Are Upper Tropospheric Moisture Gradients relevant for the Development of Deep Moist Convection?

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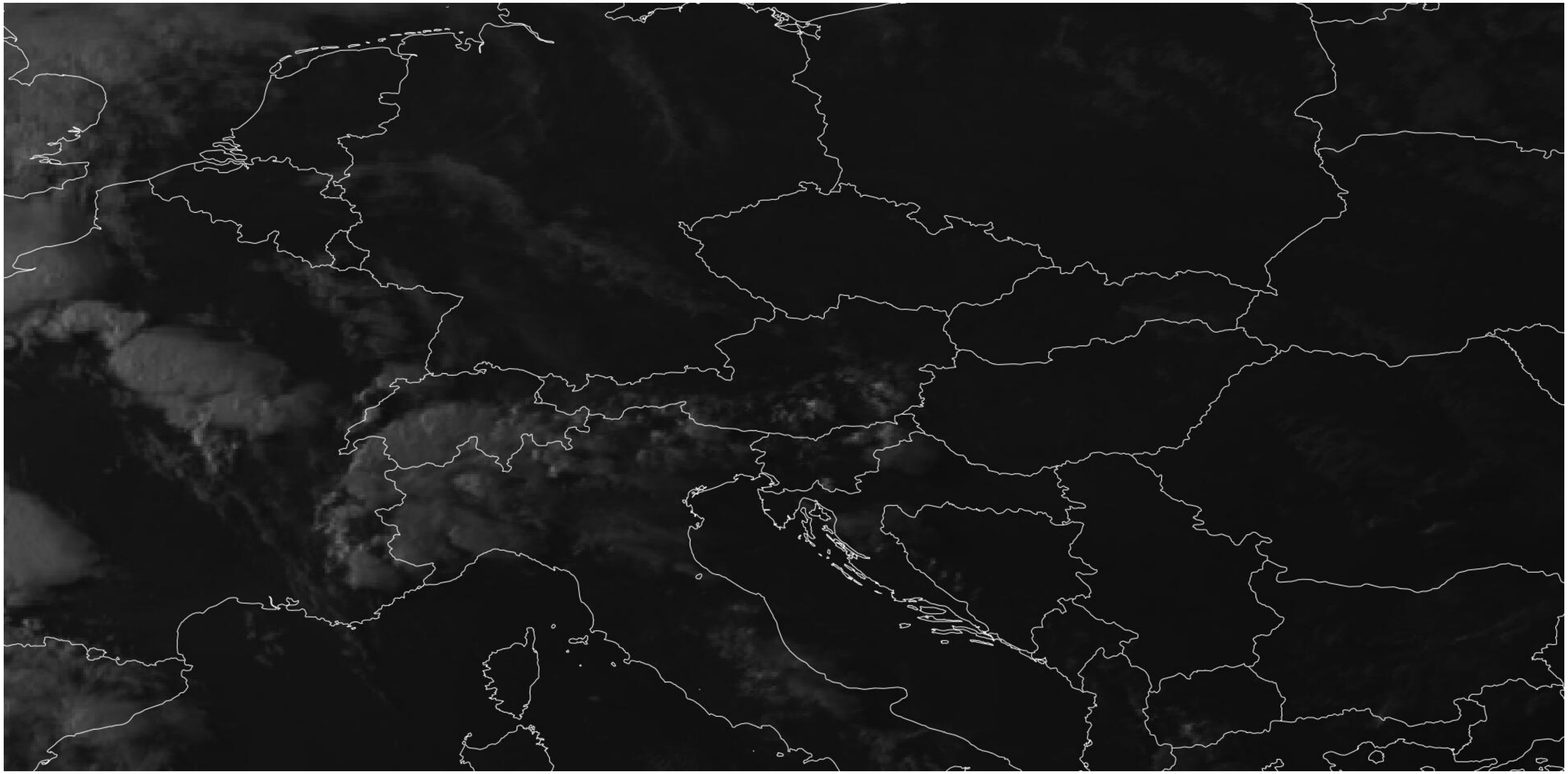
Forecasting single cell convection



- Conditions: presence of orography, absence of fronts, desired forecast lead time >3h
- Challenging task: predicting exact location, intensity and propagation of thunderstorms
- Single-cell or pulse convection, without fronts make ~30% of the summertime convection in the Eastern Alpine region, Krennert et al. (2003).

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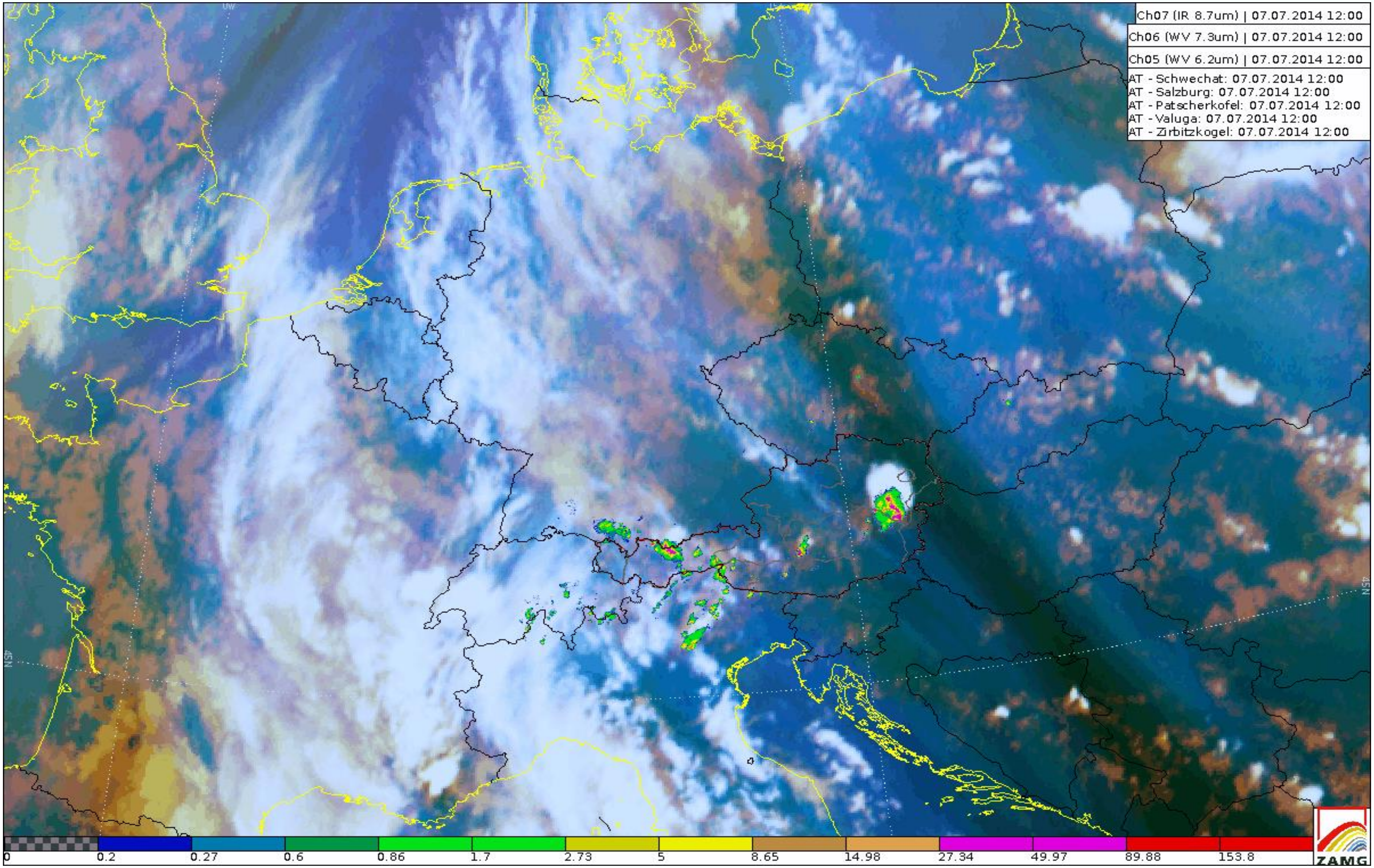
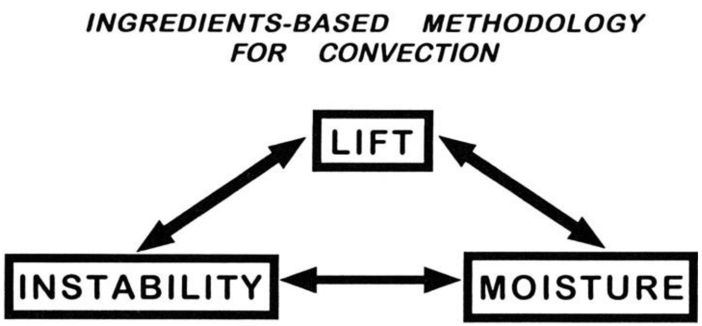
MSG RGB: IR 8.7µm (red), WV 7.3µm (green), WV 6.2µm (blue)



