EESA09 - Wind

Lecture 01

Air is made out of **Gas**, **Liquid** (cloud), and **Solid** (particulate matter). Three gasses makes up the majority (99.96%) of air, which are **Nitrogen, Oxygen,** and **Argon.**

Sinking air cools, **Rising air** warms

Wind - The movement of air systems due to differences in air pressure within our atmosphere
Planetary Wind - Associated with most meteorological variables that affect our weather and climate. This is any wind system that exists on Earth due to solar radiation or due to various forces

Wind in Mythology

Greeks - Aeolus looks after the four winds, Zephyrus (Spring/Fall), Boreas (Winter), Notos (Summer) and Eurus (Bad Weather)
Chinese - Feng Po Po looks after the winds
Japanese - Fujin/Haya-ji looks after the winds
North American - Nilch'i - Navajo believe that the wind is connected to spiritual life

History of Wind

Geological - comes from Volcanic origins, 4.6B years ago. Imbalance in systems causes things to happen. In the early days there was a lot of volcanic emissions (CO_2 and CH_4). There were 2.3 billion years of Methane and Carbon Dioxide life. This was the anaerobic age of bacteria.
Biological - 2.3 billion years ago, there was a sudden change. Oxygen appears and stabilizes in the atmosphere at 21%. Aerobic life-forms begin to appear. Links to Gaia Hypothesis

Gaia Hypothesis - James Lovelock
Life modifies the environment to best suit itself. The atmospheric constituents have been controlled by life to optimize conditions for life (life needed 21% oxygen optimally)

- Early sun produced 30% less energy
- Lots of gasses (methane/CO_2) that created huge greenhouse effect meaning hot
- Too warm, swapped from anaerobic life to aerobic life to reduce greenhouse gasses and cool down planet

Greenhouse Effect
Greenhouse gasses are an atmospheric constituent which traps outgoing radiation

- Water vapor
- Carbon Dioxide
- Methane
- Nitrous oxide
- Ozone
- Chlorofluorocarbons (CFCs)

Anthropological - Carboniferous period (sun energy converted to plant material, converted to coal and oil by pressure). Many of today's air quality problems arise from this energy release.

Atmospheric Measurements

Temperature - Thermometer
Pressure - Barometer
Humidity - Hygrometer, Psychrometer
Wind Speed - Anemometer
Wind Direction - Weather vane
Precipitation - Radar, rain/snow gauge

Lecture 02

Layers of the Atmosphere

- **Troposphere** (lowest)
    - Temperature declines with height
    - Heat is absorbed by surface so the further it is the colder it is
    - Most weather events happen here (75% of the mass of the atmosphere)
    - Seperated from stratosphere by the tropopause
- **Stratosphere**
    - Temperature increases with height, exclusively due to UV radiation by ozone
    - Ozone protects life on Earth from harmful UV radiation
- **Mesosphere**
    - Temperature decreases w/altitude, heat absorbed at base is dispersed by vertical air motions
- **Thermosphere** (highest)
    - Temperature increases with height due to absorption of solar radiation by nitrogen and oxygen, also releases kinetic energy of motion

Cloud Nomenclature

Stratus, strato - Layer clouds
Cumulus, cumulo - Puffy clouds
Cirrus, cirro - High clouds (altitude)
Nimbus, nimbo - Rain clouds
Alto - Middle atmospheric clouds

Pressure Gradient Force (PGF) - This is what causes air to move. Differences in air pressure causes a pressure gradient, and air moves from areas of high pressure to areas of low pressure.

