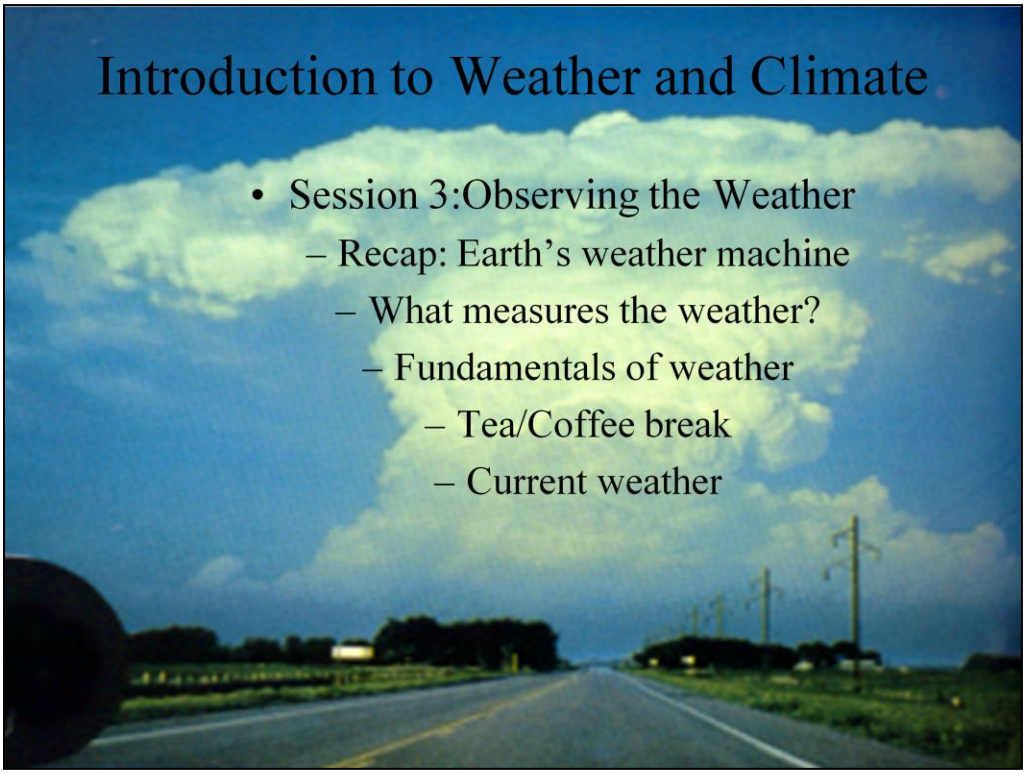
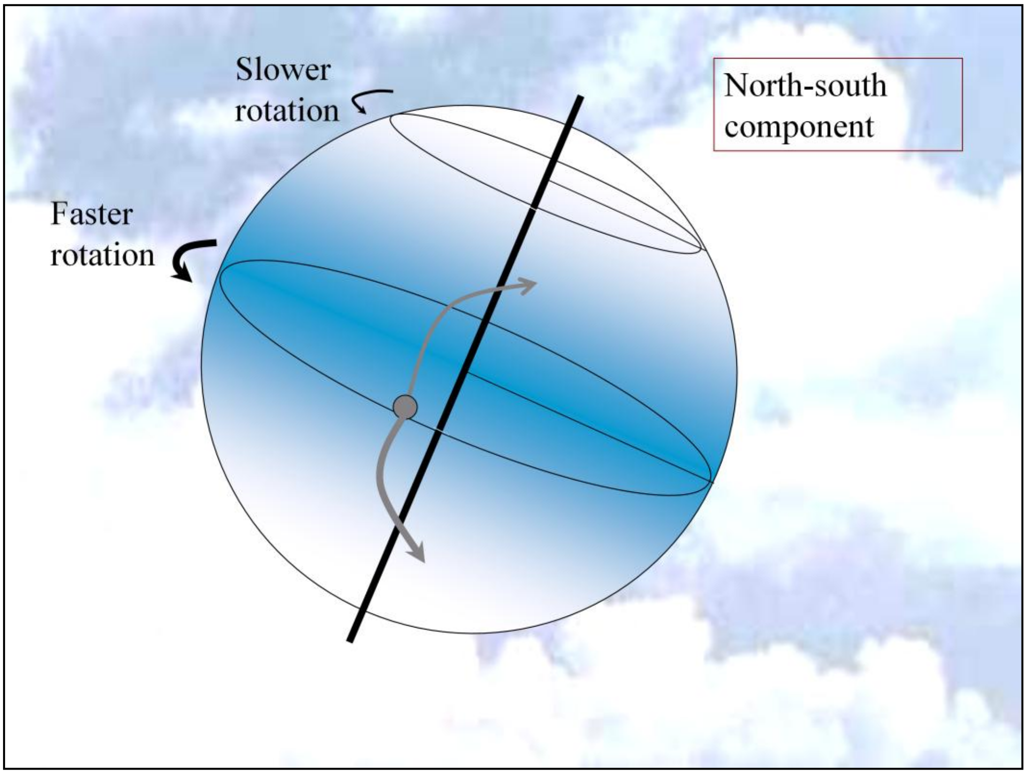
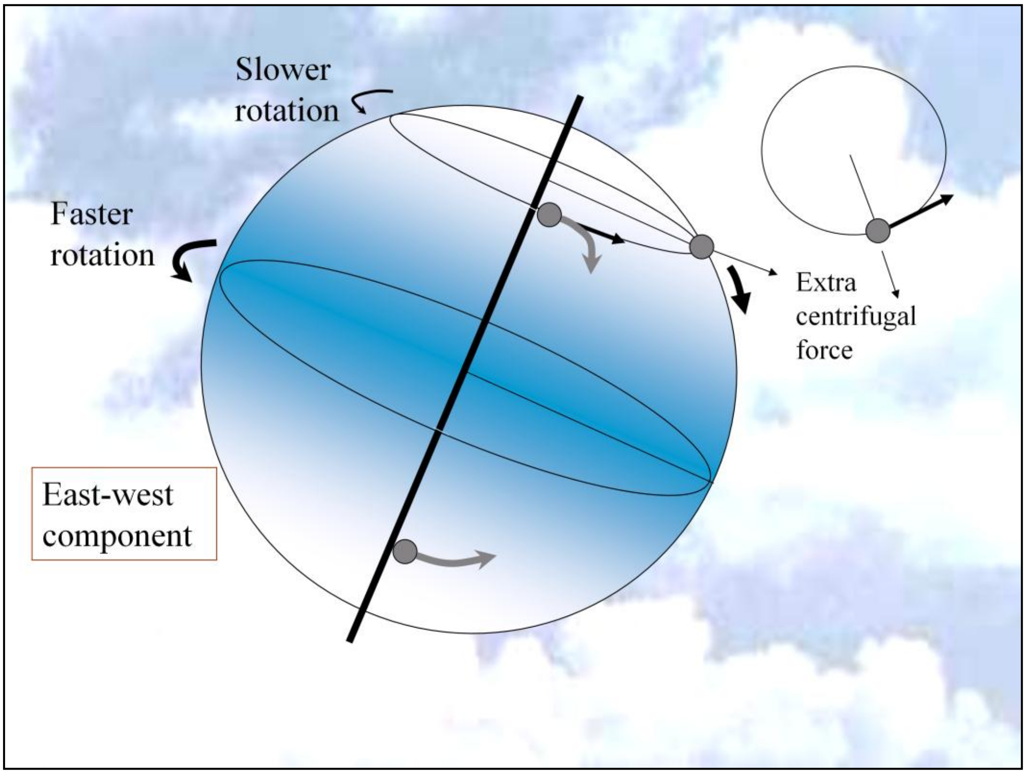
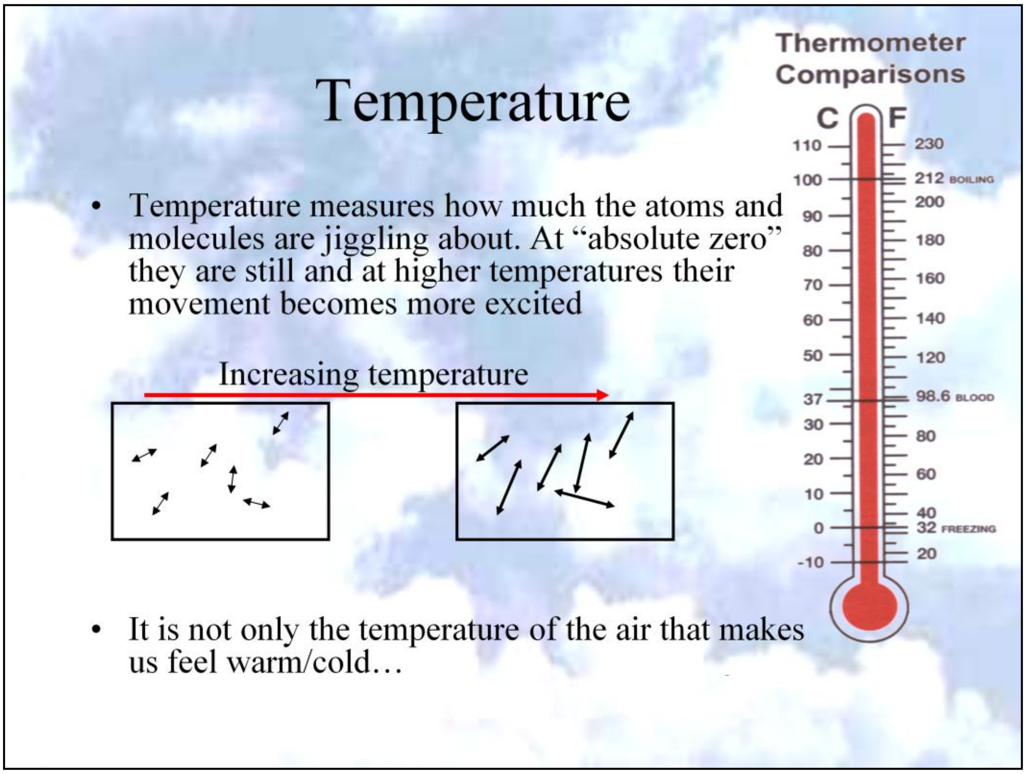

