FRONTS

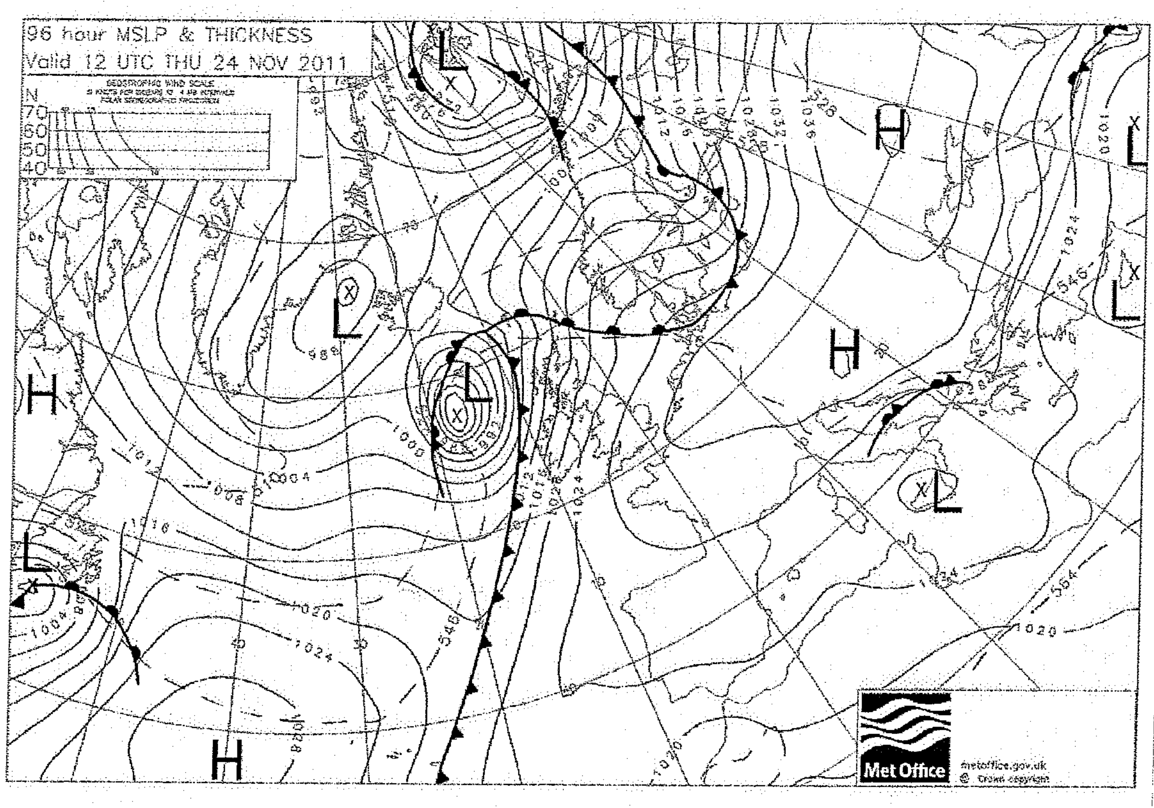
So far we've looked at the vertical structure of the atmosphere, including the hydrostatic equation for pressure, lapse rates for dry and saturated air. We've also studied the horizontal motion of air, finding that the winds are caused by a combination of pressure gradients, Coriolis and centrifugal forces, and friction.

In this lecture, we'll start to combine horizontal and vertical motion to look at the structure of weather fronts and storms.

By the end of this lecture you should be able to:

- Describe warm and cold fronts and the weather associated with them
- Describe qualitatively the formation, evolution, and dissipation of low pressure weather systems (cyclones)

My aim is that you can read one of these, and describe likely weather patterns and how they might develop over time.



This is called a SYNOPTIC chart

You have already seen the fainter contour lines: these are <u>isobars</u>, lines of constant pressure.

We can use these lines to estimate wind speeds using the approximations in the last lecture.

