Boundary Layer Processes in Midlatitude Cyclones

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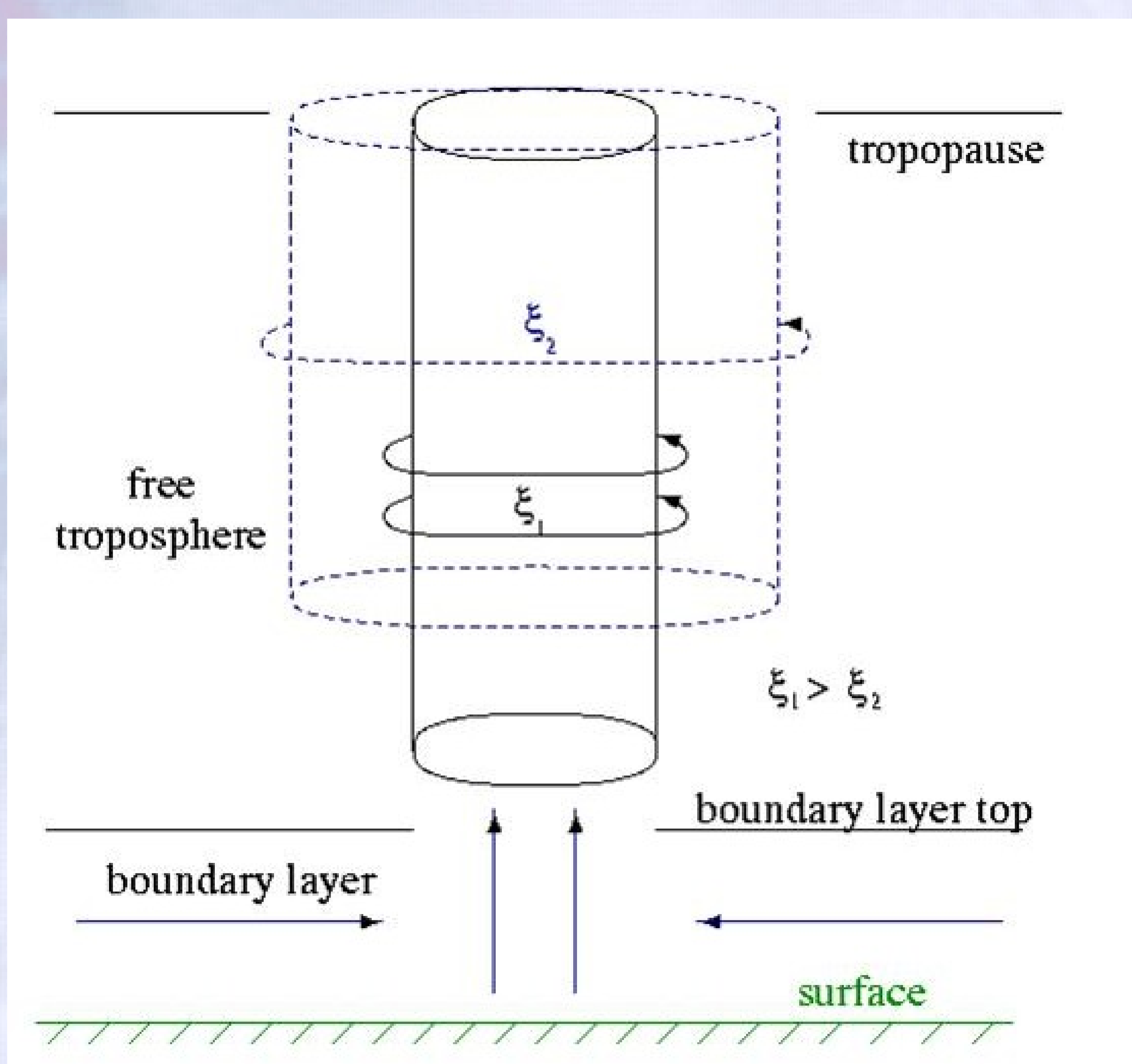
Introduction

My research focuses on the mechanisms through which boundary layer dynamics and physics provide control on the development of synoptic systems. To do this, I am simulating idealised cyclones within the Met Office Unified Model, systematically varying the surface temperature, roughness and boundary layer moisture, to develop a theoretical framework for understanding how boundary layer physics changes conceptual models of cyclone evolution.

Ekman Pumping

- Friction forces convergence of low level winds
- Continuity implies ascent above low centre

