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UNSW
THE UNIVERSITY OF NEW SOUTH WALES

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PHYS2801: Atmospheric Science
CLIM2001: Atmospheric Science

1. TIME ALLOWED – 2 hours
2. READING TIME – 10 minutes
3. THIS EXAMINATION PAPER HAS 7 PAGES
4. TOTAL NUMBER OF QUESTIONS – 12
5. MARKS AVAILABLE 100. MARKS FOR EACH QUESTION ARE SHOWN IN THE EXAMINATION PAPER.
6. ANSWER 5 DESCRIPTIVE QUESTIONS FROM SECTION 1 AND 4 QUANTITATIVE QUESTIONS FROM SECTION 2.

   I) IF YOU WORK ON MORE THAN THIS NUMBER OF QUESTIONS, PLEASE MAKE CLEAR WHICH YOU DO NOT WISH TO BE SCORED, OTHERWISE THE FIRST QUESTIONS ATTEMPTED IN EACH SECTION WILL BE MARKED.

   II) THE DESCRIPTIVE QUESTIONS (1-6) SHOULD EACH BE ANSWERED IN A SHORT PARAGRAPH OF USUALLY 3-4 SENTENCES. FOR THE QUANTITATIVE QUESTIONS (7-12), YOU WILL GENERALLY NEED TO DERIVE OR WRITE DOWN A SYMBOLIC EXPRESSION AS WELL AS PROVIDING A QUANTITATIVE ANSWER IN ORDER TO GET FULL MARKS. YOU WILL GET MOST OF THE CREDIT IF THIS EXPRESSION IS CORRECT. IF YOU SHOW YOUR WORKING YOU MAY STILL GET PARTIAL CREDIT FOR WRONG ANSWERS.

7. CANDIDATES MAY BRING AN APPROVED UNSW CALCULTOR TO THE EXAMINATION.
8. ALL ANSWERS MUST BE WRITTEN IN INK. EXCEPT WHERE THEY ARE EXPRESSLY REQUIRED, PENCILS MAY BE USED ONLY FOR DRAWING, SKETCHING OR GRAPHICAL WORK
9. THIS PAPER MAY BE RETAINED BY CANDIDATE

Section 1.

Descriptive questions [Answer 5 questions, each question is worth 8 marks. Total of 40 marks]

1) Explain how the trace gases in the atmosphere give rise to the greenhouse effect.

2) Explain how polar temperatures remain stable on long time scales even though the poles are losing more heat through infrared radiation than they gain from sunlight, even in summer.

3) Explain why the ice-albedo feedback may increase the "climate sensitivity".

4) Explain why the wet-bulb temperature is not as low as the dewpoint temperature in unsaturated air.

5) The geostrophic wind blows parallel to isobars. Close to the surface of the Earth, the wind is not perfectly geostrophic, but has a component that moves from high- to low-pressure. With the aid of a diagram showing the important forces involved, explain why this is the case.

6) It is thought that seeding clouds with unusually large aerosol particles can increase the likelihood of rain. Explain how this might work.

Section 2.

Quantitative questions [Answer 4 questions, each question is worth 15 marks. Total of 60 marks]

7) The Earth's atmosphere can be modelled as a single atmospheric layer in radiative equilibrium with the ground and the incoming solar flux. Let the ground and atmospheric temperatures be T_g and T_a respectively and assume Earth has an albedo of 0.30, solar absorptivity 0.10 and atmospheric emissivity of 0.80.

(a) Draw a flux balance diagram for Earth, labelling all fluxes in your model.

(b) Why do we consider shortwave and longwave radiation separately in the model?

(c) Now write the flux balance equations for:
i. Incoming and outgoing radiation.
ii. The atmospheric layer.
iii. The ground.

(d) Solve your equations to find the ground and atmospheric temperatures.

(e) If a volcano erupted and released high-albedo aerosols into the stratosphere, how would the temperatures change and why?

8) A geostationary satellite is imaging the Earth in the thermal infra-red with a wavelength of 10 μm. Assume the extinction coefficient of the atmosphere is k=0.0012 m^2/kg. This question addresses how far the satellite can see into the atmosphere.

(a) For imaging the surface, why is it advantageous for thermal infra-red imagers to observe at 10 μm?

(b) Determine the atmospheric density profile ρ(z) from the formulae and constants given below.

(c) Now compute the optical thickness of the atmosphere as a function of altitude. Remember the satellite is facing towards Earth and observing upwelling radiation.

(d) By applying Beer's law, determine how far the satellite can see into the atmosphere. Give your answer as an altitude in km. Assume visibility is defined by a transmission of 2%.

9) A low pressure system of radius 1000 km has formed near Sydney (35 degrees S) and is no longer developing.

(a) State the two forces that, when balanced, give the geostrophic component of the wind-speed. Starting from the formula given at the end of the question sheet, show that the expression for the zonal (*x*) component of the geostrophic wind can be written as

$$u_g = -\frac{g_0}{f}\frac{dZ}{dy}$$

where Z is the geopotential height. You may use the vector identity $\underline{k} \times \underline{k} \times \underline{a} = -\underline{a}$

(b) If the (geopotential) height of the 1000 hPa surface is 30 m lower at the centre than the edge, calculate the geostrophic wind-speed on this surface.

(c) Using the equation for the geostrophic wind-speed in (a) and the hypsometric equation, derive an expression for the thermal wind, which gives the difference in the geostrophic wind-speed at two heights

$$u_{g2} - u_{g1} = \frac{R}{f}\ln\frac{p_1}{p_2}\frac{d\bar{T}}{dy}$$

(d) If the vertically-averaged temperature at the core of the system is 5 degrees warmer than at the edge, at what pressure level does the geostrophic component of the wind-speed become zero?

