Review for First Exam
AOSC 433/633 & CHEM 433/633
Ross Salawitch

Class Web Site: http://www.atmos.umd.edu/~rjs/class/spr2013

Today:

- Albedo feedback (briefly)
- Our climate model (slowly so can be understood 😊)
- Review of highlights, first 8 lectures
- Last year’s first exam

Note: Problem Set #2 Review, Monday, 25 Feb, 6:00 pm, this room, led by Allison

21 February 2013

Radiative Forcing

Question 1.1, IPCC, 2007

Radiative Forcing of Climate is Change in Energy reaching the lower atmosphere (surface to tropopause) as GHGs rise. “Back Radiation” is most important term.
Another Satellite Measurement of Albedo

Fig. 3. Linear and second-order least-squares fits over (A) American Samoa from satellites and (B) at American Samoa from ground observations.

Pinker, Science, 2005

Another Satellite Measurement of Albedo

Fig. 5. Linear and second-order trends for (A) land areas only and (B) for oceans only.

Pinker, Science, 2005
Albedo vs Time: Synthesis (a mess 😊)


**LARGE INCONSISTENCIES**

<table>
<thead>
<tr>
<th>Climatic observations and forcings</th>
<th>Equivalent change in albedo $\times 10^3$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Enhanced greenhouse effect during industrial era $(2.4 \pm 0.2 \text{ W/m}^2)$ (6)</td>
<td>$-7 \pm 0.6$</td>
</tr>
<tr>
<td>Anthropogenic aerosol forcing during industrial era (6)</td>
<td>$+4 \pm 4$</td>
</tr>
<tr>
<td>Albedo change estimated from earthshine data (2000 to 2004) (2, 8, 9)</td>
<td>$+16$</td>
</tr>
<tr>
<td>Albedo change estimated from low-orbit satellite data (2000 to 2004) (2)</td>
<td>$-5$</td>
</tr>
<tr>
<td>Change in irradiance at Earth’s surface measured with satellites (1983 to 2001) (3)</td>
<td>$-8$</td>
</tr>
<tr>
<td>Change in irradiance at Earth’s surface measured at the surface (1985 to 2000) [Fig. 1 in (4)]</td>
<td>$-13$</td>
</tr>
<tr>
<td>Change in irradiance at Earth’s surface measured at the surface (1950 to 1990) [Fig. 1 in (4)]</td>
<td>$+20$</td>
</tr>
</tbody>
</table>

$\Delta F_{\text{Pinker}} = 2.88 \text{ W m}^{-2}$

This corresponds to an albedo change of:

$$S = 1370 \text{ W m}^{-2} / 4 = 342.4 \text{ W m}^{-2}$$

$$2.88 \text{ W m}^{-2} / 342.4 \text{ W m}^{-2} = 0.0084 \text{ or } 8.4 \times 10^{-3}$$

That is, this rise Pinker’s measurement corresponds to an 

*decrease* of $\approx 8 \times 10^{-3}$

To date, the results from different measurement and modeling approaches are inconsistent ... the magnitudes of the inconsistencies exhibited by both measurements and models of albedo changes are as large as, or larger than, the entire GHG effect when compared in terms of the albedo change equivalent [of this forcing]

See Slide 17, Lecture 8, for albedo change equiv of 2.4 W m$^{-2}$ forcing
Much harder to predict future than understand the past!

Human Forcing = GHG + Aerosol Forcing

Scenario 1: Aerosols have weak net cooling. If so, future clean up doesn’t matter much for climate, but matters a lot for air quality!

Mascioli et al., ACPD 2012
Much harder to predict future than understand the past!

Scenario 2: Aerosols have strong net cooling & there will be a concerted effort for future clean up!

This will "unleash" GHG warming

Mascioli et al., ACPD 2012
Predicting future and understanding past are linked

Mascioli et al., ACPD 2012

If we could better quantify NAA RF (net anthropogenic aerosol RF) for contemporary atmosphere, we would gain a handle on magnitude of future warming!

Much harder to predict future than understand the past!

Mascioli et al., ACPD 2012

\( \lambda_{IPCC} \) discussed in Lecture 7
Greenhouse Effect

The Greenhouse Effect
Some of the infrared radiation entering through the atmosphere but most is absorbed and re-emitted in all directions by greenhouse gases molecules and clouds. The effect of this is to warm the Earth’s surface and the lower atmosphere.

