ATMS211 Climate and Climate Change

Homework # 2
Due Date: Friday 04/13/07

1) Planetary Balance Equation

a) Using the Solar Constant ($S_0$) and Albedo (A) values given in the table below, calculate the effective emitting temperature ($T_E$) for Venus, Earth and Mars. Your answers should be in Kelvin (K). *(Hint, first calculate $E_{IN}$)*

(Stefan-Boltzmann constant ($\sigma$) = $5.67 \times 10^{-8}$ W m$^{-2}$ K$^{-4}$)

(Venus) $T_E = (E_{IN} / \sigma)^{0.25}$ (K)

Earth $T_E = (E_{IN} / \sigma)^{0.25}$ (K)

Mars $T_E = (E_{IN} / \sigma)^{0.25}$ (K)

<table>
<thead>
<tr>
<th></th>
<th>Venus</th>
<th>Earth</th>
<th>Mars</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solar Constant ($S_0$)</td>
<td>2,643 W m$^{-2}$</td>
<td>1,370 W m$^{-2}$</td>
<td>593 W m$^{-2}$</td>
</tr>
<tr>
<td>Albedo (A)</td>
<td>0.80</td>
<td>0.30</td>
<td>0.25</td>
</tr>
<tr>
<td>$E_{IN}$ (W m$^{-2}$)</td>
<td>132</td>
<td>240</td>
<td>116</td>
</tr>
<tr>
<td>$T_E$ (K)</td>
<td>220</td>
<td>255</td>
<td>210</td>
</tr>
</tbody>
</table>

b) Solar luminosity is estimated to have been 30% lower than today at the time when the solar system was formed, 4.6 billion years ago. If Earth’s albedo was the same as it is now (A = 0.3), what would have been its effective emitting temperature ($T_E$) at that time?

* (4 pts)

$E_{IN} = S_0 / 4 \times (1 - A)$ (W m$^{-2}$)

$T_E = (E_{IN} / \sigma)^{0.25}$ (K)

<table>
<thead>
<tr>
<th></th>
<th>Venus</th>
<th>Earth</th>
<th>Mars</th>
</tr>
</thead>
<tbody>
<tr>
<td>$E_{IN}$ (W m$^{-2}$)</td>
<td>1370 W m$^{-2}$</td>
<td>1370 W m$^{-2}$</td>
<td>1370 W m$^{-2}$</td>
</tr>
<tr>
<td>$T_E$ (K)</td>
<td>233 K</td>
<td>233 K</td>
<td>233 K</td>
</tr>
</tbody>
</table>

2) Greenhouse Effects

(a) Explain the Greenhouse Effect (1-2 sentences).

* (2 pts)

The natural mechanism by which a planet’s surface is warmed by infrared-absorbing gases in its atmosphere. The Earth absorbs incoming solar
radiation and emits infrared (IR) radiation. This IR radiation is absorbed by the greenhouse gases (GHG) and is re-emitted back towards the Earth.

b) What atmosphere gas has the strongest greenhouse effect?  
   \textbf{(2 pts)}
   
   \textbf{water vapor}

c) True/False  
   \textbf{(2 pts)}
   
   Clouds are a major contributor to the greenhouse effect on Earth  
   \textbf{True}

   Clouds are a major contributor to the albedo of the Earth – true or false?  
   \textbf{True}

3) Consider the three cloud types shown in the table below.

<table>
<thead>
<tr>
<th>Cloud</th>
<th>Albedo</th>
<th>Cloud-top temperature (K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type 1</td>
<td>0.2</td>
<td>220</td>
</tr>
<tr>
<td>Type 2</td>
<td>0.4</td>
<td>250</td>
</tr>
<tr>
<td>Type 3</td>
<td>0.6</td>
<td>280</td>
</tr>
</tbody>
</table>

(a) Which lets through the most solar energy?  
   \textbf{(1 pt)}
   
   Type 1

(b) Which does the most heat-trapping?  
   \textbf{(1 pt)}
   
   Type 1

(c) Which cloud top is the lowest (closest to the surface)?  
   \textbf{(1 pt)}
   
   Type 3

(d) Which, if any, of these clouds is definitely composed of liquid water droplets rather than ice crystals?  
   \textbf{(1 pt)}
   
   Type 3

(e) For Type 2, calculate $E_{\text{IN}}$ and $E_{\text{OUT}}$ (both in units of W m$^{-2}$). State whether this cloud type has a warming or cooling effect on the planet.  
   \textbf{(4 pts)}

\[ E_{\text{IN}} = S_0 (1-A)/4 = 1370 \times 0.6/(4) = 205.5 \text{ W m}^{-2} \]
\[ E_{\text{OUT}} = \sigma T^4 = 5.67 \times 10^{-8} \times 250^4 = 221.5 \text{ W m}^{-2} \]
Cooling effect because $E_{OUT} > E_{IN}$