Definitions and Atmospheric Structure

SOEE1400 : Lecture 2

Units

The units used in meteorology are a mixture of S.I. (Systeme International) units (used throughout 'scientific' meteorology) and older systems of non-SI units retained in use because of historical reasons, for convenience, or for communicating with the general public.

It is important **ALWAYS** to give the units in which a value is quoted.

Temperature

- Kelvin (K) : (SI unit) necessary for many calculations
- Degrees Celsius (°C) : (non-SI) usually used to quote temperature in general use – more readily understood and values in convenient range

0 K = -273.15 îC

conversion:

$$T_{Kelvin} = T_{Celsius} - 273.15$$

- Degrees Fahrenheit (°F) : (nonSI) widely used in America.

$$T_{Fahrenheit} = \frac{9}{5} T_{Celsius} + 32$$

Pressure

- SI unit of pressure is the Pascal (Pa), atmospheric pressure is quoted in hectopascal (hPa) = hundreds of Pascals.

1 hPa = 100 Pa

- Pressure is frequently quoted in millibars (mb)(nonSI)

1 mb = 1 hPa

- Mean sealevel pressure = 1013.25 mb.

Wind Speed

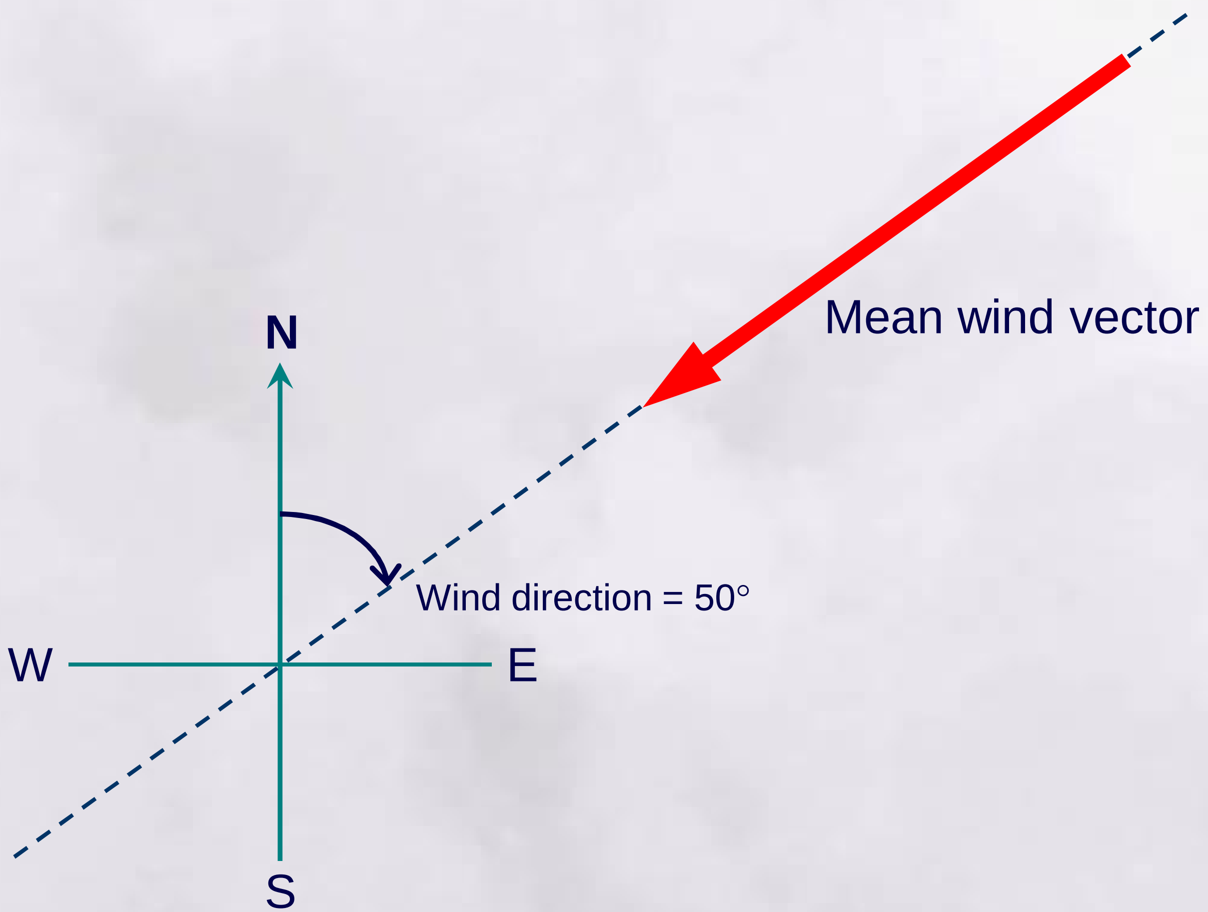
Wind speeds are quoted in a variety of different units

- Metres per second ($m\ s^{-1}$)(SI unit) – all scientific use, and frequent common use
- Knots (kt) = nauticalmiles per hour
  $= 0.514\ m\ s^{-1} \approx 0.5\ m\ s^{-1}$

- Kilometres per hour (kph) = $0.278\ m\ s^{-1}$
- Miles per hour (mph) = $0.447\ m\ s^{-1}$

Wind Direction

- It is meteorological convention to give the direction that the wind is coming **FROM**
  - Bearing in degrees from north – ie a compass bearing taken when you are facing directly into wind
  - Because of the high degree of variability in the wind – gustiness – often only the general direction is quoted: northerly, south-westerly, etc


