Review for First Exam

AOSC 433/633 & CHEM 433

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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

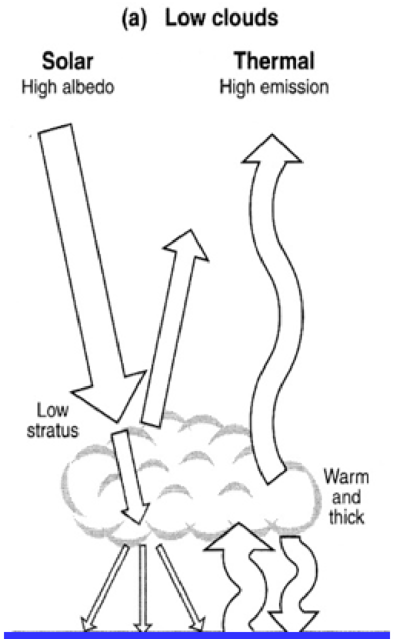
Initial Action:
Humans Release CO_2

Initial Response:
$T_{SURFACE}$ rises

Then:
Low Altitude clouds become ***more*** prevalent

Consequence:
More solar radiation reflected

Feedback:
⇨ $T_{SURFACE}$ declines: negative feedback



Planetary cooling

Negative Feedback

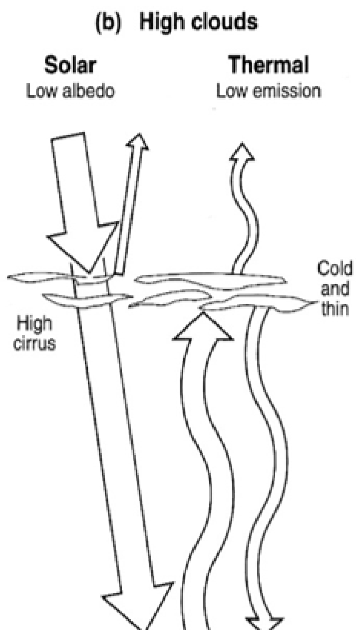
Initial Action:
Humans Release CO_2

Initial Response:
$T_{SURFACE}$ rises

Then:
High Altitude clouds become ***less*** prevalent

Consequence:
Less thermal radiation trapped

Feedback:
⇨ $T_{SURFACE}$ declines: negative feedback



Planetary warming

Feedback

Initial Action:
Humans Release Aerosols

Initial Response:
$T_{SURFACE}$ cools

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

Consequence:
More solar radiation reflected

Feedback:
⇨ $T_{SURFACE}$ 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

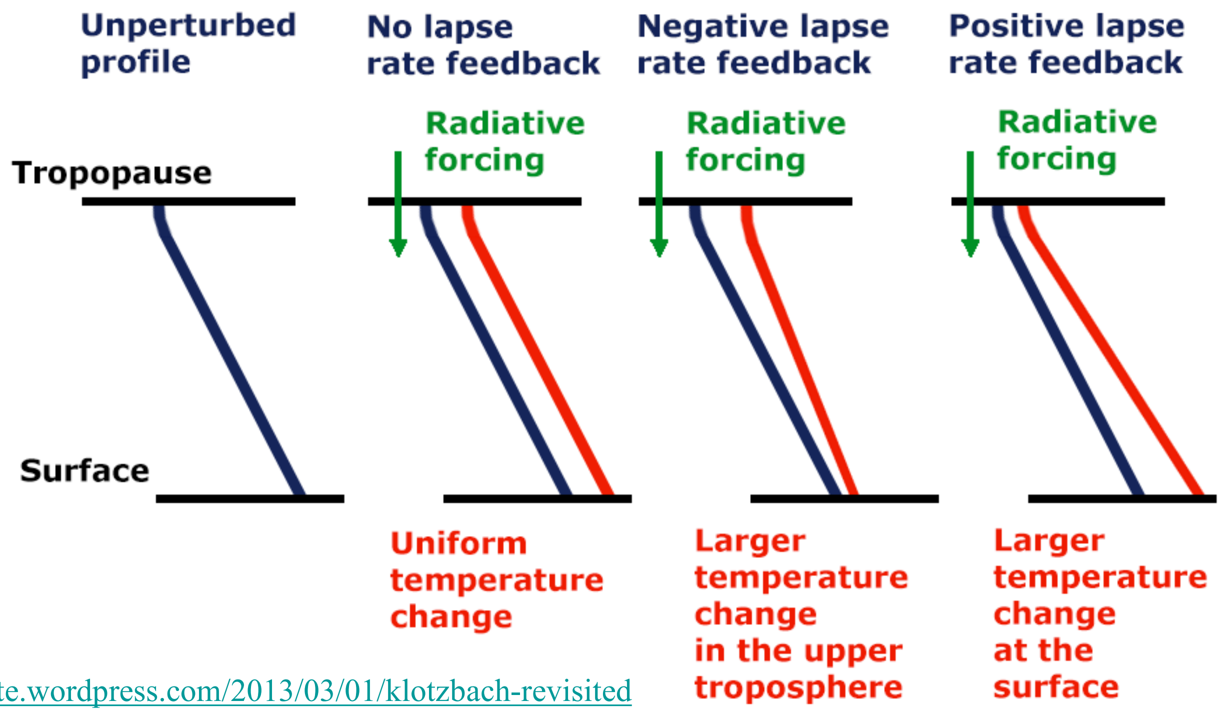
3. **ocean circulation:** ocean and atmosphere are strongly coupled:
   a) evaporation from ocean provides atmospheric water vapor & latent heat associated with condensation in clouds is largest single atmospheric heat source
   b) ocean heat capacity >> atmospheric heat capacity: oceans exert dominant 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