Introduction to Weather and Climate
• Session 3:Observing the Weather
– Recap: Earth’s weather machine
– What measures the weather?
– Fundamentals of weather
– Tea/Coffee break
– Current weather

The coriolis "force"

- The coriolis "force" acts to deflect wind to the right in the northern hemisphere and to the left in the southern hemisphere
- It is cause by the rotation of the Earth


Slower
rotation
Faster
rotation
North-south
component

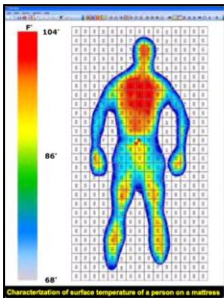

Slower
rotation
Faster
rotation
Extra
centrifugal
force
East-west
component



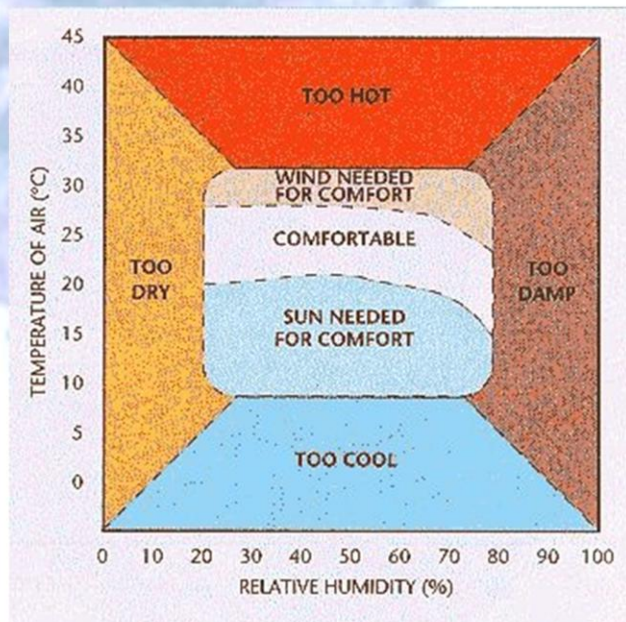
Temperature (T) – degrees Celsius (^oC) arbitrary scale from 0^oC at melting point of ice to 100^oC at boiling point of water

Also (Kelvin, K) = ^oC plus 273.15

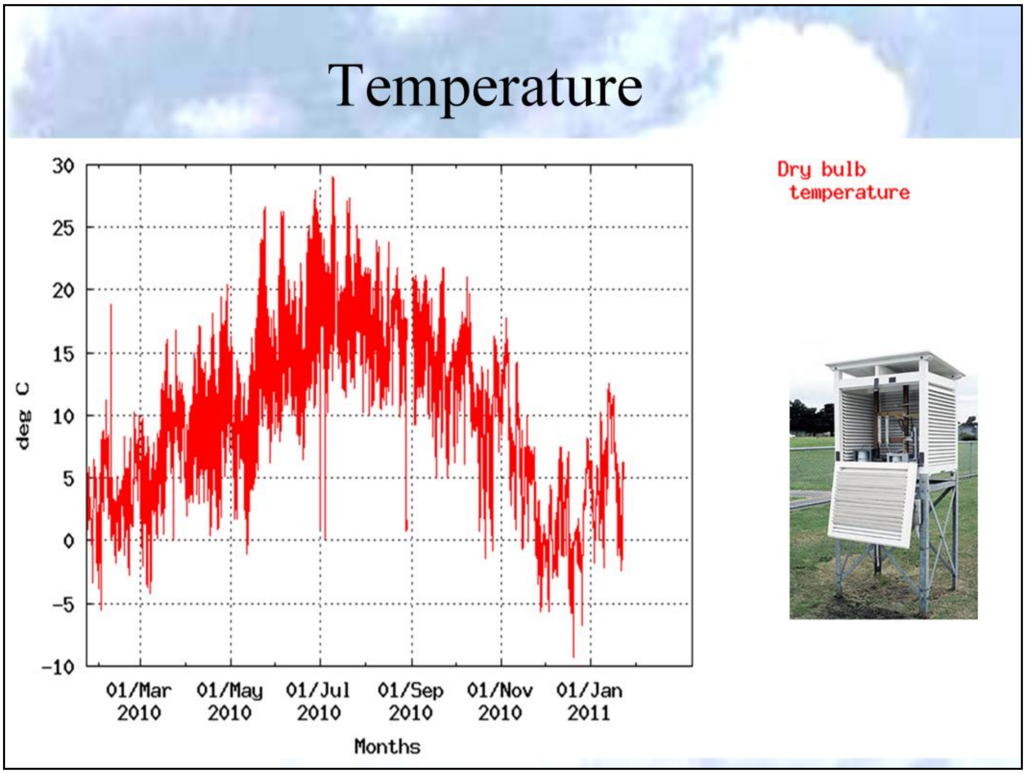
> 0 K is absolute zero, the minimum possible temperature
>
> Americans and Telegraph readers tend to use ^oF



