School of Earth and Environment
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UNIVERSITY OF LEEDS

The role of orography in convection regeneration. A case study from the Convective and Orographically-induced Precipitation Study

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Motivation – 20th July 2007 convection regeneration above Black Forest

- **North-west propagating Mesoscale Convective System passed over COPS region**
- **Squall line in outflow region – southern part decaying upstream of Black Forest**
- **Convection Regeneration above Black Forest**
- **Intensification in lee > thunderstorms and flooding in Bavaria**

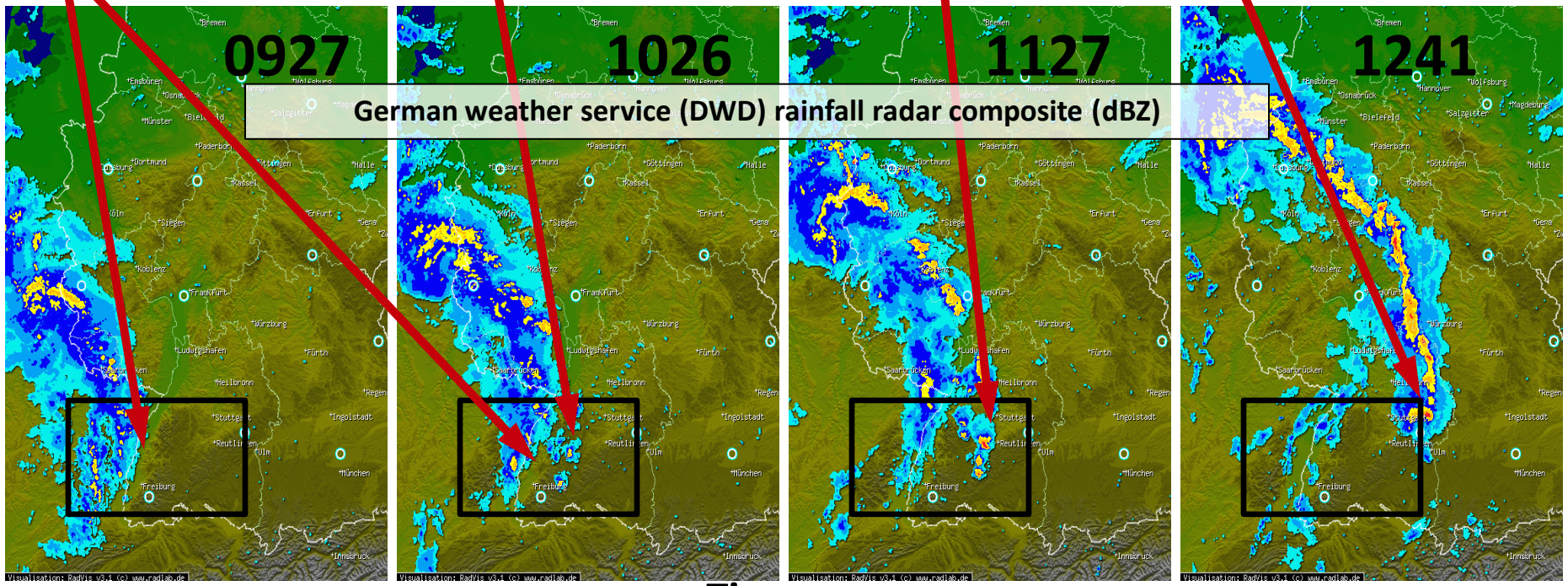
Boxes - approx location of COPS study region

Decay over Rhine Valley

Regeneration above Black Forest mountains

Intensification

Thunderstorm and squall line development



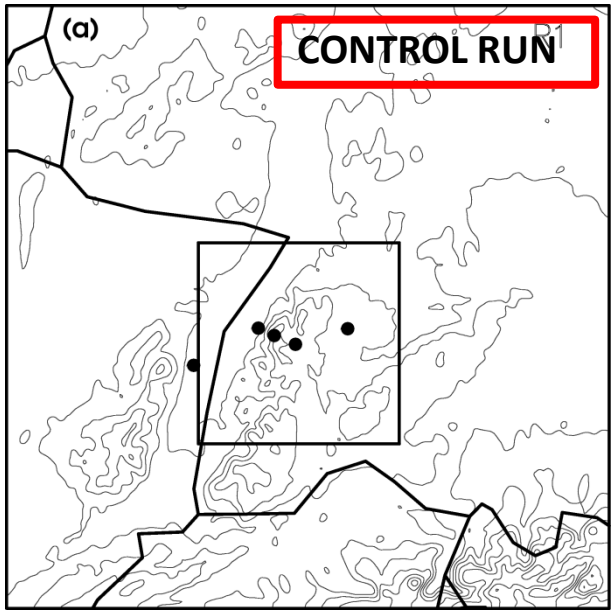
Orography responsible for convection regeneration?

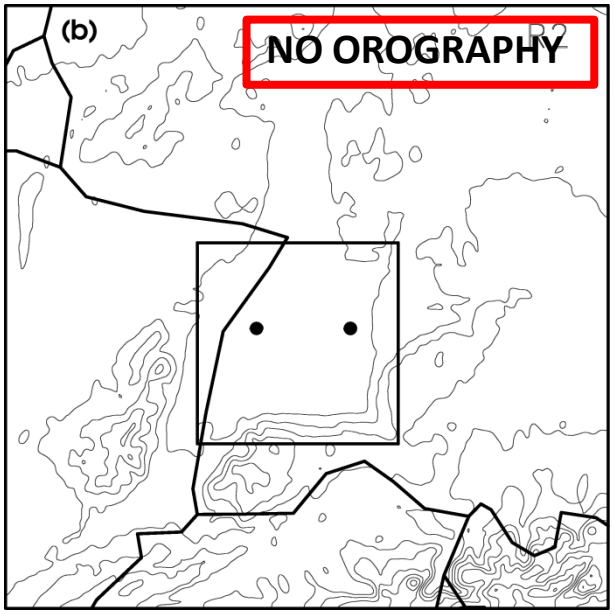
Motivation – **Orographically-generated convection poorly forecast by LAMs. This case study was no exception**

Errors from

- **Initial and lateral boundary conditions**
- **Insufficient resolution to represent orographic forcings / processes**
- **Over (under) estimation of precipitation on windward (leeward) side**

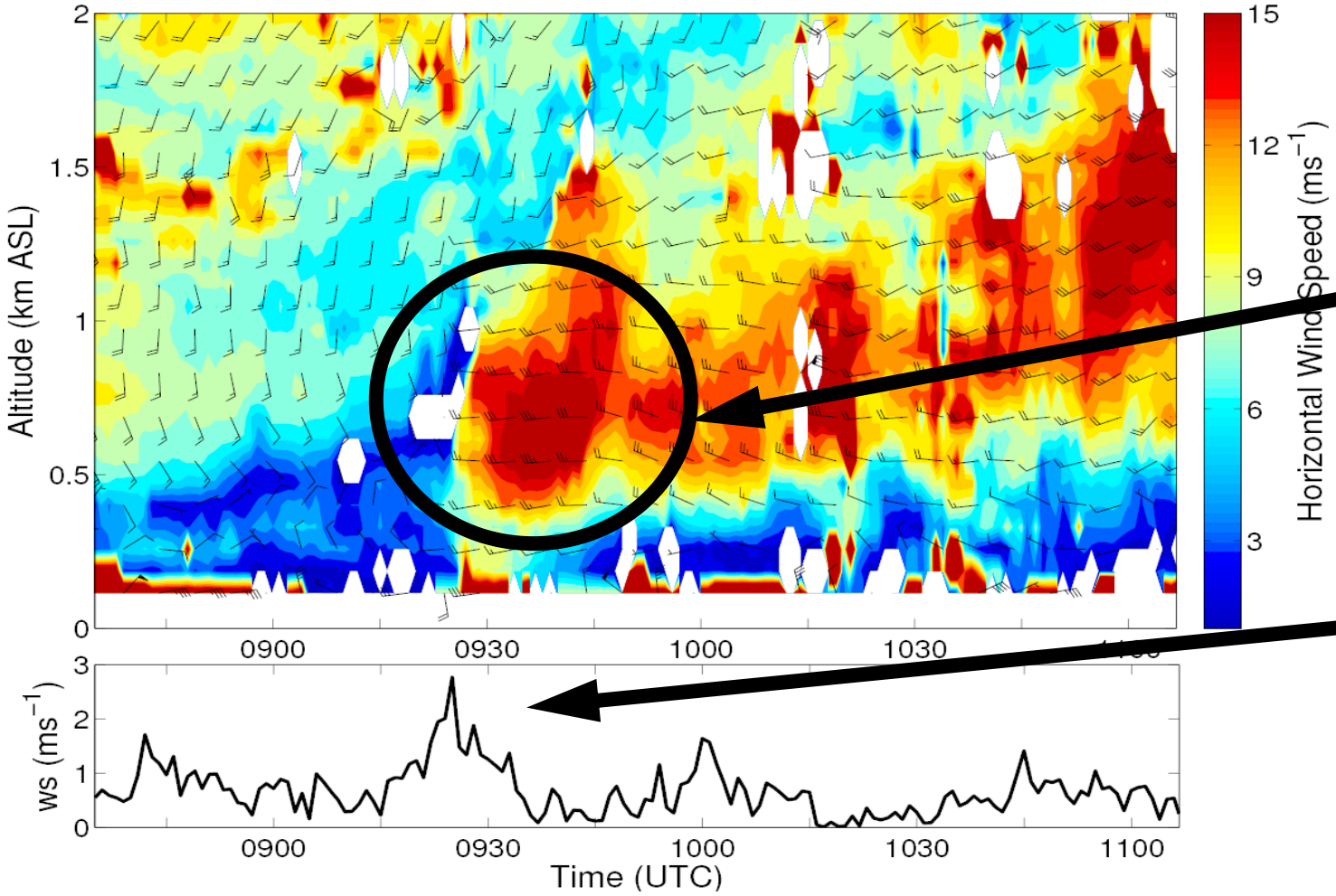
- **Poor understanding of role of orography in convection regeneration**
- **Would regeneration have occurred in absence of Black Forest ?**
- **Can high resolution modelling with modified orography explain role of the mountains in convection regeneration ?**





Observations – MCS outflow elevated due to fog in Rhine Valley.

