Slantwise circulations and convection in pre-frontal environment over central Italy: a numerical study

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Outline

- Quasi 2-D processes: symmetric instability and Delta-M ($\Delta$-M) adjustment (Morcrette and Browning, QJRMS, 2006). Relevant to mesoscale precipitating systems?
- Model experiments performed with and without orography.
- Analysis of evolutions of regions of dry and moist symmetric instability.

(Fantini et al, QJRMS, 2011, subm.).
M = \nu + f_x: pseudo-angular momentum

Q = J(M, \theta) = M_x \theta_z - M_z \theta_x

potential vorticity

Stable

Q = J(M, \theta) > 0

Unstable

Q = J(M, \theta) < 0
\[ \sigma^2 = -\alpha \, N^2 - 2S^2 \alpha - F^2 \]

is a growth rate (in geostrophic and hydrostatic balance).

\[ N^2 = g \, \theta_z / \theta_0, \quad S^2 = f \, v_z, \quad F^2 = f (f + v_x), \quad Q = F^2 \, N^2 - S^4 \]

With normal modes: \( \sim \exp (\sigma t + i(kx + mz)) \):

\( \alpha = -k/m \) is the slope of the wavefront, i.e. trajectory slope.

(\( \alpha = 0 \): horizontal traject.; \( \alpha = \pm \infty \): vertical traject.).

**DRY CASE:**

- **C. I. - Convective Instability:** \( N^2 < 0 \).
- **I. I. - Inertial instability:** \( N^2 > 0 \), \( F^2 < 0 \) \((Q < 0)\), \( \sigma^2_{\max} = -Q/N^2 \).
- **S. I. - Symmetric Instability:**

\[ N^2 > 0, \quad F^2 > 0, \quad Q < 0, \quad \sigma^2_{\max} = -Q/N^2. \]
(some) References

- Bennetts, Hoskins 1979 QJRMS
- Fischer, Lalaurette 1995 QJRMS
- Gray, Dacre 2008 QJRMS
- Holt, Thorpe 2001 QJRMS
- Hoskins 1974 QJRMS
- Jones, Thorpe 1992 QJRMS
- Morcrette, Browning 2006 QJRMS
- Ooyama 1966 JAS
- Persson, Warner 1995 JAS
- Schultz, Knox 2007 MWR
- Schumacher, Schultz, Knox 2010 MWR
- Thorpe, Rotunno 1989 JAS
- Xu 1986 QJRMS
- Xu, Clark 1985 JAS
Symmetric instability (S. I.) has been related to the formation of slantwise ascent and descent and rainbands in strong baroclinic regions.


Slantwise and upright convection are observed to co-exist

“Down-scale” event (Xu, 1986)
A case over Italy: MSG images (vis.), 30 Oct. 2008, 0915 UTC North - Central Italy

non-stationary lee waves

rain-bands

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Numerical experiments:
NH model MOLOCH, 0.9 km grid, 50 levels - 12 h simulations, from 01:00 UTC of 30/10/2008, nested in BOLAM and starting from NCEP analysis and boundary data.

500 hPa analysis (GPH and T) at 12:00 UTC, 30 Oct 2008
(modified from: NWS DIFAX weather map archive at archive.atmos.colostate.edu)

MOLOCH model domain and cross-sections
Experiment with full topography

Model accumulated precipitation at 0924 UTC

Model vertical velocity w at 700 hPa 0924 UTC
Experiment with full topography

- Normal wind and dry potential temperature 09:00 UTC
- Relative humidity and cloud condensate 09:00 UTC
Experiment with flattened topography,

Average cross-section of pseudo-momentum $M$ and dry potential temperature $\theta$, 07:12 UTC

Convection-generated "buckle" of $M$

Average cross-section: relative humidity (colour) and cloud condensate (liquid water + ice, thick lines), 08:42 UTC

Symmetrically unstable (dry or moist?)
• **Shaded**: dry statically stable, dry \( PV<0 \) → dry Symmetric Instability.
• **Thick lines**: moist \( PV<0 \), saturated and moist statically stable → moist Symmetric Instability.
• **Thin lines**: areas of absolute vorticity < 0 → Inertial Instability.

Potential temperature \( \theta \) and pseudo momentum \( \mathbf{M} \).
Averaged cross-sections

- Shaded: dry statically stable, dry PV<0 → dry Symmetric Instability.
- Thick lines: moist PV<0, saturated and moist statically stable → moist Symmetric Instability.
- Thin lines: areas of absolute vorticity < 0 → Inertial Instability.

Potential temperature $\theta$ and pseudo momentum $M$. 
• Shaded: dry statically stable, dry PV<0 → dry Symmetric Instability.
• Thick lines: moist PV<0, saturated and moist statically stable → moist Symmetric Instability.
• Thin lines: areas of absolute vorticity < 0 → Inertial Instability.

Potential temperature $\theta$ and pseudo momentum $M$. 

Averaged cross-sections
• Shaded: dry statically stable, dry PV<0 \rightarrow dry Symmetric Instability.

• Thick lines: moist PV<0, saturated and moist statically stable \rightarrow moist Symmetric Instability.

• Thin lines: areas of absolute vorticity < 0 \rightarrow Inertial Instability.

Potential temperature $\theta$ and pseudo momentum $M$. 
In this area the motion follows dry isentropes although the air is saturated.

Possible effects of condensate on buoyancy?

Thin: dry pot. temp. $\theta$.
Thick: saturated equivalent pot. temp. $\theta_{es}$.
Shaded: saturated areas /r.h.> 95%).
Comparison of cross-sections with (left) and withouth orography (right).
Summary

- Numerical simulations starting from a real situation show occurrence of S. I.

- S. I. is mixed with upright convective cells ("up-scale" development; Δ-M adjustment).

- Slanted circulation is slower than the upright convection, but develops coherently along a distance of 100 km

- Slanted motion appears locally dry/moist; dry trajectories even in saturated areas - possible role of condensate loading in reducing moist instability.