University of Redlands

**Mapping the Amirani Region of Jupiter's Moon Io Using Multispectral
Imagery and GIS**

A Major Individual Project submitted in partial satisfaction of the requirements
for the degree of Master of Science in Geographic Information Systems

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The report of Shane Edward Barrett is approved.

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ABSTRACT

Mapping the Amirani Region of Jupiter's Moon Io Using Multispectral Imagery and GIS

By
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Unique volcanic surface process present on the Galilean moon Io has made it one of the most astonishing celestial bodies ever observed. An abundance of volcanic activity on Io was not only the first discovered within the solar system, but eventually categorized Io as the most geologically active object ever studied. NASA embarked on the Galileo mission by sending a spacecraft equipped with three remote sensing instruments - Solid State Imaging Device (SSI), Near-Infrared Mapping Spectrometer (NIMS), and the Photopolarimeter-Radiometer (PPR) to study Jupiter and the Galilean moons exclusively. These three instruments provided researchers with multispectral imagery and surface temperature data so that they would attempt to assess the variety of tectonic and volcanic activity, and identify any relationships to the surface modification processes. The goal of this project was to create a prototype GIS for the Amirani region and convert data collected by the three instruments into an appropriate GIS compatible dataset. Working in a GIS, the user can manipulate and visualize the data to make it more interpretable and provide the ability to derive any useful information about it. The SSI and NIMS image datasets were co-registered to a common coordinate system. Three tabular PPR datasets were processed in a specific format to simulate actual observations made by the instrument. Another goal of this project is to communicate and distribute the results of these datasets to promote interest of GIS within the Io research community. This was done through the compilation of all of the data into an ArcIMS website that allows researchers to simultaneously examine all of the datasets through a basic internet connection and determine if the system and datasets are suitable for their research needs.

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List of Acronyms

ANUDEM	Australian National University Digital Elevation Model
ASCII	American Standard Code for Information Interchange
ENVI	The Environment for Visualizing Images
ESRI	Environmental Systems Research Institute
GIS	Geographic Information Systems
HTML	Hyper Text Markup Language
IDW	Inverse Distance Weighted
IHS	Intensity, Hue, Saturation
IFOV	Instantaneous Field of View
JPL	Jet Propulsion Laboratories
HSV	Hue, Saturation, Value
IDL	Interactive Data Language
NASA	National Aeronautics and Space Administration
NIMS	Near Infrared Mapping Spectrometer
PPR	Photopolarimeter Radiometer
RGB	Red, Green, Blue
RMS	Root Mean Square
SSI	Solid State Imaging device
TIFF	Tag(ged) Image File Format
USGS	United States Geological Survey
VBA	Visual Basic for Applications

1. Introduction

Constant volcanic activity accompanied by intense sulfurous plumes has made one of Jupiter's moons, Io, one of the most observed celestial bodies in recent history. The abundance of giant calderas, lava lakes, volcanoes, and vast lava flows have drawn as much attention to Io; both as the first celestial body with active volcanoes discovered within the solar system, and as the most geologically active object ever observed (Fischer, 1998/2001). The formation and destruction of the landforms on Io are much more rapid than any other body in the solar system, making Io a unique focus to study processes from the incomplete geologic record on Earth (McEwen et al., 2000).

These dramatic features on Io combined with Jupiter's storms and rings, inspired NASA to embark on the Galileo mission to study Jupiter and its four largest moons (Galileo, Journey to Jupiter, 2003). One of the most astonishing discoveries of the Galileo mission included surface temperature readings of Io suggesting that the volcanism there is up to 500°C hotter and more intense than any lava flow observed on Earth (Fischer, 1998/2001). Even though the composition of the molten lava on Io is believed to be comprised of similar material to the volcanoes on Earth, tectonic activity is not believed to be the origin of volcanic activity on Io (Fischer, 1998/2001). Rather, the source of the geologic activity is believed to be a barrage of tidal distortions from Jupiter pulling extensively on the surface of Io, keeping much of its interior in a molten state (Fischer, 1998/2001). Not only is the study of Io resulting in the identification of new processes that cannot be observed on Earth, it is giving scientists the opportunity to study geologic processes on a massive, global scale that may have been involved in the formation of the Earth (Fischer, 1998/2001).

On the Galileo spacecraft, the three instruments that emerged to be the most useful for studying the volcanoes on Io were the solid state imaging device (SSI), the near infrared mapping spectrometer (NIMS), and the photopolarimeter radiometer (PPR) (J. Rathbun, personal communication, January 23, 2005). The SSI was a telescopic camera, designed to map and identify changes in the surfaces of the Galilean moons by providing high spatial resolution images in visible light (Belton, n.d.). To assist the SSI with surface mapping, the NIMS instrument was designed to measure the thermal, compositional, and structural nature of the moons by measuring infrared radiation (Carlson, n.d.). The PPR instrument observed light in the visible and near infrared spectrum to provide atmospheric composition and thermal energy distribution data (Hansen, n.d.). These three instruments produced numerous stunning images during the Galileo mission, but unfortunately each instrument acquires data in a different format and resolution. The different data formats must be properly co-registered to allow researchers to accurately interpret the data and identify specific surface processes within a certain area.

To optimize research and productivity, the data needs to be compiled in a system that is easy for scientists to view and analyze specific research-based questions. One area of current research on Io involves studying the volcanic eruptions, and trying to develop a time frame or history of how the eruptions have occurred, including the subsequent lava flows (J. Rathbun, personal communication, January 23, 2005). Some lava flows can emanate from several points within the same enormous volcano or caldera, and surge outward in many dissimilar directions (Fischer, 1998/2001). From the SSI data,

researchers can determine the location of the lava flows, but they also require numerous temporal data sets in order to determine the progression of the lava. Researchers can also trace the progress of the lava flows by identifying the lava with exceedingly high temperatures using the NIMS images, compared to the cooler temperature emitted by the older lava flows using the PPR instrument (J. Rathbun, personal communication, January 23, 2005). Temperatures derived from the spectral data can not only be used to locate the current lava flows, but they can also give researchers an indication of how an eruption has occurred and how each flow has progressed within a defined time frame. Researchers are also using the NIMS data to determine if the spectral data indicates the presence of a particular material, since the contents of the lava may be an indication of the extraordinarily high temperatures (J. Rathbun, personal communication, January 23, 2005).

1.1. Client

Applying these research methods to the Amirani region of Io is the current research project of Assistant Professor of Physics, Julie Rathbun, Ph.D., of the University of Redlands. In collaboration with NASA, USGS, and the Southwest Research Institute, Professor Rathbun has been studying Io for the last six years, has participated in numerous research projects regarding Io, and has co-authored eleven published scientific papers regarding the Galilean moon.

Professor Rathbun's aspiration is to produce a stand-alone application that will allow Io researchers to observe all data from the Galileo project within the Amirani region of Io. The inclusive application will allow the user to simultaneously project the SSI, NIMS, and PPR data of the Amirani region to derive information and analyze the region's volcanic activity. The current goals of research within the Amirani region are to assess the variety of tectonic and volcanic eruptions, and identify any relationships to the surface modification processes (J. Rathbun, personal communication, January 23, 2005).

1.2. Problem Statement

Applying all of this knowledge to the mapping and interpretation of the Amirani region of Io presents a unique challenge as little to no research has been performed on Io using any form of GIS. All imagery analysis and research has been performed within independent or enterprise image processing software packages. Despite the ending of the Galileo mission five years ago, there is still an abundance of useful data researchers can utilize to interpret the surface processes of Io. The SSI, NIMS, and PPR instruments, all produced valuable data sets of Io but, unfortunately, each instrument acquired data at a different format and resolution. All of these different datasets must be processed and transformed into useable datasets that can be viewed simultaneously with one another. Also, the different data formats must be properly co-registered with one another to accurately study volcanic features on the surface of Io and derive any useful information about the moon. Figure 1-1 is the client's result of combining all of the mentioned Galileo data into an image processing system.

Figure 1-1. - Current result of combining the Galileo data in IDL.

Although IDL was useful to provide a visual of all of the data simultaneously, co-registering the data was difficult, and the overall end product was not pleasing aesthetically. By converting the data to be compatible with a GIS, the user can manipulate and visualize the data to make it more interpretable and provide the ability to derive useful information about it. The incorporation of the Galileo datasets into a GIS will be achieved by individually examining and transforming each of the provided datasets into an appropriate GIS compatible dataset. Once all of the datasets are complete, they will be stored in a controlled, centralized location to provide simple access to the datasets and their relevant information contained within the attributes and metadata.

The transformation of these data sets is to aid and improve communication among Io researchers. Most of the potential users of these datasets are located throughout the country, so a distribution system needs to be developed so that numerous interested researchers can simultaneously access the new datasets from remote locations. An ArcIMS website is ideal for this application because it would allow researchers to concurrently examine all of the datasets through a basic internet connection and determine if the system and datasets are suitable for their research needs.

2. Background and Literature Review

2.1. Early Discovery and Research

On January 7, 1610, Galileo Galilei peered through his recently constructed telescope to observe the flattened shape of Jupiter with three small points of light arranged in a line next to the massive planet (Hamilton, 2003). After a few hours of observing the points of light, Galileo noticed that the points had changed their position relative to Jupiter (Fischer, 1998/2001). For the next week, Galileo continued to observe Jupiter and the mysterious points and noticed that what he initially thought were stars had continued to change their position around Jupiter (Hamilton, 2003). During that same week on January 11th, a fourth point of light appeared that also never left the immediate vicinity of Jupiter (Hamilton, 2003). For the duration of that week, the four stars simply changed position in relation to each other and the giant planet (Hamilton, 2003). After a week of extensive observation, Galileo determined that the points of light he was observing were not in fact stars, but celestial bodies that were orbiting Jupiter (Hamilton, 2003). The image below (Figure 2-1) is a photo of the original manuscripts in which Galileo published his observations in Sidereus Nuncius, in March of 1610 (Hamilton, 2003).

Figure 2-1. - Two pages from Galileo's observations of the Galilean satellites which appeared in Sidereus Nuncius in March 1610.

(From The Discovery of the Galilean Satellites, (2003). Retrieved October 14, 2006 from Views of the Solar System Website: <http://www.solarviews.com/eng/galdisc.htm>)

A few months after Galileo's discovery, a German mathematician by the name of Simon Marius declared that he had discovered the four moons of Jupiter one week before Galileo, in late 1609 (Lopes & Williams, 2005). Marius had also already established the currently recognized names for the moons as Io, Europa, Ganymede, and Callisto; he eventually published them along with his claim of discovery in the *Mundus Jovialis* in 1614 (Lopes & Williams, 2005). Galileo immediately dismissed Marius' claim as an act of plagiarism, and it would seem as if the majority of the astronomical community did as well because the majority of literature referred to Io as the first satellite of Jupiter or by its Roman numeral designation Jupiter I until the mid-20th century (Lopes & Williams, 2005).

The Galilean moons were once again used for the advancement of knowledge in 1676, when Danish astronomer, Ole Romer, used eclipse timings of the shadow of Jupiter on the moons to deduce the first accurate measurement of the speed of light (Hamilton, 2003). In the late 18th Century, Pierre-Simon de Laplace was able to determine that "the orbital periods of Io, Europa, and Ganymede are nearly in a perfect 1:2:4 ratio" (Hamilton, 2003). Laplace's work eventually allowed researchers to come up with the first reasonable estimates of the Galilean satellites masses in 1920 (Hamilton, 2003).

2.2. Pioneer

It was not until the 1970's that people could finally look upon the Galilean moons without using a telescope. On March 2, 1972, NASA launched the Pioneer 10 spacecraft which was responsible for the very first observations beyond the asteroid belt between Mars and Jupiter (Pioneer 10 and 11, 2006). Finally, on December 2, 1973, Pioneer 10 captured the very first images of the massive planet and its moons (Fischer 1998/2001). The image in Figure 2-2 is one of the first images taken of Jupiter from the Pioneer 10 mission, and it clearly shows Jupiter's Great Red Spot and the shadow cast by Io (Fischer 1998/2001).

Figure 2-2. - Captured December 2, 1973 from the Pioneer 10 spacecraft.

(From Pioneer 10 and 11 Images, (2002). Retrieved October 12, 2006 from NASA, Pioneer Project Home Page Website: http://spaceprojects.arc.nasa.gov/Space_Projects/pioneer/PNimgs/PNimgs.html)

With the conclusion of the Pioneer 10 spacecraft, little information was discovered about Io, but the measurements of intense radiation the spacecraft recorded during its close encounter with Jupiter were absolutely crucial in developing the Voyager and Galileo spacecrafts (Pioneer 10 and 11, 2006).

Before Pioneer 10 even reached Jupiter, NASA had already launched its successor Pioneer 11 on April 5, 1973 (Pioneer 10 and 11, 2006). Although Pioneer 11 was essentially designed to study Saturn, its flight line carried it directly past Jupiter and on December 2, 1974, Pioneer 11 produced some of the most astonishing information about Jupiter and Io (Pioneer 10 and 11, 2006). Some of the images captured from Pioneer 11 found that the polar regions of Io had an orange color, which verified observations made in the mid 20th Century suggesting that Io's polar regions were red (Lopes & Williams, 2005). Not only did the data from Pioneer 11 allow researchers to make accurate estimates of the masses of the Galilean moons, but they also discovered that the density of each moon decreased as the distance from Jupiter increased (Fischer 1998/2001).

The most astonishing discovery about Io during the Pioneer 11 mission, was possibly made while image analysts were identifying patterns inside Jupiter's inner radiation belt resulting from the Galilean moons "stirring the magnetic atmosphere" (Fischer 1998/2001). The effect was most apparent around Io and, upon further investigation

using the ultraviolet spectrometer, researchers discovered a colossal hydrogen cloud surrounding an expansive area of the moon (Fischer 1998/2001). This large hydrogen ring surrounding the moon could only be explained by a thin atmosphere on Io that would need to be constantly renewed by gases escaping from the subsurface of Io (Fischer 1998/2001). Similar tests on the other Galilean moons never resulted in any similar results as those on Io, suggesting for the first time that there was some other factor happening on Io than was previously thought (Fischer 1998/2001).

2.3. Voyager

Following the success of the Pioneer series, the Voyager series was the next platform NASA would study Jupiter and the Galilean moons. The primary objective of the Voyager mission was the exploration of Jupiter and Saturn, but eventually was extended to observe Uranus and Neptune as well (Voyager, 2006). Voyager II was launched on August 20, 1977, and, just over two weeks later, Voyager I soon followed (Voyager, 2006). Finally, in March of 1979, Voyager I flew past Jupiter and the Galilean moons, taking high resolution images and conducting experiments that provided researchers with more information than they ever could have imagined (Hamilton, 2003). The first images of Io sent back to Earth in March of 1979 provided scientists with their very first detailed look of the Galilean moon, as shown in the image below (Figure 2-3) (Fischer 1998/2001).

Figure 2-3. - Captured on March 2, 1979 by Voyager I spacecraft.

(From Astronomy Picture of the Day, (1999). Retrieved October 13, 2006 from NASA, Astronomy Picture of the Day Website: <http://antwrp.gsfc.nasa.gov/apod/ap990311.html>)

During the acquisition of all of the data from the Voyager I spacecraft, image analysts were still unsure if the small, dark, circular features with dark centers were volcanoes or impact craters (Fischer 1998/2001). Images of the other Galilean satellites of Callisto and Ganymede, which were both full of impact craters that seemed to be nonexistent on Io in even the highest spatial resolution images, were continually being transmitted from the spacecraft (Fischer 1998/2001). The image below (Figure 2-4) is the result of NASA researchers creating a stunning photograph of Io from numerous frames taken from Voyager I (Fischer 1998/2001).

Figure 2-4. - Made from several frames taken on March 4, 1979 by Voyager I spacecraft.
(From Voyager Images of Io, (2003). Retrieved October 13, 2006 from NASA, Jet Propulsion Laboratories
Website: <http://www2.jpl.nasa.gov/galileo/io/vgrio.html>)

Due to the photo above, Io's surface was considered by one geologist to resemble a pizza and the Galilean moon would retain the suggestive nickname "pizza" ever since (Fischer 1998/2001).

After three historic days of Voyager I extensively imaging Io, the greatest discovery was still yet to come. As the first Voyager flyby came to an end on March 8, 1979, Voyager I recorded one last image of Io from about 4.5 million kilometers away (Fischer 1998/2001). The image was meant to be a navigational photo taken with a long exposure on a black background with a few identifiable stars in the distance (Fischer 1998/2001). The result is shown in the Figure 2-5 displaying the edge of Io as a narrow sickle. But after further observation, another smaller sickle was further identified beyond the edge of the moon (Fischer 1998/2001).

Figure 2-5. - Captured on March 8, 1979 by Voyager I spacecraft.

(From Io's Volcanic Features, (2003). Retrieved October 13, 2006 from Views of the Solar System Website: <http://www.solarviews.com/eng/iovolcano.htm>)

The first impression of the puzzling sight was that it may be another moon that simply had never been discovered before (Fischer 1998/2001). However, JPL engineer, Linda Morabito, suggested that the smaller-sickle shaped entity was a large plume blasting into the air from an active volcano (Fischer 1998/2001). Morabito had just made the biggest discovery of the Voyager I mission by identifying the first extraterrestrial volcanic eruption (Hamilton, 2003). Morabito's discovery overshadowed all of the other surprises during the previous few days by providing researchers with the most likely explanation for the patterns of Io's surface (Fischer 1998/2001). Because of this discovery, image analysts went through all of the imagery collected over the previous three days and began to identify other ongoing eruptions on Io originating in nine different craters (Lopes & Williams, 2005). Io was quickly categorized as "the most volcanically active body in the solar system" (Fischer 1998/2001).

After further research into the surface processes occurring on Io, it was discovered that the volcanic activity actually affects Jupiter and its other surrounding moons (Voyager, 2006). The majority of the material expelled from Io's volcanoes returns to the surface (Fischer 1998/2001). Some material containing elements such as sulfur, oxygen, and sodium does not return to the surface and escapes to supply Jupiter's magnetosphere, which is the region of space surrounding the planet that is influenced by Jupiter's strong magnetic field (Voyager, 2006). These same elements were also discovered within Io's orbit where they can accelerate to speeds over one tenth the speed of light (Voyager, 2006).

The source of Io's constant volcanic activity was found not to be tectonic in origin, but rather from Io's position between Jupiter and the other larger moons (Fischer 1998/2001). The excessively powerful tidal forces created from Jupiter's gravitational force pull more intensely on the near surface of Io than the side facing away from the giant planet (Fischer 1998/2001). Despite the fact that Io always faces the same direction towards Jupiter, two of the other Galilean moons, Europa and Ganymede, constantly disturb Io's orbit into an elliptical one (Munsell, 2003). These extravagant forces constantly pushing and pulling on the Galilean moon, combined with its varying distance from Jupiter subject Io to tremendous tidal forces constantly changing the shape of Io (Munsell, 2003). These driving forces can cause Io's surface to rise or fall up to 100 meters (Voyager, 2006). Unlike the force of all volcanic activity on Earth, the immense amount of friction caused the constant tidal forces generates a significant amount more heat within Io than leftover radioactive elements ever could (Fischer 1998/2001). The expansive transfer of heat and materials across the thin surface crust is ultimately affected by the self-reinforcing melting process and molten core of the moon (Fischer 1998/2001). These forces keep much of Io's subsurface crust in a liquid form that is searching for any available discharge route to the surface to relieve the intense pressure (Munsell, 2003). Therefore, "the surface of Io is constantly renewing itself, filling in any impact craters with molten lava lakes and spreading smooth new floodplains of liquid rock" (Munsell, 2003).

This rationalization of the findings made by Voyager I gives a logical explanation for all of the observations made on Io, including the lava formations, volcanic plumes, and elements released into Jupiter's magnetosphere (Fischer 1998/2001). By the end of the Voyager I flyby, researchers were clear that an entirely new planetary system had been discovered and Head scientist, Ed Stone, went on to say, "I think we have had almost a decade's worth of discovery in this two-week period" (Fischer 1998/2001).

Once the Voyager I flyby ended on March 8, 1979, and all of the new discoveries of Io were realized, Voyager II was immediately assigned to systematically observe Io's volcanoes and their plumes (Fischer 1998/2001). Unfortunately, due to the path of Voyager II, new close-up images would not be achievable, but images from different perspectives than Voyager I would still prove to be very useful (Fischer 1998/2001). It was not until July 1979 that Voyager II would reach Jupiter and its moons, but some of the first images made it apparent that Io had undergone some changes (Fischer 1998/2001). Voyager II was able to observe eight of the nine volcanoes Voyager I originally captured (Lopes & Williams, 2005). It was observed that some of the volcanoes were still active, while others had stopped all activity (Fischer 1998/2001). With some comparison to the Voyager I images, researchers discovered that plumes from some of the volcanoes were reaching heights over 300 kilometers above the surface at velocities surpassing one kilometer per second (Voyager, 2006).

In spite of a few electronic failures caused by Jupiter's intense radiation, the Voyager missions were a tremendous achievement (Fischer 1998/2001). With the success of the Voyager missions, one NASA official was quoted as saying that Voyager had achieved "a turning point in our cultural, scientific, and intellectual development" (Fischer 1998/2001). With regards to Io, researchers not only understood some of the significant physical, geological, and atmospheric processes occurring on the moon, but they could

also identify that these processes also affected the Jupiter as well (Voyager, 2006). Unfortunately, researchers would have to wait more than ten years until they could receive any new high resolution data on Io.

2.4. Ulysses

On October 6, 1990, NASA launched the Ulysses spacecraft to study the poles of the sun as well as the interstellar space perpendicular to the poles (Ulysses, 2006). Luckily for Io researchers, Ulysses needed to use Jupiter “for a gravity assist to swing out of the ecliptic plane and onward to the poles of the Sun” (Hamilton, 2003). As Voyager had previously discovered, materials that escape from Io are typically drawn to Jupiter’s magnetosphere (Voyager, 2006). The intense force of Jupiter’s magnetic field can actually pull about 1,000 kilograms of Io’s material per second (Munsell, 2003). Although scientific investigations were the secondary objective of the Ulysses spacecraft with regards to Jupiter and its moons, Ulysses was still able to observe the plasma torus surrounding Io and its interaction with Jupiter (Ulysses, 2006). The plasma torus is a doughnut-shaped cloud of intense radiation resulting from these escaping materials, predominantly sulfur and oxygen becoming ionized within the magnetic field (Munsell, 2003). Ulysses’ measurements of Io’s plasma torus were found to match previous model predictions based on the Voyager data sets (Marsden & Wenzel, 1992). However, the Ulysses data displayed some asymmetrical properties in the longitudinal distribution of the torus that was not accounted for from the Voyager data (Marsden & Wenzel, 1992). Although seemingly dwarfed by the discoveries made by the Voyager and Pioneer missions, the Ulysses mission provided researchers a significant amount of new information that contributed to the understanding of the intricately complex and vibrant plasma environment (Marsden & Wenzel, 1992). Similar to Pioneer 10, the status of the electronic instruments aboard the Ulysses spacecraft following the Jupiter flyby were crucial in the development of other spacecraft to be launched in the future (Marsden & Wenzel, 1992).

2.5. Galileo

All of the fascinating discoveries made by the Pioneer, Voyager, and Ulysses missions provided a wealth of information for researchers about Io, but also brought up a plethora of new questions about Io. The Galileo mission would finally answer some of these questions. The Galileo spacecraft was launched on October 18, 1989, actually one year prior to the Ulysses mission (Galileo, Journey to Jupiter, 2003). This was the first time that a spacecraft was sent to the outer solar system to orbit and study a single planet (Galileo, Journey to Jupiter, 2003). The major objective of the Galileo mission was to exclusively study Jupiter and its moons (Galileo, Journey to Jupiter, 2003). The Galileo mission was tremendously successful even before reaching its primary objective. En route to Jupiter, the Galileo spacecraft was the first mission ever to discover a small moon orbiting an asteroid, and was also responsible for the first recorded observations of a comet colliding with Jupiter (Galileo, Journey to Jupiter, 2003). The Galileo mission was also responsible for the first observations of Jupiter’s atmosphere using a descent probe (Galileo, Journey to Jupiter, 2003).

It was not until December 7, 1995, that the Galileo spacecraft finally began its two year mission of observing Jupiter and its satellites (Galileo, Journey to Jupiter, 2003). During that time, Galileo captured numerous images of volcanic eruptions on Io (Galileo, Journey to Jupiter, 2003). One of the first conclusions made from observations by the Galileo spacecraft was that Io's volcanism was far more complex than researchers first imagined (Fischer 1998/2001). New eruptions were found and some of the observed eruptions were at the same sites that the Voyager mission had also observed in 1979 (Fischer 1998/2001). In some regions, new lava flows and eruptions were discovered while some volcanoes had actually moved sixty kilometers away leaving a dark trail in their path (Fischer 1998/2001). All of the changes of surface feature structure, position, and color evident in the Io landscape gave researchers the impression that both typical sulfuric and silicate volcanism were contributing to the surface changes on Io (Fischer 1998/2001).

The Galileo spacecraft was equipped with numerous instruments capable of observing Io in wavelengths throughout the visible, infrared, and especially the thermal spectrum, which specifically assisted researchers in identifying hot spots on Io (Fischer 1998/2001). Using this technology, researchers identified about twenty different features over 10,000 square meters in size with temperatures surpassing 700° Celsius (Fischer 1998/2001). Of the forty-one active centers observed by the Galileo mission, twelve of the hot spots were recorded hotter than 1200° Celsius, and one even reached temperatures up to 1700° Celsius (Fischer 1998/2001). The only possible explanation for such high temperatures is that the lava must contain magnesium-rich silicates (Fischer 1998/2001). After identifying all of the hot spots on Io, researchers hypothesized that the hot spots were actually not distributed at random but seemed to form rings that surround two regions rich in sulfur dioxide (Fischer 1998/2001).

With the data from the Galileo mission, German photogrammetrists were also able to ascertain the precise shape of Io as a tri-axial ellipsoid rather than a sphere (Fischer 1998/2001). The longest axis of Io points towards Jupiter while its shortest axis, which is fifteen kilometers shorter, points in the direction of the moon's orbital motion (Fischer 1998/2001). This discovery only furthered the observations made during the Voyager missions that the tidal action by Jupiter and the other moons is responsible for Io's tremendous internal heat and volcanic activity (Fischer 1998/2001).

