Executive Summary

This document represents the final report for the ESA study "Monitoring and Modelling Individual Sources of Mass Distribution and Transport in the Earth System by Means of Satellites". The primary goal of the study was to find a means to monitor and model individual sources of mass distribution and transport in the Earth System.

The recent space-borne gravity mission, GRACE, has demonstrated the potential to provide data invaluable for observing long-wavelength changes ($\lambda > 1000$ km) in continental water and oceanic mass on a monthly basis. Signal aliasing resulting from the mismodeling of periodic ocean and atmospheric signals, generates spurious signals in the gravity field coefficients at seasonal and longer periods. The goal of this study was to investigate different mission concepts, which might allow for observing mass variations without introducing aliased signals to the extent we observe in GRACE.

The mass fields considered in this study include: atmosphere, oceans (including tides), continental water, ice (ice sheets and glaciers) and the solid earth. An 11-year (0.5^o x 0.5^o) model of the Earth Mass System (Real Earth Model) was obtained through the rigorous and consistent combination of state-of-the-art mass field components. To the extent possible, input data were used consistently in the models for ocean, atmosphere, ice, and hydrological mass variability. In addition, in the case of the oceans, fresh water flow from the hydrological model was used as one type of input to the ocean mass model.

Several initial orbit scenarios were developed to optimize our ability to observe changes in mass over the continents and oceans. A detailed and realistic closed-loop simulation tool was established and implemented which offered us the possibility to include many detailed models of all types of mass change sources. Using this tool gravity retrievals were generated for the various initial orbit scenarios using the Real Earth Mass field and associated sensor and mass field error models.

We found that temporal aliasing is intrinsic to observing gravity field changes by satellites, but e.g. leads to relatively smaller distortions for hydrology than for oceanography.

The combination of ll-SST and orbit observables does not allow the precise determination of the spherical harmonic degree 1 terms or geo-centre variations. These terms have to be derived by other means, e.g. by Satellite Laser Ranging (SLR).

As soon as sensor noise levels are sufficiently low, temporal aliasing leads to larger uncertainties in the observation of gravity field changes due to mass transports than sensor errors. The impact of temporal aliasing also depends on the choice of satellite constellation and associated orbital parameters.

In the case of high sensor noise levels, flying more pairs of satellites significantly reduces the gravity field retrieval errors. However, a much bigger improvement can be achieved by lowering the noise levels of sensor systems. Also, when flying more pairs of satellites, great care has to be taken with the choice of orbital parameters.

Single polar satellite pairs provide better performance at high latitudes (or polar areas), even at high sensor noise levels. The observation and study of mass changes due to for example the melt of the Greenland ice cap (*Wouters et al*., 2008) can already be guaranteed by flying a GRACE follow-on with the same instrumentation.

When processing space-borne gravimetric observations for retrieving mass changes due to a certain physical phenomenon, it is best to include as much as possible prior knowledge in the background gravity model. This background model is used to reduce the observations to residuals from which the signal of interest is to be retrieved.

In the presence of systematic errors, such as errors in gravity field background models (e.g. ocean tides, atmosphere), assigning weights to different observables (e.g. orbit coordinates, ll-SST observations) is a complicated optimization process. Also, the estimation of absorption/nuisance parameters in addition to the gravity field coefficients can help to mitigate the effect of such systematic errors.