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Influence of ocean tide dynamics on the climate system from the Cretaceous to present day

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Global numerical ocean models used for paleo-climate reconstructions generally only consider the ocean's general circulation, but neglect tidal dynamics. However, it has been demonstrated that tidally induced friction at the ocean bottom alters the mean ocean circulation and energy fluxes on timescales larger than one tidal period and up to climate timescales. Thereby the mean ocean circulation and temperature advection is altered and can thus affect climate.

We simultaneously modeled the ocean's general circulation and tidal dynamics for five time-slices from the Cretaceous to present day: the Albian (ca. 110 million years ago, Ma), the Cenomanian-Turonian Boundary (ca. 93 Ma, CTB), the early Eocene (ca. 55 Ma), the early Pliocene (ca. 3.5 Ma), and a pre-industrial period (ca. 1850 AD). These simulations show that the tectonic evolution of ocean basins changes the resonance conditions in the paleo-oceans over time and thus the position of amphydromic systems and the amplitudes of partial tides. Largest amplitudes of the M2 partial tide are obtained during the early Eocene when they are in the global mean by 150% larger than in the CTB, when amplitudes are smallest. The evolution of the tidal system leads to an individual interaction between tidal dynamics and the ocean general circulation for all time-slices. In the Albian a reduction of horizontal velocities of up to 50% is simulated in the deep Indo-Pacific Throughflow (IPT) below 1000m depth. This reduction is the product of tidal residual mean currents induced by tidal waves propagating from the Pacific Ocean into the Indian Ocean that oppose the prevailing eastward thermohaline currents. In all other time-slices mainly an increase in horizontal transports is simulated. In the CTB both tidal residual mean currents (less than 0.2cm/s in most of the ocean) and the general ocean circulation (less than 0.5cm/s) are small, thus leading to a tidally induced increase by 50% in horizontal velocities in almost half of the ocean below 1000m depth. The increase in horizontal velocities is largest in the early Eocene, where velocities are doubled in more than half of the deep ocean and tripled in more than 10% of the deep ocean. In the Pliocene and the pre-industrial period increases in velocities by up to 400% are simulated in the deep equatorial Pacific. In the South Atlantic sector of the Southern Ocean a tidally induced northward shift of the Antarctic Circumpolar Current decreases horizontal velocities locally by up to 1cm/s (50-75%).

The tidal alteration of velocities also influences temperature advection in the ocean. Thereby the three-dimensional temperature distribution in the ocean is altered and, especially, sea surface temperatures are changed. The influence of ocean tides on atmospheric near-surface temperatures is especially large in the Southern Ocean of the Pliocene and the pre-industrial period. Small increases in sea surface temperatures decrease sea ice concentration. This leads to a positive feedback that results in a reduction of sea ice concentration by up to 30% in the pre-industrial period and the Pliocene. This increases the heat flux from the ocean to the atmosphere and increases atmospheric 2m-temperatures by up to 4°C locally.