Ingredients-based methodology to forecast convection



Ingredients for deep moist convection DMC

Instability:

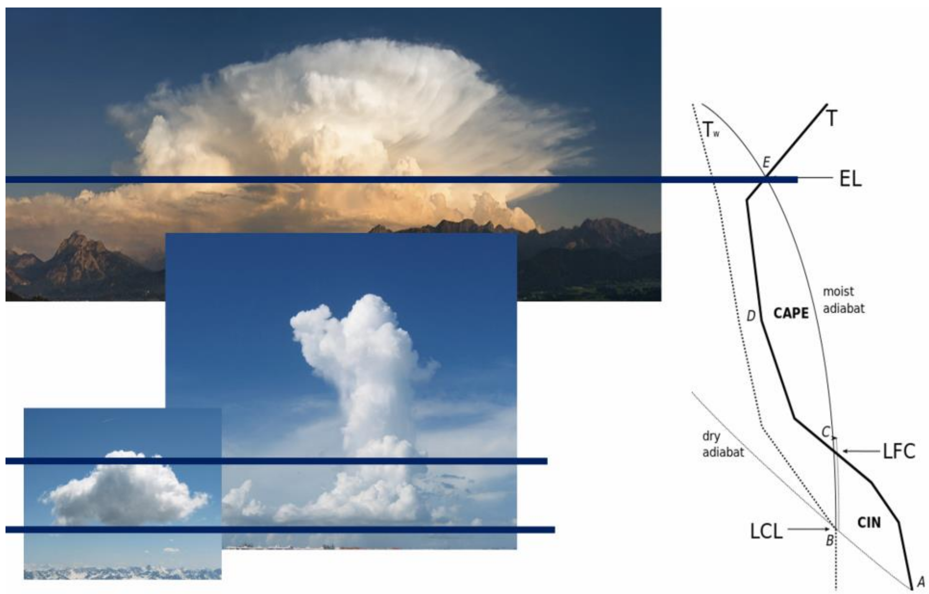
i.e. Conditional Instability, vertical lapse rate, needed to develop CAPE

Lift:

To bring air parcels to their level of free convection LFC

Moisture:

Latent heat source, to drive convection



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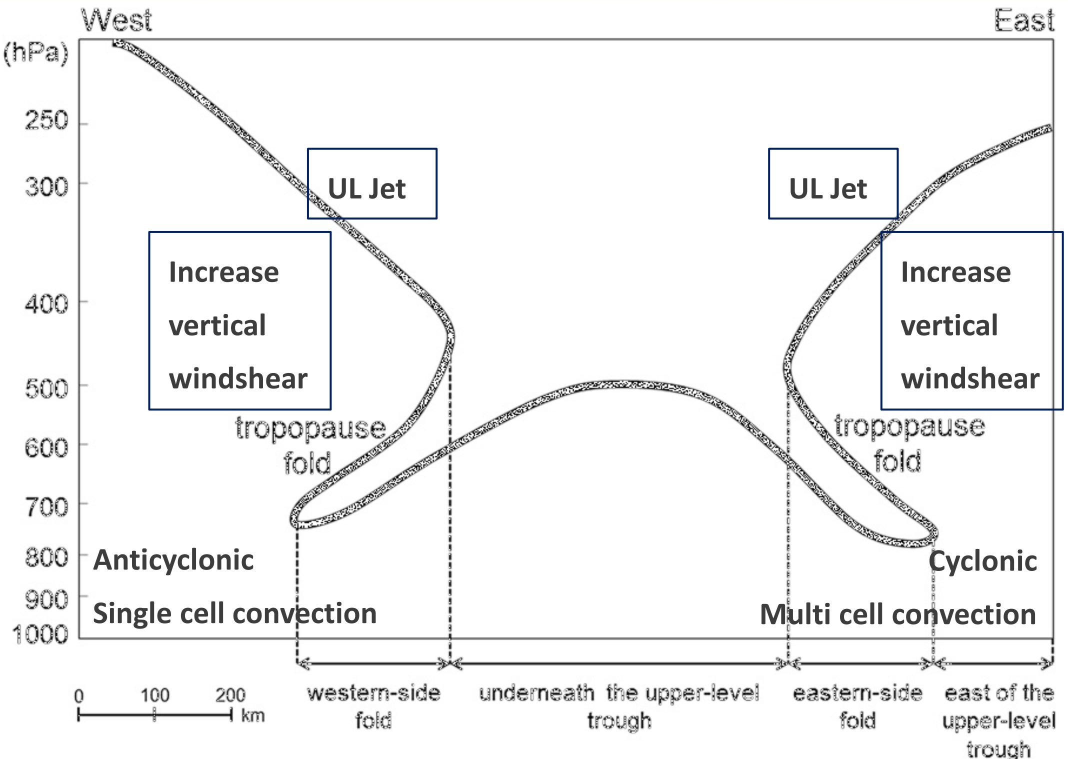
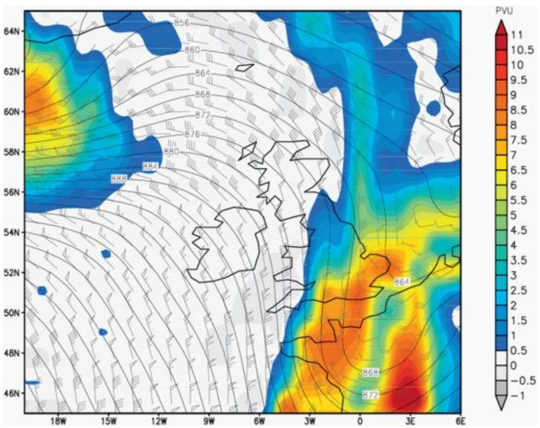
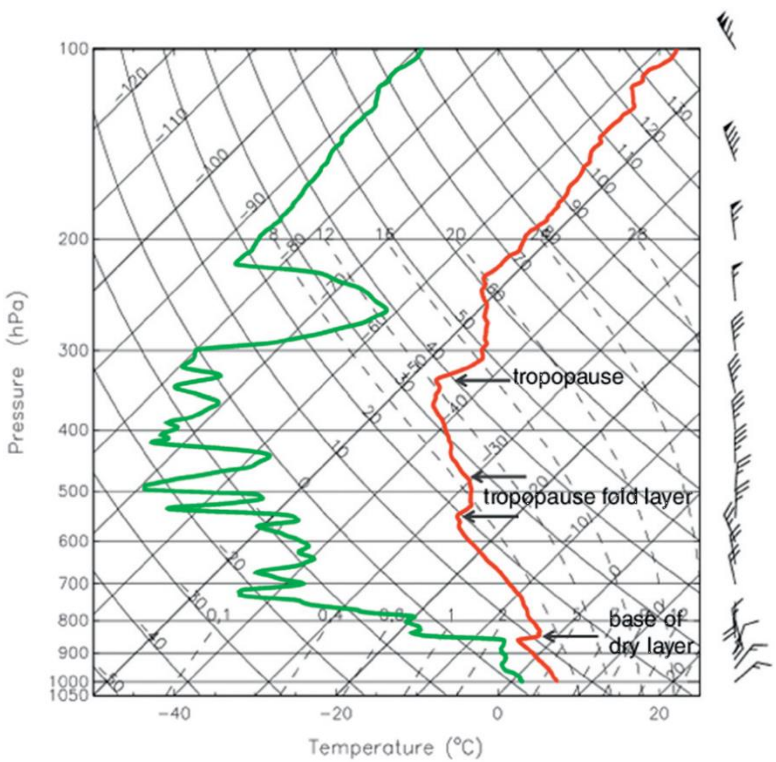
Tropopause Folds and Deep Convection, Antonescu, et al., 2013







Atmospheric lids beneath an UL PV anomaly, Russel, et al., 2008

Atmospheric lids beneath an upper-level PV anomaly and their impact on the initiation of DMC

Definition of a lid / capping inversion:

- Below the lid: moist layer and high Θ_w
- Above lid: a break in humidity with a thermal inversion, low Θ_w in the middle and upper troposphere

A lid can thus

- suppress convection
- promote convection

  in case of accumulated heat and moisture beneath, therefore creating conditional instability (loaded gun), convection tends to be more severe in the presence of a lid, although it is more likely to occur in its absence

Lid-collapse by:

- sufficient boundary-layer forcing

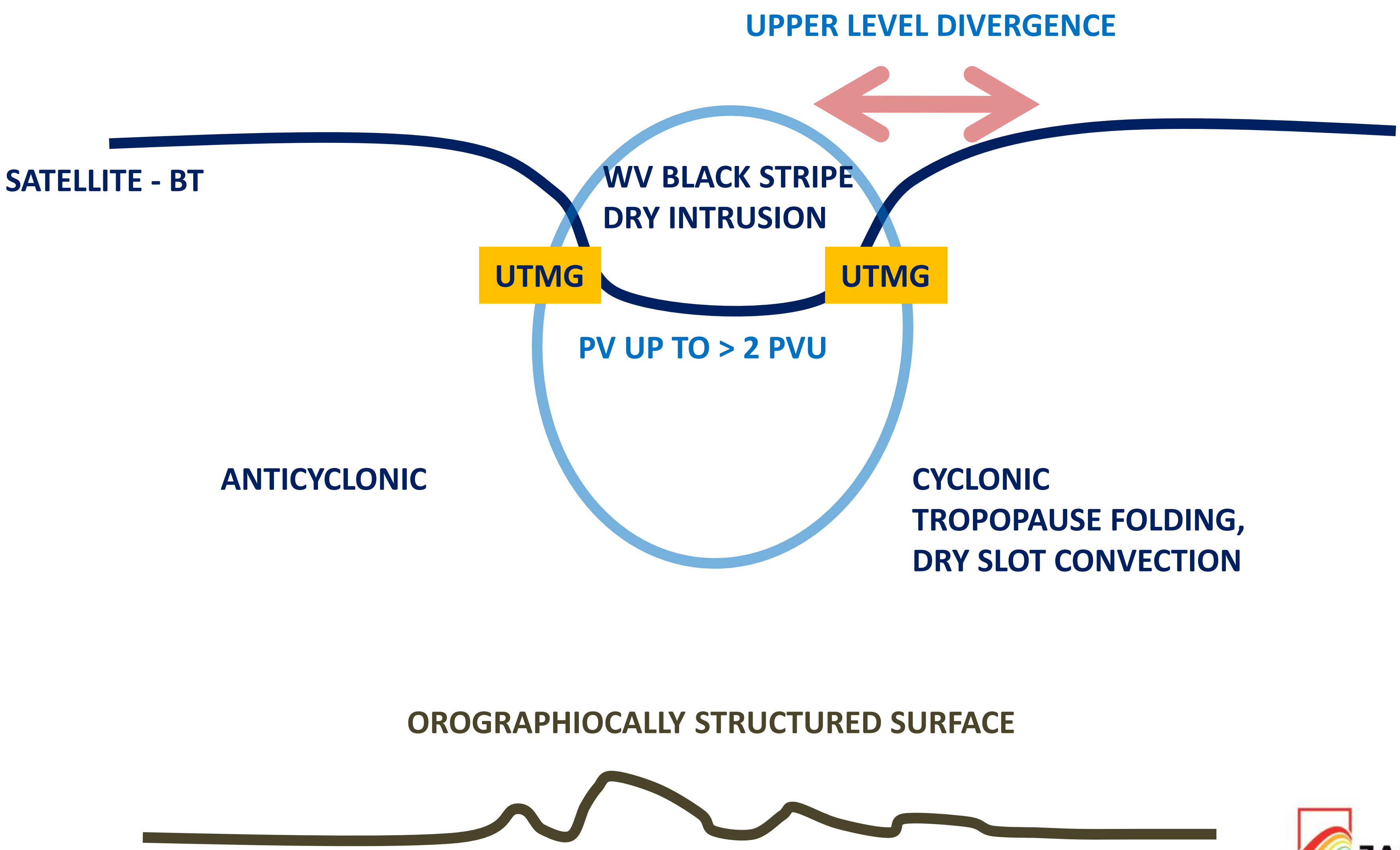
  convergence, orographic lift is needed to overcome the lid and release CI
- large-scale uplift

