Mem. S.A.It. Suppl. Vol. 11, 103

Memorie della
Supplementi

Procedures for using Geographic Information Systems for the handling and processing of scientific data from the planetary surfaces

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Abstract. The availability of large volume of data from instruments on-board scientific planetary missions justify the use of Geographic Information Systems (GIS) procedures for the study of terrestrial planets and their satellites. As mission data volumes increase the use of GIS techniques offer the planetary scientist a way for fast retrieval, storage and analysis of heterogeneous data and allows comparative analysis between different dataset that otherwise would be difficult to perform. Although GIS systems have been already used for planetary research, none provides a native generic support for studying surfaces of terrestrial planets and satellites. The work presented here describes the development of a pool of procedures in the form of computer codes and supporting files produced to provide a generic support to handle, analyze and visualize planetary remote sensed data in a selected GIS system allowing to perform the comparative analysis of different geological and geophysical planetary data. The application of procedures developed allowed to aggregate maps from different mission to Mars in order to investigate the geologic context of an area of Mars and to correlate these information with the first subsurface signals of the Mars Advanced Radar Subsurface and Ionospheric Sounder (MARSIS).

Key words. Planetary cartography – Planets: surface – Geographic Information Systems

1. Introduction

Data of planetary surfaces acquired by instruments during planetary missions is commonly stored in digital archives in a non-proprietary format that is commonly published together with the dataset. While the mapping and the analysis of a single instrument's dataset is a common process and it is normally supported by the instrument's scientific team or by a dedicated software, the comparative analysis of different data, at different resolution, taken by different missions can be problematic.

The problem of aggregation of different dataset is commonly approached by Geographic Information Systems (GIS), widely used by a large number of geoscience-related disciplines.

The use of GIS is becoming popular in the planetary science community as it offers unique characteristics not covered by conventional software systems used in planetary research; GIS techniques have been applied since

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90's for studying Venus (Price & Suppe 1993), the Moon (Giguere et al. 1996) and Mars (Dohm et al. 1997; Hare et al. 1997).

Nevertheless, the Earth-oriented approach of commonly used GIS systems does not fully satisfy a routinely use in studying planetary scientific data. As the acronym explicitly states, GIS systems have been designed to work on features located on the Earth, and the planetary coordinate systems are generally not supported. Moreover, GIS and planetary digital data use different formats.

To take full advantage of using GIS capabilities for the analysis of planetary data, we have developed procedures for implementing a generic support for terrestrial planets geometric figures and reference systems in a GIS that are here described together with procedures to handle planetary data formats. These procedures where continuously tested during development and applied to real data.

2. GIS support in planetary research

Since 1960s instruments data from planetary probes have been analyzed with dedicated software developed by research institutions directly involved in extra-terrestrial mapping projects as NASA's Jet Propulsion Laboratory (JPL) and United States Geological Survey (USGS). The JPL Multimission Image Processing Laboratory developed the Video Image Communication and Retrieval (VICAR) system for image processing while the USGS developed the Integrated Software for Imaging Spectrometers – ISIS (Gaddis et al. 1997). These systems allow to process raw sensors readings into higher level data products through a process of 3 or 4 discrete steps that starts with radiometric and geometric calibration and typically ends with map projection of the data over a reference body. As planetary mission data continue to grow in quantity and different type of sensors, new scientific observations can be made by the comparative analysis of different dataset taken by different instruments in different missions.

A GIS is a system of hardware and software used for mapping, storage, retrieval and analysis of spatially-referenced data that can be organized as distinct layers of information and combined as needed.

Besides the data detected from pixel based sensors that can be stored in a matrix format, a GIS offers the possibility to handle vector graphic primitives and to associate them with tabular entries commonly stored in Relational Database Management Systems (RDBMS). This *vector* format allow a fast retrieval of spatially-referenced information and to perform analysis on the spatial relationship between discrete geometric features.

Off-the-shelf GIS systems have been used in the last 15 years to analyze planetary data but support for planetary cartographic reference systems and planetary data formats has not been introduced, maybe due to the relatively small scientific community using these system in planetary research. Since 1999 USGS Astrogeology Program produce useful documentation and tools to use GIS systems with planetary data (Hare & Tanaka 2004).

