Boundary Layer Ventilation in Mid-Latitude Cyclones

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Introduction

Venting of the layer of air just above the Earth's surface is extremely important, particularly for moisture vapour. Here we present some work that takes into account the turbulent nature of the "boundary layer" in dispersing particles, such as moisture vapour, before advecting them on into the system.

A Case study 22nd – 26th Nov 2009.

A case was chosen based on its well defined cold front and broad warm sector..

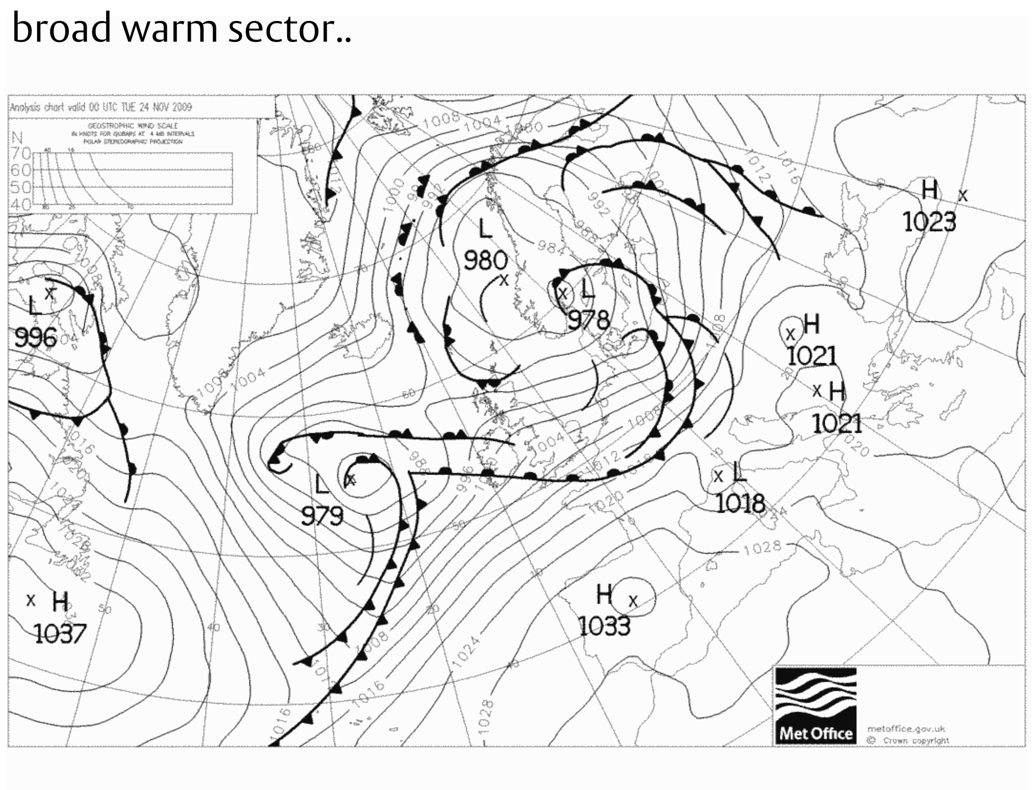

Figure 1 the UK Met Office operational analysis for 00z on the24th November 2009. The system shows a low pressure centre flanked on either side by two coherent anticyclones. The cold front is well defined, with an extremely cold outbreak of air behind the front of Arctic origin.

Modelling the case study

- The atmosphere was modelled using the Unified Model (UM)
  Vn 7.3 using a global domain configuration.
- The dispersion was modelled using NAME III Vn 5.0 .
- We took the boundary layer height as that defined by the UM.

Tracer release point 1

Tracer was released on the 22nd Nov at 12z , a point was chosen to the east of the approaching Cold front within the anticyclone. 1.0e6 particles were released over a period of 1 hour, the resulting location of the particles after 24 hours and 54 hours are shown in figures 2 and 3.

