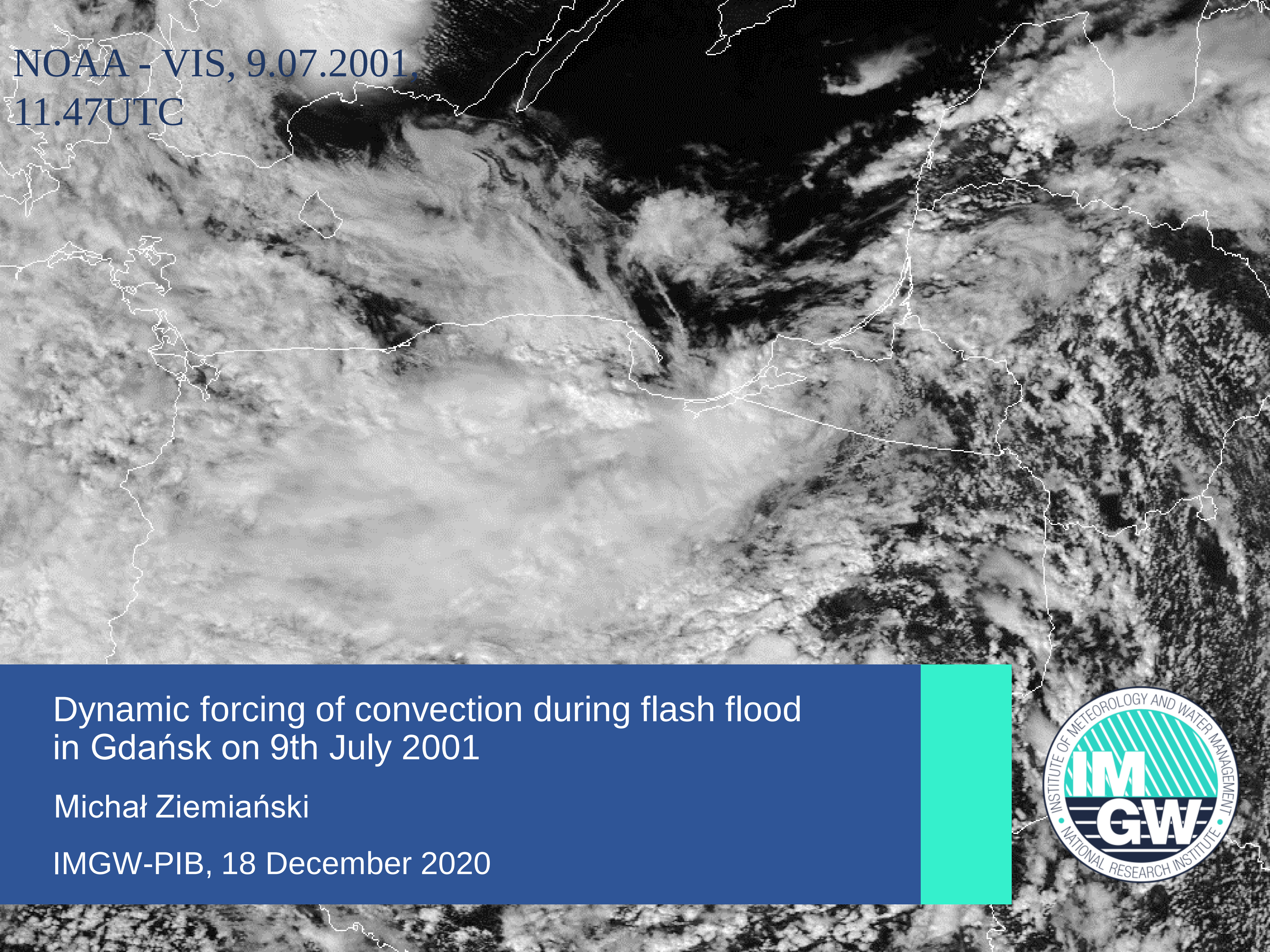


Dynamic forcing of convection during flash flood in Gdańsk on 9th July 2001

Michał Ziemiański

IMGW-PIB, 18 December 2020

- The urban flash flood in Gdańsk on 9th July 2001 brought fatalities and damages in infrastructure and properties
- in a few early afternoon hours, precipitation exceeded 100 mm …
- … but with observed CAPE of 170 J/kg and CIN of 82 J/kg it was not expected
- that suggests a presence of strong dynamic forcing of convection
- the current study aims at diagnosing that forcing and its sources

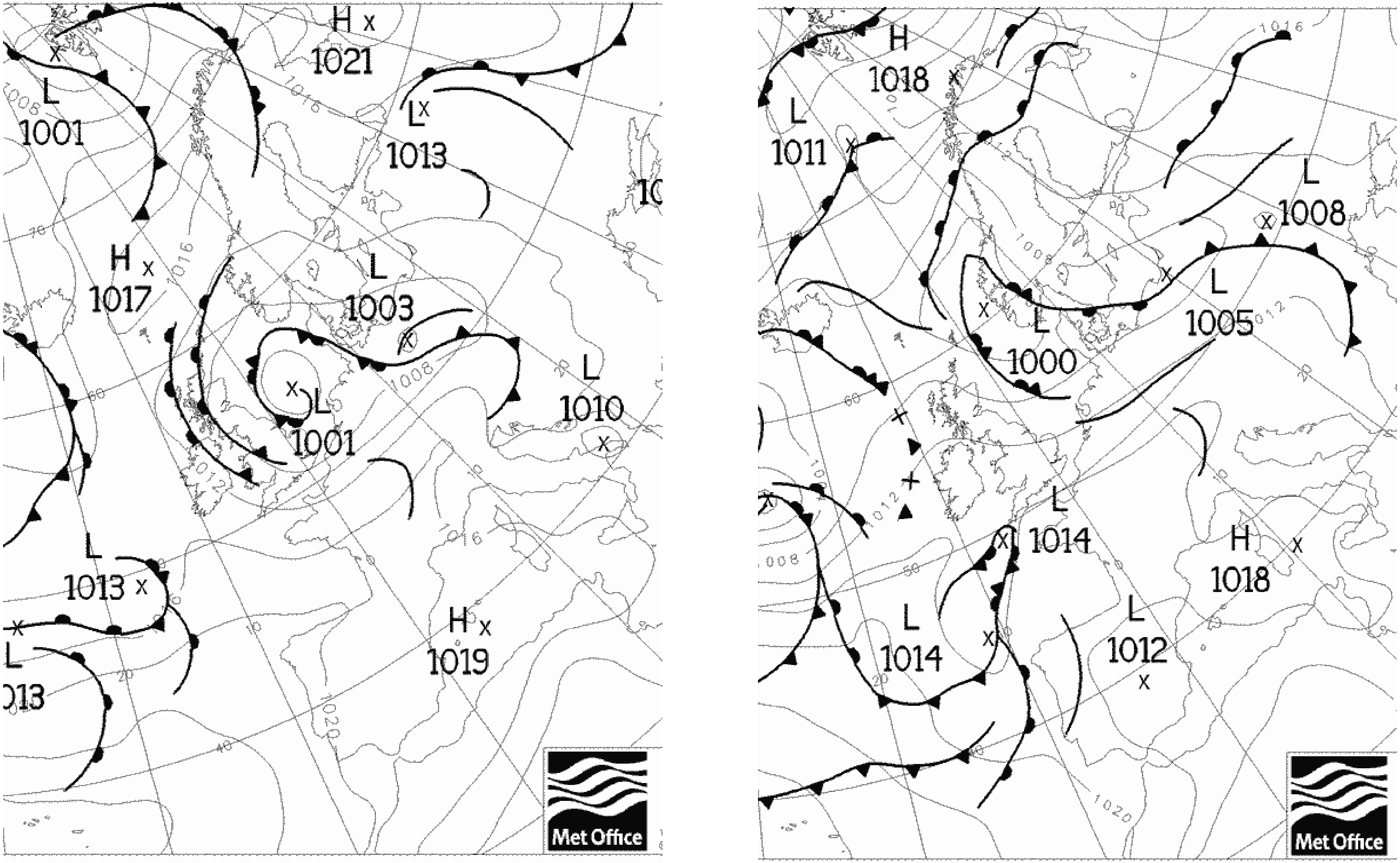
Content

Content of the presentation:

- brief overview of meteorological situation on 9th July 2001
- introduction to potential vorticity (PV) and to PV – based diagnosis of the dynamic forcing of convection
- reconstruction of the PV – based dynamic forcing of convection for that situation
- conclusions

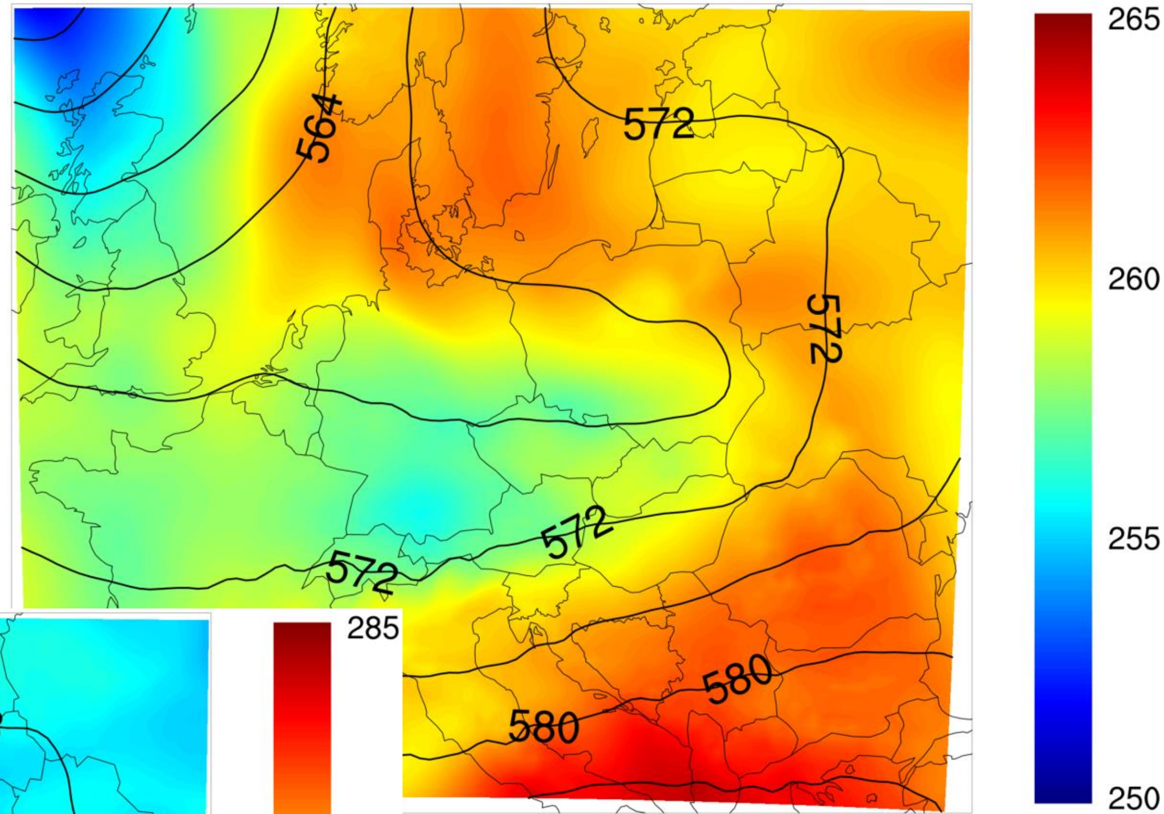
Remarks:

