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## LETTERS TO THE EDITOR



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### The King Tide Conundrum

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#### ABSTRACT

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Over the last decade the concept of “king tides” has become a common colloquial term to describe higher than normal high tides. The terminology originated in 2009, when Australia experienced their highest seasonal tides in almost 20 years. In response, a public engagement program, “The King Tides Project,” was formed that has since spread globally. Discrepancies regarding the definition and frequency of king tides can be identified between the different initiatives. This communication analyzes the multifaceted and contradictory meanings of king tides and concludes by providing a holistic and comprehensive definition.

**ADDITIONAL INDEX WORDS:** *Sea-level rise, coastal flooding.*



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“[Aquaman] comes with the King Tide.” Bruce Wayne, *Justice League*, 2017

We posit the increased use of the term “king tide” by various media outlets, including in the hit movie *Justice League*, results from the international efforts of The King Tides Project (see [www.kingtides.net](http://www.kingtides.net)). The project started in Australia in 2009 after residents were impacted by the highest seasonal tides in almost 20 years. The King Tides Project has been very successful in Australia; they are actively recruiting other countries, states, and municipalities to participate. The project’s goals are to educate the public and foster the creation of a catalog of hyperlocal flood risk data for researchers and decision makers. Because present day extreme high tides will be the normal high tide levels with future sea-level rise, the project encourages international communities to visualize this change using the tagline “snap the shore, see the future.”

Australia, Canada, Mauritius, New Zealand, Tuvalu, and the United States participate in the King Tide Project. In the United States, the states with king tide initiatives are California, Connecticut, Florida, Georgia, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, North Carolina, Oregon, Rhode Island, South Carolina, and Washington. While the King Tides Project provides global communities with valuable information, the media popularization of the term “king tide” has caused confusion because of its inconsistent definitions. This short communication discuss-

es existing definitions and offers a universally applicable definition.

#### Defining King Tides

King tide is a colloquial term, leaving the project organizers to formulate their own definitions (Table 1). Conceptually, a king tide is an exceptionally high and naturally occurring tide that causes nuisance flooding (also known as, “sunny day tidal flooding”) (Figure 1). These events occur up to several times per month. The King Tides Project, however, defines these events according to the alignment of the Sun and Moon and states a “king tide” occurs twice per year. Fortunately, many king tides can be predicted, just as any other tidal event can be. Unfortunately, atmospheric disturbances can unexpectedly raise water to king tide levels. Thus, our conundrum: Is a king tide defined by its cause (lunar and solar constituents, atmospheric disturbances) or its effect (observed water levels and flooding)? Table 1 summarizes the different definitions used by 15 of the most active king tide initiatives. It is plainly evident that there is little consistency.

According to the King Tides Project, king tides occur twice per year when there is alignment and gravitational pull between the Sun and Moon. The exact alignment of the Sun and Moon is not defined, nor is the position of Earth clearly stated. The spring tides occur during linear alignment of the Sun, Earth, and Moon (perigee). Spring tides occur twice per lunar month (twice per ~28 days, or ~25 times per year) and are referred to as king tides by the U.S. National Oceanic and Atmospheric Administration (<https://oceanservice.noaa.gov/facts/springtide.html>). The highest predicted tides (*i.e.* those formed from celestial body alignment, not atmospheric disturbances) are proxigean tides (a common scientific term) or

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Table 1. Location, organizers, definitions, and rate of occurrence for the most active King Tide Initiatives. Source: kingtides.net.