HORIZONTAL WINDS OBSERVED FROM **RHINE VALLEY** Super Site
Wind profiler (upper), AWS (lower)



MCS outflow (gust front) passed *over* super site at approx 0930 UTC (1130 local)

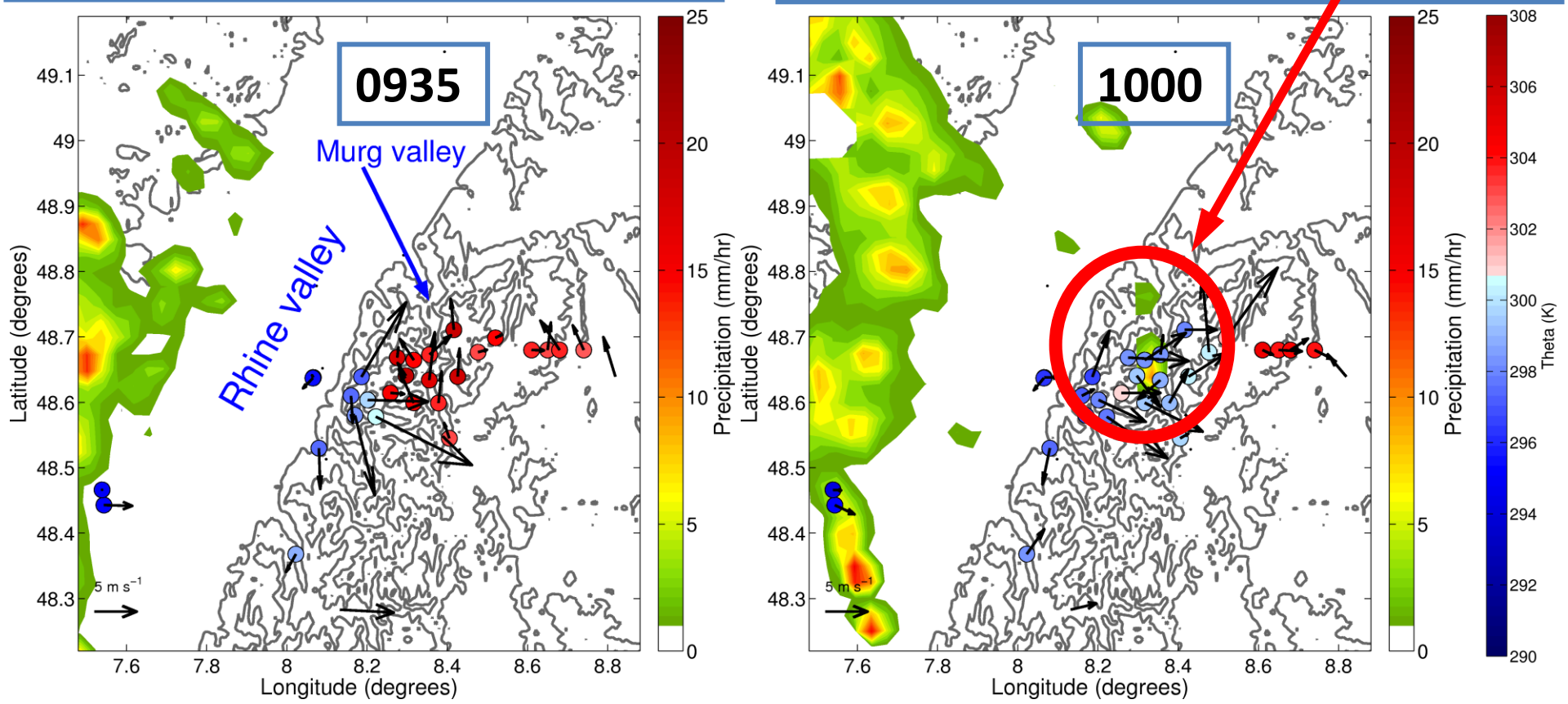
***Not* [really] seen at surface**

Observations – Convection regenerated above mountains.

Surface potential temperature and horizontal winds from AWSs, and observed surface precipitation

