國立台灣大學大氣科學系 大氣科學概論 期中考簡答

(1) Composition and heat transfer of the Earth's atmosphere (2 pts each, total 10 pts, no partial credits)

For the atmosphere near the surface of the Fiji Island, consider the following gases: CO_2, CH_4, O_2, N_2, H_2O.

A. Rank the gases by their mixing ratios from high to low:

$N_2 > O_2 > H_2O > CO_2 > CH_4$

B. Which one/ones can absorb longwave radiation?

H_2O 、 CO_2 、 CH_4

C. Which one contributes most to the total atmospheric greenhouse effect?

H_2O

D. The mixing ratio of H_2O will decrease the most if moving 5 km _ upward __ (northward/eastward/upward) from the current location.

E. Which of the following process has the least influence on the surface temperature at this location?

(i) surface evaporation

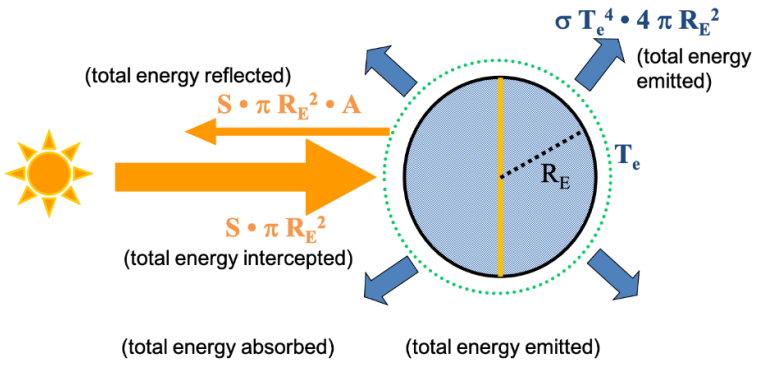
(ii) absorption of solar radiation by the atmosphere

(iii) emission of longwave radiation by the surface

(iv) convection

(2) Radiative balance of a planet (6 pts each, total 18 pts)

The figure below shows the radiative balance of a planet.



Consider two hypothetical planets:
Planet A: radius = R_E, distance to the Sun = L, effective radiating temperature = T_e
Planet B: radius=0.5R_E, distance to the Sun=L, effective radiating temperature = 0.9T_e

(List your equations clearly to show how you carry out the calculations)

A. If we define $\boldsymbol{LW_{total}}$ = the total longwave energy emitted at the top of atmosphere of the entire planet (in the unit of Watts), calculate the ratio of $\boldsymbol{LW_{total}}$ ***of planet B*** / $\boldsymbol{LW_{total}}$ ***of planet A***.

$LW_{total} = \sigma {T_e}^4 4\pi {R_E}^2$

$for\ planet\ A: LW_{total,A} = \sigma {T_e}^4 4\pi {R_E}^2$

$for\ planet\ B: LW_{total,B} = \sigma(0.9\ T_e)^4 4\pi(0.5\ R_E)^2 = 0.9^4\ 0.5^2\ \sigma {T_e}^4 4\pi {R_E}^2$

$\boldsymbol{LW_{total}}$ ***of planet B*** / $\boldsymbol{LW_{total}}$ ***of planet A*** = $\frac{(0.9^4\ 0.5^2\ \sigma {T_e}^4 4\pi {R_E}^2)}{\sigma {T_e}^4 4\pi {R_E}^2} = 0.164$

B. If $\boldsymbol{A_A}$ = ***planet albedo of planet A***., express the planet albedo of planet B in terms of $\boldsymbol{A_A}$.