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



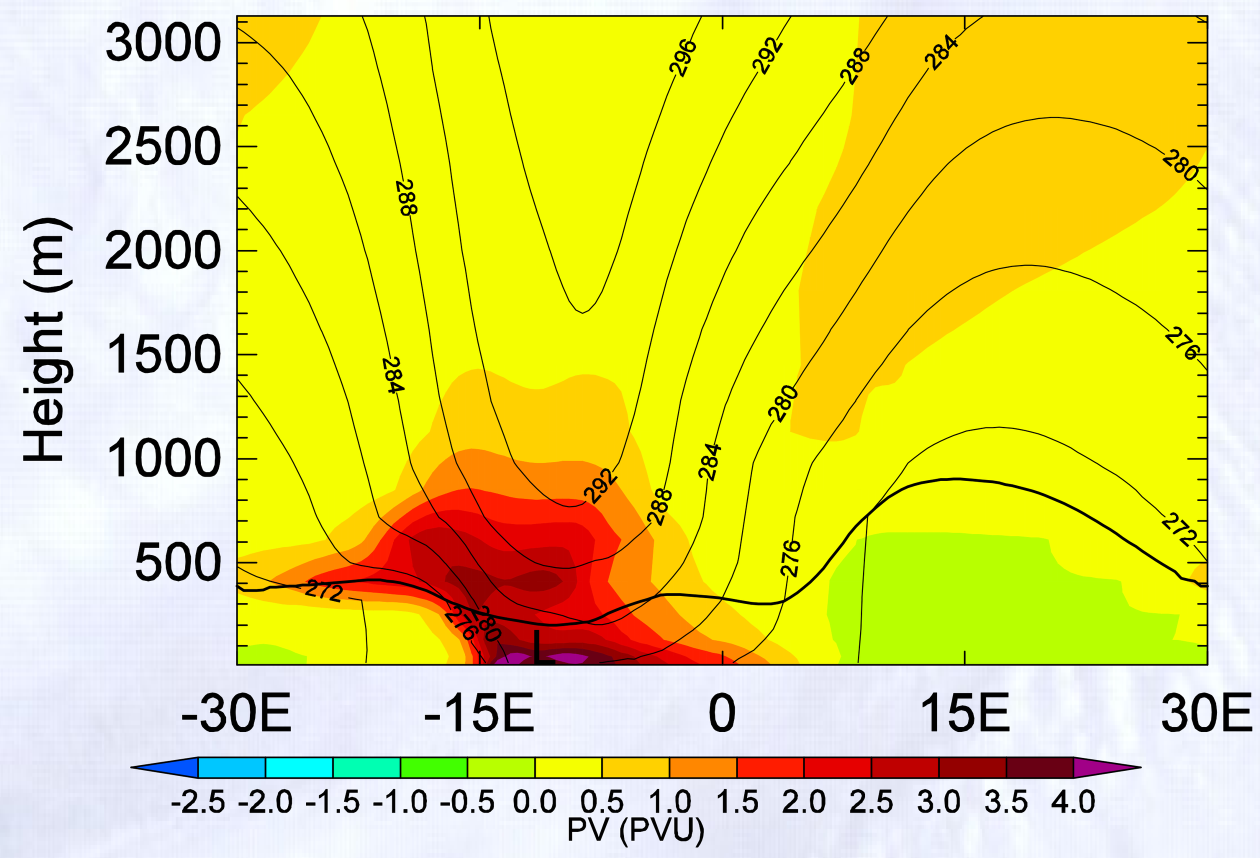
- Ascent reduces vorticity by vortex squashing in the interior
- Barotropic mechanism, what about temperature gradients and fronts?

Potential Vorticity

Within the free troposphere, PV is conserved by frictionless, adiabatic motion. However, friction and diabatic processes in the boundary layer can create or destroy PV.

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

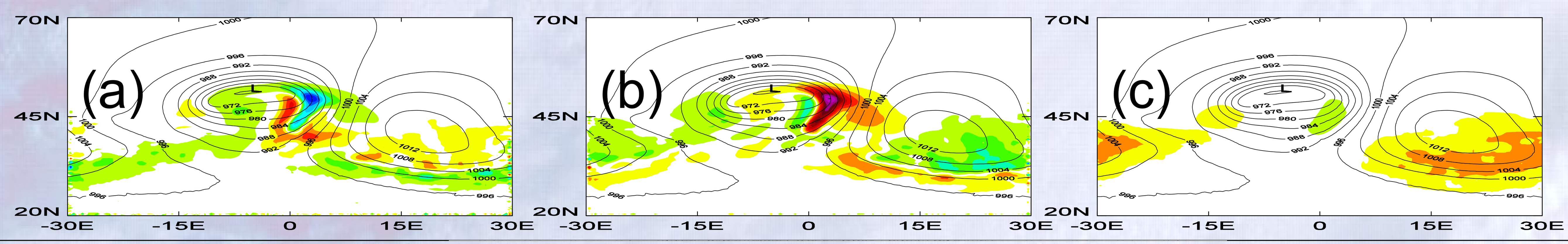
PV is generated in the warm-conveyor belt region, before being transported and vented from the boundary layer. It accumulates as a positive PV anomaly above the low centre, confined in the vertical but spread in the horizontal.



This shape is associated mainly with a PV anomaly of increased static stability. The increased static stability reduces coupling between the upper level trough and surface temperature anomaly, making their mutual reinforcement weaker.

Moisture Budget

To consider the complex airflows within a cyclone boundary layer, a depth integrated moisture budget has been derived. This simplifies a 3-D problem into a 2-D one, describing the source, transport and ventilation of moisture within the boundary layer. The budget demonstrates the source of warm-conveyor belt rain within the boundary layer.



$$\frac{\partial \widehat{\rho q}}{\partial t} = (\rho q)_h \frac{\partial h}{\partial t} \underbrace{- (\rho q)_h \, \mathbf{u}.\mathbf{n}}_{a} \underbrace{- D_q}_{b} \underbrace{+ (\rho \overline{w'q'})_0 - (\widehat{\rho \overline{w'q'}})_h}_{c}$$

Future Direction

To investigate the role of the low level moisture distribution during cyclogenesis, considering the timescales over which initial conditions and model physics are important.