High-resolution CASSINI-VIMS mosaics of Titan and the icy Saturnian satellites

R. Jaumann\textsuperscript{a,}\textsuperscript{*}, K. Stephan\textsuperscript{a}, R.H. Brown\textsuperscript{b}, B.J. Buratti\textsuperscript{c}, R.N. Clark\textsuperscript{d}, T.B. McCord\textsuperscript{e}, A. Coradini\textsuperscript{f}, F. Capaccioni\textsuperscript{g}, G. Filacchione\textsuperscript{g}, P. Cerroni\textsuperscript{g}, K.H. Baines\textsuperscript{c}, G. Bellucci\textsuperscript{f}, J.-P. Bibring\textsuperscript{h}, M. Combes\textsuperscript{i}, D.P. Cruikshank\textsuperscript{j}, P. Drossart\textsuperscript{i}, V. Formisano\textsuperscript{f}, Y. Langevin\textsuperscript{h}, D.L. Matson\textsuperscript{c}, R.M. Nelson\textsuperscript{c}, P.D. Nicholson\textsuperscript{k}, B. Sicardy\textsuperscript{i}, C. Sotin\textsuperscript{l}, L.A. Soderblom\textsuperscript{m}, C. Griffith\textsuperscript{a}, K.-D. Matz\textsuperscript{a}, Th. Roatsch\textsuperscript{a}, F. Scholten\textsuperscript{a}, C.C. Porco\textsuperscript{o}

\textsuperscript{a}DLR, Institute of Planetary Research, Rutherfordstrasse 2, D-12489 Berlin, Germany
\textsuperscript{b}Department Planetary Science and LPL, University of AZ, Tucson, AZ 85721-0092, USA
\textsuperscript{c}Jet Propulsion Laboratory, Pasadena, CA 91109, USA
\textsuperscript{d}USGS, Mail Stop 964, Box 25046, Denver Federal Center, Denver, CO, USA
\textsuperscript{e}USGS, Mail Stop 964, Box 25046, Denver Federal Center, Denver, CO, USA
\textsuperscript{f}Planetary Science Institute, 22 Fiddler’s Rd., Winthrop, WA 98862-0667, USA
\textsuperscript{g}Istituto Fisica Spazio Interplanetario, CNR, Via Fosso del Cavaliere, Roma, Italy
\textsuperscript{h}Instituto di Astrofisica Spaziale, Via Fosso del Cavaliere, Roma, Italy
\textsuperscript{i}Université de Paris-Sud-Orsay, 1 Bât. 510, 91405 Orsay Cedex, France
\textsuperscript{j}NASA Ames Research Center, Astrophysics Branch, Moffett Field, CA 94055-1000, USA
\textsuperscript{k}Lunar and Planetary Laboratory and Stewart Observatory, University of Arizona, Tucson, AZ, USA
\textsuperscript{l}University of Nantes, B.P. 24028, 44307 Nantes Cedex 3, France
\textsuperscript{m}US Geological Survey, Flagstaff, AZ 86011, USA
\textsuperscript{n}Lunar and Planetary Laboratory and Stewart Observatory, University of Arizona, Tucson, AZ, USA
\textsuperscript{o}Space Science Institute, 4750 Walnut Street, Suite 205, Boulder, CO 80301, USA

Received 21 October 2005; received in revised form 21 March 2006; accepted 4 May 2006
Available online 14 August 2006

Abstract

The Visual Infrared Mapping Spectrometer (VIMS) onboard the CASSINI spacecraft obtained new spectral data of the icy satellites of Saturn after its arrival at Saturn in June 2004. VIMS operates in a spectral range from 0.35 to 5.2 \( \mu \text{m} \), generating image cubes in which each pixel represents a spectrum consisting of 352 contiguous wavebands.

As an imaging spectrometer VIMS combines the characteristics of both a spectrometer and an imaging instrument. This makes it possible to analyze the spectrum of each pixel separately and to map the spectral characteristics spatially, which is important to study the relationships between spectral information and geological and geomorphologic surface features.