https://ourchangingclimate.wordpress.com/2013/03/01/klotzbach-revisited

- 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

Consequences of Climate Change

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

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

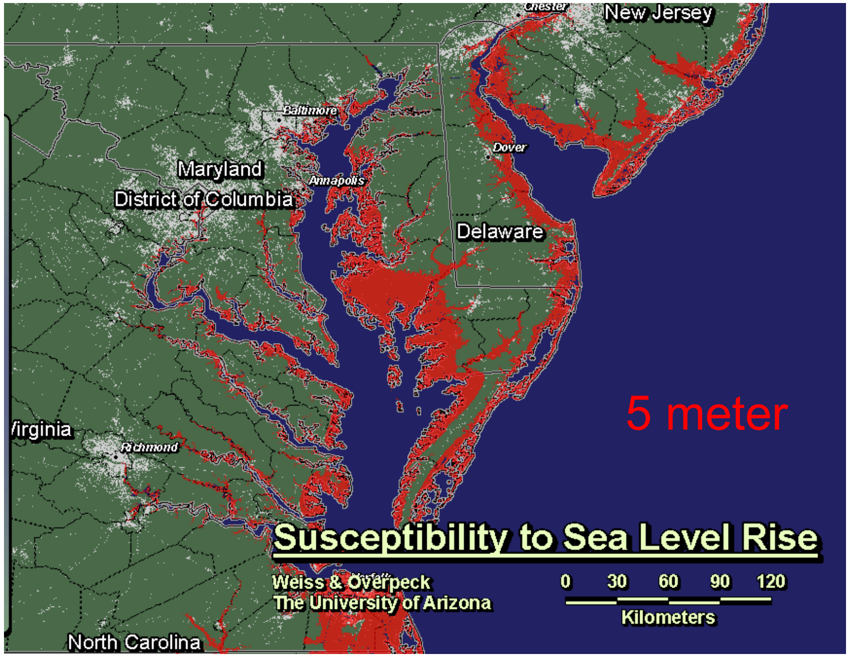
3. **World is becoming more “tropical”, including poleward migration of ecosystems, weather patterns, and tropical diseases**

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**

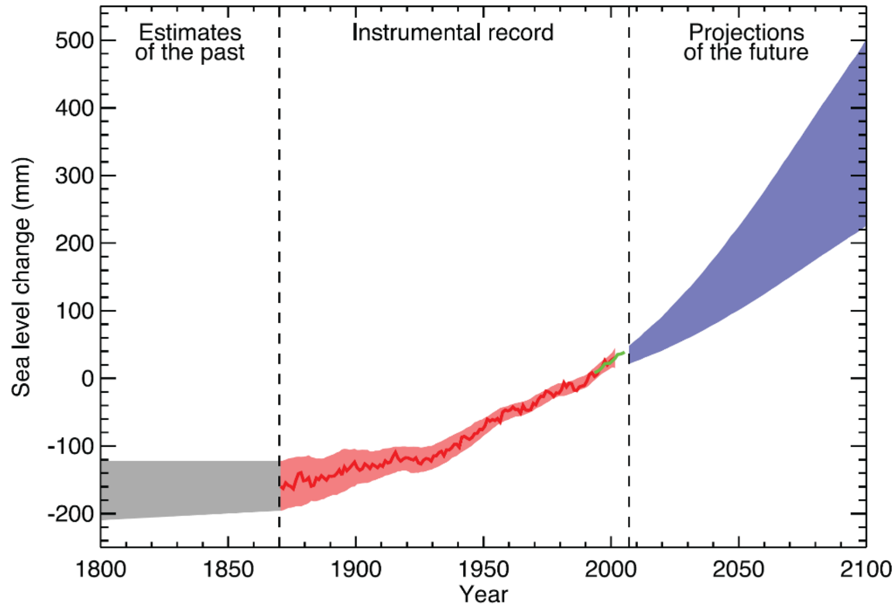


Maryland:

- **more coastline than California !**
- **more susceptible to sea level rise than all but 2 other states**