Mean wind vector
N
Wind direction = 50°
W
E
S

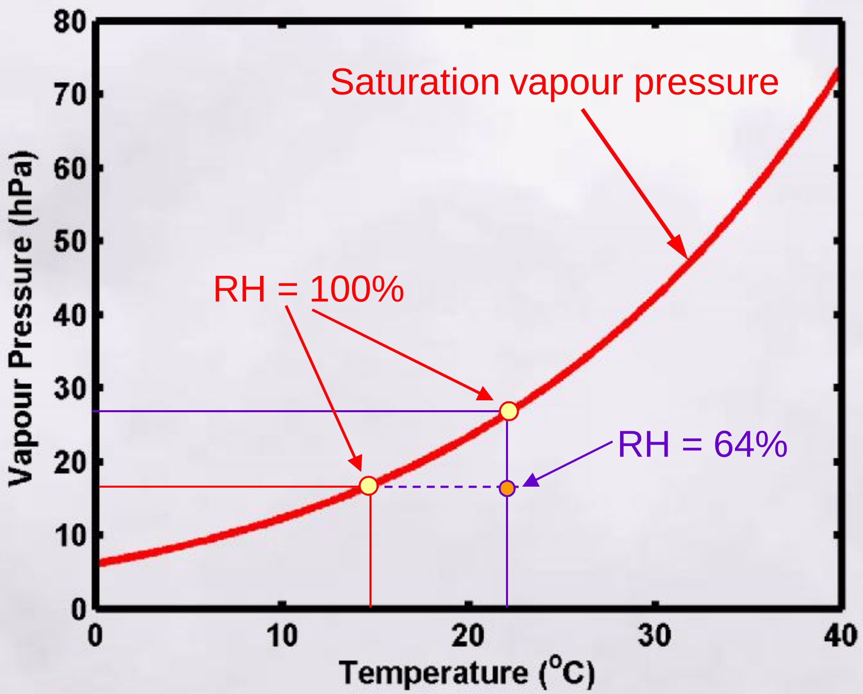
Humidity

Relative Humidity : quoted as a percentage (%) (non-SI)

= water vapour content of the air as a percentage of the maximum possible, **saturation** or **equilibrium** vapour content at that temperature.

$$RH = 100 \frac{P_v}{P_s}$$

Relative humidity is the measure most closely related to our comfort – how humid it **feels**. It is also useful in determining where cloud or fog will form: condensation of vapour to form droplets occurs when RH increases to 100%.



Clausius-Clapeyron curve, relating vapour pressure (which is proportional to the amount of water vapour in the air) to temperature.

Dew Point

The temperature to which a parcel of air with constant water vapour content must be cooled, at constant pressure, in order to become saturated.

Dew Point Depression

The difference between the temperature of a parcel of air, and its dew point temperature.

Mixing Ratio

Ratio of the mass of water vapour to mass of dry air.

$$\text{Mixing ratio} = \frac{M_v}{M_a}$$

Specific Humidity

The ratio of the mass of water vapour to the mass of moist air.

$$q = \frac{M_v}{M_v + M_a}$$

Absolute Humidity or Vapour Density

The mass of water vapour per unit volume of moist air.

Vapour Pressure

at a given temperature, vapour pressure is proportional to vapour density.

