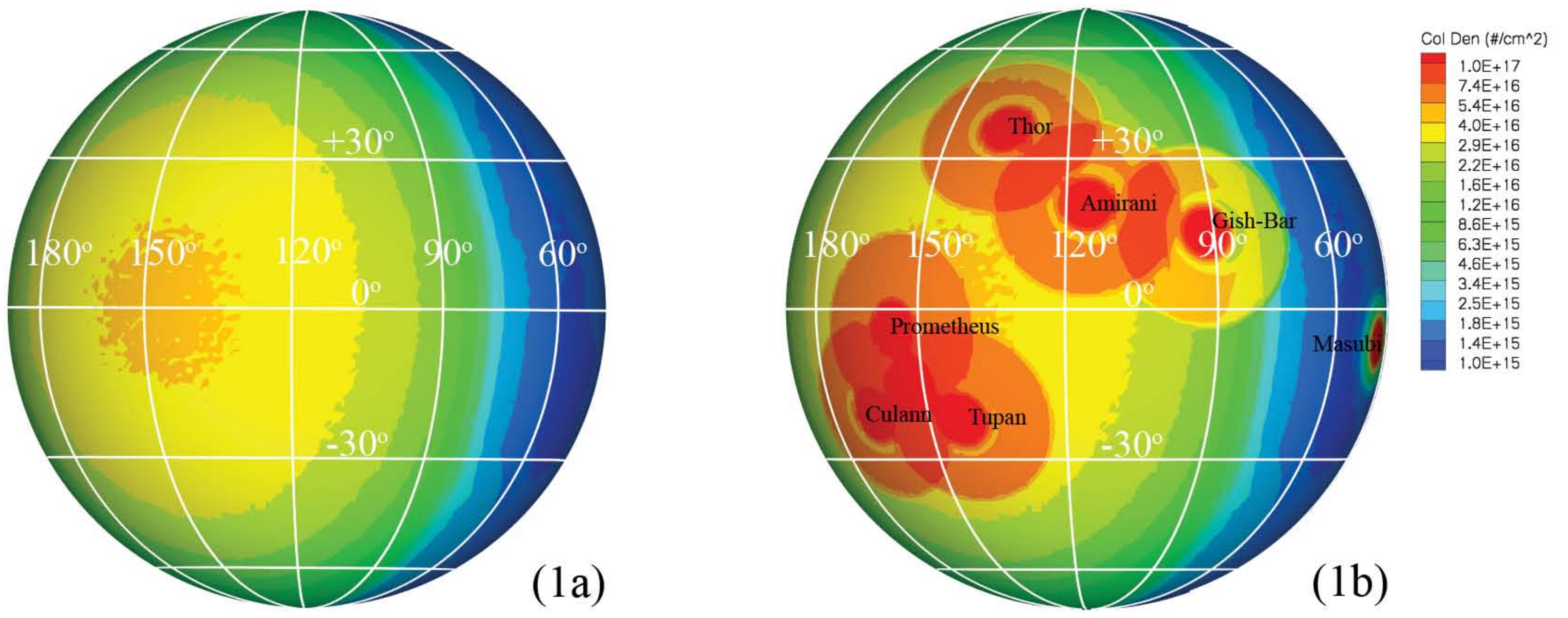
MODELING THE SUBLIMATION ATMOSPHERE OF IO

A.C. Walker[1], S. L. Gratiy[2], D. A. Levin[2], D. B. Goldstein[1], P. L. Varghese[1], L. M. Trafton[1], C. H. Moore[1]
[1]The University of Texas at Austin, [2]Penn State University (andrew.walker@mail.utexas.edu, slg284@psu.edu)

Introduction: The dynamics of Io's atmosphere are of scientific interest due to the complex interaction of the Jovian plasma torus with the tenuous atmosphere created by intense volcanic activity and sublimation from the surface. Io's rarefied atmosphere is simulated with the DSMC method. The effects of volcanic sources on Io's atmospheric density are examined by comparing a modeled sublimation atmosphere with and without plumes. To validate the atmospheric model, we present the atmospheric radiation calculations for six equally spaced subsolar longitudes on Io and compare them to the observations. We calculate the IR absorption spectra in the ν_2 vibrational band of SO$_2$ and compare them to the band depth observations. We also calculate images at Lyman-α wavelengths and compare them to existing HST observations.

