

# <sup>1</sup> eo-tides: Tide modelling tools for large-scale satellite Earth observation analysis

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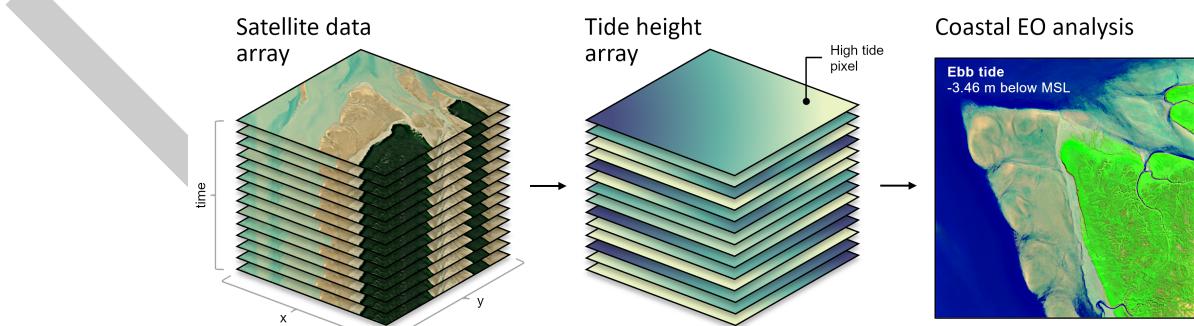
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## Summary

The eo-tides package provides powerful parallelized tools for integrating satellite Earth observation (EO) data with ocean tide modelling. The package provides a flexible Python-based toolkit for modelling and attributing tide heights to a time-series of satellite images based on the spatial extent and acquisition time of each satellite observation (Figure 1).

eo-tides leverages advanced tide modelling functionality from the pyTMD tide prediction software ([Sutterley et al., 2017](#)), combining this fundamental tide modelling capability with EO spatial analysis tools from odc-geo ([odc-geo contributors, 2024](#)). This allows tides to be modelled in parallel automatically using over 50 supported tide models, and returned in standardised pandas ([McKinney, 2010](#); [pandas development team, 2020](#)) and xarray ([Hoyer & Joseph, 2017](#)) data formats for further analysis.

Tools from eo-tides are designed to be applied directly to petabytes of freely available satellite data loaded from the cloud using Open Data Cube's odc-stac or datacube packages (e.g. using [Digital Earth Australia](#) or [Microsoft Planetary Computer's SpatioTemporal Asset Catalogues](#)). Additional functionality enables evaluating potential satellite-tide biases, and validating modelled tides using external tide gauge data — both important considerations for assessing the reliability and accuracy of coastal EO workflows. In combination, these open source tools support the efficient, scalable and robust analysis of coastal EO data for any time period or location globally.



**Figure 1:** A typical eo-tides coastal EO workflow, with tide heights modelled into every pixel in a spatio-temporal stack of satellite data (for example, from ESA's Sentinel-2 or NASA/USGS Landsat), then combined to derive insights into dynamic coastal environments.

## <sup>26</sup> Statement of need

<sup>27</sup> Satellite remote sensing offers an unparalleled method to examine dynamic coastal environments  
<sup>28</sup> over large temporal and spatial scales ([Turner et al., 2021](#); [Vitousek et al., 2023](#)). However,  
<sup>29</sup> the variable and sometimes extreme influence of ocean tides in these regions can complicate  
<sup>30</sup> analyses, making it difficult to separate the influence of changing tides from patterns of true  
<sup>31</sup> coastal change over time ([Vos et al., 2019](#)). This is a particularly challenging for continental-  
<sup>32</sup> to global-scale coastal EO analyses, where failing to account for tide dynamics can lead to  
<sup>33</sup> inaccurate or misleading insights into coastal processes observed by satellites.

<sup>34</sup> Conversely, information about ocean tides can also provide unique environmental insights that  
<sup>35</sup> can greatly enhance the utility of coastal EO data. Conventionally, satellite data dimensions  
<sup>36</sup> consider the geographical “where” and the temporal “when” of data acquisition. The addition  
<sup>37</sup> of tide height as a new analysis dimension allows data to be filtered, sorted and analysed with  
<sup>38</sup> respect to tidal processes, delivering a powerful re-imagining of traditional multi-temporal EO  
<sup>39</sup> data analysis ([Sagar et al., 2017](#)). For example, satellite data can be analysed to focus on  
<sup>40</sup> specific ecologically-significant tidal stages (e.g. high, low tide, spring or neap tides) or on  
<sup>41</sup> particular tidal processes (e.g. ebb or flow tides; [Sent et al. \(2025\)](#)).

