Mesoscale convective weather and conserved variables

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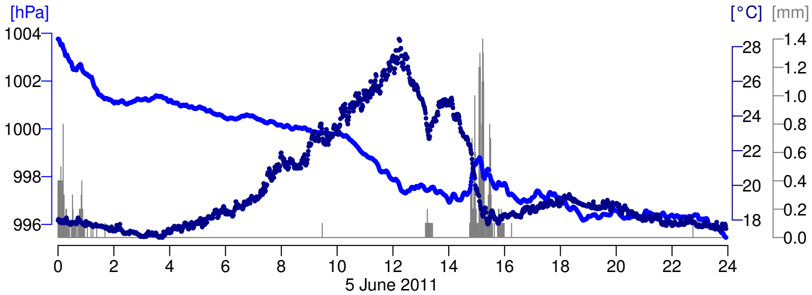
Motivation: atmospheric mesoscale extremes

High-Impact Weather – Bonn 5 June 2011



- Figure (P. Friederichs): 66-68 mm precipitation within 2 hours in Bonn $\Rightarrow$ How do we forecast this?
- Central aim Wex-Mop: Towards a next-generation mesoscale prediction system for extreme weather
- Hypothesis: Conserved quantities like PV play a role in extremes

Potential Vorticity

Definition Potential Vorticity (Ertel 1942)

$$\Pi \equiv \frac{(\omega_{\mathbf{r}} + 2\Omega)}{\rho} \cdot \nabla\theta$$

Terms

- $2\Omega \Rightarrow$ Planetary vorticity (earth rotation)
- $\omega_{\mathbf{r}} \equiv \nabla \times \mathbf{u} \Rightarrow$ Relative vorticity (rotation relative to earth)
- $\nabla\theta \Rightarrow$ Gradient of potential temperature (entropy)

- Dynamic (rotation of wind field) and thermodynamic information
- Conserved for adiabatic, frictionless flow ($\frac{d\Pi}{dt} = 0$)
- On (convective) mesoscale investigations relatively new

Π evolution

Haynes & McIntyre (1987)

$$\frac{\partial \rho \Pi}{\partial t} + \nabla \cdot (\rho \Pi \mathbf{u} - \dot{\theta} \zeta_a - \mathbf{F} \times \nabla \theta) = 0$$

- Local change Π
- Change of Π by advection
- Change of Π by diabatic effects
- F: applied force per unit volume, e.g. friction
- Since it is in divergence form, friction and diabatic effects only create Π at the boundaries

Raymond et. al. [1990] & Chagnon et. al. [2009]

- Π dipoles by heating effects, $\frac{d\rho\Pi}{dt} = \zeta_a \cdot \nabla(\dot{\theta})$
- Main component vorticity: $\zeta_a \approx \mathbf{k} \times \boldsymbol{S}$, with $\boldsymbol{S}$ the wind shear
- Maximum $\dot{\theta}$ at about 5km
- Horizontal dipoles with Π values up to 50*$\overline{\Pi}$ at storm cell, proportional to strength updraft and wind shear

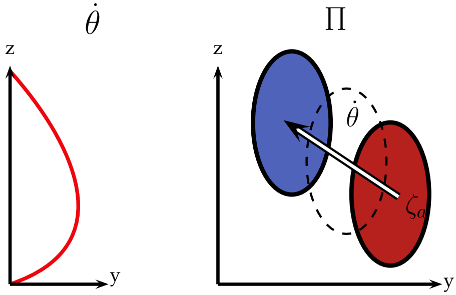


Figure: Schematic of dipole generation of storm updraft. (red: positive Π anomaly, blue: negative Π anomaly)

Lift induced by dipoles?

- On large scales, Π anomalies 'induce' vertical motion
- Positive (negative) w induced downflow (upflow) of positive Π anomaly
- Banded structures of Π? ⇒ Balanced flow around dipoles?
- Classical: new cells generated downshear
- Positive anomaly advected to updraft if streamwise vorticity exists
- Hypothesis: PV bands slightly tilted right of S

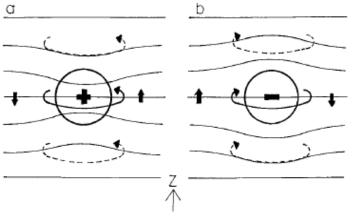


Figure: Balanced flow at PV anomalies, source: Hoskins[1997]

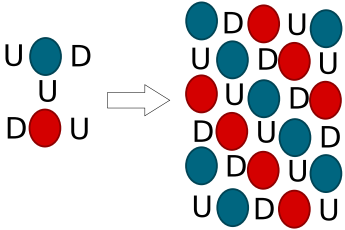


Figure: Schematic overview lift induced by dipoles

Methodology

Central question: Are there any structured PV bands and how consistent are they?
Hypothesis: PV bands, direction dependent on wind shear

Methodology:

1. Composites of storm updrafts: mean fields around a vertical velocity maxima above certain threshold (5 m/s).
2. Anisotropic spectrum: spectral energy for specific wave number and direction.