Consequences of Climate Change

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.*

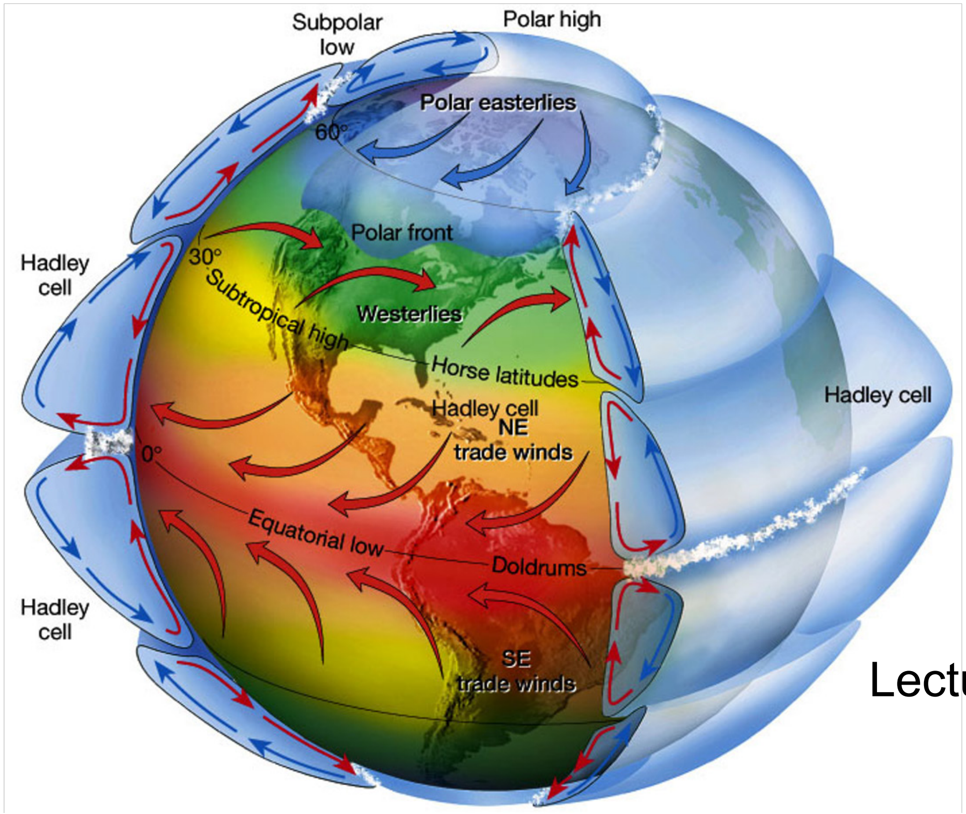
IPCC (2007)

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**

Ferrel Circulation (Modern View)

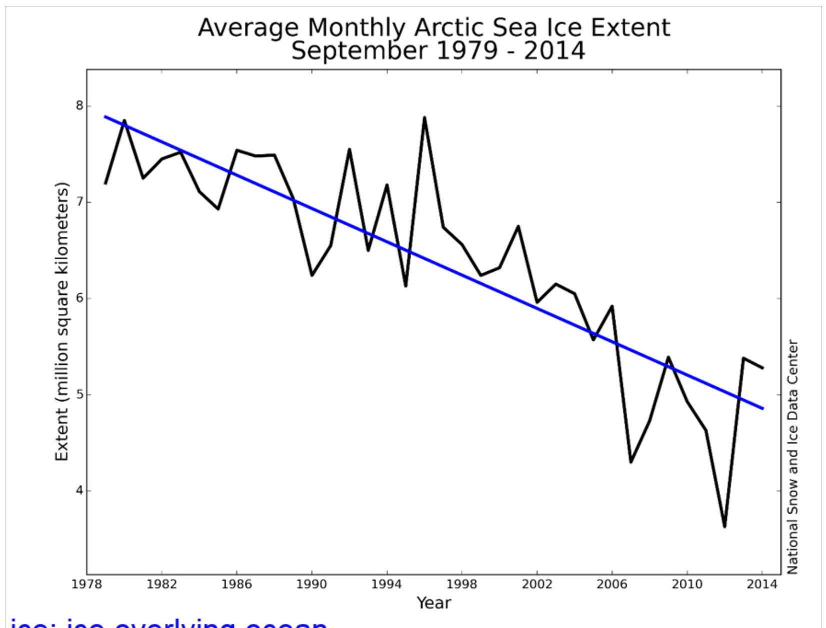


Lecture 3, Slide 27

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

Lecture 8, Slide 15

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:

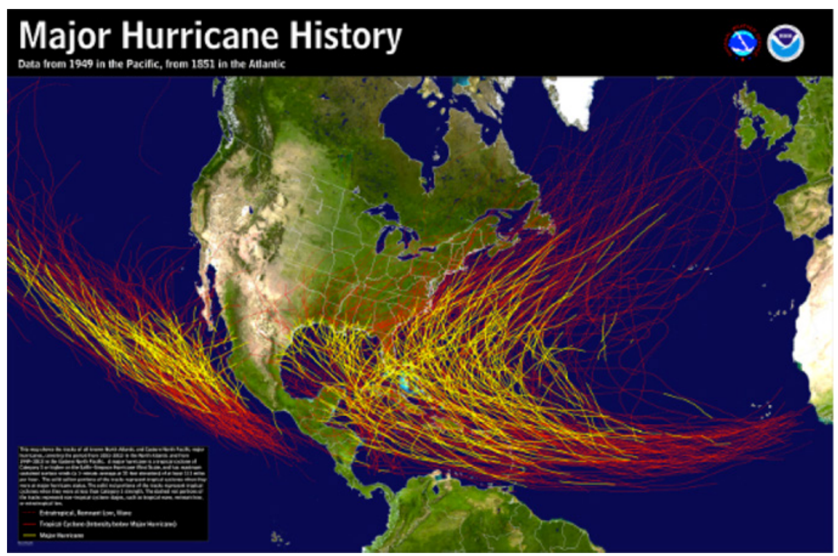
Location	Polar Bear Population Status	Risk of Future Decline
East Greenland	Data deficient	No estimate
Barents Sea	Data deficient	No estimate
Kara Sea	Data deficient	No estimate
Laptev Sea	Data deficient	No estimate
Chukchi Sea	Data deficient	No estimate
Southern Beaufort Sea	Reduced	No estimate
Northern Beaufort Sea	Not reduced	No estimate
Viscount Melville	Severely reduced	Very Low
Norwegian Bay	Not reduced	Higher

