School of Earth and Environment

Institute for Climate and Atmospheric Science

UNIVERSITY OF LEEDS

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

Victoria Smith[1*], Stephen Mobbs[1,2], Ralph Burton[1,2], Matt Hobby[1], Fumiko Aoshima[3], Volker Wulfmeyer[3], Manfred Dorninger[4] and Emily Norton[5]

[1]University of Leeds, UK

[2]National Centre for Atmospheric Science, UK

[3]University of Hohenheim, Germany

[4]University of Vienna, Austria

[5]University of Manchester, UK

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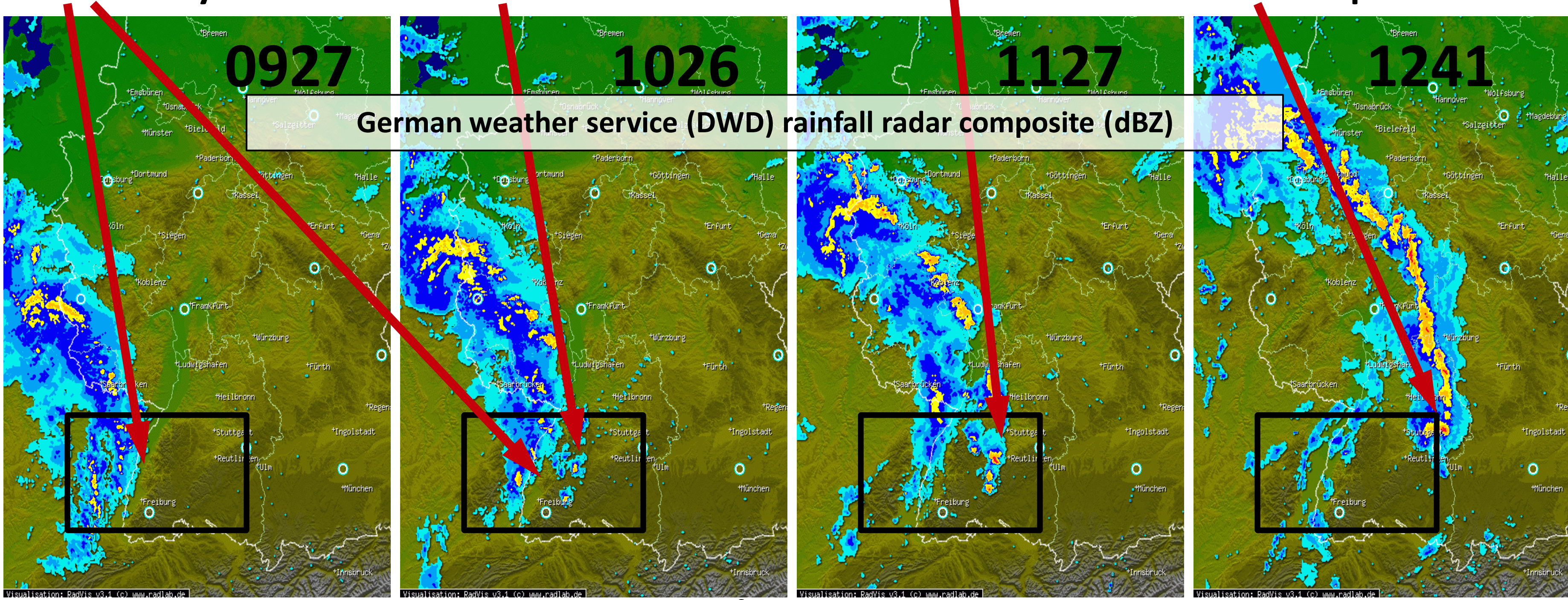
Motivation – 20th July 2007 convection regeneration above Black Forest

- **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**



Time

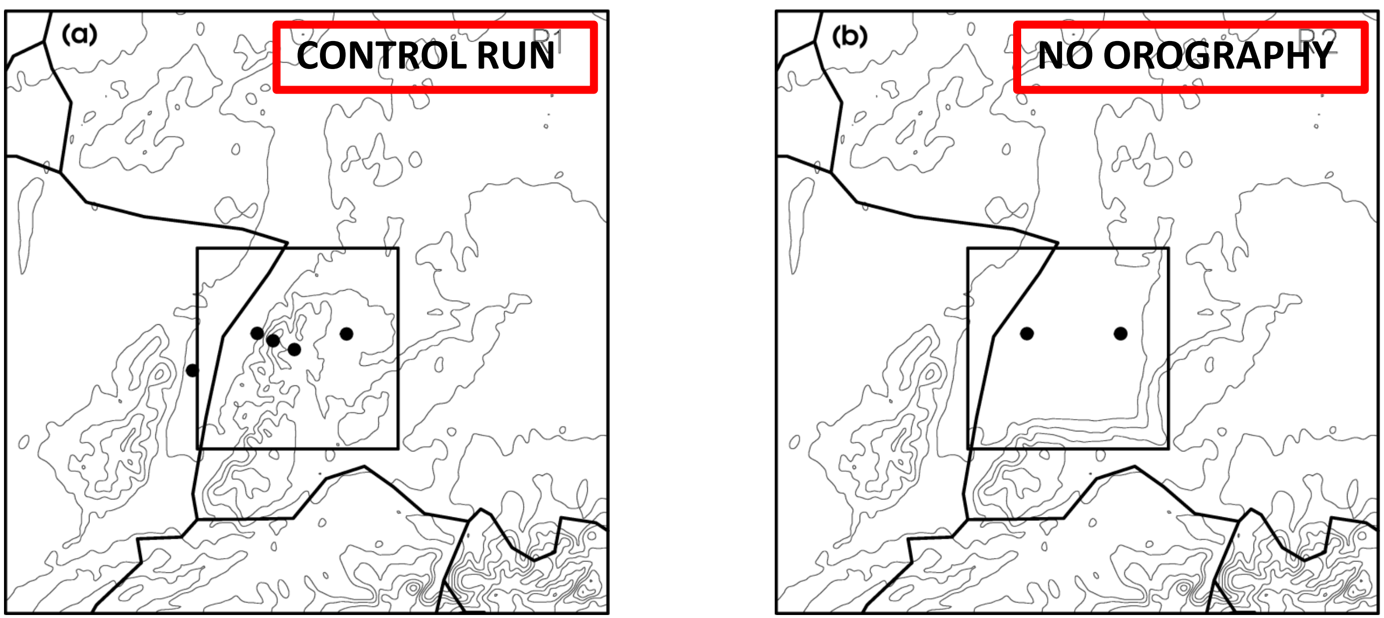
Orography responsible for convection regeneration?

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

Errors from

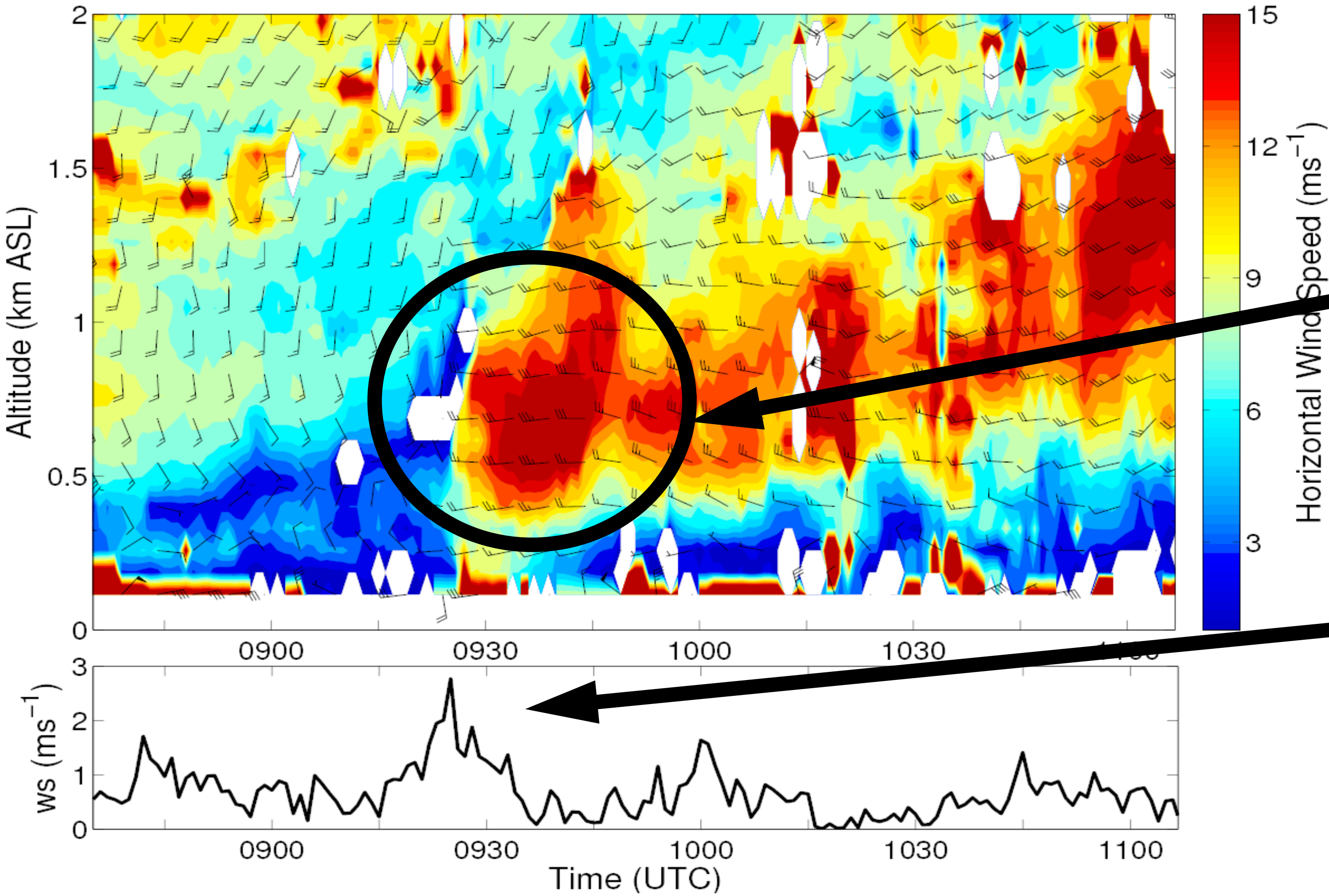
- **Initial and lateral boundary conditions**
- **Insufficient resolution to represent orographic forcings / processes**
- **Over (under) estimation of precipitation on windward (leeward) side**

