Towards understanding the role of the boundary layer in cyclones: Beyond Ekman Spindown

R. Plant and S. Belcher

Department of Meteorology,
University of Reading, UK

EGS-AGU-EUG Joint Assembly
8th April, 2003

Introduction

- Boundary layer processes can be crucial during cyclone development.

- NWP simulations without a boundary layer scheme produce much stronger systems with major structural differences.

- However, the physical mechanisms involved are not well understood.

- There are more processes acting than spindown from Ekman pumping…

A Local Budget of PV

- Measures the effect on the large-scale dynamics of each physical process parameterized in an NWP model.
- The budget is...

$$P(\underline{r},t) = P_0(\underline{r},t) + \sum_i P_i(\underline{r},t)$$

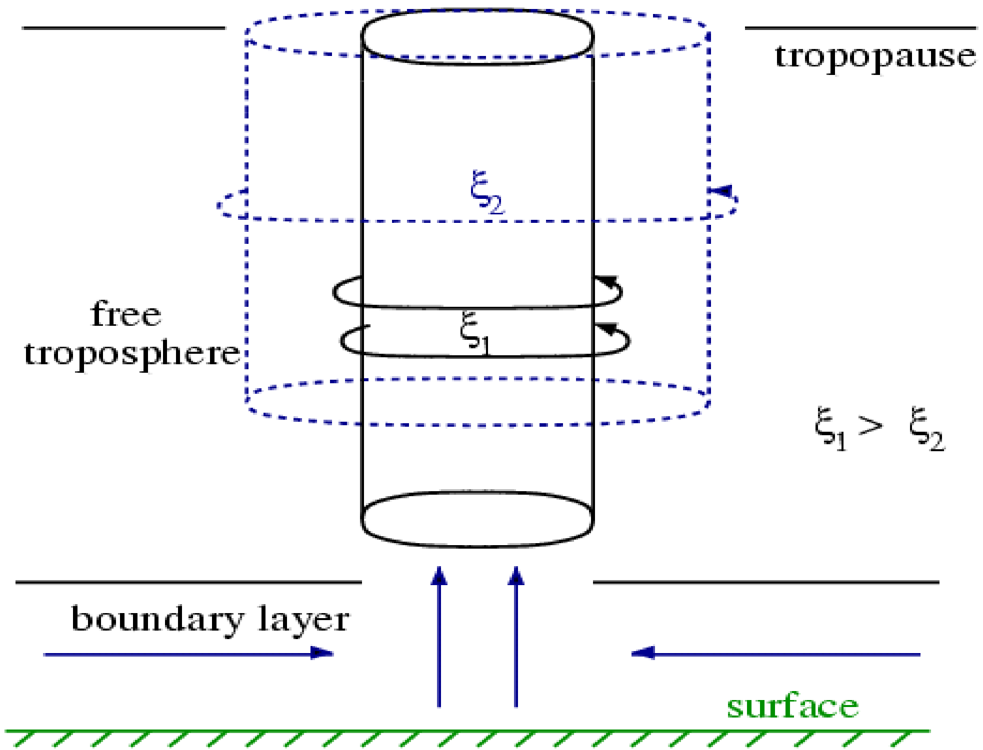
- where:
  - P_0 is the advected form of the initial PV field;
  - P_i is that part of the current PV field due to the action of each parameterized "physics" process i.

- Local PV budget also used by Stoelinga (1996).

Barotropic Friction

- Consider the barotropic frictional term $\sim \left(\nabla \times \underline{F}\right)_z \partial\theta / \partial z$
- Averaging this over the depth of the boundary layer,