The Galileo spacecraft's closest encounter with Io provided researchers with critical information about Io's magnetic field, and eventually its core (Fischer 1998/2001). Jupiter's magnetic field is actually disrupted by Io (Fischer 1998/2001). This disruption has been hypothesized to be caused by Io's own source of magnetism located in its metallic core with some residual plasma effects from Io's ionosphere (Fischer 1998/2001). After analyzing the effect of Io's gravitational field on the Galileo spacecraft, the only conclusion researchers could make is "that Io possesses a large metallic core" (Fischer 1998/2001). The composition of the core is still unknown but most researchers agree that it must be comprised of iron and/or iron sulfide (Fischer 1998/2001).

The Galileo mission had been so successful that at the end of its mission on December 7, 1997, NASA approved an additional two-year study known as the Galileo Europa mission to specifically study Europa, Jupiter's thunderstorms, and the volcanoes on Io

(Galileo, Journey to Jupiter, 2003). After an additional two years of data collection, NASA once again lengthened the mission an additional two years, known as the Galileo Millennium mission (Galileo, Journey to Jupiter, 2003). The additional four years were critical in identifying over 300 active volcanoes on Io (Fischer 1998/2001). With the increased frequency of flybys, Galileo observed that some of the smaller volcanoes that appeared to turn on and off while some of the larger volcanoes remain active for years and possibly decades (Fischer 1998/2001). The increased flybys also provided high resolution images of smaller areas that have provided researchers with some insight into the volcanic terrain of Io and some better views of extraordinary surface features (Fischer 1998/2001). Continued monitoring of Io's volcanoes made it apparent that the excessively high temperatures of the lava flows imply that the lava must be "composed of rock that was formed by a very large amount of melting of Io's mantle" (Fischer 1998/2001). This suggests that the interior of Io may be comprised of a molten mush of magma and crystals (Fischer 1998/2001). This hypothesis could clearly explain the presence of excessively hot areas, mountains, calderas, and volcanic plains (Fischer 1998/2001). With all of these features, Io give researchers the opportunity to study large, global scale magma systems that may have been a crucial factor in the formation of the Earth (Fischer 1998/2001).

The Galileo mission came to an unfortunate end on September 21, 2003, when the spacecraft was deliberately destroyed to protect one of its own discoveries (Galileo, Journey to Jupiter, 2003). The Galileo spacecraft was redirected into Jupiter's crushing atmosphere to prevent it from ever colliding with the icy moon of Europa (Galileo, Journey to Jupiter, 2003). Possibly one of Galileo's biggest discoveries was the possibility of an ocean beneath the icy crust of Europa (Galileo, Journey to Jupiter, 2003).

2.6. Galileo Instruments

2.6.1. SSI

The solid state imaging device (SSI) on the Galileo spacecraft was specifically designed to capture images of the most colorful moon in the solar system, at a resolution between 0.5 and 25 kilometers (Lopes-Gautier et al., 2000). Furthermore, imaging scientists mapped the variations in color and albedo to compare the observations made during the Voyager mission (Belton, n.d.). To accomplish this, the SSI was designed using a catadioptric telescope with a field of view of 8.1 milliradians (mrad) and a focal length of 150 centimeters (Belton, n.d.). Primarily concerned with the visual spectrum, the telescope was capable of detecting a spectral response between 0.4 and 1.1 micrometers. An eight position filter wheel was installed to allow the capture of images through different filters, which needed to be electronically combined on Earth to produce color images (Belton, n.d.).

Unfortunately, the green and violet filters within the SSI only allowed it to capture false color images at high spatial resolutions, but nonetheless these images provided researchers with a close approximation of true color (Williams, Keszthelyi, et al., 2005). McEwen et al. (2000) determined that the false color, high spatial resolution images from the SSI are essential for detailed interpretations and interpolations of the surface

processes on Io. Some of the surface characteristics that were easily identified by Williams, Keszthelyi, et al. (2005) within the high resolution imagery were plains, patera floors, flows, mountains, diffuse deposits, and volcanic plumes.

The SSI was also capable of detecting areas of surface temperatures above 700 K where recent volcanic eruptions have occurred making its data invaluable for contrasting cool and hot components such as volcanic plumes and hot spots (Williams, Keszthelyi, et al., 2005). Despite the variable functionality of the SSI, Spencer et al. (1997) found through ground observations that even bright infrared activity on the surface of Io does not always produce any visible surface changes at the collection resolution of the SSI.

2.6.2. NIMS

The near infrared mapping spectrometer (NIMS) was a state-of-the-art remote sensing instrument designed specifically for planetary spacecraft, and was capable of both spectroscopy and imaging (Carlson, n.d.). The NIMS instrument was designed using a Ritchey-Chretien telescope also equipped with a spectrometer (Carlson, n.d.). The NIMS instrument was sensitive to wavelengths from 0.7 to 5.2 micrometers, allowing it to capture surface images of the Galilean moons and data within the infrared spectrum (Carlson, n.d.).

The major objective of the NIMS instrument was to observe the surfaces of the Galilean moons and map the surface minerals at a spatial resolution of 5 to 30 kilometers (Carlson, n.d.). Due to the pattern of the spacecraft's orbit during the Galileo mission, the spacecraft was never capable of acquiring images of Io's surface at the desired scale (Carlson, n.d.). The NIMS instrument was required to make distant observations of Io resulting in imagery of spatial resolutions between 120 and 600 kilometers (Carlson, n.d.). Fortunately, the NIMS instrument was able to collect imagery of Io in every Galileo orbit that came within viewing distance of the Galilean moon (Carlson, n.d.).

With regard to Io, the NIMS instrument was responsible for monitoring the moon's volcanic activity, determining the mineral composition of the surface, and measuring the temperatures of the surface hot spots (Carlson, n.d.). Originally, the NIMS instrument was designed to capture images in 360 wavelengths, but during the mission the instrument's spectral scanning capability malfunctioned and the instrument was limited to fourteen wavelengths (Lopes-Gautier et al., 2000). Because the wavelength sensitivity of the NIMS instrument overlapped those of the SSI, most of the collected infrared data was an immensely valuable complement to the simultaneously collected SSI data, by providing a contrast of compositional information and surface temperature estimations (Spencer et al., 1997).

2.6.3. PPR

The photopolarimeter radiometer (PPR) was a Cassegrainian Dall-Kirkham telescope specifically constructed to observe light in the visible and infrared wavelengths to produce information about the atmospheric composition and thermal energy distribution of the celestial bodies it was observing (Hansen, n.d.). The space-view telescope had a 10 centimeter aperture, a 50 centimeter focal length, and a circular instantaneous field of view of 2.5 milliradians (mrad) (Hansen, n.d.). One of the major objectives of the PPR instrument was to determine the "spatial distribution of reflected solar radiation and

emitted thermal radiation for Jupiter and its satellites” (Hansen, n.d., para. 1). Consequently, the PPR instrument was “used to measure the intensity and polarization of sunlight, in the visible portion of the spectrum, which is reflected from the Jovian satellites and Jupiter” (Hansen, n.d., para. 2). Essentially, the PPR instrument was a polarimeter, photometer, and radiometer combined into a single instrument (Hansen, n.d.).

With regard to Io, the PPR instrument was primarily used in radiometry mode as a long wavelength, infrared, single aperture photometer, to detect thermal emission from cooler regions of the planets surface (Rathbun et al., 2005). The photometer was sensitive to temperatures ranging from sixty to several hundred degrees Kelvin, making it especially useful for distinguishing the thermal emissions from background temperatures and cooling areas surrounding volcanoes (Rathbun et al., 2005). Thermal emission data was typically captured from Io’s hot spots using both daytime and nighttime observations (Williams, Keszthelyi, et al., 2005). Williams, Keszthelyi, et al. (2005) also found that PPR data collected during the daytime may become contaminated by any reflected sunlight or discrete hotspots within the field of view, and the derived temperatures will not accurately indicate the actual temperature of the moon’s surface. Therefore, the PPR data collected during the daytime cannot be correctly interpreted quantitatively, but may still be used qualitatively to identify hotspots and other trends.

Rathbun et al. (2005) suggests that the only method to properly interpret the PPR data is to register the data with simultaneously recorded SSI and NIMS data. Registering the PPR data to the other images is relatively straightforward, if the images are captured from the same orbit of the Galileo spacecraft. Unfortunately, not all of the data collected by Galileo’s three instruments were captured simultaneously within an individual orbit, making registration of the data much more difficult, and sometimes near impossible (Rathbun et al., 2005).

2.7. Mapping Io

Integrating observations from all of Galileo instruments is the focus for several of mapping and analysis projects currently underway regarding Io. Planetary mapping remains a very useful and somewhat necessary technique to facilitate the interpretation of planetary surfaces, until the day that ground truth data can be obtained (Williams, 2005). One method of characterizing Io’s volcanic diversity is to make use of geologic mapping to possibly identify volcanic materials and their subsequent relationships with the local stratigraphy (Williams, 2005). Most of the mapping research done on Io is typically based on albedo variations, morphology, and spectral variations from the Galileo spacecraft, possibly classifying the produced planetary maps as geomorphological, rather than geologic (Williams, 2005).

Most recently, Williams et al. (2003) produced a geomorphological map of the Thor region on Io using a combination of SSI, NIMS and PPR data. The Thor region was initially chosen because of the multiple datasets available at a variety of resolutions and flybys to characterize the volcanism in the Thor region. The goal of their mapping process was to determine the diversity of volcanic features, eruption styles, and flow compositions within the Thor region and eventually compare and contrast Thor with other regions on Io. The comparison of these regions would include the search for

similarities and differences in volcanic activities and investigate the range of tectonic and volcanic activity on Io. By comparing the images taken from the Voyager missions, Williams et al. (2003) discovered that several of the newer dark lava flows around major plume events have reoccupied sites of earlier flows. They also identified large scale changes to the formation of the eruptive center of Zamama that produced one of the largest volcanic plumes to date. These discoveries brought them to the hypothesis that the differences of the surface features on Io are due to the relationship between tectonic and volcanic activity that occurs on and below Io's surface.

Williams' hypothesis seems to correlate with the previous research of McEwen et al. (2000), who investigated how the eruptions of Io's volcanoes modify the surface landscape and how some landforms are created. Some of the intriguing landforms observed by McEwen et al. (2000) were active lava lakes, curtains of lava, and lava flows surrounding numerous mountains, plateaus, and calderas. McEwen et al. (2000) hypothesized that the mountains, plateaus, and calderas on Io's surface are profoundly influenced by the tectonic activity and gravitational collapse of the moons surface. They also stated that the majority of the mountains on Io do not appear to be volcanoes, but more resemble large, tilted blocks bounded by steep scarps. Some of the high resolution images also reveal the presence of calderas cut into the sides of some mountains, insinuating a possible relationship between the two (McEwen, 2000). Many of these calderas may have been caused by the collapse of material over an evacuated magma chamber previously occupied by an active lava flow beneath the crust of Io (McEwen, 2000). McEwen et al. (2000) also hypothesized that the dominant lava activity and eruption styles of Io may possibly vary with latitude. They also observed at lower latitudes that the eruptions were longer lived than those in the higher latitudes. Unfortunately, no active plume events have ever been observed in the upper latitudes on Io.

The research of Lopes-Gautier et al. (2000) was specifically directed at the study of the thermal structure of hot spots, and active volcanoes on the surface of Io using NIMS infrared data. Infrared observations allowed the researchers to categorize areas of lighter terrain with lower thermal emissions, and areas of low albedo deposits directly correspond with the enhanced thermal emissions of volcanic activity. From these inferences, they could also conclude that irregular temperature distributions are consistent with areas of overlapping, cooling lava flows. This distinct discovery may also further validate Williams et al. hypothesis that recent, darker lava flows directly correlate with older, bright lava flows from a different acquisition time.

2.8. Summary

All of the discoveries on Io since Galileo first discovered the four Galilean moons of Jupiter in 1610 have provided scientists with progressively more information about Io. From the small observations made by the Pioneer missions, followed by the massive discoveries and advancements made by the Voyager missions, researchers were finally able to identify and categorize some of the features present on the surface of Io. The Galileo mission provided researchers with a tremendous amount of data from its key instruments and gave scientists insight into the surface processes on Io and how they are affecting the moon's surface. With the high resolution images captured by the SSI

combined with the thermal data captured from the NIMS and PPR instruments, scientists have not only been able to identify and categorize surface feature on Io, but also gauge the intensity and process of some volcanic activity on the moon.

By using information from the Voyager and Galileo missions, scientists have been focusing on developing geologic maps for numerous regions on Io. The goal is to eventually produce a geologic map of the entire moon that all Io researchers can agree on. The combination of the SSI, NIMS, and PPR datasets provides researchers with enough information to identify volcanic features on the surface of Io as well as the eruption styles and flow compositions of the observed features. Although there have been some planetary and geologic maps of Io produced using GIS, the NIMS and PPR datasets have never been directly utilized within them.

The combination and simultaneous visualization of the SSI, NIMS, and PPR datasets would be a valuable asset to researchers attempting to categorize the surface features and processes on the surface of Io. Current GIS systems could be a viable solution for storing, querying, analyzing and displaying all of the data captured by the Galileo spacecraft. The variability, versatility and manipulability of the display properties that are available to the user could prove to be an ability of the GIS that could optimize the interpretability of the data from the Galileo spacecraft. The GIS also allows the geographically referenced data to describe not only the location, but the characteristics of the spatial features being represented. GIS datasets can be stored within a controlled, centralized location that allows users instant access and easy distribution of the data. Within these central locations, the datasets can be assigned a common coordinate system to promote the sharing and comparison of the processed data sets.

Some of the datasets provided by the Galileo spacecraft are already in formats somewhat compatible with a GIS, but some spatial information needs to be assigned to the data. Transformations of some of the datasets is possible will need to be completed to successfully implement the use of GIS throughout the Io research community. Due to the vast amount of data collected by the Galileo spacecraft, it would be highly beneficial to prototype the implementation of Galileo data by isolation one area of Io with simultaneous coverage of numerous datasets from all three Galileo instruments.

3. Methodology and Data Processing

The methodology for this project involves the processing and transformation of data captured by the Galileo spacecraft into formats compatible within a GIS. Due to the overwhelming amount of data captured by the Galileo spacecraft, it was decided to prototype the process by selecting one area of Io with reliable data coverage from all three instruments. The Amirani region of Io was chosen for this project because of the availability of numerous overlapping datasets from each of the three instruments. The goal was to transform each of the provided datasets into additional datasets compatible with ArcGIS. Within a GIS, the data could be co-registered to a common coordinate system and would give potential users access to the tabular information as well. Also, with the compatibility of these datasets, they could be distributed to other researchers. Table 1 outlines the eight individual datasets for the project originally provided by the client.

Table 1. - Initial Data.

Name	Format	Purpose	Orbit
Color_Mosaic	Raster	Global Color Image	Multiple
BW_Mosaic	Raster	Global Grayscale Image	Multiple
SSI	Raster	Surface Image	24
NIMS_24	Raster	Multispectral Surface Image	24
NIMS_27	Raster	Multispectral Surface Image	27
PPR_24IN	Tabular	Surface Temperatures	24
PPR_24IS	Tabular	Surface Temperatures	24
PPR_27IN	Tabular	Surface Temperatures	27

A monochromatic and one color global mosaic were provided to serve as background images to compare and contrast with the other datasets. These global mosaics needed to be registered to the appropriate coordinate system of the project so that other datasets could be accurately registered to them. To compliment the global mosaics, two grids were added to the project to display the coordinate system with reference to the latitude and longitude of the moon. An additional annotation layer was also created that contains over 200 annotation features labeling the major surface features present on Io.

The SSI composite image was co-registered to the global mosaics to serve as background reference for the Amirani region. The two multispectral NIMS images were registered using the corner coordinates of each image. Two additional NIMS images were created by deriving the surface temperatures of the region by using the thermal bands of each

image. Three PPR datasets were provided in a tabular format and were transformed from their original coordinates to an ellipse type shape that was a more realistic representation of the Instantaneous Field of View (IFOV) of the instrument. The ellipses were created using a custom built script that calculated the ellipse shape based on the position of the spacecraft with relation to the position of the study area on the surface of the moon. A statistical surface was also derived from a combination of the three PPR datasets in an attempt to estimate surface temperatures throughout the Amirani region.

3.1. Processing Io Mosaics

Two global mosaics of Io were provided by the client in a Tag(ged) Image File Format (TIFF) format. One of the images was a high resolution monochromatic image and the other was a pseudo color image. These images were originally produced by the USGS using a combination of Voyager and Galileo data. The color image was displayed using three bands of red, green, and blue, but the metadata was no indication of the range of wavelengths used to capture or display the image. During the Galileo mission, the green and violet filters of the SSI malfunctioned and only captured false color imagery (Williams, Keszthelyi, et al., 2005). After some further processing on Earth, this false color imagery was manipulated to give researchers a closer approximation of the true color of Io.

The images were compiled using a simple cylindrical projection of Io and assigned a simple geographic coordinate system which allocates a unique location to any position on the moon based on a combination of latitude and longitude readings. The original images are in a coordinate system with 0° longitudes as the left extent increasing to the prime meridian of 180°, and eventually to 360° at the right extent. As for latitude, 0° is the center latitude while 90° is at the top extent and -90° is the bottom extent. As shown in the Figure 3-1, the coordinate system used for this project repositions 0° as the center meridian or longitude.

Figure 3-1. - Io coordinate system used for this project.

As compared to the coordinate systems used to map the Earth, the longitudes to the left or west of the prime meridian also increase in value as the distance from the prime meridian increases, but it may also be assigned a negative value or a west designation. To adhere to the Io coordinate system used for this project as shown in Figure 3-1, the images needed to be exported in halves. This was done by saving each half as a spatial subset of the original. Each of the mosaics was originally 11446 samples, so each half of the original image was equally exported by adjusting each subset to 5723 samples. This process worked well for the monochromatic image but after visual analysis, the color image had very poor resolution in some areas.

To compensate for these irregularities in the color image, a resolution merge was performed using the better resolution of the grayscale image. Within the software package called The Environment for Visualizing Images (ENVI), this is referred to as Image sharpening. Essentially, image sharpening merges a low resolution color image with a high resolution monochromatic image and resamples it to the highest resolution pixel between both images (ENVI User's Guide, 2005). The image sharpening process uses a Hue, Saturation, and Value (HSV) sharpening tool that "automatically resamples the hue and saturation bands to the high-resolution pixel size using a nearest neighbor, bilinear, or cubic convolution technique" (ENVI User's Guide, 2005).

Another name for this method is the color space transformation and substitution (Jensen, 2005). This transformation is typically used to "improve the interpretability of multispectral color composites" by retaining the spatial characteristics of panchromatic data while providing the spectral characteristics of the multispectral data (Jensen, 2005). This process involves transforming three spectral bands of a lower resolution data in Red, Green, and Blue (RGB) color space into three bands within Intensity, Hue, and Saturation (IHS) color space (Jensen, 2005). Once the multispectral image is within an IHS color space, the high resolution image has a contrast stretch applied to it so it approximately matches the variance and mean of the multispectral image's intensity band (Jensen, 2005). The contrast stretched high resolution image is then substituted for the intensity band and the modified IHS image is transformed back into RGB color space (Jensen, 2005).

As seen in Figures 3-2, 3-3, and 3-4, the results of the resolution merge produced a much clearer image that maintained the color of the original. Figure 3-4 displays a few areas of drastic change between the before and after images by utilizing a collage of comparisons between various subsets of the images.

Figure 3-2. - Global mosaic before the resolution merge.

Figure 3-3. - Color mosaic after the resolution merge.

Before Resolution Merge

After Resolution Merge

Figure 3-4. - Resolution merge subset comparisons.

The resolution merge result image was then exported in spatial subsets representing each half of the image. This method of exporting the resultant image as halves was necessary so each image could be efficiently co-registered to the coordinate system utilized in this project.

Within ArcGIS, the coordinate system needed to be set up before importing any images. Surprisingly, ArcGIS has an Io coordinate system within the solar system folder in its library of geographic coordinate systems. The Io 2000 coordinate system automatically sets the map units to decimal degrees but the user still needs to set the display units to decimal degrees.

The images imported into ArcGIS without any problems other than none of the images had any referencing at all. To properly register each of the images, a Visual Basic for Applications (VBA) program was written that created a new point shapefile with six points representing the known extents of the images. The six points were set with 0°, 180° and 360° longitudes and latitudes of 90° and -90°. At first the longitudes seemed correct but after processing some of the other data in this project, the 360° longitude was changed to -180°. This change seemed counter intuitive at first, but the coordinates of all the other data sets conformed to this set of points better than the originals.

Using the georeferencing tools within ArcGIS, each corner of the images was referenced with its corresponding point. Figure 3-5 shows the result of the referencing process of one of the monochromatic images.

Figure 3-5. - Screen capture of the georeferencing process.

Once both images were referenced, a quick visual check was performed to ensure the georeferencing was successful. Figure 3-6 is a pair of screen captures of the center of the mosaic to display the accuracy of the two images referenced beside one another. As displayed in Figure 3-6, the two images form one seamless image.

Figure 3-6. - Screen captures of reference mosaics beside one another.

3.2. Ancillary Data

The ancillary data were used in this project to make it easy for users to locate items on the surface of Io. To accommodate this, the world30 (ESRI, 2001) and latlong (ESRI, 2001) files from the ESRI data and maps package were imported into ArcGIS and simply exported using the Io coordinate system. Figure 3-7 shows the result and how efficient these simple files can be for referencing the surface of Io.

Figure 3-7. - Graticule lines on the monochromatic mosaic.

In addition to the graticules, an annotation layer was also created to give reference to all of the relevant surface features visible within the global mosaic imagery. These annotation features were created using a labeled reference map provided by the USGS. The result of these annotation classes allows researchers a quick reference to the surface features in the area they may be observing. Figure 3-8 displays a few areas of Io where the annotation class may assist in identifying features.

Figure 3-8. - Screen captures of Io's surface feature annotation.

3.3. Registering SSI Images

The SSI was designed to capture high resolution images of Jupiter and the Galilean moons. The orbits of the Galileo spacecraft were much different from those satellites we utilize on Earth. The Galileo spacecraft typically followed elliptical orbits around Jupiter simply passing by the Galilean moons. This meant that all of the images captured by the SSI would all be different sizes and resolutions. The SSI had an IFOV of 8.1 milliradians and an angular resolution of 10.16 urad/pixel (Belton, n.d.). The SSI data provided by the client was a mosaic of eighteen original SSI images taken during the 24th orbit of the Galileo spacecraft. Figure 3-9 diagrams the observation sequence for each of the images included in the mosaic.

Figure 3-9. - I24 AMSKGI01 observation sequence.

(From I24 SSI Io Observation Sequence, (1999). Retrieved December 8, 2006 from Elizabeth (Zibi) P. Turtle, University of Arizona Faculty Website: <http://pirlwww.lpl.arizona.edu/~turtle/ioplanning.html>)

The SSI utilized three swaths while collecting the eighteen individual images of the surface. As seen in Figure 3-9, this set of images was captured near the viewable extent of the moon from the spacecraft. As the SSI captured images closer to the edge of viewable area of the moon, the viewing angle from the collection area on surface to the spacecraft increased, making the geometries of the images inconsistent with one another. For example, the images on the right side of Figure 3-9 will have more distortion than the images on the left side due to the difference in viewing angle from the spacecraft.

The original SSI data was contained within an IDL program originally written by the client for displaying the data. The `amirani.pro` program needed to be compiled and ran within the IDL interface within ENVI to access the data. After the programs completion, the variables used in the program such as the SSI data, were accessible in ENVI by using the `import from IDL variable` command. The SSI image proved to be problematic when exporting because the pixel values of the SSI image ranged from -100 to 325. Initial exports degraded the quality of the image considerably, so the basic scaling equation in

Equation 1 was applied to the original image using ENVI's band math function. This equation allowed the image to be exported efficiently without degrading the image.

Equation 1. - SSI scaling equation.

$$NewSSI = fix((\frac{float(b1) - \min}{range}) * 255)$$

Fix is the integer function that will convert the entered band into an integer (ENVI User's Guide, 2005). B1 is the representative band to be converted as selected by the user (ENVI User's Guide, 2005). Float is the function that ensures the value used for the equation from the representative band is a floating point. Similar to the global mosaics, the SSI data was exported from ENVI as a TIFF file so that it could be imported into ArcGIS.

Also similar to the global mosaics, the SSI data had absolutely no referencing. The provided coordinates of the corners of the SSI image were given as 10 ° S to 40 ° N latitude and 60 ° W to 140 ° W longitude. The latitude coordinates were immediately changed to conform to the project's coordinate system using negative values for latitudes below the equator of Io. The VBA script developed to place the coordinate points for the mosaics was altered to now place points using the given coordinates for the SSI image. After importing the TIFF image and registering the corners to the given coordinates, it was obvious that the coordinates were not correct. As seen in Figure 3-10, neither the SSI nor the mosaic image shared any of the same surface features.

Figure 3-10. - Screen capture of first registration attempt.

Figure 3-11. - Location of first registration attempt.

After further review of a global mosaic map in Figure 3-11, it was discovered that the Amirani region was altogether on the other side of the moon from the position of the original coordinates. To compensate for this tremendous error, the longitude coordinates were transformed to negative values to conform the coordinate system. Similar to the mosaics, this seems counterintuitive, but the software would not deal with values over 180° very well. The image was imported and re-registered to the new coordinates. In this attempt, Figure 3-12 shows that the registration actually had the SSI image over the Amirani region. As displayed in Figure 3-13, the image actually shared features with the global mosaic but the features were still quite a distance from each other.

Figure 3-12. - Location of second registration attempt.

Figure 3-13. - Screen capture of second registration attempt.

Solving the locational error revealed yet another error. To compensate for this error, the image was vertically flipped and the registration was completely reversed. As displayed in Figure 3-14, the bottom right corner needed to be registered to the top right corner, and the top left corner needed to be registered to the lower left corner.

Figure 3-14. - Screen capture of vertically flipping the SSI image.

This reversal was much closer but still did not provide perfect results. Figures 3-15 and 3-16 display the differences of the surface features in both images.

Figure 3-15. - Screen capture of third registration attempt.

Figure 3-16. - Two screen captures of the difference between surface features.

The original coordinates were sufficient enough to place the SSI image close to the surface features, but the only way to accurately reference the image was to georeference the SSI image directly to the mosaic using the apparent surface features. Fifty control points of similar features in each image were selected to transform the SSI image. A first order polynomial (affine) transformation was applied to the SSI image using the fifty control points. “A polynomial equation provides a mathematical model for differential scaling and rotating across an image” (Chang, 2004). This transformation was successful in rubber sheeting the image to match the surface features in the global mosaic. As displayed in Figure 3-17, the surface features matched flawlessly with an RMS error under 0.29.

Figure 3-17. - First Order Polynomial Transformation result.

