Review for First Exam

AOSC 433/633 & CHEM 433

Ross Salawitch

Class Web Site: http://www.atmos.umd.edu/~rjs/class/spr2017

Today:

- **Climate Feedback**
- **Consequences of Climate Change**
- **Highlights of first 8 lectures**
- **Last year's first exam**

23 February 2017

Upcoming Schedule

Fri, 24 Feb, noon: P Set #2 due: either bring to me (CSS 2403), Pam (Jull 2106), or leave in my mailbox (3d floor of this building) and send email to me and Pam

Mon, 27 Feb, 6:00 pm: Review of second problem set

We will return graded problem sets at the start of the review, but only guarantee return of graded problem sets turned in prior to start of the weekend

Tues, 28 Feb, 2 pm: First Exam

Will be closed book, no notes, no calculator

Model Formulation used in *Paris Climate Agreement: Beacon of Hope*

$$\Delta T_{MDL\,i} = (1+\gamma)\,(\text{GHG RF}_{\,i} + \text{Aerosol RF}_{\,i}) \,/\, \lambda_P$$
$$+ C_o + C_1 \times \text{SOD}_{\,i-6} + C_2 \times \text{TSI}_{\,i-1} + C_3 \times \text{ENSO}_{\,i-2}$$
$$+ C_4 \times \text{AMOC}_{\,i} - Q_{OCEAN\,i} \,/\, \lambda_P$$

where

$\lambda_P = 3.2$ W m^{-2} / °C

$1+\gamma = \{ 1 - \Sigma(\text{Feedback Parameters}) / \lambda_P \}^{-1}$

Aerosol RF= total RF due to anthropogenic aerosols

SOD = Stratospheric optical depth

TSI = Total solar irradiance

ENSO = El Niño Southern Oscillation

AMOC = Atlantic Meridional Overturning Circ.

Q_{OCEAN} = Ocean heat export

Slide Shown in Lecture 4

Let's relate a change in temperature to a change in radiative forcing:

$$\Delta T = \lambda' \, \Delta F$$

λ is the climate sensitivity factor in units of

For an ideal blackbody: $F = \sigma \, T^4$

$$\frac{dF}{dT} = 4 \, \sigma \, T^3$$

Above equation can be re-arranged to yield:

$$\Delta T \approx \frac{1}{4 \, \sigma \, T^3} \, \Delta F$$

So: $$\lambda' = \frac{1}{4 \, \sigma \, T^3}$$

If we plug in value of Boltzmann's constant and global mean T at which Earth radiates to space, we find $\lambda_{BB} \approx 0.3$ K / (W m^{-2})

Here: BB refers to Black Body

Re-arranging slide shown in Lecture 4

$$\Delta T = \lambda' \, \Delta F \;\approx\; 0.3 \text{ K} / (\text{W m}^{-2}) \, \Delta F$$

Can just as easily write:

$$\Delta T \;\approx\; 0.3 \text{ K} / (\text{W m}^{-2}) \, \Delta F = \frac{1}{3.33 \text{ W m}^{-2} \text{ K}^{-1}} \, \Delta F$$

Or:

$$\Delta T \;\approx\; \frac{1}{3.33 \text{ W m}^{-2} \text{ K}^{-1}} \, \Delta F = \frac{1}{\lambda_P} \, \Delta F$$

$$\text{where } \lambda_P = 3.33 \text{ W m}^{-2} \text{ K}^{-1}$$

Back to convention used in book

Without feedbacks

$$\Delta T = \frac{1}{\lambda_P} \Delta F$$

where $\lambda_P = 3.2 \text{ W m}^{-2} \ {}^\circ\text{C}^{-1}$ (this is the most commonly used value)

With feedbacks

$$\Delta T = \frac{1+\gamma}{\lambda_P} \Delta F$$

where, according to Section 8.6 of IPCC, we define:

$$1+\gamma = \frac{1}{1-\dfrac{\lambda}{\lambda_P}} \quad \text{and}$$

$$\lambda = \text{Sum Of All Feedbacks, in units of W m}^{-2} \ {}^\circ\text{C}^{-1}$$

Tying All Together

To be consistent with formulation In book, we should have shown:

Simple Climate Model:

$$\Delta T = \frac{1 + f_{H2O}}{\lambda_P} (\Delta F_{CO2} + \Delta F_{CH4+N2O} + \Delta F_{OTHER\ GHGs} + \Delta F_{AEROSOLS})$$

where

$$\lambda_P = 3.2 \text{ W m}^{-2} \text{ }^{\circ}\text{C}^{-1}$$

Climate models that consider water vapor feedback find:

$$\lambda_{H2O} \approx 1.6 \text{ W m}^{-2} \text{ W m}^{-2} \text{ }^{\circ}\text{C}^{-1} \text{, from which we deduce } f_{H2O} = 1.0$$

Tying All Together

To be consistent with formulation In book, we should have shown:

Slightly More Complicated Climate Model:

$$\Delta T = \frac{1 + f_{\text{H2O \& LR}}}{\lambda_P} \left(\Delta F_{\text{CO2}} + \Delta F_{\text{CH4+N2O}} + \Delta F_{\text{OTHER GHGs}} + \Delta F_{\text{AEROSOLS}}\right)$$

where

$$\lambda_P = 3.2 \text{ W m}^{-2} \ {}^{\circ}\text{C}^{-1}$$

Climate models that consider water vapor & lapse rate feedback find:

$\lambda_{\text{H2O \& LR}} \approx 1.0 \text{ W m}^{-2} \text{ W m}^{-2} \ {}^{\circ}\text{C}^{-1}$, from which we deduce $f_{\text{H2O \& LR}} = 0.45$