In addition, there are lines of latitude and longitude at 10° intervals.

Example 1 : what is the wind speed in north England from that chart?

No scale, so use length of UK ~ 1000 km
on map, this is ~17 mm

North England, distance between isobars ~ 3 mm

or $1000 \times \frac{3}{17} = 180$ km

isobars labelled 1024, 1020, 1016, ...

i.e. spaced 4 mb apart

180 km between isobars

$$\Rightarrow \frac{\partial P}{\partial R} = \frac{4 \text{ mb}}{180 \text{ km}}$$

$$1 \text{ mb} = 100 \text{ Pa} \rightarrow \frac{\partial P}{\partial R} = \frac{400}{1.8 \times 10^5} = 2.2 \times 10^{-3} \text{ Pa/m}$$

Lines are straight, so ignore curvature effects
(geostrophic approx)

$$V = \frac{\nabla P}{f \rho} \qquad f = 2 \Omega \sin \lambda$$

$$\rho = 1.3 \text{ kg/m}^3$$

$$\lambda \sim 55° \quad \Omega = \frac{2\pi}{24 \times 60 \times 60} = 7.3 \times 10^{-5} \frac{\text{rad}}{\text{s}} \rightarrow f = 1.2 \times 10^{-4}$$

$\therefore V_g = 14$ m/s or ~ 30 mph, 26 knots

∴ Force 6 or 7 on Beaufort scale
(strong breeze or high wind)

Example 2: What is the wind speed around the low pressure system to the west of the UK. Use isobars around P = 992 mb

Distance between isobars is ~ 1mm or $\frac{1000}{17} \times 1$

≈ 60 km

$$|\nabla P| \approx \frac{\partial P}{\partial x} = \frac{400}{6 \times 10^{4}} \approx 6.7 \times 10^{-3} \text{ Pa/m}$$

Geostrophic wind $$V_g = \frac{\nabla P}{f\rho} = \frac{6.7 \times 10^{-3}}{1.2 \times 10^{-4} \cdot 1.3} = 43 \text{ m/s}$$

This is ~ 96 mph or 84 knots

Appears to be a hurricane! (> 73 mph)

Curved isobars, so need gradient wind

$R \sim 5 \text{ mm}$ or 300 km

$$V = -\frac{fR}{2} + \sqrt{\frac{f^2R^2}{4} + \frac{R}{\rho}|\nabla p|}$$

↑ rotating anti-clockwise

$$fR = 1.2\times10^{-4} \cdot 300\times10^{3} = 36 \text{ m/s}$$

$$\frac{R}{\rho}|\nabla p| = \frac{300\times10^{3}}{1.3} \cdot 6.7\times10^{-3} = 1.5\times10^{3} \ (\text{m}^2/\text{s}^2)$$

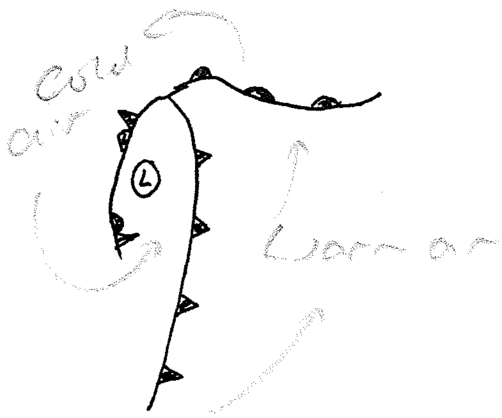
$$\Rightarrow V = -\frac{36}{2} + \sqrt{\frac{36^2}{4} + 1.5\times10^{3}} = 25 \text{ m/s}$$

56 mph or 49 knots

Force 10 storm, very bad weather, but not hurricane.

The large difference between geostrophic and gradient wind illustrates importance of checking your assumptions.

What do the solid (thick) lines mean?



These are Fronts, boundaries between ~~the~~ warm (typically moist) air and colder air.

