Chapter 10 – Atmosphere and Severe Weather

Introduction

- 1998 Ice Storm
  - Worst NA ice storm, in parts of QC, NB, and northeastern US
  - 10 cm accumulated ice
  - 57 communities in ONT and 200 in QC = disaster areas
  - 4.5 million people without power
  - 45 killed, 1000 injured
  - 100000 evacuated to shelters
  - $6.2 billion in losses
  - military brought to clear debris, medical assistance, evacuation, and canvass door to door, restore power
  - hard on economies
  - dairy/cows effected, maple trees
  - most expensive natural disaster in CDN history
- Meteorological Conditions
  - Cause: persistent flow of warm, moist air from Gulf of Mexico that rose up over a thin wedge of cold arctic air
  - Cold air driven south by northeast winds
  - Cold air settled over southern river and mountain valleys (St. Lawrence and Ottawa valleys)
  - Warm air driven north by a high-pressure system centred over Bermuda and low pressure trough located over Mississippi River valley
- Lessons learned
  - Society dependent on electricity

Energy

- Energy expressed in terawatts (tW)
  - = to 1 million megawatts or 1 trillion watts
  - total solar energy absorbed at Earth's surface is approx. 120 000 tW per year
    - heats planet, evaporates water, and produces the differential heating that causes air masses to move
    - global energy consumption by people is less than 0.01% of this value – about 13 tW per year
- Types of Energy
  - Potential energy: stored energy
    - I.e. water held behind dam contains potential energy that may be used to produce electricity
  - Kinetic energy: energy of motion
    - When book falls from shelf to ground, it loses potential energy and gains kinetic energy
  - Heat energy: energy of the random motion of atoms and molecules and can be defined as the kinetic energy of atoms or molecules within a substance
    - i.e. transferred from one body to another
    - sensible heat: heat that may be sensed or measure by a thermometer

        - latent heat: heat that is either absorbed or released when a substance changes phase (from solid to liquid, etc.)
            - ice, liquid water, and water vapour
                - latent heat of vaporization: energy required for phase change

- Heat Transfer
    - Conduction: transfer of heat through a substance by means of atomic or molecular interactions
        - Difference in temp within the substance – heat moves from an area of higher temp to one of lower temp
        - i.e. metal pot causes handle to heat up
    - Convection: transfer of heat by the movement of a fluid, i.e. water or air
        - i.e. water at the bottom of the pot warms and rises upward to displace the cooler water at the surface, cooler water sinks to bottom of the pot
        - physically mixes water by creating a circulation loop = convection cell
        - thunderstorms and in large-scale circulation of air away from the equator
    - Radiation: wave-like energy emitted by a substance that possesses heat
        - Occurs by oscillations in electric and magnetic fields – electromagnetic waves
        - i.e. heat energy radiates from the heating element in the electric stove to the pot on the stove
        - might be visible, might not

Energy at Earth's Surface

- receives energy from the sun that affects the atmosphere, oceans, land, and living things before being radiated back into space
- Earth's energy balance: equilibrium between incoming and outgoing energy
    - Energy is neither created nor destroyed
- Only a tiny fraction of total energy emitted by sun but its adequate to sustain life
- Drives hydrologic cycle, ocean waves and currents, and global atmospheric circulation
- Electromagnetic Energy: type of radiation, travels through space at the speed of like (300,000 km/s)
    - Wave form, distance between the crests or troughs of two successive waves = wavelength
    - Electromagnetic spectrum: encompasses all possible wavelengths, is large and the different types of electromagnetic radiation are defined on the basis of their wavelengths
    - Electromagnetic energy with long wavelengths (greater than 1m) = radio waves and microwaves, short lengths (less than 0.0001mm) = x-rays, gamma rays, cosmic waves
    - Infrared radiation = global warming
    - Ultraviolet radiation = influenced by ozone amount in upper atmosphere
- Energy Behaviour
    - Redirection: energy is either reflected like a light bouncing off of a mirror or scattered in different directions
        - Reflection, emission

- Transmission: passage of energy through the atmosphere, like light passing through window glass
- Absorption: alters the structure of molecules it comes into contact with or causes them to vibrate and emit energy (UV radiation)
  - Albedo – visible light
    - Dark-coloured surfaces reflect less energy than light coloured ones and have lower albedos

