INVESTIGATION OF CARBON DIOXIDE DISTRIBUTIONS ON SATURNIAN AND GALILEAN SATELLITES THROUGH FUSION OF SPECTROMETER DATA WITH GEOLOGICAL MAPS.

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Introduction: Carbon dioxide has been detected on the icy Galilean satellites as well as the icy Saturnian satellites. On all of these bodies, spectra indicate that the CO_2 appears to be bound to some other material on the surface rather than existing as ice or as trapped gas. We are working to understand the spatial distribution of CO_2 on these bodies, specifically searching for correlations with geological features. This approach may help to shed light on the origin of the bound CO_2 on the various satellites.

Determining CO_2 abundance: The band depth estimates for CO_2 on the Galilean satellites from NIMS data were measured as described in Hibbitts et al. [1], with a new calibration applied to the data. The band depth on the Sautrnian satellites is measured with respect to the continuum using a modification of this same procedure. The continuum is quite low at these wavelengths due to the presence of ubiquitous water ice, resulting in low signal-to-noise and noise-challenged estimates of band depths. Additionally, the CO_2 band is shallow on Dione, generally not exceeding 10% and in many places barely detectable. We take several steps to mitigate these effects. First, we begin with raw data available from the PDS and perform our own despiking routine, and then apply the standard radiometric and wavelength calibrations, with a modification to the wavelength calibration within the CO_2 region [2].

From these improved data sets, we select only those observations that were performed at long integration time, generally 640ms, though occasionally 320ms are used as well. We have found that although there are several large, high resolution observations of Dione at shorter integration times, that the short integration times make the detection and characterization of the CO_2 band significantly less precise than is possible with the longer integration time observations. The shape of the CO_2 band is approximated by a mathematical shape model. A modified gaussian curve is derived that best fits, in a least-squares sense, the average CO_2 absorption band from a total of approximately 100 pixels containing the strongest CO_2 bands extracted from four high-resolution, long-integration time observation from epoch 34 (observations during Cassini's 50th orbit of the system). The shape model is then used to determine the depth of bands in individual pixels by again performing a least squares fit at each wavelength within the band and a few wavelengths on the continuum to both sides of the band. A least squares fit also provides a quantitative measurement of the goodness of fit, which we use in subsequent noise analyses. If the noise of a band depth estimation is greater than 50% of the estimate, then the original spectra are averaged in a 3x3 box in an attempt to reduce the noise, and a new band depth is calculated. This greatly reduces the noise, but the resulting band depth maps still retain considerable noise pixelation.

Spatial approach: In the past, a lot of matching between spectrometer data and geological features seen in higher resolution imaging data has been done by overlaying the spectrometer data onto the image data and then essentially "eyeballing it." This works fine when the correlation is obvious between a spectral feature and a terrain feature, but to find more subtle trends we have been improving our methods.

Ongoing map data of geological units and features on the Galilean and Saturnian satellites has been collected with GIS software. We have set up a pipeline for transforming spectrometer-derived data products into GIS polygon layers. Each polygon in the database represents the boundaries of a pixel from the spectrometer (synthesized pixels in the case of NIMS), and stores information about the observation and lighting geometry, and derived values such as band depths.

The advantage of storing all the spectrometer and geological map data together as GIS polygons is that we can then run spatial queries on the data. For example, one could test the properties of pixels within fresh vs. degraded craters, or tectonized vs. untectonized terrain. We have just begun the scratch the surface on these analyses, and we present below a couple of examples, one from Ganymede and one from Dione.

Dione: We have built a GIS database of craters and tectonic features on Dione, on top of the global image mosaic [3] and additional high resolution ISS data from the PDS. The Dione database is subsequently being populated with VIMS observations. Figure 1 shows an area just to the west of the sub-saturn point, which was the target of 5 long-integration VIMS observations. Figure 1a shows that the CO_2 abundance calculated from a single VIMS observation in this area is rather noisy. Figure 1b shows the result of an attempt to increase the signal-to-noise ratio by averaging all of the overlapping observations. In this case, all of the overlapping polygon files were intersected, and a new file was created, showing average

CO_2 abundances only in areas covered by more than one observation.

Compared to the single observation (Fig. 2a), the averaged observation (Fig. 2b) appears to be more spatially coherent, though it is far from noiseless, and exhibits and average band depth of 4.9% ± 1.2%. Comparison to the underlying geological map layers shows a slight decrease in CO_2 around fresh craters (4.7%) and a slight enhancement of CO_2 around the fractures of Carthage Fossae (5.1%), which may be due to the dark material in this area (though neither of these variations is outside the error of the average band depth). Using a different observation, Stephan et al. [5] found the fractures to the east of this area to be rich in water ice and their surroundings to be richer in a dark rocky contaminant.