Despite the accuracies displayed by the first order polynomial transformation, it was inappropriate to utilize that transformation. As discussed earlier, all of the images in the mosaic were captured at different viewing angles from the spacecraft, making the geometries between all of the images inconsistent with one another. Because of this, the simple shift performed by first order transformation could not precisely transform the SSI image. To increase the accuracy of the transformation, a second order polynomial transformation was performed to attain a more desirable result. Figure 3-18 displays the results of the second order transformation which produced substantially less error than the first order.

Figure 3-18. - Second Order Polynomial Transformation result.

For even more accurate results, a third order polynomial transformation resulted in an RMS error of 0.10 as shown in Figure 3-19.

Figure 3-19. - Third Order Polynomial Transformation result.

Figure 3-20 is a collage of screen shots displaying some of the predominant surface features in the Amirani region of Io and the accuracy of the SSI registration using a third order polynomial transformation.

Figure 3-20. - SSI surface feature collage.

3.4. Processing NIMS Data

Similar to the SSI images, the final images needed to be imported from an IDL variable provided by running the amirani.pro program. This program resulted in 2 multispectral images from the 24th and 27th orbit from the Galileo Mission. The images recorded data in 15 different wavelengths ranging from 0.587 to 4.697 micrometers. Each band recorded data in the following wavelengths listed in Table 2.

Table 2. - Wavelengths of the NIMS instrument bands in microns.

1	0.587000	4	1.31280	7	2.43840	10	3.28310	13	4.13260
2	0.725800	5	1.59280	8	2.71760	11	3.56590	14	4.41450
3	1.03480	6	1.87370	9	3.00070	12	3.84890	15	4.69670

The images in Figure 3-21 are the resulting images using band 4 as a monochromatic image.

Figure 3-21. - NIMS 27 and 24 datasets displayed using band 4.

Each image was exported as an IMAGINE and ArcView.bil file containing all of the spectral bands of the images. Although these images allow the researchers with the full

information of all fifteen bands of the spectrum, they do not provide any relevant temperature information. Extracting the temperatures of each image was done through two additional IDL programs called tempfit.pro and tempfit27.pro. These programs were written and provided by the client to calculate the individual temperatures for each cell in each images. Each resulted in a new image that solely represented the surface temperatures of the moon as recorded by the NIMS instrument. Figure 3-22 displays the results of those images.

Figure 3-22. - NIMS 27 and 24 temperature datasets.

The statistics from the NIMS 24 and NIMS 27 temperature images shown in Figure 3-23 display a maximum temperature of 306° Kelvin and the data distribution begins near 200°.

Figure 3-23. - Statistics from the NIMS 27 and 24 temperature datasets.

Exporting the images to a useable format in ArcGIS proved to be more difficult than initially expected. The first export attempt was made using the ESRI GRID format from ENVI. This method appeared to convert the original values of the raster to eight bit values ranging from zero to 255. The entire standard image formats available in ENVI such as TIFF and IMAGINE all maintained the integrity of each image but also converted the entire image to eight bit pixel values and did not retain the actual temperature values of each pixel. It was decided to convert all of the data values to integers before exporting. The conversion was accomplished using Equation 2 in ENVI's band math function.

Equation 2. - ENVI's band math integer equation.

$$newimage = fix(b1)$$

(From ENVI User's Guide (2005) Research Systems Inc., Boulder, CO)

Fix is the integer function that will convert the entered band into an integer (ENVI User's Guide, 2005). B1 is the representative band to be converted as selected by the user (ENVI User's Guide, 2005). For each image, the result appeared exactly the same as before, only the data values now only appeared as integers. All of the data values calculated by the tempfit programs were to a precision of two decimal places. At most, the integer function removed up to one degree of difference between the original calculated values. For the precision of this project, one degree Kelvin would not make any significant differences between the variation of hot spots throughout the datasets and the cooler areas. The export using the GRID function was attempted again with no success again. Rather than exporting in image formats, the images were exported in a simpler format, ASCII. ENVI allows the user to export any image in ESRI ASCII GRID

format. These obviously produced ASCII text files that would need to be imported into ArcGIS.

ESRI's ArcToolbox contains a multitude of functional tools including numerous conversion tools. Fortunately, there is an ASCII to Raster tool that easily converts ESRI ASCII files into useable rasters within ArcGIS. Figure 3-24 is a screen capture of the ASCII to Raster tool interface.

Figure 3-24. - ESRI's ASCII to Raster tool interface.

The resulting images are remarkably similar to the originals exported from ENVI and maintained all of the original temperature values. Figure 3-25 is the result of the ASCII to Raster tool.

Figure 3-25. - ASCII to Raster tool result.

Now that the rasters were imported into ArcGIS, they still needed to be registered to their correct coordinates. For the 24th orbit data, the latitude range is 17° to 27.6° and the longitude range is 240.6° to 250°. For 27th orbit data, the latitude range is 10° to 37° and the longitude range is 237° to 254°. Another VBA script was created using the SSI script that placed four new reference points for each NIMS raster. The four points were placed

at their exact coordinates and the images exported earlier were referenced using bands from the visible spectrum to ensure the accuracy of the points. Unlike the SSI images, the NIMS images needed to be rotated 180° for each image to accurately line up with the surface features present on the global mosaics. The first registration of the 27th orbit data was a success. Figure 3-26 shows that the surface features line up perfectly with the features visible in the image.

Figure 3-26. - Registered NIMS 27 dataset.

Using the same technique, the temperature raster for the same orbit was registered as well. Figure 3-27 is the result of the temperature dataset registration.

Figure 3-27. - Registered NIMS 27 dataset.

As displayed in Figure 3-27, the registered temperatures display higher temperatures within the elongated black surface feature within the global mosaic. Observing the accuracy of the 27th orbit data, registration was carried over to the registration of the 24th orbit data as well. The same 180° technique was used on the next dataset to another astonishingly accurate data registration. Unfortunately, the 24th orbit data was a smaller surface area and made it a little more difficult to perfectly register the data, but visual comparisons suggested the registration was correct. Figure 3-28 displays how difficult it is to determine the overall accuracy of the registration.

Figure 3-28. - Registered NIMS 24 dataset.

The same registration method was then again applied to the temperature raster and similar results to the 27th orbit data was displayed here. As seen in Figure 3-29, the hot spots of the 24th orbit data also seemed to coincide with the dark elongated surface feature.

Figure 3-29. - Registered NIMS 27 temperature dataset.

3.5. Processing PPR Data

3.5.1. Raw Data Processing

The PPR data was initially provided by the client, but the tables are also publicly available at the Planetary Data System hosted by NASA at <http://pds.jpl.nasa.gov>. For this project, two datasets from the 24th orbit and one dataset from the 27th orbit of the Galileo mission were utilized. These datasets are labeled 24IN, 24IS, and 27IN.

The PPR datasets were stored in ASCII tables under extensions .geo and .rad files. Through a little experimentation with Microsoft's Notepad, Word and WordPad, it was found that WordPad was the best solution for extracting the data from these files. Figure 3-30 and 3-31 display the inability of Microsoft Word and Microsoft Notepad to maintain the structure of the ASCII tables once imported into them.

```
24ISAMSGI01 FROM PPRW992851427.3050244Q PROCESSED 1999/11/16
PPR GEOMETRY GENERATOR FOR .RAP FILES - VERSION JULY 1997
ADJUSTED SCLK LAT LON RA DEC INC EMI PHS DLIMB
SIPDIS TRANGE SSCLON SSCLAT SSOLON SSOLAT CONE CLOCK
2.5207983/25.40 31.79 125.08 0.00 0.00 50.04 39.69 22.07 -1.52
2.364E+04 2.507E+04 145.68 0.47 168.36 2.94 159.19 187.27
5207983/26.10 32.17 124.59 0.00 0.00 50.58 40.27 22.05 -1.48
2.365E+04 2.507E+04 145.68 0.47 168.36 2.94 159.21 178.51
5207983/26.80 32.56 124.09 0.00 0.00 51.12 40.87 22.03 -1.45
2.367E+04 2.508E+04 145.68 0.47 168.36 2.94 159.22 169.78
5207983/27.40 32.89 123.66 0.00 0.00 51.60 41.38 22.02 -1.42
2.368E+04 2.508E+04 145.68 0.47 168.36 2.94 159.23 162.29
```

Figure 3-30. - PPR data in Microsoft Word.

```
24ISAMSGI01 FROM PPRW992851427.3050244Q PROCESSED 1999/11/16
.509E+04 145.68 0.47 168.37 2.94 159.25 153.55 5207983/28.80 33.14 12.
21.57 -1.27 2.377E+04 2.511E+04 145.68 0.47 168.37 2.94 159.68 94.300
0.00 64.14 49.90 20.94 -0.99 2.392E+04 2.513E+04 145.69 0.46 168.38
25.55 94.49 0.00 0.00 74.12 58.68 20.31 -0.61 2.417E+04 2.516E+04 1
297.458 5207984/75.80 17.05 90.92 0.00 0.00 77.21 59.64 20.08 -0.
168.59 2.94 161.25 229.538 5207984/81.40 16.71 90.97 0.00 0.00 77
2.586E+04 145.76 0.45 168.60 2.94 161.25 174.728 5207984/86.10 16.42
20.08 -0.57 2.491E+04 2.589E+04 145.76 0.45 168.60 2.94 161.25 118.710
0.00 44.01 28.79 22.28 -2.05 2.492E+04 2.654E+04 145.83 0.44 168.80
0 20.27 127.20 0.00 0.00 44.29 28.94 22.26 -2.04 2.495E+04 2.657E+04
82 128.228 5207986/43.10 16.61 114.72 0.00 0.00 54.96 37.01 21.42
+44 168.82 2.94 160.37 68.908 5207986/47.80 14.46 106.52 0.00 0.00
+04 2.664E+04 145.84 0.44 168.83 2.94 160.90 9.608
```

Figure 3-31. - PPR data in Microsoft Notepad.

Figure 3-32 shows that WordPad kept the original structure of the data making interpretation easy.

```

PPR RADIOMETRY DATA REDUCTION PROCESSOR - VERSION 1996/09/10
ADJUSTED RIM/MF RIM/MOD91 PFGAIN MEDCOPSM TEMPRID FRP/SDNA/SDNB RA DEC R
5399372/82.40 5399372/85 18 02 5 114 1736 7 R19 1389 1016 0.000 0.000
5399372/83.10 5399372/85 18 02 5 114 1736 7 R19 1395 1417 0.000 0.000
5399372/83.80 5399372/85 18 02 5 114 1736 7 R19 1379 1021 0.000 0.000
5399372/84.10 5399372/87 18 02 5 114 598 11 R19 1377 3488 0.000 0.000
5399372/85.10 5399372/87 18 02 5 114 598 11 R18 1405 2883 0.000 0.000
5399372/85.80 5399372/87 18 02 5 114 598 11 R18 1376 2895 0.000 0.000
5399372/87.10 5399372/90 18 02 5 114 2881+ 2 R18 1395 1025 0.000 0.000
5399372/87.80 5399372/90 18 02 5 114 2881+ 2 R18 1392 973 0.000 0.000
5399372/88.80 5399372/90 18 02 5 114 2881+ 2 R19 1375 1782 0.000 0.000

```

Figure 3-32. - PPR data in Microsoft WordPad.

The new WordPad files were saved and then the header information was removed to make the transition to excel spreadsheets and access databases easier. With the .rad files, the headers were removed as well as a few spaces were placed in between some of the field names to help the conversion to the spreadsheet and maintain all of the data associated with each particular field. Each text file was then imported into Microsoft Excel using the basic text import wizard. Because all of the data were maintained and slightly adjusted in WordPad, the transitions were perfect as seen in Figure 3-33.

Figure 3-33. - Screen captures of the PPR data import into Microsoft Excel.

3.5.2. Tables

For the .rad files, the final four fields were removed after the conversion because there was absolutely no data present within them. Each orbit had two tables associated with it containing different data. These tables needed to be joined before they could be utilized in the GIS. This was accomplished by using the Adjusted SCLK field in the .geo files, and the Adjusted RIM/MF field which contained common entries between both tables. Each table was sorted by the field and then the .rad tables were copied and pasted over. The sort was done based on an initial inspection. All data were actually collected in a time sequence and, after a second inspection, it was discovered that the sort was not actually necessary.

To ensure the integrity of the data, each table was thoroughly checked by visual inspection and a comparison was made of the two index fields. This was done by moving the Adjusted RIM/MF field over beside the Adjusted SCLK field and inspecting each data entry. The data inspection process was quite time consuming due to the large

number of observations in each table. The 24IN table has 333 entries, the 24IS table has 87 entries, and the 27IN table has 1299 entries.

After the thorough inspection of the individual data entries, some errors were found in the temperature readings of two of the tables. In the 24IN data set, there was one reading of a negative temperature (-70.9). In the 24IS data set, there were ten negative temperatures ranging from -136.5 to -88. All of these values are displayed in Figure 3-34. After consulting the project client, it was determined that the best way to deal with these outliers was to delete them from the tables. After deletion, the 24IN table had 332 data entries, and the 24IS table had 77 entries.

62	256	28	5207987/66	18	0	5	14 739 4	R18	1423	476	0	0	41.3	155.7
61	247	45	5207987/66	18	0	5	14 739 4	R18	1412	1426	0	0	30.5	147.6
61	239	88	5207987/68	18	0	5	14 743 8	R18	1381	1161	0	0	-0.1	-70.9
61	231	05	5207987/68	18	0	5	14 743 8	R18	1414	782	0	0	32.4	149.2
61	222	23	5207987/68	18	0	5	14 743 8	R18	1407	4031	0	0	25.5	143.3
61	214	67	5207987/90	18	0	5	14 3066 12	R18	1426	2836	0	0	44.2	157.6
R1	205	84	5207987/60	18	0	5	14 3066 12	R18	1408	2896	0	0	26.5	144.7

1

2

	S	T	U	V	W	X	Y	Z	AA	AB	AC	AD	AE	AF	
E	CLOCK	RIM/MDT91	PF	GAIN	MED	COPS	TEMP	RID	F	SPD	SDNB	R	DEC	RA(DM)	(TK)
32	69.1	5207983/36	18	0	5	14 1151 9	R18	1362	3027	0	0	-18.9	-136.5		
31	137.17	5207983/32	18	0	5	14 2895+1	R18	1363	2836	0	0	-17.8	-135.3		
25	103.22	5207985/ 3	18	0	5	14 1416 7	R18	1367	736	0	0	-14.3	-130.7		
25	127.05	5207985/ 1	18	0	5	14 747 3	R18	1372	733	0	0	-9.4	-122.9		
33	119.4	5207986/45	18	0	5	14 3046 12	R18	1372	2895	0	0	-9.1	-122.3		
25	229.53	5207984/62	18	0	5	14 1153 9	R18	1375	3037	0	0	-6.2	-116		
25	86.54	5207985/ 3	18	0	5	14 1416 7	R18	1379	777	0	0	-2.4	-102.9		
32	36.3	5207983/40	18	0	5	14 730 4	R18	1379	1449	0	0	-2.1	-101.3		
.3	77.74	5207986/49	18	0	5	14 1421 7	R18	1380	740	0	0	-1.1	-94		
25	174.72	5207984/68	18	0	5	14 736 8	R18	1381	1164	0	0	-0.6	-88		
22	169.78	5207983/28	18	0	5	14 4085+6	R18	1382	1151	0	0	0.8	90.9		
19	191.34	5207986/40	18	0	5	14 736 4	R18	1383	1459	0	0	1.6	98.2		

Figure 3-34. - Screen captures of the negative temperature values in 24IN and 24IS.

To ensure that the data points would align with the other data sets in the project, the given longitudes must be converted to the coordinate system being used in this project. This is achieved by subtracting the current longitude from 360 (See Equation 3).

Equation 3. - Coordinate system conversion.

$$NEWLON = 360 - LON$$

A new field title NEWLONG was created beside the LON field for each table and the above equation was applied to create the new longitude necessary for proper data alignment. Another longitude field was added to account for other coordinate systems that use longitude values from 0° to - 180°. This field was easily calculated in Equation 4 by multiplying the original longitude values by -1.

Equation 4. - Negative coordinate system conversion.

$$NEGLON = LON * (-1)$$

Transforming the data entries from their coordinates to a shape that more accurately represented the IFOV of the PPR instrument the surface of the moon was definitely a

challenge. Although the data entries were recorded as points by the PPR instrument, the IFOV of the PPR actually allowed the collection of data in a small, circular area on the moon. The temperature value recorded by the PPR instrument was recorded and calculated as an average of surface temperatures within the IFOV of the instrument at the time of acquisition (J. Rathbun, personal communication, November 30, 2005). Since the spacecraft was never directly above (nadir) the area it was observing, the actual area on the moon that the sensor observed will appear more like an ellipse type shape rather than a perfect circle. All of the information needed to correctly display the data entries is contained within the tables. The PPR instrument on the Galileo spacecraft had an instantaneous field of view of 2.5 milliradians. Using this knowledge with the distance of the spacecraft from Io allows us to employ basic trigonometric equations in Figure 3-35 to determine the shortest width of the ellipse on the surface of the moon.

Figure 3-35. - Trigonometric function.

(From Weisstein, Eric W. "Trigonometry." From MathWorld--A Wolfram Web Resource.
<http://mathworld.wolfram.com/Trigonometry.html>)

In Figure 3-35, θ represents half of the IFOV of the PPR instrument, and a represents the distance from the spacecraft to the surface of the moon. The desired result of the equation is to determine o which is the distance of the ellipses short axis or width. Since θ and a displayed in Figure 3-35 were provided by the data, the smallest radius of the ellipse on the surface of the moon was calculated by simply rearranging the equation as displayed in Equation 5.

Equation 5. - Rearranged tangent trigonometric equation.

$$o = \tan \theta * a$$

This is also known as the short axis of the ellipse, and is shown in Equation 6 as WIDTH using the known variables.

Equation 6. - Short axis equation.

$$WIDTH = \tan(IFOV) * DISTANCE$$

Equation 7 initially scales half of the 2.5 milliradian IFOV of the PPR instrument into radians and then converts the result into degrees before completing the tangent and multiplying by the distance.

Equation 7. - Short axis equation converting IFOV to degrees.

$$WIDTH = DISTANCE * \tan\left(\frac{(2.5/2)}{1000} * \frac{180}{\pi}\right)$$

After some preliminary calculations, it was noticed that the tangent of the angular measurement in degrees, resulted in the radian measurement before it was converted to degrees. Research into the actual equation of tangent resulted in an interesting discovery. Within the Function command in Microsoft Excel, the equation requires that the number entered into the TAN function must be in radians. With this development, Equation 8 is the result of a modification to remove the degree conversion in Equation 7 to accommodate this.

Equation 8. - Final short axis equation.

$$WIDTH_KM = SIPDIS * \tan\left(\frac{(2.5/2)}{1000}\right)$$

This equation was entered into a new field created called WIDTH. The equation was copied throughout all three tables of data so that the differing widths of each data entry could be calculated. The Radius was calculated in Kilometers. Unfortunately, the project's coordinate system only allows calculations to be completed in decimal degrees. Knowing that the radius of Io is 1815 kilometers (Fischer, 1998/2001), Equation 9 was used to convert the radius distance to degrees within a new field called Width_D.

Equation 9. - Equatorial kilometers to decimal degrees conversion.

$$WIDTH_D = \frac{(WIDTH_KM / 1815) * 180}{\pi}$$

Equation 8 calculates the distance along the equator of Io, but does not account for the variation of distances at different latitudes. For example, one degree of latitude at the equator will have a longer distance than one degree of latitude at 45 degrees latitude due to the spherical shape of the moon. Equation 10 finds the accurate difference in longitude based on the previously calculated distance at the equator and the latitude of the record being calculated.

Equation 10. - Short axis equation adjusted for spherical distances.

$$ADJ_WID_D = ACOS\left(\frac{WIDTH_D - SIN(LAT) * SIN(LAT)}{COS(LAT) * COS(LAT)}\right)$$

(From Weisstein, E. W. (1999). Spherical Trigonometry. Mathworld – A Wolfram Web Resource Website Retrieved September 21, 2006 from <http://mathworld.wolfram.com/SphericalTrigonometry.html>)

As mentioned for Equation 6, Microsoft Excel requires radian measurements to calculate trigonometric functions. Equation 11 is the result of further adjusting Equation 10 to accommodate for radians. The result of Equation 10 is the final short axis measurement in degrees on a spherical surface for each ellipse.

Equation 11. - Final short axis equation.

$$ADJ_WID_D = \frac{\left(ACOS\left(\frac{\frac{WIDTH_D * \pi}{180} - SIN\left(\frac{LAT * \pi}{180}\right) * SIN\left(\frac{LAT * \pi}{180}\right)}{COS\left(\frac{LAT * \pi}{180}\right) * COS\left(\frac{LAT * \pi}{180}\right)} \right) \right) * 180}{\pi}$$

For calculating the height, the coordinates of the spacecraft also needed to be converted to the projects coordinate system. This was done for each table the same way as the longitude calculated for the data recording position by adding a new field and calculating the new longitude using the Equation 12.

Equation 12. - Spacecraft position coordinate conversion.

$$NEWSSLON = 360 - SSCLON$$

The height (Long Axis) of each ellipse was much more complicated to calculate. The height of the ellipse was a function of the radius of Io, the difference of location from the spacecraft to the area on the moon being observed, and the width of the ellipse calculated earlier (Weisstein, 1999). The height equation shown in Equation 13 divides the width of the area by the cosine angle between two points on the moon surface (Weisstein, 1999). These points are the point of interest, and the point at which the spacecraft was directly above when the observation was taken.

Equation 13. - Long axis equation.

$$HEIGHT = \frac{WIDTH_KM}{\cos(Lat_1)\cos(Lat_2)\cos(Long_1 - Long_2) + \sin(Lat_1)\sin(Lat_2)}$$

(From Weisstein, E., W. (1999). Spherical Trigonometry. MathWorld - A Wolfram Web Resource Web site. Retrieved September 21, 2006 from <http://mathworld.wolfram.com/SphericalTrigonometry.html>)

Once again, because of Microsoft excel, Equation 13 had to be adjusted slightly so that the trigonometry functions could be calculated in radians. Equation 14 is the result of that adjustment.

Equation 14. - Long axis equation adjusted for radians.

$$HEIGHT_KM = \frac{WIDTH_KM}{\cos(\frac{LAT*\pi}{180})\cos(\frac{SSCLAT*\pi}{180})\cos(\frac{(LON-SSCLON)*\pi}{180}) + \sin(\frac{LAT*\pi}{180})\sin(\frac{SSCLAT*\pi}{180})}$$

To stay consistent with the WIDTH field and to ensure the accuracy of the calculations, a HEIGHT_D field was created and calculated to get a value in degrees. Equation 15 is the same as Equation 9 for Width to convert it to degrees.

Equation 15. - Long axis to decimal degrees conversion.

$$HEIGHT_D = \frac{(HEIGHT_KM / 1815) * 180}{\pi}$$

Drawing the ellipse within VBA requires different parameters than originally anticipated. After some refinement to the procedure, the ellipse command requires the major axis (height) of the ellipse and then a ratio of the major axis to the minor axis. Rather than each dimension of ellipse, it uses the smaller ratio to construct the minor axis of each ellipse. This was performed in using Equation 16 as a simple division equation in a new field named HI_WI_RATIO.

Equation 16. - Height to width ellipse ratio.

$$HI_WI_RATIO = \frac{ADJ_WID_D}{HEIGHT_D}$$

The final aspect of the ellipse shape is the angle at which it is drawn to. The angle to which each ellipse is drawn is derived from the azimuth from the point on the surface of the moon that the spacecraft was parallel too, and the actual point of observation (Wolf & Ghilani, 2002). An azimuth is derived from coordinates using the Equation 17.

Equation 17. - Calculated azimuth equation.

$$AZIMUTH_{AB} = \tan^{-1}\left(\frac{LON_A - LON_B}{LAT_A - LAT_B}\right) + CONSTANT$$

(From Wolf, P. R., & Ghilani, C. D. (2002). *Elementary surveying: An introduction to geomatics*. Upper Saddle River, NJ: Prentice Hall.)

The constant is zero if both $(LON_A - LON_B)$ and $(LAT_A - LAT_B)$ are greater than zero (Wolf & Ghilani, 2002). If $(LAT_A - LAT_B)$ is less than zero, the constant becomes 180 (Wolf & Ghilani, 2002). If $(LON_A - LON_B)$ is less than zero and $(LAT_A - LAT_B)$ is greater than zero, the constant becomes 360 (Wolf & Ghilani, 2002). Unfortunately due to the parameters required to effectively draw each ellipse, the above equation needs to be adjusted slightly. The major axis for each ellipse in this project is the height. Unfortunately, the major axis in the procedure created for this project draws the major axis as the horizontal axis where the vertical axis would be more accurate. To account for this, the result of the equation needs to be subtracted from 90°. Also, since Microsoft Excel uses radians as the default unit for its trigonometry functions, 90° was converted to radians ($\pi/2$). With some testing, it was discovered that subtracting the result from $(\pi/2)$ eliminated the need for the constant at the end of the equation. Also, the potential for division by zero needed to be accounted for if the two points were located on the same latitude. This was accomplished by an If statement that automatically assigns a value of zero in such a case. Therefore, Equation 18 was the final equation entered into Microsoft Excel.

Equation 18. - Adjusted azimuth equation.

$$AZIMUTH_R = IF((LAT - SSCLAT) = 0, 0, (\pi/2) - (\tan^{-1}(\frac{NEWLON - NEWSSLON}{LAT - SSCLAT})))$$

For the purpose of familiarity and comparison, the radian angle was converted to degrees in Equation 19 so that the analysts could verify the accuracy of the ellipse shape and angle.

Equation 19. - Azimuth converted into degrees.

$$AZIMUTH_D = \frac{AZIMUTH_R * 180}{\pi}$$

Figure 3-36 is a screen capture of the finished table and all of the calculated fields used for the construction of the ellipses.