Negative Feedback

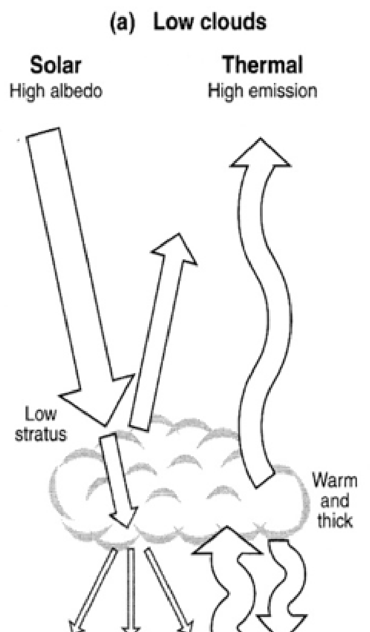
Initial Action:
Humans Release CO_2

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

↓

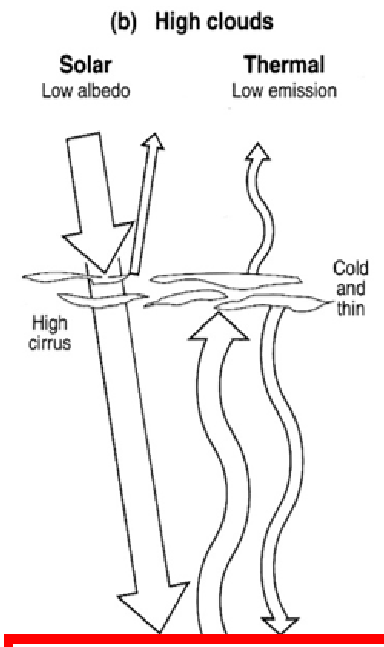
Then:
High Altitude clouds become ***less*** prevalent

↓

Consequence:
Less thermal radiation trapped

↓

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



Planetary warming

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

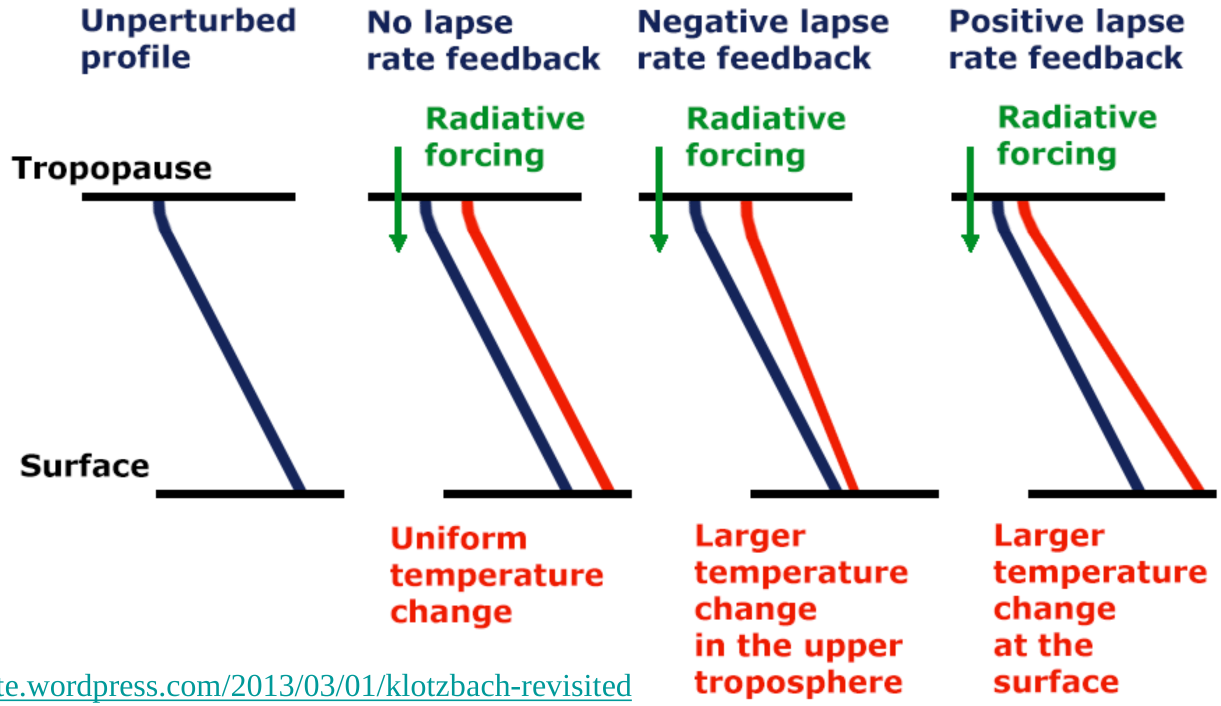
3. **ocean circulation:** ocean and atmosphere are strongly coupled:
   a) evaporation from ocean provides atmospheric water vapor & latent heat associated with condensation in clouds is largest single atmospheric heat source
   b) ocean heat capacity >> atmospheric heat capacity: oceans exert dominant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

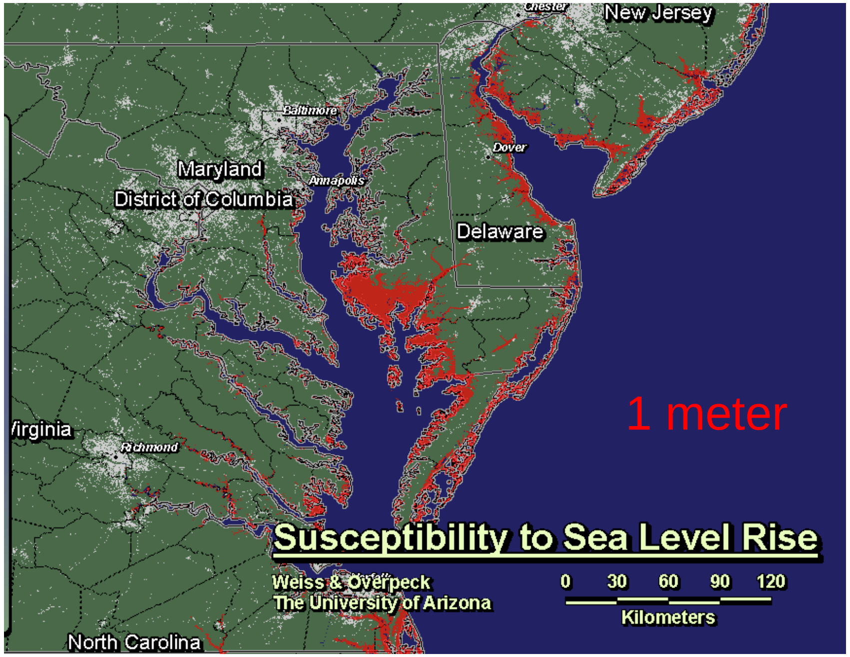
3. **World is becoming more "tropical", including poleward migration of ecosystems, weather patterns, and tropical diseases**

