Weather and Climate

What is the difference?

Why is it that I know that it is going to be very hot in a couple of months, but I can't tell if it is going to rain next week?
Questions

• Since the North Pole has 24 hours of sunlight during summer, why isn’t it the hottest place on the planet?
• Why aren’t daily temperatures highest on June 15, summer solstice, when the Sun is at its highest and the days are longest?
• What causes weather, e.g. winds, rain, etc.?
• Why does the wind in Billings nearly always come from the west?
• What about winds in other parts of the globe? Are they always from the west and why?
• What does it mean that the air is saturated with water vapor and what do relative humidity and dew point have to do with this?
• How do clouds form?
• What are the most common types and how can they help us forecast the weather?
• What the heck is ‘Adiabatic’ and what does it have to do with weather and so-called ‘upper air disturbances’? .... Plus many more.
Time Scales

weather vs climate

Weather

The conditions at a specific location at a specific time

• **Hourly**
  – e.g., this afternoon

• **Diurnal**
  – The day-night cycle - 24 hours

• **Weekly**
  – Standard long range TV weather forecast
Climate

The average conditions and their variability
(includes extremes)

– Seasonal
– Annual
– Decadal
– Century
– Geologic Timescales
Spatial Terms of Reference

• Global - The planet as a whole
• Planetary - as in planetary waves
• Hemispheric - e.g. northern hemisphere
• Zonal- implies East-West
  – a latitude band
    • e.g. subtropics 20-30° lat
• Meridional - implies North-South
• Regional
  – High Plains
  – The Mountains
• Local
  – Billings
Spatial Terms of Reference

- **Synoptic scale**
  - 500 to 3000 Kilometers
    - midlatitude cyclones, weather systems, fronts

- **Mesoscale**
  - 20 to 200 Kilometers
    - Thunderstorms

- **Microscale**
  - centimeters to 1 Kilometer
    - In-Cloud updraft, the size of a leaf
During what hour on a summer day are the Sun’s rays most intense?

What is the usually the hottest hour during a summer day?

During what month do we get the most intense and longest-lasting rays from the Sun?

What month is the hottest?
Monthly changes in hours of daylight

![Graph showing monthly changes in hours of daylight](image-url)
Earth's surface temperature is a balance between incoming solar radiation and outgoing terrestrial radiation.

Peak temperature lags after peak insolation because surface continues to warm until infrared radiation exceeds insolation.
The Job of the Atmosphere

Transfer heat from the Equator to the Poles
Radiation Budget
at the top of the Earth’s Atmosphere

Red Line is incoming radiation from the sun

Blue Line is outgoing radiation emitted by the earth

The filled in areas are heat surpluses and deficits
The Job of the Atmosphere is to let the energy out!

“Piles up” in tropics  “Escapes” near poles and aloft

The movement of the air (and oceans) allows energy to be transported to its “escape zones!”
What single cell convection would look like for a *non-rotating* earth

- Thermal convection leads to formation of convection cell in each hemisphere

- Energy **transported** from equator toward poles

- What would prevailing wind direction be over N. America with this flow pattern on a rotating earth?
What’s wrong with the 1-cell model?

Answer: The Earth Spins and ultimately it is not stable for several reasons including that it neglects the impact of the Coriolis Force.

What does a stable solution for global wind circulation on a rotating planet look like?
Coriolis Force acts to the right in the Northern Hemisphere
The Coriolis Effect deflects **moving objects** to the right in the northern hemisphere and to the left in the southern.
Fig. 7-12, p. 154

- **Polar cell**: Jet stream, flows west to east
- **Mid-latitude cell (Ferrel cell)**
- **Subtropical high-pressure belt**
- **Tropical cell (Hadley cell)**
- **Equatorial trough—low-pressure belt (Doldrums, ITCZ)**
- **Tropical cell (Hadley cell)**
- **Subtropical high-pressure belt**

- **Westerlies**: Cool air falls, warm air rises
- **Northeasterly trades**: Warm air rises
- **Southeasterly trades**: Cool air falls
- **Westerlies**: Jet stream, flows west to east
Rising warm, wet air; always rainy

Sinking cold, dry air; always clear and dry

Sinking cold, dry air; always clear and dry
Climates of the World

• Deep Tropics: hot and wet, with little seasonal variation
• Seasonal tropics: hot, with “summer” rain and “winter” dry (monsoon)
• Subtropics: dry and sunny, deserts and savannas, often with a well-defined rainy season (summer or winter)
• Midlatitude temperate zone: warm summers, cold winters, moisture varies by location but often comes in episodes throughout the year
• Polar regions: very cold, generally very dry, dark in the winter

Other Influences:
Ocean currents, “continentality,” vegetation, mountain ranges (altitude and orographic precipitation)

