

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

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## Software

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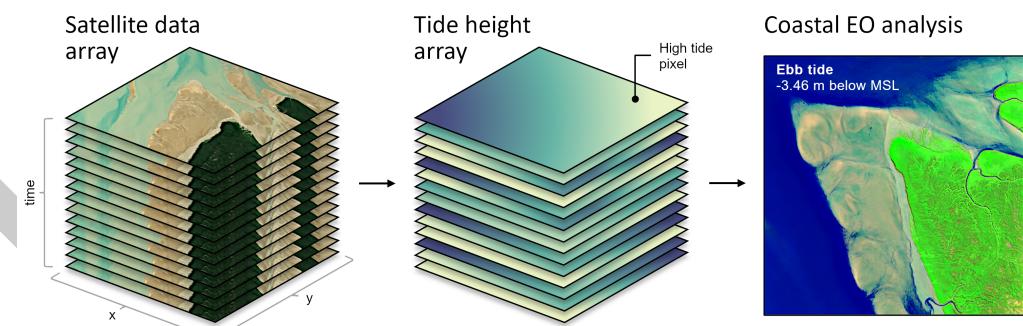
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eo-tides tools can be applied to petabytes of freely available satellite data loaded from the cloud using Open Data Cube (ODC)’s odc-stac or datacube packages (e.g. using [Digital Earth Australia](#) or [Microsoft Planetary Computer’s STAC SpatioTemporal Asset Catalogues](#)). Additional functionality allows users to assess potential satellite-tide biases and validate modelled tides with external tide gauge data — critical considerations for ensuring the reliability and accuracy of coastal EO workflows. 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 Sentinel-2 or Landsat), then combined to derive insights into dynamic coastal environments.

## <sup>24</sup> Statement of need

<sup>25</sup> Satellite remote sensing offers an unparalleled resource for examining dynamic coastal environments through time or across large regions (Turner et al., 2021; Vitousek et al., 2023).  
<sup>26</sup> However, the highly variable influence of ocean tides can complicate analyses, making it difficult  
<sup>27</sup> to separate the influence of changing tides from patterns of true coastal change (Vos et al.,  
<sup>28</sup> 2019). This is a particularly challenging for large-scale coastal EO analyses, where failing to  
<sup>29</sup> account for tide dynamics can lead to inaccurate or misleading insights into satellite-observed  
<sup>30</sup> coastal processes.  
<sup>31</sup>

<sup>32</sup> Conversely, information about ocean tides can provide unique environmental insights that can  
<sup>33</sup> significantly enhance the value of EO data. Traditionally, satellite data dimensions include  
<sup>34</sup> the geographic “where” and temporal “when” of acquisition. Introducing tide height as an  
<sup>35</sup> additional analysis dimension allows data to be filtered, sorted, and analysed based on tidal  
<sup>36</sup> dynamics, offering a transformative re-imagining of traditional multi-temporal EO analysis  
<sup>37</sup> (Sagar et al., 2017). For instance, satellite data can be analysed to focus on ecologically  
<sup>38</sup> significant tidal stages (e.g., high tide, low tide, spring or neap tides) or specific tidal processes  
<sup>39</sup> (e.g., ebb or flow tides; Sent et al. (2025)).

<sup>40</sup> This concept has been used to map coastal change at continental-scale (Bishop-Taylor et al.,  
<sup>41</sup> 2021), map intertidal zone extent and elevation (Bishop-Taylor et al., 2019; Murray et al.,  
<sup>42</sup> 2012; Sagar et al., 2017), and creating tidally-constrained coastal image composites (Sagar  
<sup>43</sup> et al., 2018). However, these methods have traditionally relied on bespoke, closed-source, or  
<sup>44</sup> difficult-to-install tide modelling tools, limiting their reproducibility and portability. To support  
<sup>45</sup> the next generation of coastal EO workflows, there is a pressing need for efficient open-source  
<sup>46</sup> tools for combining satellite data with tide modelling. eo-tides addresses this need through  
<sup>47</sup> functionality offered in five main analysis modules (utils, model, eo, stats, validation).

## <sup>48</sup> Features

### <sup>49</sup> Setting up tide models

<sup>50</sup> The `eo_tides.utils` module simplifies the setup of ocean tide models, addressing a common  
<sup>51</sup> barrier to coastal EO workflows. Tools like `list_models` provide feedback on available and  
<sup>52</sup> supported models (Figure 2), while `clip_models` can significantly improve performance by  
<sup>53</sup> clipping large high-resolution model files (e.g. FES2022) to smaller study area extents.

	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 `list_tides` output, providing a useful summary table that identifies available and supported tide models.

