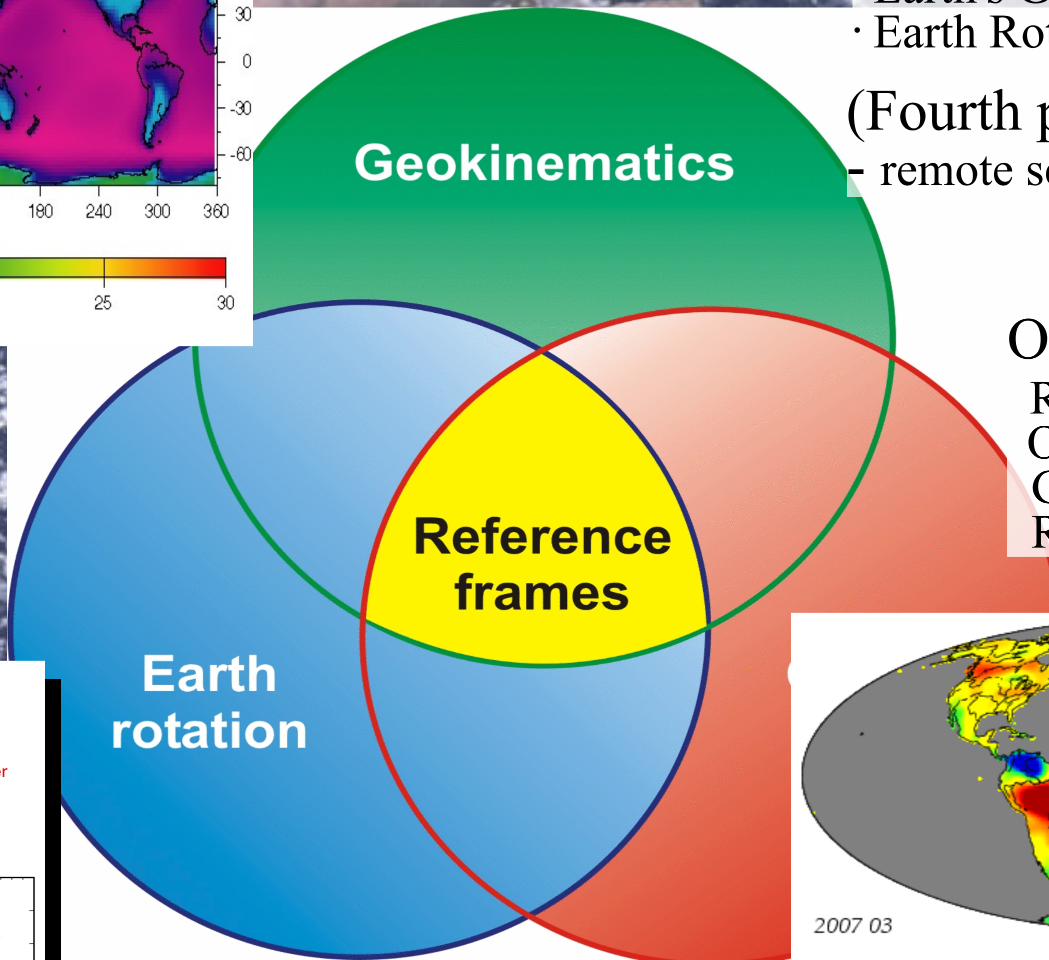


The Three Pillars of Geodesy

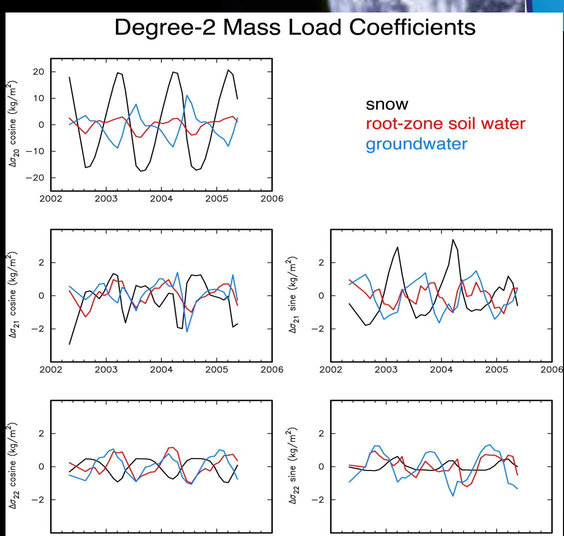
The 'three pillars of geodesy':
- Earth's Shape (Geokinematics)
- Earth's Gravity Field
- Earth Rotation

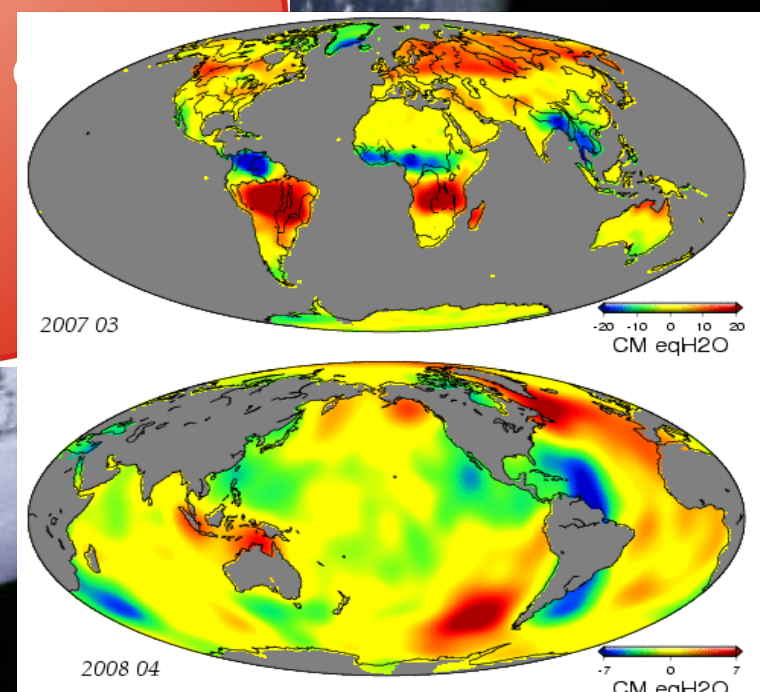
(Fourth pillar:
- remote sensing of the atmosphere)



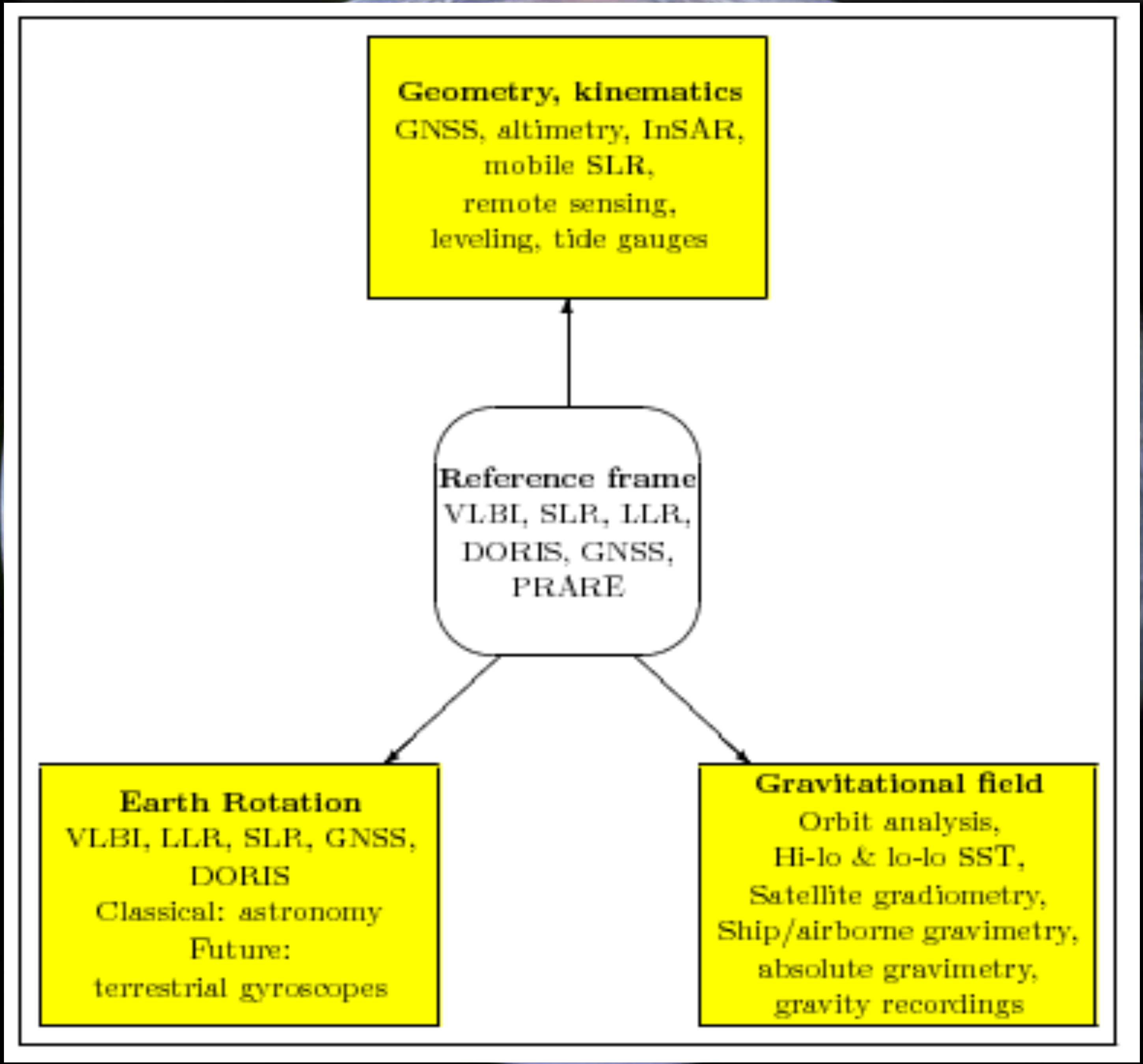


Output:
Reference Frame
Observations of the Shape, Gravitational Field and Rotation of the Earth





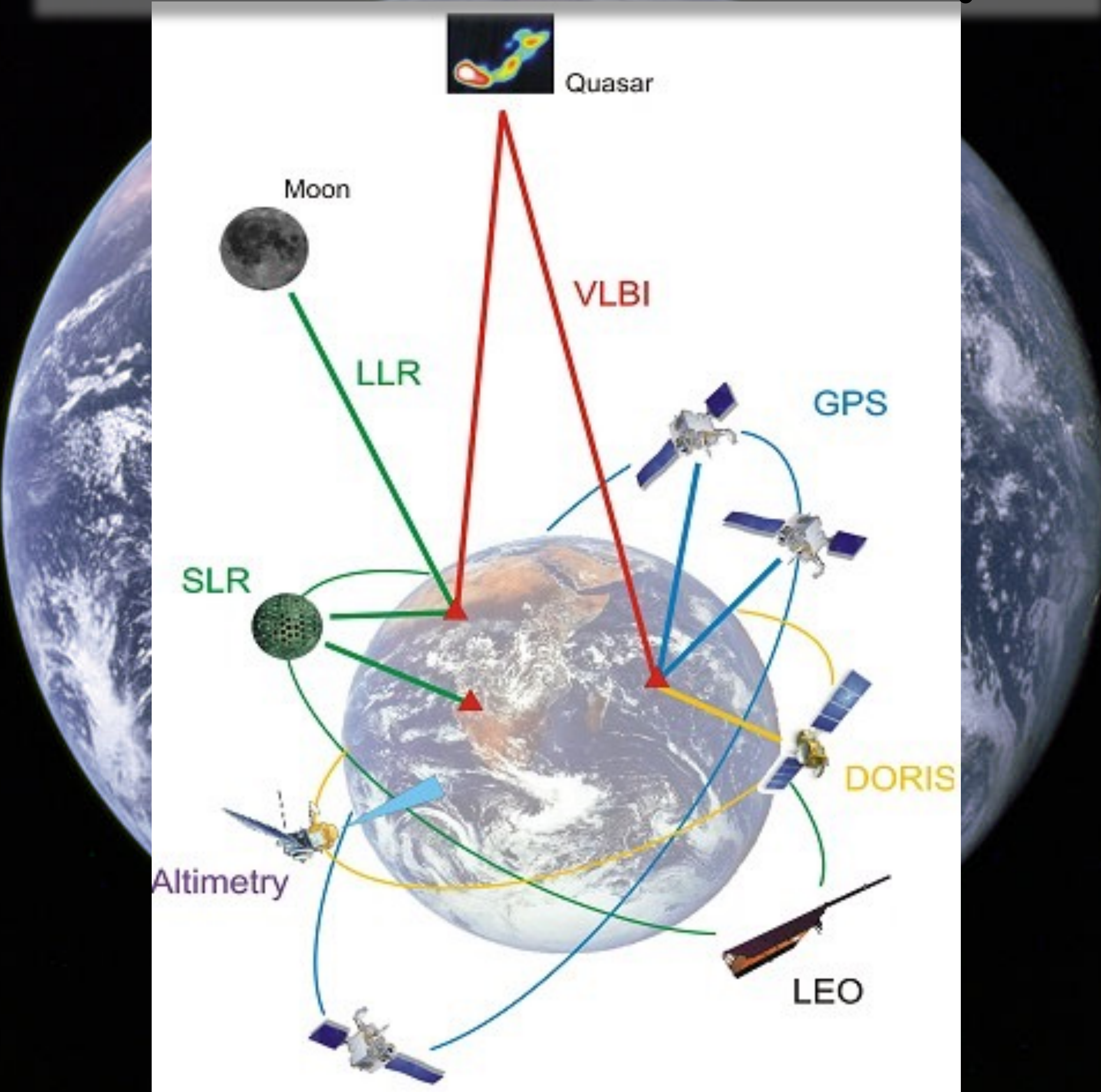
The Three Pillars of Geodesy



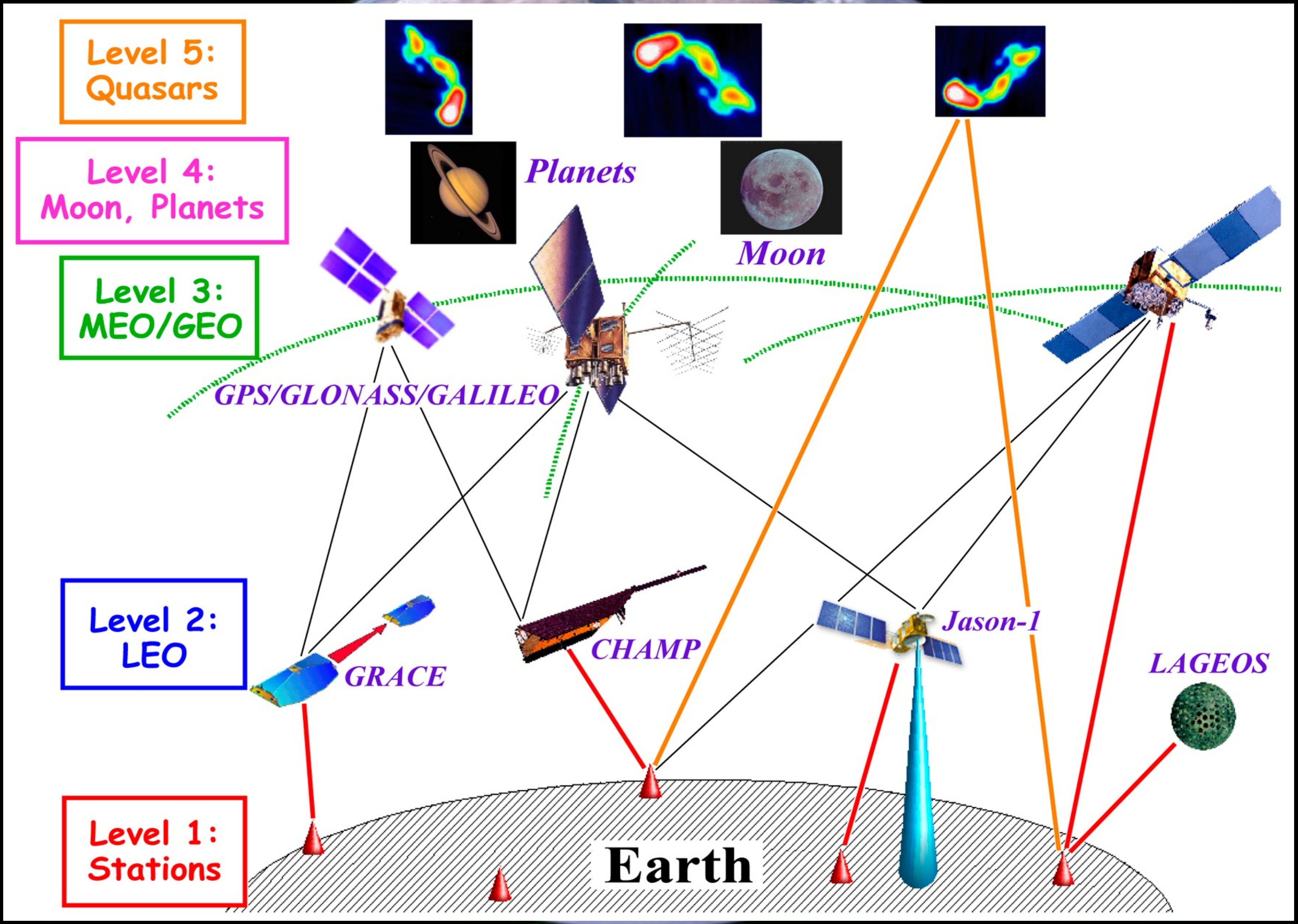
The Three Pillars of Geodesy

Component	Objective	Techniques	Responsibility
I. Geokinematics (size, shape, kinematics, deformation)	*Shape and temporal variations of land/ice/ocean surface (plates, intra-plates, volcanoes, earthquakes, glaciers, ocean variability, sea level)*	*Altimetry, InSAR, GNSS-cluster, VLBI, SLR, DORIS, imaging techniques, leveling, tide gauges*	*International and national projects, space missions, IGS, IAS, future InSAR service*
II. Earth Rotation (nutation, precession, polar motion, variations in length-of-day)	*Integrated effect of changes in angular momentum and inertia tensor (mass changes in atmosphere, cryosphere, oceans, solid Earth, core/mantle; momentum exchange between Earth system components)*	*Classical astronomy, VLBI, LLR, SLR, GNSS, DORIS, under development: terrestrial gyroscopes*	*International geodetic and astronomical community (IERS, IGS, IVS, ILRS, IDS)*
III. Gravity field	*Geoid, Earth's static gravitational potential, temporal variations induced by solid Earth processes and mass transport in the global water cycle.*	*Terrestrial gravimetry (absolute and relative), airborne gravimetry, satellite orbits, dedicated satellite missions (CHAMP, GRACE, GOCE)*	*International geophysical and geodetic community (GGP, IGFS, BGI)*
IV. Terrestrial Frame	*Global cluster of fiducial point, determined at mm to cm level*	*VLBI, GNSS, SLR, LLR, DORIS, time keeping/transfer absolute gravimetry, gravity recording*	*International geodetic community (IERS with support of IVS, ILRS, IGS, and IDS)*

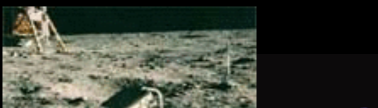
The Three Pillars of Geodesy

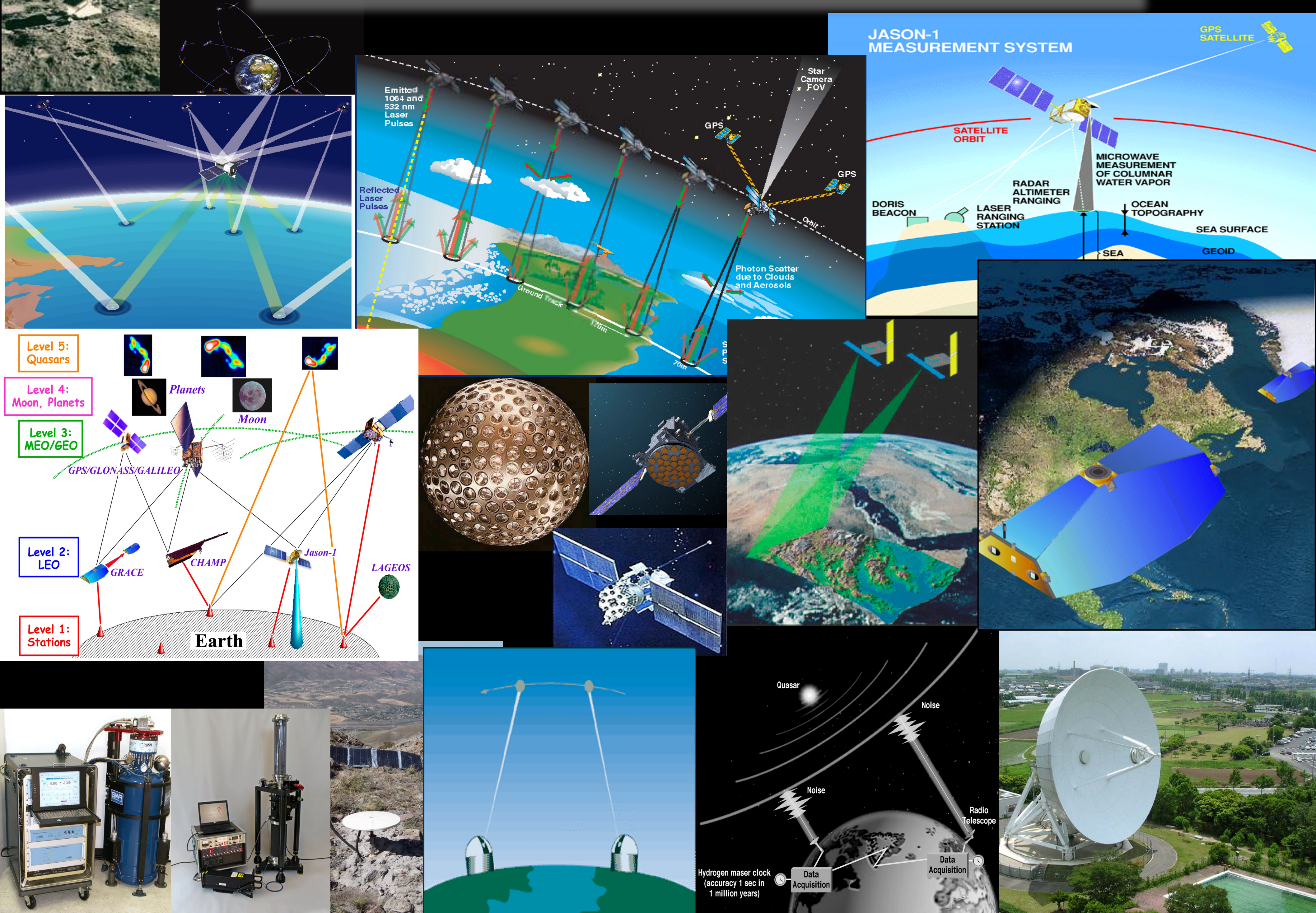


The Three Pillars of Geodesy



The Three Pillars of Geodesy





Geodetic Reference Systems

Measuring position and motion requires a reference system.

Geodetic Reference Systems

Measuring position and motion requires a reference system.

Position and motion depends on the reference system

Geodetic Reference Systems

Measuring position and motion requires a reference system.

Position and motion depends on the reference system

Ideal World:

Reference systems can be defined by:

- three coordinate axes,

- the origin, and

- a scale

Axes either being fixed in space or having a known movement with respect to something else that is fixed.

Geodetic Reference Systems

Measuring position and motion requires a reference system.

Position and motion depends on the reference system

Ideal World:

Reference systems can be defined by:

- three coordinate axes,

- the origin, and

- a scale

Axes either being fixed in space or having a known movement with respect to something else that is fixed.

Real world:

Definition of reference systems is far more complex.

Geodetic Reference Systems

Measuring position and motion requires a reference system.

Position and motion depends on the reference system

In geodesy, two reference systems are intrinsic:
- Celestial Reference System (CRS)
- Terrestrial Reference System (TRS)
and these are connected through Earth Rotation.

Geodetic Reference Systems

Measuring position and motion requires a reference system.

