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

Class Web Site: http://www.atmos.umd.edu/~rjs/class/spr2015

Today:

• Climate Feedback
• Consequences of Climate Change
• Highlights of first 8 lectures
• Last year’s first exam

Note: Problem Set #2 Review, Monday, 2 Mar, 6:30 pm, this room, led by Austin

26 February 2015
Negative Feedback

Initial Action: Humans Release CO₂

Initial Response: $T_{\text{SURFACE}}$ rises

Then:
Low Altitude clouds become more prevalent

Consequence:
More solar radiation reflected

Feedback:
$\Rightarrow T_{\text{SURFACE}}$ declines: negative feedback

Planetary cooling
Negative Feedback

Initial Action: Humans Release CO₂

Initial Response: $T_{\text{SURFACE}}$ rises

Then: High Altitude clouds become less prevalent

Consequence: Less thermal radiation trapped

Feedback: $\Rightarrow T_{\text{SURFACE}}$ declines: negative feedback
Feedback

Initial Action: Humans Release Aerosols

Initial Response: $T_{\text{SURFACE}}$ cools

Then: Aerosols cause clouds to become more reflective (1\textsuperscript{st} Ind Eff) & longer lived (2\textsuperscript{nd} Ind Eff)

Consequence: More solar radiation reflected

Feedback: $\Rightarrow T_{\text{SURFACE}}$ declines even more: ?????? feedback
Houghton Feedbacks

1. **water vapor**: warmer atmosphere holds more water due to Clausius-Clapeyron relation. Almost certainly a **positive feedback**.

2. **cloud radiation**: if initial response is rising GHGs (which warm), can either warm (positive) or cool (negative) depending on the altitude of the clouds and how the prevalence of the clouds changes. If the initial response is rising anthropogenic aerosols (which cool), can still either warm (negative) or cool (positive) … consensus is that response of clouds to aerosols enhances the direct effect (cooling) of aerosols

3. **ocean circulation**: ocean and atmosphere are strongly coupled:
   a) evaporation from ocean provides atmospheric water vapor & latent heat associated with condensation in clouds is largest single atmospheric heat source
   b) ocean heat capacity >> atmospheric heat capacity: oceans exert dominant control on rate of atmospheric change
   c) internal circulation redistributes heat: ENSO (pg 89) and Atlantic Meridional Overturning Circulation (AMOC; transports heat from EQ to pole)
   *Sign of feedback, or whether GHGs affect ocean circulation, not established!*

4. **ice albedo**: As ice melts albedo gets smaller (planet gets darker) and Earth warm: **positive feedback**
Jacobson Feedbacks

- **water vapor / T (pos):** 2 factors, ocean evaporation and Clausius-Clapeyron
- **water vapor / high cloud (pos)**
- **water vapor / low cloud (neg)**
- **snow albedo (pos)**
- **ocean solubility (pos):** solubility of CO$_2$ declines as T rises
- **permafrost release of CH$_4$ (pos):** As T rises, Arctic permafrost melts, potentially releasing methane stored within permafrost
- **bacteria (pos):** soil bacteria, which decompose organic matter releasing labile CO$_2$ and CH$_4$, thrive under warm conditions
- **plants (neg):** As T rises, plants and trees flourish, increasing global photosynthesis, which causes faster update of atmospheric CO$_2$
Lapse Rate Feedback

- Photons emitted in UT can escape to space more easily than photons emitted near surface.
- If UT warms more than surface, bulk atmospheric emissivity increases.

**UT**: upper troposphere  
**Emissivity**: efficiency in which thermal energy is radiated.

- GCMs indicate water vapor & lapse rate feedbacks are intricately linked, with the former almost certainly being positive (in response to rising GHGs), the latter almost certainly being negative, and the sum probably being positive.

- Definition of the empirical lapse rate feedback is marred by controversy, having to do with how to properly interpret UT data from various Microwave Sounding Unit (MSU) instruments.

