Global Warming

I. Factors influencing recent climate change
  A. more recent climate change (Holocene)
    1. what controls climate?
    2. what is humanities influence?
  B. important issues here
    1. changes in total solar input
    2. changes in albedo (e.g., volcanic activity)
    3. changes in "greenhouse" gas concentrations and trapping of outgoing IR
      a. how do biogeochemical cycles influence these processes
      b. positive or negative feedbacks
  C. In this discussion we will focus on three aspects of the problem
    1. what are the present-day forcings on climate
    2. is there evidence of recent climate change
      a. if so, can we separate natural variability from anthropogenic effects
    3. what's in store for the future

II. recent changes in temperature need to consider anthropogenic activity **Fig. 11.8**
  A. can't explain recent temp increase w/o anthropogenic radiative forcing
    1. radiative forcing – change in the balance between incoming and outgoing radiation
      a. climate system responds to restore balance
    2. positive radiative forcing
      a. lower atmosphere warms
  B. causes of radiative forcing
    1. change in greenhouse gasses
      a. increase/decrease IR flux out
    2. increase/decrease solar input
    3. change in planetary albedo

III. Planetary albedo **color pictures**
  A. controlled by aerosols, clouds, and ice/water/land distibution on earth's sfc.
  B. aerosols
    1. fine airborne particles
    2. tend to have a cooling effect - reflect light back to space
    3. also form cloud condensing nuclei
      b. clouds generally increase albedo
    4. aerosols produced by a number of processes
      b. volcanic activity - SO_2 oxidized to sulfate aerosols
        i. dust and aerosol prdn. from large volcanic events can significantly affect climate
        ii. need a period of protracted activity to have more than a short-term effect
      c. fossil fuel burning – also produces SO_2
        i. will their cooling effect effect counter warming effects ?
        ii. even a shorter term effect
  C. surface characteristics (ice/water/land distrib. on planets sfc) **show albedo figure**
    1. ice - high albedo (~0.8)

2. deserts and non-vegetated areas - lower albedo (~0.5)
3. oceans - low albedo, absorbs most solar radiation
4. land and aquatic plants - absorb almost all solar radiation (albedo ~0)
5. changes in sfc characteristc change global albedo
   b. e.g. - increase in the area of the oceans (sea level rise)
   c. will decr. planet albedo and inc. avg. temp.
6. similar effects associated with melting of sea ice or land-based ice

D. feedbacks also important here
1. global warming could change the rel. amounts of ice/ocean/veg/non-veg. land
2. this could change global albedo
3. mostly a positive feedback on global temp.

IV. Greenhouse effect

A. plays a role in controlling the earth's radiative balance
1. temp. controlled by a balance between
   a. the flux of incoming radiation from the sun
   b. the amount of outgoing IR radiation radiated from Earth
   c. re-distribution of radiation before radiated out to space

B. evidence of a "natural" greenhouse effect **Fig. 3-13**
1. see that some parts of the atmosphere are transparent to IR **Fig. 2.4**

C. what happens when we perturb atmospheric radiation balance with additional CO_2? **Fig. 2.8**
1. increased CO_2 lead to radiation imbalance - radiative forcing
2. balance restored by warming the lower atm - surface temp increase
3. positive feedbacks may further enhance this warming - more later
4. temp increase for a doubling of atmos CO_2 is referred to as ΔT_{2x}.

V. Atmospheric CO_2

A. Have seen that atmos CO2 has varied with glacial cycles
1. 180-200 ppm in glacials, 280-300 ppm in pre-industrial inter-glacials

B. recent increases appear to be due to anthropogenic activity **IPCC version Fig. 16.4**
1. increases due to fossil fuel burning and deforestation processes **Fig. 4**
2. increase in atmos CO_2 only half total anthropogenic CO_2 input
   a. some in oceans, some uptake by land biomass **TAR Table 2**
3. land-atmos flux is a <u>net</u> flux
   a. balance between land use change (e.g., deforestation) and terrestrial uptake sink (e.g., re-growth of new forests)

C. two issues of concern
1. where will the excess CO_2 from fossil fuel burning continue to go
   a. how will we have to change our activities to affect atmos CO_2 concentrations ?
2. what are the effects of this increasing CO_2 ?
   a. climatological and ecological
   b. use general circulation models to address this point

VI. Other greenhouse gasses

A. other greenhouse gasses are increasing with time **TAR Table 1**
1. appear to be associated with human activity

2. for some (eg, methane) why this link exists is not clear
3. important points
   a. what are the rel. contributions of these gasses to radiative forcing
   b. what are the atmos. lifetimes of these gasses