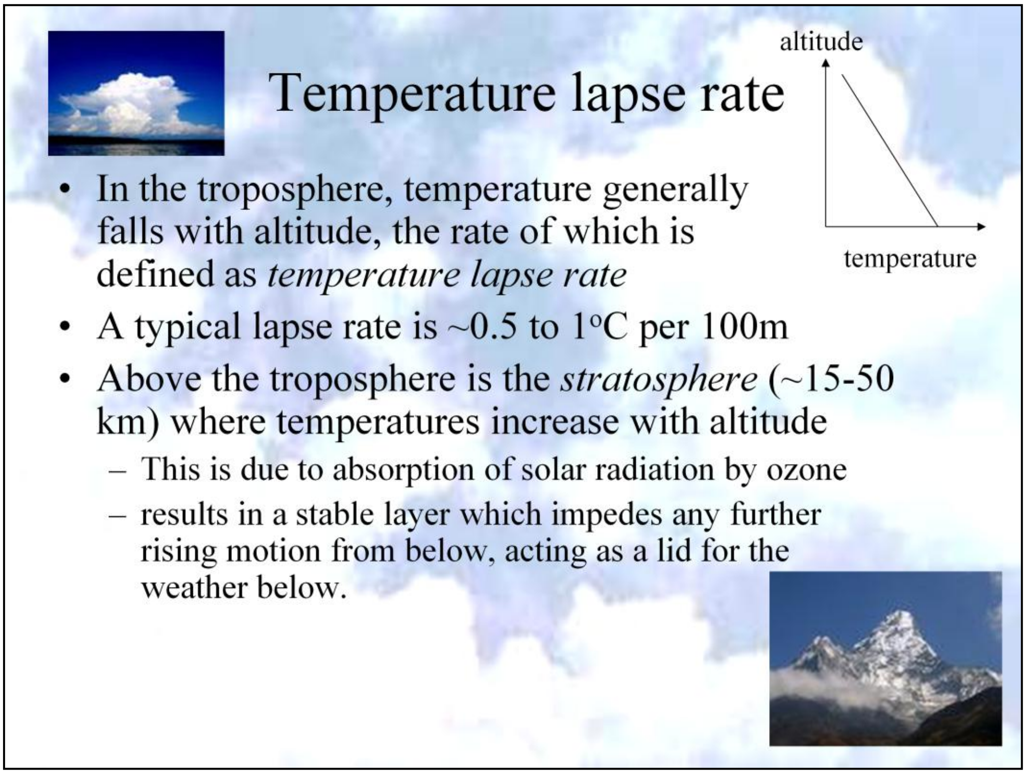
Human comfort diagram



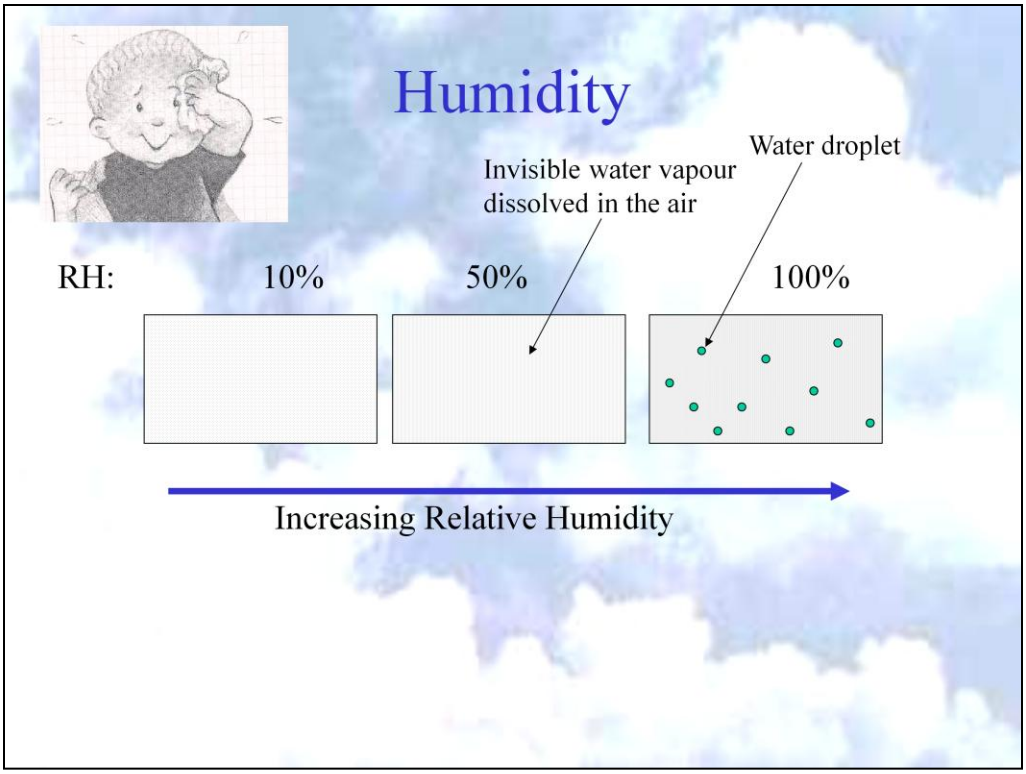
The human body has an energy balance just like the Earth (solar radiative heating, thermal radiative heating/cooling, evaporative cooling (sweat)) although this is complicated by drinking tea. Wind makes us cool because it increases the flow of energy from the body through evaporation (sweat) and sensible heat. 15^{o}C may feel cool on a cloudy day but warm on a sunny day (air temperature is measured in the well ventilated shade of, for example, a Stevenson’s screen).



The maximum and minimum temperature are routinely measured daily at meteorological stations and are used in reconstructing past changes in local temperature. The diurnal temperature range in larger on still, clear days, when solar heating is strong at the surface and is not offset by evaporative cooling during the day, while radiative thermal cooling is efficient at night without the presence of cloud which returns some of the emitted thermal radiation back to the surface. Can also be measured from satellite by choosing frequency of thermal radiation that are sensitive to surface or atmospheric temperature. Atmospheric temperature is also measured by radiosondes.



The temperature lapse rate would be much stronger than it is (ie larger drop of temperature with altitude) without the global water cycle. Evaporation at the surface cools the land/ocean while condensation in the atmosphere as clouds heats the atmosphere. There is therefore a transfer of “latent energy” from the surface to the atmopsphere. As the lapse rate increases, the warm, buoyant lower levels become unstable and will be more likely to rise upward, leading to cloud formation, heating of the profile through latent heat and reducing the lapse rate. These radiative and latent energy flows in the atmosphere help to explain the typical temperature lapse rate of around 6°C per km and is termed a radiative convective balance.



Relative Humidity – a measure of the amount of invisible (or gaseous) water (vapour) dissolved in the air relative to the maximum theoretical amount

Measured as a percentage (%)

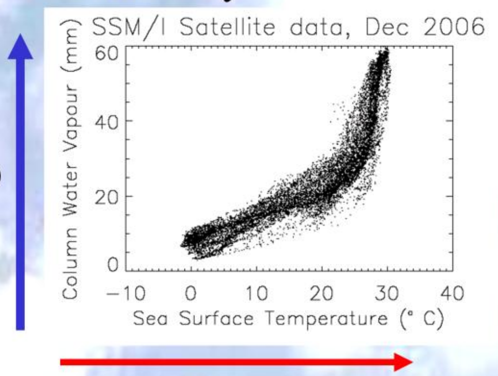
At 100% humidity, any increase in the water vapour is likely to cause condensation of liquid water drops (providing there are condensation nuclei available)

That’s why it is difficult to lose heat by sweating at high humidity because it is more difficult to evaporate more water from your body (thus cooling your skin) since the air is almost saturated

Humidity

- Warmer air can carry more water vapour

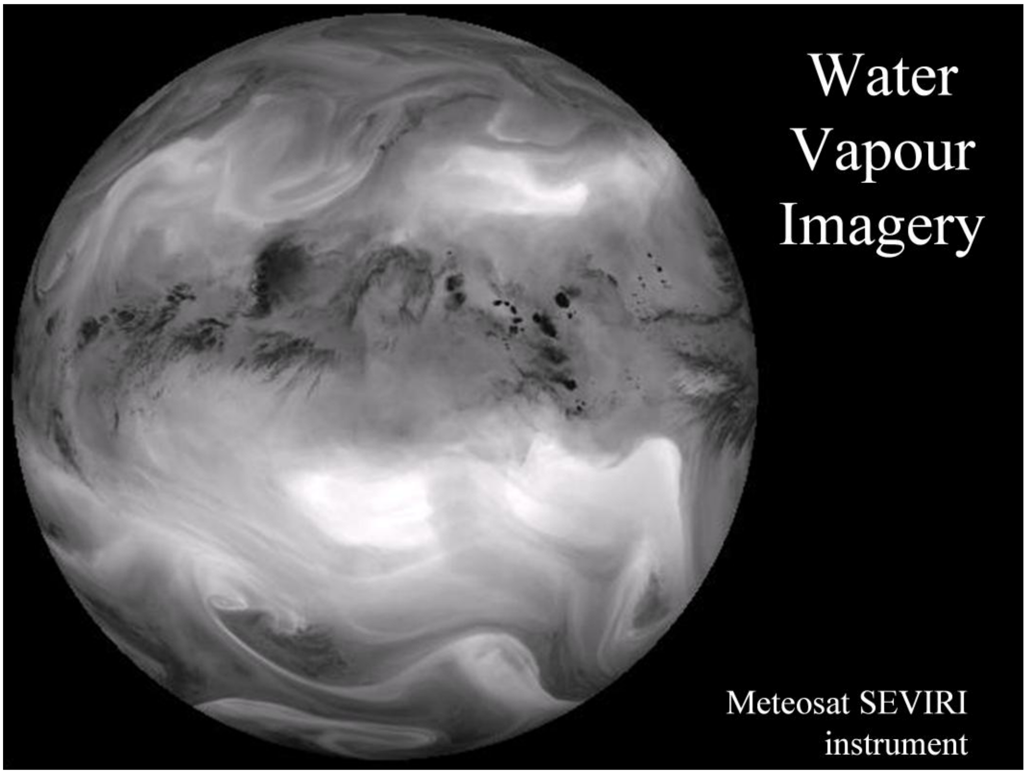
Amount of gaseous water (water vapour)



