

## MAIN CONCEPTS

### **The Earth and Its Atmosphere (Chapter 1)**

- Air is composed of many compounds, N<sub>2</sub>, O<sub>2</sub>, CO<sub>2</sub>, H<sub>2</sub>O, O<sub>3</sub>, ...
- The compounds of primary importance to weather (H<sub>2</sub>O) and climate (CO<sub>2</sub>, O<sub>3</sub>..) comprise a relatively small amount of the total air
- 3 phases of water and the heat released/absorbed when phase changes take place
- Concept of air pressure ( $P = \text{weight of air above} / \text{area}$ ); air pressure decreases with height
- vertical profile of atmospheric temperature
- regions of the atmosphere: troposphere, stratosphere and tropopause divides the two
- stratospheric ozone destruction due to CFCs (propellants and coolants)

### **Energy: Warming the Earth and the Atmosphere (Chapter 2)**

- nearly all energy driving weather comes from sun
- energy is not created or destroyed, just transferred between different forms
- types of energy in meteorology: kinetic, potential, and radiant
- temperature is measure of average kinetic energy of object
- specific heat (water vs. air and soil)
- heat transfer mechanisms: conduction, convection and radiation ( $E = \sigma T^4$ ;  $\sigma_{\text{max}} = c/T$ )
- blackbody vs selective absorbers (earth/sun vs atmospheric gases)
- atmospheric greenhouse effect

### **Seasonal and Daily Temperatures (Chapters 2 and 3)**

- Seasons are due to tilt of Earth relative to orbital plane
- seasons reversed in northern and southern hemispheres
- more solar energy reaches surface when sun is higher in sky
- tropics receive much more solar energy than polar latitudes
- heat transferred to poles from tropics by ocean currents, storm systems and latent heat
- daily temperature cycle (why maximum temperature is usually after noon)
- annual temperature cycle (why maximum temperature usually occurs in July or August)
- daytime warming near surface
- nighttime cooling near surface, radiation inversions, and effects of wind and clouds
- controls of temperature (latitude, ocean vs. land, ocean currents, and elevation)

### **Atmospheric Moisture (Chapter 4)**

- saturation: air is "holding" maximum amount of water vapor for a given temperature and pressure
- how saturation changes with changing temperature
- how wind effects evaporation rate
- Measuring moisture in atmosphere: Humidity
- specific humidity, relative humidity, and dew-point temperature
- how temperature effects relative humidity
- role of ocean temperature in determining humidity of a region

### **Condensation: Dew, Fog, and Clouds (Chapter 4)**

- in the atmosphere, water vapor condenses on small particles called condensation nuclei
- as more water vapor condenses, visibility continues to decrease until fog or cloud forms

- condensation to form clouds and fog usually occurs as air mass is cooled
- fog is a cloud that is in contact with the surface
- radiation fog best with clear nights, light wind, in valleys, wintertime
- advection fog formed as air (usually moist) advected over colder surface
- mixing fog can sometimes form when two unsaturated air masses are mixed together
- many types of clouds: try to categorize by where in atmosphere they form and whether they are stratus (layer) or cumulus (tall vertical clouds)
- clouds both reflect solar (cools the surface) and absorb/emit infrared (warms the surface)
- overall global average: clouds cool the surface

### **Stability and Cloud Development (Chapter 5)**

- rising air expands and cools; sinking air compresses and warms
- unsaturated rising air cools at dry adiabatic lapse rate =  $10^{\circ}\text{C}/\text{km}$
- sinking air warms at dry adiabatic lapse rate =  $10^{\circ}\text{C}/\text{km}$
- rising air that is saturated cools at moist adiabatic lapse rate (mean value =  $6^{\circ}\text{C}/\text{km}$ )
- moist adiabatic lapse rate less than dry adiabatic lapse rate because condensation taking place
- atmospheric stability determined by comparing temperature of rising air parcel to environmental lapse rate
- the higher the relative humidity, the more likely the atmosphere will be unstable
- increase instability by warming surface air and/or cooling air aloft
- mixing will tend to make atmosphere more unstable
- marine stratus/stratocumulus clouds off S. Cal. formed via mixing of boundary layer air
- lifting a layer of air (i.e. synoptic low pressure) will make atmosphere more unstable
- lifting a layer of air that is very moist at the bottom and dry at top can make atmosphere very unstable = convective instability
- initial uplift of air due to convection, orographic uplift, large-scale convergence, & along fronts
- rain shadows/deserts form on downwind side of mountains

