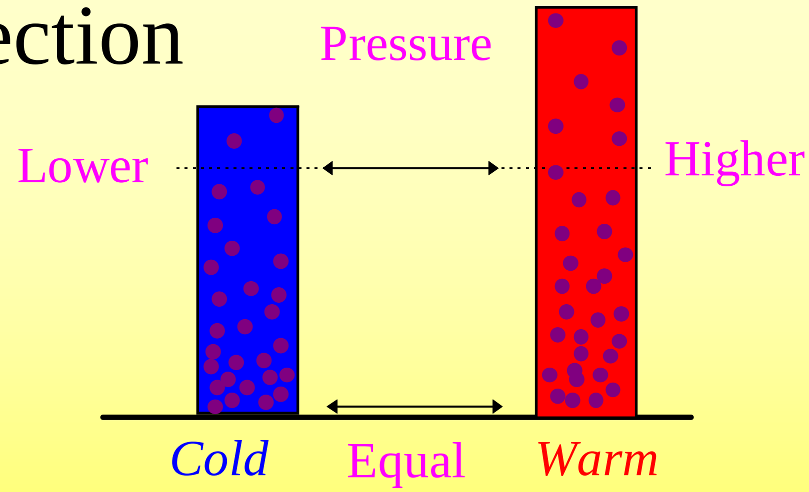
The Atmosphere in Motion

- The atmosphere moves under the influence of **forces**
- Atmospheric pressure (N m^{-2}) is therefore the key to understanding motion
- Because the atmosphere is a fluid, pressure at a given place is exerted in all directions

Example of the Influence of Pressure

- Atmospheric pressure is caused by the weight of air in a column 1 m^2 x-section
- For equal pressures on the ground, a column of cold air is shorter than one of warm air [p. 211/219/193]



- At higher levels, air naturally flows from a warm column to a cold column, thus reducing the pressure of the warm column
  - this can happen on hot afternoons, causing pressure to decrease

Measuring Pressure

- **Mercury barometer** measures the height, h, of the column
- Pressure **P** is found using the density of Hg, denoted ρ_{Hg}

$$P = \rho_{Hg} g h$$

(g is gravitational constant, 9.8 N kg^{-1})

The **aneroid barometer** is based on the compression of a sealed metal bellows [fig. 9.6/8.6]

- Electronic sensors (chpt. 1 notes)

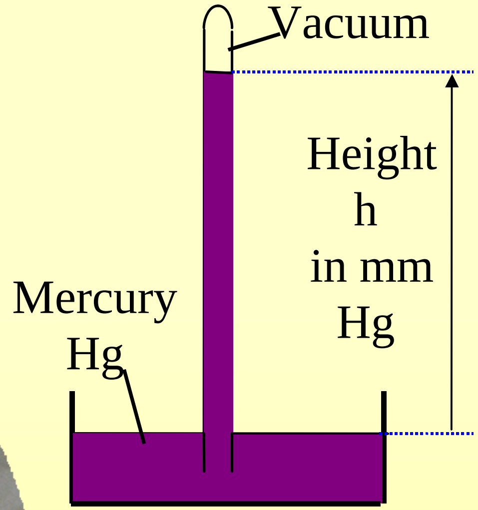
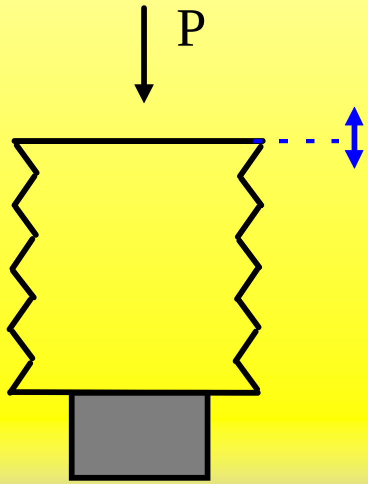


Photo: JSR



Sea Level Pressure Charts

- Station readings are reduced to sea level by applying an average altitude correction (typically +10 mb per 100 m)
- **Isobars** are drawn
  - contours are smoothed to hide small-scale wrinkles caused by sparse data, poor height correction and local anomalies
  - Result is the 'weather chart'
  - simplified charts ➔ newspapers and TV

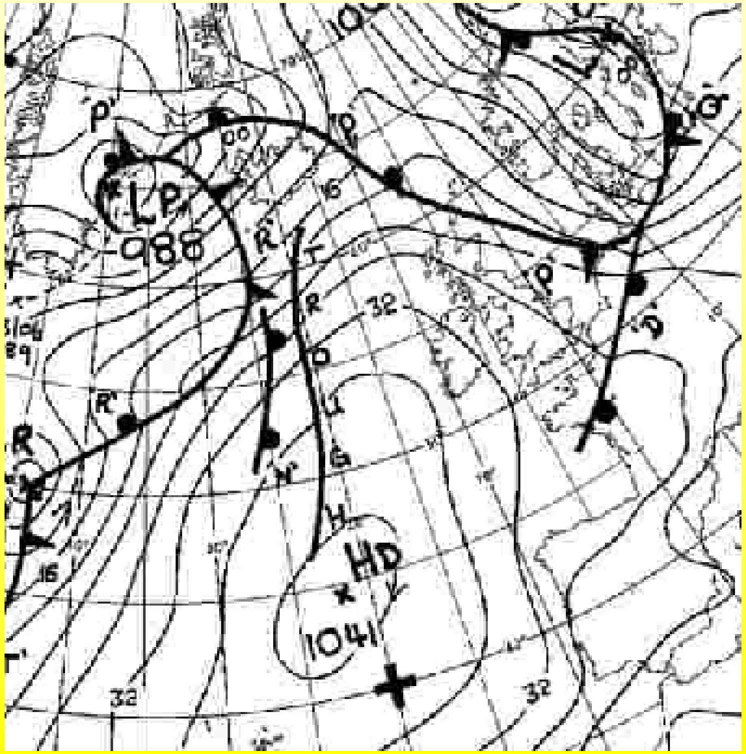
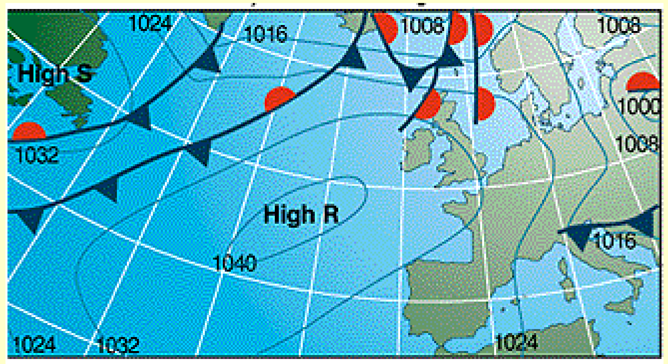
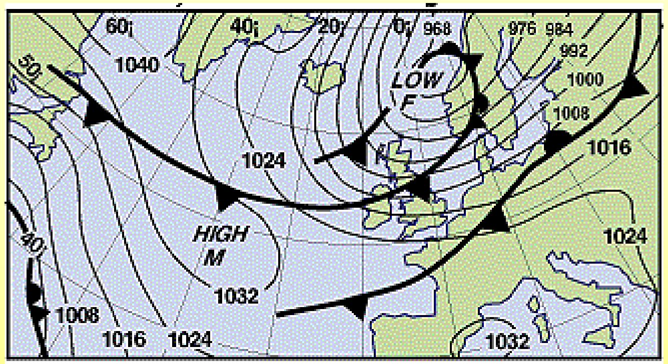
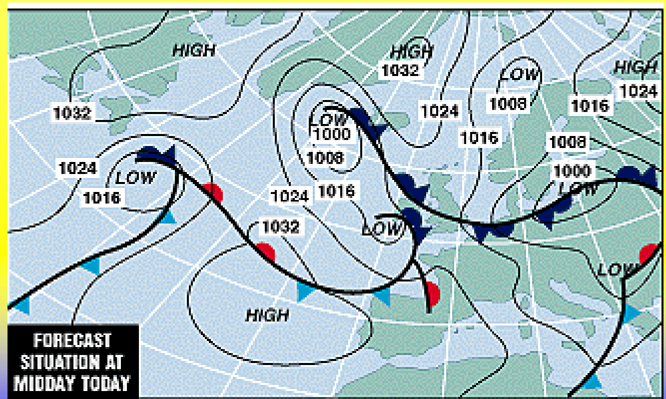