The spatial analysis of the spectral data requires the determination of the exact geographic position of each pixel on the specific surface and that all 352 spectral elements of each pixel show the same region of the target. We developed a method to reproject each pixel geometrically and to convert the spectral data into map projected image cubes. This method can also be applied to mosaic different VIMS observations. Based on these mosaics, maps of the spectral properties for each Saturnian satellite can be derived and attributed to geographic positions as well as to geological and geomorphologic surface features. These map-projected mosaics are the basis for all further investigations.

© 2006 Elsevier Ltd. All rights reserved.

Keywords: Cassini; VIMS; Imaging spectroscopy; Saturnian satellites; Map projection; Mosaics

*Corresponding author. Tel.: +49 30 67055400; fax: +49 30 67055402.
E-mail address: ralf.jaumann@dlr.de (R. Jaumann).

0032-0633/$ - see front matter © 2006 Elsevier Ltd. All rights reserved.
doi:10.1016/j.pss.2006.05.034
1. Introduction

Originally, both map projection and mosaicking software were developed at DLR (German Aerospace Center) for the processing of imaging data of Mars, that was planned to be acquired during the failed Mars 96 mission (Scholten, 1996). DLR software was used to process imaging data of planetary objects in the Jovian system observed during the Galileo mission. At present, during the current Mars Express mission, this software is in use to process imaging data of Mars (Scholten et al., 2005). In preparation of the Cassini mission, the method was adapted to imaging data of the planetary missions Voyager 1 and 2 (Smith et al., 1982) to produce high precision base maps of the Saturnian satellites. These base maps have been used for planning purposes and as a starting point for the production of improved maps using imaging data from the Cassini mission (Roatsch et al., 2003, this issue).

Planetary imaging data are usually characterized by a low number of spectral channels, each with a relatively broad bandwidth. So the method could only be applied to one channel of imaging data at a time. However, the algorithm has been extended to hyperspectral data of imaging spectrometers like the Visible and Infrared Mapping Spectrometer (VIMS) on board the Cassini spacecraft.

Since June 2004, VIMS has been observing the Saturnian satellites among other targets in order to measure reflected and emitted light from their surfaces that could be used to identify the mineralogical surface composition (Brown et al., 2005). The VIMS data are characterized by a large number of narrow spectral channels for each pixel, which form an “image cube”. These image cubes allow the analysis of a single spectrum over the whole spectral range of VIMS and the identification of individual minerals, ices and volatiles. Map projected VIMS cubes and mosaics are essential to assign the spatial distribution of these materials.

Table 1
Cassini satellite flybys between June 2004 and December 2005

<table>
<thead>
<tr>
<th>Flyby</th>
<th>Date</th>
<th>Target</th>
<th>Altitude at closest approach (km)</th>
<th>VIMS spatial resolution at closest approach (km/pix)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>2004 June 14</td>
<td>Phoebe</td>
<td>1997</td>
<td>1</td>
</tr>
<tr>
<td>A</td>
<td>October 26</td>
<td>Titan</td>
<td>1200</td>
<td>0.6</td>
</tr>
<tr>
<td>B</td>
<td>December 13</td>
<td>Titan</td>
<td>1200</td>
<td>0.6</td>
</tr>
<tr>
<td>3</td>
<td>2005 February 15</td>
<td>Titan</td>
<td>1577</td>
<td>0.79</td>
</tr>
<tr>
<td>4</td>
<td>March 9</td>
<td>Enceladus</td>
<td>500</td>
<td>0.25</td>
</tr>
<tr>
<td></td>
<td>March 9</td>
<td>Tethys</td>
<td>83,232</td>
<td>41.6</td>
</tr>
<tr>
<td>5</td>
<td>March 31</td>
<td>Titan</td>
<td>2402</td>
<td>1.2</td>
</tr>
<tr>
<td>6</td>
<td>April 16</td>
<td>Titan</td>
<td>1025</td>
<td>0.51</td>
</tr>
<tr>
<td>11</td>
<td>July 14</td>
<td>Enceladus</td>
<td>169</td>
<td>0.08</td>
</tr>
<tr>
<td>16</td>
<td>October 26</td>
<td>Dione</td>
<td>500</td>
<td>1</td>
</tr>
<tr>
<td>19</td>
<td>December 26</td>
<td>Titan</td>
<td>10,409</td>
<td>5.2</td>
</tr>
</tbody>
</table>

Targeted flybys are highlighted.