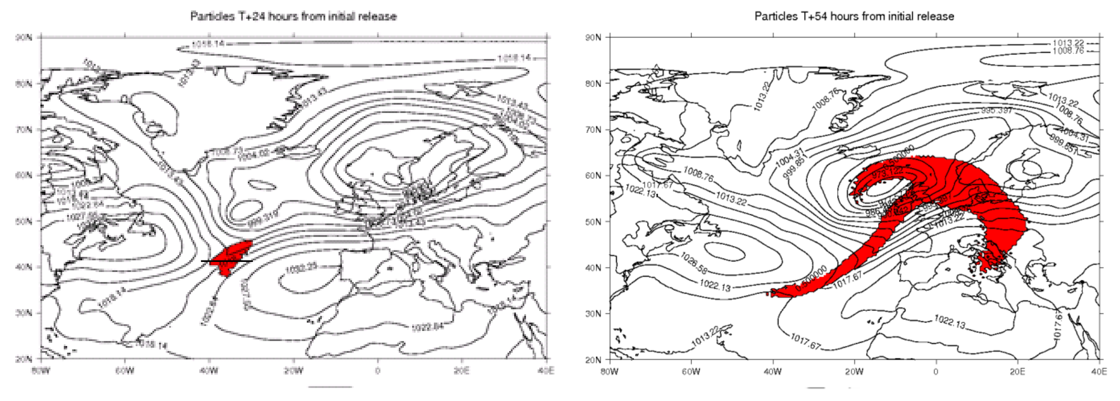

Fig 2 and 3 The location of particles released after 24 and 54 hours into the simulation respectively. The location of the cross section in fig 5 is indicated in fig 2.

The number of particles above the boundary layer top has been plotted as a function of time along with the particle waited height of the average depth of the boundary layer .

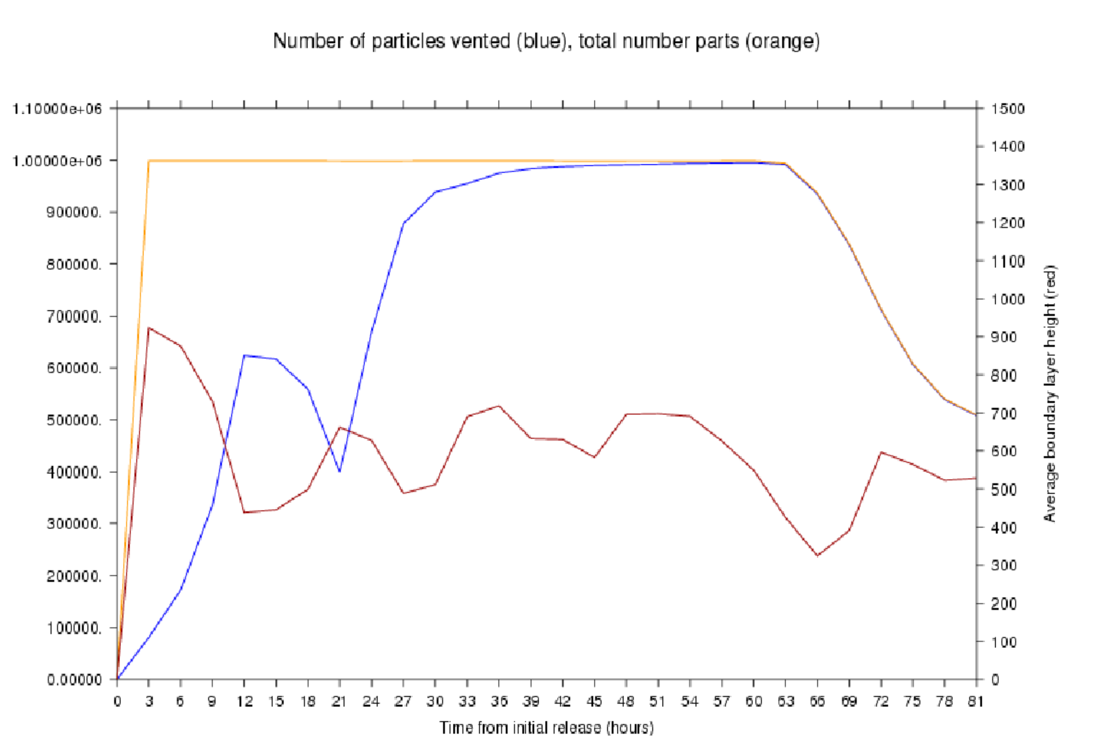

Fig 4. The number of particles vented above the boundary layer as a function of time for the first tracer release point. The number of particles that have been vented above the boundary layer (blue), The particle weighted mean boundary layer height (red), the total number of particles released into the system (orange).

