DOUBLE-DIFFUSIVE CONVECTION AND OTHER MODES OF SALINITY-MODULATED HEAT AND MATERIAL TRANSPORT IN EUROPA'S OCEAN. S. Vance[1], J. M. Brown[2], [1,2]University of Washington, Department of Earth and Space Sciences, NASA Astrobiology Institute, Box 351310, Seattle, WA 98195. [1]svance@ess.washington.edu

Overview: Accounting for thermodynamic properties of aqueous solutions relevant to Europa's ocean, we assess the affect of salinity on dynamics and heat transport from floor to ceiling in the ocean. This work builds on previous efforts [1], [2], that focused on constraining plume buoyancy, rise height, speed, and size in a homogeneously salty model ocean. We focus on buoyancy (here defined as $(\rho_{ocean}-\rho_{plume})/\rho_{ocean}$)) of a plume with excess salinity in an ocean of model-specified salinity. In order to characterize equations of state of both plume and ocean as a function of depth, we also calculate a probable temperature profile.

Method: From well-defined equations of state for the properties of water, and using heat capacities and volume contributions for relevant ions, we calculate an adiabatic temperature profile in a Europan ocean of specified ocean depth and temperature at the water-ice interface. We find that allowing an excess of salinity in an incipient plume dramatically affects its buoyancy. Using a saturated ocean composition that is supported by mass balance arguments, we obtain a probable bottom composition in a 100 km ocean of Mg^{2+}, Na^{+}, Ca^{2+}, SO_4^{2-}, and Cl^{-} from a new version of FREZCHEM that considers pressure effects on equilibrium chemistry [4].

Results: The temperature profile in Europa's ocean is surprisingly isothermal due to the small thermal expansion of water in this range of temperature and pressure (T = 263-273 K, P = 0.1-150 MPa). A 100 km ocean with bottom temperature of 272 K cools by only 0.2 K from seafloor to ceiling. Tracking buoyancy in this environment, in the saturated model we find a thermal anomaly of 0.1 K could infuse sufficient salt to keep the otherwise buoyant plume from rising. In a more dilute ocean, a very small excess in salinity causes the initially buoyant plume to become neutrally buoyant at a height dependent on ocean composition and temperature, and the respective excess of each of these in the plume. The dilute case is displayed in Fig. 1, along with the pure water ocean plume and a plume with no excess salinity.

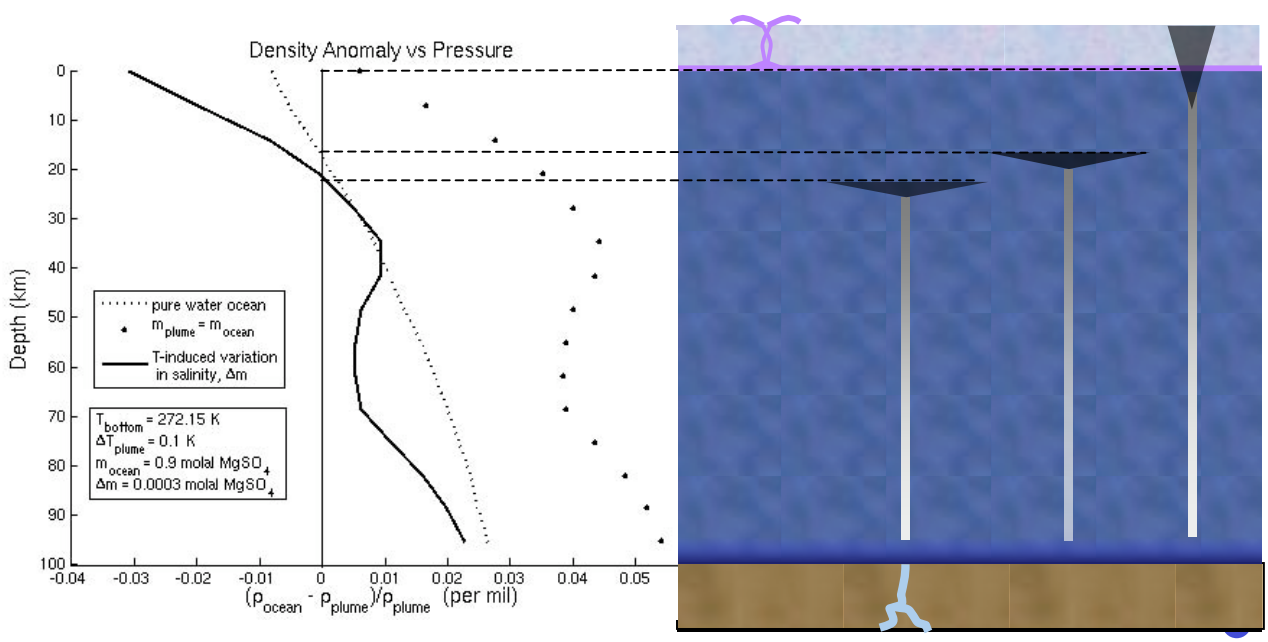

Figure 1. Buoyancy in Europa's ocean as a function of depth, in an ocean with bottom temperature 272.15 K. In a nearly isothermal ocean, the thermal expansion of water changes sign at significant depth and low temperature, creating a stagnant layer (dashed curve). The volume of mixing with salt added to both plume and ocean causes buoyancy everywhere (dotted curve on right). The solid curve (left) shows the effect of adding salt to the plume. The change in volume of mixing for $MgSO_4$ with pressure and temperature is evident in the odd shape of the buoyancy profile.

Discussion: For the dilute ocean plumes in Fig 1, one sees the effect of salinity in the ocean. The curve for pure water ocean illustrates the effect of the anomalous thermal expansion behavior of water, as pointed out by Melosh et al [4]. The thermal expansion of water changes sign at a low temperature, such that a warm upwelling becomes denser than the surrounding ocean. The volume of mixing with salt added to both plume and ocean causes buoyancy everywhere. The shape of the curve at mid-ocean depths is determined by the pressure and temperature dependence of the volumes of mixing. Adding salt to the plume shifts the buoyancy profile in the direction of neutral buoyancy, creating the potential for a stagnant layer and possible layered convection in the ocean. On the basis of a fluid-dynamical analysis, we assess plume properties including shape, riseheight, and rise speed and discuss possible connections with surface features on Europa. For example, lithospheric resurfacing may be controlled by heat storage in a lower convecting layer and dissipation at a lower temperature into an upper convecting layer, with eventual release of heat and subsequent melting of the lithosphere.

References: [1] Thomson, R. E. and Delaney, J. R. (2001) *J. Geophys. Res*., 106, 12355–12365. [2] Goodman et al. (2004) *J. Geophys. Res*., 109, E03008, doi:10.1029/2003JE002073 [3] Marion, G. M. et al. (2005) *Geochim. Cosmochim. Acta* (in press). [4] Melosh et al. (2004) *Icarus* 168, 498-502.