Geodesy, metrology for Earth system sciences…

…using high precision geodetic space techniques…

Some tide gauge (TG) records span more than 150 years and thereby realise one of the most precise memories of the Earth system. Since TGs are fixed to the Earth crust, a crustal uplift may let the TG record appear as a sea level fall. Thus, absolute sea level rise can only be proven if the actual vertical tectonic movement at the TG is known from continuously operating global navigation satellite systems (GNSS), like GPS, GLONASS or GALILEO – with a precision much better than 1mm/year.

Expanded scope of geodesy

TGs are just one example demonstrating the fundamental role of geodesy for Earth system sciences. Some 50 years ago geodesy was understood as the science for measuring and mapping the Earth surface and its gravity field. Today, the scope of geodesy has been significantly expanded. The extreme high precision and the redundancy of observations of the geodetic space techniques also allow monitoring and better understanding of many Earth system processes, like sea level rise (on global and regional scales), ocean tides and solid Earth tides, ocean circulation, melting of ice caps, changes in the global water cycle, continental water storage, properties and changes in the atmosphere, large-scale mass redistribution, deformations of the solid Earth and changes in the Earth's rotation.

Basic research and networking

The 'Deutsche Geodätische Forschungsinstitut' (DGFI), hosted at the Bavarian Academy of Sciences (BAdW), performs basic research in geodesy, and acquires, analyses and combines observations from geometric and gravimetric space techniques, such as:

- Global navigation satellite systems (GNSS);
- Very long baseline interferometry (VLBI);
- Satellite laser ranging (SLR);
- Satellite gravimetry and gradiometry (with missions such as CHAMP, GRACE and GOCE);
- Satellite altimetry (with a multi-mission scenario since 1992).

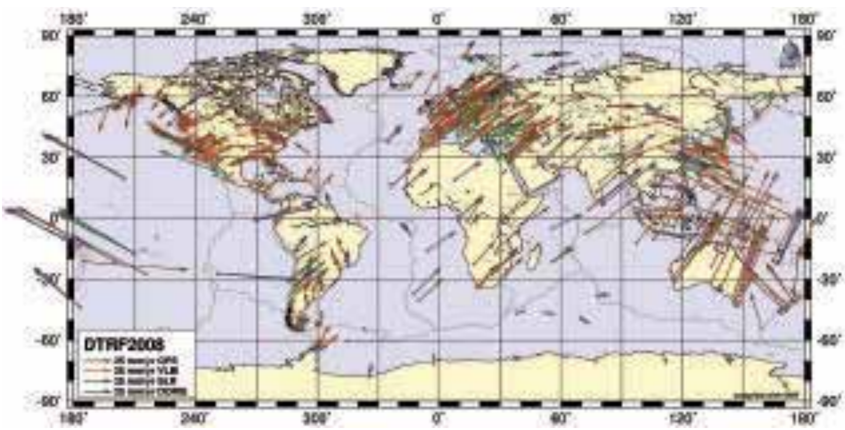
DGFI is intensively networked on national and international levels, participates in the scientific organisation of the International Association of Geodesy (IAG), cooperates with universities and the space agencies and collaborates in international scientific services organised mostly by IAG. DGFI is member of the Centre for Geodetic Earth System Sciences (CGE), a close cooperation among geodetic research institutes in Munich.

International Terrestrial Reference Frame (ITRF)

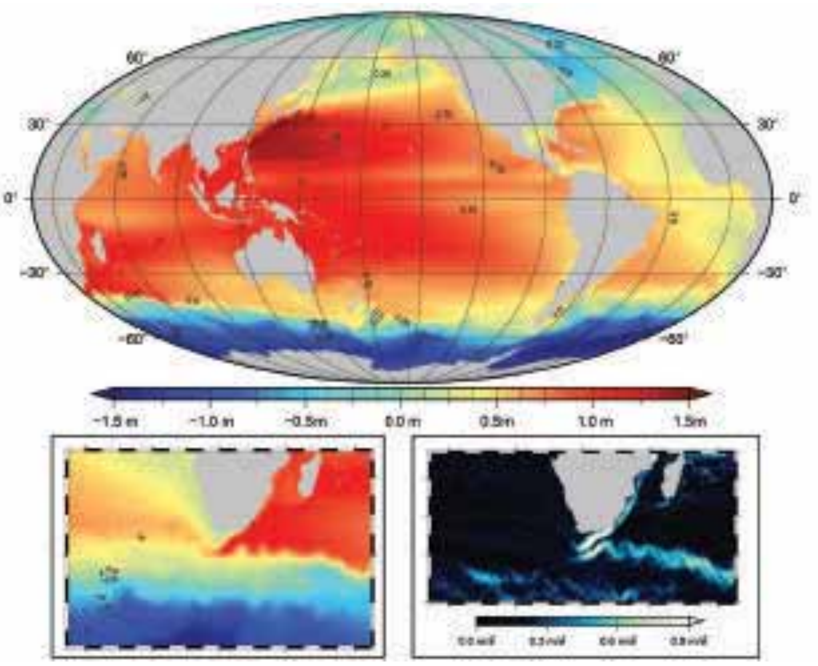
DGFI is one of two centres worldwide that are computing and gradually updating the ITRF, a global set of points, serving as reference for precise positioning, navigation and subordinated surveying on national level. The most recent realisation consists of coordinates and velocities for some 400 globally distributed sites. The DGFI solution of ITRF, called DTRF2008, was realised by an utmost rigorous mathematical combination of all precise point positioning observations, acquired up to 2008. Currently, DGFI investigates how seasonal station variations can be accounted for and how to update and maintain the ITRF in case of significant site displacements by strong earthquakes, like the Maule earthquake in Chile in February 2010.

