A Unique Reference Frame: Basis of the Global Geodetic Observing System (GGOS) for Geodynamics and Global Change

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System Earth Elements and Interactions

Geodynamics and global change are the processes within and between all elements of the System Earth:
- (solid) Geosphere
- (fluid) Hydrosphere
- (gas) Atmosphere
- (frozen) Cryosphere
- (living) Biosphere

Geodetic observations reflect the effects of the processes’ signals.

Realization of Reference Systems by Reference Frames

Reference frames define to which basic parameters geodetic values (positions, velocities, gravity, ...) refer in space and time evolution.
Any change of a status refers to a kinematic reference frame:
Nothing is fixed (panta rei), a reference motion must be defined.
Station velocities are the basis for the description of global change.

Global Change and the Geodetic Observing System

Solid Earth geodynamic processes (deformation)
Deformations Variations of rotation & Gravity field
Atmosphere, hydrosphere processes (water cycle)

Precise point positioning Surface scanning Gravity recovery

System Earth Signals and Geodetic Parameters

The signals to be observed are extremely small (sub-millimetre level). Realistic physical models and consistent geodetic reference systems are fundamental requirements for monitoring System Earth processes.

Importance of Time Dependent Reference Frames

Station velocities in the geometric reference frame (ITRF) provide the reference for the quantification of any change of positions.
They are highly correlated with variations of geodetic datum parameters: origin, orientation, scale of the coordinate systems.

The kinematic reference frame has to be established carefully!
1. Monitoring Solid Earth Deformation: Earthquake Research

Earthquakes occur mainly in boundary zones of the lithospheric plates, where accumulated stress is released. Geometric observations measure the actual strain.

Example: Mediterranean Orogen
Regional Reference Frame (relative to Eurasian plate, geodetic model: APKIM)
Global Reference Frame (ITRF)

2. Monitoring Solid Earth Deformation: Hydrology

- Gravimetric observations (GRACE geoid) reflect mass displacements
- Geometric observations (GPS) measure height variations

Precursors in Geodetic Monitoring
- Non uniform behaviour of time series in little different reference frames

Monitoring Pre-Seismic and Post-Seismic Strain
Arequipa Earthquake 2001:
- 50 cm horizontal co-seismic displacement on June 23

Precursors in Geodetic Monitoring
- Co-seismic displacement & non-linear post-seismic movements
Effect of the Reference Frame on Satellite Orbits

Satellite orbits are determined in the reference frame in which the tracking stations are given. Non modelled effects of the reference frame enter into the orbit determination. If they are periodic, the orbits are periodically distorted, too.

Station position and gravity field variations, if derived from orbits, reflect the orbit errors.

3. Monitoring the Ocean Surface by Satellite Altimetry

Monitoring sea surface changes by satellite altimetry is based on distance measurements from a known orbit. Orbits are determined from tracking stations with coordinates in the terrestrial reference frame. The accuracy of the orbit and thus of the sea surface depends on the stability and reliability of the reference frame.

Effect of Orbit Errors on Sea Surface Estimates

Geographic correlated (mean) errors of TOPEX, Jason1, GFO, and ERS-2 visible only as result of a multi-mission cross calibration. If not taken into account these errors propagate sea level estimates.

Secular Sea Surface Change from Satellite Altimetry

How to determine „mean“ sea level change?

Mean Sea Level Change from Satellite Altimetry

Mean Sea Level Change from Satellite Altimetry

4. Monitoring Sea Level Variations from Tide Gauges

The traditional way of sea level monitoring is tide gauge registration.

DGFI Network within the IGS TIGA Project (Tide Gauge Monitoring)
Sea Level Variations from Tide Gauges

Tide gauge registrations show quite different sea level changes, ranging from $-9.7 \text{ mm/year}$ to $+5.3 \text{ mm/year}$ in the western Atlantic.

Consequences:
- Monitoring vertical crustal movements by GNSS (change of the reference frame)
- Determination of geoid variations by gravity missions

Sea Level Variations from Tide Gauges

Sea level change is the sum of tide gauge records and vertical crustal movement:
- BORK: $1.2 - 1.5 = -0.3 \text{ mm/a}$
- CHUR: $-9.7 + 9.8 = 0.1 \text{ mm/a}$
- DAKA: $2.9 - 4.3 = -1.4 \text{ mm/a}$
- CART: $5.3 - 2.5 = 2.8 \text{ mm/a}$
- SIMO: $1.1 + 0.5 = 1.6 \text{ mm/a}$
- MPLA: $-1.3 + 2.1 = 0.8 \text{ mm/a}$

Only the combination of tide gauge records and sat. altimetry provides reliable results.

5. Monitoring Global Warming of the Atmosphere

One of the most discussed effects of Global Change is warming of the atmosphere and the Earth’s surface (“greenhouse effect”).

Global Temperature

There is a dramatic change from 1910 to 1940 and from 1975 to present in global temperature.

Causes for the greenhouse effect are discussed quite controversially.

Contributions to the Greenhouse Effect

95% are caused by the water vapour of the atmosphere

Geodetic observation of the Water Vapour

1. Ground-based GNSS atmosphere sounding: Water vapour estimation from ground networks
2. Space-based GNSS atmosphere sounding: Occultation observations between satellites.

http://www.gfz-potsdam.de

Principle: To measure the time delay (refractivity) of GNSS signals between known ground or satellite positions, respectively.
Atmosphere Sounding

German Network:
- Satellite Positioning System (SAPOS)®
- Bundesamt für Kartographie und Geodäsie (BKG)
- GeoForschungs-Zentrum Potsdam (GFZ)
- Neighbouring Countries

Atmosphere Sounding: Stations’ Time Series

Common trends in time series of IWV may indicate global change

Atmosphere Sounding: Effects of Reference Frames

Measurement of time delay (refractivity)

Non-modelled motions of reference stations or of the complete frame falsify the measurement of the time delay. This is problematic, in particular in long-time monitoring (decades). Reference frames with long-term kinematic stability (over decades) are the fundamental requirement.

Conclusions

The Geodetic Observing System is capable to monitor geodynamic and global change processes, including the complete water cycle.

Conclusions (continued)

- In order to detect the very small signals (millimetre in position changes and tenth of milligals in gravity changes) a highly stable and consistent unique reference frame is required.
- The stability of the reference frame has to be guaranteed over long time intervals (decades).
- The realization of such demanding reference frame has to be done by combining all geodetic observations from positioning techniques (SLR, VLBI, GPS, DORIS) and gravity missions (ENVISAT, GFO, JASON, ICESAT, CRYOSAT, GRACE, GOCE, ... ) in order to be consistent in geometry and gravity.
- Sophisticated processing and analysis methods have to be applied for the accurate and reliable representation of geodetic results for global change research.
Thank you!