- **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)

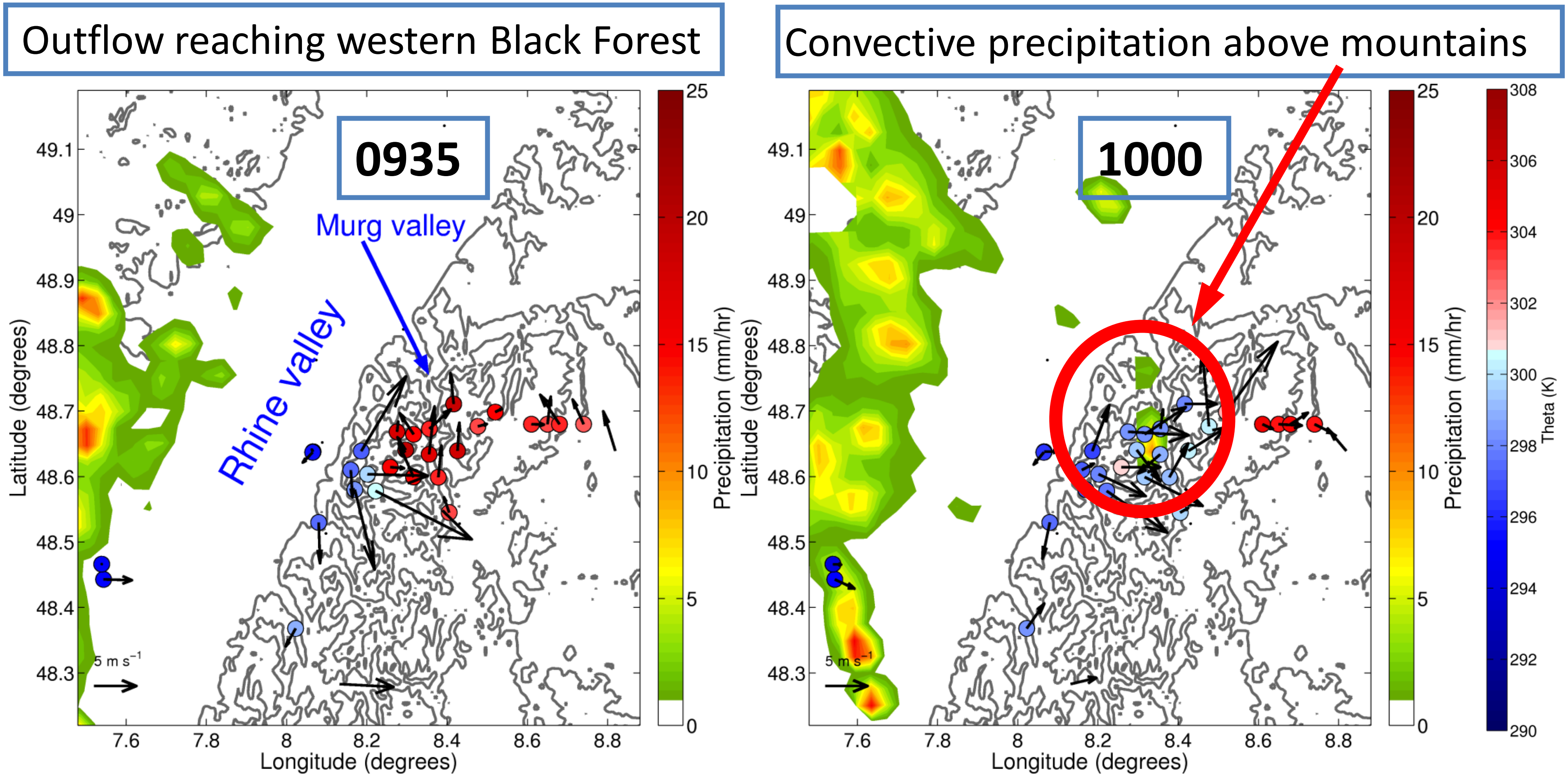


MCS outflow (gust front) passed *over* super site at approx 0930 UTC (1130 local)

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

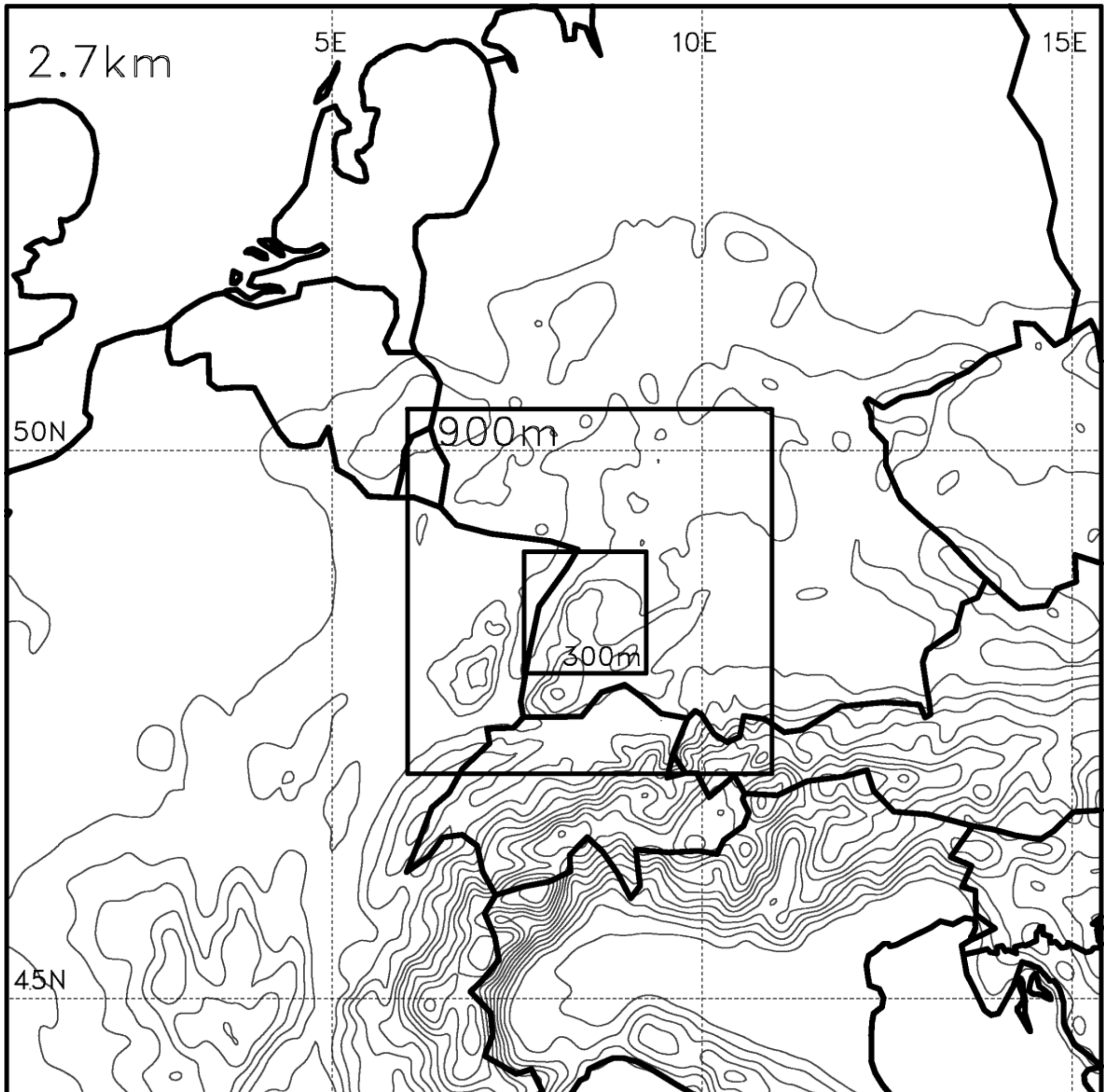
Observations – Convection regenerated above mountains.