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**

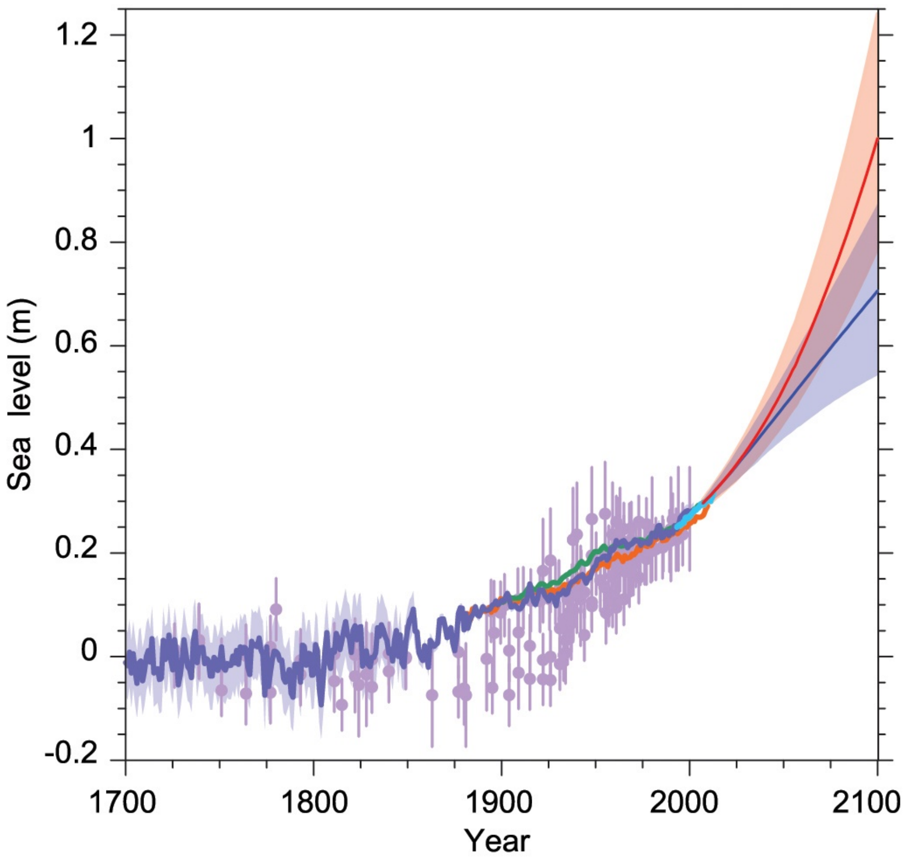


Maryland:

- **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**



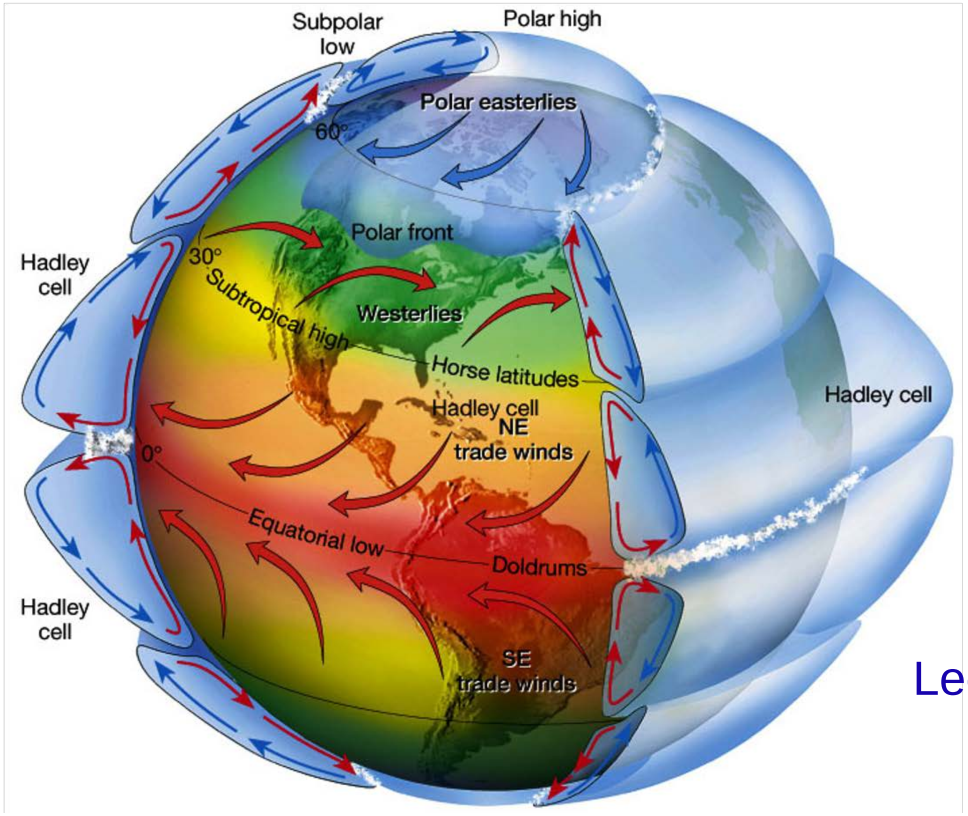
Compilation of paleo sea level data (purple), tide gauge data (blue, red and green), altimeter data (light blue) and central estimates and likely ranges for projections of global mean sea level rise from the combination of CMIP5 and process-based models for RCP2.6 (blue) and RCP8.5 (red) scenarios, all relative to pre-industrial values.