Radiative Forcing of Climate, 1750 to 2005

Radiative forcing of climate between 1750 and 2005

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GWP – Global Warming Potential

\[
\text{GWP (CH}_4\text{)} = \int_{\text{time initial}}^{\text{time final}} a_{\text{CH}_4} \times [\text{CH}_4(t)] \, dt \div \int_{\text{time initial}}^{\text{time final}} a_{\text{CO}_2} \times [\text{CO}_2(t)] \, dt
\]

where:

\[a_{\text{CH}_4} = \text{Radiative Efficiency (W m}^{-2} \text{ kg}^{-1}) \text{ due to an increase in CH}_4\]

\[a_{\text{CO}_2} = \text{Radiative Efficiency (W m}^{-2} \text{ kg}^{-1}) \text{ due to an increase in CO}_2\]

\[\text{CH}_4(t) = \text{time-dependent response to an instantaneous release of a pulse of CH}_4\]

\[\text{CO}_2(t) = \text{time-dependent response to an instantaneous release of a pulse of CO}_2\]

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### SAR: Second Assessment Report (issued in 1995)

#### Table TS.2. Lifetimes, radiative efficiencies and direct (except for CH	extsubscript{4}) global warming potentials (GWP) relative to CO	extsubscript{2} [Table 2.14]

<table>
<thead>
<tr>
<th>Industrial Designation</th>
<th>Chemical Formula</th>
<th>Lifetime (years)</th>
<th>Radiative Efficiency (W m(^{-2}) ppb(^{-1}))</th>
<th>SAR(^{1}) (100-yr)</th>
<th>Global Warming Potential for Given Time Horizon</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>20-yr</td>
</tr>
<tr>
<td>Carbon dioxide</td>
<td>CO(_2)</td>
<td>See below(^{2})</td>
<td>(1.4 \times 10^{-5}) (^{4})</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Methane</td>
<td>CH(_4)</td>
<td>12(^{5})</td>
<td>(3.7 \times 10^{-4})</td>
<td>21</td>
<td>72</td>
</tr>
<tr>
<td>Nitrous oxide</td>
<td>N(_2)O</td>
<td>114</td>
<td>(3.03 \times 10^{-2})</td>
<td>310</td>
<td>289</td>
</tr>
</tbody>
</table>

**Notes:**

1. SAR refers to the IPCC Second Assessment Report (1995) used for reporting under the UNFCCC.
2. The CO\(_2\) response function used in this report is based on the revised version of the Bern Carbon cycle model used in Chapter 10 of this report (Bern2.5GC, Joos et al. 2001) using a background CO\(_2\) concentration value of 378 ppm. The decay of a pulse of CO\(_2\) with time \(t\) is given by 

\[
\frac{a_0}{a_0 + \sum a_i e^{-\lambda_i t}}
\]

where \(a_0 = 0.217, a_1 = 0.259, a_2 = 0.338, a_3 = 0.186, \lambda_1 = 122.9\) years, \(\lambda_2 = 18.51\) years, and \(\lambda_3 = 1.186\) years, for \(t < 1,000\) years.
3. The radiative efficiency of CO\(_2\) is calculated using the IPCC (1990) simplified expression as revised in the TAR, with an updated background concentration value of 378 ppm and a perturbation of +1 ppm (see Section 2.10.2).
4. The perturbation lifetime for CH\(_4\) is 12 years as in the TAR (see also Section 7.4). The GWP for CH\(_4\) includes indirect effects from enhancements of ozone and stratospheric water vapour (see Section 2.10).

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Time constant of 172.9 years dominates from IPCC 2007 “Physical Science Basis”
**Review of Dipole Moment**

Electric dipole – charge distribution with two regions of equal and opposite sign

Dipole moment – the magnitude of the charge multiplied by the distance between charges. Direction will be toward positive charge.

\[
\begin{align*}
\text{H}^+ & \quad \text{Cl}^- \\
\text{H}^+ & \quad \text{O}^- \\
\text{O}^- & \quad \text{C}^+ & \quad \text{O}^- \\
\text{O}^- & \quad \text{C}^+ & \quad \text{O}^- \\
\end{align*}
\]

Magnitude depends on electro-negativity of individual atoms

Symmetric stretch
\[
\begin{align*}
\text{O}^- & \quad \text{C}^+ & \quad \text{O}^- \\
\text{DM} = 0
\end{align*}
\]

Asymmetric stretch
\[
\begin{align*}
\text{O}^- & \quad \text{C}^+ & \quad \text{O}^- \\
\text{DM} = 0
\end{align*}
\]

**Absorption vs. Wavelength**

Gray shaded region denotes normalized absorptivity.