### <sup>54</sup> Modelling tides

<sup>55</sup> The `eo_tides.model` module is powered by tide modelling functionality from the pyTMD Python  
<sup>56</sup> package (Sutterley et al., 2017). pyTMD is an open-source tidal prediction software that

57 simplifies the calculation of ocean and earth tides. Tides are frequently decomposed into  
 58 harmonic constants (or constituents) associated with the relative positions of the sun, moon  
 59 and Earth. pyTMD.io contains routines for reading and spatially interpolating major constituent  
 60 values from commonly available ocean tide models.

61 The `model_tides` function from `eo_tides.model` wraps pyTMD functionality to return tide  
 62 predictions in a standardised pandas.DataFrame format, enabling integration with EO data  
 63 and parallelised processing for improved performance ([Table 1](#)). The `model_phases` function  
 64 can additionally classify tides into high/low/flow/ebb phases, critical for interpreting satellite-  
 65 observed coastal processes like turbidity ([Sent et al., 2025](#)).

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

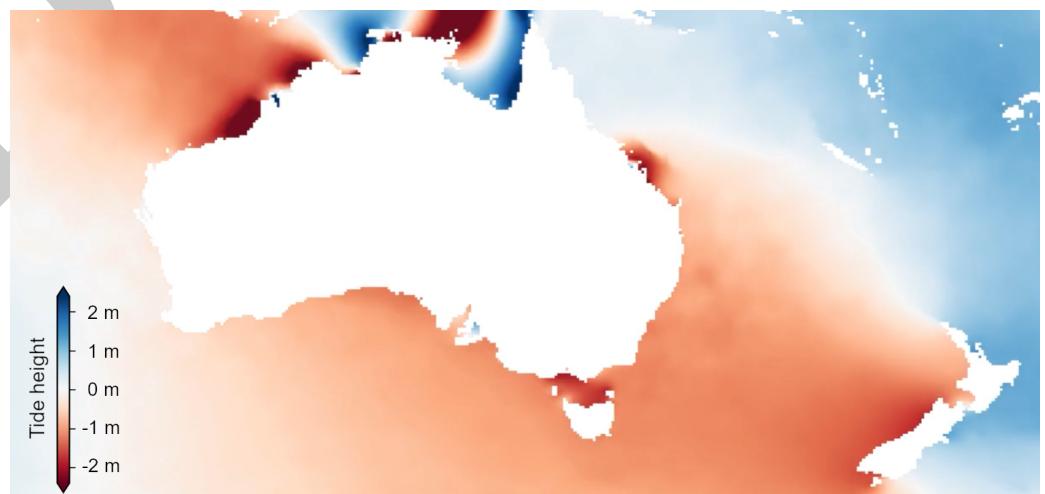
Cores	Parallelisation	No parallelisation	Speedup
8	2min 46s ± 663 ms	9min 28s ± 536 ms	3.4x
32	55.9 s ± 560 ms	9min 24s ± 749 ms	10.1x

## 66 Combining tides with satellite data

67 The `eo_tides.eo` module integrates modelled tides with xarray-format satellite data. The  
 68 `tag_tides` and `pixel_tides` functions ([Table 2, Figure 3](#)) can be applied to attribute tides to  
 69 satellite data for any coastal location on the planet, for example using open data loaded from  
 70 the cloud using ODC and STAC ([STAC contributors, 2024](#)).

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

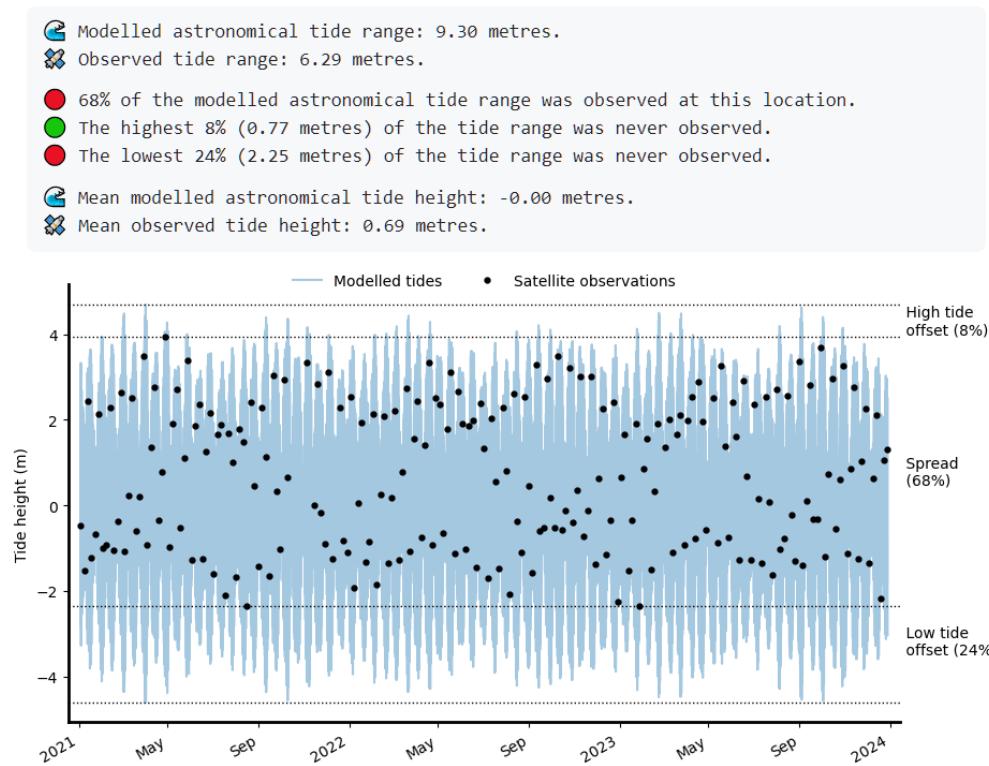
tag_tides	pixel_tides
<ul style="list-style-type: none"> <li>- Assigns a single tide height to each satellite image time-step</li> <li>- Single tide height per image can produce artefacts and discontinuities</li> <li>- Fast, low memory use</li> <li>- Ideal for local, site-scale analysis</li> </ul>	<ul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