Radative balance of planet A:

$$S\ \cancel{\pi R_E^2}\ (1 - A_A) = \sigma {T_e}^4 4\ \cancel{\pi R_E^2} \rightarrow 1 - A_A = \frac{4}{S}\sigma {T_e}^4$$

Radative balance of planet B:

$$S\ \cancel{\pi(0.5\ R_E)^2}\ (1 - A_A) = \sigma(0.9\ T_e)^4 4\ \cancel{\pi(0.5\ R_E)^2} \rightarrow 1 - A_B = \frac{4}{S}\sigma(0.9\ T_e)^4$$

The planet albedo of planet B:

$$A_B = 1 - 0.9^4\ \frac{4}{S}\sigma(\ T_e)^4 = 1 - 0.9^4\ (1 - A_A) = (1 - 0.9^4) + 0.9^4 A_A$$
$$= 0.3439 + 0.6561 A_A$$

C. If orbital change moves planet A closer to their sun to 0.9L, but the planet albedo remains the same, please calculate the <u>percentage change</u> of the effective radiating temperature of planet A after reaching equilibrium with the new orbit.

Radative balance of planet A:

$$S\ \cancel{\pi R_E^2}\ (1 - A_A) = \sigma {T_e}^4 4\ \cancel{\pi R_E^2} \rightarrow S(1 - A_A) = 4\sigma {T_e}^4 \rightarrow\ S \propto {T_e}^4$$

The change of solar constant:

$$S' = S\left(\frac{L}{0.9L}\right)^2 = S\left(\frac{1}{0.81}\right) \rightarrow \frac{S'}{S} = \frac{1}{0.81}$$

The percentage change of the effective radiating temperature of planet A:

$$\frac{T_e' - T_e}{T_e} = \frac{T_e'}{T_e} - 1 = \sqrt[4]{\frac{S'}{S}} - 1 \cong 5.4\ \%$$

(3) The change of a system x can be described as the following equation:

$$\frac{dx}{dt} = F(x)$$

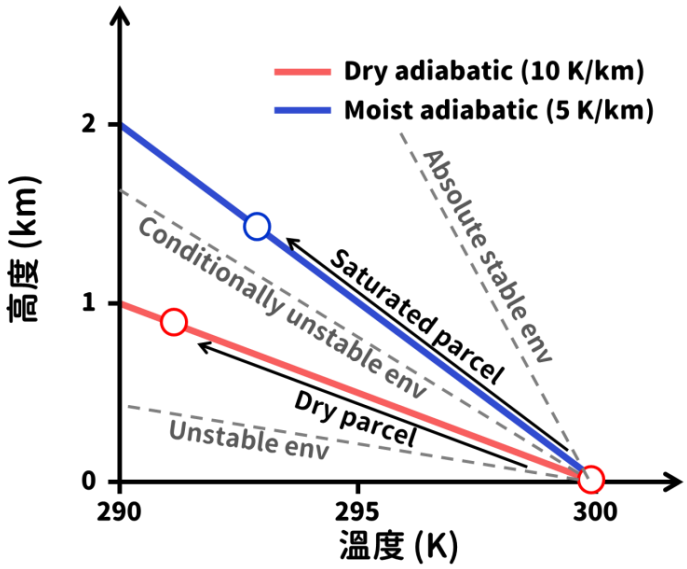
in which $F(x)$ represents the forcing of the system, $\frac{d}{dt}$ represents the change in time. Based on the above equation, answer the following question. (total 32 pts)

A. Atmospheric scientists tried to use the above equation to describe convection, they have to first choose an air parcel as a system. Discuss what is an air parcel and why is it useful in considering convection. (6 pts) What variable should we use to describe moisture in the air parcel and why? (6 pts)

空氣塊是一個假想的一塊尺度約數公里的大氣，在考慮對流過程中，可以想像空氣塊發生垂直運動時，與環境之間的物理性質差異，判斷大氣環境的穩定與否及是否會有成雲發生對流的現象。通常在描述空氣塊當中的水時，會使用的變數包含絕對溼度、相對溼度、露點溫度、水氣壓及比濕等，其中比濕在凝結未發生的情況下是守恆的物理量，因此經常被使用。

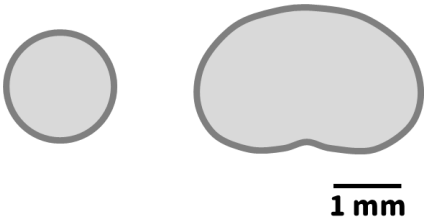
B. As the parcel moves up, it cools and expands, at some point it becomes saturated and phase changes occur. Assume the unsaturated and saturated parcel follows a "linear" temperature lapse rate. Plot the vertical profiles of the parcel and its environment for "stable" and "unstable" conditions. (10 pts)

[Hint] you need to plot "environment" and "parcel" on the same figure.



