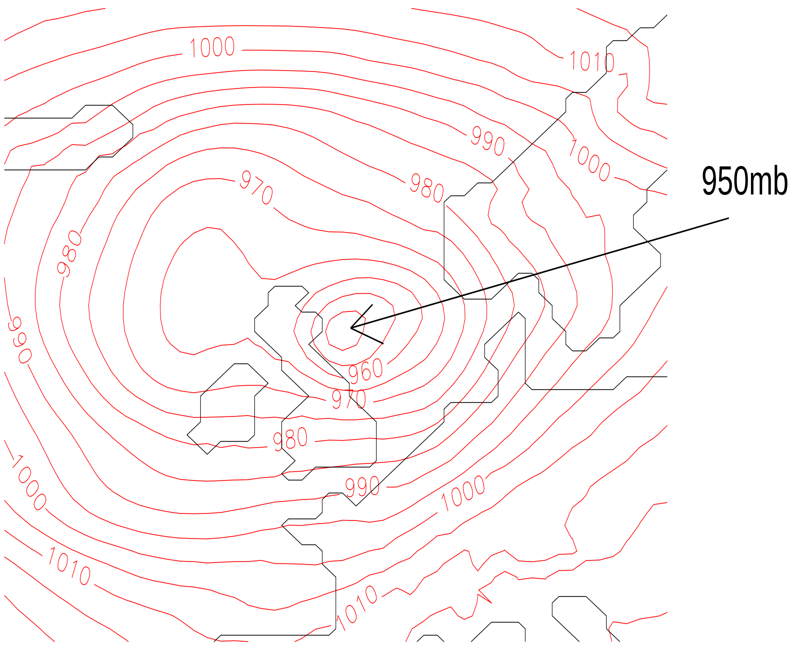
Frictional Damping of Baroclinic Waves

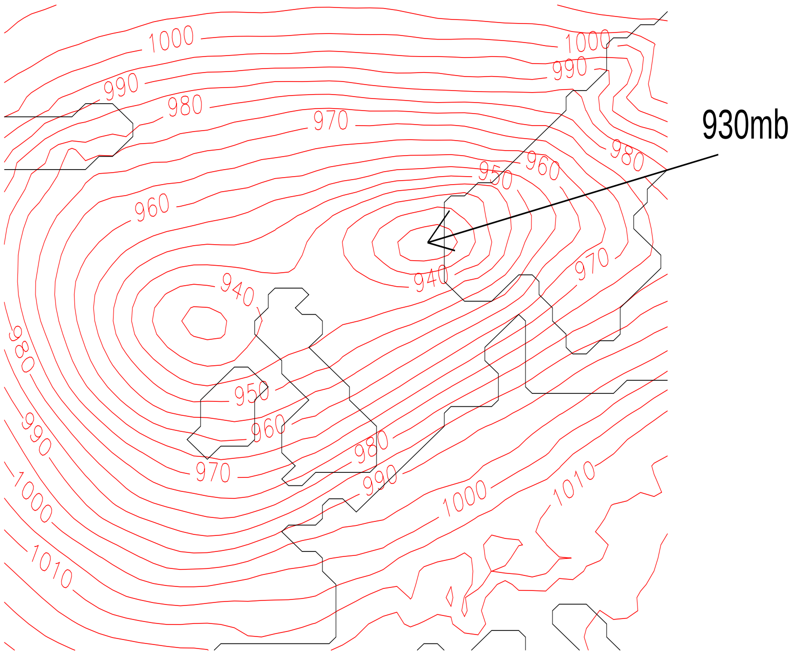
HHH, 26th May 2006

Bob Plant

With thanks to Stephen Belcher, Brian Hoskins, Dan Adamson

Motivation


Control simulation, T+60


Simulation with no boundary layer turbulence, T+60.

Simulations with and without boundary layer processes active for T+60 of storm on 12Z 31/10/00.

Surface Roughness

- Accounting for orographic and ocean wave effects has produced increased roughness in NWP
- The *increased* roughness has increased NWP skill.

- But how and why?

