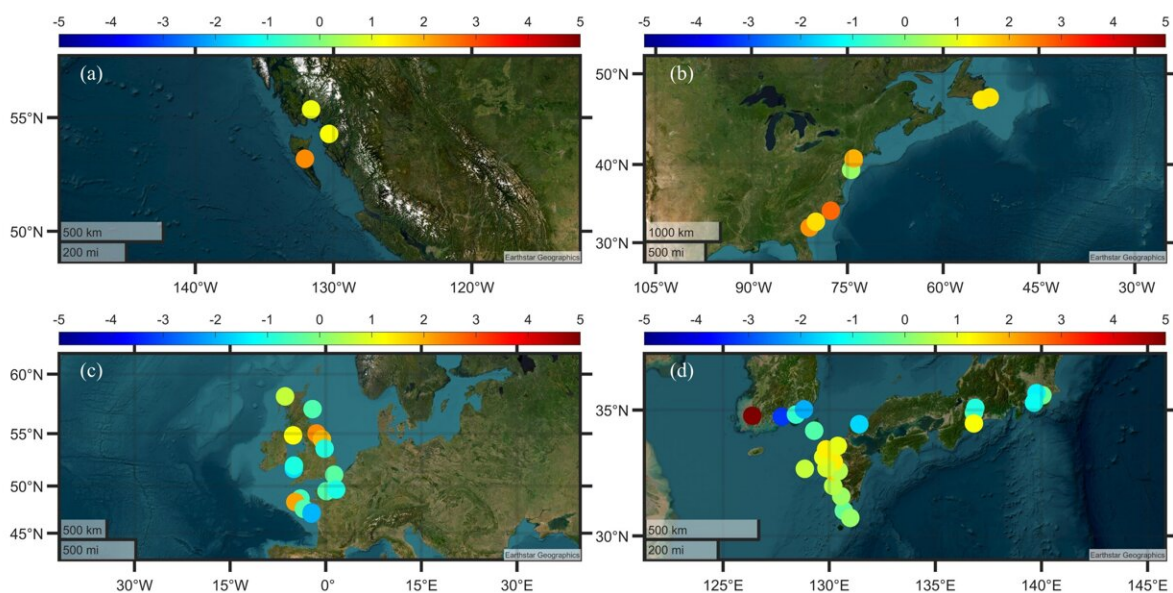


# Multi-regional observations and validation of the $M_3$ ocean tide

October 11 2023



Long-term trends of  $M_3$ . (a) Pacific Northwest, (b) Western Atlantic, (c) European Shelf, (d) Korea Strait. Marker colors indicate magnitude of increase over the full record (in mm). Credit: Science China Press

The lunar terdiurnal ocean tide has a period of approximately 8.2804 hours, and theoretically has a small amplitude. Its largest equilibrium action term is just 2.56 mm, generally considered to have little impact on shipping or other maritime activities. Thus, it has not received much

attention in previous studies, and understanding of the  $M_3$  tide's characteristics in various global regions is extremely limited.

However, water level fluctuation caused by the  $M_3$  [tide](#) in certain areas is much greater than the theoretical tidal amplitude. In addition, the  $M_3$  tide may be greatly affected by [global sea level rise](#). Therefore, in order to improve the accuracy of tidal predictions and geodesy, it is important to better understand high-order tides like  $M_3$ .

A research team led by Professor Jiayi Pan at the College of Geography and Environment of Jiangxi Normal University, including Dr. Adam Devlin, collaborated with Dr. Déborah Idier from the French Geological Survey, using water level observation data from 157 tide gauge stations in multiple regions worldwide, satellite altimetry assimilation data, and numerical simulation to systematically analyze the characteristics of  $M_3$  tides in multiple regions.

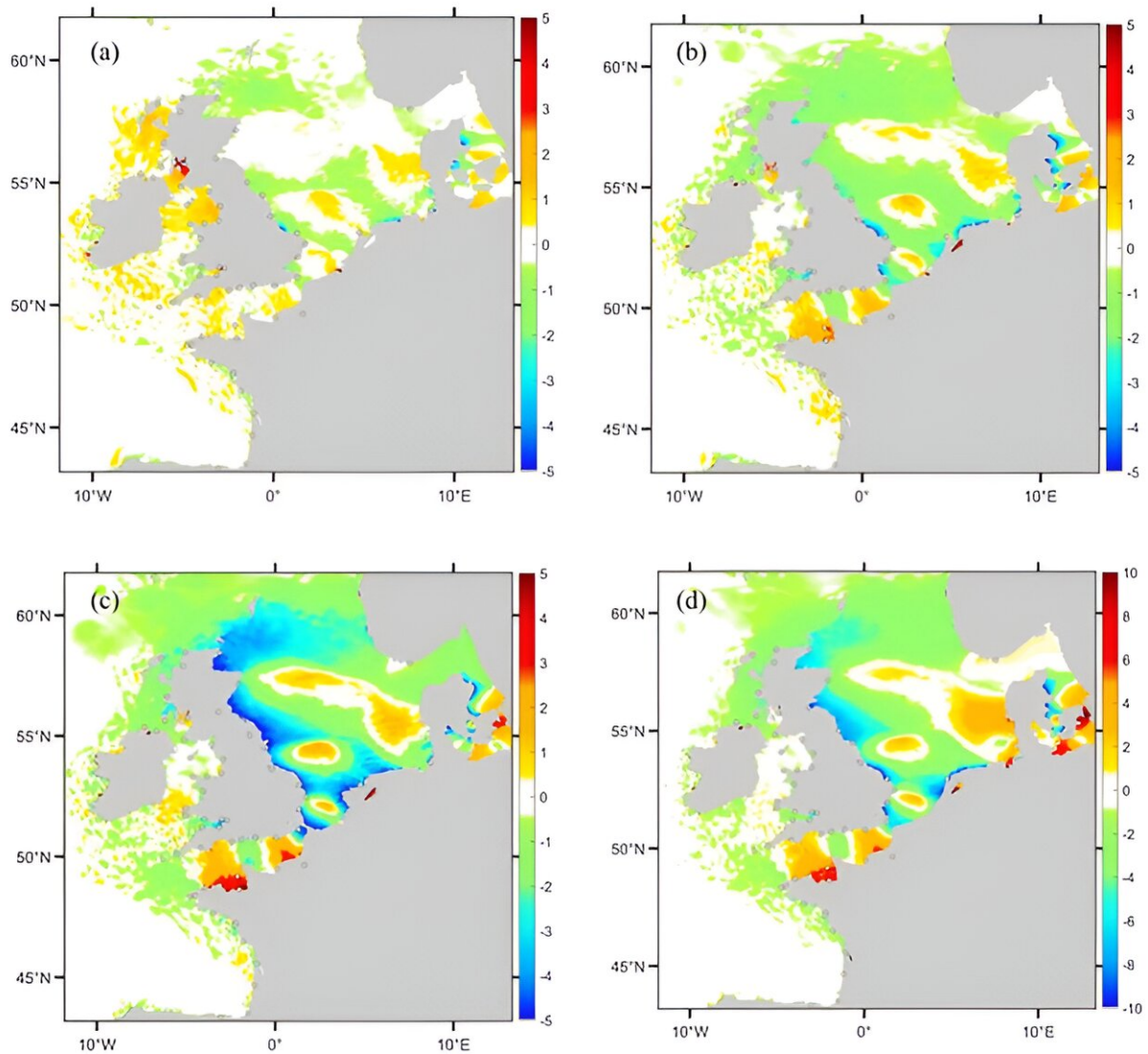
They also used a numerical model to study the future trends of  $M_3$  tides under global warming and sea level rise.

