PLANETARY GIS AT THE U.S. GEOLOGICAL SURVEY ASTROGEOLOGY SCIENCE CENTER.

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Introduction: For the past 51 years, the USGS Astrogeology Science Center (ASC) has been a resource for the integration of planetary geoscience, cartography, and remote sensing. In more recent years, the USGS ASC has supported Geographic Information Systems (GIS) for planetary data integration, geologic mapping and spatial analysis. This abstract is provides a brief overview of current GIS initiatives and related online services at ASC.

Background: One of the major roles of the USGS ASC is to support NASA missions and research programs through software focused on cartographic data processing. In particular, the Integrated Software for Imagers and Spectrometers (ISIS) [1] software is a specialized image processing package for working with planetary image data from NASA spacecraft missions such as Voyager, Viking, Galileo, Mars Global Surveyor, Mars Express, Cassini, Lunar and Mars Reconnaissance Orbiters and MESSENGER. While the products made with ISIS are science-ready cartographic products, the software was not designed for detailed geologic analysis or geomorphologic mapping and robust spatial analysis. Thus, most researchers must take these generated products into a remote sensing or GIS application for further analysis.

GIS Support: The USGS ASC, mostly through the Mapping, Remote-sensing, Cartography, Technology, and Research (MRCTR, pronounced "Mercator") GIS Lab, supports several GIS initiatives including training, tutorials, and plug-ins for Esri's ArcMap GIS and other open-source desktop GIS applications like QGIS. The MRCTR GIS Lab also provides code development for the Geospatial Data Abstraction Library (GDAL) to support planetary image formats and specialized planetary functions for online map viewers like Openlayers and ArcGIS Online. Lastly, MRCTR supports standards for metadata, map projection registries and real-time mapping servers like Web Mapping Services [2].

ArcMap GIS: While the USGS ASC does not solely endorse Esri's ArcMap GIS, we recommend it for geologic mapping and a number of spatial analysis tasks. Unique to ArcMap, Esri has worked directly with the Federal Geographic Data Consortium (FGDC) to provide support for USGS-required geologic symbology (e.g., geologic contacts and fault types) and metadata. This capability is critical to the USGS for producing publish-ready geologic maps whether for Earth or an extraterrestrial body. Working with the USGS ASC, Esri has also incorporated radius values (as recommended by the International Astronomical Union [IAU]) for nearly all planets in our Solar System and their moons within ArcMap and their forthcoming ArcGIS Pro desktop applications. As a result, ArcMap has direct map projection support for most products derived by the community [3, 4].

QGIS and GRASS GIS: QGIS, previously known as Quantum GIS, is a very capable open-source desktop GIS application. The latest release comes with built-in support for planetary map projections. In 2006, the USGS ASC and the Jet Propulsion Laboratory published a recommended coded set of planetary projections using the IAU2000 namespace [5]. Though these were made available from the projection registry site SpatialReference.org, they were not directly added to QGIS. Due to the efforts of the Lunar Reconnaissance Orbiter Camera Team at Arizona State University, these IAU2000 projection codes now ship with QGIS. Also, thanks to work by Alessandro Frigeri (currently at the Italian Institute for Space Astrophysics and Planetology), these radius definitions are also included within the GRASS environment [6].

GDAL: The Geospatial Data Abstraction Library (GDAL), released by the Open Source Geospatial Foundation (OSGeo), offers powerful capabilities for converting and processing planetary data. GDAL is a format translation library written in C++ for geospatial raster and vector data [7]. In 2007, the USGS ASC added support for the ISIS3 format within GDAL and updates to the ISIS2 reader and raw Planetary Data System (PDS) formats. In late 2014, VICAR support was added by Sebastian Walter, from the Freie Universität Berlin [8].

Any application that supports the GDAL library can now easily understand common planetary data formats, including the planet definition, projection parameters, and label information like pixel offset and multiplier. Popular applications with GDAL support include the applications noted above and many others, such as MapServer, Opticks, and Generic Mapping Tools. For applications that do not integrate GDAL, the bundled routines released with GDAL can be used to convert the ISIS and PDS formatted data into well-supported geospatial formats like GeoTIFF, GeoJPEG2000, ENVI, and many others. Lastly, GDAL's C++ code-base has been wrapped to support scripting languages like Python. Using these capabilities, the USGS ASC has created new tools for researchers, including simple image stretching and classification routines to spectral image viewers [9].

Infrastructure Services: Several behind-the-scenes online services and databases at USGS ASC provide essential GIS support for planetary data access and processing. The databases described below use the open-source PostgreSQL database and PostGIS extensions for added geospatial support.

UPC: The PDS Imaging Node's Unified Planetary Coordinates (UPC) database standardizes the numerous, disparate planetary orbital datasets into a single coordinate system [e.g., 10] and simplifies data identification and delivery for users. The UPC has two main parts: (1) a spatial database containing improved geometric and positional information about planetary image data that has been computed using a uniform coordinate system and projection onto a common planetary surface shape, (2) a process by which continual maintenance and updates of the database are performed. For GIS users, the image footprints are separated by body and instrument and can be obtained in a shapefile format.

Astropedia Data Portal and the PDS Imaging Node Annex: Astropedia is a secure, long-term access and storage repository for high-level planetary cartographic data products [11]. At the core of Astropedia are the ingestion methods, metadata parsing and cataloging, and the local data storage repository. Planned improvements to Astropedia include the addition of GIS catalog services [12]. The Annex (sponsored by the PDS Imaging Node) uses the Astropedia data portal to help planetary researchers archive and release derived geospatial products created from archived PDS data. Examples of products are cartographic and thematic maps of moons and planets, local and regional geologic and/or geomorphologic maps, topography of planetary landing sites, and tabular data. Many such products likely have been developed as a result of NASA data analysis programs, often years after active missions (and their accumulating archives) have ended.

Astrogeology Web Maps: Astrogeology Web Mapping Services (WMS) and Web Feature Services (WFS) are based on Open Geospatial Consortium standards and allow capable mapping clients to view full-resolution global and polar planetary basemaps and supporting geospatial databases. In short, a WMS service accepts queries for map-projected layers and returns requested data in a simple image format (e.g., JPEG, PNG). A WFS service returns geographical features representing data such as name, type, and the spatial geometries (point, line, or polygon) associated with the feature. Our services currently support more than 100 image layers and over 30 different planetary bodies [13]. For GIS users, these layers are also listed on Esri's ArcGIS Online data portal under the Planetary GIS group and can be directly accessed from ArcMap, QGIS or GDAL (bit.ly/PlantaryGIS).

POW and MAP2: The Map Projection on the Web (POW) [14] service allows users to convert raw PDS images to science-ready, map-projected products. Map-a-Planet 2 is a major update to the popular Map-a-Planet web site [15]. The service allows global image products to be re-projected, stretched, clipped, and converted into a variety of useful image formats. Both POW and MAP2 leverage the capabilities of Astropedia, ISIS, GDAL, and the USGS ASC processing cluster and web services.

OpenLayers Planetary Extensions: OpenLayers is a javascript library for displaying map data in web browsers. The USGS ASC developed and supports several OpenLayers 2.x extensions to properly display planetary bodies, including use of either planetocentric or planetographic latitudes, positive-east or -west longitudes, and correct scale bars [16].

Conclusion: The large variety of planetary data and services provided by Astrogeology has grown to meet the cartographic and scientific needs of planetary researchers and will continue to evolve with the needs of the community.

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