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https://ourchangingclimate.wordpress.com/2013/03/01/klotzbach-revisited
Consequences of Climate Change

1. Rising sea-level threatens many populated coastal regions, including Maryland

2. Desert areas are expanding and permafrost is melting, threatening agriculture, Arctic habitat, water supply to populated regions

3. World is becoming more “tropical”, including poleward migration of ecosystems, weather patterns, and tropical diseases

4. Hurricane intensity is increasing, affecting populations that reside in coastal regions

5. Ocean is becoming increasingly acidic, threatening vast portions of the ocean ecosystem
Consequences of Climate Change

1. Rising sea-level threatens many populated coastal regions, including Maryland

Maryland:

- more coastline than California!
- more susceptible to sea level rise than all but 2 other states
1. Rising sea-level threatens many populated coastal regions, including Maryland

FAQ 5.1, Figure 1. Time series of global mean sea level (deviation from the 1980-1999 mean) in the past and as projected for the future. For the period before 1870, global measurements of sea level are not available.

IPCC (2007)
Consequences of Climate Change

2. Desert are expanding and permafrost is melting, threatening agriculture, Arctic habitat, water supply to populated regions

3. World is becoming more “tropical”, including poleward migration of ecosystems, weather patterns, and tropical diseases
Consequences of Climate Change

2. Desert are expanding and permafrost is melting, threatening agriculture, Arctic habitat, water supply to populated regions

3. World is becoming more “tropical”, including poleward migration of ecosystems, weather patterns, and tropical diseases

Arctic Sea-Ice: Canary of Climate Change

- Sea ice: ice overlying ocean
- Annual minimum occurs each September
- Decline of ~13.3% / decade over satellite era

http://nsidc.org/arcticseaicenews/files/2014/10/monthly_ice_NH_09.png
Consequences of Climate Change

2. Desert are expanding and permafrost is melting, threatening agriculture, Arctic habitat, water supply to populated regions

3. World is becoming more “tropical”, including poleward migration of ecosystems, weather patterns, and tropical diseases

Polar bear census data:

<table>
<thead>
<tr>
<th>Location</th>
<th>Polar Bear Population Status</th>
<th>Risk of Future Decline</th>
<th>Location</th>
<th>Polar Bear Population Status</th>
<th>Risk of Future Decline</th>
</tr>
</thead>
<tbody>
<tr>
<td>East Greenland</td>
<td>Data deficient</td>
<td>No estimate</td>
<td>Norwegian Bay</td>
<td>Not reduced</td>
<td>Higher</td>
</tr>
<tr>
<td>Barents Sea</td>
<td>Data deficient</td>
<td>No estimate</td>
<td>Lancaster Sound</td>
<td>Not reduced</td>
<td>Higher</td>
</tr>
<tr>
<td>Kara Sea</td>
<td>Data deficient</td>
<td>No estimate</td>
<td>M’Clintock Channel</td>
<td>Severely reduced</td>
<td>Very Low</td>
</tr>
<tr>
<td>Laptev Sea</td>
<td>Data deficient</td>
<td>No estimate</td>
<td>Gulf of Boothia</td>
<td>Not reduced</td>
<td>Lower</td>
</tr>
<tr>
<td>Chukchi Sea</td>
<td>Data deficient</td>
<td>No estimate</td>
<td>Foxe Basin</td>
<td>Not reduced</td>
<td>Lower</td>
</tr>
<tr>
<td>Southern Beaufort Sea</td>
<td>Reduced</td>
<td>No estimate</td>
<td>Western Hudson Bay</td>
<td>Reduced</td>
<td>Very High</td>
</tr>
<tr>
<td>Northern Beaufort Sea</td>
<td>Not reduced</td>
<td>No estimate</td>
<td>Southern Hudson Bay</td>
<td>Not reduced</td>
<td>Lower</td>
</tr>
<tr>
<td>Viscount Melville</td>
<td>Severely reduced</td>
<td>Very Low</td>
<td>Kane Basin</td>
<td>Reduced</td>
<td>Very High</td>
</tr>
<tr>
<td>Norwegian Bay</td>
<td>Not reduced</td>
<td>Higher</td>
<td>Baffin Bay</td>
<td>Reduced</td>
<td>Very High</td>
</tr>
</tbody>
</table>

