

THE SO₂ CYCLE ON IO AS SEEN BY THE NEAR INFRARED MAPPING SPECTROMETER. S. Douté, *Institute of Geophysics and Planetary Physics, 3823 Slichter Hall, Box 156704 Los Angeles, CA 90095, USA (sdoute@igpp.ucla.edu)*, R. Lopes-Gautier, R. Carlson, *Jet Propulsion Laboratory, 4800 Oak Grove Drive Pasadena, CA 91109, USA*, B. Schmitt, *Laboratoire de Planétologie de Grenoble-CNRS, Bât. D de Physique, B.P. 53, 38041 Grenoble Cedex 9, France*, L. A. Soderblom, *U.S. Geological Survey Branch of Astrogeology, Flagstaff, Arizona*, Galileo NIMS Team.

The Jovian satellite Io exhibits intense volcanic activity as witnessed by the detection of numerous "hot spots" that uniformly mark its surface and emit much thermal energy [1,2]. The "hot spots" are often associated with airborne activities: plumes which are composed of gas and fine particles. At some distance around the plumes, different materials settle on the surface [3]: yellow or red diffuse deposits as well as white patches or rings that have been respectively interpreted as pyroclastic, perhaps fumarolic coating sulfur and sulfur dioxide frost. The latter compound has received attention for several decades. Indeed this is still the only molecule that has been formally and extensively identified on Io. The solid phase is recognized on the surface thanks to its numerous and strong absorption bands in the near infrared reflectance spectra of Io [4]. On the other hand, millimeter-wave observations [5] and UVS GALILEO spectra [6] show that some SO₂ gas forms a neutral, 'dense' (pressure of 3 to 40 nbar) and patchy atmosphere, likely of volcanic origin. This component, which overlies about 25 % of Io's surface, constitutes the principal SO₂ source of a global, colder and much more tenuous atmosphere (0.01 to 0.1 nbar) e.g. [6,7]. Sulfur dioxide is, therefore, an important product on Io that is closely related to volcanic activity and dominates the atmospheric processes. In particular, the frost deposits are excellent tracers to study various phenomena including volcanic production and emission, atmospheric transportation, condensation, metamorphism, irradiation and sublimation, that occur throughout the SO₂ cycle.

From June 1996 to July 1999, the Near Infrared Mapping Spectrometer (NIMS) [8] of GALILEO has offered us an important set of global-scale spectro-images of Io in the near-infrared (0.7-5.2 μm). They cover approximately 3/4 of Io's surface, with a spatial resolution ranging from 60 to 350 km/pixel and a spectral resolution of 0.024 μm (102, 216, 360 or 408 wavelengths). Since then, in October and November 1999, GALILEO performed two daring close flybys (orbits I24 and I25) of the satellite, allowing NIMS to access the regional scale (26 to 105 km/pixel) and the local scale (0.4 to 12 km/pixel). The major volcanic regions (Loki, Pele, Pillan, Prometheus, etc.) and some visible distinctive colorimetric units were principally targeted. More than a score of new images have been obtained, though with a much smaller number of wavelengths than for the global-scale observations.

These data are particularly well suited to map the distribution of SO₂ and its physical properties, to identify other components on the surface (when a sufficient spectral sampling is achieved), and to understand and follow the volcanic activity on Io. Here we focus on the first objective both at the global and regional scale.

Global-scale distribution of SO₂ We analyzed the set of global-scale images to produce two mosaics that map the distribution of SO₂ frost deposits and their granularity over $\approx 3/4$ of Io's surface [9]. For that purpose we first proposed a very simple local surface representation of Io based on previous spectroscopic studies [4,10] and thermodynamic arguments: a geographical mixture of SO₂ and other sulfur-bearing compounds (sulfur and oxides). Second, we assess the mean photometric behavior of the SO₂ frost using a sequence of NIMS spectra at two different locations over a large range of phase angles. Third, we performed the systematic inversion of a reflectance model [11] on the reflected component of the NIMS spectra. The description of the distribution and granularity mosaics can be summarized as follows : the SO₂ frost deposits seem to be present everywhere on Io, but are very unevenly distributed, the surface proportion ranging from 20 to 80 %. SO₂ is mainly concentrated in the anti-Jovian hemisphere, within several large areas centered at mid-latitudes. These SO₂ rich regions are somewhat correlated with the locations of the plumes at approximately the same longitude. The variations of SO₂ granularity are also very irregular with large evolved grains (metamorphism) at the equator and in some high latitude regions. These results contradict the distribution maps of surface materials (notably SO₂) accepted so far [12] and inferred from spectral classification of visible-ultraviolet Voyager and Galileo data. The frequent contamination of sulfur dioxide and other sulfur-bearing compounds [13] can explain this apparent contradiction. This hypothesis is in general neglected and questions the distinction criteria used in the visible and ultraviolet. The infrared is less sensitive to this kind of contamination.

We proceeded with this analysis correlating by an original visual method the two mosaics and considering the hot-spot distribution and activity type [1,2]. Four distinctive SO₂ physical units could then be distinguished that we connected to different volcanic, atmospheric and magnetospheric phenomena at a global scale.

Regional-scale distribution of SO₂ We have more recently determined the SO₂ frost distribution at smaller scales around several volcanic regions of interest : Prometheus, Culann, Marduck and Pele. The I24 and I25 NIMS images used here exist in only 14 wavelengths semi-regularly spaced between 1 and 5.2 μm , thus precluding their analysis by the previous method of modeling. However we have found a band ratio diagnostic of the local SO₂ frost coverage: the reflectance at 3.19 μm in the continuum of the spectra over the reflectance at 4.15 μm within the strong SO₂ absorption band centered at 4.03 μm . More precisely, as shown by the correlation between our large scale SO₂ distribution mosaic and the ratio map

derived from an I24 global image, the two quantities are linked by a simple linear relation. This allows us to translate ratio maps into SO₂ distribution maps with reasonable precision. The map of the Prometheus region is particularly telling with the striking SO₂ deposition ring that circles the vent. There, the frost blanket is not continuous, with coverage of 50 % to 60% indicating some irregularities for the deposition process or an heterogeneous thermal flux for the surface. Moreover the ring is not symmetric with more frost deposition east of Prometheus than west. At some distance, still east of the volcanic center, lies an SO₂ rich region already visible in our global mosaic and extending towards Bosphorus Regio. The comparison between different images of the Prometheus region taken during I24, I25 and maybe I27 (if available) may provide some indication of the temporal variability of these SO₂ frost deposits.

The SO₂ cycle In our presentation, we will give a summary of the previous results (global, regional and local views) and will illustrate them as well with our SO₂ distribution and classification maps. Furthermore, on this basis, we intend to give some insights about different processes occurring throughout the SO₂ cycle. In particular we will focus on SO₂ emission by the vents and its dynamical condensation to form deposition rings. We will also consider its subsequent remobilization by diurnal insolation, its transport in the atmosphere, its deposition by condensation, its evolution and its sublimation, destruction or burial. At the same time, we will make precise the mean atmospheric circulation patterns and we will delineate the large scale thermally active area of Io.

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