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Modeling Thermal Signatures of Active Regions and Plumes on Europa

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Abstract

We use thermal and radiative transfer models to investigate the nature and occurrence rate of hot spots and plumes on Europa. Active regions may generate several types of detectable anomalies: 1) optically thick plumes, 2) elevated surface temperatures due to high heat flow, and 3) anomalous thermophysical properties due to deposition or sintering. Using a statistical resurfacing model, we find that active regions > 1 km^2 are likely to exist somewhere on Europa at any given time. We also find that these regions are detectable by the Europa Thermal Emission Imaging System (E-THEMIS) on NASA's Europa Clipper mission.

1. Introduction

Europa's surface is geologically young ($\sim 60-100$ Myr [6]), implying a rapid resurfacing rate likely driven by an active interior [1]. The discovery of water plumes with the Hubble Space Telescope (HST) originating from Europa's fractured surface [4] may indicate that some resurfacing occurs through active cryovolcanism [5]. Such regions should exhibit elevated temperatures [3], which may persist long after plumes have decayed. Based on observations of Enceladus' water plumes, a substantial fraction of Europa's plume material may be composed of ice grains, some of which could redeposit on the surface surrounding the vents.

2. Approach and Methods

To simulate thermal IR emission by active features on Europa, we developed three models: 1) a 1-d thermal model, 2) a radiative transfer model, and 3) a statistical resurfacing model. The 1-d thermal model includes vertical conduction and plume generation by heating and sublimation from a near-surface liquid reservoir. The radiative transfer model includes emission, absorption and scattering of infrared radiation by a plume composed of ice grains and water vapor.

Resurfacing is modeled as a random process, with discrete features matching typical areas of major geologic terrains on Europa: chaos, bands, ridges, pits, and domes. In this case, the probability of N new features of type i emerging over a time interval Δt is

$$P(\Delta t, N) = \left(\frac{\Delta t}{\tilde{t_i}}\right)^N \frac{e^{-\Delta t/\tilde{t_i}}}{N!} \tag{1}$$

where $\tilde{t_i} = A_i/(f_i \dot{A})$ is the average time between the formation of feature i, the sum of which covers a fraction f_i of Europa's overall surface, with each feature having an area A_i. Europa's global average resurfacing rate is $\dot{A} \sim 1\ \mathrm{km}^2\ \mathrm{yr}^{-1}$. In the case of a thermal anomaly, Δt is the lifetime of the hot spot. We calculate $\Delta t \sim 1 - 10$ kyr for several types of thermal anomalies, including melt regions under chaos, and frictional heating on faults [2].

3. Results

Figure 1 shows a map of Europa's surface age for a model that has reached steady state after 10^7 yr. The model also tracks surface temperatures (not shown) for each type of anomaly. Figure 2 shows the decay of a hot spot initially formed by complete melting of the ice shell. A detectable temperature anomaly (> 5 K above background) persists for $\sim$ 1 kyr. Figure 3 shows the H_2O column density from a snapshot of a typical model run, with comparison to the HST vapor detection. We find that plumes generated by near-surface hot spots can readily reproduce observed plume densities. However, these features have lifetimes of ~ 100 yr, which is much longer than the probable lifetimes of the observed plumes. In addition, the model shows that the surface thermal signature of a plume reaching 200 km persists for $\sim 10\times$ the lifetime of the plume itself. Based on the radiative transfer model results, such plumes are barely detectable by E-THEMIS. Deposits of fine-grained plume material should maintain their low thermal inertia for timescales comparable to those of impact gardening or ice sintering. For reasonable grain sizes and porosity values, we find nighttime temperature anomalies of ~ 10 K are possible. These are detectable by E-THEMIS, if visible albedo is known to $< 20\%$.

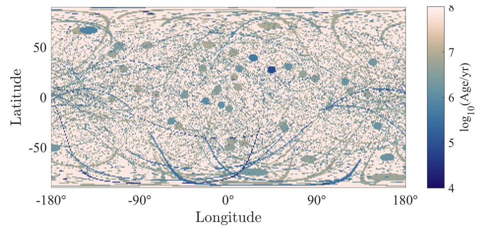

Figure 1: Global map of surface age after the statistical resurfacing model has reached equilibrium.

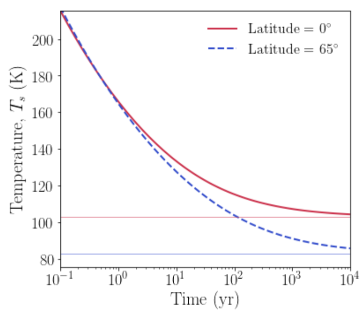

Figure 2: Modeled ice temperature for an initially melted region.

4. Summary and Conclusions

Our model results show that, given the average resurfacing rate and proposed heating mechanisms, detectable thermal anomalies are likely to be present on Europa's surface, independent of plumes. If plumes do occur, then the associated hot spots should persist for $\sim 10\times$ the plume lifetime. Deposits of fine-grained plume material may persist even longer.

Acknowledgements

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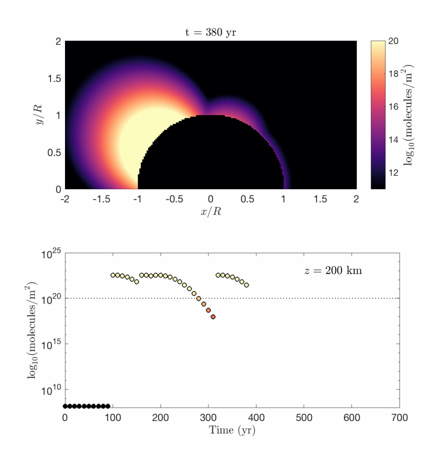

Figure 3: Modeled plume column density snapshot (top) and history (bottom). Dotted line shows the detection limit at 200 km altitude from [4].

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