AI	AJ	AK	AL	AM	AN	AO	AP
WIDTH_KM	HEIGHT_KM	WIDTH_D	HEIGHT_D	ADJ_WID_D	HI_WI_RATIO	AZIMUTH_R	AZIMUTH_D
32.300	41.432	1.019644	1.307930468	1.105585682	0.845293927	0.599720543	34.36145601
32.313	41.425	1.020039	1.307688917	1.106499819	0.846149115	0.602261261	34.5070284
32.313	41.404	1.020039	1.30704166	1.107069219	0.847003774	0.605015656	34.66484365
32.313	41.390	1.020039	1.306595438	1.107559058	0.847667936	0.607276986	34.79440828
32.313	41.367	1.020039	1.305866672	1.108050547	0.848517365	0.609831659	34.94078028
32.325	41.363	1.020434	1.305744004	1.109054911	0.849366267	0.612599362	35.09935798
32.325	41.351	1.020434	1.305361	1.109467517	0.849931565	0.614516349	35.20919326
32.325	41.337	1.020434	1.304933517	1.109715634	0.850400131	0.615873146	35.286932
32.338	41.365	1.020828	1.305817974	1.11022759	0.850216195	0.615786945	35.28199303
32.338	41.316	1.020828	1.304259137	1.11072554	0.851614153	0.619242437	35.47997813
32.338	41.240	1.020828	1.301874517	1.111225156	0.853557805	0.62360807	35.73011051
32.338	41.263	1.020828	1.302601832	1.10964875	0.851871019	0.616983076	35.35052631
32.350	41.317	1.021223	1.304284374	1.109995146	0.851037678	0.615447246	35.26252972
32.350	41.362	1.021223	1.305705403	1.110491071	0.850491289	0.615812433	35.28345338
32.363	41.352	1.021617	1.305404083	1.110837364	0.85095288	0.616340248	35.31369496
32.363	41.357	1.021617	1.305546116	1.110837364	0.850860303	0.616193013	35.30525903
32.375	41.361	1.022012	1.305674012	1.111681056	0.851423132	0.618116535	35.41546871
32.375	41.359	1.022012	1.305627467	1.111764121	0.851517105	0.618471921	35.43583081
32.375	41.365	1.022012	1.305815797	1.111681056	0.851330684	0.617968887	35.40700909
32.388	41.375	1.022407	1.306128435	1.111695489	0.851137958	0.616634901	35.33057733
32.388	41.339	1.022407	1.304993475	1.111447169	0.851687913	0.616895885	35.34553062

Figure 3-36. - Screen capture of the PPR table ellipse calculations.

3.5.3. Table Import

With all of the calculations completed, the tables were ready for import into the GIS. Each table was imported into Microsoft Access using the Link Spreadsheet Wizard. After the successful import, the file was immediately exported as a dBASE IV file which is easily readable within ArcGIS. To finally view the PPR data within a geographic space, each table was added to ArcGIS by importing each table. The Io mosaics were also added to ensure accuracy of the coordinate transformations. Each table was added to the ArcGIS display by utilizing the Add X/Y Data command in Figure 3-37 under the Tools heading at the top of the screen. The NEGLON field was used for the X field and LAT was used for the Y field.

Figure 3-37. - Screen capture of Add XY data interface.

The result of the addition of the X/Y coordinates revealed that the coordinate transforms were accurate. As displayed in Figure 3-38, all of the points from all three files are displayed within the study area. To make these files permanent, each was exported and saved as a point shapefile.

Figure 3-38. - PPR data added as XY coordinates.

3.5.4. Drawing Ellipses

Once these files were saved, the procedure to draw the ellipses could be run. The procedure was an independently developed VBA solution designed to add the PPR XY

data shapefile and draw ellipses around each point based on the individual information contained within the fields of the file. The important fields required for the program are Height, Width, Height to Width Ratio, and Angle. Once the ellipses are drawn, the procedure saves them to a new shapefile and adds them to the current display. The results of these procedures display that each set of ellipses had individually unique characteristics. Figure 3-39 shows the 24IN ellipses that were very close together and tilted to the right.

Figure 3-39. - PPR 24IN ellipses.

The 24IS data set covered the greatest area of the data sets and also had the lowest amount of points as well. The vast area covered by this data set displayed in Figure 3-40 really displays the importance of the angle and size calculations as the ellipses progressively become more elongated and tilted further towards the right.

Figure 3-40. - PPR 24IS ellipses.

The 27IN data set could possibly be the most difficult to interpret because all of the points are fairly close together. This data set also had the greatest amount of points reaching almost 1300. Figure 3-41 illustrates the complexity of this data set.

Figure 3-41. - PPR 27IN ellipses.

To capture all of the data from the original tables, the new ellipse shape files were joined to their corresponding point files through the FID fields. The join gives the new ellipse files all of the attributes from the original tables. The ellipse files were then exported and saved as shape files to absorb all of the relevant information and be contained within one single file. Figure 3-42 displays all of the PPR datasets in their ellipse form classified by temperature.

Figure 3-42. - All three PPR datasets represented by ellipses.

3.5.5. Interpolating Surfaces

Using the entire collection of PPR data points, statistical surfacing methods were employed to better interpret the distribution of surface temperatures in the Amirani region. Spatial interpolation is basically the estimation of values for an entire area using an irregular array of known data values (Chang, 2004). With regards to GIS, spatial interpolation estimates the values for every cell within a calculated grid (Chang, 2004). Therefore, spatial interpolation is a method of converting point data to a surface or raster data in order to be analyzed with other data. The value of this process is that researchers can estimate the value at any location of the study area with no recorded data through the interpolation of known temperature readings within close vicinity. Examples of common statistical surfaces used on earth include precipitation and population density (Chang, 2004).

Ideally for creating statistical surfaces, the control points used for the operation should be well distributed throughout the study area. Unfortunately, this is quite rare in most applications and is well demonstrated in Figure 3-39 where there is a large concentration of points in the center of the study area. Values estimated by spatial interpolating methods are assumed to be more similar to points closer to it than those which are further away (Chang, 2004). This is essentially the principle for the interpolation methods used to estimate the surface temperatures of the Amirani region.

The first interpolation method used to estimate the statistical surface was the inverse distance weighted method (IDW). The IDW method ensures that its estimations of each

cell in the surface are more influenced by points that are closest to it rather than points further away (Chang, 2004). The degree of influence a point will have on determining the value of a cell is expressed by the inverse of the distance from the cell to the known point raised to a user defined power (Chang, 2004). A higher power implies the rate of change within the surface is more drastic near a known point and decreases as the distance from the point increases (Chang, 2004). This is easily seen in the IDW surface calculated with the PPR data in Figure 3-43. Each individual point on the right side of the surface is heavily emphasized and the rate of change immediately surrounding them is vividly drastic.

Figure 3-43. - IDW interpolated surface.

Another surface was calculated using a geostatistical interpolation method called kriging. Somewhat similar to IDW, kriging assigns weights surrounding known values to estimate each cell within a surface (Chang, 2004). To put it simply, kriging investigates the spatial behavior of the data and estimates the values based on a semivariogram and the spatial arrangement of the known value points (Chang, 2004). The success of a Kriging interpolation heavily relies on the ability of the user to model the semivariogram. Unfortunately, the complexity of the spatial statistics behind kriging delves far beyond the scope of this project and will not be discussed. Despite this, a kriging surface was calculated using the default values in ArcGIS and resulted in the surface shown in Figure 3-44. The highly irregular resulting image further accentuates that the default values are probably not accurate and definitely does not produce a surface representative of reality.

Figure 3-44. - Kriging interpolated surface.

The natural neighbor method was the next interpolation method to be used and yielded surprising results. Natural neighbor interpolation simply estimates the cell of the surface based on the nearest known point (Chang, 2004). Although fairly simple, Figure 3-45 displays a drastic improvement in the smoothness of the surface. There is an issue with the linear similarities developing at the edges of the calculated surface making the overall surface look somewhat irregular.

Figure 3-45. - Natural neighbor interpolated surface.

To calculate another surface, the spline technique was used. Spline interpolation is a minimum curvature technique that ensures the surface passes through each known data value and has the least possible slope or curvature (Chang, 2004). The resulting surface displayed in Figure 3-46 perfectly displays why spline interpolations are recommended for smooth, continuous surfaces. Statistical surface created using the spline technique are susceptible to excessive estimations in data poor areas (Chang, 2004).

Figure 3-46. - Spline interpolation surface.

The final interpolation technique used was the topo to raster tool, also known as ANUDEM (Hutchinson, 1996). The topo to raster tool was initially designed to calculate hydrological correct digital elevation models by estimating values on a smoothed surface using data that was irregularly distributed spatially (Hutchinson, 1996). One of the keys to the success of the topo to raster function is the imposition of a global drainage condition that automatically removes any erroneous depressions that would otherwise interrupt the natural flow of a stream (Hutchinson, 1996). The algorithm also minimizes the rough weakness penalty and simultaneously imposes constraints in order to maintain the interconnected drainage structure of the area being observed (Hutchinson, 1996). All of these features make the topo to raster tool ideal for the PPR temperature data because of the algorithms optimization to calculate a smooth surface that is capable of measuring abrupt changes in the data. The result of this interpolation method applied to the PPR data calculated a very smooth surface with gradual changes throughout the surface. Figure 3-47 displays that there are still a few areas of abrupt change that is due to the lack of data throughout the outer extents of the data set. Also, a contour was calculated using the contour tool in ArcGIS so assist the surfaces interpretability.

Figure 3-47. - Topo to raster interpolation surface.

4. Geodatabase Design

To organize all of the processed data into a single storage container that retained all of the spatial attributes and geographic properties of the datasets was a critical part of this project. A geodatabase was utilized for this project because it allows the storage, retrieval, and processing of all spatial data for this project from a central location. All of the processed data could be presented and provided to the client in a single database that eliminated the need for any further processing. This organized set of data layers is the fundamental deliverable that allows researchers to interpret the various data sets and answer any questions they have about the surface of Io.

Due to the original data formats and immense amount of data processing for this project, the geodatabase was not constructed until all of the data had been processed and finalized. A personal geodatabase was utilized because of their simplicity to utilize and the relatively small amount of raster datasets to be contained within it. The final geodatabase is diagramed briefly in Figure 4-1.

Figure 4-1. - Geodatabase design.

4.1. Feature Datasets

Arctur & Zeiler (2004) describe feature datasets as organized collections of associated feature classes that share a common spatial reference and potentially network and topology objects as well. These feature classes are organized this way primarily to manage the spatial relationships common throughout the feature classes (Arctur & Zeiler 2004). The three feature datasets that were created contained all of the Ancillary, PPR, and Surface Feature data.

4.2. Ancillary

Contained within the Ancillary Feature Dataset are the three feature classes of Io30, IoLatLong, and Reference Annotation. The first two were previously created during the processing stage of the project and imported into their own feature classes. The Reference Annotation class is an annotation class created to contain the labels for the previous two feature classes.

4.3. PPR

A feature dataset was created to contain all three of the PPR files. The three PPR ellipse and point files were imported into the feature dataset to create the three distinct feature classes. Also, the contours developed for the PPR surface are contained within the feature dataset.

4.4. Domains

Domains are a way that the administrator of a geodatabase can assign a specific range of values that can be utilized throughout multiple attribute fields throughout the geodatabase. Domains ensure the integrity of the attribute values by limiting them to a specific range or choice of values. Integrity is maintained by restricting the user to select values from a specific list of coded values or from within a predefined range of values. All of the domains were created to be used across the geodatabase but the majority of them are only applicable to the PPR data. The domains were created by right clicking on the Geodatabase itself and navigating to the domains tab. Tables 3 and 4 list the ranged and coded domains used for the geodatabase.

Table 3. - Ranged domains.

Latitude	-90 to 90
Longitude	0 to 360
Negative Longitude	-180 to 180
PPR Temperature	60 to 600

Table 4. - Temperature class coded domain values.

1	< 100	6	140 – 150
2	100 – 110	7	150 – 160
3	110 – 120	8	160 – 170
4	120 – 130	9	170 – 180
5	130 – 140	10	> 180

To apply the temperature class coded domain to the PPR data, a subtype must be applied. Subtypes are similar to coded domains but within a subtype, the corresponding subtype label will be present in the attribute table instead of the coded subtype integer. Subtypes allow easier interpretation of the data by allowing a further classification of the data without manually classifying each dataset. This was done by using the temperature field to classify the temperatures into ranges of ten. An additional field called T_K_Subclass was created to host the short integer values for the subtype. Each value in the class was calculated by querying the T_K field for the ranged values. Equations 20, 21, and 22 are examples of the queries used to calculate the fields.

Equation 20. - Less than 100 query.

$$[T_K_]<100$$

Equation 21. - 120 to 130 query.

$$[T_K_]>=120\text{ AND }[T_K_]<130$$

Equation 22. - Greater than 180 query.

$$[T_K_]>=180$$

In ArcCatalog, the subtype was then applied by using the properties of each feature class and navigating to the Subtypes tab. The T_K_Subtype field was the chosen subtype field and the values were once again entered into the subtype codes. Also at this time, the domains mentioned before could be applied. The result of the subclass is that the feature classes are already classified once imported into ArcGIS so that the client and other users will not have to go through the repetition of classifying every time the file is used.

4.5. Surface Features

The Surface Features feature dataset was created to contain an annotation class that labeled all of the prominent surface features on Io. At this time, there is only one feature class within the feature dataset to do this, but it also leaves room for any expansion for other annotation possibilities.

4.6. Raster Datasets

A Raster Dataset is a container capable of representing numerous continuous valid raster data layers in a single, continuous dataset (Arctur & Zeiler 2004). Numerous raster data layers that overlap can be mosaiced together to form these continuous raster datasets (Arctur & Zeiler, 2004). Both the monochromatic and color mosaics of Io were created using the mosaic feature available through raster datasets. The other four raster datasets containing the NIMS, PPR Surface, and SSI data are all derived from a single raster data layer.

4.7. Mosaics

Each of the global mosaics was loaded into its own individual raster datasets within the geodatabase. This was done by importing the two composite images of each color representation using the Import Raster Datasets (mosaics) tool. This tool mosaics the input rasters and creates a single raster dataset within the geodatabase. During the import, the Io coordinate system was also selected. The only difference was that the two color mosaics needed three bands specified during the import process. Obviously, the monochromatic image required only one band to be successful.

4.8. NIMS

Each of the NIMS datasets was imported individually into its own raster dataset within the geodatabase. Once loaded, pyramids were built to improve the performance of the dataset. Pyramids are created to improve the display speed of raster datasets by re-sampling the data into a series of low resolution images varied in detail by the extent being viewed (Arctur & Zeiler, 2004).

4.9. PPR Surface

The PPR Surface was imported into the geodatabase using the same method as listed in the NIMS raster dataset. Similar to the NIMS dataset, pyramids were built to improve the performance of the dataset.

4.10. SSI

The SSI raster layer was imported into the geodatabase using the same method that was employed with the NIMS datasets. The final 3rd Order Polynomial Transformation image was loaded into the SSI raster dataset. Also similar to the NIMS datasets, pyramids were built to improve each datasets performance.

4.11. Metadata

Information about all of the instruments used for this project are available through the NASA and JPL websites. With regards to the GIS data, all of the metadata for the files created and manipulated in this project were created to facilitate the understanding of the data representations and the processes used to modify the datasets into their current formats. All of the metadata is available within each dataset by viewing their properties within ArcCatalog which accompanies all license levels of ArcGIS Desktop. The original and processed data is available through the University of Redlands or Dr. Julie Rathbun.

5. Distribution System

The researcher is potentially the most important part of the system as they are responsible for accessing the system and deriving useful information from the data. Since, the researchers are the purpose for the system, so the system must be built to satisfy their requirements. The vessel in which all Io researchers will be able to view the collection of data within the Amirani region will be a stand-alone ArcIMS website that will provide them with GIS functionality to view and manipulate the data. Upon the completion of the project, researchers will be able to characterize features and their distribution within the Amirani region of Io, which is essential for identifying the active volcanic and tectonic processes on the Galilean moon.

All of the data will need to be simultaneously displayed to the end user for interpretation and analysis. Since most of the end users will not be located at nearby facilities, an application will need to be developed so that the numerous interested researchers could simultaneously view the data from remote locations. An ArcIMS website will be ideal for this application because the site will be available to any of these researchers through a basic internet connection. All of the processing and data storage will be contained within the central server, making the user interface efficient enough to run on numerous types and degrees of personal computers. The default user interface will allow the designer to employ the use of basic GIS functionality such as zoom and pan. Also, the customization ability of ArcIMS will be relatively simple, making a representative user interface easy to construct. This interface could be simplified to accommodate users of the system that have minimal GIS exposure and experience. Figure 5-1 displays the custom designed user interface that researchers will be available to access at http://lucy.institute.redlands.edu/website/Io_Prototype. The interface will be customized to represent an Io type theme and will be simplified for those researchers who have limited GIS experience.

Figure 5-1. - Screen capture of the Io website created for this project.

Users could utilize any of the functional tools located on the right side of the interface, as shown in Figure 5-1, to explore and visualize the data to their needs. Functionality included in the design interface is all outlined in Figure 5-2.

Figure 5-2. - Website button functionality.

The toggle between legend and layer list function will allow the user to change the display bar on the right side of the interface to either display the layer list or the legend of the currently displayed layers. Figure 5-3 displays the difference between the layer list and the legend.

Figure 5-3. - Layer list and legend toggle.

The toggle overview map button will allow the user to view or remove the overview map in the top right corner of the map display. The zoom functions will obviously allow the researcher to increase or decrease the scale at which they are viewing the data. There are five zoom features including zoom in, zoom out, zoom to full extent, zoom to active layer and zoom to last extent. Zoom in and out simply increases or decreases the scale by a predetermined increment or by a user defined box to determine the scale at which the data will be viewed. The zoom to full extent will automatically scale the viewing frame to a scale at which all active data layers will be visible. Similarly, the zoom to active data layer will automatically scale the viewing frame the extents of the active layer as selected in the layer list. The zoom to last extent function will simply rescale the viewing frame to the previous extent. The zoom features are critical for this project because the Amirani region is only a small are of Io. Figure 5-4 individually demonstrates the zoom functions.

Reference Scale

Zoom In

Zoom Out

Zoom to Full Extent

Zoom to Active Layer

Zoom to Last Extent

Figure 5-4. - Zoom functions.

The pan function will allow the researcher to move the data displayed in any direction to capture other areas of the data without changing the scale at which the data is displayed.

Figure 5-5 displays two frames where pan has been used to view the data set more clearly.

Figure 5-5. - Demonstration of the pan function.

As demonstrated in Figure 5-6, the identify command will allow the user to point and select one or numerous features within the display and reveal the attribute data of the active layer at the bottom of the screen.

Figure 5-6. - Demonstration of the identify function.

Queries will allow the user to find or view features that have desired attributes. These attributes could be found within the active layer using a simple statement within the query interface that also will appear at the bottom of the interface once the query button will be selected. A query statement will require three parameters to execute the query: the attribute field, the operator, and the desired value. A good example would be a user wanting to identify all of the ellipses within the PPR 27IN dataset with temperature values greater than 160°K. As seen in Figure 5-7, the T_K field would be selected for the field, the greater than symbol (>) would be selected for the operator and 160 will be entered as the value.

Field	Operator	Value
T_K_	>	160

Figure 5-7. - Query statement example.

After entering the query, the user will simply press the “Add to Query String” button followed by the “Execute” button and the query will be performed. All features that meet the criteria of the query will be highlighted as a bright cyan color within the viewer and their attributes will be displayed in the table at the bottom of the screen where the query interface previously was. Figure 5-8 displays the result from the query previously demonstrated in Figure 5-7. The query resulted in one valid record from the 27IN dataset with a temperature over 160°K.

Figure 5-8. - Result of query from Figure 5-7.

For more complex queries, an “And,” “Or,” and “Not” buttons will be included. The “And” function will be typically used for including more statements within a query. For example, a user could select a range of values between two extents by selecting values above a lower value and values below a higher value. Similarly, the “Or” command will allow the user to select values on opposite ends of a range, or even multiple unique values. The “Not” function is really self explanatory; it will select features that do not comply with the query. To unselect the features from a previous query, the clear selection function instantly will clear any selections the user may have made.

To select features manually from the viewer without utilizing a query, the two select functions will simplify the selection process. Selecting by a rectangle will be similar to drawing a box with the zoom tools, except all features that intersect the rectangle will become selected. Figure 5-9 displays the select by rectangle tool in an attempt to select all ellipses from the 24ISalt dataset that intersects with the large, elongated black feature.

The selected features will once again be displayed in a bright cyan color, while the drawing rectangle will be a bright orange color.

Figure 5-9. - Demonstration of the select by rectangle tool.

The select by line/polygon feature will allow the user to draw a single or multiple lines across the display which will select every feature that it intersects with. The user essentially will place points within the display to define the extents of a line or polygon and then will press the appropriate complete button at the bottom of the screen. Figure 5-10 demonstrates the select by line/polygon tool by attempting to outline the same black feature in Figure 5-9 and selecting all the ellipses that intersect with it. With this tool, the points and lines the tool creates are designated a red color.

Figure 5-10. - Demonstration of the select by line/polygon tool.

The last button on the toolbar is the print button. This button will provide the user with a print layout of the map display and the corresponding legend including all of the visible layers of the display. Figure 5-11 is an example of the page created by the print function.

Figure 5-11. - Example print page created by the website.

Other functionality could be added to the distribution system as it becomes more useful to Io researchers throughout the world. Until such time, there is a small statement visible in Figure 5-11 for interested parties to contact the client, Julie Rathbun, for distribution of the data and corresponding. These functions were not readily available through an HTML-based site constructed with ArcIMS.

Hardware requirements for the researchers accessing the system are very broad. The system was designed to be available to all operating systems on virtually any hardware configuration available. No peripheral software other than a basic internet viewer is required for the researchers to view the system. The user is required to have an active internet connection available to them to contact the system's web address. For the design and maintenance of the system, ESRI's ArcIMS software was employed. An HTML site was the choice for construction due to the simplicity of the customization, and the accessibility to a wider range of systems is due to the fact that no additional software or viewers are necessary to view the suite.

6. Results

This project was successful in compiling the entire Galileo mission Amirani data into a centralized location compatible with a GIS platform. The geodatabase and website will optimize research and productivity of scientists by allowing them to view and analyze all of the data simultaneously. The information derived from the processed datasets will allow scientist to further their research of the volcanic eruptions on Io and developing time frames of how the eruptions and lava flows have occurred. Figure 6-1 is a view of the Amirani region with all of the processed data present except the PPR interpolated surface.

Figure 6-1. - Final processed data.

From the mosaics and SSI data, researchers can determine the location of numerous surface features present within the Amirani region. They also serve as a reference to the temperature readings within the NIMS and PPR data. Deriving temperatures from the spectral data can, not only, locate the current lava flows, but can give researchers an indication of how an eruption has occurred, and how each flow has progressed within a defined time frame. After visual inspection of the NIMS and PPR data, it is apparent that all of the higher temperature readings correspond to the darker features in the Amirani

region. The majority of these darker features have been identified as volcanic features with a distinct presence of lava. Figure 6-2 shows that the area of higher temperatures of the NIMS 27 temperature layer directly coincides with the dark, elongated feature of Amirani. Figure 6-2 also clearly demonstrates that some lava flows can emanate from several points within the same enormous volcano or caldera, and surge outward in many dissimilar directions.

Figure 6-2. - NIMS 27 temperature layer over the monochromatic mosaic.

The presence of the PPR data combined with the NIMS data strongly reinforces the identification of hot spots within the Amirani region. Figure 6-3 displays the PPR 24 IN data on top of the NIMS 24 temperature data. Despite the poor resolution of the NIMS data, the two data sets projected simultaneously identify hot spots in the same area of the elongated Amirani feature.

Figure 6-3. - NIMS 24 temperature and PPR 24 IN datasets.

The interpretation of the calculated surface using the PPR data was initially believed to be insightful to the surface processes occurring in the Amirani region. The calculated surface is essentially inappropriate because it was derived using data captured at different times, and is not an accurate representation of the actual surface temperatures. The immense variations in the surface temperatures displayed in Figure 6-4 are easily explained by the differences of surface temperatures at the various times of data collection. The result of the interpolated surface was an intellectual exercise that examined the potential of GIS functionally for other possible applications within the interplanetary GIS realm. If multiple data sets collected at the same time could be presented, the potential of the demonstrated processes could possibly be realized.

Figure 6-4. - Calculated PPR surface over the color global mosaic.

7. Discussion

7.1. Conclusions

The goal of this project was to transform data of the Amirani region collected by the Galileo spacecraft into usable GIS datasets and communicate the results to numerous Io researchers. All of the data existed in a raw form that was incompatible with a GIS environment. The global mosaic and SSI imagery were registered to conform to a coordinate system consistent with current research of the moon. The NIMS data was also registered and transformed to a statistical surface representing temperatures. The PPR data was transformed from coordinates within a table to ellipses representing the area captured within the IFOV of the PPR instrument. Another statistical surface representing temperatures captured by the PPR instrument was also calculated to estimate surface temperatures of the entire Amirani region.

The resulting GIS data was displayed within a thin client GIS user environment that is available to anyone over the internet. This small system allows researchers to view the data and its attributes over any basic internet connection so they can derive useful information about the surface within the Amirani region of Io. The simultaneous projection and manipulation of the data will assist researchers in studying the volcanic eruptions, and trying to develop a time frame or history of how the eruptions have occurred.

7.2. Accuracy

One of the most integral characteristics of this project is not simply the transformation of the data sets captured by the Galileo spacecraft into a GIS format, but the quality assurance and accuracy of the data and data management. The quality of data being used in any analysis project can directly impact the results of analysis being performed on the data. Therefore, it is vital to explore the quality of the data sets being utilized in this project so researchers can evaluate the results of the data processing. With regards to GIS data, quality often refers to resolution, precision, accuracy, and consistency of a dataset. Essentially, data errors are the difference between the data values and the values in reality. GIS data is simply attempting to represent geographical phenomena within a computer based environment that is incapable of perfectly representing reality, so the introduction of error in GIS data is unavoidable. Errors within GIS data are typically attributed to inadequate collection techniques, source data, and insufficient or poorly chosen processing techniques.

Despite the few malfunctions of the Galileo spacecraft, the mission exceeded all expectations and collected a phenomenal amount of data from Io. There are obviously no possible methods of validating the majority of the data values captured by the Galileo spacecraft with actual recorded values from the surface of the moon, so all of the data must be assumed as valid until further research can be performed on Io. For the scope of this project, it is more important to view the data in terms of its context and functionality than to trifle over the absolute accuracy of the data. However, it is still relevant to

identify any errors or concerns within the data sets so that researchers may address them when deriving useful information about the Amirani region.

Io presents a unique problem with data because the state of the surface phenomenon on Io rapidly changes over time, making any data captured of the moon basically outdated shortly after. Larger scale features such as mountain ranges remain the same over some time, but other smaller scale features like lava flows and lakes may change radically within a limited amount of time. Luckily, the Galileo mission typically captured data of Io simultaneously which allows researchers to develop a model of Io's surface at that very instance in time. Other than the mosaics, all of the data used for this project was captured during the 24th and 27th orbit of the Galileo spacecraft so the difference in capture time was minimized. Each of the datasets used in this project obviously has some form of error associated with it and some unfortunately can not be identified due to the lack of knowledge of the information used and the systems and techniques used to process them.