Atmospheric Model: The rarefied atmosphere present over much of Io can be accurately modeled by the DSMC method. DSMC uses a representative number of molecules to approximate the collisions and movements of real molecules in the gas statistically [1]. The simulation is fully three-dimensional and was run on 36 processors, where each processor's domain is a 10 degree azimuthal melon slice of the entire atmosphere. Each processor contains 1.8 x 10^5 cells and simulates ~1 x 10^7 molecules. Figures are the ensemble average of results from six runs. Volcanoes are simulated separately and overlaid on the sublimation atmosphere.



(1a) (1b)

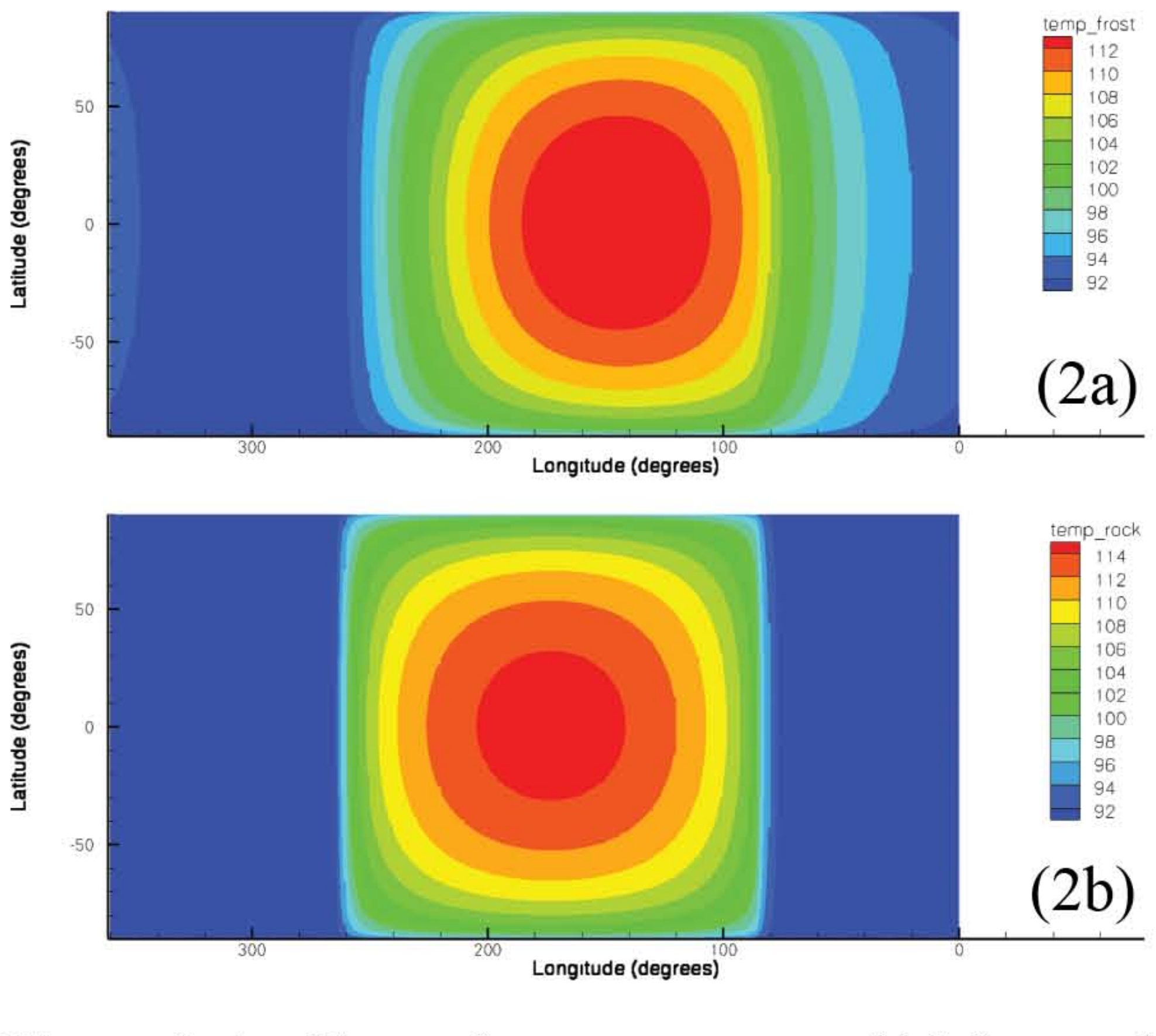
Figure 1ab - Number density contours at 3 km altitude for an atmosphere with a peak frost temperature of 115 K without volcanic sources are shown in **(a)** while contours for the same sublimation atmosphere with volcanic sources are shown in **(b)**. At a low subsolar temperature of 115 K, the volcanic sources are the dominate source of SO$_2$ gas on patches of the day-side that are within ~200 km of the volcanic vents. The sublimation atmosphere is more uniform but has a generally lower column.