  may contribute to weaken the lid

- *Increase of vertical wind speed, vertical shear, additional release of symmetric or inertial instabilities?*

  "tip the scales?"

Assumption: characteristics at UTMG 1



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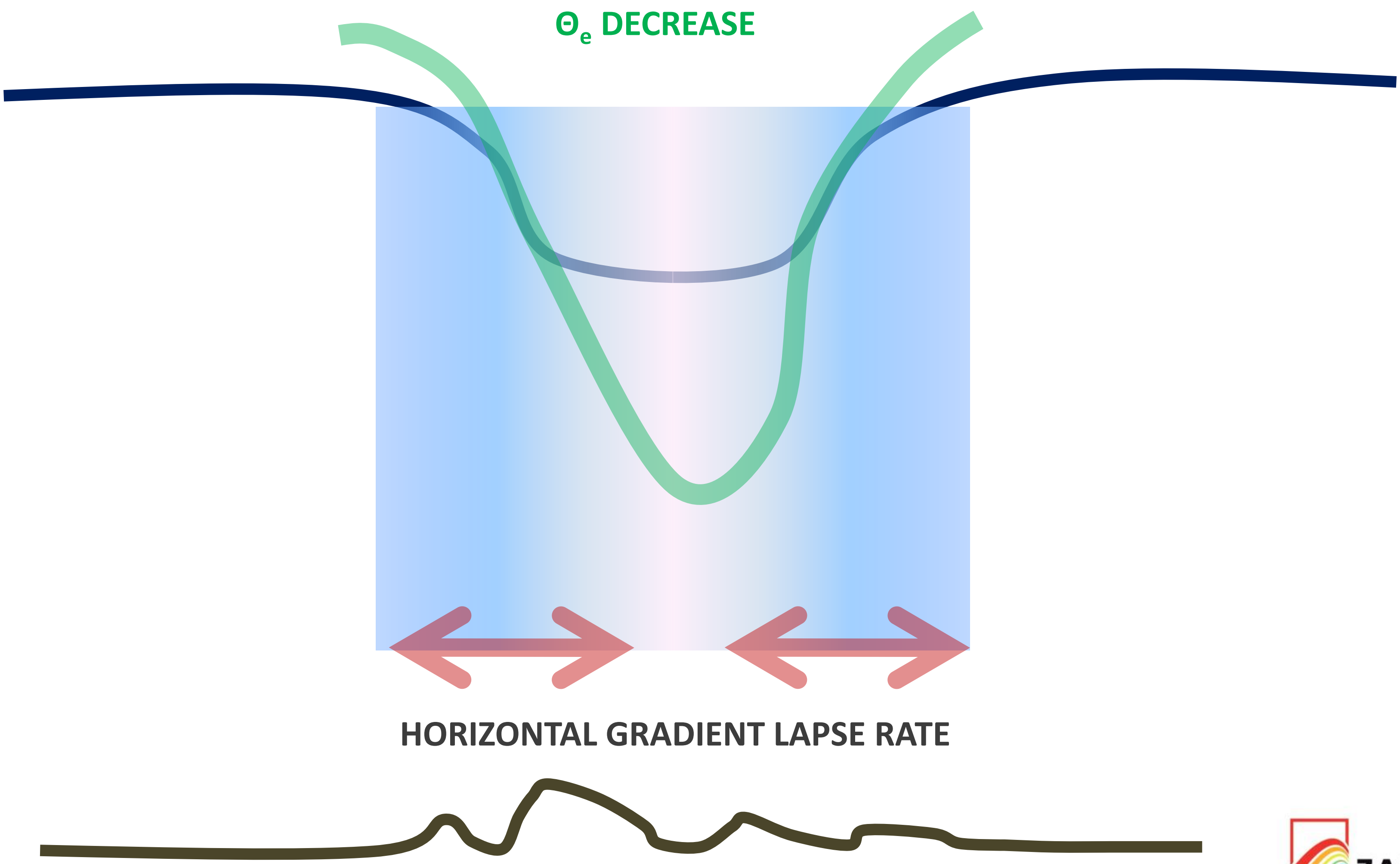
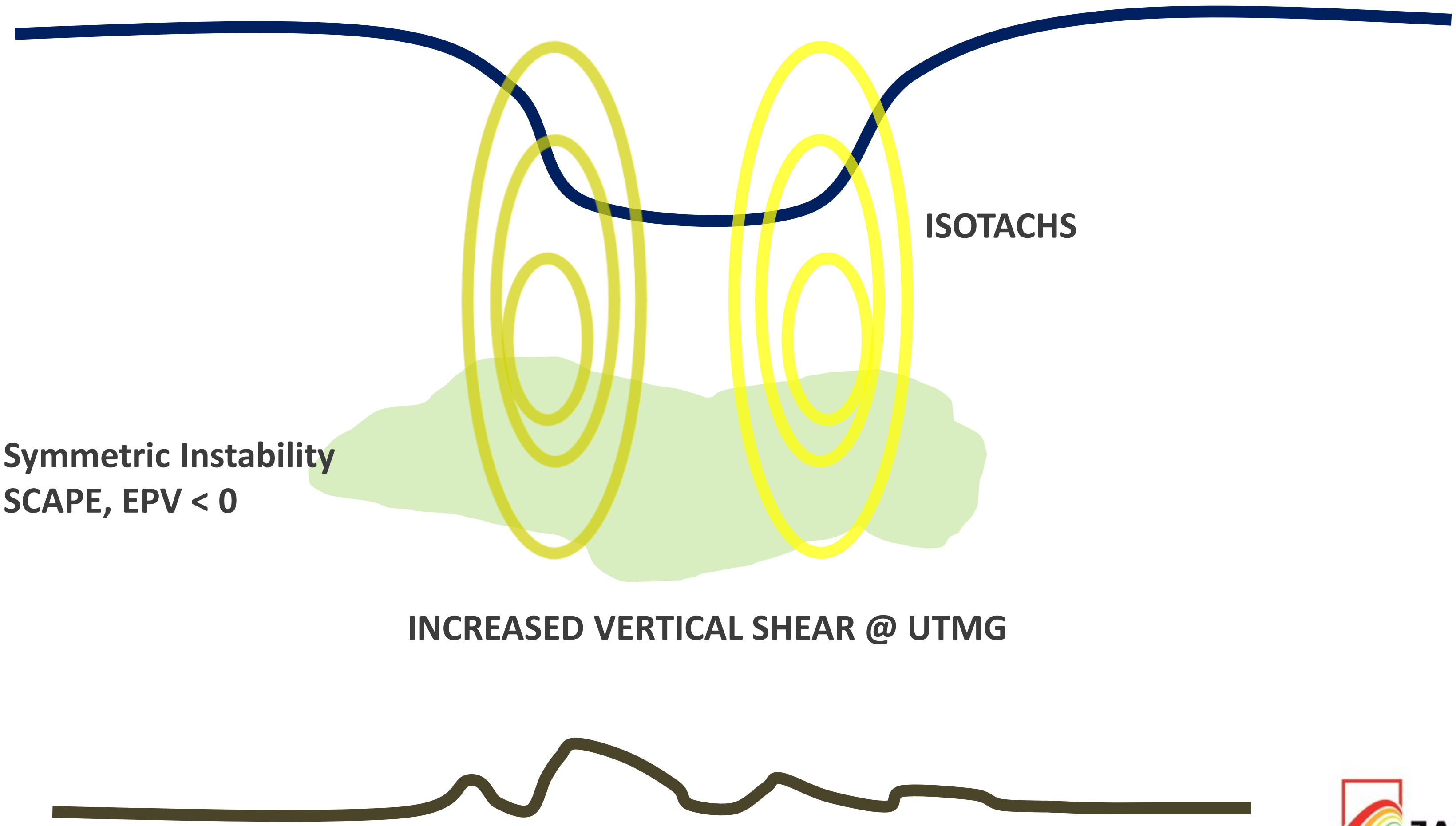
Assumption: characteristics at UTMG 2