Regional reference frames

DGFI is also contributing to SIRGAS (www.sirgas.org), a non-profit organisation realising a regional densification of the ITRF with a network of about 250 continuously operating sites covering Latin America and the Caribbean. Coordinates and velocities refer to ITRF2008 and the precision of the horizontal coordinates are estimated to ± 1.0mm. The precision of the vertical velocity is ± 1.1mm/year.



Horizontal velocities of the reference sites analysed for the DTRF2008 reference frame (for details see www.dgfi.badw.de/?258). The velocity field, clearly correlated with the tectonic plates, provides the most precise knowledge on actual plate kinematics



Separation of geoid and sea level reveals the large-scale pattern of the dynamic ocean topography (top panel). The lower left panel is a zoom to the Agulhas counter current South of Africa with very strong eddy formation. In the lower right panel, the topography has been translated into geostrophic velocities (animated time series for all panels can be seen at www.dgfi.badw.de/?333)

Dynamic ocean topography (DOT)

Combining satellite altimetry and satellite gravity allows inferring the large-scale surface circulation of the oceans, which may be assimilated into numerical models to deduce ocean mass and heat transport – essential climate variables. The surface circulation driven, e.g., by wind causes the sea level to deviate from the 'geoid', an equipotential surface at sea level used in geodesy as global height reference surface. This deviation, DOT, is only ±1-2 metres in amplitude.

Since ESA's GOCE gravity field mission led to significant improvements in modelling the Earth gravity field, the marine geoid can be computed with sufficient precision and subtracted from the sea level observed by satellite altimetry. DGFI has developed a dedicated approach to separate geoid and sea level providing not only the large-scale pattern of the steady state topography, but also a time series of DOT states indicating the life cycle of meso-scale eddies and variations in the surface velocity field.

Other contributions to Earth system sciences

Beside reference frames and ocean topography, there are quite a number of additional contributions of geodesy to Earth system sciences:

- Earth gravity field modelling is a central geodetic expertise. DGFI is involved in pre-processing of GOCE gradiometer data and investigates to what extent geophysical application gain from the significant improvements in resolution and precision achieved through GOCE;
- DGFI focuses on regional gravity field modelling with localised base functions combining satellite observations with airborne, marine and terrestrial gravity data;
- Precise geodetic space observations are to be corrected for the atmospheric delay of electromagnetic signals. But the situation can also be inverted: redundant two frequency measurements allow estimation of the electron content of the dispersive ionosphere. DGFI is developing global ionospheric prediction models, combining two frequency observations from GNSS, altimetry and the COSMIC satellites;
- DGFI is analysing range and range-rate data of the twin satellites of the GRACE gravity field mission sensing gravity variations caused by mass redistribution in and between ocean, atmosphere and hydrosphere (cryosphere). Separating the mass variation of the individual Earth system components is subject of actual research, as well as studying the impact of mass redistribution on Earth rotation;
- Global empirical models of ocean tides (e.g. EOT11a) have been derived and are applied in precise processing of space geodetic observations.

> 'DGFI is one of two centres worldwide that are computing and gradually updating the ITRF…'

The challenge

Currently geodesy is trying to consolidate a relative precision of 10^{-9} (a few mm relative to the size of the Earth). Many processes on Earth should be observed an order of magnitude better. DGFI is prepared to keep track with increasing accuracy requirements of Earth system sciences.

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