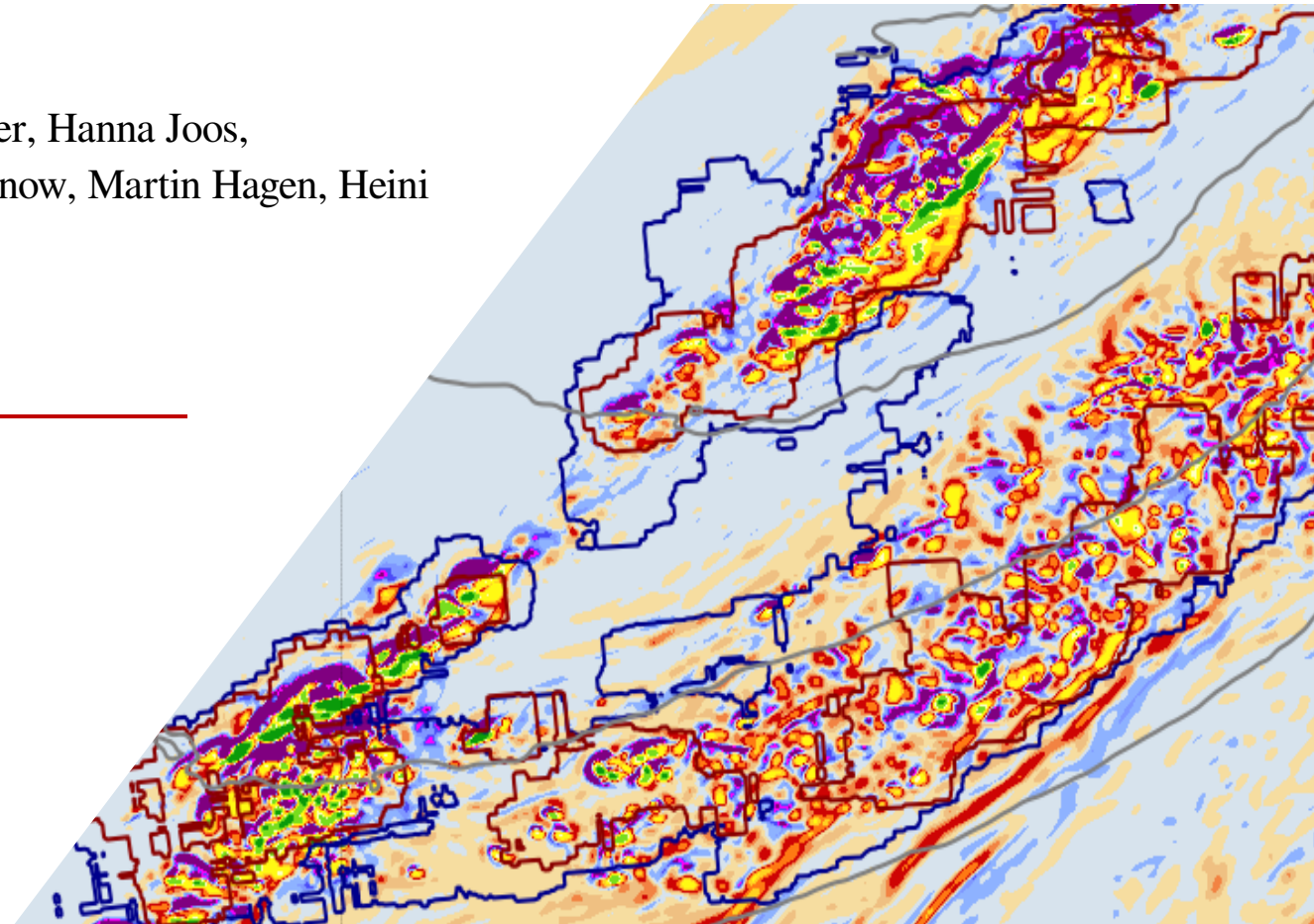
ETH
Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

Embedded convection in the WCB of *Vladiana*
IOP 3

NAWDEX workshop

Annika Oertel, Maxi Böttcher, Hanna Joos, Michael Sprenger, Heike Konow, Martin Hagen, Heini Wernli

IAC, ETH Zürich

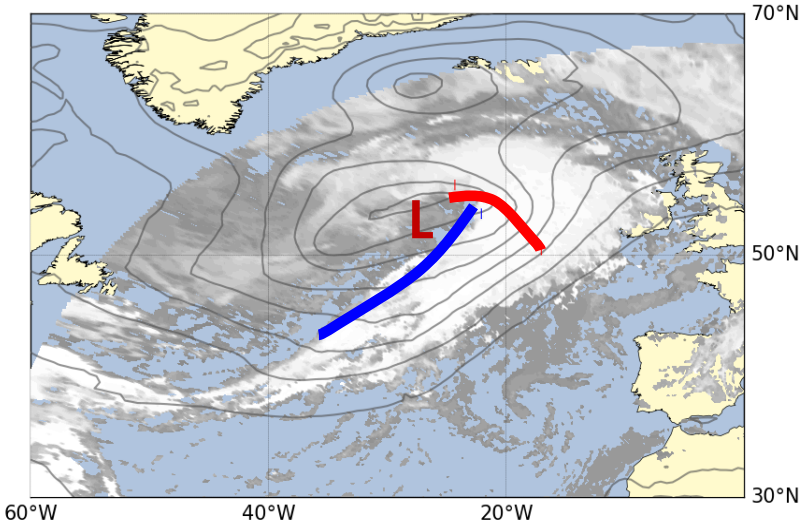


March 27, 2019

Background and Motivation

Warm Conveyor Belt (WCB)

- Strongly ascending airstreams in extratropical cyclones >> stratiform cloud band
  e.g. Harrold, 1973, QJR; Carlson 1980, MWR



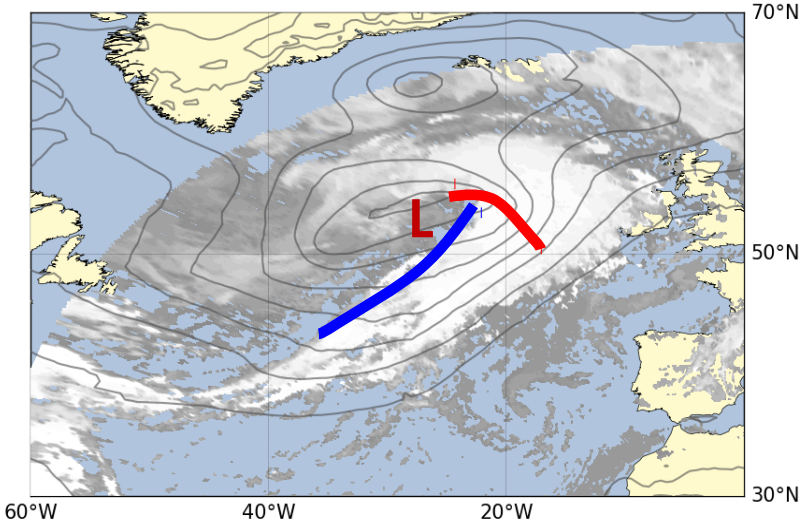
Background and Motivation

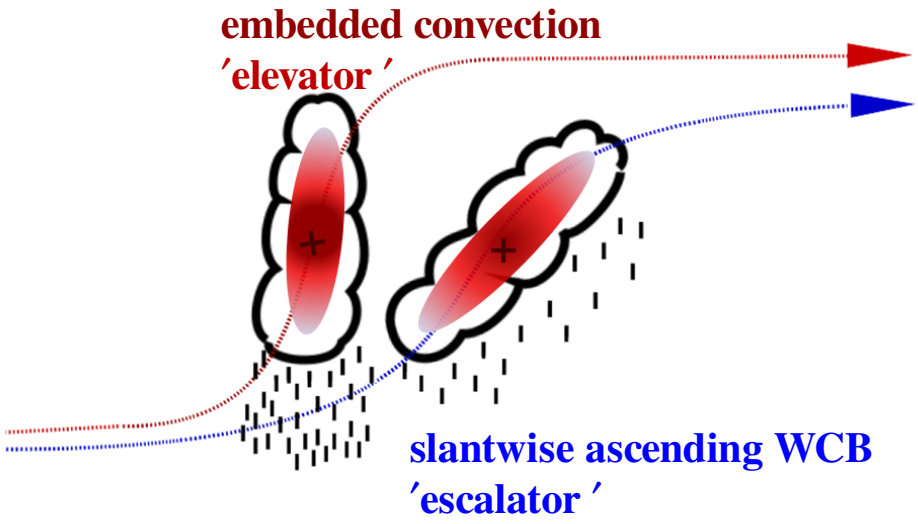
Embedded convection in WCBs

- Satellite observations
  Binder 2016, PhD thesis; Flaounas et al. 2016, QJRMS; Flaounas et al. 2018, ClimDyn; Oertel et al. 2019, QJRMS

- Convection-resolving simulations
  Rasp et al. 2016, MWR; Oertel et al. 2019, QJRMS

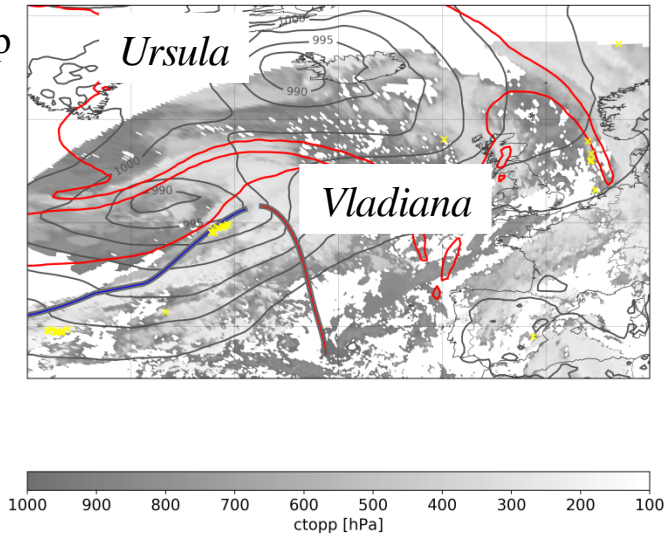
′ Escalator-elevator′ concept
Neiman et al. 1993, MWR





Vladiana Overview

18 UTC 22 Sep



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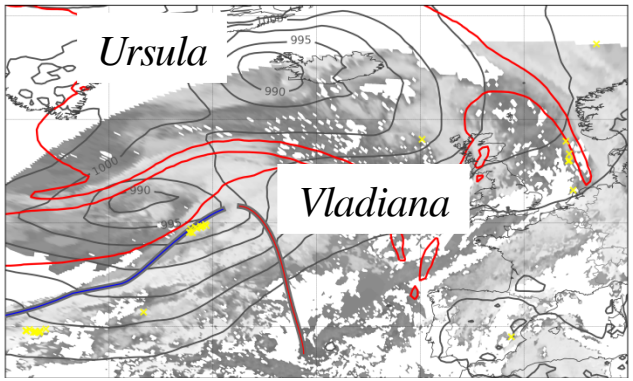
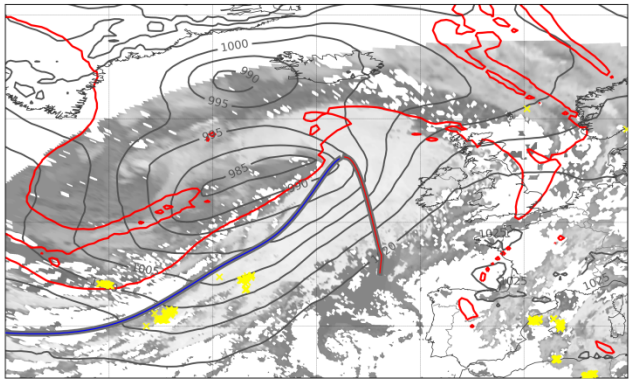
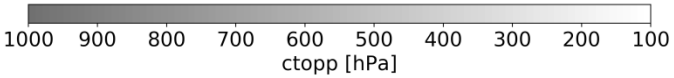


06 UTC 23 Sep





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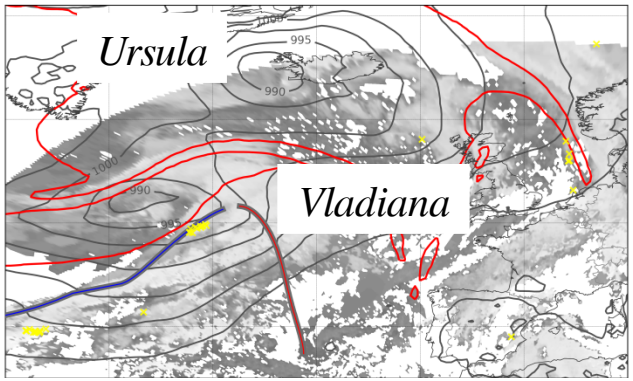

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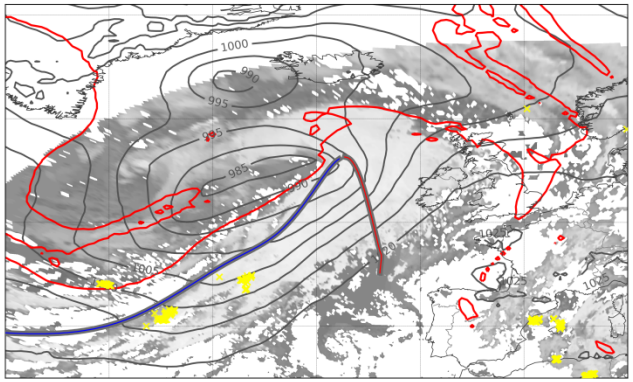

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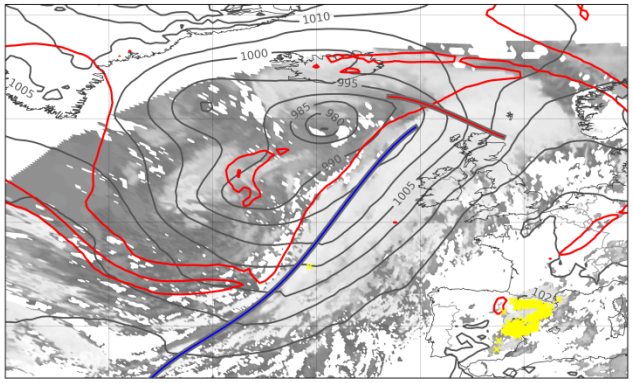

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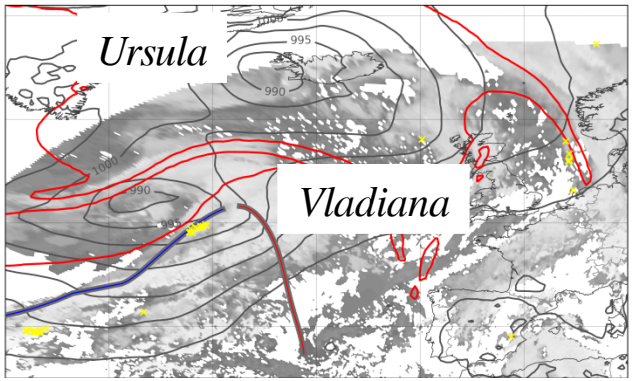