Why does wind not fall onto the surface level? Because of PGF. Pressure decreases with height, so wind wants to move upwards (because air moves from high pressure -> low pressure)

Isobars - Any point on the isobar line is the same pressure. Closely spaced isobars mean strong winds will develop, where largely spaced means weak winds.
mb/mB - millibar, a unit of pressure equal to 0.001 bars, equiv to 100N per square meter
Atmospheric Pressure tells you how much atmospheric mass is above a particular altitude
Rising air cools - equalize pressure it changes particle motion (push outwards) and decreases temperature as air rises through kinetic energy loss
High pressure - sinks, moves clockwise
Low pressure - rises, moves counterclockwise

Horizontal Pressure - horizontal pressure gradient in higher atmosphere (mid troposphere)
Vertical Pressure - vertical pressure gradient in lower atmosphere
Coriolis Force - An imaginary force due to the rotation of the earth. In Northern hemisphere, causes a deflection to the right of the motion, in SH causes a deflection to the left. The Coriolis Force is diminished near surface due to friction. Derived by Gustave de Coriolis, discovered by George Hadley

Geostrophic Wind - A balance between the **PGF** and the **Coriolis effect**, only occurs 1KM+ from surface where PGF and CF is balanced. Blows parallel to the isobar (perpendicular to the pressure gradient) and is straight (not bending)
Surface Winds - any wind below 1KM from surface, they have bent winds b/c PGF, CF, friction. Bents counterclockwise in low pressure areas, clockwise in high presure areas (in North hemi)

Air Masses
Air masses are large bodies of air whose temperature and moisture are fairly uniform across any horizontal direction at any given altitude. Typically covers thousands of kilometers.
Source regions are the areas where air masses originate.

Original Classification of Air Masses
Origin: **P -** polar (cold) **T -** tropical (warm)
Region: **c -** continental (dry) **m -**maritime (wet)
cP - continental polar - dry, cold, stable
cT - continental tropical - dry, hot, stable aloft, unstable surface
mP - maritime polar - cool, moist, unstable
mT - maritime tropical - warm, moist, usually unstable

North American Classification - by Sheridan and Kalkstein (SSC)
Origin: **P -** polar (cold) **M -** moderate (neutral) **T -** tropical (warm)
Properties: **D -** (dry) **M -** (moist)

DP - cP, cool, dry, little cloud (Canada, Alaska)
DM - no traditional source, modified or mixes
DT - cT, hot, dry (south US and Mexico)
MP - mP, cold cloudy and humid, from North Atlantic Pacific and Great Lakes
MM - cloudy but warmer, usually modifed mP
MT - mT, warm humid, Gulf of mexico, tropical atlantic

MT+ -> Subcategory of MT, hot, very humid
TR - transitional air mass
A combination of **MP and DP** are responsible for poor air quality in Toronto (pollutants from SW)

Lecture 03

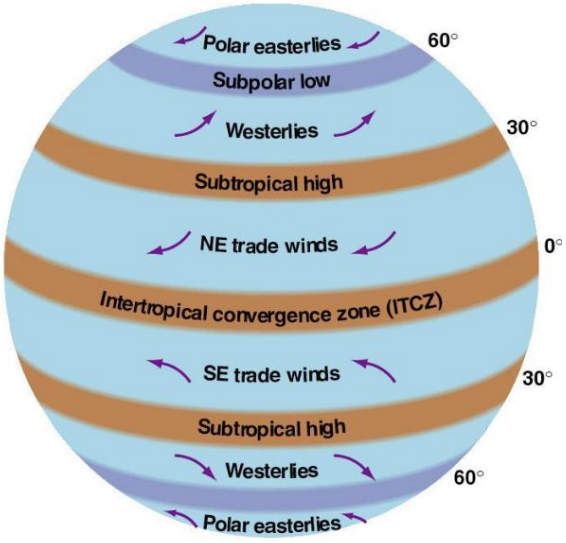
Global Circulation and Cells
Global - spans more than 10,000kms
Synoptic - spans 100 to 1000kms
Small scale - spans < 100kms

Atmospheric Circulation - polewards transportation by Wind
Cell - mass of air that moves together in a circular motion
One Cell Theory
*One large overturning atmospheric **Hadley** cell: air rises at the equator and moves polewards and sinks at pole. Named after George Hadley, British lawyer and meteorologist.*
Theory disputed by: Seasonality and land sea contrast..
Three Cell Theory
Hadley Cell - 0-30 degrees, surface flow is equatorwards and produces wind from the East

