DYNAMICS OF EUROPA'S OCEAN AND SENSITIVITY TO WATER PROPERTIES. K. M. Soderlund[1], B. E. Schmidt[1], D. D. Blankenship[1], and J. Wicht, [1]University of Texas 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), [2]Max Planck Institute for Solar System Research, 37191 Katlenburg-Lindau, Germany.

Introduction: Jupiter's satellite Europa possesses a global liquid water ocean overlain by an ice shell that mediates heat flux from the deeper interior [1-2]. Geologic features observed on the surface may provide constraints on this coupling between the ocean and ice shell. In particular, regions of disrupted ice known as chaos terrain are thought to be linked to sub-surface processes [3-4]. These features occur over a wide range of spatial scales, cover one quarter to one half of the satellite's surface, and are concentrated at low latitudes within 40^o degrees of the equator (Figure 1). The origin of these features is strongly debated given the uncertainty in ice shell thickness [6-12]. Nearly all formation hypotheses, however, suggest that heat transfer is critical. Thus, the distribution of chaos terrain may be a surficial indicator of Europa's internal dynamics and heat budget.

We hypothesize that oceanic heat transfer plays a critical role in chaos formation. Vigorous thermal convection is likely driven in the ocean by temperature differences between the hot silicate mantle and the cold ice shell [8]. The resulting currents will reorganize the flow of heat from the mantle on both global and local spatial scales [13-15], potentially leading to spatial variations in heat exchange between the ocean and ice shell. Thus, the pattern of heat flow along the ice-ocean interface in global thermal convection models may be used to assess the potential for ocean-driven processes in the ice shell.

Ocean Convection Model: We simulate Europa-like ocean dynamics through numerical models of thermal convection in a thin rotating spherical shell with control parameters chosen to represent our understanding of Europa's interior. Boundary conditions are isothermal and stress-free.

Simulated ocean currents are highlighted in Figure 2. Convection is characterized by poorly organized, three-dimensional flows (panel **a**). Turbulence mixes the system's absolute angular momentum, resulting in westward zonal flows with significant radial transport at low latitudes and in eastward zonal flows with little radial transport at high latitudes (panels **b** and **c**).

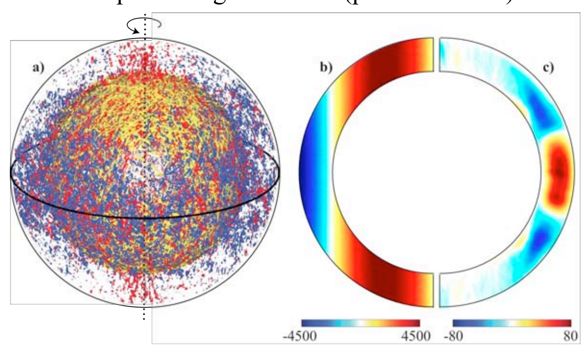

Figure 2: a) Instantaneous isosurfaces of axial vorticity. Time-averaged, axisymmetric **b)** zonal flows and **c)** radial velocity field. Dimensionless velocities measured in Reynolds number units, $Re=UD/\nu$.

