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pyTMD: Python-based tidal prediction software

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Summary

pyTMD is an open-source tidal prediction software that aims to simplify the calculation of ocean and Earth tides. It is not an ocean or load tide model, but a tool for using tidal constants provided by tide models to predict the height deflections or currents at particular locations and times. It is designed to be able to handle a wide range of model formats and can incorporate different physics schemes. This flexibility allows pyTMD to be tailored to fit specific use cases, while still allowing ease of use.

Statement of need

There are several ocean tide prediction software options available. The OSU Tidal Inversion Software (OTIS) and OSU Tidal Prediction Software (OTPS) are Fortran programs developed by Lana Erofeeva and Gary Egbert for the TPXO family of models. The Tidal Model Driver (TMD) is a MATLAB Toolbox developed by Laurie Padman, Lana Erofeeva and Susan Howard for the same family of models. An updated version of the MATLAB Toolbox (TMD3) was developed by Chad Greene. pyFES is a Python library produced by LEGOS, NOVELTIS and CLS Ocean and Climate Division, and funded by CNES (Lyard et al., in review) for the Finite Element Solution (FES) family of models. The NASA GSFC PREdict Tidal Heights (PERTH3) software is a Fortran program developed by Richard Ray and Remko Scharroo for the Goddard Ocean Tide (GOT) family of models. An updated and more versatile version of the NASA GSFC Fortran software (PERTH5) was developed by Richard Ray. PERTH5 is a more generalized program, and can read from multiple different tide model formats. These software options are typically created by or for the model providers, and, with the exception of PERTH5, singly support their specific model formats.

pyTMD is a generalized tide program that allows users to calculate both tide deflections and currents. As a tide model driver, pyTMD can read from a broad suite of models, and use different physics schemes in the internal calculations. Over 50 different models are presently supported within pyTMD, and additional models can be defined with a JSON file.

pyTMD was designed to be used by beginners and scientific researchers alike. The online documentation contains background information for both tidal modeling and prediction. The software has been used in a number of scientific publications for modeling regional tides (Freer et al., 2023; Millan et al., 2023; T. C. Sutterley et al., 2019), modeling global tides (Gregg et al., 2024; Paprotny et al., 2024), and creating several Earth observation datasets (ENVEO et al., 2021; Smith et al., 2024a, 2024b). It has also been leveraged within larger earth-observation software packages (Bishop-Taylor et al., 2025; Fitzpatrick et al., 2024).

Functionality

Ocean and Load Tides

With the harmonic method, tides are decomposed into harmonic constants, or constituents, associated with the relative positions of the sun, moon and Earth (Padman et al., 2018). These constituents are typically classified into different "species" based on their approximate period: short-period, semi-diurnal, diurnal, and long-period. `pyTMD.io` contains routines for reading major constituent values (amplitude and phase) from commonly available tide models, which typically fall within a few general formats: `OTIS-binary` (Egbert & Erofeeva, 2002; Padman et al., 2008), `OTIS-compact`, `OTIS-netcdf`, `TMD3-netcdf` (Greene et al., 2024), `GOT-ascii` (Ray, 1999), `GOT-netcdf`, `FES-ascii` (Le Provost et al., 1994) and `FES-netcdf` (Lyard et al., in review). Information for each of the supported tide models is stored within a JSON database. For tidal predictions, `pyTMD.io` interpolates the amplitude and phase lag of tide model constituents to sets of spatial coordinates.

`pyTMD` uses the astronomical argument formalism outlined in Doodson & Lamb (1921) to compute the temporal elements. For a set of temporal values, `pyTMD` 1) calculates the astronomical angles (S, H, P, N, P_s) (Meeus, 1991; Simon et al., 1994), 2) combines these angles with the "Doodson numbers" in a Fourier series to compute the equilibrium tide phase (G) of each constituent, and 3) computes the 18.6-year nodal amplitude and phase corrections (f and u) of each constituent (Dietrich, 1980; Doodson & Lamb, 1921; Pugh & Woodworth, 2014). The spatial and temporal components are then combined, and the output tidal time series is calculated through a summation over all constituents (Egbert & Erofeeva, 2002). To include more of the tidal spectrum, the contributions of "minor" constituents can additionally be estimated using inference methods (Ray, 2017; Schureman, 1958).

Long-period ocean tides can independently be predicted assuming an "equilibrium response" (Cartwright & Edden, 1973; Cartwright & Tayler, 1971; Doodson & Lamb, 1921). Here, the oceanic surface is estimated to respond instantaneously to the tide-producing forces of the moon and sun, and is not influenced by inertia, currents or the irregular distribution of land (Proudman, 1960; Ray & Erofeeva, 2014; Schureman, 1958).

Pole Tides

The Earth's rotation axis is inclined at an angle of 23.5 degrees to the celestial pole, of which it rotates about every 26,000 years (Kantha & Clayson, 2000). Superimposed on this long-term precession, the rotation axis shifts with respect to its mean pole position due to nutation, Chandler wobble, annual variations, and other processes (Desai, 2002; Wahr, 1985). Load and ocean pole tides are driven by variations in the Earth's rotation axis with respect to its mean position, along with corresponding elastic responses and secondary effects (Desai, 2002; Desai et al., 2015; Wahr, 1985). `pyTMD.predict` estimates pole tide variations following IERS Conventions by differencing the daily IERS polar motion "finals" from the reference "secular" pole positions (Petit & Luzum, 2010).

Solid Earth Tides

The tidal deformation of the solid Earth can be modeled in `pyTMD` using one of the following two methods: 1) the ephemerides formalism from Wahr (1981) and Mathews et al. (1997) as described in Petit & Luzum (2010), and 2) the tide catalog formalism outlined in Cartwright & Tayler (1971). For the ephemerides method, `pyTMD.astro` has options for calculating approximate ephemerides following Meeus (1991) and Montenbruck (1989) or using high-resolution JPL ephemerides from Park et al. (2021) with the `jplephem` package (Rhodes, 2011). The calculation for solid Earth tides includes multiple Love and Shida number corrections including the frequency-dependent and dissipative mantle anelasticity corrections from Mathews et al. (1997).

Time

pyTMD uses the `timescale` library (T. Sutterley et al., 2025) to manage temporal conversions, calculate "dynamical" time scales, and estimate Earth Orientation Parameters (EOPs).

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