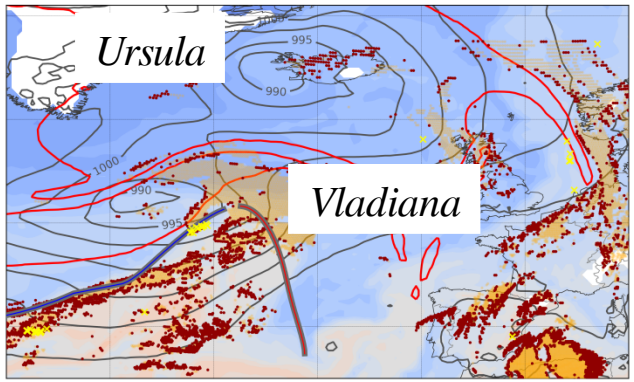

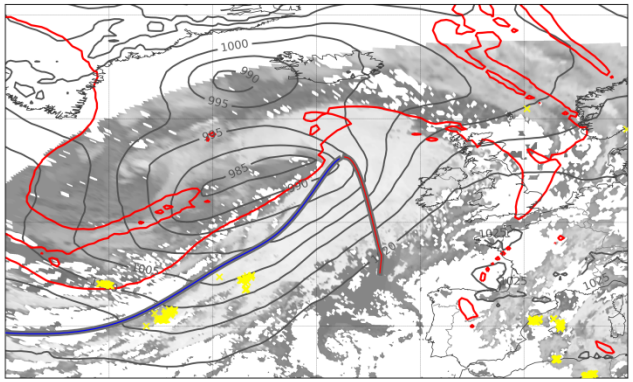

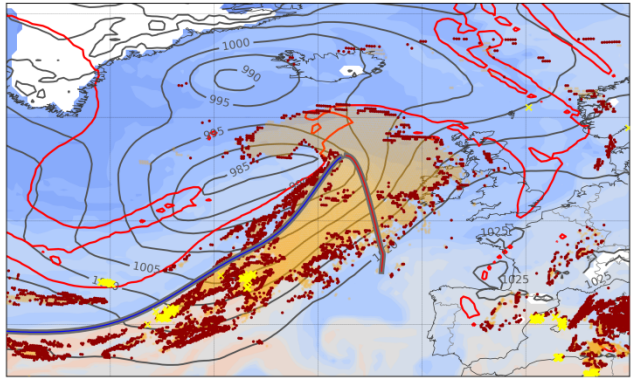

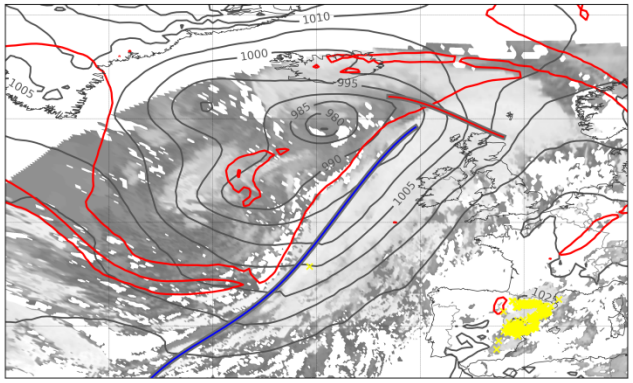

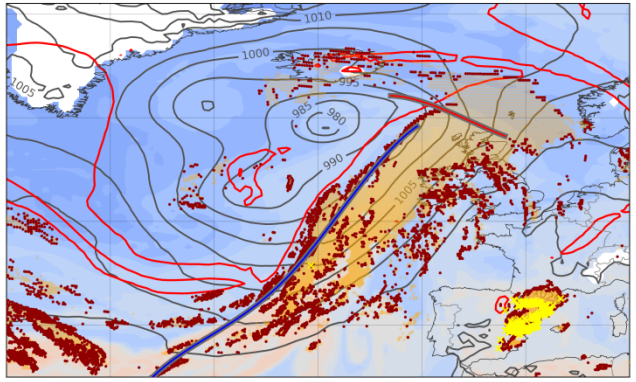

- convection [1]
- cirrus clouds

[1] EUMETSAT retrieval

Vladiana Overview

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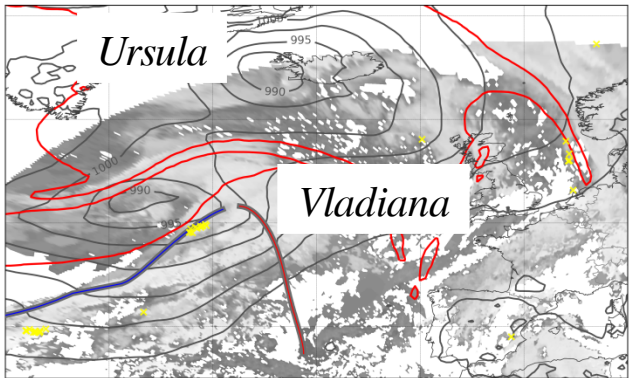

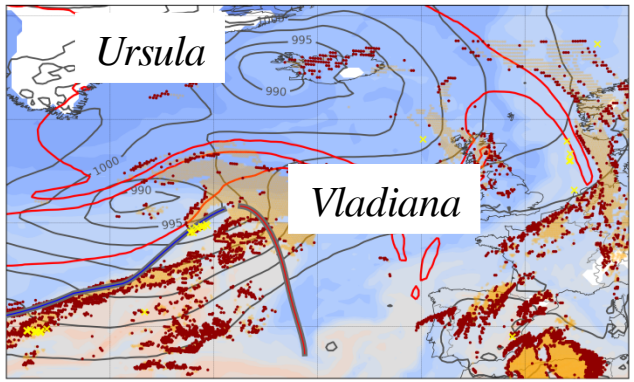

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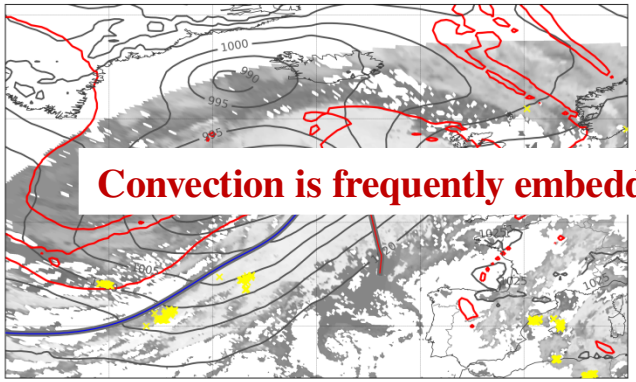
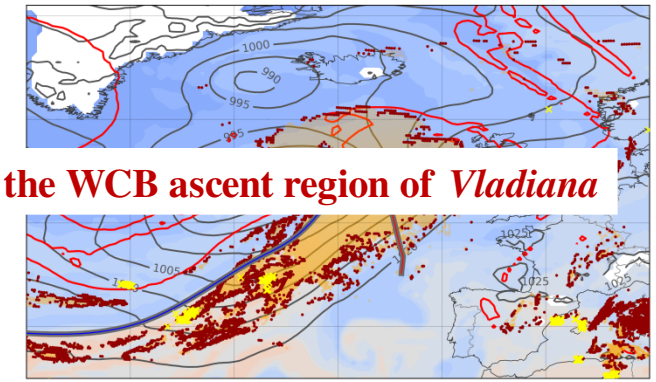
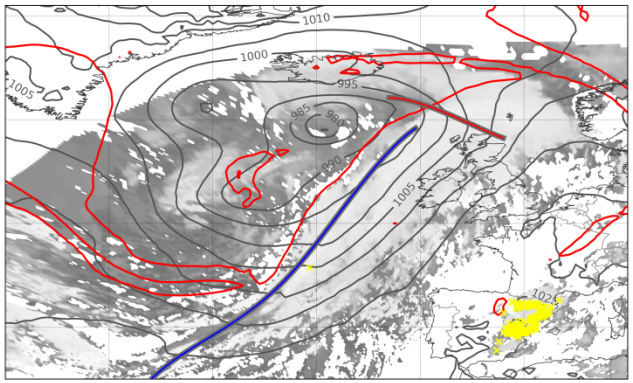
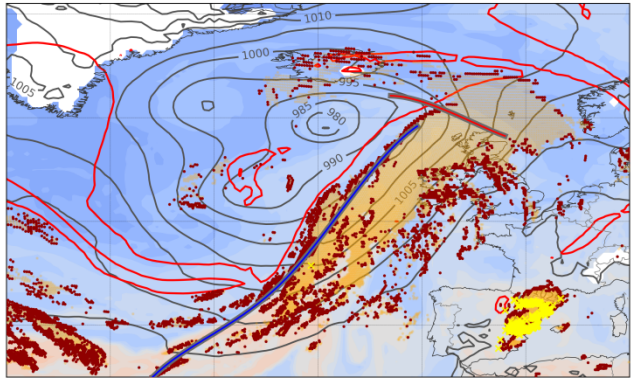




Convection is frequently embedded in the WCB ascent region of *Vladiana*

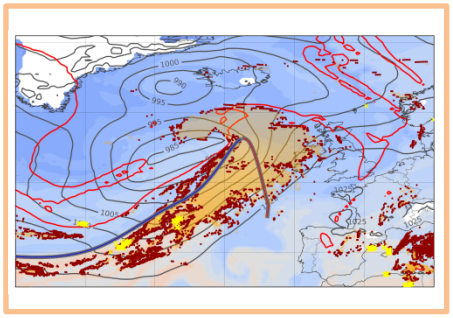




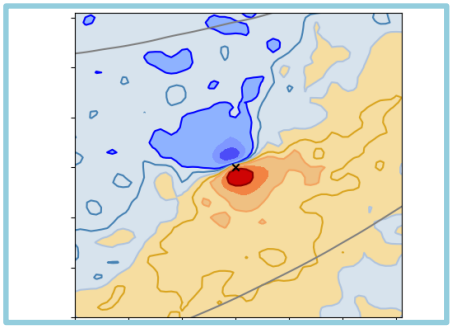
[1] EUMETSAT retrieval

Key questions

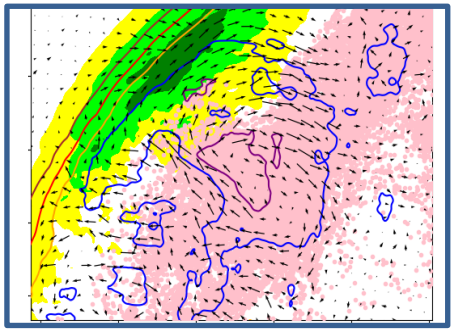
I. **Where does embedded convection occur and what are typical characteristics?**



II. **How does embedded convection in WCBs modify the PV distribution?**



III. **Is embedded convection dynamically relevant?**



COSMO simulation

- **convection-permitting COSMO simulation**

  Δlon = Δlat = 0.02° (~2 km)

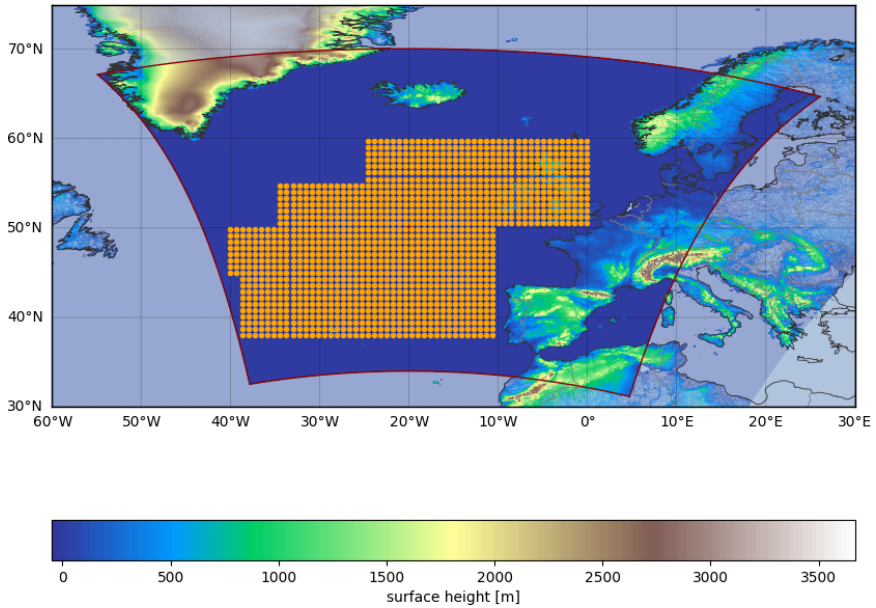
- **online trajectories**[1,2]

  calculated from **3D wind at every model timestep** (Δt = 20 s)

  >> explicit representation of vertical motion and convective WCB ascent

- WCB trajectories

  > 600 hPa / 48 h e.g. Madonna et al. 2014, JCLI

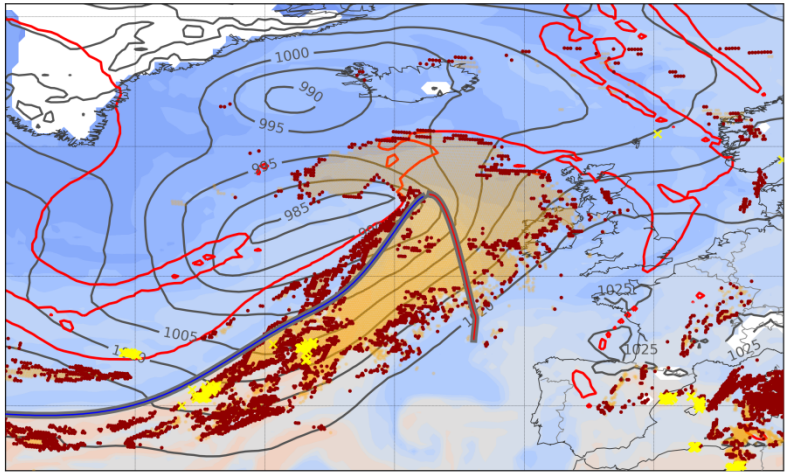


[1] Miltenberger et al. 2013, Geosci. Model Dev.

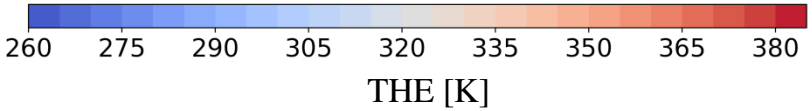
[2] Miltenberger et al. 2014, COSMO Technical Report

I Where does embedded convection occur?

- deep convection
- cirrus clouds



EUMETSAT retrieval



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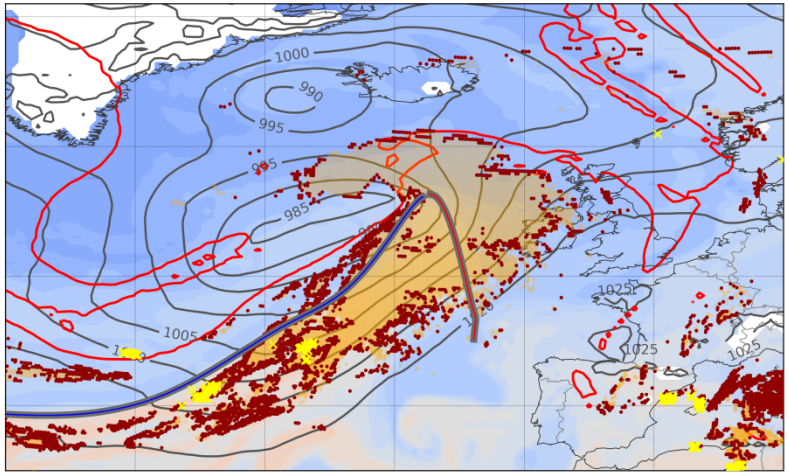

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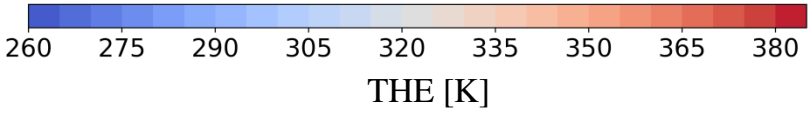
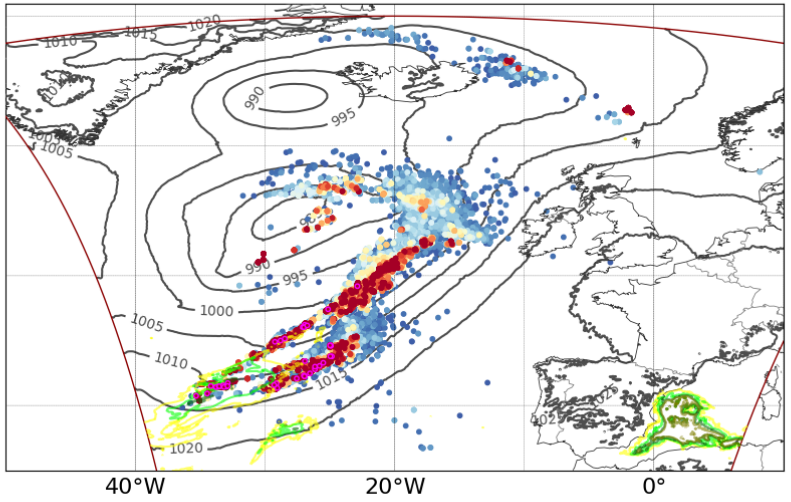
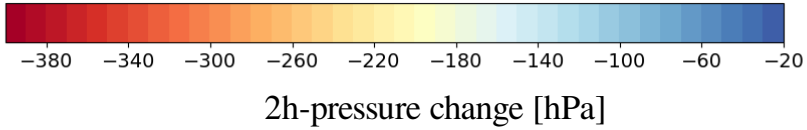


2h-pressure change along WCB trajectory ascent

convective ascent
> 400 hPa / 2 h

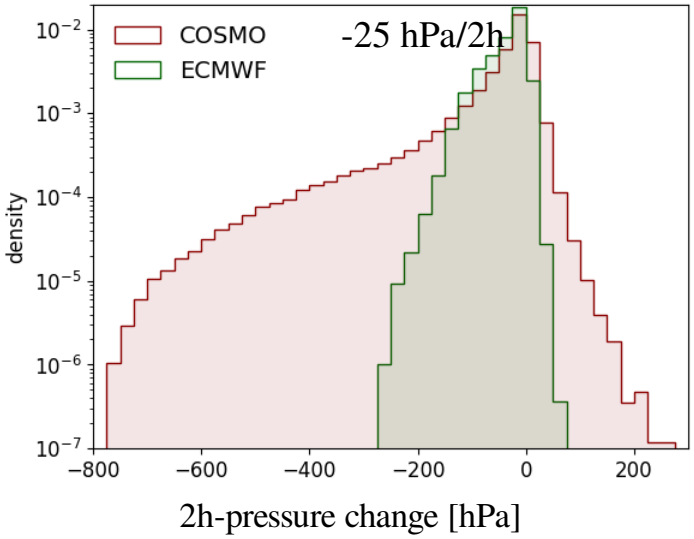


COSMO @ 2km



I What are typical characteristics of embedded convection?