- Started as a distortion of the boundary between warm and cold air called a "frontal wave"

- Low pressure systems which affect the UK generally start over the North Atlantic, travel west and last for 3 to 10 days

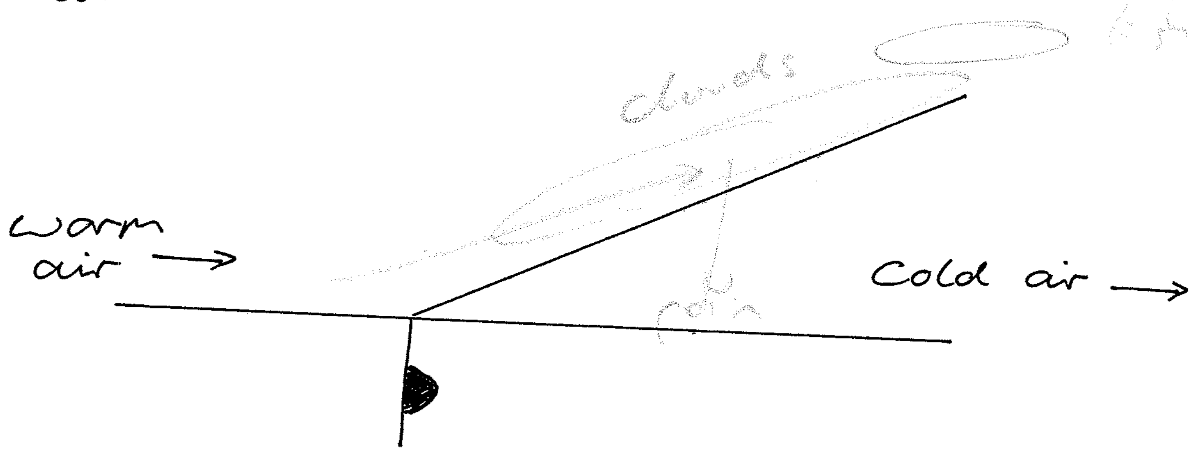
- At the centre of the system is a region of low pressure, around which the air is rotating in an anticlockwise direction (in the northern hemisphere, clockwise in the southern).

- At ground level, air usually spirals inwards towards the low-pressure region at an angle of 15 to 30°.

- Whether a low deepens (gets lower) or dissipates (gets higher) depends on air above: If more air is removed from the top than is entering at the bottom, then the low will deepen.

WARM FRONTS

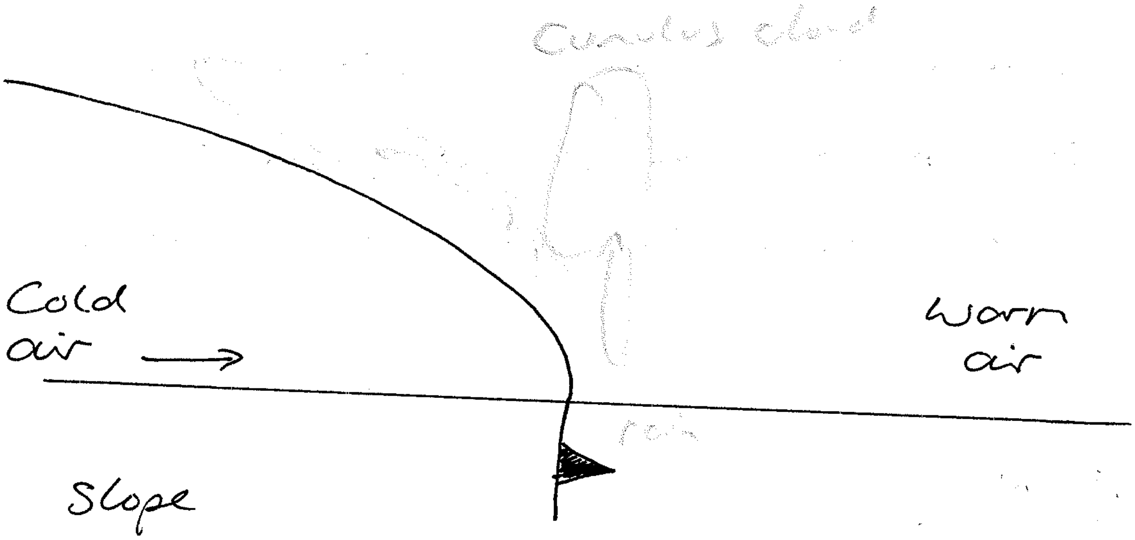
At a warm front, warm air is replacing colder air