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



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

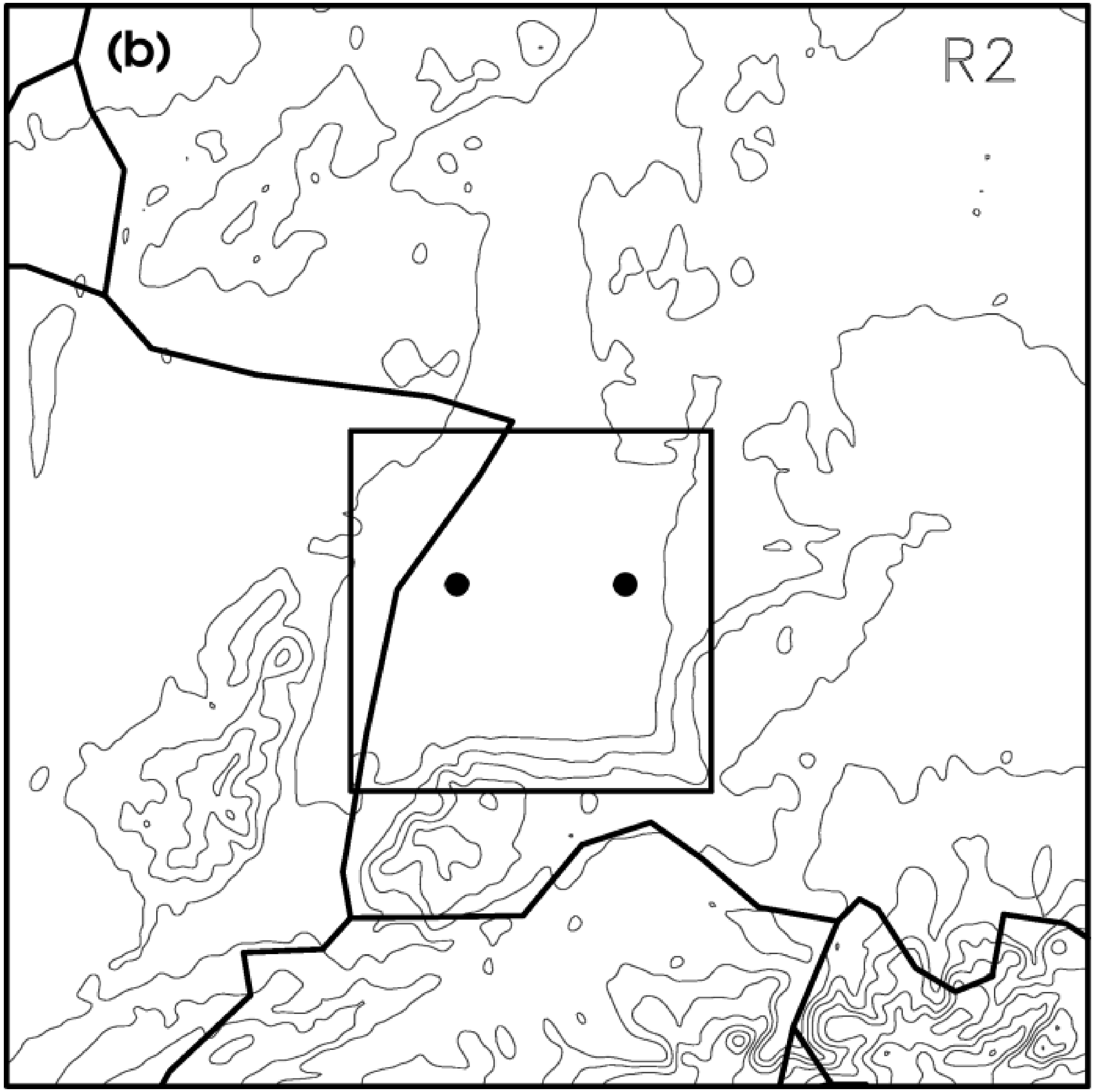
WRF modelling – control run with *'real'* orography



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

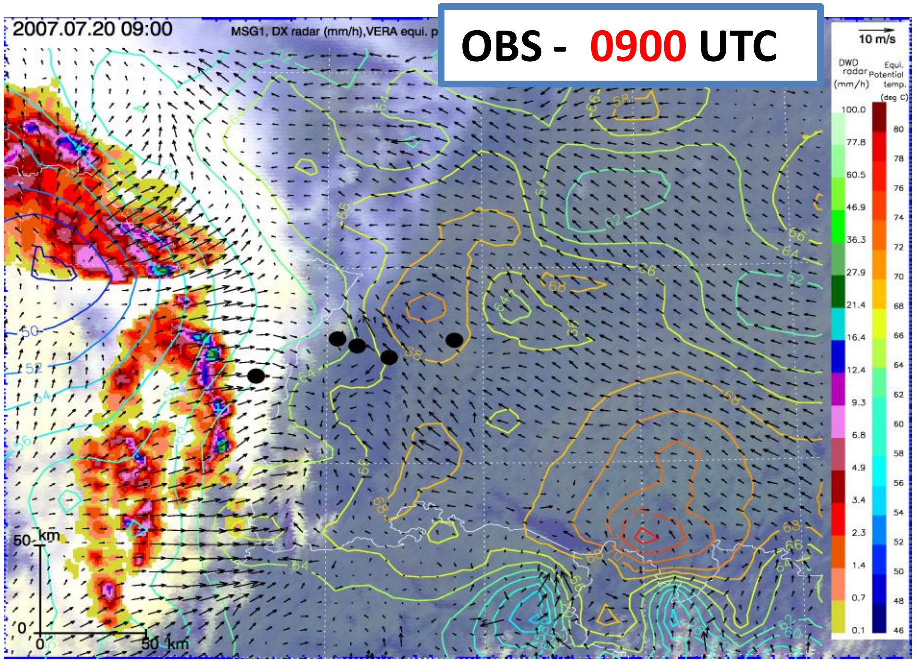
- **WRF version 3.0.1.1**
- **Initialised at 0000 UTC (0.25°ECMWF analyses)**
- **3 nested domains – 2.7km, 900m & 300m horizontal resolution**
- **120 Vertical levels**
- **All domains 400x400 grid points**
- **Morrison microphysics**
- **Standard M-O Surface layer**
- **Yonsei boundary layer**
- **Betts-Miller-Janic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

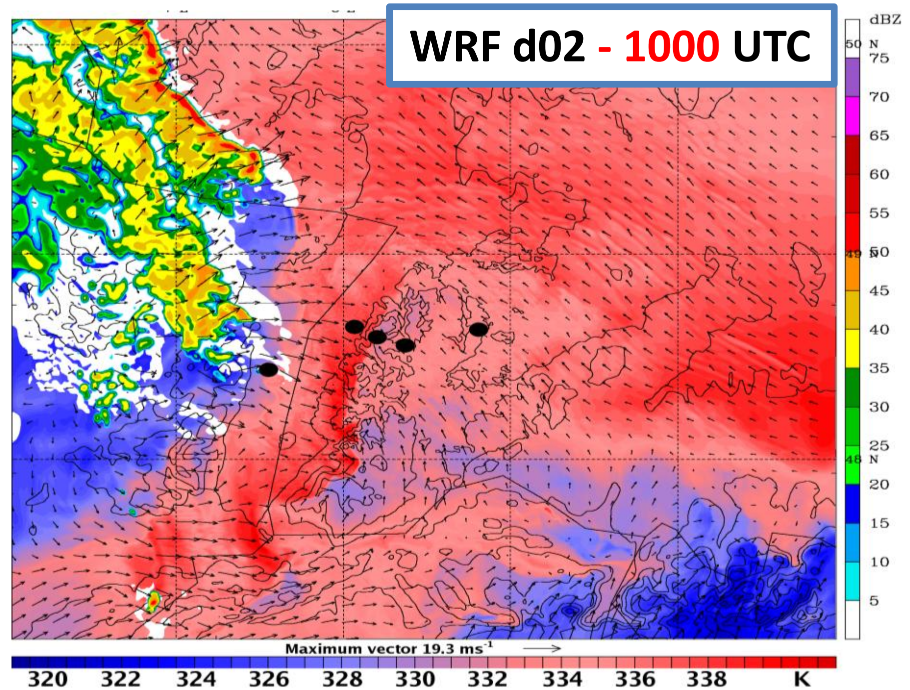
WRF modelling of case study – no Black Forest



- **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?



