Frictional Damping of Baroclinic Waves

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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

![Graph showing the bulk effect of friction with time in days on the x-axis and eddy kinetic energy in Joules per meter squared on the y-axis. The graph plots two lines labeled $R_0$ and $R_d$.](image-url)
Mechanisms for Frictional PV Generation
PV Generation

\[ \frac{DP}{Dt} = G \equiv \frac{1}{\rho} \nabla \times F \cdot \nabla \theta, \]

Average over boundary layer:

\[ \overline{D[P]} = [G] - \frac{w_h P_h}{h} + \text{small terms}. \]
Contributions to $[G]$

Ekman term:

$$[G_E] = -\frac{1}{\rho^2h^2} \Delta \theta \hat{k} \cdot \nabla \times \tau_s = -\frac{f \Delta \theta}{\rho h^2} w_E$$  \hspace{1cm} (3)

Baroclinic term:

$$[G_B] = \frac{1}{\rho^2h^2} \hat{k} \times \tau_s \cdot (\nabla_H \theta)_h \propto -\nu_s \cdot \nu_T$$  \hspace{1cm} (4)

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

\[ v_T \frac{d\theta}{dy} \]
Baroclinic Term

For a neutral wave:

\[ \theta_{\text{max}} \min \theta \]

\[ v_{\text{max}} \]

\[ v_{\text{min}} \]

\[ T_{\min} \]

\[ T_{\max} \]

\[ g_{\text{bar}} \]

b)

Perturbation zonal temperature gradient

Perturbation meridional zonal wind
Baroclinic Term

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

c)
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 vicinity 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 $\theta$ after 6 days

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Stability

Zonal-mean stability after 7 days (P1_dθ)
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