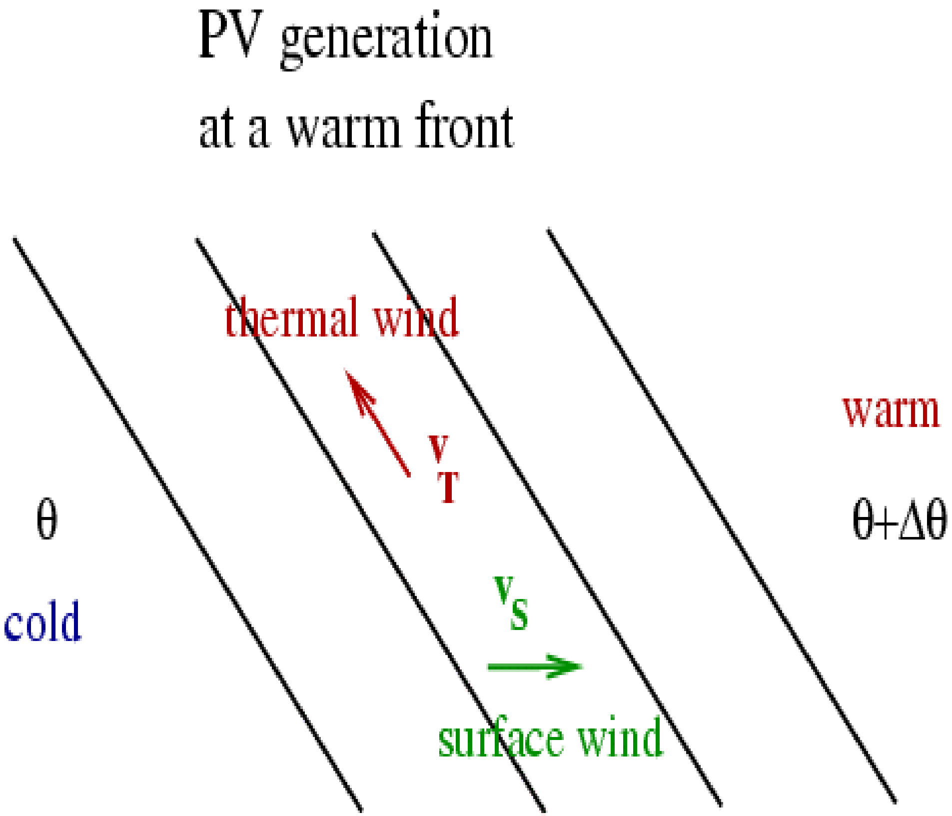
$$\overline{\frac{DP}{Dt}} \approx \frac{-f w_{Ekman}}{\rho h^2}\left[\theta(h) - \theta(0)\right]$$



Convergence over low $\Rightarrow$ uplift $\Rightarrow$ vortex tube squashing $\Rightarrow$ spindown of cyclone

Baroclinic Effects?

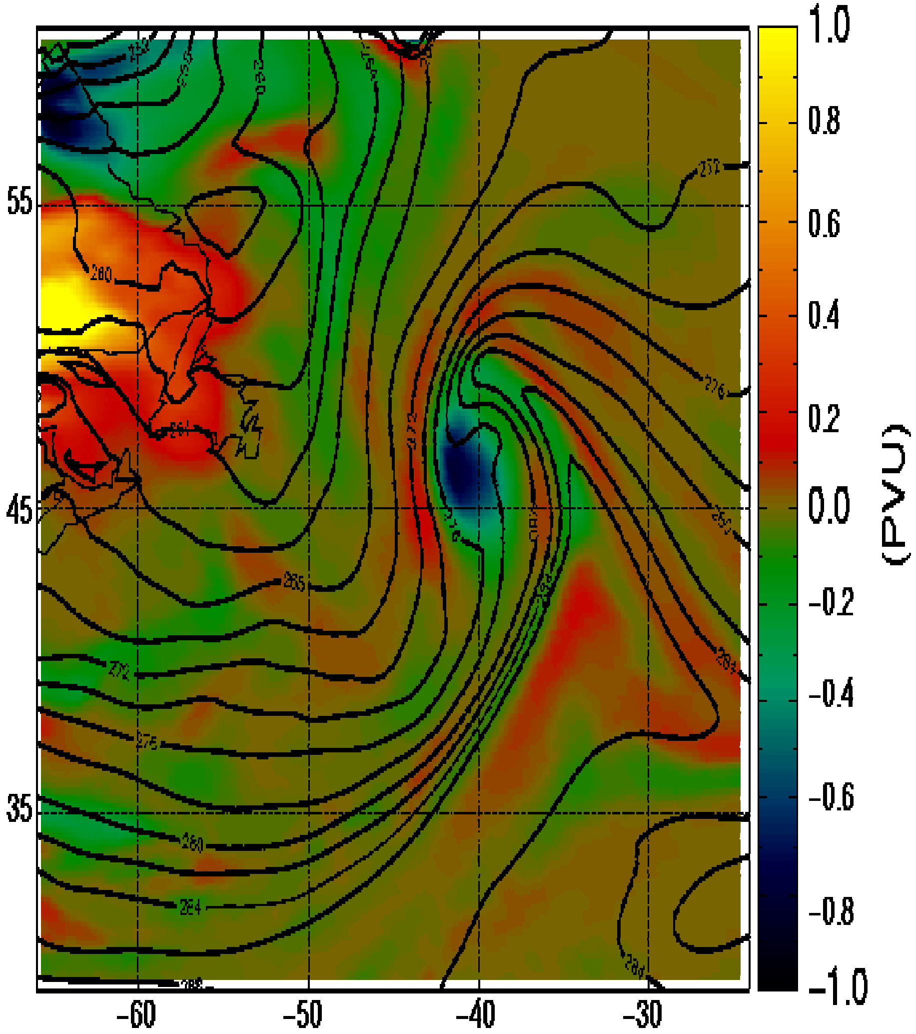
Averaging the baroclinic term $\sim (\underline{\nabla} \times \underline{F})_H \cdot \underline{\nabla}_H \theta$