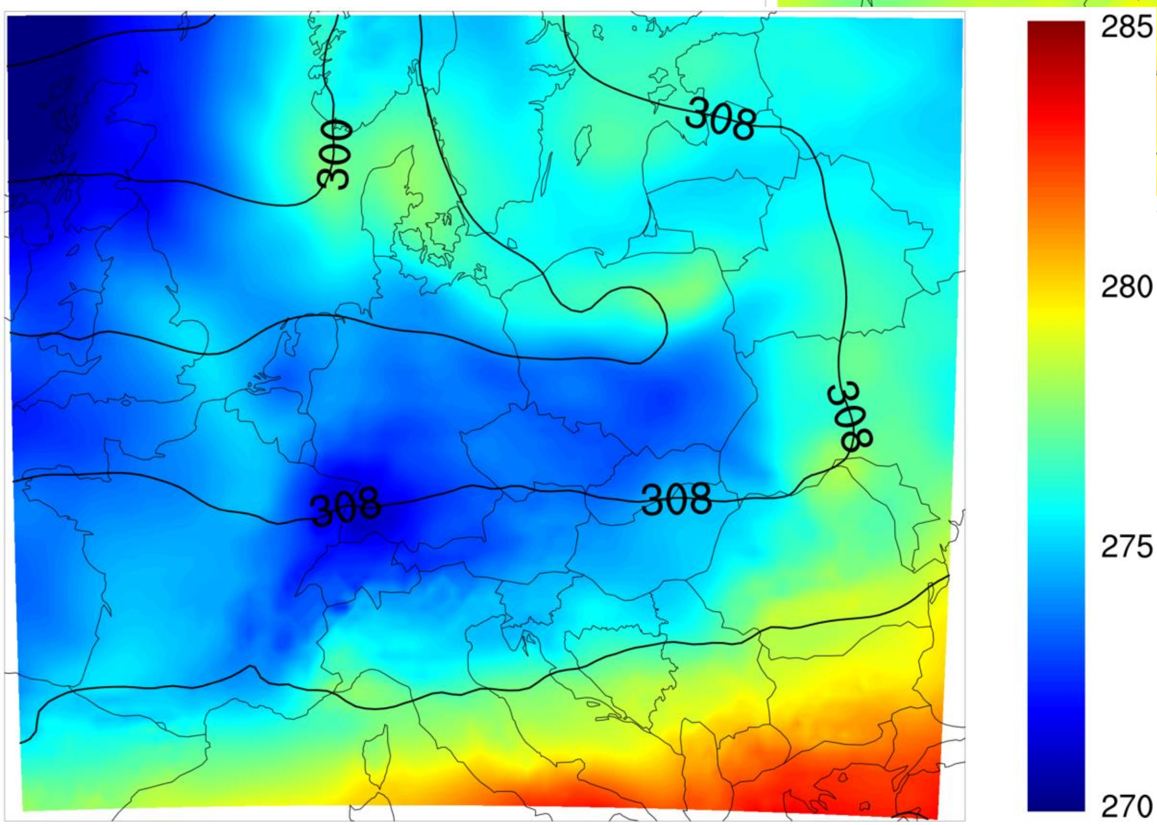
- the work still in progress



Met Office surface analysis from 00.00 UTC 8 July 2001 (left)
and from 00.00 UTC 9 July 2001 (right)

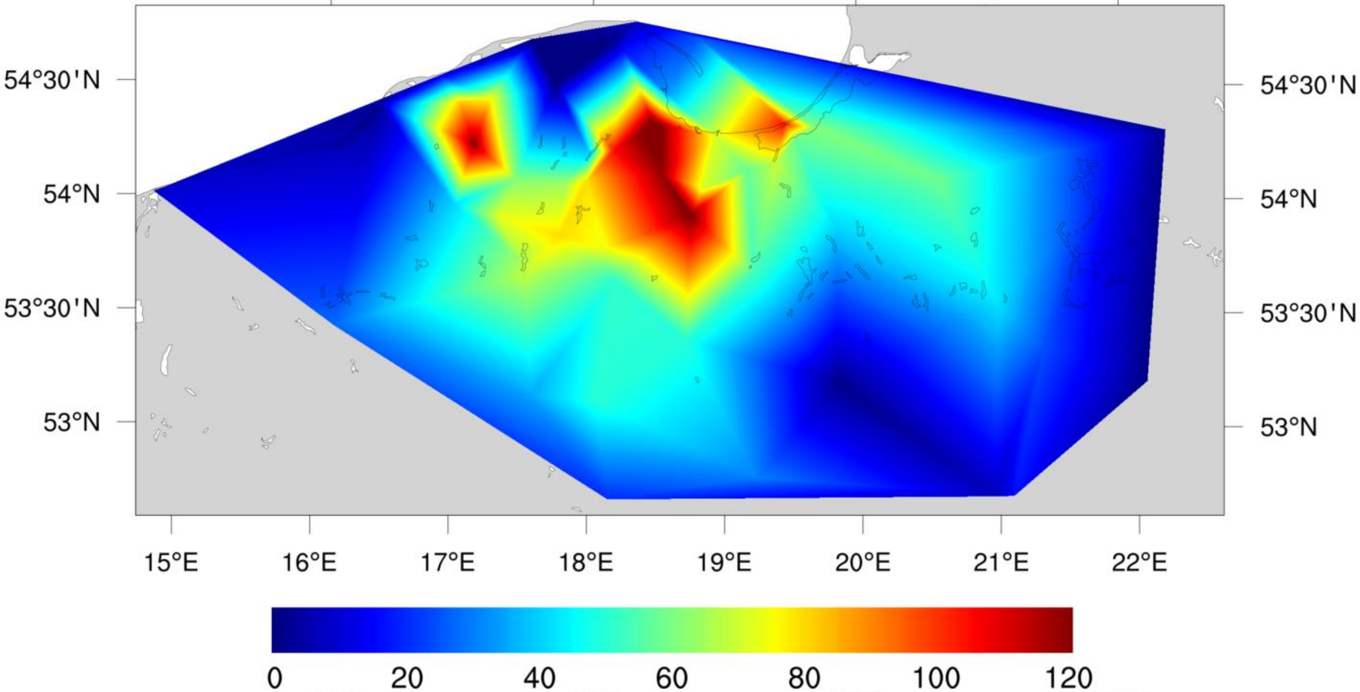
Right: 500 hPa analysis of geopotential (black contours, in dm) and temperature (in K, colours) from operational COSMO model at 00.00 UTC on 9 July 2001

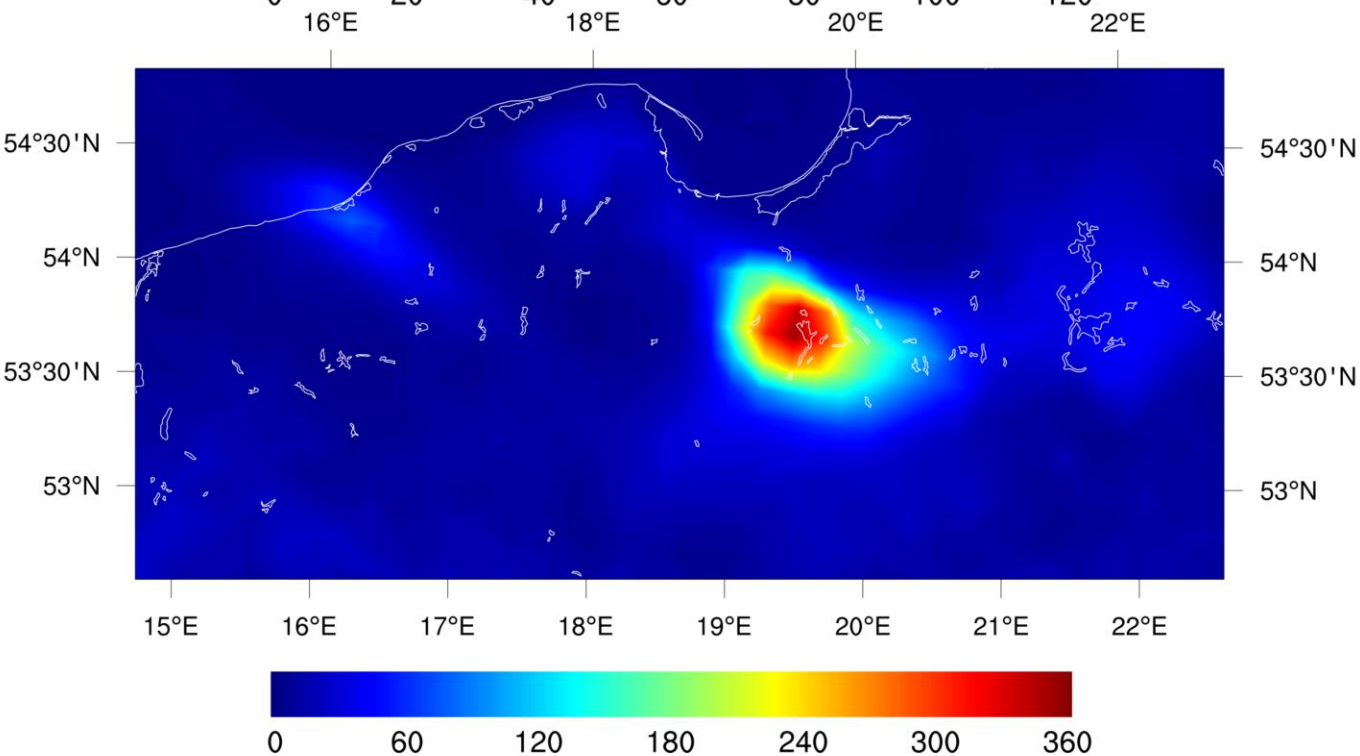




Left: 700 hPa analysis of geopotential (black contours , in dm) and temperature (in K, colo-urs) from operational COSMO model at 00.00 UTC on 9 July 2001