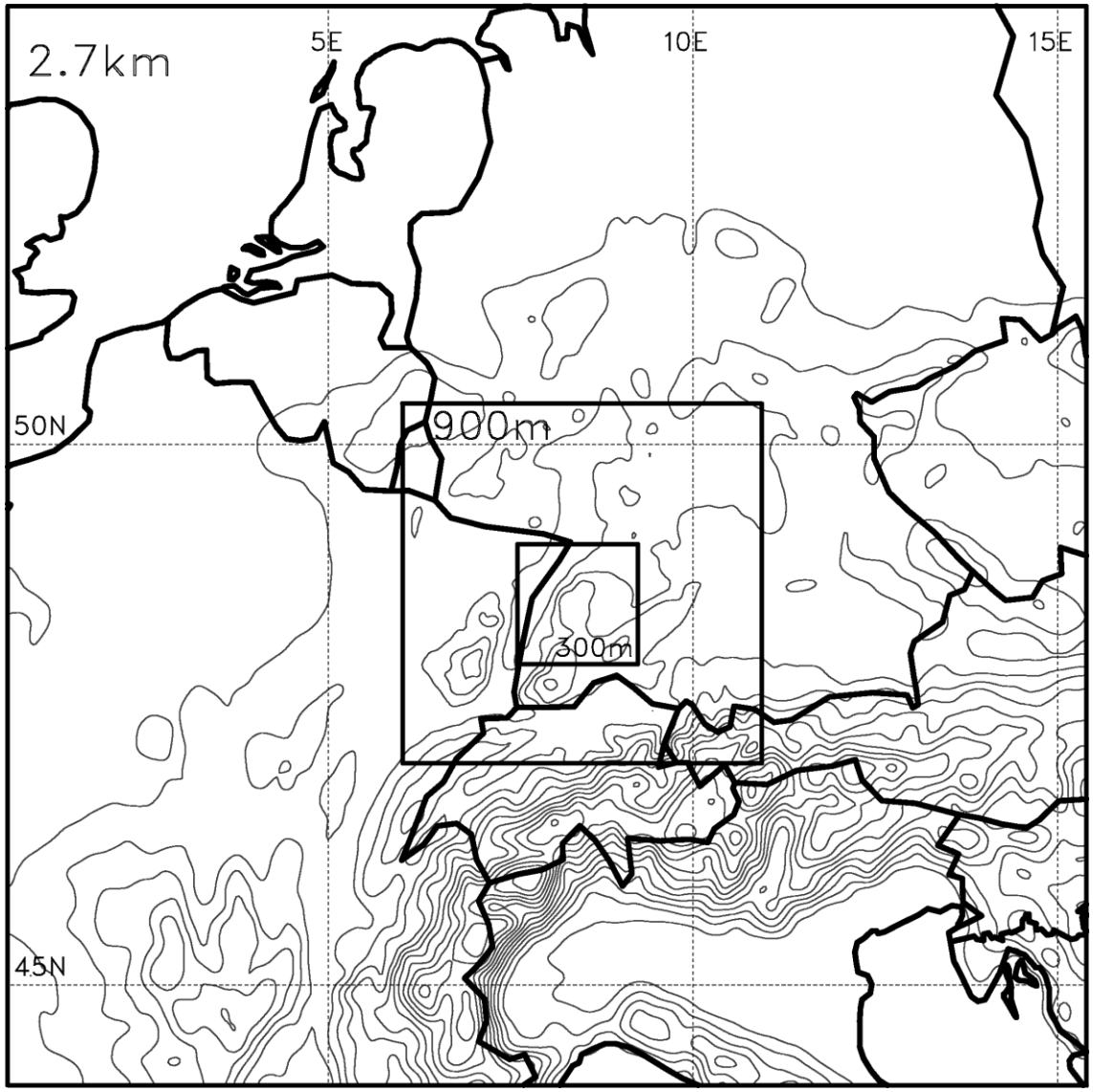
Outflow reaching western Black Forest

Convective precipitation above mountains



Detailed analysis of case study observations given in Corsmeier *et al*. 2012

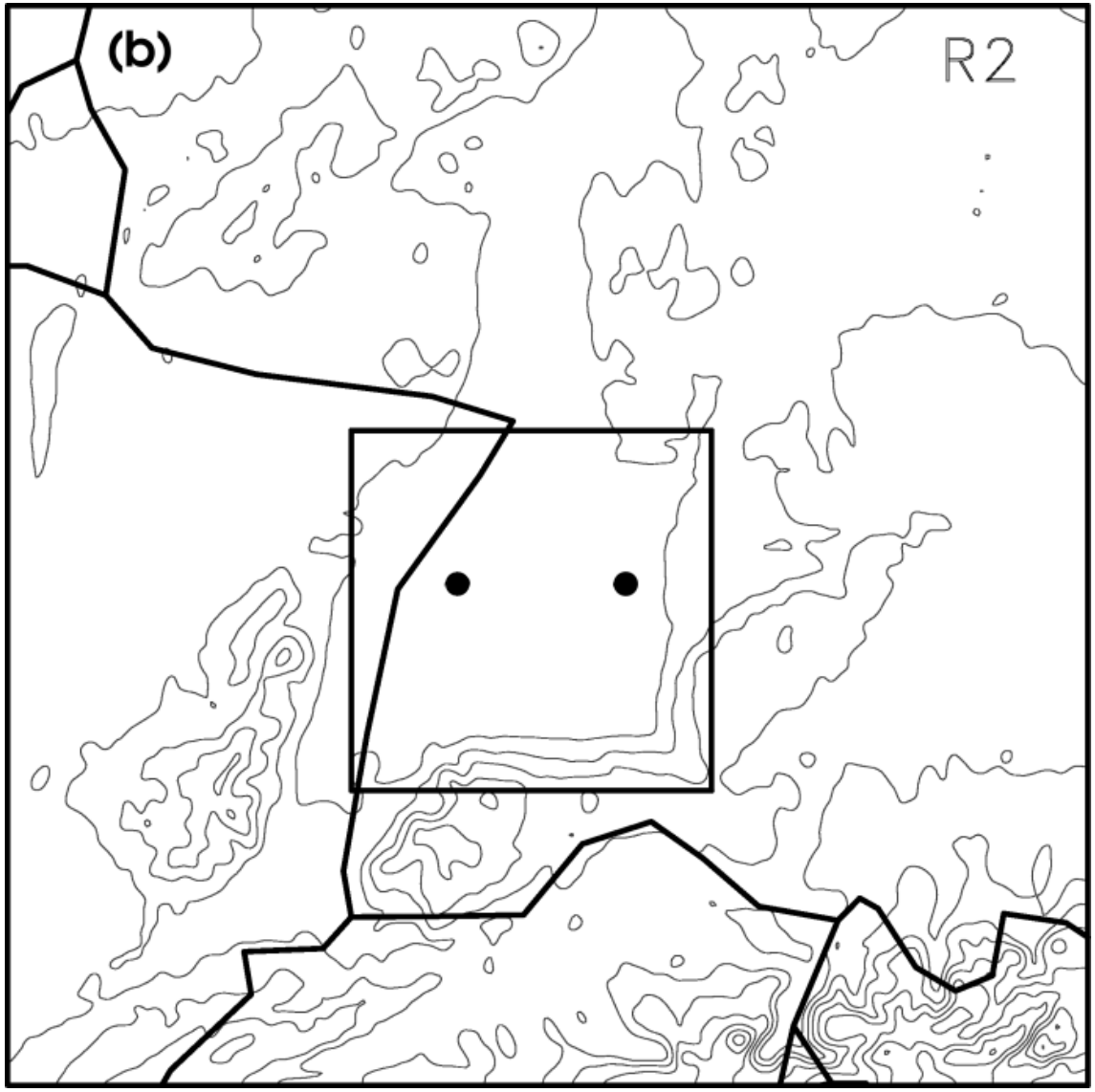
WRF modelling – control run with '*real*' orography



- **Control simulation to asses ability of WRF to reproduce key flow features**

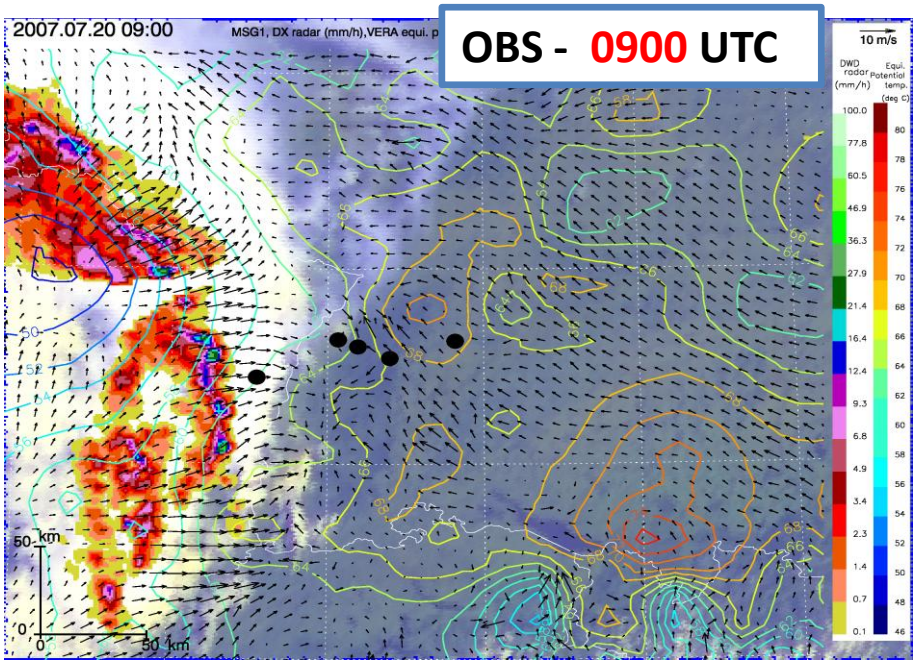
- **WRF version 3.0.1.1**
- **Initialised at 0000 UTC (0.25°ECMWF analyses)**
- **3 nested domains – 2.7km, 900m & 300m horizontal resolution**
- **120 Vertical levels**
- **All domains 400x400 grid points**
- **Morrison microphysics**
- **Standard M-O Surface layer**
- **Yonsei boundary layer**
- **Betts-Miller-Janic convection in d01**

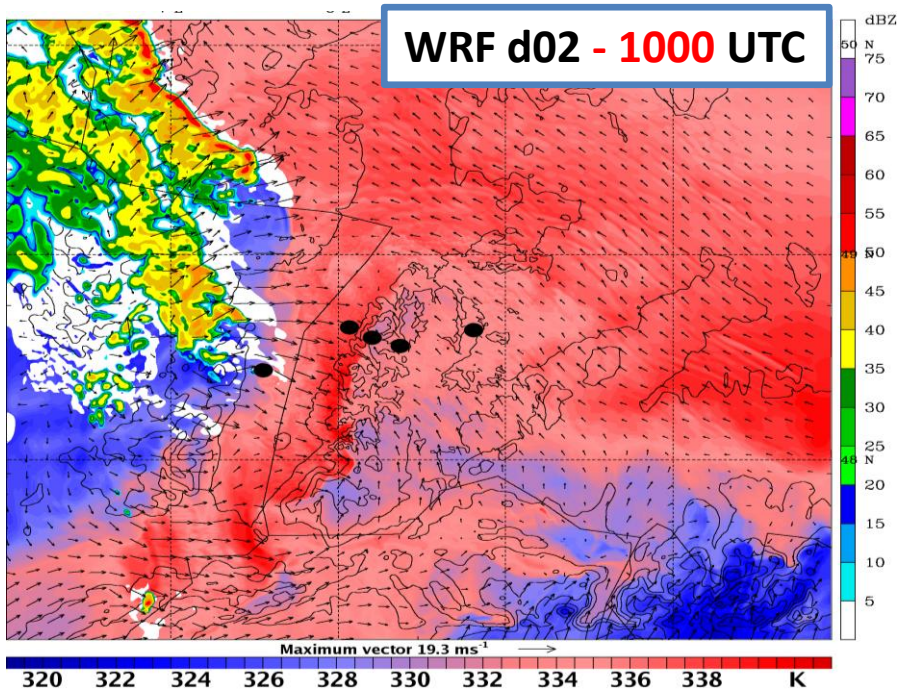
WRF modelling of case study – no Black Forest



- **Investigate role of orography by removing it**
  - **All but outer 50 grid points of inner domain set to altitude equal to Rhine valley**
  - **Smoothed at boundary**
  - **Surface properties unchanged**

WRF vs Observations – did the control run reproduce the case study?