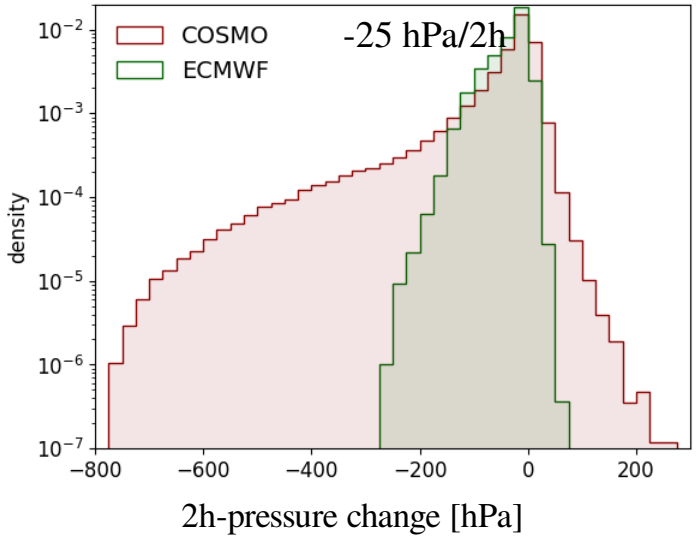
frequency distribution of 2h-pressure change along WCB trajectory ascent



- large variability of ascent rates
- embedded phases of descent
- COSMO online trajectories can resolve deep convective ascent

I What are typical characteristics of embedded convection?

frequency distribution of 2h-pressure change along WCB trajectory ascent



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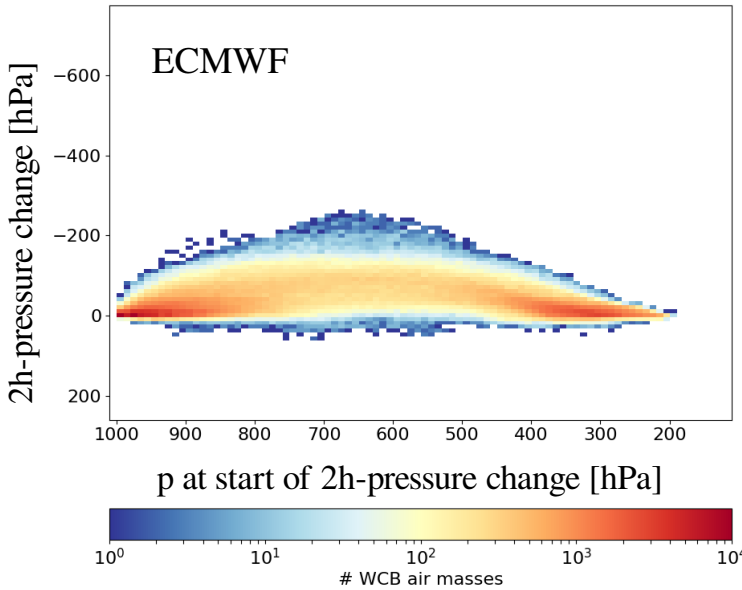

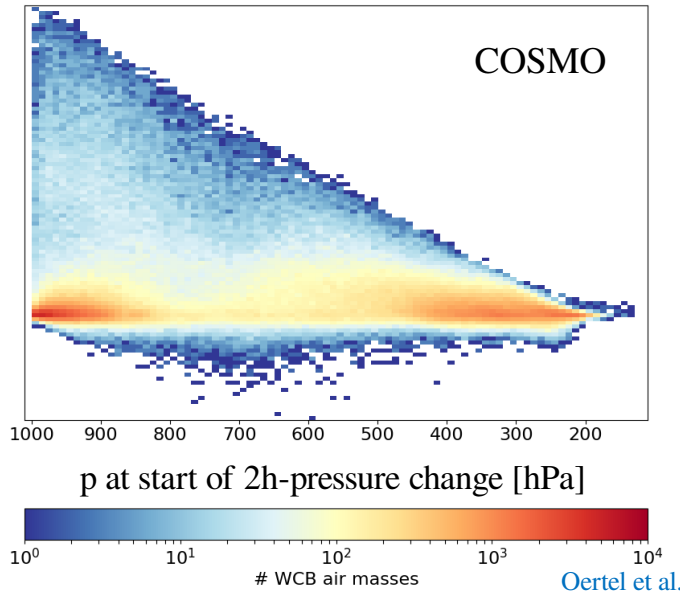

Oertel et al. 2019, QJRMS

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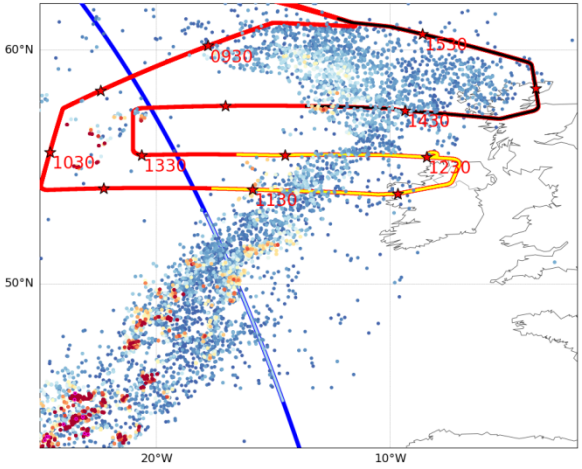

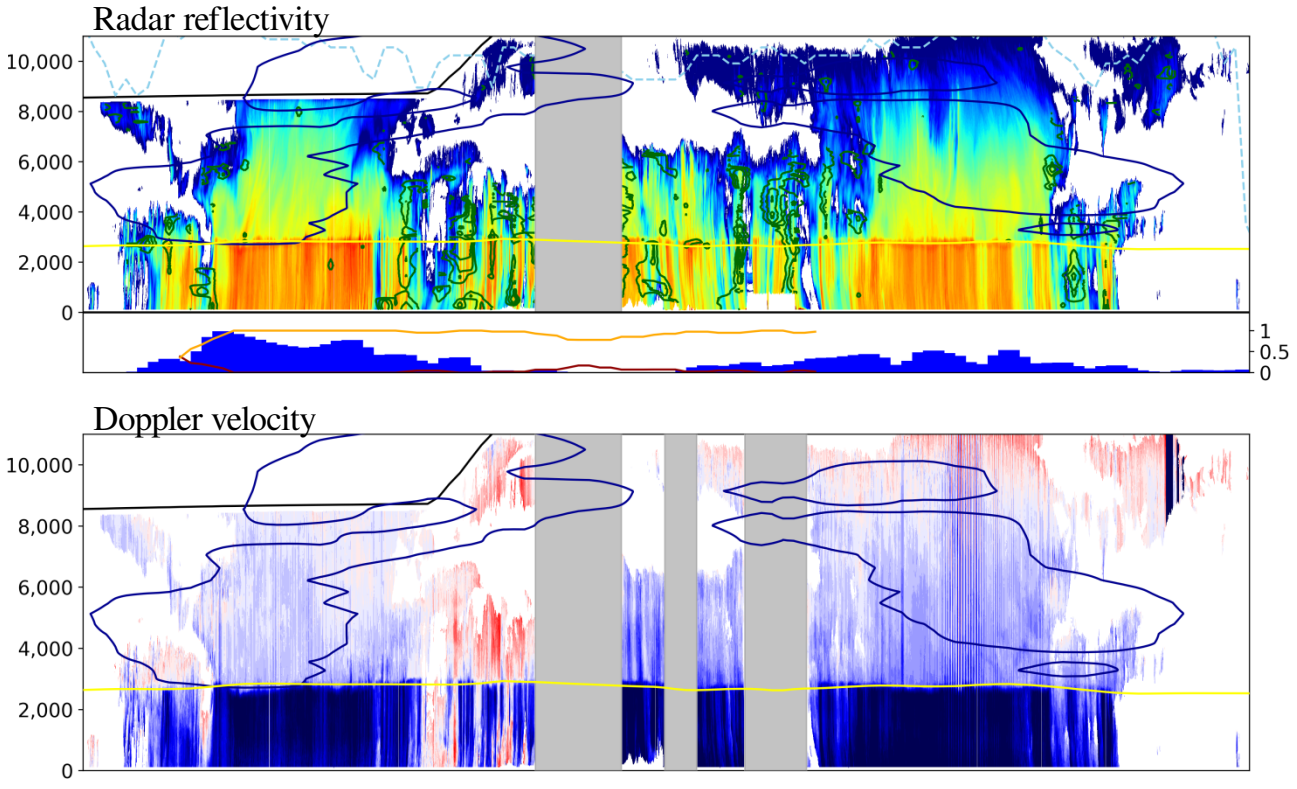

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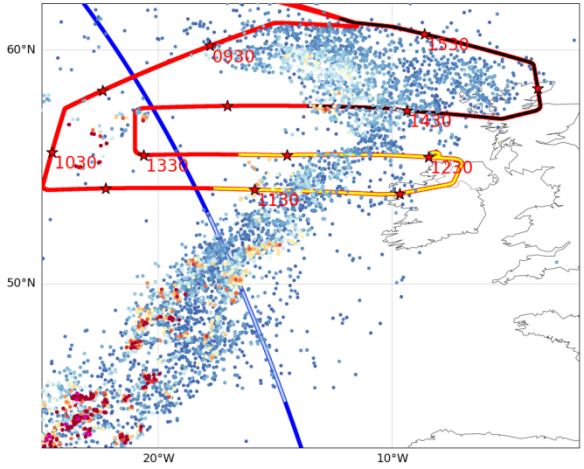
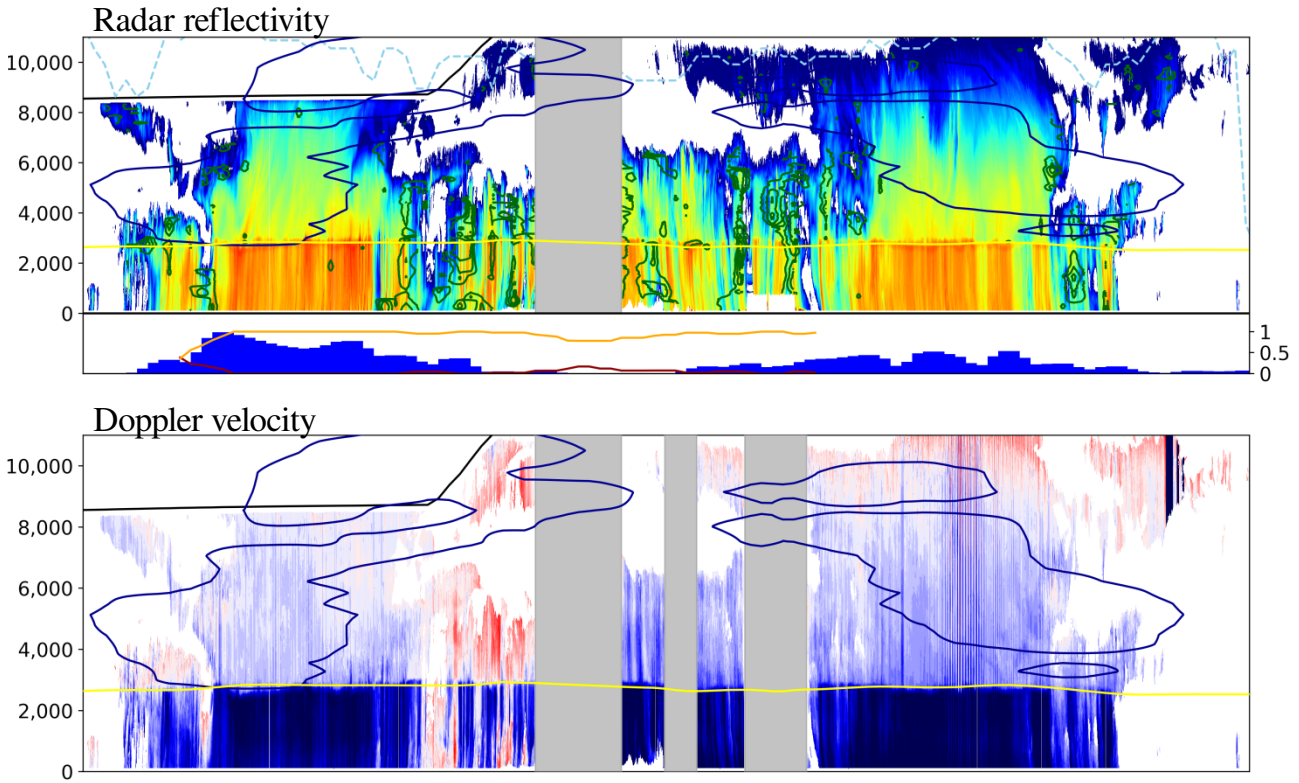


Indications for embedded convection:

- increased heterogeneity of radar reflectivity
- decreased (and more heterogeneous) Doppler velocity >> increased updraft velocity

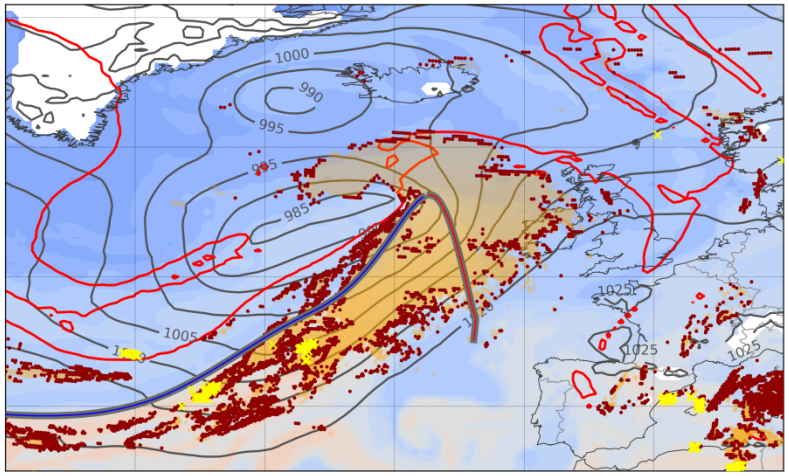
- different from (isolated) deep convective systems



Oertel et al. 2019, QJRMS

II How does embedded convection modify the PV distribution?

