Homework 4 Solutions

1. The Coriolis force does influence large-scale movement of air, so it is observed in the northern hemisphere that winds rotate counterclockwise around areas of low pressure and clockwise around areas of high pressure. The reverse is true in the southern hemisphere. However, on the much smaller spatial scale of a draining sink or toilet, the Coriolis force is almost negligible. The only forces governing the motion of the draining water are the pressure gradient force (directed towards the axis of the drain) and the centrifugal force, so the water can actually drain in either direction. The particular way a toilet or sink drains has much more to do with factors such as the shape of the drain or initial motion of the water rather that which hemisphere it's in.

2. Considering upper-level winds in the mid-latitudes, these winds are typically observed to blow parallel to the lines of constant height, and not directly from high to low pressure, because the wind is in geostrophic balance. In this situation, the pressure gradient force, directed from high to low pressure, is equally balanced by the Coriolis force, directed to the right of the mean wind (in the northern hemisphere). In the tropics, the magnitude of the Coriolis force is much weaker because the latitude is near zero. So winds in the tropics tend to be less geostrophically balanced, or blow more along the direction of the pressure gradient, leading to a much smaller spatial scale of air motions and upper-level features (such as ridges and troughs) as compared to the mid-latitudes. Because the Coriolis force is exactly zero at the equator is impossible to form hurricanes there, as we'll discuss later in the course.

3. For upper-level winds in a constant pressure gradient field, In the situation where the air is not curving about an axis of rotation geostrophic balance applies (see answer to previous question). However, when the wind is curving about an axis of rotation, namely around the base of a low pressure trough or the top of a high pressure ridge, there is an additional centripetal force that is directed towards the axis of rotation. This situation is called gradient balance. The additional centripetal force effectively reduces (increases) the strength of the pressure gradient force at the base of the trough (top of the ridge), causing the wind to slow down (speed up) at this point. Thus, the wind must speed up between the base of the trough and the top of the ridge, causing divergence of the air and upward motion to the east of the trough. To the east of the upper-level trough is typically where "interesting" weather is found, as there is large-scale lifting to create clouds, and subsequently, precipitation. Applying the same logic, sinking air and clear weather is typically found to the east of a ridge of high pressure.

4. The alien is sucked out of the ship because of the pressure gradient force. In this example it is huge, because the pressure inside the ship, assumed to be one atmosphere, rapidly decreases to zero in the vacuum of outer space. This is a very large pressure change over a very short distance! Assuming the ship were on the surface of a planet with an atmospheric pressure similar to our own, the pressure gradient would be near zero and there would be no pressure gradient force to suck the alien out.

5. (a) The pressure within the center of the closed low would range from 996 to 999 mb. (b) The dashed lines indicating ridge or trough axes should follow the points of greatest inflection of the isobars. (c) Southerly winds at point A, northwesterly winds at point B. (d) Stronger wind at point B because the pressure gradient is stronger. (e) Pressure gradient from 1 to 2: 0.008 mb per km. Pressure gradient from 3 to 4: 0.012 mb per km. f) Geostrophic wind at point A = approximately 9 m per sec, B = 13 – 14 m per sec. See p. 211 for the details on how to do this calculation.

6. Thermal turbulence is caused by differential heating that leads to convective updrafts and downdrafts in close proximity. Mechanical turbulence is the result of a change in wind direction or speed, typically as a result of air flowing over or through obstacles, such as a mountain. Thermal turbulence is most often found during a warm afternoon due to the surface heating, especially around mountains. Cumulonimbus (thunderstorm) clouds are a clear indication of thermal turbulence, as they indicate the rising plumes of warm air like the convection in the boiling pot example. Mechanical turbulence is typically found where there are fast winds and mountains to obstruct the airflow, and can be particularly intense downwind of a mountain range where rotor circulations can occur.

7. (a) A lenticular cloud indicates the presence of significant wind over elevated terrain and mountain lee wave rotor circulations. This type of turbulence can be very extreme, in the worst case exceeding the structural design capabilities of aircraft and causing them to crash. (b) A strong downdraft from a thunderstorm, or microburst, strikes the ground and spreads in all directions. As the aircraft enters the microburst it initially encounters a headwind, causing the pilot to reduce engine power to compensate. Then when crossing the middle of the downdraft, the headwind changes to a tailwind, the aircraft looses airspeed and is also pushed down. A large jet airliner in landing configuration on final approach (slow, full flaps, gear down, engines near idle) would not be able to correct for the loss of lift in strong microburst quickly enough before impacting the surface and crashing.