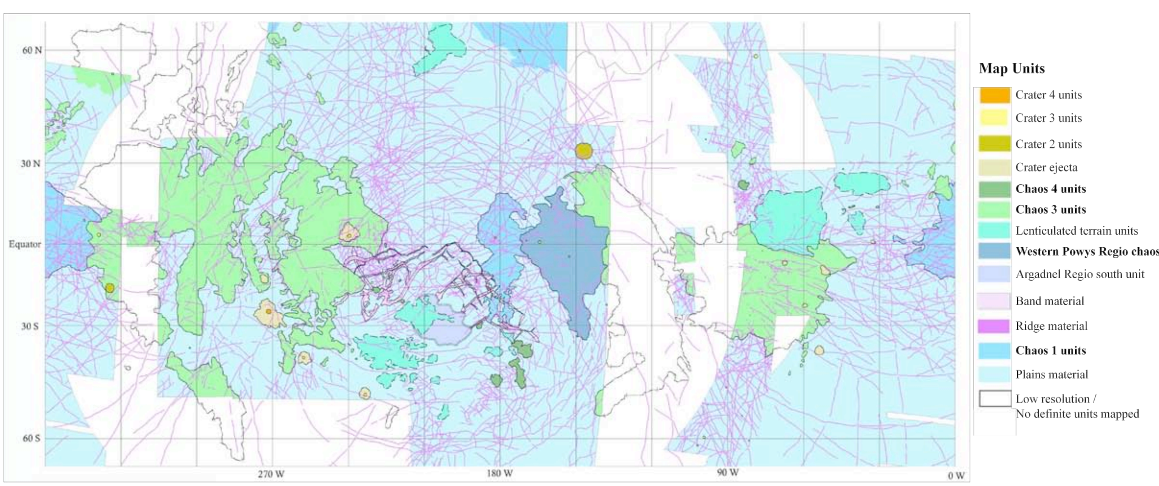

Figure 1: Geologic map of Europa from Galileo Solid State Imager data and Voyager 1 and 2 cameras showing the low latitude prevalence of chaos terrains; adapted from [3].

Simulated heat flow patterns are shown in Figure 3, with panel **a** showing a snapshot in time of the temperature field and panel **b** showing the temporal average over 225 rotations. Thermal plumes are incoherent and short-lived, yet tend to occur in patches that are concentrated at low latitudes with fewer local plumes at high latitudes. This leads to peak heat flow at the outer ocean boundary near the equator and minimal heat flow near the poles.

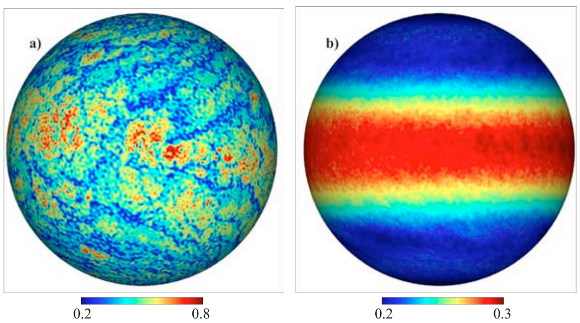

Figure 3: a) Instantaneous and **b)** time-averaged temperature at radial level r=0.992r_o, where r_o is the outer ocean boundary. Dimensionless temperatures measured relative to the temperature contrast between the inner and outer ocean boundaries.

Implications for Ice-Ocean Coupling: The enhanced delivery of thermal flux from the ocean to the ice shell at low latitudes promotes the likelihood of ocean-driven geologic activity in this region, consistent with the provenance of chaos terrain. One possible avenue for this activity is intensified regional melting near the equator and consequent reduction of ice shell thickness. If the gradient in ice shell thickness between regions is sufficiently large, a thermohaline process known as an ice pump [16] will generate "marine" ice, which is sea water slowly frozen at the base of thick ice with significant rejection (99.9%) of constituent impurities [17]. High pressures depress the melting point of water so that melting occurs over the thickest portions of the ice shell, resulting in generation of colder, freshened seawater. This buoyant water refreezes as it reaches regions of thinner ice with lower pressures, reducing ice shell thickness variations. This process is common in Antarctic ice shelves where ice pumps have produced more than a 50% contribution of marine ice to the total ice thickness of certain shelves [18]. On Europa, any substantial thickness of relatively pure marine ice may be an impetus for ice-ocean exchange through compositional diapirism [11].

Our simulation results, in combination with these terrestrial analog systems, suggest that ice-ocean coupling is fundamentally important for the full spectrum of Europa chaos formation hypotheses through enhanced equatorial oceanic heat transfer and low-latitude thinning of the ice shell if it is relatively thin [6-8] or through compositional diapirism if the ice shell is sufficiently thick [9-12].

Sensitivity to Water Properties: We will systematically test sensitivity of the dynamics' described above to the ratio of viscous to thermal diffusivities, defined as the Prandtl number, *Pr*. Currently, the model assumes that these values are equal with *Pr*=1 based on (turbulent) eddy diffusivity estimates. In contrast, *Pr*~10 is estimated assuming molecular diffusivity values of terrestrial sea water. Thus, we will present otherwise identical simulations at *Pr*=7 (for pure water) and *Pr*=14 (for saline water) to cover the range of possible Prandtl number values. Since the salinity of Europa's ocean modifies *Pr* and can only be inferred with substantial uncertainty [19], it is important to determine whether our results are robust across the range of possible values.

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