Physics Included in Model:

-Non-uniform frost coverage [2] which acts as the source for the sublimation atmosphere.
-Temperature-dependent SO$_2$ residence time on rock surface [3].
-Plasma heating modeled by radial influx of energy.
-Planet rotation (making the solution unsteady)
-Unit sticking coefficent
-Vibrational and rotational energy exchange
-Thermal inertia of the surface
-Quantized model of vibrational radiation
-Continuum model of rotational radiation

Results: The day-side atmosphere densities are controlled regionally by volcanic sources and by sublimation away from volcanic vents. Non-uniformities in the surface frost coverage are masked by the short residence time of SO$_2$ on warm rock.

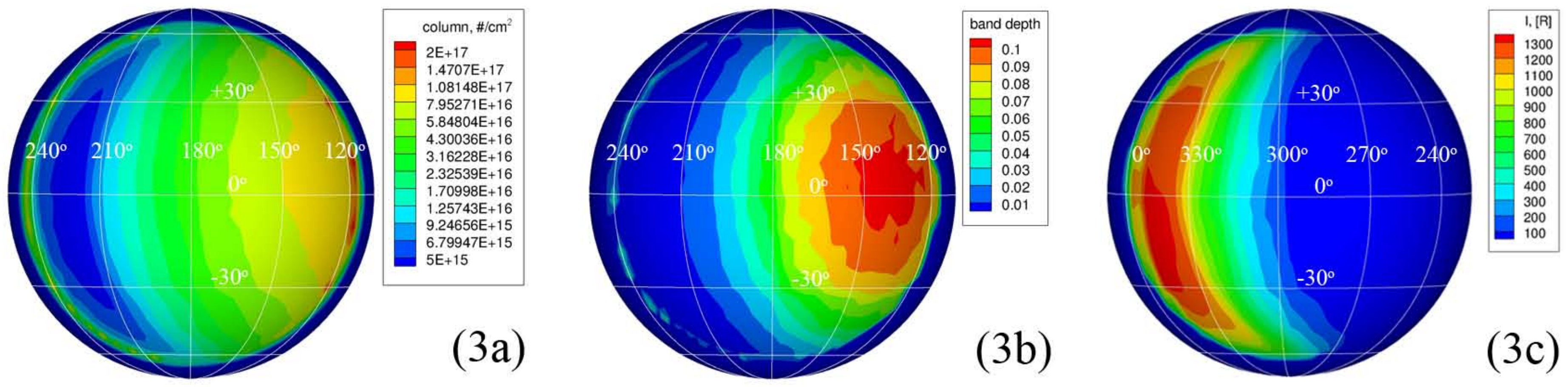
The surface temperature model predicts a large lag in frost temperatures with respect to the subsolar point which is not seen to such a large extent in observations.