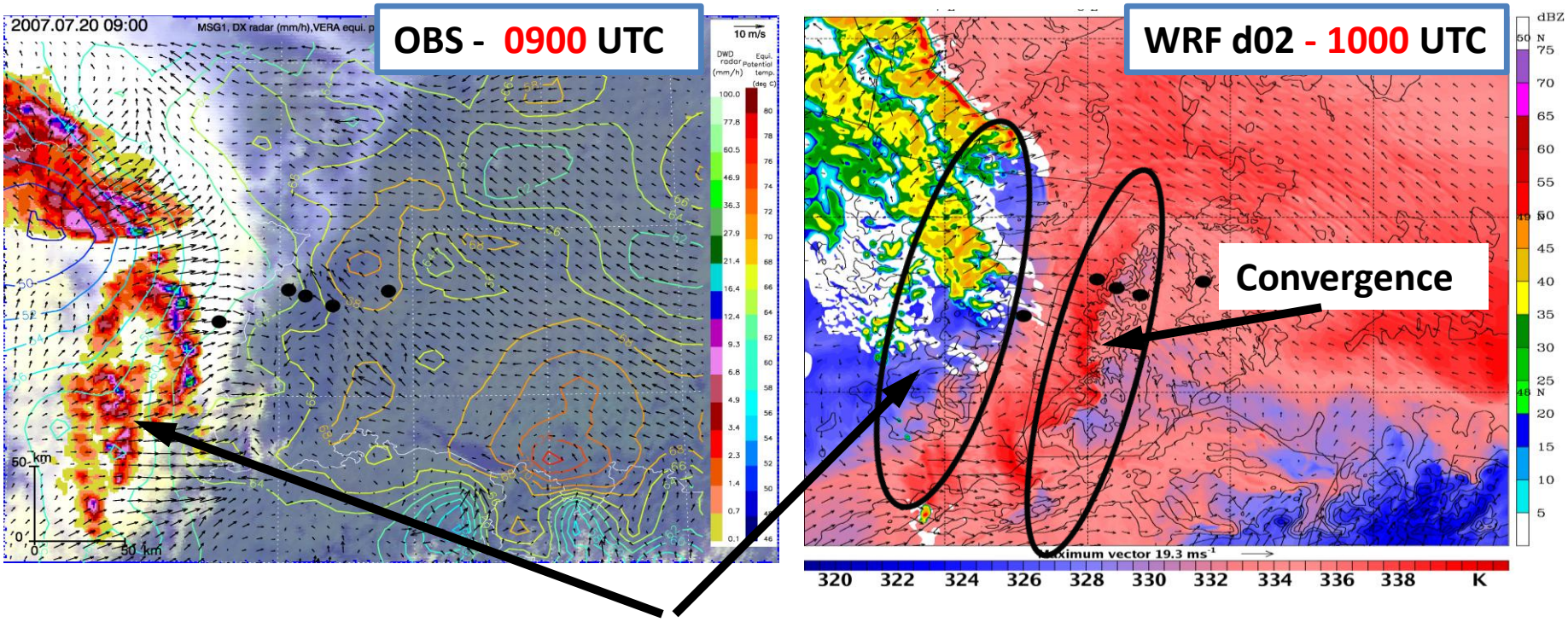


Surface obs from VERA (Steinacker *et al. 06*) fingerprint analysis

- **Surface equivalent potential temperature (θ_e)**
- **Surface wind vectors**
- **Vis satellite (obs) / 700 hPa cloud cover (WRF)**
- **Surface precipitation**

- **Features simulated 1 hour late**
- **Errors in initial and lateral boundary conditions**
- **Observations and WRF compared when features aligned NOT at same times**

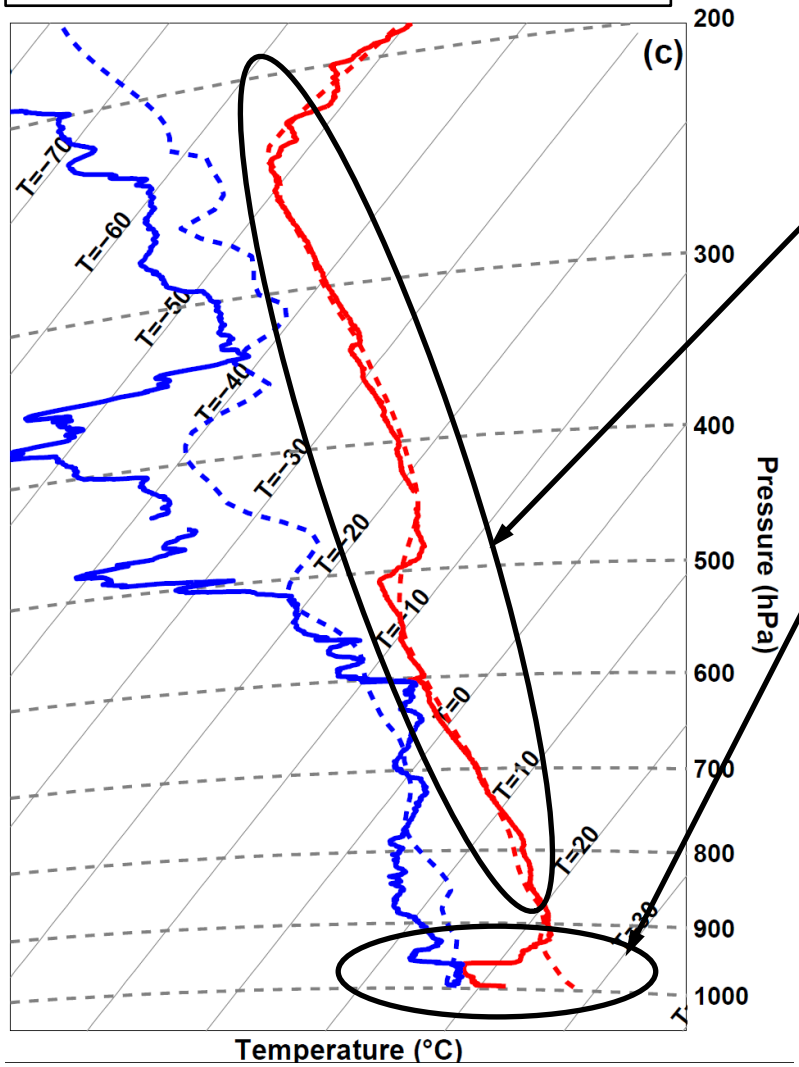
WRF vs Observations – did the control run reproduce the case study?



- **Southern part of system weaker than observations**
- **Decay over Rhine Valley because descent in lee of Vosges mountains reproduced**
- **No fog in Rhine valley in WRF – YSU scheme *aggressive* in eroding temp inversions because BL variables vertically mixed (Weisman *et al*. 2008, Burton *et al*. 2012)**
- **Convergence line at leading edge of outflow with thermally-driven easterly**

WRF vs Observations – did the control run reproduce the case study?

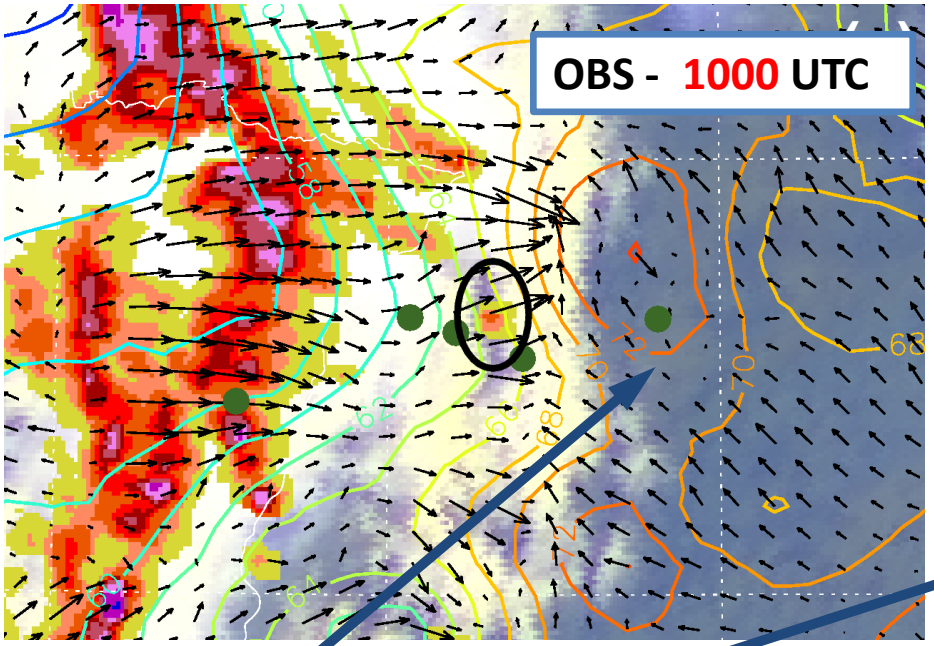
Observations at 0908 UTC and WRF at 1000 UTC

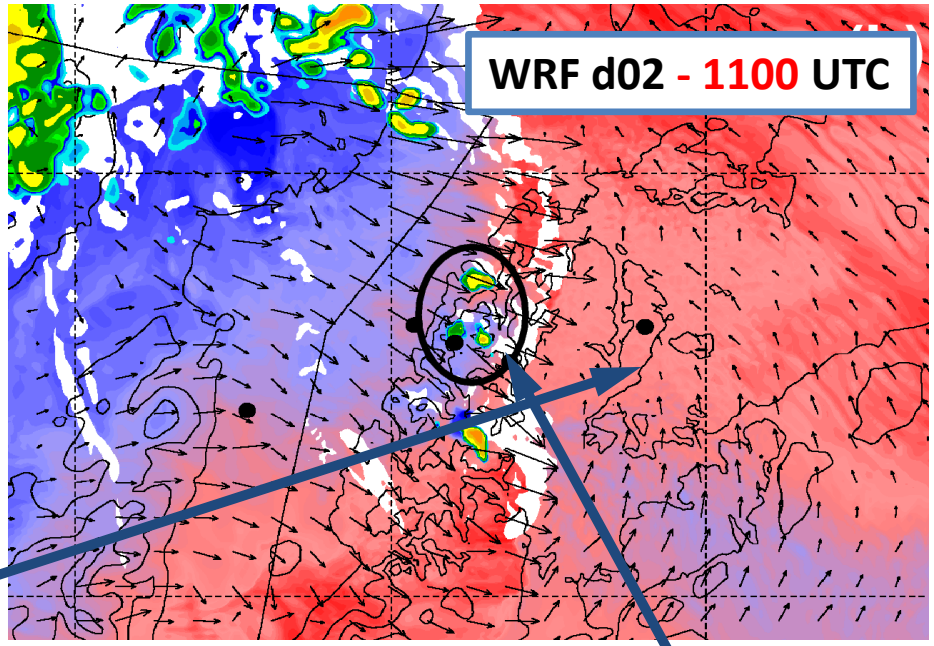


- **Troposphere profile good agreement although too moist above 650 hPa**
- **Boundary layer – very poor agreement**
- **Fog in Rhine Valley absent**
  - **Fog was present but burned off early because of aggressive mixing**

Obvious disagreement between WRF and observations in boundary layer, however...