Ferrel Cell - 30-60 degrees, thermally indirect and surface wind travels north and veers East (William Ferrel was a meteorologist and a mathematician)
Polar Cells - 60-90 degrees, near the poles, produces Polar Easterlies
Subtropical Jet - Where Hadley and Ferrel cells meet
Polar Front Jet - Where Ferrel and Polar cells meet

Disputed by: Would be okay if Earth did not rotate (due to Coriolis force), therefore wind does not bend

Note - winds are named for where they're coming from, not where they're going towards



Intertropical Convergence Zone (ITCZ) -Area of rising air at or near the equator -- heavy precipitation
Trade Winds - winds that blow to the south west, surface component of Hadley Cell (towards equator)
Subtropical high - subsiding air at 30N and 30S, little precipitation - referred as horse latitudes
Westerlies - winds blowing to the east and north in midlatitudes, surface of Ferrel cell (away from equator)
Polar Front - Division of polar air and midlatitude air
Polar easterlies - winds that blow south west from north pole (northwest from south pole) (towards equator)

<u>Jet Streams</u>

Some of the most powerful forces in the world. Breeds storms over where it goes because it pulls up air from sea surface.
Fast flowing current of air that spans thousands of km, wide, and thick. Ranges from 150-300km/h. This is why airplanes from East to West take longer than West to East
Polar Jets
For midaltitude regions, typically **Cold -** Polar Jet is south of us/**Thaw -** Polar Jet is north of us
Low pressure systems follow the jet stream

<u>Stratospheric Winds</u>

Dobson-Brewer Circulation

- Thermally driven
- Provides equator to pole transport
- Some exchange between the layers (not really vertical)

Quasi-Biennial Oscillation (QBO)

- 2-3 year oscillation in upper troposphere and strat that dictates which way air flows at the equatorial region which witches between easterly and westerly phases
- Shifting of upper level tropospheric/lower stratospheric winds from east to west
- Linked to ozone hole, hurricane frequency (stronger when westerly, weaker when east)
- This is an upper level wind

Upwelling - when wind flows parallel to the coastline, the deep water rises to the surface
El Nino and Southern Oscillation (ENSO)
The warming phase of the sea temperature is El Niño and the cooling phase as La Niña and then normal. El Niño is accompanied with high, and La Niña with low air surface pressure in the tropical western Pacific. ENSO is the singular most important factor for hurricane predictability

- El Nino/La Nina is the oceanic component

Southern Oscillation is the atmospheric component
Trade winds weaken
Absence/presence of ENSO is a large factor in predicting Hurricanes

Synoptic Phenomena
Features that cover hundreds or thousands of km
Cyclones
Hurricanes
Anticyclones
Supercell storms
Tornadoes

Lecture 04

Tropical Cyclones - Known as **Hurricanes** in North America. Means **God of Evil** in Taino
Typhoon/Taifung in western Pacific
Cyclone in Australia

Tropical Storm - Storm region with sustained wind speeds of 18m/s to 33m/s
Hurricane - Storm region with sustained wind speeds of 33m/s to 50m/s
Major Hurricane - wind speeds of 50m/s + (Cat 3+)

Saffir-Simpson Scale - rating based on wind speed and central pressure of hurricane
Cat 1 - 119-153km/h (33-42.5m/s), >980mb
Cat 2 - 154-177km/h (42.5-49m/s), 965-979mb
Cat 3 - 178-209km/h (49-58m/s), 945-964mb
Cat 4 - 210-249km/h (58-69m/s), 920-944mb
Cat 5 - > 249km/h (>69m/s), <920mb