Location	Polar Bear Population Status	Risk of Future Decline
Norwegian Bay	Not reduced	Higher
Lancaster Sound	Not reduced	Higher
M'Clintock Channel	Severely reduced	Very Low
Gulf of Boothia	Not reduced	Lower
Foxe Basin	Not reduced	Lower
Western Hudson Bay	Reduced	Very High
Southern Hudson Bay	Not reduced	Lower
Kane Basin	Reduced	Very High
Baffin Bay	Reduced	Very High

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:



Lecture 5, Slide 31

http://www.c2es.org/science-impacts/extreme-weather/hurricanes

Consequences of Climate Change

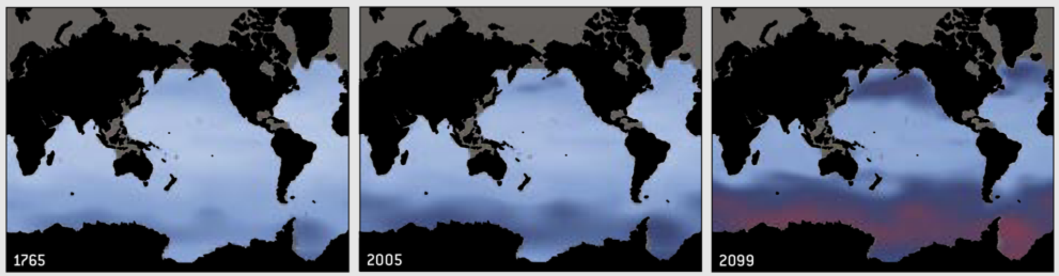
5. Ocean is becoming increasingly acidic, threatening vast portions of the ocean ecosystem

Future ocean uptake of atmospheric CO_2 will lead to ***ocean acidification***

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

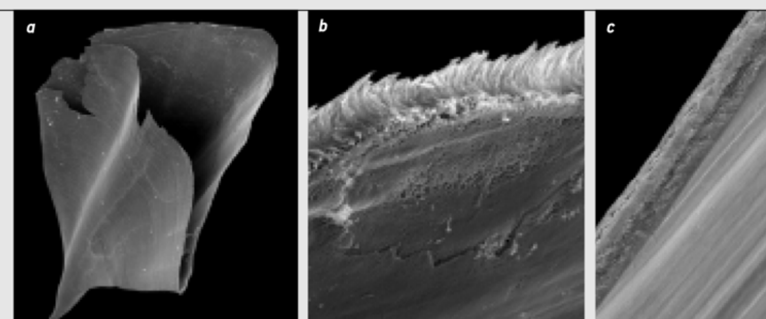
THE (RAGGED) FUTURE OF ARAGONITE

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.



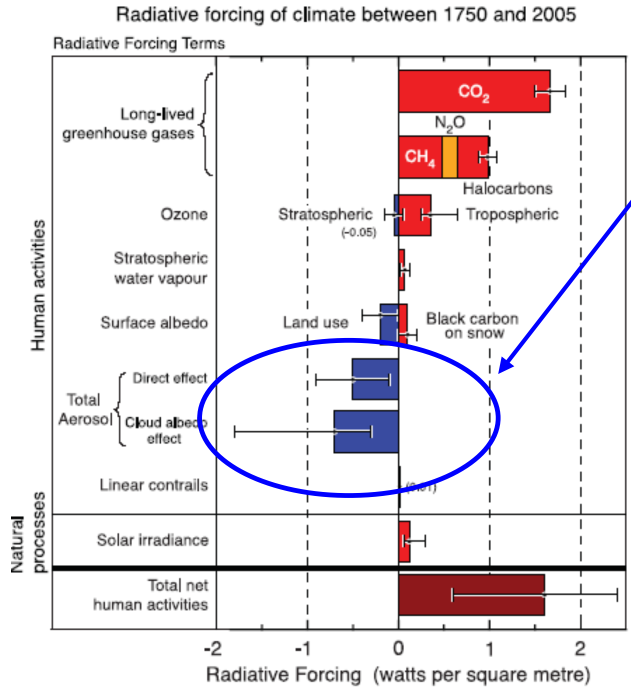
Before the Industrial Revolution (*left*), most surface waters were substantially "oversaturated" with respect to aragonite (*light blue*), allowing marine organisms to form this mineral readily. But now (*center*), polar surface waters are only marginally oversaturated (*dark blue*). At the end of this 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.

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*).



