Earth as an Extrasolar Planet

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EPOXI

Earth Model

The NASA Astrobiology Institute's VPL 3-D spectral Earth model simulates Earth's appearance to a distant observer (Tinetti *et al.* 2006, Robinson *et al.* 2010). Spatially-resolved, date-specific observations of key surface and atmospheric properties are taken from Earth-observing satellites and used as input. Specular reflectance from liquid water surfaces as well as scattering from liquid and ice water clouds are all realistically simulated in our model. Figure 1 shows a true-color image generated by our model as compared to an image from NASA's EPOXI mission.

Input Data	Source(s)
Gas mixing ratio profiles	Microwave Limb Sounder (MLS) and Tropospheric Emission Spectrometer; Atmospheric Infrared Sounder (AIRS)
Temperature profiles	MLS; AIRS
Snow and sea ice cover	Moderate Resolution Imaging Spectroradiometer
Ocean wind speed and direction	QuikSCAT

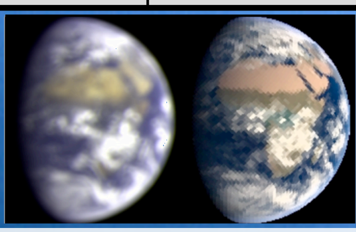

Figure 1: A true-color image of Earth taken from the EPOXI dataset (left) and from our model (right).

Validation

Model validation against disk-integrated, time-resolved observations of Earth include:
- visible photometric (0.3-1.0 μm) (NASA/EPOXI)
- NIR spectroscopic (1.05-4.8 μm) (NASA/EPOXI)
- MIR spectroscopic (6-15 μm) (AIRS)

Figure 2 shows a comparison of our model to EPOXI and AIRS data, and residuals are typically less than about 7%.

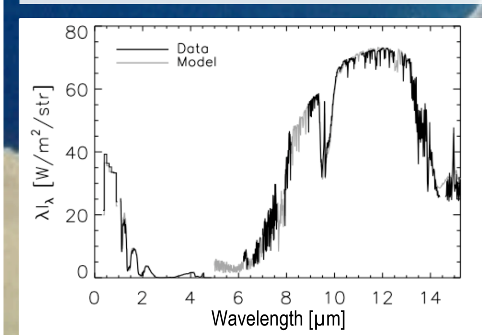

Figure 2: Spectral validation of our model from UV to MIR wavelengths (Robinson *et al.* 2010a). Gaps are regions where data are not obtained. EPOXI and AIRS data were recorded between 0.3-4.8 μm and 6-15 μm, respectively.

Abstract

The NASA Astrobiology Institute's Virtual Planetary Laboratory (VPL) 3-D line-by-line, multiple-scattering spectral Earth model generates spatially- and temporally-resolved synthetic spectra and images of Earth. The model can be used to simulate the spectrum of Earth as it would appear to a distant observer at arbitrary viewing geometry over wavelengths from the far-ultraviolet to the far-infrared on timescales from minutes to years, and can be used to understand sensitivity to global signatures of habitability and life in disk-integrated spectra of Earth.

Temperature

Clouds and continuum absorption from water vapor can prevent thermal radiation from Earth's surface from escaping to space, obscuring direct measurements of Earth's surface temperature from disk-integrated, MIR spectra. Figure 3 shows simulated disk-integrated brightness temperature spectra of Earth from our model both with and without clouds, demonstrating the ability of atmospheric effects to obscure measurements of surface temperature. This effect is slightly less pronounced in pole-on spectra.

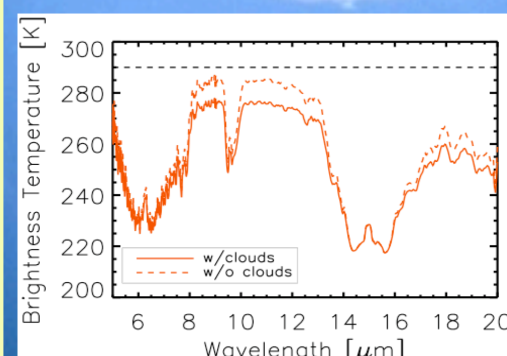

Figure 3: Equator-on, 24-hour average simulated brightness temperature spectra of Earth with and without clouds. The dashed black line shows the temperature that would have been measured in the absence of atmospheric effects (291 K).

Conclusions

- Our model successfully reproduces high-resolution spectral and phase-dependent photometric observations of Earth, at wavelengths from the ultraviolet to the mid-infrared.
- Glint from the Earth's oceans can produce as much as a 100% increase in observed brightness at crescent phases and can be discriminated from a similar brightening due to forward-scattering clouds.
- Clouds and continuum absorption from water vapor prevent direct measurement of Earth's surface temperature from disk-integrated MIR spectral observations, and reduce the maximum observed brightness temperature by as much as 20 K.

Detecting Exo-Oceans

Glint, the specular reflection of sunlight off a surface, may reveal the presence of oceans on an extrasolar planet. As an Earth-like planet nears crescent phases, the size of the ocean glint spot increases relative to the fraction of illuminated disk, while the reflectivity of this spot increases. Both effects change the planet's visible reflectivity as a function of phase, but can be mimicked by forward scattering from clouds and/or obscured by Rayleigh scattering and atmospheric absorption. Simulations of Earth's appearance over an orbit (Figure 4) show that a glinting Earth can be significantly brighter than a non-glinting Earth. Furthermore, this effect may be detectable using the James Webb Space Telescope paired with an external occulter by observing the planet's phase curve at NIR wavelengths (Robinson *et al.* 2010b).

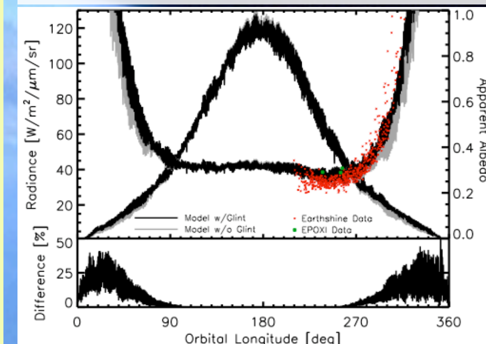

Figure 4: Simulation of Earth through a year. Black lines are the model with glint while grey lines are the model without glint. The left y-axis corresponds to the bell-shaped curves, and the right y-axis corresponds to bowl-shaped curves, where a perfect Lambert sphere would be a flat line (constant apparent albedo). Variability at small time scales is due to the rotation of the planet as well as time-varying cloud formations. Model "observations" are recorded every four hours, the system is viewed edge-on, and an orbital longitude of 0° corresponds to January 1, 2008. All data and model observations cover a wavelength range from 0.4-0.7 μm. The bottom sub-panel demonstrates the brightness excess seen in the glinting model over the non-glinting model. Earthshine data courtesy of E. Palle (Palle *et al.* 2003).

References & Acknowledgements

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