IPCC (2013)

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)

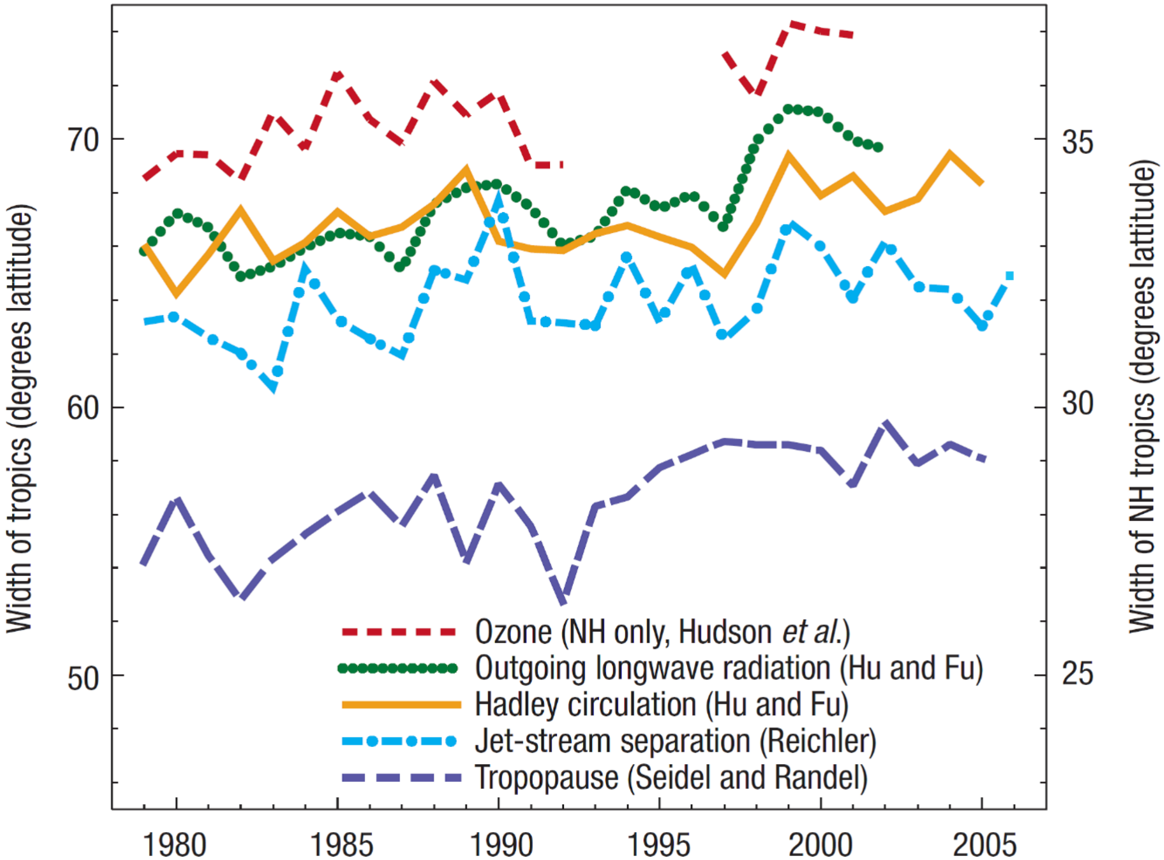


Lecture 3

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**



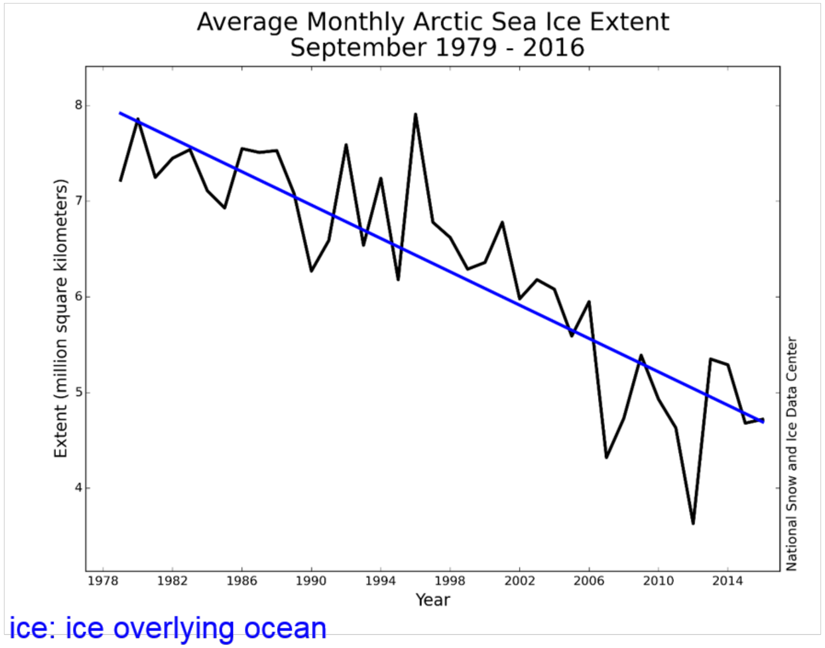
Seidel et al., 2008

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

http://nsidc.org/arcticseaicenews/files/2014/10/monthly_ice_NH_09.png

Consequences of Climate Change

Polar bear census data:

Subpopulation	Size			Trend	
	Estimate / *95% CI*	Year	Method	Relative to historic level (approx. 25-yr past)	Current (approx. 12-yr period centered on present)
Baffin Bay	1546 *690-2402*	2004	PVA *(Based on physical capture-recapture estimate from 1998)*	Data deficient	Declining
Barents Sea	2644 *1899-3592*	2004	Distance sampling	Data deficient	Data deficient
Chukchi Sea	Unknown			Data deficient	Data deficient
Davis Strait	2158 *1833-2542*	2007	Physical capture-recapture	Data deficient	Stable
East Greenland	Unknown			Data deficient	Data deficient
Foxe Basin	2580 *2093-3180*	2009/10	Distance sampling	Not reduced	Stable
Gulf of Boothia	1592 *870-2314*	2000	Physical capture-recapture	Not reduced	Stable
Kane Basin	164 *94-234*	1994-1997	Physical capture-recapture	Data deficient	Declining