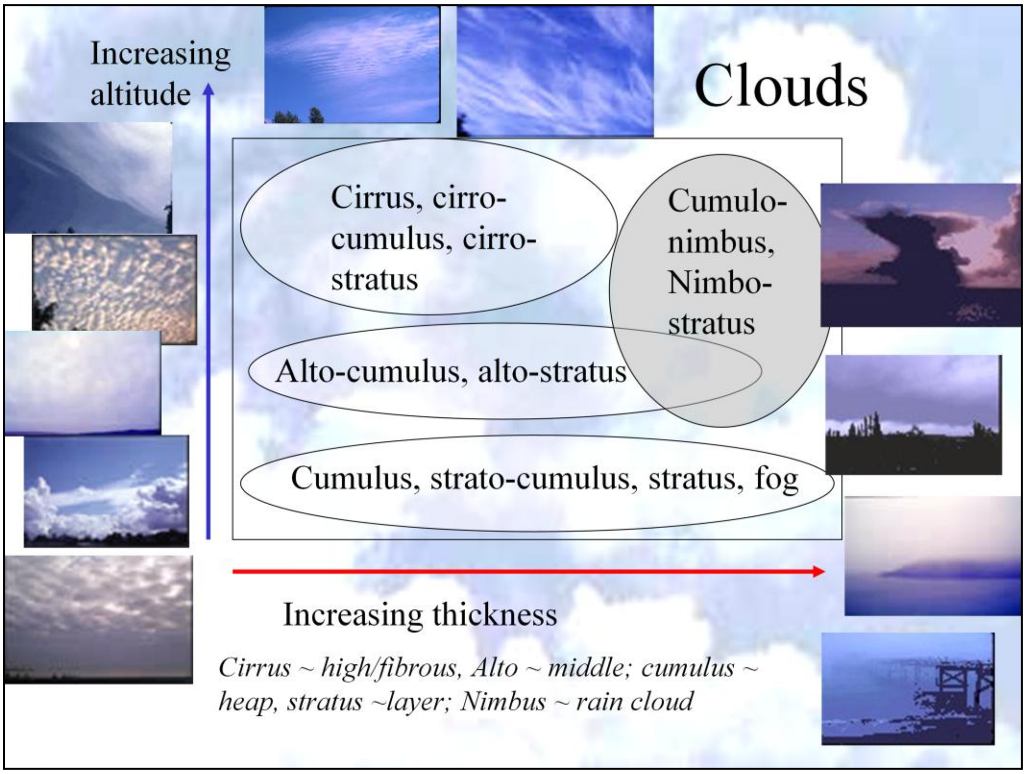
Increasing temperature

- Another measure of humidity is the *dewpoint temperature* which is the temperature that that the air must be cooled to before saturation occurs (100% relative humidity)

Microwave measurements from space are sensitive to the total amount of gaseous water vapour in the atmosphere and show the strong relationship between water vapour and temperature. Note that this total column of moisture is not the same as humidity we feel. We are more sensitive to the relative humidity which is the water vapour in the air expressed as a fraction or percentage of the maximum theoretical amount. So if relative humidity is 90% we find it difficult to cool by sweating since the air is almost full of gaseous water vapour. When relative humidity is 20% it is easy to lose heat by evaporation. The specific humidity tells as the total amount of water vapour in a mass of air (e.g. 1g of moisture per kg of air).



Certain frequencies of thermal radiation are readily absorbed by water vapour. In very humid regions (and cloudy regions) the thermal emission from the surface is absorbed by the atmosphere and re-emitted to space at much colder temperatures, and therefore lower emission (white regions in figure above). In very dry, cloud free regions, emission from the warmer surface layers can reach space (dark regions on image). Clouds are also measured in this way from space (cloud top height, cloud thickness, cloud extent).



There are a wide variety of processes that determine the formation of clouds and hence there are many distinct cloud types with differing properties (altitude, thickness, amount of water or ice, etc). See handouts and future lectures for more details.

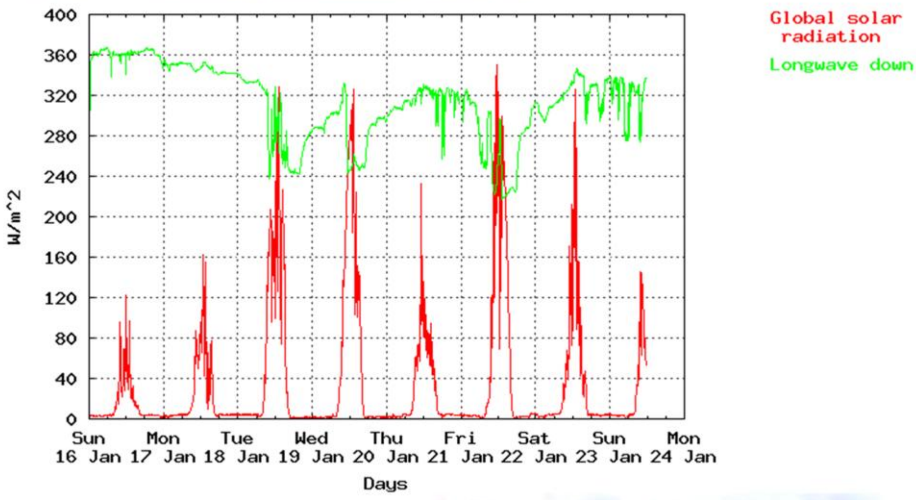
"Cloud is water vapour with attitude"

Often measured as oktas (eighths of sky cover); also as %, thickness, cloud properties, etc (difficult to define "a cloud" easily!)

In terms of atmospheric water, it is the tip of the iceberg; most of the water in the atmosphere is in the gaseous (invisible) state (water vapour)

Since liquid water and solid water (ice) in the atmosphere profoundly impacts the cooling and heating of the atmosphere through radiative energy and latent energy (condensation, evaporation,

Radiative Energy Fluxes



Radiation – not the same sort of stuff you get from nuclear waste (although sunlight can still be harmfull)

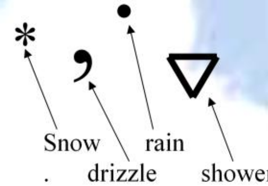
Measured by Joules of energy or Watts per square metre (a Watt is the rate of Joules per second)

The Earth is powered by energy from the sun (solar radiation)

The Earth loses heat through thermal radiation (longer wavelength than solar)

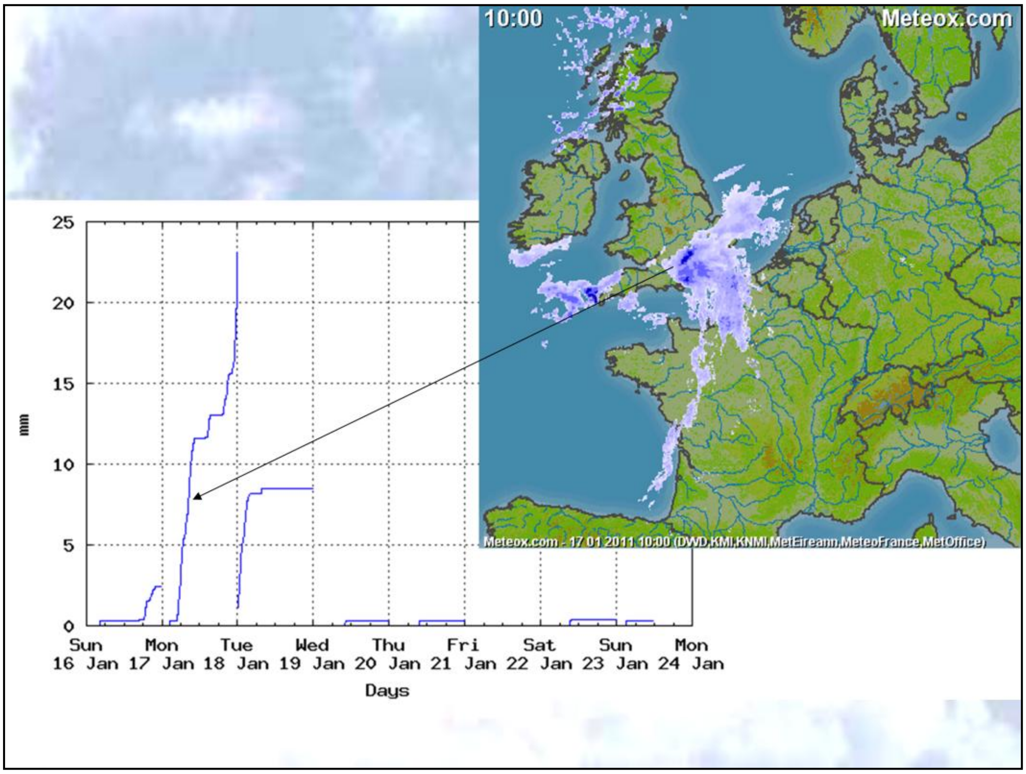
This balance is affected by the sun, the temperature and the state of the atmosphere (e.g. clouds cool in the day but heat at night)