<sup>42</sup> This concept has been used to map tidally-corrected annual coastlines from Landsat satellite  
<sup>43</sup> data at continental scale ([Bishop-Taylor et al., 2021](#)), generate maps of the extent and elevation  
<sup>44</sup> of the intertidal zone ([Bishop-Taylor et al., 2019](#); [Murray et al., 2012](#); [Sagar et al., 2017](#)), and  
<sup>45</sup> create tidally-constrained imagery composites of the coastline ([Sagar et al., 2018](#)). However,  
<sup>46</sup> these approaches have been historically based on bespoke, closed-source or difficult to install  
<sup>47</sup> tide modelling tools, limiting the reproducibility and portability of these techniques to new  
<sup>48</sup> coastal EO applications. To support the next generation of coastal EO workflows, there is  
<sup>49</sup> a pressing need for new open-source tools for combining satellite data with tide modelling.  
<sup>50</sup> `eo-tides` aims to address this need through functionality provided in five main analysis modules  
<sup>51</sup> (`utils`, `model`, `eo`, `stats`, `validation`) which are described briefly below.

## <sup>52</sup> Features

### <sup>53</sup> Setting up tide models

<sup>54</sup> The `eo_tides.utils` module simplifies the setup of ocean tide models, addressing a common  
<sup>55</sup> barrier to coastal EO workflows. Tools like `list_models` provide feedback on available and  
<sup>56</sup> supported models ([Figure 2](#)), while `clip_models` can improve performance by clipping large  
<sup>57</sup> model files to smaller regions, significantly reducing processing times for high-resolution models  
<sup>58</sup> like FES2022. Comprehensive documentation is available to [assist setting up commonly used](#)  
<sup>59</sup> [tide models](#), including downloading, uncompressing, and organizing model files.

	Model	Expected path
	EOT20	tide_models/EOT20/ocean_tides
	FES2014	tide_models/fes2014/ocean_tide
	HAMTIDE11	tide_models/hamtide
...	...	...

Summary:  
Available models: 2/50

**Figure 2:** An example output from `list_tides`, providing a useful summary table which clearly identifies available and supported tide models.

## 60 Modelling tides

61 The `eo_tides.model` module is powered by advanced tide modelling functionality from the  
 62 pyTMD Python package ([Sutterley et al., 2017](#)). pyTMD is an open-source tidal prediction  
 63 software that aims to simplify the calculation of ocean and earth tides. Tides are frequently  
 64 decomposed into harmonic constants (or constituents) associated with the relative positions of  
 65 the sun, moon and Earth. pyTMD.io contains routines for reading major constituent values from  
 66 commonly available ocean tide models, and interpolating those values spatially. pyTMD.astro  
 67 contains routines for computing the positions of celestial bodies for a given time. For ocean  
 68 tides, pyTMD computes the longitudes of the sun (S), moon (H), lunar perigee (P), ascending  
 69 lunar node (N) and solar perigee (PP). pyTMD.arguments combines astronomical coefficients  
 70 with the “Doodson number” of each constituent, and adjusts the amplitude and phase of each  
 71 constituent based on their modulations over the 18.6 year nodal period. Finally, pyTMD.predict  
 72 uses results from those underlying functions to predict tidal values at a given location and  
 73 time.

74 The `model_tides` function from `eo_tides.model` wraps pyTMD functionality to return tide  
 75 predictions in a standardised pandas.DataFrame format, enabling integration with satellite  
 76 EO data and parallelized processing for improved performance. Parallelisation in eo-tides  
 77 is automatically optimised based on available workers and requested tide models and tide  
 78 modelling locations. This parallelisation can significantly improve tide modelling performance,  
 79 especially for large-scale analyses run on a multi-core machine ([Table 1](#)). Additional functions  
 80 like `model_phases` classify high, low or flow/ebb tides, critical for interpreting satellite-observed  
 81 coastal processes like changing turbidity and ocean colour ([Sent et al., 2025](#)).

**Table 1:** A [benchmark comparison](#) of tide modelling performance with parallelisation on vs. off, for a typical large-scale analysis involving a month of hourly tides modelled at 10,000 modelling locations using three tide models (FES2022, TPXO10, GOT5.6).

