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PySHbundle: A Python tool for processing GRACE Gravimetry data into Global Surface Mass Change Datasets

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Summary

GRACE (Gravity Recovery and Climate Experiment) satellite mission has been mapping mass changes near the surface of the Earth since 2002. Since mass redistribution at shorter temporal scales is dominated by water mass transfer, GRACE has transformed Geosciences. GRACE satellite products are typically released at various levels of complexity, often referred to as processing levels. Level 1 is the satellite instrument data that is processed to obtain level 2 GRACE Spherical Harmonics data. `L2` are further processed to obtain level 3 products; global gridded mass change estimates (`L3`) expressed as terrestrial water storage anomalies (`TWSA`). `L2` data are noisy, which are filtered and corrected for known artifacts and signals from solid Earth processes to obtain `L3` products that are useful for hydrology. Processing choices, such as filter properties and type, have a significant impact on the accuracy and the resolution of final gridded output. Therefore, `L3` users must be cautious when using GRACE data for specific applications. Majority of the GRACE data user community is not well versed with `L2` data processing, and often use off the shelf `L3` product. Here we developed an open-source processing toolbox to provide users with more control over processing choices. A python module, called PySHbundle, is developed that converts GRACE `L2` Spherical Harmonics data products to `L3` `TWSA` products. With this contribution, we hope to enable further usage of GRACE data for Earth system science.

Introduction

GRACE Satellite mission measures changes in the inter-satellite distance with a microwave ranging system micrometer precision (Wahr et al., 1998). When the satellite system comes in the vicinity of a temporal mass anomaly, the relative inter-satellite distance changes and it can be inverted to estimate the mass change near the surface of the Earth. Over the continental land surface, the hydrological processes are the major driver of the variation in mass anomaly at monthly to decadal scales. However various other signals such as oceanic and atmospheric variations, high frequency tidal mass changes, systemic correlated errors, etc. are also part of the obtained GRACE signals (Humphrey et al., 2023).

several researchers in Jio sciences use level three GRACE data, which is obtained from `L2` Spherical harmonic coefficients. The procedure to convert `L2` to `L3` is called spherical harmonic synthesis. However, there are several pre-processing steps; such as anomaly calculation, replacing poor quality low degree coefficients, filtering, and correcting for signal damage due to filtering.

A few GRACE data processing tools are available based on the python programming language. These include `gravity-toolkit` (Sutterley, 2023), `ggtools` (Li, Chunxiao, 2020) and `GRACE-filter` (Rietbroek, 2021). General tools for spheric harmonic analysis are also available, such as `SHTools` (Wieczorek & Meschede, 2018). `SHbundle` provide MATLAB scripts for Spheric Harmonic Synthesis and Spheric Harmonic Analysis. The first version of the code was developed in 1994 while the latest version with upgrades can be found dated 2018.

Statement of need

Processing choices introduce subtle differences in the final product, potentially affecting results. Processing `L2` data offers flexibility for users to explore GRACE data for specific applications. This software aims to simplify access to `L2` products, allowing users to select different processing options.

The software processes widely used `L2` products from CSR, JPL, and GFZ. It closely follows the structure of the Matlab-based `SHbundle` and `GRACE Data Driven Correction (GDDC)`(Vishwakarma et al., 2017) codes, enabling cross-compatibility between Python and Matlab users.

`PySHbundle` is modular, offering tools to process GRACE data, including anomaly computation, low-degree coefficient substitution, noise reduction, and signal leakage correction. It supports future development for hydrological applications.

By using Python and the GNU license, the package is accessible globally and aligns with the FAIR principles. We aim to reduce technical and financial barriers, making it useful for researchers, students, and educational programs like the GRACE Hackweek at IIT Kanpur.

Implementation

Mathematical details of the steps involved can be referred in (Vishwakarma, 2017). Accordingly, the package consists of four main modules, `io`, `vizutils`, `pysh_core` and `shutils`.

1. `io`: extract the `L2` coefficients from any of `JPl`, `CSR` and `ITGZ` solutions. Followed by replacing the poorly measured degree 1, 2 and 3 spherical harmonics coefficients with recommended datasets.
2. `vizutils`: plots the `L2` data to visually understand the coefficients, their uncertainties, mathematical functions used for further processing.
3. `pysh_core`: Scripts for the global spherical harmonics synthesis `gshs` to convert the `L2` data to global gridded `TWSA` data (`L3`). Calculating signal leakage (`gddc`), and basin-scale average (`Basinaverage`).
4. `shutils`: Helper scripts for applying `pysh_core`. Based on the main modules, we provide examples as jupyter notebooks for understanding and using spherical harmonics data and the package.

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Future Plan

The package will be under continuous development to process data from more research centres, add more filtering and processing algorithms.

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