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Earth as an Exoplanet: Thermal Emission and Time Variability using Spatially Resolved MODIS Data

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Abstract

The search for habitable and inhabited worlds beyond Earth is a key topic in exoplanetary science. Future space missions will bring exoplanetary characterization to the next level due to their capability to detect Earth-like planets around nearby stars, which are potentially habitable. To inform future mission concepts and their (atmospheric) characterization potential, it is desirable to explore the full range of spectral signatures and variability of the only known inhabited planet, i.e. Earth.

We use Earth observation data sets that are constructed from 14 years of observations by MODIS aboard the Aqua satellite, containing 16 discrete bands located in the Mid Infrared (3.66 to 14.40 microns) wavelength regime. We analyze the data and infer the spectral radiance, spectral energy distributions (SEDs), and power spectral densities (PSDs) on four different locations on the Earth: (1) Sahara Desert, (2) Arctic, (3) Antarctica, and (4) Indian Ocean. The mean size of the target location frames was ≈ 2330 km x 2030 km. We investigate the behavior of their thermal emissions and search for evidence of planetary obliquity therein.

From the SED in figure 2, we can infer that the ozone feature around 9.7 microns is basically not detected in the Antarctica data and as Ozone is considered as one of the main bio-indicators in MIR data, it suggests that the viewing geometry plays a vital role and needs to be considered if planetary characteristics should be determined from thermal emission spectra of data-limited exoplanet observations in the future. Furthermore, from the SEDs, we obtained effective temperature estimates by fitting a black-body spectrum to the data, yielding in 279.22 ± 5.77K and 268.66 ± 3.94K for the desert and ocean frame and 226.66 ± 0.54K (Antarctica) and 244.21 ± 1.94K (Arctic) for the ice frames. For comparison, the Earth's equilibrium temperature is 255K.

The PSDs (Figure 1) revealed that 91% of all 16 MODIS channels show a well defined peak around 1 cycle per Earth-year, providing information on the planetary obliquity independently of the surface type or angular dependency. While all channels were equally appropriate for polar ice measurements, only some channels seem to be suitable for desert and ocean type planets. For a desert planet, nine channels (20-25 (3.66-4.50 µm), 29 (8.40-8.70 µm), 31-32 (10.80-12.30 µm)) seem to be favourable but only six (20-23 (3.66-4.08 µm), 27-28 (6.54-7.48 µm)) out of 16 available MODIS channels would produce a confident signal for water-worlds, where, with a significance of 11.52σ, channel 20 displayed the strongest signal.

Although rotational and seasonal variations of the Earth spectrum and their influence on the detectability of spectral signatures of habitability and life have been investigated before (e.g. [1], [2], [3], [4]), our new results are based on 14 years of observational data rather than simulations, which, to our knowledge, is the longest time baseline ever considered for investigating Earth's thermal emission in the context of exoplanet science. Our findings suggest that (1) viewing geometry does play an important role in case the thermal emission of an Earth-twin exoplanet were to be analyzed in the future, (2) thermal fluxes do vary by up to plus/minus 10-15% around 10 micron irrespective of viewing geometry, and (3) the thermal emission spectrum from an Earth-twin does encode information about seasons/planetary obliquity if the object is observed sufficiently frequently along its orbit over several years.

Acknowledgements

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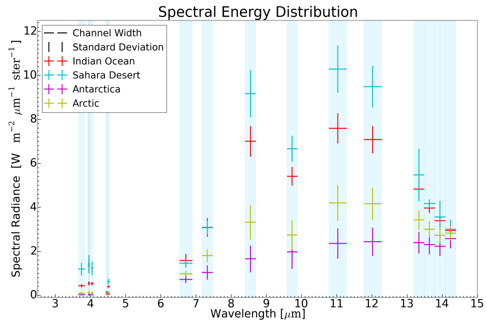

Figure 2: Spectral Energy Distribution overview of all target locations. The errorbars correspond to the bandwidth and standard deviation in the x- and y-direction, respectively.

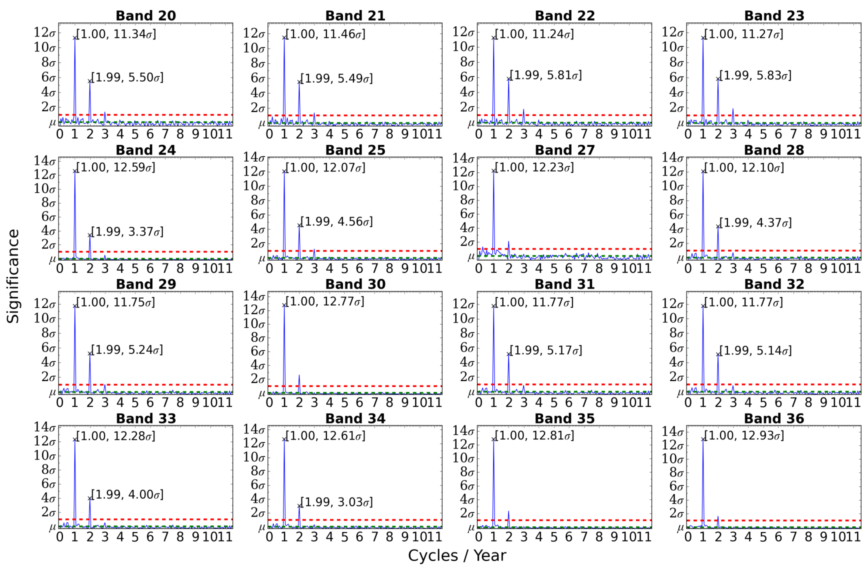

Figure 1: Calculated Power Spectral Density of the Antarctica dataset. Due to the clear periodicity in the spectral radiance signal caused by the Earth's obliquity, a relative clean power spectral density with a noise level well below 1σ can be calculated for the polar regions.