NEW APPROACH TO MEASURE EUROPA'S HYDROSPHERE THICKNESS WITH EUROPA CLIPPER.

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Introduction:

Until now the interior structure of Europa has only been derived from a moment of inertia (MOI) value inferred from the degree-2 gravity field coefficients assuming hydrostatic equilibrium [e.g., 1, 2]. Europa Clipper will be sensitive to higher degrees of its gravity field. In this work we assess whether the measurement of the gravity field at moderate resolution (degrees 2<l<20) can also be leveraged to constrain Europa's interior structure properties, with a particular focus on constraining the hydrosphere thickness (ocean and ice shell). A very simple, but representative, schematization of Europa considers the body as composed by two layers: the silicate 'core' and the hydrosphere. At long wavelengths (low degrees) the gravity signal is dominated by the seafloor topography and the associated silicate-water density contrast (e.g., [3]). The intrinsic seafloor topography-induced gravity field amplitude spectrum (C_l) can be represented with good approximation (e.g., [4]) by a power law of the type:

$$C_l = \frac{k}{l^m} \quad (1)$$

where l is the degree and k, m are coefficients describing the amplitude and slope of the spectrum. Under the assumption of negligible contribution of the ice shell to the long-wavelength gravity field (anticipated to be a very good approximation e.g., [5,6]) the amplitude spectrum can be upward continued to the radius of Europa R, assuming a radially homogeneous hydrosphere of thickness h:

$$C_l = \frac{k}{l^m} \left(\frac{R-h}{R}\right)^l \quad (2)$$

In this work we assess the capability of Europa Clipper of measuring the spectrum, from which the hydrosphere height can be determined. The method proposed here seeks to extract meaningful information from the gravity field while avoiding the direct use of every single coefficient of the spherical harmonics expansion, using instead the compact form of the amplitude spectrum. Beyond the hydrosphere thickness h, we argue that measuring k and m can constrain other fundamental interior structure properties.

Retrieval method:

We propose a two-step estimation scheme which allows an unbiased estimate of the gravity field spectrum with the use of minimal a priori information. The first step consists in a classic least squares orbit determination (OD) fit of the Europa Clipper flybys, alongside with the relevant physical parameters of the spacecraft dynamical model: gravity field of Europa, k_2 Love number, spin rate and spin axis direction. In this case we use no a priori information on the gravity field of the Europa in the orbit determination filter, allowing for a completely unbiased estimate. From the estimated spherical harmonics coefficients of the gravity field, we compute the amplitude spectrum and the associated covariance, and use this information in a Monte Carlo Markov Chain (MCMC) fit of Equation 2. The output of the MCMC fit is a first estimate of h, k, m with associated uncertainties. These can be used to construct a new gravity field spectrum, which is used as a priori information in a second step consisting of another OD inversion and MCMC fit. This second OD+MCMC fit, benefitting from data-based a priori information, leads to tighter uncertainty bounds on the estimated values of h, k, m.

Results:

Figures 1 and 2 report an example of the output of the step 1 and 2 MCMC inversions, respectively. The output of the first step shows an unbiased estimate of the true values used in the simulation with, however, large uncertainty bounds. The output of the second step shows a substantial reduction in the uncertainty, with the central value of the MCMC output within 1.5 sigma to the true simulated value. The formal uncertainty of the hydrosphere height (h) is on the order of 5km testifying to the sensitivity, and thus relevance, of the gravity field spectrum for its retrieval. The other parameters (k, m) can be associated with fundamental properties of Europa's interior: k is related to the amplitude of the silicate seafloor gravity anomalies. This quantity has been shown to be potentially a reflection of heat flow from the silicate interior, thus possibly helping to constrain the thermal state of the silicate interior [3]. m is the logarithmic slope of the seafloor gravity spectrum (thus related to the topography spectrum). Its measurement can be used as a proxy to probe and distinguish different topography compensation mechanisms. The formal uncertainties of k and m, output of the second MCMC, are 5×10^{-7} and 0.014, respectively. The numerical results reported here have been obtained for a notional average scenario ($h = 120$, $m = 2$, $k = 10^{-4}$). However, the problem is generally highly non-linear; a change in the parameters results in a change in the gravity signal amplitude, thus in the probe sensitivity. In this work we also explore the dependence of the results on the actual values of the parameters, in order to determine the detectability limits based on the true underlying interior structure of Europa.

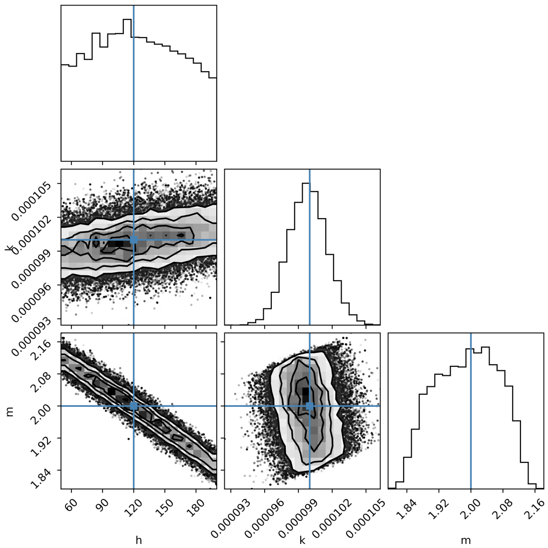

Figure 1- Output of the step 1 MCMC. The blue lines show the true simulated values of the estimated parameters.

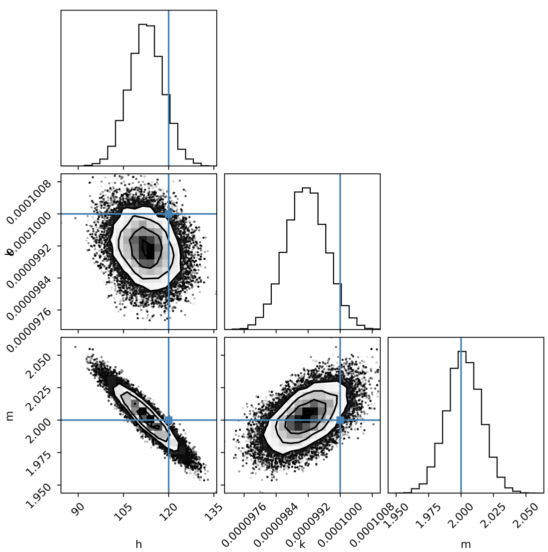

Figure 2 - Output of the step 2 MCMC. The blue lines show the true simulated values of the estimated parameters

Conclusion:

In this work we propose a novel approach for estimating the hydrosphere thickness of Europa with the Europa Clipper Gravity/Radio Science investigation. We have shown that such an approach can lead to an estimate of h which is independent to other approaches (e.g., using degree 2 gravity field and MOI) and thus provide independent validation; alternatively, it may be used in combination with other methods to improve interior structure knowledge.

While the interpretation of the estimate of h is unique, k, m are related to the mechanisms that encompass various fundamental parameters about Europa's interior. A more detailed model of Europa's interior can be used in the same inversion scheme to directly access the single parameters (layer densities, maximum topography height, elastic thickness, etc.) that make up the k and m proxies. In our presentation we will show and discuss the ongoing work aiming to translate the h, k, m representation to a more detailed modeling.

References:

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