Crib Sheet
David Archer The Long Thaw
Cooke 28/11/2013

"Globally about 2 billion dollars per year are being spent on climate change research, 50% of this in the United States. ...to put it in perspective, it amounts to only about 5% of the profits from the Exxon Mobil Oil company" (loc 310- location refers to Kindle edition**)**

14,000 y ago, Meltwater pulse 1A, equivalent of 3 Greenland ice sheets melted into ocean in a few centuries. Heinrich Events 30,000 - 70,000 BP(before present), melting of Laurentide ice sheet on N America. (loc 194)

In the past, sea level varied by 10-20 m for each 1^{o}C warming.(Loc206) ...may take thousands of years.

Total change in climate forcing from human GHG is now about 3 W/m^2, change from aerosols is -1 ~ -1.5 W/m^2. (577). The climate forcing from a large volcanic eruption -10W/m^2.Mt Pinatubo caused -4W/m^2, causing 0.6^{o}C cooling for 2 yrs. Solar variation ~ 0.1W/m^2.(589).

Last glacial max 21KBP. SL 120 m lower, 5~6^{o}C colder. Warming began 18KBP in southern hemis. Greenland remained cold until sudden rise 14KBP. Half of change to interglacial in Greenland happened in a few years. Mechanisms not fully understood, but thoughts to involve

1. N Atlantic Overturning disrupted by freshwater infusion
2. Sea ice albedo and insulation of air from water (air gets colder over ice)

Last glacial period ended suddenly, followed by sudden cold snap Younger Dryas, 12,800 - 11,500 BP. Medieval Optimum 800-1300AD, as warm as today. Little Ice Age 1300 - 1800 AD, 1^{o}C colder (probably caused by paucity of sun spots, => cooler sun).(847)

"8.2K event" 8,200 y ago, sudden cooling and draught for several centuries, due to disruption in Atlantic Ocean overturning circulation. Melting Laurentide ice sheet filled large Lake Agassiz, one side dammed by the ice sheet, caused large freshwater infusion in N Atlantic, blocking overturning.

Growth and decay of ice sheets seems to be paced by variations in Earth's orbit. 400,000 y cycle of eccentricity in E's orbit, now almost circular. Change in obliquity (plane of E's rotation), 40,000y. Large tilt causes more extreme seasons, currently near minimum tilt. Procession of axis of rotation, 20,000y.

Correlation of Temp in Antarctica and atmospheric CO_2 is astoundingly high."Even though the right answer is known in advance, models of the carbon cycle generally fall short of predicting the full change in the CO_2 in the atmosphere between the glacial and interglacial climate states"(1071)...."in the clearest climate transitions, which are the deglaciations, CO_2 goes up before the ice sheets melt" (1084).

Highest sea levels in the past 200 million years date to the Cretaceous, 100 million y ago, SL was 250~300 m higher than today, enough to submerge 1/3 of present land surface. If you melted all ice today, you would add 70m, not 300m. No agreed explanation, maybe changes in Ocean basin?

"A climate change of the magnitude of the deglaciation, 5~6^{o}C, would be catastrophic to human civilization. The forecast for future warming, 3~5^{o}C, is less than that for deglaciation, but the warming would take the planet to a climate unlike any in millions of years. A climate shift of this magnitude would rearrange the landscape and societies of the Earth"(1330). "The bottom line is that the global warming climate event is not unprecedented in Earth history. Climate changes through the glacial cycles were probably as severe as global warming has the potential to be."(1365).

"Missing sink", 2Gt C thought to go into northern land masses each year. How does this happen? some possibilities:

- longer northern growing seasons
- acid rain => nitrogen fertilization
- CO_2 fertilization

Land surfaces just about balances out as C sink or source, Deforestation almost balanced by high altitude uptake. Difficult to predict whether land will be source or sink in coming century.