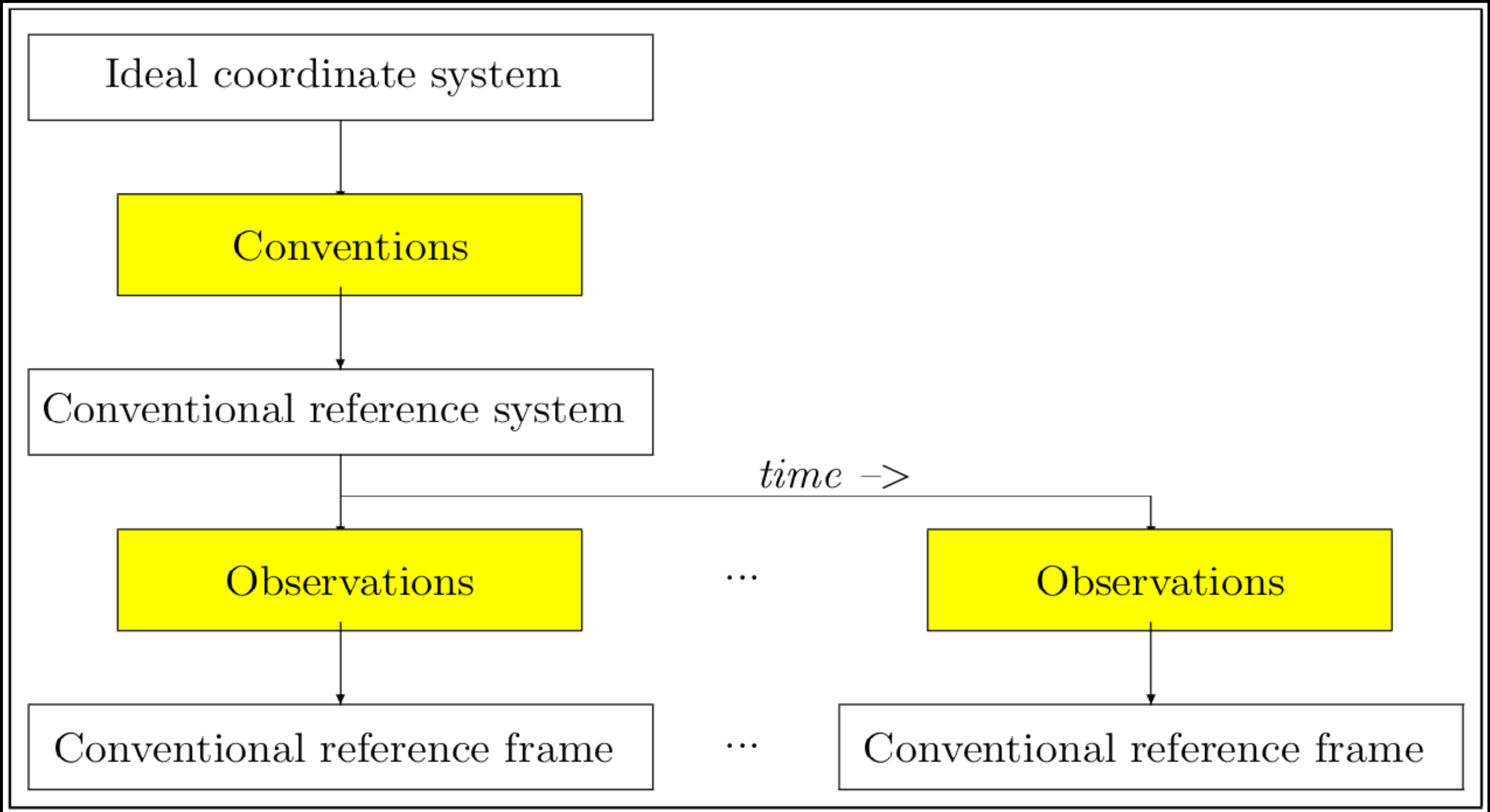
Position and motion depends on the reference system

In geodesy, two reference systems are intrinsic:
- Celestial Reference System (CRS)
- Terrestrial Reference System (TRS)
and these are connected through Earth Rotation.

It is of obvious practical advantage to agree upon one definition for these systems:
- Conventional Celestial Reference System (CCRS)
- Conventional Terrestrial Reference System (CTRS)

Geodetic Reference Systems

How to gain access to a reference system?



Geodetic Reference Systems

Today, the global reference systems agreed upon in scientific communities and increasingly used for societal applications are:

- International Celestial Reference System (ICRS)

- International Terrestrial Reference System (ITRS)

and these are connected through the Earth Rotation.

Geodetic Reference Systems

Today, the global reference systems agreed upon in scientific communities and increasingly used for societal applications are:

- International Celestial Reference System (ICRS)

- International Terrestrial Reference System (ITRS)

and these are connected through the Earth Rotation.

These two reference systems are realized through reference frames:

- International Celestial Reference Frame (ICRF)

- International Terrestrial Reference Frame (ITRF)

and the connections is provided by the

- Earth Orientation Parameters (EOPs).

Geodetic Reference Systems

Today, the global reference systems agreed upon in scientific communities and increasingly used for societal applications are:

- International Celestial Reference System (ICRS)

- International Terrestrial Reference System (ITRS)

and these are connected through the Earth Rotation.

These two reference systems are realized through reference frames:

- International Celestial Reference Frame (ICRF)

- International Terrestrial Reference Frame (ITRF)

and the connections is provided by the

- Earth Orientation Parameters (EOPs).

The Reference Systems are maintained by the International Earth Rotation and Reference Systems Service (IERS).

Geodetic Reference Systems

Today, the global reference systems agreed upon in scientific communities and increasingly used for societal applications are:

- International Celestial Reference System (ICRS)

- International Terrestrial Reference System (ITRS)

and these are connected through the Earth Rotation.

These two reference systems are realized through reference frames:

- International Celestial Reference Frame (ICRF)

- International Terrestrial Reference Frame (ITRF)

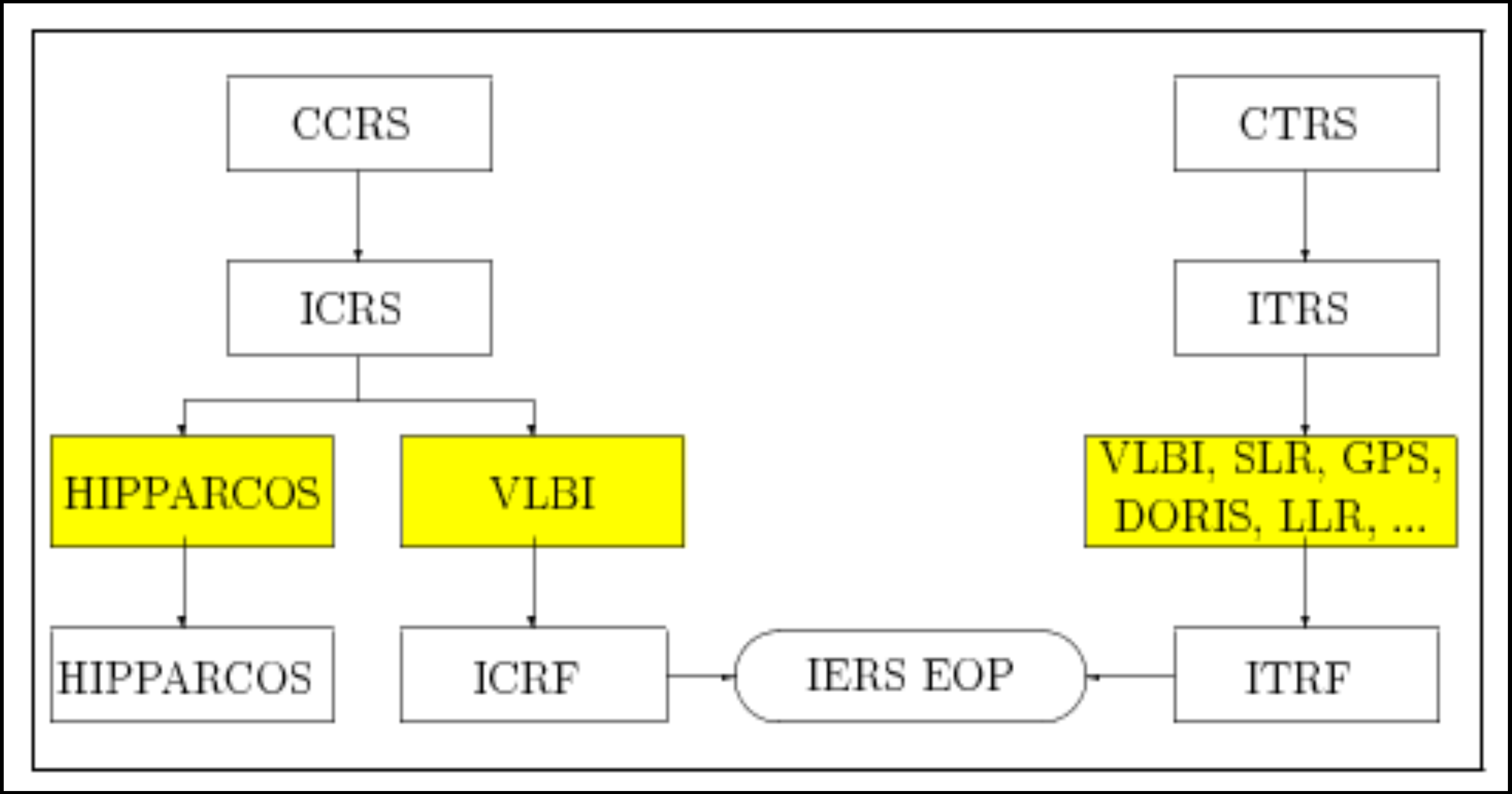
and the connections is provided by the

- Earth Orientation Parameters (EOPs).

The Reference Systems are maintained by the International Earth Rotation and Reference Systems Service (IERS).

The Reference Frames and the EOPs are determined based on observations provided by the Global Geodetic Observing System (GGOS).

Geodetic Reference Systems



Realization of ITRS through ITRF

The ITRS is realized through a reference frame specifying a set of coordinates for a network of stations.

These coordinates are given as Cartesian equatorial coordinates triples $x_i = (X, Y, Z)$ by preference.

Realization of ITRS through ITRF

The ITRS is realized through a reference frame specifying a set of coordinates for a network of stations.

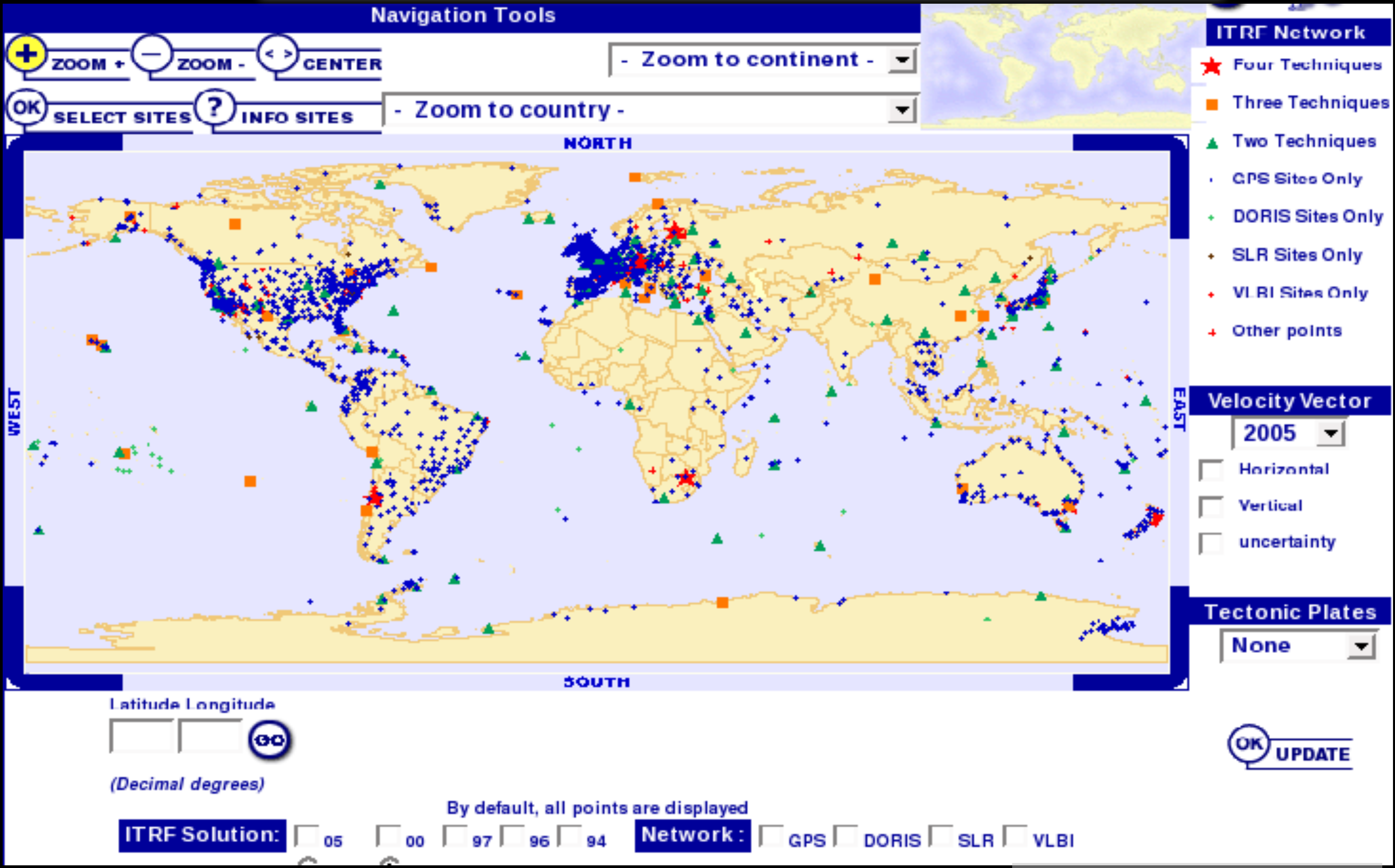
These coordinates are given as Cartesian equatorial coordinates triples $x_i = (X, Y, Z)$ by preference.

on results provided by the different IERS analysis centers. The realization consists of lists of coordinates and velocities for a selection of IERS sites, which may be tracking stations or related ground markers. The station coordinates are expressed through

$$x_i(t) = x_i^0 + v_i^0(t - t_0) + \sum_{j=1}^{k} \delta x_i^j(t), \quad i = 1, 2, 3 \qquad (4)$$

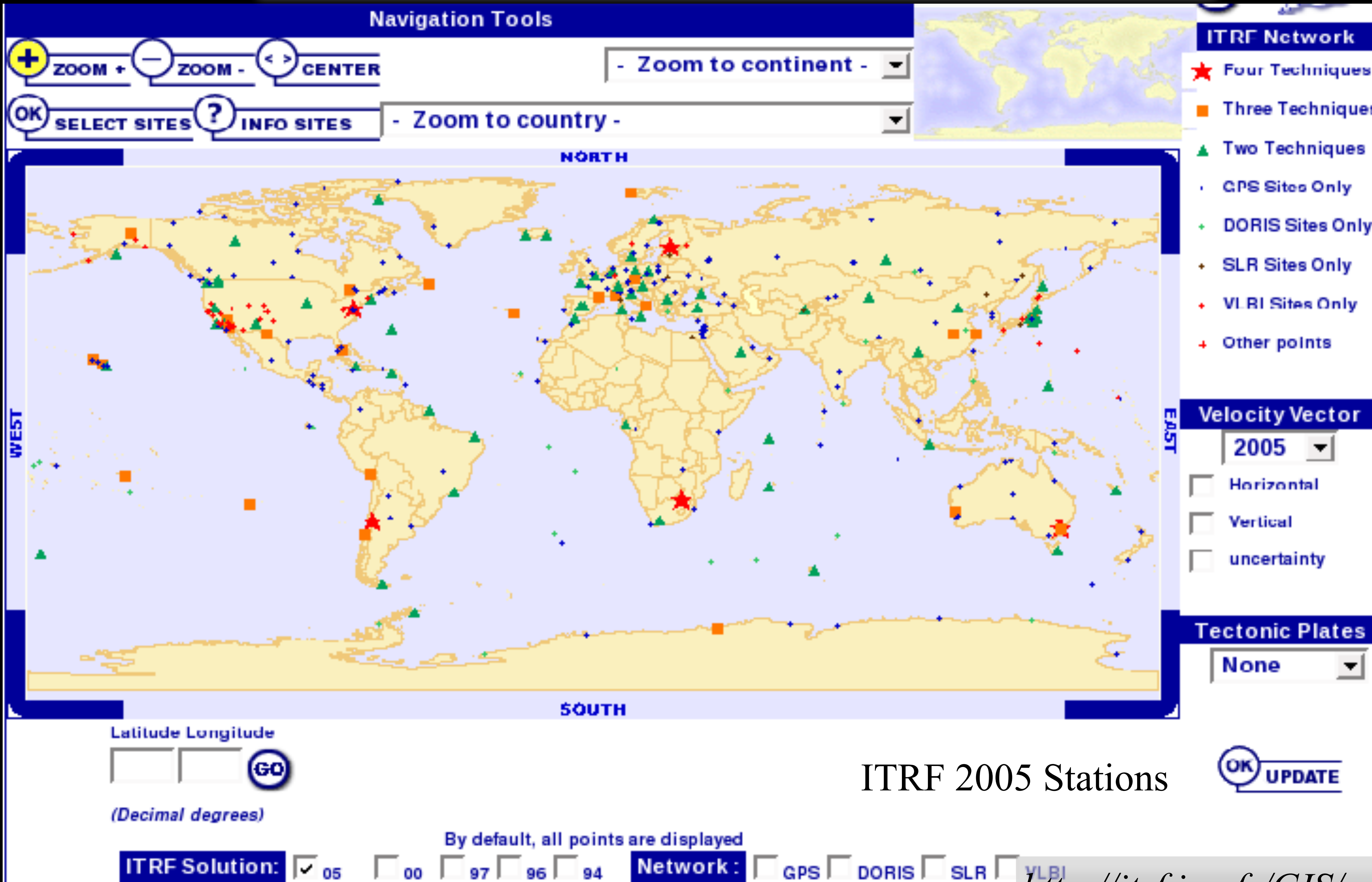
where x_i^0 and v_i^0 are the position and velocity at epoch $t = t_0$ and δx_i^k are corrections due to the k-th process inducing time variable contributions to the coordinates. Such processes are, for example, solid Earth tide displacements, ocean loading, atmospheric loading, and postglacial rebound.

