Detection of hydrological mass variations by means of an inverse tesseroid approach

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Introduction

Modern satellite missions like GRACE (Gravity Recovery and Climate Experiment) provide monthly global geopotential models allowing the analysis of the time-variable part of the Earth's gravity field. From a hydrological point of view, the monthly changes are mainly caused by variations of the Earth's water storage. The usual procedure for the detection of such hydrological mass variations is based on the elastic Love number theory, in which global spherical harmonics are used to derive geoid anomalies that can be converted into water column heights respectively terrestrial water storage values (TWS), e.g. Awange et al. (2009).

Alternative procedures in the space domain result in an inverse problem of forward modelling. This procedure is particularly suitable for regional applications. In contrast to the often used point-mass approximation, in this contribution, an approach based on tesseroidal mass bodies is proposed (Heck and Seitz, 2007). Tesseroids are bounded by geographical grid lines and surfaces of constant heights and thus directly linked to the curvature of the Earth. Therefore, tesseroid formulas are introduced as observation equations in a least-squares adjustment, in which gravity data, e.g. derived from GRACE, are utilized as observations and the heights of particular tesseroids are the unknowns. Using a constant density value of 1000 kg/m³, the solved unknown tesseroid heights can be associated with the desired TWS values (Heck and Seitz, 2008).

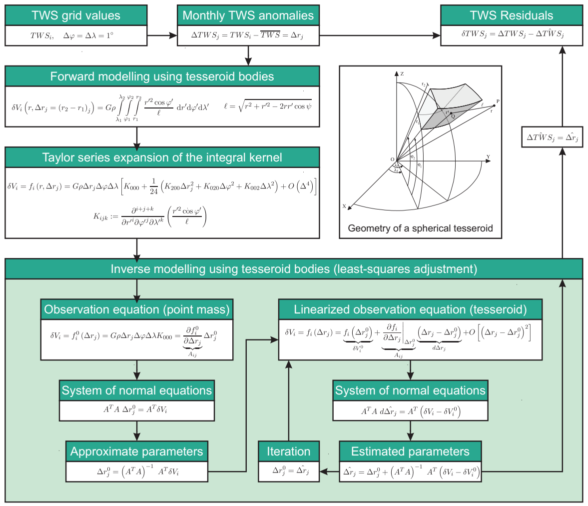
Taking the Australian continent as an example, results from a realistic closed-loop simulation are presented, showing the possibilities of the suggested tesseroid method compared to a point mass approximation.

Closed-loop simulation

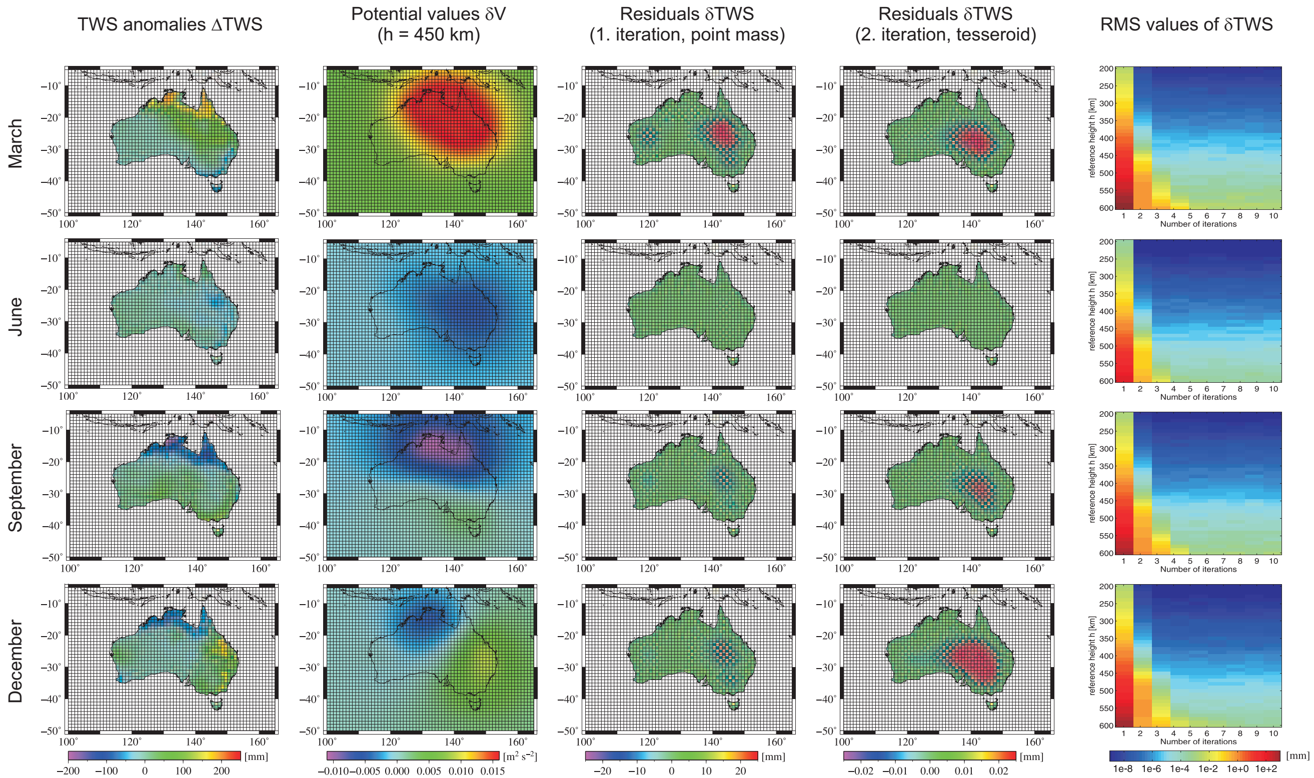
Starting with 1°x1° gridded TWS values of the year 2010 over Australia (Dijk et al., 2011), monthly TWS anomalies are constituted by subtracting the annual average.

In the first step, these TWS anomalies are associated with heights of tesseroids that are used in forward modelling to determine a 1°x1° grid of consistent potential values at satellite altitude. As the volume integral occurring in the tesseroid formula cannot be solved analytically, a Taylor series expansion of the integral kernel is carried out (Heck and Seitz, 2007).

In the second step, the generated potential values are introduced in an iterative least-squares adjustment in order to reconstruct the TWS information by inverse modelling. In the first iteration, the linear part of the observation equation is used to get approximate parameters which can be associated with a point mass. These parameters then serve as approximate values for the linearized observation equation. After each iteration step, the estimated parameters are compared to the original TWS anomalies producing residual values.



Numerical results of the closed-loop simulation



Conclusions and Outlook

- Closed-loop simulation shows a good behaviour for the developed inverse tesseroid approach.
- Compared to point mass approximation (1. iteration), the tesseroid method shows a significant reduction of the residual TWS values by three orders of magnitude.
- The magnitude of the TWS residuals highly depend on the reference height h of the potential grid.
- For the desired application of GRACE (h = 450 km) two iteration steps already show a sufficient accuracy at sub-millimeter level.
- TWS residuals for different seasons show similar grid effects which will be investigated further.
- The stability of the inverse tesseroid method in the case of noisy observations will be analysed.
- Tesseroid method will be applied to real measured GRACE data and compared to the results of alternative approaches in the frequency domain.

References:

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