Fig. 1. Comparison between two spectral channels obtained by VIMS-V (channel 8 at 0.43 μm) and VIMS-IR (channel 100 at 0.93 μm) before (a, b) and after (c, d) map projection. The data were acquired in high-resolution mode during the observation sequence ENCELADUS019 in orbit 4. The map-projected images are shown in an orthographic projection centered at 10°S and 210°W at 1 km per pixel. A chain of multiple impact craters are outlined within all images to demonstrate the differences between VIMS-V and VIMS-IR in spatial and spectral resolution.
across a specific surface to their geographic positions. Additionally, they are the basis for combining VIMS observations with data of different instruments in order to comprehensively interpret surface forming processes.

2. Instrument

VIMS covers the spectral range between 0.35 and 5.2 μm and simultaneously generates two dimensional images in each of the 352 contiguous spectral channels (Brown et al., 2005). VIMS consists of two imaging spectrometers, VIMS-V and VIMS-IR, which differ in spectral range, spectral and spatial resolution, and operation modes. VIMS-V collects the reflected visible light of the target in 96 spectral channels between 0.35 and 1.05 μm, with a spectral resolution of 7.3 nm and an instantaneous field of view (IFOV) of 0.167 x 0.167 mrad. VIMS-V uses a two-dimensional CCD-array detector to provide a two-dimensional spatial coverage in a push broom mode. It views one row of a square scene at a time. The CCD is read out after each row is acquired, and then the scanning mirror moves to the next row in the scene to build up a two-dimensional image. The infrared channel VIMS-IR includes 256 wavebands in the near and thermal IR from 0.85 to 5.2 μm, with a spectral resolution of 16 nm and an IFOV of 0.25 x 0.5 mrad. VIMS-IR has only one linear array of detectors and uses a secondary mirror to obtain the spatial coverage as VIMS-V in a whiskbroom mode, where it views only a single spatial pixel per exposure.

VIMS data have been acquired in a nominal and a high-resolution mode. Nominally, the data collection of VIMS-V and VIMS-IR are synchronized by the instruments electronics to produce data, which appear as if they were collected by a single instrument. Therefore VIMS-V and VIMS-IR are observing within the same exposure time and acquire data of a specific scene row by row. A nominal IFOV of 0.5 x 0.5 mrad is achieved by summing of 3 x 3 pixels with VIMS-V and continuously integrating two IFOV’s of VIMS-IR (Brown et al., 2005). The total field of view (FOV) of VIMS-V and VIMS-IR is up to 64 x 64 pixels, which therefore consist of 3 x 3 x 64 pixels of VIMS-V and 2 x 64 pixels in the case of VIMS-IR.

VIMS can also operate at higher spatial resolution. In this case, both VIMS-V and VIMS-IR work separately, which increases the pixel ground resolution by a factor of 2 in the VIMS-IR detector (IFOV of 0.25 x 0.5 mrad), and by a factor of 3 in the VIMS-V detector (IFOV 0.167 x 0.167 mrad). The maximum FOV of 64 x 64 pixels do not change in a high-resolution mode. Therefore instead of one VIMS-V and one VIMS-IR pixel with 0.5 x 0.5 mrad as in the nominal mode, one VIMS-IR pixel with 0.25 x 0.5 mrad correspond to one VIMS-V pixel with 0.167 x 0.167 mrad. Although, the spatial dimension of resulting image cubes are the same for VIMS-V and VIMS-IR the 96 images of VIMS-V and the 256 images of VIMS-IR show different regions of the target with different spatial resolutions.

3. Observations

Table 1 summarizes the flybys absolved by the Cassini spacecraft until December 2005. Cassini has made five close flybys at the largest satellite Titan. The first two flybys are named Titan A (October 26, 2004) and B (December 13, 2004). These flybys took place in the mission phase prior to the soft landing of the Huygens probe on the surface of Titan. Three more close flybys until September 1st in 2005, following the Huygens landing, are Titan 03, 05, and 06. The highest pixel ground resolutions so far were achieved in flybys Titan A and B with nominal values as high as 0.6 km per pixel.

