Numerically Simulating Tidal Dissipation in the Icy Satellites

Hamish C. F. C. Hay\(^1\) (hhay@pl.arizona.edu), Isamu Matsuyama\(^1\).
Lunar and Planetary Laboratory, Department of Planetary Sciences, University of Arizona

SUMMARY:
- We developed a numerical model to model tidal flow and ocean dissipation in icy satellites, neglecting the presence of an icy lid.
- The model is applied to Titan and Enceladus using both Rayleigh (linear) and bottom (quadratic) drag.
- We find excellent agreement between our results and recent analytical work.
- Obligity tide Rossby wave resonant features become independent of ocean depth under the bottom drag regime for thick oceans.
- For Titan, obliquity tide dissipation may reduce the rate of outward orbital migration.
- Gravity wave resonances can cause inward migration, although this is only possible in shallow oceans.
- Eccentricity tides are unlikely to heat Enceladus as resonances only occur in shallow oceans.

The Model:
- Finite difference code to solve the Laplace Tidal Equations, called ODIS (Ocean Dissipation in Icy Satellites), based on [1].
- Can run with any drag model. We use both Rayleigh and bottom drag. The latter can only be applied numerically.
- Grid is fixed in latitude and longitude.
- Solvable quantities are staggered in space over the grid (see Figure 1).

Our Method:
- We ran over 20,000 simulations covering a variety of ocean thicknesses and drag coefficients for both Titan and Enceladus.
- Applied the eccentricity and obliquity tides separately.
- Calculated energy dissipation for each simulation and tested the results against [2] and [3].

Results:
- We find excellent agreement with the semi-analytical work of [2] for Rayleigh drag, and good agreement away from gravity wave resonances with the scaling laws developed by [3] for bottom drag.
- Gravity resonances occur at the same ocean thicknesses in the bottom drag regime, although the Rossby wave resonance becomes independent of ocean depth. This has implications for obliquity tide heating in thick oceans, as is expected for Titan [4, 5].
- Semimajor axis change calculated for Titan from dissipation in its ocean and from Saturn.

Figure 1. Staggered grid across the model domain. Velocities are located at the cell walls and surface displacement is a cell centered quantity.

Figure 2. Model resolution and convergence tests. The numerical solution converges onto the analytical value as resolution increases (left). Error tests indicate between first and second order convergence (right).

Table: Tidal Equations, called ODIS (Ocean Dissipation in Icy Satellites)

A. Bottom drag: ODIS captures all resonances. The Rossby wave resonance becomes independent of ocean depth.
B. Bottom drag compares well with scaling laws from [3].
C. Semimajor axis migration can be both outward and inward.

D. Bottom drag eccentricity tide gravity wave resonances are still very strong in the bottom drag regime.
E. Bottom drag again compares well with scaling laws from [3].

References:

About the author:
Hamish is a second year graduate student at the Lunar and Planetary Laboratory in Tucson, Arizona. Originally from Scotland, with an MSci degree in Geophysics from Imperial College London, his interests lie in planetary interiors, orbital evolution, and numerical modelling. This work is supported by a NASA Earth and Space Science Fellowship and the NASA Habitable Worlds Program.