Online Open-Book Examination Climate System and Atmosphere, June 15, 2021 (Part 1: 4 points; Part 2: 5 points; 1 point for free)

Some constants and equations (not all are needed):

S_0 = 1361 Wm^{-2}; g = 9.81 ms^{-2}; c_p = 1005 J/kg; albedo earth = 0.298; average temperature near the earth surface 288 K; $\sigma = 5.67 \times 10^{-8}$ W $m^{-2}K^{-4}$.

The saturated water vapor pressure in Pa at any given temperature T in °C
$e_s = 611 * \exp[17.67 * T/(T + 273.15)]$

1 mole = 6.023×10^{23} molecules

R_g = 8.3143 $JK^{-1}mol^{-1}$; R = 287 J $kg^{-1}K^{-1}$;

$$pV = nR_gT = \rho \frac{R_g}{m_a} T = \rho RT$$

$$p_s = g \int_0^\infty \rho dz$$

Equation of motion: $\frac{D\mathbf{u}}{Dt} + \frac{1}{\rho}\nabla p + g\hat{\mathbf{z}} + f\hat{\mathbf{z}} \times \mathbf{u} = \mathcal{F}$

Total angular momentum at the latitude φ: $A = \Omega a^2 \cos^2\varphi + ua \cos\varphi$

Coriolis acceleration $-2\ \Omega \times U = (2\Omega \sin\varphi\ v - 2\Omega \cos\varphi\ w, -2\Omega \sin\varphi\ u, 2\Omega \cos\varphi\ u)$

Rossby number: $R_0 = U/fL$

Volume of a sphere = $4/3\ \pi r^3$

Geostrophic wind: $(u_g, v_g) = (-1/f\rho\ \partial p/\partial y, 1/f\rho\ \partial p/\partial x) = (-g/f\ \partial z/\partial y, g/f\ \partial z/\partial x)$
Earth radius = 6370 km;

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Part1. Short Essay questions (4 of a total of 10 points, be as complete and concrete as possible, but "complete" is not the same as "lengthy")

1. Which air mass exerts a greater surface air pressure
1) warm air or cold air? Explain why. 0.5
2) humid air or dry air? Explain why. 0.5

2. Why is the moist adiabatic lapse rate smaller than the dry adiabatic lapse rate? In the Earth's atmosphere, under what conditions vertical profiles of potential temperature is constant? under what conditions vertical equivalent potential temperature is constant? 1.0

3. Why is the relative humidity around 30°N and 30°S between 900 mbar and 700 mbar lower than that at other latitudes? 0.5

4. List and explain at least two weather and climate phenomena that relate to the conservation of angular momentum. 0.5

5. The vertical profiles of CO_2 and O_3 in Sodankyla (67.4º N, 26.7º E) are provided in Figure 1. Why does the concentration of CO_2 decrease with altitude between 12 and 20 km? Why is O3 so abundant in the stratosphere in Sodankyla? 0.5

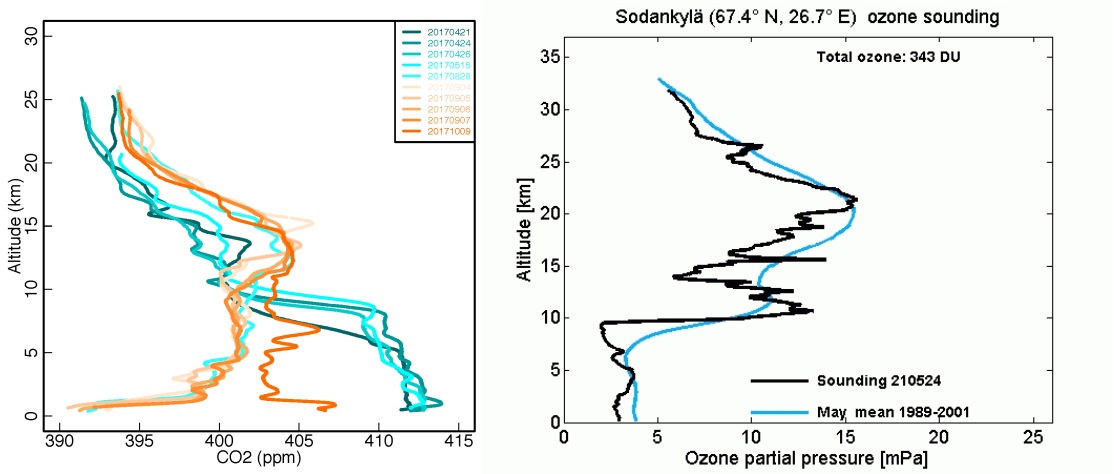

Figure 1. Measurements in Sodankyla (67.4º N, 26.7º E). (Left) several vertical profiles of CO_2 in 2017; (right) a vertical profile of O_3 on May 24, 2021 as well as the average of May profiles during the period 1989-2001 (https://fmiarc.fmi.fi/o3.php)

6. From your knowledge of the meridional overturning circulation of the ocean and rudimentary biology, explain why the Peruvian fishery is very productive. 0.5

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Part2. Problem solving (5 of a total of 10 points: Problem 1: 2 points; Problem 2&3: 1.5 points)

1. A bubble of air (spherical and behaving like an ideal gas) with a radius of 2 mm rises from the bottom of a deep lake 20 meters to the surface. The temperature at the bottom is 4°C. At the surface the temperature is 27°C and pressure equals 1 bar. The pressure of a meter of water is 0.1 bar. Assuming no gas exchange between the bubble of air and surrounding water.

   a) Assuming no gas exchange between the bubble of air and surrounding water. Find the radius of the bubble at the moment it reaches the surface. 0.8
   b) Assuming no gas exchange between the bubble of air and surrounding water and the air bubble is saturated with water vapor at the bottom of the lake; calculate the relative humidity of the air bubble at the surface. 0.6
   c) Assuming the air bubble is always saturated with water vapor during the process (i.e. water vapor is constantly added to the bubble during the rise); Find the radius of the bubble at the moment it reaches the surface. (If you cannot find an answer from a), using the radius of 5 mm when it reaches the surface) 0.6

2. Consider a low-pressure system at 53°N, whose air pressure versus distance r to the center of low pressure is given by:

   $p = 1013 - 25\, e^{-r^2/R^2}$ hPa with $R = 600$ km and temperature 260 K.

   a) Calculate the geostrophic wind (a function of r, assuming constant Coriolis parameter) 0.5
   b) At which radius do you find the maximum wind velocity? 0.5
   c) Calculate the maximum geostrophic wind 0.5

3. A parcel of air in the Earth's atmosphere starts at the equator with a relative easterly zonal velocity of 5 m/s and moves to 30°N conserving angular momentum.
a) What will be its zonal relative velocity when it gets to 30°N? 1.0
b) What will be its zonal relative velocity when it gets to 30°N if the air parcel is in the atmosphere of Venus instead of the Earth? 0.5

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