Subpopulation	Size			Trend	
	Estimate / *95% CI*	Year	Method	Relative to historic level (approx. 25-yr past)	Current (approx. 12-yr period centered on present)
Lancaster Sound	2541 *1759-3323*	1995-1997	Physical capture-recapture	Data deficient	Data deficient
Laptev Sea	Unknown			Data deficient	Data deficient
M'Clintock Channel	284 *166-402*	2000	Physical capture-recapture	Reduced	Increasing
Northern Beaufort Sea	980 *825-1135*	2006	Physical capture-recapture	Not reduced	Stable
Norwegian Bay	203 *115-291*	1997	Physical capture-recapture	Data deficient	Data deficient
Southern Beaufort Sea	907 *548-1270*	2010	Physical capture-recapture	Reduced	Declining
Southern Hudson Bay	951 *662-1366*	2012	Distance sampling	Not reduced	Stable
Viscount Melville Sound	161 *121-201*	1992	Physical capture-recapture	Data deficient	Data deficient
Western Hudson Bay	1030 *754-1406*	2011	Distance sampling	Reduced	Stable

Tables on this website updated frequently:
http://pbsg.npolar.no/en/status/status-table.html

Consequences of Climate Change

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

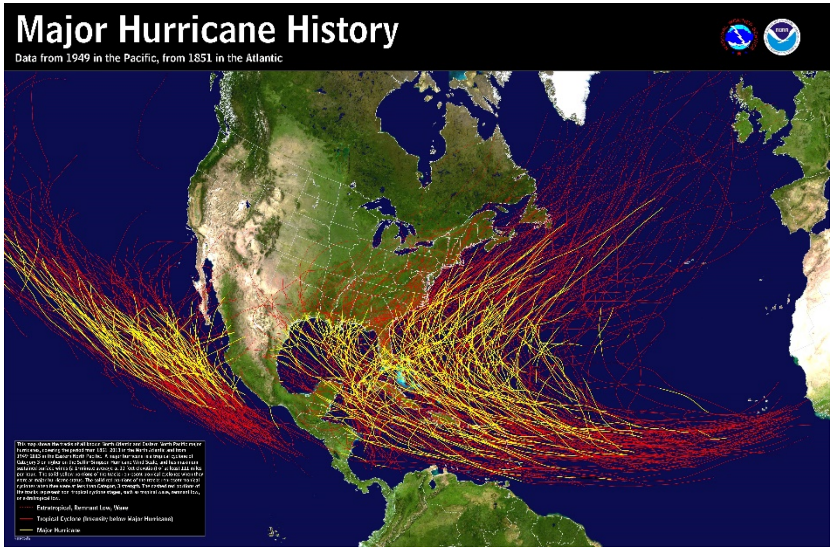
- Projection of the effect of global warming on hurricanes requires conducting calculations on a ~20-km grid ("serious supercomputer")
- Some simulation project that at end of century, rising GHGs will lead to:

  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:



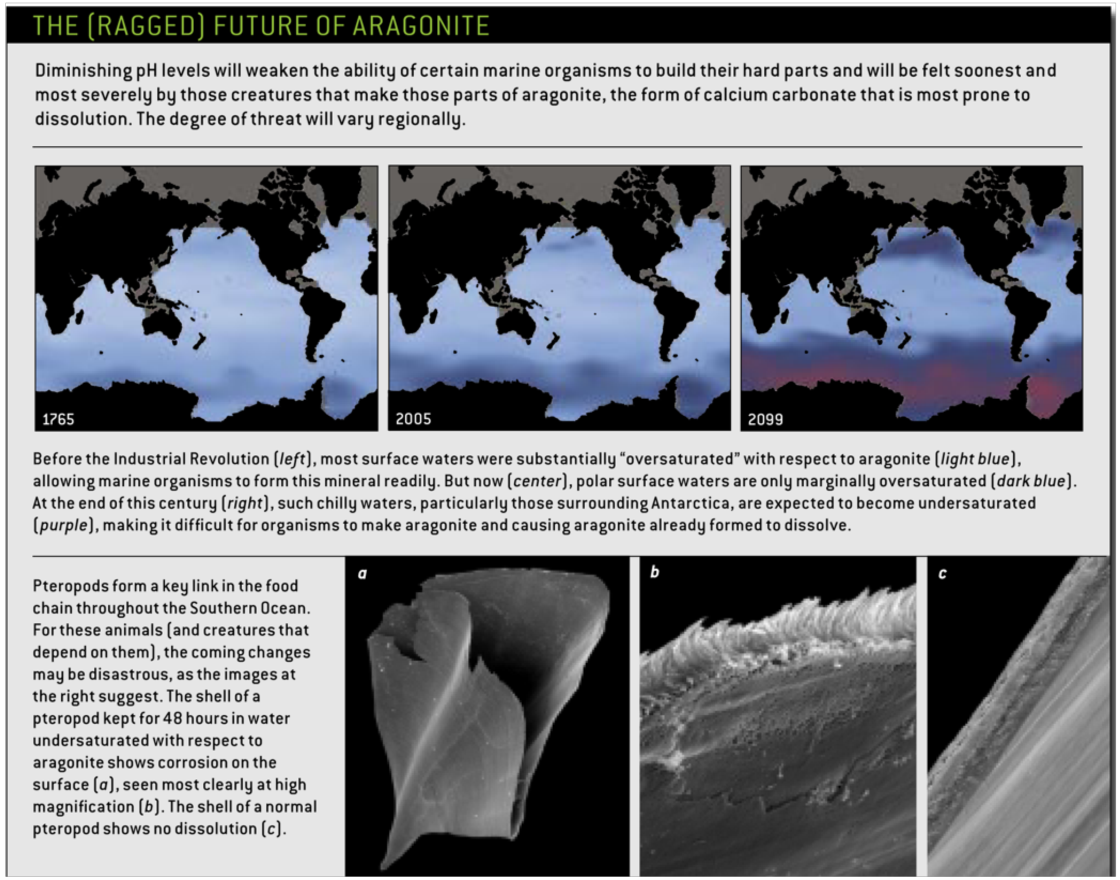
http://www.c2es.org/science-impacts/extreme-weather/hurricanes