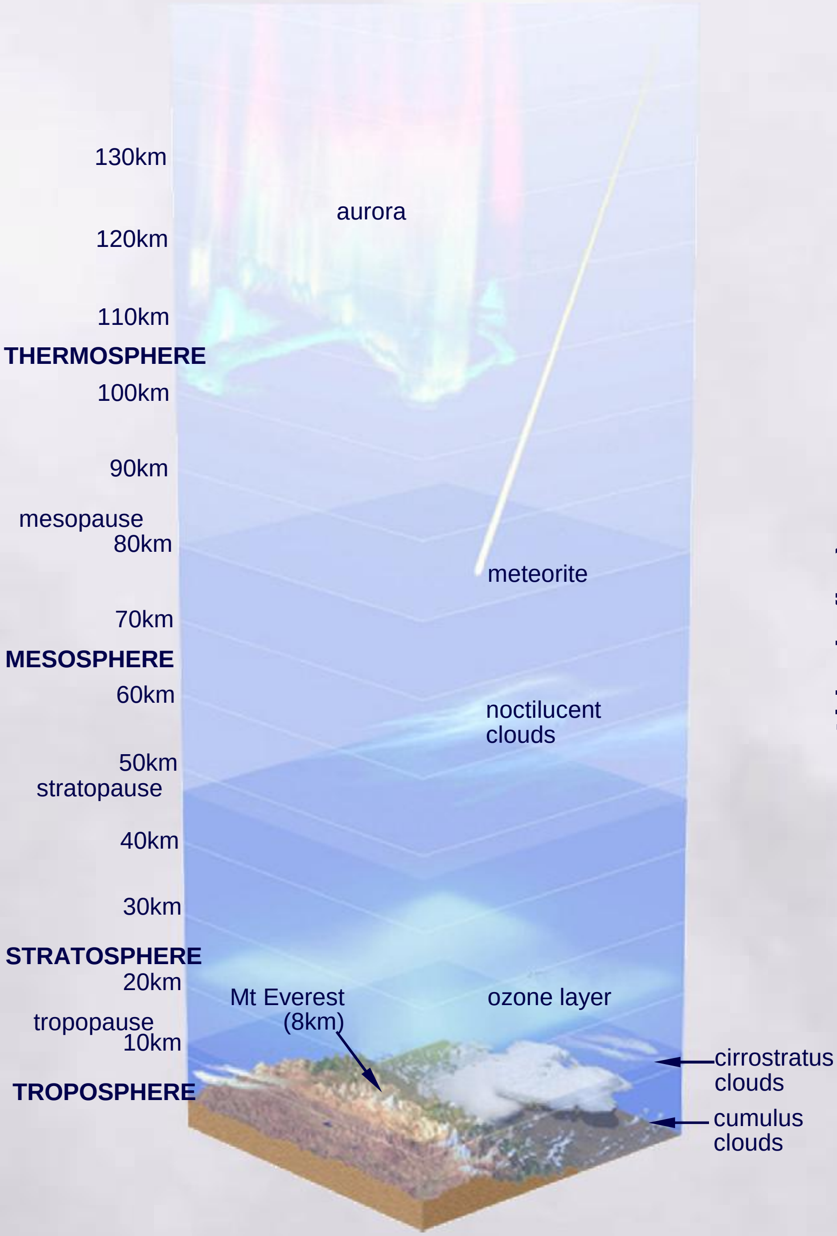
Time

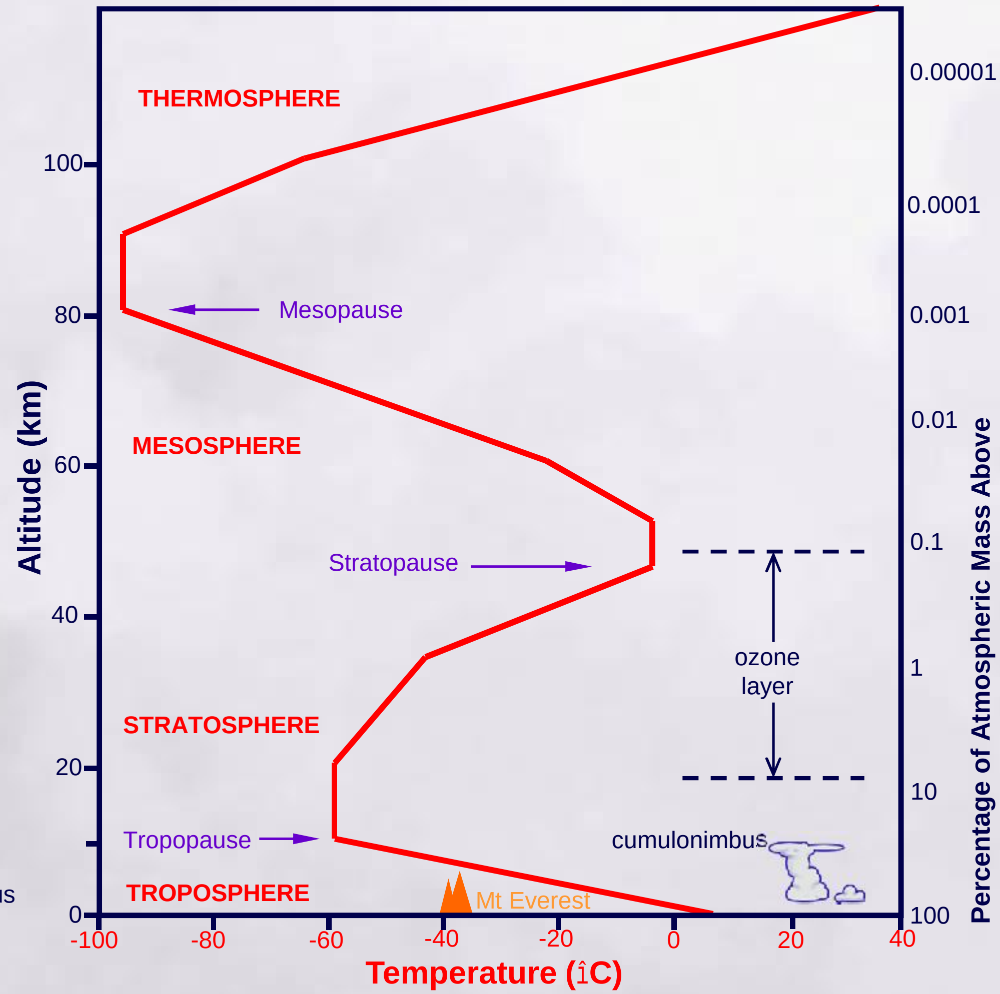
- Time is usually quoted in 24-hour form and in UTC (coordinated universal time). This is (almost) the same as GMT

e.g. 1800 UTC

  - Analysis of meteorological conditions to make a forecast requires measurements made at *the same time* over a very wide area - including multiple time zones (possibly the whole world). Using UTC simplifies the process of keeping track of when each measurement was made

