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pyTMD: Python-based tidal prediction software

Tyler C. Sutterley [1¶], **Susan L. Howard** [2*], **Laurie Padman** [3*], and **Matthew R. Siegfried** [4*]

1 Polar Science Center, Applied Physics Laboratory, University of Washington, Seattle, WA, USA **2** Earth & Space Research, Seattle, WA, USA **3** Earth & Space Research, Corvallis, OR, USA **4** Hydrologic Sciences & Engineering Program, Department of Geophysics, Colorado School of Mines, Golden, CO, USA ¶ Corresponding author * These authors contributed equally.

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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 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 for the TPXO family of models (Egbert & Erofeeva, 2002). The Tidal Model Driver (TMD) is a MATLAB Toolbox developed for the same family of models (Padman et al., 2022). An updated version of the MATLAB Toolbox (TMD3) was developed to use a custom consolidated netCDF4 format (Greene et al., 2024). pyFES is a Python library produced for the Finite Element Solution (FES) family of models (Lyard et al., in review) funded by CNES. The NASA GSFC PREdict Tidal Heights (PERTH3) software is a Fortran program developed for the Goddard Ocean Tide (GOT) family of models. An updated and more versatile version of the NASA GSFC Fortran software (PERTH5) 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 from a broad suite of models. Over 50 different models are presently supported, and additional model schemas 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 (Cartwright, 1999; Doodson & Lamb, 1921). 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, or complex amplitude) 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 tide model constituents to sets of spatial coordinates.

`pyTMD` uses the astronomical argument formalism outlined in Doodson & Lamb (1921) to compute the temporal elements. Temporal conversions and "dynamical" time scales are managed in `pyTMD` with the `timescale` library (T. Sutterley et al., 2025). 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 each constituent's equilibrium tide phase (G), and 3) computes each constituent's 18.6-year nodal amplitude and phase corrections (f and u) (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). Additional "minor" constituents can be "inferred" to include more of the tidal spectrum (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, which it rotates about every 26,000 years (Kantha & Clayson, 2000). Superimposed on this long-term precession, the rotation axis shifts due to nutation, Chandler wobble, annual variations, and other processes (Desai, 2002; Wahr, 1985). Load and ocean pole tides are driven by these variations in the Earth's rotation axis, along with corresponding elastic responses and secondary effects (Desai, 2002; Desai et al., 2015; Wahr, 1985). `pyTMD` follows IERS Conventions (Petit & Luzum, 2010) to estimate load and ocean pole tide variations, which are based on Desai (2002). The daily IERS polar motion "finals" are kept up-to-date using the `timescale` library (T. Sutterley et al., 2025).

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 by 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). For both calculation methods, `pyTMD` can include multiple adjustments to the Love and

Shida numbers including the frequency-dependent and the mantle anelasticity corrections from Mathews et al. (1997).

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