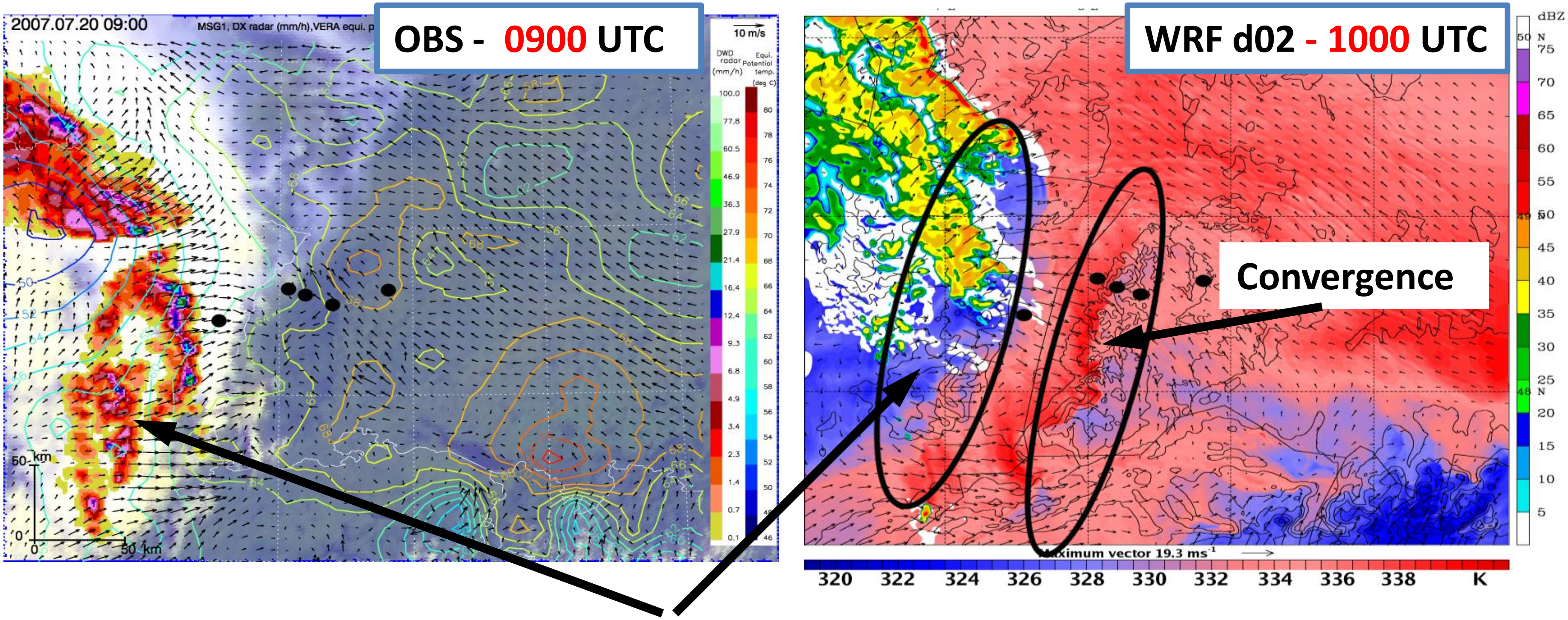


Surface obs from VERA (Steinacker *et al. 06*) fingerprint analysis

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

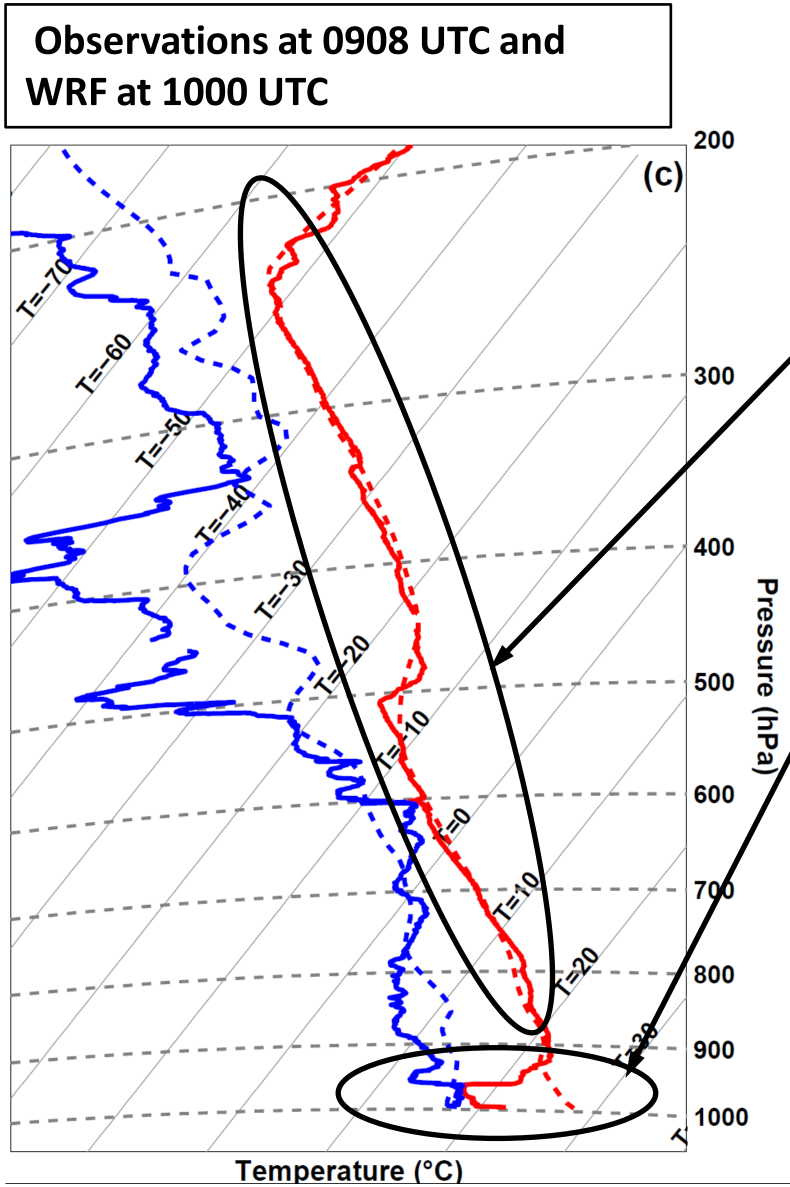
- **Features simulated 1 hour late**
- **Errors in initial and lateral boundary conditions**
- **Observations and WRF compared when features aligned NOT at same times**

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?

