**Conceptual Summary/Outline of Topics Covered Before 2nd exam**

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 $\sigma$ (68% of trials within $1\sigma$)
   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: $\beta$-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 $\lambda_{max}$ )
            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 $\lambda$.
        iii. If $\lambda$ 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. Coriolus 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 2$^{nd}$ 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)