The Atmosphere: the thin envelope of gases that surrounds Earth, responsible for weather

- Composition of the Atmosphere:
  - Nitrogen and oxygen mostly
  - Small amounts of argon, water vapour, and carbon dioxide
  - Water vapour = cloud formation and atmospheric circulation
    - Humidity = amount of water vapour or moisture in the atmosphere at specific temp
- Structure of the Atmosphere
  - Very thin
  - Entire atmosphere lies below an altitude of 100km
  - 4 major layers
    - lowest = troposphere – extends from the ground to an altitude between 8-16 km (spend our entire lives in this part besides airplane rides), rapid decrease in temp upward, water vapour of clouds
  - Clouds: composed of small water droplets or ice crystals – needed for rain, snow, thunder, lightning, or rainbows
    - Puffy, fair-weather cumulus clouds that resembles pieces of floating cotton
    - Towering cumulonimbus clouds release tremendous amounts of energy during thunderstorms through condensation of water vapour

Weather Processes

- Atmospheric Pressure: aka barometric pressure
  - Weight of a column of air at a point on or above earth's surface
  - Force exerted by gas molecules on the surface
  - Greater at sea level than top of mountain (where there;s less air)
  - Below an altitude of 50 km
  - Air rises and cools in areas of low atmospheric pressure = clouds
  - High pressure = drier air slowly descends, producing clear skies
  - Convergence: air flows horizontally from areas of high pressure to areas of low pressure
  - Divergence: flow of air out of a region and is accompanied by a reduction in atmospheric pressure – driving force for wind
  - Low-pressure centres (L) and high pressure centres (H)
- Vertical Stability of the Atmosphere
  - Parcel of air = small volume of air
  - Atmospheric stability = tendency of a parcel of air to remain in place or to change its vertical position

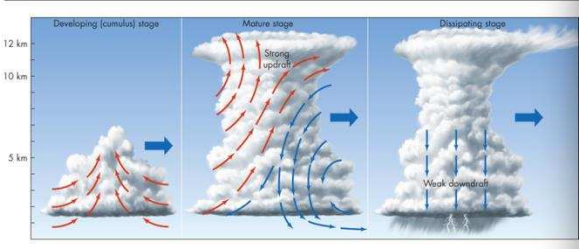
- Fronts
  - Boundary between cool and warm air
  - Stationary front: boundary does not move much
  - Occluded front: cold front may overtake the warm front and come into contact with another cool air mass

Hazardous Weather

- Thunderstorms
  - Thousands are always occurring on earth, usually in equatorial regions
  - i.e. Kampala experience storms 7/10 days
  - most frequency in NA along Front Range of Rocky Mountainss in Colorado and New Mexico, belt encompassing all of Florida and the southern parts of Georgia, Alabama, Mississippi, and Louisiana
  - Require special set of atmospheric conditions
    - Water vapour must be present in the troposphere to feed clouds as the storm forms
    - Temp gradient must exist in the troposphere, so that rising air can rapidly cool and become emplaced over warmer, moist air
    - Updraft must force moist air upward to cooler level of the atmosphere
  - As moist air is forced upward, it cools and water vapou condenses to form a cumulus cloud
  - **Cumulus stage**: upward growth as the moisture supply and updraft persist
    - Look like head of cauliflower
    - Continuous release of latent heat due to water vapour condensation, which warms the surrounding air and causes it to rise farther
    - Precipitation starts by 2 mechanisms
      - The cloud expands into colder air, causing water droplets to freeze into ice crystals and snowflakes that fall until they enter warmer air and melt to form raindrops
      - In warm air in the lower part of the cloud, large droplets collide with smaller droplets and coalesce to become raindrops, when they become too large to be supported by the updraft, they begin to fall and create downdraft
  - Coriolis effect: the apparent deflection of a moving object because of Earth's rotation. The deflection is to the right in the northern hemisphere and to the left in the Southern hemisphere
  - **Mature stage**: begins when downdraft and falling precipitation leave the base of the cloud, has updrafts and downdrafts and continues to grow till it reaches the top of the unstable atmosphere near the tropopause
    - Produces most intense precipitation, thunder, and lightening
  - **Dissipative stage** (final stage): begins when the supply of moist air is blocked by downdrafts at the lower levels of the cloud
    - Cause some of the falling precipitation to evaporate
    - Deprived of moisture, thunderstorm weakens, precipitation decreases, and cloud dissipates
  - Last less than an hour and do little change