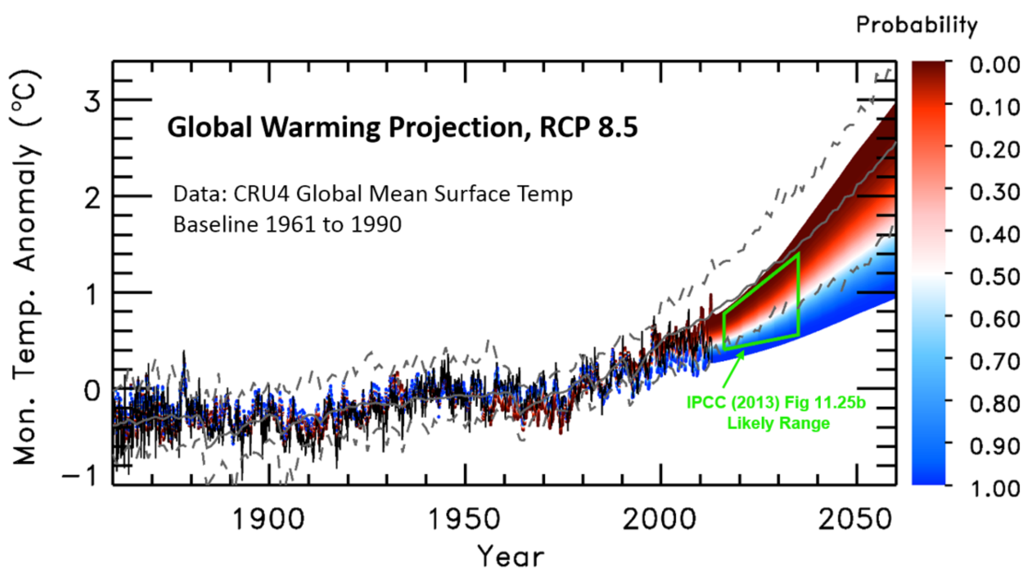
Doney, The Dangers of Ocean Acidification, *Scientific American*, March, 2006

Predicting future and understanding past are linked

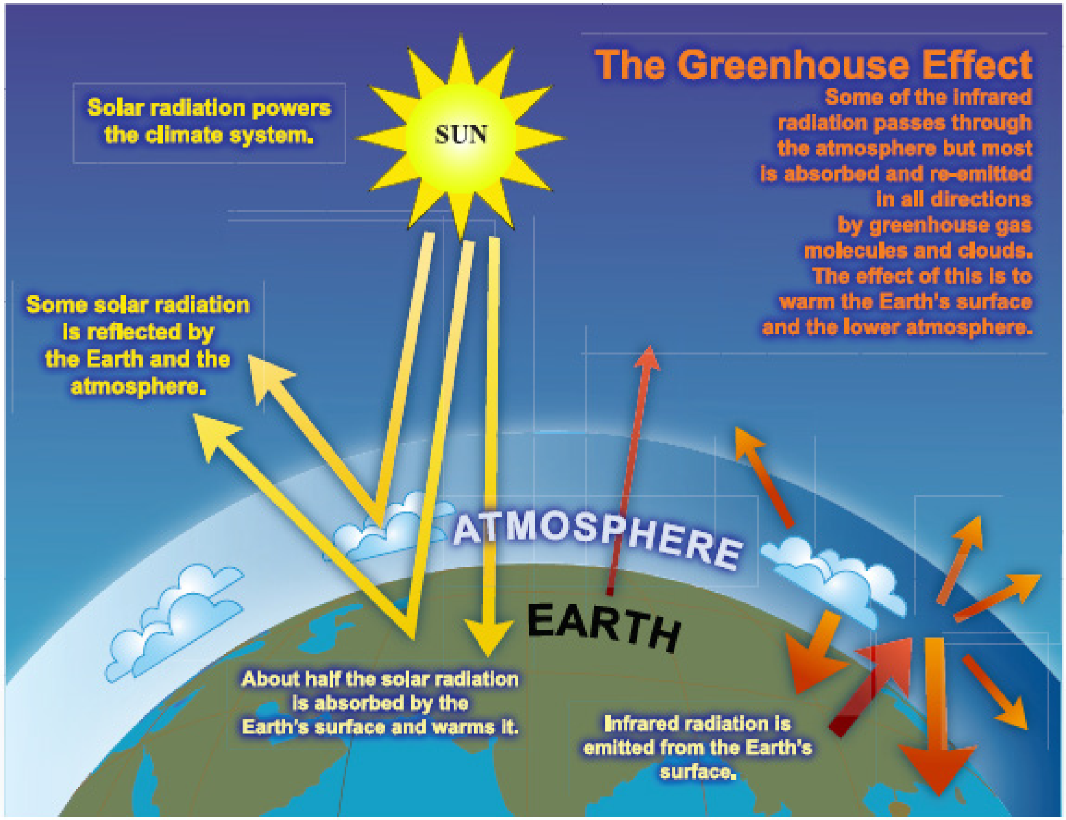


Large uncertainty in knowledge of the RF due to Anthro Aerosols means we can fit the climate record near equally well with a suite of models that possess various strengths of climate feedback …. but future warming will be dictated by ***which*** feedback value is correct

