Friction in Mid-latitude Cyclones

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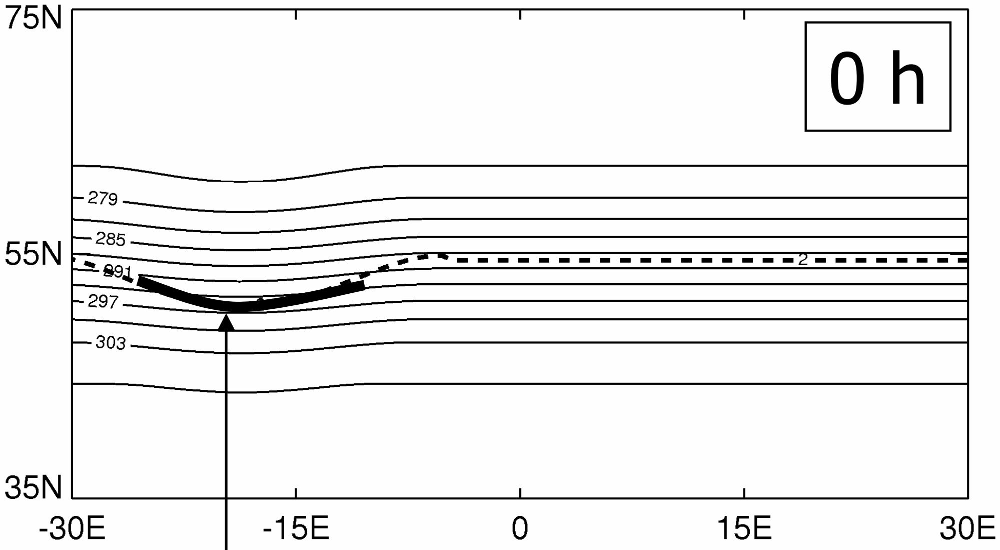
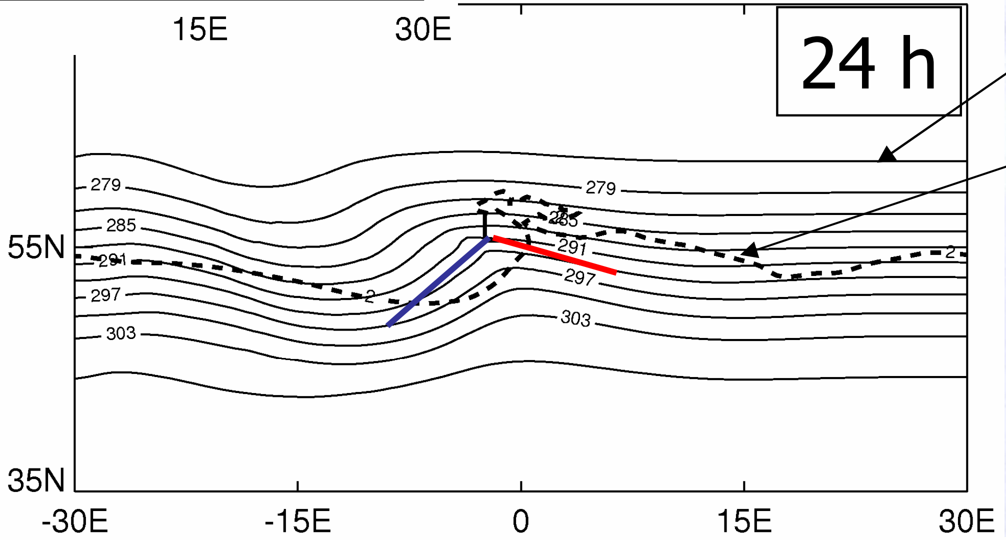
Motivation

- Many studies have shown the significance of friction in formation and dissipation of cyclones
- Up to 50% reduced growth rate
- Met Office Unified Model still has trouble with cyclone depth
- Underlying physical mechanism not well understood