8. Between the U.S. and Brazil lies the intertropical convergence zone (ITCZ), the area of the rising branch of the Hadley Cell where thunderstorms in tropics tend to form. As this zone completely encircles the earth, it is impossible to avoid on any flight that crosses the equator. When flying through these thunderstorms, aircraft may experience extreme thermal turbulence. For example, Air France 447 from South America to Europe most likely went down as a result of extreme turbulence as it flew though a thunderstorm in the ITCZ over the middle of the tropical Atlantic.

9. Some acceptable answers include: a) flash flooding: occurs in gullies, streams, low lying roads and other draining basins when thunderstorms drop large amounts of rain. A particular problem in Arizona because of the dry soil doesn't absorb water well. b) Heavy rain and blowing dust, which can reduce visibility to zero and cause traffic hazards, especially on freeways. c) lightning, associated with thunderstorms d) Tornadoes: though weak they do happen in Arizona, particularly in the northern part of the state.

10. Bora winds occur when air cold air pools over a high plateau and then drains down the mountain slopes at a very fast speed. This can occur during winter in regions where large mountain plateaus are bounded by steep mountain ranges, such as the Columbia River Gorge or Front Range of the Rockies in Colorado. Chinook and Santa Ana winds are the results of compressional heating of air on the lee side of a mountain range. Chinooks occur on the lee side of the Rockies and is literally translated as "snow eater" from its Native American language root. If these winds travel through narrow mountain canyons, such as the case with Santa Anas in California they may be accelerated to very fast speeds.

11. During the day, the mountains heat faster than the surrounding air, causing wind to flow up the sides of the mountain slopes. Rising air at the top of the mountains may form cumulus clouds if there is sufficient moisture in the atmosphere and the rising air reaches its lifting condensation level. If there is a relatively large amount of atmospheric instability and moisture, these clouds may develop into thunderstorms

during the late afternoon and early evening. These storms move out into lowland regions as the mountains start to cool faster than the surrounding air during the evening, causing wind to flow down the mountain slopes. This type of thunderstorm development is typical in Tucson during the monsoon, as the city is surrounded by mountains on three sides.

12. Because of the difference in heat capacity of land vs. water, the land will heat faster than the ocean during the day and be warmer. As warm air rises over the land, low pressure forms over the land and cool air from the sea is drawn toward the low pressure. The sea breeze can act as a trigger for thunderstorms, and often does in a place like Florida. At night the land cools more rapidly than the water, so the ocean is relatively warmer at night and the circulation is reversed.

13. The main function of the general circulation of the atmosphere is to transport heat from the equator towards the pole. The uneven distribution of heating on Earth arises from the fact that tropics receive more solar radiation than near the poles. In the tropics, this is accomplished by a thermally direct circulation, or Hadley Cell, that rises near the equator and sinks at approximately 30 degrees latitude. In the mid-latitudes, by contrast, where the effect of the Earth's rotation is greater, it is accomplished by regional-scale eddies, or mid-latitude cyclones (to be discussed more in-depth later in the course). These eddies essentially reflect the low pressure troughs and high pressure ridges observed on upper-level circulation maps.

14. In the tropics, the large-scale atmospheric circulation is governed by a thermally direct circulation, or Hadley Cell. Within this cell, air rises near the equator to form a band of thunderstorms, called the intertropical convergence zone (ITCZ). In the vicinity of the equator is where nearly all of the world's major rainforests are found because these areas receive rainfall within the ITCZ on a fairly regular basis. As the air is transported away from the ITCZ towards the poles, it sinks and compressionally warms in the subtropical areas, about 30 degrees latitude poleward of the equator. The sinking and warming air forms semi-permanent areas of high pressure under which the atmosphere is fairly stable and there is little clouds and precipitation, causing deserts to tend to form in these areas.

15. ENSO refers to a quasi-periodic warming of the sea surface temperature in the eastern tropical Pacific. This causes changes in the atmospheric circulation and rainfall across the entire Pacific basin and also affects large-scale circulation patterns in the mid-latitudes. During El Niño winters, the southern part of the United States typically experiences above average rainfall and cooler than average temperatures, while the northern part of the United States experiences below normal rainfall and above normal temperatures. These effects are approximately reversed during a La Niña, when the eastern tropical Pacific is cooler than normal.

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