(whole domain of operational COSMO model is shown)





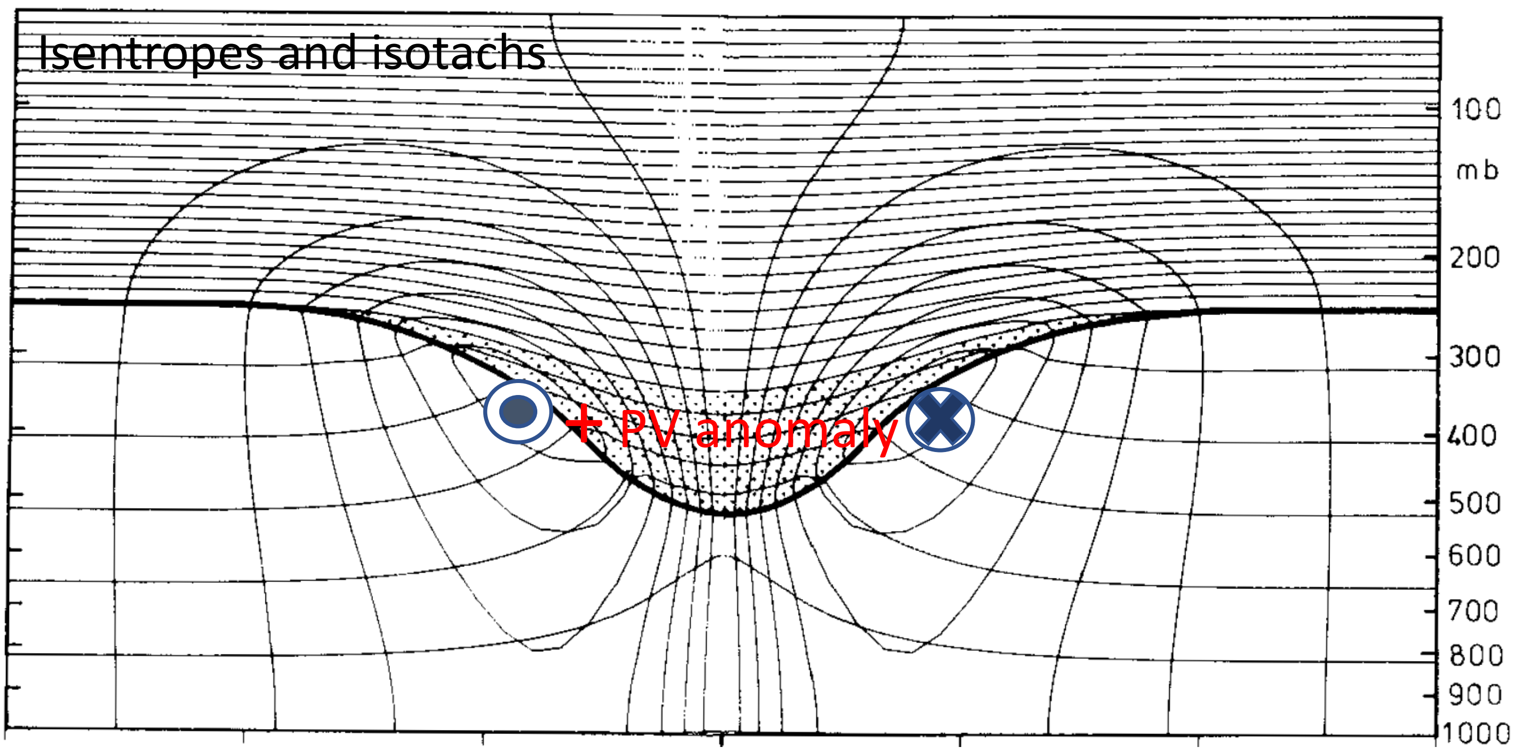
- Top: precipitation on rain gauges from 06.00 to 06.00 UTC on 9/10 July 2001

- bottom: precipitation from the COSMO model for 00.00 to 18.00 UTC on 9 July 2001

- operational COSMO model from 2001: horizontal grid step of 14 km, 37 vertical levels

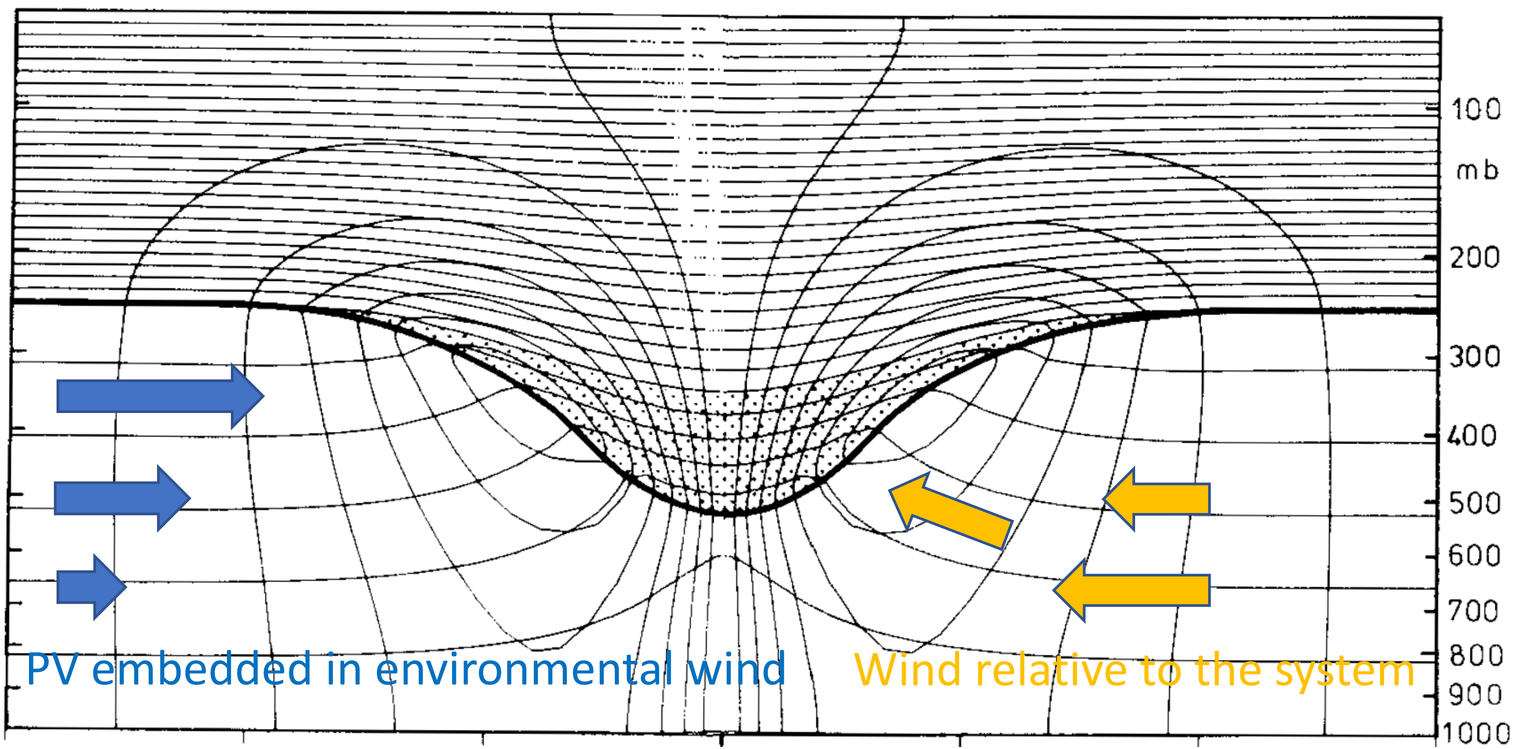
PV and its invertibility

- Potential vorticity: $PV = \vec{\omega} \cdot \nabla\theta/\rho$ (where $\vec{\omega}$ is vorticity, θ is potential temperature and ρ is density) is conserved by adiabatic and frictionless flow
- in synoptic scales PV is dominated by vertical components of $\vec{\omega}$ and $\nabla\theta$: is smaller in troposphere (below 1 PVU) and larger in stratosphere (range of 10 PVU)
- PV may be inverted to diagnose wind and temperature for specified balances (hydrostatic, geostrophic) and boundary conditions (HMR 1985, AT 1986):



