ENABLING EUROPA IMAGES THAT "JUST WORK": IMPROVED IMAGE LOCATIONS THROUGH PHOTOGRAMMETRIC CONTROL NETWORK DEVELOPMENT. M. T. Bland, L. A. Weller, E. D. Smith, R. L. Fergason. USGS Astrogeology Science Center, Flagstaff AZ (mbland@usgs.gov).

Motivation: With its potentially habitable subsurface ocean, young surface, and stunning geology, Jupiter's moon Europa is one of the most scientifically compelling bodies in the Solar System. Consequently, the moon is a target for future exploration. The multi-flyby Clipper mission is currently scheduled for launch in the 2020s, and a Europa Lander mission concept is also in development. Our understanding of Europa, and all future mission planning activities, is primarily based on data acquired by the Voyager and Galileo missions (as well as telescopic observations), including several hundred images returned by the three spacecraft. Unfortunately, the imaging data are difficult to use due to inaccuracies of up to tens of kilometers in image locations. These inaccuracies result in misalignment of overlapping image observations, which creates a significant barrier to efficient use of the dataset: images must be photogrammetrically controlled before geologic analysis or mission planning can be performed. Although several controlled mosaics have been generated (https://astrogeology.usgs.gov/search/map/Europa/Voyager-Galileo/Europa_Voyager_GalileoSSI_global_mosaic_500m, and also see work by P. Schenk [1]) these are typically projected to a constant resolution (500 m/pixel for the USGS mosaic) that results in a loss of information where higher resolution images are available. Additionally, not all of the imaging data is included in the control network or the resulting mosaic, leaving much of the dataset without improved locations. Even those images that were included in the networks and mosaic (many of which are only partially visible) are not available as individual images with improved location information.

Here we describe an effort by the USGS (L. Weller technical lead) to improve the locations of Voyager and Galileo images to enable more efficient use of the existing dataset for scientific analysis and mission planning.

Technical Approach: We are improving Voyager and Galileo image locations by creating a new photogrammetric control network in ISIS (Integrated Software for Imagers and Spectrometers) [2, 3] (currently using v3.9.0) and updating the NAIF (Navigation and Ancillary Information Facility) pointing and, potentially, spacecraft kernels (i.e., the SPICE, Spacecraft, Planet, Instrument, C-matrix, Events kernels). These kernels will be made available to the community and will enable users to instantly utilize images with accurate locations.

To facilitate control network development, we are generating a Voyager-only network and a Galileo-only network and then joining the two into a single combined network. At the time of writing, the Voyager network is nearly complete and the Galileo network is still under development. We use a different approach to network generation in each case.

The Voyager-Europa Network. Development of the Voyager-Europa control network used an existing network originally developed by the RAND corporation as a starting point (available at https://astrogeology.usgs.gov/search/map/Europa/ControlNetworks/Europa_data). The RAND network (updated from the original described in [4]) included 120 Voyager 1 and 2 images, 178 tie-points, and 1924 image measures. We improved this original network by performing an "as-is" photogrammetric bundle solution (using ISIS' *jigsaw* application [5]) and then manually evaluating and improving each tie point. The resulting average residual was 0.66 pixels. We then added an additional 106 Voyager 1 and 2 images with resolution better than 30 km/pixel to the network and manually co-registered them. Automated methods failed to provide quality matches on the low-resolution images with highly variable viewing geometry. The current Voyager-Europa network thus includes 226 images, 187 tie-points, and 4852. Bundling of this network resulted in an average residual of just 0.69 pixels. A small amount of "clean up" work is ongoing.

The Galileo-Europa Network. Development of the Galileo-Europa network is utilizing ISIS' *findfeatures* application, which includes numerous feature-based descriptor/extractor matching algorithms from the OpenCV library [6]. We ran *findfeatures* on 481 Galileo images using both the fast/brief and sift/sift algorithms, resulting in 49,463 tie-points and 126,976 measures (Fig. 1). We are currently in the process of identifying and bridging disconnected sets of images. These disconnects typically occur when a given observation sequence differs substantially in resolution (sometimes by a factor of 10 or more) or illumination from an overlapping observation. Extremely poor SPICE and very slim image overlaps also contribute to failures in automated methods. Because work is ongoing, the exact number of points and measures (and potentially even the number of images) will continue to evolve as new points are added manually and false matches are identified. For 481 framing camera images it is unnecessary to have tens of thousands of points,

and the final network may have substantially fewer. Additionally, it may be impossible to control high-resolution images that overlap only very low-resolution data. Once a fully-connected network is established we will perform a photogrammetric bundle solution to update image positions (pointing and spacecraft kernels).

A unified Voyager-Galileo network. Once the Galileo-Europa network is completed we will join the Voyager-only and Galileo-only networks into a single network. We have identified a set of 45 moderate resolution Galileo images that will be used to bridge the lower-resolution Voyager images to the Galileo dataset. In most cases, matching higher resolution Galileo images to Voyager data is not possible, even with manual methods. A final bundle solution will be performed to establish final image locations across the combined dataset.