Consequences of Climate Change

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

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

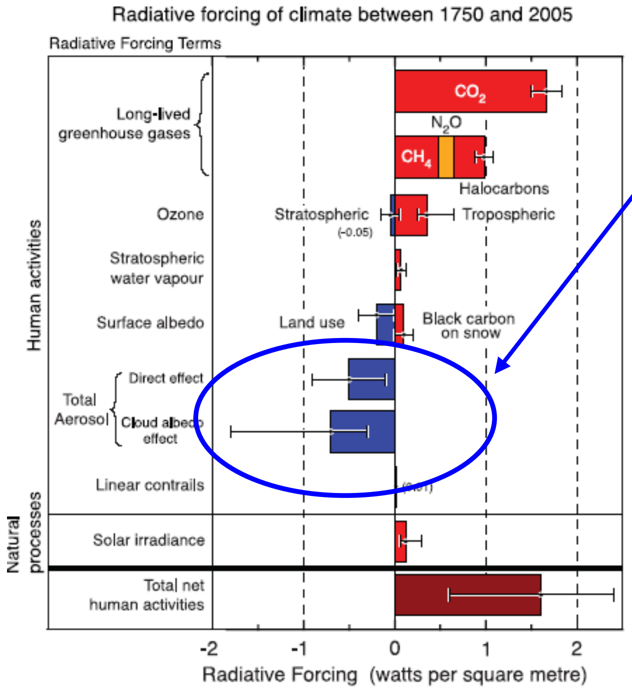
Bad news for ocean dwelling organisms that precipitate shells (basic materials)



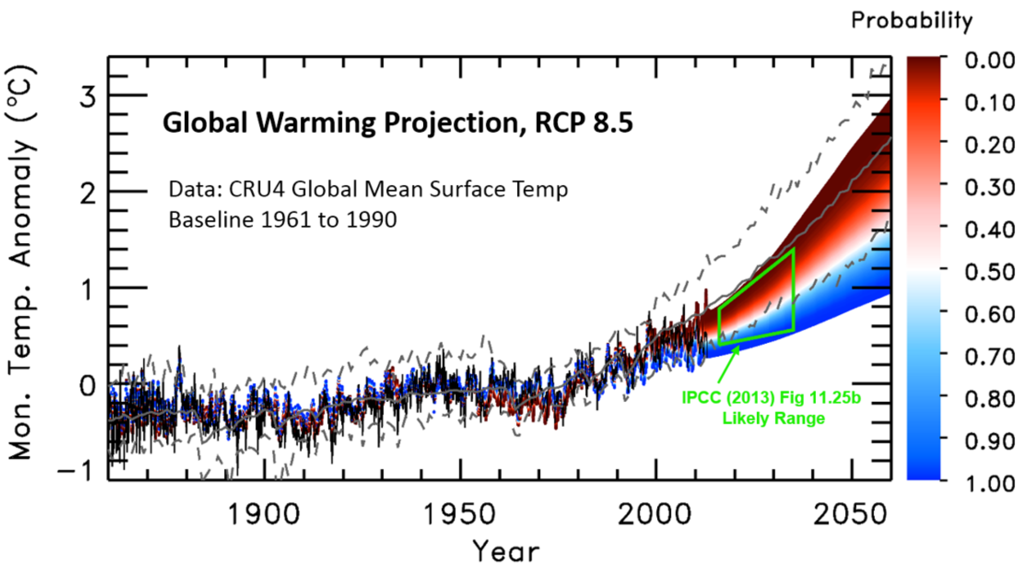
Doney, The Dangers of Ocean Acidification, *Scientific American*, March, 2006