B. CH_4
1. appears to be due to
   a. increased prdn and/or increased atmospheric residence time
   b. cattle & rice paddies may be the major cause of anthropogenic incr.
   c. decreased methane oxidation in the atmosphere
2. methane has a rel short atmos residence time
   a. less of a long term effect than CO_2 or N_2O
3. rate of methane increase appears to be slowing with time **IPCC figure**
4. but …. methane clathrates **show clathrate pictures**
   a. frozen-methane ice compounds
      i. another possible source of methane
   b. found in some marine sediments and in high latitude/Arctic soils
   c. these are regions where projections of global warming suggest largest temperature changes
   d. global warming could release this methane
   e. could then provide a strong positive feedback for further warming
   f. also a geotechnical hazard

C. Water vapor
1. previous discussions suggested that changes in water vapor might explain rapid climate changes associated with D-O events
2. water vapor is the principal greenhouse gas
3. incr. warming should lead to increased evaporation
4. more water vapor and more warming - positive feedback
5. the amt. of water vapor also effects cloud formation

VII. Combined radiative forcing

A. positive and negative forcings **IPCC Fig**

B. atmospheric residence times important as well
1. extent to which these will be long-term forcing effects should inputs change

C. CO_2 contributes about 60% of the GHG radiative forcing (based on present day levels)
1. methane - 20%; CFC's – 14%; N_2O – 6%

VIII. Clouds **Fig. 3-18**

A. can both cool and warm
1. either reflect solar radiation from above or trap IR heat from below
2. balance between albedo effects and greenhouse effects

B. preliminary studies suggest clouds may have an overall net cooling effect
1. could then have a neg. feedback on greenhouse related global warming

IX. Evidence to date of climate change **show slide**

A. temperature records **show IPCC/Mann fig.**
1. combines proxy records (tree rings, sediment records) with actual measurements

2. see several trends
3. long-term cooling trend
   a. orbital variability and/or reduction in solar irradiance
4. multi-decadal to century variations
   a. poss, related to changes in solar irradiance
5. short-term (sub-decadal) variation
   a. sulfate aerosols and gasses - explosive volcanic eruptions
6. some of these external forcings are also modulated by internal variations in ocean/atmos processes
7. last 100 yrs natural forcing factors have been overwhelmed by anthropogenic greenhouse gas increases
   a. again, not monotonic trends
   b. recent increase appears to exceed the ~0.5°C range over the past 1000 yrs
   c. counter the recent long-term trend

B. other evidence **back to list slide**
1. atmospheric temp records
2. ocean warming
   a. global heat budgets
   b. all components of the Earth system are gaining heat
   c. oceans dominate
3. glacier melting
4. ecosystem changes
   a. high latitude tundras have gone from CO_2 sinks to sources
   b. increased temperatures have increased decomposition of peat
   c. began to see change in early 1980's
   d. prior to this these regions appear to have been CO_2 sinks for ~9,000 yrs
5. hydrologic cycle changes
   a. models of global warming predict that warming should lead to a more vigorous hydrologic cycle
   b. recent work has shown that northern (high lat) ocean waters are getting fresher and that low lat (equat.) waters are getting saltier
   c. appear to be occurring globally
   d. changes in salinity in the N Atl has implications for ocean circulation

C. IPCC conclusions **go thru slides**

X. CO_2 removal processes **show 90's IPCC budget figure**

A. examination of the IPCC perturbation budget shows where anthro CO_2 is going
   1. only aprox. half accumulates in atmos.
   2. some goes into ocean
      a. constrained by ocean circ. and efficiency of the biol. pump
   3. much recent work has focussed on uptake by terr. systems

B. N. Hemisphere reforestation
   1. in the 1980's IPCC budget this was rel. small and poorly constrained
   2. recent work suggests that this term is much larger
      a. better constrained using a variety of techniques

C. this uptake appears to counter CO_2 sources from land-use changes (deforestation)

D. mechanisms of how this uptake occurs remains elusive
    1. models and analyses suggest several possibilities
    2. CO_2 fertilization, changes in land management practices
    3. anthropogenic N deposition
        a. studies of forests suggest that this N deposition accounts for <20% of this proposed terr uptake.

E. problems with many of these removal processes are that the feedbacks seem to be positive
    1. global warming reduces their strength
    2. land use changes are also likely to saturate
        a. minimizing the sink strength with time

XI. Long-term models of atmopspheric CO2 increase **Fig. 16-2**

A. see discussions in book

XII. Projections of future atmos. CO_2 increases **Fig. 16-3**

A. approach it 2 ways
    1. look at how changes in emission affect atmos CO_2
    2. look at what are allowable emissions to stabilize CO_2 at different levels

B. all of these models are simply C cycle models
    1. don't include the complexities/feedbacks of incr. CO_2
    2. don't include the resulting effects on ocean/atmos/land processes due to changes in temp and/or radiative forcing

C. emission scenarios
    1. lead to substantial radiative forcings and temp increase
    2. doubling of atmos CO_2 (200-400 ppm) leads to a 4 W/m^2 radiative forcing
    3. ΔT_{2x} on the order of 1.5-4.5°C