Location	King Tide Initiative Organizer	King Tide Definition	Occurrence
Australia <sup>†</sup>	Green Cross Australia “The King Tides Project”	An especially high tide event that occurs when there is an alignment of the gravitational pull between Sun and Moon	2 times per year
British Columbia <sup>‡</sup>	BC Government	Also known as perigean spring tides; extreme high tide events that occur when the Sun and Moon’s gravitation forces reinforce one another at times of the year when the Moon is closest to Earth	2 times per year
California <sup>§</sup>	Partnership: various state agencies and nonprofits	A regular phenomenon where high tides are higher than normal; these extreme, spring high tides occur during full or new moons when the Earth is at its perigee	3–4 times per year
Florida <sup>  </sup>	Tampa Bay and Sarasota Bay Estuary Programs	Occur when the Moon and Sun align on one side of the Earth and their gravitational forces combine to create higher tides than normal	2 times per year
Georgia <sup>¶</sup>	City of Tybee	Unusually high tides brought on by the alignment of the Moon, Sun, and Earth that causes nuisance flooding	3–4 times per year
Gulf of Maine Region, NE U.S./Atlantic Canada <sup>#</sup>	Gulf of Maine Council on the Marine Environment–Climate Network	Highest tides that occur over the course of a year when the gravitational pull of the Sun and Moon reinforce each other; also known as perigean spring tides, they occur when the Moon is closest to the Earth	3–4 times a year
Maine <sup>††</sup>	Piscataqua Region Estuaries Partnership (PREP)	An especially high tide that occurs when the gravitational pull of the Sun and Moon reinforce one another when the Moon is closest to the Earth	2 times per year
Maryland <sup>‡‡</sup>	Maryland Department of Natural Resources	Also known as perigean spring tide, when the Sun, Moon, and Earth align when the Moon is closest to Earth	Almost every month
New Jersey <sup>§§</sup>	Barnegat Bay Partnership	An extremely high tide resulting from the alignment of the Sun and Moon	1–2 times per year
New York and New Jersey <sup>    </sup>	New York–New Jersey Harbor Estuary Program and local partners	Naturally occurring higher-than-normal tides that occur when the spring tide coincides with the perigee	Almost every month
New Zealand <sup>¶¶</sup>	Auckland Council	The highest tides observed over the course of the year; when full or new Moon occurs during the perigee	Almost every month
North Carolina <sup>##</sup>	University of Chapel Hill Institute of Marine Science	The highest tide events of the year—when there is an alignment of the gravitational pull between the Sun and Moon	2 times per year
Oregon <sup>†††</sup>	Oregon Shores Conservation Coalition and the Surfrider Foundation	Extreme high tides, normally during winter, when the Moon is closest to the Earth	3–4 times per year
South Carolina <sup>‡‡‡</sup>	Department of Health and Environmental Control	Are typically caused when a spring tide takes place during the perigee and must be $\geq 2$ m (6.6 ft) above MLLW	Almost every month
Washington <sup>§§§</sup>	Washington Sea Grant and Washington State Department of Ecology	Higher tides that occur naturally when the Sun and the Moon align, causing an increased gravitational pull on the Earth’s oceans	3–4 times per year

<sup>†</sup><http://www.witnesskingtides.org/what-are-king-tides.aspx><sup>‡</sup><https://www.flickr.com/groups/kingtidephotos/discuss/72157660659161640/><sup>§</sup><http://california.kingtides.net/><sup>||</sup>[http://www.tbep.org/tampa\\_bay\\_a\\_climate-ready\\_estuary-about\\_king\\_tides.html](http://www.tbep.org/tampa_bay_a_climate-ready_estuary-about_king_tides.html); <https://sarasotabay.org/sarasota-bay/sea-level-rise/><sup>¶</sup><http://seagrant.noaa.gov/News/Article/ArtMID/1660/ArticleID/502/Georgia-Sea-Grant-Uses-New-Smartphone-App-to-Map-King-Tide-Flood><sup>#</sup><http://gulfofmaine.kingtides.net/><sup>††</sup><http://prepeestuaries.org/2014-king-tide-photo-contest/><sup>‡‡</sup><http://dnr.maryland.gov/climateresilience/Pages/default.aspx><sup>§§</sup><http://longislandsoundstudy.net/2011/09/capture-the-king-tide/><sup>||||</sup><http://www.harborestuary.org/aboutestuary-climatechange-tides.htm><sup>¶¶</sup><http://auckland.kingtides.org.nz/about/what-are-king-tides/><sup>##</sup><http://nckingtides.web.unc.edu/king-tide/><sup>†††</sup><http://www.oregonkingtides.net/><sup>‡‡‡</sup><http://www.scdhec.gov/HomeAndEnvironment/Water/CoastalManagement/KingTidesHelp/><sup>§§§</sup><http://washington.kingtides.net/>