Note the anti-correlation between boundary layer height and number of parcels vented up until 21 hours when venting from the cold front becomes dominant and all the particles are vented out of the boundary layer.

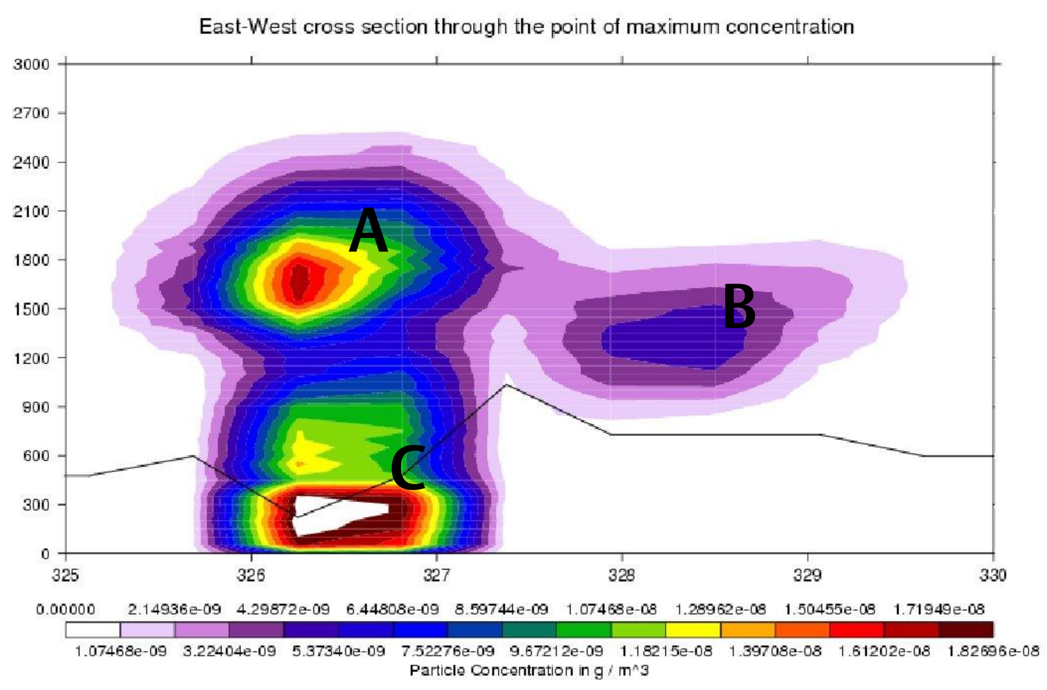

Fig 5. An East – West cross section through the plume, 27 hours into the simulation. Three structures are present here, A – The concentration of particles that are lifted up due to sloping potential temperature contours, B – Particles that have passed through the boundary layer top during advection. C - Particles that have been mixed back down into the boundary layer.

A cross section through the resulting plume at T+27 hours shows us that the flow has temporarily been split into three distinct pathways.

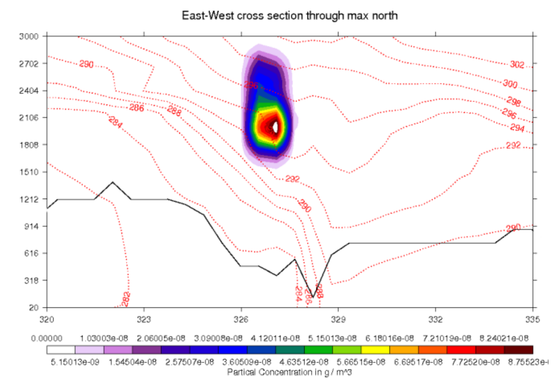

Fig 6. A run with the turbulence component turned off, showing the particles that have been lifted up onto the frontal surface