C. Water droplets eventually fall out and form precipitation. Draw schematically what a rain droplet looks like with proper scale and briefly describe its formation. (5 pts)

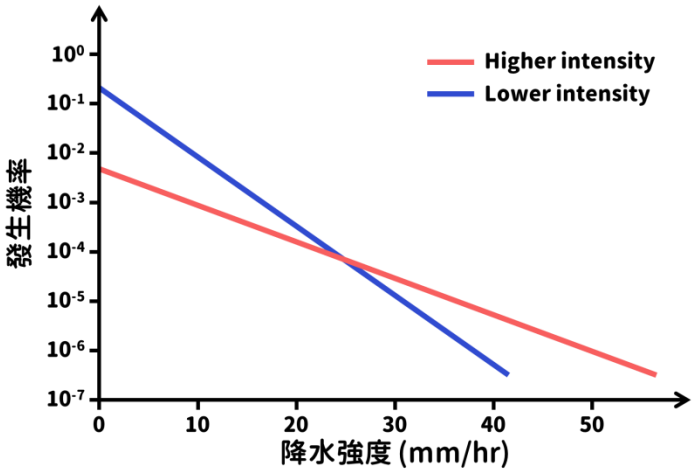
雨滴的形成與大氣中的凝結與碰撞過程有關，雨滴在落下的過程中雨滴碰撞合併會使其成長或破碎。雨滴的形狀主要受到表面張力和空氣的阻力作用，在水滴較小時主要受到表面張力影響，使形狀大致呈現圓形；大的水滴會使空氣阻力的作用開始明顯，水滴會逐漸變得扁平。



D. Total precipitation [mm] ＝ intensity [mm/hr] × duration [hr]. Plot schematically the probability distribution with two locations that have the same total precipitation with very different intensities. (5 pts)

[Hint] 國小自然

在具有相同的降水量的情況，在降水強度較高的區域，會有較少的小雨發生機率及較高的強降水發生機率；降水強度低的區域反之。



(4) Winds and circulation (total 30 pts)

A. What drives the wind*? Please write down the three dominant forces that maintain the large-scale flow in the atmosphere and explain their physical concepts. (15 pts) (*In atmospheric science, we define wind as the velocity relative to the earth surface.)