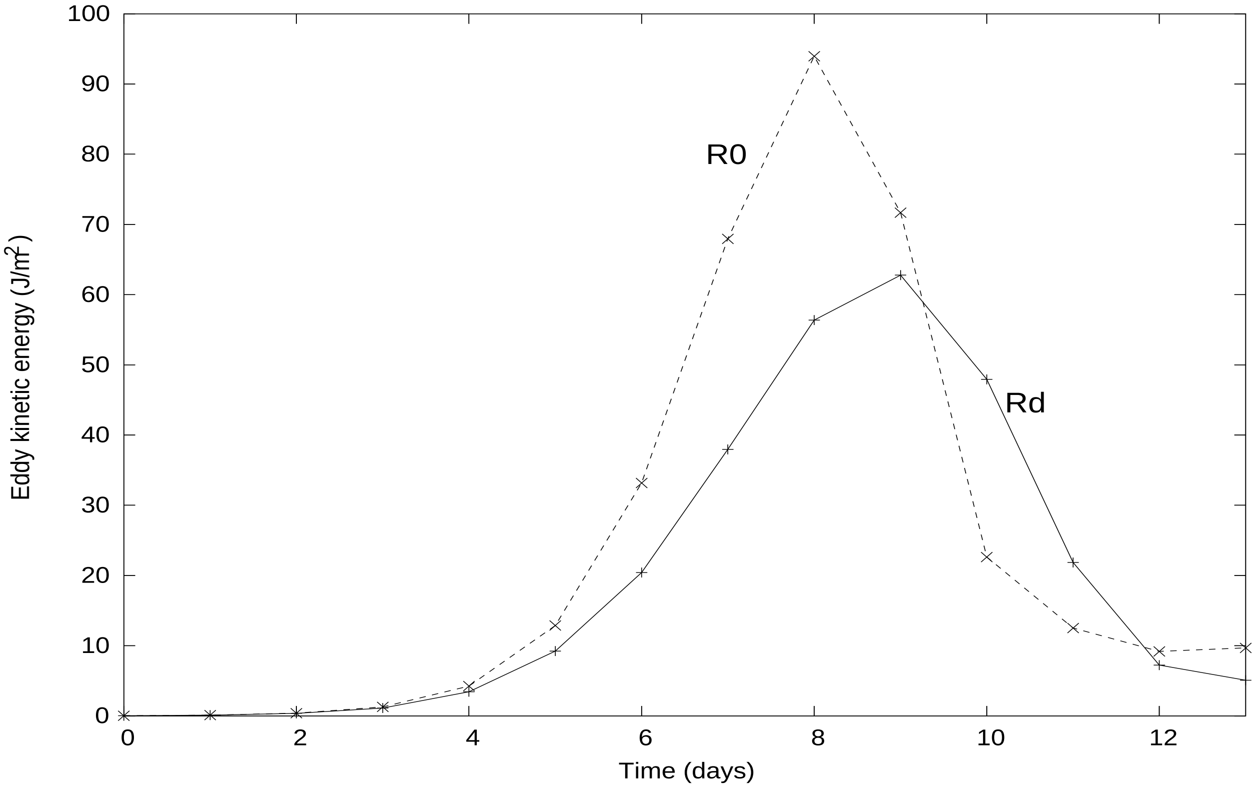
- (How much roughness should be there?)
- Has become a real issue in deciding between competing (but very different) parameterizations of orographic effects.

Some Context

- Potential vorticity framework
- Baroclinic wave studies with IGCM:
  - LC1 and LC2
  - Added simple (but realistic) boundary layer scheme
- Three cyclones in UM (different forcing mechanisms) with careful diagnosis of PV generation by model physics

- Here, focus will be on LC1, with friction but no boundary layer heat fluxes

Bulk Effect of Friction



Mechanisms for Frictional PV Generation

PV Generation

(1) $$\frac{DP}{Dt} = G \equiv \frac{1}{\rho}\underline{\nabla} \times \underline{F} \cdot \underline{\nabla}\theta,$$

Average over boundary layer:

(2) $$\frac{\overline{D}[P]}{\overline{D}t} = [G] - \frac{w_h P_h}{h} + \text{small terms.}$$

Contributions to $[G]$

Ekman term:

$$(3) \qquad [G_E] = \frac{-1}{\rho^2 h^2}\Delta\theta\,\hat{\underline{k}} \cdot \underline{\nabla} \times \underline{\tau}_s = -\frac{f\Delta\theta}{\rho h^2} w_{\mathrm{E}}$$

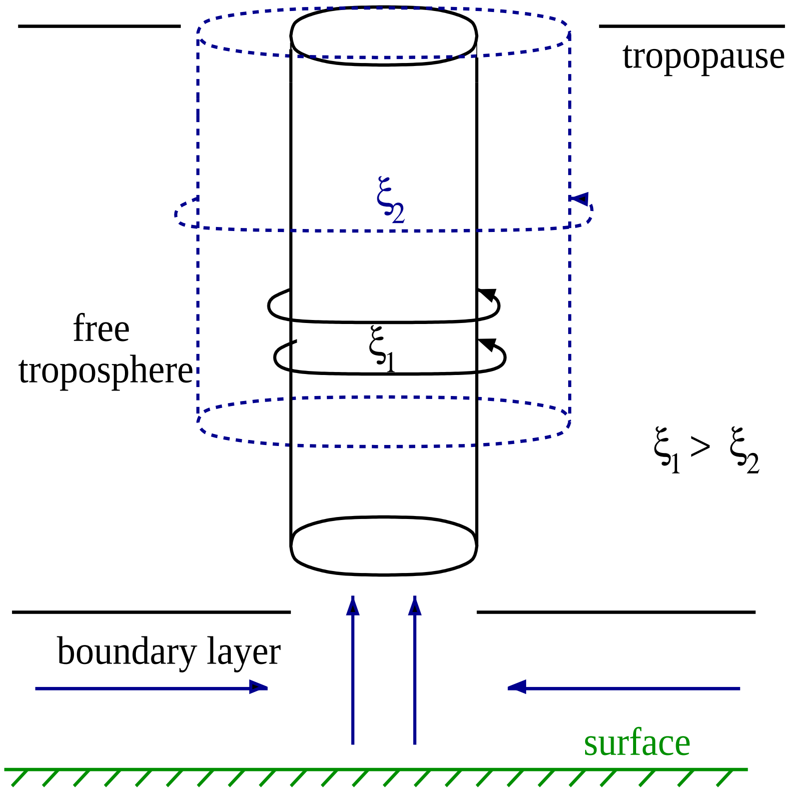
Baroclinic term:

$$(4) \qquad [G_B] = \frac{1}{\rho^2 h^2}\hat{\underline{k}} \times \underline{\tau}_s \cdot (\underline{\nabla}_H \theta)_h \propto -\underline{v}_s \cdot \underline{v}_T$$

and some small terms.