**Figure 3:** An example spatial tide height output produced by the `pixel_tides` function.

## 71 Calculating tide statistics and satellite biases

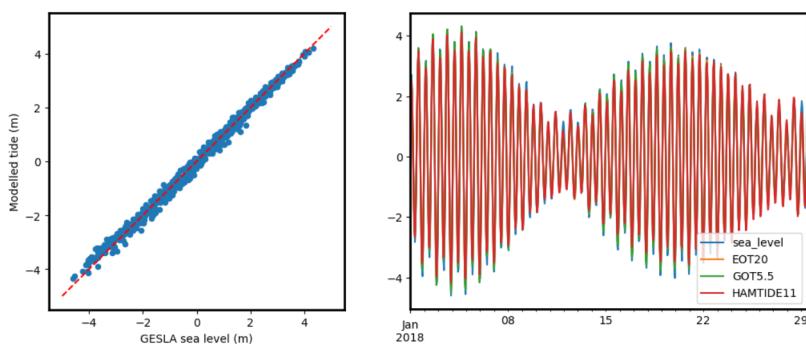
72 The `eo_tides.stats` module identifies biases caused by complex tide aliasing interactions that  
 73 can prevent satellites from observing the entire tide cycle (Bishop-Taylor et al., 2019; Eleveld  
 74 et al., 2014; Sent et al., 2025). The `tide_stats` and `pixel_stats` functions produce useful  
 75 statistics that summarise how well satellite data captures real-world tides (Figure 4).



76 **Figure 4:** An example of tidally-biased satellite coverage, where only ~68% of the astronomical tide  
 77 range is observed.

## 76 Validating modelled tides

77 The `eo_tides.validation` module validates modelled tides against observed sea-level measurements,  
 78 assisting users to evaluate and select optimal models for their application (Figure 5).



79 **Figure 5:** A comparison of multiple tide models (EOT20, GOT5.5, HAMTIDE11) against observed sea  
 80 level data from the Broome 62650 GESLA tide gauge.

## 79 Research projects

80 Early versions of eo-tides functions have been used for continental-scale intertidal mapping  
81 ([Bishop-Taylor et al., 2024](#)), multi-decadal shoreline mapping across Australia ([Bishop-Taylor](#)  
82 [et al., 2021](#)) and [Africa](#), and for correcting satellite-derived shoreline in the CoastSeg Python  
83 package ([Fitzpatrick et al., 2024](#)).

## 84 Acknowledgements

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86 repository ([Krause et al., 2021](#)). This paper is published with the permission of the Chief  
87 Executive Officer, Geoscience Australia.

