Friction in mid-latitude cyclones: More than Ekman pumping!

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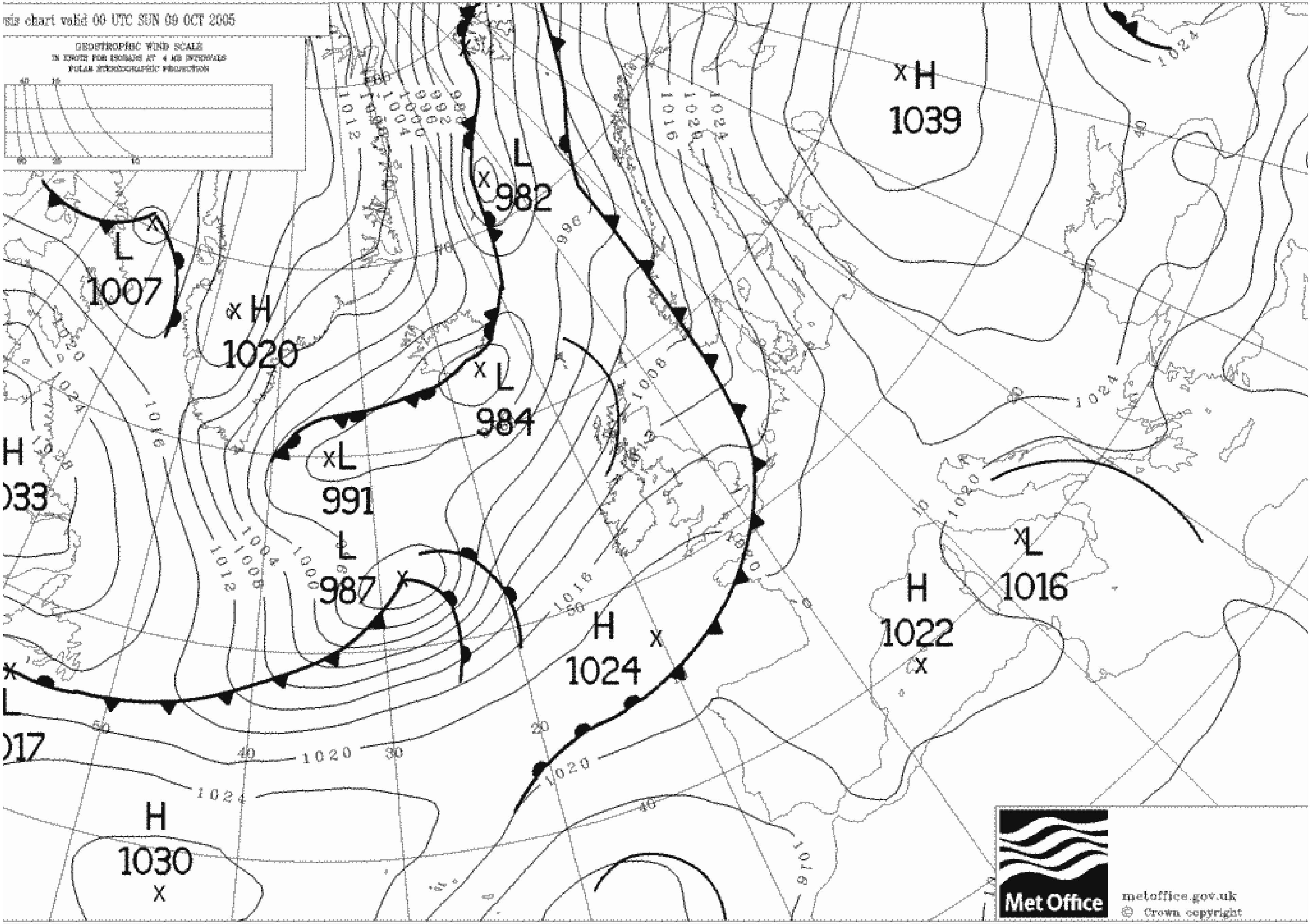
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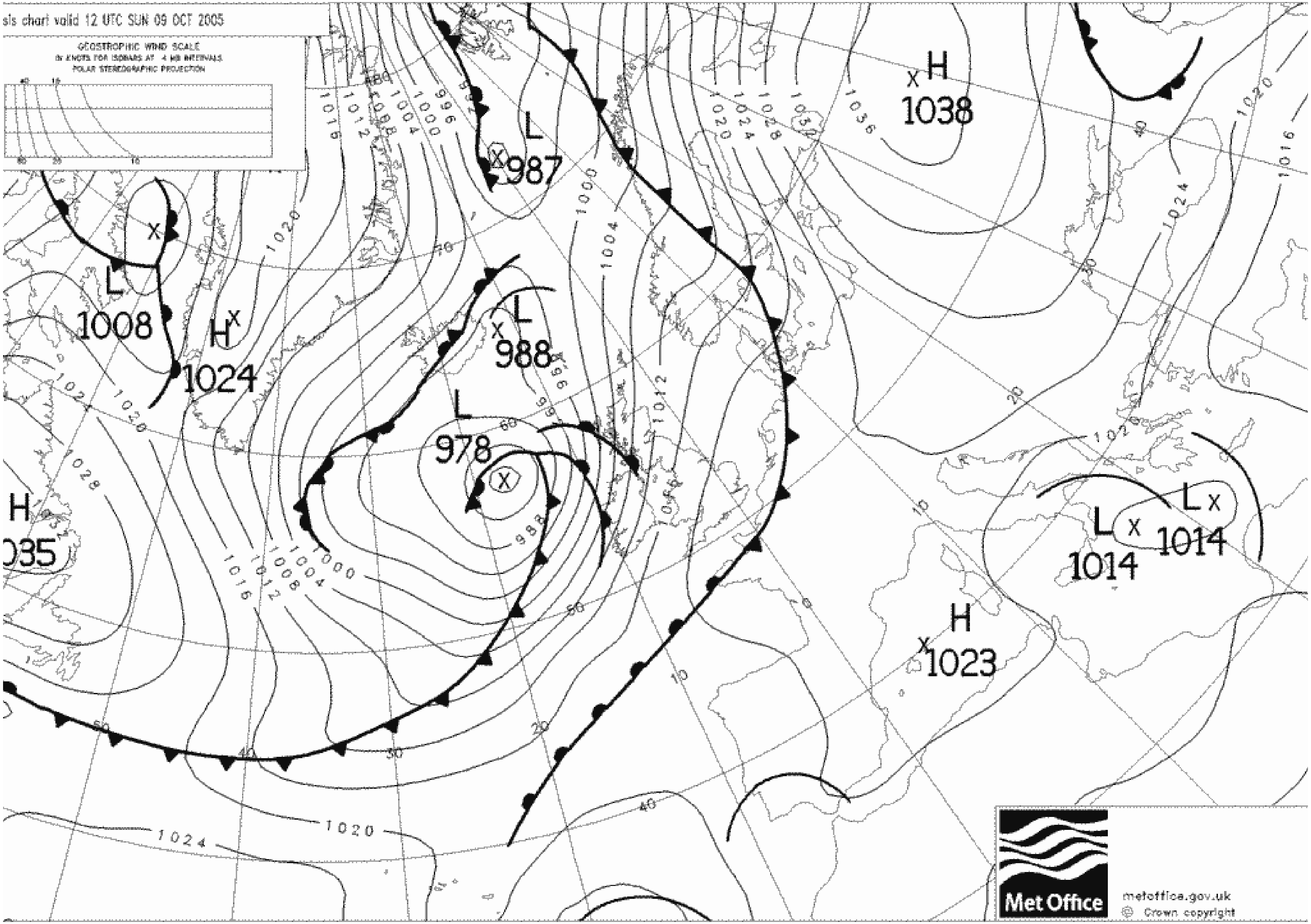
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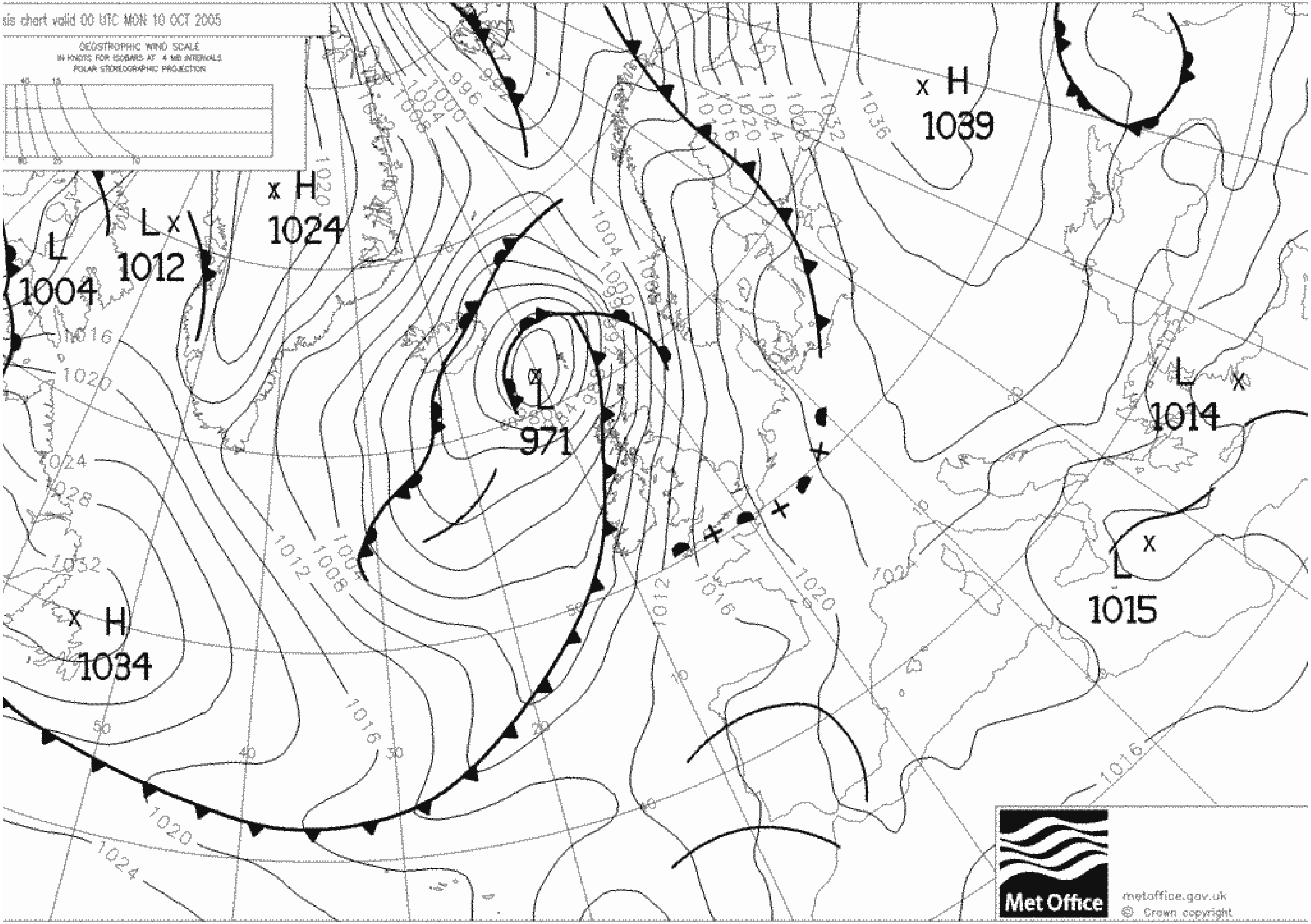
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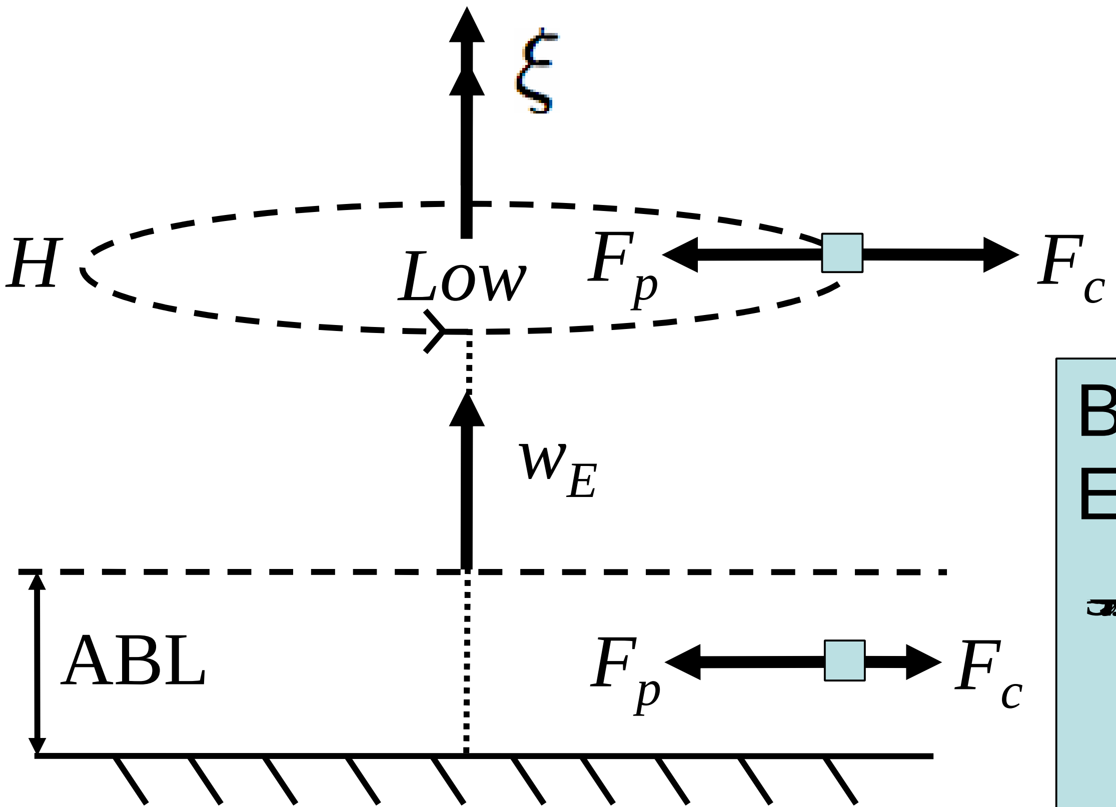
Motivation