- deep convection
- cirrus clouds

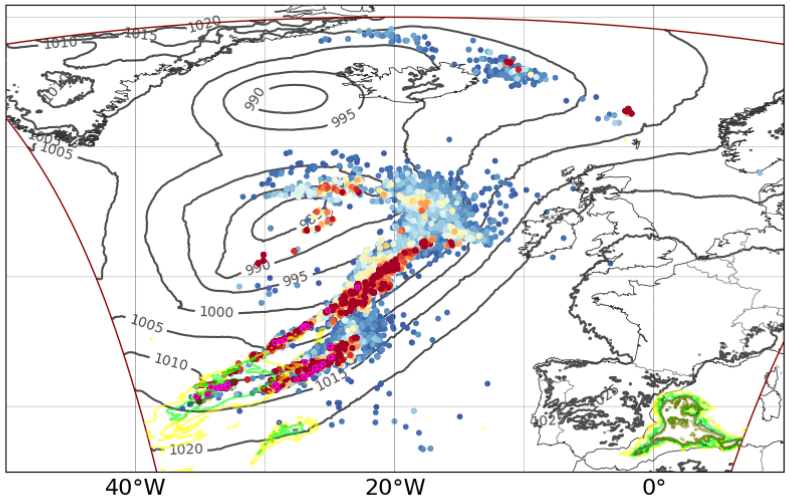


EUMETSAT retrieval

260 275 290 305 320 335 350 365 380

THE [K]

convective ascent
> 400 hPa / 2 h



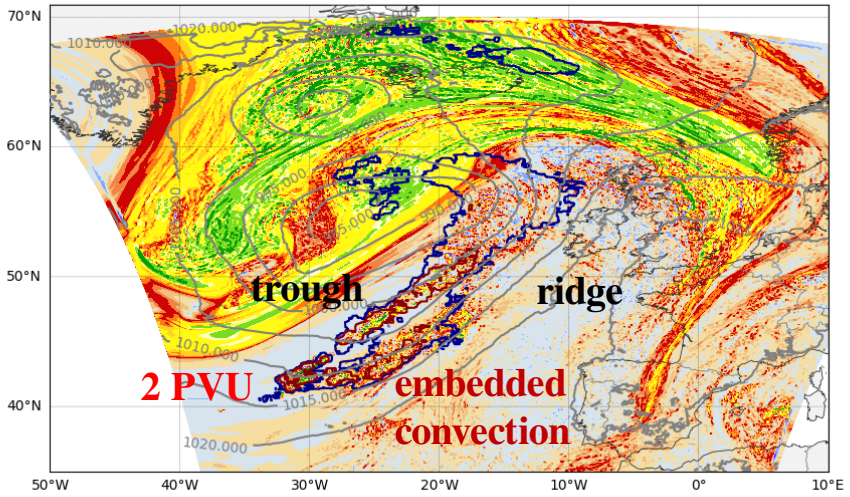
COSMO @ 2km

−380 −340 −300 −260 −220 −180 −140 −100 −60 −20

2h-pressure change [hPa]

II How does embedded convection modify the PV distribution?

PV@325K



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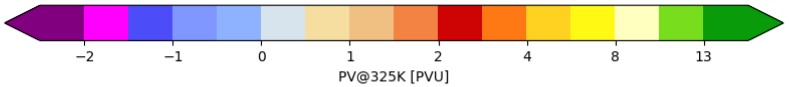
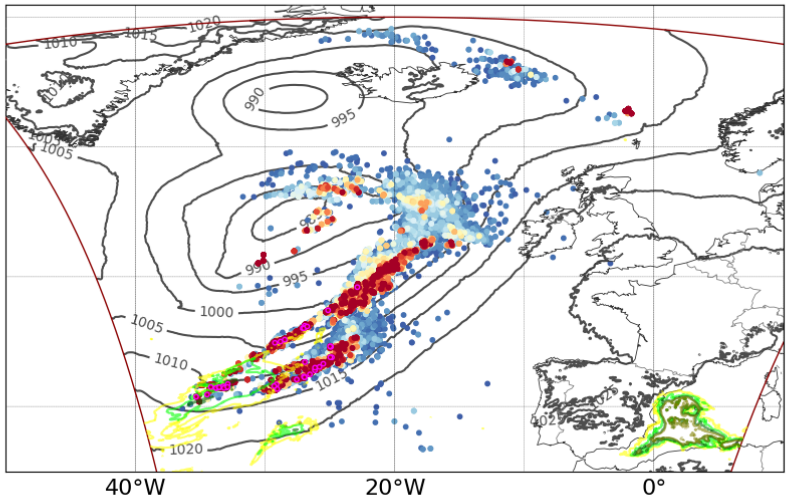


convective ascent
> 400 hPa / 2 h



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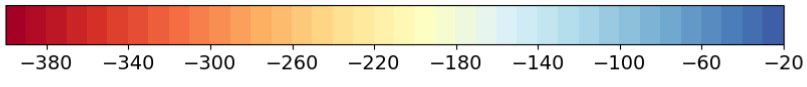
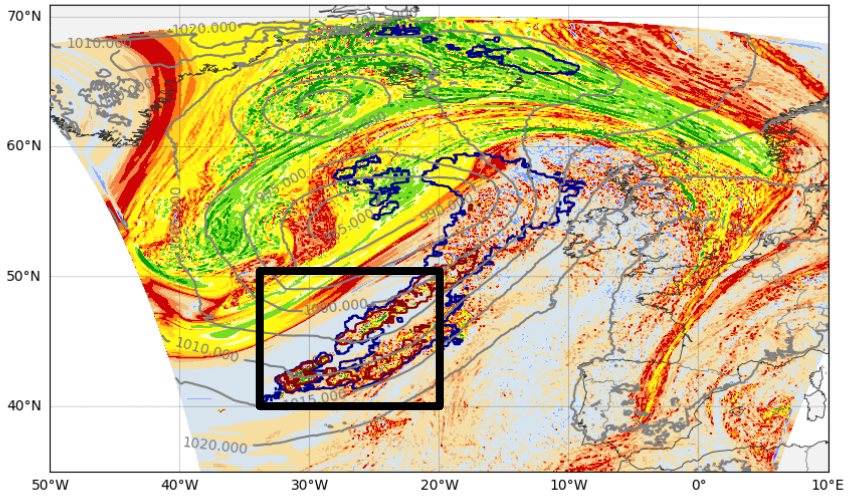


II How does embedded convection modify the PV distribution?

PV@325K



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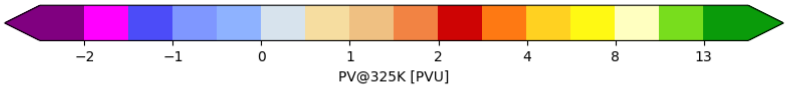

convective ascent
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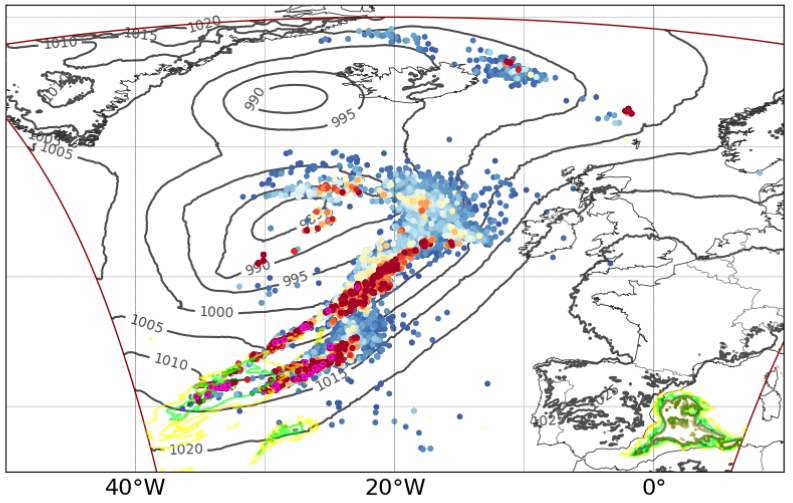

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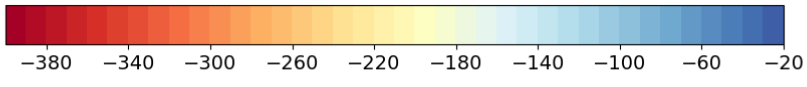

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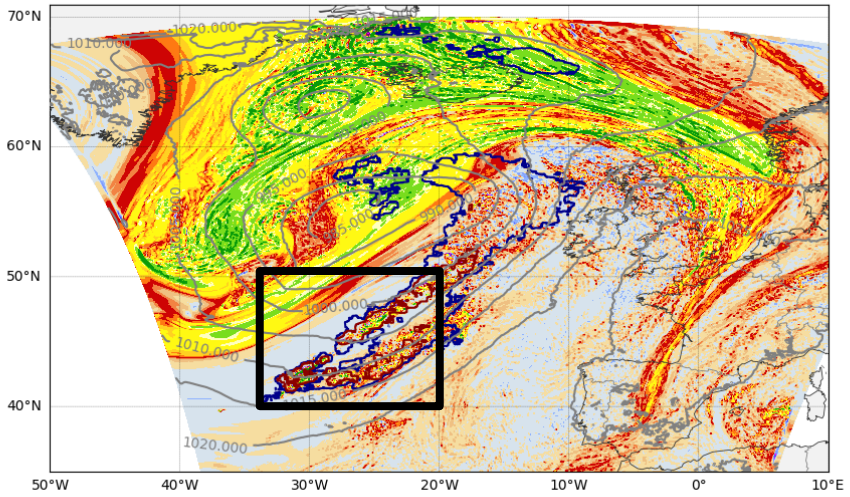
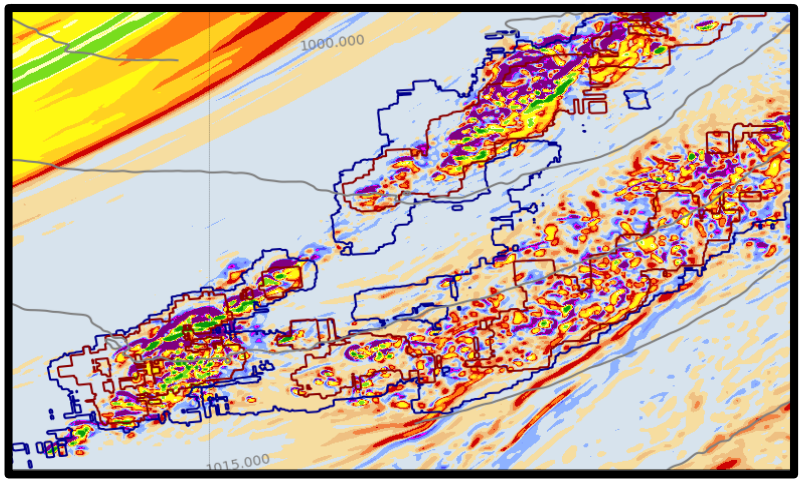
PV@325K





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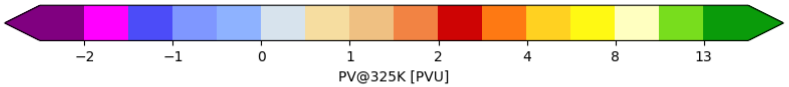


II How does embedded convection modify the PV distribution?

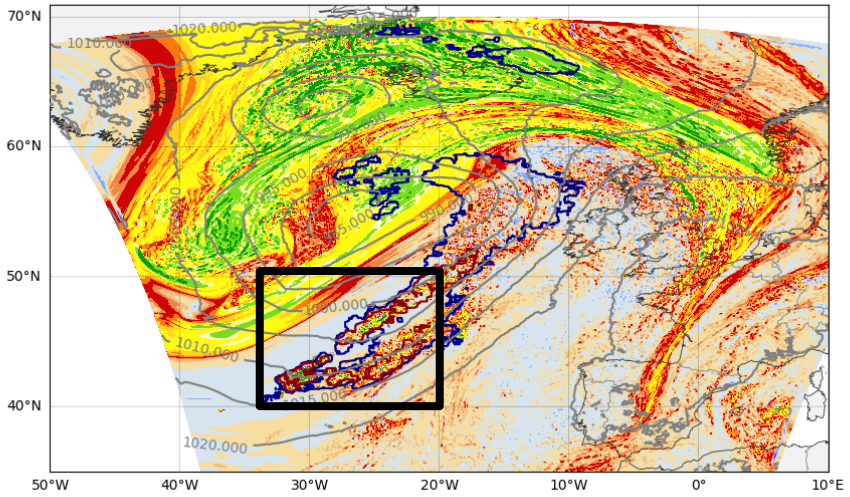
Composites for convective WCB trajectories

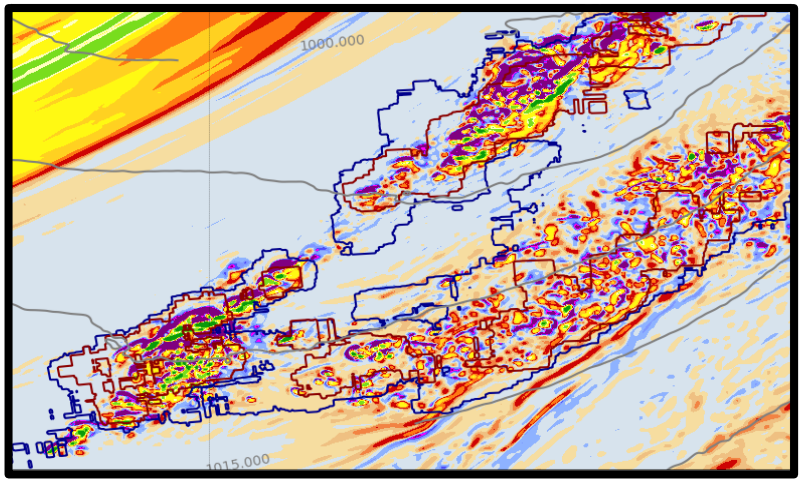
> **600 hPa / 3h**

> **convective WCB ascent**

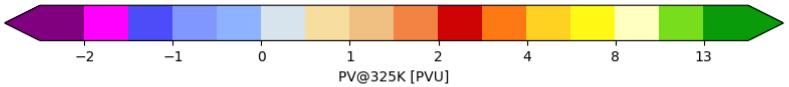
~2000 WCB trajectories

PV@325K





COSMO @ 2km



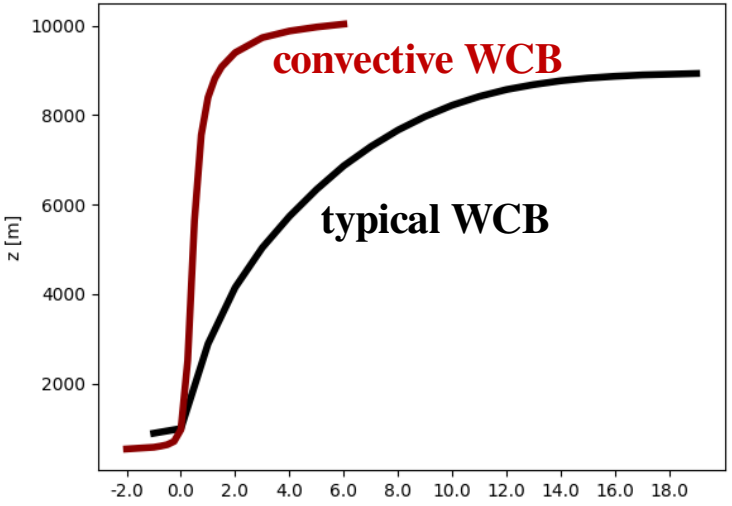
II How does embedded convection modify the PV distribution?