風的根本來自於太陽對於地球的加熱，不均勻的加熱使得能量需要透過風來重新分配。最主要驅使大尺度環流的作用力為：

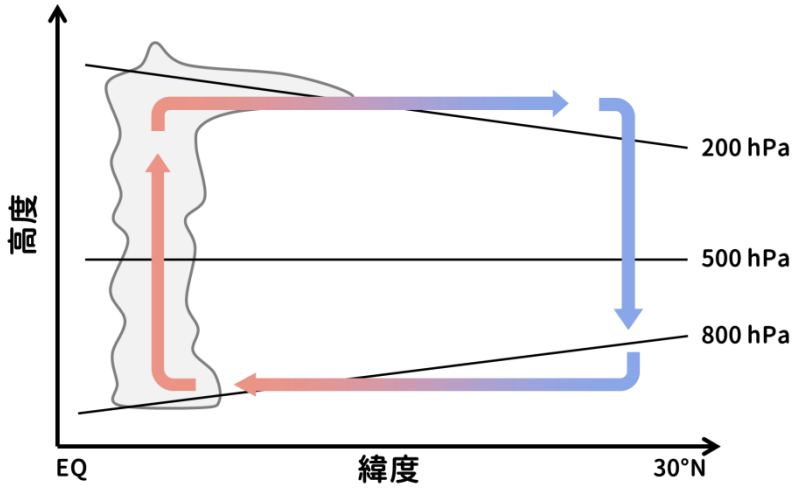
重力:源自於萬有引力,在垂直方向上與氣壓梯度力大致達到靜力平衡。

科氏力：地球旋轉坐標系下的假想力，在極區最大而赤道為 0，在北半球會使運動物體受到向右方的作用力，南半球則反之。

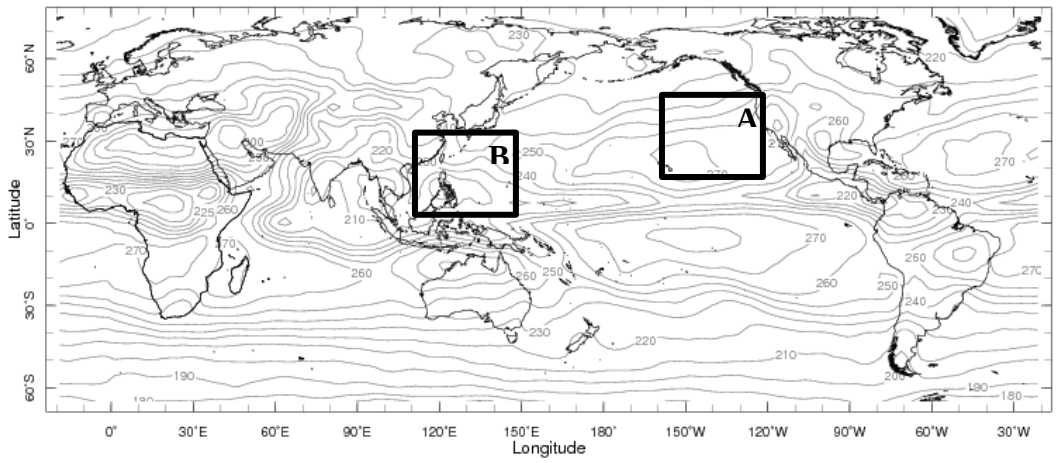
氣壓梯度力：來自於氣壓水平或鉛直方向的梯度所產生的力，由氣壓大處指向氣壓小處。能與科氏力平衡形成地轉風。

B. What is the "thermally direct circulation"? Please use the concept of hydrostatic balance, ideal gas law, and pressure gradient force to describe how heating in the atmosphere drives a circulation. Please scratch a few isobars (lines representing constant pressure) to help explain the mechanisms. Your sentences should be complete and logically consistent. (15 pts)

熱力直接環流是指由大氣的熱力性質差異而直接驅動的環流。考慮赤道與北半球中緯度之間不均勻的加熱時，大氣水平方向的氣溫不同，根據理想氣體方程，空氣密度將呈現北高南低的分布，除了在赤道容易產生對流及中緯度下沉外，根據靜力平衡方程，赤道較厚的氣柱及中緯度較薄的氣柱產生了南北向的氣壓梯度力，最終形成熱力直接環流。



(5) The figure below shows the average outgoing longwave radiation (OLR) values in units of W/m^2 observed by satellite at the top of atmosphere of our Earth during Jul-Sep, 2022. Contours on the map are plotted at an interval of 10 W/m^2. (These data are from the NOAA NCEP Climate Prediction Center).



Jun-Aug 2022

Please use the concept of atmospheric circulation, convection, and greenhouse effects to explain why the value in region A is higher than the value in region B. Your sentences should be complete and logically consistent. (10 pts)

A 區及 B 區分別是沃克環流的下沉區及上升區，在 A 區中，層積雲環境使輻射冷卻非常強，能量在這個區域呈現損失的情形。而在 B 區，對流的發展使向外長波輻射的冷卻較弱，溫室效應較 A 區強，對流向上傳送能量後進一步將能量傳送至 A 區，使沃克環流得以維持。