3. The development environment

In order to implement features useful for managing planetary data it has been selected the Geographic Resources Analysis Support System, GRASS (Neteler & Mitasova 2002) since it is the only GIS that offers important key features in the same system: 1) it provides freedom to use, copy, study and modify the code, as it is Free Software distributed with the General Public License (Stallman 1999); 2) it is available for almost all the computers architectures; 3) it has a modular structure, and new modules can be easily added without interfering with general program behaviour; 4) it is written in C and library functions can be accessed also from higher level languages as Perl or Python (Frigeri 2006); 5) it can be used via the Graphical User Interface (GUI) or via the system shell allowing the user to make simple scripts for iterations or for producing chains of processing operations; 6) it handles most diffused GIS data formats, allowing data exchange with existing systems throughout non-proprietary formats.

The development process has been divided into three main problems: the implementation of planetary bodies reference shape, the support for dealing with planetary coordinate reference systems, and the data format handling.

3.1. Ellipsoidal parameters

Ellipsoidal parameters describe the ellipsoid that best-fit the mathematical figure of a planet, the geoid in the case of the Earth or the areoid in the case of Mars.

The ellipsoidal parameters are required to pass from body-fixed coordinates (longitude and latitude) to planar maps coordinates through mathematical relationships called projections.

If data going to be compared is delivered in different cartographic projection, to co-register the dataset a reprojection process is necessary and this implies knowing the ellipsoidal parameters of the planetary body.

Ellipsoidal parameters of the solar system bodies issued by the International Astronomical Union (IAU) have been introduced in GRASS so that distance measurements are correctly computed and data can be re-projected on different cartographic projections.

Ellipsoidal parameters of the solar system main bodies have been made available to GRASS through the European Petroleum Survey Group (EPSG) coded method, using the ID scheme recently proposed by Hare et al. (2006). EPSG codes are stored in an ASCII file generated by a script we have developed that extract IAU2000 ellipsoidal parameters from the Navigation and Ancillary Information Facility (NAIF) planetary constants *kernel* (Acton 1996). The EPSG codes related to the planetary bodies are then used by GRASS (or any other modern GIS) to start sessions and set the ellipsoidal parameters and the projection to be used. The use of EPSG codes is a good start as it represent a standard widely approved and understood by most GIS but hopefully it will be replaced by informations stored in eXtensible Markup Language (XML) that guarantees several advantages over a simple plain text file (Goldfarb & Prescod 2003).

3.2. Coordinates and cartographic reference systems

Starting from 1970 the International Astronomical Union (IAU) defined two body-fixed rotating coordinate systems for planets: the planetocentric and the planetographic (Seidelmann et al. 2002). In GIS systems the body-fixed rotating coordinates assumed are the ones traditionally used on the earth: longitude ranging from -180 to 180 degrees and a latitude corresponding to the planetographic definition. Planetocentric coordinates are commonly used in celestial mechanics and not normally handled by GIS.

As map projected planetary data can be delivered using planetocentric coordinates, care must be taken to handle this data in a GIS in the case we are dealing with ellipsoidal shape of the planet and ellipsoidal form of projection equation. Among all the planets and satellites of the solar system, only Earth and Mars present a sensible flattening, thus requiring an ellipsoidal figure to perform cartographic operations.

The widely used solution for dealing with Mars coordinates in a GIS is to assume a sphere as the reference surface so that planetographic and planetocentric latitude coincide, but this does not solve all the problems a researcher may face, and introduces scale errors (Hare et al. 2005). Moreover latest high resolution instruments, allow to produce large scale maps of Mars using cartographic projections that consider the ellipsoidal figure of Mars (Gehrke et al. 2006).

To introduce a general approach for dealing with planetary data in a GIS system it has been implemented into GRASS the feature of direct and inverse transformation of data from the planetographic to the planetocentric system.

While for vector geometry the transformation is straightforward, involving a simple coordinate transformation, for the matrix data (called *raster* in GIS context) it has been necessary to implement a resampling algorithm.

The *raster* reprojection module we have developed (called *r.pc2pg*) is so capable to transform raster data from one system to the other allowing the user to choose the interpolation algorithm among the nearest neighbor resampling, the bilinear interpolation or the cubic convolution. This module is useful when it is necessary to co-register planetary *level 2* (map projected) data archived in different reference system.

3.3. Data handling

To preserve a continuously increasing data volume from planetary missions, in 1980s NASA developed the Planetary Data System (PDS), an archive that provides usable planetary data products to the scientific community (McMahon 1996). PDS data are stored in different 'nodes' corresponding to research institutions that host data of a specific subject. PDS files can store a wide range of information from instrument readings to documentation and bibliographic references; this task can be accomplished thanks to the metadata information stored into the PDS file themselves. Metadata information are stored in ASCII strings in the PDS file or in an auxiliary file and consists in an Object Description Language (ODL) that stores information in simple keyword/value pairs. Following the successful NASA experience, the European Space Agency established the Planetary Science Archive (PSA) that stores planetary data taken by ESA's mission in PDS format (Zender et al. 2006); this guarantees a full compatibility between the two planetary archives and tools to access the data.