Tables on this website updated frequently:

http://pbsg.npolar.no/en/status/status-table.html
4. Hurricane intensity is increasing, affecting populations that reside in coastal regions

- Projection of the effect of global warming on hurricanes requires conducting calculations on a ~20-km grid ("serious supercomputer")
- Some simulation project that at end of century, rising GHGs will lead to:
  a) ~30% decrease in annual mean occurrence number of tropical cyclones, due to larger increases in T at 250 mbar than at surface, which causes a more stable atmosphere
  b) increase in maximum surface winds of the tropical cyclones that do occur:
    i.e., hurricanes less frequent but more powerful  Oouchi et al., Journal Meteor. Soc. Japan, 2006

- Confounding factor:

http://www.c2es.org/science-impacts/extreme-weather/hurricanes
Consequences of Climate Change

5. Ocean is becoming increasingly acidic, threatening vast portions of the ocean ecosystem

Future ocean uptake of atmospheric CO₂ will lead to **ocean acidification**

**Bad news for ocean dwelling organisms that precipitate shells (basic materials)**

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**THE (RAGGED) FUTURE OF ARAGONITE**

Diminishing pH levels will weaken the ability of certain marine organisms to build their hard parts and will be felt soonest and most severely by those creatures that make those parts of aragonite, the form of calcium carbonate that is most prone to dissolution. The degree of threat will vary regionally.

Before the Industrial Revolution [left], most surface waters were substantially 'oversaturated' with respect to aragonite [light blue], allowing marine organisms to form this mineral readily. But now [center], polar surface waters are only marginally oversaturated [dark blue]. At the end of this century [right], such chilly waters, particularly those surrounding Antarctica, are expected to become undersaturated (purple), making it difficult for organisms to make aragonite and causing aragonite already formed to dissolve.

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Pteropods form a key link in the food chain throughout the Southern Ocean. For these animals (and creatures that depend on them), the coming changes may be disastrous, as the images at the right suggest. The shell of a pteropod kept for 48 hours in water undersaturated with respect to aragonite shows corrosion on the surface [a], seen most clearly at high magnification [b]. The shell of a normal pteropod shows no dissolution [c].

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Predicting future and understanding past are linked.

Large uncertainty in knowledge of the RF due to Anthro Aerosols means we can fit the climate record near equally well with a suite of models that possess various strengths of climate feedback. ... but future warming will be dictated by which feedback value is correct.

Hope et al., in prep, 2015
Greenhouse Effect

Some solar radiation is reflected by the Earth and the atmosphere.

Some solar radiation is absorbed by the Earth's surface and warms it.

Infrared radiation is emitted from the Earth's surface.

The Greenhouse Effect

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

Solar radiation powers the climate system.

FAQ 1.3, Figure 1. An idealised model of the natural greenhouse effect. See text for explanation.
Radiative Forcing of Climate is Change in Energy reaching the lower atmosphere (surface to tropopause) as GHGs rise. “Back Radiation” is most important term.
GWP – Global Warming Potential

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

where:

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

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

CH\(_4\) (t) = time-dependent response to an instantaneous release of a pulse of CH\(_4\)

CO\(_2\) (t) = time-dependent response to an instantaneous release of a pulse of CO\(_2\)
## GWP – Global Warming Potential

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

**Table TS.2. Lifetimes, radiative efficiencies and direct (except for CH₄) global warming potentials (GWP) relative to CO₂.** Table 2.14