Hurricane Formation is by tropical storms fueled by sea surface temperatures and latent heat release **26.5C** threshold is necessary but not sufficient (temp of the sea)
Begins at Intertropical Convergence Zone (5-20N)
Groups of thunderstorms become self-sustaining
Convergence of surface winds, rising air releases latent heat, upper atmosphere warms and expands resulting in divergence. Eye is at divergence characterized by sinking air.
Energy for hurricane comes directly from transfer of heat from warm ocean surface
Dynamics - what affects length and strength of a cyclone?
Sea Surface Temperature (SST) - warmer the strface, stronger and longer the winds
Upper wind structure - strong upper level winds inhibit cyclone longevity
QBO and El Nino presence
El Nino condition - enhances Eastern pacific hurricanes, supresses Atlantic hurricanes
Landfall - cuts off cyclone from water vapor and SSTs

Dr William Gray - introduced the **Gray Index forcasting** Atlantic basin hurricanes, having factors:
QBO
ENSO
SST
Sahel rainfall (related to larger scale air flow which affects hurricane development)

Why are anamolous hurricane seasons here? Scientists debate… William vs Keery:
William Gray - Atlantic Multidecadal Oscillation (AMO)

- **35-40 year cycle** where the ocean changes in salinity (also affects SST (sea surface temperature))
- **Salination increases Temperature increases Hurricane activity**
- By his reasoning the thermohaline circulation should be stronger than usual but it actually 30% weaker

Kerry Emanuel - Global Warming increases SST

Coastlization of americans is increasing
Americans are increasingly wealthy and stand to lose more when hurricanes hit

More hurricanes reaching great lakes -> may be **North Atlantic oscillation** (causes easterlies/westerlies to become stronger bringing in storm systems)

Lecture 05

Midlatitude Cyclones also called a low, low pressure, frontal system occur in midlatitude (35-60)

- most storms in south ontario in fall/winter/spring are midlatitude cyclones (Colder seasons have more storms with more intensity). **mT meets cP**
- Freezing rain are a result of midlaltitude cyclones during winter

Stationary Front - alternating blue triangles and red semi-circles

- Stable
- Low pressure trough
- Horizontal wind shear
- Low moisture, lack of latent hear (unable to fuel storm)

Cold Front - designated blue line w/triangles facing warm air

- Cold air pushing into a warm air mass
- Heavy precipitation where front mT air is forced up
- Strong temperature gradient
- Change in moisture
- Shift in wind direction and pressure change

Warm Front - designated red line w/red semicircles facing cold air

- Warm air pushing into a cold air mass
- Gentle precipitation

Occluded Front

- Warm front and Cold front collide into each other -> Occuluded front (pink circle and triangle all on one side)
- Very cold zone
- Warm air is forced above surface
- Warm front-style precipitation

Polar Front Theory - the mechanism for the formation of midatitude cyclones

Division of polar and midlatitude air

Between the ferrel cell and polar cells

This is where all the midlatitude cyclones develop

Also called Norwegian Cyclone Model

In the atmosphere (upper level)

Step 1

Stationary front w/strong horizontal wind shear will cause a disturbance (cP and mT air masses)

When this happens, a low pressure center develops (creates a disturbance)

Step 2

A cold front pushes to the south and warm front pushes to the north

The pivot point is the lowest local pressure and precipitation begins

Step 3

Wave moves east or northeast, center pressure continues to drop

Large bands of precipitation have formed

Step 4

Faster moving cold front catches up with warm front, reducing size of warm sector

Step 5

Occlusion occurs as cold front impacts warm front

Most intense part of the storm

Widespread precipitation

Step 6

Storm dissipates after occlusion, source of energy (mT air) is cut off (energy because latent heat)

Great Lakes Climatology - midlatitude cyclones are major cause of erosion and sediment transport. Only 20% are locally generated, most are from Gulf of Mexico or Rockies.