To import PDS map projected data into GRASS it has been used the Python programming language that offers unique capabilities of fast application development (Rossum 1997). Python scripts have been developed to extract informations from PDS files and to call GRASS binary import modules.

The library that GRASS uses for importing and exporting data, the Geographic Data Abstraction Library (GDAL), recently introduced the support to handle ISIS *Cube* data (Warmerdam 2006), so that *level 2* data of ISIS can be directly imported into GRASS.

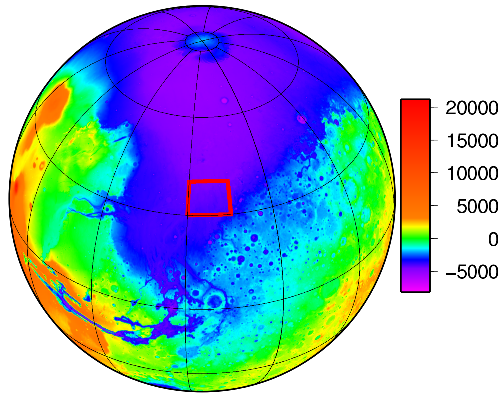

Fig. 1. Topography of western northern hemisphere of Mars, color scale represents elevation in meters. Color coding of topography enhances the patterns of the outflow channels around Chryse Planitia. The red frame indicates the study area.

4. Example of data aggregation and processing: Chryse Planitia, Mars

GRASS GIS with the procedures developed has been used to investigate a subregion of Chryse Planitia, Mars in order to provide a geologic context to data acquired by the Mars Advanced Radar for Ionospheric and Subsurface Sounding (MARSIS), the sounder on board Mars Express ESA's mission to Mars.

Chryse Planitia is a large basin with a diameter of about 1700 km centered at 320.0^o E, 26.7^o N (planetocentric coordinates) located in the northern equatorial region of Mars; the topography reported in Figure 1 show the outflow channels that confine with the region at south and west while toward north the area opens toward the northern low-plains.

Footprints of MARSIS data frames acquired along Mars Express orbits 1892 and 1903 have been imported from PDS into a GRASS *vector* format that represent the surface location of singular frames as points associated to their respective frame information (Figure 2).

To analyze the surface of Mars in the study area we imported into GRASS data from Mars Global Surveyor (MGS) and Mars Express archives. The topography has been extracted from the global topography of Mars produced