Assumption: characteristics at UTMG 3



Types of Mesoscale Instabilities

Static instabilities PI / CI:

- Air parcel is displaced and accelerated vertically

Inertial instability II:

- Air parcel is horizontally accelerated, away from an equilibrium position

Symmetric instability SI / PSI / CSI:

- May occur in an atmosphere that is statically and inertially stable
- Air parcel may be accelerated away from its original position if it is displaced, along a slantwise path

Schultz and Schumacher, 1999:

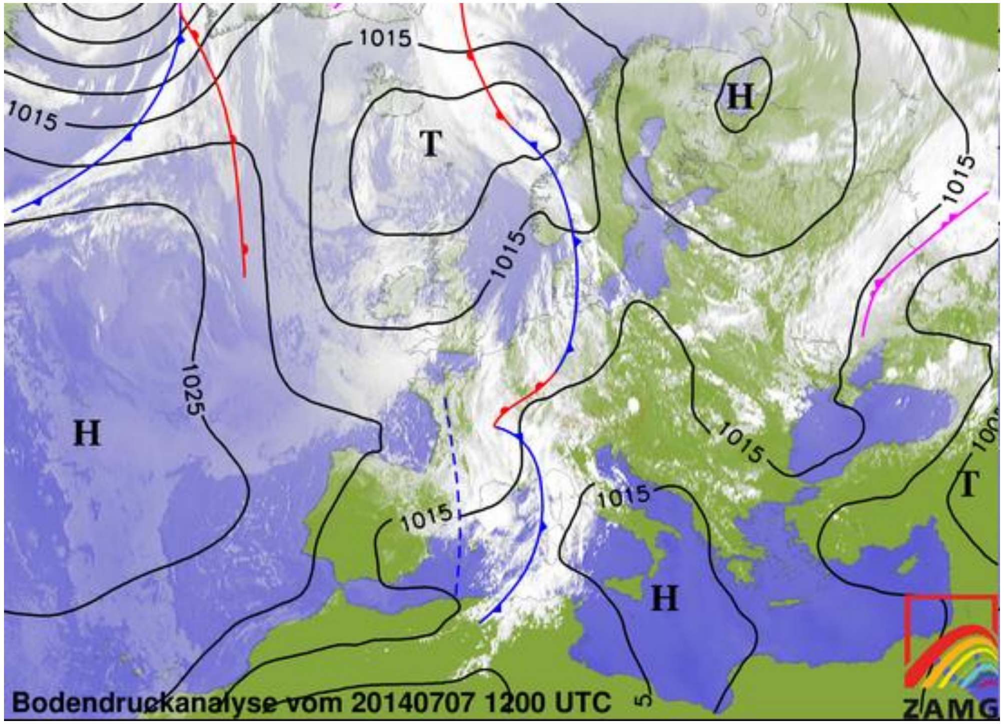
- Coexistence of CI/PI and CSI/PSI may lead to both gravitational and slantwise convection
- Gravitational convection: ms^{-1}
- Slantwise convection: cms^{-1} -> “tip the scales?”

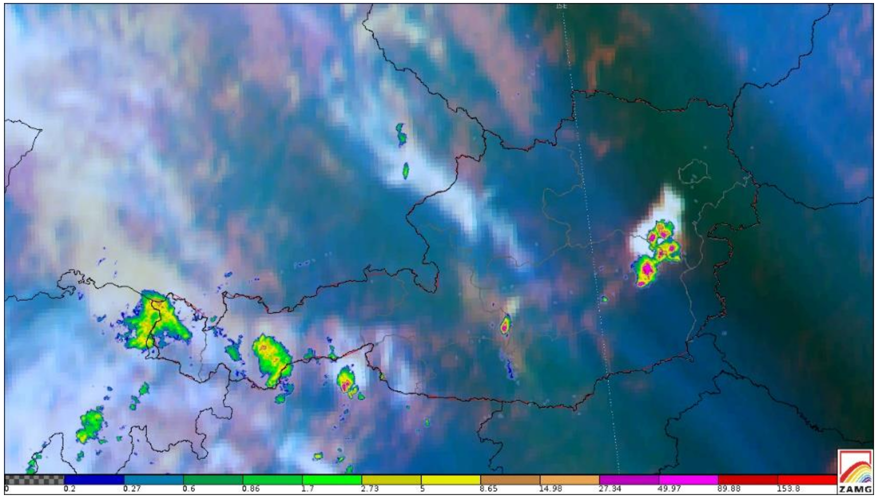
- Indicators for conditional (CI), inertial (II), and conditional symmetric instability (CSI) can be found along the UTMG:
  - Horizontal and vertical gradients of relative humidity RH,
  - Horizontal and vertical gradients of Θ_e
  - Horizontal and vertical wind shear, gradients of horizontal wind speed
  - negative Equivalent Potential Vorticity EPV (Mc Cann, 1995), between 900 and 700 hPa