Slope ~ 1/150 to 1/300
(1 km up for 150 km along)

COLD FRONTS

At a cold front, cold air is replacing warm air



Slope

$\sim \frac{1}{50}$ to $\frac{1}{100}$ i.e. much steeper than warm front.

- Warm fronts
  - Shallow gradients so air is slowly lifted upwards to Dew point and condensation → cloud appears over a wide area
  - Approaching warm front first appears as high Cirrus clouds, then stratus, then rain over a wide area (Nimbostratus)
  - Rainfall gradually increases as the front approaches

- Cold fronts
  - Steeper gradient, so air is forced rapidly upwards.
  - Leads to strong convection Cumulus clouds
  - In strong fronts these can lead to thunderstorms and even tornadoes

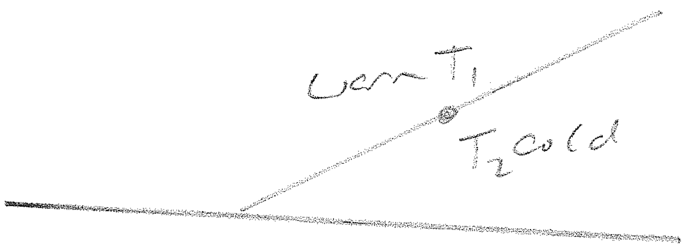
The motion of warm and cold fronts is a complicated process, one of the things which make forecasting difficult. Some of the effects involved are:

1. Geostrophic or Gradient wind

Dominant effect, rotating counter-clockwise around the low

e.g. geostrophic $V_g = \frac{|\nabla p|}{f\rho}$

Assume a sharp boundary



$T_1 > T_2$

either side of front pressure matches

$P_1 = P_2$ ideal gas law $P = \rho k_B T$

$\Rightarrow \rho \propto \frac{1}{T} \Rightarrow V_g \propto T$

$$\frac{V_{g1}}{V_{g2}} = \frac{T_1}{T_2}$$

warm air rotates faster than cold

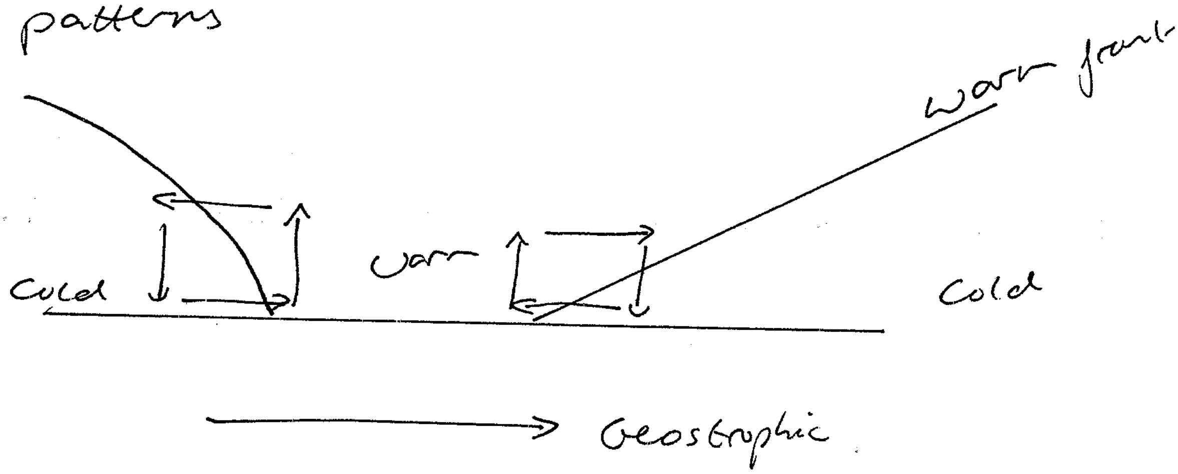
2. Difference in densities leads to "Isallobaric" effects