Composites for convective WCB trajectories

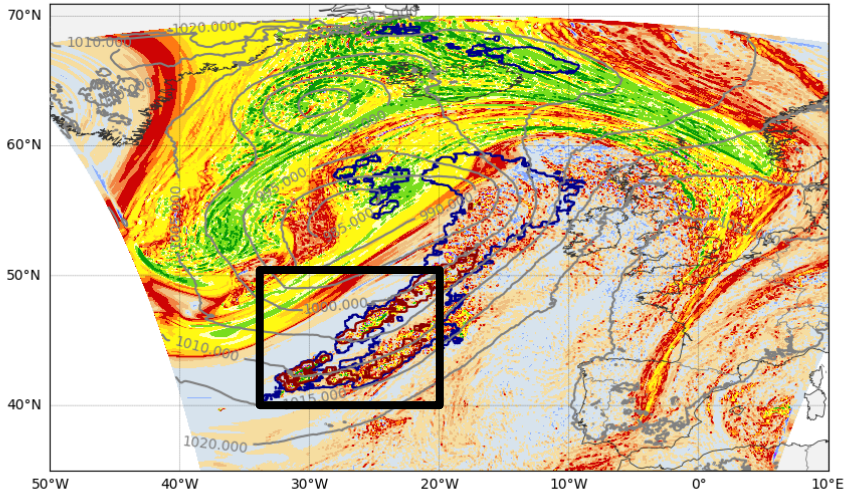
> **600 hPa / 3h**

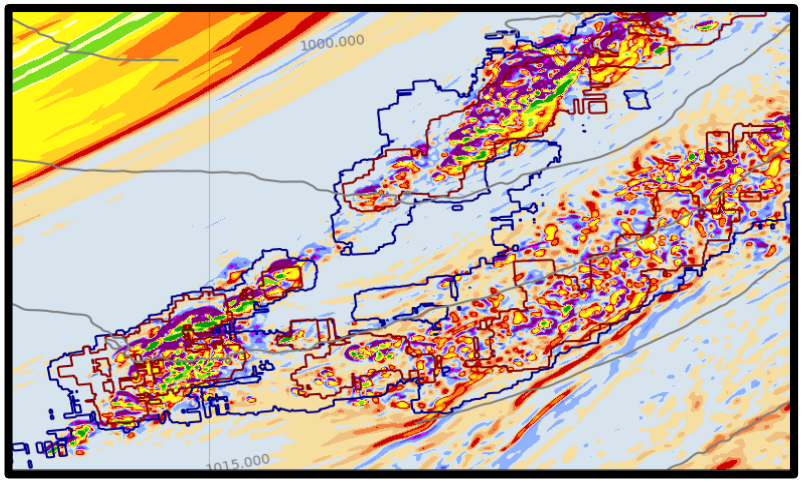
> **convective WCB ascent**

~2000 WCB trajectories

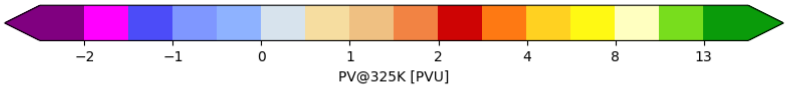


PV@325K





COSMO @ 2km



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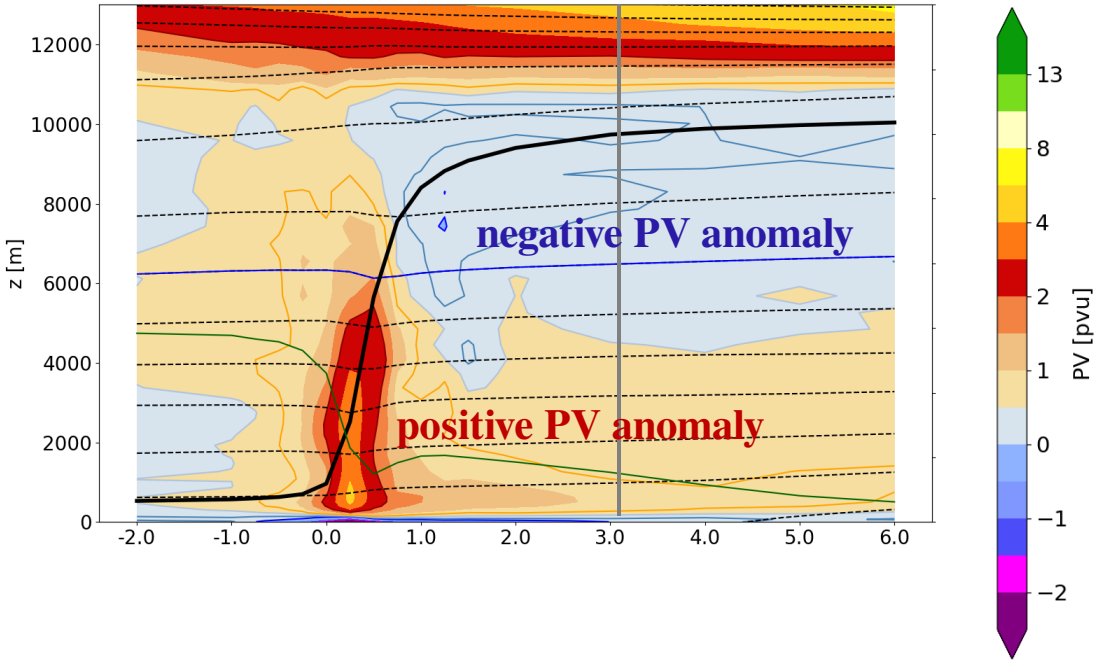
convective WCB



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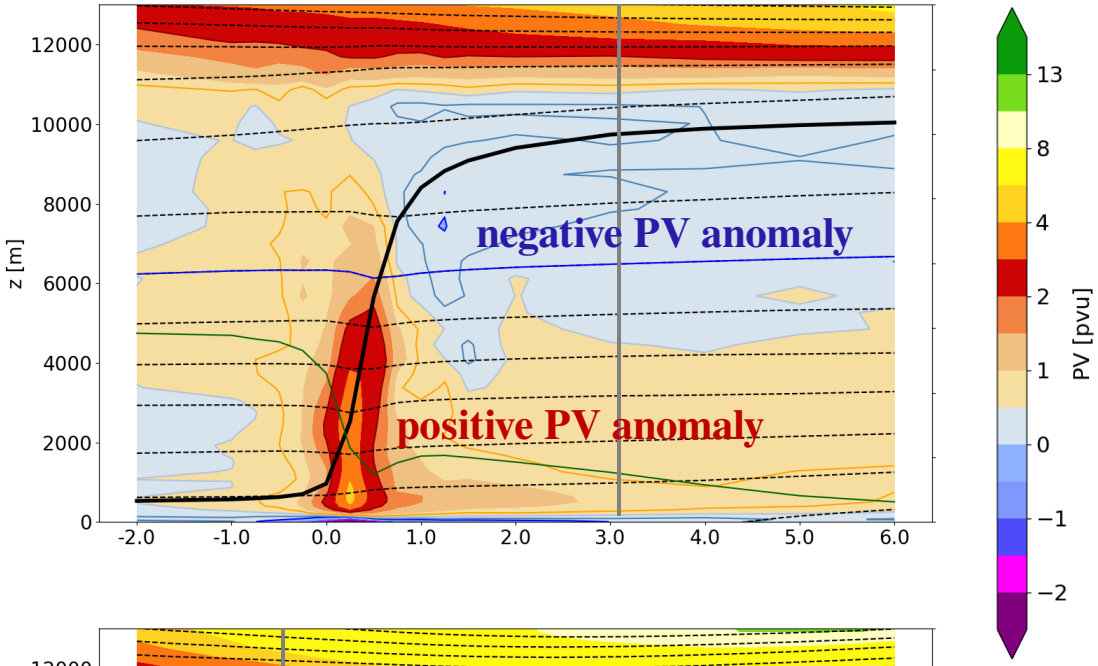
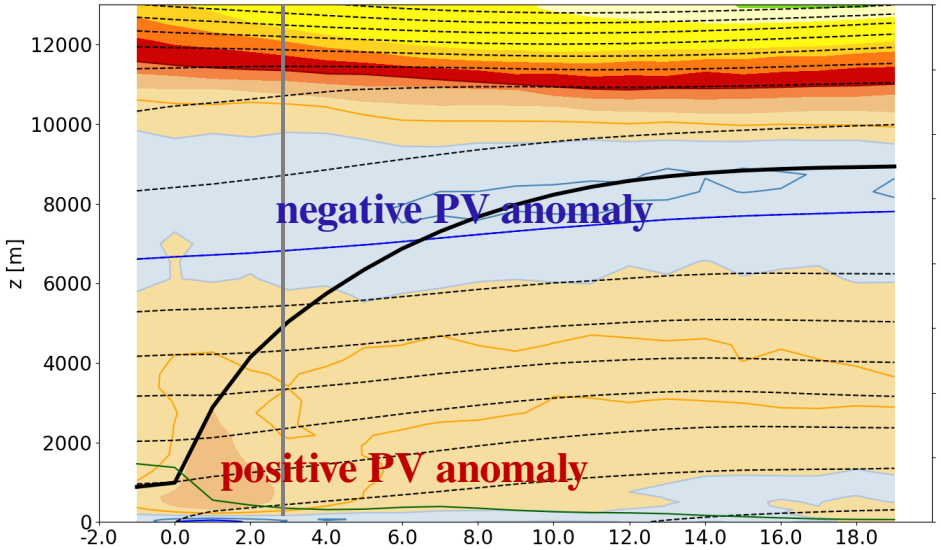


“average” WCB
>> typical ascent



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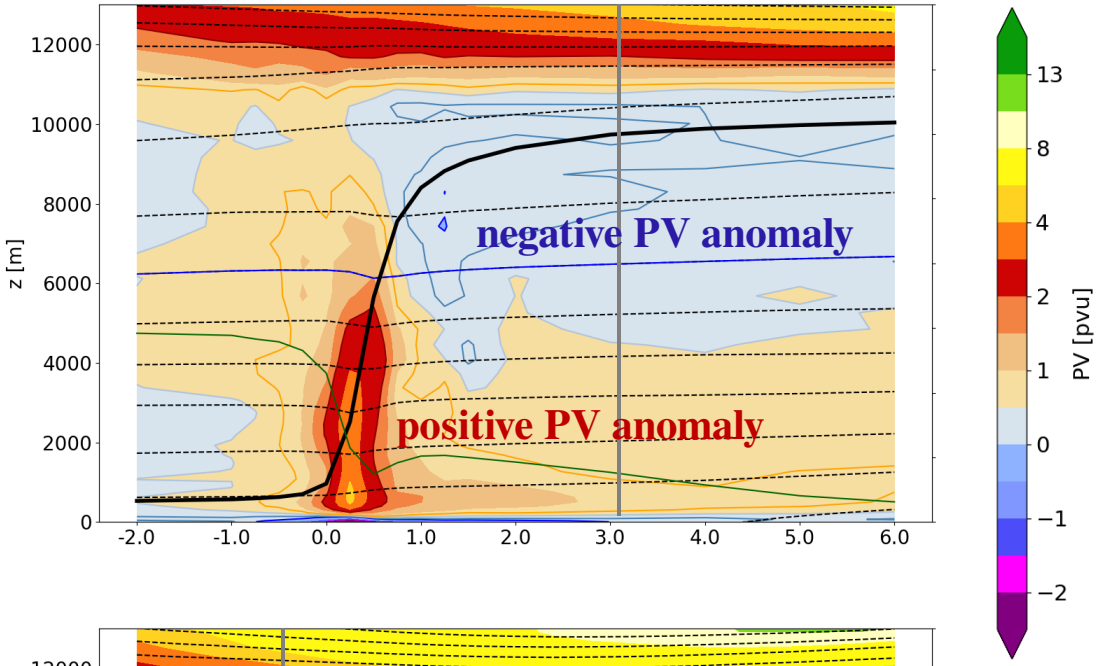
convective WCB



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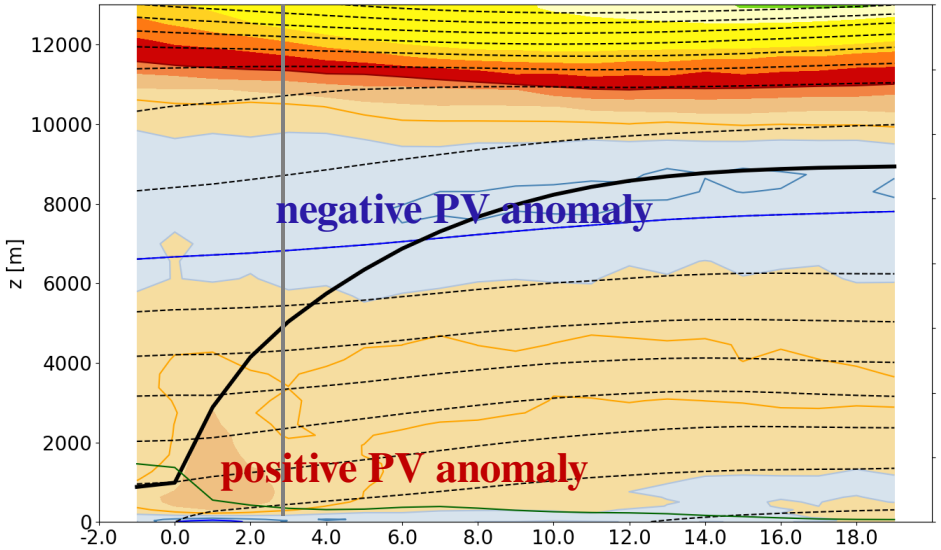
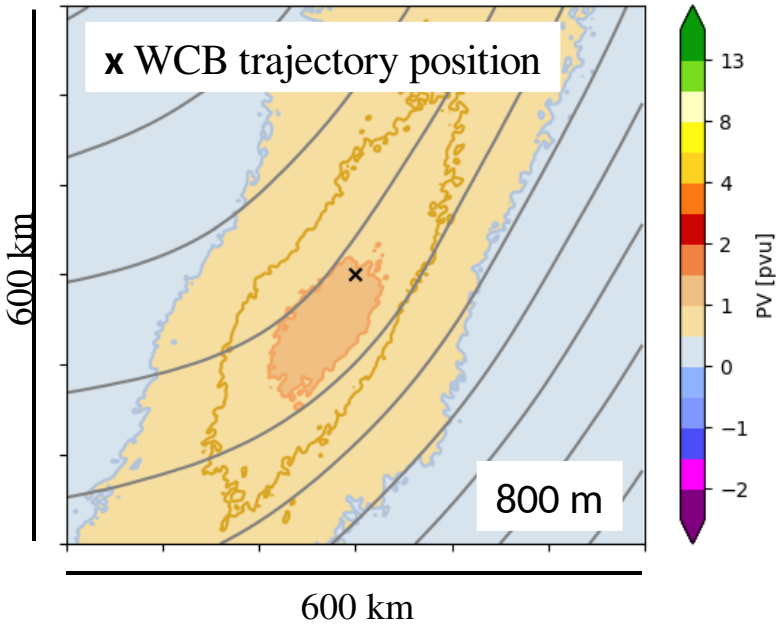


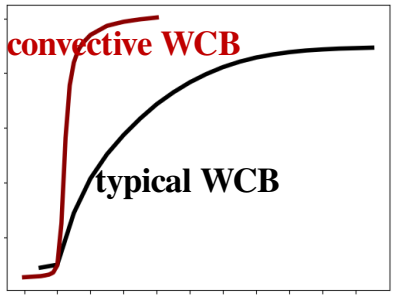
Stronger **low-level positive** and **upper-level negative PV** anomalies along convective WCB ascent

II How does embedded convection modify the PV distribution?

positive low-level PV anomaly

typical WCB





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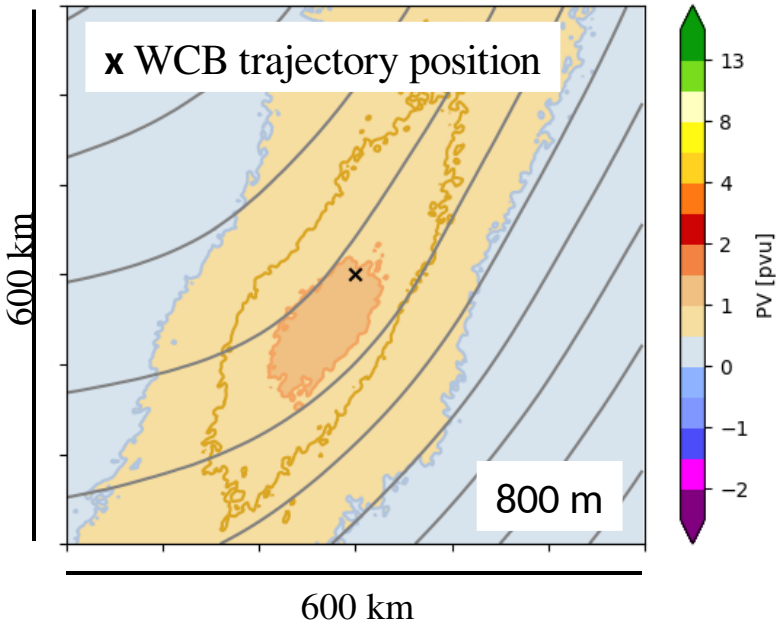
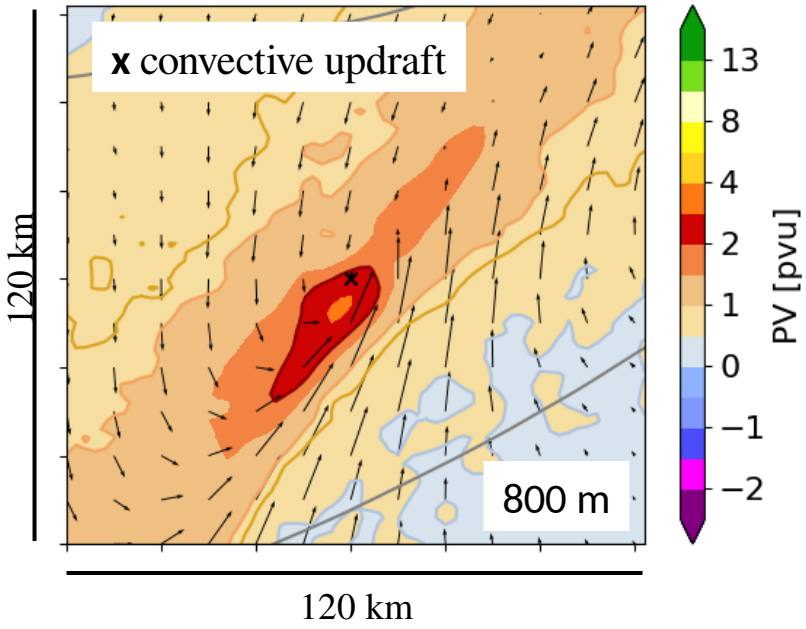
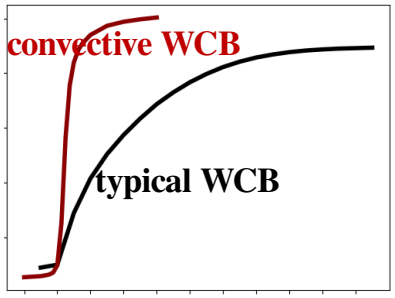
positive low-level PV anomaly