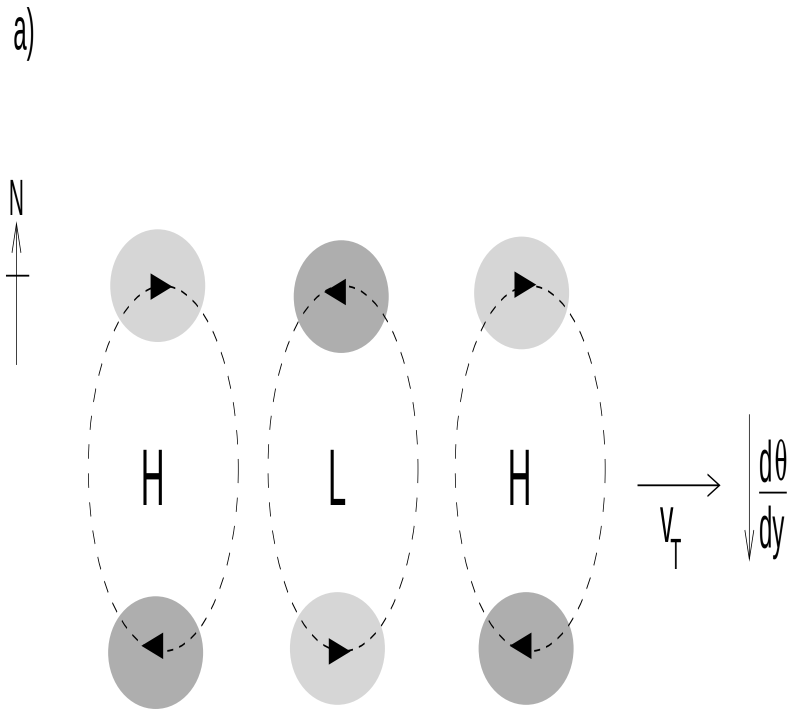
Ekman Pumping

Convergence over low → ascent → vortex-tube squashing → spindown of barotropic vortex



Reduces PV over the low

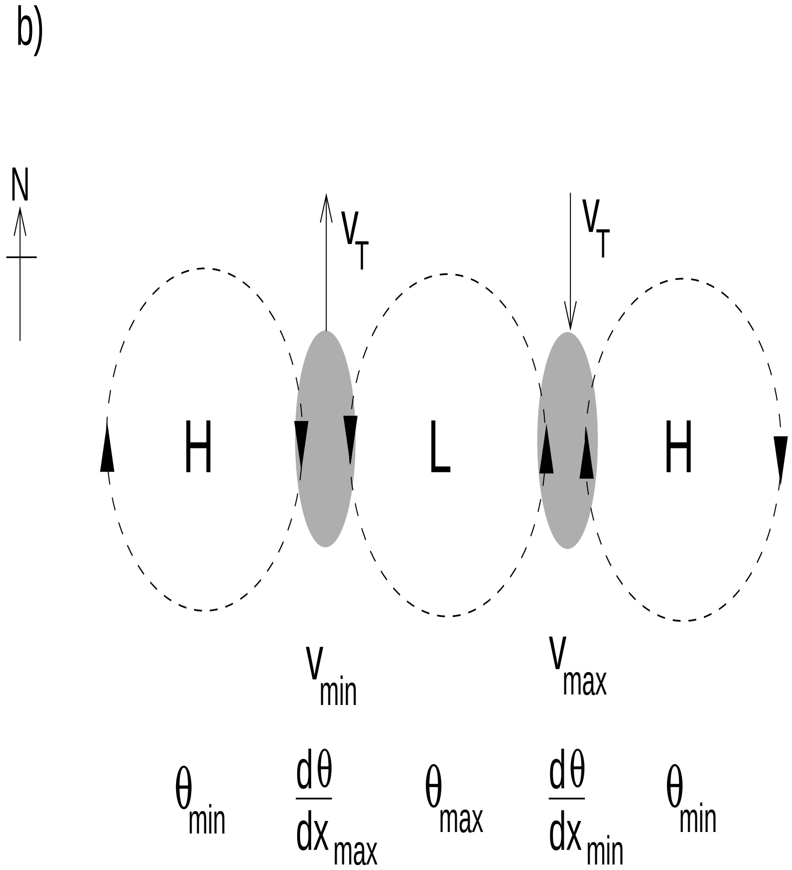
Baroclinic Term



Basic-state temperature gradient
Perturbation surface zonal wind

Baroclinic Term

For a neutral wave:

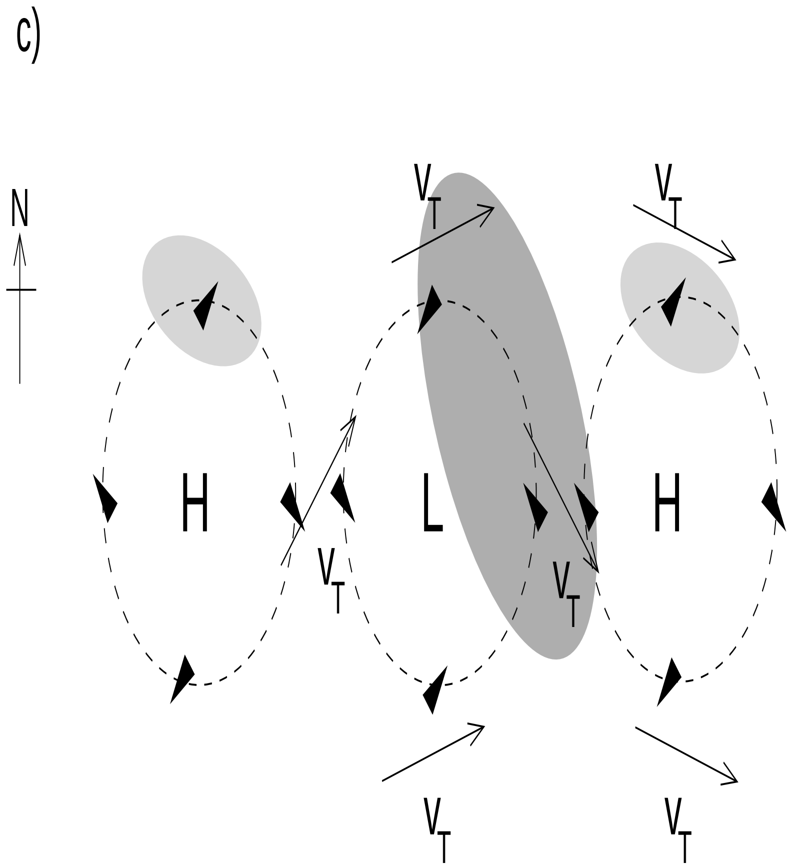


Perturbation zonal temperature gradient

Perturbation meridional zonal wind

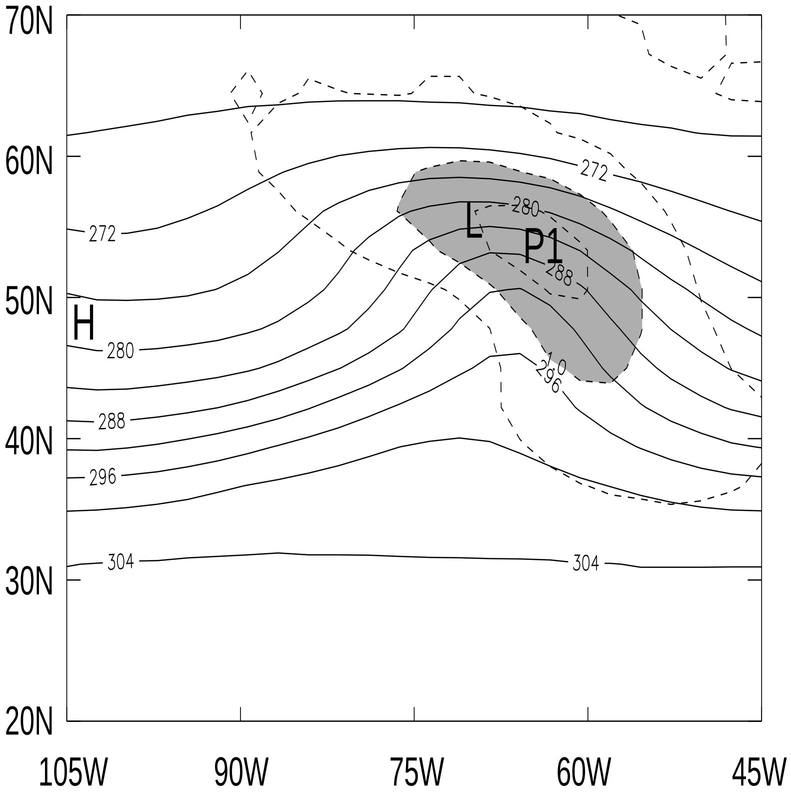
Baroclinic Term

Combine these and account for wave growth and frictional turning of the wind:



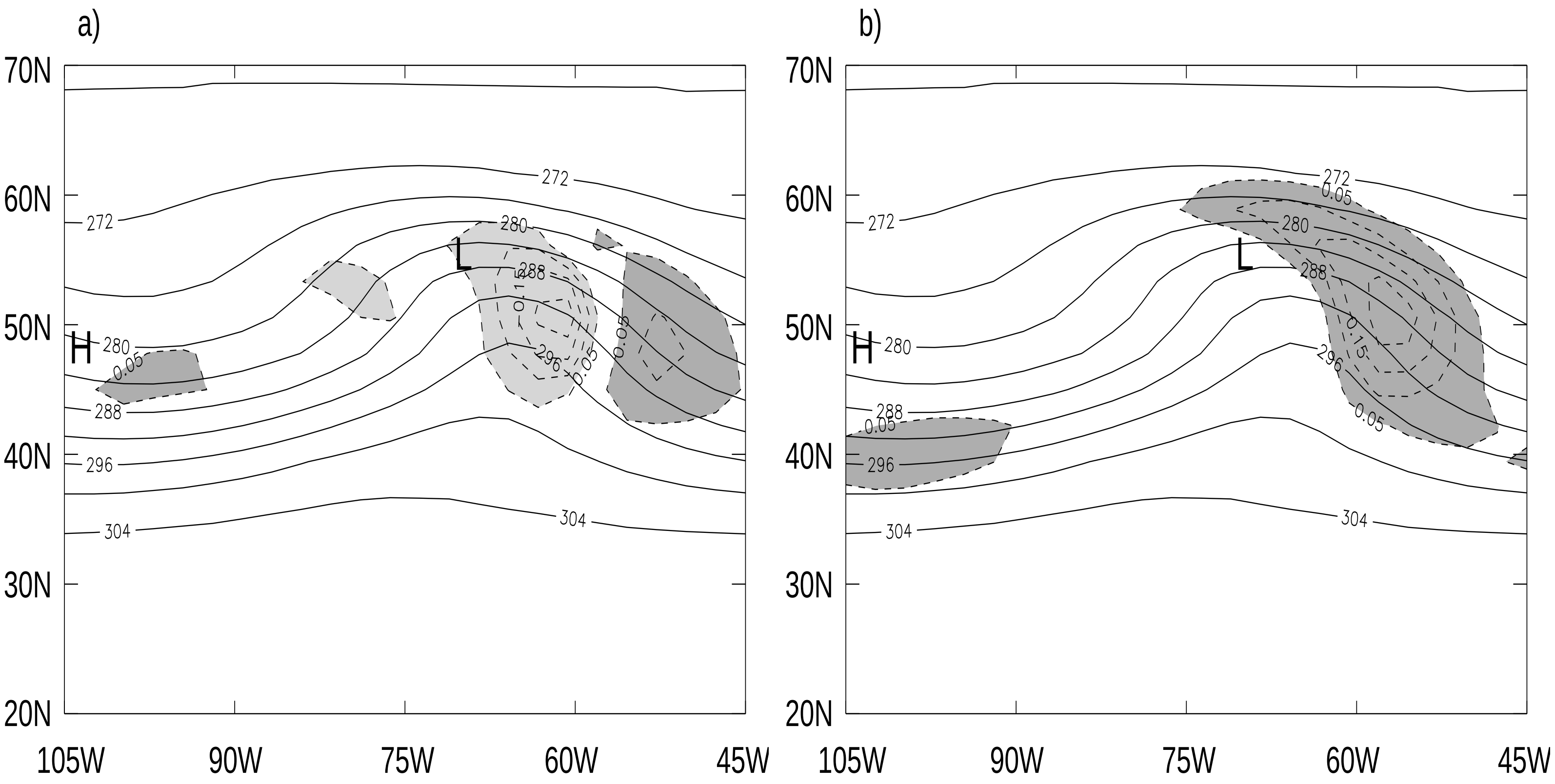
Low-level PV Evolution of the Wave

Near-Surface PV



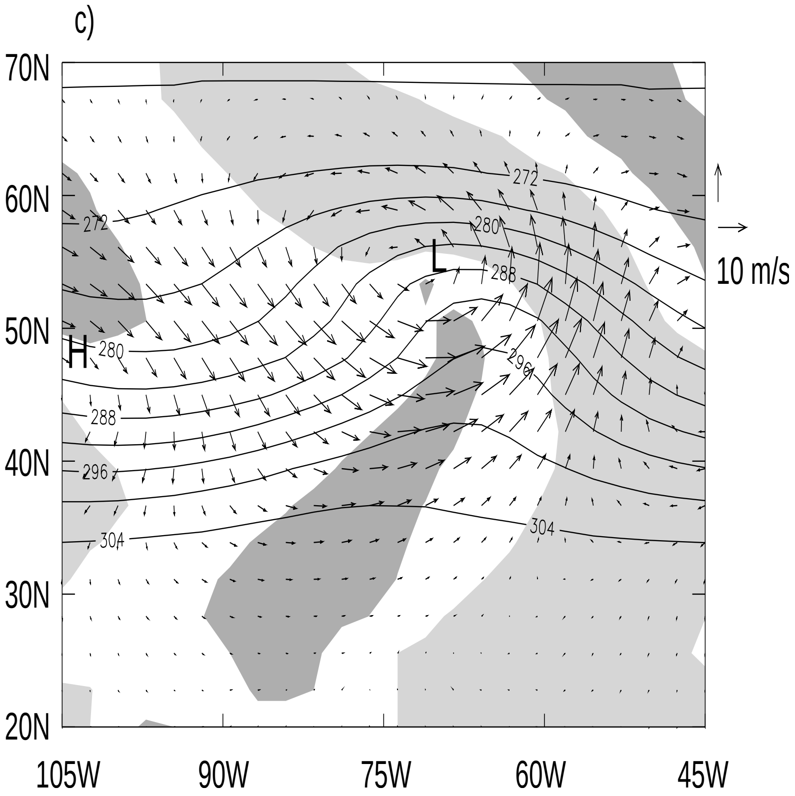
PV at $\sigma = 0.98$ after 4 days

Where Does This Come From?