(2a) (2b)

Figure 2 ab - The surface temperature of **(a)** frost and **(b)** "rock" (non-frost) as a function of latitude and longitude for a subsolar longitude of 180°. There is a noticeable lag in frost temperature with respect to "rock" temperatures due to the frost's higher thermal inertia.

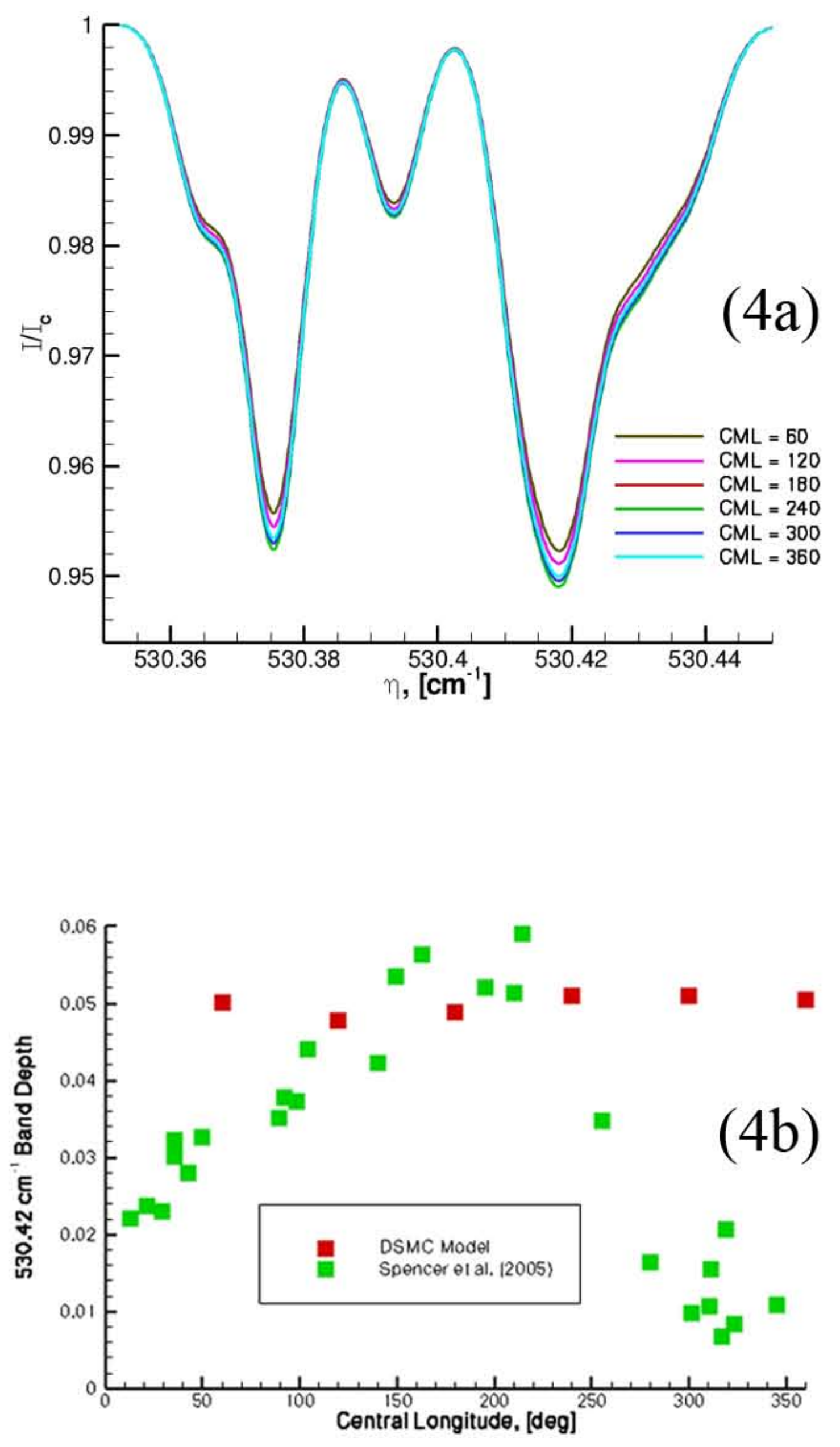
Radiation Model: To model the atmospheric radiation, a 3-D spherical-shell radiative transfer model was developed utilizing the backward Monte Carlo method [4]. In this method photon bundles are traced in a time-reversed manner from the detector toward the atmosphere until they are absorbed by the planetary surface or gas. The model is capable of calculating both the solar UV/visible radiation scattered by the planetary atmosphere/surface as well as IR/mm radiation emitted by the atmosphere/surface. First, we model the radiation arriving at an Earth-based detector from the atmosphere of Io in the range 530.35-530.45 cm^{-1} of the ν_2 vibrational band of SO$_2$ and compare it to spectral observations of the sunlit hemisphere of Io during 2001-2005 [5]. Second, we calculate images of Io at solar Lyman-α (1216 Å), which is reflected from the surface and is strongly absorbed by SO$_2$ gas; these are compared to HST/STIS observations during 1997-1998 [6].