ITRF



http://itrf.ign.fr/GIS/

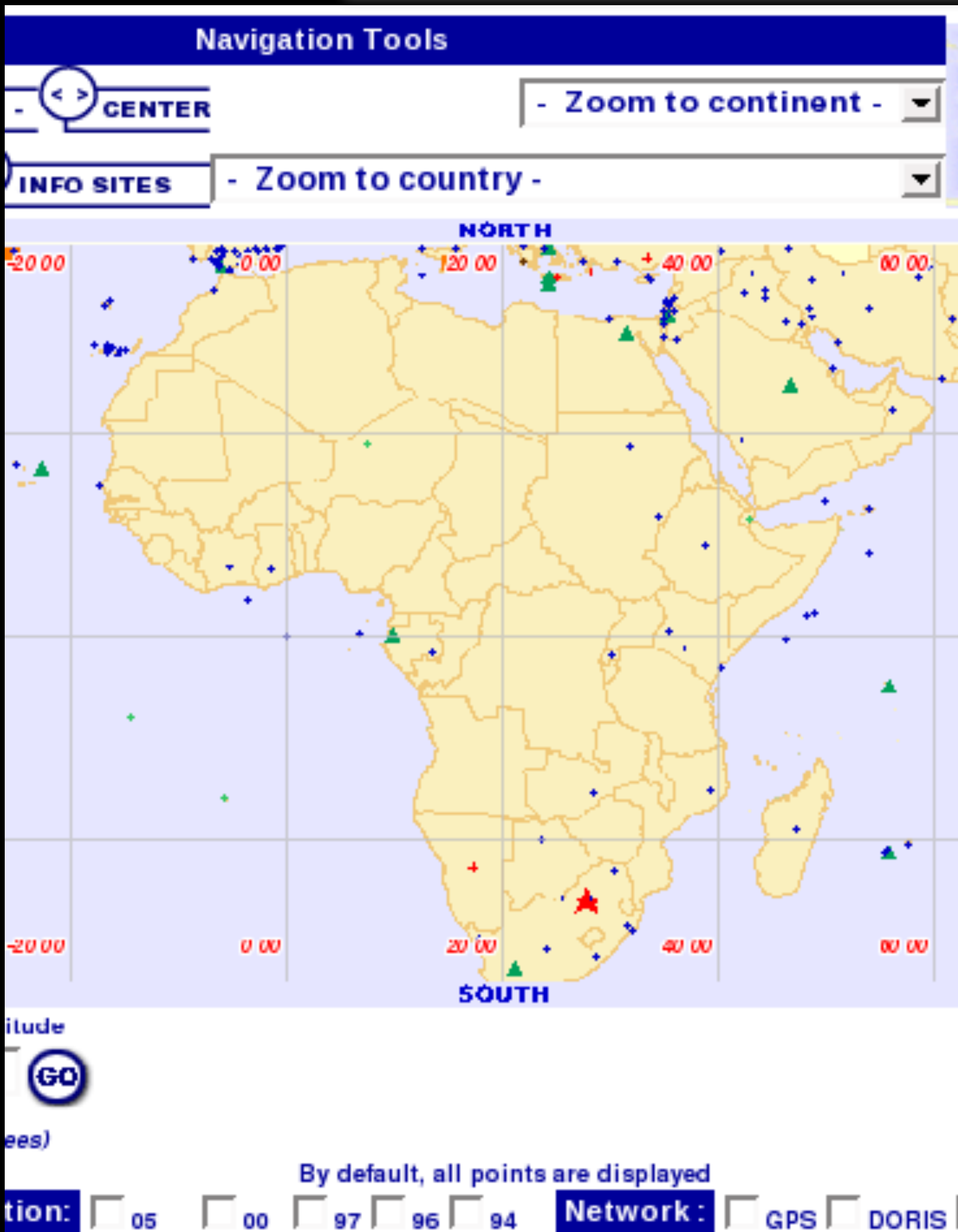
ITRF

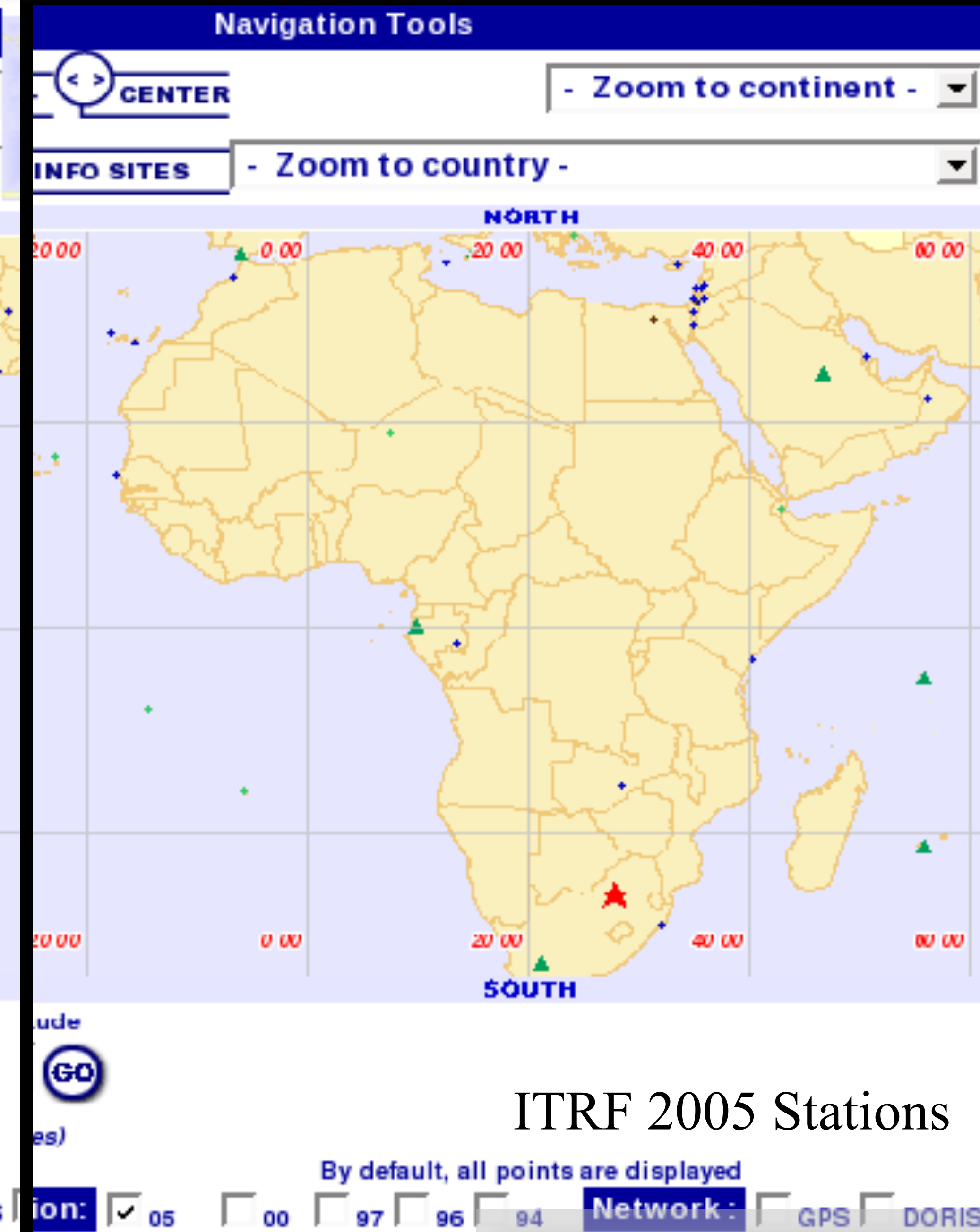


ITRF 2005 Stations

http://itrf.ign.fr/GIS/

ITRF

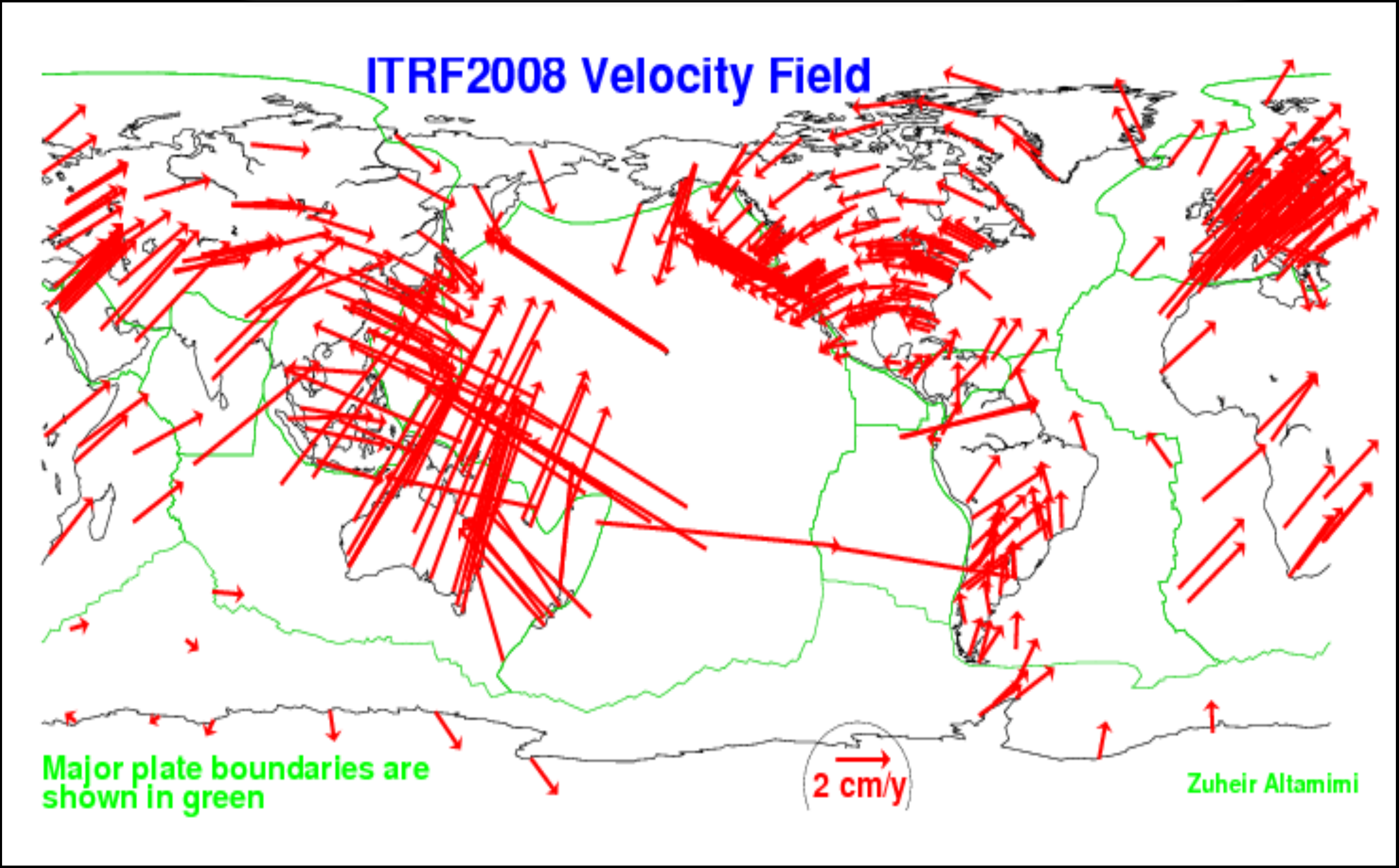




ITRF 2005 Stations

http://itrf.ign.fr/GIS/

ITRF

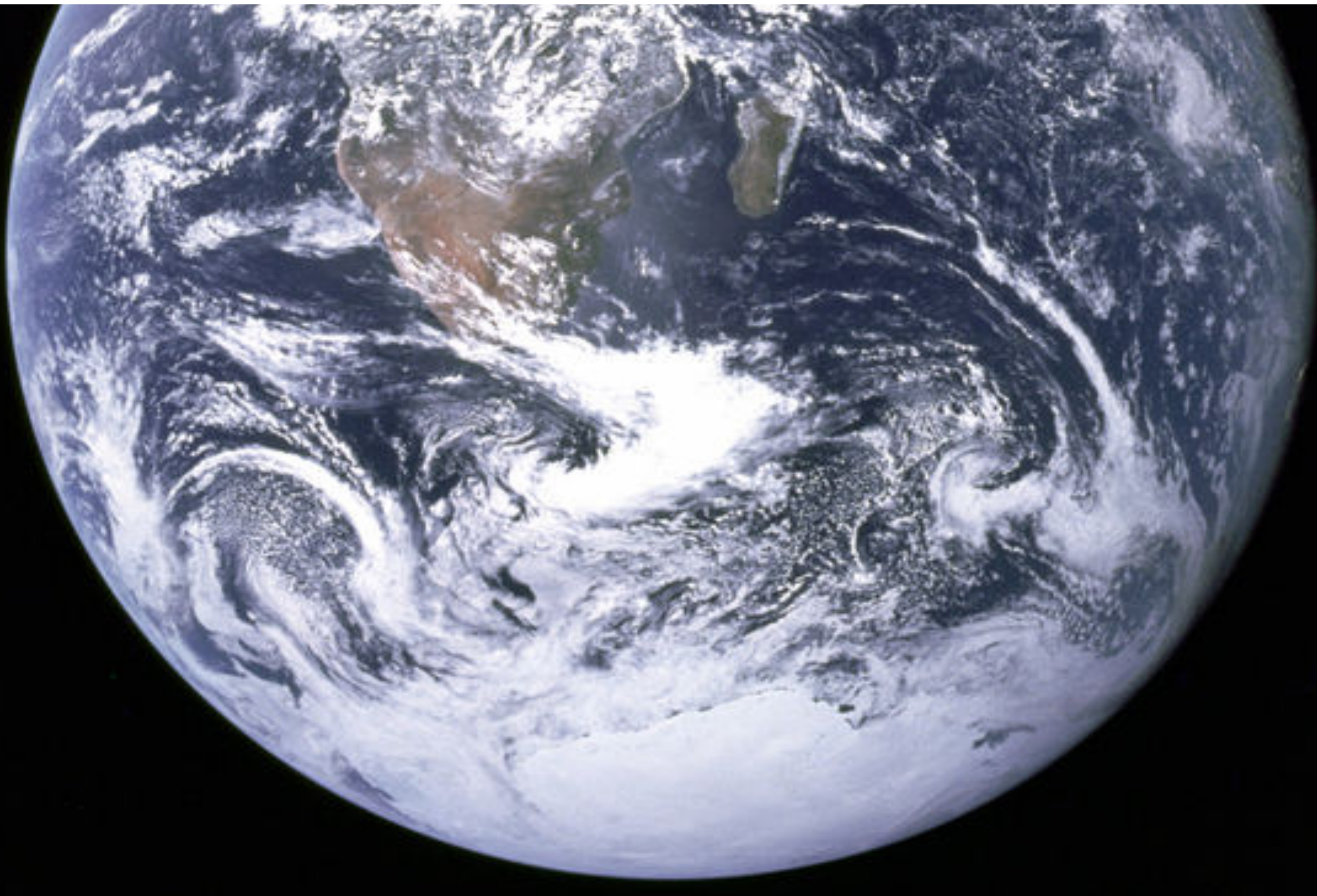


http://itrf.ign.fr/GIS/

Hydrogeodesy

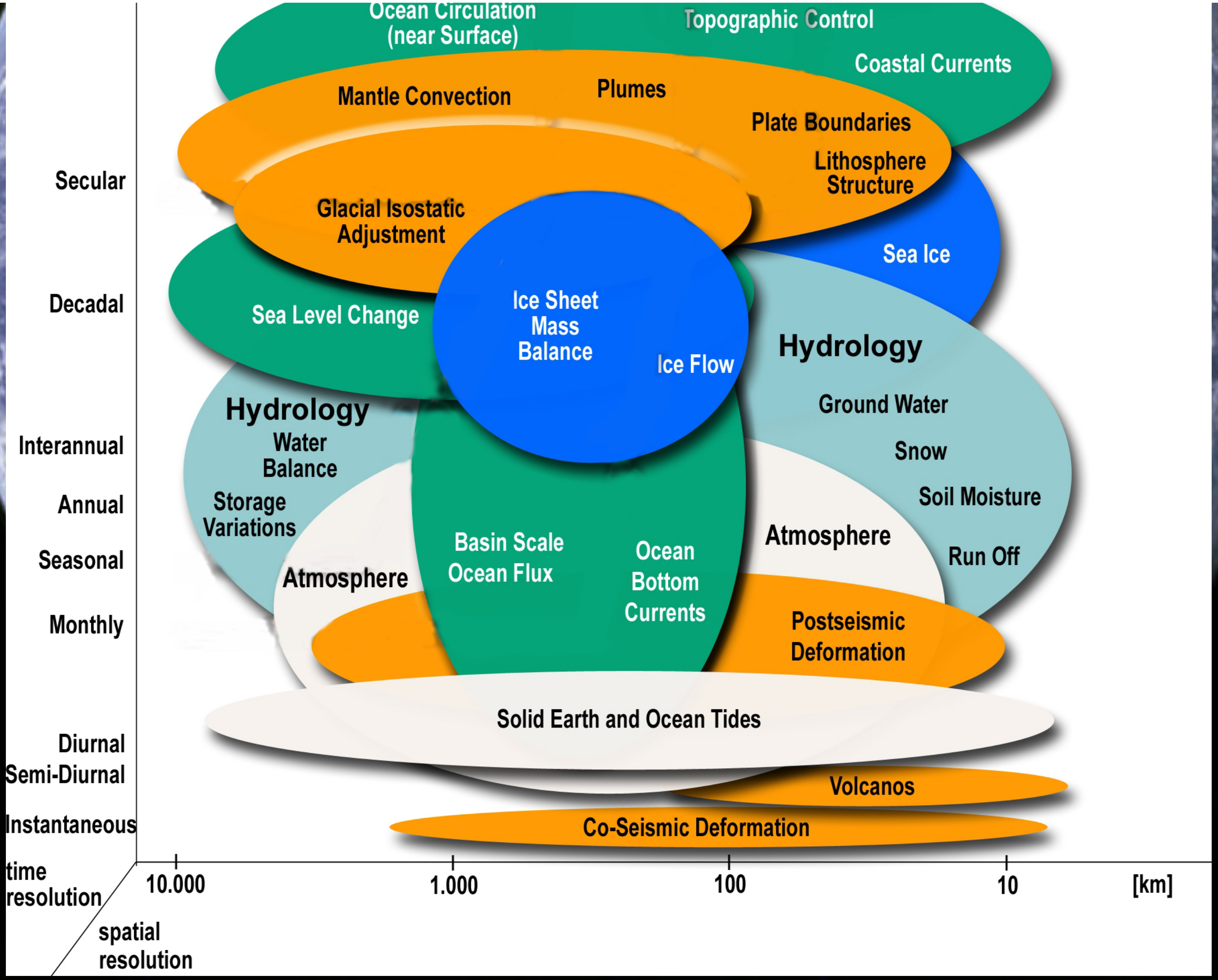
Hydrogeodesy

Hydrogeodesy applies geodetic techniques to study and monitor the (terrestrial) hydrology.



Hydrogeodesy

Hydrogeodesy applies geodetic techniques to study and monitor the (terrestrial) hydrology.

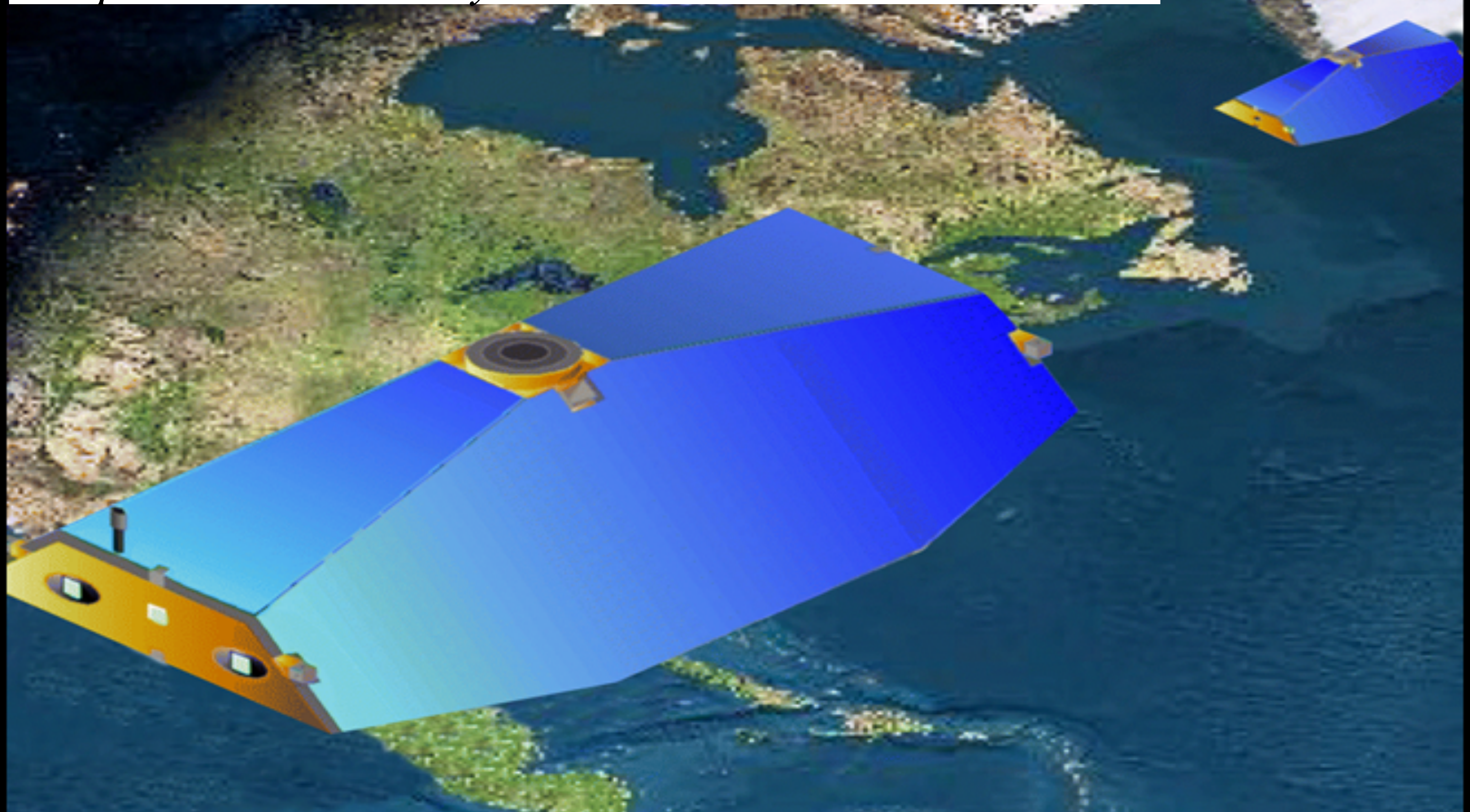


Observed and Derived Variables

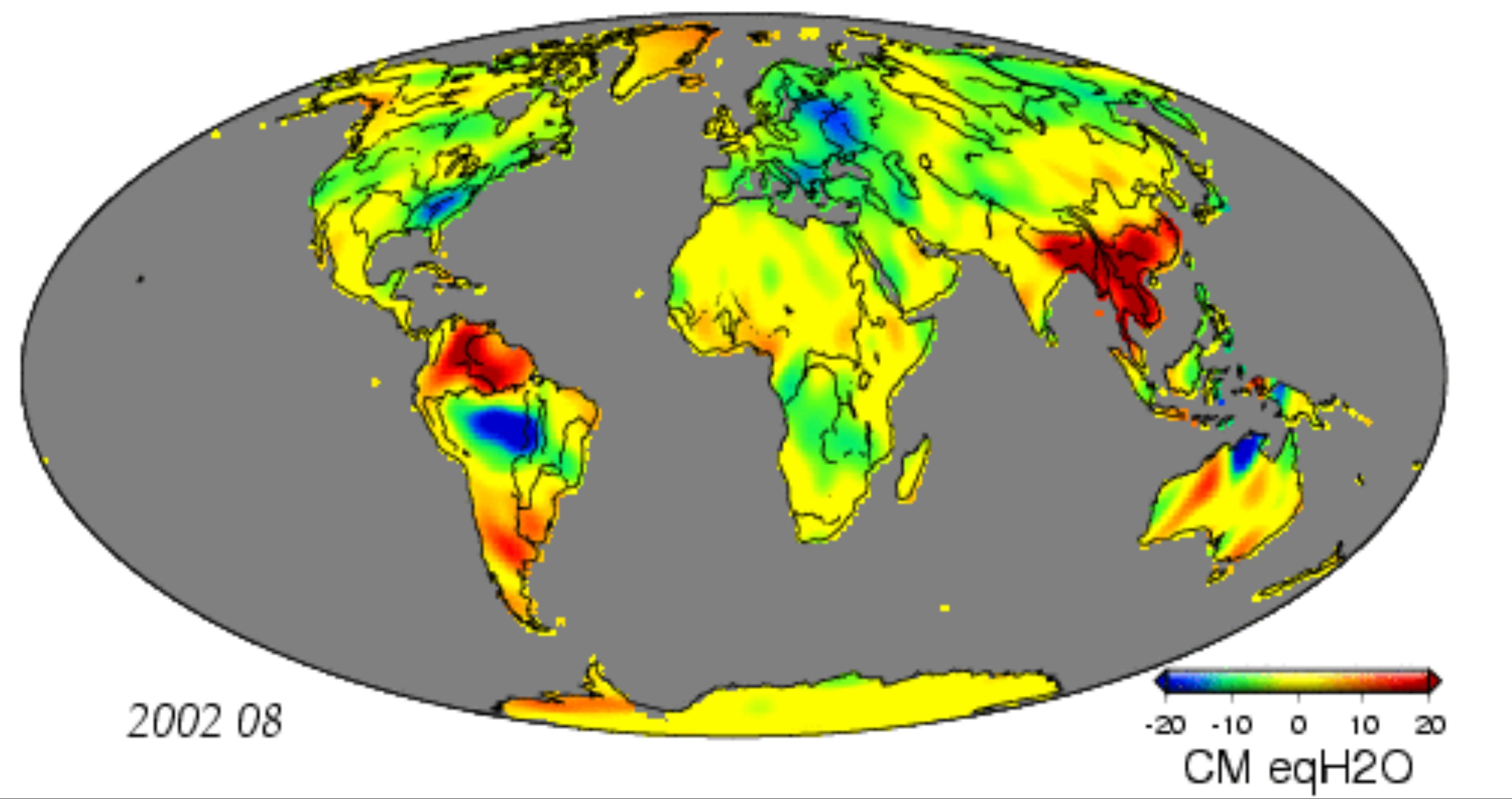
Domain	Essential Climate Variables ECV's
Atmospheric (over land, sea and ice)	Surface: air temperature, precipitation, air pressure, surface radiation budget, wind speed/ direction, water vapour Upper air: earth radiation budget, upper air temperature, wind speed/ direction, water vapour, cloud properties Composition: CO_2, methane, ozone, other long lived greenhouse gases, aerosol properties
Oceanic	Surface: sea-surface temperature, sea-surface salinity, sea level, sea ice, sea state, currents, ocean colour, CO_2 partial pressure Sub-surface: temperature, salinity, currents, nutrients, carbon, ocean tracers, phytoplankton
Terrestrial	River discharge, water use, ground water, lake levels, snow cover, glaciers and ice caps, permafrost and seasonally frozen ground, albedo, land cover (vegetation type, fraction of photosynthetically active radiation), leaf area index, biomass, fire disturbance

Hydrogeodetic Variables: Gravity

GRACE: Gravity Recovery And Climate Experiment
Spatial scales: > 150 km
Temporal scales: 1 day to 1 decade



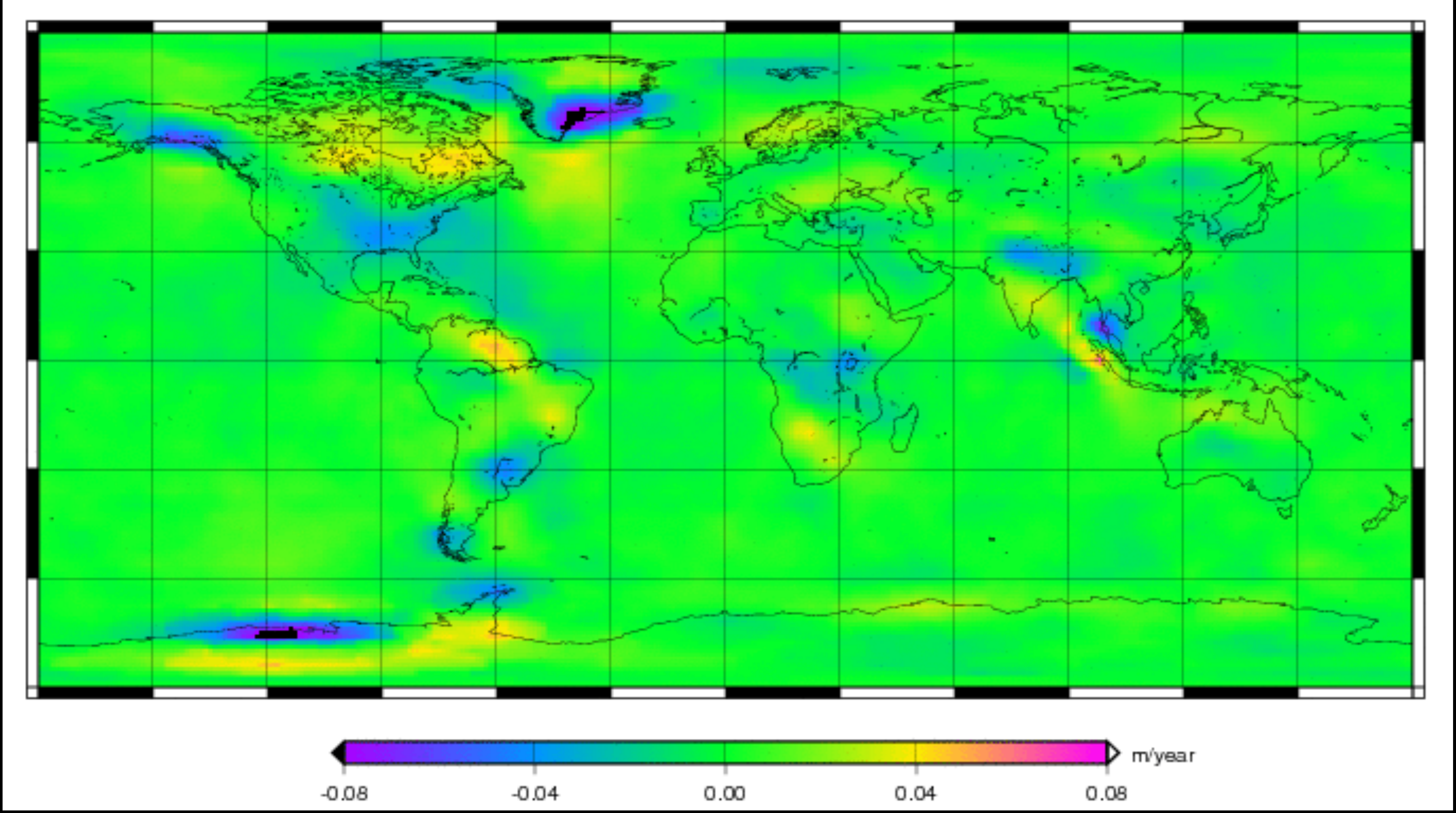
Hydrogeodetic Variables



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

Satellite Gravity Missions (GRACE)

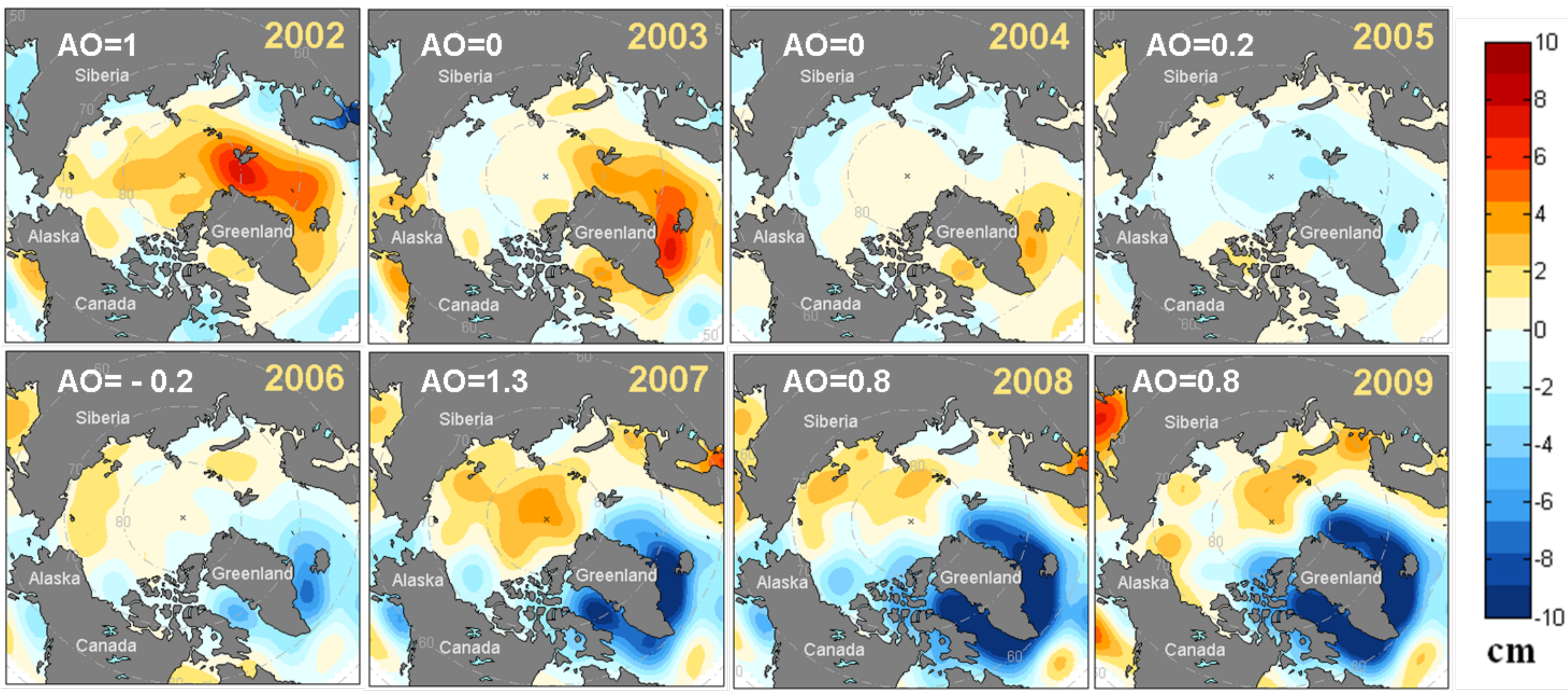
Hydrology: Secular trends in Land Water storage



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

GRACE Reveals Changes in Arctic Ocean Circulation Patterns

Variations in the Arctic Ocean circulation are associated with clockwise and counterclockwise shifts in the front between salty Atlantic-derived and less salty Pacific-derived upper ocean waters.
Orientation of the front is climatically important because it impacts sea ice transport.