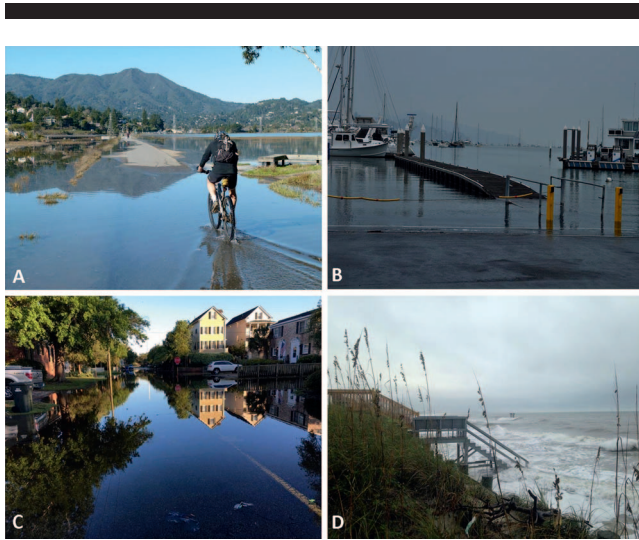


Figure 1. Examples of the effects of king tides in coastal communities. (A) Flooding in a road in Strawberry, California, on 5 December 2017. (B) Flooded dock in Sausalito, California, on 3 January 2018. (C) Flooding in a Charleston, South Carolina, neighborhood on 24 April 2017. (D) Coastal erosion near the Springmaid Pier, Myrtle Beach, South Carolina, on 28 September 2015. Credit: (A) by Jef Poskanzer and (B) by Robert Sanford, California King Tide Photo Initiative (<https://www.flickr.com/groups/cakingtides/>). (C) by Luke Schimmel and (D) by Christopher Stout, South Carolina King Tide Initiative (<https://mycoast.org/sc/king-tides/photos>).

perigean spring tides (according to the National Oceanic and Atmospheric Administration [NOAA]). These tides occur when the new or full Moon cycle temporally coincides with the perigee of the Moon (*i.e.* when the Moon is closest to the Earth). The perigean spring/proxigean tides occur 3–4 times per year and result in higher high tides compared to “normal” spring tides. Inspection of the definitions in Table 1 reveals that many king tide initiatives do not seem to understand the intricacies of the Earth–Sun–Moon relationships.

However, not all king tide definitions rely solely on tidal constituents. Atmospheric disturbances regularly raise water levels beyond those generated exclusively by tidal forcing. As a result, some places recognize a king tide based solely upon the water level. In South Carolina, a king tide is a spring tide greater than 2 m (6.6 ft) above mean lower low water (MLLW). In 2017, the South Carolina Office of Coastal Resource Management predicted 35 king tide events, but observed 128 (SCDHEC, 2018). This fivefold exceedance demonstrates the

power of atmospheric conditions to increase sea levels well beyond the predicted tidal levels. The timing of king tides with atmospheric disturbances also plays a significant role in this underprediction; between November and March the Earth is closer to the Sun, resulting in higher spring high tides and increased potential for king tides (Patel, 2006; Woodworth and Blackman, 2004). Other periodic phenomena, such as the El Niño Southern Oscillation, can produce entire seasons of extreme high tides that cause persistent coastal flooding and erosion. For example, in 2015, California Sea Grant warned its communities that king tides and coastal flooding were expected to be even higher than expected due to El Niño (NOS, 2016).

### Toward Solving the Conundrum

The King Tides Project is a forward-thinking public engagement initiative that allows scientists and citizens to visualize the impacts of rising sea levels on their communities. As coastal scientists, we should actively participate in this conversation and contribute to the King Tide Initiative and other similar public outreach efforts. However, for the success of this and other king tide initiatives, a “king tide” must be defined consistently and accurately. The definition should include its cause and potential impacts. The definition should refrain from predicting an absolute number of occurrences but may state a minimum number of occurrences based on known celestial circumstances. We suggest: *King tides occur during spring tides and atmospheric disturbances, such as the passing of a low pressure system or during an El Niño event. The impact of a king tide includes road closures, overwhelmed stormwater systems, damage to transportation infrastructure, and coastal erosion.*

### ACKNOWLEDGMENTS

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