Mesoscale Atmospheric Systems

Frontal instability

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Fronts and cyclones: a classical egg & chicken problem?

Two contrasting concepts:

1) Baroclinic instability theory and idealized experiments
   (e.g., Charney 1947, Eady 1949, Davies et al. 1991, Thorncroft et al. 1993, ...)

   and observational evidence, e.g., from ERICA field experiment 1989
   (e.g., Shapiro and Neiman 1993, Neiman et al. 1993, ...)

   indicate that **fronts are generated** during cyclone intensification

2) Observation-based Bergen school cyclone model
   (Bjerknes and Solberg 1922)

   and frontal instability analyses
   (e.g., Schär and Davies 1991, Joly and Thorpe 1991, Dacre and Gray 2006, ...)

   indicate that cyclones develop as instabilities on **pre-existing fronts**
Baroclinic instability: the Eady model

→ see “Large-scale dynamics” lecture course, books by Holton or Gill

dimensionless growth rate

growth rate maximum at \( \delta = 0.8031 \), corresponding to about 4000 km

short wave cut off at \( \delta = 1.1997 \)
Idealized experiment of baroclinic instability
(see also lecture about surface fronts)

regions with strong temperature gradient (fronts) evolve DURING simulation due to deformation of large-scale flow induced by cyclones and anticyclones
ERICA IOP4 (4 Jan 1989)
Intense frontogenesis during cyclone intensification

T on 850 hPa

06 UTC 4 Jan

00 UTC 5 Jan

Neiman et al. 1993
The Bergen school cyclone model

Key ingredient is *pre-existing* “polar front” (the dashed line)
UK October storm 1987
Wave on pre-existing front developed into devastating storm
00 UTC 15 Oct 06 UTC 16 Oct

Distance between frontal wave cyclones is much smaller than most unstable wavelength of Eady model!

Morris 1988
Frontal waves and low-level PV band

trailing cold fronts are typically associated with low-level band of enhanced PV values due to intense condensational heating
Idealized instability studies for frontal waves

Basic states

- Surface temperature maximum ahead of front ("warm band")
- Near-surface PV maximum

Schär and Davies 1990

Joly and Thorpe 1990
Idealized linear instability analysis of surface fronts

\[ \lambda_{opt} = \frac{2 \pi}{k_{opt}} = 800 \text{ km} \]

Joly and Thorpe 1990
When do frontal waves develop into deep cyclones – and when not?

Challenging question ...

• interesting from theoretical viewpoint
  (do we understand dynamical processes?)
• relevant from practical viewpoint
  (forecasting)
The role of environmental deformation

Hypothesis:

frontal-waves can develop only if environmental deformation decreases below a critical threshold value

i.e., the process that contributes to the formation of the front acts also to suppress instability!

Renfrew et al. 1997
The role of environmental deformation

no growth of frontal waves experiencing deformation > critical threshold

Renfrew et al. 1997
Concept of barotropic frontal-wave instability

Step 1

Deformation field → Vertical motion → Latent heat release → Positive PV anomaly strip

Step 2

Deformation field reduces → PV strip breaks up → Cyclonic circulation → Frontal waves

Dacre and Gray 2006