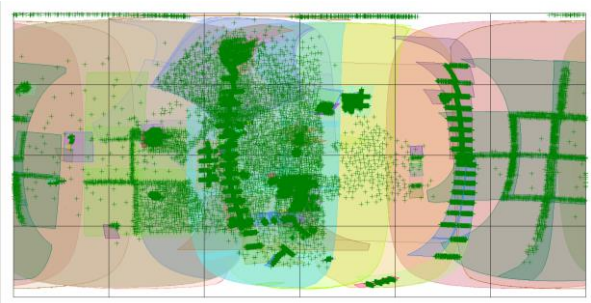

Figure 1: The distribution of tie-points (green) on Galileo image footprints (0-360º lon., ±90º lat. Grid) for our Galileo-Europa network.

Data that "just works": Although a fully connected Galileo-Europa network is still in production, sufficient progress has been made to provide an indication of the utility of the improved dataset. Figure 2 shows output from a QGIS project containing five different image observations of Conamara Chaos with pixel scale varying from 9.3 m/pixel to 182 m/pixel. The images have had their locations updated (preliminary-control, updates are continuing) so that relative locations are accurate between each observation and with lower-resolution context observations at 1.2 and 1.5 km/pixel. Unlike the existing "static" USGS mosaic, which has a degraded pixel scale of 500 m/pixel, the use of individual images with updated pointing enables images to be viewed at full resolution while retaining the geologic context from surrounding, lower-resolution images. Additionally, unlike a static mosaic, the user can choose between (or compare) two observations with similar resolution but very different viewing geometry. Critically, the burden on the user is minimized: once the updated kernels are applied the images are immediately ready for analysis.

Availability and future direction: Control network development is scheduled for completion by September of 2020. The resulting finalized SPICE kernels will be immediately available through the USGS' Astropedia data portal (https://astrogeology.usgs.gov/search). Subsequently, ISIS' *spiceinit* application will be modified to default to the updated kernels. A photometrically uncorrected mosaic will also be completed but is lower priority given the existence of a high-quality color mosaic from P. Schenk [P. Schenk, Pers. Comm.]. Data will also be made available in a science-ready Geospatial Information System (GIS) comliant format.

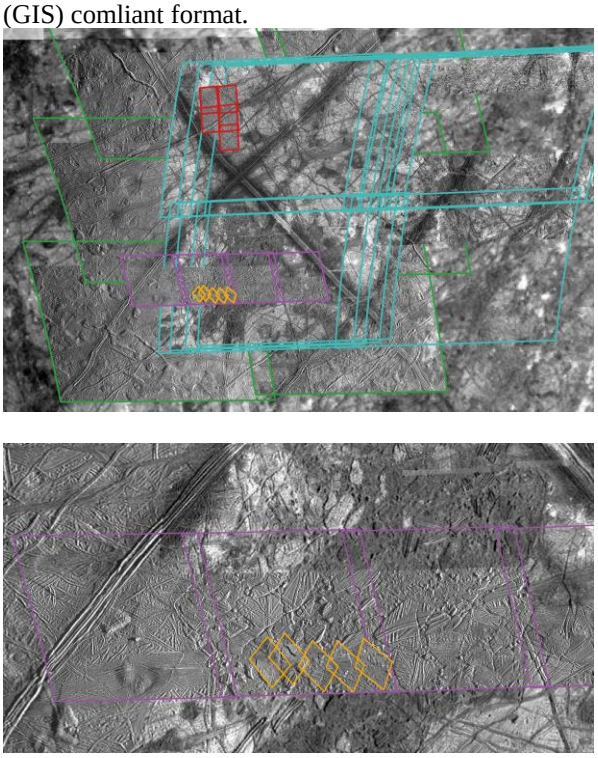

Figure 2: Example of data integration enabled by our improved image locations. (Top) Five different moderate- and high-resolution observations of Conamara Chaos on lower-resolution background images. Colored polygons indicate image footprints. (Bottom) The same scene but enlarged to illustrate how high-resolution images can be utilized with lower-resolution observations. Such high-resolution images are not available in the existing global mosaic. For reference, the combined length of the highest resolution observation (orange diamonds) is 40 km.

References: [1] Schenk P. (2009) *AGU*, P51E-1171. [2] Sides et al. (2017) *LPS XLVIII*, #2739. [3] https://github.com/USGS-Astrogeology/ISIS3.
[4] Davies M. E. et al. (1979) *Report – Rand Corp.* R-2532-JPL/NASA. [5] Edmundson K. L. et al. (2012) *ISPRS* I-4, 203-208. [6] Becker K. J. et al. (2016) *LPS XLVII*, #2959.