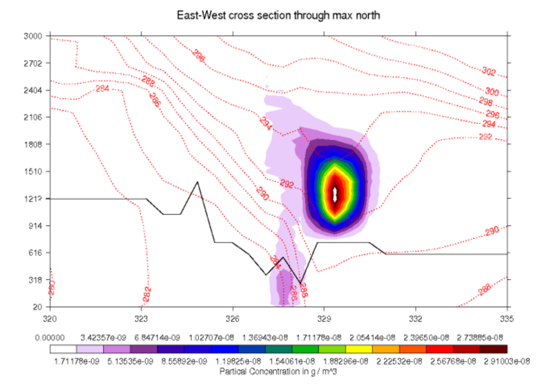

Fig 7. A run where particles were released just above the boundary layer top demonstrating the lack of re-entrainment and thus the lack of friction affecting their trajectory.

- Pathway A is the result of the non – turbulent aspect of the flow and the lifting of the parcel along lines of constant potential temperature as the particles interact with the cold front.
- Pathway B can be seen to be as a result of particles that have left the boundary layer as a result of turbulent mixing and the slope of the boundary layer as we get closer to the cold front. Figures 5 and 6 demonstrate this.
- Pathway C is the result of the continual mixing down of particles due to turbulence. (However it is clear from figure 4 that they are all removed by 48 hours into the simulation.)

Tracer release point 2

A point within the cold outbreak was chosen for the release of tracer 2 behind the cold front.

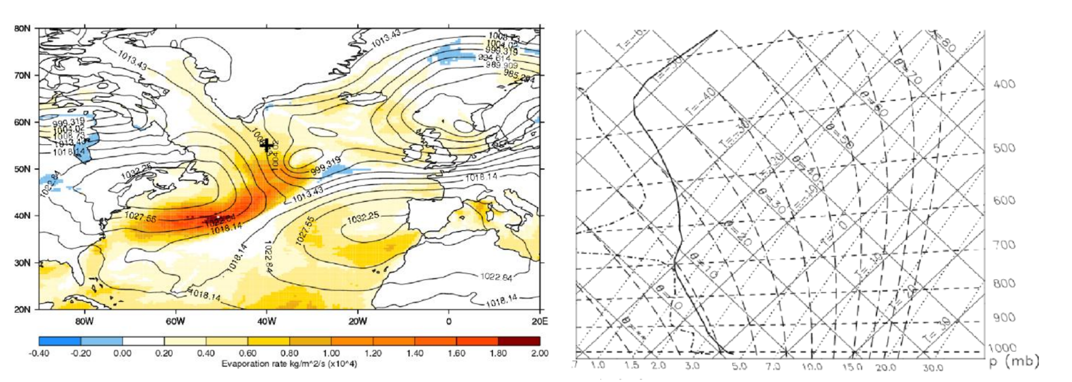

Fig 8 and 9 The location of release for trajectory 2 and the accompanying atmospheric profile for the release location.

The atmosphere is very unstable here and we might expect mixing to occur to a height of 700 hPa. However the venting rate is still closely related to the slope of the boundary layer.

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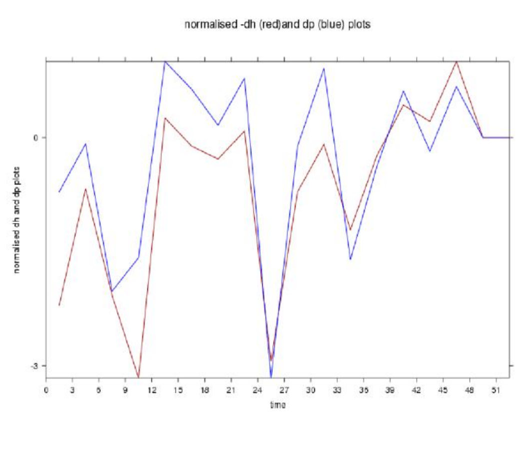

Fig 11. Normalised curves for the rate of change of boundary layer height (red) and the rate that particles are being vented from the boundary layer (blue).

