SYNTHETIC SPECTRA FROM A GCM SIMULATION OF A MODEL EXO-EARTH. S. I. Ipatov, *Department of Terrestrial Magnetism, Carnegie Institution of Washington, Washington, D.C.* (siipatov@hotmail.com), J. Y-K. Cho, *Astronomy Unit, School of Mathematical Sciences, Queen Mary, University of London, London, UK* (J.Cho@qmul.ac.uk)

Introduction: Several Earth-like planets outside the solar system have recently been detected [1]. Estimated 35% of stars harbor Earth-like planets. Hence, many more are expected to be detected in the near future.

To assess the detectability of biosignatures that may be present on these planets, we have performed a series of general circulation model (GCM) simulations of putative "extrasolar Earths". These planets are identical in all respects to the model Earth, except for different rotation periods. In this work, we use the outputs from the GCM simulations to compute model spectra. Such synthetic spectra can be useful for guiding and interpreting observations.

Model: The GCM used is CCM3, a global atmospheric model. It is a spectral model that solves the *primitive equations*. The model includes parameterizations of various important physical processes and boundary conditions such as shortwave and longwave radiation, moist convection, cloud fraction, and land surface types. Temperature-pressure profiles at each grid point over the globe, along with distributions of radiatively active species, are used to generate the spectra off-line.

For the spectra calculation, we use SBDART, a code that computes plane-parallel radiative transfer in the atmosphere in clear and cloudy conditions [2]. The code solves the radiative transfer equation and is based on a collection of highly developed, reliable physical models. These include a database of scattering efficiency, scattering albedo, and asymmetry factor for clouds composed of spherical water or ice droplets. The database is constructed using a Mie scattering code and covers a range of particle size from 2 to 128 μm. SBDART uses band models that provide clear sky atmospheric transmission from 0 to 50000 cm^{-1} from detailed line-by-line calculations degraded to 20 cm^{-1}.

We have checked the SBDART code using climatological temperature and species distributions of the Earth (which is also the initial conditions of our GCM simulations) as inputs. We have also checked the code against results described in [2]. We analyze the total upward flux at 1 km and 11 km altitudes in the wavelength range between 1 and 18 μm. The GCM simulation resolution is T85L19, which correspond to 128 longitude and 64 latitude points and 19 layers (pressure levels) over the full globe. SBDART is used to compute the mean spectrum for different regions over the model planet. For all regions, we compare the spectra for the initial atmosphere with atmospheres after 2 years of model runs for planets with rotation period P from 0.167 to 100 days. Here we present results from P = 1 and P = 100 cases – "Earth" and "exo-Earth", respectively. Figs. 1-3 present spectra from the common initial condition, Earth, and exo-Earth.

Results: GCM simulations show significant differences in the distribution of fields important for spectra, due to different rotation periods [3]. The differences in the distribution are not simple. For example, the distribution of total cloud is fairly zonal for both the Earth and the exo-Earth, but less "banded" on the exo-Earth: three bands in the meridional direction, from the north pole to the south pole, are present on the Earth but only one (near the equator) on the exo-Earth with P = 100. In the latter planet, the southern polar region is nearly devoid of clouds.

Longitudinal averages of outgoing longwave flux at fixed latitudes (not adjusted for surface element orientation) show that the flux is greatest at the equator and decreases toward the poles on both the Earth and the exo-Earth (Figs. 1-2). For both planets, spectra near the equator (at 1 and 11 km altitudes) at the end of the GCM run duration are essentially the same. Moreover, the spectra are not different from that of the initial state. In contrast, the fluxes of the two planets differ significantly near the poles in the ~5-10 μm and ~13-16 μm bands; Earth's spectrum is still close to that of the initial state. The *difference* between the fluxes at 11 km and 1 km in the above two bands is also larger for the exo-Earth, compared with the corresponding difference for the Earth. And, the difference near the south pole is much greater than near the north pole; hence, most of the contribution in the overall difference in the two planets comes from the southern polar region. All of these features are primarily due to the different cloud coverage on the exo-Earth compared to that on the model Earth.

When the influence of viewing geometry is taken into account, the total flux when the planet is viewed centered on (lon,lat) = (0^o,0^o) is reduced by a factor of 2 since the line of sight is not perpendicular to the surface elements. However, the general behavior is not different than that described above, when the flux for each surface element is simply integrated unadjusted for variation in the orientation. This is consistent with the similarity of the spectra in the equatorial region on both planets: areas from the higher latitudes do not contribute significantly. The peak values of the spectra also differ by no more than 5% when the planet is viewed centered at lon = 90° or 270° with lat = 0° – or from the north pole (with full longitude range). For the view centered on the south pole, the peak is smaller by a factor of 1.2 compared to that for the view centered on the north pole, again showing the asymmetry of the two poles. In the south pole view, the difference between the fluxes at 11 and 1 km at ~6-8 µm band for the exo-Earth is *smaller* than that for the Earth – or the common intial state (Fig. 3).