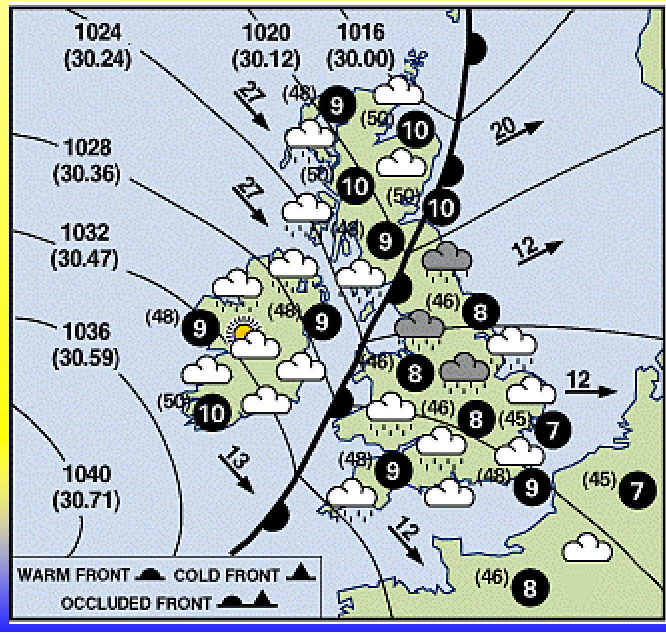
Chart Features

- Hills ⇔ **anticyclones**
- Hollows ⇔ **depressions**
  - mid-latitude cyclones
- **Ridges** and **Troughs**
- **Fronts** show lines where different air masses meet

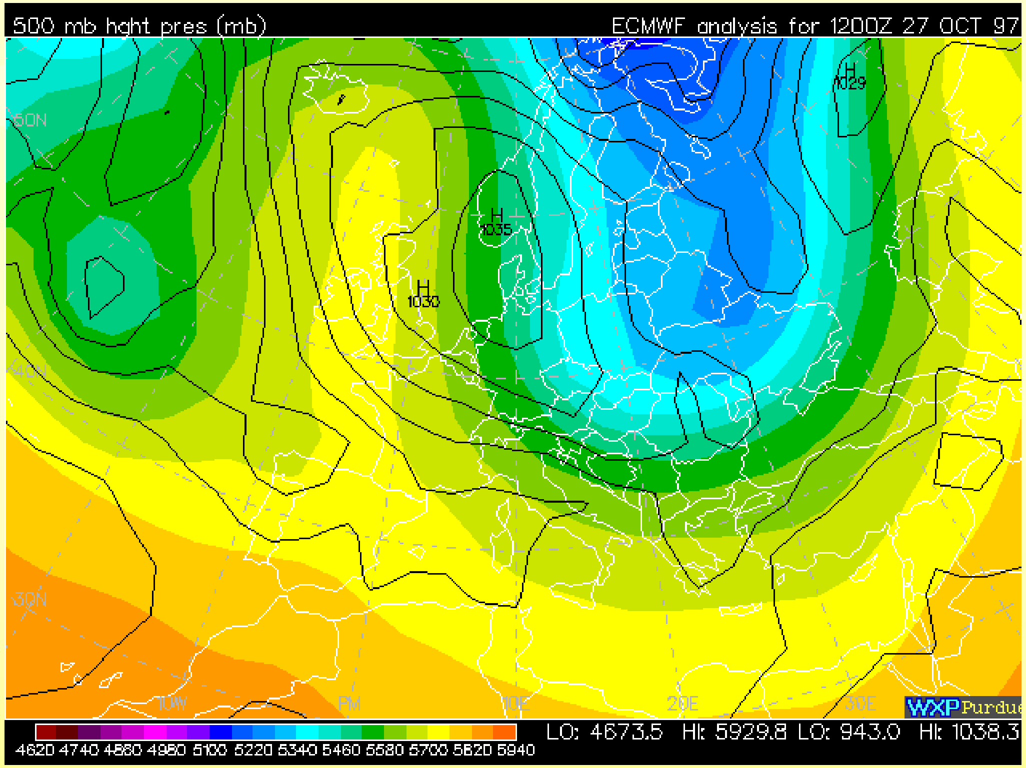








Upper-Level Charts



- Upper level charts are drawn as **isobaric surfaces** that show heights of a surface of constant pressure, e.g. 500 mb [fig. 9.13/8.13]. Mainly produced by computer model (see above + sl press)
- Contour lines represent constant heights, as on an ordnance survey map (strictly speaking, geopotential heights)
- The 500 mb chart records heights about 5500 m
  - high heights often mean warm air aloft