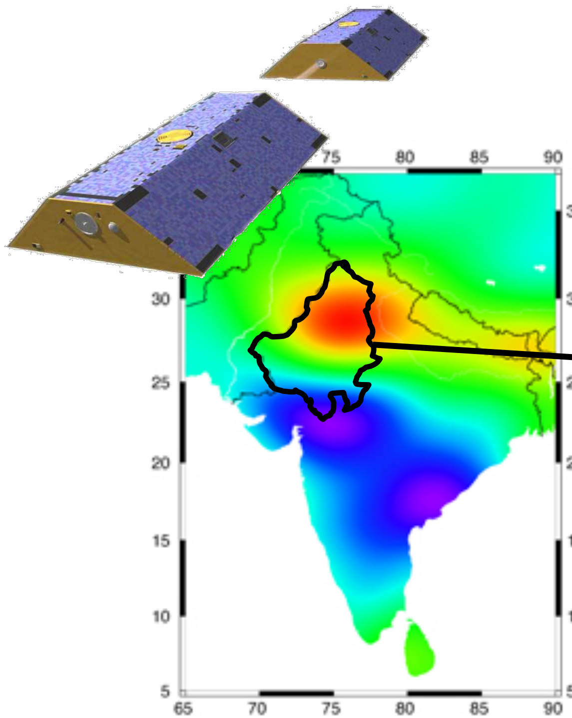


Morrison et al., *GRL*,2007

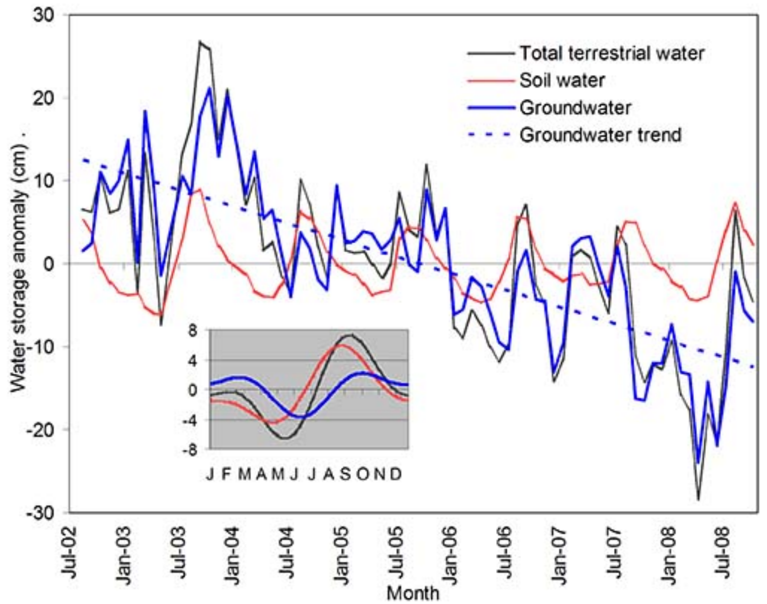
GRACE Quantifies Massive Depletion of Groundwater in NW India

The water table is declining at an average rate of 33 cm/yr

GRACE is unique among Earth observing missions in its ability to monitor variations in all water stored on land, down to the deepest aquifers.



Trends in groundwater storage during 2002-08, with increases in blue and decreases in red. The study region is outlined.



Time series of total water from GRACE, simulated soil water, and estimated groundwater, as equivalent layers of water (cm) averaged over the region. The mean rate of groundwater depletion is 4 cm/yr. Inset: Seasonal cycle.

During the study period, 2002-08, 109 km^3 of groundwater was lost from the states of Rajasthan, Punjab, and Haryana; triple the capacity of Lake Mead

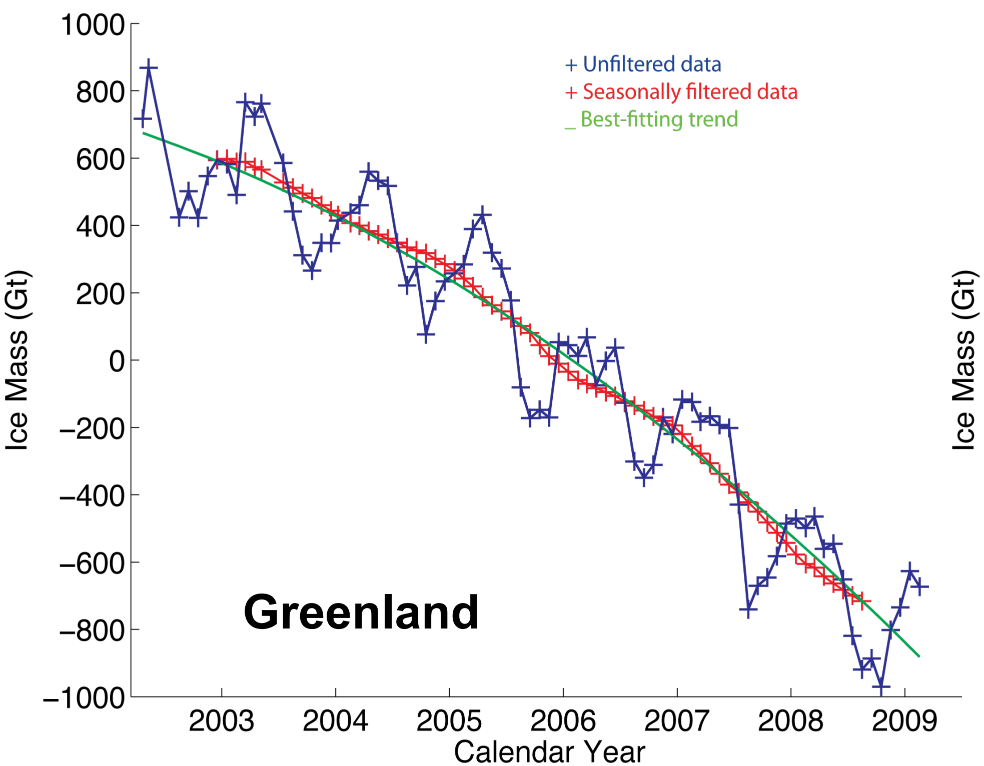
Rodell, Velicogna, and Famiglietti, *Nature*, 2009

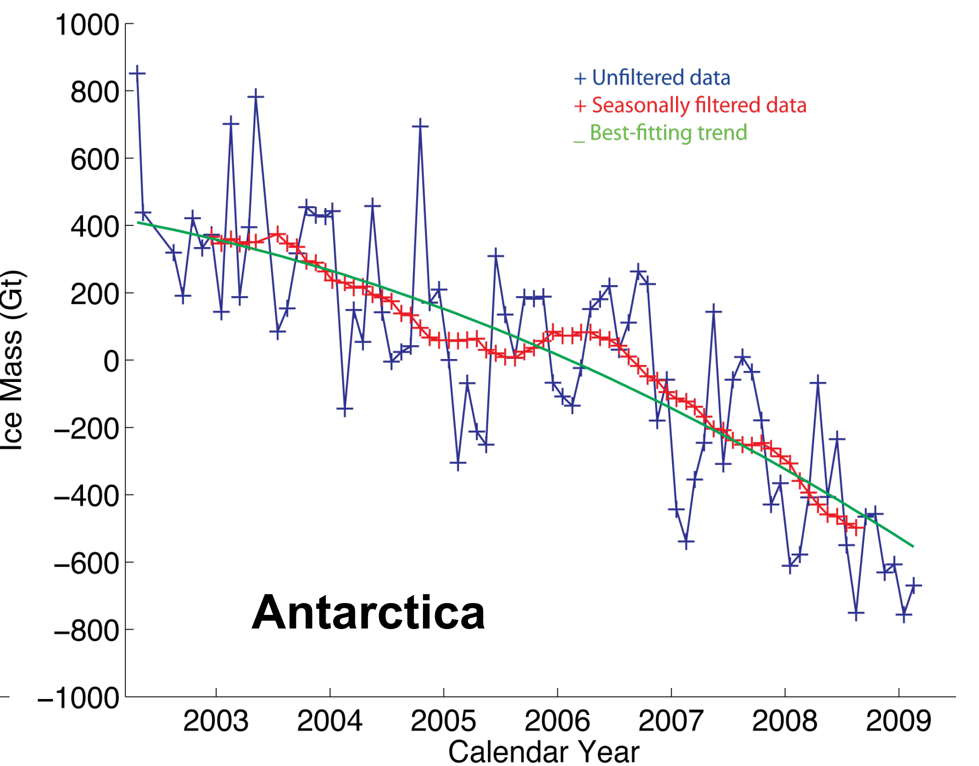
GRACE Detects Accelerated Ice Mass Loss in Greenland and Antarctica

During the period of April 2002 to February 2009 the mass loss of the polar ice sheets was not constant but increased with time, implying that the ice sheets' contribution to sea level rise was increasing.

Greenland:
- mass loss increased from 137 Gt/yr in 2002–2003 to 286 Gt/yr in 2007–2009
- acceleration of -30 ± 11 Gt/yr^2 in 2002–2009.

Antarctica:
- mass loss increased from 104 Gt/yr in 2002–2006 to 246 Gt/yr in 2006–2009
- acceleration of -26 ± 14 Gt/yr^2 in 2002–2009.

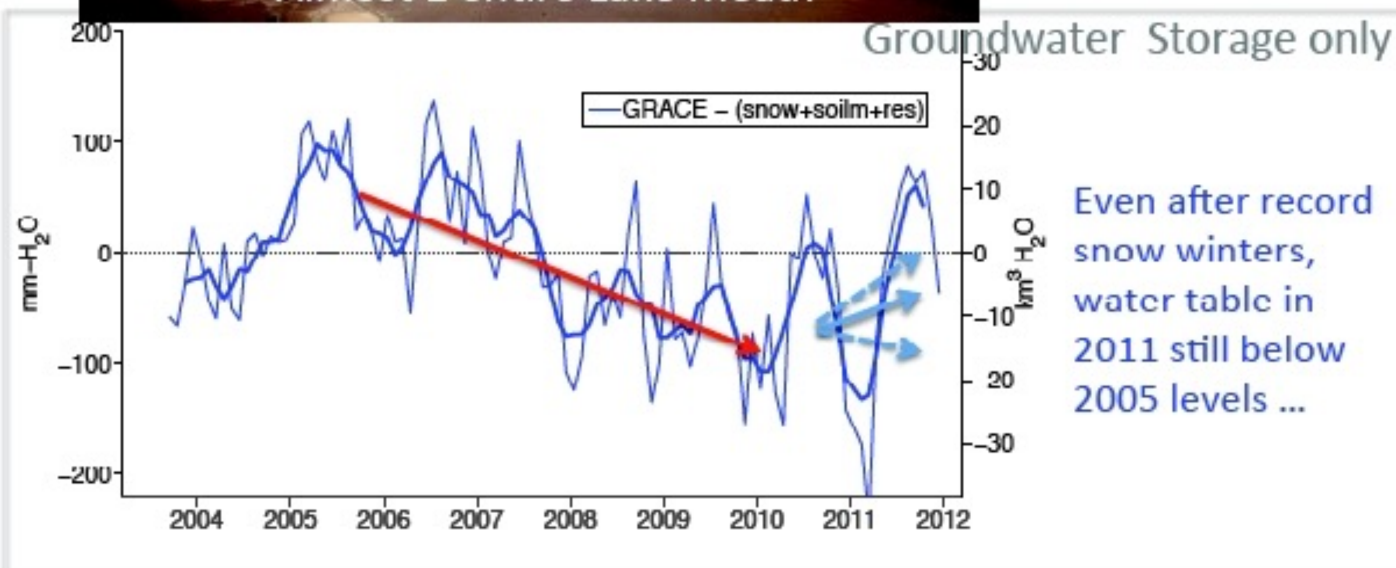




Velicogna, *GRL*,2009

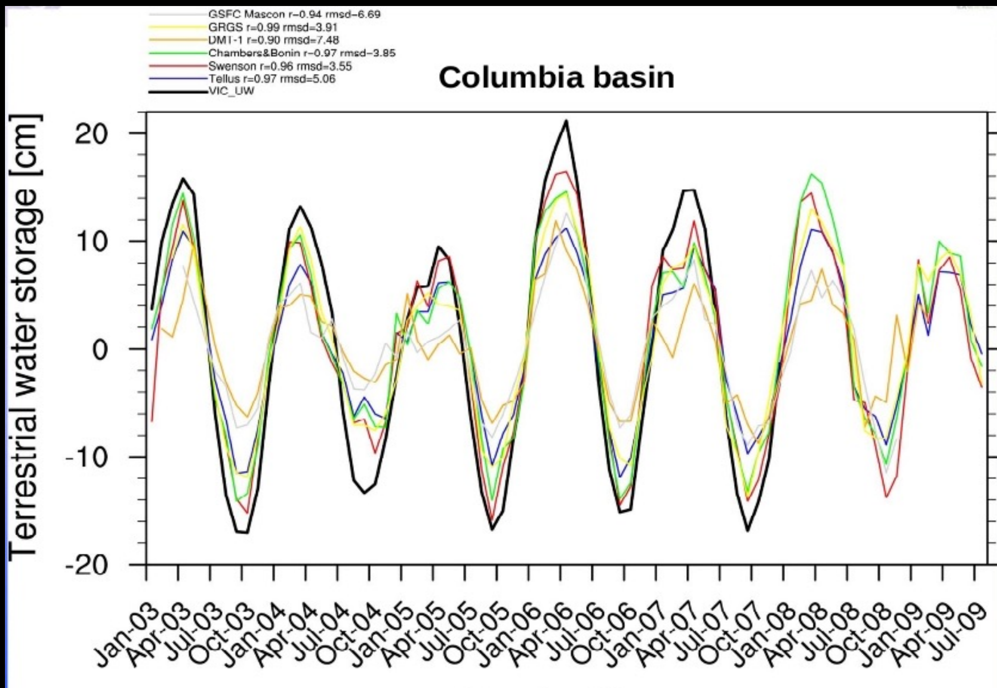
Groundwater Change (2003-2011)

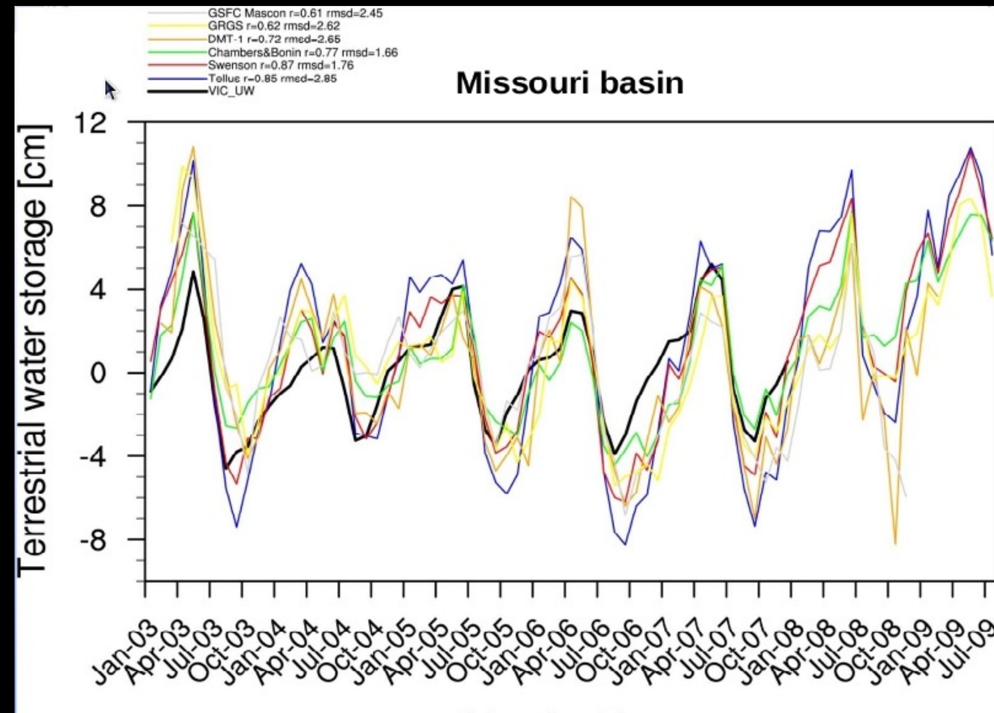
Map from Famiglietti et al., 2011

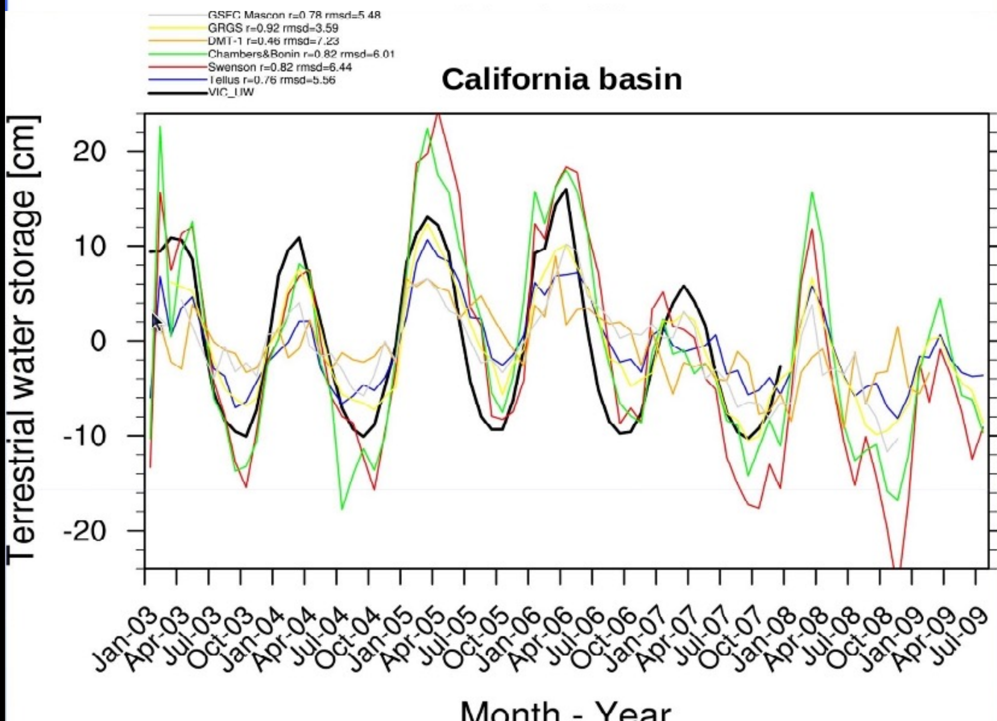


GRACE Science Team Meeting, 11-12 November 2010, Potsdam, Germany

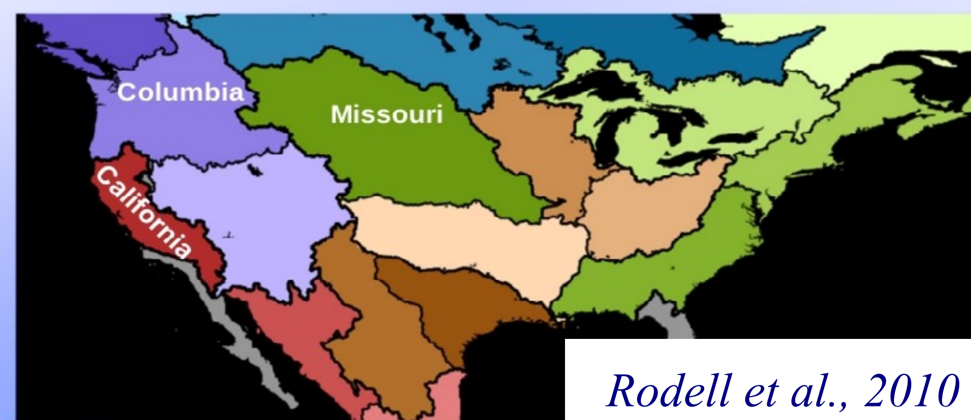
GRACE Hydrology Products Versus University of Washington Hydrology Data







UW - GRACE	California		Columbia		Missouri	
	R	*RMS*	*R*	*RMS*	*R*	*RMS*
UW - Tellus	0.76	5.56	0.97	5.06	0.85	2.85
UW - Swenson	0.82	6.44	0.96	***3.55***	***0.87***	1.76
UW - DMT-1	0.46	7.23	0.90	7.48	0.72	2.65
UW - GSFC Mascon	0.78	5.48	0.94	6.69	0.61	2.45
UW - Chambers&Bonin	0.82	6.01	0.97	3.85	0.77	***1.66***
UW - GRGS	***0.92***	***3.59***	***0.99***	3.91	0.62	2.62



Rodell et al., 2010

Hydrogeodetic Variables: Gravity

Absolute gravimetry
Spatial scales: order 100 m to global
Temporal scales: up to decades/decades

Relative gravimetry
Spatial scales: order 100 m
Temporal scales: up to interannual

Gravimetry

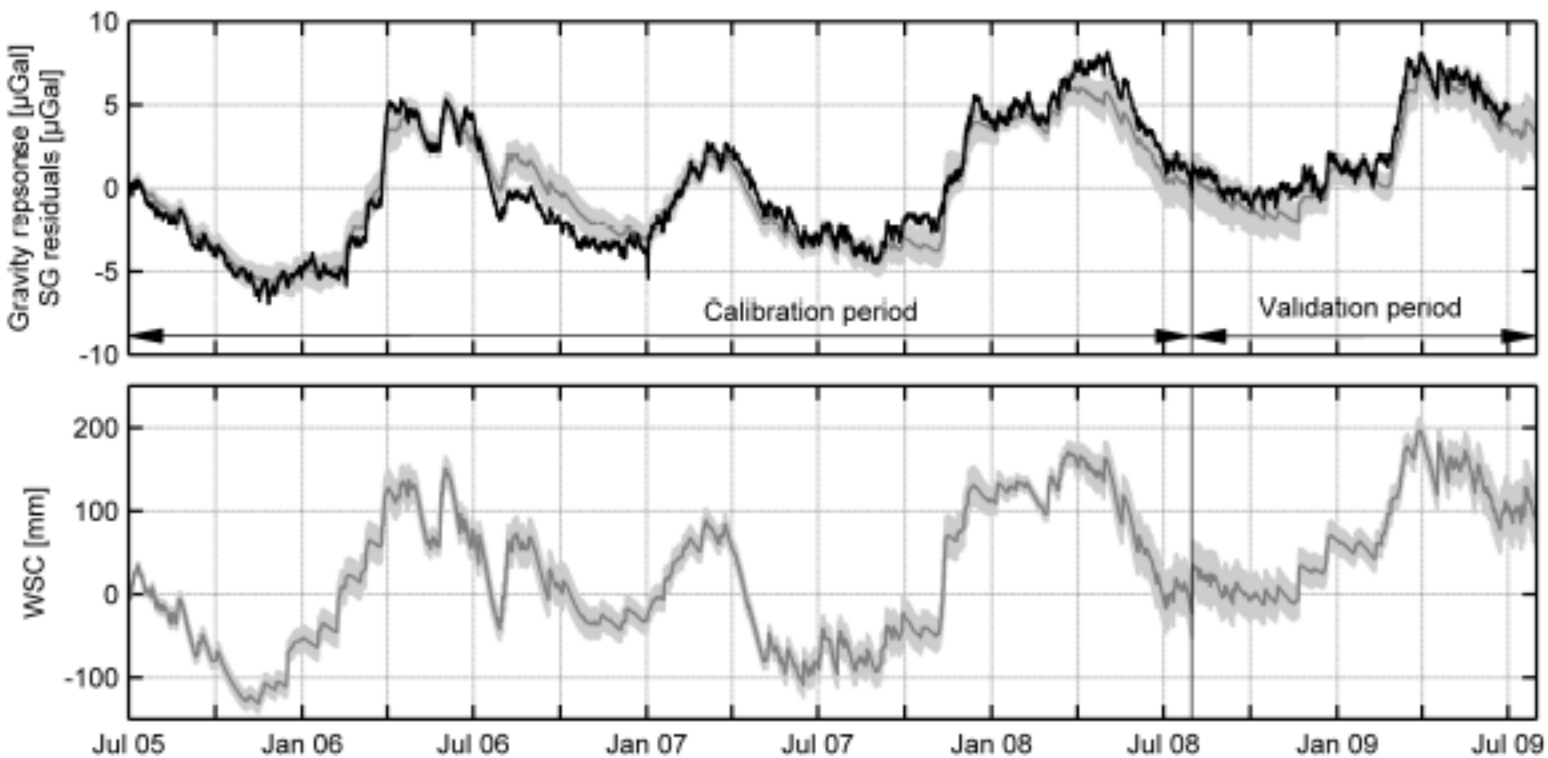


Fig. 7. SG residuals (black line) and modelled gravity response (grey band) (top). Modelled water storage change (bottom). The model was calibrated against the SG residuals for the period of 1 July 2005 to 30 July 2008.