Vertical Structure: Temperature



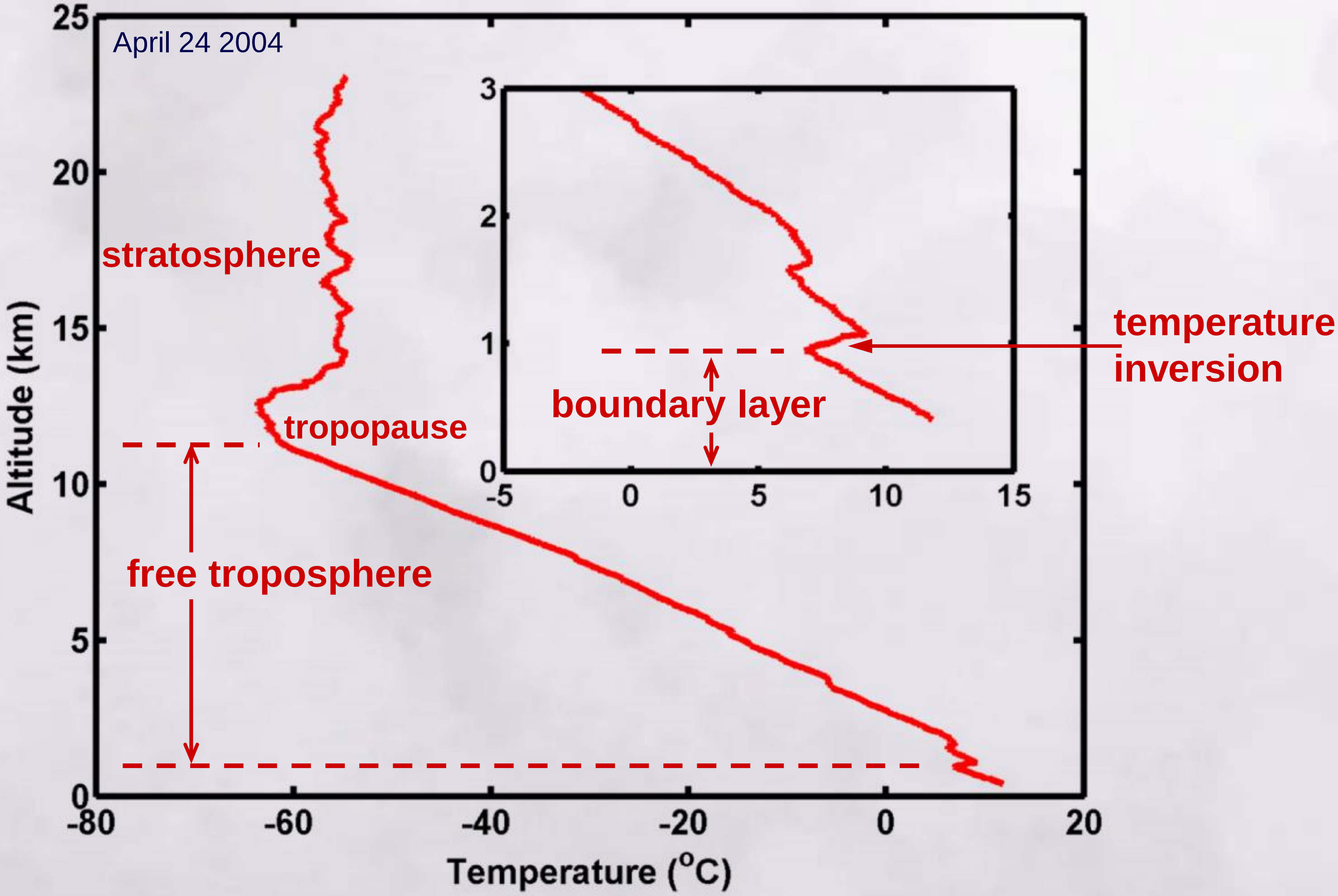


Vertical Structure

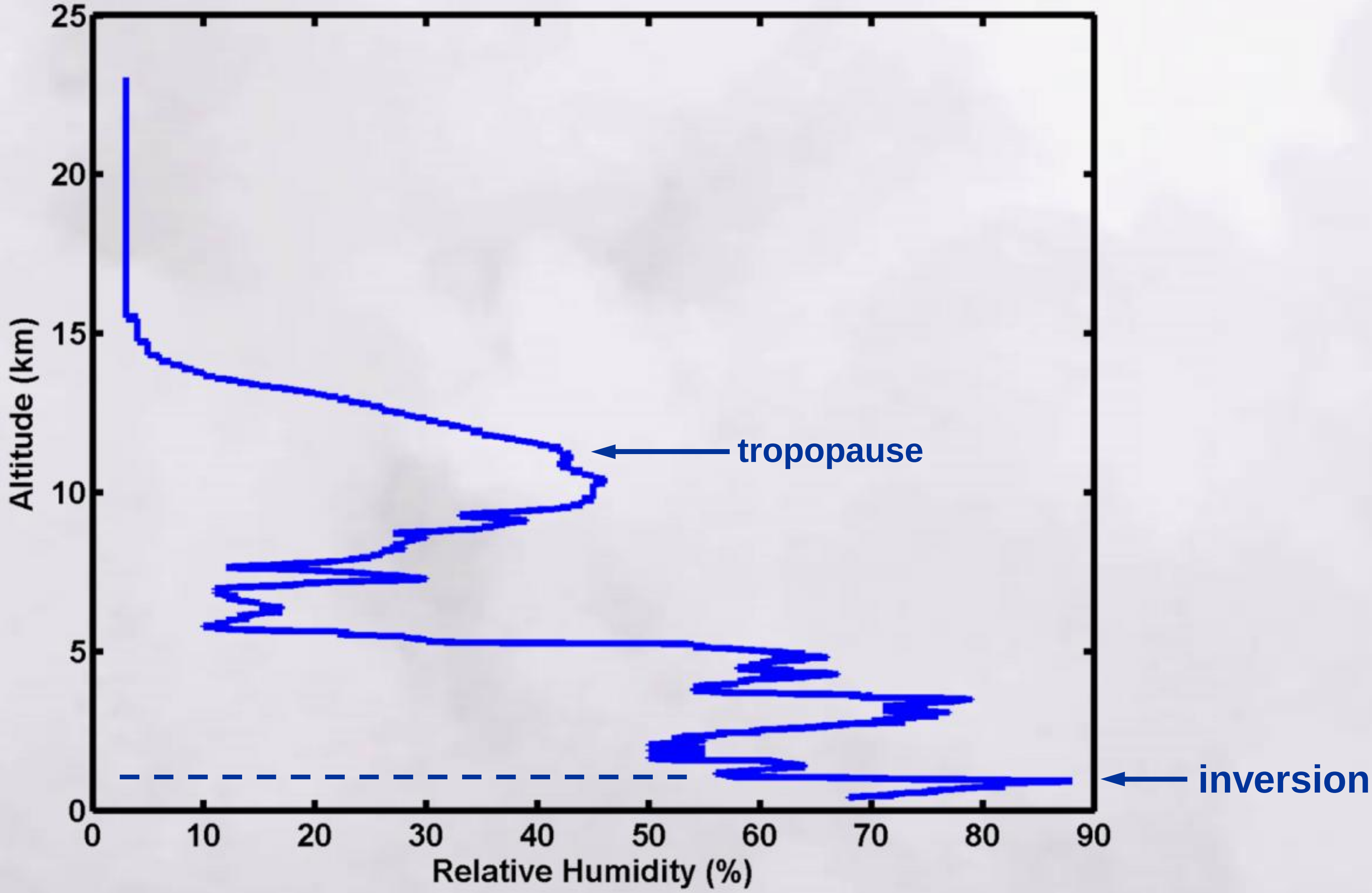
- **TROPOSPHERE**
  - Lowest layer of atmosphere
  - ~8km deep at poles, ~16km deep at equator. Depth varies both spatially & with time.
  - Region where virtually all ‘weather’ occurs. Most of the water vapour in the atmosphere is concentrated in the lower troposphere.
  - Temperature generally decreases with altitude (though with significant variability)
  - Capped by a region of increasing temperature (a temperature inversion) or isothermal layer, the ***Tropopause.***
  - The tropopause acts as a lid, preventing the exchange of air between troposphere and stratosphere.