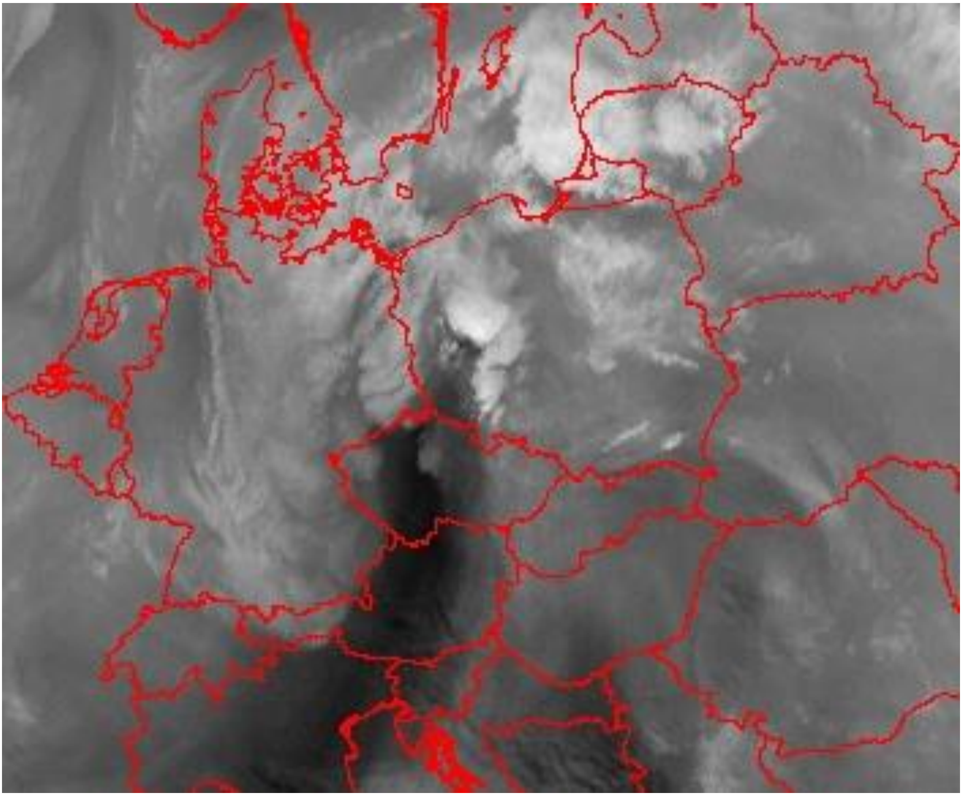
PV and dynamic forcing of convection

- Dynamic forcing: dynamics of stability ($\partial\theta/\partial z$): below the positive PV anomaly of stratospheric origin, stability is reduced: dynamic forcing
- when upper-level positive PV anomaly moves faster than air below, there is a zone of ascent (isentropic upgliding) in the transition area between the zones of stronger and weaker stability: stability diminishes there: dynamic forcing
- in line with basics of synoptic meteorology: area of ascent ahead of upper-level troughs (synoptic manifestations of positive upper-level PV anomalies):

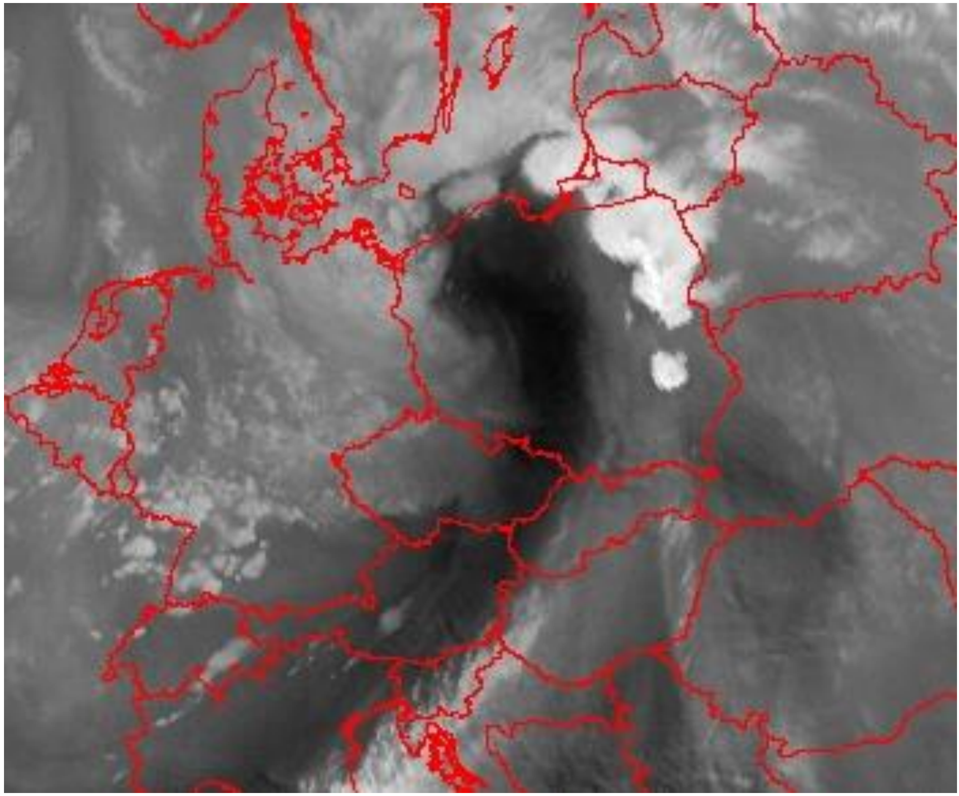


PV and dynamic forcing of convection

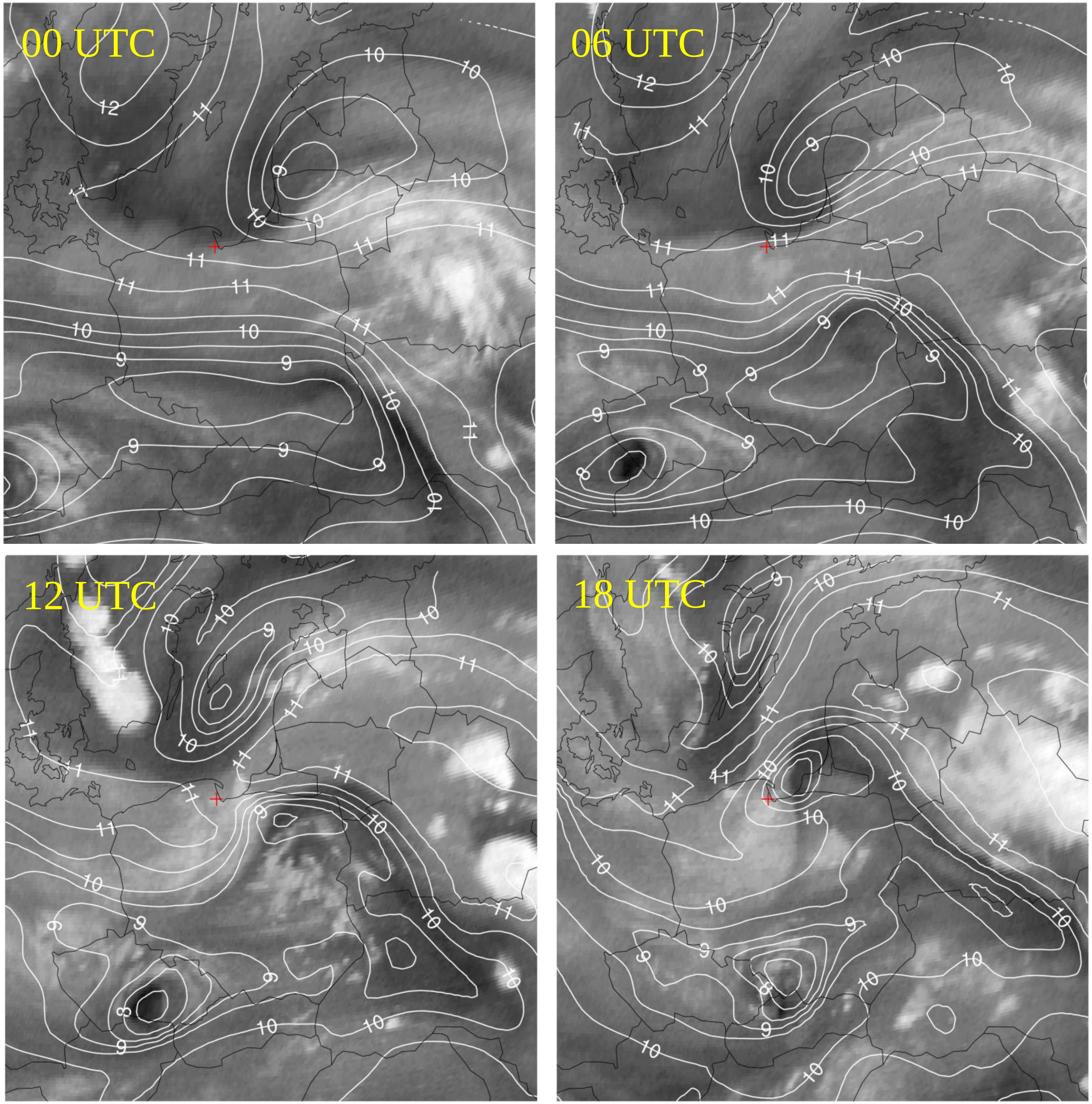
- Intrusions of dry stratospheric air having large PV (positive PV anomalies) are seen as dark areas in WV satellite images (Appenzeller, Davies 1992)
- on their leading edge an area of ascent and dynamic forcing of convection shoud be expected:



Meteosat WV, 17.06.2016, 0700 UTC



Meteosat WV, 17.06.2016, 1215 UTC



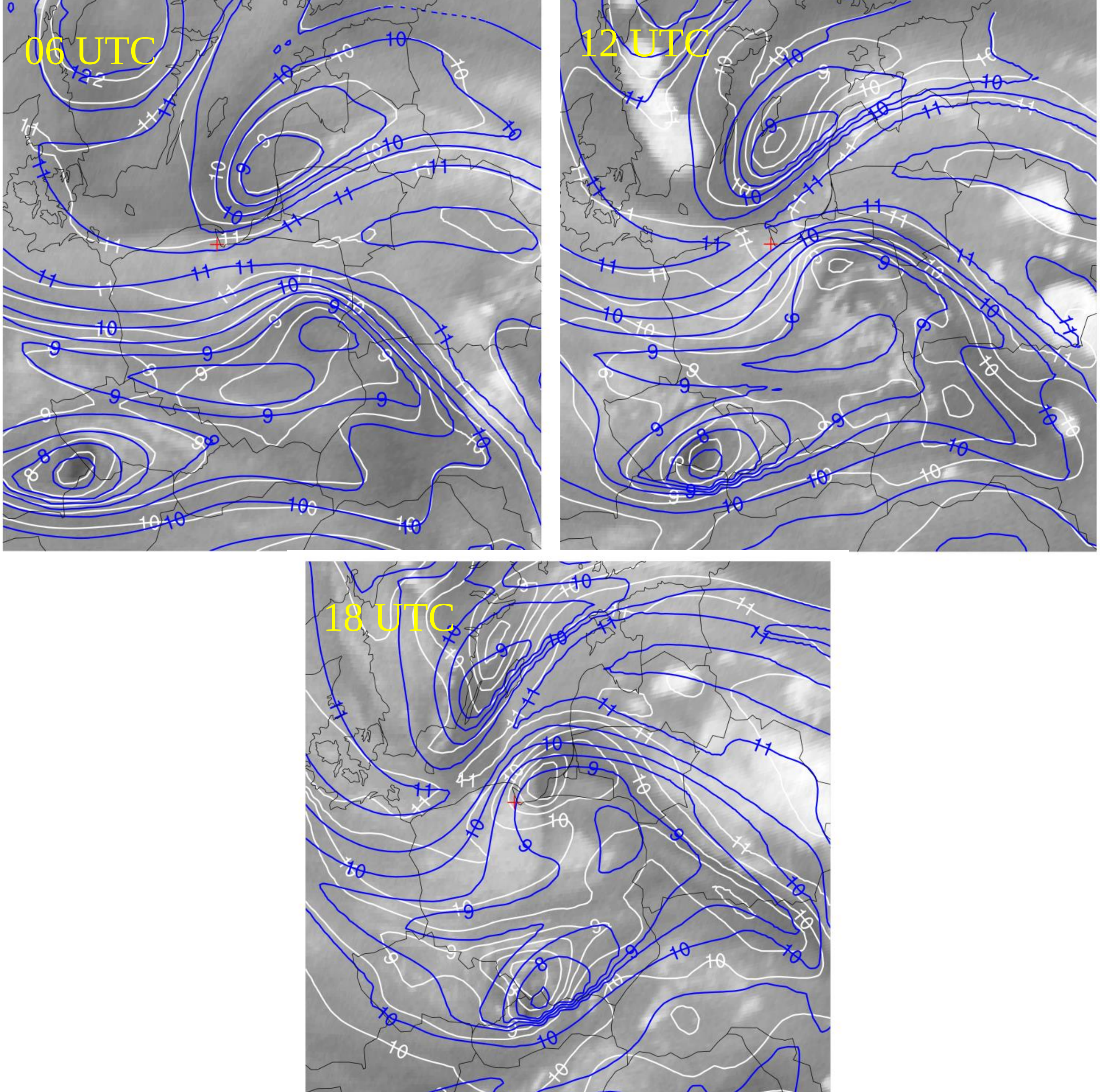
Back to our case:

Evolution of WV 6.2 μm Meteosat channel (grey) and altitude of COSMO model tropopause (at PV = 1.7 PVU; contours every 0.5 km) on 9 July 2001:

- disparities betwe-en the PV and WV fields and their evolutions
- potential problem with model diagnosis of the forcing

PV thinking in use

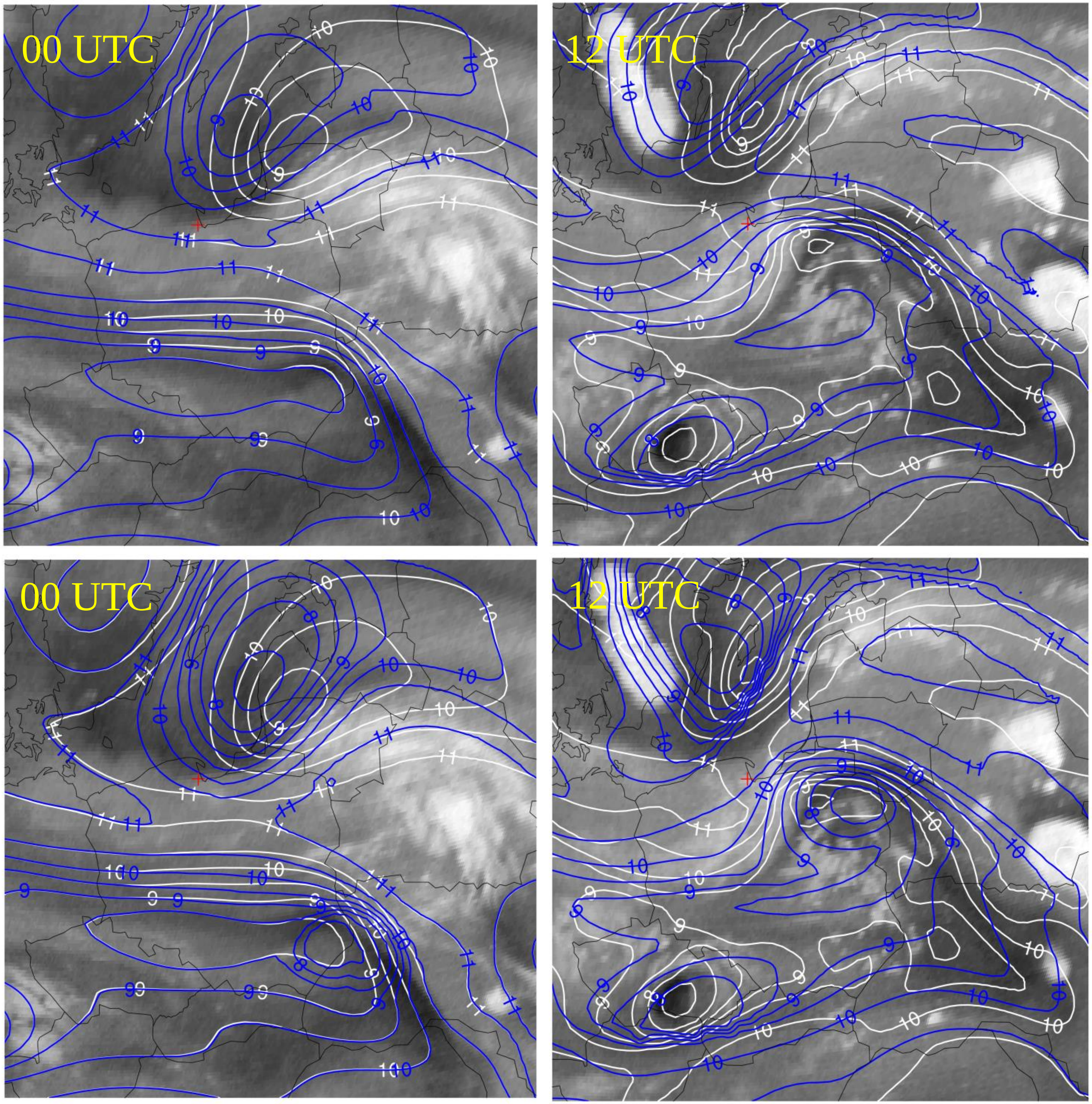
- General consequence of PV invertibility: in synoptic and meso scales the atmospheric dynamics can be understood as an interplay beetween PV perturbations which are carried by the flow (induced by themselves)
- mathematically, the idea can be represented by a model having PV as its prognostic variable and diagnosing atmospheric parameters via its inversion (omega equation allows to diagnose vertical velocity and non-rotational flow)
- for mesoscale processes a non linear balance (NLB) is required (Raymond 1990; Davies & Emanuel 1990)
- here, it is sufficient to have PV conserved, but that can be (in principle) relaxed
- the PV-NLB model: adiabatic and frictionless, 27 lev. between 700 and 80 hPa, 10 min. time step, horizontal grid of 28 km, whole COSMO domain, IC and BC from operational COSMO model, reduced rotational wind (85%) (ZT 2001)
- main advantages: focus on pure dynamics and ability to experiment (prognostically) with alternative/modified initial PV perturbations
- the goal: to find out a PV configuration which evolves in accordance with WV observations and to assess its influence on the convective forcing over the Gdańsk area



Practical test of the PV-NLB model:

Evolution of tropopause topography according to the COSMO (white) and the PV-NLB (blue) models

- start at 00 UTC with COSMO PV distribution
- similar evolution of tropopause depressions

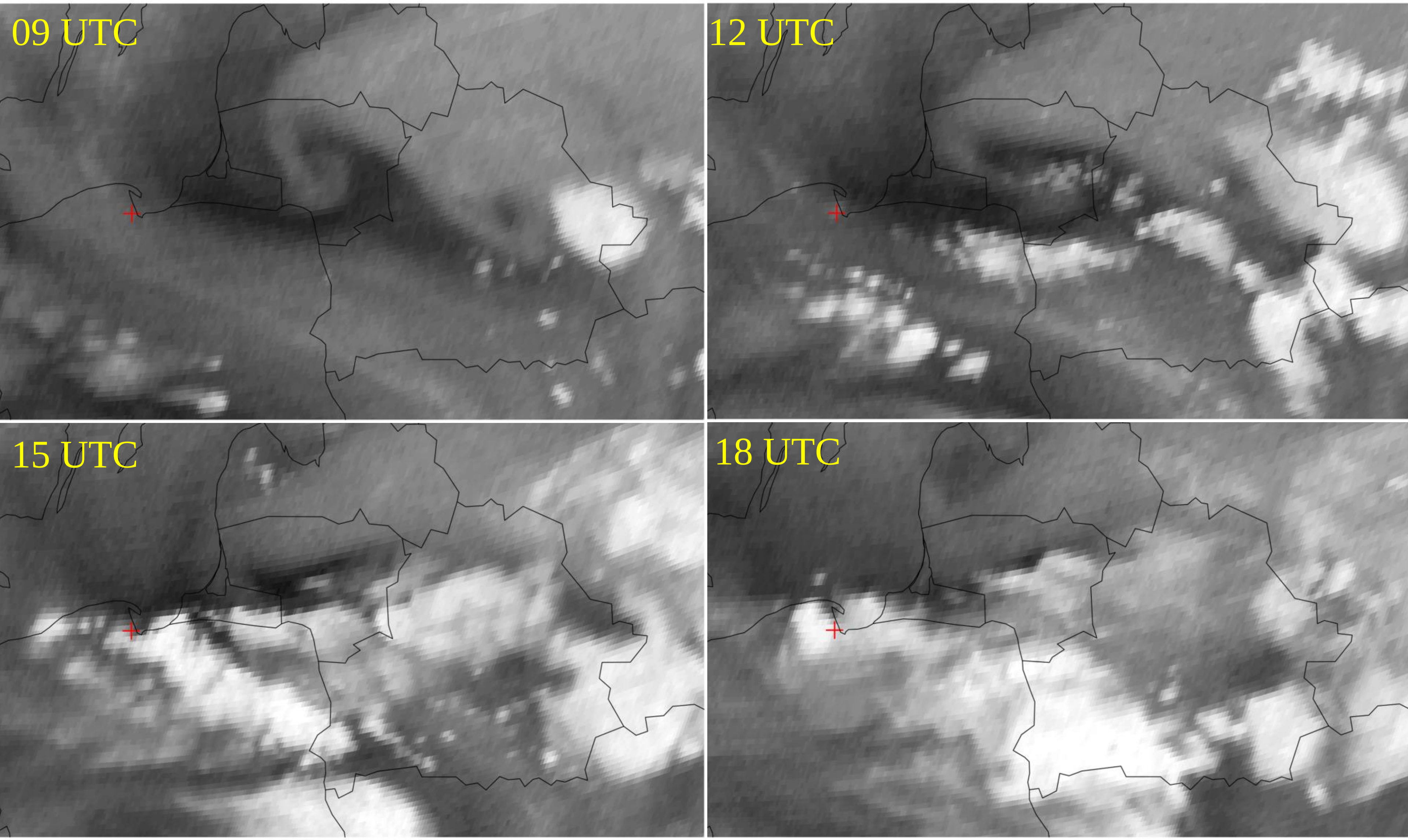


Tropopause modification experiments (blue for NLB, white for COSMO) :

top: initial positions of the depressions shifted toward their WV positions, and 12 hour forecasts

bottom: additional deepening of the depressions

result: lack of realistic evolution of the tropopause



Potential missing factor: a day before (8.07.2001): extensive deep convection east of Gdańsk (over NE Poland, Lithuania and Belarus) in afternoon hours below dark WV area (suggesting a presence of upper-level positive PV anomaly): a source of (horizontally) extensive diabatically produced tropospheric PV anomalies