- Increased surface roughness has improved skill in NWP forecasts:
  - Orographic roughness (Milton & Wilson 1996)
  - Ocean surface waves (Doyle 1995)
  - Stable flow around hills (Lott & Millar 1997)
- What is the mechanism?

Effect of friction on cyclones

- Baroclinic waves
  - Growth rate reduced by 50% (Valdes & Hoskins 1988)
  - Reduced eddy kinetic energy (Jones 1992)
- NWP forecasts
  - Improved surface winds and minimum pressure (Doyle 1995)
- But what is the mechanism?

Ekman pumping



Barotropic Vorticity Equation:

But mid-latitude cyclones are baroclinic!

Potential Vorticity

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

- Natural generalisation of vorticity:
  - Function of vorticity and temperature gradient
- PV useful because:
  - Conserved under adiabatic, inviscid flow
  - With balance condition, PV can be inverted
  - And so instantaneous PV

    $\rightarrow$ instantaneous dynamics

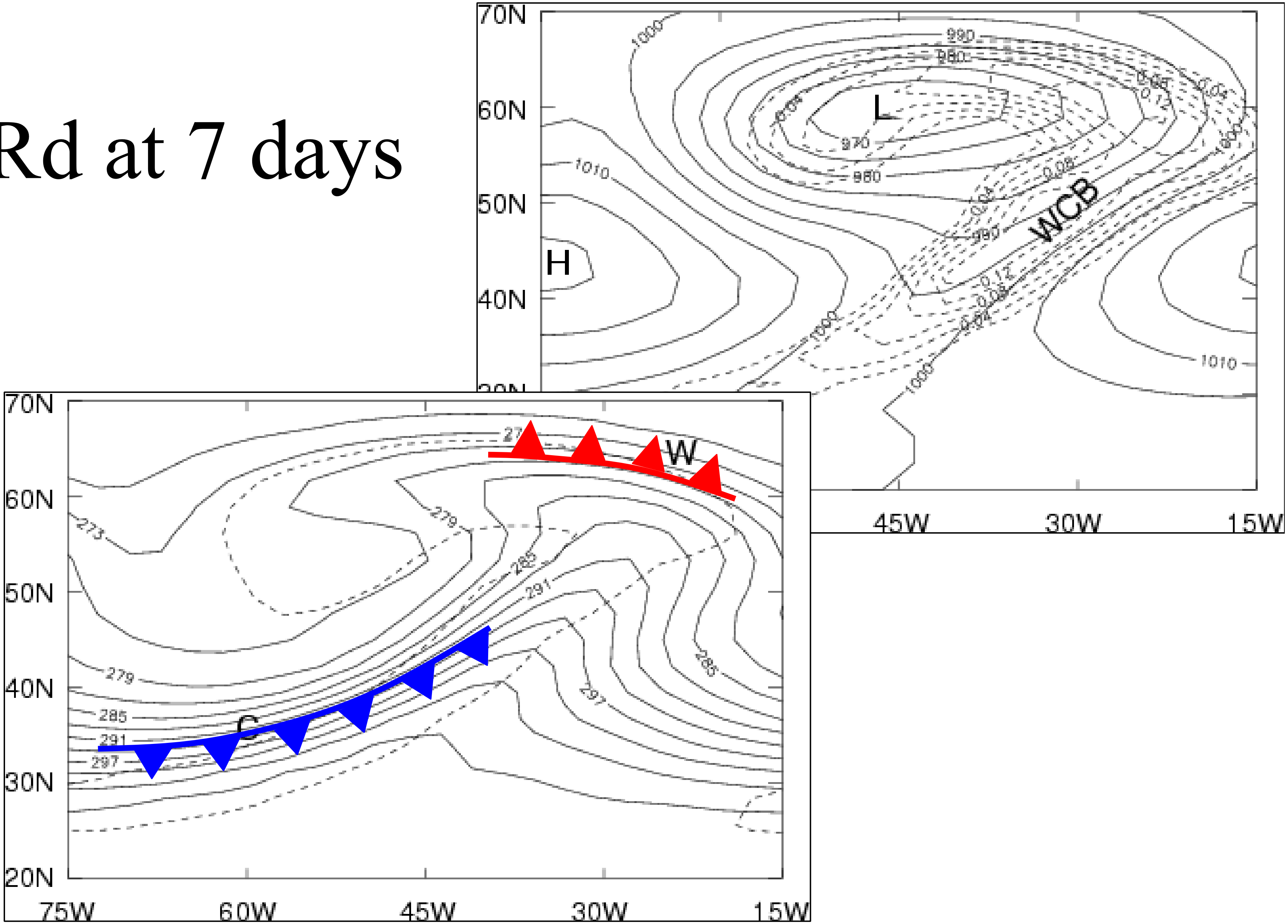
Outline of talk

- PV view of baroclinic wave as model of mid-latitude cyclone
- PV with boundary layer friction
- Mechanisms for boundary layer generation of PV
- Mechanism for reduced baroclinic growth
- A case study
- Conclusions

Baroclinic lifecycle

- Numerical simulations: Reading IGCM
- LC1 of Thorncroft et al:
  - Meridional temperature gradient
  - Perturb with wavenumber 6 linear mode
- Role of boundary layer friction:
  - R0: Inviscid, adiabatic simulation
  - Rd: Boundary layer representation