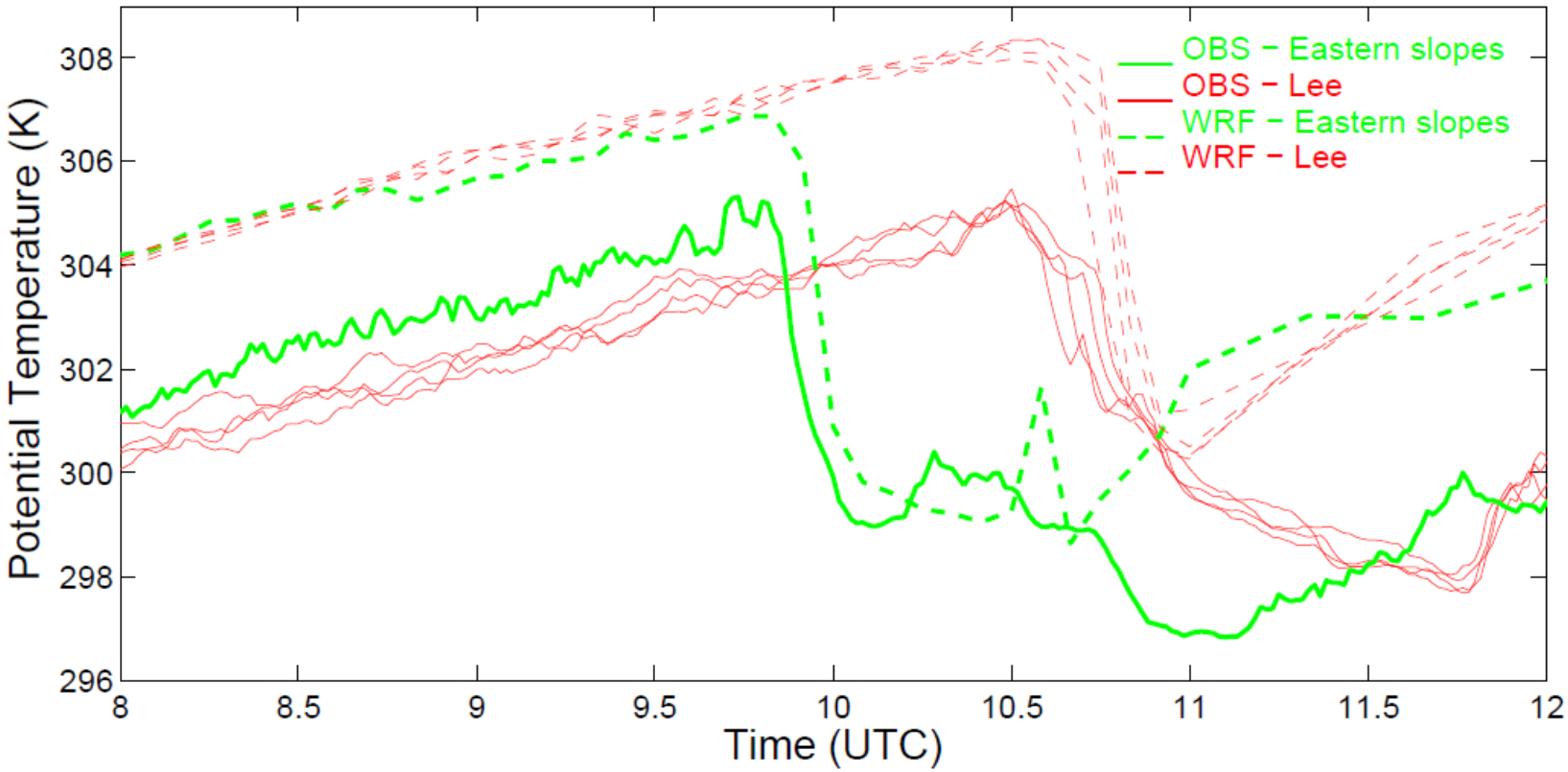
WRF vs Observations – did the control run reproduce the case study?





- **Weaker but *successful* convection above crests of Black Forest (Will be shown in more detail in later slide)**
- **Thermally-driven plain-mountain flow *not* generated > weaker convergence**
  - **Later (not shown) show simulated precipitation significantly less than observations**
  - **WRF diverges most clearly in southern end of regenerated convection**

Inability of WRF to reproduce thermal flow



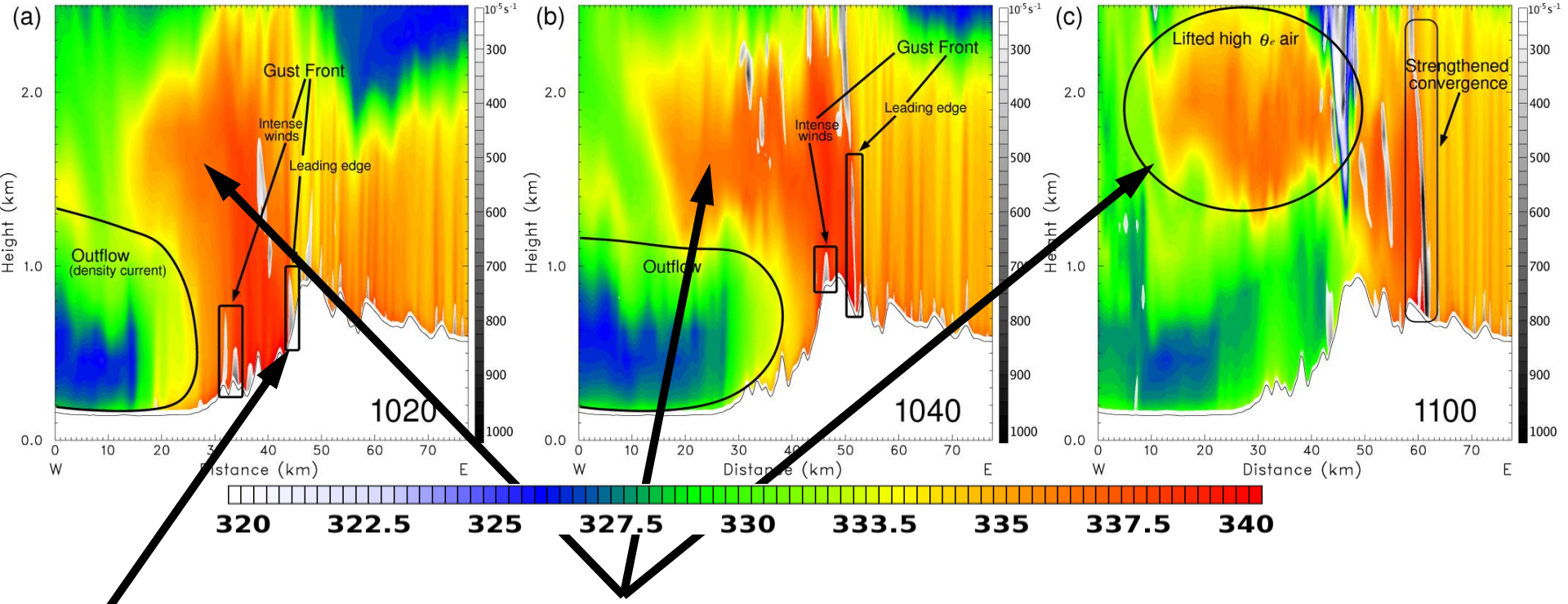
- Temperature gradient of 1 K developed during the morning of the 20th July between the plain and the mountain (over a distance of ~30 km) drove a thermal plain-mountain flow
- No temperature gradient in WRF
- Too well-mixed countergradient BL parameterisations fail to allow generation of temperature gradients

Successful simulation of flow features

- **Model error attributed to boundary layer parameterisation mixing issue and errors in initial conditions**
- **Convection regenerated above mountain crests occurred *despite* model error**
- **Convection less intense; but similarly located to observations**
- **WRF therefore 'useful' for investigating role of orography in convection regeneration above crests of Black Forest mountains**