Image cubes were also taken of the medium-sized icy Saturnian satellites Mimas, Enceladus, Tethys, Dione, Rhea, Hyperion, Iapetus and Phoebe. Among these data so far only those of Enceladus, Dione and Phoebe have pixel ground resolutions better than 1 km per pixel suitable for differentiating spectral units on their surfaces. Data from Phoebe were collected only once during the Saturn

<table>
<thead>
<tr>
<th>Maps and mosaics</th>
<th>Mean radius used for the VIMS maps (km)</th>
<th>Orbit</th>
<th>VIMS observation sequence</th>
<th>Pixel ground resolution of the input cubes (km/pixel)</th>
<th>Map resolution (km/pxl)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tethys mosaic</td>
<td>536.3</td>
<td>4</td>
<td>TETHYS001</td>
<td>35.23 (hires)</td>
<td>10</td>
</tr>
<tr>
<td>Dione mosaic</td>
<td>562.3</td>
<td>16</td>
<td>DIONE205</td>
<td>1.04–34.6 (hires)</td>
<td>1</td>
</tr>
<tr>
<td>Enceladus mosaic</td>
<td>252.31</td>
<td>4</td>
<td>ENCELADUS019</td>
<td>10.28–4.24 (hires)</td>
<td>1</td>
</tr>
<tr>
<td>Enceladus mosaic</td>
<td>252.31</td>
<td>11</td>
<td>ENCELADUS108</td>
<td>30.1–10.6</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>ENCELADUS110</td>
<td>19.3–5.25</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>ENCELADUS111</td>
<td>13.9–7.47</td>
<td>1</td>
</tr>
<tr>
<td>Titan (hires)</td>
<td>2575</td>
<td>A</td>
<td>HiRes005</td>
<td>50.73–17.77</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>B</td>
<td>HiRes004</td>
<td>13.26–0.65</td>
<td>1</td>
</tr>
<tr>
<td>Titan mosaic (hires)</td>
<td>2575</td>
<td>5</td>
<td>HIRES001</td>
<td>3.24–2.05</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>6</td>
<td>HIRES001</td>
<td>28.8–12.77</td>
<td>2</td>
</tr>
<tr>
<td>Titan mosaic (global)</td>
<td>2575</td>
<td>A-19</td>
<td>—</td>
<td>115.3–55.6</td>
<td>10</td>
</tr>
</tbody>
</table>
Orbit Insertion phase of the Cassini Mission (Phoebe 0, June 11, 2004).

4. Processing

After receipt on ground raw image cubes are generated at NASA-JPL and distributed to the VIMS team. The first processing step is to apply the radiometric calibration software (Coradini et al., 2004; McCord et al., 2004). The next step is the geometric correction and map projection of the VIMS image cubes, which requires precise geometric calibration information of the VIMS instrument for each pixel, position of the Cassini spacecraft and pointing data of each flyby. The VIMS team developed the geometric calibration procedure separately for VIMS-V and VIMS-IR before the launch. The position of the spacecraft and the pointing data of each flyby are received as SPICE (Spacecraft Planet Instrument C-matrix Events) kernels from http://naif.jpl.nasa.gov.

Usually, map projections of planetary imaging data are based on reference bodies, which describe the shape of the planetary objects. In the case of Dione, Rhea, Titan and Iapetus spheres, and in the case of Mimas, Tethys and Enceladus tri-axial ellipsoids are defined as references in the report of the International Astronomical Union (Seidelmann et al., 2002). These reference parameters are being continuously improved due to the increasing knowledge of the Saturnian satellites obtained during the Cassini mission (Porco et al., 2005a; Thomas, 2005). For the VIMS maps, these newly derived parameters are used to calculate the surface intersection points. The coordinate

![Map projected VIMS cube of Tethys observed during orbit 4 in March 2005 in an orthographic map projection centered at 2°N and 216°W with a map resolution of 10 km per pixel, (a) seen by VIMS-V at 0.43 μm (channel 8) and (b) by VIMS-IR at 2 μm (channel 166), compared to (c) a Voyager/Cassini-ISS base map (Courtesy: Cassini ISS imaging Team).](image-url)
system chosen for the VIMS maps is the IAU “planetographic” system consisting of planetographic latitude and positive west longitude.