Rd at 7 days



70N
60N
50N
40N
30N
20N
75W
60W
45W
30W
15W
L
H
WCB
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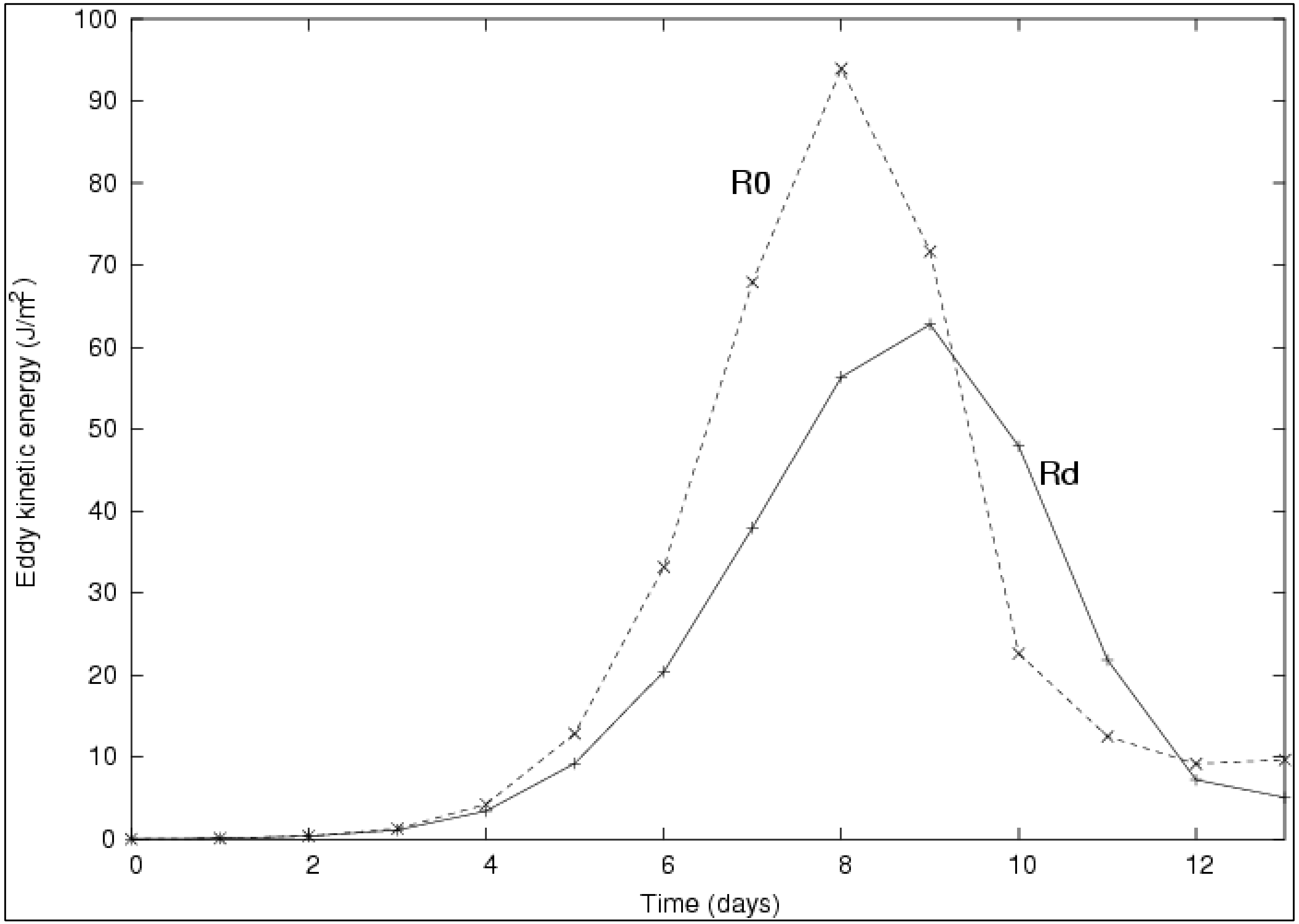
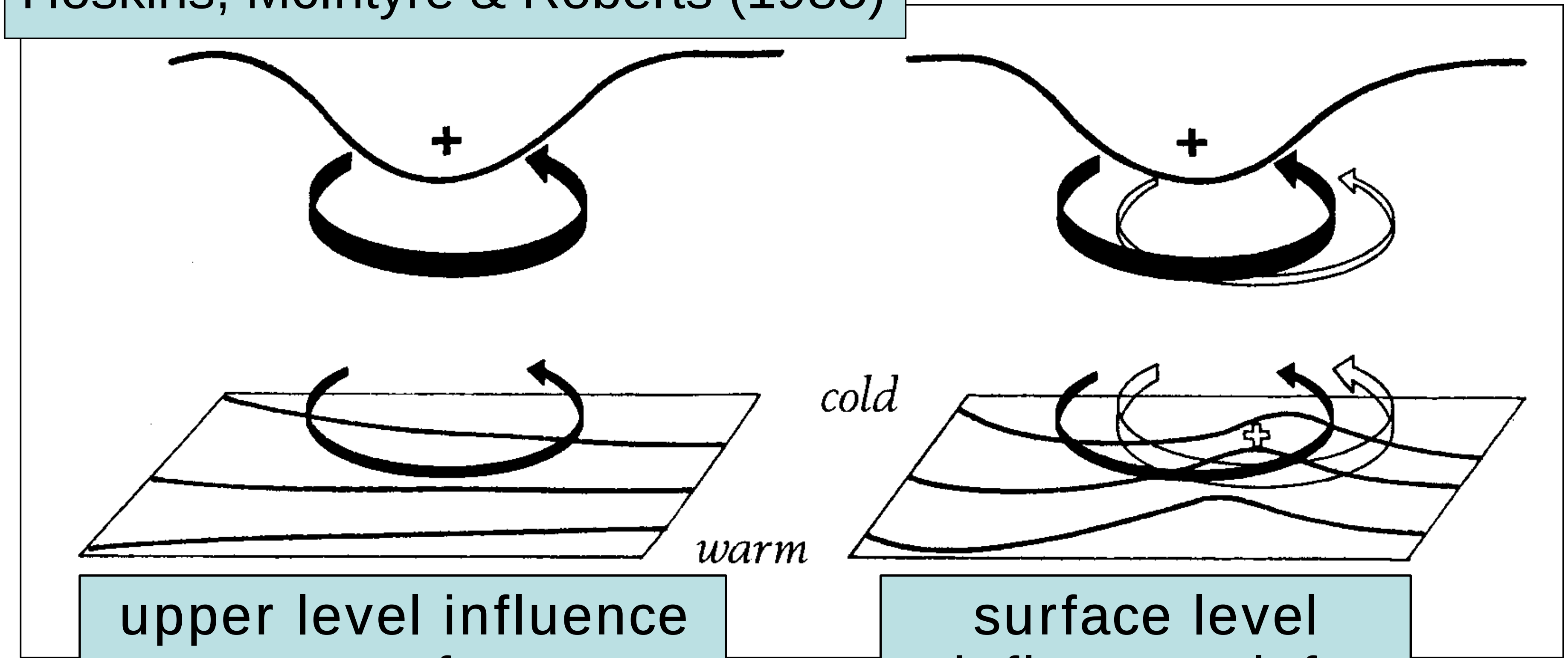
970
960
1000
1010
279
285
291
297
273

Bulk effect of friction



PV view of baroclinic instability

Hoskins, McIntyre & Roberts (1985)



upper level influence on surface

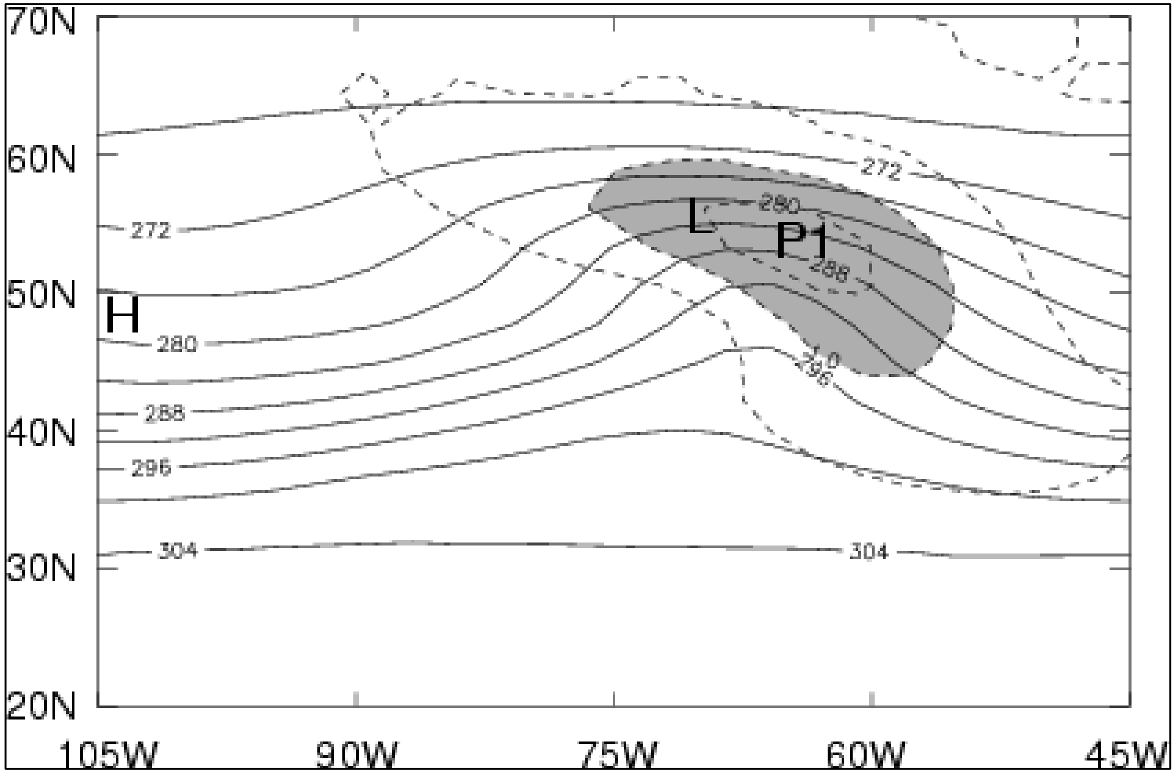
surface level influence aloft

How does friction change this picture?

PV with boundary layer friction

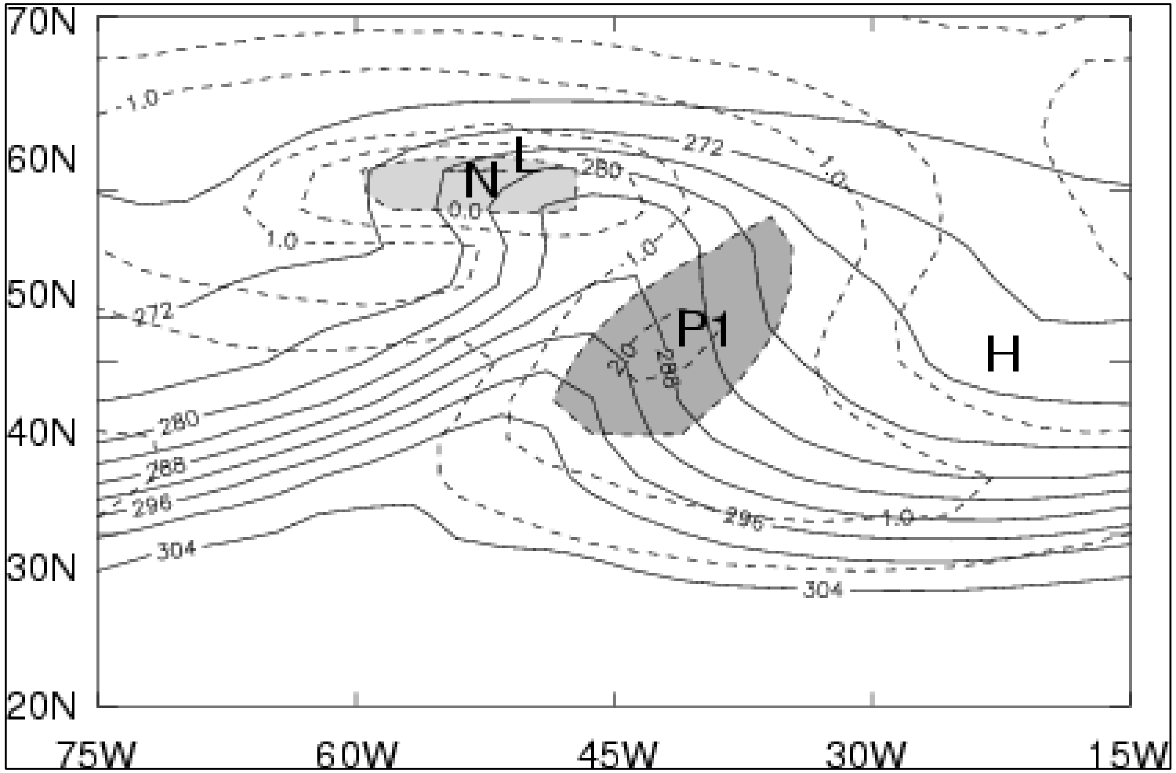
Adamson, Belcher, Hoskins & Plant (2006)
QJRMS 132 101-124