SS Edmund Fitzgerald - 1975 (ship name)

sank as a result of a giant midlatitude rainstorm, created a song

The perfect storm - 1991 (halloween storm) (Sebastian Junger)

created from tail end of Hurricane Grace and Hurricane 8 (unnamed)

created a book called perfect storm, and a 2000 movie

Ice storm 1998

huge amount of damage, 15k troops deployed to help

series of 4 storms passed to the south of toronto, went over the escarpment (wind picked up moisture)

Toronto's regional topography - we're shielded by the Niagara Escarpment and Oak Ridges Moraine

Shielded from huge precipitation events (vs stuff like buffalo, rochester, etc)

Freezing Rain

cold/warm/cold combo (cold means snow, warm melts, cold supercools the water and freezes before it hits the ground)

when ice accumulation is more than 6mm, then its called **ice storm**

Lecture 06 – Thunderstorms and Tornadoes

Thunderstorms are **convective** storms – caused by surface heating, the only storm that has thunder and lightning. They must develop from air masses that are vertically unstable.

Categories: **Ordinary, Multi-cell, Supercell, Mesoscale Convective Complexes (MCC)**

Hydrometeors – huge collections of ice crystals and water droplets in the cumulonimbus clouds

Gust Front – develops as downdraft spreads along horizontal surface (sustains the storm)

Normal Thunderstorms have one cell – the convective cell (formed by updraft/downdraft/gust front)

Ordinary Thunderstorms – developed near large air masses, little vertical wind shear – change of hrz. Wind w/height

Cumulus Stage hot air rises and falls, forms the cumulus clouds **updraft**

Mature Stage is warm air is rising forming clouds and large water drops fall down as rain **downdraft**

Dissipating after a certain time when the energy is all gone, the storm dissipates

Short lived, usually < 1 hour, diameter 1km or less

Multi-cell Thunderstorm – downdraft forms downwind of updraft, storm lasts longer, gust front of one storm initiates or reduces another storm

Supercell Thunderstorm – Form with strong vertical wind shear – surface winds (mT air) and upper level wind (cP air), forms from the cold front of a midlatitude cyclone, **Tornadoes, Microbursts, and Hail** can form

Downdraft does not cut off updraft, storm can last several hours. Gust front does not cut anything off.

Microbursts can form – creates pockets of bursts of radial surface winds

Mesoscale Convective Complexes (MCC) – multiple thunderstorms (not multicells), form in circular fashion (100K+ sq. km) 12 hours or more, self sustaining, heavy precipitation

Squall Line – characteristic of SCT or MCC – a narrow band of high winds forms in the upper air, the cold front of the midaltitude cyclones

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Lightning – cumulonimbus clouds have negative charge, heavier so they go to base of cloud, attract positive charges from the ground – 90% of time the lightning starts at cloud base and goes to surface

Several cm in diameter, air heats to 30K C, radio waves called **sferics** are produced - lightning detection systems use it

Stepped leader – the forked lightning that forms, leads the lightning towards the ground, 50 meters 3m volts, further steps take 50/100 meters each until surface is reached, called **dart leaders**

Sheet Lightning occurs between clouds, **Heat lightning** describes lightning that occurs at a distance (silent), **Dry Lightning** describes when precipitation evaporates in downdraft and doesn't reach the surface

Hail – largest form of solid precipitation and 2nd costliest natural weather disaster in Canada (**Coffeyville** hailstone big) Formed in cumulonimbus clouds, supercooled water droplets freeze on contact with ice pellets, grow due to updraft cycles and create a layer of glaze (liquid) and rime (bubbles), occurs mostly on lee side of Rocky Mountains

Tornadoes form due to **Thunderstorms -** See it all summer in southern Ontario. They are rotating columns of air that reaches the ground, also called **Twisters** or **Cyclones.** They are formed by **funnel clouds**. They spin **CCW,** 100-600m in diameter, and have peak winds of 400km/h but only last a few minutes.