7.2.1. Mosaics

As mentioned before, the mosaics were provided by the USGS, and there was no documentation provided about the processing techniques used to create them. Williams, Keszthelyi, et al. (2005) described the SSI malfunction on the Galileo mission which only allowed the SSI to capture images in false color. The relevance of this information relates to the processing of the mosaics within this project. The original color mosaic was manipulated using image processing software and the GIS exposing it to transformations and renderers that changed the colors throughout the image. The difference between the original image in Figure 7-1 and the transformed resolution merge result in Figure 7-2 is rather distinguishable. Despite the increased resolution of the new image, its representation of reality may not be entirely correct.

Figure 7-1. - Original color mosaic of Io.

Figure 7-2. - Resolution merge color mosaic of Io.

7.2.2. SSI

Similar to the mosaics, the SSI data went through some prior processing before being presented for this project. The original SSI images for the Amirani region were mosaiced and warped to create one single image. Unfortunately, the resolution of the SSI image was remarkably downgraded during this process and was comparably less comprehensible than the global mosaics. Figure 7-3 shows a small scale area of the Amirani region using the monochromatic mosaic while Figure 7-4 also shows the same region using the processed SSI image. Like the mosaic comparison, the differences are astonishing.

Figure 7-3. - Monochromatic global mosaic image of the Amirani region.

Figure 7-4. - SSI image of the Amirani region.

This difference in resolution brings up the question of positional accuracy with regards to the georeferencing process used to register the SSI image to the global mosaic. Even at a small scale, the surface features used to register the SSI image are relatively unclear in the SSI image compared to the global mosaic. Regardless, the transformations of the SSI image yielded low RMS errors, and the resulting SSI image mimics the global mosaic at a lower resolution.

7.2.3. NIMS

The resolution of the NIMS datasets was also a concern with regard to the analysis of the data. Somewhat similar to the SSI image, the resolutions of the NIMS images were much lower than that of the global mosaics, making registration of the images difficult. Each NIMS image seemed to be correctly registered simply using the coordinates provided for each corner of the images, but the surface features were not clearly distinguishable enough in the NIMS 24 image to georeference it to the mosaic.

The other concern of the NIMS datasets is concerned with the temperature deriving programs used to calculate a statistical surface representing the temperatures of the surface. Any data conversion will result in some amount of expected error but the challenge is to identify these errors and mitigate them when possible. The temperatures calculated by the tempfit program could possibly be correct, but the derived temperatures do not coincide with the temperatures captured by the PPR data. The minimum temperature within the calculated datasets is near the 200° mark, as shown in Figure 3-23, but the maximum temperature recorded by the PPR instrument is 187.6°. This is best displayed in Figure 7-5 showing the lowest temperature areas of the NIMS 27 temperature model overlapped by numerous PPR 24 IS readings between 180° and 110°.

Figure 7-5. - NIMS 27 temperature data displayed simultaneously with PPR 24 IS data.

7.2.4. PPR

Most of the accuracy issues with regards to the PPR datasets involve the actual data collection itself. Throughout the three datasets, eleven negative temperature values were found and excluded from this project. The cause of these anomalies is still unknown. Another potential issue arises when comparing daytime and nighttime observations because the average temperatures between the two observations will be tremendously different. These differences between observations are rather apparent when comparing the daytime observations of 24IN to the nighttime observations of 27 IN. As displayed in Figure 7-6, the two were classified using the same scheme and display remarkable differences in temperatures over the same area.

Figure 7-6. - PPR 24 IN day observations compared to 27 IN night observations.

These differences in temperature are also considered when the statistical surfaces were created for the PPR data. Although these surfaces are just a statistical estimation of temperatures over areas where data was not collected, it is important to know that variations in surface temperature are present.

7.3. Future Directions

This project was essentially responsible for prototyping a system and methods for transforming Galileo spacecraft data into GIS. The efficiency of the overall direction of this project is highly dependent on the satisfaction and commitment of the Io research community to pursue this any further. There are most likely unseen improvements that can be made immediately to some of the aspects of the project by advanced GIS users and Io researchers. Once the Io research community is satisfied with the outcome and management of the system in place, data transformation and inventory of additional datasets can commence.

The basic foundation for data transformation is a set for researchers to begin transforming the massive amounts of data that exist within the Io data libraries. All of the datasets listed within this project are simply subsets of the vast quantity of data captured by the Galileo spacecraft during its mission. Numerous other SSI, NIMS, and PPR datasets could be processed within a minimal amount of time and added to the database. The system is essentially open to any additional datasets that may become available such as the geologic maps currently being produced by different researchers around the country. The initial learning process and amount of time required to initialize researchers to further their work will be strenuous, but the information they could possibly gain from compiling all of their data into a system that could be manipulated could produce invaluable results.

There are a few methodologies that became apparent once the project was completed that could potentially assist researchers through the processing and interpretation of the Galileo datasets. Some of the PPR datasets have a large amount of ellipses distributed within a small area making the overlapping ellipse somewhat difficult to interpret. If there was an approved accurate method of averaging the ellipses, the interpretation of the surface temperatures could be made a lot less complicated. Another issue that could be addressed would be the evaluation of the PPR datasets before initiating any analysis. An automated process that could identify and remove any records containing negative temperatures would be invaluable and potentially save a lot of time for future researchers. Finally, if there were more ways to automate any of the processes used for this project, numerous hours of time could be saved. The ultimate goal would be to input one of the original datasets provided by the Galileo spacecraft and the push a button to provide the user with a final processed dataset would be immediately valuable to numerous researchers throughout the world.

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Appendix A – Global Mosaic Processing Flow Chart & Description

1. Import the Image file

- *Platform:* ENVI 4.2
- *Method:* File -> Open Image File

2. Apply Linear Stretch (For Color Mosaic Only)

- *Platform:* ENVI 4.2
- *Method:* Enhance -> [Image] Linear 0-255

3. Perform a Resolution Merge (For Resolution Merge Dataset Only)

- *Platform:* ENVI 4.2
- *Method:* Transform -> Image Sharpening -> HSV
 - Select Input RGB (GLL_color_Simp_Clon180_8bit.tif)
 - Select High Resolution Input (Io_SSI_VGR_bw_Equi_Clon180_8bit.tif)

4. Export as Spatial Subsets

- *Platform:* ENVI 4.2
- *Method:* File -> Save Image As -> Image File
 - Spatial Subset – Adjust Samples (eg. Change 11445 to 5723)
 - Output File Type – TIFF/GeoTIFF

5. Open Registering.mxd

- *Platform:* ArcGIS 9.1
- *Method:* File -> Open

6. Open VBA Script

- *Platform:* ArcGIS 9.1
- *Method:* Tools -> Macros -> Visual Basic Editor
 - Select RegisterMosaics - Ensure data path and filename are appropriate

NOTE!! – If the file that is going to be created already exists in the selected directory, the program will not execute.

7. Run RegisterMosaics Module

- *Platform:* ArcGIS 9.1
- *Method:* Tools -> Macros -> Macros -> RegisterMosaics

8. Import Spatial Subsets

- *Platform:* ArcGIS 9.1
- *Method:* File -> Add Data...

9. Add Georeferencing Toolbar

- *Platform:* ArcGIS 9.1

- *Method*: View -> Toolbars -> Georeferencing

10. Georeference Mosaics to Points

- *Platform*: ArcGIS 9.1
- *Method*: Georeferencing Toolbar Buttons
 - Set Layer: to mosaic needed to be georeferenced
 - Add Control Points Button
 - First select corner of image
 - Second select corresponding point of MosaicPoints.shp

11. Export Georeferenced Image

- *Platform*: ArcGIS 9.1
- *Method*: Right-Click File in Table of Contents -> Data -> Export Data...
 - Spatial Reference – Data Frame (Current)
 - Output Raster - Use Renderer – Check
 - Format - TIFF

12. Apply Linear Stretch (Display for Color Mosaics)

- *Platform*: ArcGIS 9.1
- *Method*: Right-Click File in Table of Contents -> Properties -> Symbology
 - Stretch – Type – None

Appendix B – SSI Processing Flow Chart & Description

1. Run amarani.pro program

- *Platform*: ENVI 4.2 – IDL 6.2
- *Method*: File -> Open
- *Method*: Run -> Compile amarani.pro
- *Method*: Run -> Run amarani

2. Import Image from IDL Variable

- *Platform*: ENVI 4.2
- *Method*: File -> Import from IDL Variable
 - Select Import Variable: IMG: Floating Point Array (1225x793)
- *Method*: Load Band

3. Scale the Image

- *Platform*: ENVI 4.2
- *Method*: Basic Tools -> Band Math
 - Equation: $\text{fix}(((\text{float}(\text{b1}) - \text{min})/\text{range})*255)$
 - eg. $\text{fix}(((\text{float}(\text{b1}) - (-100))/425.786591)*255)$

4. Export the Image

- *Platform*: ENVI 4.2
- *Method*: File -> Save Image As -> Image File
 - Output File Type – TIFF/GeoTIFF

5. Open Registering.mxd

- *Platform*: ArcGIS 9.1
- *Method*: File -> Open

6. Import SSI Image & Global Mosaic

- *Platform*: ArcGIS 9.1
- *Method*: File -> Add Data...

7. Open VBA Script

- *Platform*: ArcGIS 9.1
- *Method*: Tools -> Macros -> Visual Basic Editor
 - Select RegisterSSI - Adjust data path, filename, and coordinates

NOTE!! – If the file that is going to be created already exists in the selected directory, the program will not execute.

8. Run RegisterSSI Module

- *Platform:* ArcGIS 9.1
- *Method:* Tools -> Macros -> Macros -> RegisterSSI

9. Add Georeferencing Toolbar

- *Platform:* ArcGIS 9.1
- *Method:* View -> Toolbars -> Georeferencing

10. Georeference SSI Image to Points

- *Platform:* ArcGIS 9.1
- *Method:* Georeferencing Toolbar Buttons
 - Set Layer: to SSI image needed to be georeferenced
 - Add Control Points Button
 - First select corner of image
 - Second select corresponding point of SSIPoints.shp

NOTE: Original Image needed to be vertically flipped to match Global Mosaic

11. Georeference SSI Image to Global Mosaic

- *Platform:* ArcGIS 9.1
- *Method:* Georeferencing Toolbar Buttons
 - Set Layer: to SSI image needed to be georeferenced
 - Add Control Points Button
 - First select point on SSI image
 - Second select corresponding point on Global Mosaic
- *Method:* Georeferencing -> Transformation -> 3rd Order Polynomial

12. Export Georeferenced Image

- *Platform:* ArcGIS 9.1
- *Method:* Right-Click File in Table of Contents -> Data -> Export Data...
 - Spatial Reference – Data Frame (Current)
 - Output Raster - Use Renderer – Check
 - Format - TIFF

13. Apply Linear Stretch (Display)

- *Platform:* ArcGIS 9.1
- *Method:* Right-Click File in Table of Contents -> Properties -> Symbology
 - Stretch – Type – None

Appendix C – NIMS Processing Flow Chart & Description

1. Run amarani.pro program

- *Platform*: ENVI 4.2 – IDL 6.2
- *Method*: File -> Open
- *Method*: Run -> Compile amarani.pro
- *Method*: Run -> Run amarani

2. Import Image from IDL Variable

- *Platform*: ENVI 4.2
- *Method*: File -> Import from IDL Variable
 - Select Import Variable: NIMSIMG: Floating Point Array (48x54x15)
 - Select Import Variable: NIMS27IMG: Floating Point Array (86x136x15)
- *Method*: Load Band

3. Export the Image (For Original Images Only)

- *Platform*: ENVI 4.2
- *Method*: File -> Save Image As -> Image File
 - Output File Type – ERDAS IMAGE

4. Run tempfit.pro (or tempfit27.pro) program (For Temperature Datasets Only)

- *Platform*: ENVI 4.2 – IDL 6.2
- *Method*: File -> Open
- *Method*: Run -> Compile tempfit.pro
- *Method*: Run -> Run tempfit

5. Convert Image to Integers (For Temperature Datasets Only)

- *Platform*: ENVI 4.2
- *Method*: Basic Tools -> Band Math
 - Equation: fix(b1)

6. Export the Image (For Temperature Datasets Only)

- *Platform*: ENVI 4.2
- *Method*: File -> Save File As -> ASCII
 - Output Style – ESRI ASCIIGRID

7. Open Registering.mxd

- *Platform*: ArcGIS 9.1
- *Method*: File -> Open

8. Import NIMS Image & Global Mosaic

- *Platform*: ArcGIS 9.1

- *Method*: File -> Add Data...

9. Open VBA Script

- *Platform*: ArcGIS 9.1
- *Method*: Tools -> Macros -> Visual Basic Editor
 - Select RegisterNIMS2X - Adjust data path, filename, and coordinates

NOTE!! – If the file that is going to be created already exists in the selected directory, the program will not execute.

10. Run RegisterNIMS2X Module

- *Platform*: ArcGIS 9.1
- *Method*: Tools -> Macros -> Macros -> RegisterNIMS2X

11. Add Georeferencing Toolbar

- *Platform*: ArcGIS 9.1
- *Method*: View -> Toolbars -> Georeferencing

12. Georeference NIMS Image to Points

- *Platform*: ArcGIS 9.1
- *Method*: Georeferencing Toolbar Buttons
 - Set Layer: to NIMS image needed to be georeferenced
 - Add Control Points Button
 - First select corner of image
 - Second select corresponding point of NIMS2XPoints.shp

NOTE: Original Images needed to be rotated 180° to match Global Mosaic

13. Export Georeferenced Image

- *Platform*: ArcGIS 9.1
- *Method*: Right-Click File in Table of Contents -> Data -> Export Data...
 - Spatial Reference – Data Frame (Current)
 - Output Raster - Use Renderer – Check
 - Format – IMAGINE Image

Appendix D – PPR Processing Flow Chart & Description

1. Import the .geo or .rad File in WordPad

- *Platform*: Microsoft WordPad
- *Method*: File -> Open...
 - Files of Type – All Documents (*.*)

2. Remove the Header Information (First Two Lines) and Save

- *Platform*: Microsoft WordPad
- *Method*: Keyboard: Delete
- *Method*: File -> Save As...
 - Save as Type – Text Document

3. Import and Save the .geo or .rad WordPad File in Excel

- *Platform*: Microsoft Excel
- *Method*: File -> Open...
 - Files of Type – All Files (*.*)
 - Original Data Type – Delimited – Check
 - Delimiters – Space - Check
- *Method*: File -> Save As...

4. Join .geo and .rad Tables

- *Platform*: Microsoft Excel
- *Method*: Copy -> Paste

5. Remove any Records with Negative Temperature Values

- *Platform*: Microsoft Excel
- *Method*: Data -> Sort
 - Sort by – T(K)
 - Ascending - Check
- *Method*: Select Row -> Right-Click -> Delete

6. Add and Calculate Location and Ellipse fields

- *Platform*: Microsoft Excel
- *Method*: Insert -> Columns
- *Field Name* - NEWLON
 - Equation: =360-LON
- *Field Name* - NEGLON
 - Equation: =LON*(-1)
- *Field Name* - NEWSSCLON
 - Equation: =360 - SSCLON
- *Field Name* - WIDTH_KM
 - Equation: =SIPDIS*TAN((2.5/2)/1000)
- *Field Name* - WIDTH_D
 - Equation: =((WIDTH_KM/1815)*180)/PI()
- *Field Name* - ADJ_WID_D
 - Equation: =(ACOS((COS(WIDTH_D*PI()/180)-
SIN(LAT*PI()/180)*SIN(LAT*PI()/180))/(COS(LAT*PI()/180)*COS(LAT*PI()/180))))
*180/PI()
- *Field Name* - HEIGHT_KM
 - Equation:
=WIDTH_KM/(COS(LAT*PI()/180)*COS(SSCLAT*PI()/180)*COS((LON-
SSCLON)*PI()/180)+SIN(LAT*PI()/180)*SIN(SSCLAT*PI()/180))
- *Field Name* - HEIGHT_D
 - Equation: =((HEIGHT_KM/1815)*180)/PI()
- *Field Name* - HI_WI_RATIO
 - Equation: =ADJ_WID_D/HEIGHT_D
- *Field Name* - AZIMUTH_R
 - Equation: =IF((LAT-SSCLAT)=0,0,PI()/2-(ATAN(((NEWLON-
NEWSSLON)/(LAT-SSCLAT)))))
- *Field Name* - AZIMUTH_D
 - Equation: =AZIMUTH_R*180/PI()
- *Method*: File -> Save

7. Import and Export the Table from Access

- *Platform:* Microsoft Access
- *Method:* File -> Open
 - Files of Type – All Files (*.*)
 - First Row Contains Column Headings – Check
- *Method:* File -> Export...
 - Save as Type – dBASE IV (*.dbf)

8. Open DrawPPREllipses.mxd

- *Platform:* ArcGIS 9.1
- *Method:* File -> Open

9. Import PPR Table & Global Mosaic

- *Platform:* ArcGIS 9.1
- *Method:* File -> Add Data...

10. Add PPR Table as Points

- *Platform:* ArcGIS 9.1
- *Method:* Tools -> Add X/Y Data...
 - Choose a Table – Current PPR Data Table
 - X Field – NEGLON
 - Y Field - LAT

11. Save PPR Point Events as a Shapefile

- *Platform:* ArcGIS 9.1
- *Method:* Right-Click Events File in Table of Contents -> Data -> Export Data...
 - Use the same coordinate system as – the data frame - Checked

12. Open VBA Script

- *Platform:* ArcGIS 9.1
- *Method:* Tools -> Macros -> Visual Basic Editor
 - Select PPR2XLXEllipses - Adjust data path and filenames

NOTE!! – If the file that is going to be created already exists in the selected directory, the program will not execute.

NOTE!! – The Name of the Point shapefile to be used for the script must exactly match the listed shapefile name in the script or the program will not execute.

13. Run PPR2XIXEllipses Module

- *Platform*: ArcGIS 9.1
- *Method*: Tools -> Macros -> Macros -> PPR2XIXEllipses

14. Join the Ellipse Shapefile Table to the Point Shapefile Table

- *Platform*: ArcGIS 9.1
- *Method*: Right-Click Ellipse File in Table of Contents -> Joins and Relates -> Join...
 - 2. Choose the table to join – Point Shapefile
 - 1. Choose the field in this layer – FID
 - 3. Choose the field in the table - FID

15. Save Ellipse File as a Shapefile

- *Platform*: ArcGIS 9.1
- *Method*: Right-Click Ellipse File in Table of Contents -> Data -> Export Data...
 - Use the same coordinate system as – the data frame - Checked

Appendix E – Final Project Proposal

Executive Summary

Constant volcanic activity accompanied by intense sulfurous plumes has made one of Jupiter's moons, Io, one of the most observed celestial bodies in recent history. The abundance of giant calderas, lava lakes, volcanoes, and vast lava flows have drawn as much attention to Io as not only the first active volcanoes discovered within the solar system, but the most geologically active object ever observed. These dramatic features on Io combined with Jupiter's storms and rings, inspired NASA to embark on the Galileo mission to exclusively study Jupiter and its four largest moons. On the Galileo spacecraft, the three instruments that emerged to be the most useful were the solid state imaging device (SSI), the near infrared mapping spectrometer (NIMS), and the photopolarimeter radiometer (PPR). These three instruments produced numerous stunning images during the Galileo mission, but unfortunately each instrument acquires data in a different format and resolution.

To optimize research and productivity, the data needs to be compiled in a system that is easy for scientists to view and analyze specific research based questions. With the assistance of Dr. Julie Rathbun, researcher Shane Barrett will co-register, compile, and inventory all of the existing data of the Amirani region into a stand alone, GIS application for other researchers to simultaneously project all of the data, and accurately analyze the features present there. The majority of current research on Io involves studying the volcanic eruptions, and trying to develop a time frame or history of how the eruptions have occurred, including the subsequent lava flows. Deriving temperatures from the spectral data can not only locate the current lava flows, but can give researchers an indication of how an eruption has occurred, and how each flow has progressed within a defined time frame. Most of the actual geologic and morphologic analysis will be performed by Dr. Julie Rathbun who has participated in numerous research projects regarding Io for the last 6 years, and has co-authored eleven published scientific papers regarding the Galilean moon. The initial compilation of data and construction of the application will be facilitated by the various imagery analysis and geographic information science experiences Shane Barrett gained while obtaining his undergraduate degree.

Solution Overview

Initially, a remote sensing software package will be employed to import, and mosaic the imagery data obtained from the Galileo spacecraft, specifically the SSI and NIMS datasets. Due to the limited coverage and inconsistency of acquisition times, the NIMS dataset will also need to be registered to the SSI images to ensure the accuracy of further analysis. Some analyses may also require the NIMS data to be classified in a specific manner, which would also need to be performed using a remote sensing software package. PPR data is stored in the form of two ASCII text files and will need to first be converted into a form of surface temperature map, and registered to the other imagery data. Once all of the Galileo data is correctly registered, it will need to be exported in a format that is readable by ESRI software. Using ArcCatalog, a new geodatabase will be constructed to completely contain all of the data files produced by the remote sensing software. The geodatabase will be using an Io projection defined under the solar system projections within the ArcGIS software. Depending on the outcome of the NIMS and

PPR data, portions of the datasets may be converted or possibly digitized into usable shapefiles for improved user capabilities, performance, and detailed attribute data entry. These digitized data sets may include temperature readings from the NIMS and PPR data, or possibly surface features, such as volcanoes, calderas, or lava flows.

Once the data has finally been compiled, the stand alone application will be constructed with further discussions with the client. The application may possibly be constructed using ArcObjects, and Visual Basic programming to develop a basic viewer with general layer capabilities to view the existing datasets. Another option of the stand alone application may be to construct an ArcIMS website for the researchers involved, to provide them with a little more functionality than the ArcObjects option. Once the project is complete, researchers will be able to characterize features, and their distribution within the Amirani region of Io, which is essential for identifying the active volcanic and tectonic processes on the Galilean moon.

Scope of Work

Task 1 - Data Acquisition & Exploration

The researchers will meet to discuss the overall implementation of the project, and potential methodologies to complete the task within the allotted time. At this time, the researchers will also acquire the data collected from the Galileo spacecraft and begin to explore the data types, formats, acquisition times, and orbits. The researchers will have to differentiate the separate data from each instrument and collaborate on methods to display and register each data type. Some data types may need to be converted or modified to be displayed properly as well. Projections, extents, and coordinate systems must also be either determined or defined during the exploration stage as well to ensure accuracy during the registration phase.

Task 2 - Data Registration

Each data set will be imported into a remote sensing software package to accurately display each image. Every additional image will then need to be co-registered using a georeferencing method within the remote sensing software. Registering will be done by data type first starting with the SSI data because it will be the most accurate of all three sets of data. The NIMS and PPR data may then be registered to the SSI data using the same methods.

Task 3 - Data Export & Import

Once all of the data is accurately registered, it will need to be exported from the remote sensing software in a format compatible with ESRI GIS software suites. The format types available will include TIFF, IMAGE, and GRID files. Once exported, the data will be imported into the GIS software and analyzed for accuracy.

Task 4 - Geodatabase Design

Once all of the data is imported into the GIS, a geodatabase will be created and designed to properly inventory all of the data into a single package. The structure will be a personal geodatabase containing 2 distinct raster datasets designated to each data type. These raster catalogs will have their spatial reference properties defined by the specific Io 2000 projection defined within the projected coordinate systems within the ESRI

software. All of the existing data will then be imported and mosaic into their specific raster catalogs.

Task O - Surface Feature Data Creation (Optional)

From the combined data sets, surface features will become more visible. These surface features may be better represented as a point, line, or polygon file and could be digitized into their own file for ease of use and identification by the end user.

Task 5 - Stand Alone Application Development

All of the data needs to be simultaneously projected to the end user for analysis. Since most of the end users will not be located at nearby facilities, an application needs to be developed so numerous interested researchers can access the data. An independent viewer may be constructed using ArcObjects, and Visual Basic programming to develop a basic viewer with general layer capabilities to view the existing datasets. Another option of the stand alone application may be to construct an ArcIMS website for the researchers involved, to provide them with a little more functionality that the ArcObjects option. The choice between the two formats will be determined after the all of the image processing has been completed. The overall size of the data may not be small enough to compile onto a single CD that could be distributed to the users, so a website would be the most applicable option. If the data isn't very large, a small, basic GIS viewer with simple functionality will be constructed, compiled with the data, and sent to the user

Flow Process Diagram

Deliverables

- Georeferenced image data (**Task 2**)
- Georeferenced Ellipsoid PPR data (**Task 2**)
- Geodatabase containing all georeferenced data (**Task 4**)
- Finished MIP Paper documenting the entire project (**Task 5**)
- Georeferenced surface feature data (**Task O**)
- Stand Alone Application/ Website containing all georeferenced data (**Task 5**)
- Data CD containing all original and processed data (**Task 5**)
- Final hard & digital maps for display in documentation and for client (**Task 5**)
- Basic training for direct contact users (**Task 5**)
- Final presentation of entire project for advisors, clients, and public (**Task 5**)
- Basic application/website help documentation (**Optional Task 5**)

Assumptions

- All data from the client was collected with a recorded location
- Client will give clear and concise direction of what the final product will entail
- Client will provide support regarding the data
- ENVI software will be available
- Clients and other users hardware and software is capable viewing stand alone application or website
- Future releases of GIS software will be capable of reading and displaying final geodatabase and its contents
- The final project will be useful to the client and other researchers
- The provided data is authentic and an accurate representation of the study area

Schedule

The schedule has been design in such a way that generously allots time to each task required to finish the project. These timelines are more or less deadlines for each task, not excepted completion dates. Assuming the project flows as planned; the final presentations and documentations will be presented sometime in November.