PV in frictional lifecycle I



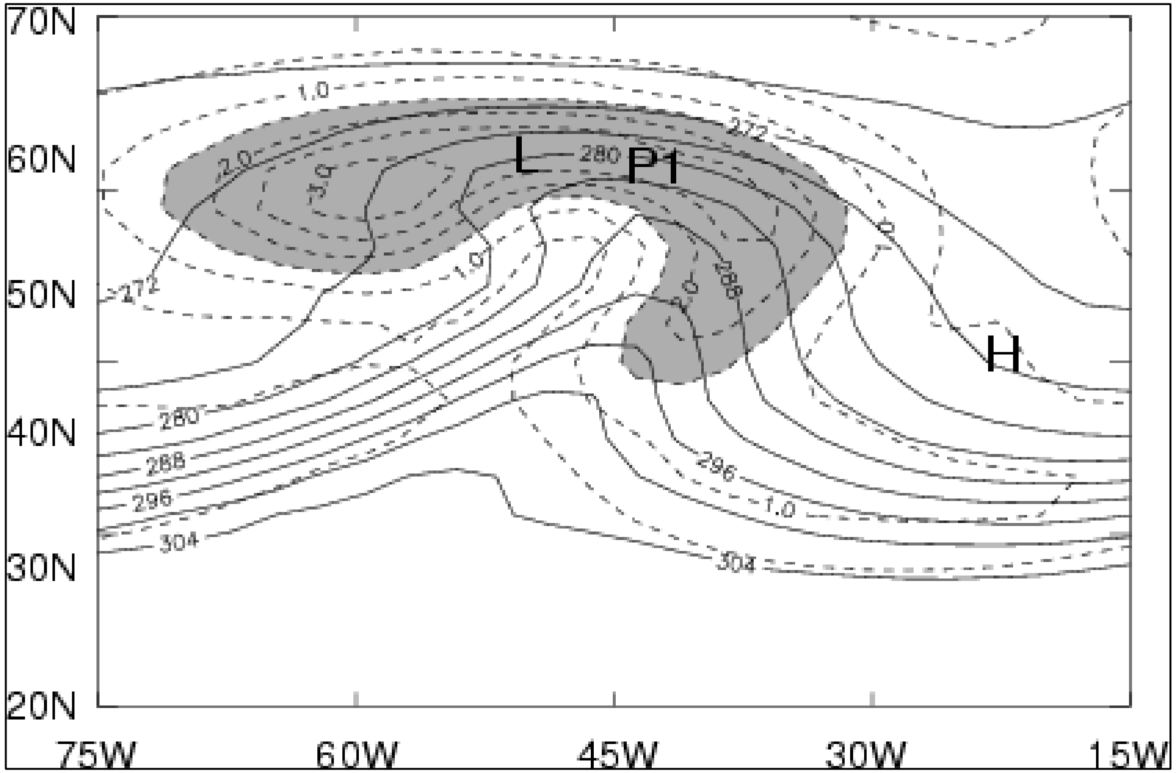
Day 4

PV in frictional lifecycle II



Day 6

PV in frictional lifecycle III



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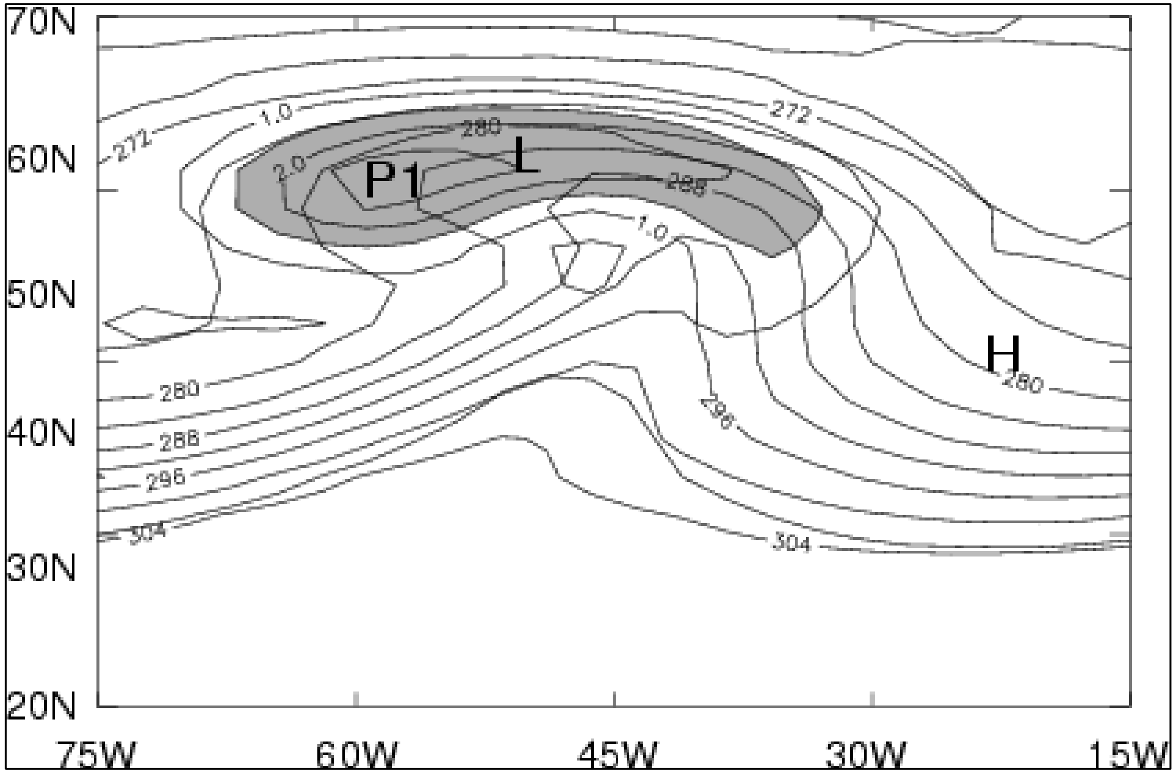
PV in frictional lifecycle IV



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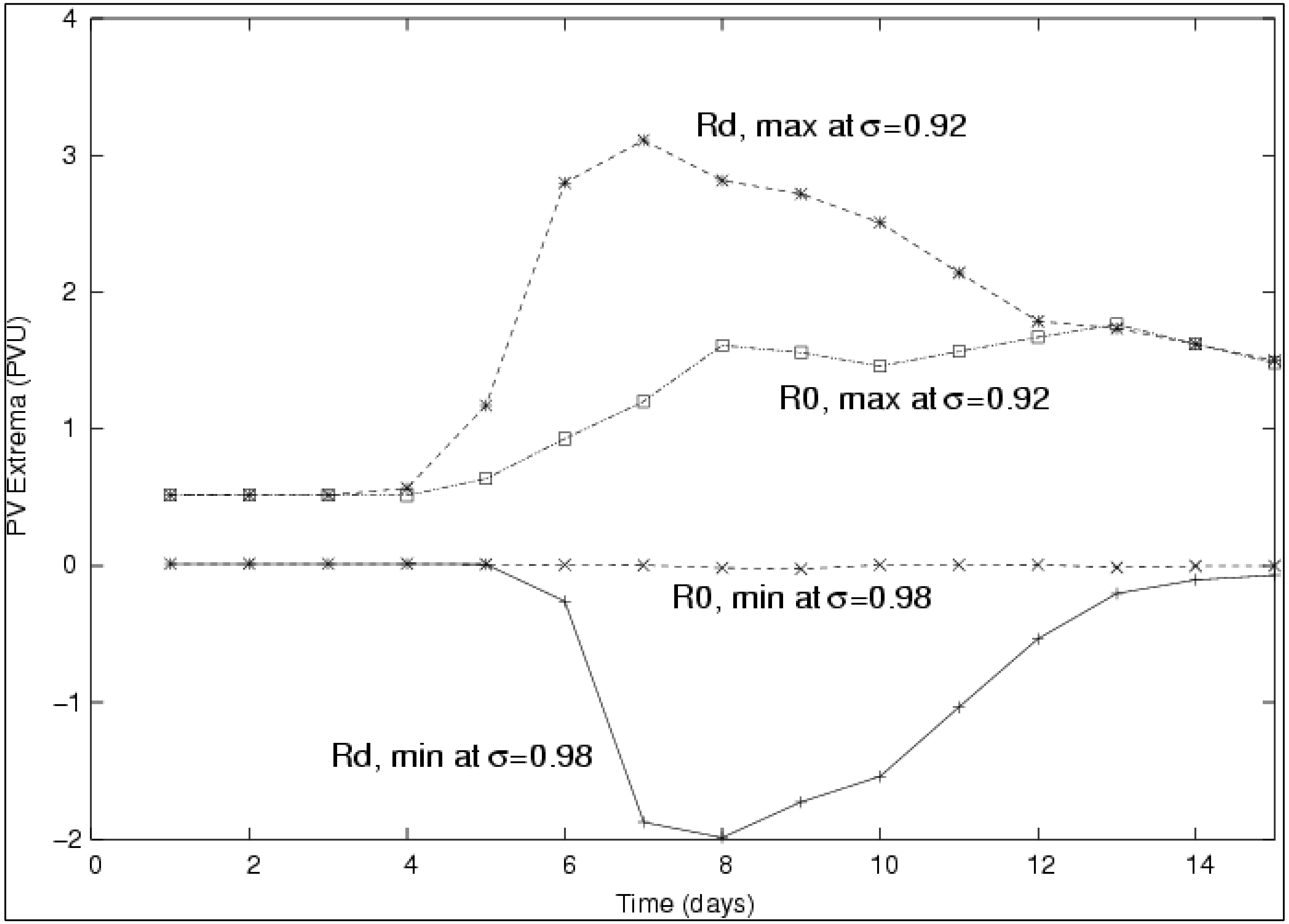
Evolution of PV