Hope et al., in prep, 2015

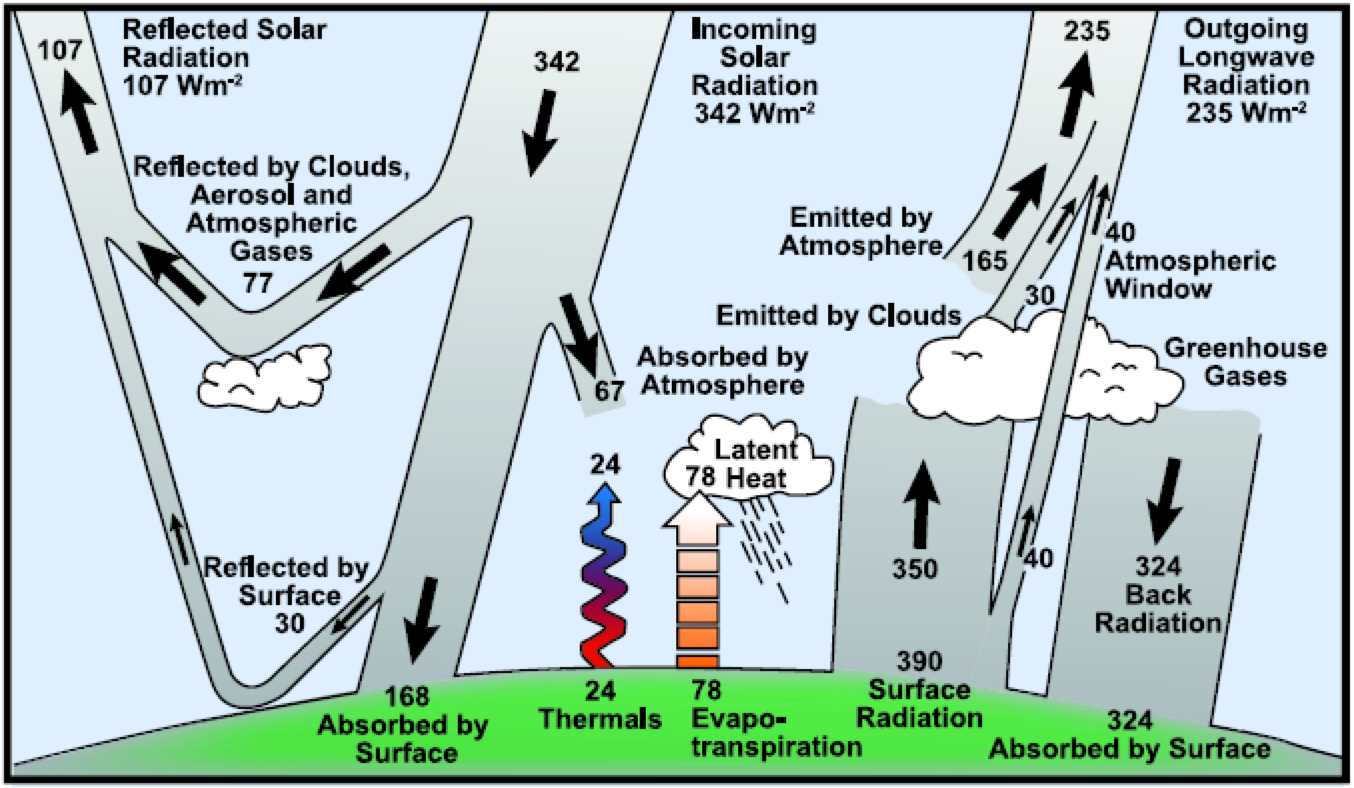


Greenhouse Effect



FAQ 1.3, Figure 1. *An idealised model of the natural greenhouse effect. See text for explanation.*

Radiative Forcing



FAQ 1.1, Figure 1. *Estimate of the Earth's annual and global mean energy balance. Over the long term, the amount of incoming solar radiation absorbed by the Earth and atmosphere is balanced by the Earth and atmosphere releasing the same amount of outgoing longwave radiation. About half of the incoming solar radiation is absorbed by the Earth's surface. This energy is transferred to the atmosphere by warming the air in contact with the surface (thermals), by evapotranspiration and by longwave radiation that is absorbed by clouds and greenhouse gases. The atmosphere in turn radiates longwave energy back to Earth as well as out to space. Source: Kiehl and Trenberth (1997).*

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.

GWP – Global Warming Potential

$$\text{GWP}(\text{CH}_4) = \frac{\displaystyle\int_{\text{time initial}}^{\text{time final}} a_{\text{CH4}} \times [\text{CH}_4(\text{t})]\ \text{dt}}{\displaystyle\int_{\text{time initial}}^{\text{time final}} a_{\text{CO2}} \times [\text{CO}_2(\text{t})\ \text{dt}]}$$

where:

a_{CH4} = Radiative Efficiency (W m^{-2} kg $^{-1}$) due to an increase in CH_4

a_{CO2} = 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 CH_4) global warming potentials (GWP) relative to CO_2. {Table 2.14}*

Industrial Designation or Common Name (years)	Chemical Formula	Lifetime (years)	Radiative Efficiency ($W\ m^{-2}\ ppb^{-1}$)	Global Warming Potential for Given Time Horizon			
				SAR‡ (100-yr)	20-yr	100-yr	500-yr
Carbon dioxide	CO_2	See below[a]	[b]1.4×10^{-5}	1	1	1	1
Methane[c]	CH_4	12[c]	3.7×10^{-4}	21	72	25	7.6
Nitrous oxide	N_2O	114	3.03×10^{-3}	310	289	298	153

Notes:

‡ SAR refers to the IPCC Second Assessment Report (1995) used for reporting under the UNFCCC.

[a] 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 (Bern2.5CC; 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

$a_0 + \sum_{i=1}^{3} a_i \cdot e^{-t/\tau_i}$ where $a_0 = 0.217$, $a_1 = 0.259$, $a_2 = 0.338$, $a_3 = 0.186$, $\tau_1 = 172.9$ years, $\tau_2 = 18.51$ years, and $\tau_3 = 1.186$ years, for $t < 1{,}000$ years.

[b] 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).

[c] 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) .