Precipitation

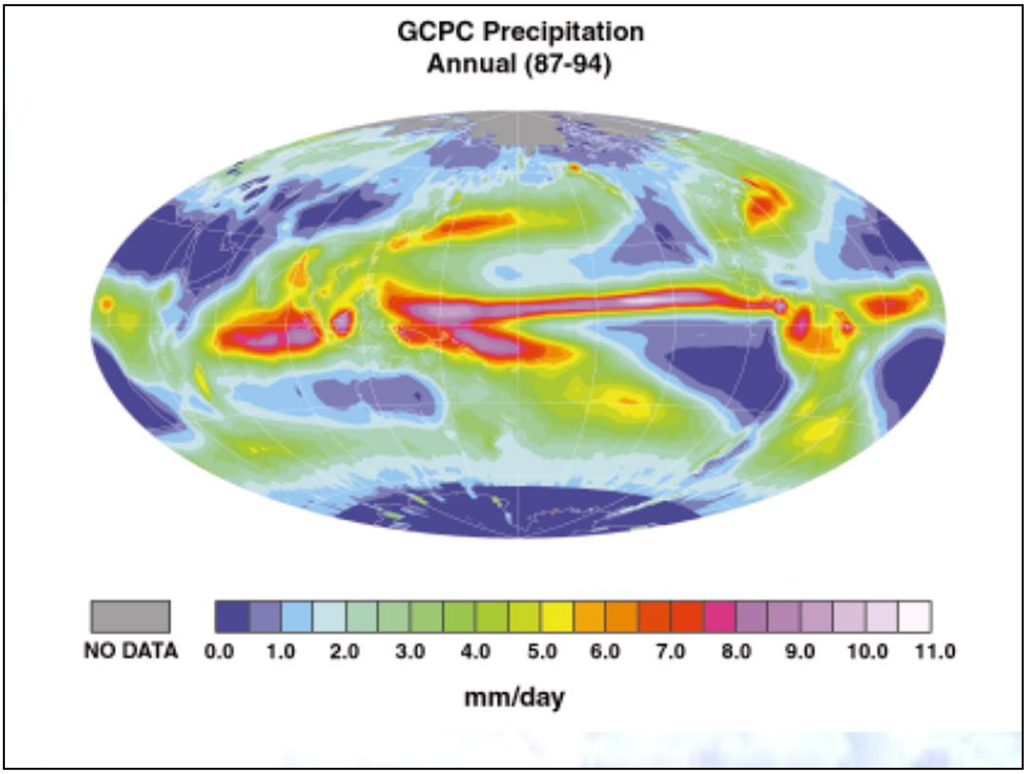


- Precipitation – rain, snow, hail, etc
- The "reverse" of precipitation is evaporation
- Can be measured in mm (over a period of time) or as a rate (mm per day)
- Since energy is released on condensation of water droplets and energy absorbed when water evaporates, the atmospheric thermal structure is strongly influenced by precipitation in addition to radiation

Precipitation includes rain, snow, sleet, hail, graupel, etc. It doesn't actually rain very often, believe it or not, but extreme rainfall or lack of any rainfall are clearly of importance to societies and the ecosystems and infrastructure upon which they depend. Measuring very light or very heavy precipitation is a great challenge.



Radar and tipping bucket rain gauges are used to measure rainfall rates.

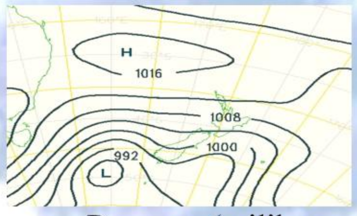


Precipitation is also estimated from satellite as well as surface rain gauges (which are limited in areal coverage). The figure above shows the wet tropical belt of the Inter-Tropical Convergence Zone (ITCZ) as well as regions of mid latitude weather systems that we experience (e.g. top right red patch) and the dry land and oceanic deserts of the sub-tropics (blue).

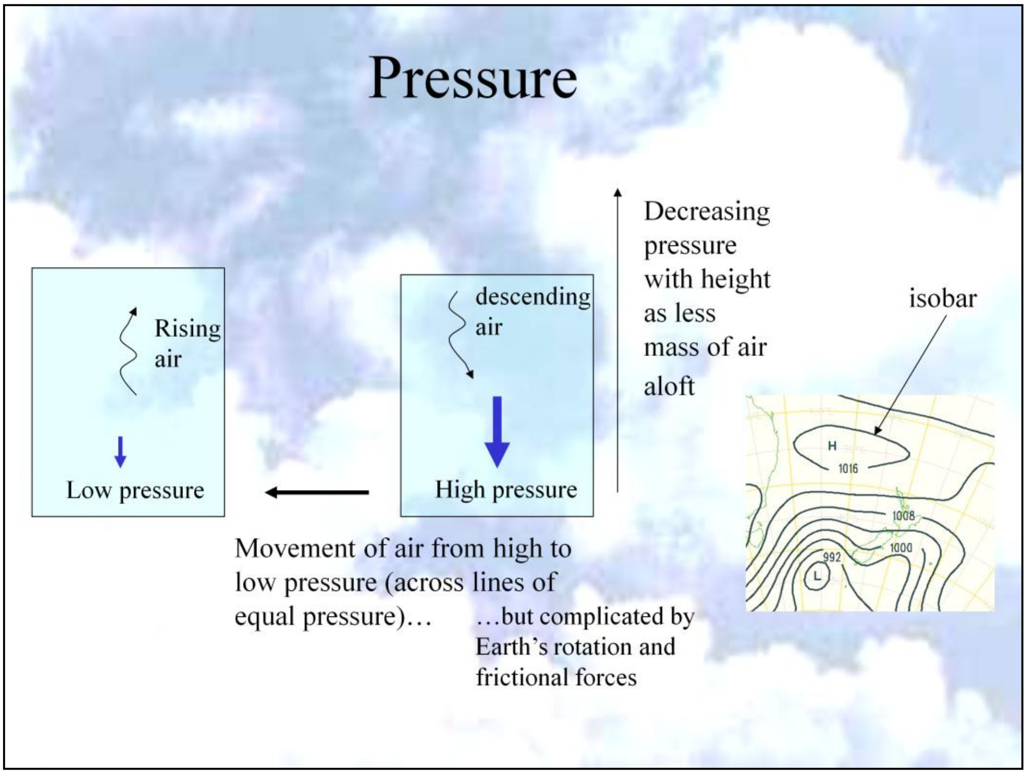
Wind

- Wind – speed and direction important
- Can cause damage, blow pollutants about and (worse still) blow in cold air with lots of rain…
- Measured in metres per second (m/s); Beaufort scale (0-12)
- Vertical wind speeds (up/down) also extremely important despite their tiny values compared to horizontal wind speed
- Wind is simply movement of air;
  - this movement is caused by a combination of forces pulling in different direction.
  - For example, there is a pressure gradient force acting to push air under higher surface pressure to lower pressure regions

Pressure

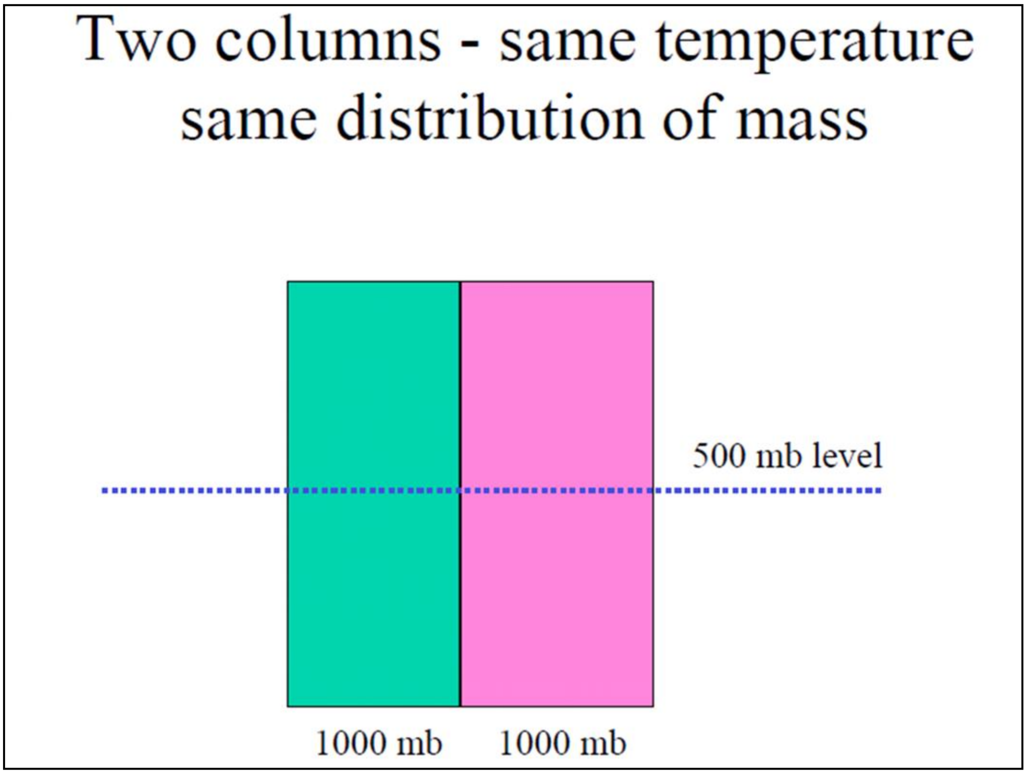


- Pressure (milibar or 100s of Pascals)
- A measure of how much atmosphere is weighing down on your head (the more atmosphere, the greater pressure)
- Important for winds (rather than giving you a headache): air will tend to slide down from High pressure to Lower pressure… although the earth's rotation complicates this…
- Rising air is associated with surface low pressure; descending air is associated with surface high pressure
- An *isobar* measures equal lines of pressure (just as an isotherm measures lines of equal temperature)
- Global annual average pressure at sea level is 1013 mb



Atmospheric pressure relates to the mass of air above your head.

