Contribution of Altimetry Time Series for a Global Geodetic Observing System

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Importance of altimetry
Satellite altimetry has demonstrated its high value in Earth system science. It provides precise maps of the mean sea level. Time series of nearly 15 years enable reliable estimates of low frequency and large scale climatic signals (sea level rise). Tides in open ocean, seasonal, as well as intra-seasonal variations have been quantified with high precision. Synergies between missions with different space-time sampling have the additional capability to resolve mesoscale variability (eddies). Finally, high resolution data from a few geodetic phases enable invaluable improvements of bathymetry and gravity anomalies. All this underlines that altimetry has to be an essential component of the Global Geodetic Observing System.

The GGOS-D project focuses on an utmost rigorous integration of all relevant observation techniques. While the combination of techniques for precise point positioning (GNSS, SLR, VLBI) is already exercised in the context of the ITRF solutions, the integration of satellite altimetry has not been considered so far. The question is therefore: how to combine the altimetry observations with other space geodetic techniques? What are the specific contributions of satellite altimetry and where are intersections with the parameter space of other space techniques?

Contribution of Satellite Altimetry
Obviously, satellite altimetry cannot contribute to point positioning. However, as the mean sea level is nearly coinciding with an equipotential surface of the Earth gravity field, the measurement of sea surface heights allows to derive precise information on the marine gravity field. The algorithms to obtain gravity anomalies from satellite altimeter data are well established and high resolution data (with grid spacing of up to $2' \times 2'$) from Sandwell & Smith or Anderson & Knudsen are available since long time. The high resolution gravity field determination is however not a primary goal of the GGOS-D project. GGOS-D focuses on the *consistent combination* of all geodetic space techniques and considers *temporal variations* in particular for the low degree harmonic coefficients of the Earth gravity field.

Consistency and Standards
Consistency requires to verify if the processing of altimeter data is performed with the standards that were agreed on in the context of the GGOS-D project. In most cases standards can be easily applied (e.g. the use of a specific reference ellipsoid or a common ocean tide model). However, there are also inconsistencies which are difficult to avoid. The treatment of permanent tides is realized differently in point positioning and satellite altimetry. While altimetry does *not correct* for the permanent deformation of the solid Earth (which corresponds to a »*zero-tide system*« and is in agreement with the IAG resolution of 1983) the point positioning techniques apply such corrections and provide coordinates for an »unobservable« *tide-free system*.

Impact of ocean water mass redistribution
Temporal variations of the low degree harmonics of the Earth gravity field can be

derived from water mass redistribution. Satellite altimetry observes the geometric variations of the mean sea level composed by two effects, water mass redistribution and volume change. In order to identify changes in the water mass the steric effect, e.g. the expansion/contraction of water due to changes in salinity and temperature are to be estimated and subtracted from the observed sea level anomalies. For these computations following approach was applied:

1. *Sea level anomalies* (the deviation of the instantaneous sea level from a mean sea level) were performed for every 10-day cycles of TOPEX, the most stable altimeter mission with an observation period of 10 years. The significant seasonal variations of the sea level anomalies is well known from previous investigations.
2. *Steric anomalies*, e.g. the water level deviation from a standard ocean due to density variations in the upper layer were first taken from the OMCT model. The available model run lacks however on a significant change of the driving forces in the year 2000. Therefore new computations were based on monthly dynamic heights derived by Ishii for the period 1950–2005 through integration of objectively analysed Temperature/Salinity profiles down to 700 m depth (see Figure 1). These steric anomaly time series was interpolated to the 10 day cycles of TOPEX.
3. *Mass anomalies* have been estimated by subtracting the steric anomalies from the sea level anomalies. These mass anomalies were finally transformed to surface mass loads which were developed to a series of spherical harmonics coefficients describing up to degree and order two the effect of water mass redistribution on the Earth gravity field (see Figure 2)

The time series are to be compared with results achieved by data from gravity field missions, by satellite laser ranging to the LAGEOS satellites, by solutions of low Earth orbiting (LEO) satellites or the C04 time series of the International Earth Rotation Service (IERS). However, the comparison must consider that the ocean mass redistribution is not the only source for the variations of the harmonic coefficients. There are comparable density variations in other components of the Earth system, e.g. in the atmosphere, in the cryosphere or the continental hydrology.