Model Setup

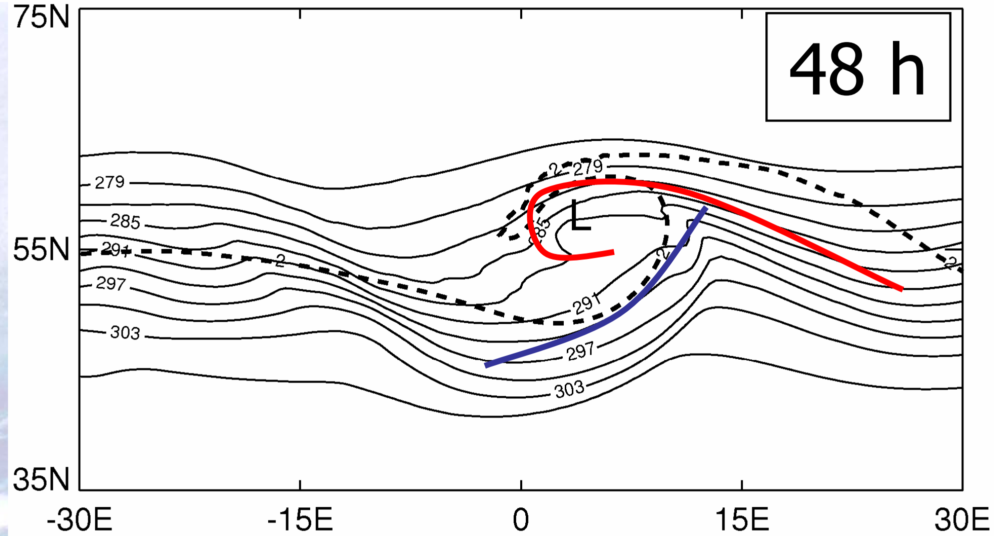


Upper Level Trough



Near-surface Temperature

Tropopause



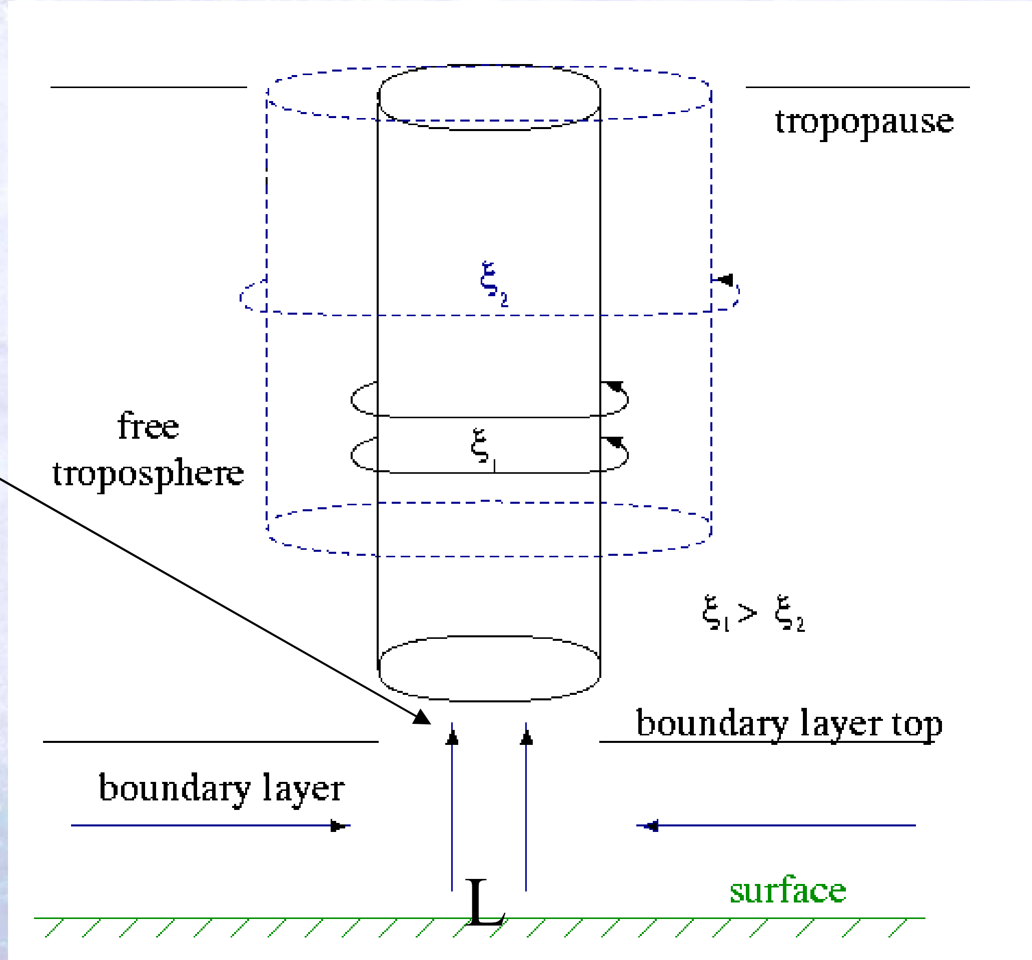
Idealised, dry setup – only dynamics and boundary layer scheme operating