Motion is Governed by Newton's Laws

- 2nd law says, essentially, that force (F) acting on a mass (m) causes acceleration (a)

$$F = ma$$

N kg m s^{-2}

- Note that if there is *no force acting*, then there is no acceleration and the *velocity remains constant*

Forces Determining Wind

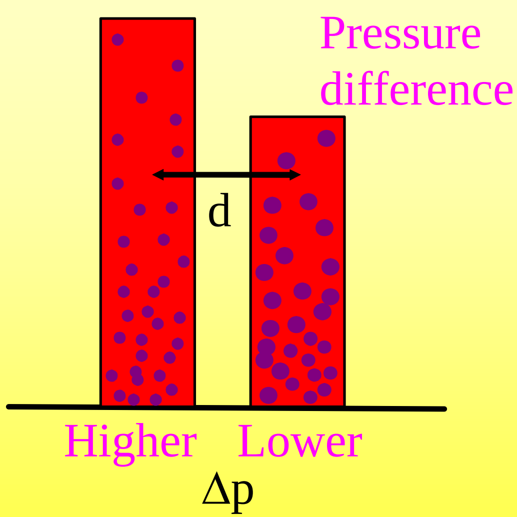
- **Pressure Gradient Force** (PGF)
- **Coriolis**
- **Friction**

- Centripetal force is the name of a resultant of two or three forces

Pressure Gradient Force

- **Pressure gradient** force is exerted at right angles to isobars
  - isobars far apart:
    - weak pressure gradient
      - weak pressure gradient force; light winds
  - isobars close together:
    - strong pressure gradient
      - strong pressure gradient force; strong winds

$$PG = \frac{\Delta p}{d}$$

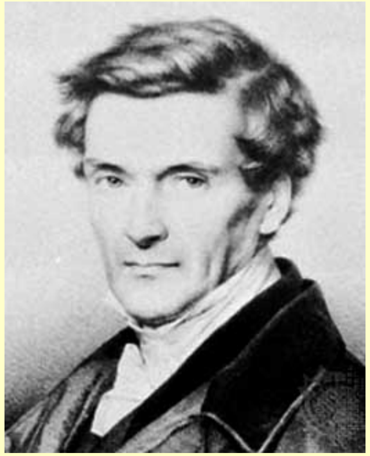


- On a large scale, air experiences the additional **Coriolis Force**

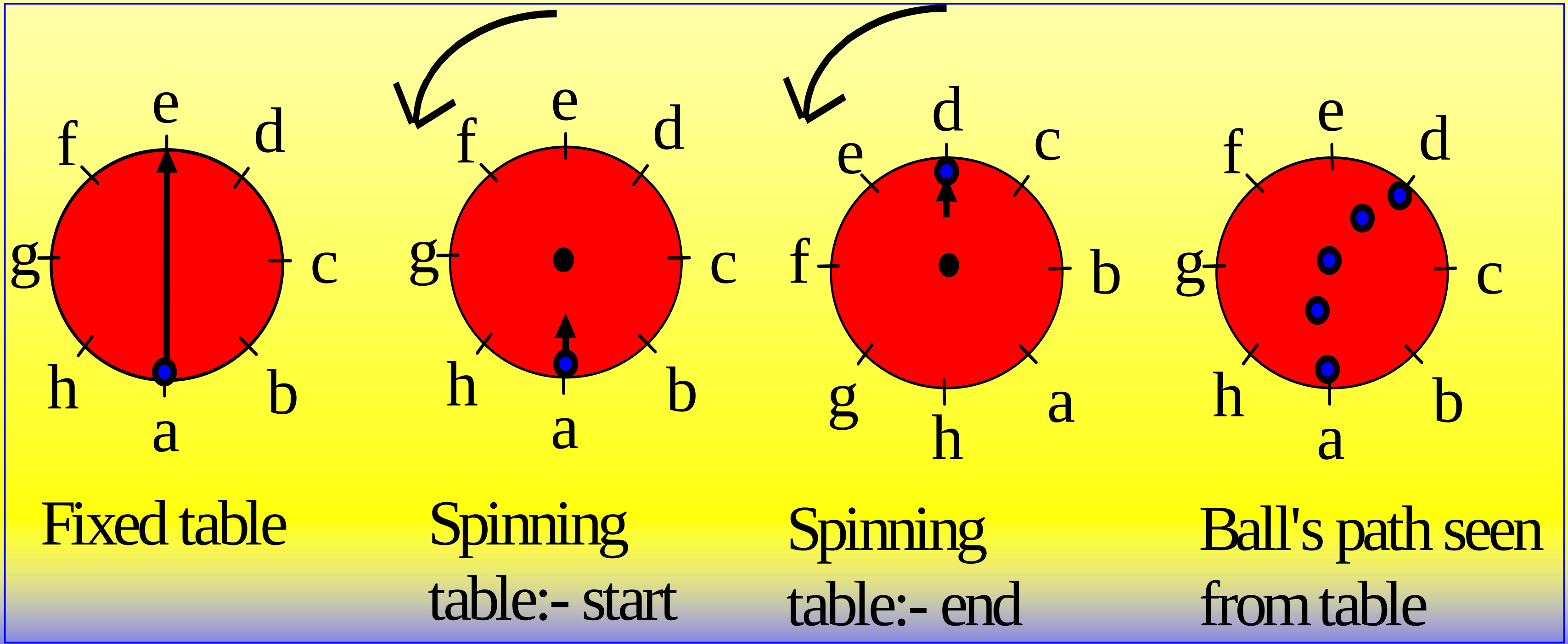
Coriolis Force

Gaspard Gustave de Coriolis

1792 - 1843



- The Coriolis force is the **apparent** force that explains the deflection observed in a body moving across a rotating surface when seen from the surface

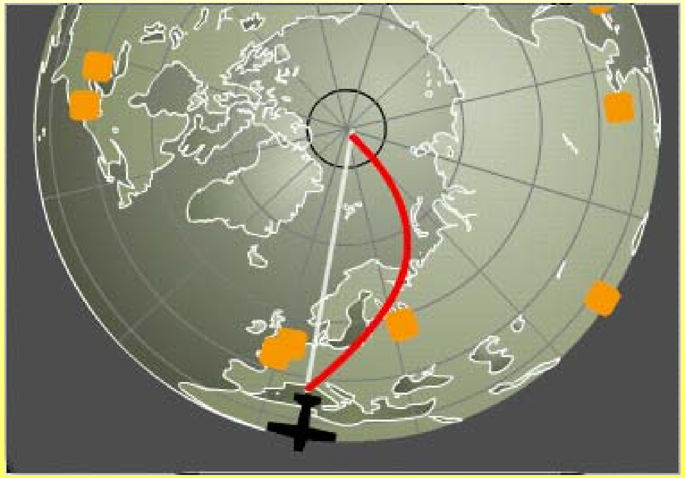


Consequences of the Coriolis Effect

On a merry-go-round in the night,
Coriolis was shaken with fright.
Despite how he walked,
'Twas like he was stalked,
By some fiend always pushing him right.