10) A spacecraft is cruising through the air on a planet that is identical to the Earth (same atmospheric composition and surface gravity), except with no water vapour, and an unknown atmospheric mass. This atmosphere is well-mixed and neutrally stable. The cabin pressure and temperature are 850 hPa and 20 °C, the cruising altitude is 10 km, the cruising pressure is 200 hPa and temperature is 200 °C.

(a) Use the first law of thermodynamics to derive the dry adiabatic lapse rate formula, and evaluate it for this planet.

(b) Describe what is meant by a "scale height". Using the temperature measured outside the spacecraft, estimate a scale height for the atmosphere of the planet, and from that an approximate surface pressure.

(c) The airlock on the spacecraft is breached, causing the cabin pressure to equalise suddenly with that outside. What is the new temperature in the cabin? Hint: use the 1st law of thermodynamics to derive an expression for the temperature change given by rapid transition between two pressure values.

11) Use the F160, or *skew T – ln p* diagram provided to answer this question.

(a) Plot the following sounding

	Pressure level (hPa)	Air temperature (°C)	Dew point (°C)
A	1000	30	21.5
B	970	25	21
C	900	18.5	18.5
D	850	16.5	16.5
E	800	20	5
F	700	11	-4
G	500	-13	-20
H	250	-35	-50

(b) Are the layers AB, BC, CD etc stable, unstable, or in neutral equilibrium?

(c) What is the relative humidity of the air at 1000 hPa?

(d) At which levels are you most likely to find non-convective cloud?

(e) Mark on the chart where there is an inversion.

(f) For air that is forced to rise from the 1000 hPa level, mark on the chart and state in numbers

i. The lifting condensation level.
ii. The level of free convection.
iii. The cloud top level.

12) Pure water droplets in the atmosphere can either grow by condensation or evaporate depending on the droplet size and the environmental conditions. For the case where the number of water molecules per unit volume (n) is 3.3×10^{28}, the super saturation (S) expressed as a fraction is 0.05, the surface energy of water (σ) is 0.076 J m^{-2}, and the temperature (T) is 278 K.

(a) Compute the radius of a droplet that is in unstable equilibrium (i.e. the smallest drop that will grow).

(b) Using the equation for growth rate given at the end of the question sheet, derive an expression that relates the radius of the drop to time. Take the radius of the drop at time t=0 as r=r_0; the diffusion coefficient of water vapour as D; the water vapour density far away from the drop as ρ_v; the water density at the surface of the drop as ρ_l, and the super saturation as S.

(c) Given the following values, use your expression from (b) to calculate how large the drop will be after 1 minute, if the starting radius is equal to the value found in part (a)

$D = 2.2 \times 10^{-5}$ m^2 s^{-1}

$\rho_v = 6.0 \times 10^{-3}$ kg m^{-3}

$\rho_l = 1000$ kg m^{-3} .

Formulae:

Hydrostatic	$\frac{dp}{dz} = -\rho g$
Equation of state	$P\alpha = RT$
Hypsometric equation	$Z_2 - Z_1 = \frac{R}{g_0}\bar{T}\ln\frac{p_2}{p_1}$
Planck's law	$E_\lambda = \frac{c_1}{\lambda^5 \exp(c_2/\lambda T) - 1}$
Wien's law	$\lambda_m = \frac{2897}{T}\mu m$
Stefan-Boltzmann law	$E = \sigma T^4$
Beer's law	$E_\lambda = E_0 \exp{-\sigma_\lambda sec\varphi}$
Optical thickness	$\sigma_\lambda = \int k_\lambda \rho dz$
Rayleigh scattering	$k_\lambda \propto N\lambda^{-4} r^6$
Potential temperature	$\theta = T\left(\frac{p_0}{p}\right)^{\frac{R}{c_p}}$
Clausius-Clapeyron	$\frac{de_s}{dT} = \frac{L_v e_s}{R_v T^2}$
Geopotential	$d\varphi = gdz$ $\qquad \varphi = g_0 Z$
Momentum	$\frac{d\underline{u}}{dt} = -\nabla\varphi - f\underline{k} \times \underline{u} + \underline{F}$
Coriolis parameter	$f = 2\Omega\sin\theta$
Kelvin's equation	$r = \frac{2\sigma}{nk_B T \ln\frac{e}{e_s}}$
Rate equation for drop growth	$r\frac{dr}{dt} = \frac{D\rho_v S}{\rho_l}$
Super saturation	$S = \frac{e}{e_s} - 1$

Useful Constants:

Apparent molecular weight of air		28.964 g mol^{-1}
Standard pressure		1013.25 hPa
Gas constant for dry air	R_d	287.05 J kg^{-1} K^{-1}
Gas constant for water vapour	R_v	461.5 J kg^{-1} K^{-1}
Specific heat of dry air	C_p	1005 J kg^{-1} K^{-1}
	C_v	718 J kg^{-1} K^{-1}
Density of dry air at 273K, 1013.25hPa		1.293 kg m^{-3}
Latent heat of vapourisation of water at 273K	L_v	2.5 x 10^6 J kg^{-1}
Solar constant	S	1368 W m^{-2}
Stefan-Boltzmann constant		σ 5.67 x 10^{-8} W m^{-2} K^{-4}
Radiation constants		c_1 3.74 x 10^{-16} W m^{-2}
	c_2	1.44 x 10^{-2} m K
Planck's constant	h	6.626 x 10^{-34} J s
Boltzmann constant		k_B 1.38 x 10^{-23} m^2 kg s^{-2} K^{-1}