ID	Task Name	Start	Finish	Duration	2006											
					Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	
1	Data Acquisition & Exploration	1/9/2006	3/31/2006	60d
2	Data Registration	4/3/2006	6/30/2006	65d
3	Data Export & Import	7/3/2006	7/28/2006	20d
4	Geodatabase Design	8/1/2006	8/31/2006	23d
5	Surface Feature Data Creation	9/1/2006	9/29/2006	21d
6	Stand Alone Application Development	9/1/2006	11/30/2006	65d
7	Documentation	1/9/2006	12/15/2006	245d

Appendix F – Project Design Specification

Executive Summary

Constant volcanic activity accompanied by intense sulfurous plumes has made one of Jupiter's moons, Io, one of the most observed celestial bodies in recent history. The abundance of giant calderas, lava lakes, volcanoes, and vast lava flows have drawn as much attention to Io as not only the first active volcanoes discovered within the solar system, but the most geologically active object ever observed. These dramatic features on Io combined with Jupiter's storms and rings, inspired NASA to embark on the Galileo mission to exclusively study Jupiter and its four largest moons. On the Galileo spacecraft, the three instruments that emerged to be the most useful were the solid state imaging device (SSI), the near infrared mapping spectrometer (NIMS), and the photopolarimeter radiometer (PPR). These three instruments produced numerous stunning images during the Galileo mission, but unfortunately each instrument acquires data in a different format and resolution.

To optimize research and productivity, the data needs to be compiled in a system that is easy for scientists to view and analyze specific research based questions. With the assistance of Dr. Julie Rathbun, researcher Shane Barrett will co-register, compile, and inventory all of the existing data of the Amirani region into a stand alone, GIS application for other researchers to simultaneously project all of the data, and accurately analyze the features present there. The majority of current research on Io involves studying the volcanic eruptions, and trying to develop a time frame or history of how the eruptions have occurred, including the subsequent lava flows. Deriving temperatures from the spectral data can not only locate the current lava flows, but can give researchers an indication of how an eruption has occurred, and how each flow has progressed within a defined time frame. Most of the actual geologic and morphologic analysis will be performed by Dr. Julie Rathbun who has participated in numerous research projects regarding Io for the last 6 years, and has co-authored eleven published scientific papers regarding the Galilean moon. The initial compilation of data and construction of the application will be facilitated by the various imagery analysis and geographic information science experiences Shane Barrett gained while obtaining his undergraduate degree.

Functional Requirements Overview

- The system shall be provided through an ArcIMS website (ESRI Internet Service software)
- The system shall be digitally stored on a server within Lewis Hall at the University of Redlands, California
- The system shall be available to all computer systems with any operating system through a basic internet connection
- The system shall have an appropriately customized interface that represents the study area
- The system shall store all of the required SSI, NIMS and PPR data sets in a personal geodatabase
- The system shall provide the user with basic Zoom in and out capabilities within the interface

- The system shall provide the user with basic Pan capabilities within the interface
- The system shall provide the user the ability the change the display properties of the selected layers if necessary
- The system shall provide the user the ability to save the current display as a .jpeg or .tiff image
- The system shall provide the user the ability to turn data layers On or Off in the interface display

System Description

Once the data has finally been compiled, the stand alone application will be constructed after further discussions with the client. The vessel to which all Io researchers will be able to view the collection of data within the Amirani region will be a stand alone ArcIMS website to provide them with GIS functionality to view and manipulate the data. Once the project is complete, researchers will be able to characterize features, and their distribution within the Amirani region of Io, which is essential for identifying the active volcanic and tectonic processes on the Galilean moon.

All of the data needs to be simultaneously projected to the end user for analysis. Since most of the end users will not be located at nearby facilities, an application needs to be developed so numerous interested researchers can simultaneously access the data.

An ArcIMS website would be ideal for this dilemma because it would be made available to any of these researchers through a basic internet connection. All of the processing and data storage would be contained within the central server, making the user interface efficient enough to run on numerous types and degrees of personal computers. The default user interface allows the designer to employ the use of basic GIS functionality such as zoom and pan. Also, the customization ability of ArcIMS is relatively simple making a representative user interface easy to construct. This interface can be simplified to accommodate users of the system that have minimal GIS exposure and experience.

System Architecture

The architecture of the system is fairly simple. The major component of analysis and research for Io is the SSI, NIMS, and PPR data. All of these data sets were captured from the Galileo spacecraft from different sensors, at different times, and from different orbits of the moon. All of these data sets must be processed and eventually transformed into useable datasets acceptable by the GIS. These data sets will be compiled into a personal geodatabase for storage and advance capabilities. The geodatabase must also be stored preferable on the same server as the ArcIMS site for simple access for the system. The ArcIMS site must be able to read and display the components of the geodatabase so the researcher can view the data. The researcher is potentially the most important part of the system. The researcher is responsible for accessing the system and deriving useful information from the data to accurately identify the active volcanic and tectonic processes on the Galilean moon. The researchers are the purpose of the system, so the system must be built to satisfy their requirements.

The researcher will actively access the data through a custom designed interface. The interface will be customized to represent an Io type theme as well as simplified for those researchers who have limited GIS experience. Functionality included in the design

interface will include zoom, pan, layer properties, layer presence, and exporting as an image file. If possible, the system will only have these specific buttons on the interface to avoid confusion by the researchers. The zoom function will obviously allow the researcher to increase or decrease the scale at which they are viewing the data. The pan function will allow the researcher to move the data displayed in any direction to capture other areas of the data without changing the scale at which the data is displayed. The layer presence or function will allow the researcher to display or remove the selected data layer from the current display. The layer properties function will allow the researcher to change the display properties of the selected layer such as color or transparency. Finally, the save function will allow the researcher to export the current display extent as a image file such as a .jpeg or .tiff.

System Environment

Hardware requirements for the researchers accessing the system are very broad. The system shall be designed to be available to all operating systems on virtually any hardware configuration available. However, a recommendation of a minimum 900 Mhz processor and 512 MB of RAM shall be made. No peripheral software other than a basic internet viewer will be required for the researchers to view the system. The user will be required to have an active internet connection available to them to contact the system's web address. For the design and maintenance of the system, ESRI's ArcIMS software will be employed. For some windows based systems two other sites may be constructed. A HTML site will be designed and in this case, some windows operating system users may be required to download and install a free version of ArcExplorer, also provided by ESRI. In another potential variation, a Java site may also be constructed that would require the user to have the latest version of Java installed on their local machine.

Software Design

The software employed for this system will be ESRI's ArcIMS internet software. This software will be utilized to design the website and eventual interface that the researcher can access to view the data from Io. The finished website will be hosted on a central server in Lewis Hall at the University of Redlands in southern California. The server

currently operates on a Windows Server 2003 operating system. To configure ArcIMS website to the server, Apache and Tomcat configuration will be used.

The only inputs of the system website will be the SSI, NIMS, and PPR data layers contained within a personal geodatabase. From these inputs, the researchers will be able to identify surface processes and relationships from the simultaneously projected data. Unfortunately due to the simplicity of the system, there will be no data flow once the website is finalized. The processes of the interface will include basic functionality provided in the default ArcIMS software package. The functionality includes zoom, pan, layer properties, layer presence, and exporting as an image file. These functions will be available through the interface as a labeled button. The users can access the function by clicking on the button through the mouse cursor. The click will either present a dialog box for the user to specify the parameters of the command, or change the cursor to another shape and allow the user to interactively utilize the tool in the viewer.

Database Design

The SSI, NIMS, and PPR data will all be contained within a personal geodatabase with an appropriate naming scheme. The SSI data will be contained within a managed raster catalog to organize the individual raster images in the same projection and coordinate system. The images will also be compiled into one mosaic also contained within the catalog. Similar to the SSI, the NIMS data will also be contained within a managed raster catalog. The only real difference between the two data sets will be that the NIMS data will be contained in a multi spectral format, where the SSI is in a panchromatic image format. The PPR may be the systems most simple data type but it requires the most complex storage system. The PPR data will be stored within a feature dataset in two separate feature classes representing different orbits of the spacecraft. In addition to the PPR data, another feature dataset may be created to contain any surface features that may be created during the analysis portion of the project.

These datasets have no relationship to one another other than location in space

User Interface Design

The basic Io interface will allow a researcher to add layers into the display frame from the Io Geodatabase and view them. The user will have the ability to change their display properties, zoom, pan, and save the display in a jpeg or tiff format through command buttons beside the display frame. The viewer will look quite basic, and consequently have basic functionality.

http://gis.sarup.uwm.edu/gis4/changing_the_frameset_for_htmlvi.htm

The presented image is a screenshot of a default viewer available through ArcIMS. The interface for this project system will somewhat resemble this image, built with some subtle differences. First, the interface will be customized to represent an Io type theme, such as maybe black, yellow, orange, and grey type color scheme. Also the title will reflect the Io system. Next, the functionality will be limited to only a few selected

commands. Zoom, Pan, Save, Display Properties, and layer presence will be the only functions available to the user, and consequently those will be the only buttons available on the toolbar present on the right side of the viewer in the presented image. Due to the lack of buttons, they too will be customized to show labels as well as pictures, and the size of the actual button will be increased for clarification.

Appendix G – Implementation Plan

Executive Summary

Constant volcanic activity accompanied by intense sulfurous plumes has made one of Jupiter's moons, Io, one of the most observed celestial bodies in recent history. The abundance of giant calderas, lava lakes, volcanoes, and vast lava flows have drawn as much attention to Io as not only the first active volcanoes discovered within the solar system, but the most geologically active object ever observed. These dramatic features on Io combined with Jupiter's storms and rings, inspired NASA to embark on the Galileo mission to exclusively study Jupiter and its four largest moons. On the Galileo spacecraft, the three instruments that emerged to be the most useful were the solid state imaging device (SSI), the near infrared mapping spectrometer (NIMS), and the photopolarimeter radiometer (PPR). These three instruments produced numerous stunning images during the Galileo mission, but unfortunately each instrument acquires data in a different format and resolution.

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Updated Schedule

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					Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	
1	Data Acquisition & Exploration	1/9/2006	3/31/2006	60d												
2	Data Registration	4/3/2006	8/30/2006	108d												
3	Data Export & Import	8/1/2006	9/29/2006	44d												
4	Geodatabase Design	3/1/2006	4/28/2006	43d												
5	Surface Feature Data Creation	9/1/2006	9/29/2006	21d												
6	Stand Alone Application Development	7/3/2006	8/29/2006	42d												
7	Documentation	1/9/2006	12/15/2006	245d												

Deliverables and Milestones

- Georeferenced image data (**Task 2**)
- Georeferenced Ellipsoid PPR data (**Task 2**)
- Geodatabase containing all georeferenced data (**Task 4**)
- Finished MIP Paper documenting the entire project (**Task 5**)
- Georeferenced surface feature data (**Task O**)
- Stand Alone Website containing all georeferenced data (**Task 5**)
- Data CD containing all original and processed data (**Task 5**)
- Final hard & digital maps for display in documentation and for client (**Task 5**)
- Basic training for direct contact users (**Task 5**)
- Final presentation of entire project for advisors, clients, and public (**Task 5**)
- Basic website help documentation (**Optional Task 5**)

Updated Risk Mitigation Plan

Risk is a part of any project done, and therefore, also a part of this project. The first and most critical risk has to be associated with the data. Once again the data is in different formats, sizes, and scales and may possibly be the most difficult task of this project. Processing this data into one useable form will take a lot of time and effort, but is the most vital component of the project. Without the association of the data types, the project will be an utter failure. The critical risk of data registration has already been realized and is being dealt with as well by utilizing the raw data from the Galileo spacecraft rather than trying to manipulate existing preprocessed data. There still may be risks involved with the registration itself that will have to be dealt with. These risks should be avoidable by the familiarization of georeferencing and the associated data properties.

A marginal risk associated with the data as the image processing software. I have previous experience using ENVI software, but haven't been exposed to it in well over a year. Re-familiarizing myself with the software package may take a few days prior to the actual beginning of the data processing. Similar to the registration, the ENVI software problem has been looked at, and I have spent some time familiarizing myself with the software a little more. The last serious risk to the project may be the absence of the client and advisors during some of the processing phases of the project. Their knowledge and insight to the project could be invaluable during these processes, and their absence may delay the certain aspects of the project until their return. They are potentially the response to all of the other previously listed risks.

Testing Approach

The testing approach of the system in my MIP will be based on two simple factors; is the data displayed correctly, and can the users effectively view the data. This testing will primarily be performed by my client, Julie Rathbun. She will primarily be testing the

final data product to ensure that all of the data sets are simultaneously projected correctly over the same area of the Amirani region. She will also be the primary inspector of the Website containing all of the data to ensure data quality and functionality of the website. My client will also be testing the website to ensure that new users will easily be able to use the site without any difficulty. All of the primarily testing during construction of the website will be performed at the University of Redlands campus until the final completion when we will begin testing availability of the website on personal computers.

Testing for the site is already underway for the duration of the construction and customization of the site, as well as the data quality. The functionality of the website will be tested until the completion of the final project when final test will be performed by Julie and me. The website is scheduled to be finished in mid-August and the data is scheduled to be finished by the end of September. This essentially leaves me with two and a half months to ensure the website and data are ready for final testing and distribution. The final testing will be complete when the two criteria stated earlier are fulfilled. If the data is correctly projected of the Amirani Region in an ArcIMS website that is accessible to Io researchers that can easily and effectively view the data, the project testing will be complete.

Test Methodology

One method of testing the accuracy of the data projection is to compare the spatial coordinates of all three data sets. I have recently received a script that can transform the original Isis cubes (images) from the Galileo spacecraft into an ArcGIS compatible image. Since two of the data sets are image datasets, this script may be all of the testing needed to ensure the correct projection of the two datasets. Also, the PPR data was capture to mimic the SSI data in the sense that some specific PPR shots were specifically recorded at the exact center of an SSI image capture. These points could then be transformed to match the image data if needed. To also capture a bit more accuracy from the data, the buffer created around the PPR data points will be derived from a calculation based on the position and distance of the spacecraft in relation to the moon. This calculation will ensure the size (and hopefully shape) of each buffer will be as accurate as possible. These three tests may provide the methods necessary to provide my client with enough confidence to begin performing research on the study area.

Testing for the final website is seemingly less complicated. Ongoing testing will be performed on the functionality of the website during the construction and customization of the site. These tests will be concerned with the functions available to the user, and identifying any potential trouble areas. The website must be extremely easy to use so these tests can be more opinion type views of the site from people other than myself. Julie is more knowledgeable about the users that will utilize this system and her opinions about the overall “feel” of the site will be invaluable to me. Both of us will also test the availability of the site once it is finally published. We will attempt to access the site from school and home from a few different platforms of personal computers as well as personal settings. These tests will determine if the website is truly accessible to most of our users.

Test Scope

The functionality of the system is relatively simple and the consequent testing will be simple as well. The viewer functions of the site include various zoom and a single pan command. These will obviously be tested by trying each of these buttons while the data is displayed. Since these features are strictly “out of the box” functions, I expect no difficulty with them at all. All of the various data set layers will be present in the table of contents within the viewer with a small check box to represent their presence in the viewer. All layers will be tested by checking or un-checking the box and clicking the refresh map button. The other function of exporting the viewer display as an image file is also another “out of the box” feature and is simply tested by performing the action.

Test Acceptance

As stated earlier, the client has two simple expectations of this project. Once the data is displayed correctly in a simple viewer where users can easily and effectively view the data, the project testing will be complete. Once the client examines the methods and accuracies of the data transformations as well as its final display, I am confident she will be pleased with the result. As for the viewer, she must personally inspect the viewer and its simple functionality to ensure it allows her and others to perform the research she needs. Once these criteria are met, the test will be successfully completed.

Test Environment

Site Requirements

There are different requirements for hardware and software for the two separate criteria. For the data and website construction tests, all of the testing will be performed on my personal Sony Vaio laptop computer with a 2.0 GHz Intel processor, 1GB of RAM, and 100 GB of storage space utilizing a Microsoft Windows XP operating system. Software on this laptop includes Microsoft Office, Internet Explorer 7, ENVI 4.2, ArcIMS 9.1, and ArcGIS 9.1(ArcInfo License). These will be the only software packages required for these tests. For the final website testing, numerous different platforms will be utilized running numerous different operating systems, software packages, and internet browsers. The completed website will be hosted by a server at the University of Redlands exclusively dedicated to the deployment of ArcIMS websites by the Redlands Institute, and students of the MSGIS program. This server will be the final container for the customized website, as well as the final data sets to view on the website.

Staffing and Training

No special staffing or training will be required for these tests

Test Data

No specific test data will be used for any testing either, only the original and transformed data will be utilized in these tests.

Schedule

Testing Schedule

Item	Expected Completion Date
Website	August 31, 2006
Data	September 30, 2006
Final	October 15, 2006

Adoption Plan

The first and foremost challenge for the website application is to make the website easy to understand and use. My client has stressed this to me on numerous occasions. If the functions, data layers, or any other part of the website is difficult to understand, the website will need to be adjusted until my client is satisfied with its simplicity. This will be avoided by keeping the website clear of any extra functions that the users don't need, and labeling the existing functions and data layers very well so there would be no question whatsoever what the user would be viewing or applying.

The ability of the website to be viewed on numerous types of hardware and software configurations will be another challenge that my client sees as crucial to the success of this website. A lot of the Io researchers around the continent utilize Macintosh hardware and software. It is critical that the website be compatible with these configurations or the convenience of the website could be at a loss. By using HTML and Java applet compatible website designs, the website should be viewable through most Macintosh configurations, as well as a multitude of internet browsers capable of decoding HTML code, or by the utilization of individual Java applets specified for their operating system.

The proper combination of the three data layers is essentially the basis for this entire project and must be successful for any of the other factors of this project to even exist. Through scripts, image processing, and geoprocessing, I assured my client that this project would be a success and I fully intend to keep that promise.

Deployment Plan

Deployment of the Io Viewer to the research community will be the first of its kind in this specific field of interest. Not only will this be a prototype for the simultaneous projection of the three specific data types using any form of GIS, but it will also be the first time an interactive viewer was used to distribute the results over the internet. The prototype will initially be deployed at the University of Redlands for the client, Julie Rathbun to explore and eventually approve for her uses among the Io research community. The website will be developed using ArcIMS 9.1 and hosted on an independent server dedicated to serving ArcIMS websites for the Redlands Institute and students of the MSGIS program. All of the data will be compiled and stored on the server and distributed through the website using an ArcGIS 9.1 project file (.mxd). The website will be created and deployed in an HTML format so most users will be able to view the site on their local computer utilizing a multitude of thin client internet browsers.

For the deployment to be successfully completed, there are numerous other activities that must be completed, presented, and approved by the client. The most time consuming element of the deployment process will be the complete documentation of the entire

project, containing all information from the exploratory beginnings through to the final delivered product. This documentation will also contain a small user's manual for the simplistic website, complete metadata for all of the data layers involved, and a number of prototype maps created using the processed data sets. All of the documentation, data, and maps will also be provided on a CD for further distribution. The final results of the Io project will be presented to a final committee for approval at the completion of the project. This presentation could be thought of as a thesis defense or an educational presentation to any number of interested individuals. A few presentations about the project will be given to a number of different audiences.

The final delivery of the completed system to the client will be relatively simple. Most of the system configuration and requirements will be dealt with during the testing of the system. There will be no need for data conversion or any software installation because the final system will be provided exclusively through the internet. The final component of the project deployment will be to provide the client with a brief introduction to the system and how to utilize the functionality of the website. If the deployment of the new system needed to be labeled as anything, it would probably be referred to as a location conversion because it will only be deployed at one site as a prototype for other researchers to view.

Training Plan

Training for the final product of the project will be exceedingly simple for the Io project. The objectives of the training will be focused on helping the client understand and have the ability to utilize the Io website and processed data. Luckily, Julie has some experience with GIS and already understands the basic functionality of ESRI's ArcGIS. These objectives will be easily reached by performing some one-on-one training with Julie to explore the datasets provided to her on CD, and through the website. Through the data exploration training, the processes performed on the data will be discussed to the client so she fully understands how the final product was derived. These final datasets will be explored using ArcGIS, and the provided website. The website training should be exceedingly easily given Julie's experience with GIS and its functionality. Regardless, the training will include demonstrating the accessibility and functionality of the website.

Operations Plan

The nature of the final Io project viewer was to be a prototype for other researchers throughout the continent to view and evaluate the systems capability, to determine if GIS was a feasible platform for extended research with interstellar datasets. Due to this fact, the expected life cycle of this website is relatively short. The website will be hosted at the University of Redlands and up kept with minimal maintenance by the Redlands Institute staff. The website will be one of many already hosted on the server by the institute.

Appendix H – Registering Mosaics VBA Code

Option Explicit

Sub CreateRegisteringPointsForMosaics()

'Declare variables

Dim sWSName As String

Dim sFCName As String

'Assign Values

sWSName = "C:\ShanesDocs\MySchool\MIP\ProcessedData\Registering"

sFCName = "MosaicPoints.shp"

'Set up a simple fields collections

Dim pFieldsEdit As IFieldsEdit

Set pFieldsEdit = New esriGeoDatabase.Fields

'Create a field

Dim pFieldEdit As IFieldEdit

Set pFieldEdit = New esriGeoDatabase.Field

'Shape field

pFieldEdit.Name = "Shape"

pFieldEdit.Type = esriFieldTypeGeometry

'Declare and Set Geometry Defenitions for new Shapefile

Dim pGeomDefEdit As IGeometryDefEdit

Set pGeomDefEdit = New GeometryDef

pGeomDefEdit.GeometryType = esriGeometryPoint

Set pGeomDefEdit.SpatialReference = New UnknownCoordinateSystem

Set pFieldEdit.GeometryDef = pGeomDefEdit

'Add Field

pFieldsEdit.AddField pFieldEdit

'Id field

Set pFieldEdit = New esriGeoDatabase.Field

pFieldEdit.Name = "ID"

pFieldEdit.Length = 10

pFieldEdit.Type = esriFieldTypeInteger

'Add Field

pFieldsEdit.AddField pFieldEdit

'X field


```

Set pFieldEdit = New esriGeoDatabase.Field
pFieldEdit.Name = "X"
pFieldEdit.Length = 10
pFieldEdit.Type = esriFieldTypeDouble

'Add Field
pFieldsEdit.AddField pFieldEdit

'Y field
Set pFieldEdit = New esriGeoDatabase.Field
pFieldEdit.Name = "Y"
pFieldEdit.Length = 10
pFieldEdit.Type = esriFieldTypeDouble

'Add Field
pFieldsEdit.AddField pFieldEdit

'Open a Workspace
Dim pWF As IWorkspaceFactory
Set pWF = New ShapefileWorkspaceFactory

Dim pFWS As IFeatureWorkspace
Set pFWS = pWF.OpenFromFile(sWSName, 0)

'Create a FeatureClass
Dim pFC As IFeatureClass
Set pFC = pFWS.CreateFeatureClass(sFCName, pFieldsEdit, Nothing, _
    Nothing, esriFTSimple, "Shape", "")

'Create insert cursor
Dim pIFCursor As IFeatureCursor
Set pIFCursor = pFC.Insert(True)

'Create feature buffer
Dim pIFBuffer As IFeatureBuffer
Set pIFBuffer = pFC.CreateFeatureBuffer

'Create a point
Dim pPoint As IPoint
Set pPoint = New Point

'1st point
pPoint.PutCoords 0, -90
Set pIFBuffer.Shape = pPoint
pIFBuffer.Value(2) = 1
pIFBuffer.Value(3) = 0

```

```
pIFBuffer.Value(4) = -90  
pIFCursor.InsertFeature pIFBuffer
```

```
'2nd point  
pPoint.PutCoords 0, 90  
Set pIFBuffer.Shape = pPoint  
pIFBuffer.Value(2) = 2  
pIFBuffer.Value(3) = 0  
pIFBuffer.Value(4) = 90  
pIFCursor.InsertFeature pIFBuffer
```

```
'3rd point  
pPoint.PutCoords 180, -90  
Set pIFBuffer.Shape = pPoint  
pIFBuffer.Value(2) = 3  
pIFBuffer.Value(3) = 360  
pIFBuffer.Value(4) = -90  
pIFCursor.InsertFeature pIFBuffer
```

```
'4th point  
pPoint.PutCoords 180, 90  
Set pIFBuffer.Shape = pPoint  
pIFBuffer.Value(2) = 4  
pIFBuffer.Value(3) = 360  
pIFBuffer.Value(4) = 90  
pIFCursor.InsertFeature pIFBuffer
```

```
'5th point  
pPoint.PutCoords -180, -90  
Set pIFBuffer.Shape = pPoint  
pIFBuffer.Value(2) = 5  
pIFBuffer.Value(3) = 360  
pIFBuffer.Value(4) = -90  
pIFCursor.InsertFeature pIFBuffer
```

```
'6th point  
pPoint.PutCoords -180, 90  
Set pIFBuffer.Shape = pPoint  
pIFBuffer.Value(2) = 6  
pIFBuffer.Value(3) = 360  
pIFBuffer.Value(4) = 90  
pIFCursor.InsertFeature pIFBuffer
```

```
'Save it  
pIFCursor.Flush
```

```

'Set to Nothing
Set pFieldsEdit = Nothing
Set pFieldEdit = Nothing
Set pGeomDefEdit = Nothing
Set pIFBuffer = Nothing
Set pIFCursor = Nothing

'Create a simple Marker simple
Dim pSMS As ISimpleMarkerSymbol
Set pSMS = New SimpleMarkerSymbol
pSMS.Style = esriSMSSquare

'Specify a color
Dim pColor As IRgbColor
Set pColor = New RgbColor
pColor.RGB = RGB(0, 255, 0)
pSMS.Color = pColor

'Create a simple renderer
Dim pSimpleRenderer As ISimpleRenderer
Set pSimpleRenderer = New SimpleRenderer
Set pSimpleRenderer.Symbol = pSMS

'Get Document
Dim pMxDoc As IMxDocument
Set pMxDoc = ThisDocument

'Get Map
Dim pMap As IMap
Set pMap = pMxDoc.FocusMap

'Create a FeatureLayer and set the FeatureClass
Dim pFL As IFeatureLayer
Set pFL = New FeatureLayer
Set pFL.FeatureClass = pFC

'Declare Variables
Dim pLayer As ILayer
Set pLayer = pFL
pLayer.Name = sFCName
pLayer.ShowTips = True

'Adds Layer
pMap.AddLayer pFL

'Get 1st Layer and assign renderer

```

```
Dim pGFLayer As IGeoFeatureLayer
Set pGFLayer = pMap.Layer(0)
Set pGFLayer.Renderer = pSimpleRenderer
```

```
'Update ToC and refresh content
pMxDoc.UpdateContents
```

```
'Declare Active View and Refresh Map
Dim pAV As IActiveView
Set pAV = pMxDoc.ActivatedView
pAV.Refresh
```

```
End Sub
```