Diabatic evolution of PV

- Diabatic processes produce PV dipols: $DPV/Dt = \vec{\omega} \cdot \nabla\dot{\theta}$
- their patterns and amplitudes are scale dependent: on a storm scale the dipols are mainly horizontal with amplitude ~10 PVU, on mesoscale weaker and more vertically oriented (Chagnon and Gray 2009 (CG))
- HMR: for larger scale effects, the PV integrated over fine grain structures matters („coarse grain approximation”)
- assumption: coarse grain approximated diabatic PV is alike the one from NWP parameterised convection

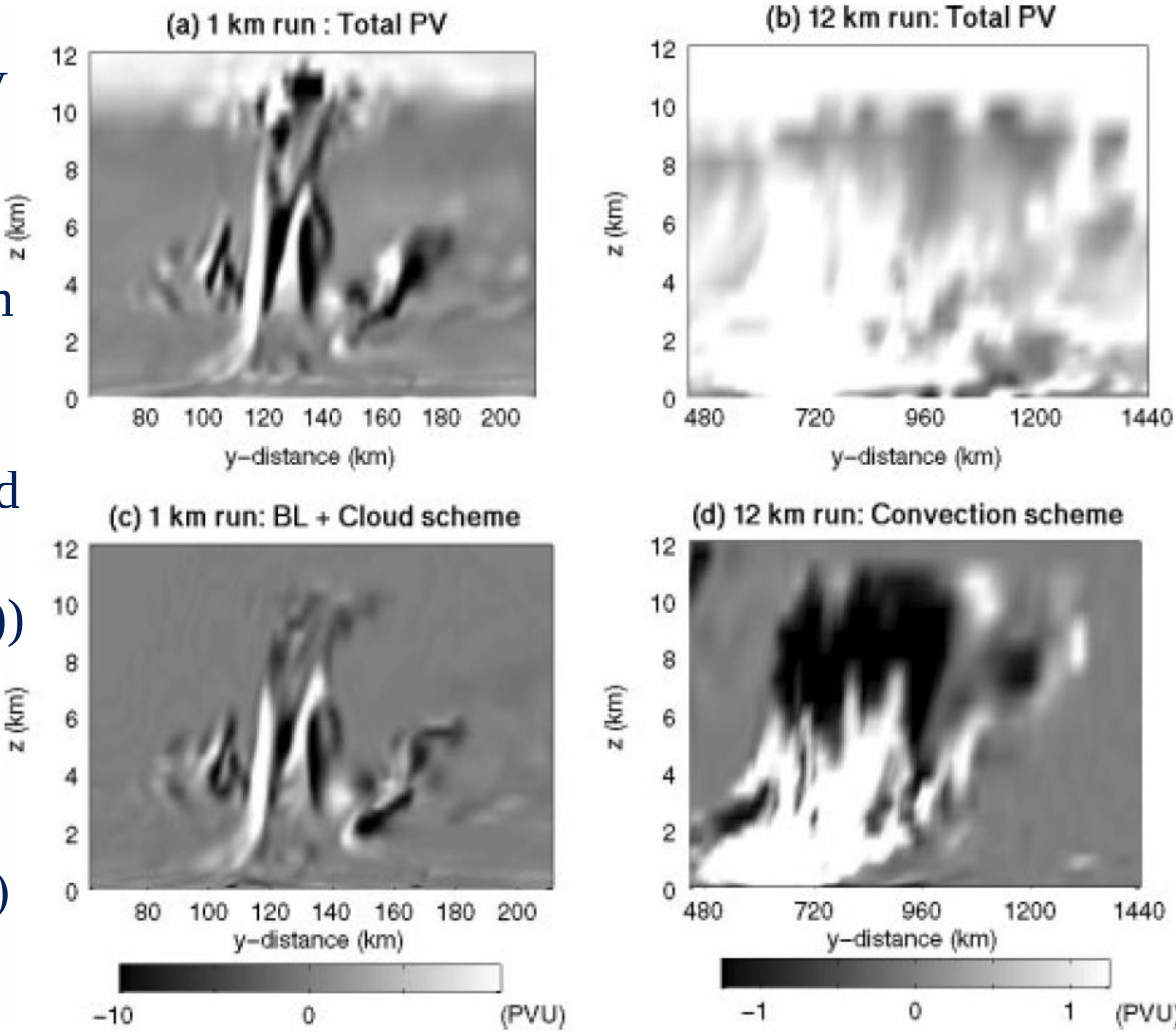
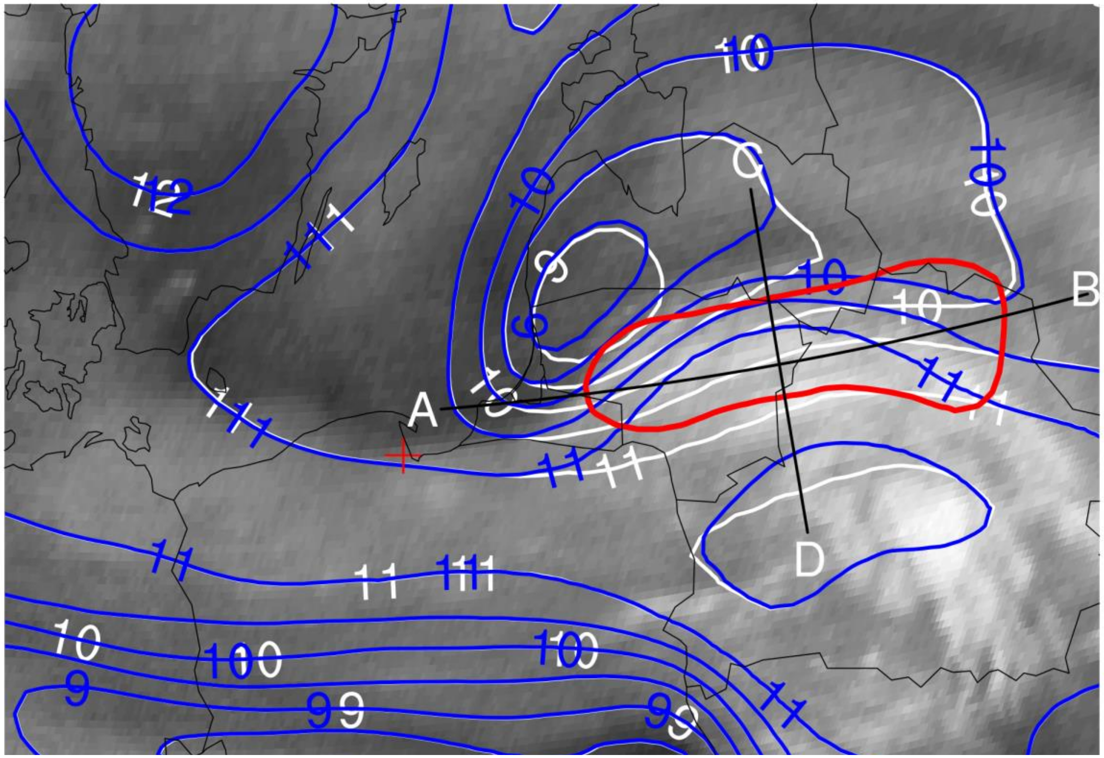
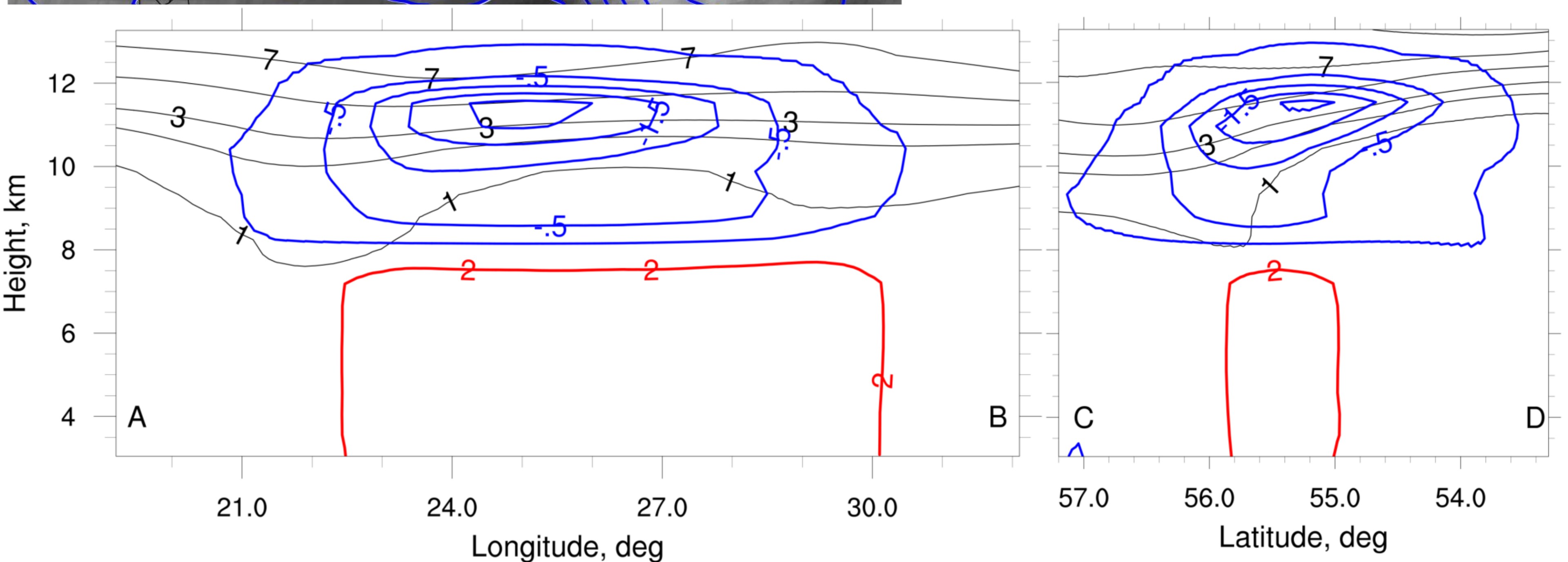