<table>
<thead>
<tr>
<th>Industrial Designation or Common Name (years)</th>
<th>Chemical Formula</th>
<th>Lifetime (years)</th>
<th>Radiative Efficiency (W m⁻² ppb⁻¹)</th>
<th>SAR (100-yr)</th>
<th>Global Warming Potential for Given Time Horizon</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon dioxide</td>
<td>CO₂</td>
<td>See below&lt;sup&gt;a&lt;/sup&gt;</td>
<td>b1.4x10⁻⁵</td>
<td>1</td>
<td>1 1 1</td>
</tr>
<tr>
<td>Methane&lt;sup&gt;c&lt;/sup&gt;</td>
<td>CH₄</td>
<td>12&lt;sup&gt;c&lt;/sup&gt;</td>
<td>3.7x10⁻⁴</td>
<td>21</td>
<td>72 25 7.6</td>
</tr>
<tr>
<td>Nitrous oxide</td>
<td>N₂O</td>
<td>114</td>
<td>3.03x10⁻³</td>
<td>310</td>
<td>289 298 153</td>
</tr>
</tbody>
</table>

**Notes:**

<sup>a</sup> The CO₂ 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 (Bern2.5CC; Joos et al. 2001) using a background CO₂ concentration value of 378 ppm. The decay of a pulse of CO₂ with time t is given by:

\[ a_0 + \sum_{i=1}^{3} a_i \cdot e^{-t/\tau_i} \]

where \( a_0 = 0.217, a_1 = 0.259, a_2 = 0.338, a_3 = 0.186, \tau_1 = 172.9 \text{ years}, \tau_2 = 18.51 \text{ years}, \) and \( \tau_3 = 1.186 \text{ years}, \) for \( t < 1,000 \text{ years}. \)

<sup>b</sup> The radiative efficiency of CO₂ 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).

<sup>c</sup> The perturbation lifetime for CH₄ is 12 years as in the TAR (see also Section 7.4). The GWP for CH₄ 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.

Magnitude depends on electro-negativity of individual atoms

Symmetric stretch

\[ \text{O}^- \quad \text{C}^+ \quad \text{O}^- \]

DM = 0

Asymmetric stretch

\[ \text{O}^- \quad \text{C}^+ \quad \text{O}^- \]

DM = 0
Absorption vs. Wavelength

Gray shaded region denotes normalized absorptivity.

Atmospheric window (~7–12 μm): wavelength range that is "transparent" to outgoing radiation.

Masters, Intro. to Environmental Engineering and Science, 2nd ed.
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><strong>Chlorine gases</strong></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><strong>HCFCs</strong></td>
<td>1–17</td>
<td>0.01–0.12</td>
</tr>
<tr>
<td>Methyl chloroform (CH₂CCl₂)</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 (CH₂Br)</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") =

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

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

\[ \alpha = 60 \]

HFCs (anthropogenic halocarbons containing only fluorine, carbon, & hydrogen) and thus pose no threat to the ozone layer

Halons (anthropogenic halocarbons containing bromine) much worse for ozone than CFCs (anthropogenic halocarbons containing chlorine)
Link Between Ozone-Depleting Substances (ODS) and Climate Change

Most ozone depleting substances have a significant “GWP”

Velders et al., PNAS, 2007

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First Exam

- Tuesday, 3 March, 2:00 pm to 3:15 pm, Room CSS 2416
- 7 to 8 questions like 2013 exam, each 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*

- 633 students should be prepared to answer a question about 1 of the 3 specific supplemental readings that have been assigned to them

- We will be present: *please ask if a question requires clarification*
Final Exam Preparation Advice

• Review lectures, admission tickets, and learning outcome quizzes

• Students who have completed the readings and absorbed the material will get more out of any course (and do much better on the exams) than students who skim the readings; students who have kept up with the readings can “relax” as they prepare for the exam

• Do not pull an all-nighter trying to memorize every last detail: much better to show up well rested

• The decision to have 2 “in class” exams is responsive to student feedback from early years when we only had a mid-term