ASSESSING THE DETECTABILITY OF EUROPA'S SEAFLOOR TOPOGRAPHY FROM EUROPA CLIPPER GRAVITY DATA. Z.W. Koh[1], F. Nimmo[2], J.I. Lunine[1], E. Mazarico[3], and A.J.Dombard[4] [1] Dept.Astronomy, Cornell Univ., Ithaca NY, zk74@cornell.edu, [2] Dept.Earth and Planetary Sciences, Univ. of California, Santa Cruz CA., [3] Goddard Spaceflight Center, Greenbelt MD, [4] Earth and Environmental Sciences, Univ. of Illinois at Chicago, Chicago IL.

Introduction: Jupiter's moon Europa presents a unique opportunity to study the geologic forces shaping not only its ice crust and massive liquid water ocean beneath, but the lunar-sized rocky mantle as well. With a global hydrothermal heat flux possibly within a factor of two that of the Earth [1], Europa presents a unique opportunity to study how size affects the tectonic style of planetary bodies with large amounts of water. However, the surface of the rocky mantle is the seafloor of Europa, and the ocean above is overlain by an ice crust with its own geology. Hence, the principal method by which Europa's seafloor topography can be gleaned is gravity data, to be provided by NASA's Europa Clipper mission under development for launch in the middle of the decade.

We follow in the footsteps of previous work that established the importance of gravity data for determining Europan seafloor topography [2,3]. Here we extend that work in several ways, including testing the gravity signature of a wider range of possible topographies and lithospheric thicknesses and spacecraft close-approach distances. We also consider the possibility of a Europan seafloor modelled after other geologically active terrestrial bodies in our Solar System, namely Earth, Venus and Io. Through this we explore the ability to distinguish between plate-tectonic style versus (for example) shield-volcanic dominated topographies.

Model Approach: Our model assumes four contributing sources to the total gravity observed by Europa Clipper, (i) the degree-2 shape of Europa caused by tidal and rotational effects, (ii) short-wavelength topography at the surface and at the ice-ocean interface, (iii) long-wavelength variations in the ice shell thickness, and (iv) the seafloor topography. We particularly focus on (iv) the seafloor topography, and mapping out how it affects the total gravity signal depending on the different parameters varied. The other three sources are held constant, and are based on best estimates from Galileo limb profiles [4].

To explore possible seafloor topographies we generate a random set of spherical harmonic coefficients C_{lm}, S_{lm} [5] and constrain them to obey a power law (Kaula's law [3]), varying the amplitude and slope of the power spectrum. The resulting gravity anomaly is found from:

$$C^g_{lm} = \frac{l+1}{2l+1} 4\pi G\rho \left(1 - \frac{z}{R}\right)^{l+2} C^h_{lm} \qquad (1)$$

and equivalently for the other coefficient S_{lm}, where superscripts g and h refer to the gravity and topography coefficients respectively, ρ is the density contrast at the interface, and z and R are the radial distances from the interface or center of Europa respectively to where the gravity is calculated. In addition we vary the (i) radius of the seafloor or mantle, (ii) spacecraft altitude, and (iii) compensation state of the seafloor. Varying (i) and (ii) are relatively simple when computing equation (1). To account for (iii) the effect of compensation, we follow the approach of previous work [3,5], multiplying each topographic coefficient by a factor F_l where:

$$F_l = \frac{1}{1 + \frac{\rho_c - \rho_w}{\rho_m - \rho_c} C_l} \qquad (2)$$

In this equation ρ_c is the density of the crust, ρ_w is the density of the ocean, ρ_m is the density of the mantle, and C_l is defined as in [6, eqn. 27], a quantity characterising the degree of compensation. At short wavelengths, loads are flexurally supported and hence uncompensated. At long wavelengths, loads cause the lithosphere to deflect, reducing topographic amplitude (Airy compensation).

Admittance and Coherence: To characterise the relationship between surface gravity and surface (ice shell) topography, we also evaluate the admittance and coherence of our model. We expect that at long wavelengths where the seafloor topography dominates the total gravity, surface gravity and topography are largely unrelated, whereas they agree at small wavelengths where the seafloor signal has attenuated. If we express the load on the elastic crust as a Fourier series of loads at different wavelengths [7], then the admittance is the ratio between the gravity anomaly caused by a load on the elastic crust, and the magnitude of the topography. We can define admittance as Z(k) [8]:

$$Z(k) = \frac{< \bar{g}\bar{h}^* >}{< \bar{h}\bar{h}^* >} \qquad (3)$$

where k is the wavenumber, $\bar{g}$ and $\bar{h}$ are the Fourier transforms of the surface gravity and topography, the asterisks denote complex conjugates, and the angle brackets denote the average value over a wavenumber band centred at k. We should find due to the linear correlation of surface topography and gravity that the admittance converges at small wavelengths to $Z = 2\pi\rho_u G$ where G is the gravitational constant and ρ_u is the density of the surface load, which agrees with our results.

We compute the coherence γ^2 between gravity and topography of our model [8]:

$$\gamma^2 = \frac{<\bar{g}\bar{h}^*>^2}{<\bar{g}\bar{g}^*><\bar{h}\bar{h}^*>} \quad (4)$$

and find similarly that the surface gravity and topography are coherent at small wavelengths, such that γ^2 converges to 1.