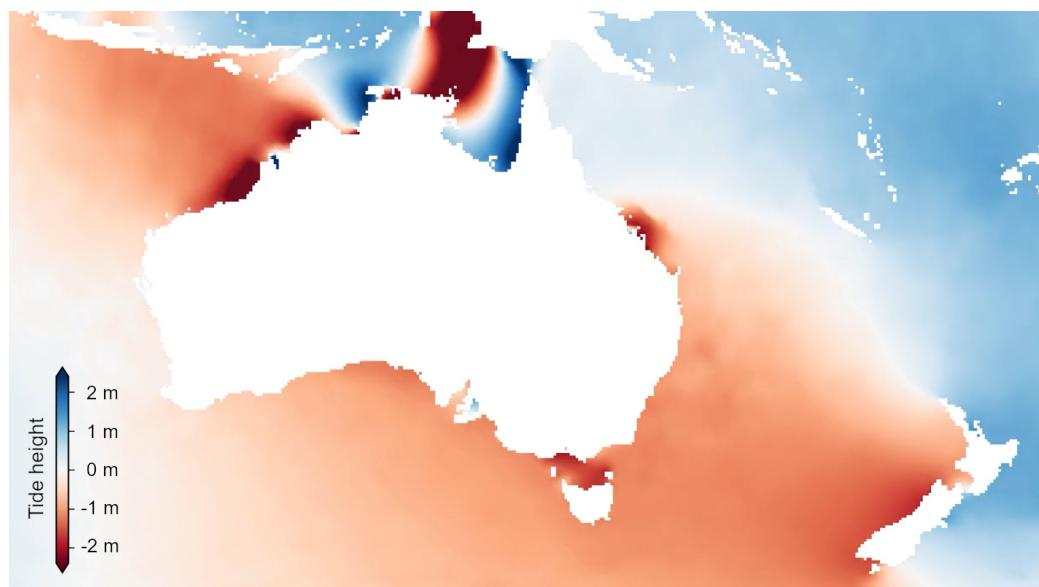
Cores	Parallelisation	No parallelisation	Speedup
8	2min 46s ± 663 ms	9min 28s ± 536 ms	3.4x
32	55.9 s ± 560 ms	9min 24s ± 749 ms	10.1x

## 82 Combining tides with satellite data

83 The `eo_tides.eo` module integrates modelled tides with xarray-format satellite data. For  
 84 tide attribution, eo-tides offers two approaches that differ in complexity and performance:  
 85 `tag_tides` assigns a single tide height per timestep for small-scale studies, while `pixel_tides`  
 86 models tides spatially and temporally for larger-scale analyses, producing a unique tide height  
 87 for each pixel in a dataset ([Table 2](#)). These functions can be applied to free and open satellite  
 88 data for any coastal or ocean location on the planet, for example using data loaded from the  
 89 cloud using the [Open Data Cube](#) and SpatioTemporal Asset Catalogue ([STAC contributors, 2024](#)).

**Table 2:** Comparison of the `tag_tides` and `pixel_tides` functions.

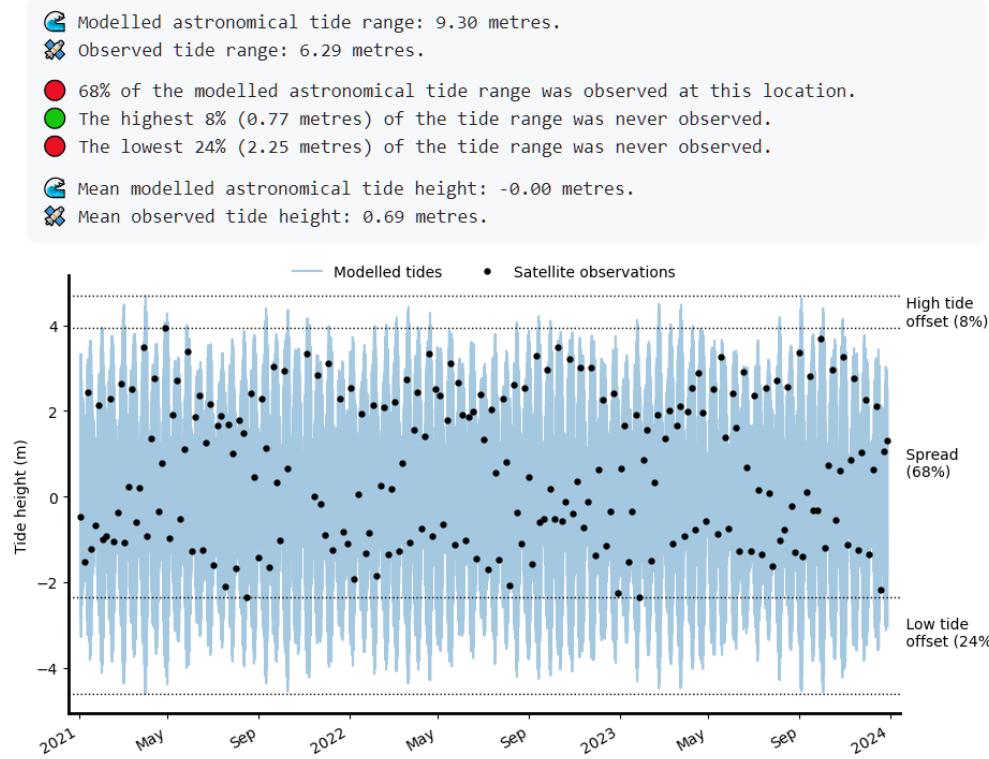
<code>tag_tides</code>	<code>pixel_tides</code>
<ul style="list-style-type: none"> <li>- Assigns a single tide height to each satellite image timestep</li> <li>- Ideal for local or site-scale analysis</li> <li>- Fast, low memory use</li> <li>- Single tide height per image can produce artefacts and discontinuities</li> </ul>	<ul style="list-style-type: none"> <li>- Assigns a tide height to every individual pixel through time to capture spatial tide dynamics</li> <li>- Ideal for large-scale coastal product generation</li> <li>- Slower, higher memory use</li> <li>- Produce spatially seamless results across large extents</li> </ul>