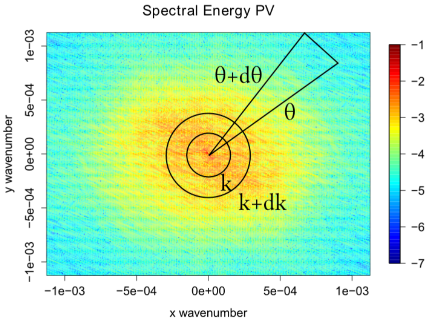


Figure: Calculation of energy for specific direction and scale

Data used

- COSMO-DE: nonhydrostatic weather model, centred over Germany, resolution 2.8 km
- EPS system used: 20 ensemble members
- Two cases to test hypothesis: 05-06 (local convection) and 22-06 (convection along cold front)

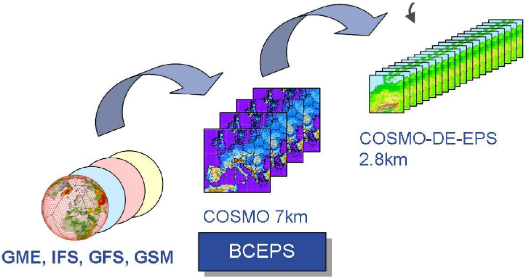


Figure: COSMO-DE-EPS, 20 ensemble members out of 4 different b.c. and 5 physical perturbations. Source: DWD (Theis et al: Beschreibung des COSMO-DE-EPS und seiner Ausgabe in die Datenbanken des DWD.)

Π dipoles 05-06: no alignment

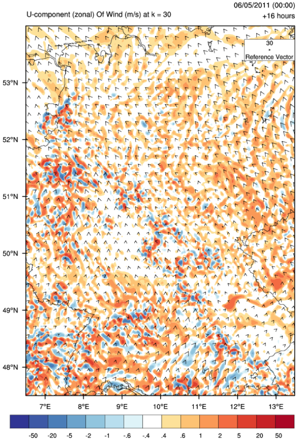


Figure: Π and wind speed at ≈ 3km for 05-06-16h UTC

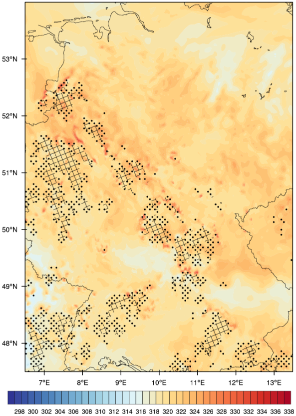


Figure: θ at ≈ 3km and precipitation for 05-06-16h UTC

Π dipoles 22-06: coherent alignment

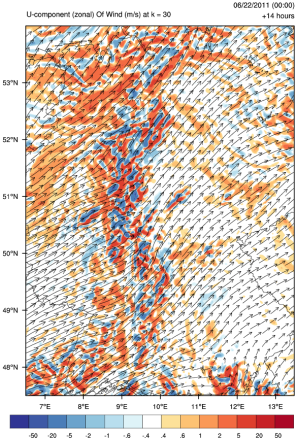


Figure: Π and wind speed at level 30 for 22-06-14h UTC

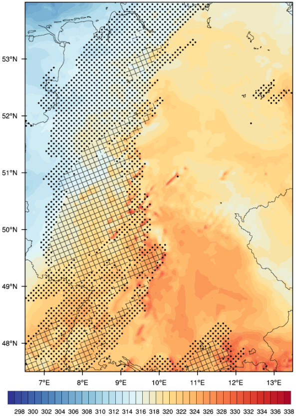
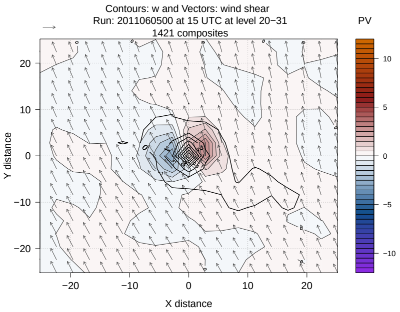


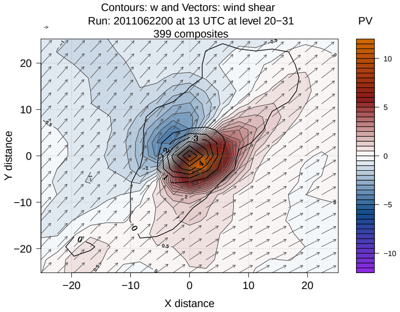
Figure: θ at level 30 and precipitation for 22-06-14h UTC