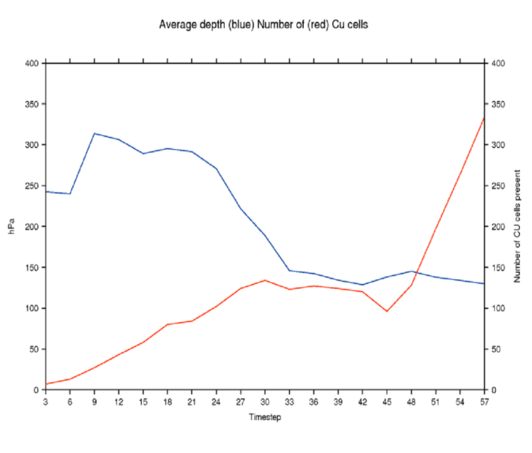

Fig 12. The average depth of Cumulus clouds (blue) and the total number of Cumulus clouds (red) within the domain of the particles spread.

The time of maximum Cu depth and the maximum number of Cu cells correlates well with the times when the rate of particles vented deviates from the rate at which the boundary layer height is changing.

Conclusions

- The Warm conveyor belt splits into two distinct streams.
- Stream A is produced by the uplift on the Cold frontal surface.
- Stream B is due to the drop in Boundary Layer height and horizontal advection of particles out of the Boundary Layer.
- Behind the cold front most of the particles remain within the boundary layer.
- Initially as the particles are quite concentrated venting occurs due to the size of the cumulus clouds
- Later on as the particles become more diffuse venting occurs due to the number of cumulus.

Which means that

- **The Boundary layer structure is important for initialising the properties of air parcels which then go onto affect the overall system dynamics.**
- **The cloud structure at the top of the boundary layer is extremely important when considering the dispersion of particles / moisture within the system.**

Climatology work

In order to investigate boundary layer venting by multiple systems we will construct a climatology of the mass flux through the boundary layer.

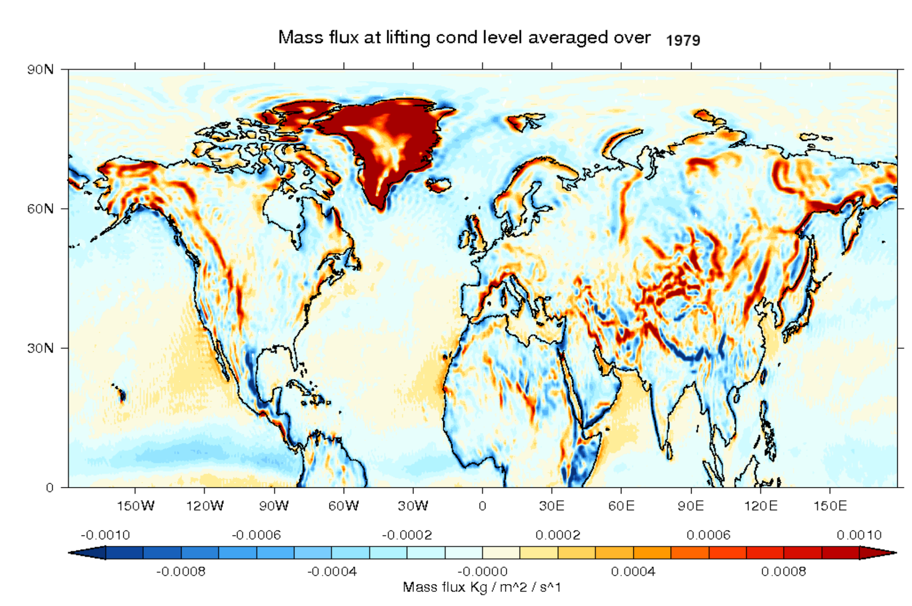

Fig 13 The mean mass flux through the lifting condensation level for 1979.

Fig 13 shows the mass flux through the lifting condensation level, averaged out over 1979. If we can compute the mass flux through the boundary layer top then we can start investigating the overall effect of transporting material out of the boundary layer.

Acknowledgements

- Jeffrey Chagnon for pointing me towards a suitable case study.
- Lois Steenman – Clark for help with my UM simulations
- Helen Dacre for helping me to set up the NAME simulations.
- All the IT staff at Reading without whom this work would have proved impossible.