**Figure 3:** An example tide height output produced by the `pixel_tides` function, showing spatial variability in tides across Australasia for a single timestep.

### 91    **Calculating tide statistics and satellite biases**

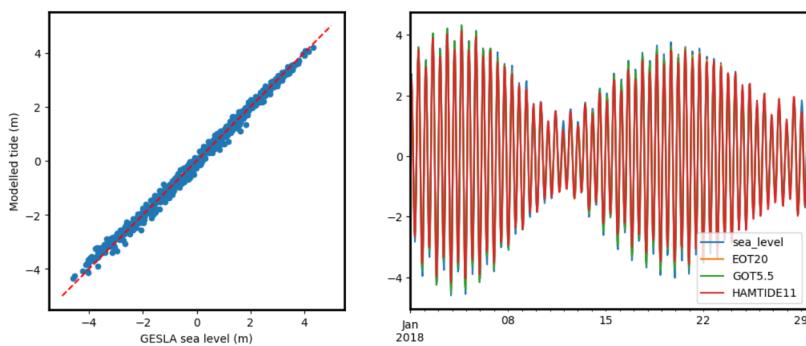
92    The `eo_tides.stats` module identifies biases caused by complex tide aliasing interactions  
93    interactions between tidal dynamics and satellite observations. These interactions can prevent  
94    satellites from observing the entire tide cycle (Eleveld et al., 2014; Sent et al., 2025), and  
95    cause coastal EO studies to produce biased or misleading results (Bishop-Taylor et al., 2019).  
96    The module produces a range of useful automated reports, plots and statistics that summarise  
97    how well a satellite time series captures real-world tidal conditions (Figure 4).



**Figure 4:** An example of tidally-biased satellite coverage, where the sensor only observes ~68% of the modelled astronomical tide range and never observes the lowest 24% of tides.

## 98     Validating modelled tides

99     The `eo_tides.validation` module validates modelled tide heights using high-quality sea-level  
 100    measurements from the GESLA Global Extreme Sea Level Analysis (Haigh et al., 2023) archive,  
 101    providing error metrics like RMSE and MAE (Figure 5). It enables comparison of multiple tide  
 102    models against observed data, allowing users to choose optimal tide models for their specific  
 103    study area or application (Figure 5).



**Figure 5:** An example comparison of modelled tides from multiple global ocean tide models (EOT20, GOT5.5, HAMTIDE11) against observed sea level data from the Broome 62650 GESLA tide gauge.

## 104 Research projects

105 Early versions of eo-tides functions have been used for continental-scale intertidal zone  
106 mapping (Bishop-Taylor et al., 2024), multi-decadal shoreline mapping across Australia (Bishop-  
107 Taylor et al., 2021) and Africa, and to support tide correction for satellite-derived shorelines as  
108 part of the CoastSeg Python package (Fitzpatrick et al., 2024).

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113 published with the permission of the Chief Executive Officer, Geoscience Australia. Copyright  
114 Geoscience Australia (2025).

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