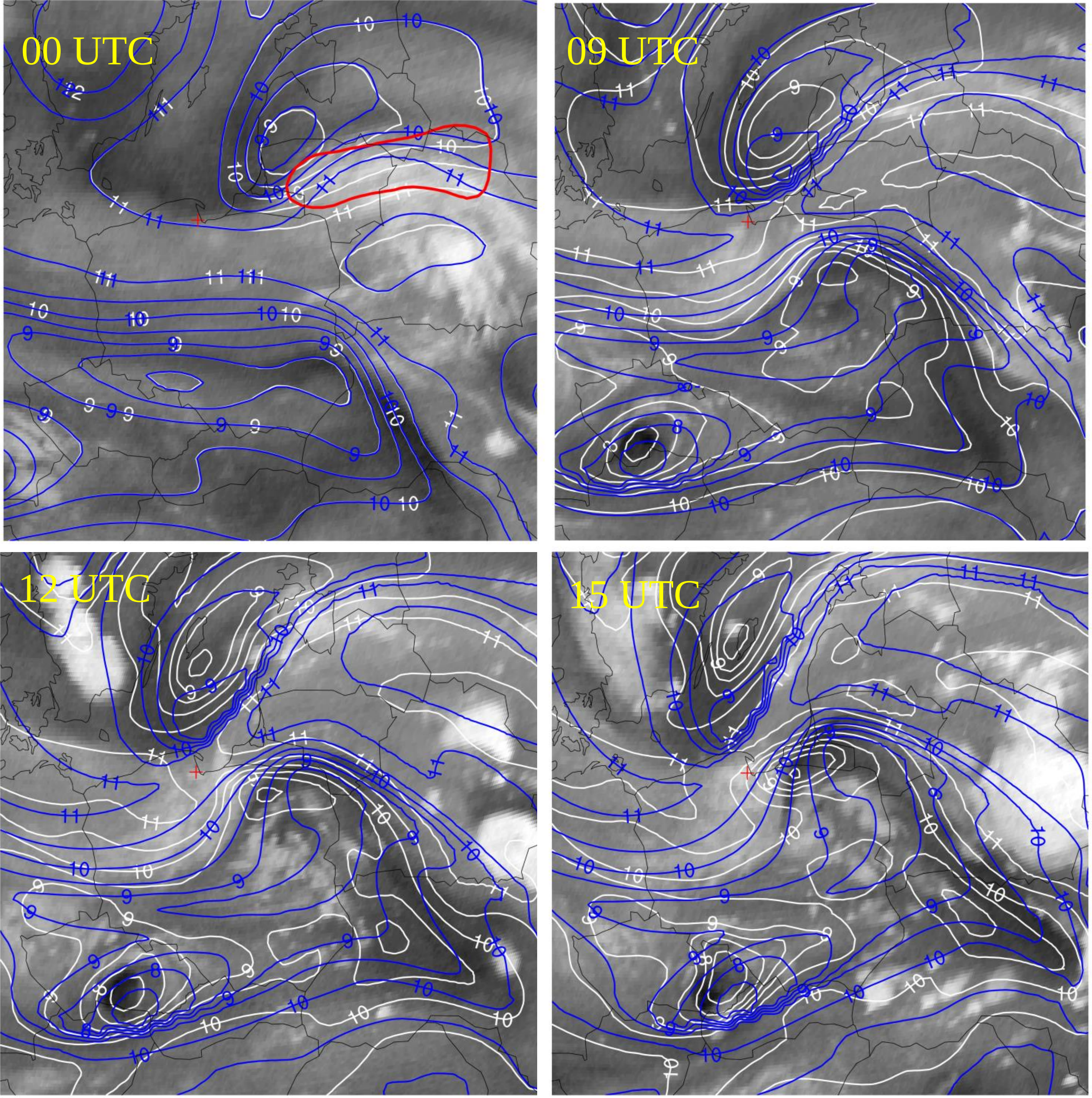
Figure 11 from CG showing vertical cross sections through PV distribution produced by a convective-scale (a) and convection-parametrised (b) NWP models



Coarse grain representation of diabatically modified PV

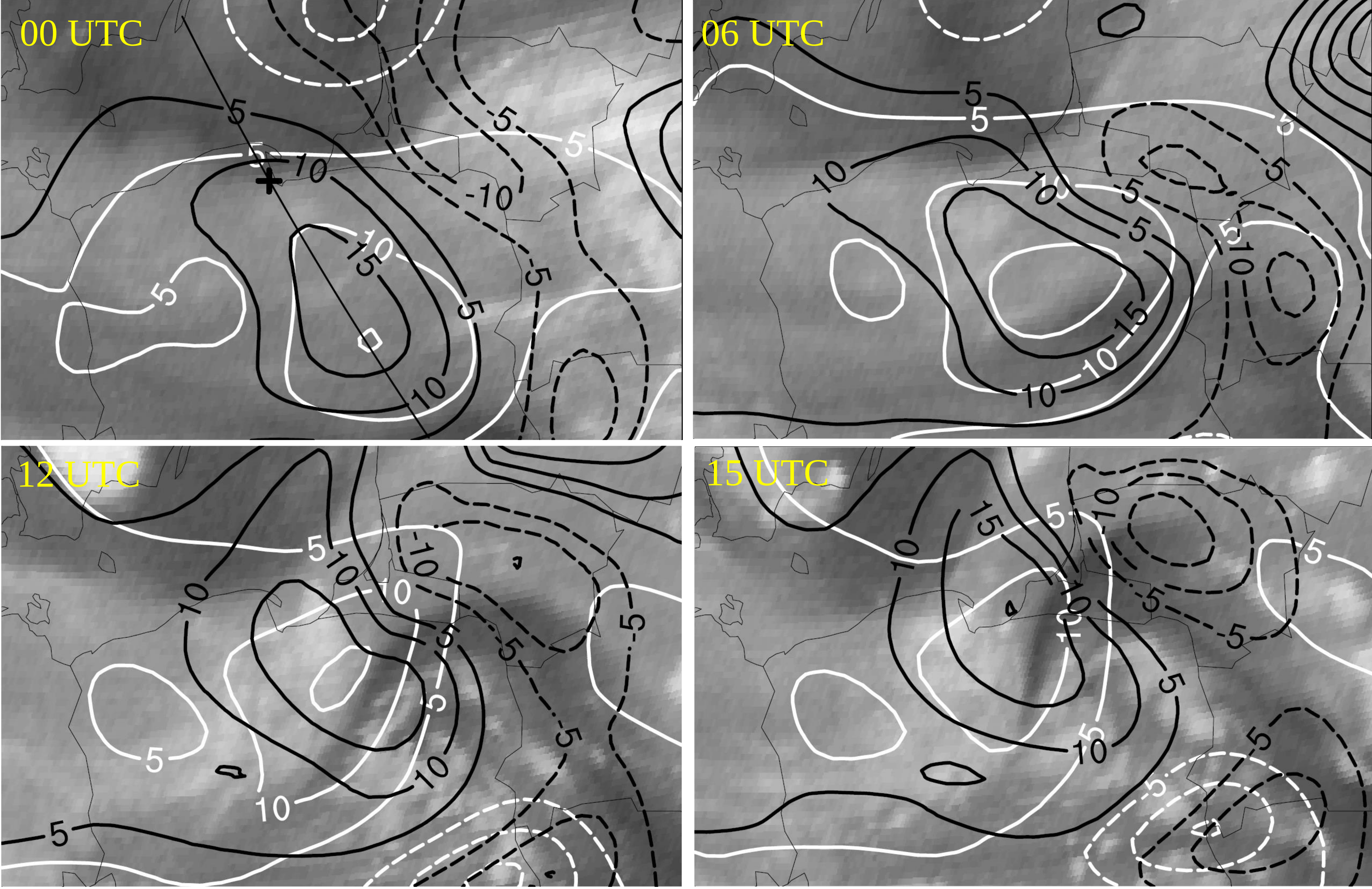
- positive lower part of the dipol: assume uniform PV of unknown aplitude
- negative upper part of the dipol: in the WV cloudy area, implement PV values from model analysis in neighbour cloudy areas