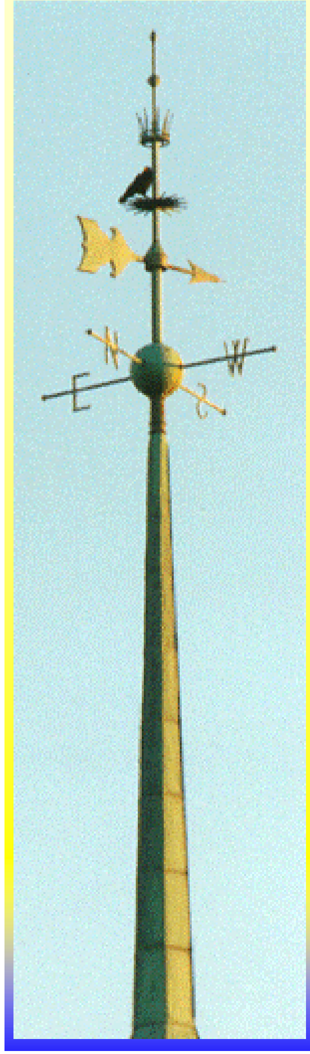
Courtesy APS

- Coriolis force ∝
  - mass of ball
  - speed of ball
  - angular speed of rotation



- Result is a description of the geometrical effect of rotation of the observer
  - try the exercise in Ahrens' CD/web page

Coriolis Effect on Winds

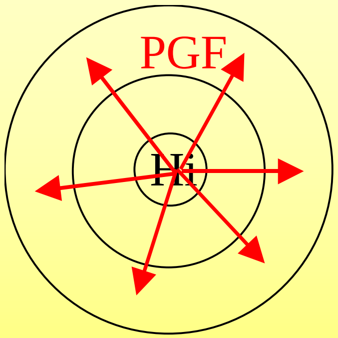


- Coriolis 'force' deflects winds to the right in the Northern hemisphere
  - this is true whatever the wind direction
  - the effect is zero at the equator and greatest at the pole
  - the stronger the wind, the greater the deflection
  - the effect is not noticeable on local winds like sea breezes, because the acceleration is small
  - the Coriolis force acts at right angles to the wind and hence alters its direction, not its speed

Photo: JSR

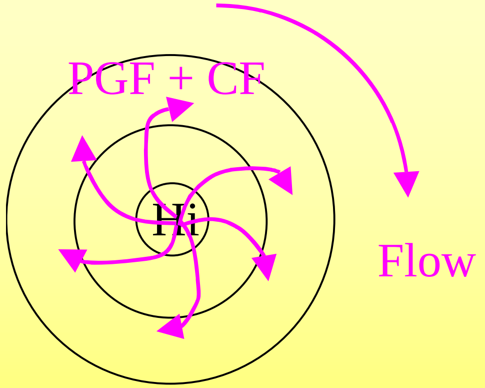
Coriolis Controls the Direction of Circulation

- High pressure in N hemisphere

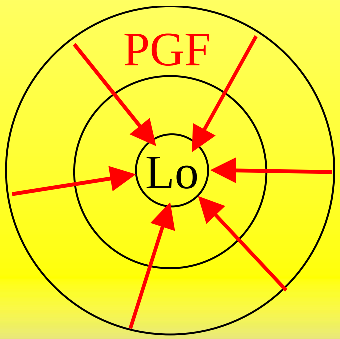


+ Coriolis

bend to right

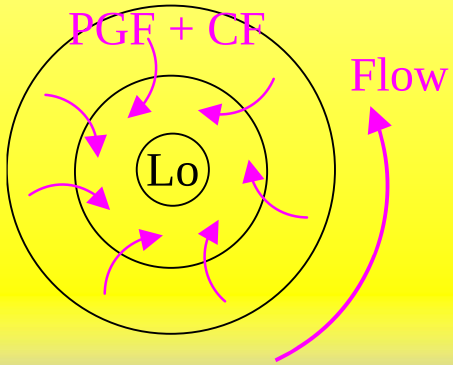


- Low pressure in N hemisphere



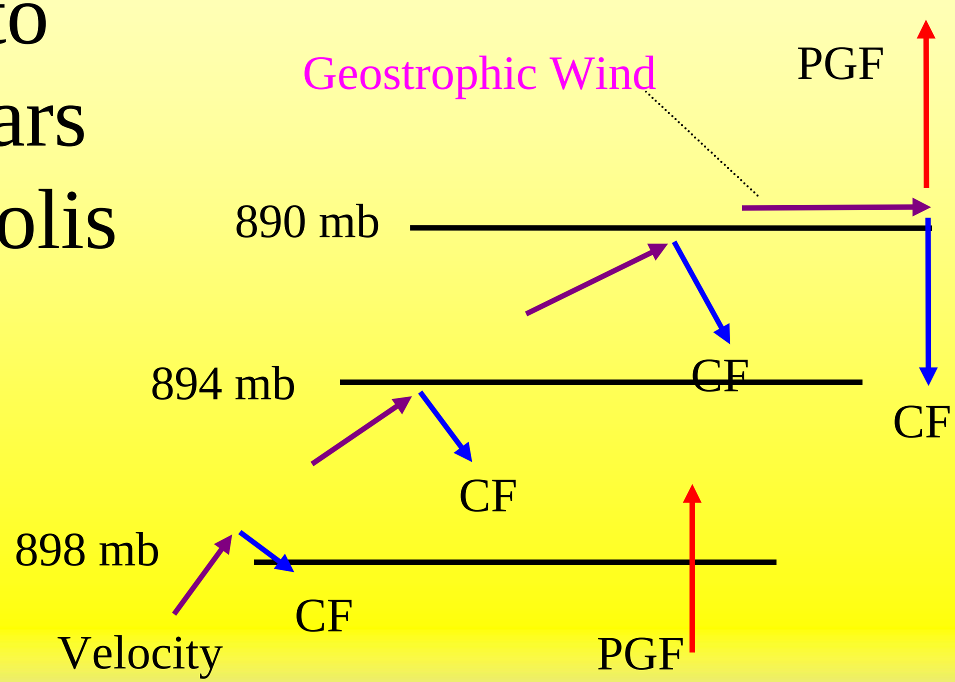
+ Coriolis

bend to right



Nature of the Geostrophic Wind

- Winds aloft (above ~1000 m) are caused by combined effects of pressure gradient force (PGF) and Coriolis 'force' (CF) [fig. 9.23/9.23/8.23]
- A wind that begins to blow across the isobars is turned by the Coriolis 'force' until Coriolis 'force' and PGF balance

