Slope and roughness characteristics derived from high-resolution images of Galilean satellites

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Topographic data is fundamental information to investigate geology at various scales. The Galileo spacecraft has obtained high-resolution images of the Galilean satellites at a scale up to approximately ten meters per pixel, which provide an insight into diverse geologies and surface materials associated with tectonics, cratering, and sublimation. Putative subsurface oceans on Europa, Ganymede, and Callisto indicated by inductive magnetic fields and aurorae shifting are top priority for the next planetary exploration. Measuring topography at a scale of ten-meter also could be essential for designing radar sounder, laser altimeter, and lander. These instruments are expected to detect putative subsurface oceans on Jovian icy satellites. Nevertheless, no quantitative topographic data at the scale has yet been obtained, except for the surface of Europa. This is mainly consequence of previous digital elevation models (DEMs) with spatial resolutions higher than 50 m being only available for the southeast region of the Tyre crater of Europa (33 m/pixel). Current knowledge of topographic features of the Galilean satellites is only derived from stereo image (SI) analysis or photoclinometry (PC) because of the absence of laser altimetry data. The slopes and roughness strongly depend on the spatial resolution of topographic data. In general, higher spatial resolution provides steeper slope histograms. We reexamined high-resolution images obtained by the SSI camera onboard the Galileo spacecraft using SI analysis and PC.

As for SI analysis, we used Integrated Software for Imagers and Spectrometers (ISIS3) produced by USGS to calibrate the SSI raw images radiometrically and perform bundle adjustment. Then we applied NASA’s Ames Stereo Pipeline software (ASP) to compute DEMs. ASP is a suite of automated SI analysis tools developed by NASA and designed for processing planetary images. To compute the slope, we i) selected a pixel from a DEM, ii) computed a least squares plane in a seven-pixel square centered around the selected pixel, iii) obtained the gradient of the least squares plane (the slope is defined as the gradient), and iv) performed (i) to (iii) over the entire DEM. Then, the total surface area of each DEM was normalized to 1. To compute roughness, we defined the roughness as the Allan deviation of differences in height (i.e. RMS deviation). In detail, we i) measured the difference in height between two points separated by a given distance (i.e. window length) along lines of constant longitude, ii) performed (i) over the entire DEM and collected differences in height over the entire DEM, and (iii) computed the Allan deviation of all differences in height obtained in (ii).

PC uses apparent brightness to estimated slope at each pixel, assuming a photometric function. We applied a photometric function that fits lunar-like surface. In order to compute roughness, we converted the slopes into height differences for each pixel. Then we integrated the height differences along the line of sight to construct one-dimensional topographic cross-section from line to line. Here roughness is defined as the Allan deviation of differences in height between two points separated by a given distance along the line of sight. We showed an average of the Allan deviation values for each window length among the all one-dimensional topographic profiles.

As a result, we obtained the slope histograms and roughness from SI analysis and PC. We found that most of Ganymede and the region of Callisto showing abundant knobs appear to be very rough surfaces as steep as 10 to 30º, while Europa and the region of Callisto without knobs mostly appear to be smoother than 10º. These results are far from previous estimates based on topographic data with the lower resolution. Also, this implies that instrument performances are expected to be strongly

affected by the steep slopes in the former areas.