- **The Boundary Layer**
  - A sublayer of the troposphere
  - In contact with the surface every day
  - Experiences direct effect of friction at surface
  - Dominated by turbulence and surface exchange processes: heat, moisture, momentum
  - Exhibits large diurnal changes in many properties: depth, temperature,…
  - Depth varies from a few 10s of metres (in very stable conditions), to ~2km over tropical oceans. A few 100 m to ~1 km is typical.
  - Temperature decreases with altitude.
  - Usually capped by a temperature inversion that inhibits mixing with the air in the *free troposphere* above.
  - N.B. A well defined boundary layer is not always present

Temperature Profile



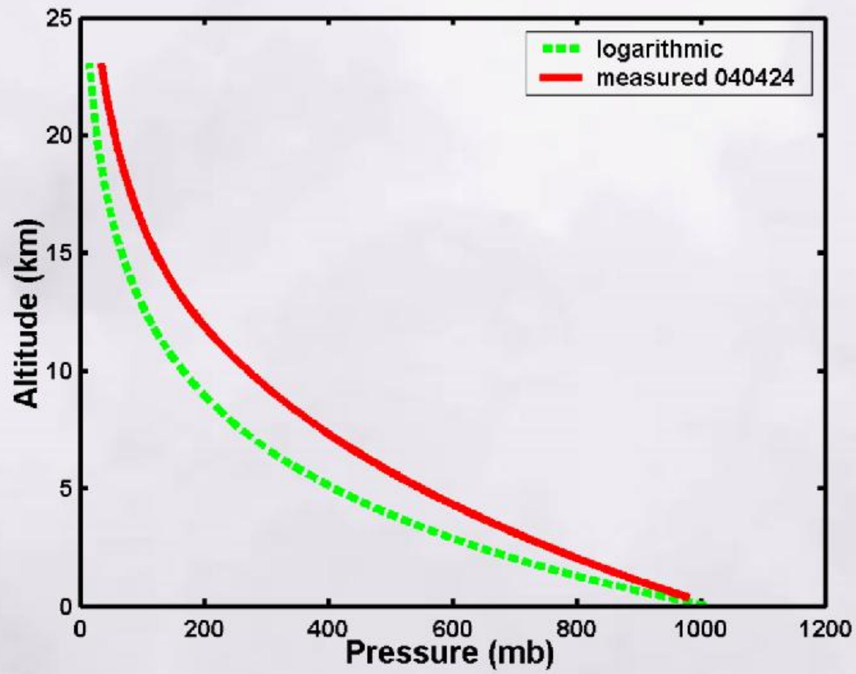
Humidity Profile



- STRATOSPHERE
  - Extends from top of tropsphere to ~50 km.
  - Temperature generally increases with altitude during summer – lowest temperature at the equatorial tropopause. Has a more complex structure in winter.
  - Contains the majority of atmospheric ozone (O_3). Absorption of ultraviolet produce a maximum temperature at the stratopause (sometimes exceeding 0°C).
  - Interaction with the troposphere is limited, and poorly understood.

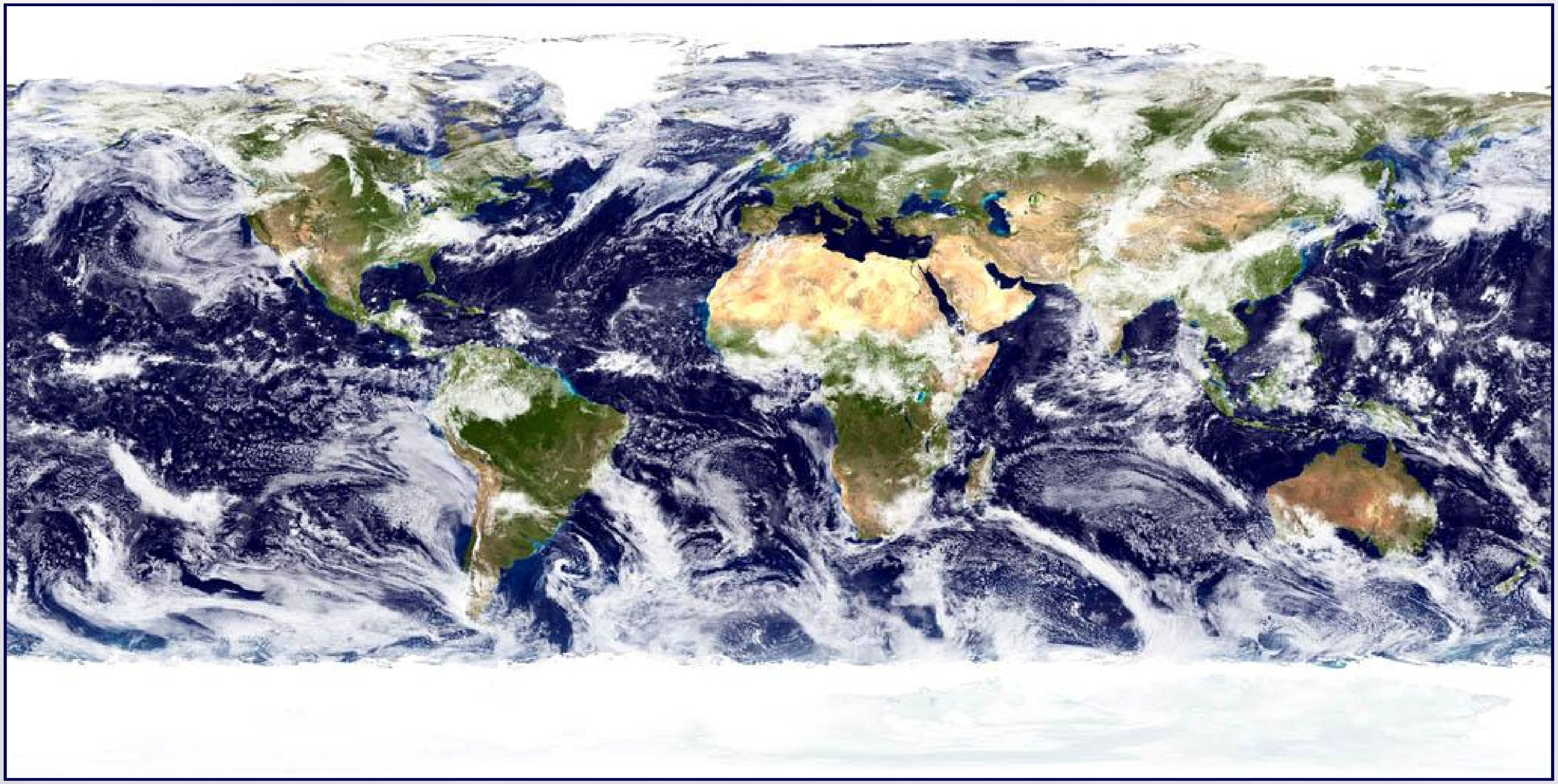
Vertical Structure: Pressure

- The pressure at any point is the result of the weight of all the air in the column above it.
- Upwards force of pressure exactly balances downward force of weight of air above
- Decreases approximately logarithmically with altitude
  - Departures from logarithmic profile are due to changes in air density resulting from changes in temperature & moisture content.