They form in **Supercell Thunderstorms,** at the storm base. A Thunderstorm is required for a Tornado, but not reverse. They were measured on the **Fujita Scale,** categorized from **F0 – F6,** Weak, Strong, Violent

Weaknesses: estimated wind speed from dmg may be misleading because diff. infrastructure can withstand dmg Rankings are subjective due to only indicator being dmg (can be hard to tell when no dmg indicators) sbj. to bias

Most commonly seen: **Leeside of Rockies** (US) and **Southern Alberta/SW Ontario** (Canada)

Enhanced Fujita Scale – overtook the default Fujita scale, it introduced the **EF0-EF6** categorization, which better accounted for construction quality and adds structures and vegetation and expands degrees of damage

Etkin - ENSO events on Canada Tornado freq – cool temperatures La Nina surpress tornadic activity due to absence of strong wind shear. More Tornadoes during El Nino and fewer during La Nina. Recent climate warming may increase freq.

Great Lakes inhibit tornadic activity because milder winter cooler summer, many Ontario tornadoes are obscured by precipitation and **Lake Breeze** may generate convection for storm formation on a SW to NE axis towards Quebec

Cao – upward trend of 1.6 tornadoes more per decade, multivariate ENSO index and tornado frequency is related as well

Lecture 07 – Polar Lows, Firestorms, Sandstorms and NAO

Polar Lows – poleward of the polar front, cold polar air and warm tropical air, storms can form. These storms are **polar lows**, sometimes called **Polar Hurricanes** or **Arctic Hurricanes**

Formed when bitter cold Arctic air moves over warmer ocean water, change in surface properties is called **Arctic Front** It's a **tightly circular storm** resembling a tropical cyclone. The core is warm, like a hurricane but not like a midlatitude cyclone. Polar lows fully develop within 24h and dissipate within a couple of days, exceeding 50km/h speeds, dissipates over land due to cut-off from energy source. **200-1000km** in diameter, November to March in NPacific, NAtl. and NZeal.

Firestorms are self sustaining surface fires, caused by forest fires as well as human actions like targeted explosions

Combustion makes heat energy go up, rises in a **chimney effect** and induces convergence of surface air, which fuels and sustains firestorms by giving and renewing oxygen and drawing debris to burn. These are usually in Forests or Wars.
Clouds can form due to firestorms, air rises and ash from firestorms provide cloud condensation nuclei, **pyrocumulus** clouds are formed – grey or white in color above the firestorm, also follows volcanic eruptions.
Dust Storms/Sand Storms are winds that generate clouds of dust. Dust is loose surface material or volcanic emission (soil, silicon dioxide, clay, silt, sand [in order of size]). **Sand Storms** are **LARGER** dust storms.
They are created when winds exceed **20km/h** throwing the dust into the atmosphere, rising up to 5000m into the air.
Dust storms are not dependent on latent heat, clouds that are created are just from suspended dust particles.
Haboob is Arabic for **blown** which thunderstorm downdrafts lift sand up into thunderstorm, up to 150km horizontally
Found in **Saraha (Haboob), Arabian, Gobi** deserts and parts of Australia and southern US
Dust Storms occur often on **Mars**, no other storms form due to lack of water.
Saharan Transport of Dust can be found in NA and SA, due to the **North Atlantic Oscillation (NAO)**
The **NAO** is the pressure variations in North Atlantic Ocean, Icelandic low and Bermuda highs (high/low is pos/neg)

- **Positive Phase** of **NAO** occurs when pressure between the two is greater than the average difference between
  Colder drier winds in NE Canada, fewer winter storms and winters are warmer. Sand transport increased
  Easterly trade winds are enhanced by stronger clockwise circulation around the Azores/Bermuda highs
- **Negative Phase** is when the pressure difference is less than the average difference, low Icelandic and Bermudas

Lecture 08 – Thermal Winds and Urban Heat Islands

Land/Sea Breezes arise from differential heating of earth's surface during the day. Land heats and cools faster than water. Air moves from the land and sinks at the water at the surface creating a cool breeze, or a **Lake/Sea breeze.**
At night, the air rising over water and sinking over land is a warmer **land breeze**
Sea Breezes are strongest in summer, **land breezes** are stronger in winter