Role of orography in convection regeneration

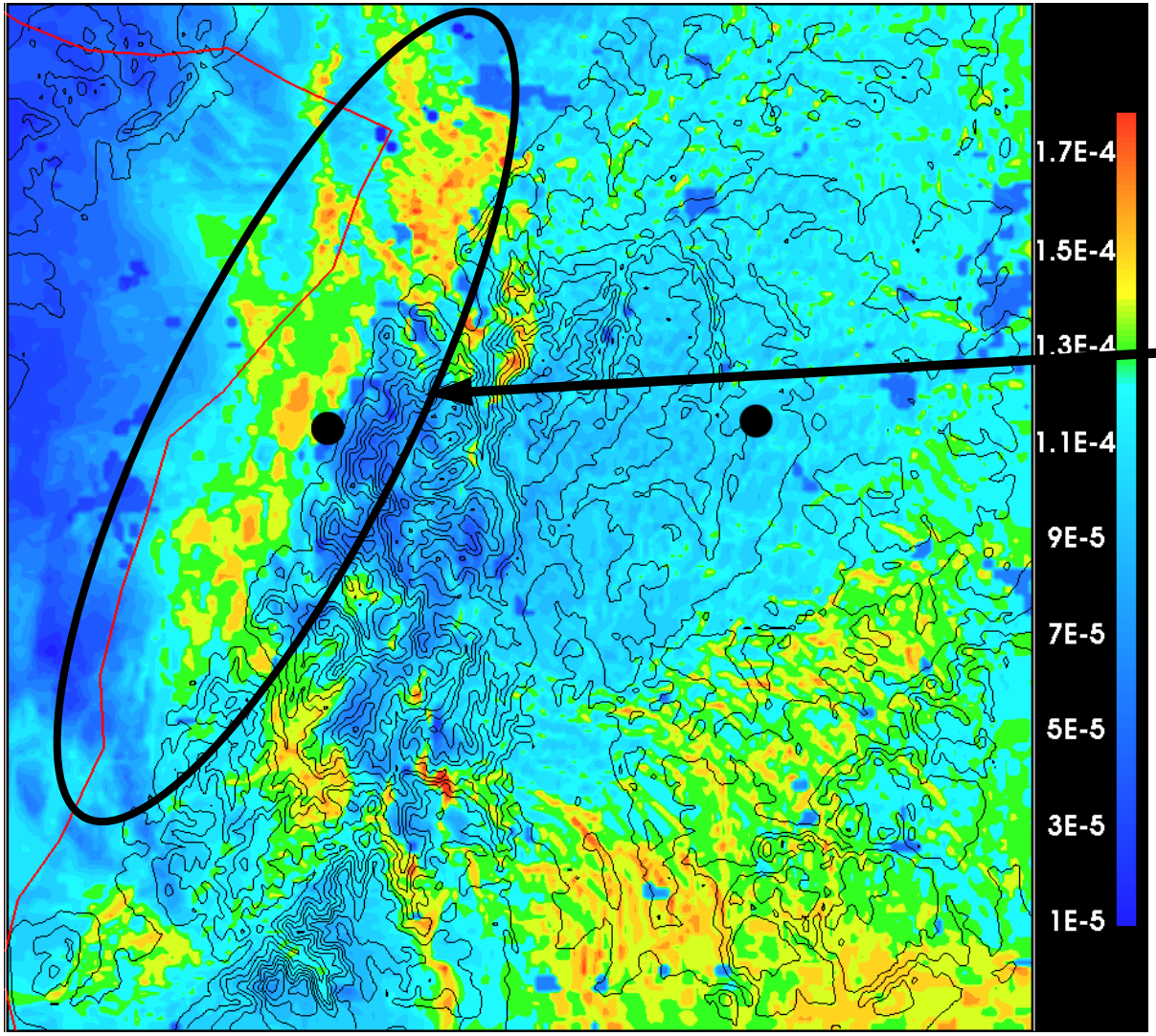
Results from control run – equivalent potential temperature and convergence (grey)



- **Outflow undercut and lifted warm moist valley air above mountain height**
  - **Elevated warm / moist buoyant air**
- **Convergence ahead of outflow when gust front encountered orography**
- **Convection initiated above mountains**
- **Convergence strengthened but was weaker than observations because thermal plain-mountain not generated**

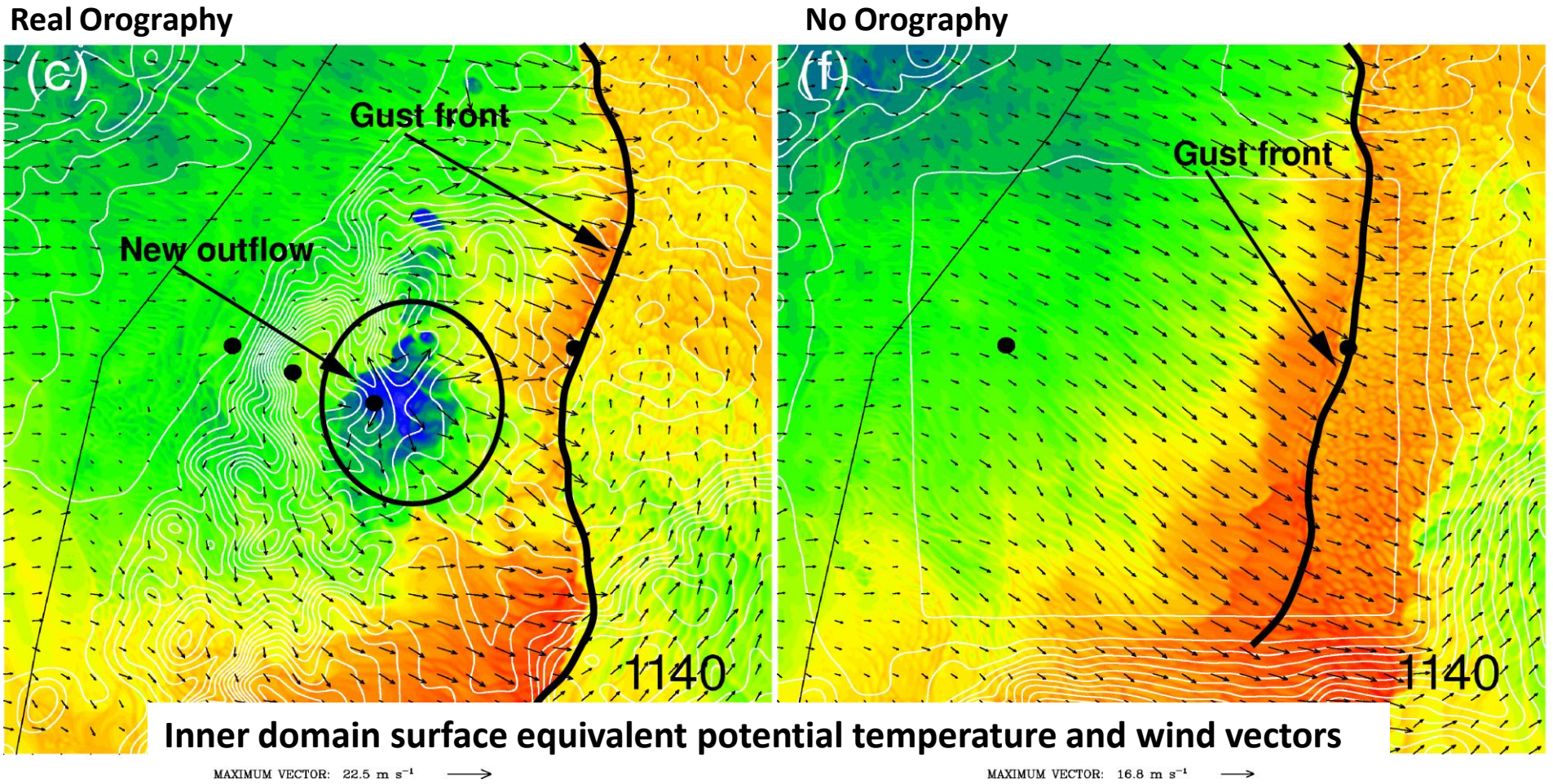
Origin of high Θ_e air behind gust front

Surface moisture flux (SSR and SSM are marked)



- Comparison of cross sections of potential temperature and equivalent potential temperature suggest that higher Θ_e is from moisture
- From simulated surface moisture flux we estimate that 1 kg m^{-2} s^{-1} of water is transferred to the boundary layer
- If mixing occurs up to an altitude of approximately 1 km, the mixing ratio will increase from 10.5 g m^{-3} to 11.5 g m^{-3} over a period of ~2 hrs, which equates to an increase of ~3 K