Composites

- Average Π, **u**, etc. around (50x50 km) a storm updraft
- Height integrated (3-7.5km) PV, vertical velocity and 0-6 km wind difference (vectors)
- Mean value subtracted to get perturbed fields
- Clear Π anomalies, consistent with direction wind shear



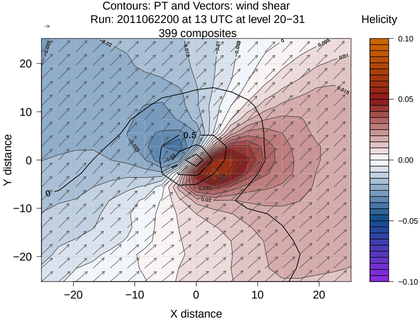
(a) 05 June 2011 15h



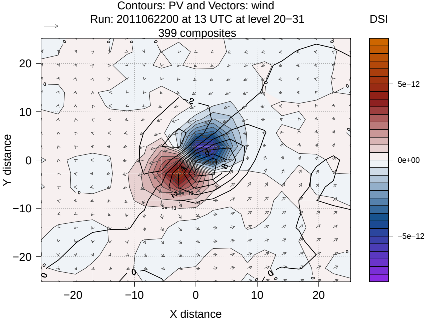
(b) 22 June 2011 13h

Composites

- Clear anomalies for helicity and the dynamical state index (which measures deviation from stationary, adiabatic atmosphere)
- Flow around positive anomaly anticyclonic, so at least quasi-balanced



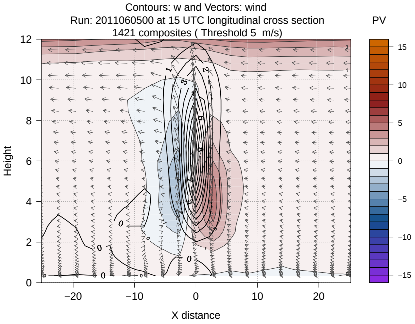
(c) 22 June 2011 13h



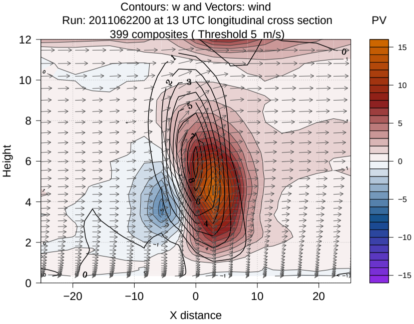
(d) 22 June 2011 13h

Composites

- Longitudinal cross section, PV dipoles visible over large part of atmosphere
- Maximum values at about 5-6 km.
- Updraft slightly tilted to the east with height for 22-06



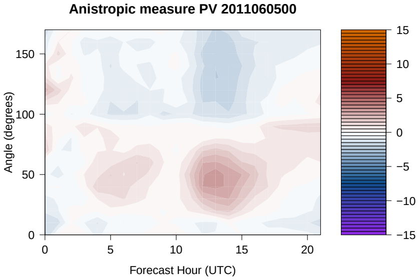
(e) 05 June 2011 15h



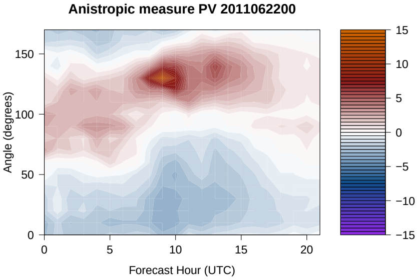
(f) 22 June 2011 13h

Anisotropic measure

- Fraction of energy in specific direction on convective scale (16-44 km)
- Prefered direction slightly to the right of wind shear?



(g) 05 June 2011



(h) 22 June 2011

Conclusion/Outlook

- Π conserved in COSMO-DE model (not shown)
- Organisation of storm cell structures can be explained with PV thinking
- Dipoles quasi-balanced, adjustment?
- Composites show that dipoles are consistent in strength and direction
- Possible use: predictor for severe weather like (convective) precipitation and wind gusts?

Choice threshold composites

- Only interested in convective cells
- Non-zero DSI expected (since it is the deviation from adiabatic, stationary atmosphere)
- Threshold of 3 m/s or more will work

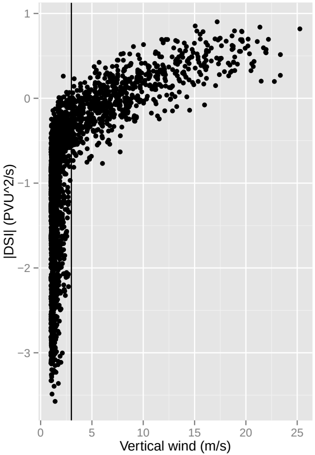


Figure: Height (3-7.5km) averaged w agains $|DSI|$ for 22-06 17h UTC