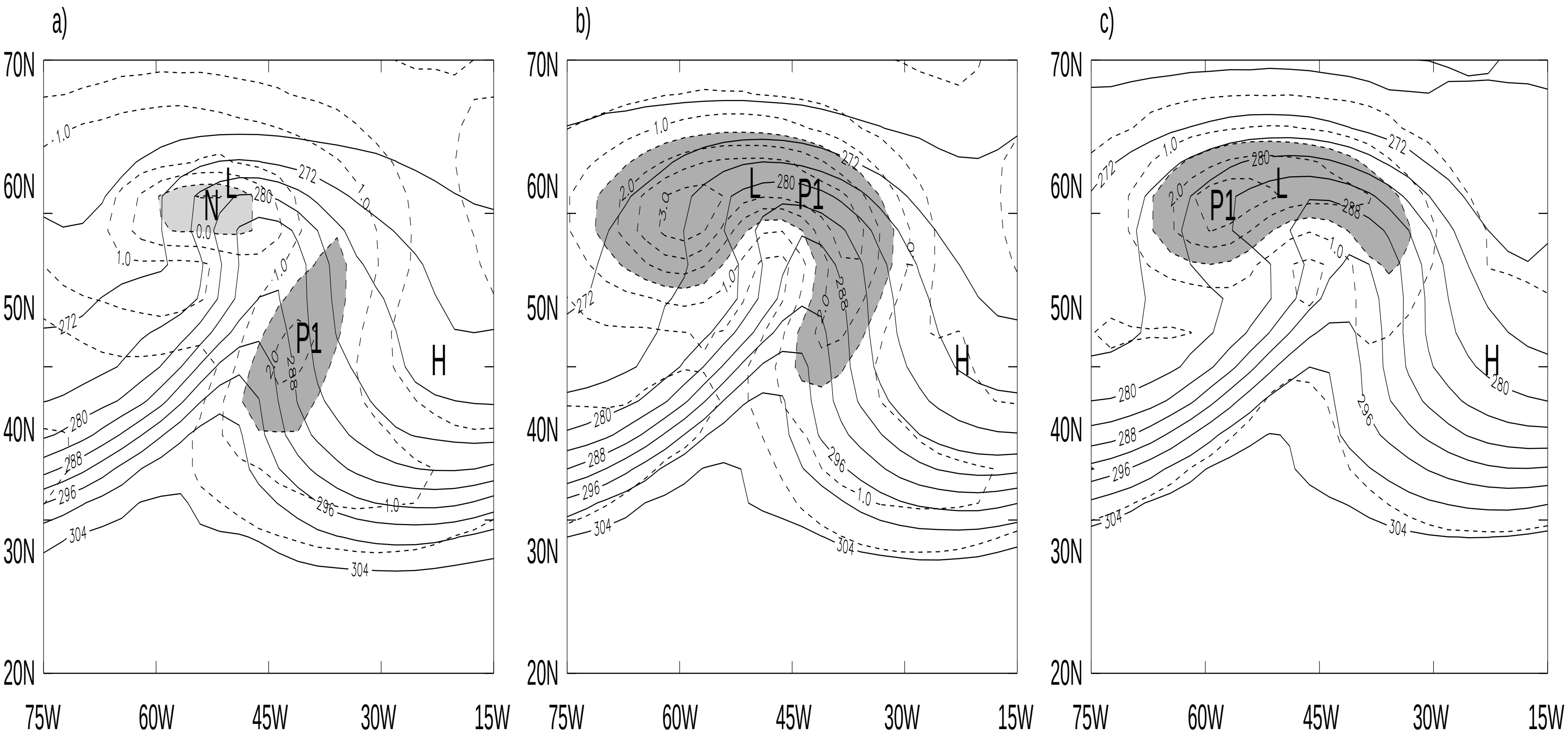
Ekman (left) and baroclinic (right) generation terms