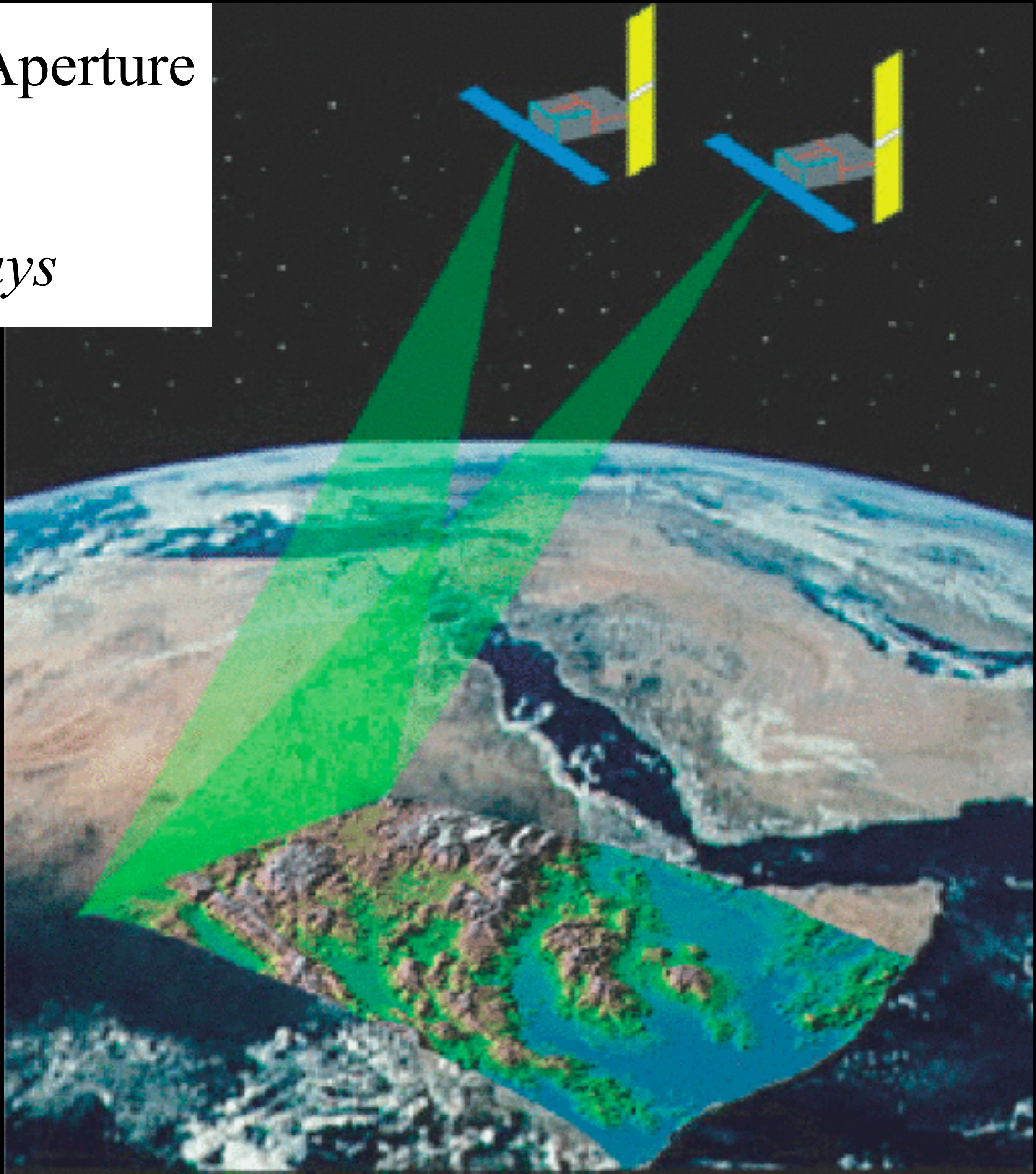
Creutzfeldt et al., 2010

Hydrogeodetic Variables: Geometry

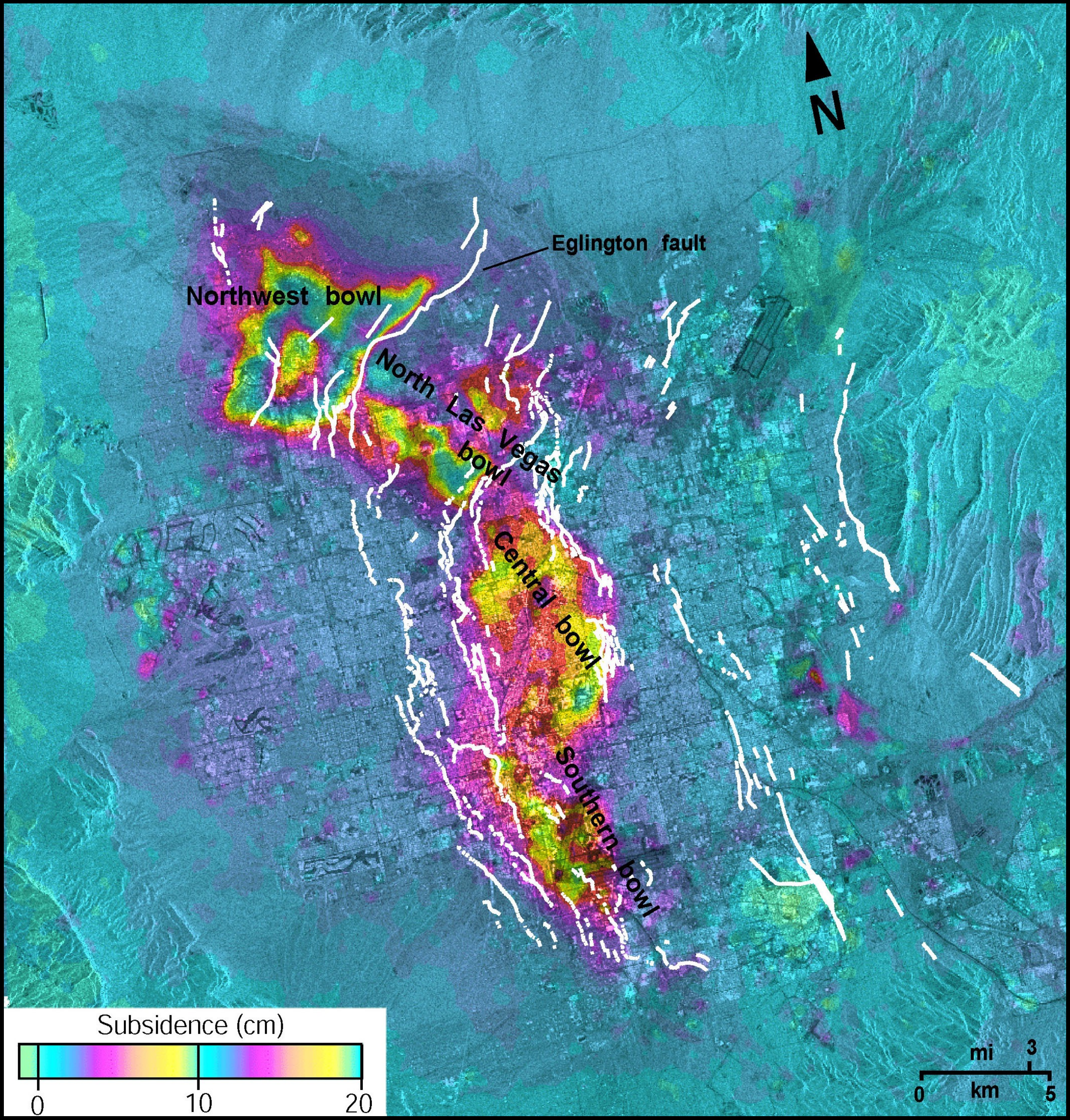
Interferometric Synthetic Aperture Radar (InSAR)

Spatial scales: order 25 m

Temporal scales: < ~10 days



InSAR-Determined Surface Displacements



Subsidence 1992-1997

Four subsidence bowls

Aquifer system response strongly controlled by faults

Faults are subsidence barriers

Subsidence rate is decreasing

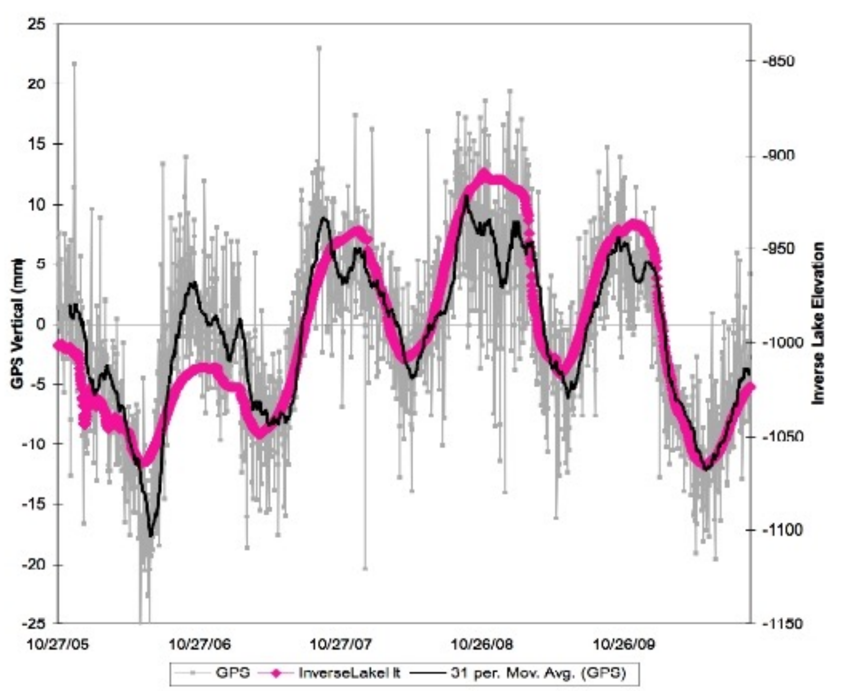
Amelung et al., 1999

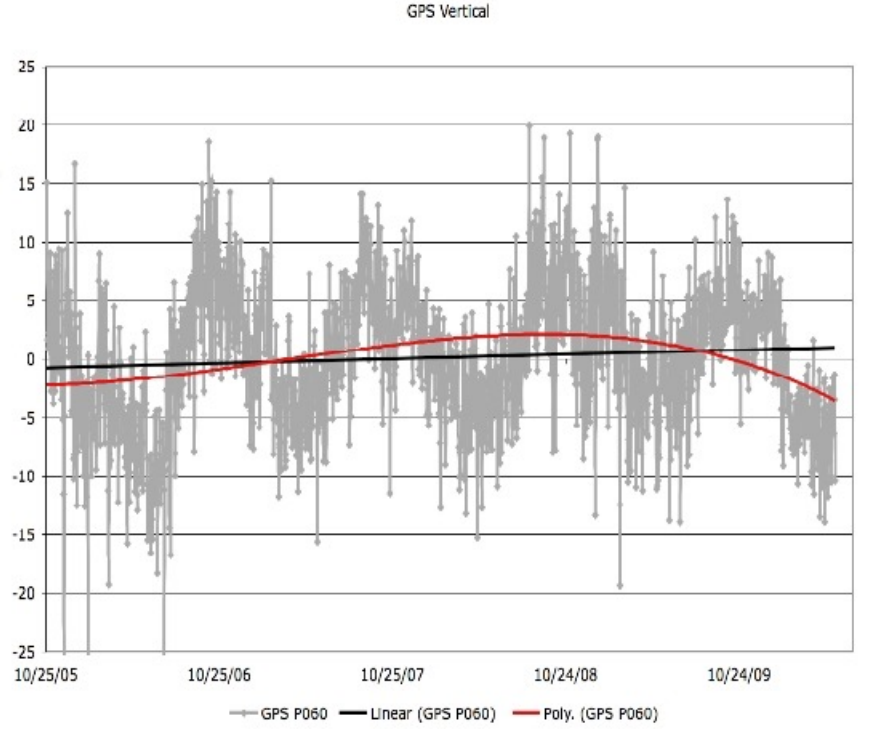
Hydrogeodetic Variables: Geometry

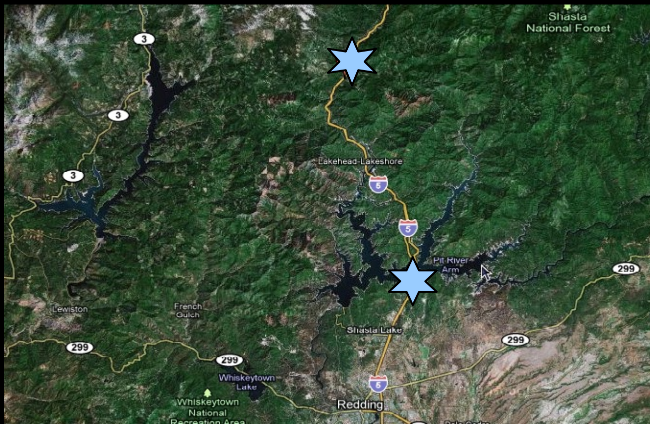
Global Positioning System (GPS)/
Global Navigation Satellite Systems (GNSS)
Spatial scales: 1 m to global
Temporal scales: 1 s to decades/secular

GPS-Determined Surface Displacements

P349: Close to Lake Shasta, California; affected by lake loading
P060: Not affected by lake loading; but effects of subsurface loading

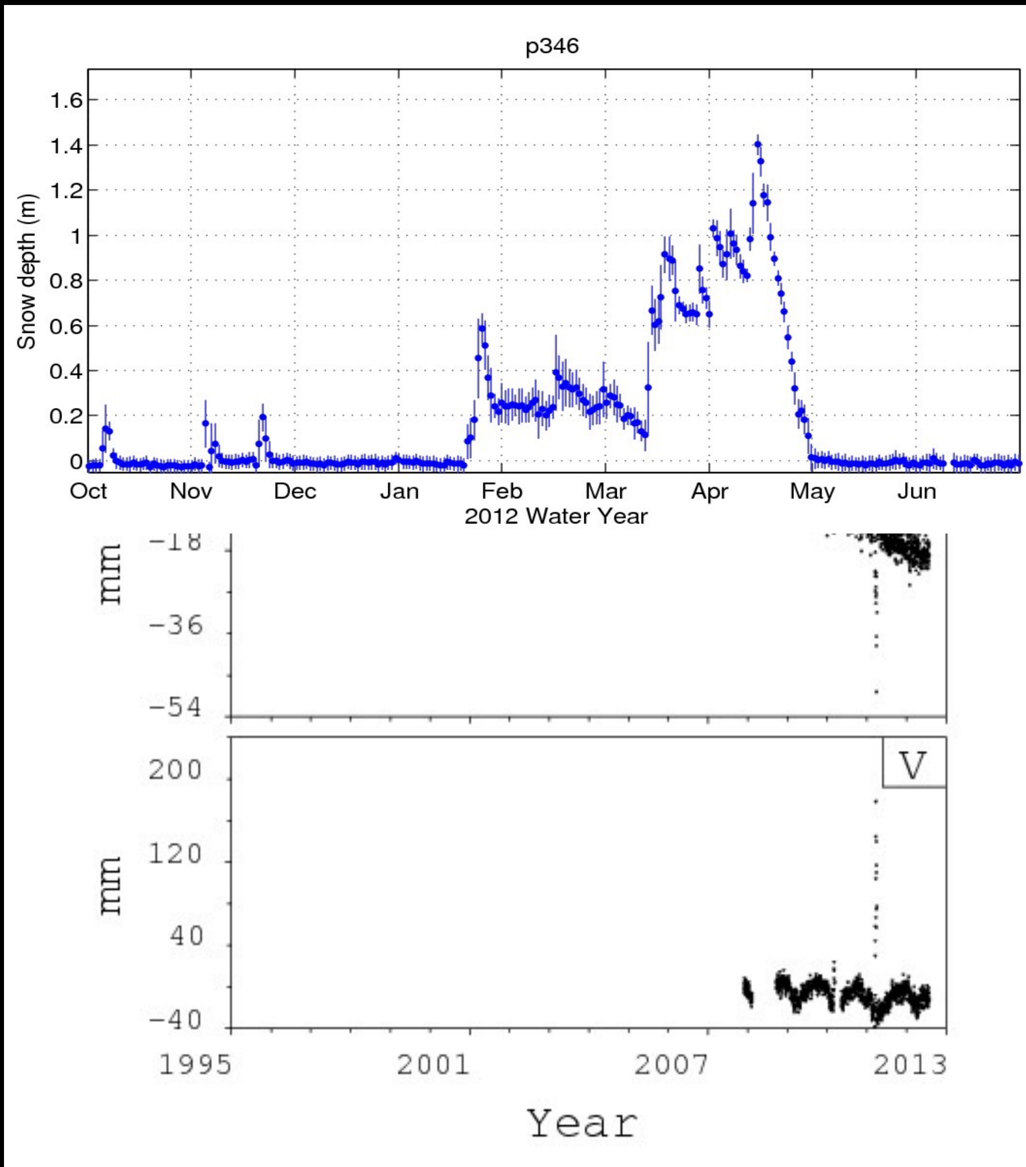


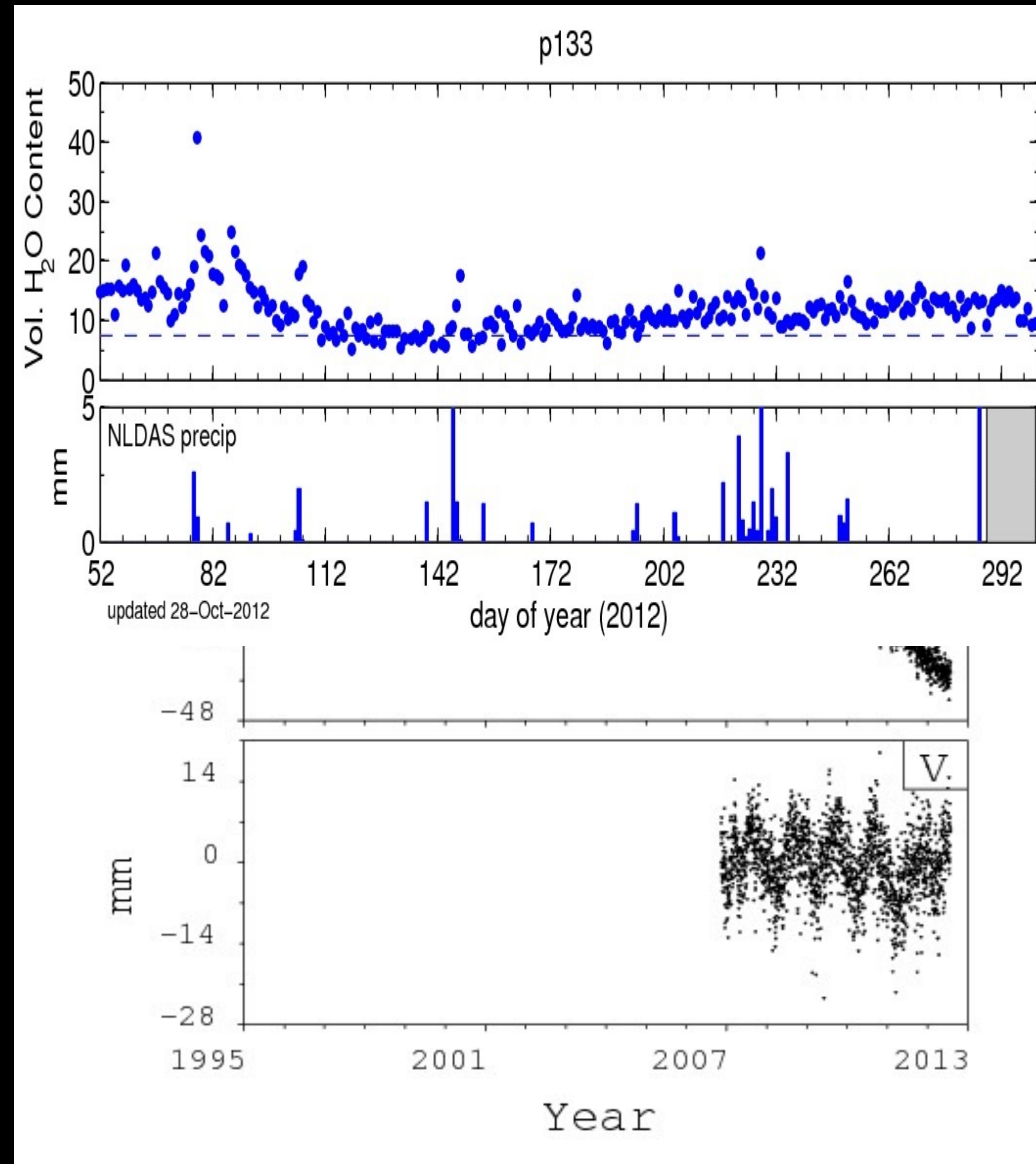




GPS Multipath: Snow Depth and Soil Moisture

P346: California, Sierra Nevada, alpine area, 2039.4 m
P133: Nevada, open shrubland, 1782 m



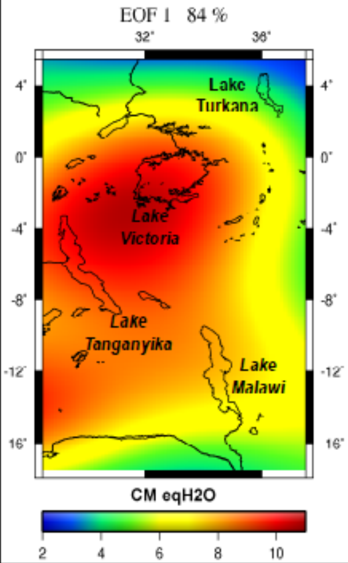


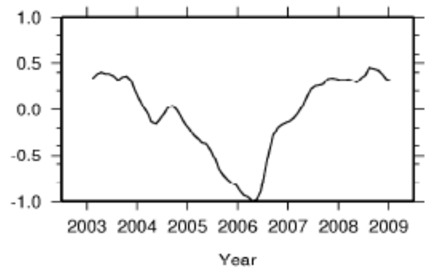
Combining Gravity and Geometry

Example: GRACE and Satellite Altimetry

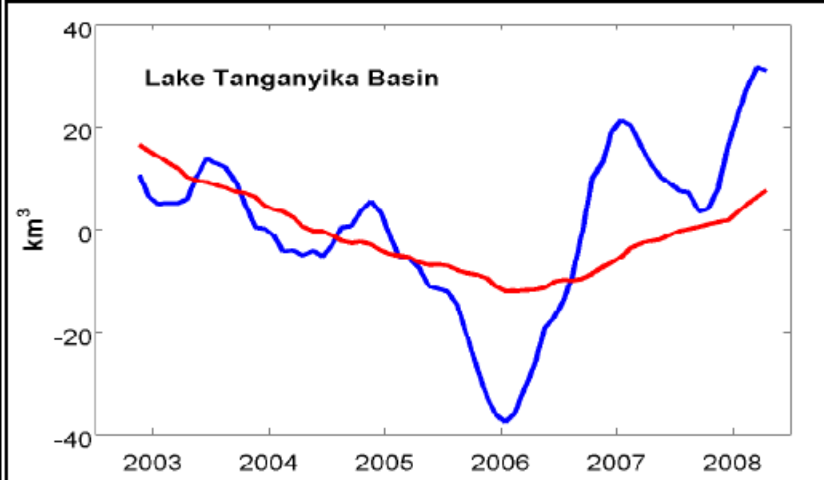
Hydrology:
Seasonal and interannual changes in land-water storage

Issue: Increased spatial and temporal resolution through combination of satellite gravity, surfaces displacements, and in situ gravity

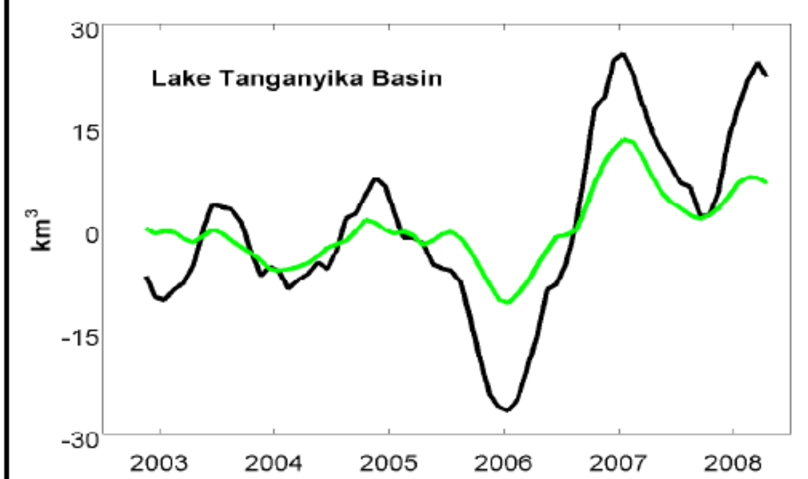




Inter-annual pattern of water storage variations in the East-African lake region based on a statistical analysis (EOF decomposition) of GRACE data.



Total water storage from GRACE for the catchment of Lake Tanganyika (blue) and lake water storage from altimetry (red).



GRACE-based subsurface water storage in black (lake storage removed) (black) and simulation results of the global hydrological model WGHM (green).

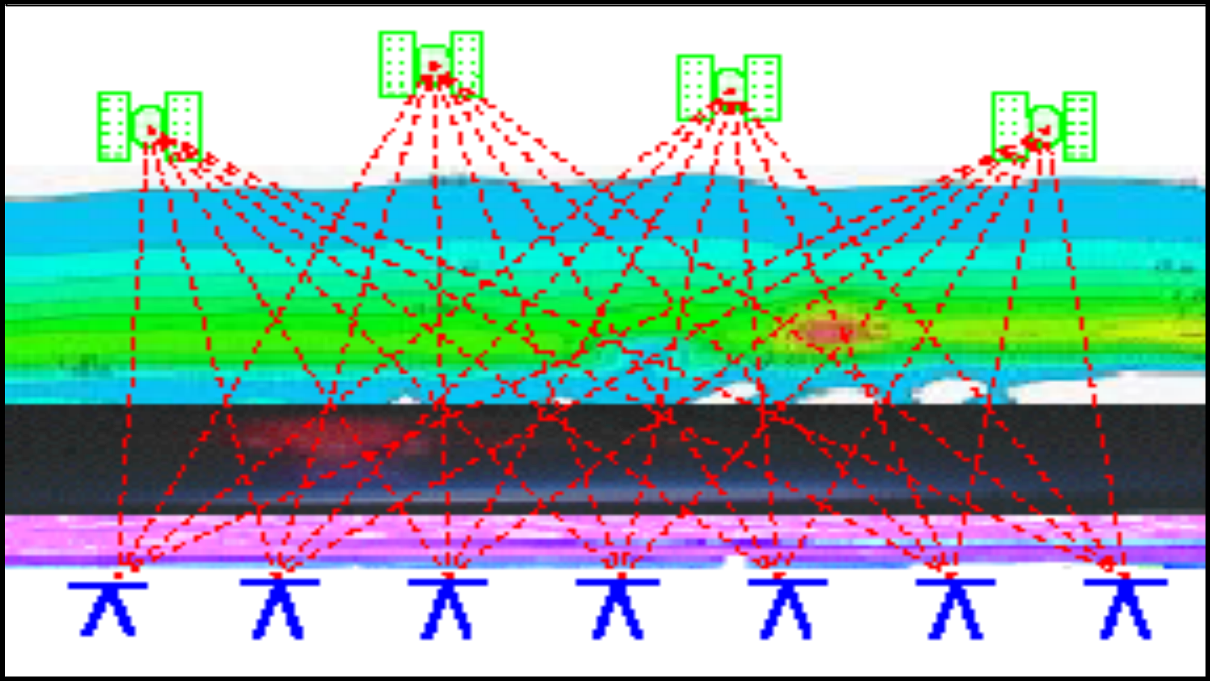
Becker et al., 2009

Utilizing “Noise”

Example: Tropospheric Water Content

Tropospheric Water Content

Atmospheric Water Vapor:
- numerical weather forecasting (extremes);
- climate change monitoring.