Fig. 1 shows a comparison between the images of two spectral channels obtained by VIMS-V (channel 8 at 0.43 μm) and VIMS-IR (channel 100 at 0.93 μm) before and after the geometric correction and map projection. The images show a part of Enceladus that was observed during the first close flyby in March 2005 (orbit 4). The observation was acquired in high-resolution mode. Before the map projection the VIMS-V and VIMS-IR cubes have the same image size of 64 × 64 pixels but differ in spatial resolution. This can be seen in the location and size of a chain of impact craters, which are outlined in the images of Fig. 1a and b. After map projection, both the visible and the infrared part of the VIMS cube co-register (Fig. 1c and d). A similar effect can be recognized in the spectral domain. Fig. 2a shows a single spectrum of Enceladus measured at point (P [32, 32]) within the VIMS cube as indicated in Fig. 1a and b. The spectrum shows the well-known absorption bands of water ice at 0.9, 1.04, 1.25, 1.5, 2 and 3 μm. However, the visible and the infrared part of the spectrum do not fit together, because of the misregistration of VIMS-V and VIMS-IR. The resulting reprojected spectrum in Fig. 2b represents the true spectral characteristics of a specific point on the surface (P [185, 144], Fig. 1c and d) for the entire spectral range of VIMS.

A nearest-neighbor algorithm is used to resample the original data during the map projection process. This interpolation method does not modify the original spectral

---

**Fig. 4.** VIMS mosaic of Dione including 37 individual VIMS cubes observed during orbit 16 in October 2005 (a) seen by VIMS-V at 0.43 μm (channel 8) and (b) by VIMS-IR at 2 μm (channel 166). The pixel ground resolution of the VIMS observation ranges between 1.04 and 34.6 km per pixel. The VIMS mosaic was used to produce (c) a spectral map of the varying depth of the water ice absorption at 2 μm. To compare the VIMS observation to (d) a Cassini-ISS mosaic (Courtesy: Cassini ISS imaging Team) a map resolution of 1 km per pixel was chosen in an orthographic map projection centered at 0°S and 172°W.
information (Fig. 1b) but changes the position of the original pixel in each spectral channel due to the transformation into the new map projection. However, it has to be ensured not to lose spatial (and spectral) information during the map projection process, due to wrong map resolution adjustment. To avoid the loss of spatial (and spectral) information the map resolution of the resulting map oversamples the original pixel ground resolution at least by a factor of two. In the case of the high-resolution mode the map resolution is chosen depending on the pixel ground resolution of VIMS-V.

The final step of the image processing is the combining of different map projected VIMS cubes into a single mosaic. To guarantee VIMS mosaics of high spectral and spatial quality, individual maps were selected according to the following criteria: (1) pixel ground resolution, (2) signal-to-noise ratio, and (3) illumination conditions. Only VIMS cubes with an original pixel ground resolution of at least 100 km per pixel were included in the mosaics. The individual maps are sorted by pixel ground resolution, and the image cube with the highest resolution is located on top of the mosaic. The selected map resolution of the mosaic is defined by the image data cube with the highest spatial resolution of the set. No limb observations are used in the mosaicking process. In order to guarantee the accuracy of the VIMS maps and mosaics their quality have been checked by comparison with maps of Voyager and Cassini ISS imaging data (Roatsch et al., 2006). Usually, the accuracy of maps based on lower spatial resolution VIMS data is within the limit of one VIMS pixel. If the inaccuracy exceeds one pixel, an additional registration of the VIMS data to ISS base maps has been applied.

5. Maps

Figs. 3–9 show examples of resulting map projected cubes and mosaics of Dione, Tethys, Enceladus and Titan with examples of their scientific interpretation. For representation purpose an orthographic map projection was chosen for all mosaics, which show the satellites as seen from the Cassini spacecraft. The projection parameters used are described below and are summarized in Table 2. For comparison corresponding maps based on Voyager and Cassini ISS (Courtesy: Cassini Imaging Team) imaging data were added.