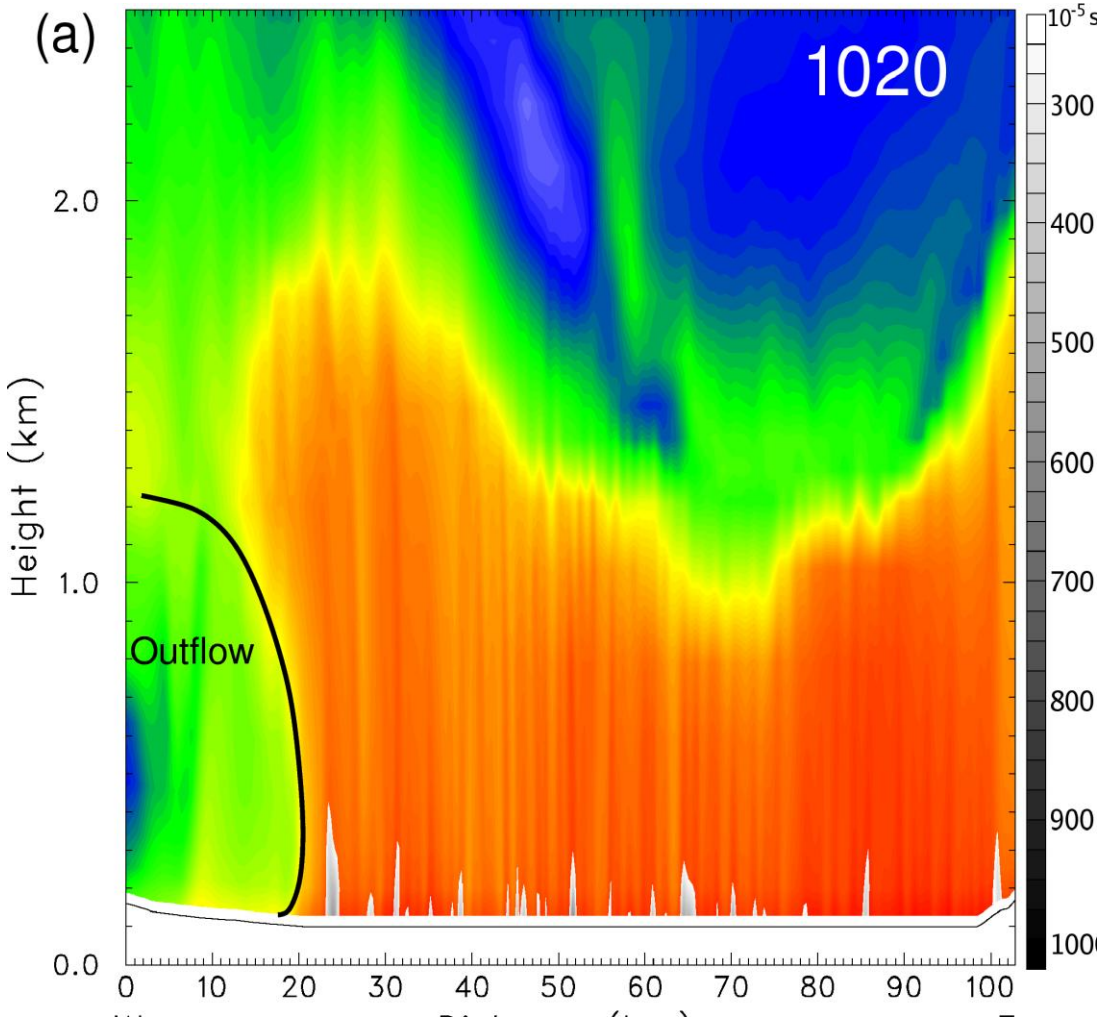
Convection regeneration without orography?



Convection regeneration didn't occur without Black Forest

Downstream convection – **no orography case**

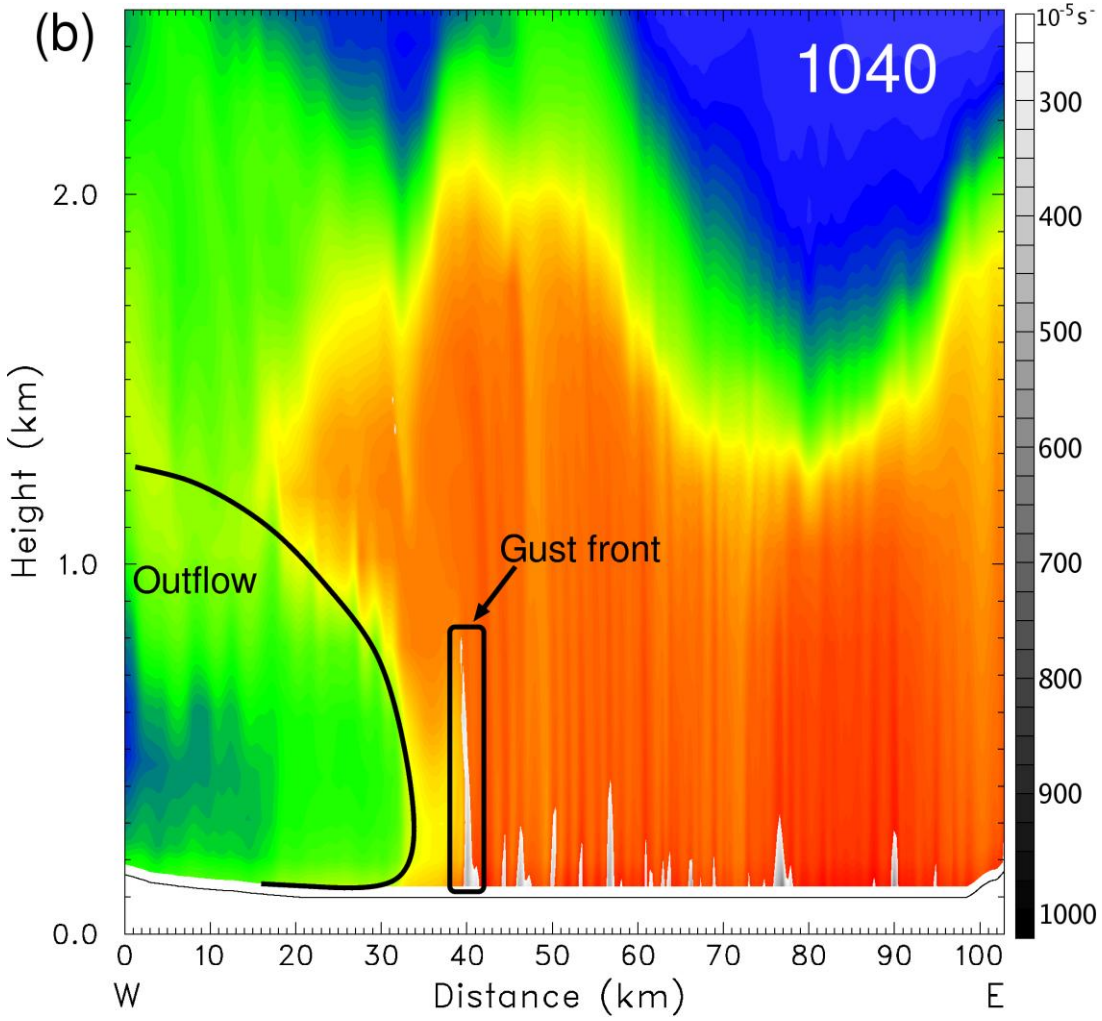
Inner domain cross sections of θ_e and convergence for no orography case



- **Outflow propagated across domain undisturbed – density current**
- **Warm moist valley air undercut and still lifted as in real orography case**
- **Higher θ_e from prolonged influence of moisture flux insufficient for convection**
- **Convergence and updrafts generated *IMMEDIATELY* as outflow encountered orography of Swabian Jura**

Downstream convection – **no orography case**

Inner domain cross sections of θ_e and convergence for no orography case



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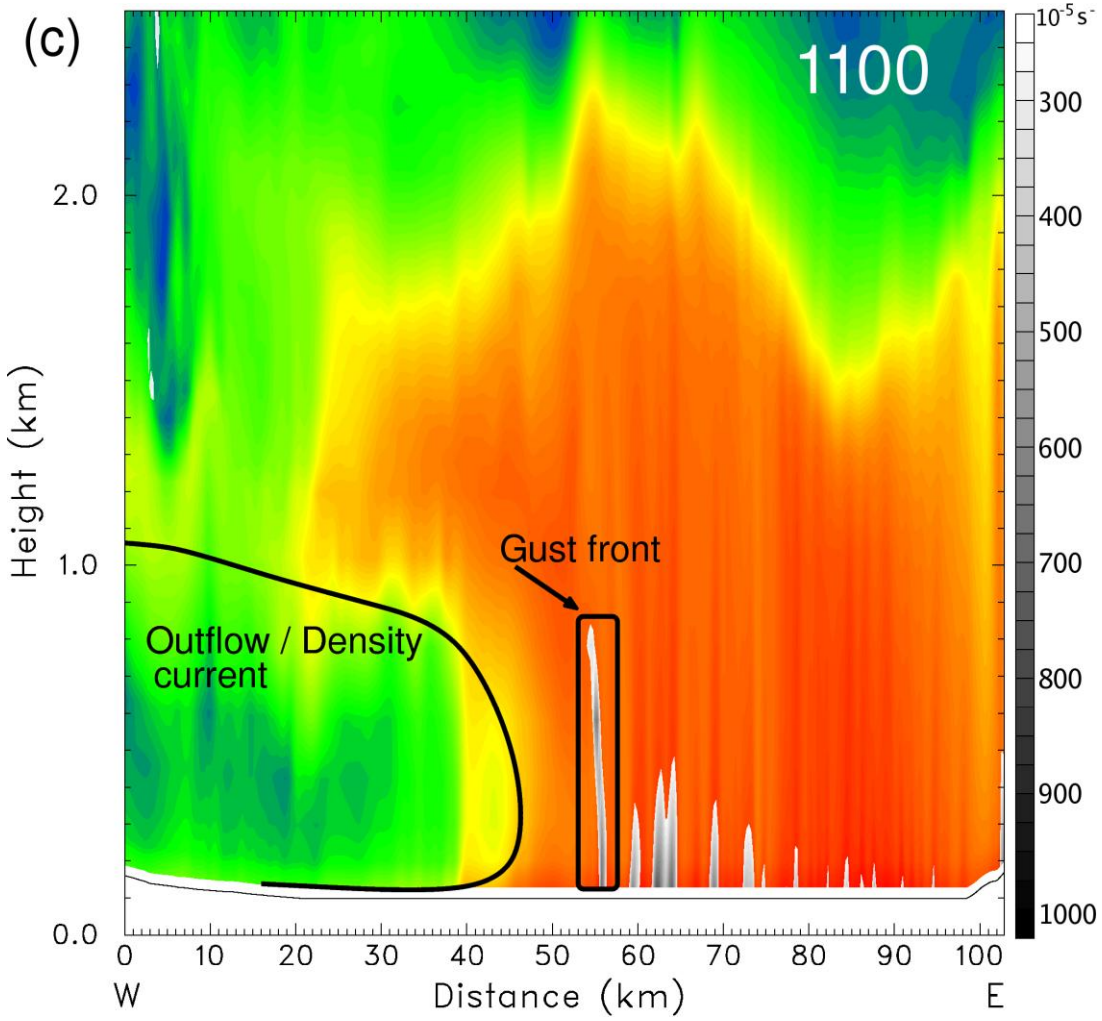

