(lecture on 4/29/08)

Causes and Future of Global Warming

==========

Chapter 18 - Causes of Warming Over the Last 125 Years
the entire chapter

Chapter 19 - Future Climatic Change
the entire chapter

==========

Causes of Warming Over the Last 125 Years

What caused the rising temperature of the last 100+ years?
must determine how much is natural first
remainder will be human-caused

Solar Variability: Satellite monitoring of variations in the sun's output and observation of sun-like stars indicates that variation in solar irradiance not likely to be responsible for more than 0.1 °C of the 0.7 °C temperature rise since the late 1800s.

El Niños & Volcanic Eruptions: Warming events from strong El Niños and cooling events from explosive volcanic eruptions had only temporary effects (1 to 2 years) on climate.

Industrial Age CO_2: Atmospheric CO_2 concentration has been rising since the beginning of the industrial revolution as measured in ice core air bubbles and using the instrumental record beginning with 1958 (the Keeling curve). Only about half of the CO_2 emitted in power plants, factories, cars, etc. remains in the atmosphere. Some of our industrial era CO_2 has dissolved in the shallow mixed layer of the ocean and some has gone in to producing additional biomass (increased photosynthesis). We are well above the natural glacial-interglacial CO_2 range.

Methane from Agriculture: Methane is a much more potent greenhouse gas than CO_2, but it occurs in much lower concentrations than CO_2 because it quickly oxidizes. Methane is produced in the guts of livestock and by vegetation decaying in rice paddys. Atmospheric CH_4 concentration has been rising with the swelling of Earth's human population, as measured in ice core air bubbles and using the instrumental record beginning in the early 1980s. We are well above the natural glacial-interglacial CH_4 range.

Chlorofluorocarbons: CFCs are also very powerful greenhouse gases. They were produced as a refrigerant and for cleaning circuit boards in the electronics industry. They were discovered to be harmful to Earth's shielding ozone layer and have been phased out for most uses. They are next in importance after methane but their atmospheric concentration is on the decline.

Anthropogenic Agents with Cooling Effects

Sufate Aerosols: SO_2 emissions from burning fossil fuels produce minute sulfate aerosol particles in the air. Sulfate aerosols absorb some heat but their greater effect is reflecting sunlight. Sulfate aerosols therefore produce a cooling effect, but the magnitude is a subject of debate. Volcanoes are natural sources of SO_2 and sulfate aerosols. Sulfate aerosols are today well above the natural background levels, aside from those resulting temporarily from large volcanic eruptions.

Brown Cloud Haze: The brown haze of industrial pollution that hangs over industrialized regions in North America, Europe, and now especially Asia diminishes the sunlight reaching the Earth's surface, cooling the surface. This locally/regionally masks the effect of global warming. However the sunlight is absorbed at 2 to 3 km altitude warming the atmosphere there.

Tropical Deforestation: The large-scale clearing of the tropical rainforests in the Amazon and Indonesia returns CO2 to the air, which would tend to warm climate. But the high heat and poor tropical soil results in a somewhat barren landscape with a higher albedo than the rainforest had. The result is a net small cooling agent.

Totals

CO_2 Equivalents: Since the beginning of the Industrial Era

- CO_2 has risen ~35%
- CH_4 has risen ~150% - equivalent to a CO_2 rise of 12%
- all other greenhouse gases have produced the equivalent to a CO_2 rise of 13%
- Total CO_2 Equivalent Rise: ~60%

Change in Radiative Forcing: anthropogenic greenhouse gases have added 2.7 W/m^2 to the natural, preindustrial greenhouse effect of 150 W/m^2

- that is 1.8% of the total greenhouse effect
- 1% of the total incoming solar radiation

Climate Models

Predicted Temperature Rise Under 2X CO_2 Conditions

- Clear Sky models result in ~1.25 °C temperature rise
- but considering feedbacks in the climate systems

Range: 0.5 °C to 5 °C temperature rise (more recent models suggest 1.5 °C to 5 °C)

Modeling 2X CO_2 World:

Doubling atmospheric CO_2 from ~280 ppm (preindustrial) to 560 ppm should result in 1.25 °C temperature rise just from the additional CO_2, but also

Feedbacks:

2.5 °C temperature rise due to increased water vapor, and
0.6 °C rise due to decrease in ice and snow and decreased albedo
but more water vapor may mean more clouds…

Biggest Feedback-Related Uncertainty - feedback effects of clouds

Will there be more clouds or just more water vapor?

If more cloud, what kind?