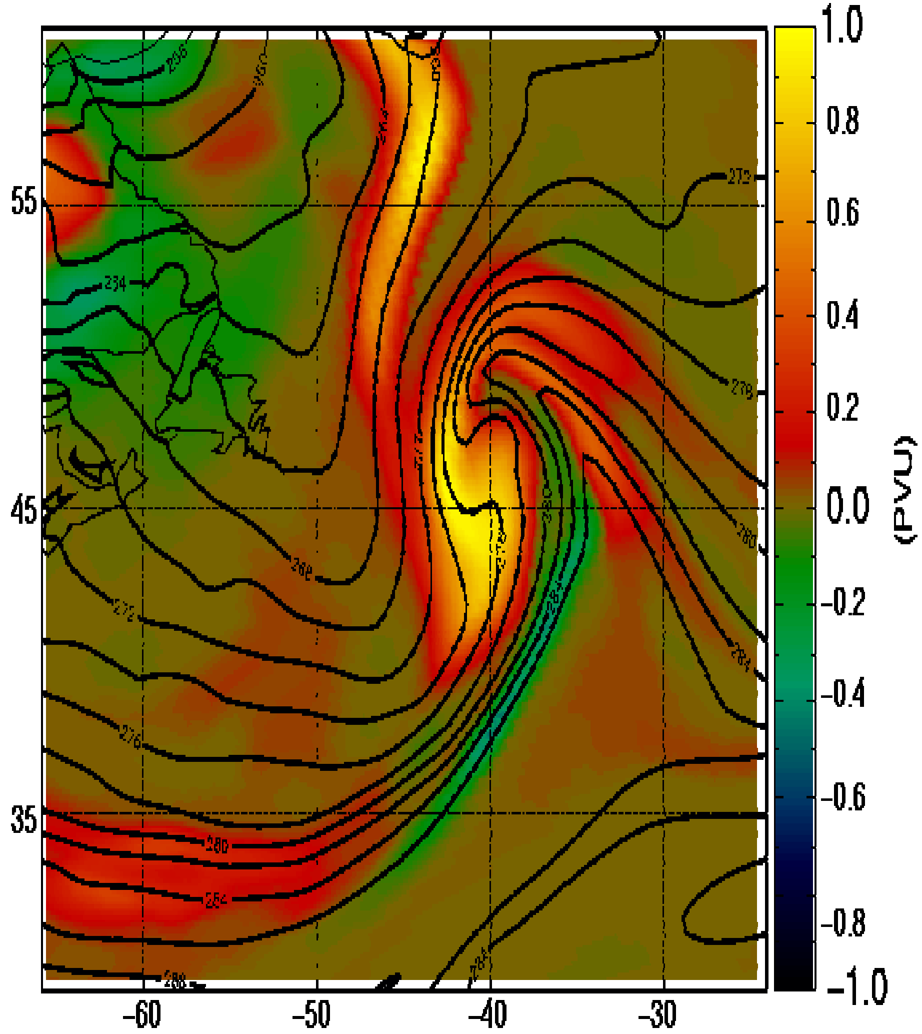
$$\overline{\frac{DP}{Dt}} \approx \frac{-f\overline{\theta}}{\rho g h^3} \underline{\tau}_S \cdot \underline{v}_T$$

PV generation if surface wind has component opposite to the thermal wind.