All satellites were observed at least once with a low spatial resolution of less than 50 km per pixel. However, most VIMS observations were acquired in high-resolution mode and exhibit pixel ground resolutions, which are higher by a factor of 2 (VIMS-IR) or 3 (VIMS-V). Fig. 3 shows a global map of Tethys, which represents a single VIMS observation resampled at 10 km per pixel. The figure includes images of two spectral channels obtained by VIMS-V (channel 8 at 0.43 \( \mu \)m) and VIMS-IR (channel 166 at 2 \( \mu \)m). Despite having the same projection parameters, the differences in pixel ground resolution of VIMS-V and VIMS-IR are still visible in the maps. So, the large impact crater Penelope can only be seen in the map of VIMS-V and also in the Cassini ISS base map (Courtesy: Cassini Imaging Team; Fig. 3c).
Dione, Enceladus and Titan were observed with pixel ground resolutions better than 1 km per pixel, allowing the correlation of spectral characteristics with specific surface features. The first Dione mosaic was derived from 37 VIMS observations acquired during orbit 16 in October 2005 (Fig. 4). The pixel ground resolution of the input cubes varies between 1.04 and 34.6 km per pixel. In the case of Dione, the surface intersection point of each pixel was calculated based on a tri-axial ellipsoid (Thomas, 2005). However, an orthographic projection requires a sphere as a reference body. So the calculated values were resampled into the new grid using a mean radius. Like the VIMS map of Tethys, the mosaic of Dione illustrates the differences in spatial resolution between VIMS-V (Fig. 4a) and VIMS-IR (Fig. 4b). VIMS-IR observations provide a complete coverage of the anti-Saturnian hemisphere of Dione. However, VIMS-V shows a lack of coverage because of the high-resolution mode and results in a smaller coverage but with a higher spatial resolution than the VIMS-IR observations. The mosaic is in good agreement with imaging data of Cassini-ISS that represent the sequence acquired in correlation with VIMS. The VIMS mosaic has been used to map the varying depth of the water ice absorption at 2 μm (Fig. 4c), which is an indicator for variations of the amount and the particle size of water ice. Distinct differences of shallower absorptions on the trailing side and deeper absorptions on the leading side indicate possibly hemispherical differences of the physical properties of the surface ice. These differences are also to be seen in the imaging data (Fig. 4d), which lead to the suggestion of more impurities on the trailing hemisphere of Dione.

Two mosaics of Enceladus with different projection parameters are shown to emphasize different regions of the satellite’s surface—the equatorial and the south polar region. Like Dione, the orthographic projection was produced using the mean radius of the satellite. Fig. 5 shows a VIMS mosaic of Enceladus based on 7 VIMS observations acquired during the first close flyby (Orbit 4)
in March 2004. The mosaic also includes the individual VIMS observation of Fig. 1. The pixel ground resolution of the input cubes ranges from 10.28 to 4.24 km per pixel. The VIMS mosaic is generated with a map resolution of 1 km per pixel and is centered at 10°N and 210°W. The VIMS mosaic has been used to produce a color composite of the VIMS channels 121, 135 and 166 at 1.25, 1.5 and 2 μm (Fig. 5a), which characterize variations in the spectral properties of water ice (Fig. 5a). Distinct surface features like cratered and tectonically resurfaced terrain (Kargel & Pozio, 1996) can be distinguished (Fig. 5b). A preliminary spectral map is added (Fig. 5c), which represents the varying depth of the water ice absorption at 2 μm. The varying band depth of water ice absorptions across the surface of Enceladus is indicative of different particle sizes and deepen as the particle size increases (Clark, 1981a). This leads to the suggestion of smaller particles in older heavily cratered terrain and larger particles in relatively younger resurfaced regions (Jaumann et al., 2006).