- Existence of EPV minima and SCAPE maxima near the first onset of DMC

Case Study, Eastern Austria: 7 July 2014, 0800-1200 UTC, Kainz 2016

- WRF Simulations:
  - 2 nested (ECMWF) domains,
  - resolution 20 / 0,8 km (D1 / D3),
  - PBL: MYJ; MP: WSM6; LS: RUC-3; ω:Grell3D (only in D1)





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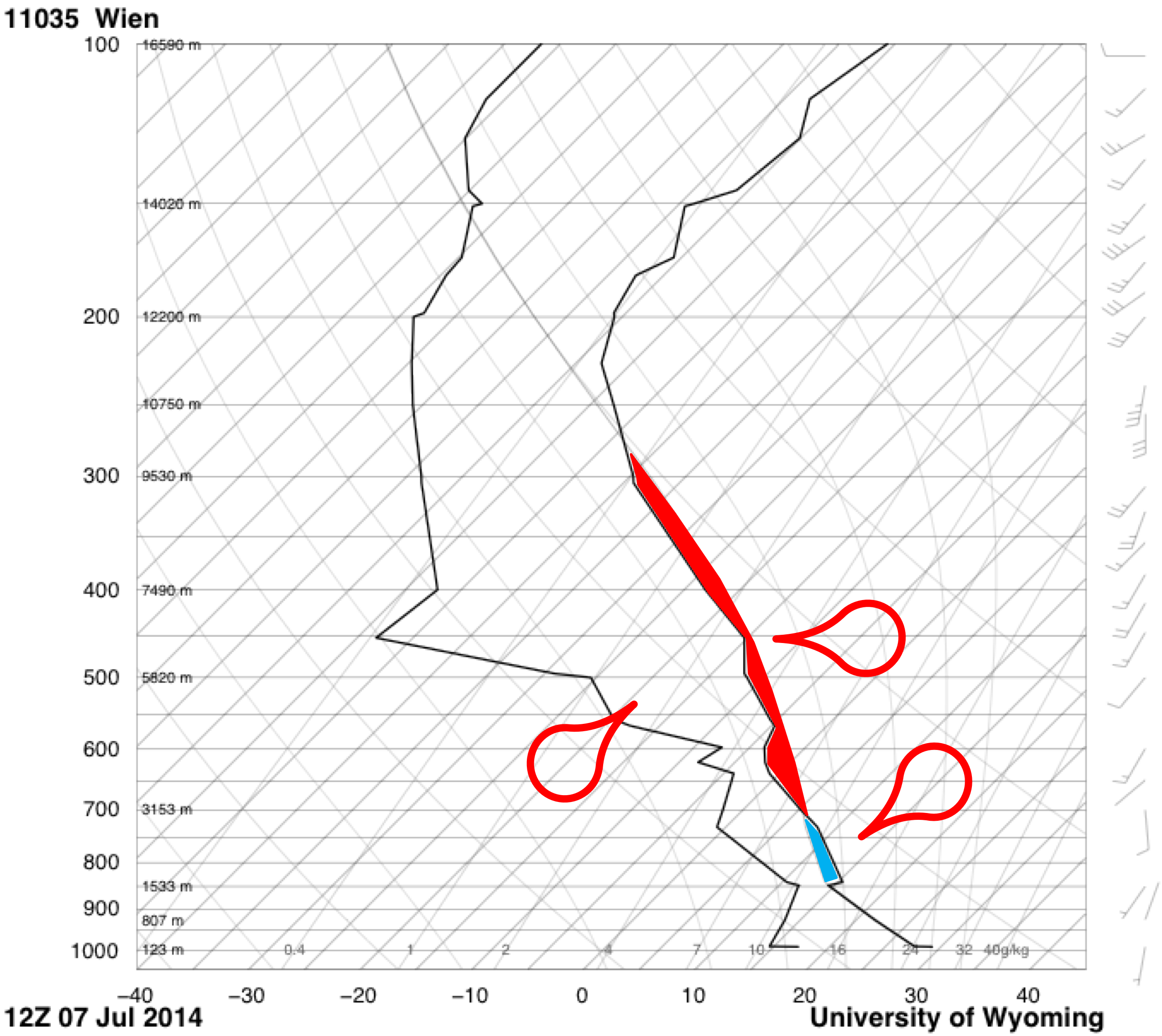
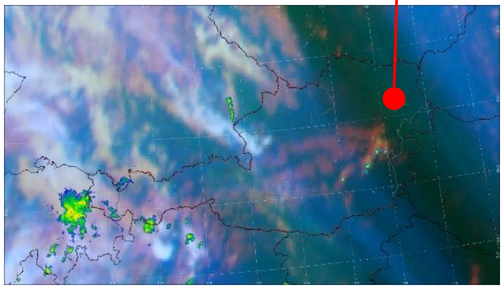
Proximity Sounding

