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The ANU GRACE visualisation web portal

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ABSTRACT

The launch of the Gravity Recovery and Climate Experiment (GRACE) space gravity mission opened new horizons to the scientific community for environmental monitoring. Through the provision of estimates of temporal changes in the Earth's gravity field, the products generated from the GRACE mission have enabled studies of mass balance changes in polar regions, deformation caused by very large earthquakes, glacial isostatic adjustment and quantification of water exchanges through various hydrological processes. International analysis centres provide estimates of the Earth's temporally varying gravity field in the form of spherical harmonic coefficients which are then used to quantify the geophysical processes that have caused the changes in the Earth's gravity field. We have designed an online, publicly available web application that performs the computations to convert the spherical harmonic representations (of the French Groupe de Recherche en Géodesie Spatiale) of the gravity field into estimates of crustal deformation and/or water loads, and provides users with the ability to visualise the estimates. Derived products are also available to download as numerical values for further analysis. This paper describes the scientific basis and technical approaches used by the web portal (grace.anu.edu.au/evasph.php).

1. Introduction

The Gravity Recovery and Climate Experiment (GRACE) mission is a space gravity mission designed to measure changes in the Earth's gravity field from which mass movement on Earth can then be monitored (e.g., Tapley et al., 2004). Redistributions of mass in the Earth's atmosphere, oceans and continental water stores (surface water, soil moisture, groundwater) cause changes in the strength of the Earth's gravity field, both spatially and temporally. Through the detection of such changes, it is possible to quantify the variations in mass and hence constrain models of the geophysical processes that are occurring on and within the Earth. Observations from GRACE have been used to study the mass loss of Greenland and Antarctica (e.g., Velicogna and Wahr, 2006; Luthcke et al., 2006), large-scale continental hydrology (e.g., Rodell et al., 2011), floods (e.g., Leblanc et al., 2009) and even the elastic and visco-elastic deformation of the Earth (e.g., Davis et al., 2004; Tregoning et al., 2009a, 2009b; van der Wal et al., 2008).

The GRACE mission and observations are described in detail elsewhere (e.g. Case et al., 2002; Thomas, 1998; Bettadpur, 2007). In brief, the rate of change of distance between the two satellites orbiting the Earth is affected by changes in the strength of the Earth's gravity field. These range changes are measured precisely using a K/Ka-band microwave system, along with the position of the spacecraft using GPS, non-gravitational accelerations (caused by atmospheric drag, solar radiation pressure and thrust events) and the orientation of the spacecraft using star tracking cameras. Converting these observations into estimates of the Earth's gravity field is an involved process that requires estimating the orbits of the satellites along with the gravity field of the Earth.

Since 2004, several international research groups have made publicly available their estimates of the Earth's gravity field as derived from GRACE observations, most notably the Center for Space Research at the University of Texas at Austin (CSR), the GeoForschungsZentrum (GFZ) and the Jet Propulsion Laboratory (JPL). Monthly gravity fields are provided in the form of sets of spherical harmonic coefficients, which may be multiplied by Legendre polynomials (trigonometric functions) and various constants (listed in Table 1) to recover the strength of the gravity field at a given location. Spherical harmonic field provided by these centres already have the gravitational changes caused by atmospheric mass, tidal and non-tidal ocean movement taken into account. Because of unmodelled systematic errors in the analysis of the GRACE observations, certain steps need to be undertaken to mitigate correlations between some estimated spherical harmonic coefficients (the so-called "de-striping" filter (e.g., Swenson and Wahr, 2006) to remove north–south striped patterns in the GRACE gravity fields) and to reduce the contribution of noise in higher degree coefficients (through spatial filters (e.g., Wahr et al., 1998)). However, many users are interested in only the end product and how it describes the mass changes on Earth and do not have the expertise to start from the original range rate observations or the available spherical harmonic models.

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There are interactive online tools that provide this type of functionality for GRACE solutions that require destriping and/or spatial filtering. For example, the 'University of Colorado Real-Time GRACE Data Analysis Site' (http://geoid.colorado.edu/grace) where time series and spatial plots of equivalent water height can be generated (CSR, GFZ or JPL solutions), and "The PO.DAAC Ocean ESIP Tool" (http://gracetellus.jpl.nasa.gov/poet) where equivalent water height spatial maps can be generated. Both of these sites are limited to outputting the computations as mass changes in terms of equivalent water height.

In this paper we describe a new website (grace.anu.edu.au/evasph.php) that allows users to generate estimates of geophysical parameters from GRACE spherical harmonic fields, for user-selected locations and/or regions of the Earth. The GRACE fields can be computed to generated estimates of change in geoid height, changes in load in terms of equivalent water height or in terms of elastic or viscoelastic deformation of the surface of the Earth. Time series can be generated at single points or for user-defined regions. We describe briefly the mathematical theory that is used to perform the computations (and associated uncertainties of the estimates) as well as tools that are used to interface between the user, website and background software that actually performs the computations. We provide examples of some of the capabilities of the website and actual computations.

