Estimates of the dissipative heat generated by oceans on icy satellites in the outer solar system. R. Tyler, Planetary Geodynamics Laboratory, Code 698, NASA Goddard Space Flight Center, Greenbelt, MD 20771, and Department of Astronomy, University of Maryland College Park, Email: robert.h.tyler@nasa.

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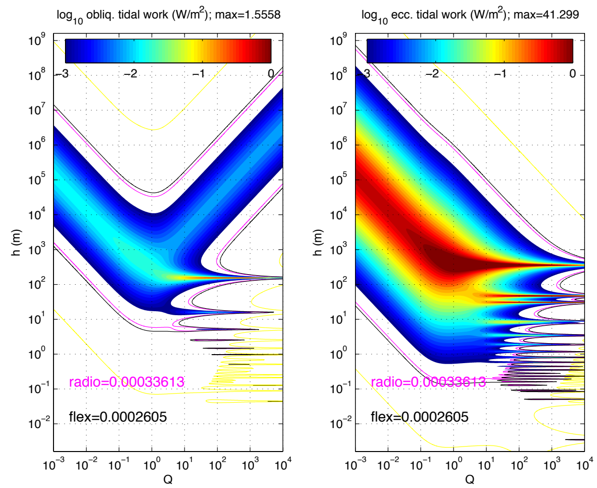
The tidal flow response and associated dissipative heat generated in a satellite ocean depends strongly on the ocean configuration parameters as these parameters control the form and frequencies of the ocean's natural modes of oscillation; if there is a near match between the form and frequency of one of these natural modes and that of one of the available tidal forcing constituents, the ocean can be resonantly excited, producing strong tidal flow and appreciable dissipative heat generation. Of primary interest in this study are the ocean parameters that can be expected to evolve (notably, the ocean depth in an ocean attempting to freeze, and the stratification in an ocean attempting to cool) because this evolution can cause an ocean to be pushed into a resonant configuration where the increased dissipative heat of the resonant response halts further evolution and a liquid ocean can be maintained by ocean tidal heat. In this case the resonant ocean tidal response is not only allowed but may be inevitable.

Previous work on this topic is extended to describe the resonant configurations in both unstratified and stratified oceans on Europa, Ganymede, Callisto, Mimas, Enceladus, Tethys, Dione, Rhea, Titan, Iapetus, Miranda, Ariel, Umbriel, Titania, Oberon, and Triton. under free-surface assumptions (expected to be applicable on thin ice-cover oceans such as Europa) as well as the alternative situation where the ocean is expected to be constrained by a thick ice layer (e.g. Ganymede). It is shown that plausible scenarios are available that provide for each of these satellites having moved into a resonant state involving strong ocean tides and elevated heat generation.

The dissipative heating rates due to tidal flow are compared with other estimates of heat generated through tidal flexing and radiogenic sources. A general feature is that the ocean tides can easily provide more heat than these other sources provided the ocean configuration parameters (depth h and specific dissipation Q) are such to provide a resonant response. In Fig. 1 we provide an example of this for Enceladus. We show the log10 heating (averaged over the globe and through a tidal cycle) as a function of the unknown h and Q. The color scale has been trimmed to ignore heating values less than 1 mW/m^2 and over 1 W/m^2. The resonance peaks seen are a predictable consequence of the natural modes of oscillation of a rotating spherical ocean and involve various waves which have been described since long in the literature of Geophysical Fluid Dynamics.



The tidal dissipative heating on Enceladus (log10 scale with respect to 1 W/m^2) as a function of the unknown depth h and specific dissipation Q. The depth may represent the physical ocean depth (in the barotropic case) or a stratification weighted equivalent depth (in the baroclinic case). The left frame refers to the tides due to obliquity (assuming a 0.1 degree obliquity angle for reference) and the right frame refers to tides due to eccentricity. Heating for a different obliquity value reference is easily obtained noting that the heating values in the left frame vary with the square of the obliquity angle. The right frame is independent of obliquity angle. For comparison, contours showing the heating rate values for radiogenic (pink) and tidal flexing (black) are included [1].

References:

[1] Hussmann H. and Choblet G. and Lainey V. and Matson D. L. and Sotin C. and Gabriel T. and Van Hoolst T. (2010) Space Sci. Rev. 153: 317-348.