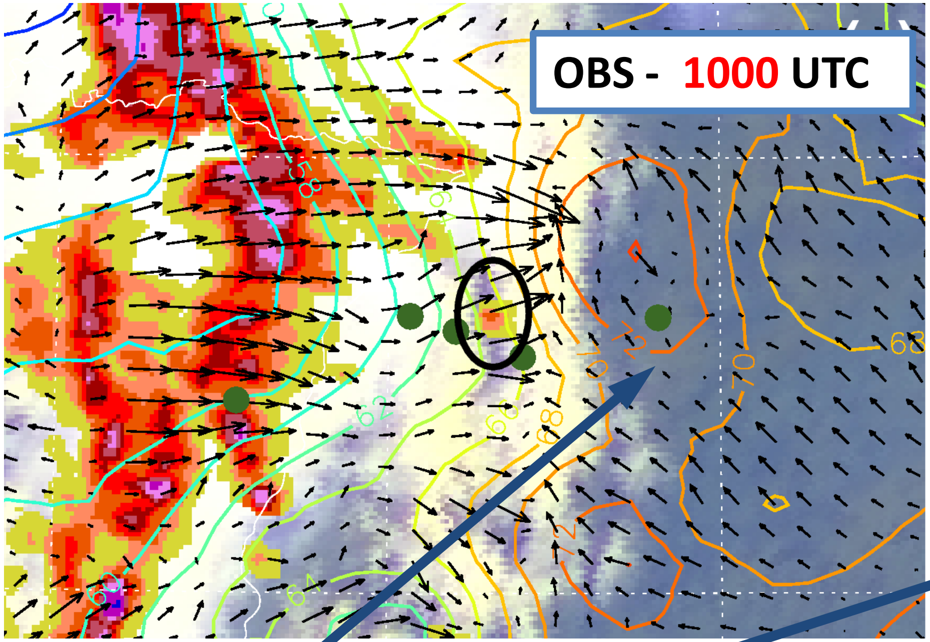


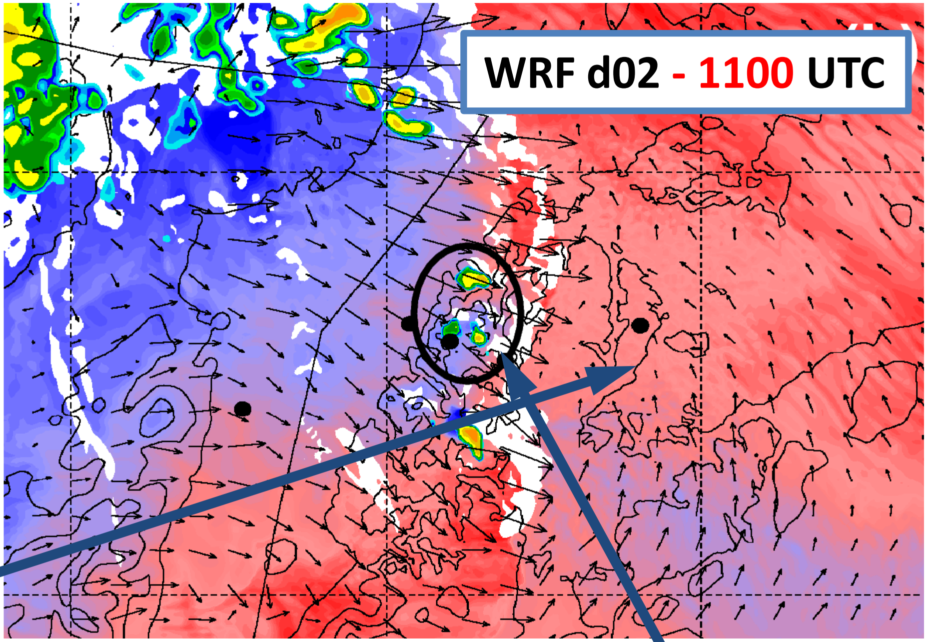
- **Troposphere profile good agreement although too moist above 650 hPa**

- **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...

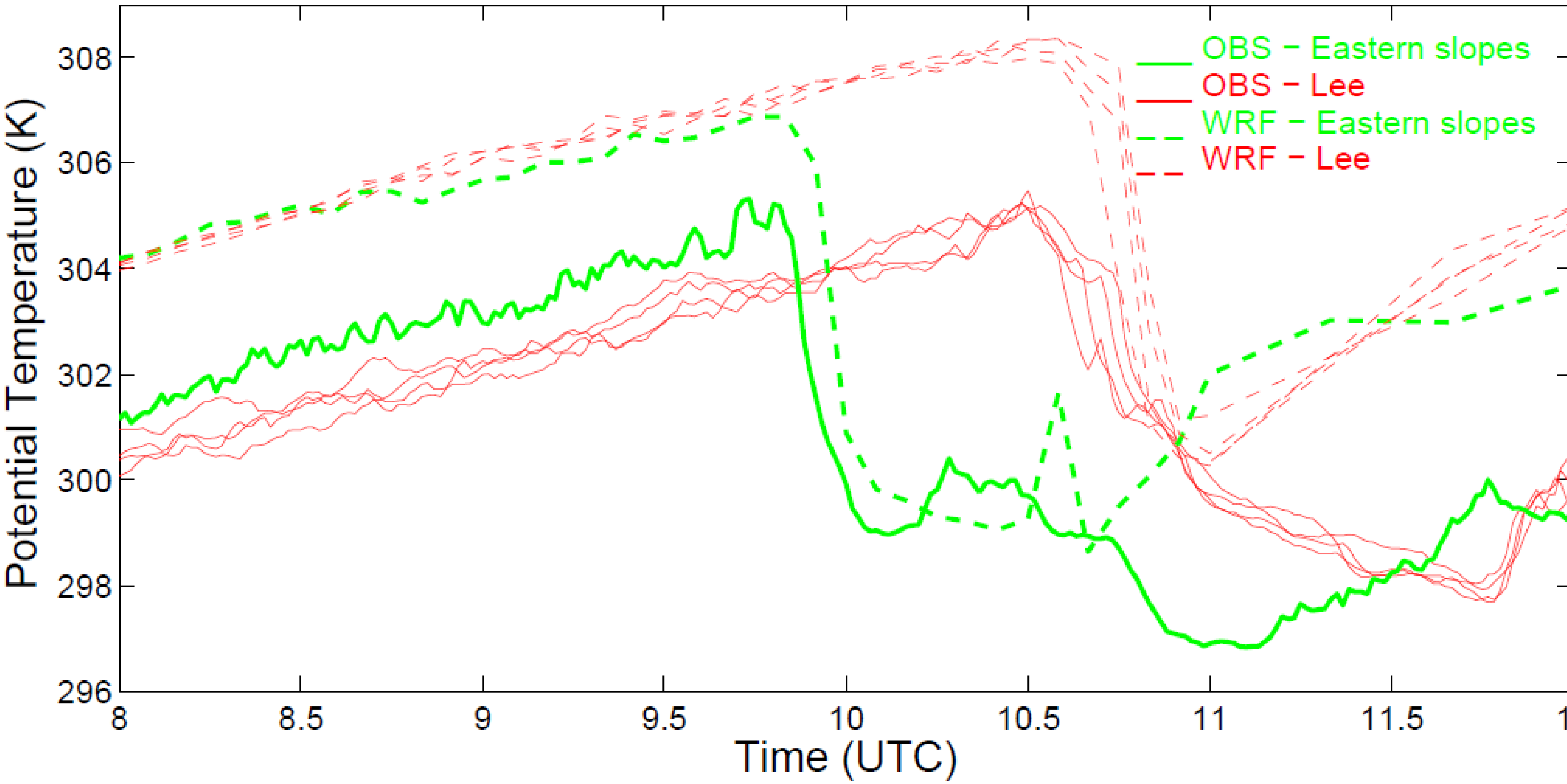
WRF vs Observations – did the control run reproduce the case study?





- **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



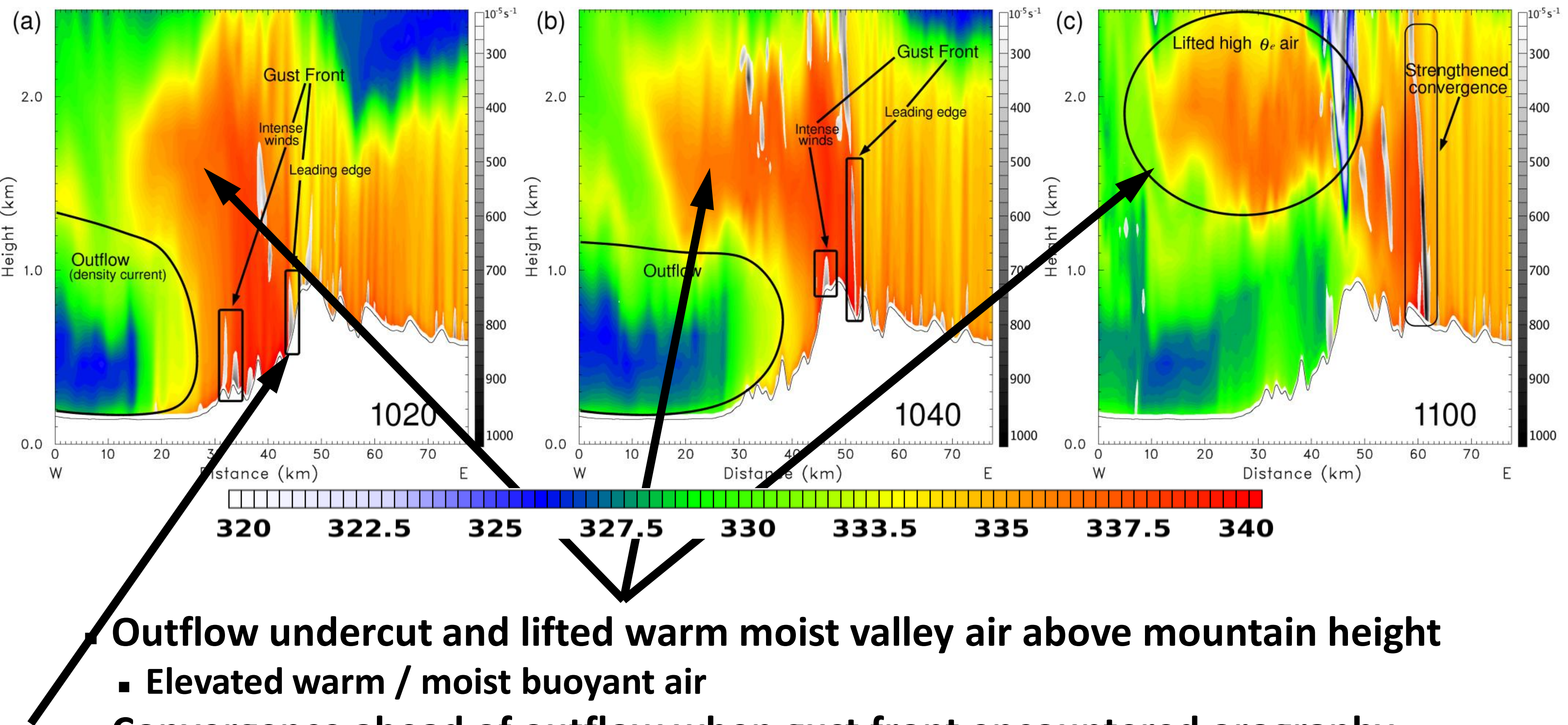
- Temperature gradient of 1 K developed during the morning of the 20th July between the plain and the mountain (over a distance of ~30 km) drove a thermal plain-mountain flow
- No temperature gradient in WRF
- Too well-mixed countergradient BL parameterisations fail to allow generation of temperature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

