Climate and Radiation

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Presentation at Caltech
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Today’s Outline

- What is Radiation? (Review)
- What is the Greenhouse Effect? (Review)
- GCM Prediction of Future (IPCC)
- Use of Spectral Data
- Conclusions
Blackbody Radiation

\[ B_\nu(T) = \frac{2\hbar \nu^3}{c^2} \frac{1}{e^{\hbar \nu/kT} - 1} \]
Atmosphere: Processor of energy

Sunlight = driver of

\[ f_\odot = 350 \, W \cdot m^{-2} \]
Mean equilibrium temperature

\[ f \left( \pi r^2 \right) (1 - \alpha) = \sigma T^4 (4\pi r^2) \]

\[ T = \left( \frac{(1 - \alpha) f}{4\sigma} \right)^{1/4} \]

\[ f = 1400 \text{ } W/m^2 \]
\[ \alpha = 0.31 \]
\[ \sigma = 5.67 \times 10^{-8} \text{ } Wm^{-2}K^{-4} \]

(\textit{Appendix 1, p. 462, G + Y})

\[ T = \left( \frac{(0.69)(1400)}{5.67 \times 10^{-8}} \right)^{1/4} = 255 \text{ } K \]

**Ts = 288 K**

\[ \Delta T = 33 \text{ } K \]

\[ \begin{align*}
\text{Sun} & \quad \pi r^2 \\
\text{emitting area} & \quad = 4\pi r^2
\end{align*} \]
<table>
<thead>
<tr>
<th>Process</th>
<th>Total Power (Watts)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sunlight</td>
<td>$2 \times 10^{17}$</td>
</tr>
<tr>
<td>Seawater evaporation</td>
<td>$3 \times 10^{16}$</td>
</tr>
<tr>
<td>Photosynthesis</td>
<td>$1 \times 10^{14}$</td>
</tr>
<tr>
<td>Geothermal flux</td>
<td>$3 \times 10^{13}$</td>
</tr>
<tr>
<td>Tides</td>
<td>$2 \times 10^{13}$</td>
</tr>
<tr>
<td>Energy use by man (1980)</td>
<td>$1 \times 10^{13}$</td>
</tr>
<tr>
<td>UV energy to make $O_3$ layer</td>
<td>$1 \times 10^{13}$</td>
</tr>
<tr>
<td>Hydroelectric Power</td>
<td>$3 \times 10^{11}$</td>
</tr>
<tr>
<td>Winds</td>
<td>$2 \times 10^{11}$</td>
</tr>
<tr>
<td>Volcanoes</td>
<td>$4 \times 10^{10}$</td>
</tr>
<tr>
<td>Earthquakes</td>
<td>$1 \times 10^{10}$</td>
</tr>
</tbody>
</table>
Radiative Transfer

- Absorption
- Aerosol / Molecules
- Scattering / Reflection on a cloud
- Scattering from a cloud
- Transmission through a cloud
- Scattering within a cloud
- Transmission through a cloud
- Absorption on the ground
- Scattering / Reflection on the ground
Global Heat Flows

Reflected Solar Radiation: 107 W m\(^{-2}\)

Incoming Solar Radiation: 342 W m\(^{-2}\)

Outgoing Longwave Radiation: 235 W m\(^{-2}\)

Emitted by Atmosphere: 165 W m\(^{-2}\)

Absorbed by Surface: 30 W m\(^{-2}\)

Absorbed by Atmosphere: 67 W m\(^{-2}\)

Latent Heat: 78 W m\(^{-2}\)

Thermals Evapotranspiration: 168 W m\(^{-2}\)

Surface Radiation: 390 W m\(^{-2}\)

Absorbed by Surface: 324 W m\(^{-2}\)

Atmospheric Window: 40 W m\(^{-2}\)

Greenhouse Gases: 324 W m\(^{-2}\)

Kiehl and Trenberth 1997
Top-of-atmosphere
Surface
Net
Differences
Kiehl and Trenberth 1997
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Observational Dataset

