

CONVECTIVE TRANSPORT PROPERTIES OF ICY SATELLITE OCEANS AND IMPLICATIONS FOR HABITABILITY K. M. Soderlund¹, B. E. Schmidt², J. Wicht³, D. D. Blankenship¹. ¹University of Texas at Austin, John A. and Katherine G. Jackson School of Geosciences, Institute for Geophysics (UTIG), J.J. Pickle Research Campus, Bldg. 196; 10100 Burnet Road (R2200), Austin TX 78758-4445, USA. (krista@ig.utexas.edu). ²School of Earth and Atmospheric Sciences, Georgia Institute of Technology, 311 Ferst Drive, Atlanta, GA 30332-0340, USA. ³Max Planck Institute for Solar System Research, 37191 Katlenburg-Lindau, Germany.

Introduction: Icy satellites in the outer solar system can have liquid water oceans (or seas) beneath their surfaces [1,2], making them potentially habitable. These oceans are thermodynamically possible because of the tidal heating that results from the satellites' proximity to their host planet. In combination with radiogenic heating and secular cooling, tidal heating in the mantle amounts to a sizeable fraction of the net heat flux emanated from these satellites that is transferred convectively through the ocean [3,4,5]. We use rotating convection theory, combined with numerical models of global thermal convection, to investigate oceanographic processes in ice-covered moons, such as Europa and potentially Enceladus.

Convective Transport Properties: Convection is able to efficiently redistribute heat and chemicals through fluid motions. Experiments have shown that convection characteristics depend critically on the relative importance of rotation [6,7]. In rotationally-constrained spherical systems (Figure 1, top row), convection manifests as columnar vortices aligned with the rotation axis with multiple east-west currents that alternate in direction, similar to the zonal winds of Jupiter [8]. These columns act to pump heat in the axial direction, which causes heat transfer to peak near the poles [9]. In sharp contrast, convection in weakly-constrained systems is no longer organized by the Coriolis force, leading to chaotic fluid motions (Figure 1, bottom row). Here, three east-west currents develop, similar to the zonal winds of Neptune [10]. Low latitude turbulence and Hadley-like cells enhance heat transfer near the equator [11]. We use convective regime scaling laws with internal structure and chemistry models to predict the influence of rotation on icy satellite oceans and infer the subsequent dynamics [5].

Implications for habitability: From these convective transport properties, we infer the ocean current velocities and material transport timescales. Currents and turbulence will determine the rate and locations of mixing between the mantle and ice shell, which is important for the distribution of potential bionutrients and salinity variations with depth and latitude.

In addition, heat transfer from the ocean will influence where the ice shell melts and freezes. Melting of the ice shell and freezing of the ocean will impact the salt budget, especially near the ice-ocean interface, a

habitable environment in analogous terrestrial ice shelves. Moreover, accreted ice depleted in salts, and therefore buoyant, may lead to upwelling thermocompositional diapirs in the ice shell associated with poorly understood downwelling systems that would tightly link the surface and subsurface dynamics [5,12].

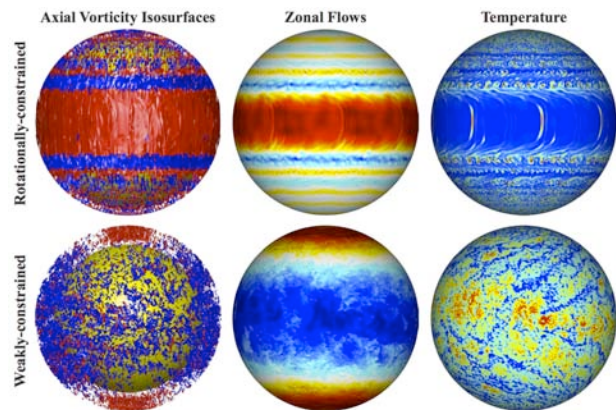


Figure 1: Instantaneous convective flow structures, east-west currents, and temperature fields in convection simulations. *Top:* rotationally-constrained model from [9]; *bottom:* weakly-constrained model from [12]. *Left:* Isosurfaces of axial vorticity, $\zeta = (\nabla \times \mathbf{u}) \cdot \mathbf{z}$, in the bulk fluid. Red (blue) indicates cyclonic (anticyclonic) vorticity; the inner yellow sphere represents the mantle. *Middle:* Zonal flows along the outer boundary, where red (blue) indicates eastward (westward) flow. *Right:* Superadiabatic temperature, where red (blue) indicates warm (cool) fluid. Adapted from [5].

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