Appendix I – Registering SSI Code changes to Appendix H

This is the unique name of the sub-routine so a user can identify it

`Sub CreateRegisteringPointsForSSI()`

This is the name of the point shapefile that the program will create

`sFCName = "SSIPoints.shp"`

These are the individual points to be created by the program

'1st point

`pPoint.PutCoords -140, -10`

`Set pIFBuffer.Shape = pPoint`

This is the point number

`pIFBuffer.Value(2) = 1`

This is the point longitude

`pIFBuffer.Value(3) = 220`

This is the point latitude

`pIFBuffer.Value(4) = -10`

`pIFCursor.InsertFeature pIFBuffer`

'2nd point

`pPoint.PutCoords -140, 40`

`Set pIFBuffer.Shape = pPoint`

`pIFBuffer.Value(2) = 2`

`pIFBuffer.Value(3) = 220`

`pIFBuffer.Value(4) = 40`

`pIFCursor.InsertFeature pIFBuffer`

'3rd point

`pPoint.PutCoords -60, -10`

`Set pIFBuffer.Shape = pPoint`

`pIFBuffer.Value(2) = 3`

`pIFBuffer.Value(3) = 300`

`pIFBuffer.Value(4) = -10`

`pIFCursor.InsertFeature pIFBuffer`

'4th point

`pPoint.PutCoords -60, 40`

`Set pIFBuffer.Shape = pPoint`

`pIFBuffer.Value(2) = 4`

`pIFBuffer.Value(3) = 300`

`pIFBuffer.Value(4) = 40`

`pIFCursor.InsertFeature pIFBuffer`

This is the color that the points will appear in ArcMap

`pColor.RGB = RGB(255, 0, 0)`

Appendix J – Registering NIMS 24 Code changes to Appendix H

Sub CreateRegisteringPointsForNIMS24()

sFCName = "NIMS24Points.shp"

'1st point

pPoint.PutCoords -110, 17

Set pIFBuffer.Shape = pPoint

pIFBuffer.Value(2) = 1

pIFBuffer.Value(3) = 250

pIFBuffer.Value(4) = 17

pIFCursor.InsertFeature pIFBuffer

'2nd point

pPoint.PutCoords -110, 27.6

Set pIFBuffer.Shape = pPoint

pIFBuffer.Value(2) = 2

pIFBuffer.Value(3) = 250

pIFBuffer.Value(4) = 27.6

pIFCursor.InsertFeature pIFBuffer

'3rd point

pPoint.PutCoords -119.4, 17

Set pIFBuffer.Shape = pPoint

pIFBuffer.Value(2) = 3

pIFBuffer.Value(3) = 240.6

pIFBuffer.Value(4) = 17

pIFCursor.InsertFeature pIFBuffer

'4th point

pPoint.PutCoords -119.4, 27.6

Set pIFBuffer.Shape = pPoint

pIFBuffer.Value(2) = 4

pIFBuffer.Value(3) = 240.6

pIFBuffer.Value(4) = 27.6

pIFCursor.InsertFeature pIFBuffer

pColor.RGB = RGB(0, 0, 255)

Appendix K – Registering NIMS 27 Code changes to Appendix H

Sub CreateRegisteringPointsForNIMS27()

sFCName = "NIMS27Points.shp"

'1st point
pPoint.PutCoords -106, 10
Set pIFBuffer.Shape = pPoint
pIFBuffer.Value(2) = 1
pIFBuffer.Value(3) = 254
pIFBuffer.Value(4) = 10
pIFCursor.InsertFeature pIFBuffer

'2nd point
pPoint.PutCoords -106, 37
Set pIFBuffer.Shape = pPoint
pIFBuffer.Value(2) = 2
pIFBuffer.Value(3) = 254
pIFBuffer.Value(4) = 37
pIFCursor.InsertFeature pIFBuffer

'3rd point
pPoint.PutCoords -123, 10
Set pIFBuffer.Shape = pPoint
pIFBuffer.Value(2) = 3
pIFBuffer.Value(3) = 237
pIFBuffer.Value(4) = 10
pIFCursor.InsertFeature pIFBuffer

'4th point
pPoint.PutCoords -123, 37
Set pIFBuffer.Shape = pPoint
pIFBuffer.Value(2) = 4
pIFBuffer.Value(3) = 237
pIFBuffer.Value(4) = 37
pIFCursor.InsertFeature pIFBuffer

pColor.RGB = RGB(0, 255, 255)

Appendix L – Drawing PPR 24 IN Ellipses VBA Code

Option Explicit

Sub CreateEllipseShapefile24IN()

```
'-----  
'Add PPR Shapefile  
'-----  
  
'Declare variables  
Dim sWSName As String  
sWSName = "C:\ShanesDocs\MySchool\MIP\ProcessedData\PPR\Processing"  
Dim sFCName As String  
sFCName = "24INPPR.shp"  
  
'Opening a Workspace  
Dim pWF As IWorkspaceFactory  
Set pWF = New ShapefileWorkspaceFactory  
  
Dim pFWS As IFeatureWorkspace  
Set pFWS = pWF.OpenFromFile(sWSName, 0)  
  
'Open a FeatureClass  
Dim pFC As IFeatureClass  
Set pFC = pFWS.OpenFeatureClass(sFCName)  
  
'Create a FeatureLayer and set the FeatureClass  
Dim pFL As IFeatureLayer  
Set pFL = New FeatureLayer  
Set pFL.FeatureClass = pFC  
  
'Create a Layer and set as FeatureClass  
Dim pLayer As ILayer  
Set pLayer = pFL  
pLayer.Name = "24INPPR.shp"  
pLayer.ShowTips = True  
  
'Add layer in the Map  
Dim pMxDoc As IMxDocument  
Set pMxDoc = ThisDocument  
  
'Declare Map and set to current Map Document  
Dim pMap As IMap  
Set pMap = pMxDoc.FocusMap
```



```

'Add FeatureClassLayer to Map
pMap.AddLayer pFL

'Update ToC and refresh content
pMxDoc.UpdateContents

'Declare Active View and Refresh it
Dim pAV As IActiveView
Set pAV = pMxDoc.ActivatedView
pAV.Refresh

'-----
'Create Ellipse File
'-----

'Declare Variable
Dim sNFCName As String
sNFCName = "24INEllipses.shp"

'Set up a simple fields collections
Dim pFieldsEdit As IFieldsEdit
Set pFieldsEdit = New esriGeoDatabase.Fields

'Create a field
Dim pFieldEdit As IFieldEdit
Set pFieldEdit = New esriGeoDatabase.Field

'Shape field
pFieldEdit.Name = "Shape"
pFieldEdit.Type = esriFieldTypeGeometry

'Declare and Set Geometry Defenitions for new Shapefile
Dim pGeomDefEdit As IGeometryDefEdit
Set pGeomDefEdit = New GeometryDef
pGeomDefEdit.GeometryType = esriGeometryPolygon
Set pGeomDefEdit.SpatialReference = New UnknownCoordinateSystem

'Set Field Collections to Geometry Defenitions
Set pFieldEdit.GeometryDef = pGeomDefEdit

'Adds Geometry Definitions fields
pFieldsEdit.AddField pFieldEdit

'Id field
Set pFieldEdit = New esriGeoDatabase.Field

```

```

pFieldEdit.Name = "ID"
pFieldEdit.Length = 5
pFieldEdit.Type = esriFieldTypeInteger

'Adds Id filed
pFieldsEdit.AddField pFieldEdit

'Create a FeatureClass
Dim pNFC As IFeatureClass
Set pNFC = pFWS.CreateFeatureClass(sNFCName, pFieldsEdit, Nothing, _
    Nothing, esriFTSimple, "Shape", "")

'Declare and set table to FeatureClass
Dim theTable As ITable
Set theTable = pFC

'Declares an index for the FID field
Dim indFldIndex As Long
indFldIndex = theTable.FindField("FID")

'Declares an index for the HEIGHT_D field
Dim indHeight As Long
indHeight = theTable.FindField("HEIGHT_D")

'Declares an index for the ADJ_WID_D field
Dim indWidth As Long
indWidth = theTable.FindField("ADJ_WID_D")

'Declare an index for the HI_WI_RATIO field
Dim indRatio As Long
indRatio = theTable.FindField("HI_WI_RATI")

'Declare an index for the AZIMUTH_R field
Dim indAngle As Long
indAngle = theTable.FindField("AZIMUTH_R")

'Declares and sets a cursor to the first record
Dim pCursor As IFeatureCursor
Set pCursor = pFC.Search(Nothing, True)

'Declare and sets a row to the cursor
Dim theRow As IRow
Set theRow = pCursor.NextFeature

'Declares and sets the feature to the cursor at the row
Dim pFeature As IFeature

```

```

Set pFeature = theRow

'Loops while the row has values in it
Do While Not theRow Is Nothing

    'Declare and sets variables to the corresponding value in the table
    Dim intI As Integer
    intI = theRow.Value(indFldIndex)
    Dim dblWidth As Double
    dblWidth = theRow.Value(indWidth)
    Dim dblHeight As Double
    dblHeight = theRow.Value(indHeight)
    Dim dblRatio As Double
    dblRatio = theRow.Value(indRatio)
    Dim dblAngle As Double
    dblAngle = theRow.Value(indAngle)

    'Declare Ellipse Variables
    Dim pPolygon As esriGeometry.IPolygon
    Dim pConstructEllipticArc As esriGeometry.IConstructEllipticArc
    Dim pEllipticArc As esriGeometry.IEllipticArc
    Dim pSeg As esriGeometry.ISegment
    Dim pSegcoll As esriGeometry.ISegmentCollection
    Dim pRing As esriGeometry.IRing
    Dim pGeomColl As esriGeometry.IGeometryCollection
    Dim pEnv As esriGeometry.IEnvelope
    Dim pSR As esriGeometry.ISpatialReference
    Set pSR = Nothing

    'Declare and set point feature to current feature
    Dim pPoint As IPoint
    Set pPoint = pFeature.Shape

    'Determine extent of ellipse
    Set pEnv = pPoint.Envelope

    'Set Envelope spatial reference to the current map's
    Set pEnv.SpatialReference = pMap.SpatialReference

    'Create Ellipse Elements
    Set pEllipticArc = New esriGeometry.EllipticArc
    Set pEllipticArc.SpatialReference = pSR
    Set pConstructEllipticArc = pEllipticArc

    'Draw ellipse from center point, from angle, central angle, rotation angle, semi
    major axis, minor Major Ratio

```

```
pEllipticArc.PutCoordsByAngle False, pPoint, 0, 2 * 3.14159265358979, dblAngle,  
dblHeight, dblRatio
```

```
'Draw Ellipse  
Set pSeg = pEllipticArc  
Set pSegcoll = New esriGeometry.Ring  
pSegcoll.AddSegment pSeg  
Set pRing = pSegcoll  
Set pPolygon = New esriGeometry.Polygon  
Set pPolygon.SpatialReference = pSR  
Set pGeomColl = pPolygon  
pGeomColl.AddGeometry pRing
```

```
'Create insert cursor  
Dim pIFCursor As IFeatureCursor  
Set pIFCursor = pNFC.Insert(True)
```

```
'Create feature buffer  
Dim pIFBuffer As IFeatureBuffer  
Set pIFBuffer = pNFC.CreateFeatureBuffer  
Set pIFBuffer.Shape = pPolygon  
pIFBuffer.Value(2) = intI  
pIFCursor.InsertFeature pIFBuffer
```

```
'Set Envelope to Nothing  
Set pEnv = Nothing
```

```
'Save it  
pIFCursor.Flush
```

```
'Set to Nothing  
Set pFieldsEdit = Nothing  
Set pFieldEdit = Nothing  
Set pGeomDefEdit = Nothing  
Set pIFBuffer = Nothing  
Set pIFCursor = Nothing
```

```
'Set the cursor to the next feature  
Set theRow = pCursor.NextFeature
```

Loop

```
'Create a FeatureLayer and set the FeatureClass  
Dim pNFL As IFeatureLayer  
Set pNFL = New FeatureLayer  
Set pNFL.FeatureClass = pNFC
```

```
'Declare Variables
Dim pNLayer As ILayer
Set pNLayer = pNFL
pNLayer.Name = sNFCName
pNLayer.ShowTips = True

'Adds Layer
pMap.AddLayer pNFL

'Get 1st Layer and assign renderer
Dim pNGFLayer As IGeoFeatureLayer
Set pNGFLayer = pMap.Layer(0)

'Update ToC
pMxDoc.UpdateContents

'Refresh Content
pAV.Refresh

End Sub
```

Appendix M – Drawing PPR 24 IS and 27 IN Ellipses Code changes to Appendix L

This is the unique name of the sub-routine so a user can identify it

`Sub CreateEllipseShapefile24IS()`

This is the name of the PPR point shapefile being imported to create the ellipses

`sFCName = "24ISPPR.shp"`

This is the display name of the point shapefile in the Table of Contents within ArcGIS

`pLayer.Name = "24ISPPR.shp"`

This is the name of the Ellipse shapefile that the program will create

`sNFCName = "24ISEllipses.shp"`

`Sub CreateEllipseShapefile27IN()`

`sFCName = "27INPPR.shp"`

`pLayer.Name = "27INPPR.shp"`

`sNFCName = "27INEllipses.shp"`

Appendix N – Sample Metadata for PPR data utilizing PPR_24IN

PPR_24IN

Metadata also available as

Metadata:

- [Identification Information](#)
- [Data Quality Information](#)
- [Spatial Data Organization Information](#)
- [Spatial Reference Information](#)
- [Entity and Attribute Information](#)
- [Distribution Information](#)
- [Metadata Reference Information](#)

Identification_Information:

Citation:

Citation_Information:

Originator:

Files: 24inamskgi01.geo & 24inamskgi01.rad, Contributors: Galileo Spacecraft, NASA, JPL

Publication_Date: 2006

Title: PPR_24IN

Geospatial_Data_Presentation_Form: vector digital data

Online_Linkage:

\\SHANE_BARRETT\C\$\ShanesDocs\MySchool\MIP\ProcessedData\FinalData\Geodatabase\Io.mdb

Description:

Abstract:

Ellipses of the PPR data captured during the 24th orbit of the Galileo Spacecraft

Purpose:

PPR data captured surface temperatures of Io between 60 and 600 degrees Kelvin

Time_Period_of_Content:

Time_Period_Information:

Single_Date/Time:

Calendar_Date: 1999

Currentness_Reference: ground condition

Status:

Progress: Complete

Maintenance_and_Update_Frequency: As needed

Spatial_Domain:

Bounding_Coordinates:

West_Bounding_Coordinate: -117.894770

East_Bounding_Coordinate: -112.042960
North_Bounding_Coordinate: 25.641660
South_Bounding_Coordinate: 21.566170
Keywords:
Theme:
Theme_Keyword_Thesaurus: None
Theme_Keyword: PPR, Polygons, Ellipses, Temperatures
Place:
Place_Keyword: Io
Temporal:
Temporal_Keyword: 1999
Access_Constraints: None
Use_Constraints: None
Point_of_Contact:
Contact_Information:
Contact_Person_Primary:
Contact_Person: Dr. Julie Rathbun
Contact_Organization: University of Redlands
Contact_Position: Physics Professor
Contact_Address:
Address_Type: mailing and physical address
Address: 1200 East Colton Avenue
Address: P.O. Box 3080
City: Redlands
State_or_Province: California
Postal_Code: 92373-0999
Contact_Voice_Telephone: (909) 793 2121
Contact_Electronic_Mail_Address: Julie_Rathbun@redlands.edu
Data_Set_Credit: Galileo Spacecraft, NASA, JPL
Native_Data_Set_Environment:
Microsoft Windows XP Version 5.1 (Build 2600) Service Pack 2; ESRI
ArcCatalog 9.1.0.780

Data_Quality_Information:

Lineage:
Process_Step:
Process_Description:
Executed custom script that draws an ellipse for each record within the point shapefile based on their unique location, short axis, long axis and azimuth and saves them as a polygon shapefile
Process_Contact:
Contact_Information:
Contact_Organization_Primary:
Contact_Organization: University of Redlands
Contact_Person: Shane Barrett
Contact_Position: Master's Student

Process_Step:

Process_Description:

Table was joined to the corresponding point shapefile table and exported as a final polygon shapefile

Process_Contact:

Contact_Information:

Contact_Organization_Primary:

Contact_Organization: University of Redlands

Contact_Person: Shane Barrett

Contact_Position: Master's Student

Process_Step:

Process_Description: Metadata imported.

Source_Used_Citation_Abbreviation:

C:\DOCUME~1\SHANE_~1\LOCALS~1\Temp\xml30.tmp

Spatial_Data_Organization_Information:

Direct_Spatial_Reference_Method: Vector

Point_and_Vector_Object_Information:

SDTS_Terms_Description:

SDTS_Point_and_Vector_Object_Type: G-polygon

Point_and_Vector_Object_Count: 332

Spatial_Reference_Information:

Horizontal_Coordinate_System_Definition:

Geographic:

Latitude_Resolution: 0.000010

Longitude_Resolution: 0.000010

Geographic_Coordinate_Units: Decimal degrees

Geodetic_Model:

Horizontal_Datum_Name: D_Io_2000

Ellipsoid_Name: Io_2000_IAU_IAG

Semi-major_Axis: 1821460.000000

Denominator_of_Flattening_Ratio: infinity

Vertical_Coordinate_System_Definition:

Altitude_System_Definition:

Altitude_Resolution: 0.000010

Altitude_Encoding_Method:

Explicit elevation coordinate included with horizontal coordinates

Entity_and_Attribute_Information:

Detailed_Description:

Entity_Type:

Entity_Type_Label: PPR_24IN

Attribute:

Attribute_Label: OBJECTID

Attribute_Definition: Internal feature number.

Attribute_Definition_Source: ESRI
Attribute_Domain_Values:
Unrepresentable_Domain:
 Sequential unique whole numbers that are automatically generated.
Attribute:
Attribute_Label: Shape
Attribute_Definition: Feature geometry.
Attribute_Definition_Source: ESRI
Attribute_Domain_Values:
Unrepresentable_Domain: Coordinates defining the features.
Attribute:
Attribute_Label: ID
Attribute_Definition: Identifying Number
Attribute_Definition_Source: University of Redlands
Attribute:
Attribute_Label: FID_1
Attribute_Definition: Identifying Number
Attribute_Definition_Source: University of Redlands
Attribute:
Attribute_Label: ADJUSTED_S
Attribute_Definition: Time of sample, taken from corresponding ASCII data file (.geo)
Attribute_Definition_Source: NASA
Attribute:
Attribute_Label: ADJUSTED_R
Attribute_Definition:
 Spacecraft clock RIM count, which increments by one (1) every 60 and 2/3 seconds, or 91 minor frames (.rad)
Attribute_Definition_Source: NASA
Attribute:
Attribute_Label: LAT
Attribute_Definition: Latitude of FOV intercept point (.geo)
Attribute_Definition_Source: NASA
Attribute:
Attribute_Label: LON
Attribute_Definition: Longitude of FOV intercept point (.geo)
Attribute_Definition_Source: NASA
Attribute:
Attribute_Label: NEGLON
Attribute_Definition:
 LON adjusted to conform to coordinate systems with negative values west of the central meridian (Equation=LON*(-1))
Attribute_Definition_Source: University of Redlands
Attribute:
Attribute_Label: NEWLON
Attribute_Definition:

LON adjusted to conform to coordinate systems between 0 and 360 degrees
(Equation=360-LON)

Attribute_Definition_Source: University of Redlands

Attribute:

Attribute_Label: RA

Attribute_Definition: Right ascension of scan platform boresight (.geo)

Attribute_Definition_Source: NASA

Attribute:

Attribute_Label: DEC_

Attribute_Definition: Declination of scan platform boresight (.geo)

Attribute_Definition_Source: NASA

Attribute:

Attribute_Label: INC

Attribute_Definition: Solar incidence angle (sun-intercept-zenith) at the FOV
(.geo)

Attribute_Definition_Source: NASA

Attribute:

Attribute_Label: EMI

Attribute_Definition: Emission angle (spacecraft-intercept-zenith) at the FOV
(.geo)

Attribute_Definition_Source: NASA

Attribute:

Attribute_Label: PHS

Attribute_Definition: Phase angle (sun-intercept-spacecraft) at the FOV (.geo)

Attribute_Definition_Source: NASA

Attribute:

Attribute_Label: DLIMB

Attribute_Definition: Angle between FOV center and nearest point on body limb
(.geo)

Attribute_Definition_Source: NASA

Attribute:

Attribute_Label: SIPDIS

Attribute_Definition: Distance from spacecraft to FOV intercept point, km (.geo)

Attribute_Definition_Source: NASA

Attribute:

Attribute_Label: TRANGE

Attribute_Definition: Distance from spacecraft to target body center, km (.geo)

Attribute_Definition_Source: NASA

Attribute:

Attribute_Label: SSCLON

Attribute_Definition: Longitude of sub-spacecraft point (.geo)

Attribute_Definition_Source: NASA

Attribute:

Attribute_Label: NEWSSCLON

Attribute_Definition:

SSCLON adjusted to conform to coordinate systems between 0 and 360 degrees
(Equation= $360 - \text{SSCLON}$)

Attribute_Definition_Source: University of Redlands

Attribute:

Attribute_Label: SSCLAT

Attribute_Definition: Latitude of sub-spacecraft point (.geo)

Attribute_Definition_Source: NASA

Attribute:

Attribute_Label: SSOLON

Attribute_Definition: Longitude of sub-solar point (.geo)

Attribute_Definition_Source: NASA

Attribute:

Attribute_Label: SSOLAT

Attribute_Definition: Latitude of sub-solar point (.geo)

Attribute_Definition_Source: NASA

Attribute:

Attribute_Label: CONE

Attribute_Definition: Scan platform cone angle (0-180) (.geo)

Attribute_Definition_Source: NASA

Attribute:

Attribute_Label: CLOCK

Attribute_Definition: Scan platform clock angle (0-360) (.geo)

Attribute_Definition_Source: NASA

Attribute:

Attribute_Label: RIM_MOD91

Attribute_Definition:

Spacecraft clock MOD91, or minor frame counter, adjusted to represent the time at which the PPR instrument acquired the data sample pair for this record (.rad)

Attribute_Definition_Source: NASA

Attribute:

Attribute_Label: PF

Attribute_Definition: Programmed filter/retarder wheel position (.rad)

Attribute_Definition_Source: NASA

Attribute:

Attribute_Label: GAIN

Attribute_Definition: Radiometry gain step (.rad)

Attribute_Definition_Source: NASA

Attribute:

Attribute_Label: MED

Attribute_Definition:

PPR operation mode, 0 - Transition, 1 - Cycle, 2 -

PP/PH(PhotoPolarimetry/Photometry), 3 - Photometry, 4 - Radiometry, 5 -

Position Select (.rad)

Attribute_Definition_Source: NASA

Attribute:

Attribute_Label: COPS

Attribute_Definition:

C - calibration lamp flag, O - boom sequence operation flag, P - number of positions, S - number of samples (.rad)

Attribute_Definition_Source: NASA

Attribute:

Attribute_Label: TEMP_RID

Attribute_Definition:

Temp - science temperature presented as a character integer, R - temperature range flag, ID - temperature ID (.rad)

Attribute_Definition_Source: NASA

Attribute:

Attribute_Label: FRP

Attribute_Definition: Filter Position (.rad)

Attribute_Definition_Source: NASA

Attribute:

Attribute_Label: SDNA

Attribute_Definition:

Sample A Data - the first PP/PH science data sample of the simultaneously obtained pair corresponding to the orthogonal polarization components separated by the PPR Wollaston prism or a radiometry scene sample (.rad)

Attribute_Definition_Source: NASA

Attribute:

Attribute_Label: SDNB

Attribute_Definition:

Sample B Data - second of the pair of PP/PH science data samples or a science temperature data sample if Sample A Data is radiometry data (.rad)

Attribute_Definition_Source: NASA

Attribute:

Attribute_Label: RA1

Attribute_Definition:

Right ascension of the instrument boresight direction for the spacecraft scan platform (.rad)

Attribute_Definition_Source: NASA

Attribute:

Attribute_Label: DEC1

Attribute_Definition:

Declination of the instrument boresight direction for the spacecraft scan platform (.rad)

Attribute_Definition_Source: NASA

Attribute:

Attribute_Label: RAD_DN_

Attribute_Definition: Radiometry Data Number (.rad)

Attribute_Definition_Source: NASA

Attribute:

Attribute_Label: T_K_

Attribute_Definition: Brightness Temperature recorded in Kelvin (.rad)

Attribute_Definition_Source: NASA

Attribute:

Attribute_Label: WIDTH_KM

Attribute_Definition:

Ellipse short axis in kilometers (Equation= $SIPDIS * \tan((2.5/2)/1000)$)

Attribute_Definition_Source: University of Redlands, Weisstein (1999)

Attribute:

Attribute_Label: HEIGHT_KM

Attribute_Definition:

Ellipse long axis in kilometers

(Equation= $WIDTH_KM / (\cos(LAT * \pi() / 180) * \cos(SSCLAT * \pi() / 180) * \cos((LON - SSCLON) * \pi() / 180) + \sin(LAT * \pi() / 180) * \sin(SSCLAT * \pi() / 180)))$)

Attribute_Definition_Source: University of Redlands, Weisstein (1999)

Attribute:

Attribute_Label: WIDTH_D

Attribute_Definition:

Ellipse short axis in decimal degrees (Equation= $((WIDTH_KM / 1815) * 180) / \pi()$)

Attribute_Definition_Source: University of Redlands

Attribute:

Attribute_Label: HEIGHT_D

Attribute_Definition:

Ellipse long axis in decimal degrees (Equation= $((HEIGHT_KM / 1815) * 180) / \pi()$)

Attribute_Definition_Source: University of Redlands

Attribute:

Attribute_Label: ADJ_WID_D

Attribute_Definition:

Adjusted Ellipse short axis in Degrees

(Equation= $(\arccos((\cos(WIDTH_D * \pi() / 180) - \sin(LAT * \pi() / 180) * \sin(LAT * \pi() / 180)) / (\cos(LAT * \pi() / 180) * \cos(LAT * \pi() / 180)))) * 180 / \pi()$)

Attribute_Definition_Source: University of Redlands, Weisstein (1999)

Attribute:

Attribute_Label: HI_WI_RATI

Attribute_Definition:

Ratio of Height (long axis) to Width (short axis)

(Equation= $ADJ_WID_D / HEIGHT_D$)

Attribute_Definition_Source: University of Redlands

Attribute:

Attribute_Label: AZIMUTH_R

Attribute_Definition:

Azimuth derived from coordinates of NEWSSCLON and SSCLAT to NEWLON and LAT in radians (Equation= $\text{IF}((LAT - SSCLAT) = 0, 0, \pi() / 2 - (\text{ATAN}(((NEWLON - NEWSSCLON) / (LAT - SSCLAT)))))$)

Attribute_Definition_Source: University of Redlands, Wolf & Ghilani (2002)

Attribute:

Attribute_Label: AZIMUTH_D

Attribute_Definition:

Azimuth derived from coordinates of NEWSSCLON and SSCLAT to NEWLON and LAT in degrees (Equation=AZIMUTH_R*180/PI())

Attribute_Definition_Source: University of Redlands

Attribute:

Attribute_Label: Shape_Length

Attribute_Definition: Length of feature in internal units.

