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How to properly convert Stokes coefficients into mass anomalies?

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The primary source of information about mass transport in the Earth's system is the Gravity Recovery And Climate Experiment (GRACE) satellite mission. GRACE data allow temporal variations of the Earth's gravity field to be estimated, which are usually represented as time-series of monthly solutions consisting of Stokes (or spherical harmonic) coefficients up to a given maximum degree. To compute on this basis a time-series of mass anomalies (e.g., in terms of equivalent water heights), one can perform a spherical harmonic synthesis, having applied a proper scaling to the Stokes coefficients (Wahr et al, 1998). Such an approach, however, is based on the assumption that mass transport takes place at the surface of an ideally spherical Earth. The errors introduced by this assumption were tolerable at the early days of GRACE mission, when the maximum spherical harmonic degree of recoverable mass transport signals was estimated to be in the range of 30 to 60. Since that time, however, the spatial resolution of mass transport models has increased. Depending on the location and data processing methodology, spherical harmonic expansion up to degree 90–120 or higher is needed to recover mass transport signals without distortions. Furthermore, an even higher maximum degree will likely be considered when processing data from the GRACE Follow-On mission, which is to be launched in 2017. It is, therefore, important to quantify the errors that may be introduced by the spherical Earth assumption and, if necessary, to modify the formula of Wahr et al (1998) in order to make the accuracy of results consistent with the information content of mass transport models. In the presented study, various assumptions about the Earth's shape (i.e. shape of the surface at which mass transport occurs) are considered: the actual shape defined in line with a digital terrain model; an ellipsoid of rotation; and a sphere. In this way, we quantify the errors introduced by an inaccurate representation of the Earth's shape, for different geographical locations and maximum spherical harmonic degrees. On this basis, we develop recommendations regarding a suitable approximation of the Earth's shape. In addition, we propose an empirical modification of the formula of Wahr et al (1998) that allows the accuracy of results to be increased without increasing the numerical complexity of computations.