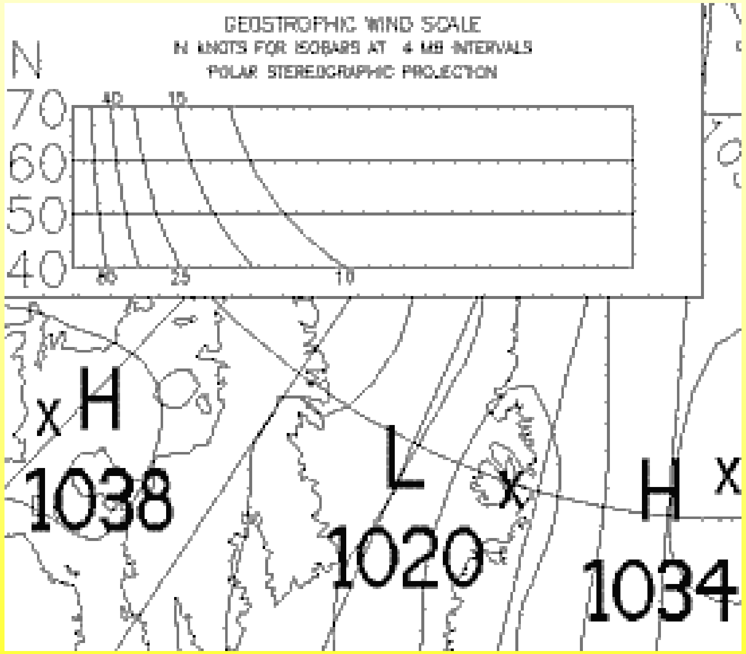


Strength of the Geostrophic Wind

- The geostrophic wind blows when [p. 226/235/207]

$$CF = PGF$$

- The wind strength (V_g) depends on the pressure gradient ($\Delta p/d$), the reciprocal of the air density (ρ) and a Coriolis parameter (f) that depends on latitude [p. 226/235/208]

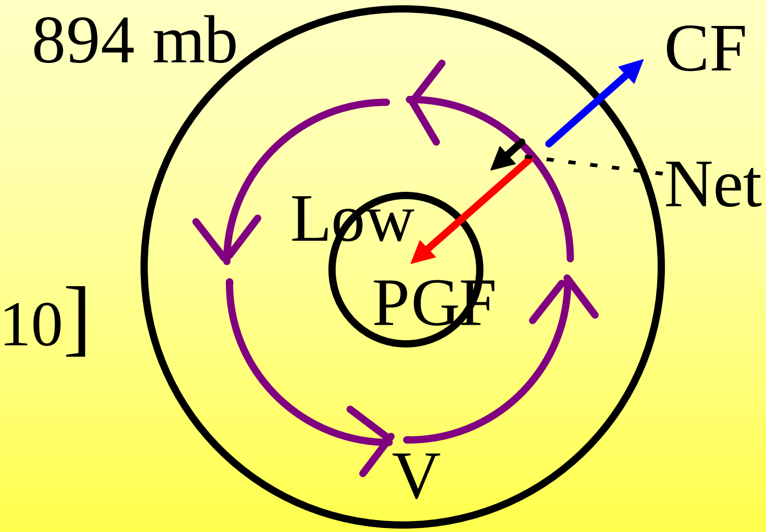


$$V_g = \frac{1}{f\rho}\frac{\Delta p}{d}$$

➢ winds increase in strength as you go aloft

Cyclonic Flow and the Gradient Wind

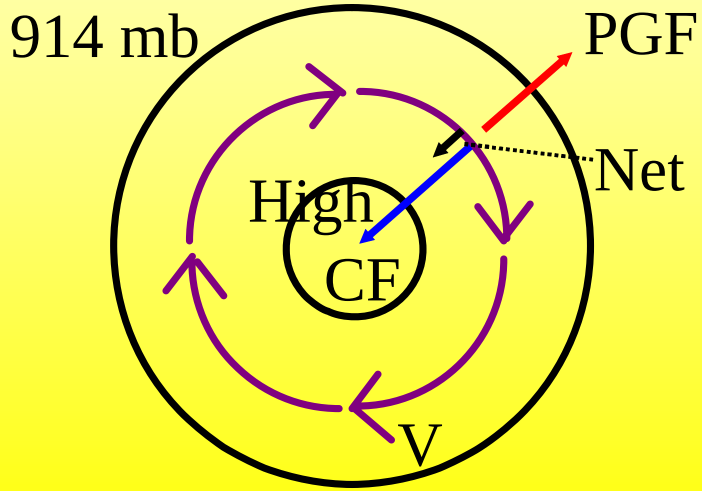
- General idea that winds aloft blow parallel to isobars is true even when isobars are curved
- BUT wind blowing in a circle needs a net force directed centrally to maintain the flow [p. 229/236/210]
  - this net force is called **centripetal force**
  - net force = PGF - CF
  - net force per unit mass is V^2 / r where r is the radial distance of the wind from the cyclone centre



Cyclonic Flow

Anticyclonic Flow

- Likewise with anticyclones, the **gradient wind** results from a difference between Coriolis force and pressure gradient force
  - centripetal force = CF - PGF
  - for weak cyclones and anticyclones, the centripetal force is small compared with the other 2 forces
- Winds rotate **clockwise** around **anticyclones** in the Northern hemisphere