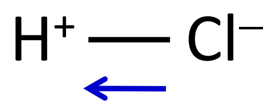
from IPCC 2007 "Physical Science Basis"

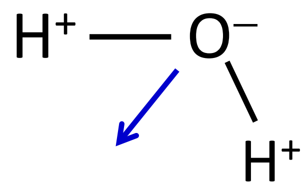
Time constant of 172.9 years dominates

Review of Dipole Moment

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

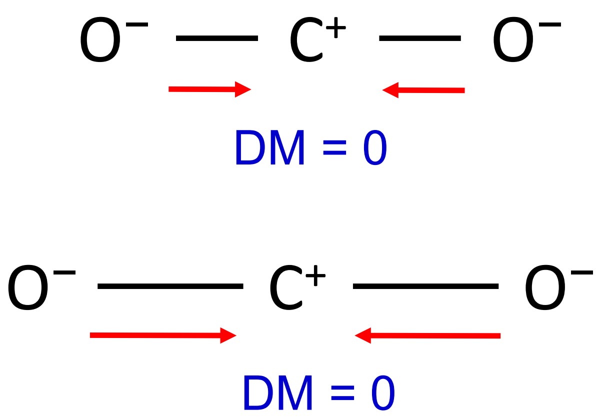
Dipole moment – the magnitude of the charge multiplied by the distance between charges. Direction will be toward positive charge.



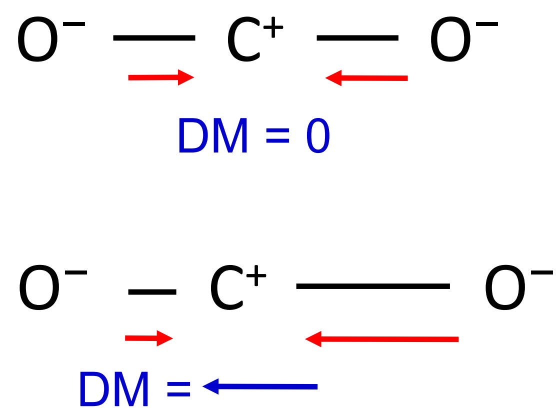


Magnitude depends on electro-negativity of individual atoms

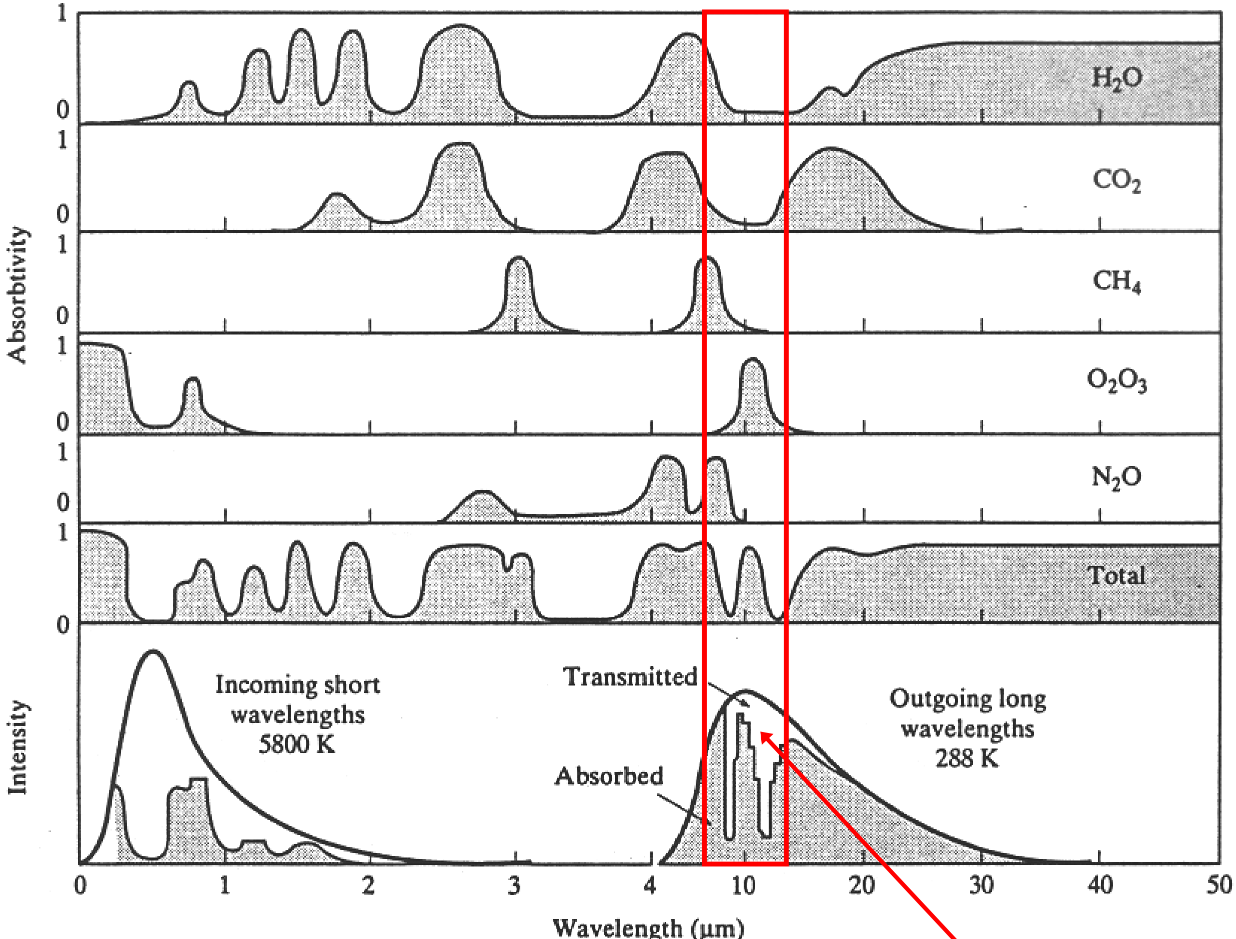
Symmetric stretch



Asymmetric stretch



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.

