

ATS 351 Lab 9
Due November 9, 2009

1. (1 point) Consider the single cell model of the Earth covered in the lab lecture. (HINT: for the following questions the answer is either at the equator or at the poles)
 - a. Where is the warmest air found?
 - b. Where is the highest surface pressure found?
 - c. Where would you expect rising air?
 - d. Where would you expect sinking air?

2. (1 point) Below is the 3 cell model of the Earth's general circulation



Identify each of the meteorological features by correctly associating the letter with the features listed below.

Equatorial low:

Northeast trade winds:

Westerlies:

Polar front:

Southeast trade winds:

Polar easterlies:

3. (2 points) Using the global precipitation distribution map provided in lecture, explain why there is a large amount of annual precipitation over the equator but low amounts in the subtropics.

4. (1 point) Describe the conditions in the Pacific Ocean during an El Nino event. How do these differ during a La Nina event?

5. (1 point) What type of weather (cold/warm, wet/dry) would you expect over North America during a strong El Nino? During a strong La Nina?

6. (1 point) CFC's were once mass-produced as an inert gas for use in aerosol cans and other things (this usage peaked in the 70's), until it became apparent that CFC's were causing an ozone hole. The inert nature of CFC's means that they mix well and can be present anywhere in the atmosphere; additionally, they can be absorbed into the oceans. However, measurements show that some regions of the deep oceans have no trace of CFC's. Why do you think this is?

7. (2 points) The intertropical convergence zone (ITCZ) features deep, tropical convection which pushes air high into the troposphere. When this air hits the tropopause, it is forced to travel north or south. For this problem, we will use the concept of conservation of angular momentum to determine how much the Coriolis force would accelerate an air parcel being pushed 10° north out of the ITCZ, assuming that it has no initial east-west (zonal) velocity.

The Coriolis force is best described by the principle of conservation of angular momentum. Basically, this principle states that when the radius of a spinning object decreases, its angular

velocity must increase to compensate. This applies to the Earth in the sense that as you move from the equator to the poles, the distance to the axis of the Earth's rotation decreases (at the equator, the distance is simply the Earth's radius, and at the poles it is zero). Thus, if an air parcel at rest at the equator is moved northward or southward, it must accelerate in the east-west direction. The total angular momentum principle can be written as equation 7.1.

$$7.1 \quad \frac{D}{Dt}[(\Omega a \cos \phi + u)a \cos \phi] + \frac{1}{\rho} \frac{\partial p}{\partial \lambda} = F_{\lambda} a \cos \phi$$

The first term of eq. 7.1 is the change of total angular momentum, the second term represents change in pressure with longitude, and the last term represents friction effects. is the rotation of the Earth, ϕ is the latitude, "a" is the radius of the Earth, and "u" is the velocity of the parcel in the east-west (zonal) direction. For this problem, we'll assume zonally symmetric, frictionless flow, which eliminates the second and third terms. This gives us eq. 7.2.

$$7.2 \quad \frac{D}{Dt}[(\Omega a \cos \phi + u)a \cos \phi] = 0$$

The fact that the D/Dt expression is equal to zero indicates that the quantity inside the brackets doesn't change as the air parcel moves around. From this we can rewrite eq. 7.2 with the initial and final velocities and latitudes. Note that there is no u_i term because we assumed no initial zonal velocity for the parcel.

$$7.3 \quad (\Omega a \cos \phi_i) a \cos \phi_i = (\Omega a \cos \phi_f + u_f) a \cos \phi_f$$

The "i" subscripts indicate initial values, and the "f" subscripts indicate final values. Solving this equation for the final velocity u_f gives equation 7.4

$$7.4 \quad u_f = \Omega a \left[\frac{\cos^2 \phi_i}{\cos \phi_f} - \cos \phi_f \right]$$

- a. Use equation 7.4 to find the final zonal wind speed of a parcel which moved from 0°N to 10°N. Use the following constants

$$\Omega = 7.292 \times 10^{-5} \text{ radians/sec rotation rate of the Earth}$$

$$a = 6.38 \times 10^6 \text{ meters radius of the Earth}$$

- b. Using equation 7.4, find the zonal velocity that an air parcel will attain if it has no initial zonal velocity at the equator and moves to 30°N. Given that typical jet stream winds are on the order of 35 meters per second, is your answer a reasonable wind speed? What implications might this have on the single cell atmospheric circulation model?

8. (1 point) Around the beginning of the 20th century, Vagn Walfrid Ekman, a Swedish oceanographer, noticed that icebergs tended to drift to the right of the prevailing wind, rather than with the wind. Ekman later developed a theory to explain this observation, which is the basis of what is now known as the Ekman spiral and Ekman transport. In this problem, you will find the drift velocity of an iceberg based on the wind stress on the surrounding ocean using Ekman's equations.

First, we will assume a balanced state where the geostrophic ocean transport, wind stress, sea-surface height, and Ekman transport are all balanced. This is represented in equation one. Don't worry about the vectors, as they will be dealt with in later steps.

$$8.1 \quad \vec{f} \times (\vec{u}_g + \vec{u}_{Ek}) = -g \Delta \eta + \frac{1}{\rho} \frac{\partial \tau}{\partial z}$$

These forces will be acting on the ocean throughout the depth of the Ekman layer (the layer which feels these effects), and the iceberg will then drift with the ocean. To get the combined effect over the entire depth of the Ekman layer, eq. 8.1 must be vertically integrated to give equation 8.2.

$$8.2 \quad \vec{f} \times U_{Ek} = \frac{\tau}{\rho}$$

For eq. 8.2, U_{Ek} is the vertically-integrated Ekman transport (the transport over an entire layer). By making some assumptions about the Ekman layer, U_{Ek} can be represented as the velocity of the transport multiplied by the depth of the layer. Making this assumption, substituting the full equation for "F", and solving for the velocity yields equation 8.3.

$$8.3 \quad u_{Ek} = \frac{\tau}{2\Omega\rho H \sin\phi}$$

Use equation 8.3 to determine the drift velocity of an iceberg at 70° N. Use the following constants. Express your answer in centimeters per second.

- $\tau = 0.1 \text{ N/m}^2$ surface wind stress
- $\rho = 1000 \text{ kg/m}^3$ density of water
- $H = 10 \text{ m}$ depth of the Ekman layer
- $\Omega = 7.292 \times 10^{-5} \text{ rad/sec}$ rotation rate of the Earth