MERCURY'S CRUST AND LITHOSPHERIC PROPERTIES FROM HIGH-RESOLUTION GRAVITY FIELD MODELS. S. Goossens[1], A. Genova[2], P. B. James[3], E. Mazarico[1], [1]NASA Goddard Space Flight Center, 8800 Greenbelt Road, Greenbelt, MD 20771 (email: sander.j.goossens@nasa.gov), [2]Sapienza, University of Rome, Via Eudossiana 18, 00184, Rome, Italy, [3]Baylor University, One Bear Place #97354, Waco, TX 76798.

Introduction: The MErcury Surface, Space ENvironment GEochemistry, and, Ranging (MESSENGER) mission [1] was the first spacecraft to orbit Mercury and make global measurements. Of particular interest to the work presented here are the measurements of Mercury's gravity field [2] and topography [3]. Because of its highly elliptical orbit around Mercury, the best resolution data were obtained in the northern hemisphere. The mission consisted of several phases with different altitudes and locations of the periapsis. During the final extended mission phase, the spacecraft orbited the planet at altitudes as low as 15 to 25 km above the surface. This especially increased the sensitivity to smaller scale gravitational features in areas of low altitude tracking data coverage.

Models of a planet's gravity field are generally expressed in spherical harmonics, which are functions with global support. When data coverage varies geographically, smoothing needs to be applied to prevent unrealistic variations in the gravity field model. This can result in the suppression of small-scale features even in parts where data coverage is sufficient.

Here, we present an analysis of the tracking data that uses line-of-sight accelerations derived from the Doppler data. Such accelerations are shown to be more sensitive to small-scale features. We determine models of Mercury's gravity field expressed in spherical harmonics up to degree and order 180 using these accelerations. These models result in improved correlations between gravity and topography, which indicates improved gravity field models because at higher degrees gravity is expected to correlate well with topography [4]. We then use these models in a study of the transfer function between gravity and topography, admittance, to determine properties of the crust and lithosphere such as density and thickness.

Data and Methods: We use all of the available tracking data for MESSENGER. Our analysis of these data is based on the processing for the HgM008 model [5]. We follow the same procedures: we determine MESSENGER's orbit around Mercury using the Deep Space Network (DSN) Doppler data, and generate partial derivative equation systems that describe the sensitivity of the data with respect to estimated parameters. These estimated parameters include the spacecraft state and gravity parameters. We express the gravity field in spherical harmonics, because these are used widely in geophysical analysis. Instead of using these partial derivatives for the Doppler data, we transform them into partial derivatives for line-of-sight acceleration data. We divide the tracking data into passes sorted by DSN station combinations, obtaining time series per pass for each unique combination. We then perform a spline fit on the residuals and partials, numerically differentiate both, and thus obtain an equation system that now expresses the sensitivity of acceleration data with respect to the same estimated parameters. This equation system can then be solved in standard ways. Because we use global spherical harmonics, we still require smoothing, in the form of Kaula constraints [6].

Gravity results: We determined models based on both the standard analysis of Doppler data, and based on the line-of-sight (LOS) data. We evaluate our models in terms of correlations between gravity and topography. We use topography determined with the Mercury Laser Altimeter (MLA) instrument [7,8]. We find that the LOS models often show improved correlations with topography in areas where the spacecraft altitude was low and where tracking data were collected. We show an example in Figure 1, where we applied localized analysis [9] to compute the correlations.

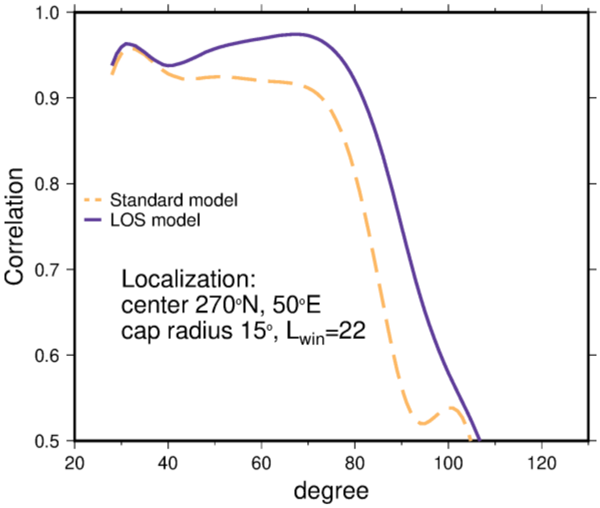

Figure 1: Localized correlations between gravity and topography. The line-of-sight (LOS) model has improved correlations with topography.