(3a) (3b) (3c)

Figure 3abc - (a) Column density of Io's atmosphere at zero phase angle for a subsolar longitude of 180°. **(b)** Disk resolved band depth for the strongest feauture in the spectrum centered at 530.42 cm^{-1} for the same phase angle and subsolar longitude. **(c)** Lyman-α intensity (in Rayleighs) of the modeled atmosphere at zero phase angle and a subsolar longitude of 300°.

Results: Band depth calculations indicate a much stronger absorption and column on the evening portion of the visible disk. The atmosphere lags the subsolar point as a result of thermal inertia of the surface frost. The shape of the spectrum is identical to the one observed by Spencer *et al.* [5], however the observations show a band depth variation for different subsolar longitudes (fig. 4b) whereas our current simulations do not. The disagreement may result from the fact that the simulated residence time of SO$_2$ on Io's rocky surface could be incorrect due to contamination of the surface by other species. The temporal lag is again apparent on the modeled Lyman-α images, where the morning portion of the atmosphere is bright while the evening portion is completely opaque. The magnitude of the Lyman-α brightness is similar to the observations [6], however the observations do not show a thermal lag but rather indicate that Io carries it's atmosphere as an equatorial belt.



(4a) (4b)

Figure 4ab - (a) Disk integrated 530.35-530.45 cm^{-1} spectrum of the atmosphere normalized to the surface continuum. **(b)** Variation in the band depth at 530.42 cm^{-1} calculated based on the DSMC model atmosphere and compared to the observations by Spencer *et al.* [5].

Conclusions:

-Io's atmosphere is volcanically dominated within 200 km of the volcanic vents and by frost sublimation far from the vent at a subsolar temperature of 115K.
-The shape of the spectrum is identical to the one observed by Spencer *et al.*, however the modeled band depth is larger than the obervations.
- The modeled atmosphere is insensitive to the underlying frost fraction as indicated by the constant band depth for different subsolar longitudes.
-Lyman-α images do not indicate noticeable lag in the atmosphere with respect to the subsolar point as predicted by our model.
-Volcanic sources could influence the intensity of Lyman-α near the limb and improve agreement with observations.

References: [1] Bird, *Molecular Gas Dynamics and the Direct Simulation of Gas Flow*, Oxford University Press, 1994. [2] Doute *et al.*, *Icarus*, **149**, 107-132, 2004. [3] Sandford and Allamandola, *Icarus*, **106**, 478-488, 1993. [4] Walters *et al.*, *Int. J. Heat Mass Transf.*, **5**, 131-176, 1992. [5] Spencer *et al.*, *Icarus*, **176**, 283-304, 2005. [6] Feldman *et al.*, *Geophys. Res. Lett.* **27**, 1787-1789, 2000. [7] Rathbun *et al. Icarus*, **169**, 127-139, 2004.