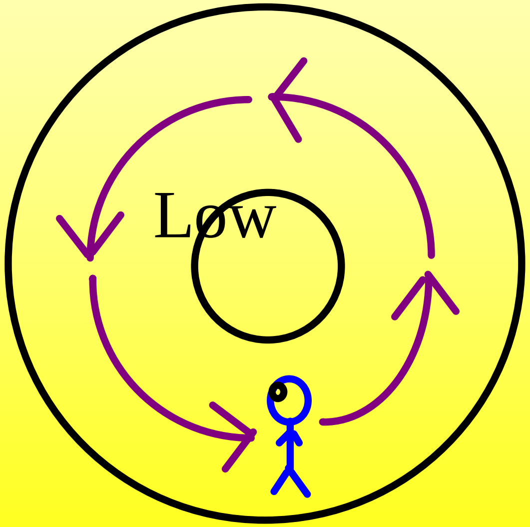


Anticyclonic Flow

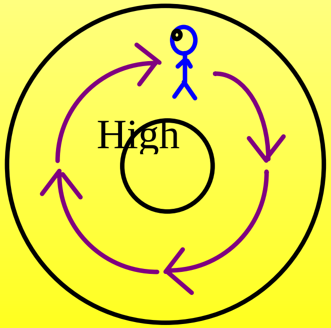
Buys-Ballot's Law

Courtesy: http://www.paweathercentre.com

- **Sailors' version**: stand facing the wind and the lower pressure is to your right



Cyclonic Flow

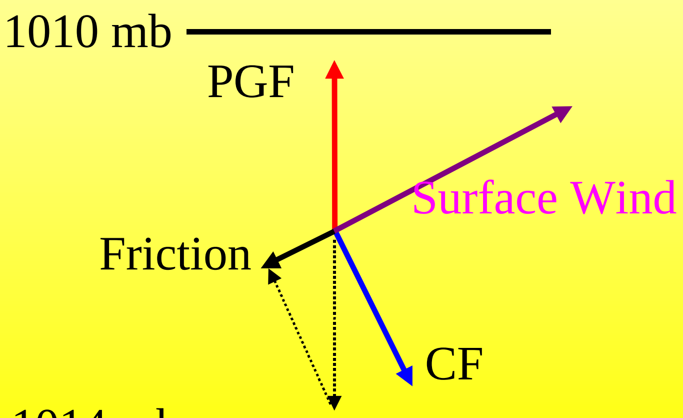


Anticyclonic Flow

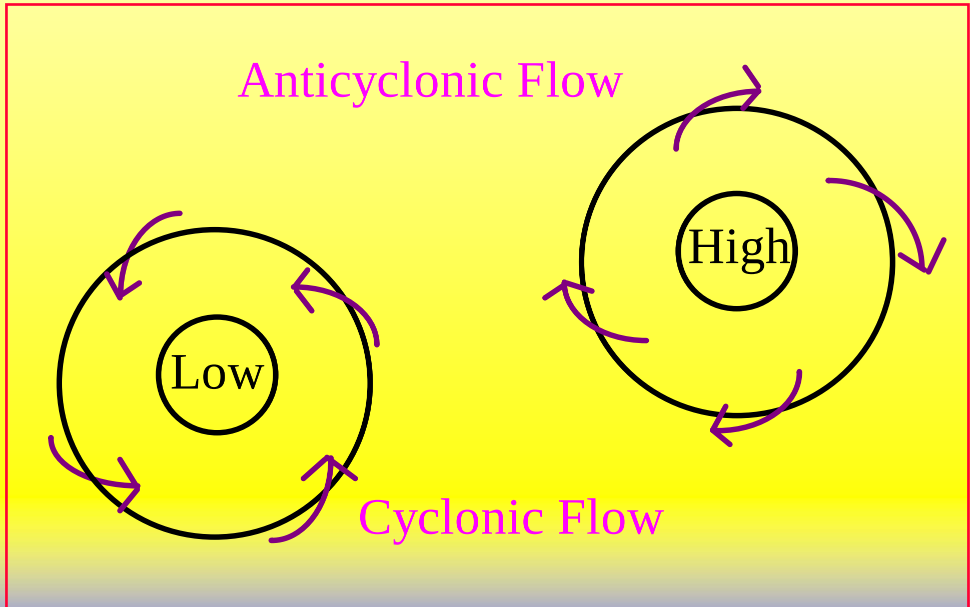
C.H.D. Buys – Ballot (1817 – 1890)

Surface Winds

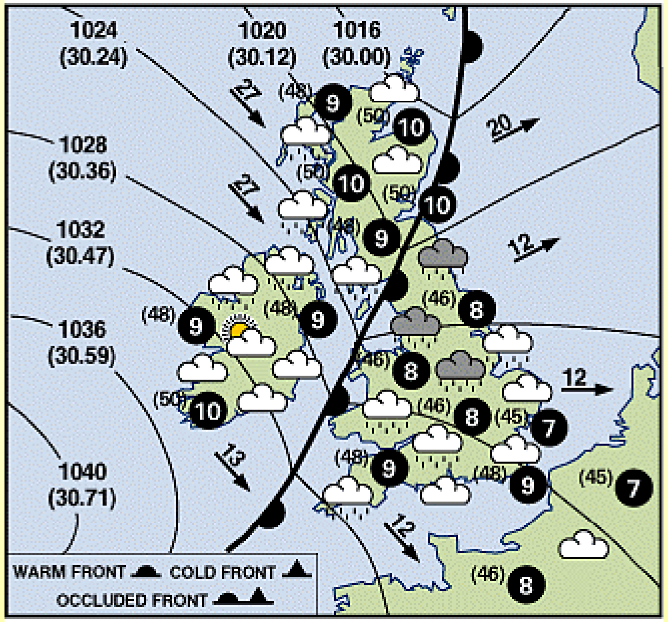
- **Friction** with the ground slows winds, reducing the Coriolis force which is no longer opposite PGF
- The result is an *inflow* of air towards the centre of low pressure and an *outflow* of air from anticyclones