Admittance analysis: An analysis of the admittance between gravity and topography can yield insights into the structure of the crust and lithosphere. We apply an admittance model that has been used previously for volcanic complexes on Mars [10,11]. We apply it to Mercury because this model has several features that also apply to Mercury. There is bottom and top loading, which are in phase. This means that in the theoretical model correlations between gravity and topography are assumed to be one. Our models based on the LOS data are especially suitable for such an analysis due to the improved correlations.

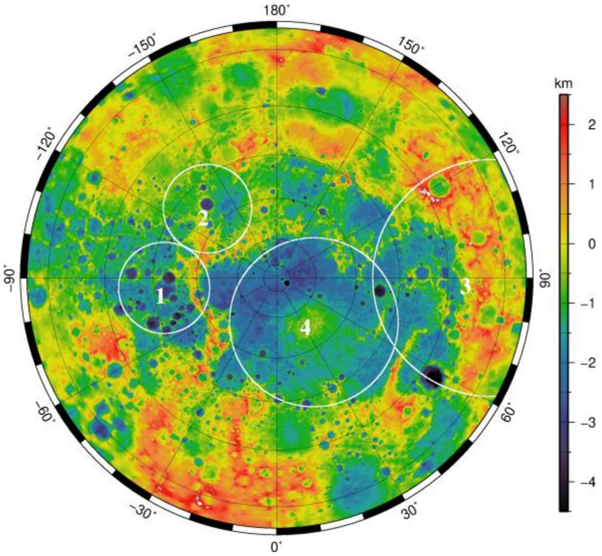

Figure 2: The selected areas where correlations between gravity and topography are deemed high enough for an admittance analysis. Circles indicate the cap radius applied in the localized analysis. Topography from MLA data.

We selected 4 areas on Mercury with high correlations for such an analysis (Figure 2). The locations represent different kinds of areas: the high-Mg region, the Strindberg crater with lobate scarps, heavily cratered terrain, and the northern rise in the northern smooth plains unit. For each area we compute the theoretical admittance by varying the crustal and load density, the crustal and elastic thickness, the load depth, and the load parameter that indicates the ratio between top and bottom loading. From a grid search we determine the best fit model, where we compute the fit as the root-mean-squares of the deviation in admittance between the measured and theoretical spectrum for a range of spherical harmonic degrees. We determine this range from the correlations, and use only the degrees where correlations are larger than 0.8. Once we have determined a best fit model, we apply a Markov Chain Monte Carlo (MCMC) method to map the distributions of the parameters that fit the admittance within the given error bars. We determine the errors on admittance from the deviations of the correlations from unity [10].

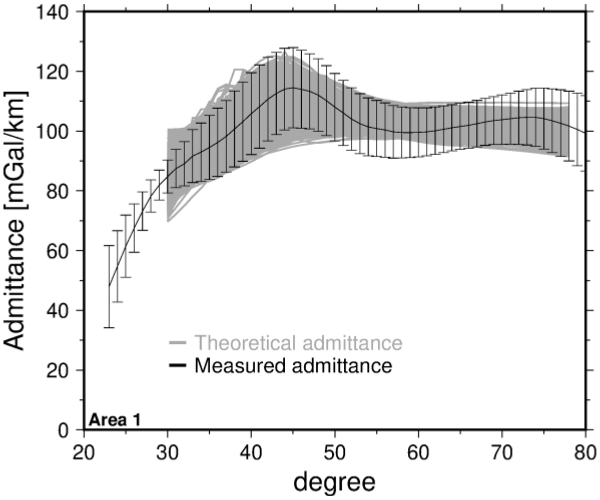

Figure 3: Measured and fitted admittance (approximately 4000 models) for area 1.

In Figure 3 we show the measured and fitted spectra (including the associated errors) for area 1. This indicates that our MCMC method indeed maps out the models for which the admittance is within the errors. From this sets of models, we can determine the distribution for the parameters for each area.

From these results, we find that densities and elastic thickness are the parameters that are best determined overall. We find generally low densities for the first three areas, around 2600 kg m^{-3}, and a higher density for the northern rise. Elastic thickness is generally low and varies between 11 and 30 km. We also compare our results to a recent analysis [12] and find that our densities are mostly compatible with the 12 % porosity values from that study.

Acknowledgments: Tracking data for MESSENGER can be found at the geosciences node of the PDS. Topography data are also available at the PDS. We acknowledge support from NASA grant 80NSSC17K0218.

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