Ekman Pumping

- Boundary layer forces convergence
- Continuity forces ascent:

$$\boxed{w_e = \frac{1}{f_0}\mathbf{k}.\nabla \times \boldsymbol{\tau}_{\mathbf{s}}}$$

- Ascent squashes vortex, reducing vorticity
- What about temperature?



Potential Vorticity

$$\mathrm{PV} = \frac{1}{\rho}\boldsymbol{\zeta}.\nabla\theta$$

$$\frac{D}{Dt}(\mathrm{PV}) = \frac{1}{\rho}\left(\boldsymbol{\zeta}.\nabla\left(\frac{D\theta}{Dt}\right) + (\nabla\times\mathbf{F}).\nabla\theta\right)$$

Diabatic Term:
- Surface heat fluxes
- Latent heat fluxes

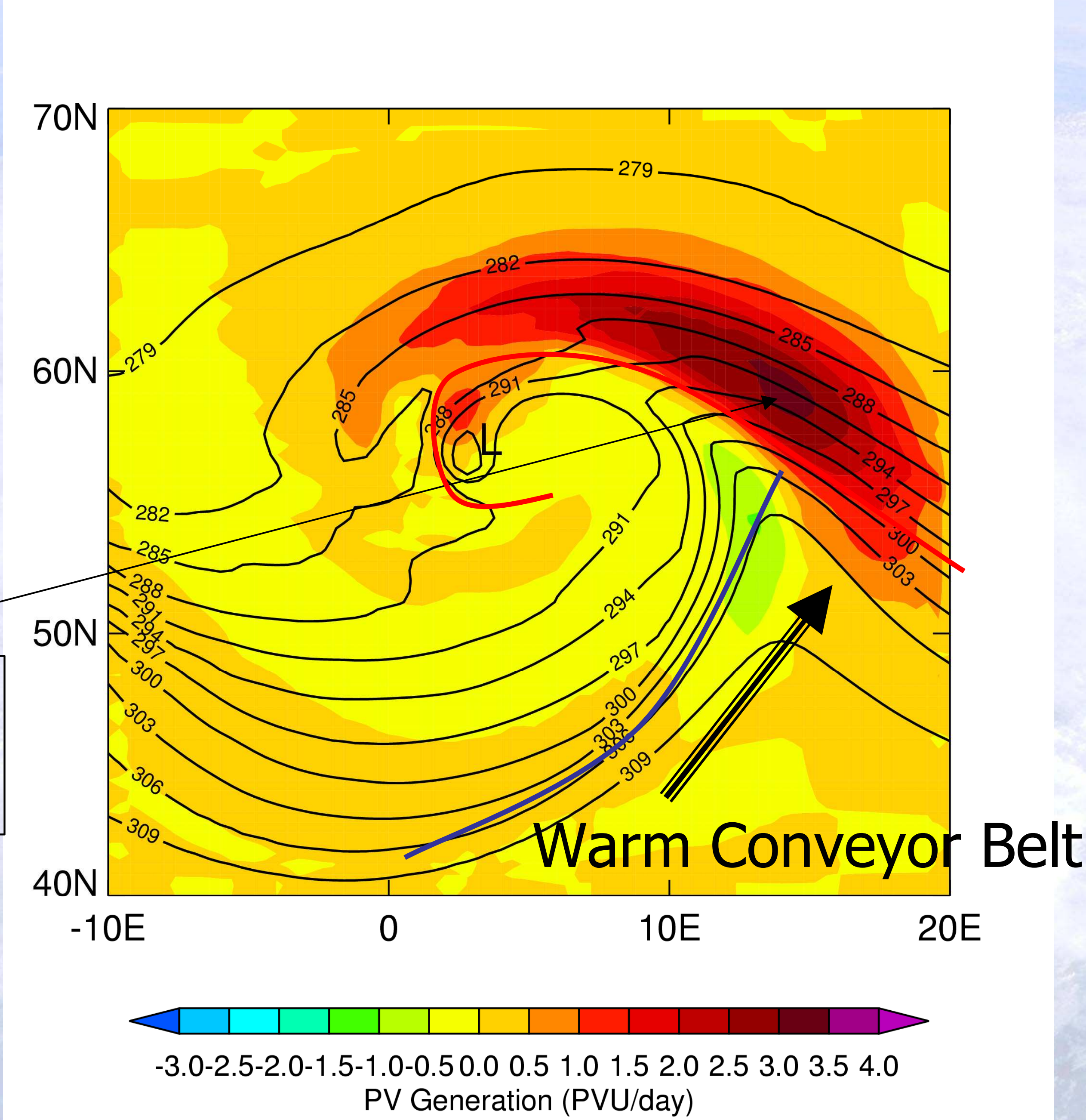
Frictional Term:
- Ekman pumping
- Baroclinic mechanism