Frictional PV in FASTEX IOP15 Intensification

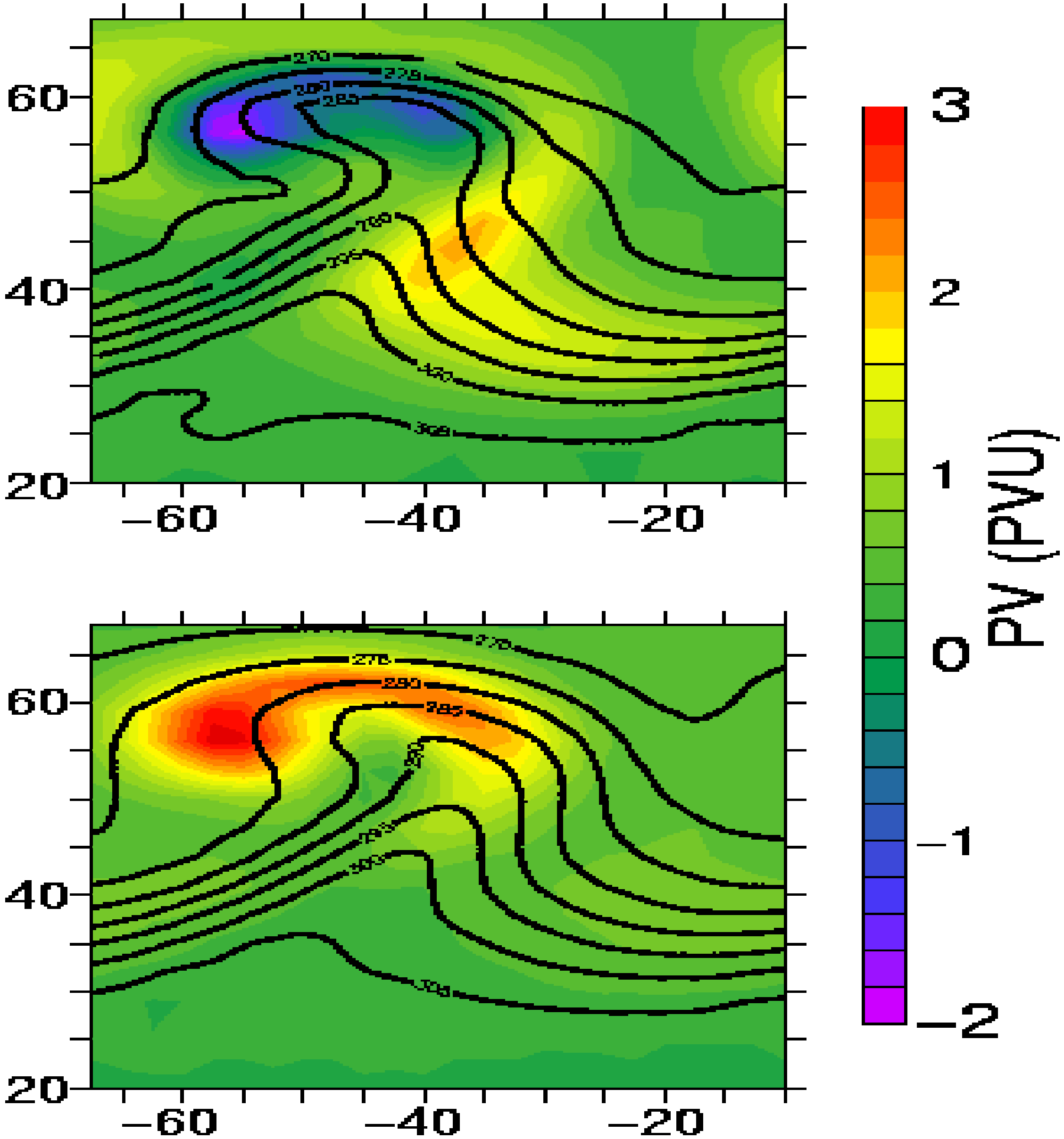


Barotropic frictional PV on 900mb, at T+24.



Baroclinic frictional PV on 850mb, at T+24.