- **Monsoon** is a land/sea breeze except it occurs over a larger area (continental) and over longer span (seasonal)

Valley Breezes develop in valleys daily – land heats faster than air above it during day, air flows up sides of valleys causing upwards wind, at night the land cools faster and flows down towards the valley sides. Important to hikers.
Katabatic Wind is when air pools over the **glacier** and becomes denser, when moving away it goes rapidly downhill.
Chinook is Canadian wind on the leeside of mountains, air going up windward side condenses into clouds and releases heat, leeside of mountain the air warms rapidly and is dry, can rapidly change temperature of the leeside of the mountain.

Urban Heat Island – The warming of urban areas compared to surrounding rural areas, more noticeable at night or winter
Pollution, Temperature, Precipitation, Cloudiness, Thunderstorms **higher,** Sunshine hours, Relative Humidity, Visibility, Wind Speed **lower.** Mainly due to **pavement, less greenery, reduced albedo, snow removal, pollution**
Heat islands are linked to city population – biggest difference is minimum daily temperature **(Tim Oke),** urb contribs. 30%
Toronto Downtown is a heat island, consistently 3C warmer at night throughout the year. UHI increases over time **(Munn)**
Both daily min and max temperatures are increasing, diurnal temperature range has been decreasing because **country breeze** no longer cools city at night (hot air rises, cool air rushes in) but diminished due to urban sprawl **(Rozanov/Gough)**

Lecture 09 – Pollutants and Measuring Wind

Two aspects of Arctic Pollutations – **Arctic Haze** and **Persistent Organic Pollutants (POP)**
Arctic Haze peaks during spring, pollutants appear and pool, removal of the haze is due to Arctic Ocean and surrounding waters. Mainly sulfate (90%) and soot/dust. 10-20x greater than normal levels of sulfate, due to **Coal Burning.**
Pooling pollutants happen due to **temperature inversion** when ground near the poles are cold due to lack of sunlight. Temperature increases with height, preventing air from rising so inhibits mixing and precipitation. **Eurasia** causes most.
Persistent Organic Pollutants are toxic organic compunds with long lifespans that concentrate as the move up food chain, examples being

- **PCBs,** used as coolant, skin conditions and liver dmg, released into Great Lakes and bio-magnified by fish
- **DDT,** insecticide in WW2, affects birds and toxic to aquatic life and fish, banned in US/Canada
- **Chlordane,** insecticide banned in Canada, nervous system disorders and digestive system problems
- **Heptachlor,** insecticide (white powder), linked to nervous system damage

POPs are ubiquitous in the arctic despite no local sources and has not been reduced – **(Wania/Mackay 1993)**
Cold Temperatures allow for pollutants to concentrate, not saturating the air. Arctic air traps, cold temp slows breakdown
Impacts the arctic biota – high levels of PCBs found in arctic polar bears and ringed seals
Banned in most countries – 12 POPs '**Dirty Dozen**' and became international law to ban usage and production of each

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Anemometers measure wind speed, **weather vanes** measure direction, higher level winds are measured by **radiosonde**

- **Deflection** anemometers were invented by Leon Alberti in 1450, then **Robert Hook** created **Hook Anemometer**
- **Pressure** anemometers were created by **Janes Lind**
- **Cup** anemometers were created by **Thomas Robinson**
- Other types include **Wind Mill** and **Thermoelectric**

Laser Radar anemometers uses Doppler principles to measure wind speed

Upper Level Winds are measured by radiosondes (weather balloons) launched from meteorological stations. Creates a **synoptic** (simultaneous) observation of the atmosphere. Supplemented by **dropsondes** – packages dropped from airplanes They calculate the strength of upper level wind through PGF, horizontal pressure gradients and latitude.

Wind Chill depends on both wind temperature and wind speed. Temperature does not decrease with wind but increases heat loss. Under **windless** conditions, an **epiclimate** or **nanoclimate** forms around the skin – protective and conductive to heat.