XIII. Changes in greenhouse gasses cause changes in radiative forcing

A. how do we link these changes in radiative forcing to temperature changes

B. how can these changes be incorporated into climate models

C. assess the potential climate change associated with rising CO_2

D. what other feedbacks are associated with rising atmos CO_2 and increased radiative forcing

XIV. can use simple 1-d radiative-convection models **Fig. 18-3**

A. assume an average Earth surface and a vertically structured atmosphere
    1. calculate radiative balance in such a model (energy in = energy out) to get average surface temperatures
    2. force this model with rising levels of greenhouse gasses

B. such models predict a ΔT_{2x} of <2°C

C. other factors in the climate system also change in response to rising atmos CO_2

D. these feedbacks can't be dealt with in 1-d models
    1. are incorporated into 3-d general circulation models
    2. generally predict a larger ΔT_{2x}
    3. system operates in a positive feedback mode

XV. Climate feedbacks **models figure**

A. have discussed many in the past
B. play a role in amplifying climate change associated with glacial cycles
  1. water vapor feedback
  2. snow and ice albedo
  3. clouds
  4. ocean circulation
    a. affect climate in several ways
    b. high heat capacity of water means that the oceans warm more slowly than the atmos.
    c. buffers temperature changes
    d. also stores heat for later release
    e. ocean circulation plays a major role in redistributing heat globally

XVI. General circulation models - GCM's **Fig. 6-3**

A. complex numerical models that simulate ocean/atmosphere circulation with regard to energy balance and changes in specific forcing factors that affect these circulation processes
B. changes in temp will induce changes in other components of the earth system that may be either positive and negative feedbacks to global warming
C. GCM's have the potential to include these feedback (vs. 1-d radiative-convection models)
D. in spite of their imperfection these models are one of the ways to obtain info on possible future global change
  1. see later
  2. also can be used to help pinpoint where additional data is needed
E. link GCM's to carbon cycle models or ecosystem models
  1. examine linkages between physical forcings/feedback and biogeochemical processes in these other models

XVII. GCM general results - equilibrium models **back to Fig. 18-3**

A. a doubling of atmospheric CO_2 will likely lead to a 1.5 - 4.5 °C increase in avg. global temperature
  1. this is the equilibrium response due to the increased radiative forcing due to greenhouse gasses
  2. doesn't say when will this occur
    a. how quickly will climate respond to these changes
    b. will other positive or negative feedbacks that will change this initial response
B. global responses vary in space and time (seasonally) **Fig. 6-6**
  1. warming enhanced in high latitudes
  2. precipitation tends to increase
    a. related to increased evap. associated with warming
    b. more vigorous hydrologic cycle
  3. combined with temp changes this may lead to dramatic shifts in vegetation zones around the globe

XVIII. Transient responses of GCMs

A. many GCMs run the model to equilibrium and then change the boundary conditions (ie, double CO_2)
   1. these models assume oceans respond instantaneously to radiative forcing
   2. high heat capacity of the water means that oceans take longer to warm up
      a. thermal drag of the ocean

B. in transient models land also heats up faster than water

C. once transient response models reach equilibrium they generally show the same temperature increase predict the same show similar patterns as equilibrium models
   1. takes some time to occur after change in CO_2 **Fig. 6-5**
   2. uncouples emissions and temp increases **emissions/temp graph**

D. thermal drag also means that once the oceans warm up they will retain heat even as CO_2 levels/radiative forcing drop

XIX. IPCC model results (2001 TAR) **IPCC Figures**

A. use a hybrid of simple and complex transient response GCMs

B. these results use simple climate models that are tuned (calibrated) to complex models to yield an equivalent response in temperature and sea level rise
   1. allows these models to be run for a much larger number of scenarios
   2. predict significant changes in temp and seal level
      a. IPCC results predict a temp change of 1.4 – 5.8°C by 2100
   3. also predict changes in precipitation patterns

C. these model results allow for a re-examination of ΔT_{2x}
   1. previous IPCC "best estimate" was 3.8°C including possible feedbacks
   2. the calibration discussed above predicts a similar value of 1.7 – 4.2°C
   3. other model studies yield similar results
      a. re-inforces the IPCC result
   4. data since 2001 consistent with these model results **Fig. 1**

XX. Summary

A. greenhouse effect exists
   1. greenhouse gases are involved some way in past climate change

B. past climate changes can occur rapidly - decadal scales
   1. D-O events
   2. greenhouse gases are increasing due to human activities

C. rate of increase in unprecedented **mod Vostok record**

D. increasing evidence that we are beginning to see the effects of global warming

E. proposed future increases in temp are unprecedented in recent Earth history

F. suggest that increasing greenhouse gasses will lead to major climate and ecological changes

G. If we believe that we need to deal with incr. atmos. CO_2 how do we do it?
   1. demise of the Kyoto protocol
   2. present climate meetings in Bali on the 4^{th} Assessment Report