### **Precipitation (Chapter 6)**

- not all clouds produce precipitation
- cloud drops and ice crystals need to grow large enough to fall as precipitation
- collision-coalescence process occurs as drops of different size fall at different terminal velocities
- taller clouds generally produce larger raindrops; drizzle usually from relatively thin low stratus
- ice-crystal process occurs where ice crystals co-exist with supercooled water drops
- Bergeron process allows ice crystals to grow quickly at expense of liquid water drops
- snow falls from cloud frozen and remains frozen until ground
- sleet is snow that melts then re-freezes before reaching surface
- freezing rain is snow that melts and then refreezes when hits surface
- hail forms in updrafts of large cumulus clouds

### **Air Pressure and Winds (Chapter 6)**

- horizontal variations in pressure drive atmospheric motions
- pressure changes much faster in vertical than in horizontal
- pressure maps made from pressure readings from network of weather stations
- isobar = line of constant pressure
- each pressure reading needs to be corrected for any errors and adjusted for altitude

- constant height map = shows atmospheric pressure at constant height, often sea level
- constant pressure map = shows height (above sea level) of a certain pressure (i.e. 500mb)
- high heights usually correspond to higher pressures; low heights with lower pressures
- ridges associated with warmer air and surface high pressure; troughs with colder air/surface low
- direction and speed of wind determined by balance of forces acting on the air
- 4 forces we need to consider: 1) pressure gradient force; 2) Coriolis; 3) centripetal; and 4) friction
- horizontal pressure gradient force (PGF) initiates wind
- vertical pressure gradients is usually balanced by gravity (hydrostatic), so no vertical winds
- Coriolis due to our rotating reference frame; acts to the right of the wind direction in N. Hem.
- geostrophic flow = balance between Coriolis and PGF; flow is parallel to isobars
- centripetal force due flow around curved isobars
- for equal isobar spacing, wind around high is faster than wind around a low due to centripetal
- friction force always acts in opposite direction to wind
- friction causes the wind to cross isobars; in towards a low pressure, out and away from high
- as friction increases, angle that wind crosses isobars also increases
- in general, friction over land stronger than over water

### **Wind: Small-Scale and Local Systems (Chapter 7)**

- know wind notation; westerly vs. easterly, onshore vs. offshore, prevailing wind
- wind force is proportional to the velocity squared
- as size of wind system increases, it's timescale (or lifetime) also increases
- eddies denotes rotating wind and come in many sizes
- some eddies can form from vertical wind shear; in clear-air this is clear-air turbulence
- flow over a mountain can initiate eddies or waves in the air - may get lenticular clouds
- thermal circulations due to uneven heating of the surface (sea-breeze and monsoons are this type)
- sea-breeze circulation occurs during day and is due to different specific heats of land and water
- in sea-breeze, wind at surface is onshore, wind aloft is offshore
- land-breeze is opposite of sea breeze and occurs during night when land cools more than water
- wind over lake may increase and veer in direction due to change in friction force
- monsoon circulation like sea-breeze, but occurs on seasonal scale rather than daily
- Asian monsoon most prominent; in winter wind if offshore near surface; onshore in summer
- summer Asian monsoon is wet and stormy period as warm moist air flows onto land
- Santa Ana winds: particular wind system in Southern California
- warm and dry conditions due to descending air warming at dry adiabatic lapse rate

### **Wind: Global Systems (Chapter 7)**

- know 3-cell model of general atmospheric circulation
- Hadley cell, Ferrel cell, and polar cell
- tradewinds are on return branch of Hadley cell: NE in N. Hem. and SE in S. Hem.
- ITCZ where SE and NE tradewinds meet - get convergence that further aids rising air
- ITCZ region of convection and frequent precipitation
- subtropical highs under descending branch of Hadley and Ferrel cells
- sinking air of subtropical highs warms and RH decreases -- these are desert regions
- subtropical highs not a continuous belt due to land masses: Pacific High and Bermuda High
- polar lows under ascending branches of Ferrel and polar cells

- Aleutian Low in Pacific and Icelandic Low in Atlantic
- in summer, subtropical high intensifies while polar low weakens; opposite in winter
- polar front where warm mid-latitude westerlies meet cold polar easterlies - convergence region
- polar jet stream due to PGF that sets up along front due to different temperature differences
- subtropical jet stream where Hadley cell meets Ferrel cell
- El Nino is warming of surface water in central and eastern tropical Pacific
- relocation of warm water pool alters Hadley circulation and affects jet stream location and intensity
- during El Nino, So. California often (but NOT always) experiences higher than normal precipitation
- divergence aloft will cause a surface low pressure area to form
- jet streaks and the exit region of a trough in the jet stream are areas of upper level (aloft) divergence

