※ 注意：全部題目均請作答於試卷內之「非選擇題作答區」，請標明題號依序作答。

Multiple Choice: Please choose the most appropriate answer [25 points]

1. What fraction of the solar radiation that arrives at the top of the atmosphere is absorbed at the Earth's surface? **a)** 90%, **b)** 50%, **c)** 20%, **d)** 10% [5 points]

2. How large is the rate of terrestrial radiation emission from the Earth's surface compared to the solar radiation that arrives at the top of the atmosphere, globally averaged? **a)** 110%, **b)** 50%, **c)** 25%, **d)** 10% [5 points]

3. The energy balance in the troposphere is an 'approximate' balance between the two largest terms which are, **a)** heating by ozone and cooling by emission from water vapor, **b)** heating by ozone and cooling by emission from carbon dioxide, **c)** heating by condensation of water and cooling by longwave emission from water vapor, **d)** heating by absorption of solar radiaton by water vapor and cooling by longwave emission from water vapor. [5 points]

4. Suppose the direction of Earth's rotation were reversed, so that the sun rises in the west and sets in the east. Otherwise, the reverse Earth's boundary conditions (e.g., insolation at the top of the atmosphere) remain unchanged from what they are now. How would the annual mean zonal mean surface wind direction be? **a)** northeasterly in northern tropics and northeasterly in northern midlatitudes, **b)** northwesterly in northern tropics and southeasterly in northern midlatitudes, **c)** northeasterly in northern tropics and southwesterly in northern midlatitudes, **d)** southwesterly in northern tropics and northeasterly in northern midlatitudes, **e)** southwesterly in northern tropics and southeasterly in northern midlatitudes [5 points]

5. Suppose the rotation speed of the Earth's was doubled. Otherwise, the fast-spinning Earth's boundary conditions (e.g., insolation at the top of the atmosphere) remain unchanged from what they are now. How would the atmospheric circulation change? **a)** The edge of the Hadley cell would expand poleward and the upper level subtropical jet would be stronger than current condition. **b)** The edge of the Hadley Cell would expand poleward and the subtropical jet would be weaker than current condition. **c)** The edge of the Hadley cell would shrink and there will be multiple jets in mid-to-high latitudes. **d)** The edge of the Hadley cell would shrink and the subtropical jet would shift poleward, detaching from the Hadley cell, due to stronger Coriolis effect [5 points]

Calculation Problems: Please list all steps [30 points]

Some constants you may need:　　1AU (astronomical unit) is about 1.5×10^{11} m

Solar luminosity 3.9×10^{26} W　　Stefan-Boltzmann constant 5.67×10^{-8} W $m^{-2}K^{-4}$

Earth's radius 6.37×10^{6} m　　Earth's rotation speed 7.292×10^{-5} s^{-1}

air densitiy ρ 1.2 kg m^{-3}　　specific heat at constant pressure $c_p = 1004$ J $kg^{-1}K^{-1}$

6. Pluto's orbit around the sun is extremely eccentric. At its closest point (perihelion), Pluto's distance from the sun is 29.7 AU. At its farthest point (aphelion), Pluto's distance from the sun is 49.5 AU. Pluto's Bond albedo is about 0.5. What would be Pluto's effective temperature at perihelion and aphelion if it were at all times a perfect blackbody in equilibrium with the insolation? [10 points]

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7. If the Earth north of 60°N loses 100Wm^{-2} of energy to space in the annual average, what is the annual average northward flux of energy in the atmosphere and ocean across 60°N? Give your answer in petaWatts (10^{15} Watts). [10 points]

8. Calculate and compare the rates at which longwave emission and sensible heat flux vary with surface temperature Ts. In other words, if the surface temperature rises by 1°C, by how much will the longwave and sensible cooling increase? (Hint: The blackbody emission from the surface can be linearized about some reference temperature T_o = 288K. The sensible heat flux and be calculated by bulk aerodynamic formula. Assume aerodynamic transfer coefficients for temperature $C_d = 2 \times 10^{-3}$ air densitiy ρ is 1.2 kg m^{-3}, specific heat at constant pressure c_p is 1004 J kg^{-1}K^{-1} and wind speed at reference height U = 5 m s^{-1}.) [10 points]

Short Answer Questions: Please use complete sentences to answer the questions [45 points]

9. In the stratosphere, the temperature increases with altitude. The stratopause is the region where a maximum in temperature occurs. This maximum is a direct result of the absorption of ultraviolet radiation by ozone. However, the height of stratopause does not align with the height with maximum ozone (See Figure 1). Please explain why the altitude of maximum absorption rate is higher than the altitude that ozone partial pressure peaks. [5 points]

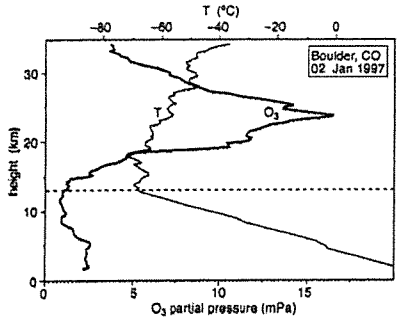

Figure 1. A typical winter ozone profile in middle latitude (Boulder, CO, USA, 2 Jan. 1997). The heavy curve shows the profile of ozone partial pressure, and the light curve temperature plotted against altitude up to about 33km. The dashed line shows the approximate position of the tropopause.

10. Please describe (1) what is Gulf stream (2) its formation mechanisms, and (3) its affect on climate. [15 points]

11. Water is essential to life on Earth. Water in its liquid, gaseous, and frozen phases ties together major pieces of the Earth/climate system - air, clouds, ocean, lakes, vegetation, snowpack, and glaciers. Please discuss the role of water in our climate system. Please provide specific examples in your discussions. [15 points]

12. Polar amplification refers to the observation that any change in the net radiation balance (for example greenhouse intensification) tends to produce a larger change in temperature near the poles than the planetary average. Please list two mechanisms causing polar amplification. [10 points]

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