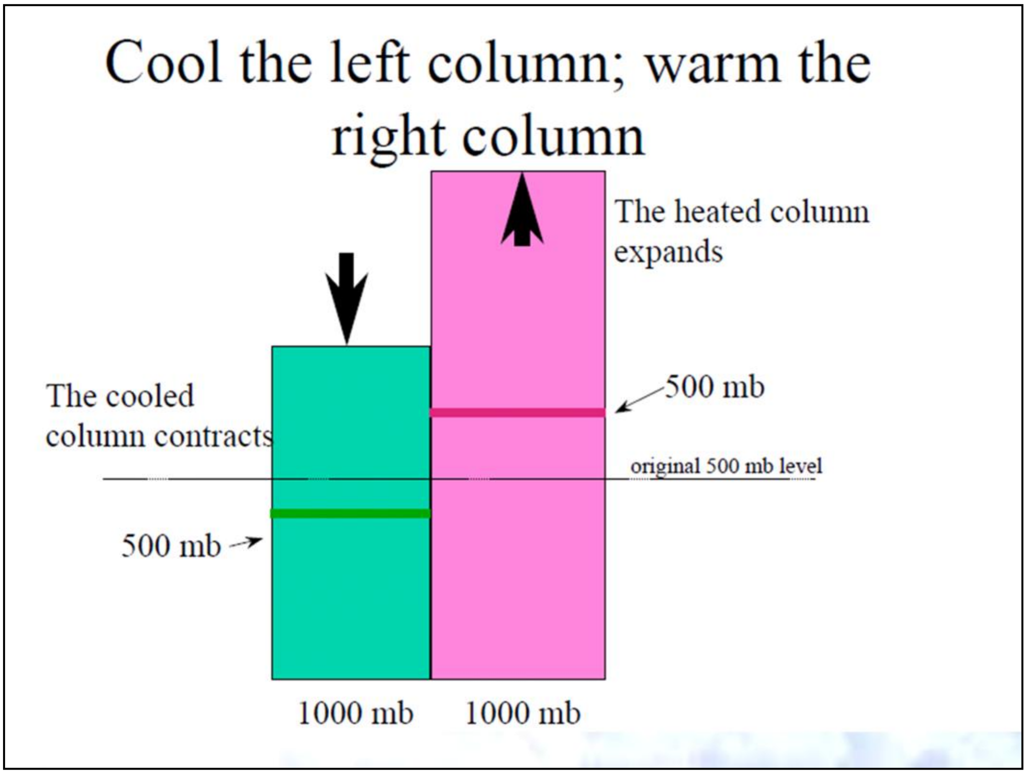
Surface pressure is around 1000mb which is 100000 Pascals. Above each square metre, the pressure relates to the mass aloft times the acceleration due to gravity (around 10 m/s^2). This means that the mass is nearly 10000 kg! Air may seem thin but….there is a lot of it.



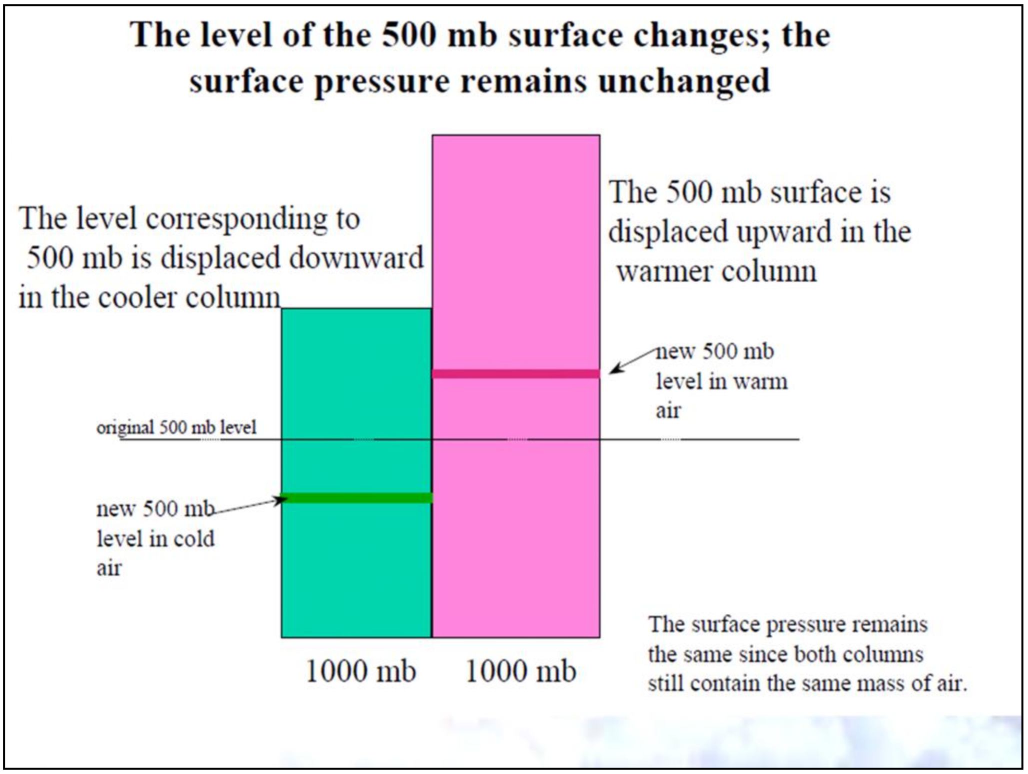
Why do we have movement of air at the surface? A thought experiment:

We have two identical columns of air of surface pressure 1000mb. The horizontal line shows the line above which resides half of the atmosphere (thus the pressure here is about half the surface pressure).

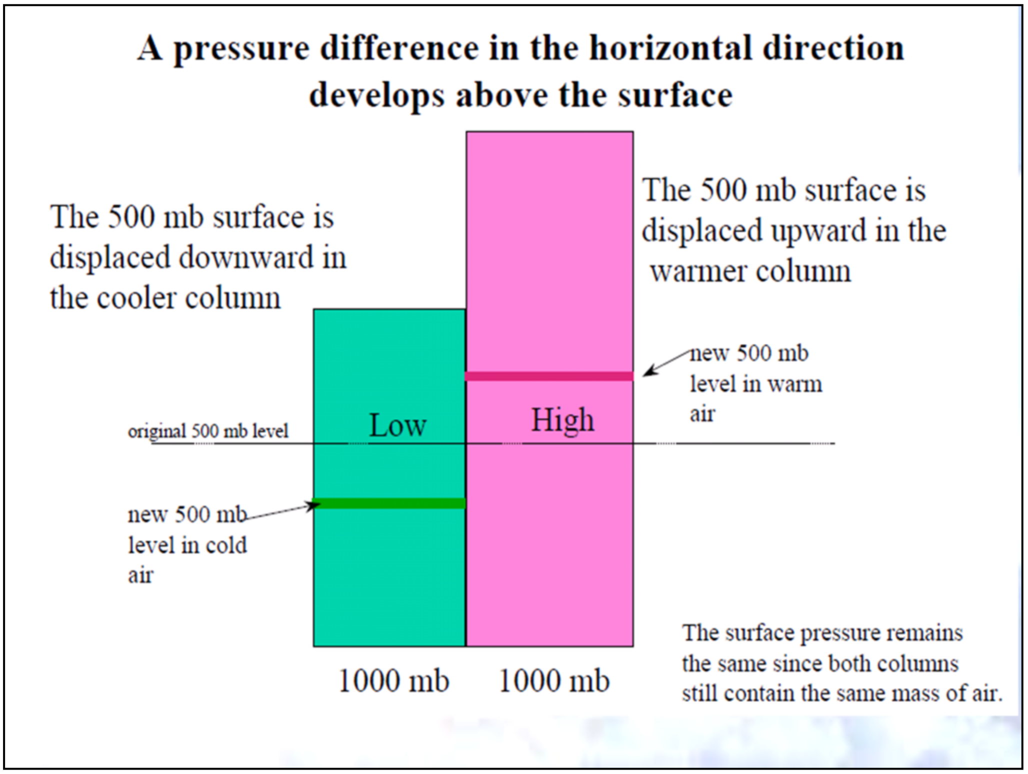
If we heat the column on the right, the air expands and becomes less dense. Cooling the column on the left will cause the air to contract and become more dense.



The heated column expands and the cooled column contracts. At the surface, the pressure remains constant because the mass of air aloft has not changed. However, at the horizontal line, the contracted column has relatively less atmosphere aloft while the expanded column has relatively more atmosphere aloft now.