Attribute_Definition_Source: ESRI

Attribute_Domain_Values:

Unrepresentable_Domain: Positive real numbers that are automatically generated.

Attribute:

Attribute_Label: Shape_Area

Attribute_Definition: Area of feature in internal units squared.

Attribute_Definition_Source: ESRI

Attribute_Domain_Values:

Unrepresentable_Domain: Positive real numbers that are automatically generated.

Attribute:

Attribute_Label: T_K_Subclass

Attribute_Definition: Subclass of T_K

Attribute_Definition_Source: University of Redlands

Distribution_Information:

Resource_Description: Downloadable Data

Metadata_Reference_Information:

Metadata_Date: 20061208

Metadata_Contact:

Contact_Information:

Contact_Person_Primary:

Contact_Person: Shane Barrett

Contact_Organization: University of Redlands

Contact_Position: Master's Student

Contact_Address:

Address_Type: mailing and physical address

Address: 1200 East Colton Avenue

Address: P.O. Box 3080

City: Redlands

State_or_Province: California

Postal_Code: 92373-0999

Country: USA

Contact_Voice_Telephone: (909) 522 4792

Contact_Electronic_Mail_Address: Shane_Barrett@redlands.edu

Metadata_Standard_Name: FGDC Content Standards for Digital Geospatial

Metadata

Metadata_Standard_Version: FGDC-STD-001-1998

Metadata_Time_Convention: local time

Metadata_Extensions:

Online_Linkage: <<http://www.esri.com/metadata/esriprof80.html>>

Profile_Name: ESRI Metadata Profile

Metadata_Extensions:

Online_Linkage: <<http://www.esri.com/metadata/esriprof80.html>>

Profile_Name: ESRI Metadata Profile

Appendix O – Sample Metadata for NIMS data utilizing NIMS_24

NIMS_24

Metadata also available as

Metadata:

- [Identification Information](#)
- [Data Quality Information](#)
- [Spatial Data Organization Information](#)
- [Spatial Reference Information](#)
- [Entity and Attribute Information](#)
- [Distribution Information](#)
- [Metadata Reference Information](#)

Identification Information:

Citation:

Citation Information:

Originator: File: 24inamskgi01, Contributors: Galileo Spacecraft, NASA, JPL

Publication Date: 1999

Title: NIMS_24

Geospatial Data Presentation Form: remote-sensing image

Online Linkage:

\\SHANE_BARRETT\C\$\ShanesDocs\MySchool\MIP\ProcessedData\FinalData\Geodatabase\Io.idb\c_32\r_1.img

Description:

Abstract:

Multispectral image capturing infrared radiation captured during the 24th orbit of the Galileo Spacecraft

Purpose: NIMS data captured high surface temperatures of Io

Time Period of Content:

Time Period Information:

Single Date/Time:

Calendar Date: 1999

Currentness Reference: ground condition

Status:

Progress: Complete

Maintenance and Update Frequency: As needed

Spatial Domain:

Bounding Coordinates:

West Bounding Coordinate: -119.400000

East Bounding Coordinate: -110.000000

North Bounding Coordinate: 27.600000

South_Bounding_Coordinate: 17.025000
Keywords:
Theme:
Theme_Keyword_Thesaurus: None
Theme_Keyword: Multispectral, Imagery, Temperatures
Place:
Place_Keyword: Io
Temporal:
Temporal_Keyword: 1999
Access_Constraints: None
Use_Constraints: None
Point_of_Contact:
Contact_Information:
Contact_Person_Primary:
Contact_Person: Dr. Julie Rathbun
Contact_Organization: University of Redlands
Contact_Position: Physics Professor
Contact_Address:
Address_Type: mailing and physical address
Address: 1200 East Colton Avenue
Address: P.O. Box 3080
City: Redlands
State_or_Province: California
Postal_Code: 92373-0999
Country: USA
Contact_Voice_Telephone: (909) 793 2121
Contact_Electronic_Mail_Address: Julie_Rathbun@redlands.edu
Native_Data_Set_Environment:
Microsoft Windows XP Version 5.1 (Build 2600) Service Pack 2; ESRI
ArcCatalog 9.1.0.780

Data_Quality_Information:

Lineage:
Process_Step:
Process_Description: Imported from IDL variable using Amirani.pro program
Process_Contact:
Contact_Information:
Contact_Organization_Primary:
Contact_Organization: University of Redlands
Contact_Person: Shane Barrett
Contact_Position: Master's Student
Process_Step:
Process_Description: Exported as ERDAS IMAGINE image file
Process_Contact:
Contact_Information:
Contact_Organization_Primary:

Contact_Organization: University of Redlands
Contact_Person: Shane Barrett
Contact_Position: Master's Student
Process_Step:
Process_Description:
Georeferenced images by registering corners to extent coordinates points
produced by custom script
Process_Contact:
Contact_Information:
Contact_Organization_Primary:
Contact_Organization: University of Redlands
Contact_Person: Shane Barrett
Contact_Position: Master's Student

Spatial_Data_Organization_Information:
Direct_Spatial_Reference_Method: Raster
Raster_Object_Information:
Raster_Object_Type: Pixel
Row_Count: 54
Column_Count: 48
Vertical_Count: 1

Spatial_Reference_Information:
Horizontal_Coordinate_System_Definition:
Geographic:
Geographic_Coordinate_Units: Decimal degrees
Planar:
Planar_Coordinate_Information:
Planar_Coordinate_Encoding_Method: row and column
Coordinate_Representation:
Abscissa_Resolution: 0.195833
Ordinate_Resolution: 0.195833
Geodetic_Model:
Horizontal_Datum_Name: D_Io_2000
Ellipsoid_Name: Io_2000_IAU_IAG
Semi-major_Axis: 1821460.000000
Denominator_of_Flattening_Ratio: infinity

Entity_and_Attribute_Information:
Detailed_Description:
Entity_Type:
Entity_Type_Label: Band_1
Entity_Type_Definition: Wavelength: 0.587000 microns
Entity_Type_Definition_Source: NASA, JPL
Attribute:
Attribute_Label: ObjectID

Attribute_Definition: Internal feature number.
Attribute_Definition_Source: ESRI
Attribute_Domain_Values:
Unrepresentable_Domain:
 Sequential unique whole numbers that are automatically generated.
Attribute:
Attribute_Label: Value
Attribute:
Attribute_Label: Count
Detailed_Description:
Entity_Type:
Entity_Type_Label: Band_2
Entity_Type_Definition: Wavelength: 0.725800 microns
Entity_Type_Definition_Source: NASA, JPL
Attribute:
Attribute_Label: ObjectID
Attribute_Definition: Internal feature number.
Attribute_Definition_Source: ESRI
Attribute_Domain_Values:
Unrepresentable_Domain:
 Sequential unique whole numbers that are automatically generated.
Attribute:
Attribute_Label: Value
Attribute:
Attribute_Label: Count
Detailed_Description:
Entity_Type:
Entity_Type_Label: Band_3
Entity_Type_Definition: Wavelength: 1.03480 microns
Entity_Type_Definition_Source: NASA, JPL
Attribute:
Attribute_Label: ObjectID
Attribute_Definition: Internal feature number.
Attribute_Definition_Source: ESRI
Attribute_Domain_Values:
Unrepresentable_Domain:
 Sequential unique whole numbers that are automatically generated.
Attribute:
Attribute_Label: Value
Attribute:
Attribute_Label: Count
Detailed_Description:
Entity_Type:
Entity_Type_Label: Band_4
Entity_Type_Definition: Wavelength: 1.31280 microns
Entity_Type_Definition_Source: NASA, JPL

Attribute:
Attribute_Label: ObjectID
Attribute_Definition: Internal feature number.
Attribute_Definition_Source: ESRI
Attribute_Domain_Values:
Unrepresentable_Domain:
 Sequential unique whole numbers that are automatically generated.

Attribute:
Attribute_Label: Value
Attribute:
Attribute_Label: Count
Detailed_Description:
Entity_Type:
Entity_Type_Label: Band_5
Entity_Type_Definition: Wavelength: 1.59280 microns
Entity_Type_Definition_Source: NASA, JPL
Attribute:
Attribute_Label: ObjectID
Attribute_Definition: Internal feature number.
Attribute_Definition_Source: ESRI
Attribute_Domain_Values:
Unrepresentable_Domain:
 Sequential unique whole numbers that are automatically generated.

Attribute:
Attribute_Label: Value
Attribute:
Attribute_Label: Count
Detailed_Description:
Entity_Type:
Entity_Type_Label: Band_6
Entity_Type_Definition: Wavelength: 1.87370 microns
Entity_Type_Definition_Source: NASA, JPL
Attribute:
Attribute_Label: ObjectID
Attribute_Definition: Internal feature number.
Attribute_Definition_Source: ESRI
Attribute_Domain_Values:
Unrepresentable_Domain:
 Sequential unique whole numbers that are automatically generated.

Attribute:
Attribute_Label: Value
Attribute:
Attribute_Label: Count
Detailed_Description:
Entity_Type:
Entity_Type_Label: Band_7

Entity_Type_Definition: Wavelength: 2.43840 microns
Entity_Type_Definition_Source: NASA, JPL
Attribute:
Attribute_Label: ObjectID
Attribute_Definition: Internal feature number.
Attribute_Definition_Source: ESRI
Attribute_Domain_Values:
Unrepresentable_Domain:
 Sequential unique whole numbers that are automatically generated.
Attribute:
Attribute_Label: Value
Attribute:
Attribute_Label: Count
Detailed_Description:
Entity_Type:
Entity_Type_Label: Band_8
Entity_Type_Definition: Wavelength: 2.71760 microns
Entity_Type_Definition_Source: NASA, JPL
Attribute:
Attribute_Label: ObjectID
Attribute_Definition: Internal feature number.
Attribute_Definition_Source: ESRI
Attribute_Domain_Values:
Unrepresentable_Domain:
 Sequential unique whole numbers that are automatically generated.
Attribute:
Attribute_Label: Value
Attribute:
Attribute_Label: Count
Detailed_Description:
Entity_Type:
Entity_Type_Label: Band_9
Entity_Type_Definition: Wavelength: 3.00070 microns
Entity_Type_Definition_Source: NASA, JPL
Attribute:
Attribute_Label: ObjectID
Attribute_Definition: Internal feature number.
Attribute_Definition_Source: ESRI
Attribute_Domain_Values:
Unrepresentable_Domain:
 Sequential unique whole numbers that are automatically generated.
Attribute:
Attribute_Label: Value
Attribute:
Attribute_Label: Count
Detailed_Description:

Entity_Type:
Entity_Type_Label: Band_10
Entity_Type_Definition: Wavelength: 3.28310 microns
Entity_Type_Definition_Source: NASA, JPL
Attribute:
Attribute_Label: ObjectID
Attribute_Definition: Internal feature number.
Attribute_Definition_Source: ESRI
Attribute_Domain_Values:
Unrepresentable_Domain:
 Sequential unique whole numbers that are automatically generated.
Attribute:
Attribute_Label: Value
Attribute:
Attribute_Label: Count
Detailed_Description:
Entity_Type:
Entity_Type_Label: Band_11
Entity_Type_Definition: Wavelength: 3.56590 microns
Entity_Type_Definition_Source: NASA, JPL
Attribute:
Attribute_Label: ObjectID
Attribute_Definition: Internal feature number.
Attribute_Definition_Source: ESRI
Attribute_Domain_Values:
Unrepresentable_Domain:
 Sequential unique whole numbers that are automatically generated.
Attribute:
Attribute_Label: Value
Attribute:
Attribute_Label: Count
Detailed_Description:
Entity_Type:
Entity_Type_Label: Band_12
Entity_Type_Definition: Wavelength: 3.84890 microns
Entity_Type_Definition_Source: NASA, JPL
Attribute:
Attribute_Label: ObjectID
Attribute_Definition: Internal feature number.
Attribute_Definition_Source: ESRI
Attribute_Domain_Values:
Unrepresentable_Domain:
 Sequential unique whole numbers that are automatically generated.
Attribute:
Attribute_Label: Value
Attribute:

Attribute_Label: Count
Detailed_Description:
Entity_Type:
Entity_Type_Label: Band_13
Entity_Type_Definition: Wavelength: 4.13260 microns
Entity_Type_Definition_Source: NASA, JPL
Attribute:
Attribute_Label: ObjectID
Attribute_Definition: Internal feature number.
Attribute_Definition_Source: ESRI
Attribute_Domain_Values:
Unrepresentable_Domain:
 Sequential unique whole numbers that are automatically generated.
Attribute:
Attribute_Label: Value
Attribute:
Attribute_Label: Count
Detailed_Description:
Entity_Type:
Entity_Type_Label: Band_14
Entity_Type_Definition: Wavelength: 4.41450 microns
Entity_Type_Definition_Source: NASA, JPL
Attribute:
Attribute_Label: ObjectID
Attribute_Definition: Internal feature number.
Attribute_Definition_Source: ESRI
Attribute_Domain_Values:
Unrepresentable_Domain:
 Sequential unique whole numbers that are automatically generated.
Attribute:
Attribute_Label: Value
Attribute:
Attribute_Label: Count
Detailed_Description:
Entity_Type:
Entity_Type_Label: Band_15
Entity_Type_Definition: Wavelength: 4.69670 microns
Entity_Type_Definition_Source: NASA, JPL
Attribute:
Attribute_Label: ObjectID
Attribute_Definition: Internal feature number.
Attribute_Definition_Source: ESRI
Attribute_Domain_Values:
Unrepresentable_Domain:
 Sequential unique whole numbers that are automatically generated.
Attribute:

Attribute_Label: Value
Attribute:
Attribute_Label: Count

Distribution_Information:
Resource_Description: Downloadable Data
Standard_Order_Process:
Digital_Form:
Digital_Transfer_Information:
Transfer_Size: 0.000

Metadata_Reference_Information:
Metadata_Date: 20061208
Metadata_Contact:
Contact_Information:
Contact_Organization_Primary:
Contact_Organization: University of Redlands
Contact_Person: Shane Barrett
Contact_Position: Master's Student
Contact_Address:
Address_Type:
REQUIRED: The mailing and/or physical address for the organization or individual.
City: REQUIRED: The city of the address.
State_or_Province: REQUIRED: The state or province of the address.
Postal_Code: REQUIRED: The ZIP or other postal code of the address.
Contact_Voice_Telephone: (909) 522 4792
Contact_Electronic_Mail_Address: Shane_Barrett@redlands.edu
Metadata_Standard_Name: FGDC Content Standards for Digital Geospatial Metadata
Metadata_Standard_Version: FGDC-STD-001-1998
Metadata_Time_Convention: local time
Metadata_Extensions:
Online_Linkage: <<http://www.esri.com/metadata/esriprof80.html>>
Profile_Name: ESRI Metadata Profile

Appendix P – SSI Metadata

SSI

Metadata also available as

Metadata:

- [Identification Information](#)
- [Data Quality Information](#)
- [Spatial Data Organization Information](#)
- [Spatial Reference Information](#)
- [Entity and Attribute Information](#)
- [Distribution Information](#)
- [Metadata Reference Information](#)

Identification Information:

Citation:

Citation Information:

Originator: File: I24AMSKGI01, Contributors: Galileo Spacecraft, NASA, JPL

Publication Date: 1999

Title: SSI

Geospatial Data Presentation Form: remote-sensing image

Online Linkage:

\\SHANE_BARRETT\C\$\ShanesDocs\MySchool\MIP\ProcessedData\FinalData\Geodatabase\Io.idb\c_45\r_1.img

Description:

Abstract:

Captured high resolution (0.5 - 25 km) images of the surface of Io

Purpose: Map and identify changes in the surfaces of Io

Time Period of Content:

Time Period Information:

Single Date/Time:

Calendar Date: 1999

Currentness Reference: ground condition

Status:

Progress: Complete

Maintenance and Update Frequency: As needed

Spatial Domain:

Bounding Coordinates:

West Bounding Coordinate: -142.402771

East Bounding Coordinate: -67.862861

North Bounding Coordinate: 41.388852

South_Bounding_Coordinate: -9.054890

Keywords:

Theme:

Theme_Keyword_Thesaurus: None

Theme_Keyword: SSI, image, surface, raster

Place:

Place_Keyword: Io

Temporal:

Temporal_Keyword: 1999

Access_Constraints: None

Use_Constraints: None

Point_of_Contact:

Contact_Information:

Contact_Person_Primary:

Contact_Person: Dr. Julie Rathbun

Contact_Organization: University of Redlands

Contact_Position: Physics Professor

Contact_Address:

Address_Type: mailing and physical address

Address: 1200 East Colton Avenue

Address: P.O. Box 3080

City: Redlands

State_or_Province: California

Postal_Code: 92373-0999

Country: USA

Contact_Voice_Telephone: (909) 793 2121

Contact_Electronic_Mail_Address: Julie_Rathbun@redlands.edu

Native_Data_Set_Environment:

Microsoft Windows XP Version 5.1 (Build 2600) Service Pack 2; ESRI

ArcCatalog 9.1.0.780

Data_Quality_Information:

Lineage:

Process_Step:

Process_Description: Imported from IDL variable using Amirani.pro program

Process_Contact:

Contact_Information:

Contact_Organization_Primary:

Contact_Organization: University of Redlands

Contact_Person: Shane Barrett

Contact_Position: Master's Student

Process_Step:

Process_Description:

Image scaled to an 8-bit image Equation: $\text{NewSSI} = \text{fix}(((\text{float}(\text{b1}) - \text{min}) / \text{range}) * 255)$

Process_Contact:

Contact_Information:
Contact_Organization_Primary:
Contact_Organization: University of Redlands
Contact_Person: Shane Barrett
Contact_Position: Master's Student
Process_Step:
Process_Description: Exported as TIFF file
Process_Contact:
Contact_Information:
Contact_Organization_Primary:
Contact_Organization: University of Redlands
Contact_Person: Shane Barrett
Contact_Position: Master's Student
Process_Step:
Process_Description: Georeferenced to Global BW_Mosaic using 50 control points

Spatial_Data_Organization_Information:
Direct_Spatial_Reference_Method: Raster
Raster_Object_Information:
Raster_Object_Type: Pixel
Row_Count: 829
Column_Count: 1225
Vertical_Count: 1

Spatial_Reference_Information:
Horizontal_Coordinate_System_Definition:
Geographic:
Geographic_Coordinate_Units: Decimal degrees
Planar:
Planar_Coordinate_Information:
Planar_Coordinate_Encoding_Method: row and column
Coordinate_Representation:
Abscissa_Resolution: 0.060849
Ordinate_Resolution: 0.060849
Geodetic_Model:
Horizontal_Datum_Name: D_Io_2000
Ellipsoid_Name: Io_2000_IAU_IAG
Semi-major_Axis: 1821460.000000
Denominator_of_Flattening_Ratio: infinity

Entity_and_Attribute_Information:
Detailed_Description:
Entity_Type:
Entity_Type_Label: Band_1
Attribute:

Attribute_Label: ObjectID
Attribute_Definition: Internal feature number.
Attribute_Definition_Source: ESRI
Attribute_Domain_Values:
Unrepresentable_Domain:
Sequential unique whole numbers that are automatically generated.
Attribute:
Attribute_Label: Value
Attribute:
Attribute_Label: Count

Distribution_Information:
Resource_Description: Downloadable Data
Standard_Order_Process:
Digital_Form:
Digital_Transfer_Information:
Transfer_Size: 0.000

Metadata_Reference_Information:
Metadata_Date: 20061208
Metadata_Contact:
Contact_Information:
Contact_Organization_Primary:
Contact_Organization: University of Redlands
Contact_Person: Shane Barrett
Contact_Position: Master's Student
Contact_Address:
Address_Type: mailing and physical address
Address: 1200 East Colton Avenue
Address: P.O. Box 3080
City: Redlands
State_or_Province: California
Postal_Code: 92373-0999
Country: USA
Contact_Voice_Telephone: (909) 522 4792
Contact_Electronic_Mail_Address: Shane_Barrett@redlands.edu
Metadata_Standard_Name: FGDC Content Standards for Digital Geospatial Metadata
Metadata_Standard_Version: FGDC-STD-001-1998
Metadata_Time_Convention: local time
Metadata_Extensions:
Online_Linkage: <<http://www.esri.com/metadata/esriprof80.html>>
Profile_Name: ESRI Metadata Profile
Metadata_Extensions:
Online_Linkage: <<http://www.esri.com/metadata/esriprof80.html>>
Profile_Name: ESRI Metadata Profile

Appendix Q – Sample Metadata for Mosaics data utilizing Color Mosaic

Color_Mosaic

Metadata also available as

Metadata:

- [Identification Information](#)
- [Data Quality Information](#)
- [Spatial Data Organization Information](#)
- [Spatial Reference Information](#)
- [Entity and Attribute Information](#)
- [Distribution Information](#)
- [Metadata Reference Information](#)

Identification_Information:

Citation:

Citation_Information:

Originator:

File: GLL_color_Simp_Clon180_8bit.tif, Contributors: Voyager Spacecraft, Galileo Spacecraft, NASA, JPL, USGS

Publication_Date: 2006

Title: Color_Mosaic

Geospatial_Data_Presentation_Form: remote-sensing image

Online_Linkage:

\\SHANE_BARRETT\C\$\ShanesDocs\MySchool\MIP\ProcessedData\FinalData\Geodatabase\Io.idb\c_43\r_1.img

Description:

Abstract: A color global mosaic of Io

Purpose:

Global mosaic provides a background on which other data can be displayed. Also used for identification and relation of features on the surface of Io.

Time_Period_of_Content:

Time_Period_Information:

Single_Date/Time:

Calendar_Date: 2006

Currentness_Reference: publication date

Status:

Progress: Complete

Maintenance_and_Update_Frequency: As needed

Spatial_Domain:

Bounding_Coordinates:

West_Bounding_Coordinate: -180.000000

East_Bounding_Coordinate: 180.000001
North_Bounding_Coordinate: 90.000000
South_Bounding_Coordinate: -90.000000
Keywords:
Theme:
Theme_Keyword_Thesaurus: None
Theme_Keyword: Imagery, Mosaic, Color, Surface, Global
Place:
Place_Keyword: Io
Temporal:
Temporal_Keyword: 2006
Access_Constraints: None
Use_Constraints: None
Point_of_Contact:
Contact_Information:
Contact_Person_Primary:
Contact_Person: Dr. Julie Rathbun
Contact_Organization: University of Redlands
Contact_Position: Physics Professor
Contact_Address:
Address_Type: mailing and physical address
Address: 1200 East Colton Avenue
Address: P.O. Box 3080
City: Redlands
State_or_Province: California
Postal_Code: 92373-0999
Country: USA
Contact_Voice_Telephone: (909) 793 2121
Contact_Electronic_Mail_Address: Julie_Rathbun@redlands.edu
Native_Data_Set_Environment:
Microsoft Windows XP Version 5.1 (Build 2600) Service Pack 2; ESRI
ArcCatalog 9.1.0.780

Data_Quality_Information:

Lineage:
Process_Step:
Process_Description: Exported in halves as subsets
Process_Step:
Process_Description:
Georeferenced images by registering corners to extent coordinates points
produced by custom script

Spatial_Data_Organization_Information:

Direct_Spatial_Reference_Method: Raster
Raster_Object_Information:
Raster_Object_Type: Pixel

Row_Count: 5723
Column_Count: 11446
Vertical_Count: 1

Spatial_Reference_Information:

Horizontal_Coordinate_System_Definition:

Geographic:

Geographic_Coordinate_Units: Decimal degrees

Planar:

Planar_Coordinate_Information:

Planar_Coordinate_Encoding_Method: row and column

Coordinate_Representation:

Abscissa_Resolution: 0.031452

Ordinate_Resolution: 0.031452

Geodetic_Model:

Horizontal_Datum_Name: D_Io_2000

Ellipsoid_Name: Io_2000_IAU_IAG

Semi-major_Axis: 1821460.000000

Denominator_of_Flattening_Ratio: infinity

Entity_and_Attribute_Information:

Detailed_Description:

Entity_Type:

Entity_Type_Label: Band_1

Attribute:

Attribute_Label: ObjectID

Attribute_Definition: Internal feature number.

Attribute_Definition_Source: ESRI

Attribute_Domain_Values:

Unrepresentable_Domain:

Sequential unique whole numbers that are automatically generated.

Attribute:

Attribute_Label: Value

Attribute:

Attribute_Label: Count

Detailed_Description:

Entity_Type:

Entity_Type_Label: Band_2

Attribute:

Attribute_Label: ObjectID

Attribute_Definition: Internal feature number.

Attribute_Definition_Source: ESRI

Attribute_Domain_Values:

Unrepresentable_Domain:

Sequential unique whole numbers that are automatically generated.

Attribute:

Attribute_Label: Value
Attribute:
Attribute_Label: Count
Detailed_Description:
Entity_Type:
Entity_Type_Label: Band_3
Attribute:
Attribute_Label: ObjectID
Attribute_Definition: Internal feature number.
Attribute_Definition_Source: ESRI
Attribute_Domain_Values:
Unrepresentable_Domain:
Sequential unique whole numbers that are automatically generated.
Attribute:
Attribute_Label: Value
Attribute:
Attribute_Label: Count

Distribution_Information:
Resource_Description: Downloadable Data
Standard_Order_Process:
Digital_Form:
Digital_Transfer_Information:
Transfer_Size: 0.000

Metadata_Reference_Information:
Metadata_Date: 20061208
Metadata_Contact:
Contact_Information:
Contact_Organization_Primary:
Contact_Organization: University of Redlands
Contact_Person: Shane Barrett
Contact_Position: Master's Student
Contact_Address:
Address_Type: mailing and physical address
Address: 1200 East Colton Avenue
Address: O.O. Box 3080
City: Redlands
State_or_Province: California
Postal_Code: 92373-0999
Country: USA
Contact_Voice_Telephone: (909) 522 4792
Contact_Electronic_Mail_Address: Shane_Barrett@redlands.edu
Metadata_Standard_Name: FGDC Content Standards for Digital Geospatial
Metadata
Metadata_Standard_Version: FGDC-STD-001-1998

Metadata_Time_Convention: local time

Metadata_Extensions:

Online_Linkage: <<http://www.esri.com/metadata/esriprof80.html>>

Profile_Name: ESRI Metadata Profile