

Conceptual Summary/Outline of Topics Covered Throughout Semester

- a) Probabilities:
 - a. One random event is independent of the next
 - b. Probabilities of exclusive events multiply (“and”)
 - c. Probabilities of inclusive events add (“exclusive or”)
 - d. All probs sum to 1 (normalization)
 - e. Probs must be non-neg
 - f. You can observe 1 thing many times or many things once
 - g. Particular outcomes are likely because their multiplicity is high
- b) Measurements have uncertainties
 - a. Uncertainty is characterized by σ (68% of trials within 1σ)
 - b. Reduce uncertainties by taking multiple readings
- c) Exponential growth and decay
 - a. Applies when what-you-will-have depends on what-you-have-now
 - b. Frequency of compounding varies
 - c. Continuous compounding (only) leads to $N=N_0e^{\lambda t}$
 - d. Applies to decay (radioactive) if $\lambda < 0$
- d) Philander Chap 1
 - a. Changes in the environment can be exponential in nature and we don’t know at what stage in the growth curve we presently exist.
 - b. Scientific results have uncertainties. Don’t use this as an excuse for failing to make policy decisions (e.g. Failure to act on NE fisheries).
 - c. Policy should mirror scientific method: periodically review and adjust as observations indicate success/failure
- e) Philander A1.2 and Ruddiman and Broecker
 - a. Past climates help us understand present and future, since we can’t conduct a controlled experiment.
 - b. Past climates recorded in archives:
 - i. Sediment cores (lake and ocean)
 - ii. Ice cores
 - iii. Glacial moraines
 - iv. Corals
 - v. Tree rings
 - vi. Loess (windborne dust)
 - vii. Historical records (accidental)
 - viii. Deliberate historical and instrumental
 - c. Methods of dating
 - i. Radiometric
 - 1. atomic structure and isotopes
 - 2. radioactivity: β -decay, e^- capture, fission
 - 3. ^{14}C : origin and fate and limitations
 - 4. Rb/Sr: challenges and advantages
 - ii. Layer counting
 - iii. Cross correlation (including magnetic field reversals)
 - d. Limits on resolution of dates in archives
- f) Philander Chapter 2
 - a. Planet (actually, its climate) is both fragile (our perspective) and robust (life in general)
 - b. Emphasis on role of observation as guide for scientific inquiry and refinement of theory (e.g. caloric theory of heat)
 - c. Conservation laws (momentum, charge, energy/mass, angular momentum)
 - d. Chaos: Strong dependence on initial conditions

- i. Limits on weather predictability due to limited knowledge of initial conditions
 - ii. “Chaotic” is not the same as “random” or “without order”
 - iii. Different scales of predictability: seasonal (yes) vs. weekly (no)
 - e. Models: Eliminate all irrelevant properties. Strip system to essence to make predictions possible. The “essence” depends on the question you are trying to answer. A model that is good for one purpose might not be good for another.
- g) Philander A2.1
 - a. Gaia Hypothesis and Daisyworld: focus on feedbacks
 - i. Feedback: use of info about present state of system determines actions used to regulate system.
 - ii. Positive vs. negative feedbacks
- h) Philander Chapter 3 and A3.2-3.5
 - a. Temperature regulation of planets:
 - i. Distance from sun
 - ii. Albedo
 - iii. Atmospheric thickness and composition
 - b. Heat transfer: Heat is random (disordered) motion of molecules
 - i. Radiation: Continuum of E-M wavelengths and energies
 - 1. Amount and wavelength is proportional to T^4
 - 2. Wien’s law (T from λ_{max})
 - 3. Blackbody curves: Information from area and peak, units.
 - 4. Kirchhoff: good absorbers are good emitters
 - ii. Conduction: collisions of molecules with adjacent molecules (good and poor conductors)
 - iii. Convection (really a subclass of conduction).
 - 1. Fluid (air, water, magma) in contact with hot surface
 - 2. Heat transfer to interface layer of fluid by conduction, followed by bulk motion carrying heated fluid away.
 - 3. In absence of active device for circulation of fluid, gravity is essential (buoyancy driven convection)
 - 4. Can be very effective (i.e. leads to rapid heat transfer).
 - iv. How does insulation work (fiberglass batting, space blankets, etc.): suppression of convection, poor conductor.
 - c. Scattering of Light
 - i. Young’s double-slit experiment proves wave nature of light
 - ii. Depends on both size of scatterer and λ .
 - iii. If λ is large compared to R, scattering $\propto \lambda^{-4}$
 - iv. Leads to blue skies and sunsets
 - d. Absorption and emission of light
 - i. Einstein Photoelectric effect proves particle nature of light: essential for discrete absorption lines.
 - ii. Bulk (blackbody) vs. Molecular/Atomic (spectral lines)
 - e. Greenhouse effect
 - i. Radiative balance: energy in = energy out
 - ii. Transparent atm in visible, opaque in IR
 - iii. Models of increasing sophistication
 - 1. blackbody, no albedo, no atm.
 - 2. albedo, no atm
 - 3. no albedo, single-layer atm
 - 4. albedo, single-layer atm
 - 5. no albedo, multi-layer atm
 - 6. etc...
- i) Philander Chapter 4 and A4.1-4.2
 - a. Atmosphere is no longer static or dry
 - b. Concepts of pressure: with and without gravity.
 - c. Ideal gas law (conceptual derivation)