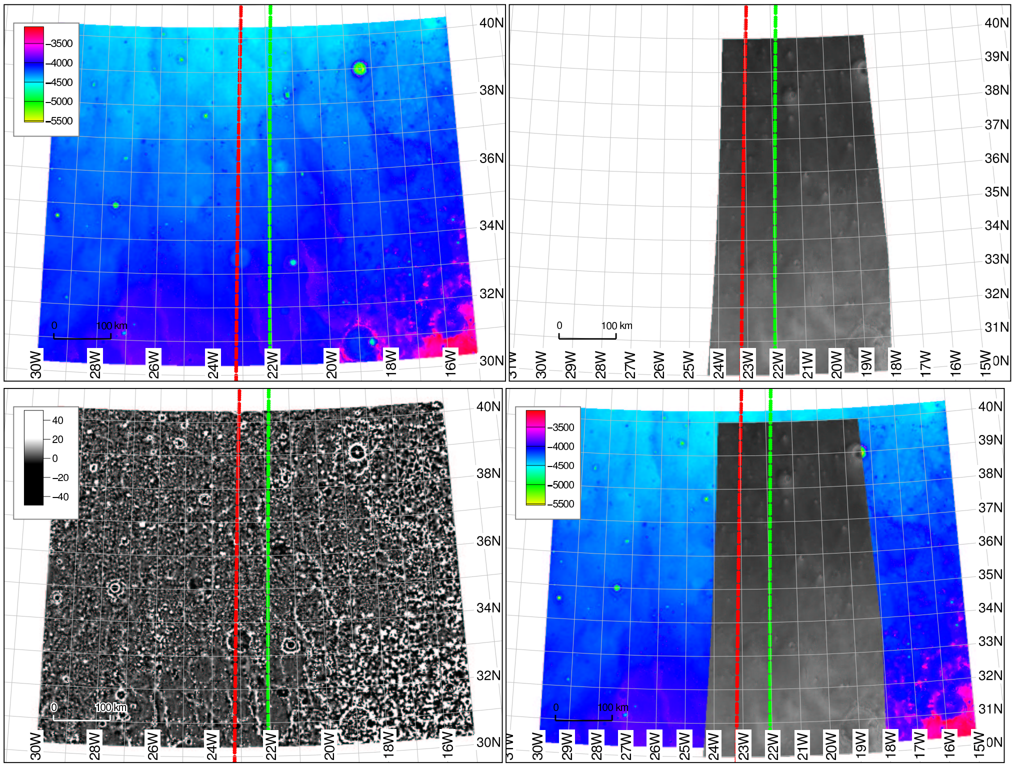

Fig. 2. Data of the studied area (located by the red frame in Figure 1), in Lambert Conformal Conic projection using the IAU2000 ellipsoidal parameters; the grid reports the planetographic reference system. Points indicate location of footprints of MARSIS data frames for MEX orbit 1892 (green) and 1903 (red), all color scales are in meters *Top Left:* MGS MOLA/MEGDR topography; *Top Right:* Mars Express High Resolution Stereo Camera (HRSC) image h1564-0008, infrared band – resolution of 100 meters per pixel; *Bottom Left:* De-regionalized topography: among others, note *ghost crater* centered at 24.4W 32.6N; *Bottom Right:* MEGDR topography from Mars Global Surveyor and Mars Express HRSC data plotted into the same map.

by the MGS/Mars Orbiter Laser Altimeter (MOLA) instrument team (Smith et al. 2002) with a resolution of about 450 meters per pixel at the equator, while the imagery data is from High Resolution Stereo Camera (HRSC) PDS map-projected data archive released in 2006 (Neukum et al. 2006).

Topographic and imagery data together allow to inspect at different resolutions the morphology of the area that is mostly flat and shows some impact craters. From the topographic map (Figure 2, Top Left) it is possible to detect circular depressions morphologically different from typical impact craters, and they are not easily detectable on HRSC imagery (Figure 2, Top Right). These features are commonly referred as *ghost craters*, impact craters that have been largely buried under deposits of other material; they are very important in the study of the geologic evolution of a planetary surface since their detection can constrain the timing of geologic events (Kreslavsky & Head 2001).

To investigate more in depth on the presence of these features in the study area we used spatial filtering capabilities of GRASS GIS. We applied a convolving median filter with a radius of 5 km to the topographic data; this allowed us to eliminate the regional topographic trend to enhance subtle topographic variations. The de-regionalized topography is reported in Figure 2 (Bottom Left), where topographic variations from -50 (black) to 50 (white) meters are reported. The map produced by the processing reveals the presence of subtle circular features that were not directly detectable from the topographic map. The results obtained by suggest a model of subsurface scenario that can be used to support planetary radar data interpretation.

These investigations agree with the interpretations of the first subsurface soundings from Mars acquired by MARSIS that detected signals from subsurface geometries that resemble buried craters in the studied area of Chryse Planitia, along orbits 1892 and 1903 (reported in Figure 2); processing of radar echoes suggests that infilling material can be of sedimentary origin, in agreement with the geological context of the area (Picardi et al. 2005).

5. Conclusions

Geographical Information Systems can extend significantly the range of analysis that can be made by planetary scientists; in particular GIS offers the opportunity to combine different type of data into discrete layers of information and to analyze them by various techniques.

Issues related to practical difficulties have been approached and procedures were developed to solve common problems found in dealing planetary data in a GIS.

Developing procedures using Free Software allow a fast implementation and test of procedures, as well as it provides full control on the behavior of the code; legal issues related to Free Software licenses encourage the collaboration between singular scientists, scientific research institutions and agencies.

The procedures developed for using GRASS GIS with planetary data have been applied to investigate the geologic context where subsurface data from MARSIS have been acquired, showing the practical use of a working GIS environment in the support of current and future experiments.

Data extracted from MOLA and HRSC archives together with footprints of MARSIS data frames have been aggregated in the same reference system. In this way results of the analysis of the topography performed into GRASS GIS can be spatially correlated with the locations of MARSIS data frames and be used to support the interpretation of the radar data.

Acknowledgements. We are grateful to Roberto Orosei (INAF/IASF – Roma, Italy) for introducing us to the Planetary Data System.

We acknowledge Markus Neteler (ITC/IRST – Trento, Italy) and all the Geographic Resources Analysis Support System developers and user communities for their work and enthusiasm on the GRASS project.

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