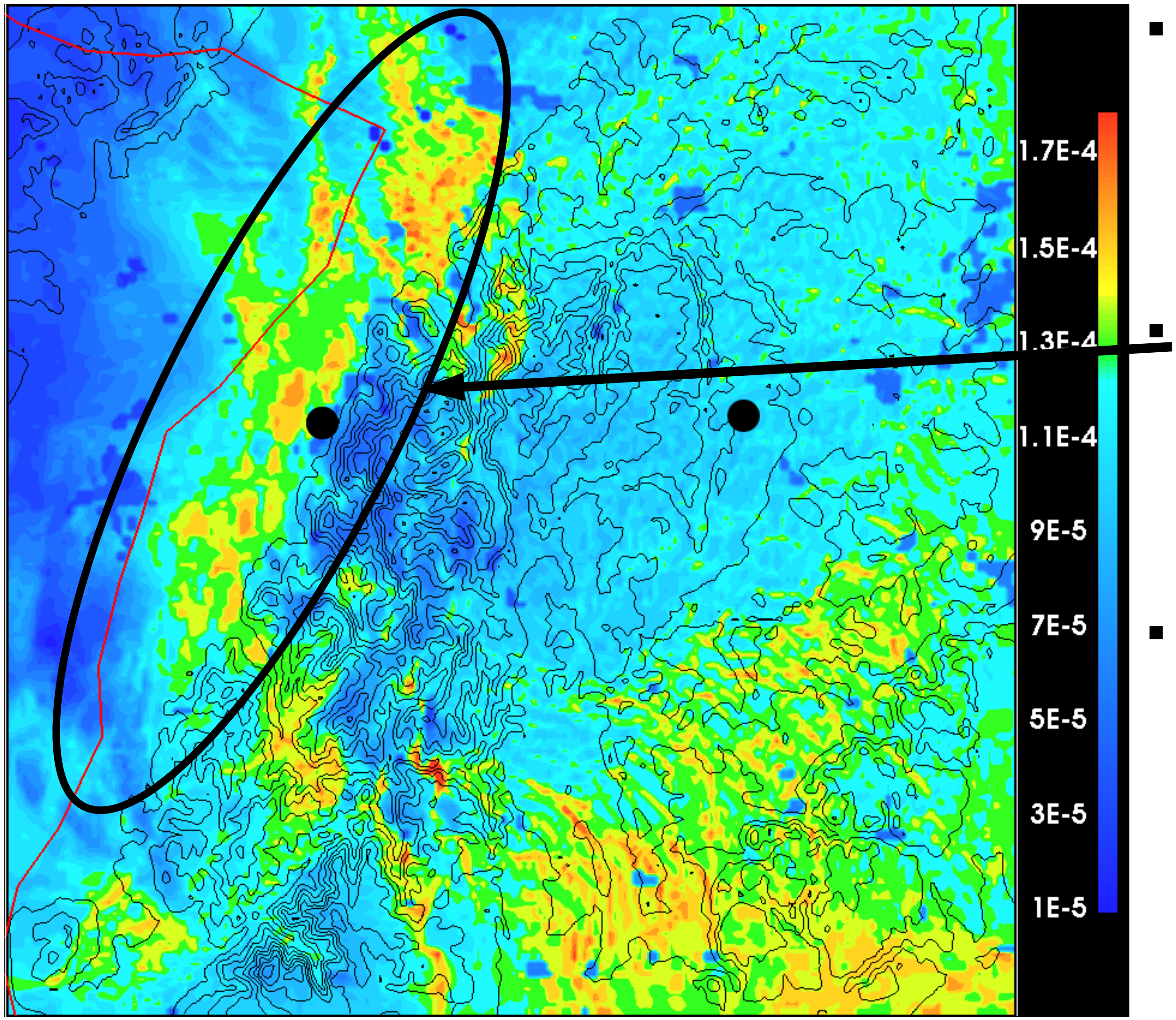
Results from control run – equivalent potential temperature and convergence (grey)



- **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**

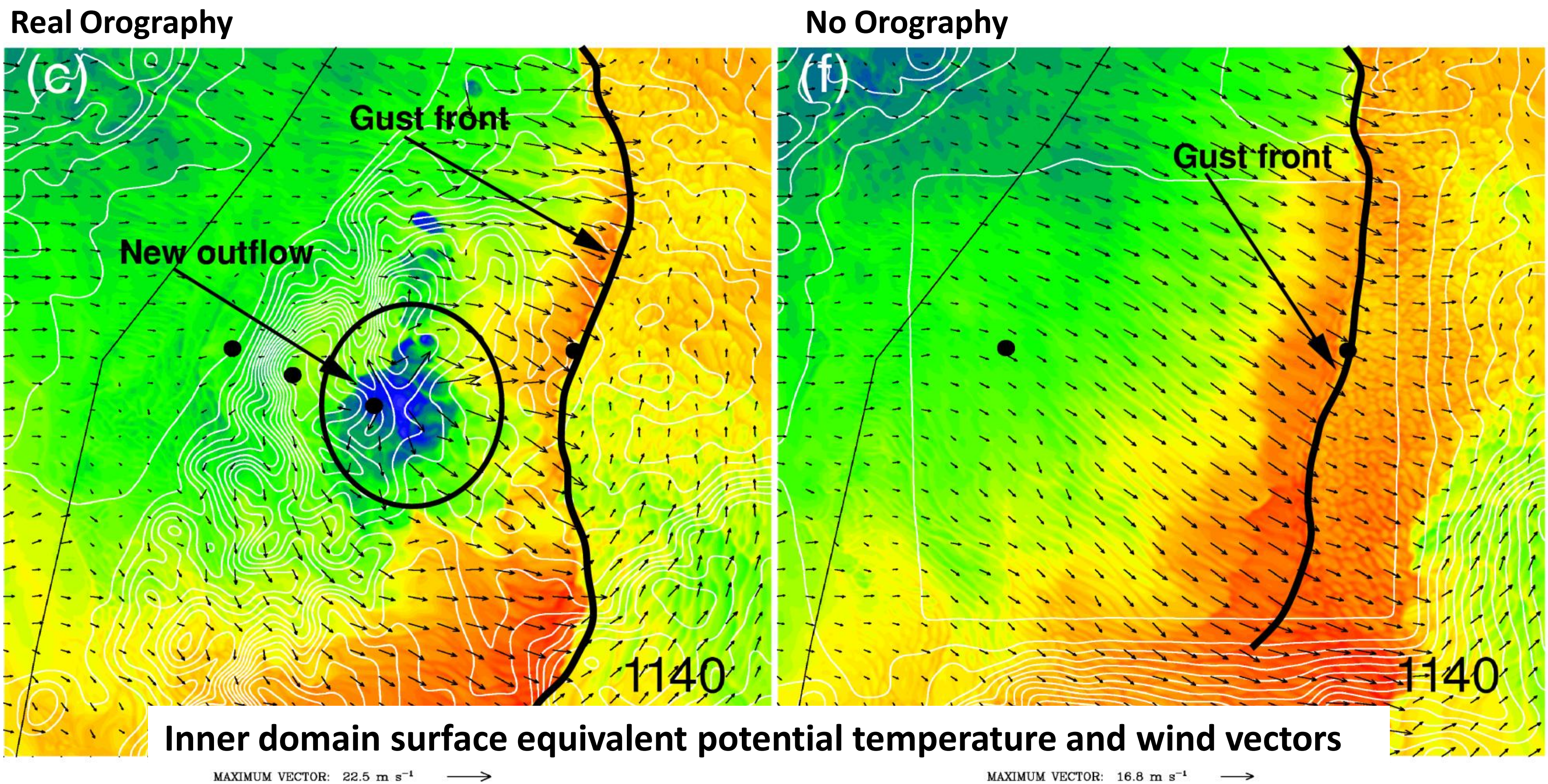
Origin of high Θ_e air behind gust front