typical WCB



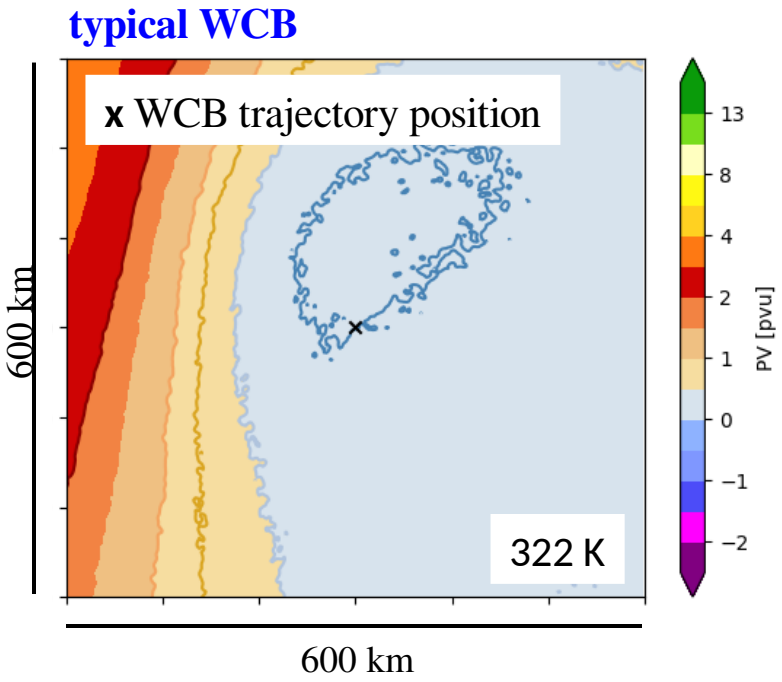
convective WCB

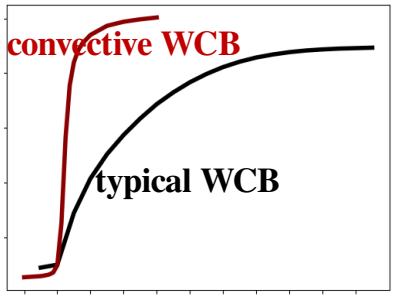




II How does embedded convection modify the PV distribution?

upper-level PV anomalies





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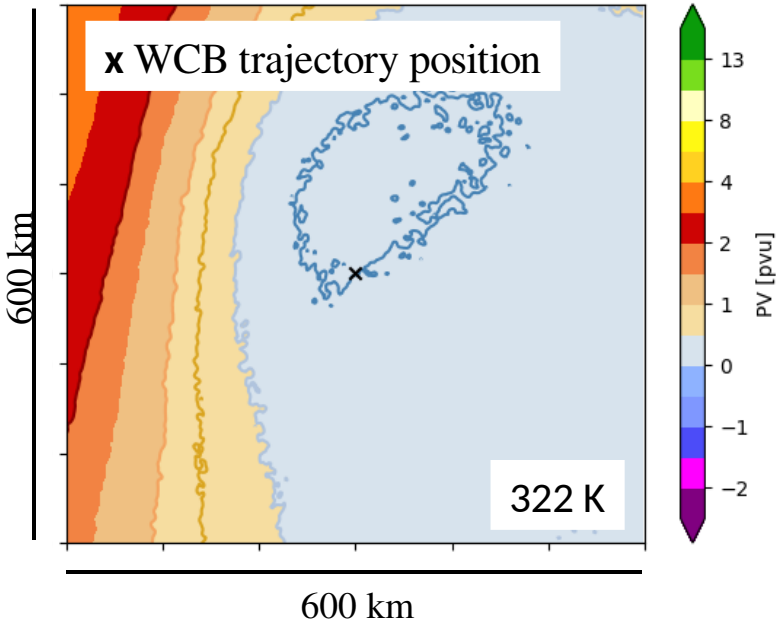
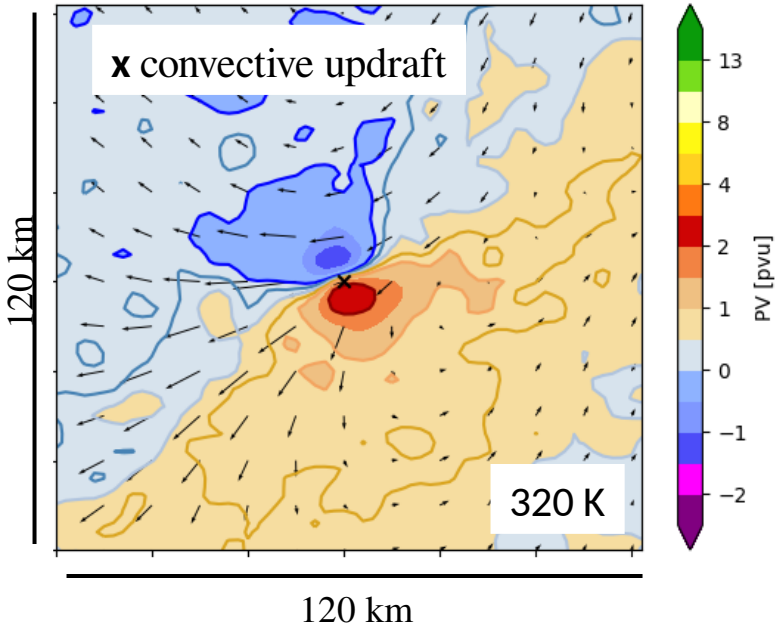
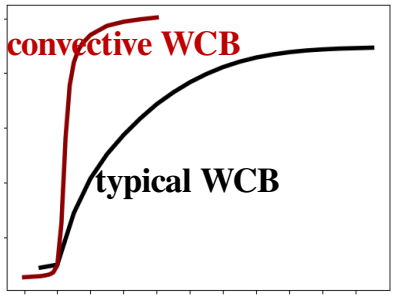


convective WCB





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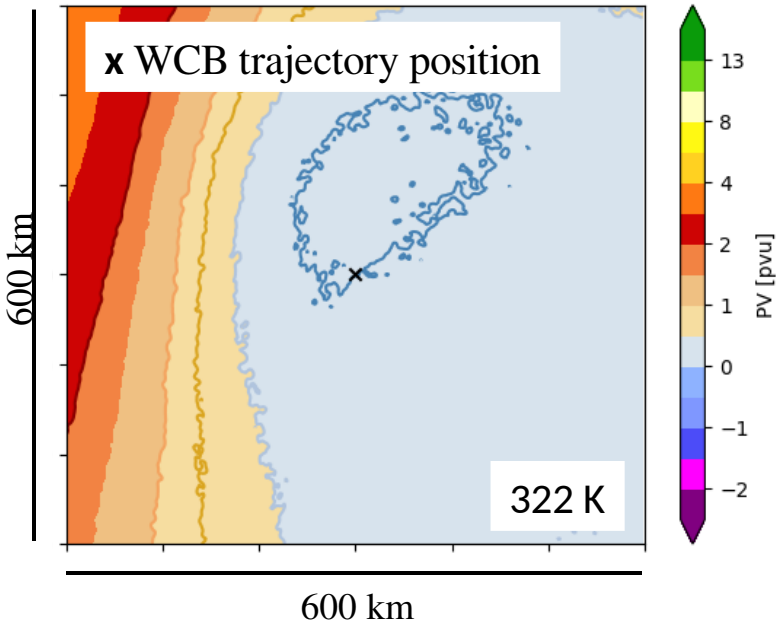
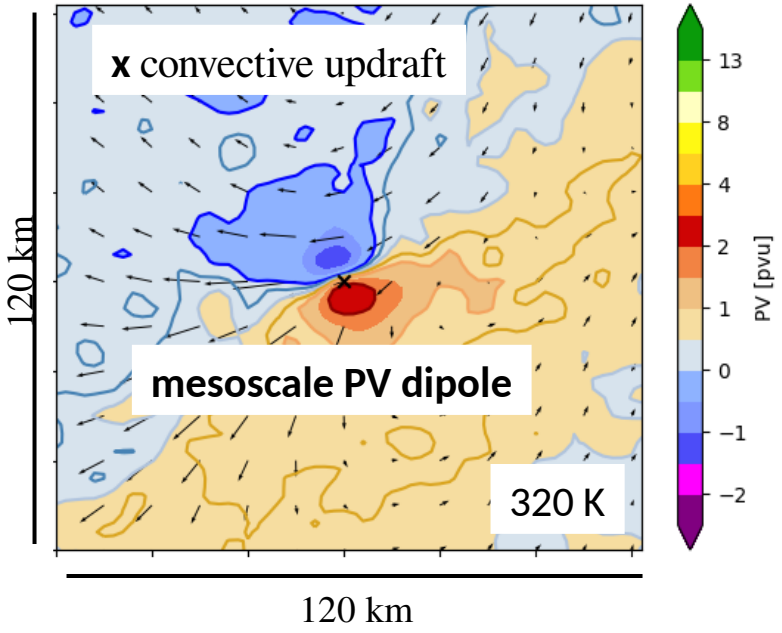
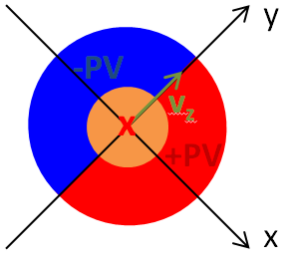


convective WCB



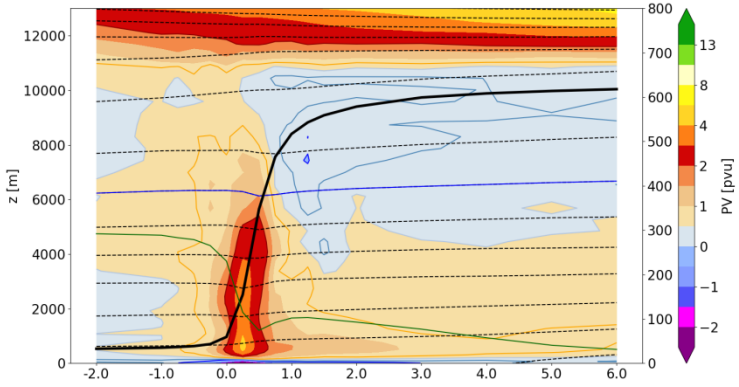
PV modification in isolated convection

e.g. Chagnon and Gray, QJRMS; Weijenborg et al. 2015, Tellus; Weijenborg et al. 2017, QJRMS



$$PV_x \sim (w_y - v_z) \cdot \Theta_x$$

II How does embedded convection modify the PV distribution?



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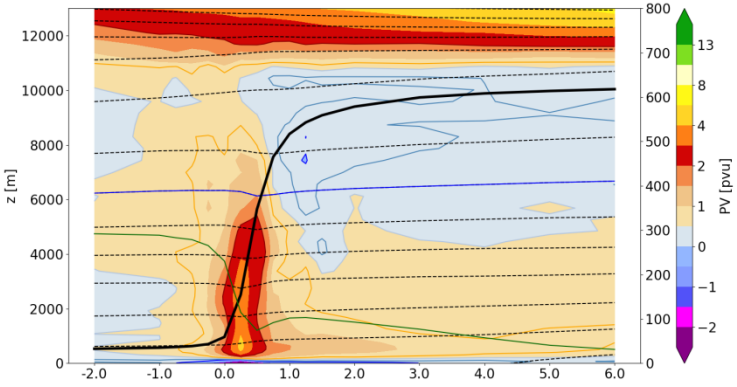
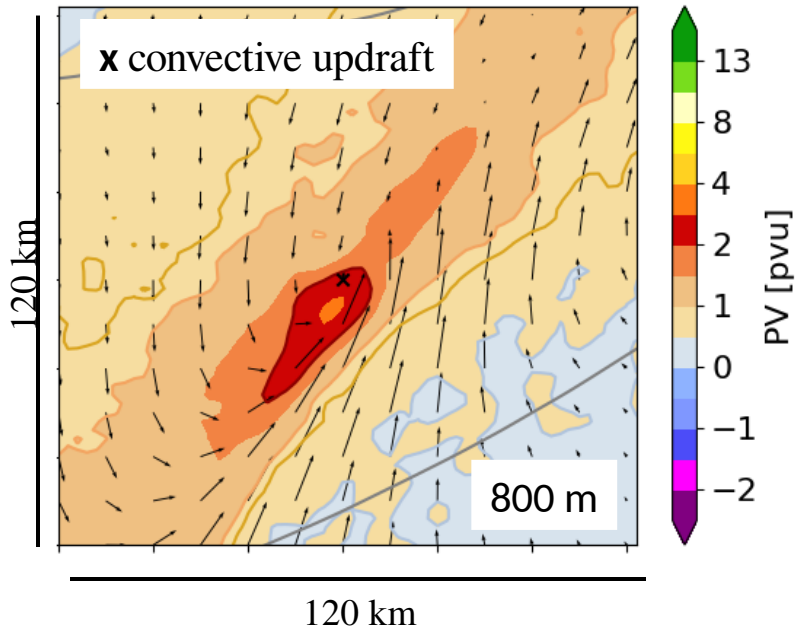


low-level positive PV anomaly



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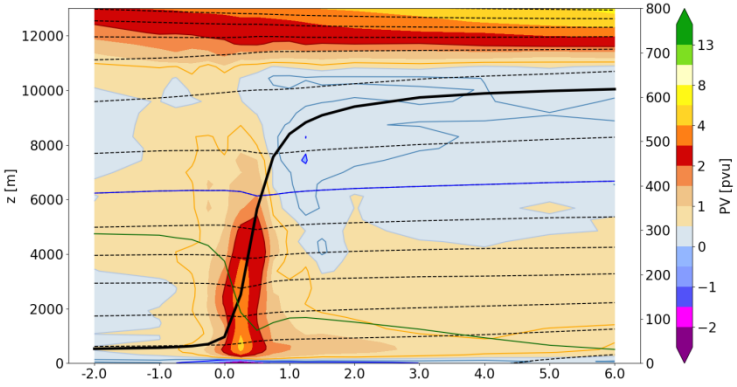

