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SIO 217a Atmospheric and Climate Sciences I: Atmospheric Thermodynamics

Fall 2014 Final Exam (No calculators, notes, books, PDAs.)

Curry and Webster, Ch. 1-8, 12, 13

No calculators or other devices are allowed. Write all calculations explicitly in terms of numbers, but you do not need to evaluate the exact numerical answer. Remember, if any question seems unclear or if you think there is missing information, state what is unclear and make a reasonable assumption about the missing information so that you can proceed with your answer.
And, of course, show your work!

Here are some numerical values, some of which may be useful on this exam:
Average radius of Earth: 6370 km
Mean reflectivity of the Earth: 0.31
Mean molecular weight of dry air: 29 g/mole
Mean molecular weight of water vapor: 18 g/mole
Gas constant for dry air, $\boldsymbol{R_d}$: 287 J deg^{-1} kg^{-1}
Gas constant for water vapor, $\boldsymbol{R_v}$: 461 J deg^{-1} kg^{-1}
Specific heat at constant pressure, $\boldsymbol{c_p}$: 1004 J deg^{-1} kg^{-1}
Specific heat at constant volume, $\boldsymbol{c_v}$: 717 J deg^{-1} kg^{-1}
Latent heat of vaporization for water at 273K, $\boldsymbol{L_{lv}}$: 2.5×10^{6} J kg^{-1}
Solar luminosity: 3.92×10^{26} W
Earth-sun distance: 1.50×10^{11} m
Stefan-Boltzmann constant, $\boldsymbol{\sigma}$: 5.67×10^{-8} W m^{-2} K^{-4}

1. **Köhler/Clouds/Stability Question (20 pts):** Warm clouds are typically found in the lower troposphere and contain droplets of liquid water.
   a. Are particles required to form clouds in Earth's atmosphere?
   b. Will adding particles cause subsaturated air to exceed RH=100%?
   c. Can a cloud form if RH<100%?
   d. If the parcel rises in cloud adiabatically, what is the lapse rate for the parcel <u>in the cloud</u>?
   e. Sketch and state how you would derive the lapse rate in part (c).
   f. What quantity describes the potential energy that is available for convection in the cloud?

2. **Definitions Question (15 pts):** Define the following terms in 10 words or less; an equation, graph, or sketch may be added if appropriate:
   a. potential temperature
   b. absorptivity
   c. hydrostatic balance
   d. conditionally stable
   e. state function

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3. **Term Project Question (10 pts)**: Answer TWO of the following questions for the four cloud types considered as part of the term projects (Arctic, Marine Stratus, Cumulus, Cirrus); be brief, but include graphs, sketches, or key variables in your answer.
   a) Which cloud types have high and which have low reflectivity? Explain why.
   b) Which cloud type has reflectivity that is the most sensitive to aerosol concentration?
   c) Which cloud types form more and which form less precipitation? Explain why.
   d) Which cloud has precipitation that is most sensitive to aerosol size?

4. **First/Second Laws Question (15 pts):** In a saturated air parcel, the temperature changes are often largely due to the condensation of water. State the assumptions of your approach.
   a) Write the consequences for du and dh from the first law of thermodynamics, assuming an adiabatic, reversible process with no pressure change.
   b) Show how (a) can be used to calculate the change in temperature resulting from the amount of water condensed in cloud.
   c) State the assumptions that you made in the calculation in (b).

5. **Clausius Clapeyron Question (20 pts):** A local company has proposed to produce freshwater from the water vapor in ambient air at Point Loma. Assume the air at their Point Loma site is at sea level and is 20°C and 100% RH. The saturation vapor pressure (of water) at a temperature of 20°C is 21 hPa. Then they cool the air using passive geothermal cooling (by expansion in a duct) to 10°C. (Assume that no water actually freezes, so that you remain just above freezing throughout.) State how you would find the values below from the information provided in this exam for the air (after this cooling), including any laws, equations, and assumptions used, and simplifying as much as possible:
   a. saturation vapor pressure (of water) at 10°C.
   b. specific humidity.
   c. potential temperature.
   d. the amount of water expected to condense to liquid for each kg of air cooled.
   e. [BONUS] whether and how (or why not) this could be used to generate power.

6. **Climate Model Sensitivity Question (20 pts)**
   a. Define climate sensitivity (e.g. for $2xCO_2$) and give an approximate value (specify units).
   b. Why do different global climate models get different temperature changes for the same forcing (e.g. for $2xCO_2$)?
   c. Does the simple climate model from Ch. 12 include forcings, feedbacks, or both? Describe the model and explain what is and isn't included and why.
   d. Explain, without using scientific jargon, why the Earth warms when additional greenhouse gases are added to the atmosphere.

Congratulations, you are done! Now go back and check your work so that you make sure you didn't misread something.