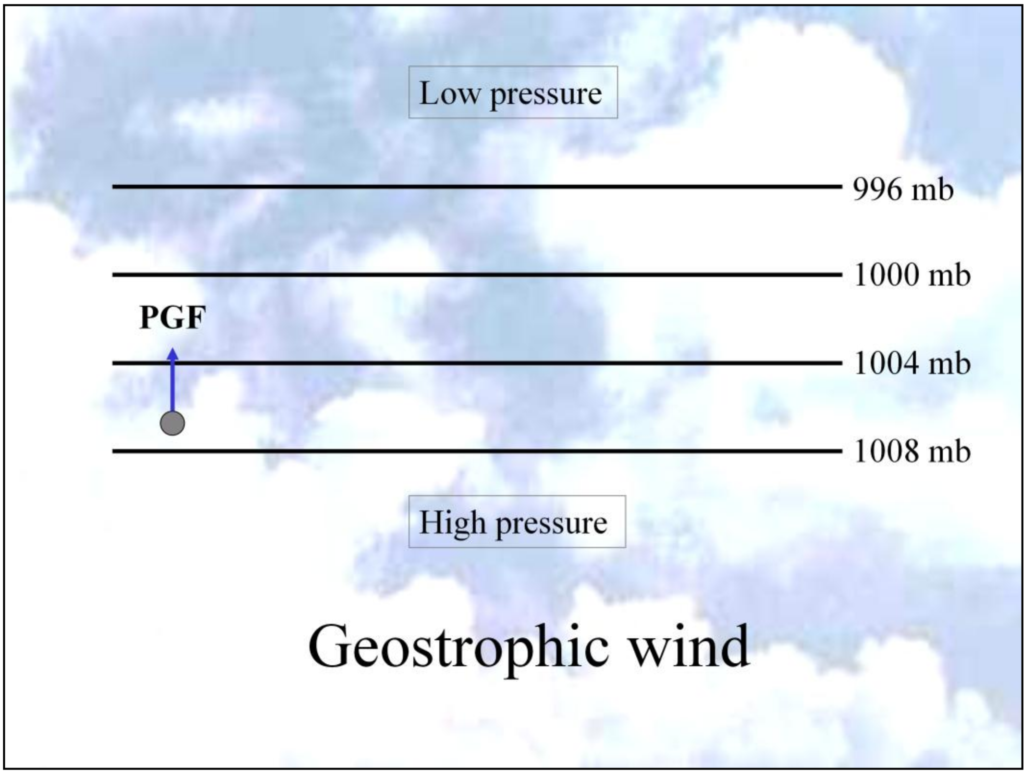


At the horizontal line, the expanded column has more atmosphere aloft and so the pressure is higher than before. The reverse is true for the contracted column which results in lower pressure. Since air flows from high pressure to low pressure, air aloft will flow from the relatively higher pressure from the heated column to the cooled column.

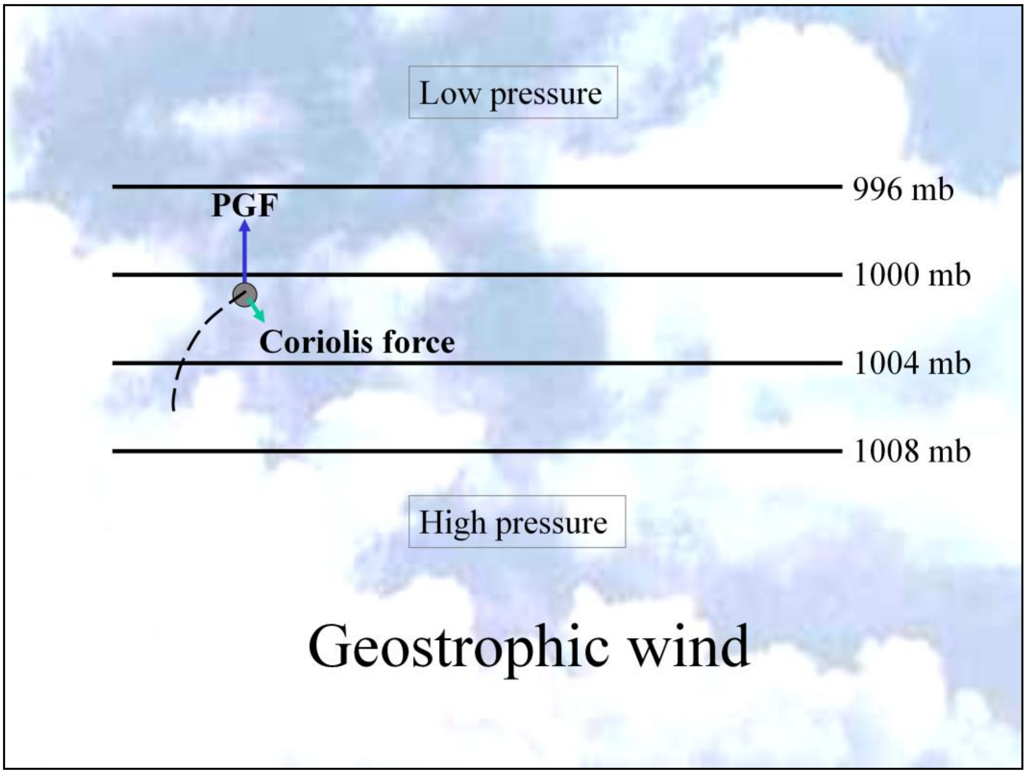


The flow of air aloft from the warm, expanded column to the cooled column results in a loss of mass from the warm column and therefore a reduction of surface pressure. The flow of air into the contracted, cooled column increases the mass of air here, increasing surface pressure. Thus, at the surface air flows from the cooled column (higher surface pressure) to the warmed column (lower surface pressure). This sets up a circulation of air. Where will the air rise?

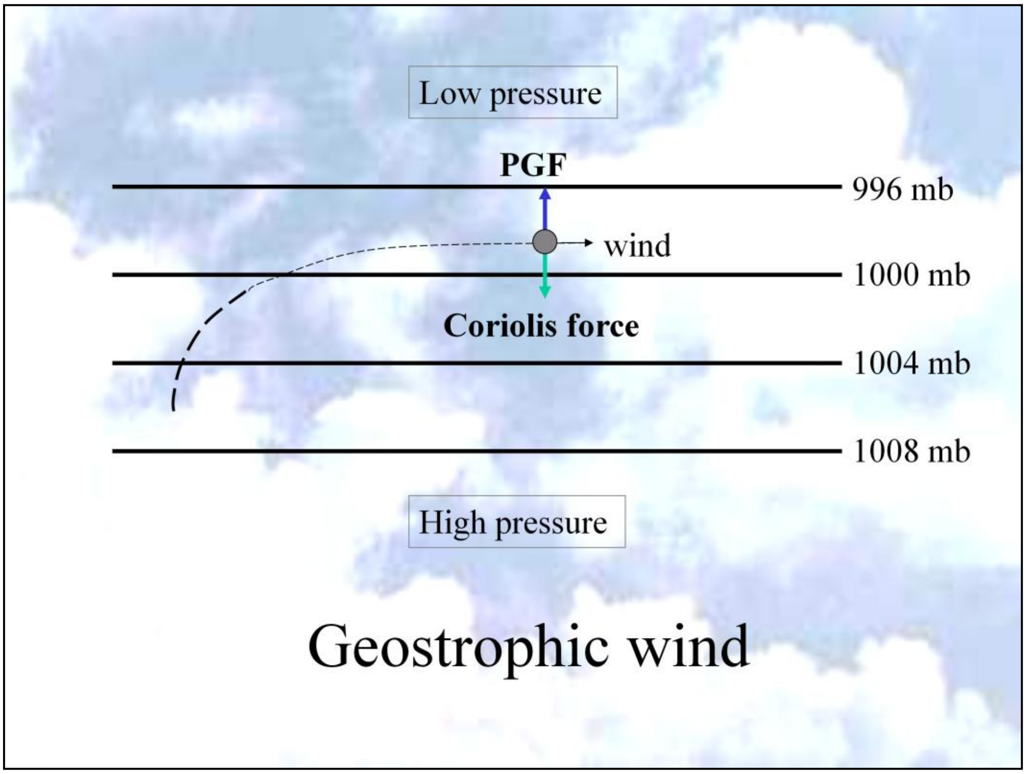
This simple, theoretical model explains simply how uneven heating of the planet can introduce the large-scale circulation of air that is instrumental for our weather and climate.



Air initially flows from high pressure to low pressure, across the isobars, due to the pressure gradient force.



As the air moves, the coriolis force will begin to act, giving the air a nudge to wards the right in the northern hemisphere and to the left in the southern hemisphere.