### **Thunderstorms and Tornadoes (Chapter 10)**

- two categories of thunderstorms: i) air-mass (ordinary); and ii) severe
- air-mass thunderstorms self-destruct as downdrafts overwhelm updrafts
- severe thunderstorms form in areas with strong vertical wind shear
- both types of thunderstorms gain energy from release of latent heat within the clouds
- downdrafts initiated by drag of ice crystals and enhanced by the cooling from entrainment
- gust front created as downdrafts hit surface and spread out horizontally
- tornadoes produced only in severe thunderstorms
- need change in wind direction in the vertical for tornadoes to form: this will help form mesocyclone
- tornado forms within mesocyclone: exact mechanism not well understood.
- lightning occurs as charges separate in cloud.
- need combo of supercooled water, hail and ice crystals to get charge separation
- thunder produced when lightning heats air causing air to expand -> produces shockwave

### **Hurricanes (Chapter 11)**

- mature hurricane composed of several cloud bands
- inflow at surface is cyclonic; outflow at top is anticyclonic
- eye is an area of descending air that warms due to compression
- need surface convergence for hurricanes to form
- convergence can occur due to easterly waves, the ITCZ, or along fronts that extend far enough equatorward
- need warm surface water (> 26-27C=80F); no strong upper winds or vertical shear; and some coriolis force (must be a little away from equator). these limit formation to roughly 5-20 deg latitude.
- hurricanes steered by upper level circulation - often by the subtropical highs
- storm surge is the rise in sea level produced by hurricane. due to high waves, wind, and low press.

### **Air Pollution (Chapter 14)**

- both natural and human sources of pollution
- natural pollution from volcanoes, forest fires, dust storms, etc..
- usually air pollution not a problem until certain atmospheric conditions aggravate situation
- primary pollutant vs. secondary pollutant
- aerosols are reflect sunlight and serve as CCN - both are cooling processes
- photochemical smog produced from NO<sub>2</sub>, VOCs, and sunlight to produce ozone
- photochemical smog is a secondary pollutant and is the dominant smog type in the southwest US due to the large amount of sunlight

- photochemical smog mostly in summer while sulfur type smog from heating usually in winter
- inversions can create very polluted conditions by trapping pollutants near surface
- radiation inversion forms at night - limited to a few hundred feet and usually dissipates during day
- subsidence inversion occurs with high pressure region over area.
- Los Angeles is prime area for subsidence inversion in summer - Pacific high usually nearby and sea breeze brings in cool air that helps maintain inversion
- acid rain produced when sulfur emissions mix with cloud droplets that later fall as rain.

### **Climate Change (Chapter 13)**

- weather is atmospheric state and a particular time; climate is weather averaged over many times
- natural climate change has been occurring since beginning of earth - makes it hard to pick out change due to human influences
- measure climate change usually with temperature; but precipitation and sea level also useful
- much of earth's history temperatures were much warmer  $\sim +10^{\circ}\text{C}$ : no ice caps or glaciers
- temps cool for periods of millions of years - Ice Ages: glaciers and ice caps form
- we are currently in the Pleistocene Ice Age
- within Ice Ages are periods of slightly warmer temps called Interglacial periods that last tens of thousands of years
- we are currently in an interglacial period. 20000 years ago sea level 100m lower than today
- during last 1000 years mean global temperature varied  $\pm 1^{\circ}\text{C}$ .
- Medieval climatic optimum from about 1000-1300 was warm period-Vikings explored world
- 1350-1800 "Little Ice age" was cold period- exploration reduced or delayed, crops failed and famines occurred.
- last 100 years: 1900-1940 temp increased; 1940-1970 temps constant; 1970-2000 temps warm again.
- human activity may explain last 30 years of warming, but what causes the other warming/cooling episodes. Many different time scales
- Continental drift may explain ice ages; periods of fast drift with more volcanic activity - aerosol cooling in stratosphere
- Milankovitch Theory - Earth orbital cycles - may explain interglacial periods
- tilt of axis varies from 22 to 24.5 degrees. less tilt = less seasonal variation = cooler summers (less snow melt) and warmer winters (more snowfall in polar latitudes).
- eccentricity of orbit: currently at 0.97 (close to circle) in 50000years, 0.91 = more seasonal variation
- precession: 23000years.
- periods of high and low volcanic activity may explain shorter periods of temperature change
- volcanoes put out sulfur gases that may enter stratosphere and stay for several years. these gases combine with water vapor and produce sulfuric acid particles that reflect and absorb sunlight that cause surface temperature to cool.

### **Light, Color, and Atmospheric Optics (Chapter 15)**

- White light is combination of all visible wavelengths
- Understand difference between reflected light and emitted light
- angle of reflected light is same as angle of incident light
- scattered light is going in many directions
- scattering usually by small particles and molecules (atmosphere and clouds)
- sky is blue due to selective scattering (Rayleigh scattering) of air molecules (mostly  $\text{N}_2$  and  $\text{O}_2$ )
- orange/red color of sunsets due to thicker atmosphere and blue light now scattered away
- refraction of light (bending) is due to density differences
- rainbows due to refraction and reflection of visible light by water droplets