Mechanisms for boundary layer generation of PV

Frictional generation of PV

- Evolution equation for PV with friction

- Depth integrated evolution

cf Cooper, Thorpe & Bishop 1992

Frictional generation of PV

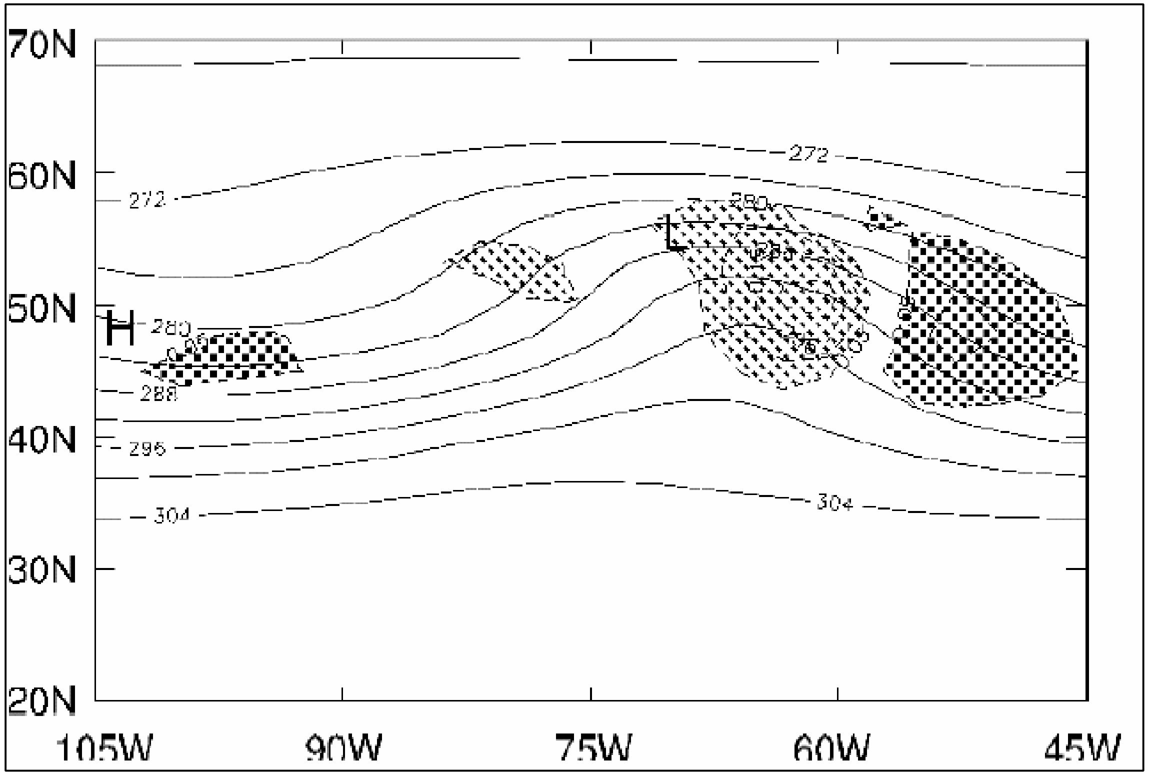
- Ekman generation:

- Baroclinic generation:

- Ratio:

But caution: need angles to be right!

PV generation: Ekman



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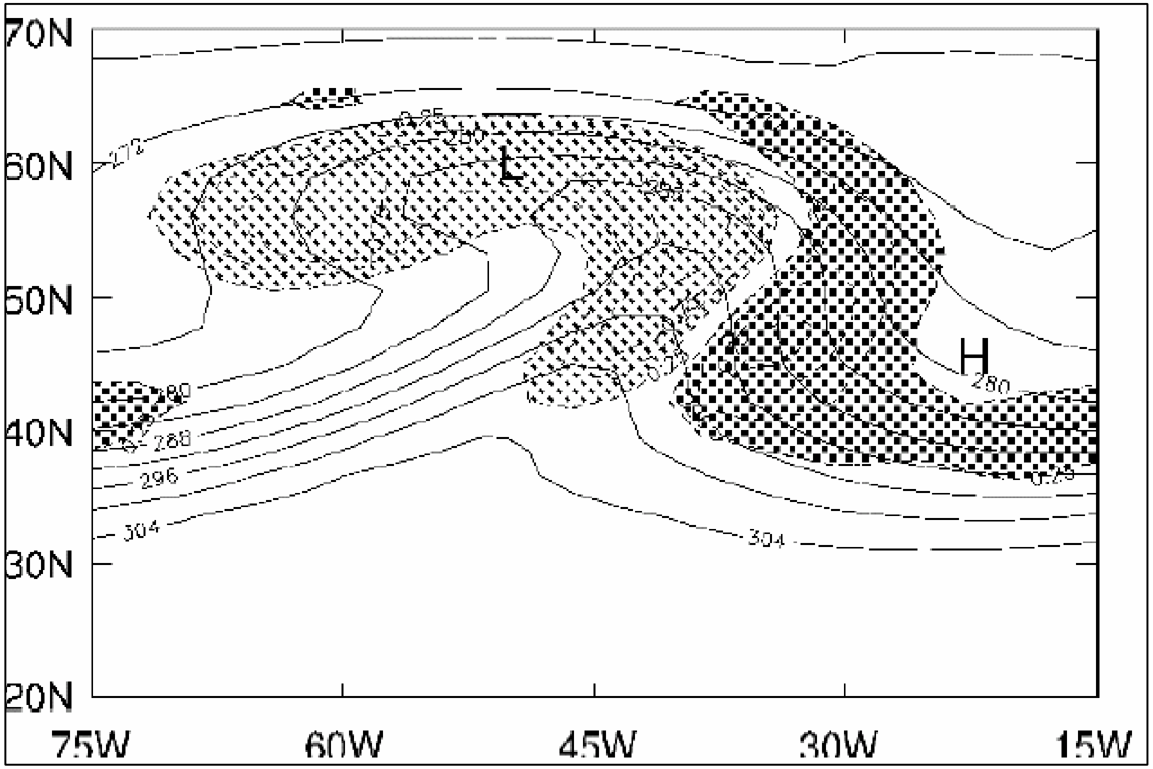
PV generation: Ekman



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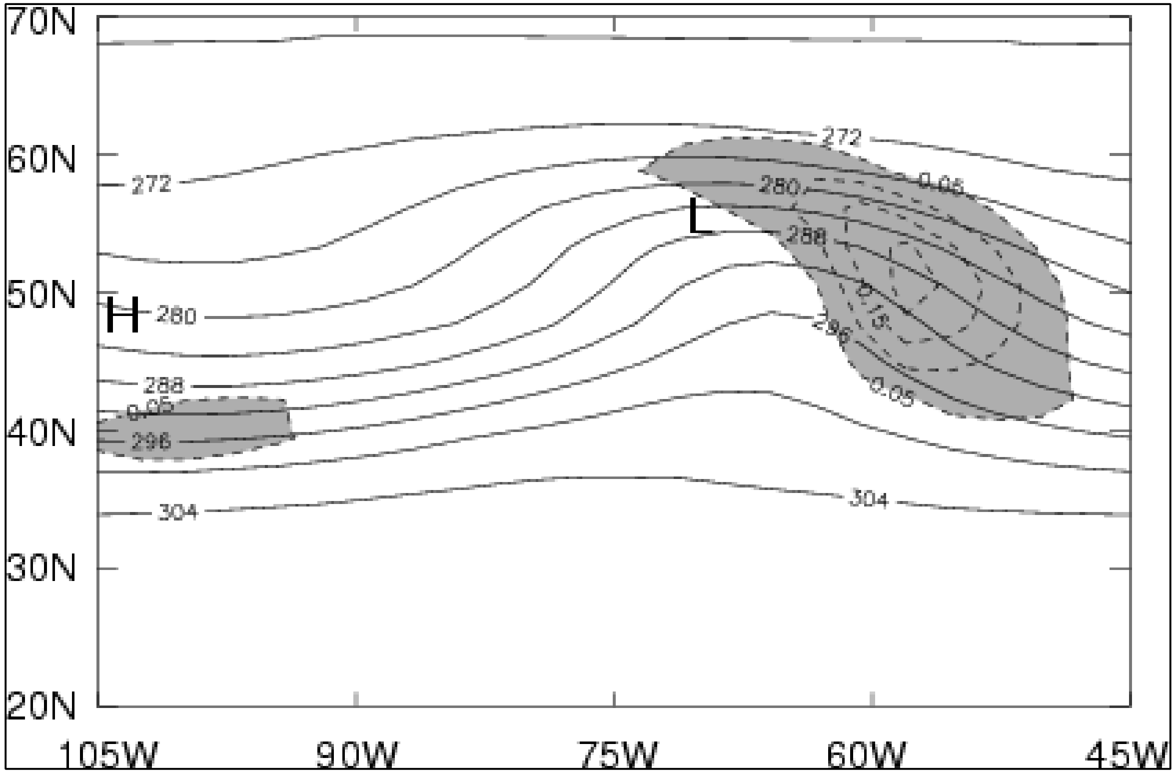
PV generation: Baroclinic