Comparison with the Theory



Near surface winds and angle between v_s and v_T

Transport of Generated PV



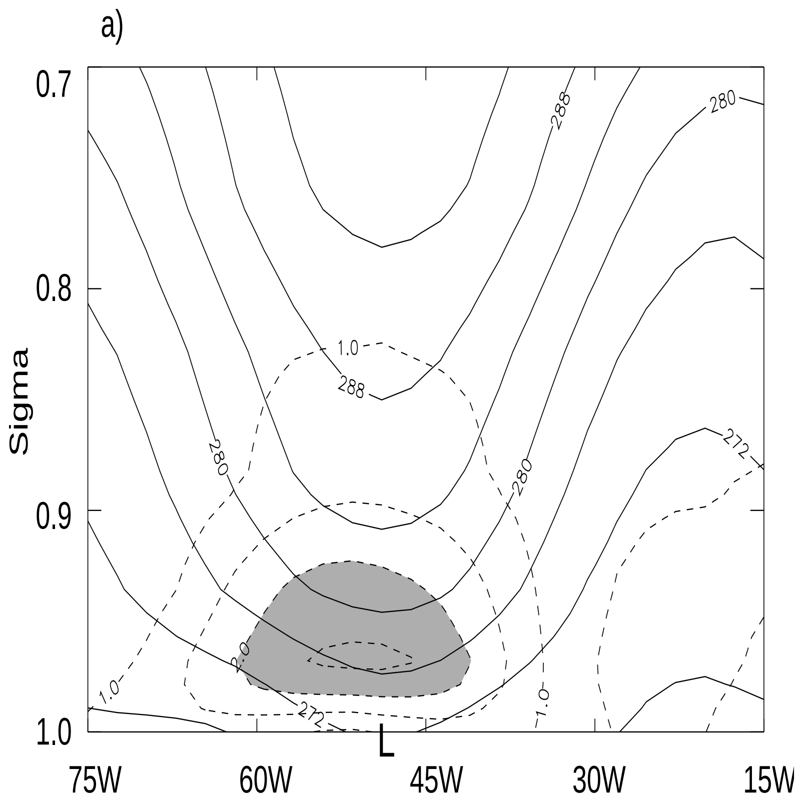
PV at $\sigma = 0.98$ (left), $\sigma = 0.955$ (left) and $\sigma = 0.92$ (right) after 6 days

Transport of Generated PV

- Negative low-level PV in vicinty of low
  - Generated by Ekman mechanism close to low
  - Remains localized
- Positive PV to north and east
  - Generated by baroclinic mechanism
  - Advected out of boundary layer by warm conveyor belt

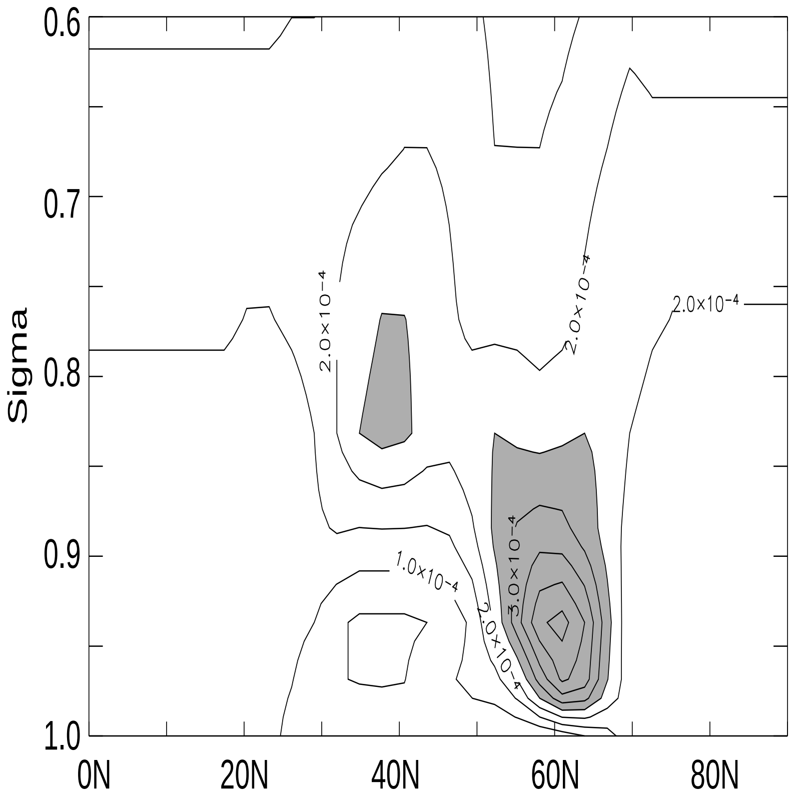
How Does This Damp the Wave?

Cross Section



PV and θ after 6 days

Stability



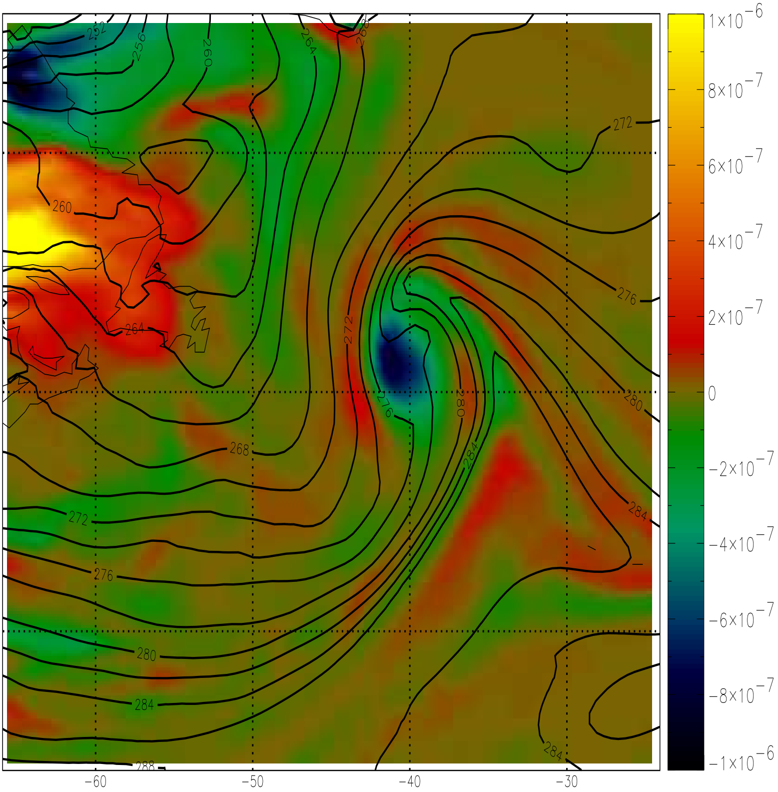
Zonal-mean stability after 7 days (P1$_{d\theta}$)