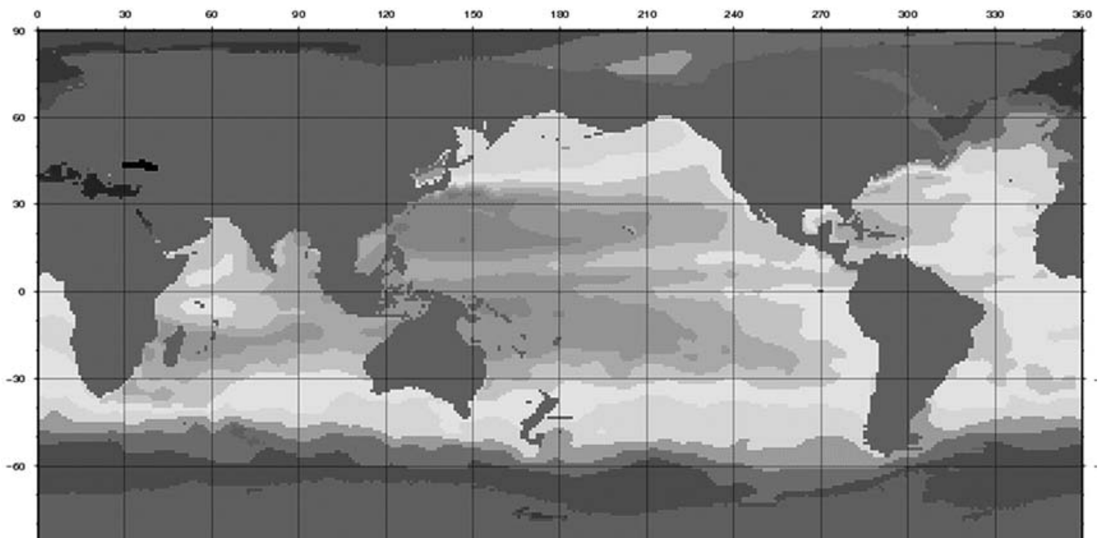

Figure 1: Steric anomalies for December 2005, an example of the data provided

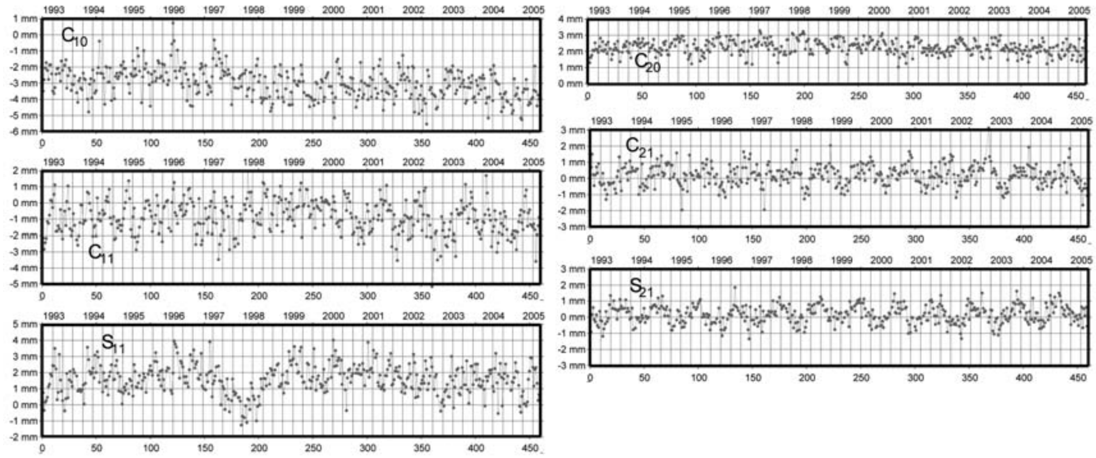

Figure 2: Time series of selected harmonic coefficients (scaled by the radius of the Earth R), derived from ocean water mass anomalies for the period 1993–2005. Left: all degree one coefficients (C10, C11, S11) related to variations in the centre-of-origin. Right: some of the degree two coefficients, related to the variations in flattening (C20 on top) and to the orientation of the rotation axis (C21, S21). All coefficients show more or less clear the expected seasonal variations. The outstanding variation of S11 (the y-shift of the centre-of-origin) is related to the strong December 1997El-Nino event

A reprocessing of the altimeter time series will include the mass variations in other system components. The altimeter time series can also be extended by using the additional observation of the Jason-1 altimeter mission.