Ganymede: Hibbitts et al. [6] investigated CO_2 distributions on Ganymede, concentrating on broad global patterns as well as comparisons to geolgic sketch maps in high resolution target areas. They found that CO_2 appears to be more abundant in dark terrain than bright terrain, and is not abundant in fresh craters or the polar cap. Since the time of that study, improved calibration of the NIMS data as well as the completion of the global geologic map of Ganymede [7] has made this problem worth revisiting.

Though we found the same general trends of more CO_2 than average in the dark terrain and less in fresh craters, the error bars associated with these measurements are large. One issue to overcome is the variation in band depth from one overlapping observation to another, possibly due to variations in spatial resolution, and are effects that we could deal with in a similar fashion to the overlapping Dione data.

Other satellites: We are currently working on VIMS data from Iapetus, and will bring the latest results to the conference. We are also improving the analysis of CO_2 distributions on Callisto. Previous work on Callisto [8] found high concentrations of CO_2 within fresh impact craters.

References: [1] C. A. Hibbitts et al. (2000), *JGR* 105, 22541-22557; [2] Cruikshank et al. (2009), in prep.; [3] T. Roatsch et al. (2008), *PSS* 56, 1499-1505; [4] R. N. Clark et al. (2008), *Icarus* 193, 372-386; [5] K. Stephan et al. (2008), *LPSC XXIX*, #1717; [6] C. A. Hibbitts et al. (2003), *JGR* 108, doi:10.1029/2002JE001956; [7] G. W. Patterson et al. (2007), *LPSC XXXVIII*, #1098; [8] C. A. Hibbitts et al. (2002), *JGR* 107, doi:10.1029/2000JE001412.

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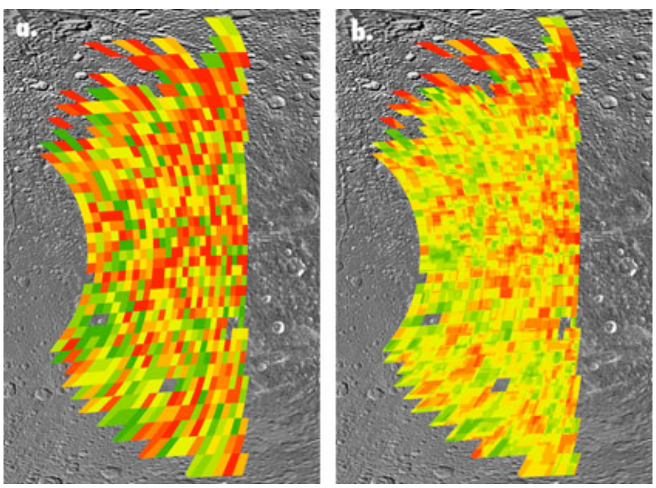

Figure 1. VIMS-derived CO_2 abundance map overlaid on Dione ISS mosaic. Red is high abundance (up to 12% band depth), green is low (approaching zero band depth). (a) Abundance calculated from one VIMS observation (VIMS_050DI_DIONE002_PRIME). (b) Noise reduced by combining and averaging five overlapping VIMS observations.

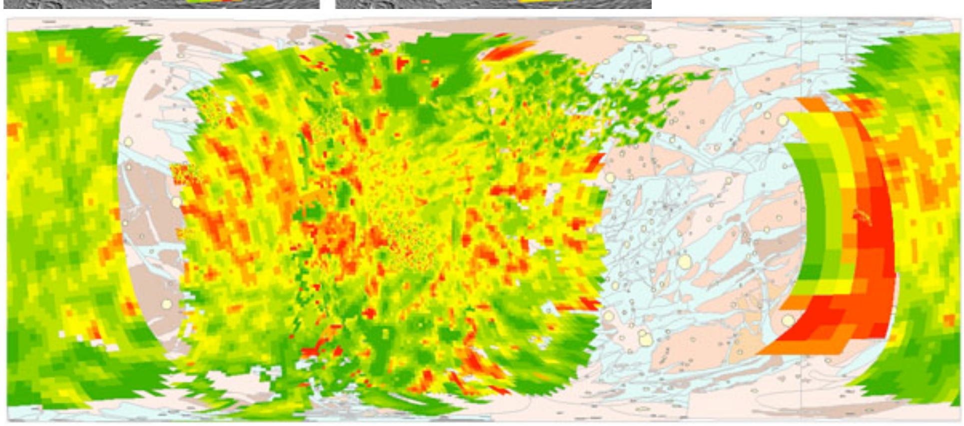

Figure 2. CO_2 band depths from 14 separate NIMS observations overlaid on the global geological map of Ganymede derived from Galileo SSI and Voyager observations [7]. Red areas show up to 20% band depth, dark green pixels approach zero.