Friction + CF + PGF = 0

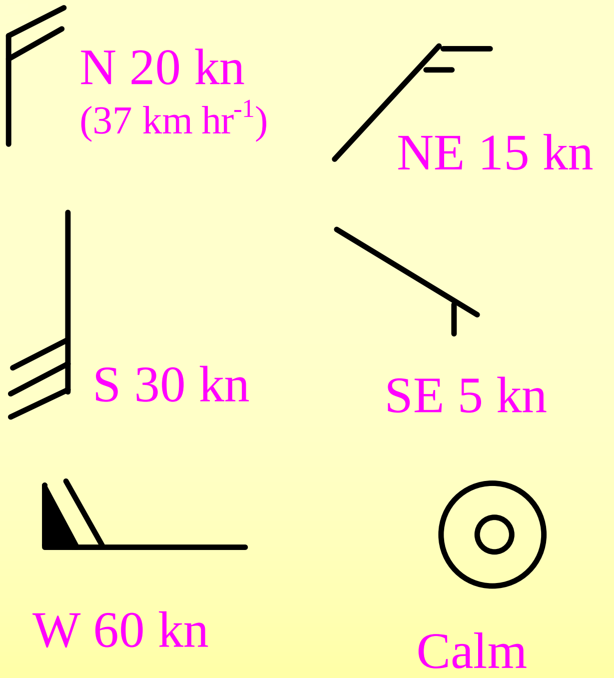


Summary

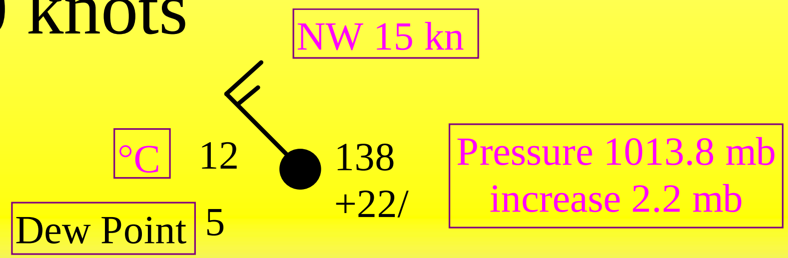


- These rules are a good guide
- Wind strength is controlled by pressure gradient
- Winds aloft flow approximately parallel to isobars
- Winds blow **anticlockwise around depressions**, clockwise around anticyclones in the N. hemisphere
- Surface winds blow slightly in towards the centre of depressions and slightly outwards from anticyclones
- Buys-Ballot's law is approximately true for surface winds, the low pressure being about 60° to the right

Wind Arrows

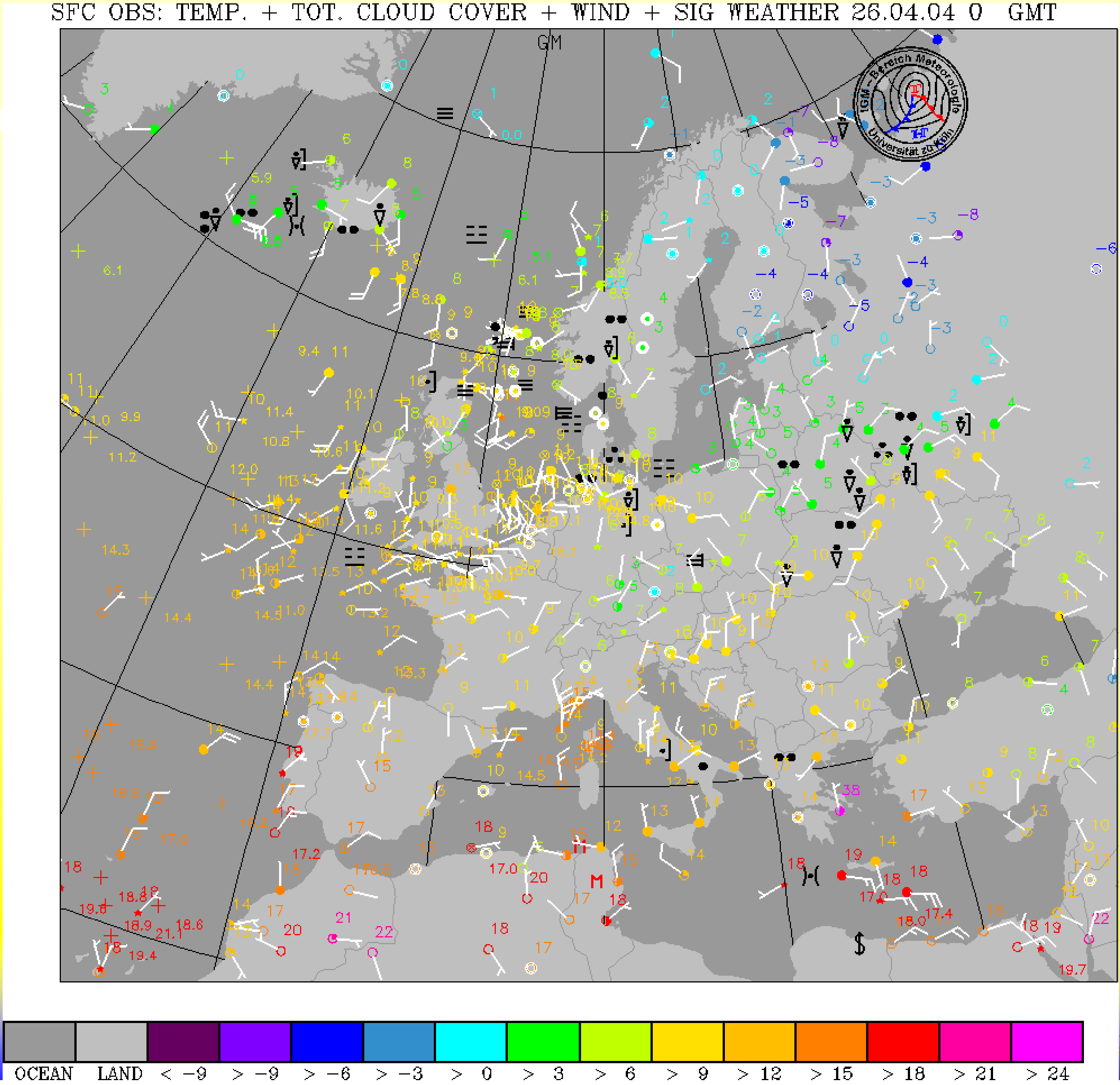


- Wind is described by the **direction it comes from**
- Wind arrows are drawn in the direction the wind is **going to**
- Arrow heads are omitted [appendix B]
- Feathers are drawn to represent wind speed
  - a whole feather represents 10 knots
  - a half feather, 5 knots
  - a solid triangle, 50 knots
  - 1 knot ≡ 1.85 km hr^{-1} (~0.5 ms^{-1})