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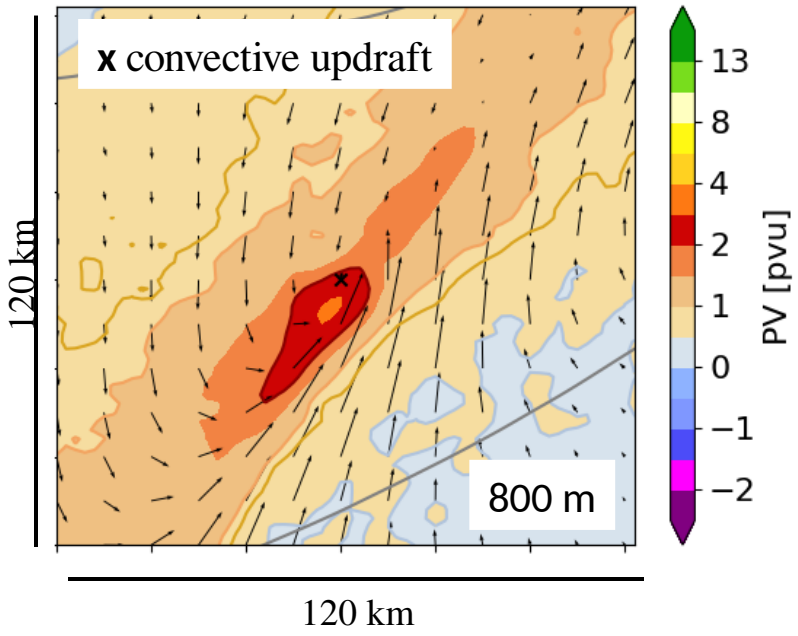
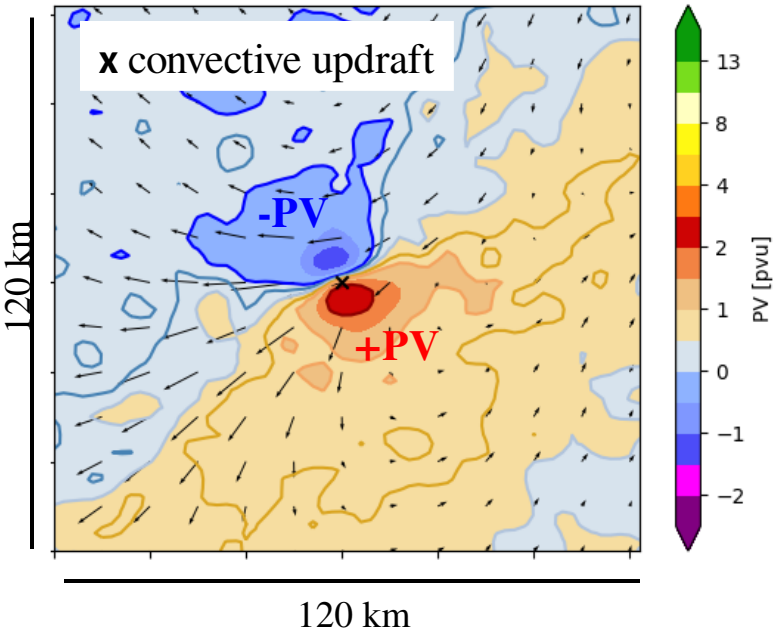


upper-level PV dipole



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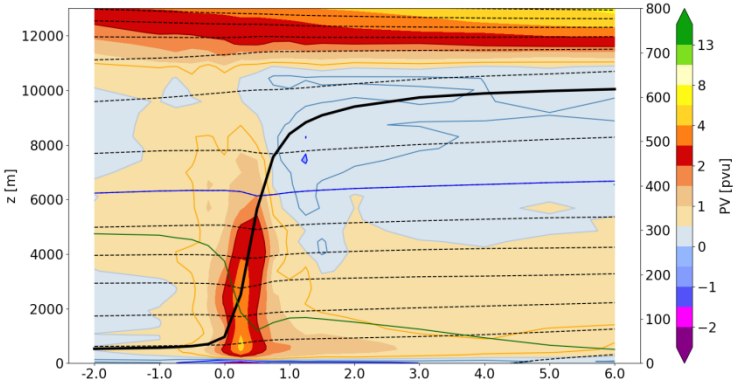

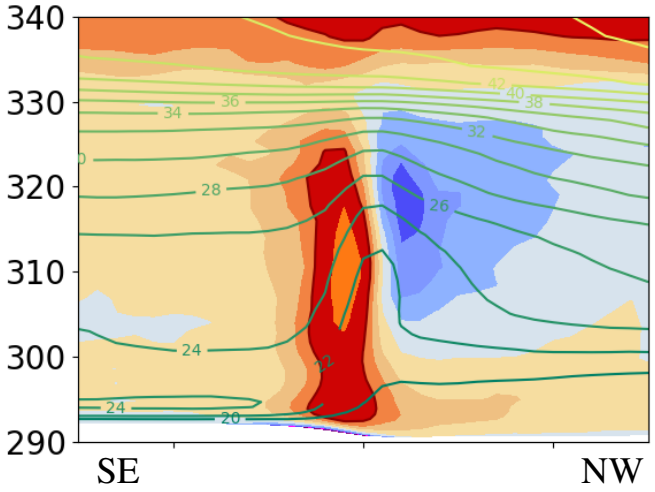

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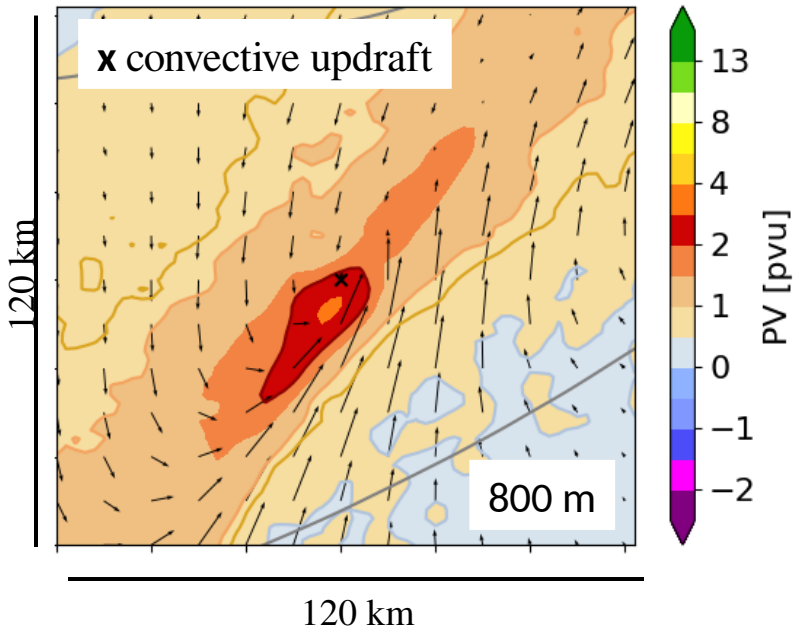

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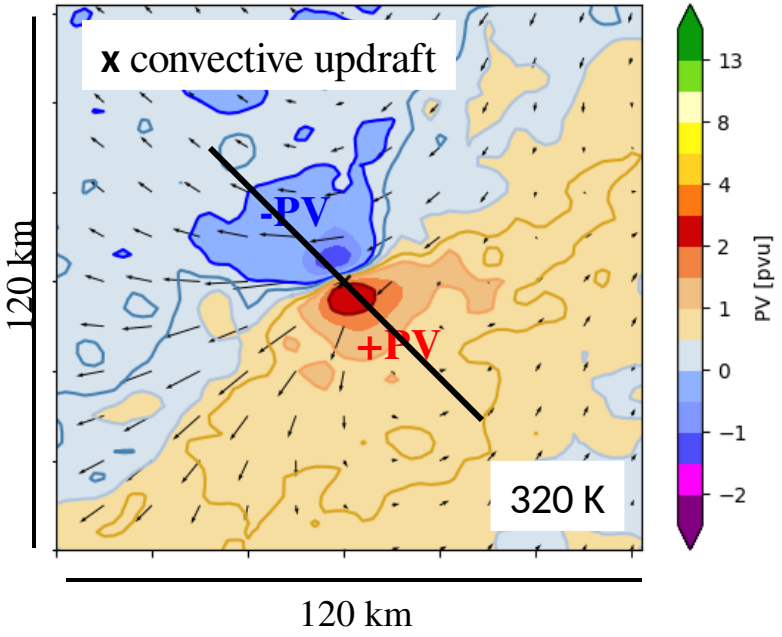
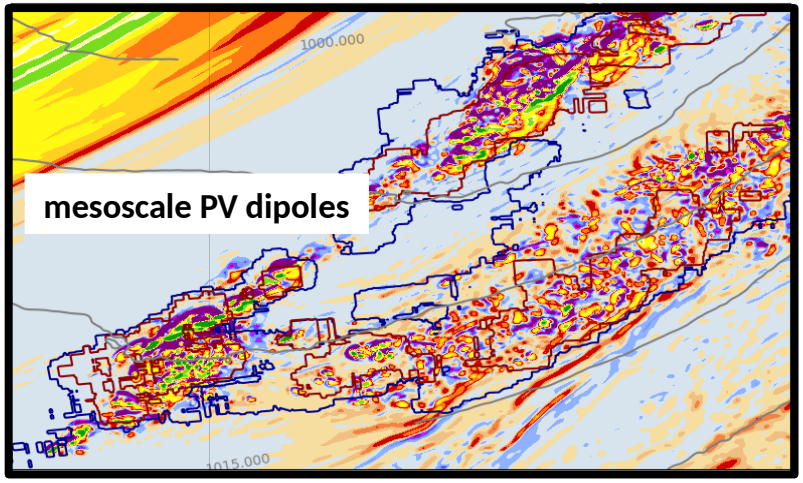


III Is embedded convection dynamically relevant?

1) existence of PV anomaly on a larger-scale

>> **coarse-graining** on 60 km



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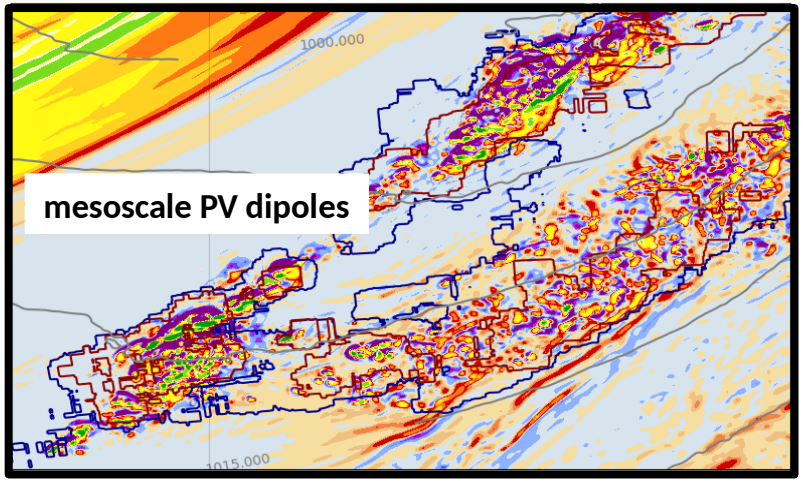

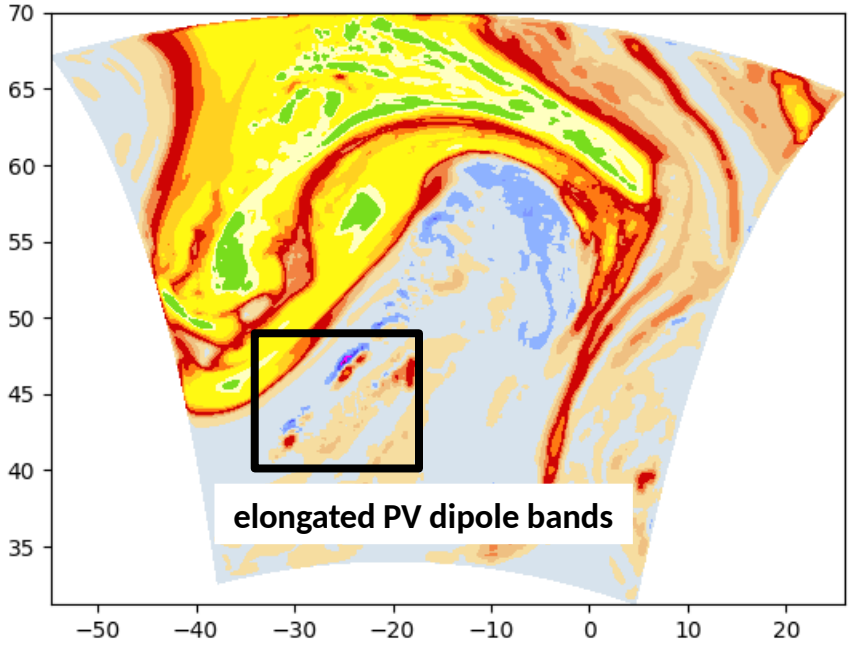

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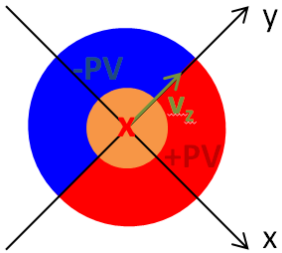
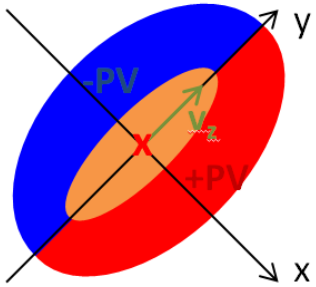
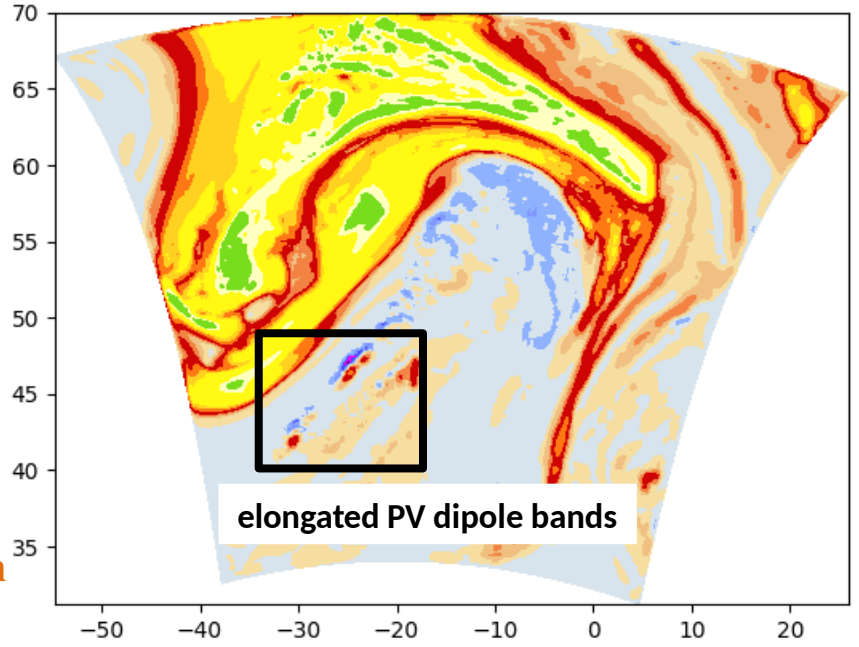


circular convective updraft



elongated convective region



III Is embedded convection dynamically relevant?

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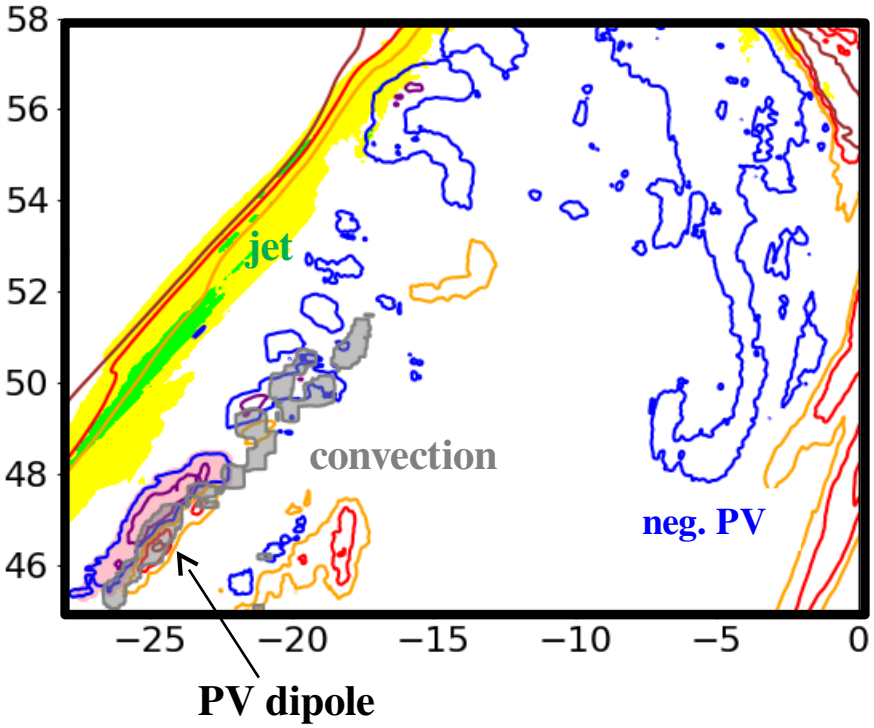