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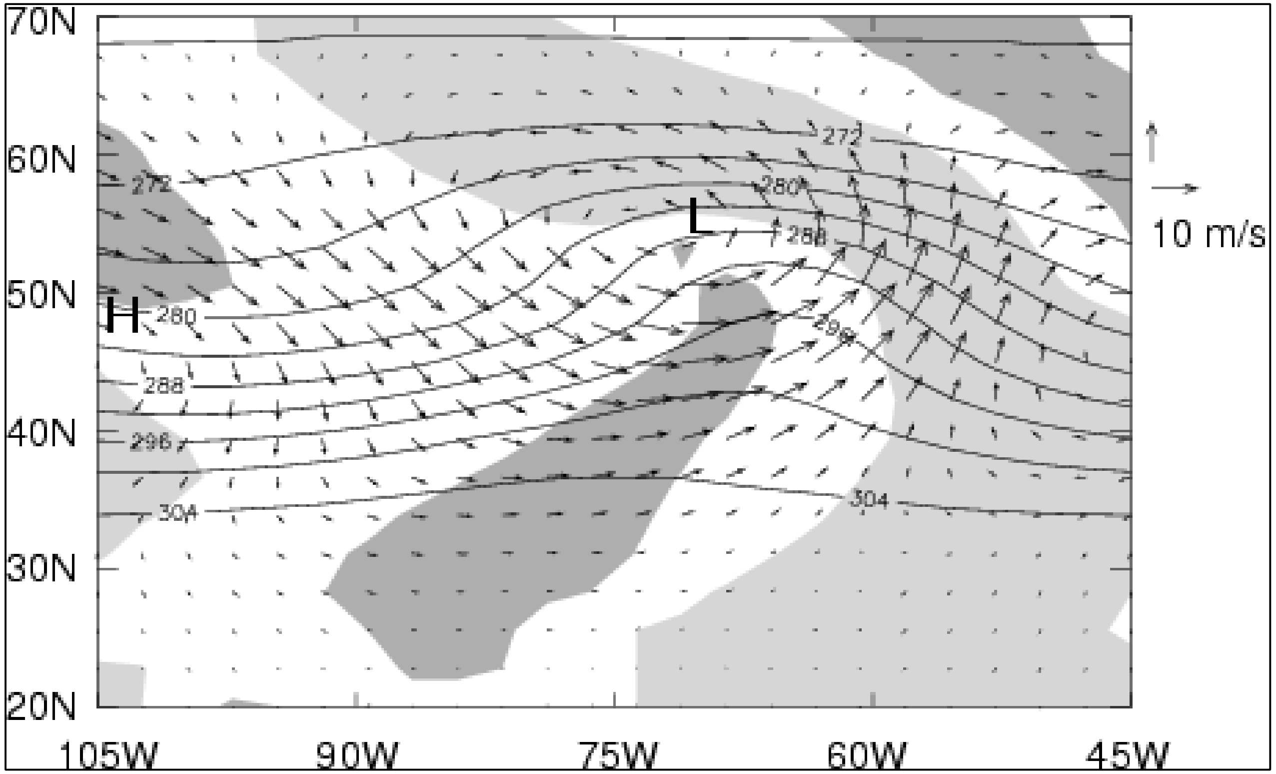
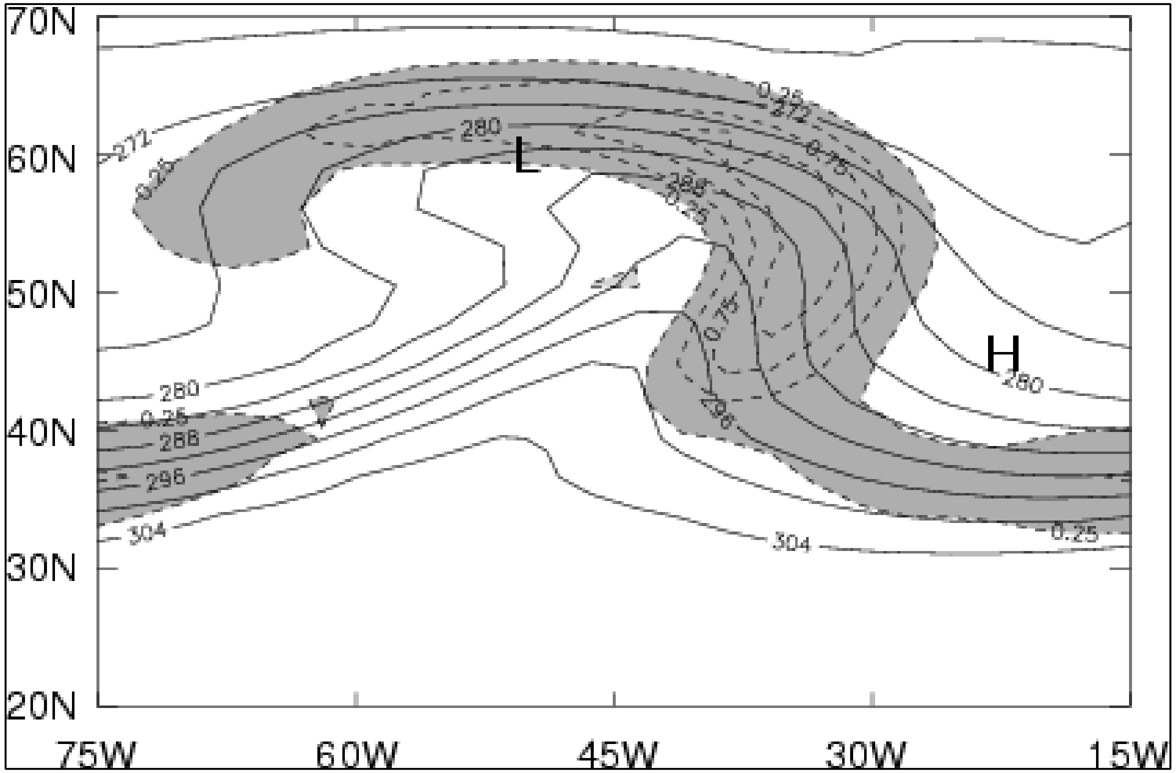
PV generation: Baroclinic



Day 4

PV generation: Baroclinic



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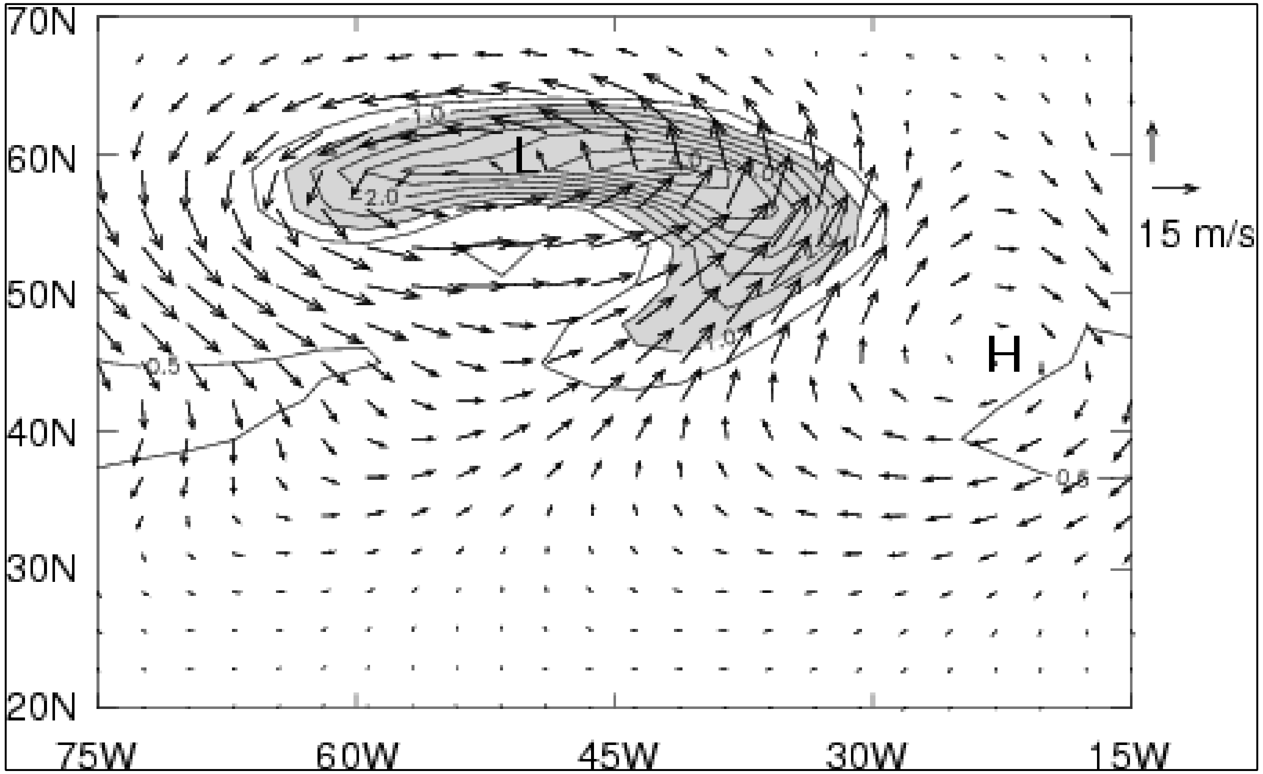
PV flux out of boundary layer

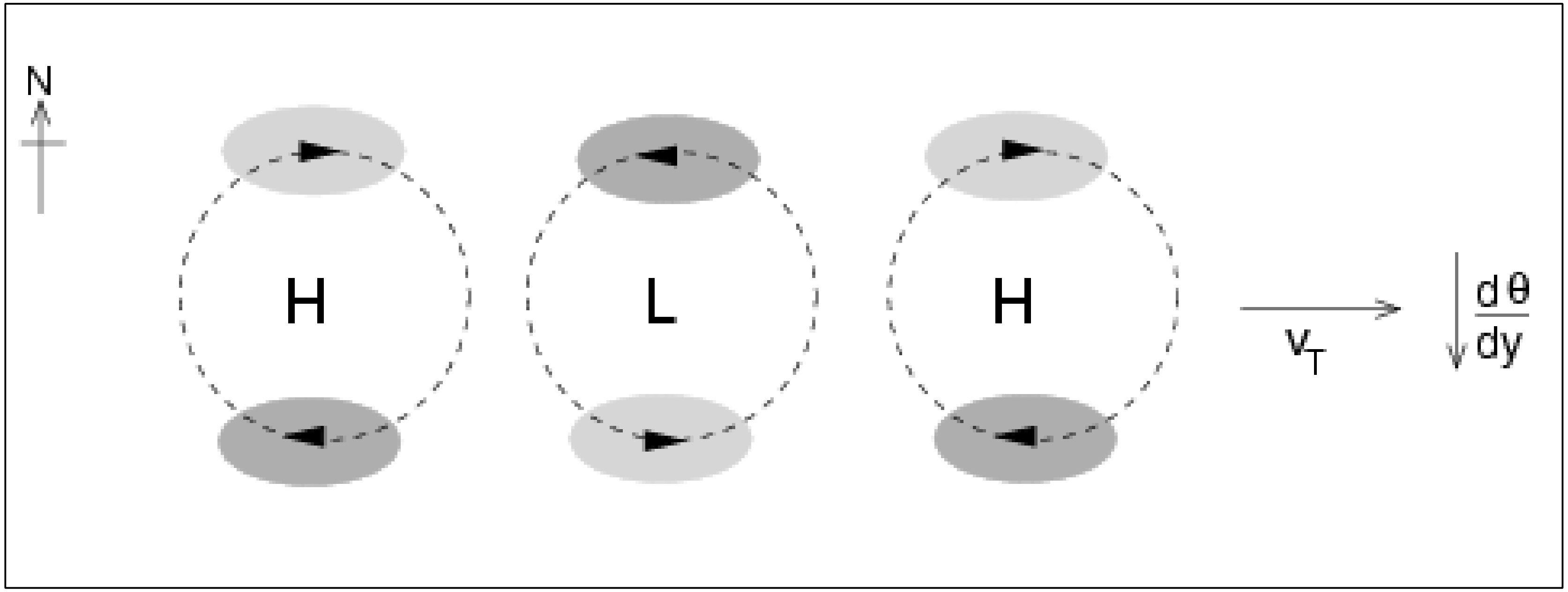


Day 6

Generation of low level PV

- Negative low-level PV in vicinity of low:
  - generated by Ekman mechanism
  - Remains localised
- Positive PV North and East of low:
  - generated by Baroclinic mechanism
  - Advected out of boundary layer by warm conveyor belt