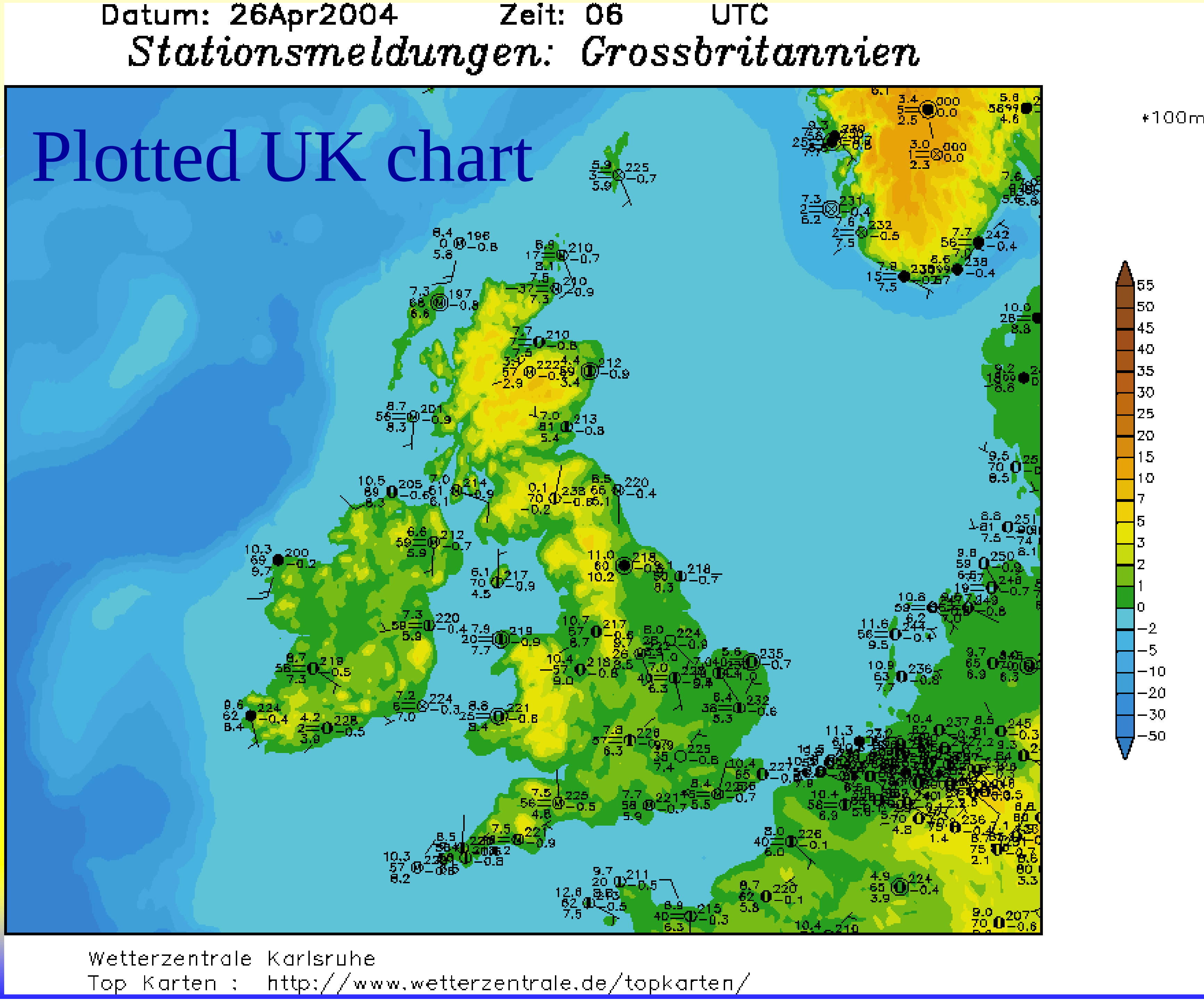


Abbreviated surface station symbol

Use of wind arrows



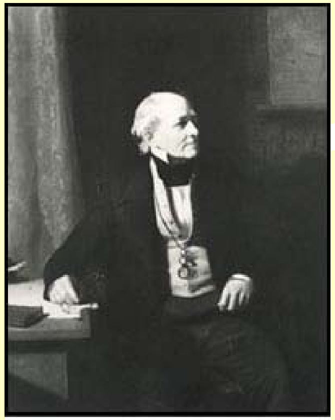
Plotted UK chart



Beaufort Wind Scale

Photo: JSR

- Wind strength used by sailors
- All shipping weather forecasts
  - it is also used on land
- The scale covers winds of 'force' 0 to 'force' 12
  - e.g. **force 4**: *moderate breeze*; 11 - 16 knots; small waves, becoming longer, frequent white horses; on land wind raises dust and lose paper; small branches move
  - **force 8**: *gale*; 34 - 40 knots; moderately high waves of greater length, edges of crests begin to break into spindrift, foam is blown in well-marked streaks; on land, wind breaks twigs off trees, walking is difficult. [App C]



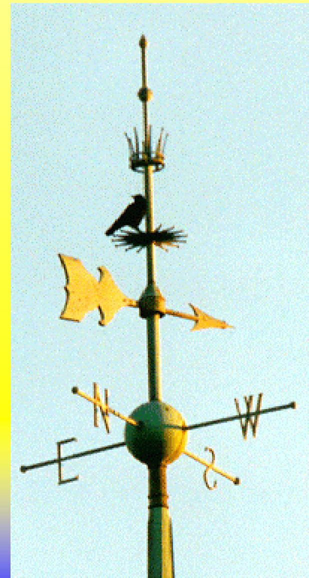
Admiral Beaufort Photo Crown copyright

Francis Beaufort (1774 – 1857)

- Beaufort was a Royal Navy officer who, after active service, promoted the Navy's involvement in a wide range of science in his capacity as Hydrographer
- Beaufort's scale concentrates on the **effect** of the wind
  - in the original description, each point was described in terms of the speed of a man-of-war and the sails it could carry
  - similar scales existed many years before Beaufort's version was officially adopted by the RN in 1838
  - the scale has been adapted and updated for international use over the years
  - Beaufort commissioned Robinson to find the wind speeds for the scale points – hence the Robinson cup anemometer

Measuring Wind

- An **anemometer** measures wind speed
  - most common type is the Robinson cup anemometer
  - the cups rotate at a speed proportional to the wind
- A **windvane** measures wind direction
  - the vane orients itself downwind
  - the vane actuates the centre arm of a variable resistor



Photos: JSR

What use is a barometer?

- Relates observation to weather chart detail
  - e,g, pressure high or low
- **Change** in pressure indicative of pressure gradient
  - change in pressure is important forecasting aid

Photo: JSR

A National Observatory

- Mt. Aigoual in the Cevennes, run by Meteo France

Photo: JSR