- high, thin clouds warm the atmosphere
- low thick clouds cool the atmosphere

If clouds produce a moderately negative feedback (say -1.85 °C) then net global mean temperature will rise by 1.25 °C + 2.5 °C + 0.6 °C - 1.85 °C = 2.5 °C

Checking the Models - Determining Climate Sensitivity to Greenhouse Gases

Paleoclimate Data: Comparing model climate sensitivities to greenhouse gases with estimates of Glacial Max and Cretaceous Greenhouse climates (CO_2 & temp estimates) indicates that climate is relatively more highly sensitive to changes in greenhouse gases.

So true projected temperature rise should be at the higher end of projections.

CO_2 Rise and Modern Temperature: The 0.7 °C rise in temperature is smaller than predicted for the current level of CO_2 (should be ~1 °C). Maybe climate is not so sensitive to changing greenhouse gas concentrations as thought???

But, don't forget…

Lag Time: Climate hasn't fully responded to the increase in CO_2 due to response time.

The atmosphere and ocean surface respond fast.

The deep ocean, below 100 m, responds slowly.

(the deep ocean has, by far, the greatest thermal capacity)

Anthropogenic Cooling Agents: Climate hasn't fully responded to the increase in CO_2 due to cooling caused by sulfate aerosols and brown cloud haze. They have diminished the warming caused by greenhouse gases by perhaps 15%.

What Caused Rising Temperature in the 20th Century

Natural vs. Anthropogenic Climate Forcing

Climate Models that incorporate both natural and anthropogenic forcing match the observed climate trends. (IPCC, 2007)

Climate models that only use natural forcing do not predict 20th century warming.

Future Climatic Change

Population is rising to nearly 10 billion by the end of the 21st century. That will require more energy and more food. Current energy and agriculture systems are the principal causes for the increase in greenhouse gas concentrations.

Projected Carbon Emissions: Under the Kyoto protocol, signatory nations agreed to work quickly to reduce carbon emissions back to 1990s levels. However, under the most optimistic realistic projections, global carbon emissions (including non-signatory nations) wouldn't level off and then begin to decrease until somewhere in the middle of this century. Pessimistic projections in which we continue along our present rate of rising emissions considers that CO_2 emissions may not peak and begin to decline until well into the next century, due primarily to economics.

Projected Atmospheric CO_2 Concentrations: Under the more optimistic emission projection, atmospheric CO_2 concentration will rise to double the preindustrial concentration near the turn of the next century and then gradually decline over hundreds of years. Under the pessimistic projection, CO_2 concentrations might peak at more than four times the preindustrial level two or three hundred years from now, a century or more after the emission peak, but during a period of continuing high emissions. The Earth has not experienced over 1000 ppm CO_2 for tens of millions of years. These projections just consider CO_2. ignoring methane, and other greenhouse gases.

Eventual Fate of Anthropogenic CO_2 Pulse

- dissolving into deep ocean (hundreds of years)
- dissolving $CaCO_3$ (thousands of years),
  thus acidifying the deep oceans - the next chemistry experiment!

Melting of Methane Clathrate in Seafloor Sediments and Permafrost

another potentially dangerous positive feedback as rising temperature in the Arctic unlocks methane frozen in the permafrost and warming of the oceans potentially melts frozen methane in seafloor sedimentary strata of the continental shelves

Projected Temperature Increases From CO_2 Pulse

(assuming 2X CO_2 = 2.5 °C equilibrium temperature rise*)*

Earth's climate won't reach equilibrium unless we keep greenhouse gases high.

Earth's Temperature Future

We are likely to reach temperatures not seen for millions of years.

Temperature Rise by Latitude: In a 2x CO_2 world, temperature rise at high latitudes will be much greater than the global average temperature rise.

Antarctic and Greenland Ice Sheets:

won't all melt - too big

ice shelf breakup

2x CO2 World

The world in 2100 may be like the world 10 m.y. ago
less ice, greener deserts

4x CO_2 World

The world in a few centuries may be like the world 50 m.y. ago
little or no sea ice or mountain glaciers, forests in the high arctic

Changes in Length of Season

In a 2x CO_2 world, mid latitude summer will be longer and winter shorter by ~1 month.

Lingering Effects of CO_2 - CO_2 has a long residence time

Even if we stopped emitting all CO_2 today,
CO_2 concentrations would gradually decline
and climate effects would gradually diminish
over hundreds of years.

Changing Precipitation: IPCC (2007) climate models of future precipitation project wetter tropics and mid to high latitudes but drier subtropics.

The current IPCC estimate (2007)
indicates 0.2 - 0.6 meters of sea level rise by 2100.

Based on factors for which uncertainty can be estimated.

But that estimate does not include such factors as
increased flow of Greenland and Antarctic glaciers
and the effect of losses of Arctic Ocean sea ice
because the uncertainties are difficult to estimate.

The actual sea level rise could be much greater
- but that is uncertain!