Near the surface a 1mb change in pressure is equivalent to $\approx$7m change in altitude.

Length Scales



- **“Local”** (*microscale, or boundary-layer scale*)
  - Time: few hours to ~1 day
  - Distance: <2 km
  - Phenomena: local convection, small cumulus, fog, hill/valley drainage flows, variations in surface wind,…
- **Regional** (*mesoscale*)
  - Time: hours to days
  - Distance: a ***few*** to several 100 km
  - Phenomena: thunderstorms, fronts, land-sea breezes,…
- **Large scale** (*synoptic scale*)
  - Time: up to ~10 days
  - Distance: several 100 to several 1000 km
  - Phenomena: high and low pressure systems
- **Planetary scale**
  - Time: days to months
  - Distance: several 1000 km, to global scale
  - Phenomena: storm tracks, polar vortices, Hadley circulation etc.

There is a huge discrepancy between the length scales associated with horizontal and vertical gradients of most quantities of interest. In general vertical gradients are much larger than horizontal ones.

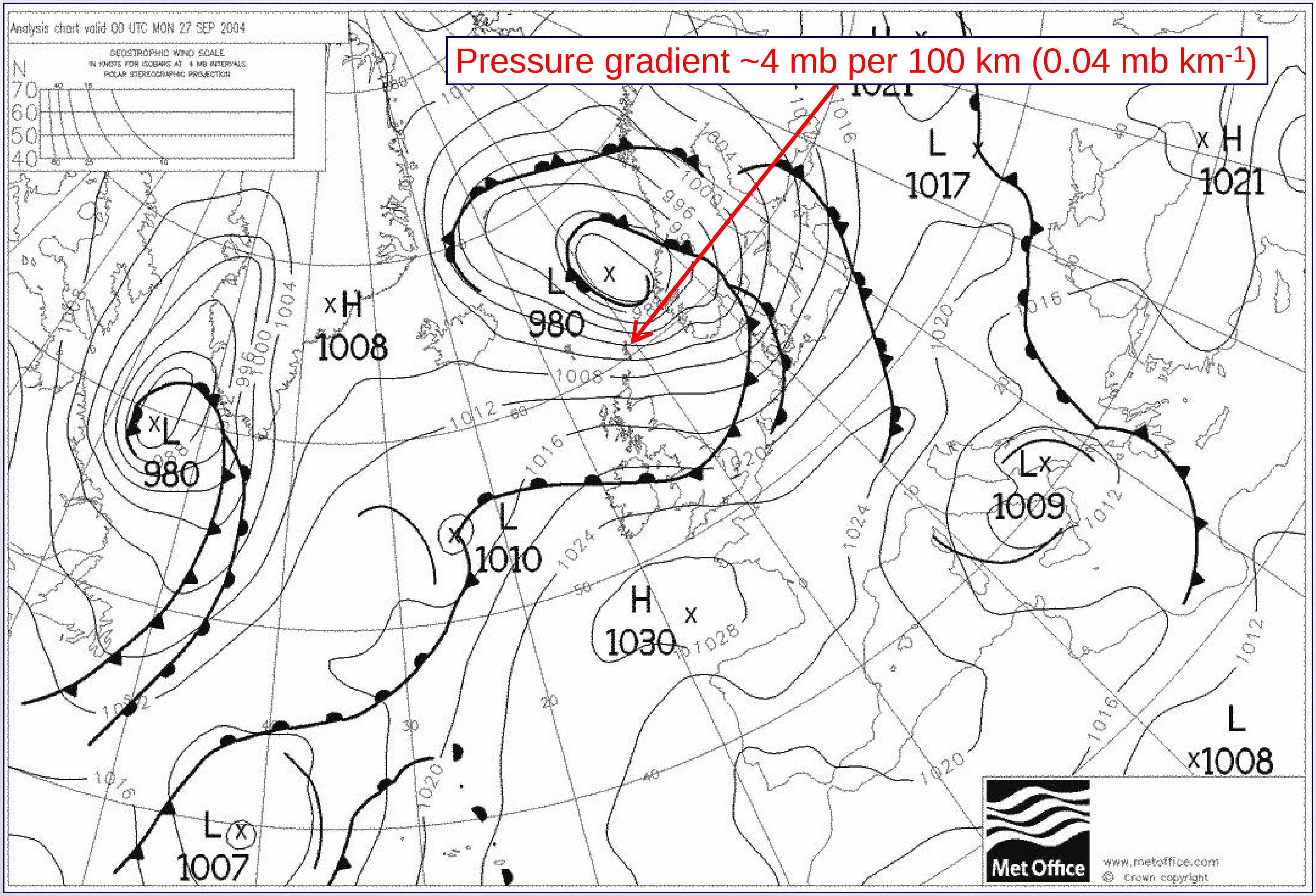
Pressure

vertical gradient:

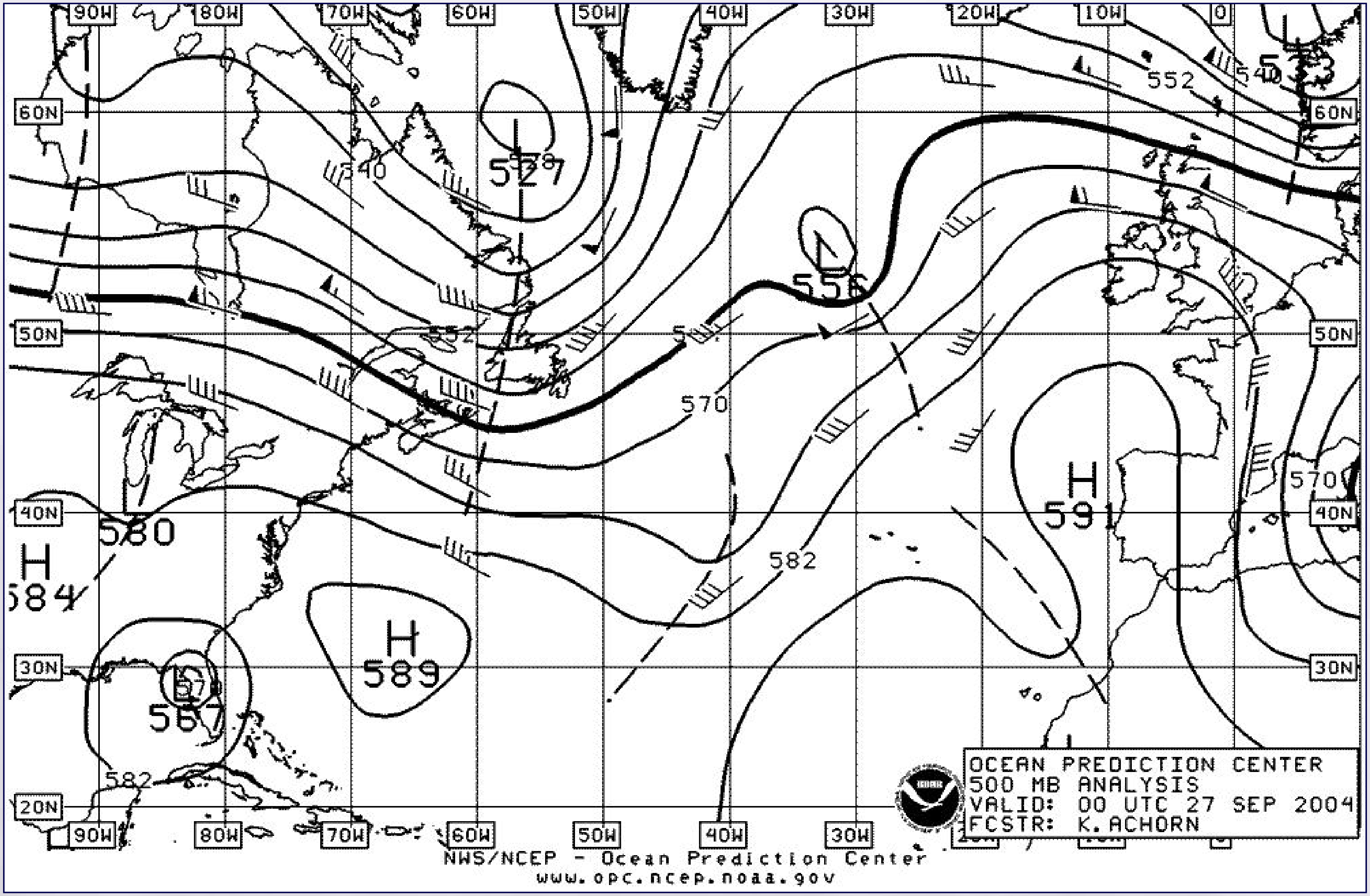
~0.14 mb m^{-1}

horizontal gradients: < 0.1 mb km^{-1}

(typically ~0.01 mb km^{-1})



SLP 4mb contours : Analysis 0000-040927



500mb surface height (dm) : 60m contours : Analysis 0000-040927

Temperature

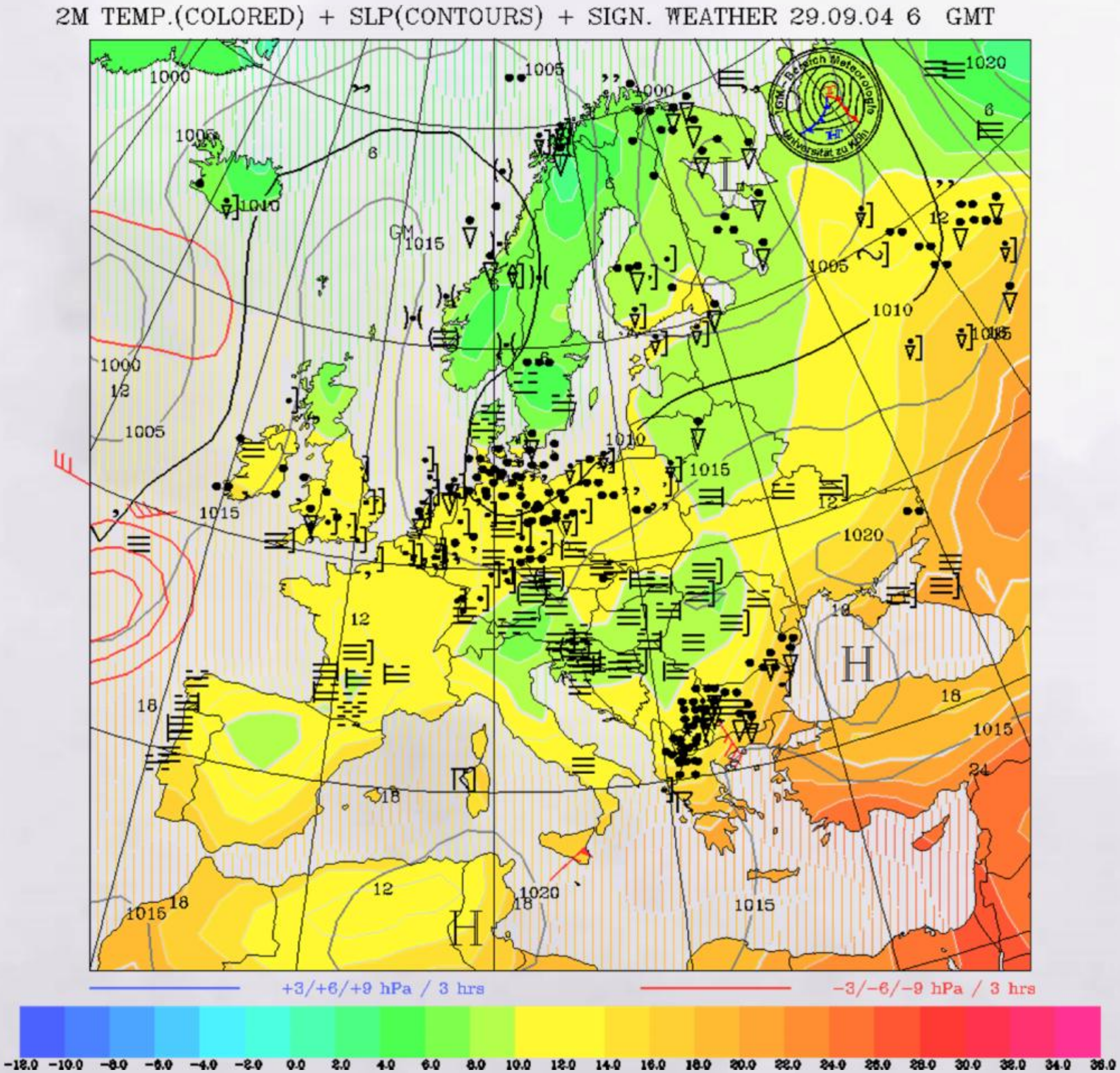
vertical gradients:

typically ~0.01 °C m^{-1}
can be larger locally, e.g. boundary layer temperature inversion up to ~0.2 °C m^{-1}

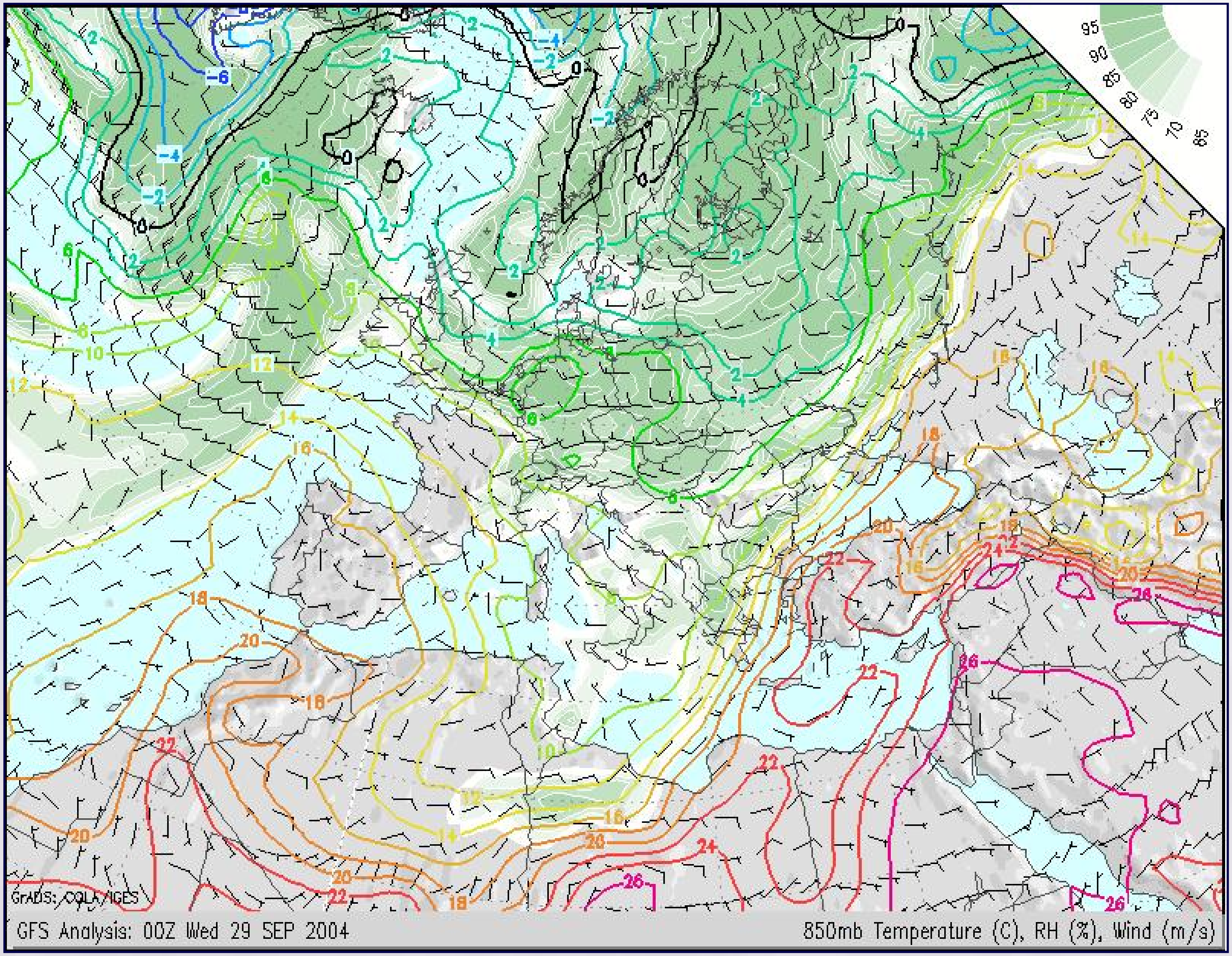
horizontal gradients:

On a large scale typically < 1°C per 100 km (0.01 °C km^{-1}), up to ~5 °C per 100 km within frontal zones.
Local effects (e.g. solar heating in sheltered spots) may result in larger gradients on small scales.

N.B. How warm **we** feel is not a good indicator of the air temperature.



Surface temperature analysis 0600-040929 : 2°C contours



850mb temperature (2 °C contours), RH (%), wind (m s^{-1}) : analysis 0000-040929

Summary

- Atmosphere is divided vertically into several distinct layers.
- Only the lowest layer – the troposphere – is closely connected to “weather”.
- A shallow sublayer of the troposphere, the boundary layer, is directly influenced by the surface & dominated by turbulent mixing.
- Largescale horizontal gradients of pressure, temperature, etc are generally much smaller than vertical gradients.
- A consequence of this is that the forcing processes that drive synoptic weather systems are almost horizontal. Large-scale vertical motions are slow.