Also Seen in Baroclinic Waves

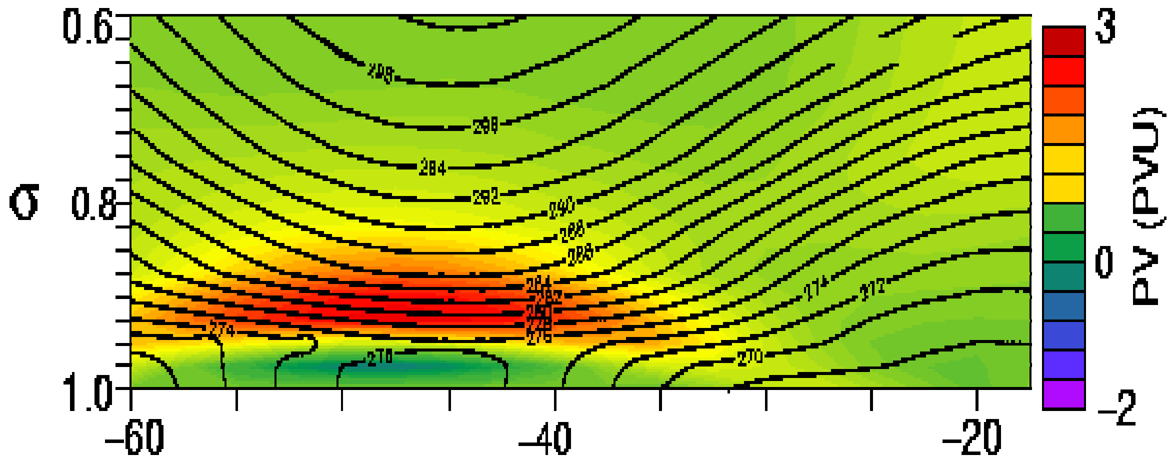


PV close to surface, σ=0.98, day 6.

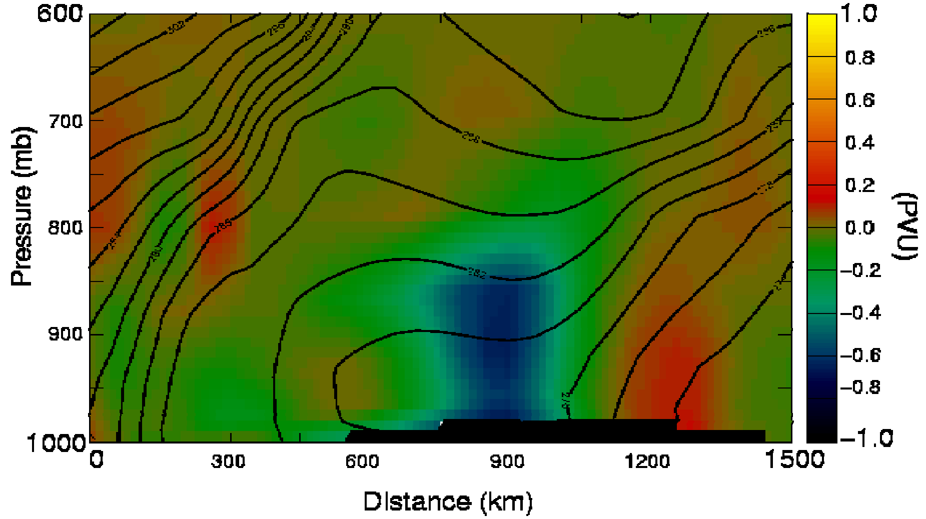
Adamson et al (2002): lifecycle simulation of frictionally-damped, dry baroclinic wave.

PV near top of boundary layer, σ=0.92, day 6.