Baroclinic Mechanism

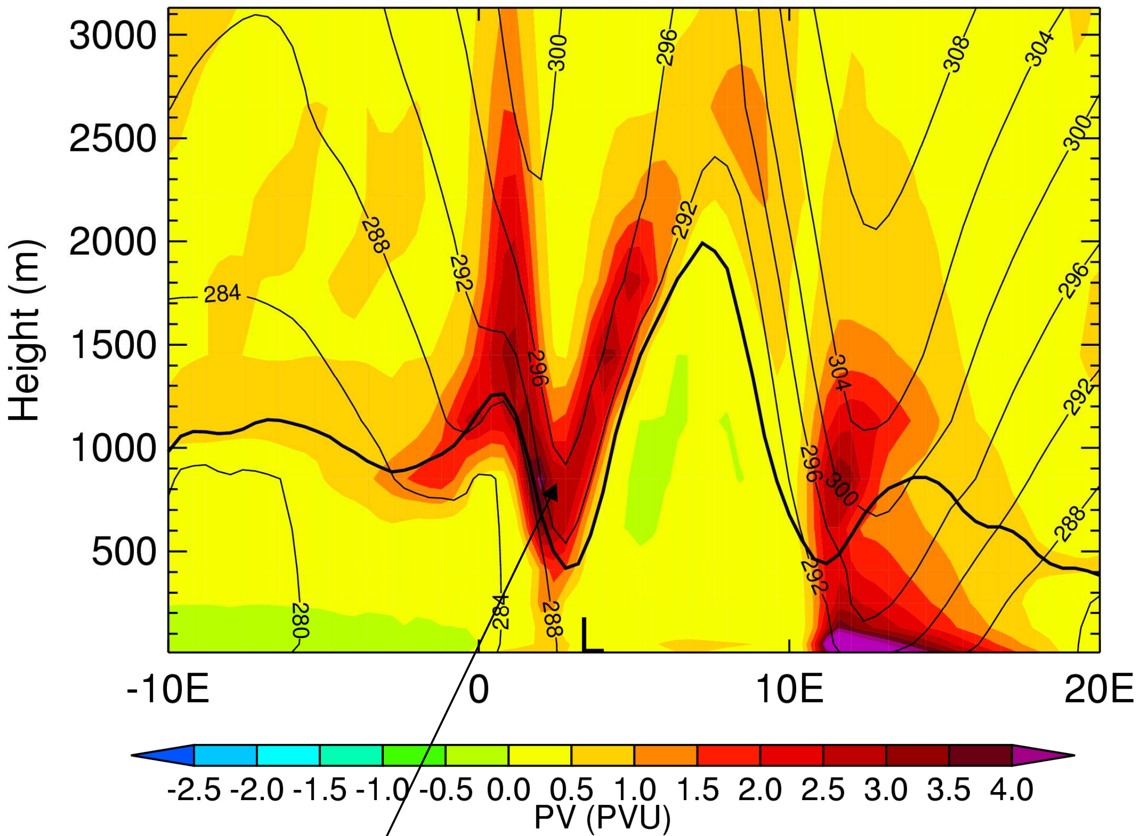
Depth averaged PV generation in boundary layer:

$$\boxed{[G_B] = \frac{1}{\rho^2 h^2}\mathbf{k}\times\boldsymbol{\tau}_\mathbf{s}.(\nabla_H\theta)_h}$$

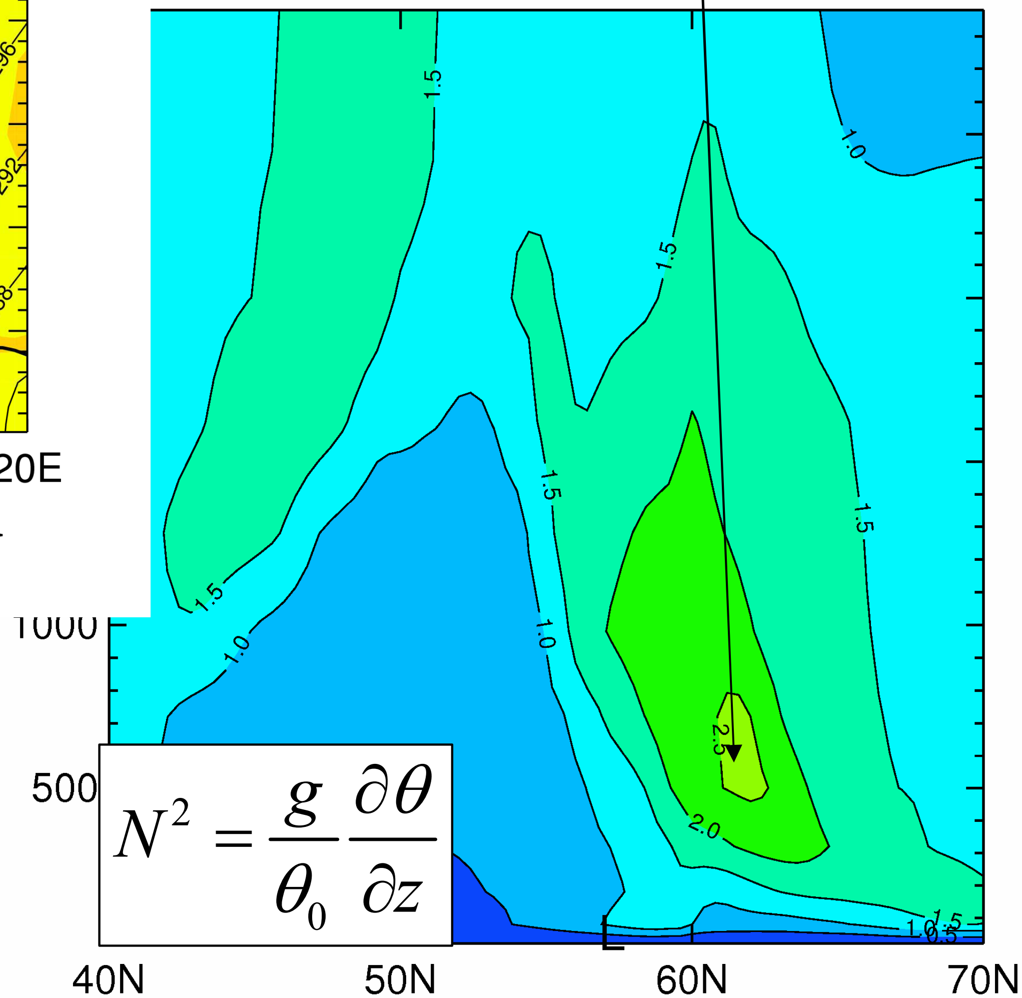
Depends on alignment of surface and thermal winds



