Lecture 1: Introduction

1. Bacon's Idols of the Hearth, Cave, Market Place and Theatre
2. CO_2 increase leads to temperature increase
   a. Proposed by Callendar in 1938---and previously by Arrhenius in 1896
   b. Controversial in terms of politics ideology and economics
   c. Roles of intellectual inertia and "file drawer" bias
   d. Also confirmation bias for some enthusiasts
3. Global Warming Evidence
   a. Measured CO_2 increase (311-400 ppm since 1957)
   b. Measured temperature increase (>0.7^{o}C since 1900)
   c. Measured sea-level rise (2-3 mm/ yr)
   d. Observed retreat of mountain glaciers and Arctic sea ice
   e. 2015 was the warmest year on record; 2016 may be warmer
4. Correlation does not prove causation.

Lecture 2: History of the Earth's climate

1. CO_2 has a significant role in climate. It is controlled by:
   a. Photosynthesis, weathering of igneous rocks, solution in the sea, oxidation of fossil fuels and other organic carbon….
2. Earth History:
   a. Earth cools enough to have liquid water ~ 4.1 Bya
      i. Sun 70% as bright as it is now
   b. Cyanobacteria start to make O_2 from CO_2 ~ 3.5 Bya
      i. $6CO_2 + 6H_2O + h\nu \rightarrow C_6H_{12}O_6 + 6O_2$
   c. Biological result is glucose, $C_6H_{12}O_6$, or $CH_2OH(HCOH)_4HCO$
   d. Aerobic respiration: $C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$ + biological energy
   e. Anaerobic respiration: $C_6H_{12}O_6 \rightarrow 3CH_4 + 3CO_2$ + less biological energy
3. Great Oxidation Event, 2.3 Bya
   a. $2Fe^{++}O + O_2$ (soluable) $\rightarrow$ $Fe^{+++}{}_2O_3$ (insoluble)
   b. Formed banded iron deposits and ozone layer which protects terrestrial life from soar UV
4. Two Snowball Earth events 2.5 & 0.75 BYA
   a. Planet (mostly) covered with ice
   b. Ice-albedo feedback. Sun was 15-20% dimmer than now
5. Supercontinents: Rodinia 1.2-0.75 Bya & Gondwana 550 Mya
   a. Then Pangaea formed 300-250 Mya and broke up to form modern continents
6. Multicellular life emerges at about 570 Mya.
   a. Earth was warm and seas transgressed over the land at the start of the Cambrian (540 Mya).
7. Extinctions: 5 including KT [Cretaceous-Paleogene (Tertiary)], which wiped out the dinosaurs (65 Mya) and "Great Dying", Permain-Triassic (251 Mya), and Ordovician-Silurian (440 Mya).
   a. KT due to meteor impact, others perhaps due to starts or ends of glacial episodes
8. Glacial episodes 520, 300 MYA and now

9. Isotopes (δ18O, δD, δ13C) as proxies for climate.
    a. Heavy isotopes (^{18}O) evaporates less easily and condenses more easily so that the lighter isotope (^{16}O) ends up in growing icecaps, leading to more abundant ^{16}O in the sea, biological debris, and sediments
10. Cenozoic 100 Kyr glacial cycles forced by changes in the Earth's orbital eccentricity
11. Historical temperatures: Medieval Optimum (~1000 ya), Little Ice age, then 20th and 21st Century Warming
12. Based upon instrumental record and diverse proxies

Lecture 3 Causes of Climate:

1. Climate changes naturally
2. Changes are forced by variations in:
    a. Orbital eccentricity, 100,000 yr period
    b. Obliquity, 41,000 yr period
    c. Precession, 21,000 yr period
    d. Ice age tempo is set by these orbital changes
    e. 90 kyr cooling 10 kyr warming
    f. Cool summers, when high-latitude ice doesn't melt and warm (sort of) winters when lots of snow falls, favor advance of the ice
    g. That is low eccentricity, low obliquity, and perihelion in winter
    h. Direct forcing is too small to explain temperature changes
3. Solar and galactic external forcing don't seem to be key factors
4. Cosine effect concentrates heating in the tropics
5. Nearly all of the heat absorbed by the planet is eventually radiated back to space
6. Atmosphere circulations and ocean currents move it poleward
7. Radiation to space is more broadly distributed
8. Radiation: Stefan-Boltzmann & Wien's Law (see slide 15 of the mid-term review)
9. Blackbody equilibrium temperature: Heating through absorbed visible radiation balances emitted infrared radiation
10. Atmosphere is (more-or-less) transparent to incoming visible (wavelength 0.4-0.7 µm) radiation and opaque to outgoing IR (wavelength longer than 0.4 µm)
11. Water vapor is main greenhouse gas, but CO_2 is the most important *anthropogenic* greenhouse gas.
12. CO_2 blocks the long wavelength end of 10 µm infrared window
13. Seasonal and latitudinal distribution of insolation
14. Strong midsummer solar radiation (sun is low in the sky, but never sets) in Arctic and Antarctic, which gets reflected from snow or ice, but absorbed by open water, tundra, or bare rock.
15. Ice and cloud albedo feedbacks accentuate CO_2 forcing
16. Raising of effective radiation altitude in tropics and middle latitudes
17. No measurable AGW effect on tropical cyclones so far