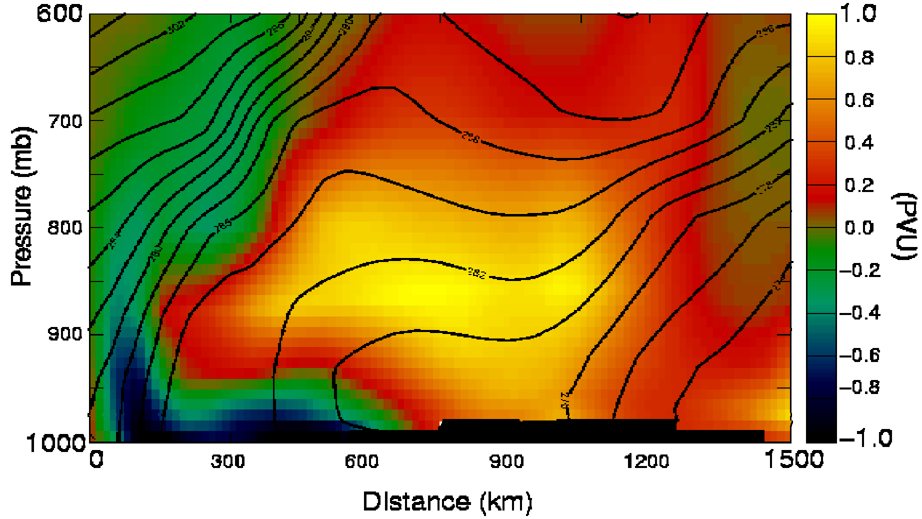
Does this Strengthen the Cyclone?



X-section through baroclinic wave.



X-section of barotropic PV in IOP15, T+24.

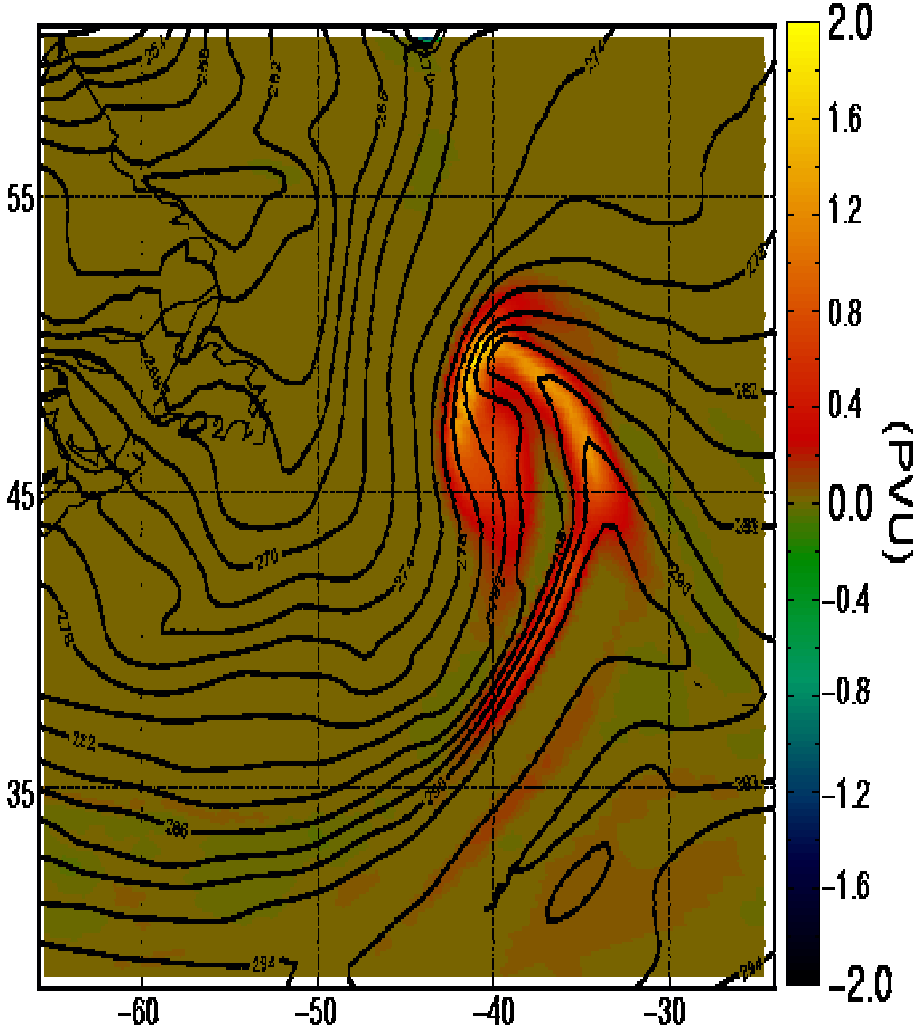


X-section of baroclinic PV in IOP15, T+24.