Lecture 5

Predicting future and understanding past are linked

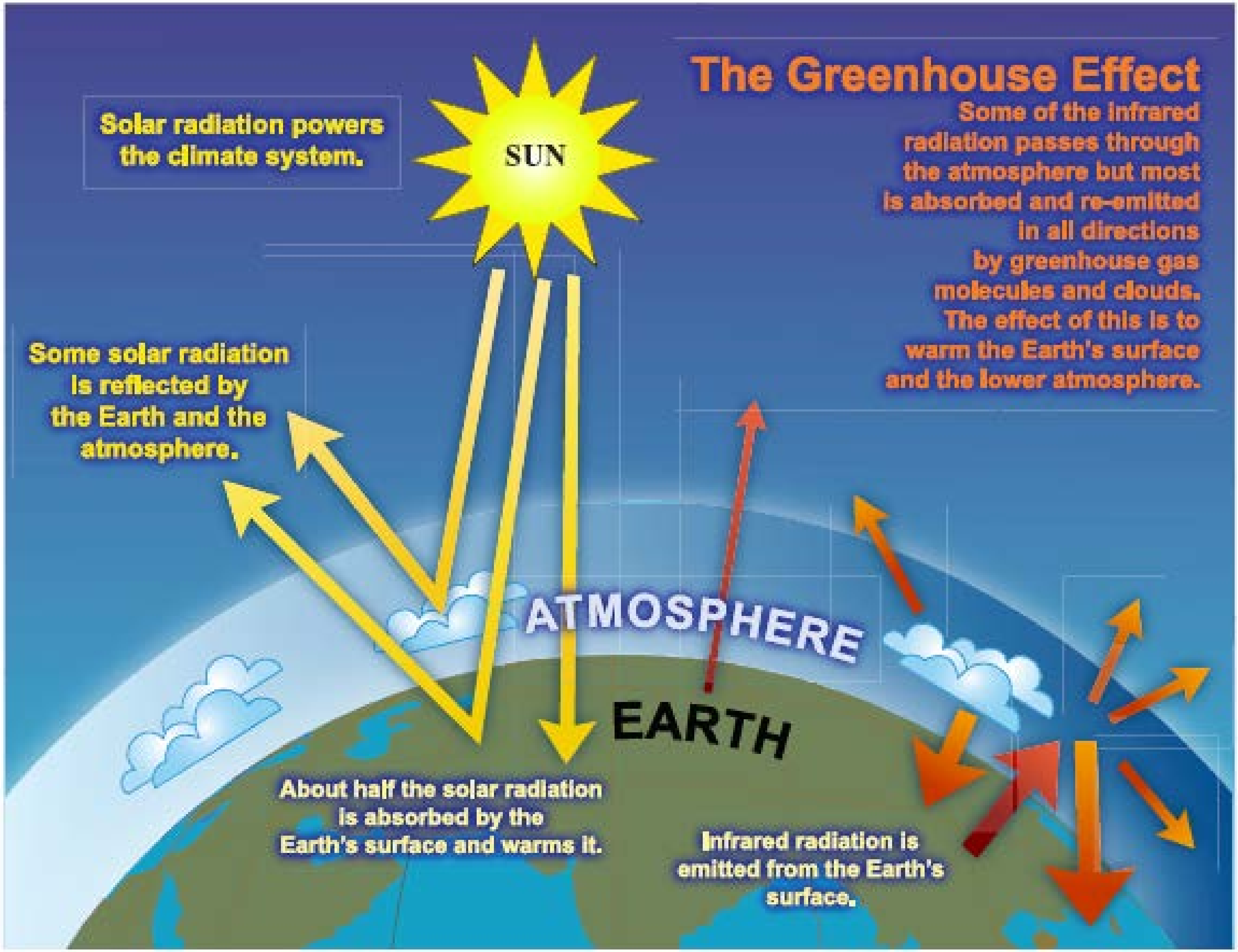


Large uncertainty in knowledge of the RF due to Anthro Aerosols means we can fit the climate record near equally well with a suite of models that possess various strengths of climate feedback …. but future warming will be dictated by ***which*** feedback value is correct



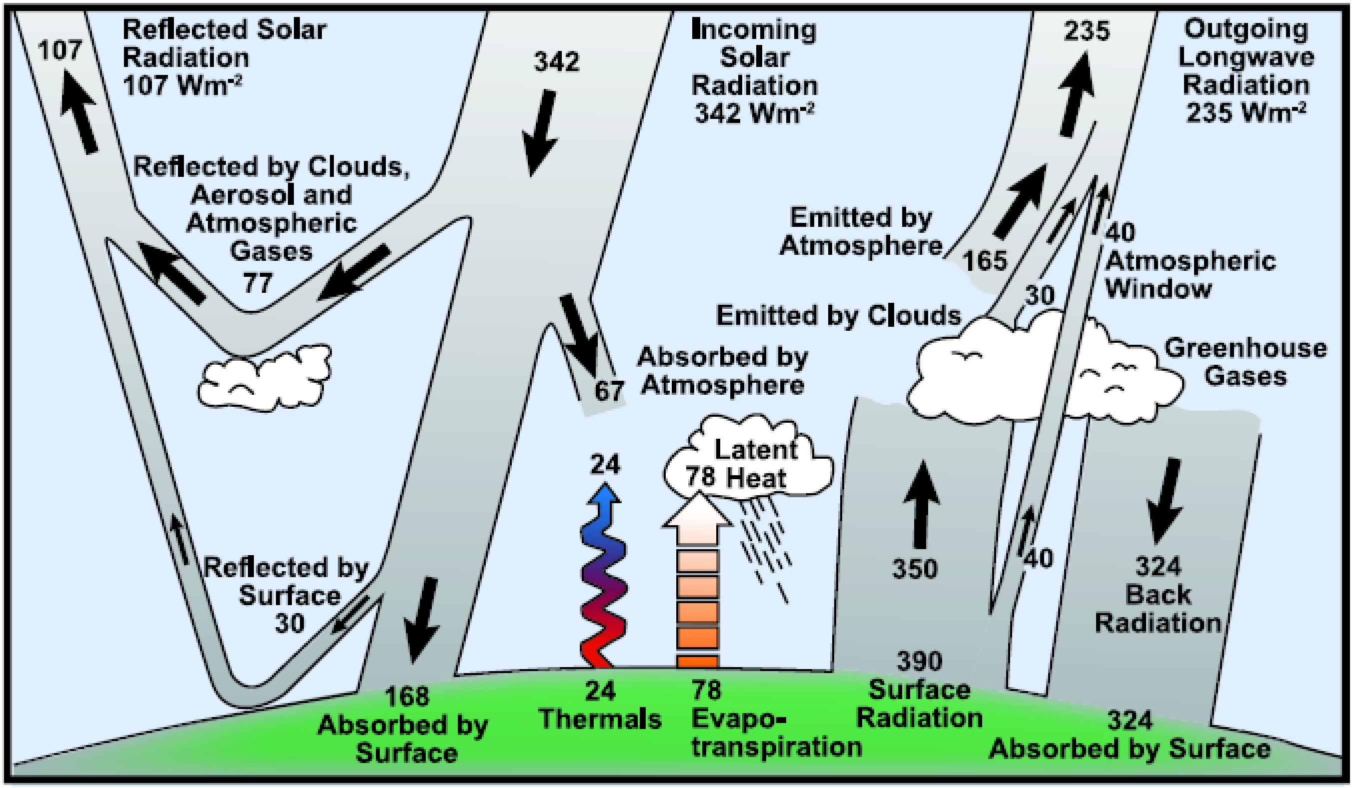
Lecture 8

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

$$\mathrm{GWP}\ (\mathrm{CH_4}) = \frac{\int_{\text{time initial}}^{\text{time final}} a_{\mathrm{CH4}} \times [\mathrm{CH_4}(t)]\ dt}{\int_{\text{time initial}}^{\text{time final}} a_{\mathrm{CO2}} \times [\mathrm{CO_2}(t)\ dt]}$$

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"