- **AIRS (Atmospheric Infrared Sounder)**

  - **Lifetime:** May 2002 – Present
  - **Spectral coverage:** 650-2665 cm\(^{-1}\)
  - **Spectral resolution (FWHM):** \(\nu/1200\) cm\(^{-1}\)
  - **Field of view:** 13.5 km
  - **SNR:** 600-4000
  - **Calibration bias:** 0.07-0.5 K in BT
  - **Orbit:** Sun-synchronous, 1:30 PM sampling
  - **Swath Width:** 1650 km, twice daily swath

  (~9 times of the FOVs per AMSU-A FOV)
Absorption in Earth’s Atmosphere

\[ \text{H}_2\text{O} \]

\[ \text{O}_3 \]

\[ \text{H}_2\text{O} \]

\[ \text{CO}_2 \]
Greenhouse gases and radiance

- Outgoing thermal infrared spectra (W/m²/cm⁻¹/sr) $I(v)$
  - Integrand of OLR, containing many pieces of useful information
  - Fundamental to climate diagnostics

By courtesy of John Dykema
Concentrations of Greenhouse Gases from 0 to 2005

- **Carbon Dioxide (CO₂)**
- **Methane (CH₄)**
- **Nitrous Oxide (N₂O)**

Year

0 500 1000 1500 2000

CO₂ (ppm), N₂O (ppb)

CH₄ (ppb)
x: Machida et al. [1995]
+: Bernard et al. [2006]
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Multi-model Averages and Assessed Ranges for Surface Warming

Global surface warming (°C)

Year

1900 2000 2100

A2 A1B B1 Year 2000 Constant Concentrations 20th century

B1 A1T B2 A1B A2 A1FI
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Inter-month spectral variation, 37: 30S-0 ocean, all, 01

![Graph showing inter-month spectral variation with labeled axes and data points for different years (04, 07, 10).](image-url)
Offsetting errors

The seemingly good agreement (-1.1 W m\textsuperscript{-2} difference) of the total-sky OLR broadband flux may be fortuitous and arise due to a cancellation.

<table>
<thead>
<tr>
<th>Unit: W m\textsuperscript{-2}</th>
<th>OLR</th>
<th>Window band</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total sky</td>
<td>Clear sky</td>
</tr>
<tr>
<td>CERES</td>
<td>241.73</td>
<td>275.87</td>
</tr>
<tr>
<td>AM2</td>
<td>240.63</td>
<td>263.43</td>
</tr>
<tr>
<td>AM2-CERES</td>
<td>-1.10</td>
<td>-12.44</td>
</tr>
</tbody>
</table>

![Graph showing overestimation and underestimation](image)
Observational Dataset

• IRIS (Infrared Interferometer Spectrometer)

  Lifetime:  Apr 70 – Jan 71
  Spectral coverage:  400-1600 cm\(^{-1}\)
  (in this study, 400-1400 cm\(^{-1}\))
  Spectral resolution (FWHM):  2.8 cm\(^{-1}\)
  Field of view:  95km in diameter
  (~6.25 times of the FOV of ERBE, 15% of an AM2 grid box)
  SNR:  20~100
  Calibration bias:  0.25-0.75K in BT
  Orbit:  Sun-synchronous, 10:30AM/PM sampling
  700,000 good spectra over 10 months
Observational Dataset

- **AIRS (Atmospheric Infrared Sounder)**
  
  - **Lifetime:** May 2002 – Present
  - **Spectral coverage:** 650-2665 cm\(^{-1}\)
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Conclusions

Radiation plays a fundamental role as the source of energy

Spectral radiance provides detailed picture of energy exchange

Radiation as diagnostic of climate change (potential)
Thanks

- Yung’s Group at Caltech
- Trenberth (NCAR)
- Prof. Xianglei Huang (U Michigan)

- Ref: Goody and Yung (1989)
- Huang and Yung (2005) JGR 110