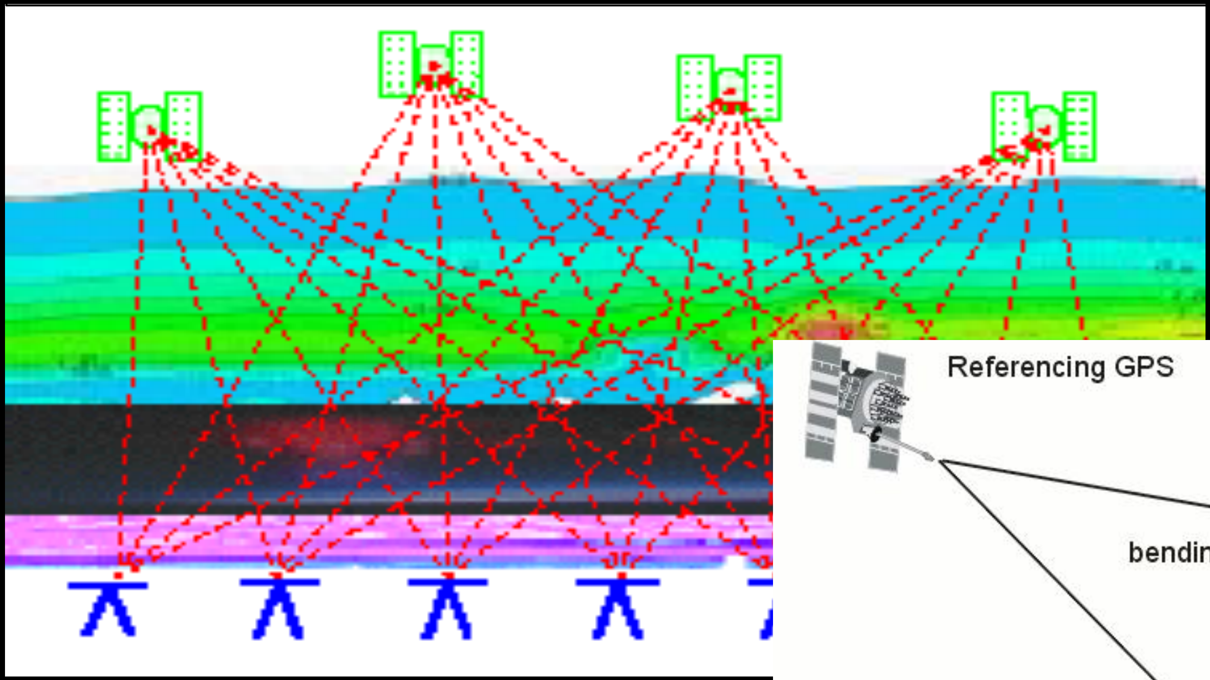


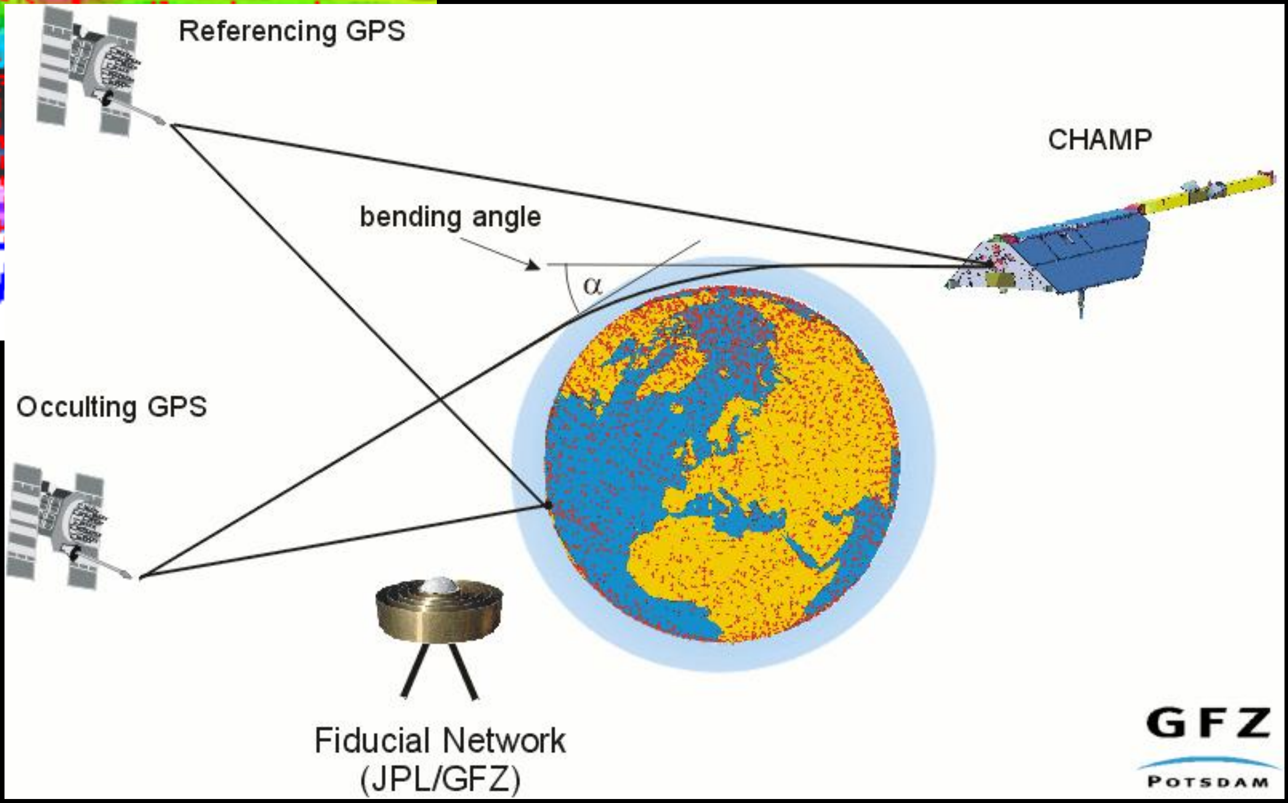
Challenges:
- high spatial resolution;
- low latency;
- long-term stability (climate)

Tropospheric Water Content

Atmospheric Water Vapor:
- numerical weather forecasting (extremes);
- climate change monitoring.

Challenges:
- high spatial resolution;
- low latency;
- long-term stability (climate)

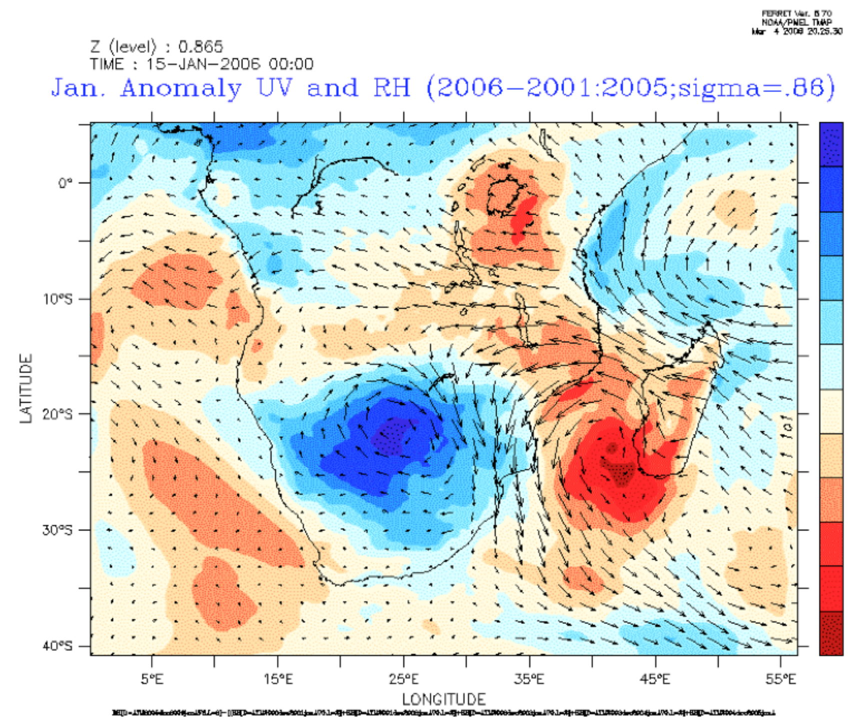




Tropospheric Water Content

Atmospheric Water Vapor
- high societal relevance: drought and dry spells are linked with meningitis outbreaks

Challenges:
- high spatial resolution;
- low latency;
- long-term stability (climate)

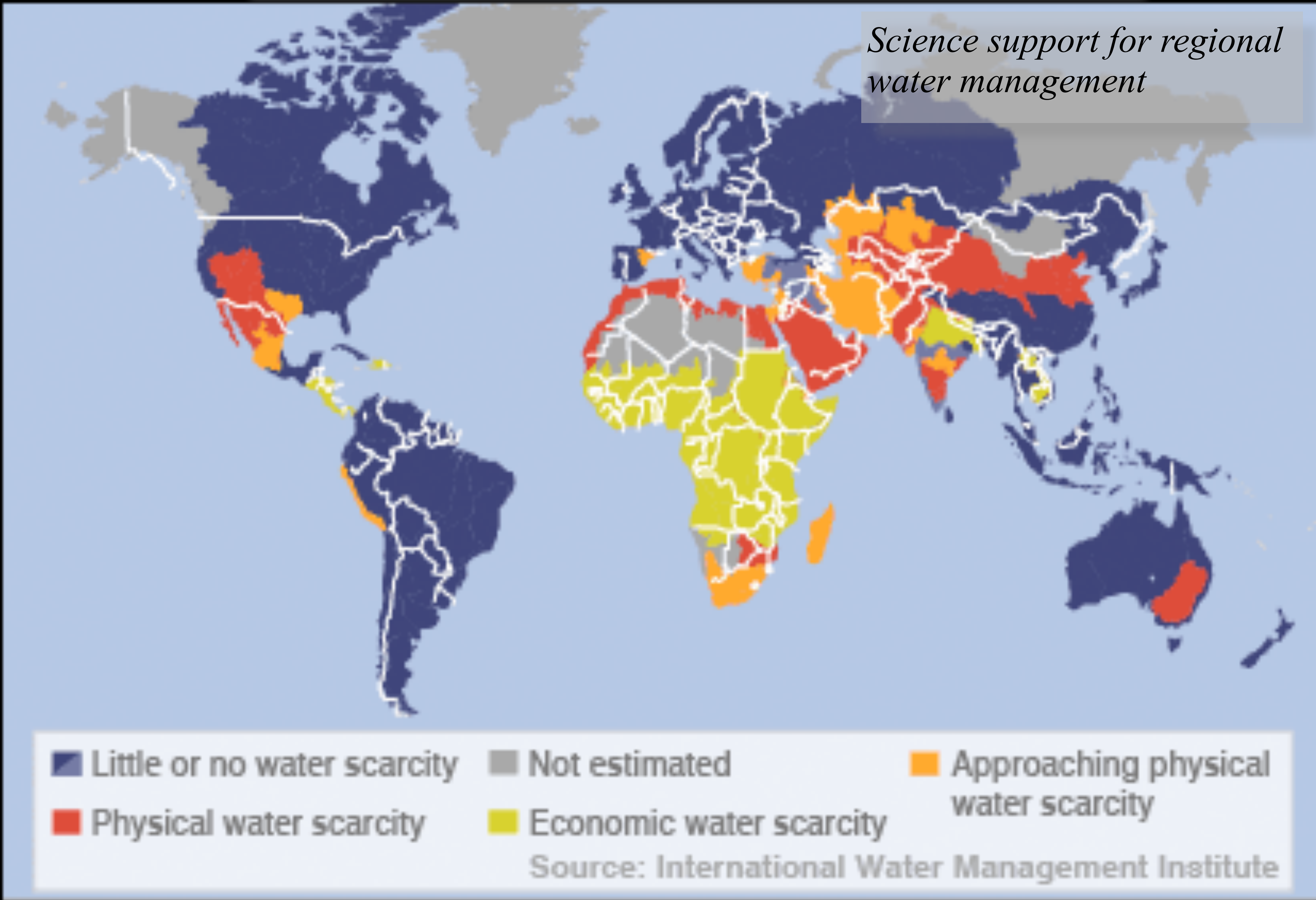


Left: annihilated wildlife in Tanzania during the 2005 record drought.
Right: Prediction of drought conditions based on vertically integrated relative humidity. Although the model results appear to be qualitatively realistic, one cannot confirm the model results because the upper air coverage is too sparse over the region.

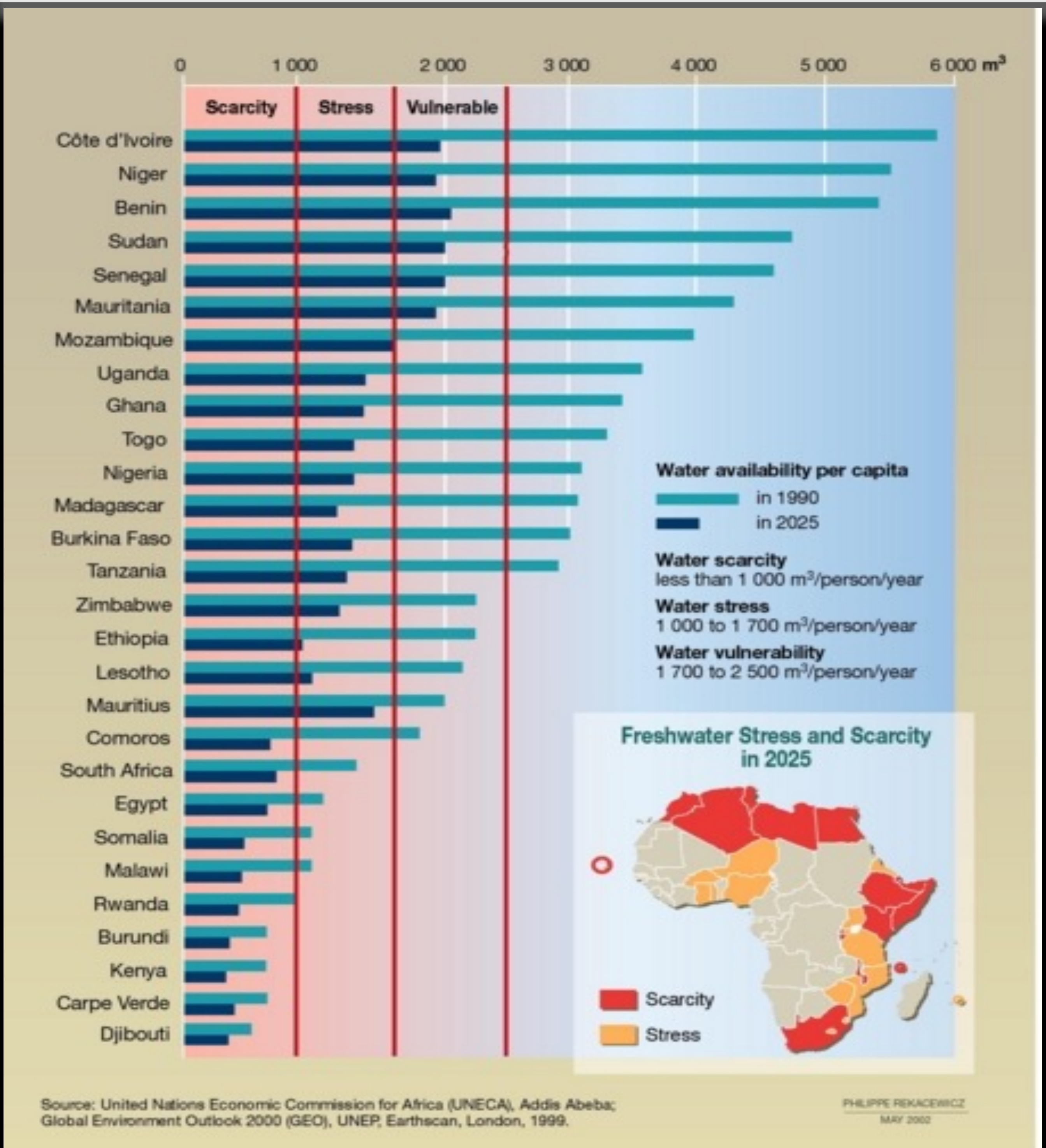
From Calais, 2009

Societal Benefits

Science support for regional water management



Societal Benefits

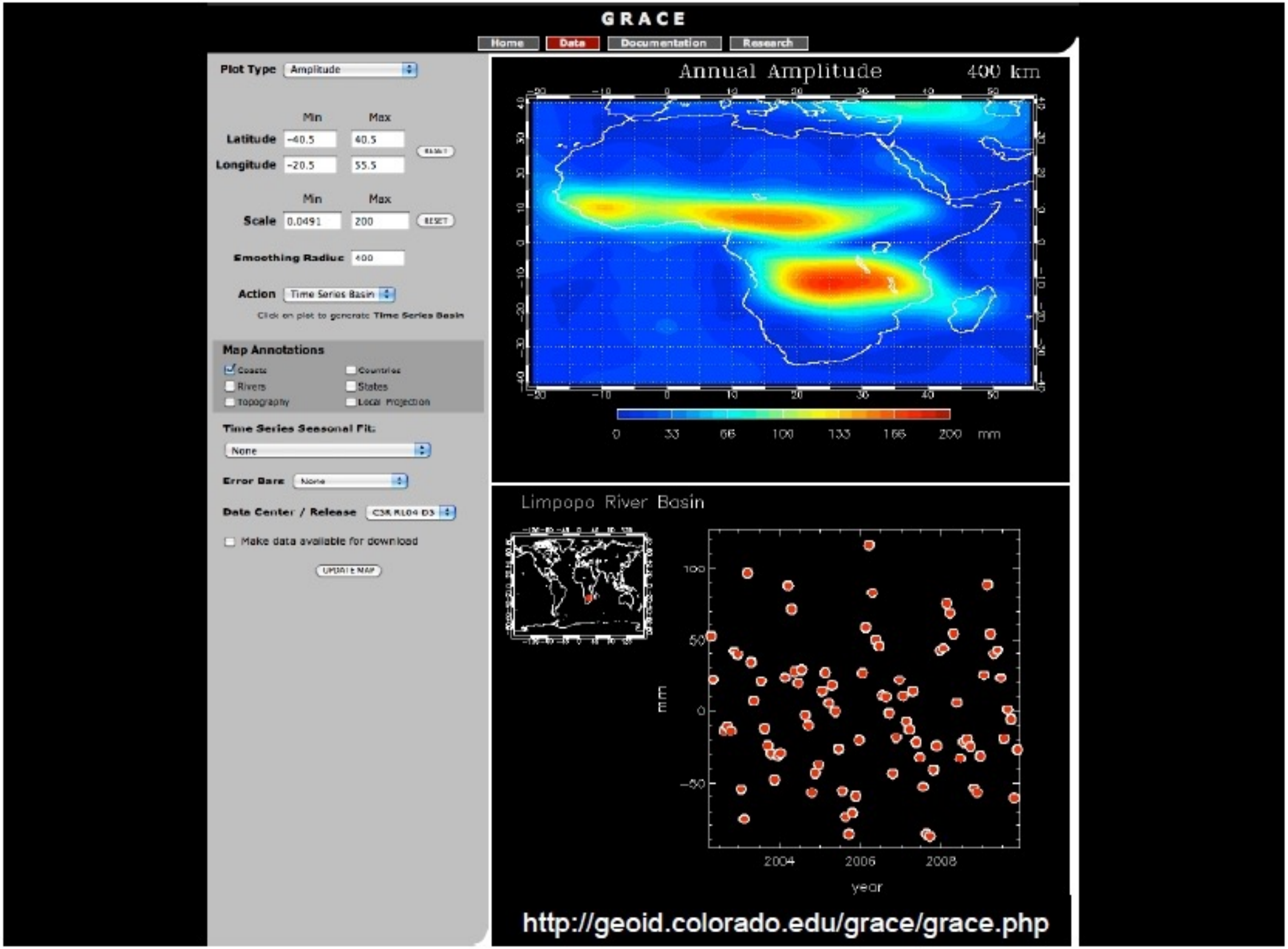


Available Products

Geodetic Products for Hydrology:

- (until recently) Hydrogeodesy products mostly limited to GRACE;
- Several data centers providing a number of products;
- Products not easy-to-use;

Available Products



Available Products

Geodetic Products for Hydrology:

- (until recently) Hydrogeodesy products mostly limited to GRACE;
- Several data centers providing a number of products;
- Products not ready-to-use;
- Community-validated GRACE hydrology products are (*still not available and*) needed;
- Comparison of different GRACE products and hydrology data shows no clear-winner; different products seem to perform better in different regions;
- Large data archives of GPS time series are emerging (UNR has more than 10,000 stations), although not specifically for hydrology;

Available Products

Nevada Geodetic Laboratory

Serving science and society with detailed observations of surface displacements and strains ...

Disclaimer | Copyrights | Citations | Acknowledgements

NGL | Data Web | Parameters | Maps | Animations | Regions | Stations | Analysis | Data Archive