Baroclinic Mechanism 2



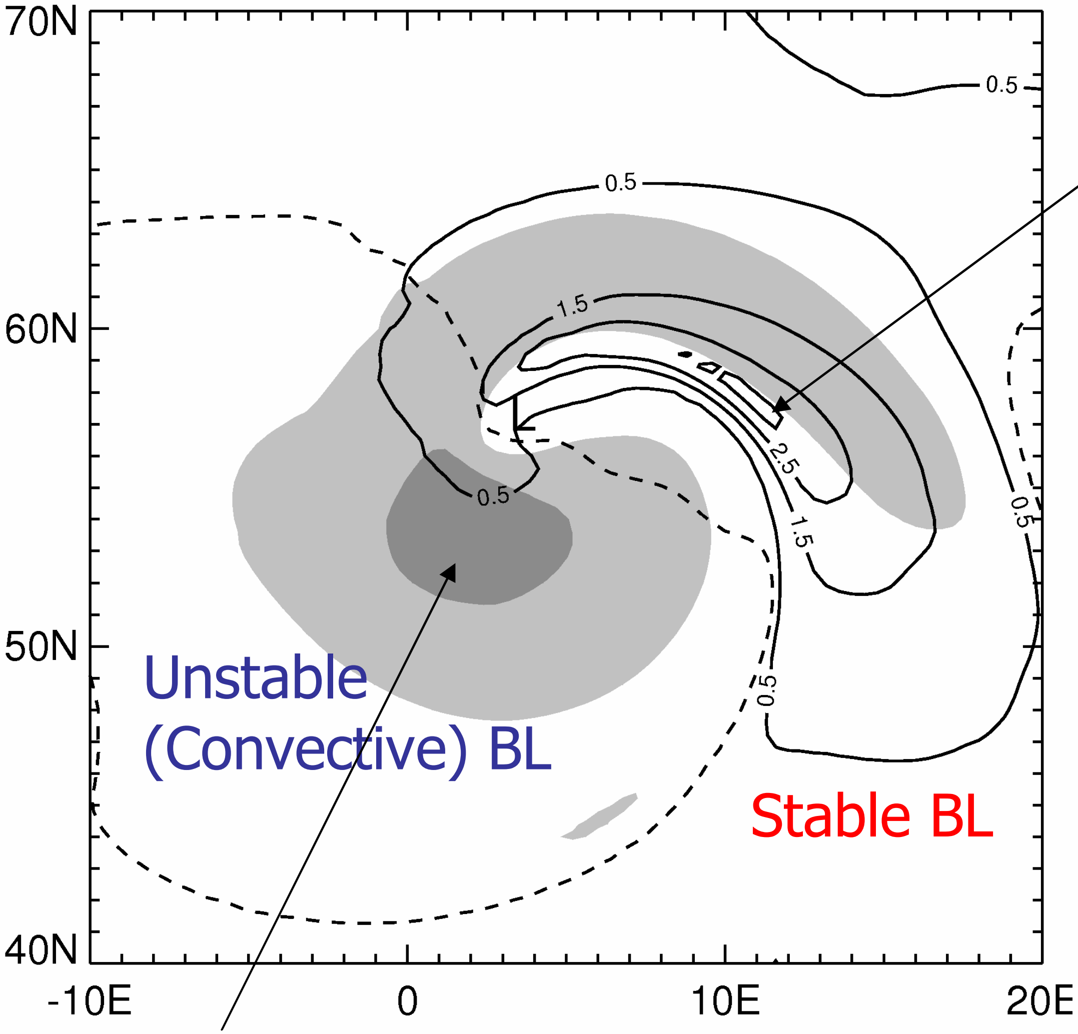
Mainly Static Stability Anomaly



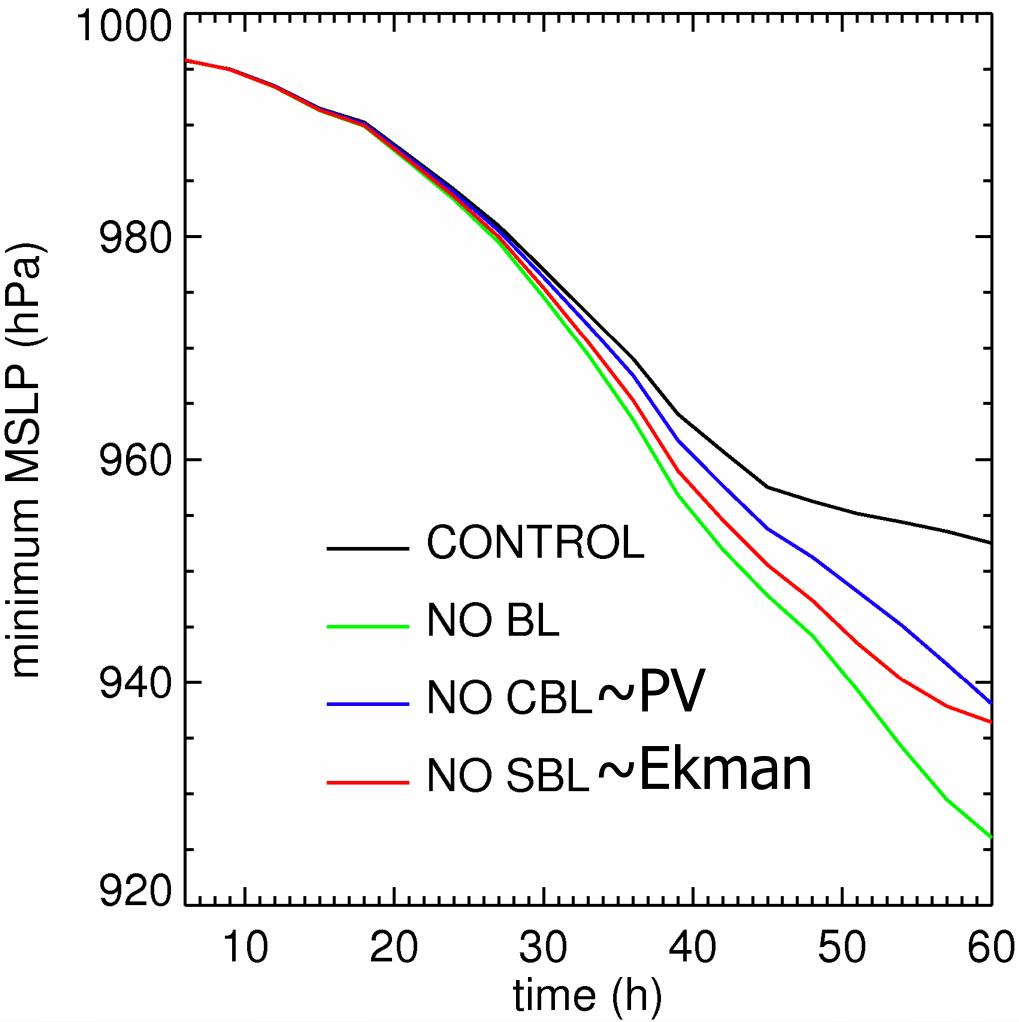
$$N^2 = \frac{g}{\theta_0}\frac{\partial \theta}{\partial z}$$

PV accumulates above Low centre

Boundary Layer Stability



PV mainly
in SBL



~PV

~Ekman

Surface
stress
mainly
In CBL

Summary

- Boundary layer friction has a large affect on cyclone development
- Ekman pumping is significant, but not the only process acting
- PV perspective provides another mechanism, which appears similarly important

Switching off BL

- Surface stress parameterised in terms of "eddy diffusivities"

$$\tau_{xz} = \rho K_m \frac{\partial u}{\partial z}$$

- Define SBL by $\theta(\text{level 1}) > \theta(\text{surface})$

- Set $K_m = 0$ here