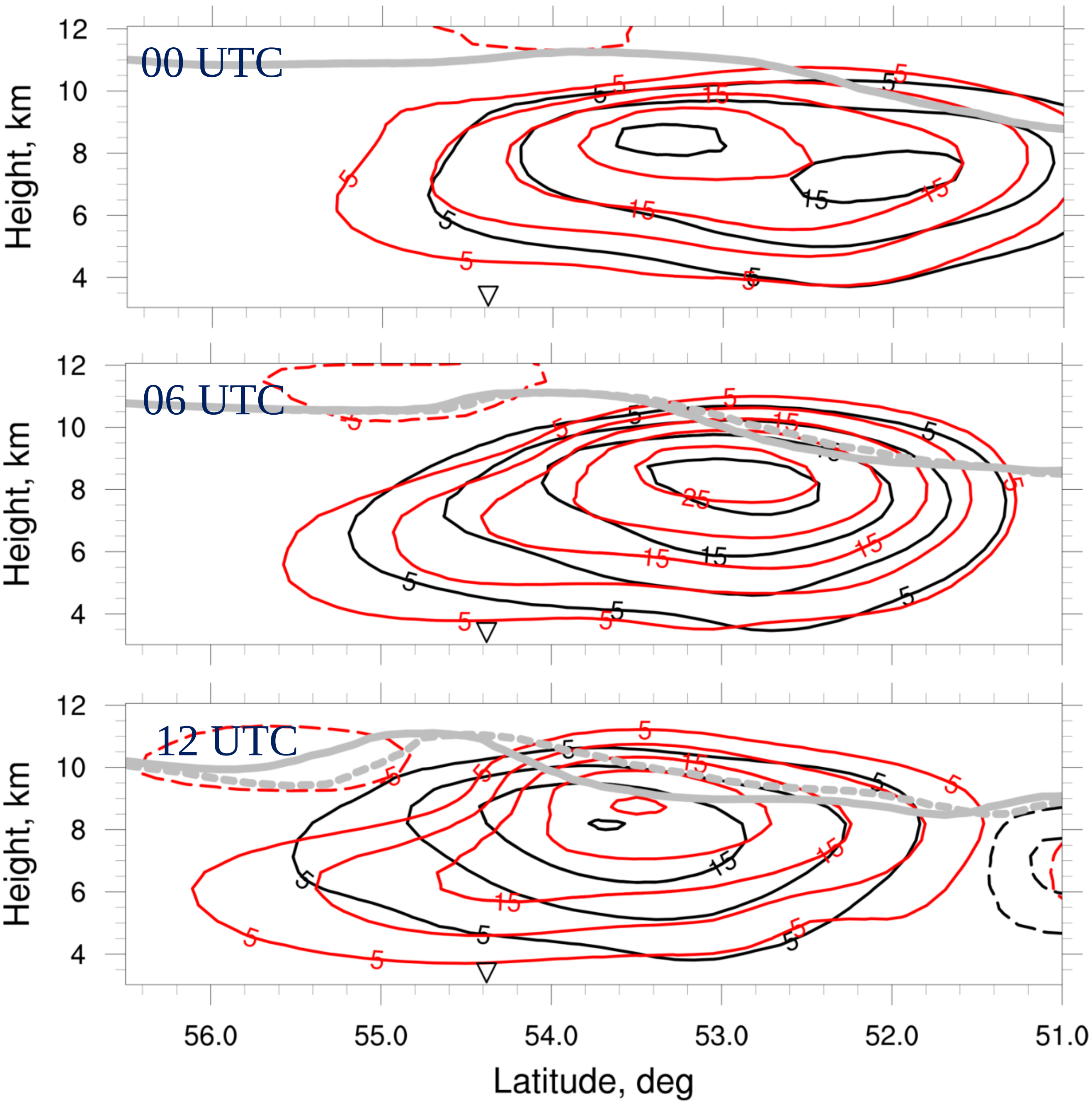


Prognostic experiments with different amplitudes of positive diabatic PV anomaly are performed:

- for PV amplitude of 2.25 PVU the evolution of both PV depressions is now very close to the WV diagnosis
- diabatatic PV anomaly seems to be the missing factor



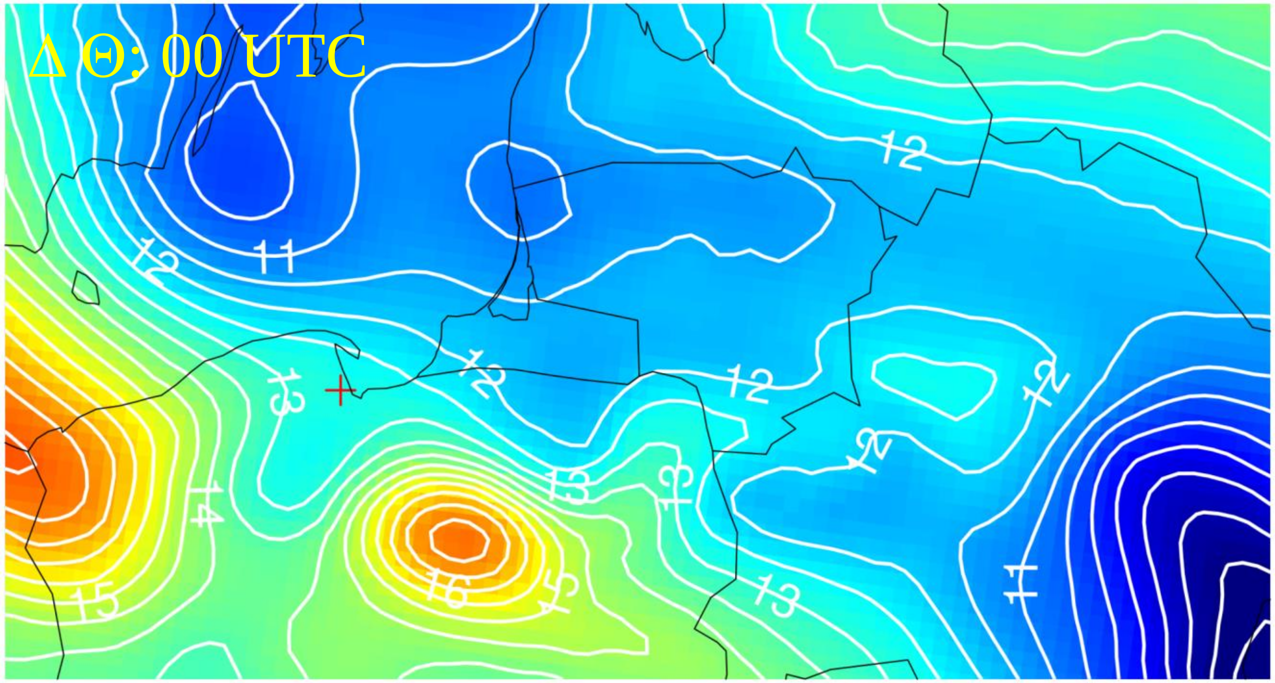
NLB vertical velocity (mm/s): induced by original PV (white) and with additional diabatic PV anomaly (black) at 6 km altitude: about 50% increase of ascent ahead of southern PV anomaly (also in Gdańsk region); ascent area related to southern PV anom.

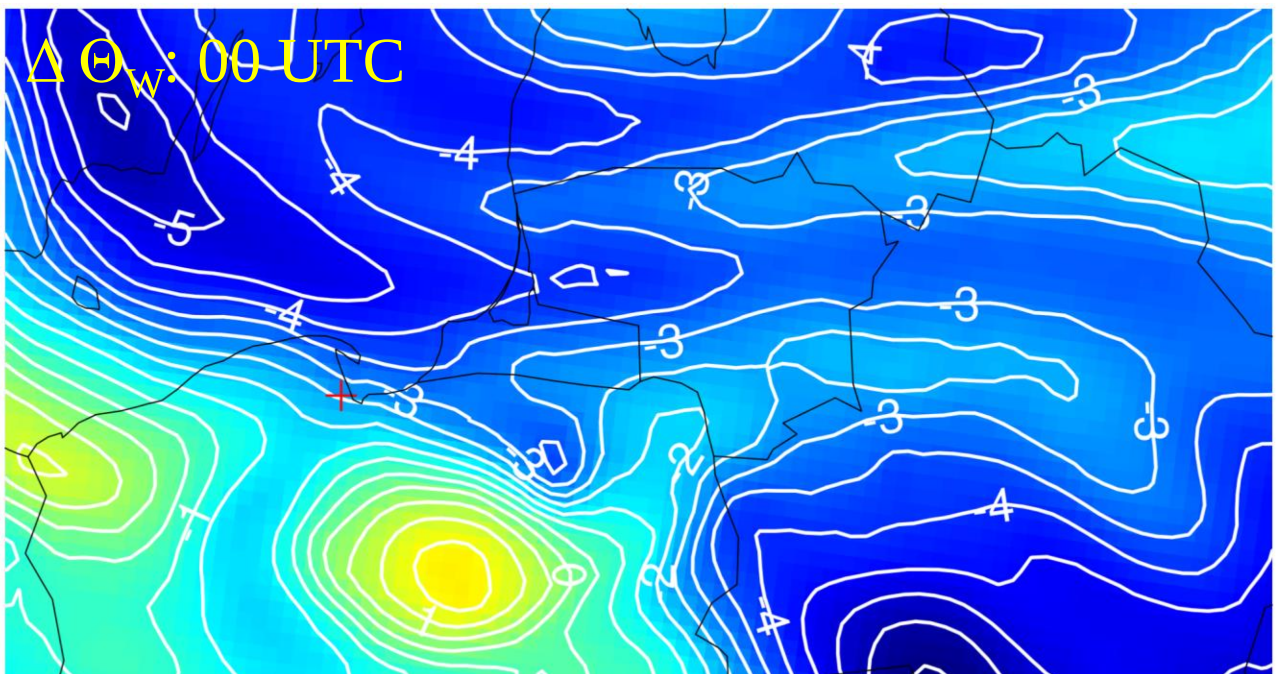


Vertical cross-section:

NLB vertical velocity (mm/s) and tropopause (grey) over Gdańsk (triangle)

- induced by the original PV (black) and with additional diabatic PV (red)
- increased prolonged vertical stretching of air columns responsible for destabilization





Role of the northern (Baltic) upper-level PV anomaly:

Stability at 00 UTC diagnosed by the COSMO model

- Δ Θ (top) and Δ Θ_W (middle) between altitudes of about 6 and 0.7 km (in K)
- top: reduced (absolute) stability below northern upper PV anomaly
- bottom: it has a form of potential (moist) instability, also over Gdańsk area

Conclusions and discussion

- NLB PV prognostic model allows for a realistic analysis of the atmospheric dynamics, including the dynamic forcing of convection
- a hypothesis can be formulated that the convection over Gdańsk resulted from an interplay between dynamic effects of a set of mesoscale PV perturbations:
  - two of stratospheric origin: ‚northern' one providing an initial diminished stability and ‚southern' one providing an additional lifting
  - another, of diabatic origin, generated by the previous day convection
- the role of the latter is still to be clarified: was it necessary to release the instability, does it work via direct lifting or via spatial locking of the ‚northern' PV anomaly (or both) ?
- generally: the correct convective forecast may sometime depend on the correct prediction of the previous convective activities (via effects of their coarse-grain diabatic PV anomalies)
- such dependence may increase the predictability of the secondary convection, but an ability to assimilate those previous PV anomalies may be of crucial importance for the quality of the NWP forecast

Thank you!

Michał Ziemiański

18. 12. 2020, Gdańsk