Global Station List

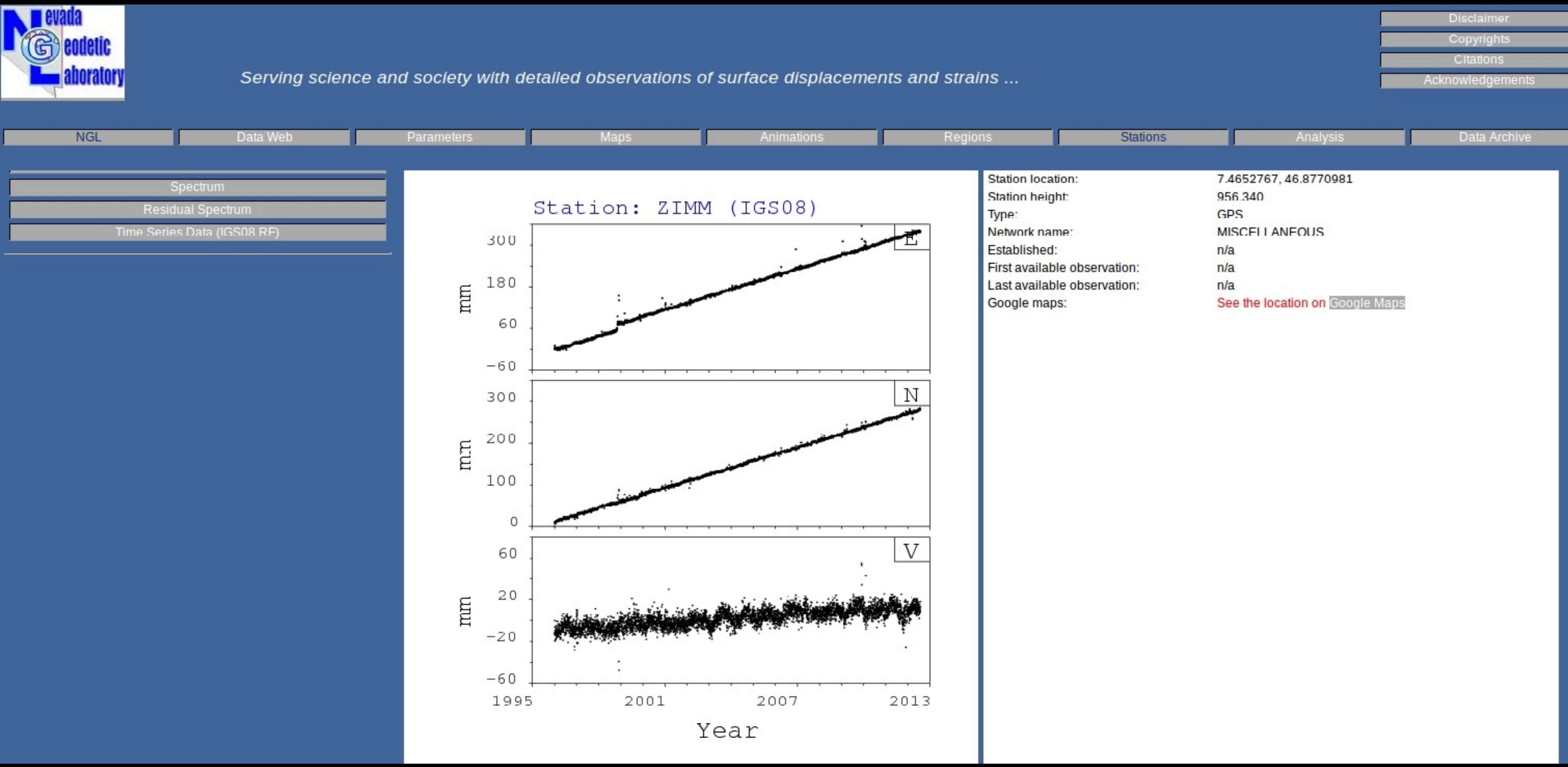
Help for Users

Earth's Surface Displacement

Station List

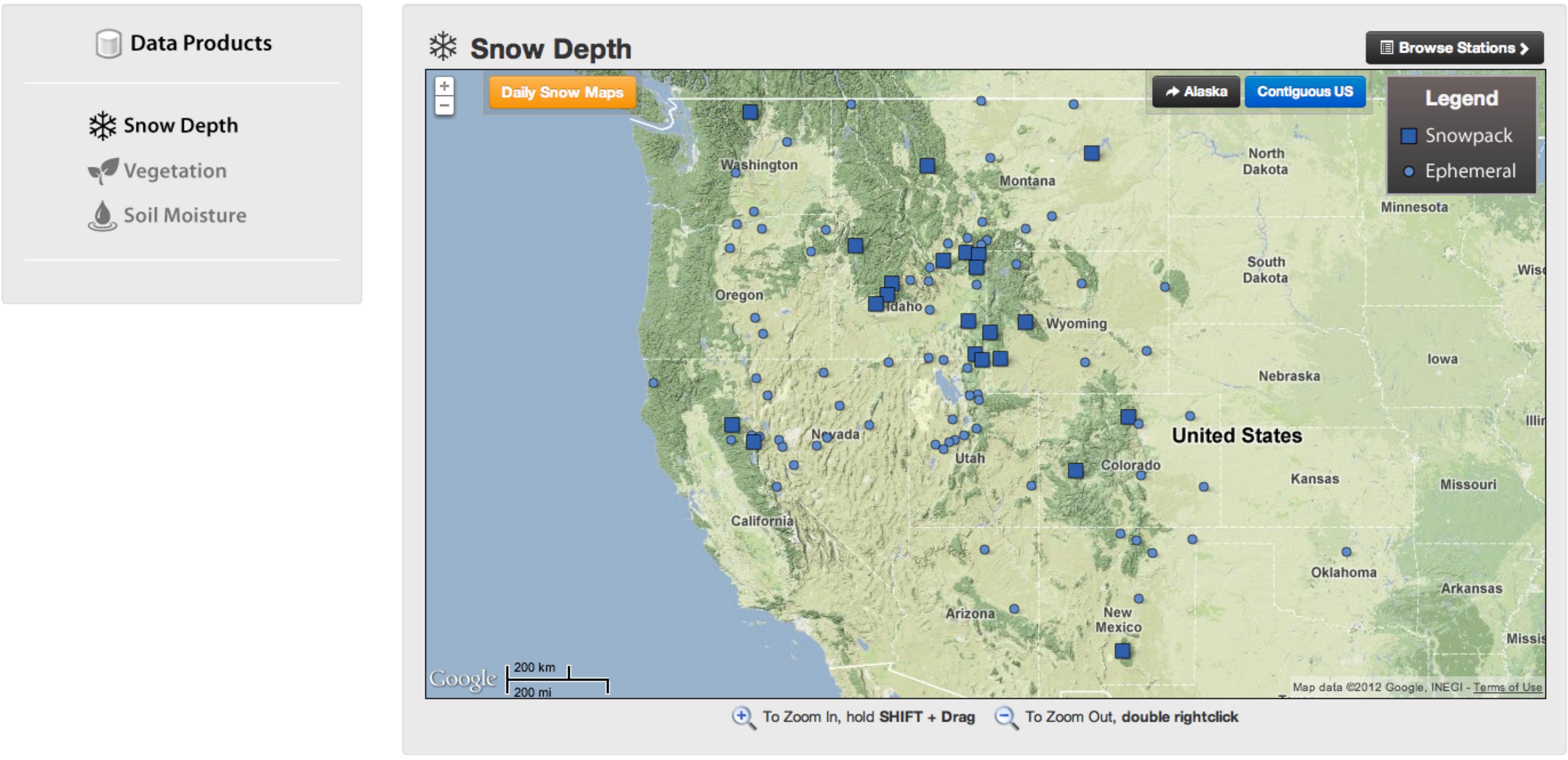
00NA	019B	01NA	02NA	1000	1LSU	1NSU	1ULM	20NA	21NA	299C	2TRY	4CDA	4CRN	4CRY	4GRM	4HLN	4HVB	4MC0	4MCY
4VIR	4WCK	4YAT	59WE	5LIT	5PTS	7OAK	7ODM	AACH	AARS	AASI	AAUC	AB01	AB02	AB04	AB06	AB07	AB08	AB09	AB11
AB12	AB13	AB14	AB15	AB17	AB18	AB21	AB22	AB25	AB27	AB28	AB33	AB35	AB36	AB37	AB39	AB41	AB42	AB43	AB44
AB45	AB46	AB48	AB49	AB50	AB51	AB53	ABAN	ABCC	ABEA	ABED	ABEP	ABER	ABGS	ABMF	ABMS	ABPD	ABPO	ABPW	ABQ1
ABQ2	ABQ5	ABQ6	ABRK	ABVI	ABYW	AC02	AC03	AC06	AC07	AC08	AC09	AC10	AC11	AC12	AC13	AC14	AC15	AC16	AC17
AC18	AC19	AC20	AC21	AC23	AC24	AC25	AC26	AC27	AC28	AC30	AC31	AC32	AC33	AC34	AC35	AC36	AC37	AC38	AC39
AC40	AC41	AC42	AC43	AC44	AC45	AC46	AC47	AC48	AC50	AC51	AC52	AC53	AC55	AC57	AC58	AC59	AC60	AC61	AC62
AC63	AC64	AC65	AC66	AC67	AC69	AC70	AC71	AC72	AC74	AC75	AC76	AC77	AC78	AC79	AC80	ACCE	ACHO	ACL1	ACNS
ACOM	ACOR	ACPM	ACRA	ACSO	ACU1	ACU2	ACU4	ACU5	ACU6	ADA1	ADAN	ADAR	ADD0	ADD1	ADE0	ADE1	ADE2	ADEE	ADEL
ADIS	ADIY	ADKS	ADN1	ADOB	ADRI	AFAL	AFHT	AFKB	AFKL	AFYN	AGAR	AGDE	AGDS	AGIO	AGMC	AGMT	AGNA	AGNE	AGPS
AGR1	AGRD	AGRI	AGU1	AGUA	AGUE	AGUI	AHID	AHTI	AHUP	AHVZ	AICI	AIES	AIGL	AILT	AINP	AIRA	AIRS	AIS1	AIS2
AIS5	AIS6	AISD	AIZK	AIZW	AJAC	AJAL	AKDG	AKGG	AKHR	AKLV	AKMO	AKRB	AKSI	AKSR	AKTO	AKUR	AL10	AL13	AL15
AL20	AL30	AL35	AL40	AL46	AL50	AL55	AL60	AL62	AL70	AL76	AL81	AL82	AL83	AL84	AL90	AL92	ALA1	ALA2	ALAC
ALAJ	ALAL	ALAM	ALAN	ALAR	ALAS	ALAT	ALAW	ALB1	ALB2	ALBA	ALBE	ALBH	ALBI	ALBU	ALBY	ALC1	ALC2	ALCA	ALCE
ALCH	ALCI	ALCL	ALCN	ALCO	ALCT	ALCU	ALDA	ALDB	ALDE	ALDI	ALDO	ALDS	ALE1	ALE2	ALEB	ALEP	ALES	ALEX	ALFA
ALFE	ALFO	ALG2	ALG3	ALGC	ALGO	ALGR	ALH1	ALHA	ALHC	ALHL	ALIA	ALIC	ALIF	ALIN	ALJA	ALLA	ALLG	ALME	ALMR
ALNB	ALNC	ALON	ALPE	ALPP	ALRE	ALRT	ALSA	ALSC	ALSE	ALSP	ALT1	ALTA	ALTH	ALUM	ALUT	ALUY	ALW2	ALWJ	ALX2
ALYT	AMAR	AMAS	AMB2	AMBE	AMBL	AMC2	AMER	AMHU	AMMN	AMNH	AMOS	AMPE	AMRI	AMST	AMTS	AMU1	AMU2	AMUN	AMUR
ANA1	ANAT	ANAU	ANAV	ANAY	ANC1	ANC2	ANCA	ANCG	ANCN	ANCY	AND1	AND2	ANDA	ANDE	ANDG	ANDO	ANDR	ANDS	ANDU
ANG1	ANG2	ANG3	ANG4	ANG5	ANG6	ANG7	ANGE	ANGL	ANGO	ANGS	ANIP	ANKR	ANMU	ANP1	ANP5	ANP6	ANRK	ANT1	ANTA
ANTB	ANTC	ANTE	ANTH	ANTI	ANTL	ANTO	ANTV	ANTW	AO01	AOA1	AOML	AOPR	APEL	APEX	API1	APOL	APPL	APRI	APSA
APSL	APTO	APVY	AQUI	AQUM	ARAC	ARAN	ARAR	ARBT	ARBU	ARC1	ARCA	ARCE	ARCH	ARCM	ARCO	ARD1	ARDH	ARDL	ARDU
AREL	AREQ	AREV	AREZ	ARFY	ARG1	ARGI	ARGU	ARHP	ARHR	ARIB	ARIS	ARIT	ARKI	ARKL	ARLI	ARLN	ARLO	ARLR	ARM1
ARM2	ARM3	ARMD	ARMH	ARMI	ARMY	ARNA	ARNG	ARNP	ARNR	AROL	ARP2	ARP3	ARP5	ARP6	ARP7	ARP8	ARPG	ARPK	ARRA

Available Products

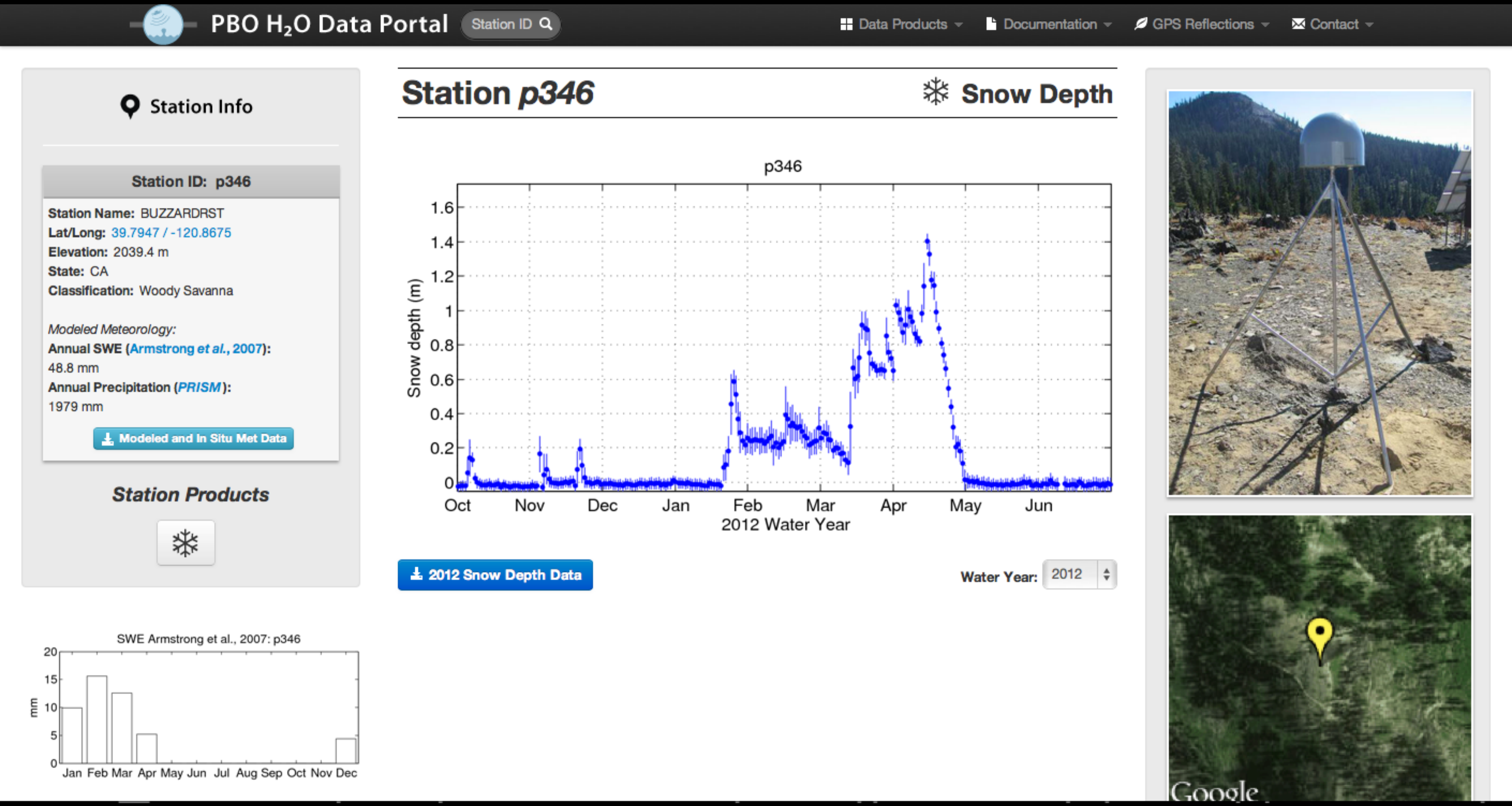


Available Products

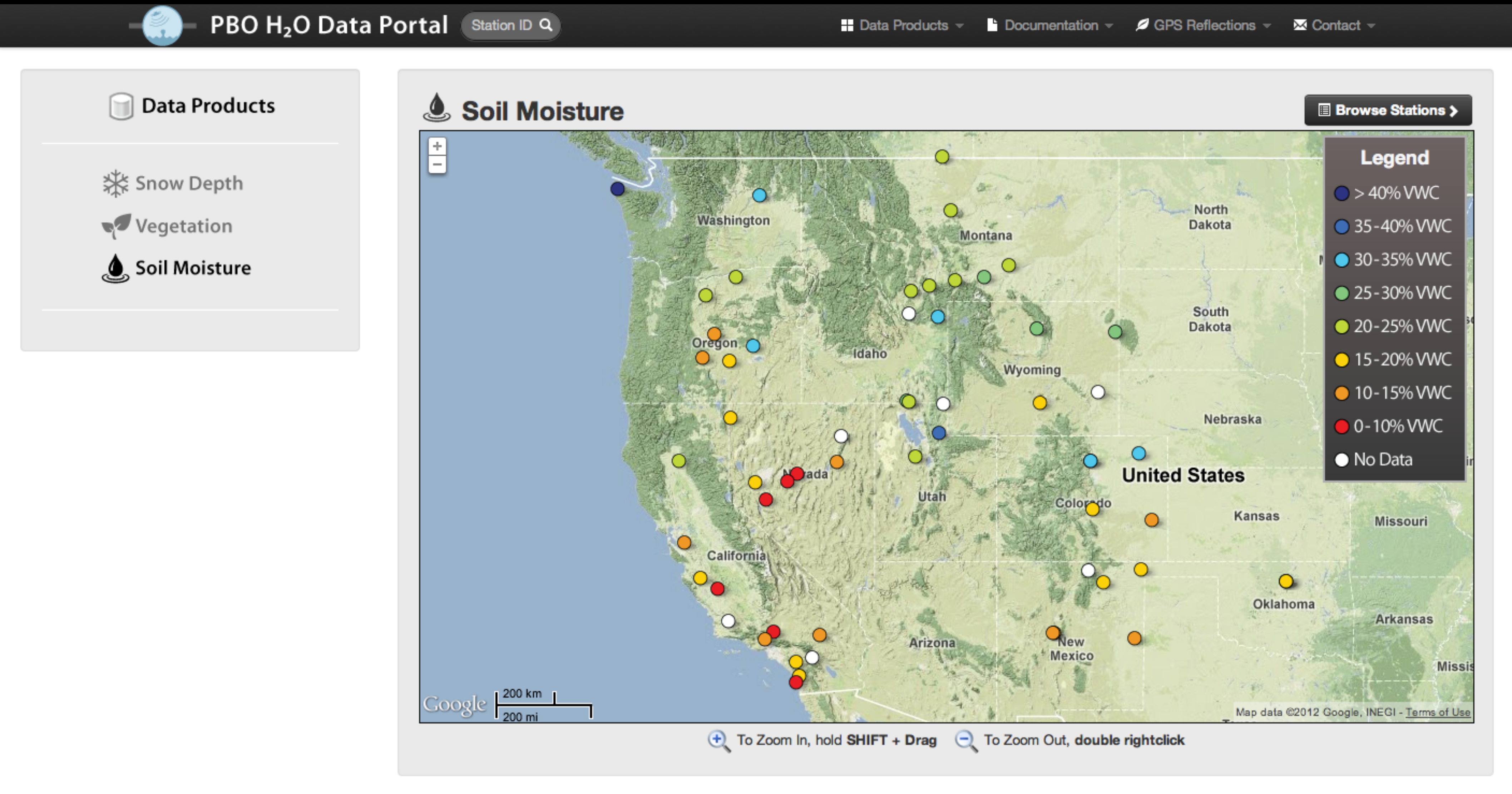
Available Products



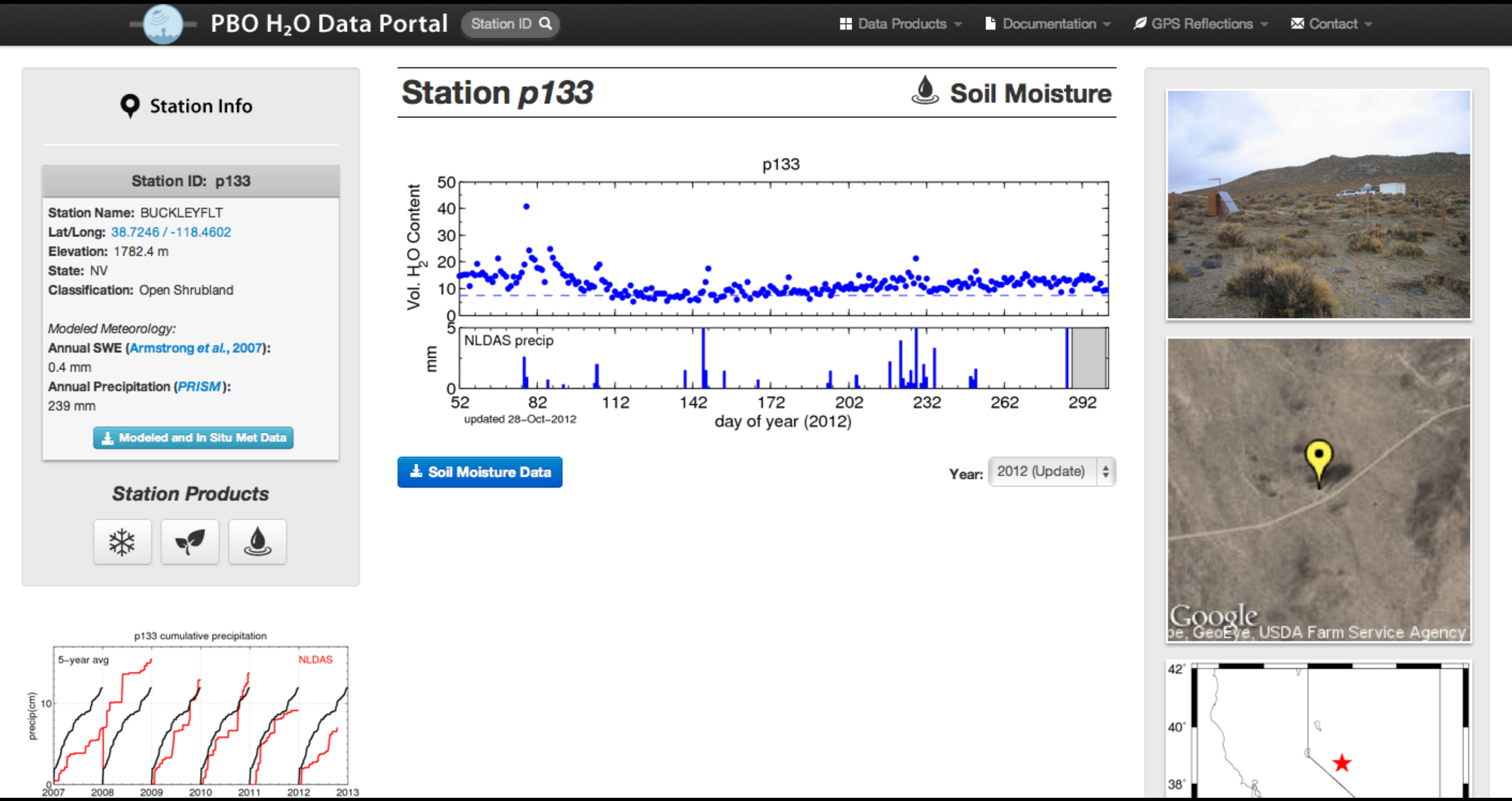
Available Products



Available Products



Available Products

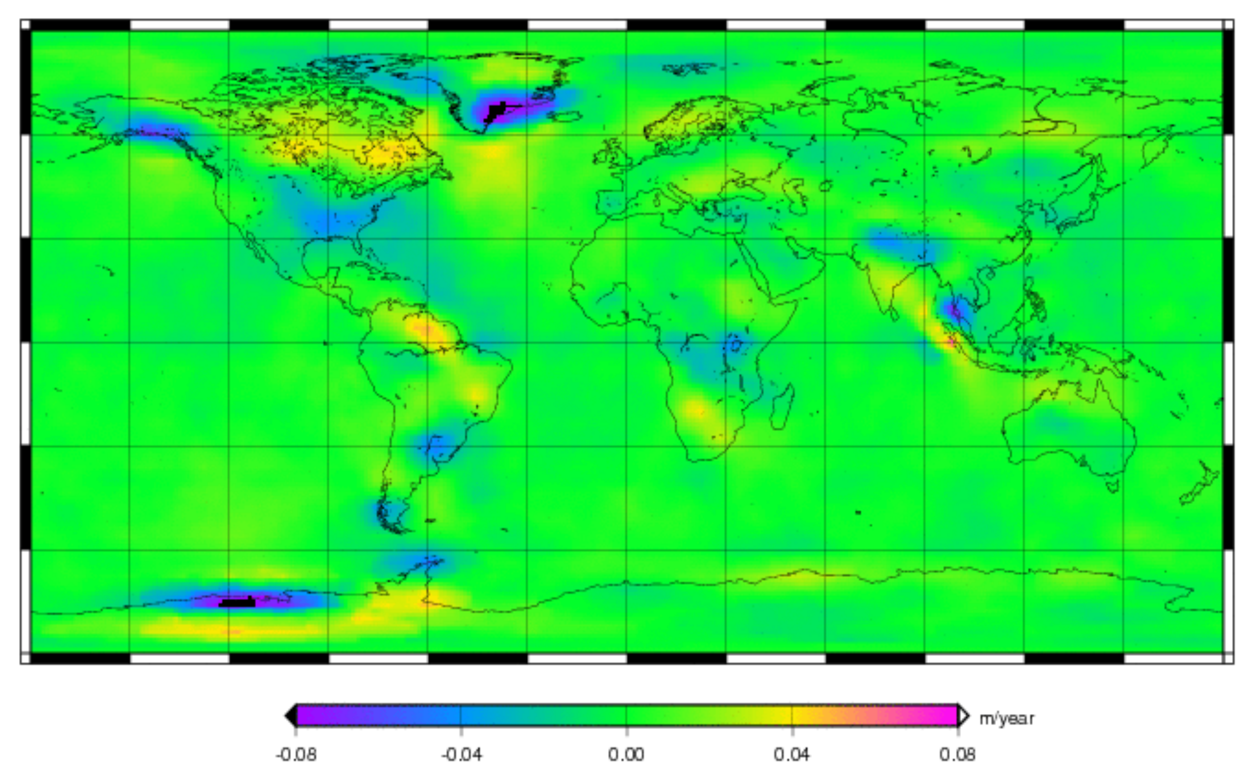


Available Products

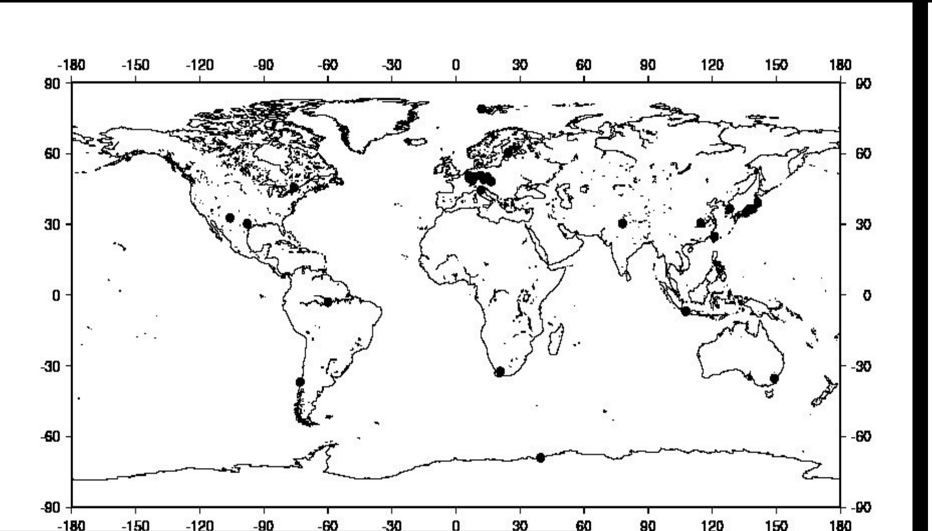
Geodetic Products for Hydrology:

- (until recently) Hydrogeodesy products mostly limited to GRACE;
- Several data centers providing a number of products;
- Products not ready-to-use;
- Community-validated GRACE hydrology products are (*still not available and*) needed;
- Comparison of different GRACE products and hydrology data shows no clear-winner; different products seem to perform better in different regions;
- Large data archives of GPS time series are emerging (UNR has more than 10,000 stations), although not specifically for hydrology;
- InSAR increasingly available, although no global repository for hydrology;
- *Land surface water storage and run-off from satellite altimetry*