"heavier cold air can push warm light air out of the way easier than the warm air can push the cold air ahead of the warm front"

- Paraphrase USA Today.

3. Secondary circulation

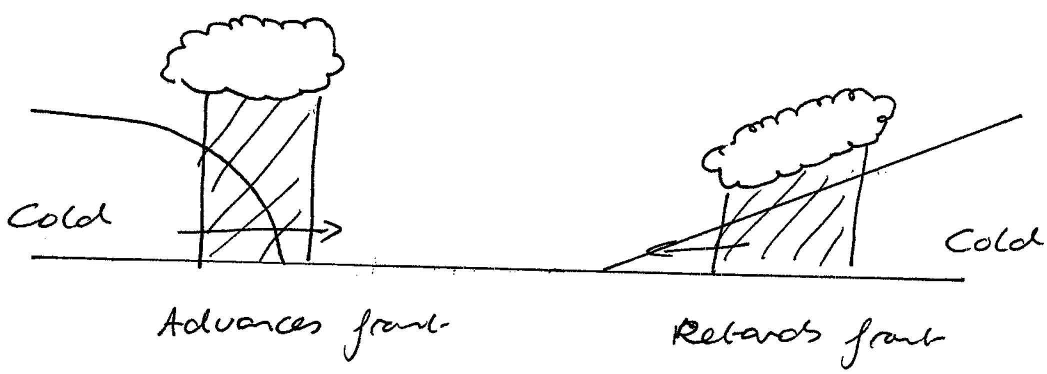
Rising warm air can set up circulation patterns