Discussion: In this work, we observe the following common features in the synthetic spectra: 1) both planets have a broad CO_2 absorption band centered around 14 µm; 2) clouds tend to muffle longwave spectral signatures; 3) there is essentially no difference in the spectra near the equator for an "Earth" rotating 100-day rotation period; however, in some regions (e.g., near the southern pole), there can be a distinguishable difference, indicating that viewing angle matters; 4) when integrated over the planetary disk, the spectral signal is reduced; however, even when integrated signal, differences between Earth and an exo-Earth can still be seen (e.g., southern pole at 11 km altitude).

In summary, one-dimensional modeling, which cannot explicitly incorporate circulation, is clearly limited because of anisotropy. Our results here suggest spectral signal cannot be used to infer rotation rate since viewing geometry is in general not known a priori. For observations, our calculations also suggest that ~5-10 and ~13-16 µm bands would be the best wavelength ranges to consider, at least for a model exo-planet which is Earth-like in all respects except for the rotation period.

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References: [1] Udry, S. et al. (2007) *A&A*, 469, L43-L47. [2] Ricchiazzi P., Yang S., Gautier C., Sowle D. (1998) *BAMS*, 79, 2101-2114. [3] Cho. J. Y-K. and Ipatov, S. *ApJ*, in preparation.

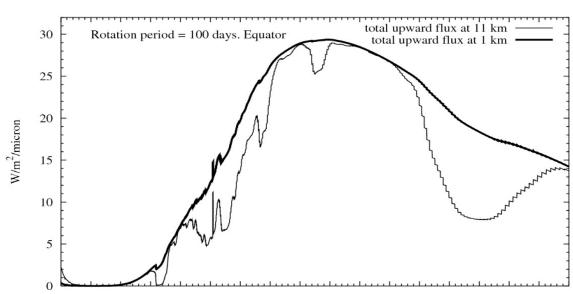

Fig. 1. Spectra (outgoing LW flux) at the equator for two different altitudes, 1 km (upper line) and 11 km (lower line). At the equator, the spectra are nearly identical for Earth and exo-Earth. For the Earth, the spectrum is same as in the initial state.

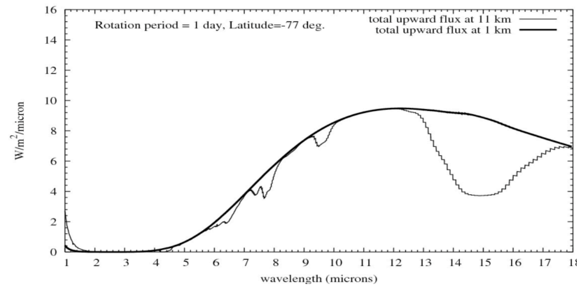

Fig. 2a. Longitudinally averaged spectra at latitude = −77° for model Earth. The lines are as in Fig. 1. Compare with the spectra at the equator in Fig. 1: the flux is significantly reduced at all wavelengths.

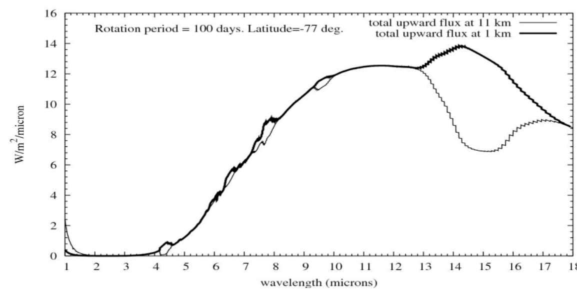

Fig. 2b. Longitudinally averaged spectra at latitude = −77° for model exo-Earth. The lines are as in Fig. 1. Compare with the spectra at the equator in Fig. 2a: absorption in the ~5-10 µm range is significantly reduced, although not in the ~13-16 µm range at 11 km altitude.

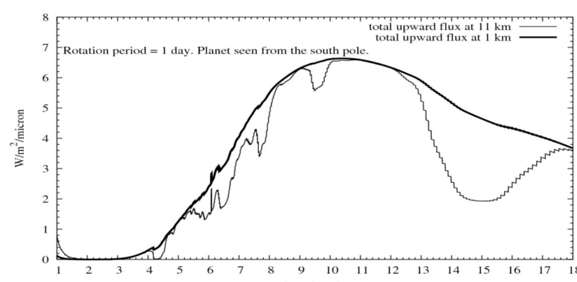

Fig. 3a. Disk-integrated spectra including the weighted contribution of the surface element orientation for Earth. The planet is seen from the south pole.

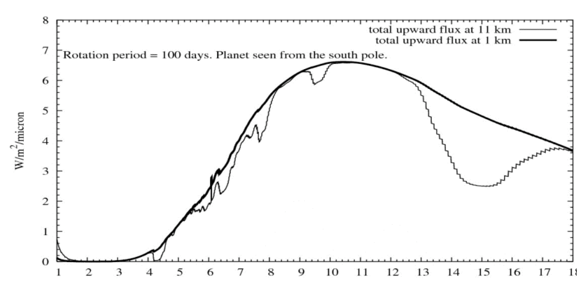

Fig. 3b. Spectra as in Fig 3a for the exo-Earth.