Table 1
Values of Fn used when evaluating Eq. (1) for different geophysical interpretations of the causes of gravity changes. R is the mean radius of the Earth (6371 km), ρ_e is the average density of the Earth (5515 kg/m^3), ρ_w is the density of water (1000 kg/m^3), h_l, k_l are elastic Love load numbers (Pagiatakis, 1990).

Geophysical process	Fn	Source
Geoid height	R	Wahr et al. (1998)
Equivalent water height	$\frac{R\rho_e}{3\rho_w}\frac{2l+1}{1+k_l}$	Wahr et al. (1998)
Visco-elastic vertical deformation	$1.1677l-0.5233$	Purcell et al. (2011)
Elastic vertical deformation	$R\frac{h_l}{1+k_l}$	Davis et al. (2004)
Elastic horizontal deformation	$R\frac{l_l}{1+k_l}$	Farrell (1972)

2. The Data Visualisation Tool (DVT)

The Data Visualisation Tool (DVT) is a web-based application that provides access to the data products via an easy-to-use web interface. The interface is built using PHP, a server side scripting language designed for producing dynamic web pages. Google Maps API is used to provide a map interface that allows users to specify a geographical location or region by double-clicking on the map. Interaction between users and the interface as well as communication between interface and the backend server is handled by a client-side script written in JavaScript. jQuery, a general purpose Javascript library, is used throughout to simplify some of the coding tasks. A PHP script running on the server parses the input parameters, feeding them to Fortran programs for computation. Results from the Fortran programs are then passed to either the Generic Mapping Tools (Wessel and Smith, 1998) to produce spatial plots or returned back to the client script to produce time series plots using the JavaScript Visualisation library, dygraphs. Data files generated are also made available through URL links for users to download the computed numerical values.

The web interface is made up of two components: the google map interface on the left for inputting geographical locations/regions, and a configuration panel on the right for other information needed for computation. A screenshot of this interface is shown in Fig. 1.

The DVT is able to generate three types of solutions:

1. Spatial plots of the gravity field changes for any user-defined rectangle regions on the Earth. It can also generate movies by

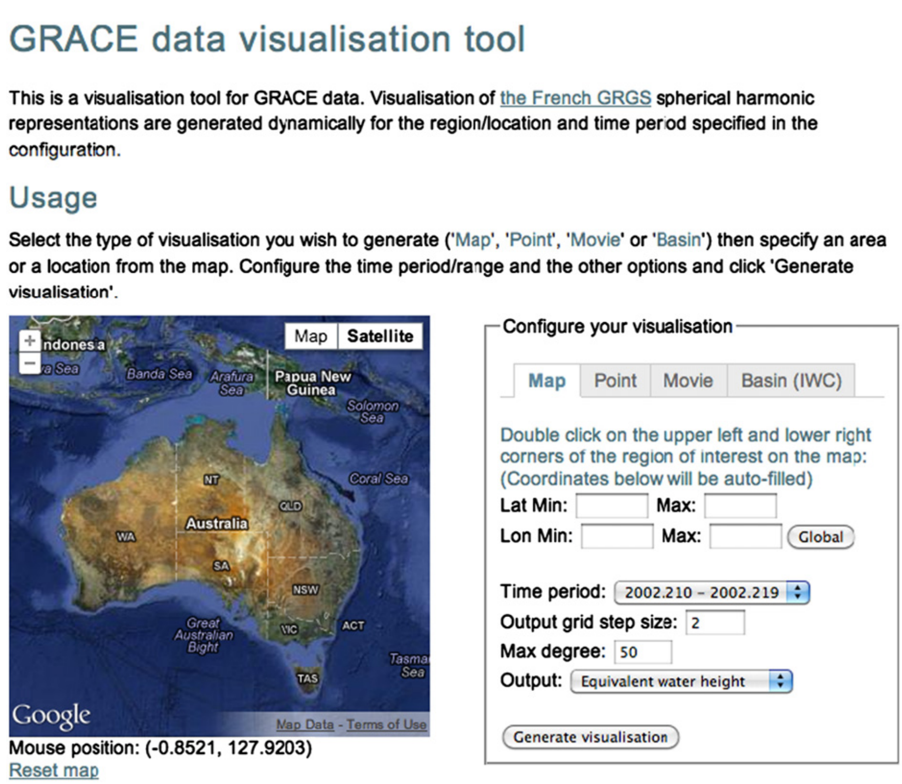

Fig. 1. Map plot configuration.