- Common in afternoon and evening hours

Figure 10.17 Life Cycle of a Thunderstorm



An idealized diagram showing stages in the development and dissipation of a thunderstorm. Red arrows show updrafts of warm air and blue arrows show downdrafts of cold air. The large blue arrows show the direction that the storm is moving.

- Lightning: consists of flashes of light produced by the discharge of millions of volts of electricity, common during thunderstorms
  - Discharges momentarily heat the air in their paths to temps as high as 30 0000 degrees C, 5x hotter than the surface of the sun
  - Rapid heating causes the surrounding air to expand rapidly, producing thunder
  - Bolts start and end in clouds
  - Cloud-to-ground lightning = complex
    - Strong difference in electrical charge between clouds and the ground is required for lightning to overcome the natural insulating property of air
  - Stepped leader: column of electrically charged air advances downward from the base of a cloud
    - As it approaches ground, a spark surges upward from a tall object and attaches to the leader
  - Return stroke: the downward flow of electrons during a cloud-to-ground lightning discharge. This discharge produces the bright light of a lightning flash
    - Lighting flash appears to flicker to the human eye
    - Although the lightning strike appears to come down from the base of the cloud, the electrical discharge actually moves upward from the ground
  - Kills 7 people in CAN each year, 60-70 injuries
  - Kills 100 people in US and more that 300 injuries
- Severe Thunderstorms
  - Canada's Atmospheric Environment Services classifies a thunderstorm as severe if it has wind speeds in excess of 90 km/h or hailstones larger than 1.5 cm, or generates tornado
  - Last several hours to several days
  - Conditions of a severe storm:
    - Wind shear produced by winds blowing in different directions
    - high water-vapour content in the lower troposphere
    - uplift of hair
    - and existence of dry air mass about a moist air mass
  - 3 types of severe storms:
    - Mesoscale Convective Complexes
      - Most common

        - Very large clusters of self=propagating storms in which the downdraft of one cell leads to the formation of a new cell nearby
        - 12+ hours
        - downdrafts come together to form outflow boundaries – curved lines of thunderstorms that travel long distances
    - Squall lines
        - Average 500 km in length and are lines of individual storm cells
        - Parallel to cold fronts
        - Gust front: downdrafts originating on the backside of the storms may surge forward
        - Drylines: air mass boundary similar to a front but along which the air masses differ in moisture content rather than temp
    - Supercells
        - Most damaging
        - Deeply rotating updraft flanked by smaller updraft elements
        - Breeding ground for most large tornadoes
        - Derechos: largest straight-line windstorm, produce severe tornado-strength wind gusts along a line that is at least 400 km long
            - Exceed 90 km/h
        - Microbursts: smaller thunderstorm downburst
- Hail
    - $1 billion in damages/year
    - common in Great Plains
- Tornadoes
    - Most violent
    - Kill average of 50 people per year
    - Shapes of ropes to funnels
    - Spinning column of wind or vortex must extend downward from a cloud and touch the ground
    - Funnel clouds: funnel-shaped vortices that don't touch the ground (more common than tornadoes)
    - Organization stage: wind shear causes air to begin to roate wihin the thurderstorm
        - Mesocyclone: large vertically rotating column of air
        - Wall cloud
    - Mature stage: visible funnel extends from the thunderstorm cloud to the ground and moist air is drawn upward
        - Suction vortices: small intense whirls – responsible for greatest damage
    - Shrinking stage: supply of warm mosit air is reduced, funnel tilts and narrows, winds increase
    - Rope stage (final): upward-spiralling air comes into contact with downdraft and tornado begins to move erratically
    - Can skip stages or go through all of them
    - Material tornado picks up gives the dark colour
    - Diameters of 10s of metres and wind speeds of 65/km to over 400 km/h
    - Classification: based on max wind speeds and damage they produce, assigned values on the Enhanced Fujita Scale