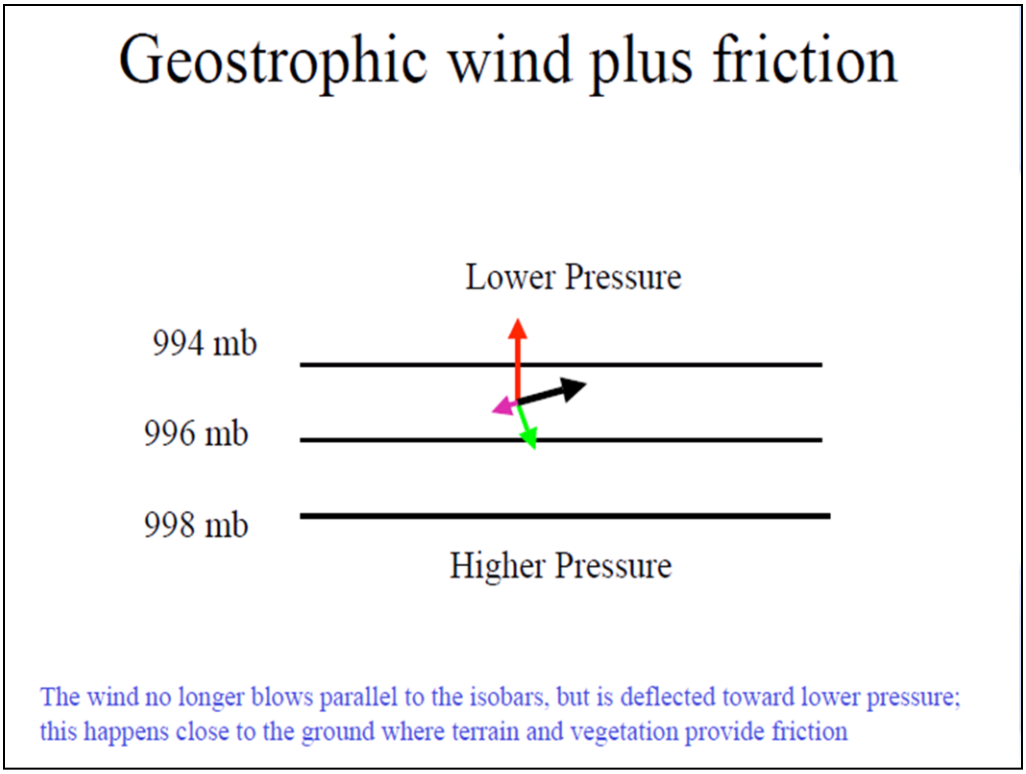


Eventually, the parcel of air reaches a speed at which the pressure gradient force is exactly balanced by the coriolis force. This speed is termed the geostrophic wind and is a theoretical estimate of how strong the wind will be, given the pattern of isobars (isobars close together mean stronger wind).

At 50^{o}N geostrophic wind ~ 3000/*x; x* is the distance between 4 mb interval isobars

E.g. if 300 km between 4 mb interval isobars, geostrophic (expected) wind ~ 3000/300 =10 m/s

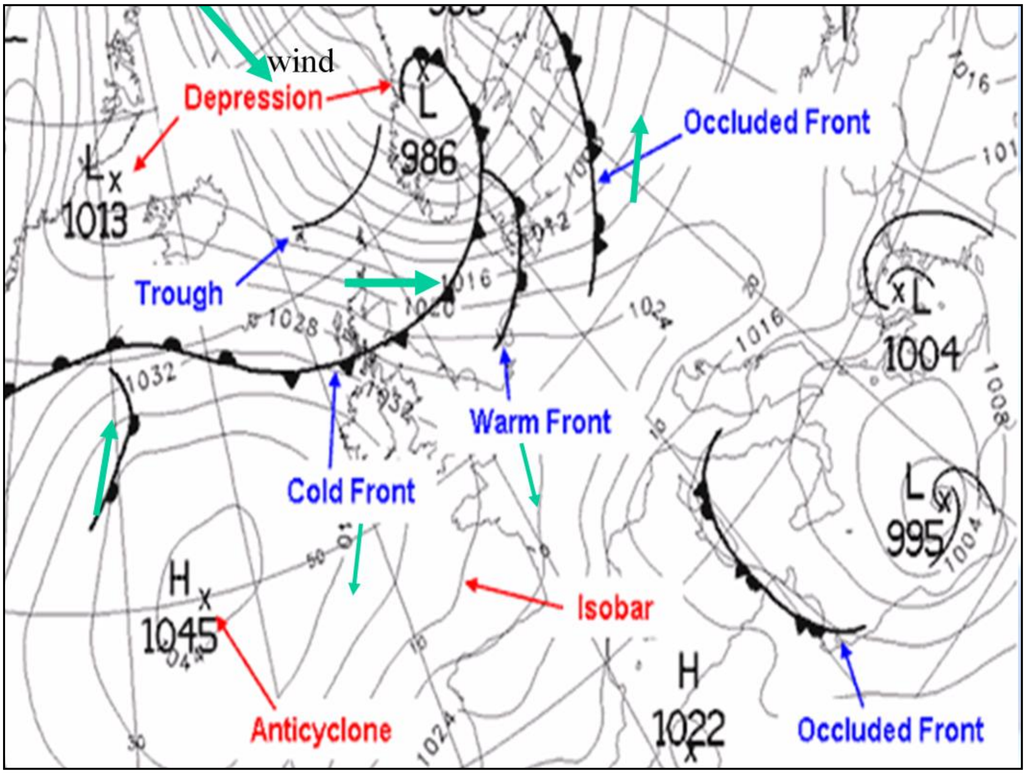
In practice, the curvature of the isobars and friction near the surface affect this



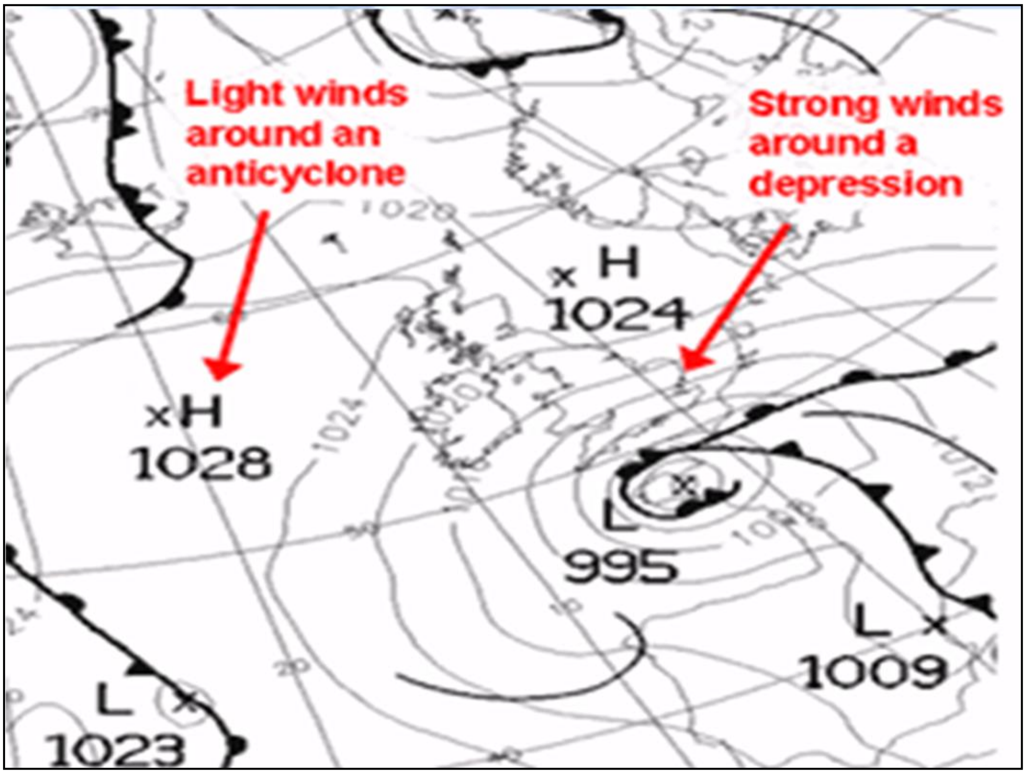
Friction complicates things: a three-way tug of war! The result of this is that wind tends to blow along isobars but slightly towards the lower pressure. Additionally, if the isobars are curved you get another force (centrifugal, what you experience on a roundabout).

Synoptic Chart

- Invented in Scandinavia
- A convenient way of displaying the important information on the current weather situation
- Isobars – lines of equal pressure, important for the wind speed and direction and the movement of air masses
- Fronts – battleground between cold and warm air and likely source of clouds and rain



The effect of the coriolis force causes air to flow anti-clockwise around a low pressure and clockwise around a high pressure in the northern hemisphere. The reverse is true in the southern hemisphere.


Light winds around an anticyclone
Strong winds around a depression
H 1028
H 1024
L 995
L 1009
L 1023

Some key points

- Warm air expands, becoming buoyant
- Warmer air holds more gaseous water vapour
- Air flows from high pressure to low pressure
- Surface pressure relates to the mass of air aloft; pressure diminishes rapidly with altitude

Conclusions and outlook

- Aspects of the weather are important for society
  - Direct: Temperature, Rainfall, Wind, ...
  - Indirect: Pressure, humidity, ...
  - Extremes are important
- Measuring the weather
  - Ground based instruments (e.g. Met field site)
  - Radiosondes
  - Satellite instruments increasingly important
- Observations are vital for:
  - Determining current changes in the weather
  - Building physical models
  - Initialising weather forecast models