Lecture 4: Climate Models

1. Models used to understand & predict both weather and climate
2. Based upon the partial differential equations that describe the atmosphere

   a. Prognostic equations yield the time rate of change of one variable as a function of the other variables at a specific time
   b. Diagnostic equations relate variables at a specific time but not their rates of change
3. Grid-point GCMs
   a. Prognostic and diagnostic equations
      i. Prognostic: Contain time rate of change of one variable
      ii. Diagnostic: Relate variables independently of time changes
   b. Leap-frog time marching, for example
   c. Dynamics: Wind and Pressure
   d. Physics: Radiation, Convection, Surface properties, friction
   e. Role of resolution-
      i. CFL Criterion: $\Delta tC/\Delta x < 1$
      ii. Moore's Law: Computing power doubles every 18 months
   f. Toy, spectral, and finite element models
   g. Marching Problems: Advance the state variables forward in time using prognostic equations.
   h. Jury Problems obtain solutions subject to specified boundary conditions usually by eliminating time changes algebraically or assuming that they are slow
   i. Sensitivity to Initial Conditions: Result of a marching process can be very different if the starting point is only slightly different
4. Models reproduce 20th Century climate, but <u>only</u> with anthropogenic forcing
   a. Without Anthropogenic forcing, the modeled planet cools slightly
5. Coupled Model Intercomparison Project runs the same simulations with different models.
6. Greenhouse gas emissions modeled:
   a. CO_2, NO_2, CH_4, CFCs
   b. CO_2 is most important: Increasing 1.5 ppm/yr or 3-4Gt/yr
7. Emission Scenarios:
   a. A1F, A1B, A1T: Globalization with fossil fuels, mixed, and green energy productions. Population maximum in mid 21st Century
   b. A2: Slower and more fragmented economic growth. Continuing population growth
   c. B1: Greener globalization. Population max in mid 21^{st} Century, as in A1
   d. B2: Lower-tech with growing population through 2100
   e. Predicted warming ranges from 2C (B1) to 4C (A1F)

Lecture 5: Photosynthesis

1. Photosynthesis makes sugars $6CO_2 + 6H_2O \text{ --> } C_6H_{12}O_6 + 6O_2$ in chloroplasts of plants
2. Role of ATP
   a. Made (regenerated ADP --> ATP) when sun shines on Chlorophyll in green plats
   b. Used in Calvin-Benson cycle to make glucose, converting ATP → ADP.
   c. Glucose is used in mitochondria (of plants & animals) to make ATP (ADP --> ATP)
   d. ATP supplies energy for everybody's metabolism (ATP --> ADP)
3. C3 Photosynthesis (rice wheat)

   a. CO_2 absorbed directly from air with stomata open when it's hot
   b. Photosynthesis in palisade cells
   c. Energy efficient, water inefficient
   d. Better in wetter, cooler, high CO_2 environments
   e. Elevated CO_2 increase yields, but decreases protein production
4. C4 Photosynthesis (maize, corn)
   a. CO_2 stored in spongy mesophyll cells as bicarbonate (HCO_3^-) during the night
   b. Released as CO_2 in bundle sheath cells
   c. Photosynthesis in chloroplasts
   d. Less energy efficient, more water efficient
   e. Better in dryer, warmer, low CO_2 environments
   f. Not so responsive to elevated CO_2
5. CAM Crassuleacean acid metabolism(Cacti)
   a. Absorb CO_2 during the night, phorosynthesize during the day
6. Bottom line: Higher CO_2 levels and warmer temperatures may extend areas where crops grow.
7. But protein content of C3 crops (rice, wheat) may decrease (Bloom's hypothesis)