Gas	Atmospheric Lifetime (years)	Ozone Depletion Potential (ODP) [c]
Halogen source gases		
Chlorine gases		
CFC-11	45	1
CFC-12	100	0.82
CFC-113	85	0.85
Carbon tetrachloride (CCl_4)	26	0.82
HCFCs	1–17	0.01–0.12
Methyl chloroform (CH_3CCl_3)	5	0.16
Methyl chloride (CH_3Cl)	1	0.02
Bromine gases		
Halon-1301	65	15.9
Halon-1211	16	7.9
Methyl bromide (CH_3Br)	0.8	0.66
Hydrofluorocarbons (HFCs)		
HFC-134a	13.4	0
HFC-23	222	0

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

continuous

$$\text{ODP (species "}i\text{")} = \frac{\text{global loss of } O_3 \text{ due to unit mass emission of "}i\text{"}}{\text{global loss of } O_3 \text{ due to unit mass emission of CFC-11}}$$

$$\approx \frac{(\alpha\, n_{Br} + n_{Cl})}{3} \; \frac{\tau_i}{\tau_{CFC\text{-}11}} \; \frac{MW_{CFC\text{-}11}}{MW_i}$$

where :

τ is the global atmospheric lifetime

MW is the molecular weight

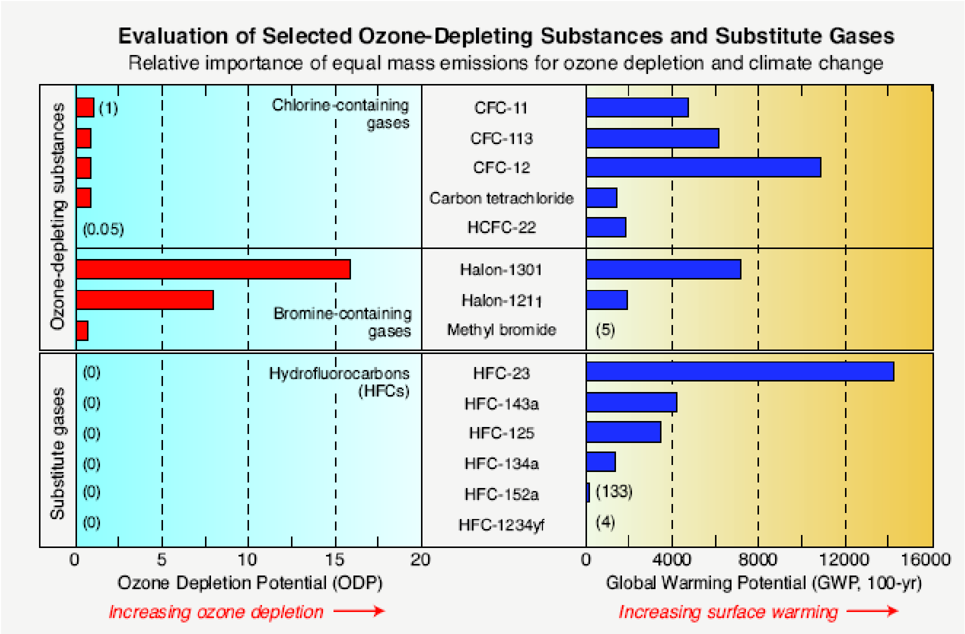
n is the number of chlorine or bromine atoms

α is the effectiveness of ozone loss by bromine relative to ozone loss by chlorine

$\alpha = 60$

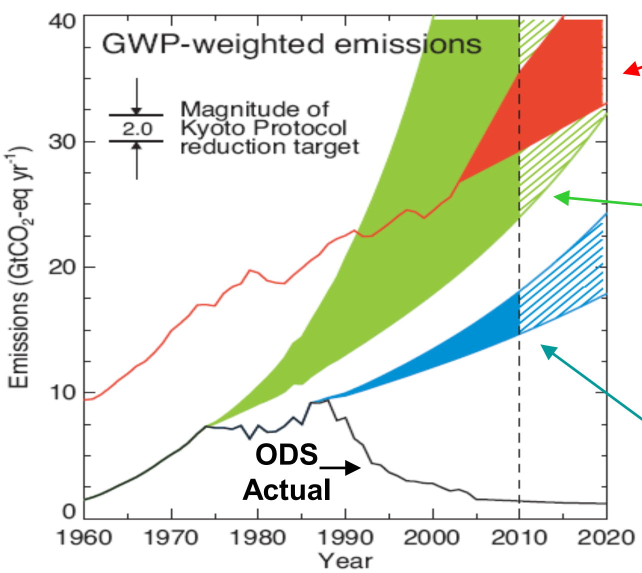
Halons (anthropogenic halocarbons containing bromine) much worse for ozone than CFCs (anthropogenic halocarbons containing chlorine)

Link Between Ozone-Depleting Substances (ODS) and Climate Change



Twenty Questions and Answers About The Ozone Layer: 2010 Update (WMO, 2010)

Most ozone depleting substances have a significant "GWP"



GWP weighted emissions of CO_2

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

GWP weighted emissions of CFCs, without Montreal Protocol

Velders *et al.*, *PNAS*, 2007

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