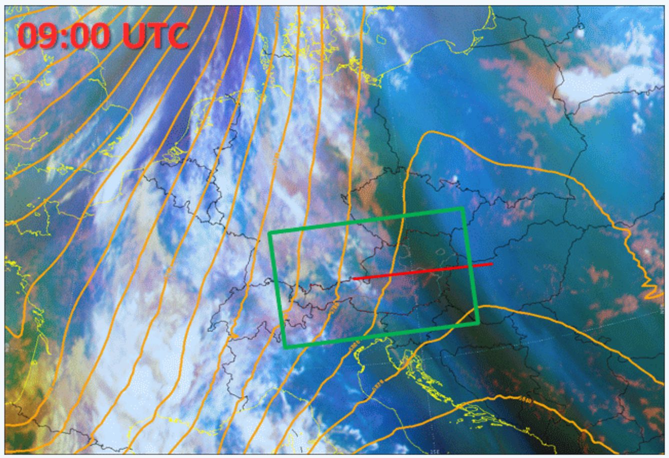


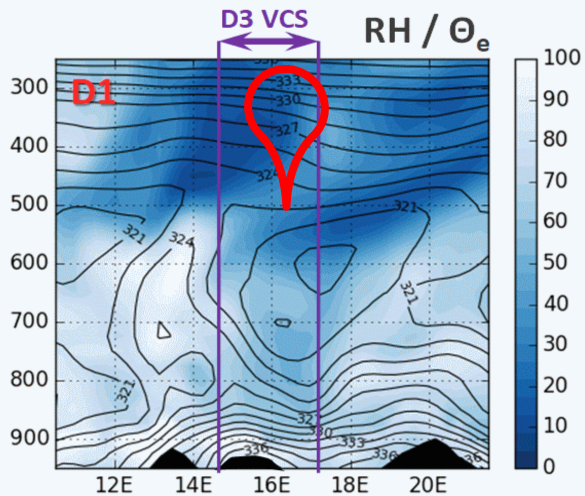
SLAT	48.25
SLON	16.36
SELV	200.0
SHOW	−1.18
LIFT	−1.72
LFTV	−2.15
SWET	170.9
KINX	30.90
CTOT	23.30
VTOT	26.10
TOTL	49.40
CAPE	395.0
CAPV	479.5
CINS	−78.1
CINV	−53.4
EQLV	273.5
EQTV	273.0
LFCT	703.6
LFCV	719.1
BRCH	180.8
BRCV	219.5
LCLT	284.8
LCLP	819.9
MLTH	301.5
MLMR	10.69
THCK	5697.
PWAT	32.35

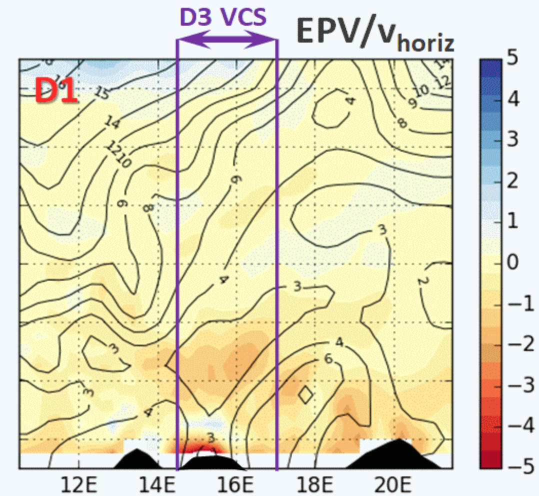
11035



Indicators for symmetric instabilities 1







7 July 2014, 0900 UTC, MSG RGB: IR 8.7µm (red)/ WV 7.3µm (green) / WV 6.2µm (blue); orange lines: 500 hPa Geopotential; red line: VCS D1; green square: D3, D1 bigger than image plane

D1 (3), resolution 20 km, Relative Humidity [%] (shaded), Θ_e [K] (lines)

D1 (3), resolution 20 km, EPV [PVU] (shaded), Horizontal Wind Component [m/s]

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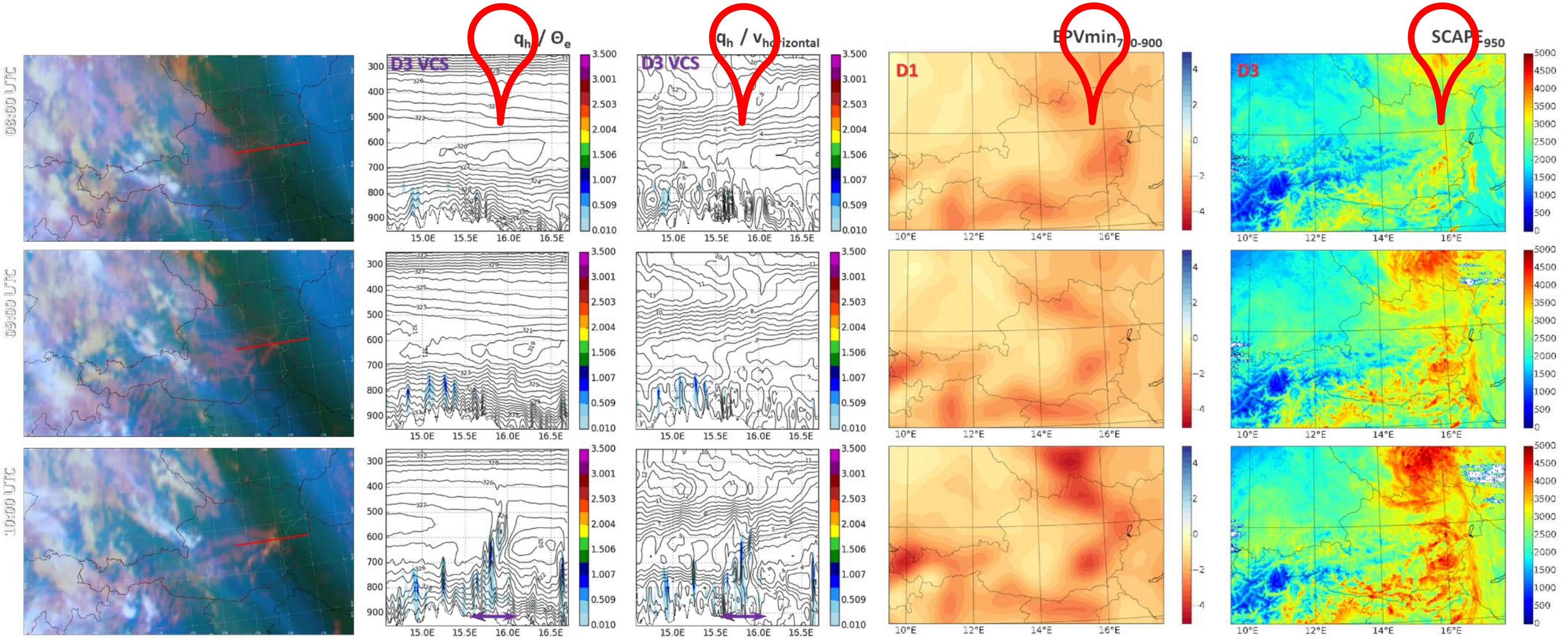
Indicators for symmetric instabilities 2



WRF simulation D3, VCS:
Total hydrometeor mixing ratio [g/kg];
q_h (shaded)
Left: Equivalent Potential Temperature
Θ_e [K], (lines, left side)
Rihght: Horizontal component of true wind speed
[ms^{-1}](lines, right side)

Left: Negative EPV, 900-700 hPa
[PVU=10-6*K*m2/kg*s],
Right: Symmetric Available Potential Energy SCAPE [J/kg], integrated from 950 hPa, after Dixon (2000)