Table 10.1 Enhanced Fujita Scale of Tornado Intensity

Scale	Wind Speeds[1]	Typical Damage[2]
EF0	105–137 km/h	Light damage
EF1	138–177 km/h	Moderate damage
EF2	178–218 km/h	Considerable damage
EF3	219–266 km/h	Severe damage
EF4	267–322 km/h	Devastating damage
EF5	> 322 km/h	Incredible damage

    - Waterspouts: tornadoes developed over water
    - Occurrence of Tornadoes
        - Most common in the US
        - Great Plains – Tornado Alley
        - i.e. Joplin Missouri 2011
        - deadliest tornado in DN history = Regina Cyclone
- Blizzards, Extreme Cold, and Ice Storms
    - High winds, blowing snow, low visibility, and low temps for extended period
    - Ground blizzards: without snowfall, reword existing snow to rpdouce whiteout conditions with visibility limited to a few metres or less
    - Wind chill, frostbite
    - Extreme cold
    - Ice storms = prolonged periods of freezing rain
        - Conditions:
            - Ample moisture is present in the warm air mass south of the front
            - Warm air overlies a shallow layer of cold air
            - Objects on the ground are at or below the freeing temp
- Fog: cloud in contact with the ground
    - Forms either by condensation as air cools or by the evaporative addition of water vapour to already cool air
- Drought: extended period of unusually low precipitation that produces a shortage of water for people, animals, and plants
    - Causes:
        - Diminished growth and yield
        - Dust storms and related erosion
        - Famine
        - Ecosystem damage
        - Hunger
        - Malnutrition
        - Dehydration and diseases
        - Population migrations, producing international refugees
        - Reduced electricity production
        - Shortages of water for industrial users
        - Social unrest
        - War

1. **Meteorological drought** is a lengthy period with lower than average precipitation. Meteorological drought usually precedes the other two types of drought.
2. **Agricultural drought** affects crop production. This condition can arise either from low precipitation or when soil conditions and erosion caused by poor agricultural practices cause a shortfall in water available to crops.
3. **Hydrological drought** occurs when the amount of water in aquifers, lakes, and reservoirs is below average for a lengthy period. It commonly materializes more slowly than other types of drought because it involves stored water that is used but not replenished. Like agricultural drought, it can be triggered by other than just a reduction in rainfall. For example, Kazakhstan recently received money from the World Bank to restore water that had been diverted to other nations from the Aral Sea under Soviet rule.

    - affect more people in CAN and US than any other natural hazard
- Dust and Sand Storms:
    - Dust
        - Transport silt
        - Strong windstorms that transport large amounts of fine sediment
        - Wind velocities exceed 48 km/h and visibility is less than 800m
    - Sand
        - Move large amounts of sediment
        - Transport sand not silt
- Heat Waves: periods of heat that are longer and hotter than normal
    - Deadliest natural hazard
    - Kill average of 200 people per year
    - Same as combined # of deaths from flooding, lightning, tornadoes and hurricanes
    - Ridges: elongated areas of high pressure

Human Interaction with Weather

- Plowing cropland after fall harvet leaves topsoil exposed to wind == dust storms
- Land-use
- Pavement and sparse parkland = higher temps
- Global warming

Links with Other Hazards

Natural Service Functions of Severe Weather

- Lightning = primary ignition of natural fires, which are vital in prairie and forest ecosystems
- Windstorms = health of forests
- Blizzards = source of water
- Aesthetic value
- Exciting
- Tourism

Minimizing Severe Weather Hazards

- Forecasting and Predicting Weather Hazards
    - Doppler Radar stations – predict paths of tornadoes and other severe storms
    - Doppler effect = change in wavelength

- Tornado Watches and Warnings
  - Watch = public advisory that one or more tornadoes might develop in a specified area
  - Warning: tornado sighted or detected by Doppler radar – take immediate action
- Adjustment
  - Mitigation
    - Wind resistant structures
    - Back up power sources
    - Development and installation of warning systems
  - Preparedness
    - Clothing
    - Travel plans