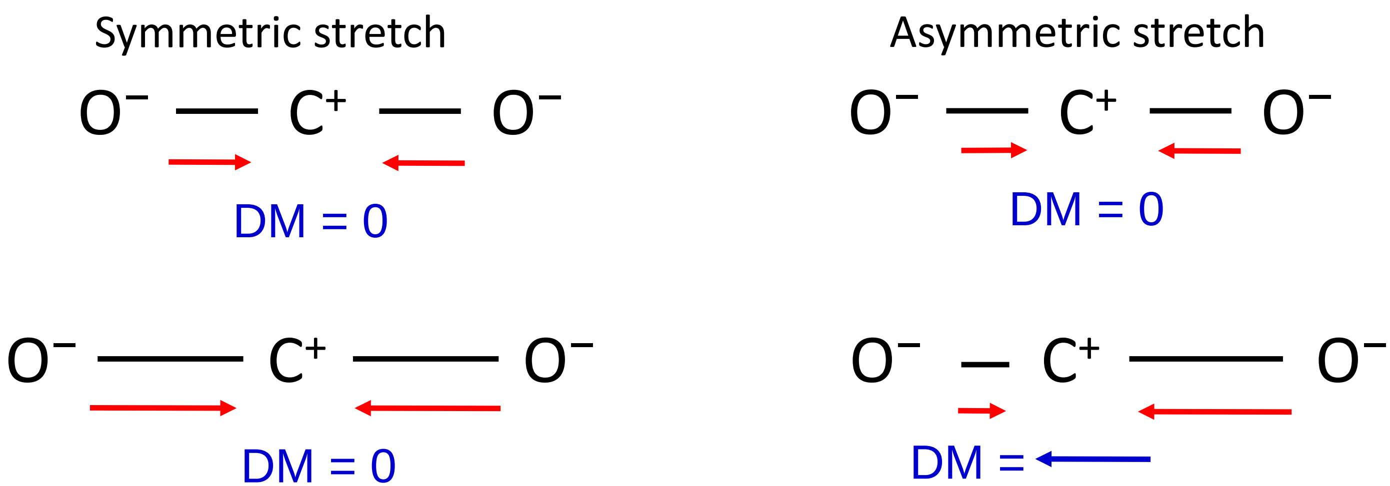
Time constant of 172.9 years dominates

Review of Dipole Moment

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

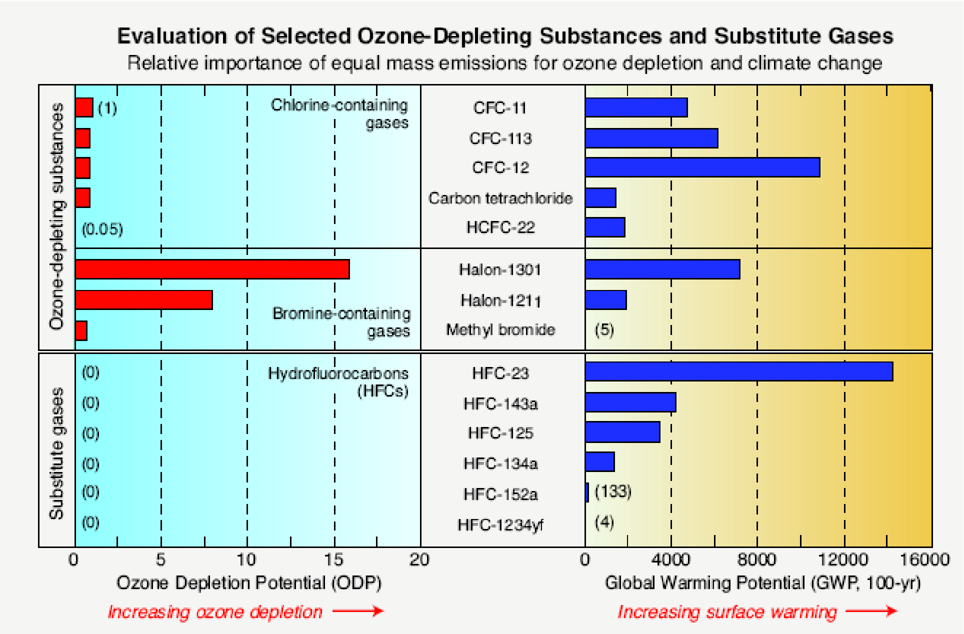
Dipole moment – the magnitude of the charge multiplied by the distance between charges. Direction will be toward positive charge.

Magnitude depends on electro-negativity of individual atoms



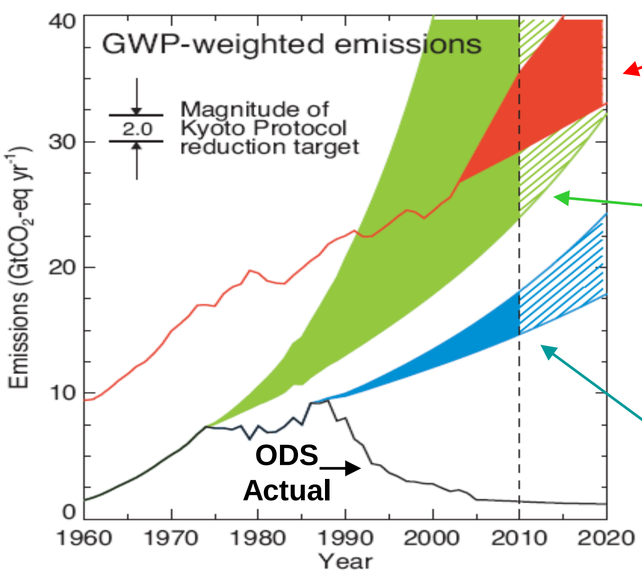
28

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, 2015

AOSC & CHEM 433, Atmospheric Chemistry and Climate

Early-Term Examination **Tues, 3 Mar 2015**

By writing my name below I acknowledge having followed the UMd Honor Code for this exam:

I pledge on my honor that I have not given or received any unauthorized assistance on this examination.

Name: ______________________________

There are 7 questions, 100 points total for the exam.

Please write your name *only on this page* and turn in the exam stapled together. We prefer to grade exams without knowledge of whose exam we are reading/discussing.

If you need extra space, please continue on the back of a page. Blank paper is also available and should be inserted into your replies if used. We'll have staple remover and stapler in the front of the room.

If you are unsure what we are asking, please call one of us over for clarification.

Good luck!

First Exam

- Tuesday, 28 February, 2:00 pm to 3:15 pm, Room CSS 2416
- About 7 questions like 2015 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*

- 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