Anemograph displays continuous wind speed on a chart but does not denote direction

Wind Rose gives directional wind data, but also includes speed information. Displays 16 directions, 4 per quadrant.

Beaufort Scale is a classification scale of winds – 13 levels from 0 to 12, 12 is above 120km/h.

Fujita Scale is for tornadoes

Saffir-Sampson scale is for hurricanes

Sonic boom is the sound associated with the shock waves created whenever an object travelling through the air travels faster than the speed of sound

Mach Speed is the ratio of an object to the speed of sound. When M is greater than 1, object is exceeding speed of sound. Sonic boom results when this happens, objects that approach speed of sound create a cone of condensation – **Prandtl-Glauert singularity.**

Bull Whips are also sonic booms, snapping sounds occur when lower end of whip exceeds the speed of sound

Lecture 10 – Wind Power

Flying – in 15th century Leonardo da Vinci drew up flying machines but didn't have **engineering** skills to complete them. **19th century Otto Lilienthal** did over 2000 glider flights, but the first manned flight was by the **Wright Brothers** in 1903. Possible due to **Bernoulli's Principle –** that is, a fluid that is moving faster has a relatively **lower pressure**. The shape of a wing causes air to flow faster over the top of the wing than it does beneath, creating lift under the wing and

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Sailing is transport of humans or goods over water, in **knarrs** or **cogs** in Norse, **junk rigs** in China, and **lanteen** in Europe. Age of Sail started in 13th century when people could navigate over entire planet. The **lift or pull** is horizontal instead of vertical, wind flows faster over front than back, creating **PGF** that pulls sail forwards.

Power Generation by wind takes on many forms – grain grinding and water pumping – the **horizontal** axis has been found to be more efficient and dominates current and historical design.

Wind Turbines are natural extensions of windmills, used to generate electricity. 1% of Canada is powered by wind power. Horizontal-axis or vertical-axis variety, it contains

- **Blade** which converts wind into rotational shaft energy
- **Drive Train** which includes gearbox and generator
- **Tower** which supports drive train and rotor/blade

It requires **high** initial cost and the **noise, visuals** and **avian** life loss are potential factors.

Europe is strongest market for wind energy with currently around 74,767 MW of installed capacity in 2019

North America also has growth, around 35,086 MW total in 2019

Latin America has around 1406 MW, China has around 26GW, India at 11GW, Pacific at 500MW, Africa at 170MW

Lecture 11 – Global Warming

Weather is the current conditions of the atmosphere, temperature, humidity, winds, etc.

Climate is the description of typical atmospheric conditions, typical weather. This can be averages, variabilities, extremes. It is influenced by:

- **Latitude** affects the angle of incidence of sunlight
- **Global Circulation** means jet streams, frequency and creation of storms, ocean currents, etc.
- **Air masses** are pushed around by prevailing winds and provide cold/warm moist or dry air
- **Geography** features such as oceans or mountains influence local climate (land/sea/ocean/valley/etc. breeze)
- **Land Cover** urban heat islands are caused by surface albedo, evapotranspiration, etc.

Aerosols are small particles suspended in the air – can take a very long time for them to fall back to lower atmosphere. They reflect sunlight and reduce amount that reaches earth's surface, causing noticeable cooler conditions – 1816 has an event called **Year Without Summer,** or **Eighteen Hundred Froze to Death** which was eruptions that caused lots of aerosols

Solar Variations are strength of the Sun on Earth. **Maunder Minimum** were the decades where sunspots cycles stopped and no sunspots occurred.

Milankovitch Theory is the fact that the wiggles and wobbles of an Earth's orbit serve as pacemakers for glacial periods Timescales of Milankovitch cycles are 21000, 41000 and 100000 years.

Water Vapor is the most important feedback cycle – amount of water vapor very closely correlates to air temperature, warmer air can and does hold more water.

Atmosphere-Ocean General Circulation Models are the way that modern climate change is predicted