Estimated Stability Effects

Effect on linear growth rate of Eady wave:

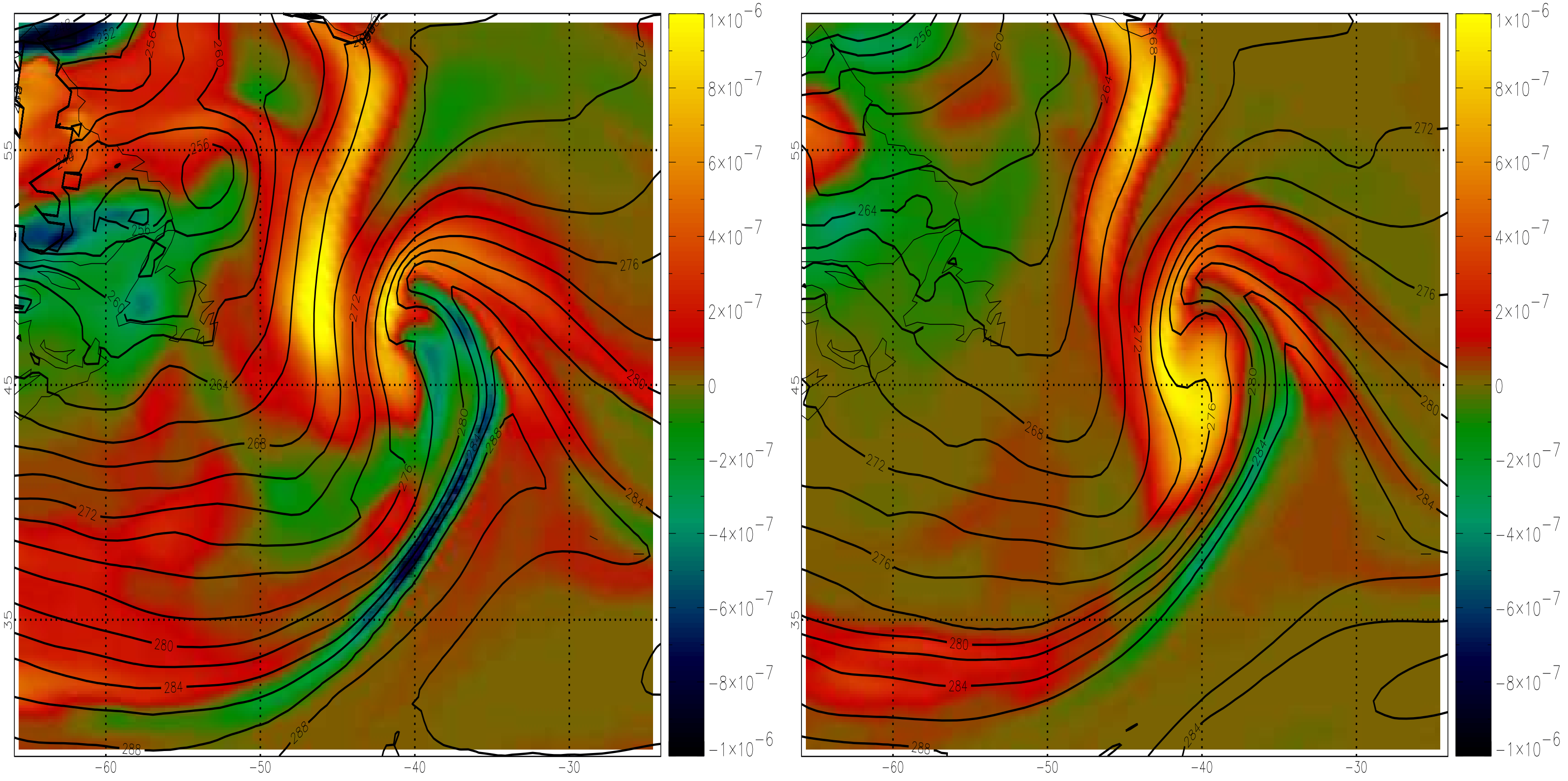
- Using resulting N
- 25% reduction directly from increased N
- 15% reduction because Rossby radius increases so that wavenumber 6 is no longer optimal

Case Study (FASTEX IOP15)



PV attributed to barotropic frictional effects, T+24, 900mb

Case Study



PV attributed to baroclinic frictional effects, T+24, 950 and 850mb

Conclusions

- Ekman pumping spins down a barotropic vortex
- PV is generated baroclinically on the NE of a low (robust mechanism)
  - Positive PV carried out of boundary layer
  - Associated static stability anomaly
- Case studies suggest $\sim 1/3$ of PV generation from friction