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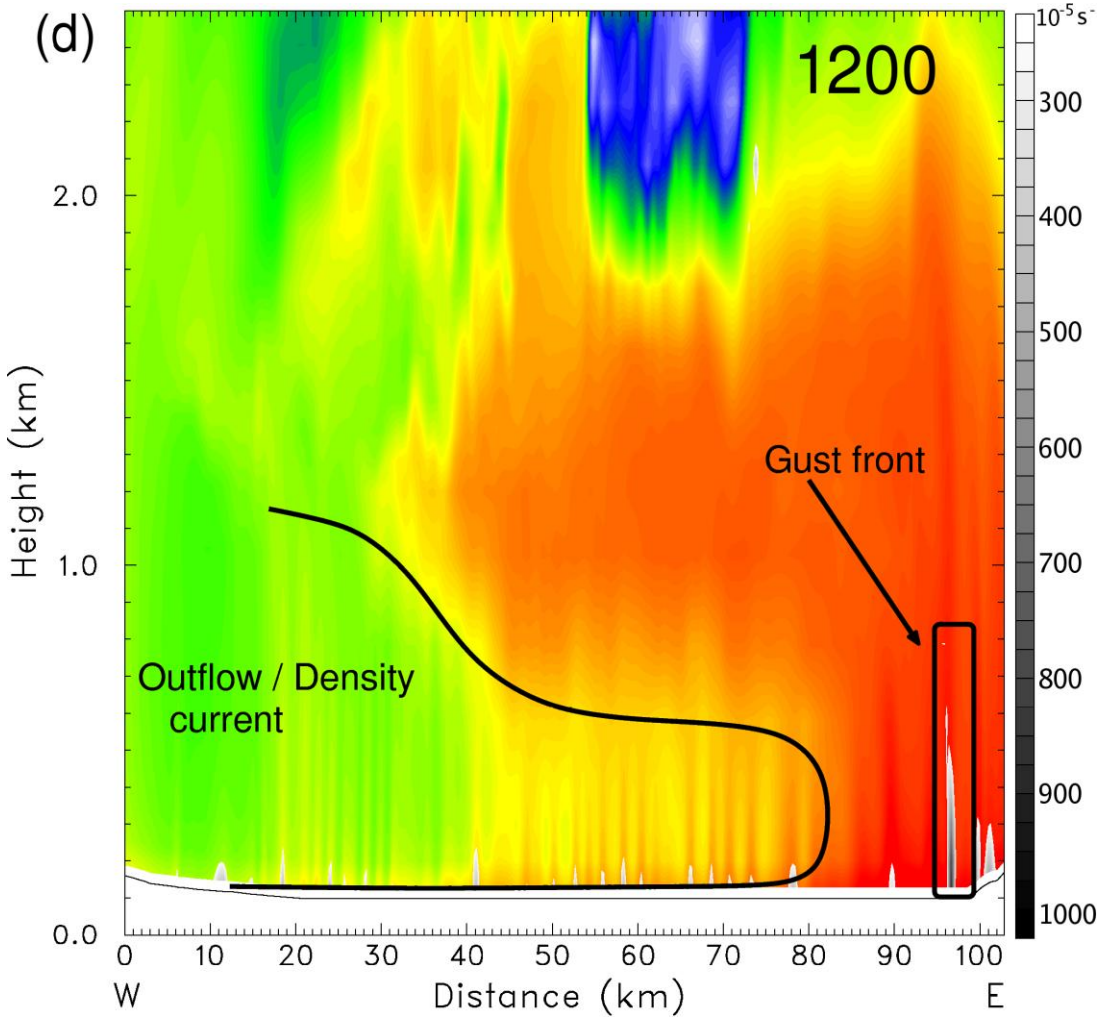
Downstream convection – **no orography case**

Inner domain cross sections of θ_e and convergence for no orography case



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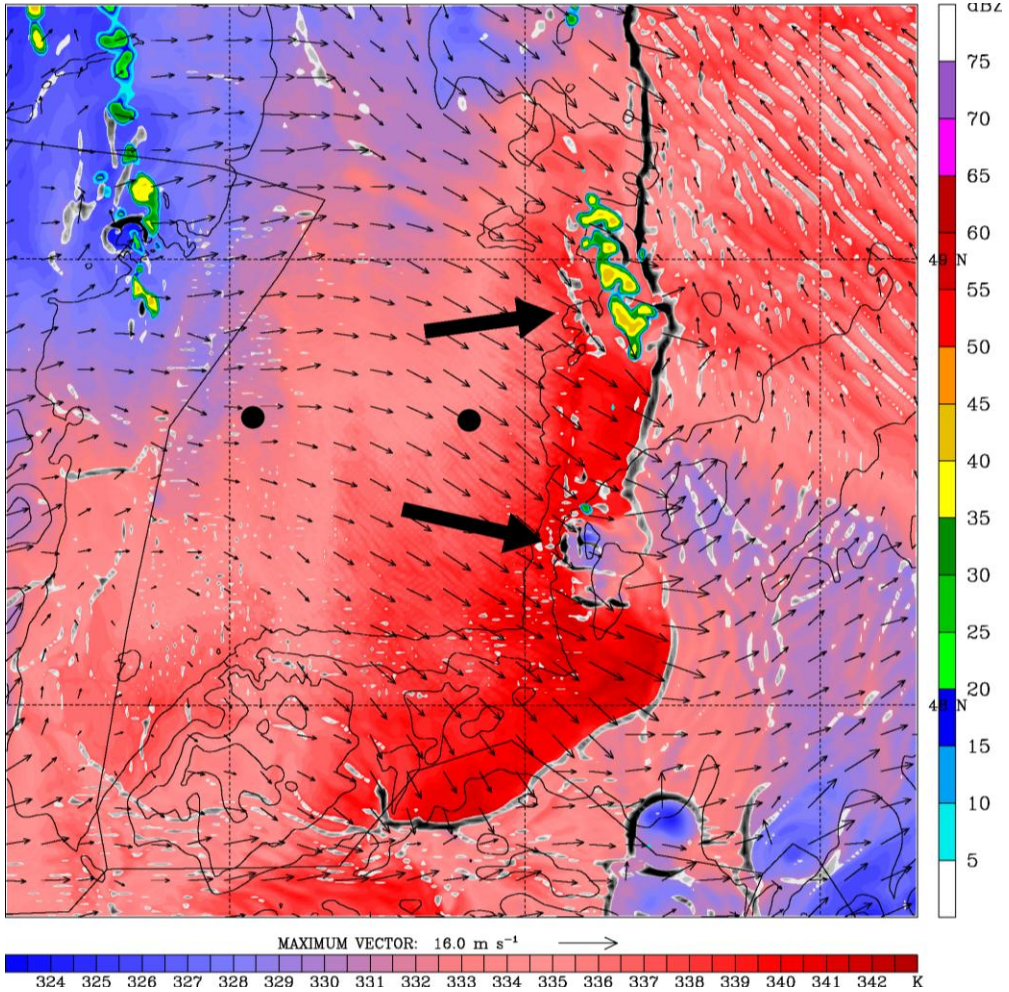
Downstream convection – no orography sumulation

Middle domain surface θ_e, wind vectors, convergence and precipitation for no orography case at 1240 UTC



- **Outflow propagated across domain undisturbed**
- **Warm moist valley air undercut and lifted as in real orography case**
- **Convergence and updrafts generated IMMEDIATELY as outflow encountered orography of Swabian Jura**

- **20 minutes later, convection regeneration above mountain crests**
- **Convection regeneration occurred instantly when outflow encountered some orography**

CONCLUSIONS

- **Convection regeneration occurred because MCS outflow encountered significant orography**
- **Undercutting of warm moist air generated elevated region of warm / moist buoyant air**
- **Development of convergence line, resulting from forced orographic lifting and intensification of a gust front**
- **Boundary layer parameterisation critical for development of thermal gradients**
- **Prolonged undercutting of warm and moist air by MCS outflow insufficient for convection**
- **For this case, small but significant forcing required from orography**

Thank you for listening.

Any Questions?

References

Burton, R. R., A. Gadian, A. Blyth, and S. D. Mobbs (2012). The representation of boundary layer processes in a high-resolution numerical model: a sensitivity study from the COPS experiment. Met. Zeit. COPS Special issue. In Prep

Corsmeier, U., N. Kalthoff, C. Barthlott, A. Behrendt, P Di Girolamo, M. Dorninger, J. Handwerker, C. Kottmeier, H. Mahlke, S. Mobbs, G. Vaughan, J. Wickert, and V. Wulfmeyer (2011). Driving processes for deep convection over complex terrain: A multiscale analysis of observations from COPS-IOP9c. Q. J. R. Meteorol. Soc.

Weisman, M. L., C. Davis, W. Wang, K. W. Manning, and J. B. Klemp (2008). Experiences with 0-36-h explicit convective forecasts with the WRF-ARW model. Weather and Forecasting 23(3), 407–437.

The results from this presentation will be submitted to a Met. Zeit. COPS Special issue, which is planned to be published online in late 2012.