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**

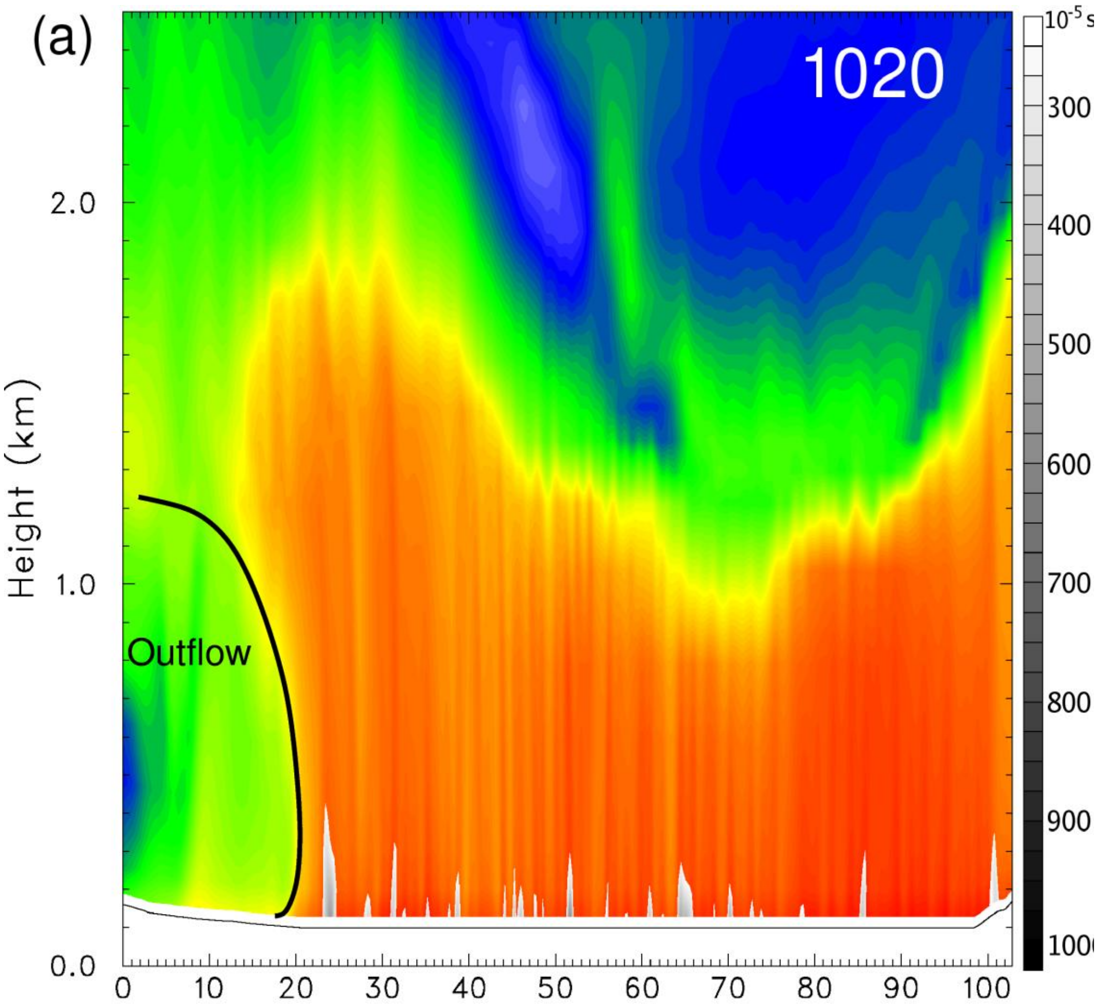
Convection regeneration without orography?



Convection regeneration didn't occur without Black Forest

Downstream convection – <u>**no orography case**</u>

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 – <u>**no orography case**</u>

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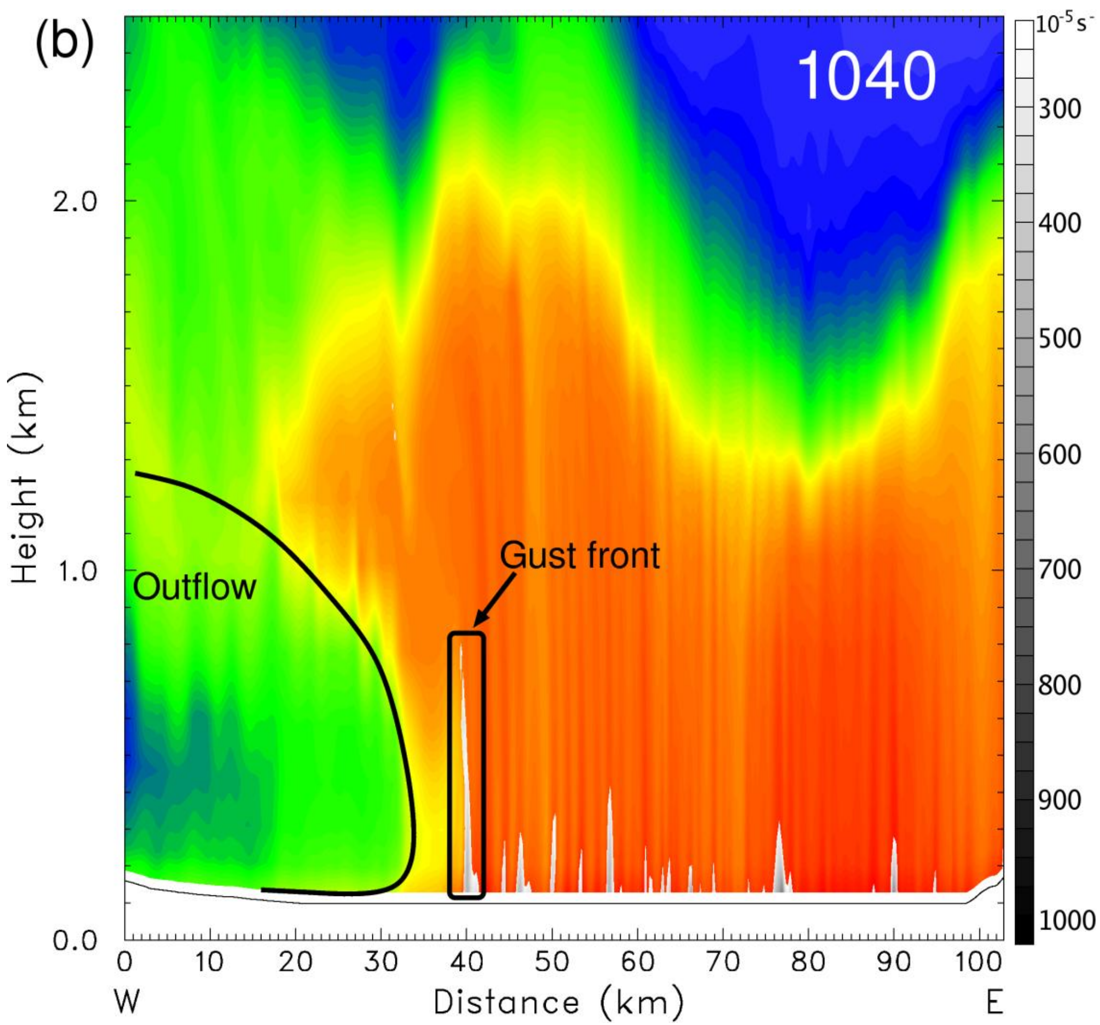