Orographic = lift due to the presence of mountains
It is humid at the Equator and dry at the Poles
It is humid at the Surface and dry at high altitudes.
An illustration of sea-surface temperature showing the general direction and pattern of surface current flow. Sea-surface temperatures were measured by a radiometer aboard NOAA-7 in July 1984. The purple color around Antarctica and west of Greenland indicates water below 0°C, the freezing point of fresh water. Note the distortion of the temperature patterns we might expect from the effects of solar heating alone—the patterns twist clockwise in the Northern Hemisphere, counterclockwise in the Southern.
The Gulf Stream
Atmospheric Water
The Hydrologic Cycle

About 90% returns to the tropical oceans.
Water's unique molecular structure and hydrogen bonds enable all 3 phases to exist in earth's atmosphere.
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Properties of Water

• **Physical States**
  – only natural substance that occurs naturally in three states on the earth’s surface

• **Heat Capacity**
  – Highest of all common solids and liquids

• **Surface Tension**
  – Highest of all common liquids

• **Latent Heat of Fusion**
  – Highest of all common substances

• **Compressibility**
  – Virtually incompressible as a liquid

• **Density**
  – Density of seawater is controlled by temperature, salinity and pressure
  – Liquid has maximum density at +4°C; solid phase has lower density!
Energy associated with phase change

80 calories  100 calories  540 calories!
Water vapor pressure

- Molecules in an air parcel (e.g., $N_2$, $O_2$, $H_2O$) all contribute to pressure

- The VAPOR PRESSURE, $e$, is the pressure exerted by water vapor molecules in the air
Water vapor saturation

- Water molecules move between liquid and gas phases.
- When the rate of water molecules entering the liquid equals the rate leaving the liquid, we have equilibrium.
  - The air is said to be saturated with water vapor at this point.
  - Equilibrium does not mean no exchange occurs.
No water vapor

Flat water surface covered

Pure H$_2$O
Evaporation rate  Condensation rate
Evaporation rate  Condensation rate
What happens if I heat this?
Expressing the water vapor pressure

e = vapor pressure;  \( e_s \) = saturation vapor pressure

- **Relative Humidity (RH)** is ratio of actual vapor pressure to saturation vapor pressure
  - \( 100 * \frac{e}{e_s} \) (\( e \) = vapor pressure, \( e_s \) = saturation vapor pressure)
  - Range: 0-100% (+)
  - Air with RH > 100% is supersaturated

- RH can be **changed** by
  - Changes in *water vapor* content, \( e \)
  - Changes in *temperature*, which alter \( e_s \)
Warm air can hold more water vapor
Dewpoint Temperatures

Dewpoint temperature
the temperature at which dew forms, i.e. condensation
When Rh = 100%

• Dewpoint temperature is a measure of the water vapor content of the air
• It is not a measure of temperature!
Clouds and stability of the Upper Atmosphere
Why is stability important?

• Vertical motions in the atmosphere are largely controlled by vertical stability

• There are two types of vertical motion:
  – **forced motion** such as forcing air up over a hill, over colder air, or from horizontal convergence
  – **buoyant motion** in which the air rises because it is less dense than its surroundings - **stability** is especially important here
A rock, like a parcel of air, that is in stable equilibrium will return to its original position when pushed.

If the rock instead accelerates in the direction of the push, it was in unstable equilibrium.
Stability in the atmosphere

An Initial Perturbation

Stable

Unstable

Neutral

If an air parcel is displaced from its original height it can:
- Return to its original height - Stable
- Accelerate upward because it is buoyant - Unstable
- Stay at the place to which it was displaced - Neutral
“Lapse rate”

• The lapse rate is the change of temperature with height in the atmosphere

• There are two kinds of lapse rates:
  – Environmental Lapse Rate (~ 4°/1000 m)
    • What you would measure with a weather balloon
  – Parcel Lapse Rate
    • The change of temperature in an air parcel as it rises
    • This is an adiabatic process (i.e., no heat exchange occurs across parcel boundary)
    • Air cools as it rises
    • Dry air cools faster than moist air!!!!!
Air stability and adiabatic rates
Absolute instability (examples)

(a) The rising, unsaturated air parcel at each level is warmer and lighter than the air around it. If given the chance, the air parcel would accelerate away from its original position.

(b) The rising, saturated air parcel is warmer than its surroundings. If given the chance, it also would move away from its original position.
How to make a cloud
Condensation

- Condensation is the phase transformation of water vapor to liquid water
- Water does not easily condense without a surface present
  - Vegetation, soil, buildings provide surface for dew and frost formation
  - Particles act as sites for cloud and fog drop formation
Where do Cloud Condensation Nuclei (CCN) come from?