Scaling of topographies of Earth, Venus and Io: We focus on geologically active bodies like Earth, Venus and Io, since geologically inactive analogues such as the Moon were previously examined [2]. We chose Earth as a candidate due to its unique plate tectonics. We also chose Venus and Io as bodies whose surface geology is rejuvenated by extensive volcanism.

We obtained surface topography data for Venus from the Magellan probe's altimetry analysis [9], as well as surface gravity data for Earth from the GRACE mission [10]. There does not currently exist a global topographic or gravity map for Io, hence we used topographic power estimates derived from limb profile analysis [11] to constrain randomised spherical harmonic coefficients and generate Io's short wavelength topography. Note that derivation of long-wavelength topography in [12] assumes the surface topography of Io to be compensated at a fairly shallow depth, which would imply that the effective gravity signal at this degree is small enough to be negligible.

Finding the standard Kaula scaling to produce unphysically large gravity anomalies for Venus, we considered instead a simple treatment of dynamic topography supported by convection. Surface topography resulting from convective plumes can be written as:

$$h = \alpha \Delta T \delta \quad (5)$$

where α is the thermal expansivity, ΔT is the temperature contrast with background material, and δ is the thickness of the hot region. Since the maximum thickness is the mantle thickness d, the maximum dynamic topography is $\alpha \Delta T d$. The resulting gravity anomaly Δg will be due to the surface topography (mass excess) and subsurface buoyant region (mass deficit). Assuming the characteristic wavenumber of convection scales inversely with mantle thickness, and subtracting the surface contribution, the gravity anomaly Δg scales as:

$$\Delta g \approx 2\pi G \rho \alpha \Delta T d e^{-1} \quad (6)$$

ρ is the density and *e* Euler's number. Thus Δg resulting from dynamic topography should scale with the thickness of the mantle d, hence roughly with the radius of the planet. We implement this by first rescaling the surface topography by the size of the body to the size of Europa's mantle. We then compute the resulting gravity of

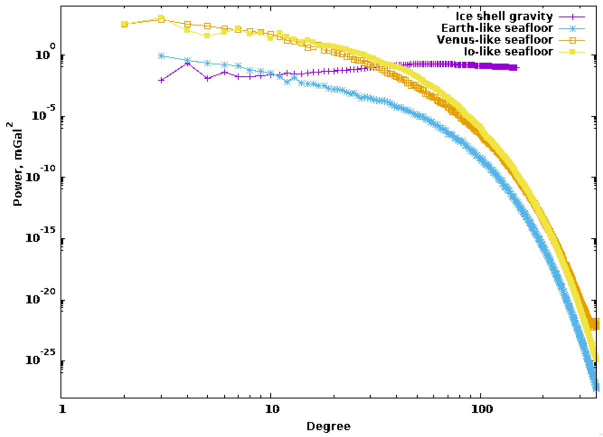

Figure 1: A power spectrum comparison of the ice shell gravity against the seafloor gravity modelled after Earth, Venus and Io.

that topography if it were at Europa's ocean-mantle interface, i.e. using equation (1) but substituting for Europa's seafloor's parameters. This results in a gravity anomaly that scales with d, ρ and the attenuation term in equation (1).

Results: Figure 1 shows power vs degree of the surface gravity for an Io, Earth, and Venus-like seafloor,the latter two scaled to the size of Europa's rocky mantle. An Earth-like seafloor with plate tectonics would not be visible at short wavelengths after degree $\sim$ 10, whereas a Venus- or Io-like seafloor would dominate the gravity spectrum up to degree $\sim$ 35. This implies a spatial resolution of $\sim$ 900km for a scaled-Earth-like seafloor, and $\sim$ 250km for an Io-like or scaled-Venus-like seafloor. Given that the width of a mid-ocean ridge is typically of order 10km, it is unlikely we would be able to distinguish the presence of Earth-like plate tectonics by gravity signal if they were to exist in Europa's mantle. However we might well be able to detect the signature of volcanically-dominated geology, whether Venusian or Ionian in style.

Acknowledgments: This work was supported by NASA through the Europa Clipper Project.

References: [1] Lowell R.P. and DuBose M. (2005) *GRL, 32,* L05202. [2] Dombard A.J. and Sessa A.M. (2019) *Icarus, 325,* 31-38. [3] Pauer M. et al. (2010) *JGR Planets, 115,* E12005. [4] Nimmo F. et al. (2007) *Icarus, 191,* 183-192. [5] Nimmo F. et al. (2011) *JGR, 116,* E11001. [6] Turcotte D.L. et al. (1981) *JGR, 86(B5),* 3951–3959. [7] Barnett D.N. et al. (2006) *Icarus, 146,* 404–419. [8] McKenzie D. and Fairhead D. (1997) *JGR, 102,* 27,523–27,552. [9] Rappaport N.J. and Sjogren W.L. (2006) *NASA PDS.* [10] Data access http://www2.csr.utexas.edu/grace/RL06.html [11] White O.L. et al. (2014) *JGR Planets, 119,* 1276–1301. [12] Ross M.N. et al. (1990) *Icarus, 85,* 309–325.