Cold waters of ocean are exposed to atmosphere only in very high latitudes, although oceans cover 70% of E, these waters are just 2~3%. Transfer to deep ocean must pass through this small area. This cold dense water is made only sporadically, in coldest weather and under sea ice. (isolated from atmos). "If Greenland were to melt within a century, it would probably stop the formation of deep water in the North Atlantic. If surface waters warm, the density of the surface waters will decrease. There is also projected to be an increase of rain and snowfall in high latitudes, associated with the warming. If surface waters freshen, the density of surface waters would decrease still further. Future ocean stagnation could also slow the flow of heat into the ocean, affecting the rates of climate change and sea level rise"(1527).

Current models find that a 20~40% of a slug of new CO_2 will remain in atmos after 100 yrs. BAU scenarios give release of 1000~2000GtC to 2100. [that would be 500 ~ 1000ppm of which 100 ~ 400 remain in 2100. That puts us between 490 and 790ppm in 2100]. Releasing ALL fossil fuel carbon, incl coal would give 4000~5000GtC.

model simulations predict an increase of 10~15 ppm atmos CO_2 per 1^{O}C warming, as a result of ocean degassing. At end of ice ages the increase in CO_2 is much greater than can be explained by temp effect on solubility alone. Maybe changes in ocean circulation? "Simple calculations of the potential impact of ocean warming on the carbon budget do not look too terribly apocalyptic, but until the CO_2 rise at the end of the last ice age is understood, it will be difficult to be too confident about a forecast for the future."(1852).

Largest potential source of CO_2 is frozen methane, called calthrates or hydrates deposits. Most in ocean but some in permafrost. It will take centuries to warm the water column to the depth of hydrates (600-700m, but in arctic, 200m). Will it get to atmos quickly? Seismic studies show

"wipeout zones" where layer structure of sediment col. is gone. Thought to be caused by explosions of escaping gas. Evidence is in pockmarks and landslides, as off coast of Norway, Storegga slide, 2-3Ky after the warming of water at end of last glacial max. Storegga excavated top 250 m of floor in swath hundreds of km wide, stretching halfway to Greenland. Methane can leave the sediment in 3 forms, dissolved CH_4, bubbles of gas, and frozen hydrate. Methane bubbles can rise only a few hundred meters before they dissolve. Methane hydrates released from sediment could float in water like ice - this would be most efficient route to atmos.

"So far, no one has proposed any scenario by which a large fraction of the methane in the ocean hydrates could escape to the atmos all at once"(1899).

Thermokarst erosion happens when land ice is exposed to ocean, ice melts, land collapses exposing more ice etc. Northern coast of Siberia has been eroding in this way for thousands of years, but rates are accelerating. Waters of northern Siberian shelf have large concs of methane from coastal erosion. Total amounts of calthrate methane in permafrost are poorly known, 10 ~ 400GtC.

Ice sheets

Models and data from interglacials predict that Greenland ice sheet would melt significantly if summer temps were 3^{o}C warmer than today. How fast? models predict slow melt, but geo record contains many events of melting on order 100y, which models cannot reproduce. When ice sheet starts melting, friction from flow generates heat, accelerating flow.

West Antarctica Ice Sheet is marine, i.e. grounded below sea level. It is buttressed by Ross ice shelve. If these collapse (as did Larson B , March 5, 2002 (200 m thick, size of Rhode Island). Meltwater ponds are forming on the Ross. Ice sheet surface sends heat downward by moulins, why doesnt meltwater freeze? Not understood. WAIS would contribute 5 m SLR if it melted.

During Heinrich events and Meltwater pulse 1A, ice sheets collapsed in one century. "It appears that a 3^{o}C difference in global mean temperature has a huge impact on sea level, somewhere in the neighborhood of 50 meters. If the ice melts in a millennium, then a fossil fuel release of 2000Gt C would elevate temperatures to above 3^{o}C for that long. If on the other hand the ice takes 10 millennia to melt, then 5000GtC would be required to ultimately melt that much ice"(2082).

If we stay under 2^{o}C, then we will stabilize around 1^{o}C and the sea will rise by 4 or 5 meters...this is based on the last interglacial period where E was 1^{o}C warmer and sea 4 ~ 5 m higher. On longer time scales from the low glacial sea levels to Eocene high, indicates 10 ~ 20m SLR for each ^{o}C warming. (p147)