Six key research areas were selected, and hourly tide gauge data were analyzed using a harmonic method with a window of nine years and a time step of three months to determine the  $M_3$  amplitude and to produce a continuous time series of the admittance amplitudes of  $M_3$ . The analysis results show that the  $M_3$  amplitude at most locations in the research areas is much larger than the equilibrium tide value.

In the western Pacific region, larger  $M_3$  amplitudes were observed in places such as the East China Sea, the northern South China Sea, Surabaya in Indonesia, and the northeastern seas of Australia. The amplitude is relatively moderate on the west coast of Kyushu Island and the central coast of China, but it significantly increases in the Ariake Sea. In the Korea Strait, the  $M_3$  amplitude is greater than or equal to 10.0

mm, and gradually decreases in the direction of the eastern Sea of Japan.

The  $M_3$  amplitude of TPXO in Tokyo Bay and Nagoya Bay is about half of the observed value. In the North American region, the  $M_3$  amplitude in the Northwest Pacific region is between 18.3 and 22.6 mm, but it is much smaller at Bella Bella in the south. In the European continental shelf area, the  $M_3$  tide is generally large in the complex coastline of the European continental shelf area, with large variations between sub-regions.



Spatial fields of the changes in the  $M_3$  under different SLR scenarios on the European Shelf (a) 0.5 m SLR, (b) 1.0 m SLR, (c) 2.0 m SLR, (d) 3.0 m SLR. Color bars express changes from the base run (no SLR) of MARS in units of mm. Note different color scale used for the maximum SLR in (d). Credit: Science China Press

The  $M_3$  amplitude in the Scottish Sea area is almost always greater than 20 mm, reaching 39.3 mm in Tobermory. The amplitude in the North Irish Sea is also large, especially in the Liverpool area and its vicinity (27–37 mm), reaching about 52 mm in Millport. Because there is a tidal node nearby, the amplitude of  $M_3$  in the Isle of Man Sea area is close to zero. The amplitude in the southern Irish Sea is lower, but it significantly increases in the Bristol Strait.

The investigators also conducted in-depth analysis of data from 61 tide gauge stations that had longer records to determine secular changes in  $M_3$  amplitudes. This demonstrated that different geographic areas exhibit different characteristics in the long-term changes in  $M_3$  amplitude. For example, in the Northwest Pacific region and along the North Atlantic coast of North America, the  $M_3$  amplitude shows a significant positive growth.

At most tide gauge stations in Europe, the  $M_3$  amplitude shows a negative long-term trend. This trend has also been confirmed in certain areas in Japan and Korea, where the  $M_3$  amplitude shows both strong positive and negative trends. In order to gain a deeper understanding of the impact of sea level rise on  $M_3$ , the researchers used the MARS model for simulation and analysis. These simulations considered different sea level rise scenarios, ranging from 0.5 m to 3.0 m.

The results show that with an increase in sea level rise, the  $M_3$  amplitude in some areas will first increase, but when it reaches a certain threshold, the amplitude will then decrease. This phenomenon is particularly evident in the Irish Sea and Bay of Biscay. In other areas, such as the English Channel, the  $M_3$  amplitude continues to increase. Such different sub-regional responses to an essentially uniform forcing highly suggest a significant resonance mechanism on the European Shelf.

These findings provide valuable information about changes in  $M_3$

amplitude and also reveal the potential impact of sea level rise on the resonance produced by the European continental shelf sea. This change in resonance may be a key factor causing long-term changes in  $M_3$  [amplitude](#). This research result allows us to better understand the impact of sea level rise on the  $M_3$  tide.

The first author of this research paper is Dr. Adam Devlin from Jiangxi Normal University (currently working at the University of Hawaii), and the corresponding author is Professor Pan Jiayi from Jiangxi Normal University. Dr. Déborah Idier from the French Geological Survey also participated in the research.

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