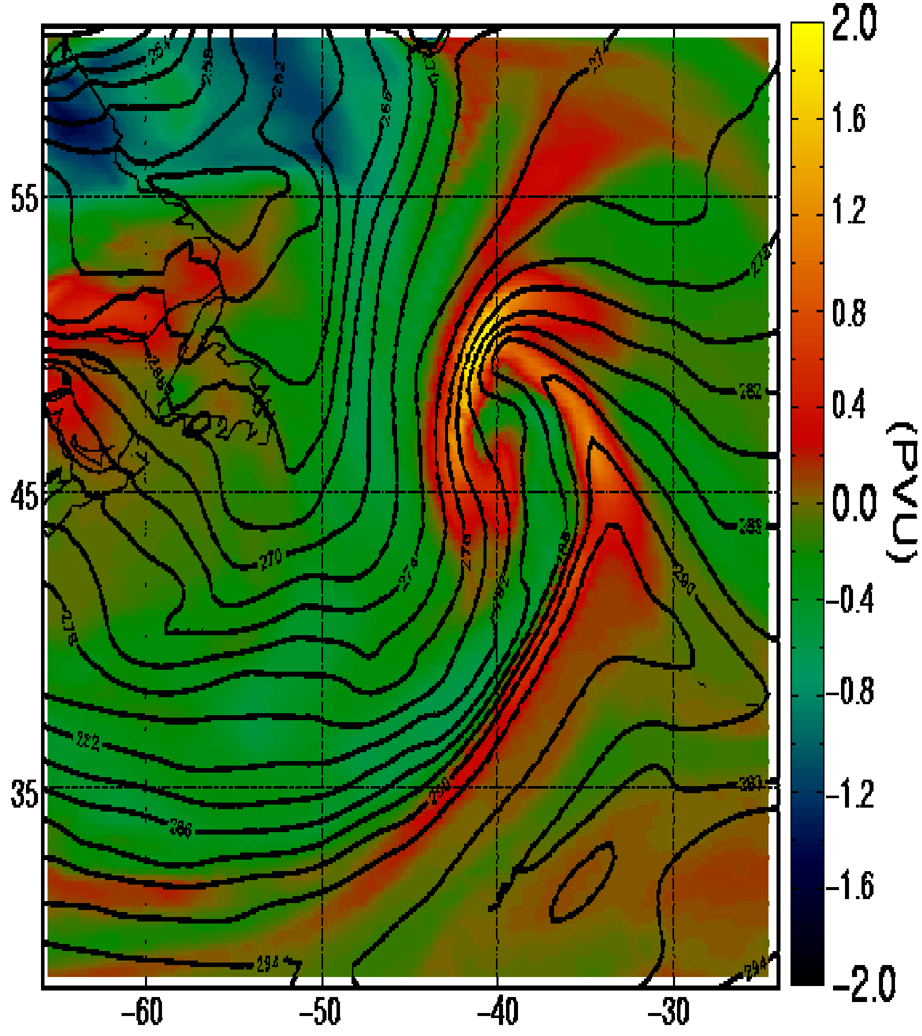
Diabatic Heating Mechanisms

- Latent heating during motion attributable to the large-scale (resolved grid-scale) dynamics.
- Explicit microphysical scheme.
- Convection.
- Heat fluxes in the boundary layer.
- Latent heating forced by boundary layer mixing.
- Radiation.

LH due to Resolved Scale Dynamics



PV due to LH from dynamics on 900mb, T+24.



PV due to all model physics on 900mb, T+24.

Other Diabatic Processes

- From the microphysical scheme, evaporative cooling occurs in descending air in the cold conveyor belt.
- Results in +ve PV at the top of the boundary layer.

- Contribution from convection highly case dependent.
- May contribute strongly to +ve mid-level anomalies.

- Positive surface fluxes destroy PV in warm sector.
- Comparable strength to the Ekman pumping.

- LW and SW radiation contribute weakly in general.
- Can sometimes see LW cooling at top of deep convective clouds.

Conclusions

- A local PV budget provides a way to disentangle and to compare effects of model physics.

- Ekman pumping is a barotropic, frictional process which destroys PV over a low.

- Baroclinic frictional processes generates PV at warm front which is transported over low.

- Diabatic PV generation typically 2 or 3 times larger than frictional generation.

- Latent heating due to the resolved-scale dynamics is the main diabatic effect in most cyclones.

A Shameless Advertisement

You can find more details of this work at…

www.met.rdg.ac.uk/~sws00rsp/blpv.html