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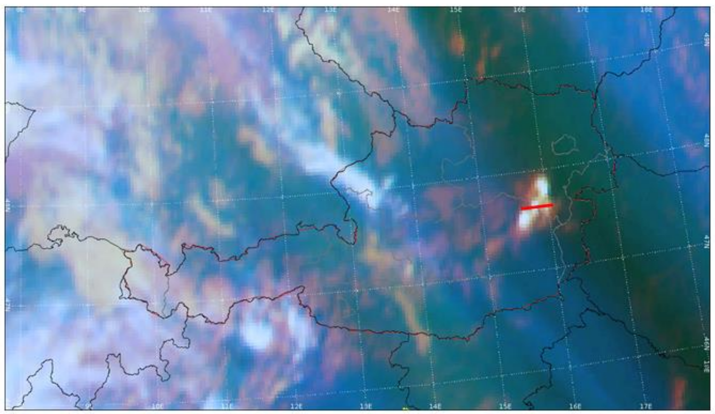
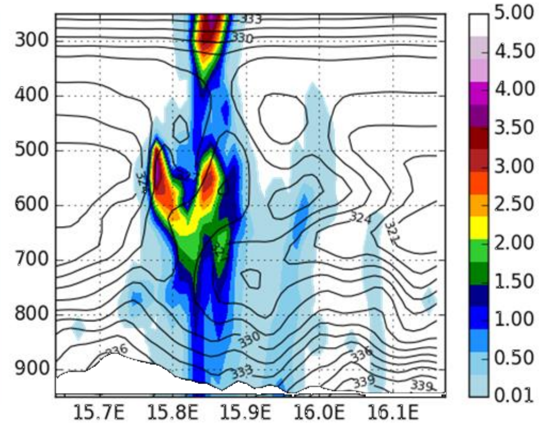
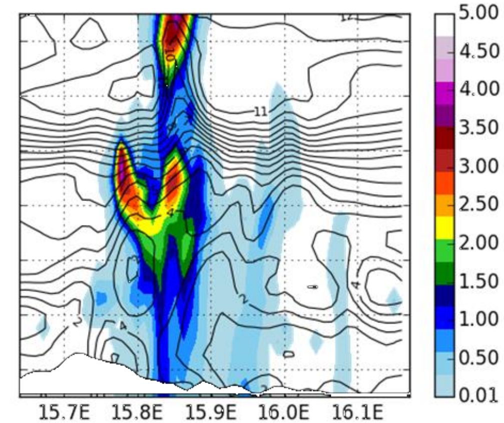
Resulting DMC

10:30 UTC

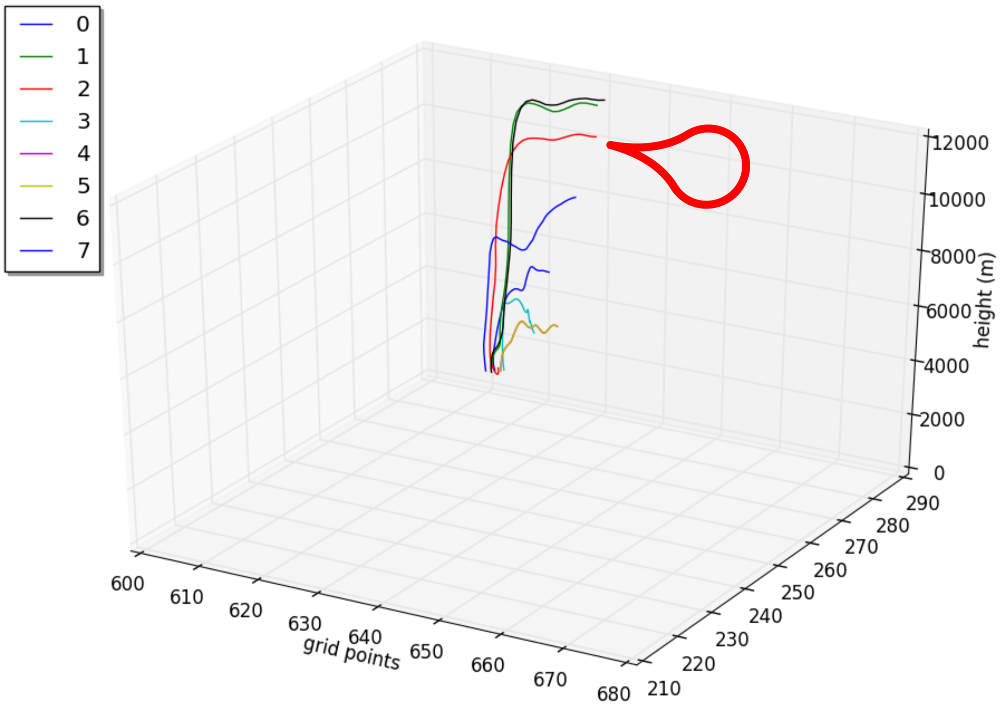




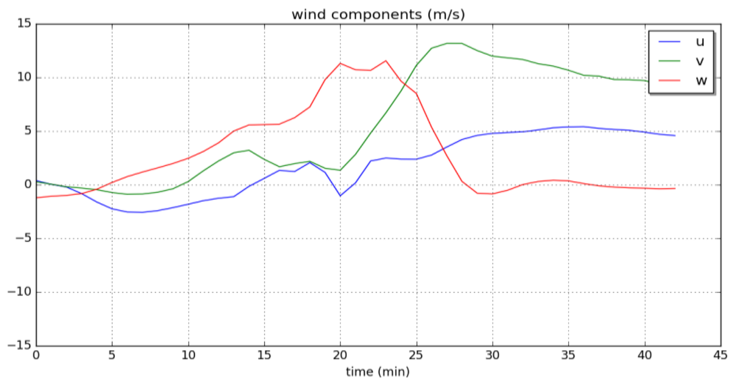


Parcel Trajectory Analysis

Calculation of eight 45-min forward trajectories, initiated at 2000 m above ground



- Wind components along trajectory 2 (red) as time series (below)
- vertical component seems to dominate, indicating upright convection
- After approx. 25 minutes,
  - decrease of vertical component,
  - increase of horizontal components
  - while updraft reaches tropopause



Despite existing indicators for symmetric instabilities, no clear signal for slantwise convection in the model

Conclusions

- DMC development from pre-existing shallow convection in the vicinity of pronounced horizontal and vertical Θ_e gradient and wind shear
- Distinct indication of SCAPE and lower-mid-level negative EPV, WRF simulations showed, that initial shallow convective towers reaching these levels before DMC evolution succeeds
- Coexistence of CI, II and CSI along the UTMG seems plausible
- Release of SCAPE indicates potential for slantwise convection seen in model layers between mid- and low levels of the troposphere
- Slantwise convection mechanism not visible in model trajectories, gravitational convection predominates trajectory path

Remaining Questions:

- Impact of (advected) increasing wind shear in pre convective environments on lift and / or lid removal
- MTG application facilities will certainly lead to new approaches and results

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