- d. Temperature: a willingness to give up energy
 - e. Heat Capacity and Specific Heat Capacity
 - f. Conceptual description of hydrostatic balance
 - g. Combination of hydrostatic balance and pressure leads to barometric equation (in case of isothermal atmosphere)
 - h. Pressure equilibrium and adiabatic processes \Rightarrow adiabatic lapse rate
 - i. Stability of atm as function of observed lapse rate
- j) Philander Chapter 5 and A5.1-5.3
- a. Sensible vs. Latent heat
 - b. Heat of fusion/vaporization
 - c. Partial pressures
 - d. Vapor pressure (e), saturation vapor pressure (e_s) and relative humidity
 - e. Clausius-Clapeyron relation
 - f. Runaway greenhouse
 - g. Condensation nuclei and supersaturation
 - h. The origin of deserts
 - i. Cold, Warm and Stationary fronts and precipitation
- k) Philander Chapter 6 and A6.1, 6.2 and 6.4
- a. Pressure gradient as driving force for winds
 - i. Sea breezes
 - ii. Monsoons
 - b. Isobaric surfaces and baroclinic structure.
 - c. Definition of velocity, acceleration, vector addition and $F=MA$
 - d. Inertial reference frames and fictitious forces
 - e. Coriolis force for motion in the horizontal plane
 - f. Conservation of angular momentum
 - g. Geostrophic balance
 - h. Gradient winds
- l) Philander Chapter 7, and review of 2nd law
- a. Entropy as a measure of disorder vs. multiplicity
 - b. Connection between multiplicity and probability
 - c. Connection between energy, multiplicity, and temperature
 - d. Heat flow driven by most likely outcomes
 - e. Spatial structure of planet's radiation balance
 - f. Hierarchy of models requiring:
 - i. Radiation balance
 - ii. Albedo
 - iii. Multi-layer atmosphere
 - iv. Convection
 - v. Hydrology
 - vi. Topography
 - vii. Detailed radiative properties of atmosphere
 - viii. Energy, momentum, angular momentum and mass conservation
 - g. Differences between data-assimilation models and full GCMs
 - h. Fundamental limitations of models (sparse data and computational resources)
- m) Philander Chapter 8 and Appendix 8
- a. Vertical distribution of nutrients and biology
 - b. Thermohaline circulation
 - i. Density of seawater and equation of state
 - ii. Evaporation/precipitation
 - iii. Deep-water formation and thermohaline shutdown
 - c. Spatial patterns of biological productivity
 - d. Wind-driven currents
 - i. Subtropical gyres
 - ii. Ekman transport and upwelling
 - iii. Coastal (Ekman) upwelling

- iv. Equatorial undercurrent
 - e. Desalination
- n) Philander Chapter 10 and Appendix A10
 - a. CO₂ sources and sinks on geological time scales (volcanism, weathering, tectonics)
 - b. Venus: runaway greenhouse → photolysis → water loss
 - c. Mars: small → heat loss → no tectonics → no CO₂ recycling
- o) Philander Chapter 11 and appendix A11
 - a. Why are poles colder than equator? Reduced intensity of light flux.
 - b. What causes seasons?
 - i. Tilt of axis
 - ii. Eccentricity of orbit
 - c. What causes ice ages?
 - i. Eccentricity cycle
 - ii. Obliquity cycle
 - iii. Precession cycle
 - d. Evidence of ice ages and the link with solar forcing
- p) Philander Chapter 12 and appendix A12
 - a. Multinational policy-making bodies: WMO and IPCC
 - b. Tropospheric vs. stratospheric ozone
 - c. Ozone depletion vs. climate change
 - d. Halogens as depleters of stratospheric ozone
 - e. Atmospheric monitoring and other records of ozone depleting compounds
- q) IPCC report: Working Group I (The science of climate change) Summary for Policymakers
 - a. Structure of the report and the IPCC process
 - b. What has changed since previous reports
 - c. Historical records and evidence of warming
 - d. Human actions driving climate change
 - e. Projections of future climate change
- r) Philander Chapter 13
 - a. Link between climate and the carbon cycle
 - b. The carbon cycle on geological and human time scales
 - c. Interconnected feedbacks in the climate leading to uncertainties
 - i. Water vapor
 - ii. Clouds
 - iii. Albedo (Ice, clouds, land use)
 - iv. Carbon cycling and CO₂ in atmosphere
 - v. Black-body radiation
- s) Student presentations: See file of abstracts distributed by e-mail.