During the second close flyby (Orbit 11) VIMS observed the south polar region of Enceladus (Fig. 6). The mosaic includes cubes of three VIMS observation sequences obtaining 4, 5 and 14 individual observations each with a pixel ground resolution from 30.1 to 10.6, from 19.3 to 5.25, and from 13.9 to 7.47 km per pixel, respectively. The mosaic is centered at 50°S and 180°W and has a map resolution of 1 km per pixel. The Enceladus mosaic is shown as seen by the first spectral channel of VIMS-V at 0.35 μm (Fig. 6a) and the spectral channel 166 of VIMS-IR at 2 μm (Fig. 6b). Each map shows different spectral properties of the satellite’s surface. Almost no surface features are distinguishable in VIMS-V indicating more or less pure water ice on the surface. However, at a wavelength of 2 μm VIMS data separate the so-called “tiger stripes” at the south pole from the older cratered terrain (Brown et al., 2006; Jaumann et al., 2006). These spectral features can be enhanced in the mosaic using a color composite of the spectral channels 121, 137 and 260 at 1.25, 1.5 and 3.6 μm (Fig. 6c), which combines the variations in band depth of water ice absorptions at 1.25 and 1.5 and in the intensity of a reflection peak at 3.6 μm, which are indicative of different particle sizes of water ice (Lebofsky and Feierberg, 1985) and show greater particles in the vicinity of the “tiger stripes” and smaller particles in older cratered terrain (Jaumann et al., 2006).

Orbits A and B provided the first high-resolution VIMS observations of Titan. Fig. 7 shows a mosaic centered at 10°S and 170°W resampled at 2 km per pixel that has been produced using 57 single VIMS observations acquired during Orbit A and 59 VIMS observations during Orbit B. The pixel ground resolution of the input cubes of Orbit A ranges from 50.73 to 17.77 km per pixel, and of Orbit B from 13.26 to 0.65 km per pixel. Titan’s atmosphere is transparent in the atmospheric windows at 1.07, 1.28, 1.58, 2.0, 2.9, and 5.0 μm allowing the identification of surface features. Thus in the case of Titan, VIMS can be used as a multi-spectral camera in order to analyze the surface morphology. In the visible spectral range no surface features are detectable due to the dense atmosphere (Fig. 7a). However, in the infrared e.g. at 2 μm distinct
features become visible (Fig. 7b). Differences between these channels can be enhanced using ratios (Fig. 7c) which show the typical dark and bright terrain features on Titans surface (Sotin et al., 2005).

Further high-resolution VIMS observations of Titan followed in orbits 5 and 6. The resulting mosaic (Fig. 8) combines VIMS cubes of these orbits and shows Titan at 0.9 μm (VIMS channel 99) (Fig. 8a), at 2 μm (VIMS channel 166) (Fig. 8b) and as a ratio of these two channels (Fig. 8c). The mosaic is based on 2 individual VIMS observations acquired in orbit 5 and 11 individual VIMS observations in orbit 6 with ground pixel resolutions of the input cubes varying from 3.24 to 2.05 and from 28.8 to 12.77 km, respectively. The mosaic was produced with a projection center at 0°N and 30°W and represents the opposite hemisphere of Titan with a map resolution of 2 km per pixel.

A global mosaic of Titan is derived from VIMS observations acquired during Orbit A to Orbit 19. The ground pixel resolutions of the input cubes vary between 115.3 and 55.6 km per pixel. Fig. 9 shows the global mosaic of Titan including the high-resolution mosaic of Fig. 7. The mosaic is centered at 0° and 14°W and resampled to 2 km per pixel corresponding to the map resolution of the high-resolution mosaic in Fig. 7.

6. Conclusion

The geometric reprojection and map projection of each pixel in a VIMS cube is necessary to analyze each single spectrum over the whole spectral range of the VIMS instrument and to combine different VIMS cubes acquired at different viewing geometries and operation modi into a VIMS mosaic.

The projected VIMS mosaics are the basis to map the distribution of individual materials like water ice, minerals and volatiles across the surfaces of the Saturnian satellites. Each of these mosaics is essential for linking the spectral properties across the surfaces of these moons with geographic coordinates and therefore with morphological and geological features discovered with other instruments on board the Cassini spacecraft. Additionally map
projected VIMS cubes will allow the study of photometric effects and temporal changes of atmospheric features on Titan.

The nominal Cassini mission will continue until 2008 including 39 further flybys of Titan, and five close flybys of the other icy Saturnian satellites (Iapetus, Rhea, Dione, Enceladus). The increasing amount of data during the nominal Cassini mission will make it possible to complete and improve our coverage of the Saturnian satellites. Especially the upcoming Titan flybys will provide VIMS data with ground pixel resolutions of better 1 km per pixel allowing a detailed geologic mapping of the surface.

References