**Atmospheric window (\(\sim 7\text{–}12 \mu\text{m}\)):** wavelength range that is “transparent” to outgoing radiation.

Masters, Intro. to Environmental Engineering and Science, 2nd ed.

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### Ozone Depletion and Halocarbons

**Table Q7-1. Atmospheric Lifetimes and Ozone Depletion Potentials of some halogen source & HFC substitute gases.**

<table>
<thead>
<tr>
<th>Gas</th>
<th>Atmospheric Lifetime (years)</th>
<th>Ozone Depletion Potential (ODP)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Halogen source gases</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chlorine gases</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CFC-11</td>
<td>45</td>
<td>1</td>
</tr>
<tr>
<td>CFC-12</td>
<td>100</td>
<td>0.82</td>
</tr>
<tr>
<td>CFC-113</td>
<td>85</td>
<td>0.85</td>
</tr>
<tr>
<td>Carbon tetrachloride (CCl₄)</td>
<td>26</td>
<td>0.82</td>
</tr>
<tr>
<td>HFCs</td>
<td>1–17</td>
<td>0.01–0.12</td>
</tr>
<tr>
<td>Methyl chloroform (CH₃CCl₃)</td>
<td>5</td>
<td>0.16</td>
</tr>
<tr>
<td>Methyl chloride (CH₃Cl)</td>
<td>1</td>
<td>0.02</td>
</tr>
<tr>
<td><strong>Bromine gases</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Halon-1301</td>
<td>65</td>
<td>15.9</td>
</tr>
<tr>
<td>Halon-1211</td>
<td>16</td>
<td>7.9</td>
</tr>
<tr>
<td>Methyl bromide (CH₃Br)</td>
<td>0.8</td>
<td>0.66</td>
</tr>
<tr>
<td><strong>Hydrofluorocarbons (HFCs)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HFC-134a</td>
<td>13.4</td>
<td>0</td>
</tr>
<tr>
<td>HFC-23</td>
<td>222</td>
<td>0</td>
</tr>
</tbody>
</table>

**ODP (species "i")** =

\[
\frac{\text{global loss of } O_3 \text{ due to unit mass emission of } i}{\text{global loss of } O_3 \text{ due to unit mass emission of CFC-11}} \approx \frac{(\alpha n_{\text{Br}} + n_{\text{C}}) \frac{\tau_i}{\tau_{\text{CFC-11}}} \frac{MW_{\text{CFC-11}}}{MW_i}}{3}
\]

where:

- \( \tau \) is the global atmospheric lifetime
- \( MW \) is the molecular weight
- \( n \) is the number of chlorine or bromine atoms
- \( \alpha \) is the effectiveness of ozone loss by bromine relative to ozone loss by chlorine

\[\alpha = 60\]

**Halons (anthropogenic halocarbons containing bromine) much worse for ozone than CFCs (anthropogenic halocarbons containing chlorine)**

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**HFCs (anthropogenic halocarbons containing only fluorine, carbon, and hydrogen) and thus pose no threat to the ozone layer**
Link Between Ozone-Depleting Substances (ODS) and Climate Change

Most ozone depleting substances have a significant “GWP”

GWP weighted emissions of CO₂

GWP weighted emissions of CFCs, without early aerosol propellant ban (i.e., no ban on CFCs)

GWP weighted emissions of CFCs, without Montreal Protocol

First Exam

– Tuesday, 26 February, 2:00 pm to 3:15 pm, Room CSS 2416
– 7 questions (multi-part)
– Closed book, no notes
– Conceptual questions that will not require a calculator
– Just you, a writing implement, and the exam booklet
– Backbone of course is the lectures; exam questions may draw upon material from the readings that has been emphasized in lecture
– We will be present: please let us know if a question requires clarification If so, we’ll announce to entire class 😊
Final Exam Preparation Advice

− Review lectures, admission tickets, and learning outcome quizzes

− Best to not pull an all-nighter trying to do all of the readings and memorize every last detail: better to show up well rested

− Students who have completed the readings and absorbed the material will get more out of any course than students who skim the readings; students who have kept up with the readings should “relax” as they prepare for the exam

− The decision to have 2 “in class” exams is responsive to student feedback from early years of this class, which had only a mid-term

− We hope students are motivated by a desire to understand how humans are impacting atmospheric composition and climate … in addition perhaps a desire for a particular grade 😊