Acts to speed up cold front and slow warm front

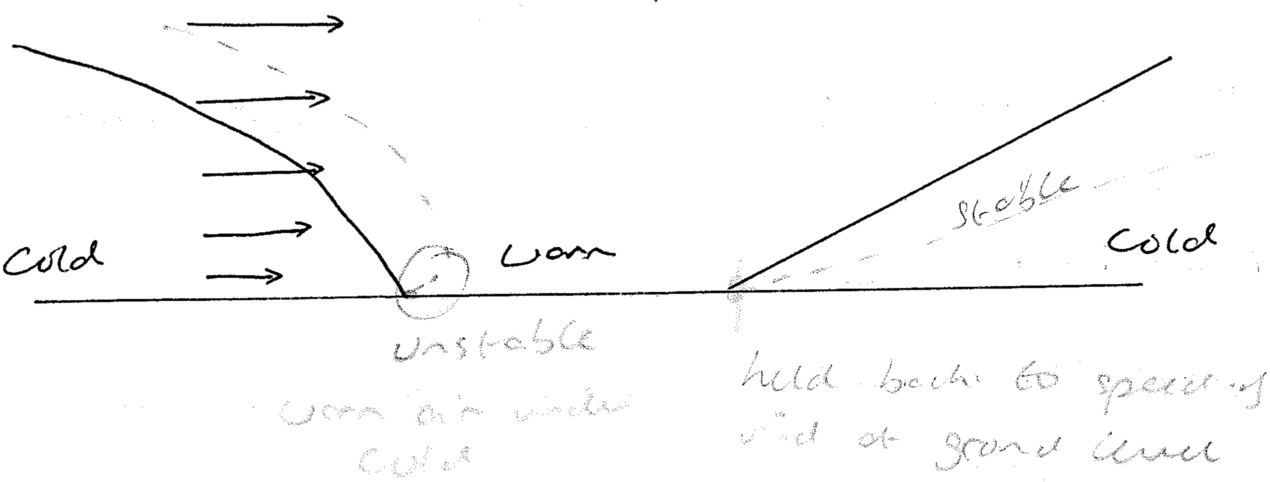
4 Precipitation cooling

precipitation and down-drafts can cool air



5. Friction with the ground / sea
"Planetary Boundary Layer" or PBL effect

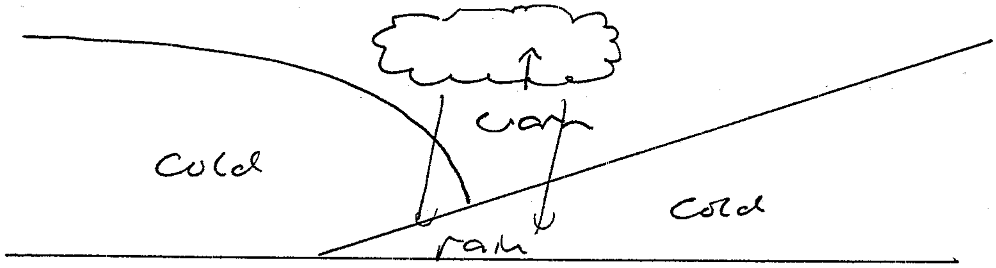
- Wind close to the ground is slowed by friction. Wind therefore generally increases with height.



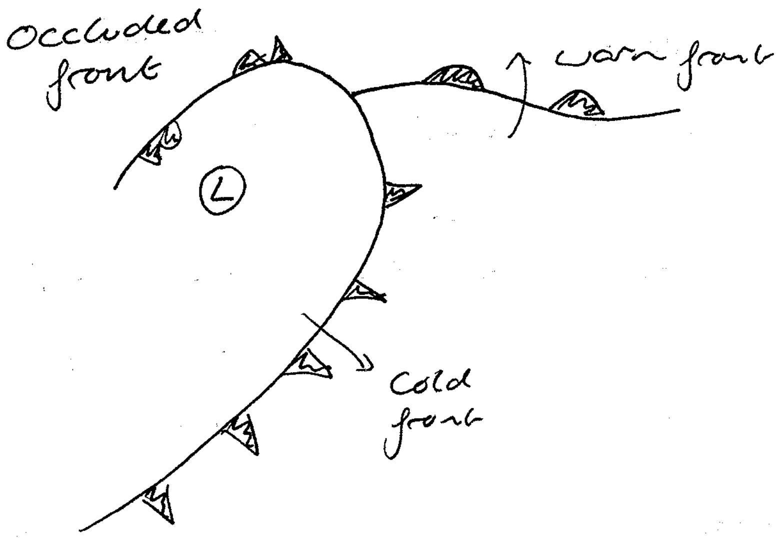
⇒ Cold front not as restricted by friction with the ground

⇒ Net effect is that cold fronts usually move faster than warm fronts

Cold fronts catch up with warm fronts, leading to an "Occluded front"



This has started to happen in the synoptic chart



When this happens the low pressure system will begin to dissipate.

How do these systems form and persist?

→ Depends on converging and diverging flows higher in the atmosphere: planetary scale structures known as Rossby waves

(Next lecture)

SUMMARY

- Low pressure systems (cyclones) are associated with warm and cold fronts
- Begin as a perturbation to the boundary between warm and cold air masses
- Cold air moves south whilst warm air moves north. The Coriolis force then twists the boundary into the typical 'comma' shape
- Warm fronts are where the warm air is replacing cold air. The gradients are shallow, leading to cloud over a wide area and light rain
- Cold fronts are steeper, leading to more violent lifting of warm, moist air to its dew point. They tend to be associated with heavier rain or thunderstorms.
- Cold fronts tend to move faster than warm fronts. Eventually catch up and form "occluded fronts". Rain eventually stops as warm air is lifted.
- Once the front is occluded, the cyclone dissipates as no longer being driven by rising warm air.