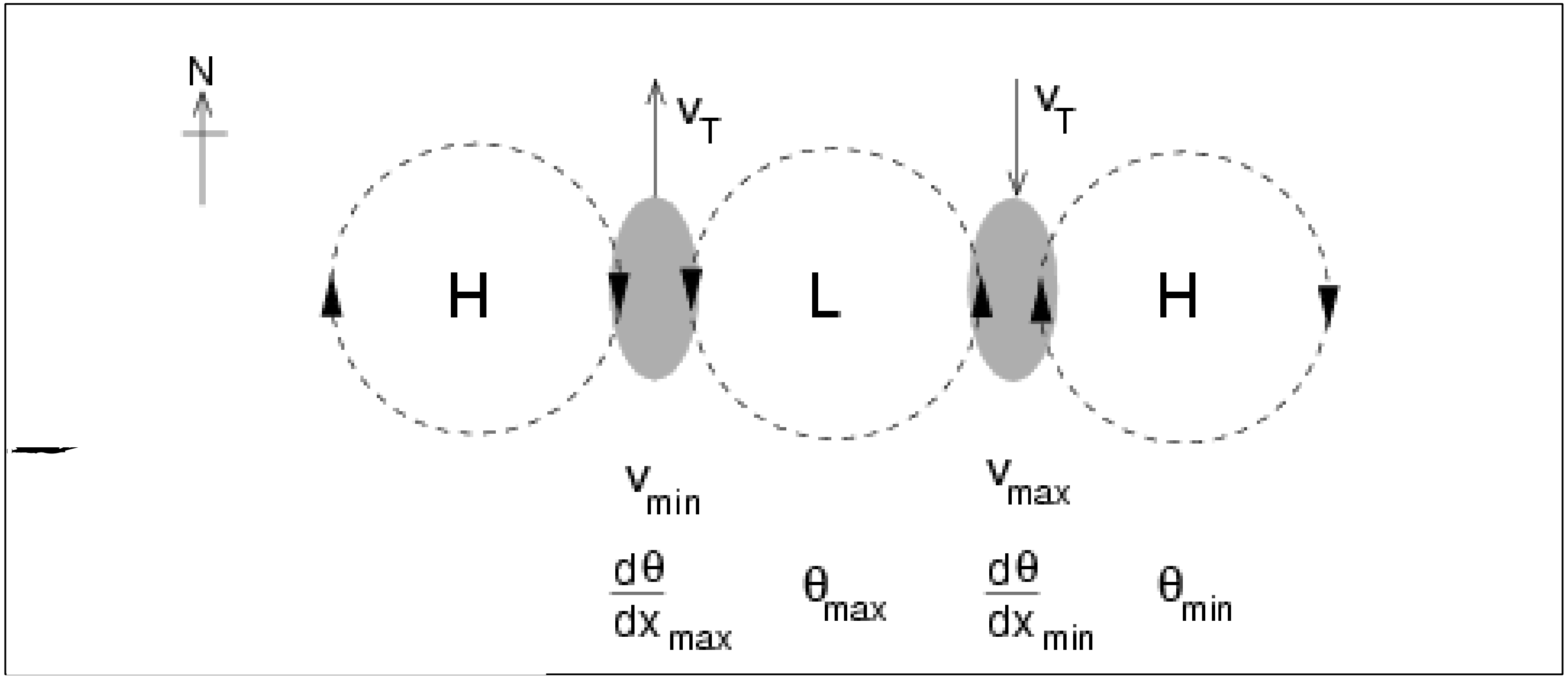
Baroclinic mechanism I



Meridional temperature gradient

Zonal wind perturbations

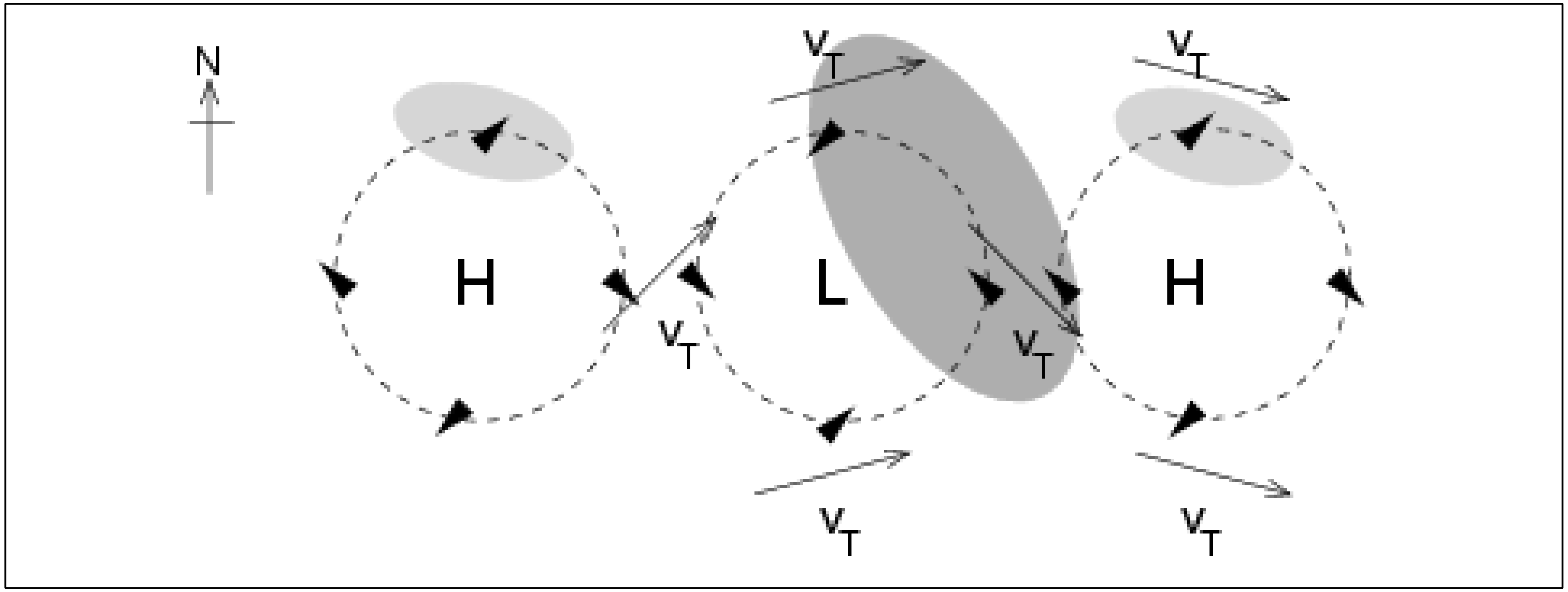
Baroclinic mechanism II



Meridional wind perturbations

Zonal perturbation temperature gradient

Baroclinic mechanism III

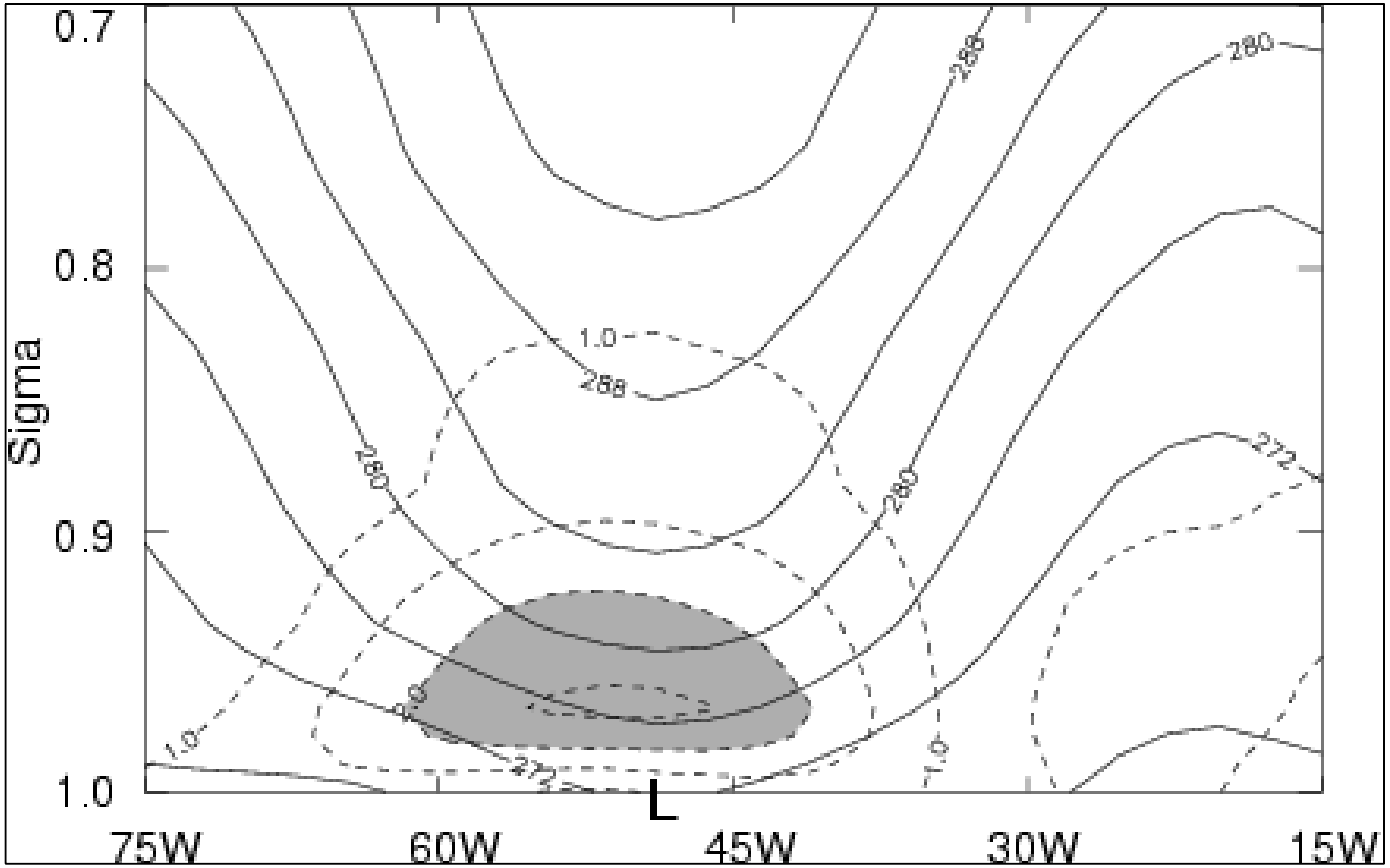


Frictional turning of surface winds

→ **Primary generation: positive to N & E of low**

Mechanism for reduced cyclone growth

Reduction in baroclinic growth



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Increased stability

cf Nakamura & Held (1982)