## 88 References

- 89 Bishop-Taylor, R., Nanson, R., Sagar, S., & Lymburner, L. (2021). Mapping Australia's  
90 Dynamic Coastline at Mean Sea Level using Three Decades of Landsat Imagery. *Remote  
91 Sensing of Environment*, 267, 112734. <https://doi.org/10.1016/j.rse.2021.112734>
- 92 Bishop-Taylor, R., Phillips, C., Newey, V., & Sagar, S. (2024). *Digital Earth Australia Intertidal*.  
93 Commonwealth of Australia (Geoscience Australia). <https://doi.org/10.26186/149403>
- 94 Bishop-Taylor, R., Sagar, S., Lymburner, L., & Beaman, R. J. (2019). Between the tides:  
95 Modelling the elevation of australia's exposed intertidal zone at continental scale. *Estuarine,  
96 Coastal and Shelf Science*, 223, 115–128. <https://doi.org/10.1016/j.ecss.2019.03.006>
- 97 Eleveld, M. A., Van der Wal, D., & Van Kessel, T. (2014). Estuarine suspended par-  
98 ticular matter concentrations from sun-synchronous satellite remote sensing: Tidal  
99 and meteorological effects and biases. *Remote Sensing of Environment*, 143, 204–215.  
100 <https://doi.org/10.1016/j.rse.2013.12.019>
- 101 Fitzpatrick, S., Buscombe, D., Warrick, J. A., Lundine, M. A., & Vos, K. (2024). CoastSeg: An  
102 accessible and extendable hub for satellite-derived-shoreline (SDS) detection and mapping.  
103 *Journal of Open Source Software*, 9(99), 6683. <https://doi.org/10.21105/joss.06683>
- 104 Hoyer, S., & Joseph, H. (2017). xarray: N-d labeled arrays and datasets in python. *Journal of  
105 Open Research Software*, 5(1). <https://doi.org/10.5334/jors.148>
- 106 Krause, C., Dunn, B., Bishop-Taylor, R., Adams, C., Burton, C., Alger, M., Chua, S., Phillips, C.,  
107 Newey, V., Kouzoubov, K., Leith, A., Ayers, D., & Hicks, A. (2021). *Digital Earth Australia  
108 notebooks and tools repository*. <https://github.com/GeoscienceAustralia/dea-notebooks/>;  
109 Commonwealth of Australia (Geoscience Australia). <https://doi.org/10.26186/145234>
- 110 McKinney, Wes. (2010). Data Structures for Statistical Computing in Python. In Stéfan van  
111 der Walt & Jarrod Millman (Eds.), *Proceedings of the 9th Python in Science Conference*  
112 (pp. 56–61). <https://doi.org/10.25080/Majora-92bf1922-00a>
- 113 Murray, N. J., Phinn, S. R., Clemens, R. S., Roelfsema, C. M., & Fuller, R. A. (2012).  
114 Continental scale mapping of tidal flats across east asia using the landsat archive. *Remote  
115 Sensing*, 4(11), 3417–3426. <https://doi.org/10.3390/rs4113417>
- 116 odc-geo contributors. (2024). Opendatacube/odc-geo. In *GitHub repository*. GitHub.  
117 <https://github.com/opendatacube/odc-geo>
- 118 pandas development team. (2020). *Pandas-dev/pandas: pandas* (latest). Zenodo. <https://doi.org/10.5281/zenodo.3509134>
- 119 Sagar, S., Phillips, C., Bala, B., Roberts, D., Lymburner, L., & Beaman, R. J. (2018).  
120 Generating continental scale pixel-based surface reflectance composites in coastal regions

- 122 with the use of a multi-resolution tidal model. *Remote Sensing*, 10(3), 480. <https://doi.org/10.3390/rs10030480>
- 123
- 124 Sagar, S., Roberts, D., Bala, B., & Lymburner, L. (2017). Extracting the intertidal extent and  
125 topography of the australian coastline from a 28 year time series of landsat observations.  
126 *Remote Sensing of Environment*, 195, 153–169. <https://doi.org/10.1016/j.rse.2017.04.009>
- 127 Sent, G., Antunes, C., Spyракος, E., Jackson, T., Atwood, E. C., & Brito, A. C. (2025). What  
128 time is the tide? The importance of tides for ocean colour applications to estuaries. *Remote  
129 Sensing Applications: Society and Environment*, 37, 101425. <https://doi.org/10.2139/ssrn.4858713>
- 130
- 131 STAC contributors. (2024). *SpatioTemporal Asset Catalog (STAC) specification*. <https://stacspec.org>
- 132
- 133 Sutterley, T. C., Alley, K., Brunt, K., Howard, S., Padman, L., & Siegried, M. (2017). *pyTMD:  
134 Python-based tidal prediction software*. Zenodo. <https://doi.org/10.5281/zenodo.5555395>
- 135 Turner, I. L., Harley, M. D., Almar, R., & Bergsma, E. W. J. (2021). Satellite optical imagery  
136 in Coastal Engineering. *Coastal Engineering*, 167, 103919. <https://doi.org/10.1016/j.coastaleng.2021.103919>
- 137
- 138 Vitousek, S., Buscombe, D., Vos, K., Barnard, P. L., Ritchie, A. C., & Warrick, J. A. (2023).  
139 The future of coastal monitoring through satellite remote sensing. *Cambridge Prisms:  
140 Coastal Futures*, 1, e10. <https://doi.org/10.1017/cft.2022.4>
- 141 Vos, K., Splinter, K. D., Harley, M. D., Simmons, J. A., & Turner, I. L. (2019). CoastSat: A  
142 Google Earth Engine-enabled Python toolkit to extract shorelines from publicly available  
143 satellite imagery. *Environmental Modelling & Software*, 122, 104528. <https://doi.org/10.1016/j.envsoft.2019.104528>
- 144