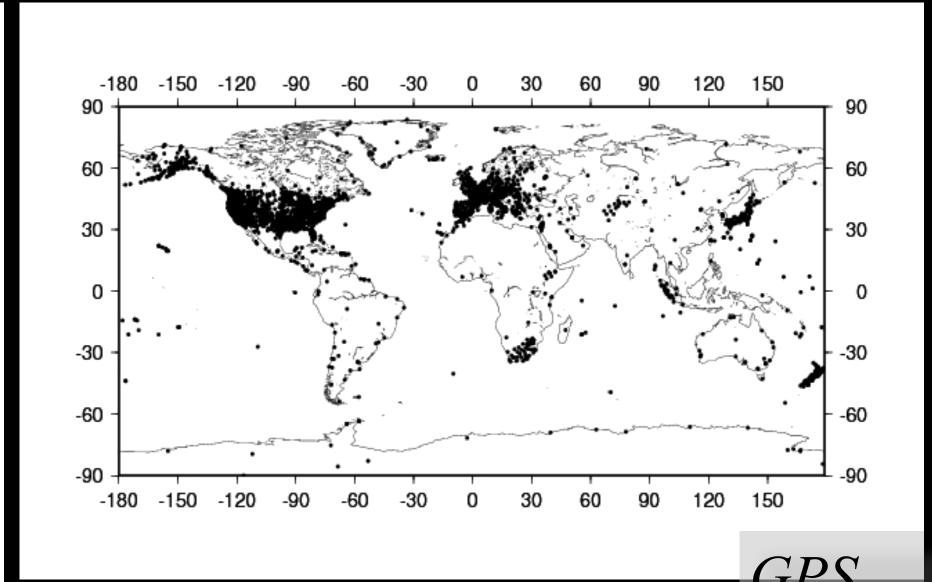
Infrastructure Issues



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

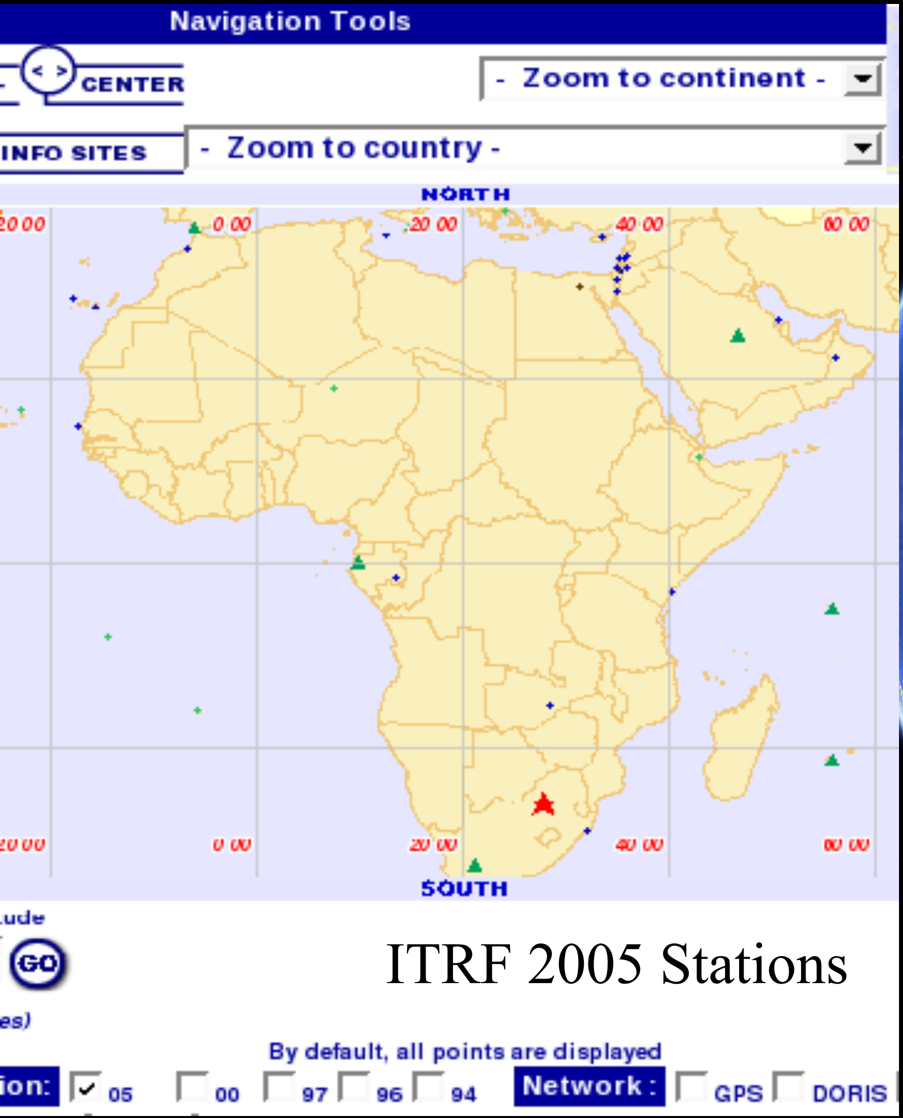


Superconducting Gravimeters (GGP)

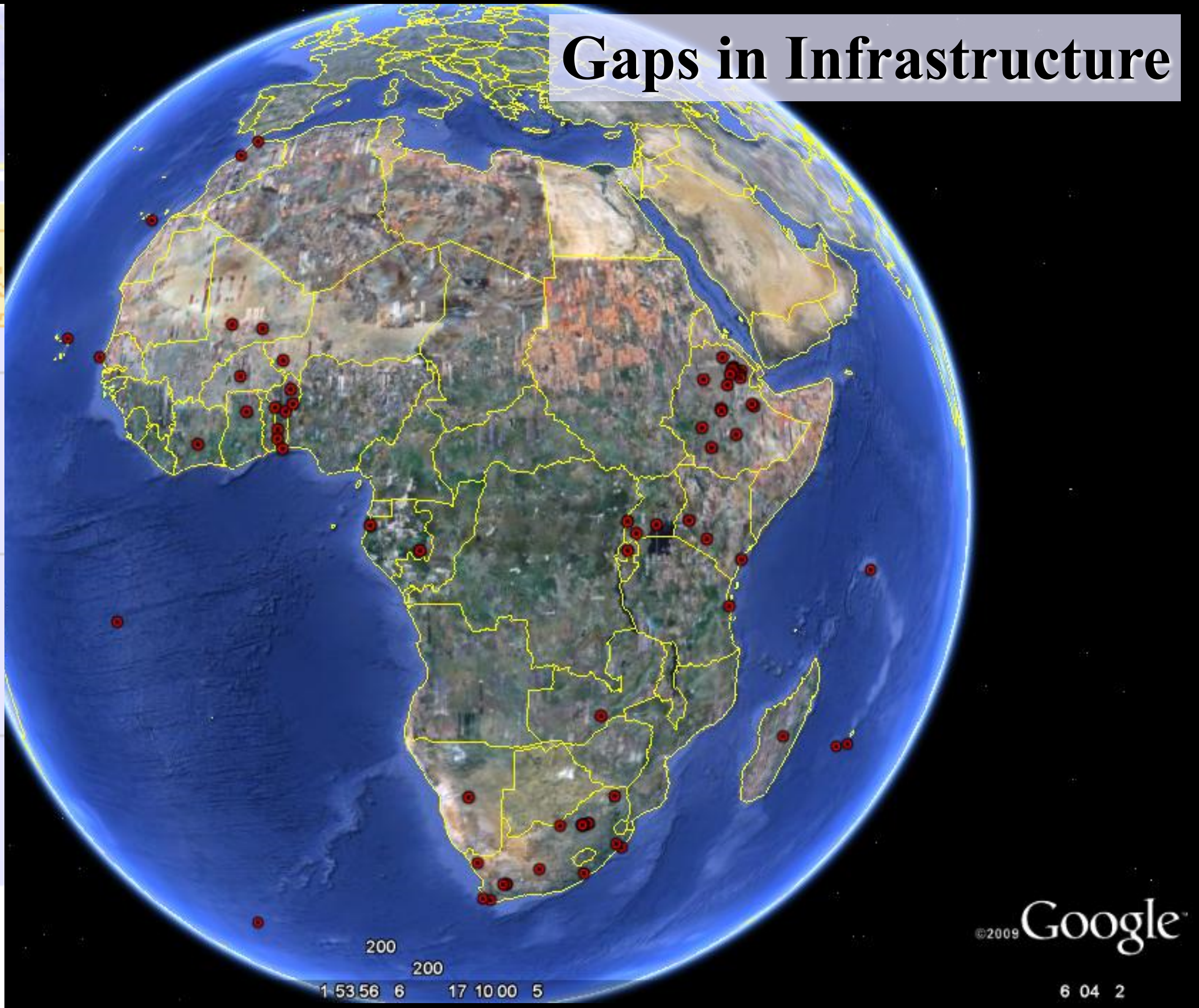


GPS

Gaps in Infrastructure



ITRF 2005 Stations



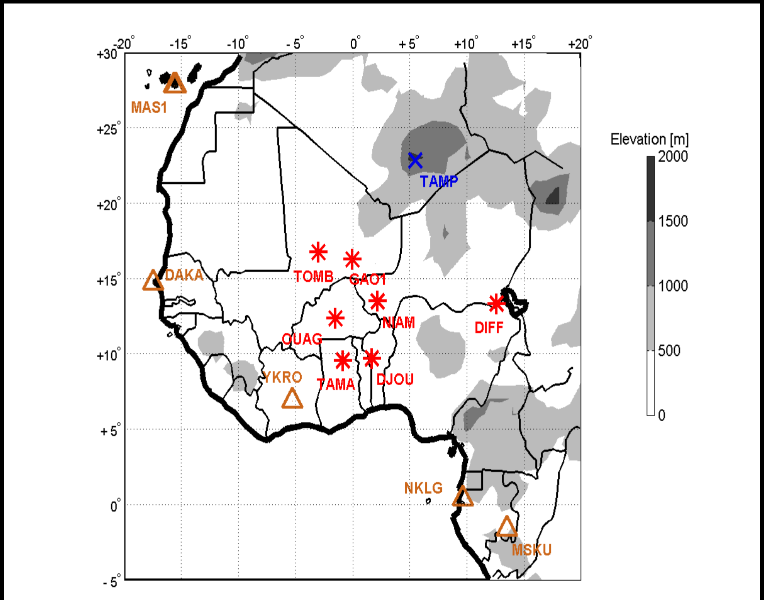
Issue: Many science applications depend on access to long-term stable, accurate reference frame.

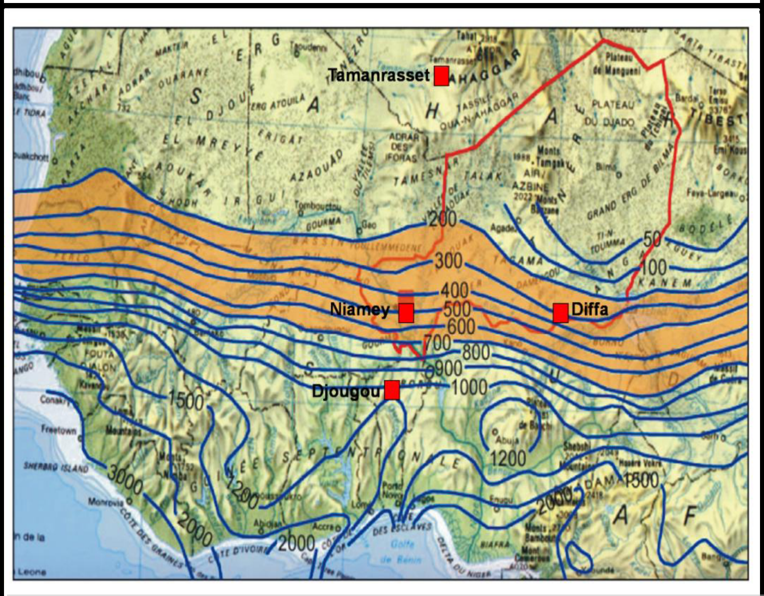
Challenge: Increase number of ITRF stations; co-location of techniques;

Increase number of GNSS stations providing access to reference frame (AFREF)

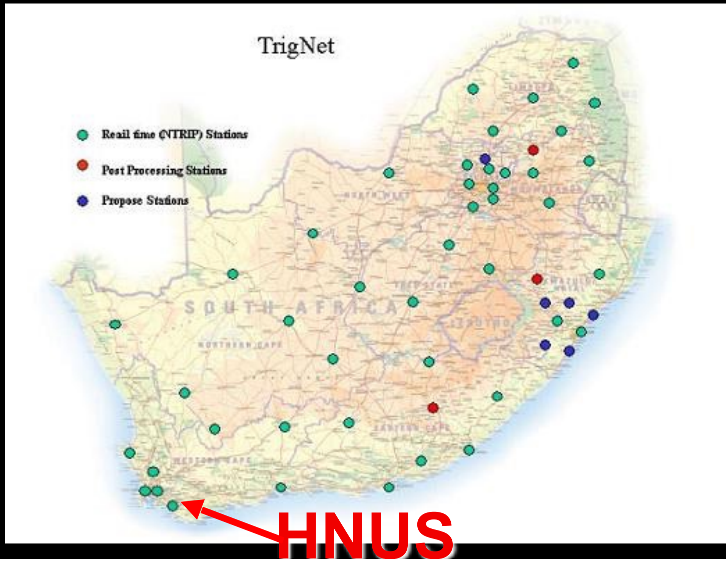
Hydrology: Groundwater storage and water management

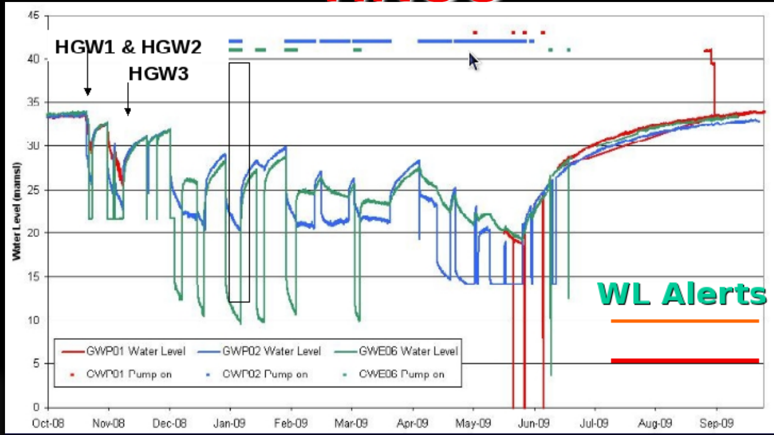
Issue: determination of hydrological parameters; assimilation in models





GHYRAF Project; Hinderer et al., 2009

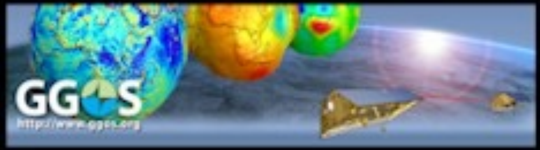




Hermanus Project; Hartnady et al., 2009

IGCP 565 Project

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



Back to workshop page ...
WaterNet Symposium
Hydrogeodesy Tutorial
WRC-DWA

Workshop 5 (October 29-30, 2012):

Overview
Venue, Registration, Hotel
Committees
Abstract Submission
Deadlines
Workshop Program: html, print version
Anticipated Output

Participating Organizations:

Group on Earth Observations
WaterNet
AfricaArray
GGOS

Hydrogeodesy Tutorial (4 hours, day and time to be determined):

Overview
Program

IGCP 565 Project Workshops

IGCP 565 Workshop 5: *Water Security for Africa: Bringing Together Research, Monitoring, and Managing*

October 29-30, 2012
Johannesburg, South Africa

Background: The IGCP 565 Project "Developing the Global Geodetic Observing System into a Monitoring System for the Global Water Cycle" has been organizing a sequence of annual workshops which successively addressed scientific questions related to the development of products for regional water management. The first workshop held in 2008 in San Francisco, USA identified the open scientific questions related to the water cycle and regional water management and the extent to which geodetic observations could help improve monitoring and address the scientific questions. Considering the importance of satellite gravity missions, the second workshop organized in Graz, Austria, developed a road map for future satellite gravity missions. The third workshop convened in Reno, Nevada, USA focused on the separation of tectonic and hydrological signals in geodetic observations. The fourth IGCP 565 workshop held in Johannesburg, South Africa, focussed on the assimilation of geodetic observations into hydrological land model schemes to better simulate terrestrial water storage and transfer, and had a particular focus on local to regional scales. The fifth and final workshop, which again will be held in Johannesburg, South Africa, will demonstrated the applicability of hydrogeodesy to practical problems, with a focus on water budget and resource management at river basin scales.

Sponsors: The workshop is jointly organized by the IGCP 565 Project, the Group on Earth Observations (GEO), the Global Geodetic Observing System (GGOS), and the Water Research Commission (WRC), WRC Project No: K5/1851.

Scope: The final workshop of the IGCP 565 Project has the goal to bring together representatives of research, monitoring and managing programs and

Results and Critical Issues

Main results, conclusions:

- GRACE has contributed tremendously to our knowledge about water cycle mass redistributions from global down to 300 km spacial scales and sub-monthly temporal scales;
- InSAR and GPS provide information on groundwater change;
- GPS provides soil moisture and snow depth;
- In situ gravity provides groundwater changes;
- GRACE, GPS and Earth rotation show significant discrepancies;
- GRACE (mostly) agrees with land water storage model predictions;
- GRACE data products show differences, depending on the group producing them;
- GRACE data products are difficult to understand and apply in disciplines outside of geodesy, particularly hydrology;
- Considerable need for capacity building outside expert communities.

Results and Critical Issues

Issues that need to be addressed to further develop hydrogeodesy:

- Multi-sensor hydrogeodetic observations (GRACE, GPS - co-located with meteorological stations, in situ gravimetry) and model assimilation to increase spatial and temporal resolution;
- Product assessments;
- Cross-validation (particularly seasonal variations and secular trends) both between geodetic techniques and other sensors;
- Error analysis;
- Infrastructure gaps (GPS, in situ gravimetry);
- Easy-to-use, community vetted products;
- User guides (web based) and capacity building (work bench).

Results and Critical Issues

Recommendations from IGCP 565 Workshop (2010):

- Development of integrated modeling framework (tectonics and hydrology) for gravity, surface displacements, rotation;
- hydrogeodetic data portal;
- capacity building;
- Decision support interface between science and applications;
- Demonstration pilot projects (Central Valley, California; Nile River Delta) reach out to regional water management.

The Global Framework

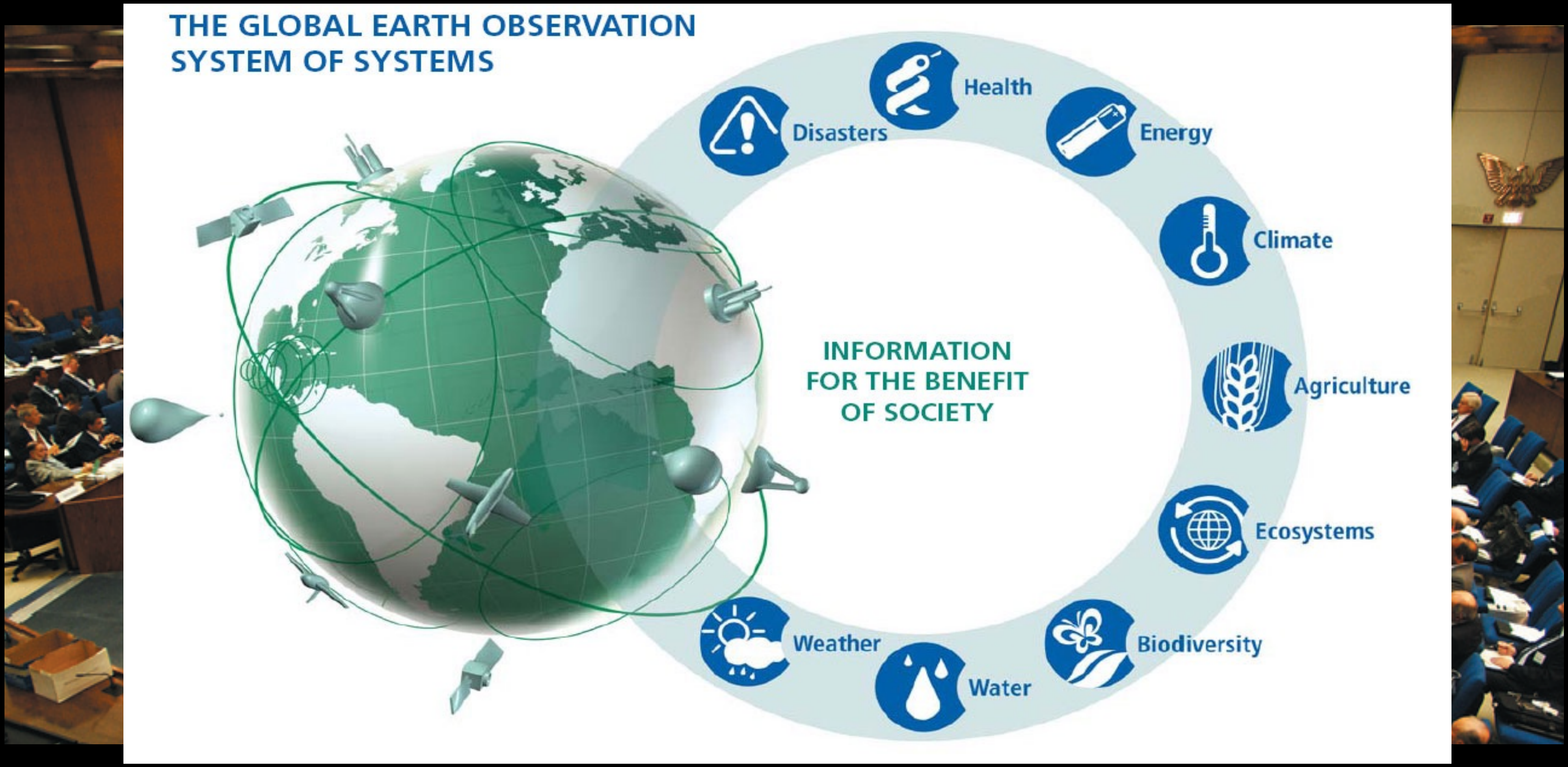
GEO, the Group on Earth Observations

An Intergovernmental group with 86 Member Countries and >60 Participating Organizations

The Global Framework

GEO, the Group on Earth Observations

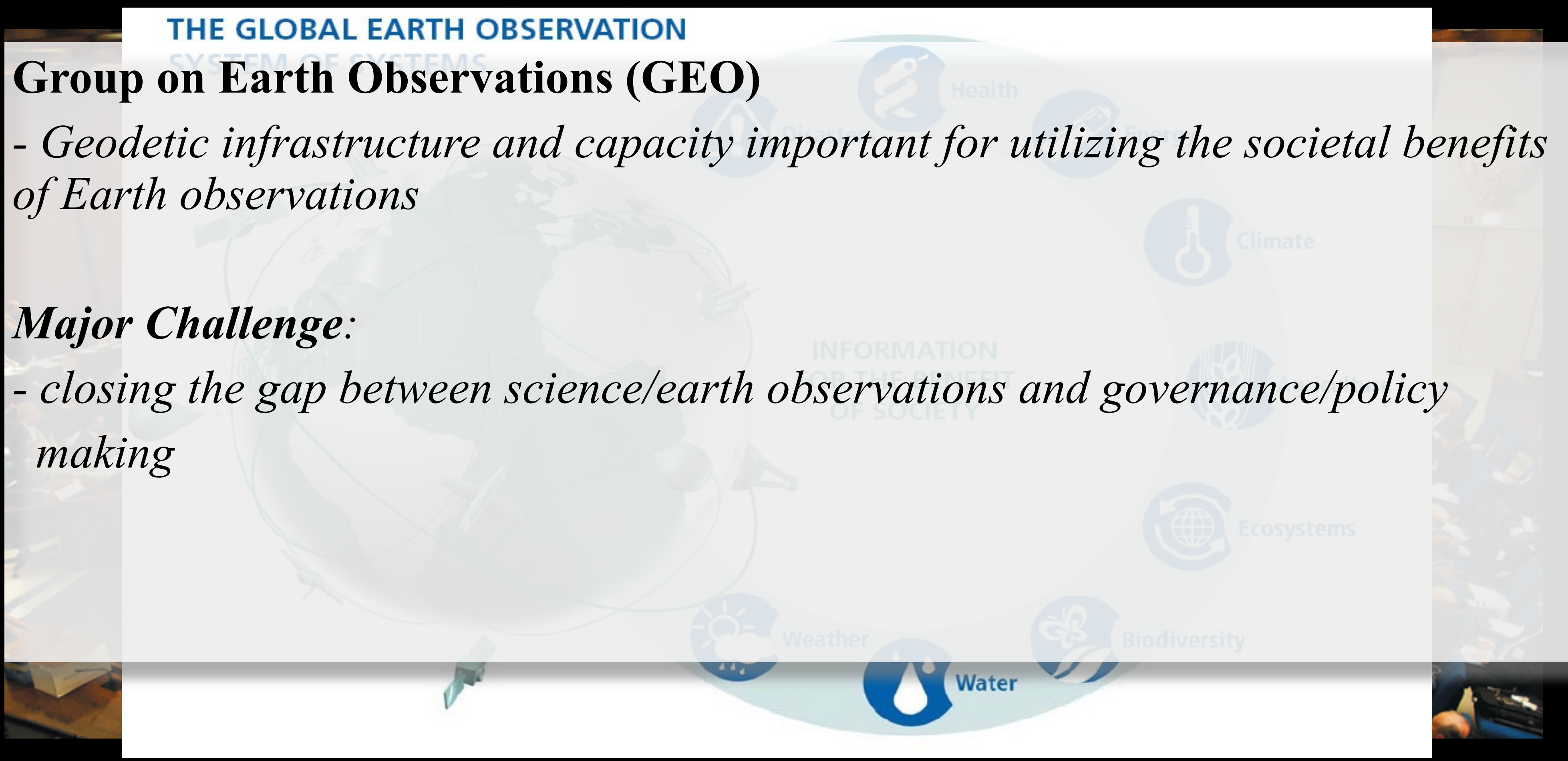
An Intergovernmental group with 86 Member Countries and >60 Participating Organizations



The Global Framework

GEO, the Group on Earth Observations

An Intergovernmental group with 86 Member Countries and >60 Participating Organizations



Group on Earth Observations (GEO)

- Geodetic infrastructure and capacity important for utilizing the societal benefits of Earth observations

Major Challenge*:*

- closing the gap between science/earth observations and governance/policy making