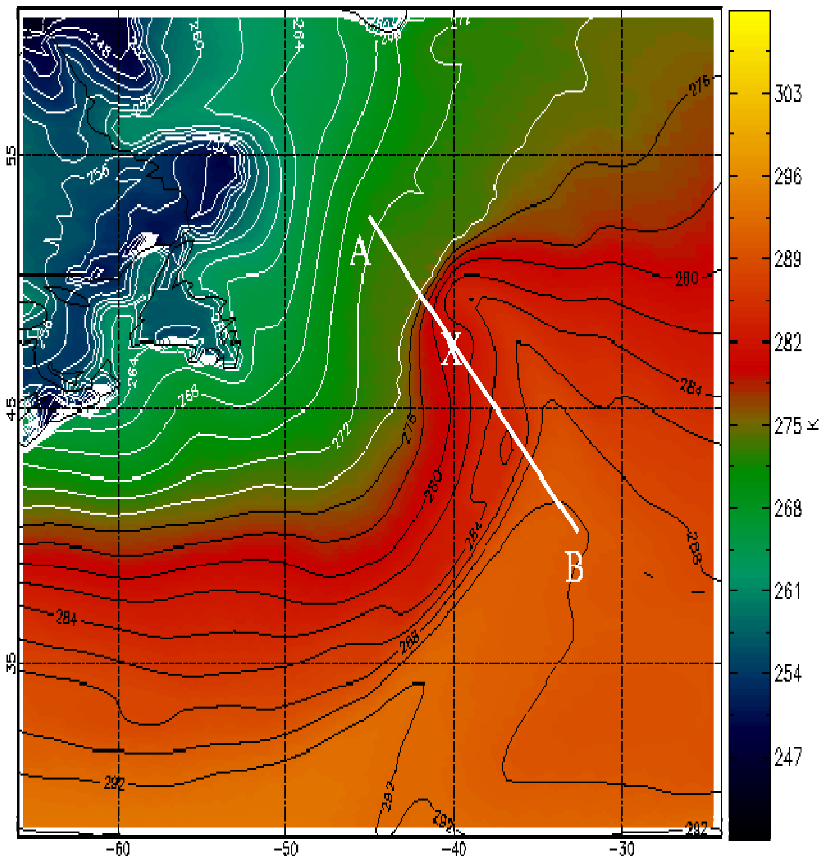
Reduced growth rate

- Growth rate of Eady wave:
- Heuristic calculation:
  - Use measured *N*
  - Growth rate reduced by 40%
  - 25% due directly to reduced static stability
  - 15% because Rossby radius increases so that wavenumber 6 no longer optimal

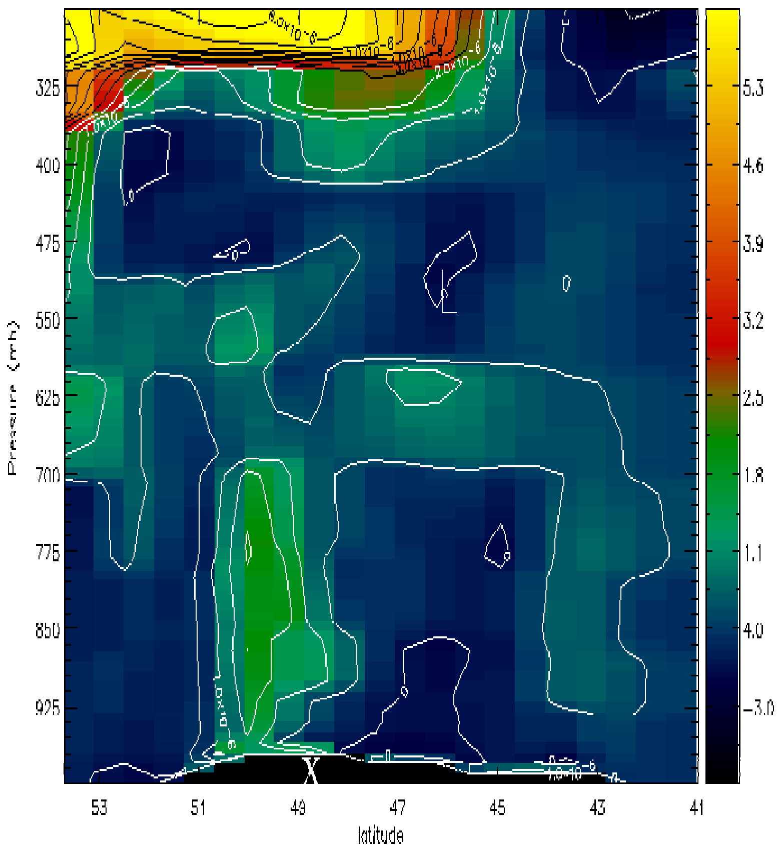
A case study

FASTEX IOP 15

FASTEX IOP15

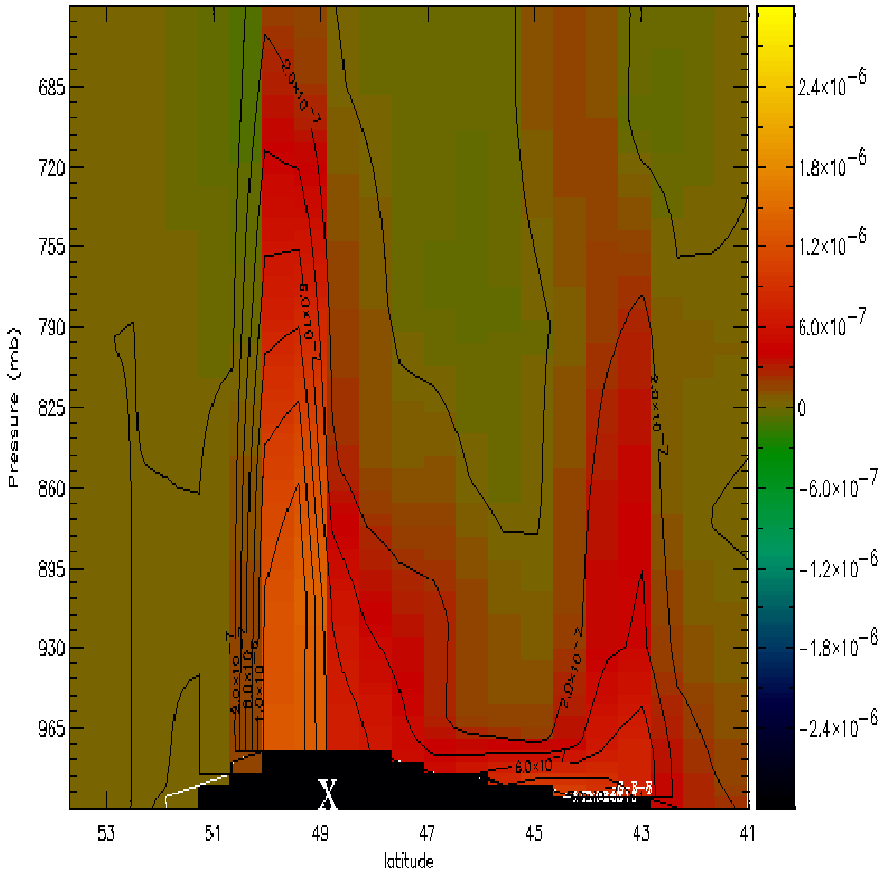


Temperature

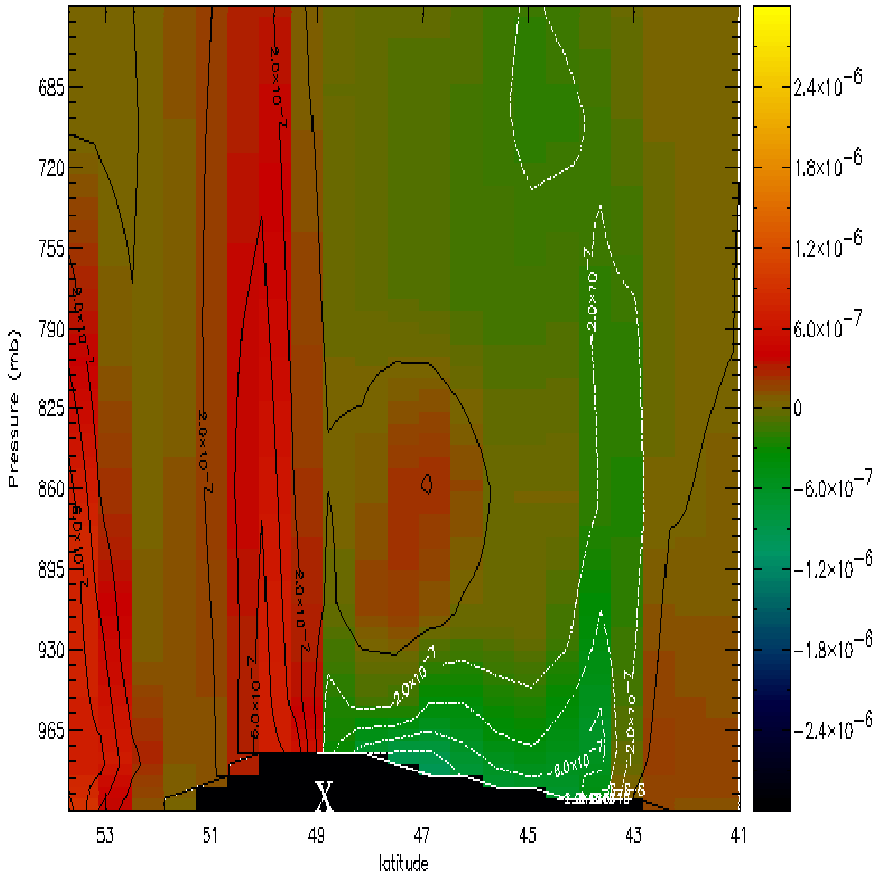


PV on cross section

PV generated by physics



PV from heating



PV from G_B

Conclusions

- Boundary layer friction generates PV through two mechanisms:
  - Ekman generation:
    - Destroys PV near low centre
    - PV remains near low centre
  - Baroclinic generation:
    - Generates PV NE of low - robust mechanism
    - PV fluxed out of boundary by warm conveyor belt

Conclusions

- Growth rate of baroclinic wave reduced
  - Baroclinically generated PV reduces static stability and so reduces coupling between upper and lower level PV
- Case study:
  - Latent heating: 2/3 PV from physics
  - Friction: 1/3 PV from physics