- Good CCN are hygroscopic (they “like” water,)

- Natural CCN
  - Sea salt ($\text{Na}^+, \text{Cl}^-, \text{SO}_4^{2-}, \text{K}^+, \text{Mg}^{2+}$)
  - biogenic sulfur emissions
  - vegetation burning

- CCN from human activity
  - Pollutants from fossil fuel combustion ($\text{CO}_2, \text{SO}_2$)
Smog over China
Fogs

- Fogs are clouds in contact with the ground
- Several types of fogs commonly form
  - Radiation fog
  - Advection fog
  - Upslope fog
  - Evaporation (mixing) fog
Clouds

• Clouds result when air becomes saturated away from the ground

• They can
  – be thick or thin, large or small
  – contain water drops and/or ice crystals
  – form high or low

• Clouds impact the environment in many ways
  – Temperature, precipitation (snow/rain), pollutant processing, climate change, kill?, etc...
Cloud Classification

- Clouds are categorized by their height, appearance and vertical development
  - **High Clouds** - generally above 16,000 ft at middle latitudes
    - Main types: **Cirrus, Cirrostratus, Cirroccumulus**
    - (wispy; high altitude ice)
  - **Middle Clouds** – 7,000-23,000 feet
    - Main types – **Altostratus, Altoocumulus**
  - **Low Clouds** - below 7,000 ft
    - Main types – **Stratus, stratocumulus, nimbostratus**
    - (layered; stable)
  - **Vertically “developed” clouds** (via convection)
    - Main types – **Cumulus, Cumulonimbus**
    - (cottony; beautiful day, but it might rain)
Cloud type summary

- **HIGH CLOUDS**
  - Cirrostratus
  - Halo around sun
  - Cirrocumulus (mackerel sky) 7000 m

- **MIDDLE CLOUDS**
  - Altostratus (sun dimly visible)
  - Altocumulus

- **LOW CLOUDS**
  - Nimbostratus
  - Stratus

- **CLOUDS WITH VERTICAL DEVELOPMENT**
  - Cumulonimbus
  - Anvil top

- **Precipitation**
  - Steady precipitation
  - Showery precipitation
Cirrus
Cirrus Display at Dawn
Stratus from below
Stratus from above
Stratus over the ocean
Puffy cumulus
Vertically “developed” clouds

- **Cumulus**
  - Puffy “cotton”
  - Flat base, rounded top
  - More space between cloud elements than strato-cumulus

- **Cumulonimbus**
  - Thunderstorm cloud
  - Very tall, often reaching tropopause
  - Individual or grouped
  - Large energy release from water vapor condensation

*Vertical Instability Aloft!*
Cumulonimbus
Cumulonimbus with Pileaous caps
Cumulonimbus Clouds Spawn Tornadoes
Cirrocumulus

Cirrocumulus at Sunset
Altostratus
Lenticular clouds downwind of mountains
Rain drop size and shape

**FIGURE 1**
Which of the three drops drawn here represents the real shape of a falling raindrop?
Precipitation and the ice crystal process

- At mid and northern latitudes most precipitation is formed via ice crystal growth

- Supercooled cloud drops and ice crystals coexist for $-40^\circ < T < 0^\circ$ C
  - Lack of freezing nuclei to glaciate drops

- Ice crystals can grow by
  - Water vapor deposition
  - Capture of cloud drops (accretion/riming)
  - Aggregation
Air Mass Source Regions

- mP: Maritime polar air masses
- cP: Continental polar air masses
- cT: Continental tropical air masses
- mT: Maritime tropical air masses
- CA: Arctic air masses

Summer only
Billings’ rain shadow

- cP air from Asia and frozen polar regions is carried across the Pacific, circulating around Aleutian low.
- Contact with the ocean warms and moistens the air near the surface, transforming it to an unstable mP air mass.
- As the mP air moves inland it crosses several mountain ranges, removing moisture as precipitation.
- The drier mP air is transformed back to cP air as it travels across the cold, elevated interior of the U.S.
Fronts

A Front - is the **boundary between air masses**; normally refers to where this interface intersects the ground (in all cases except stationary fronts, the symbols are placed pointing to the direction of movement of the interface (front))

**Warm Front**

**Cold Front**
Two air masses entering a region, such as the U.S. middle latitudes, have a front, or transition zone, between the strong temperature and humidity differences.

Four different fronts are used on weather maps.

http://www.rap.ucar.edu/weather/satellite/
Cold Fronts: cold, fast, steep and stormy
Warm Fronts: warm, slow and wet
Air Mass Fronts

Two air masses entering a region, such as the U.S. middle latitudes, have a front, or transition zone, between the strong temperature and humidity differences.

Four different fronts are used on weather maps.

http://www.rap.ucar.edu/weather/satellite/
Severe Thunderstorm Structure

Tropopause

Overshooting top

Mammatus

Anvil

Wind

Rain

Hail

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