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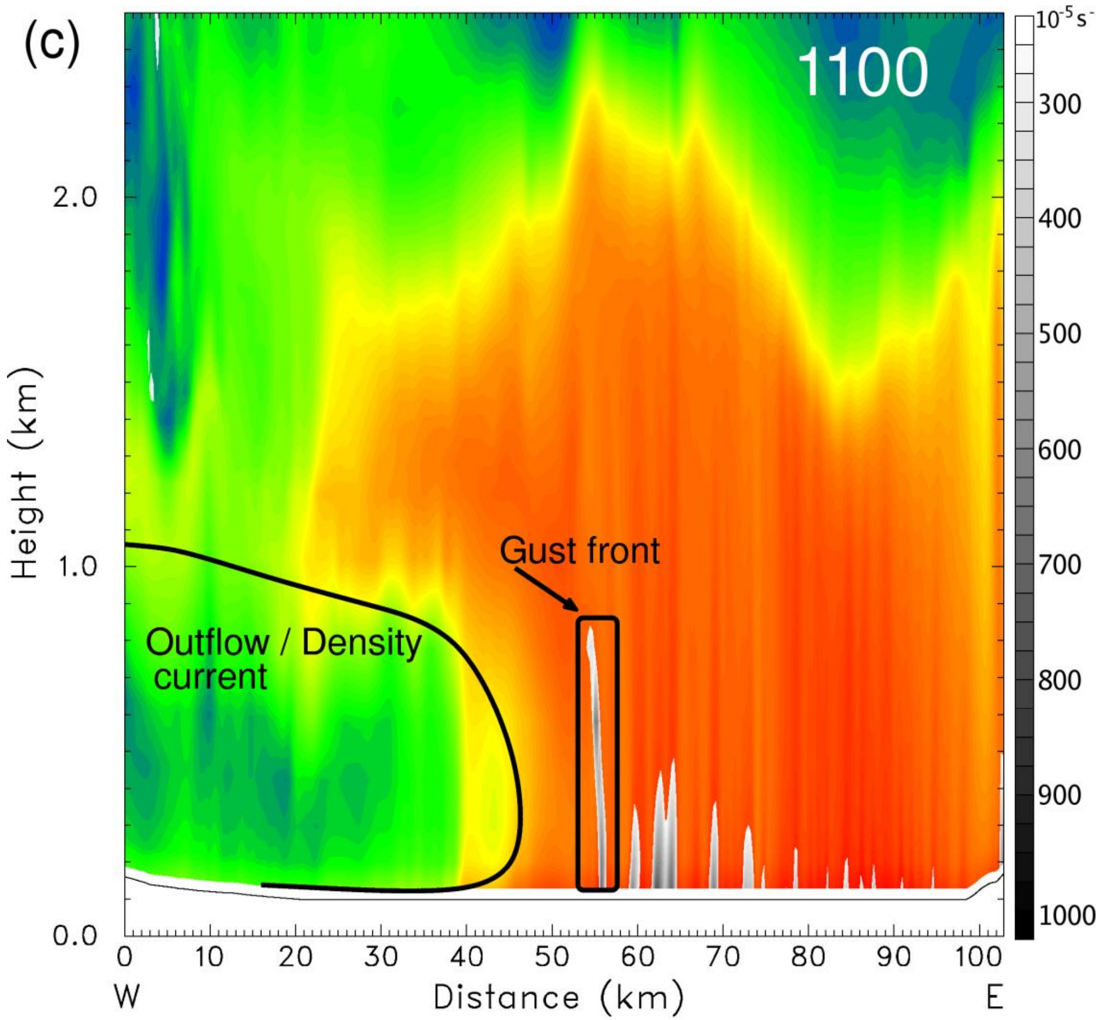

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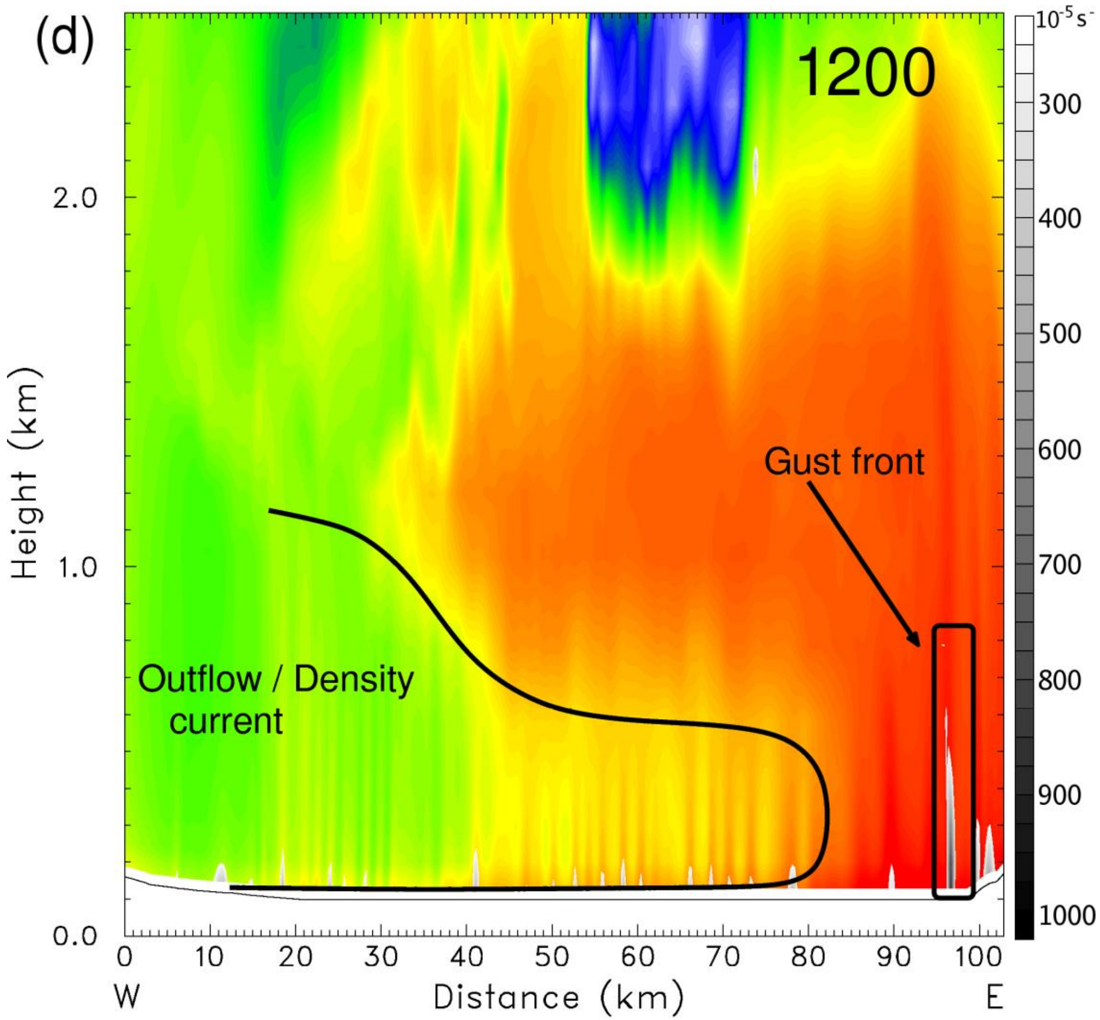

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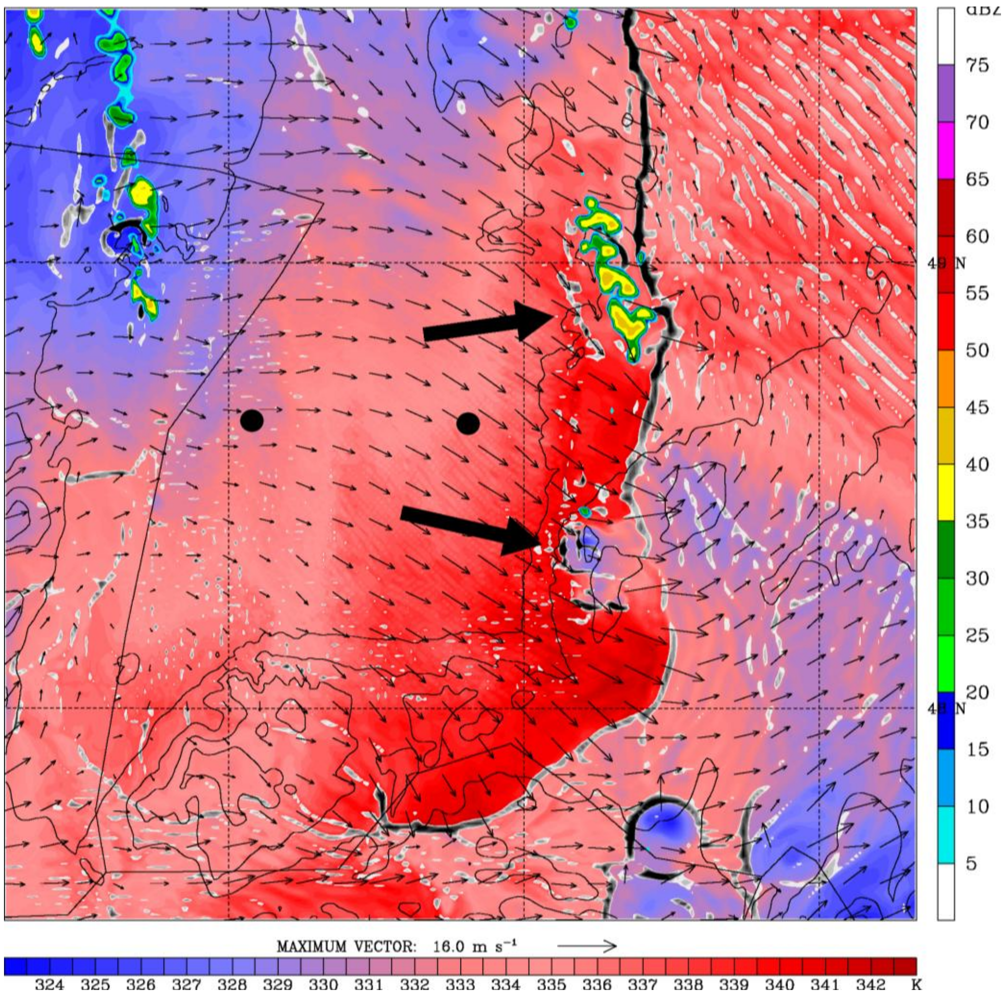
Downstream convection – no orography sumulation

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

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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.