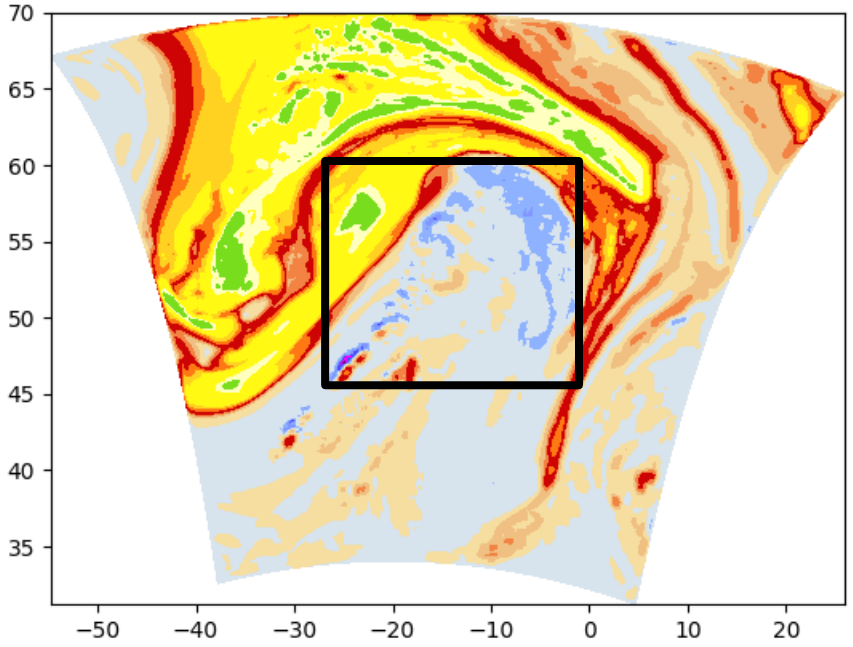

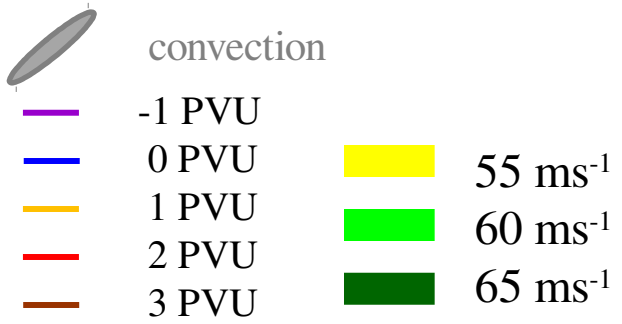

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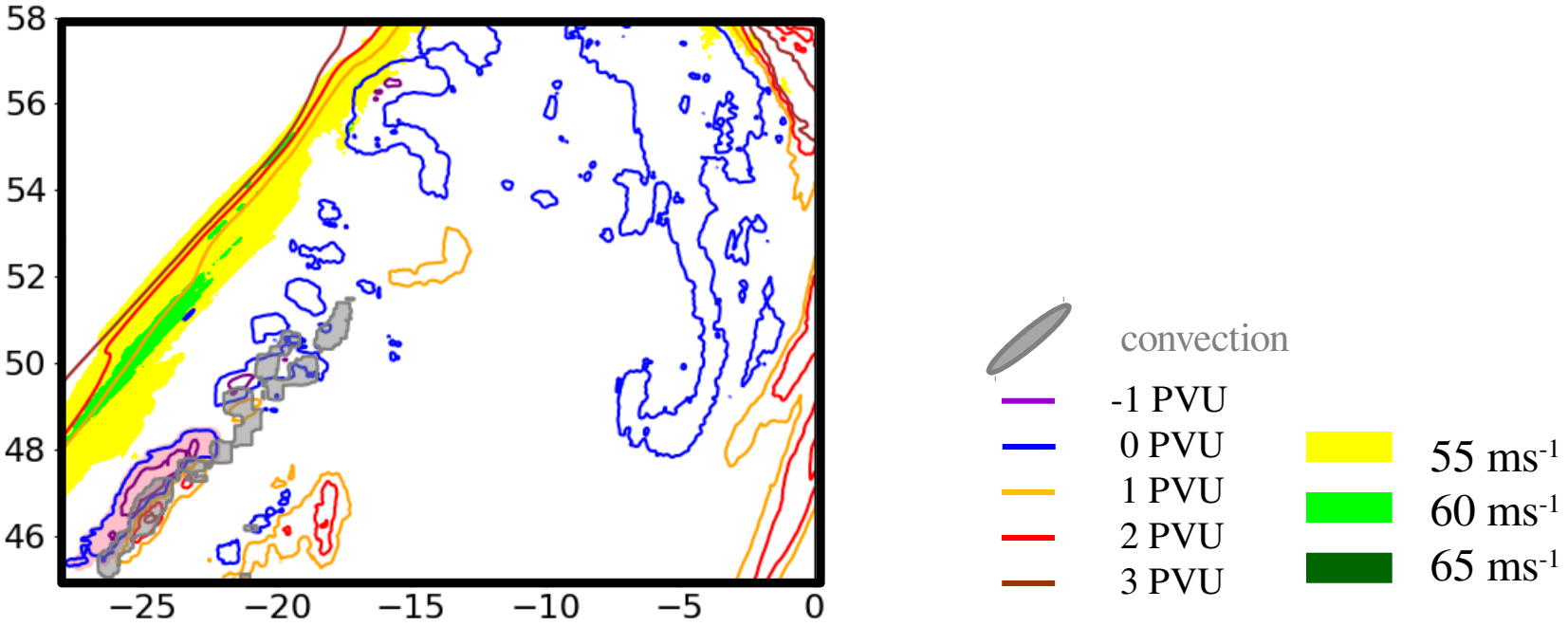

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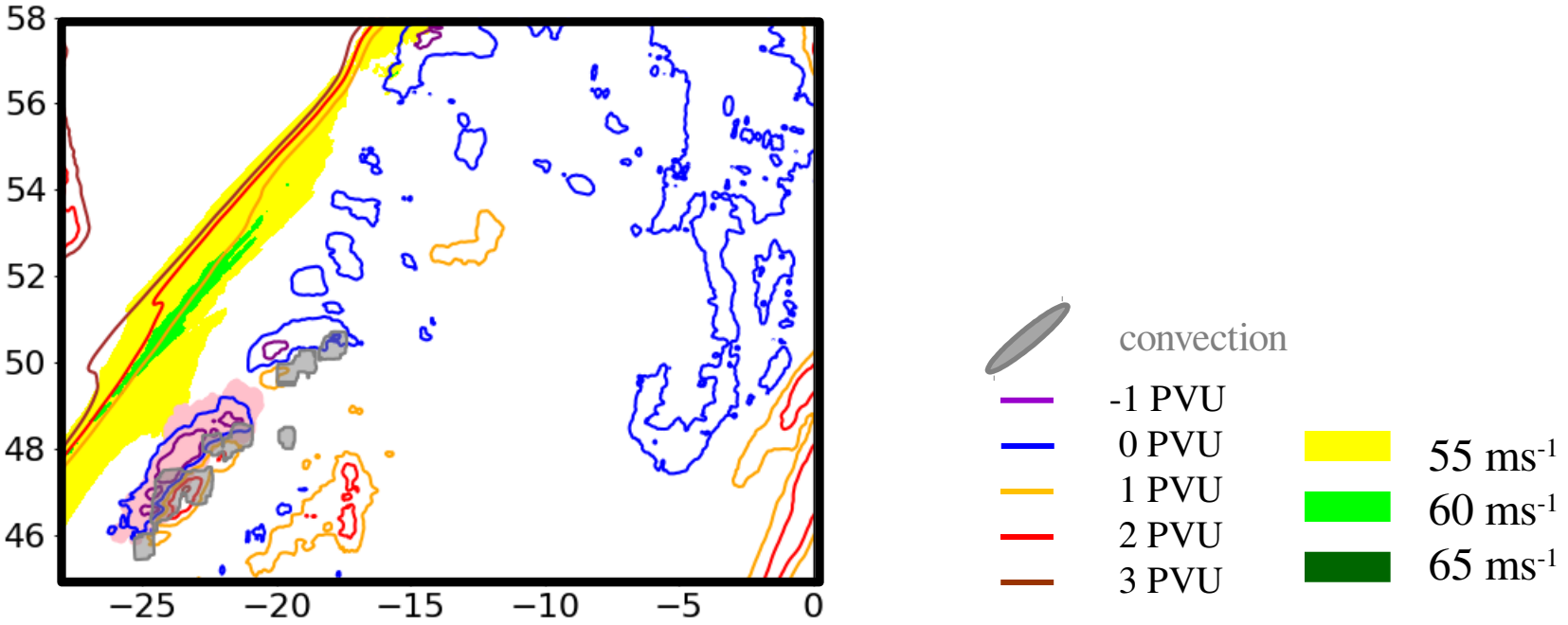

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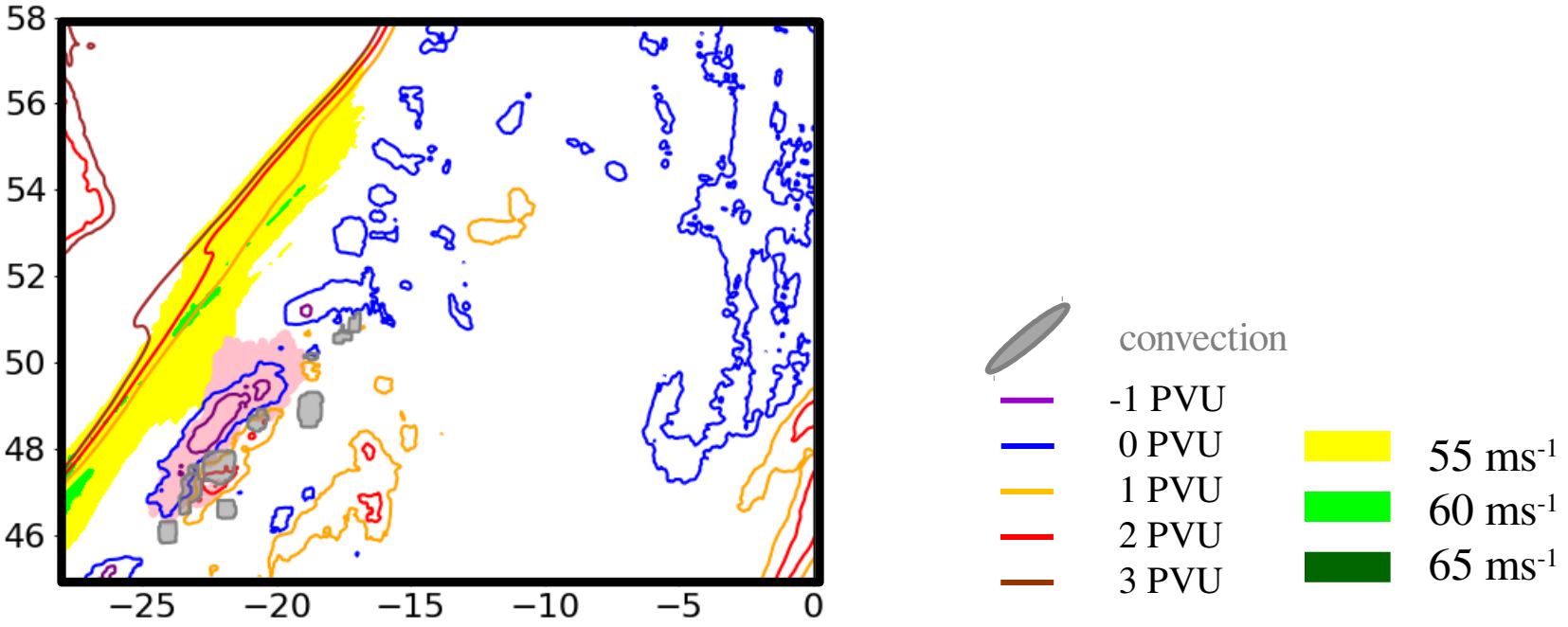

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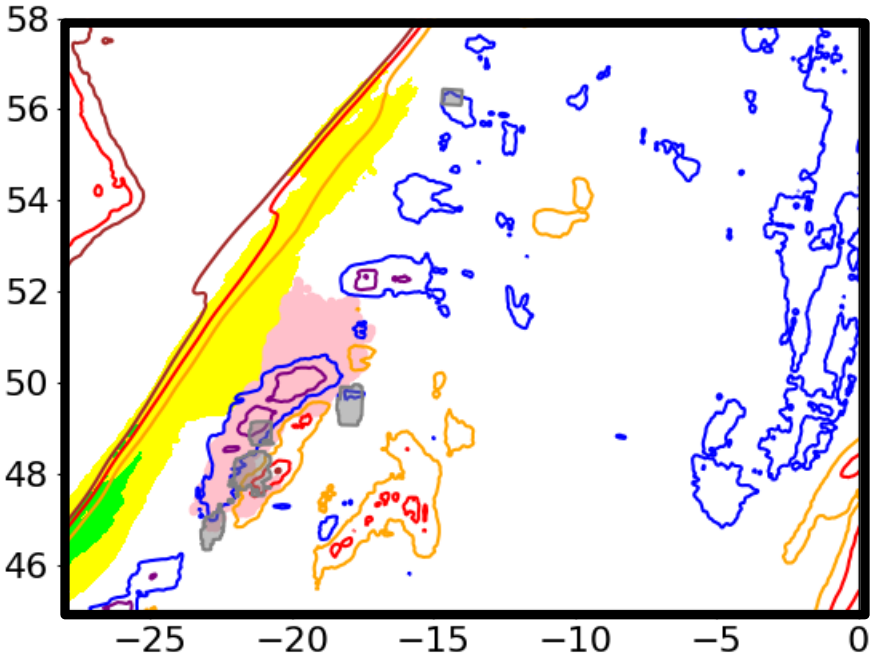

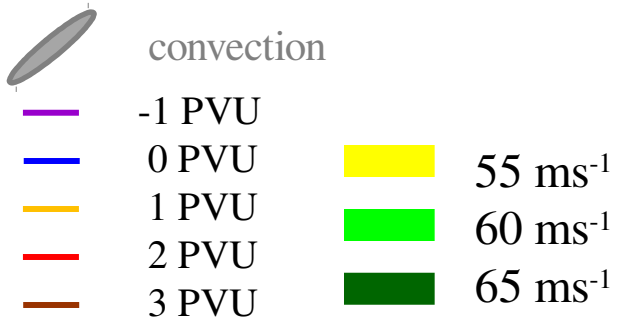

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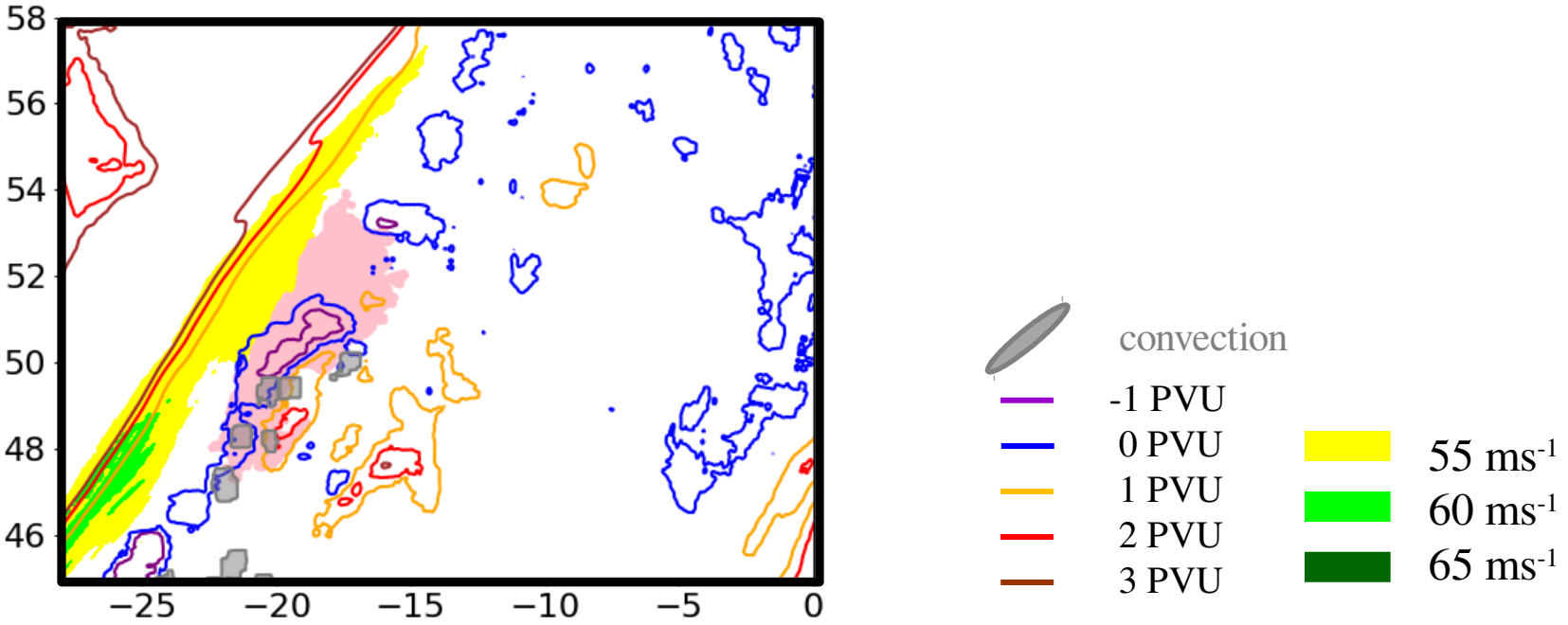

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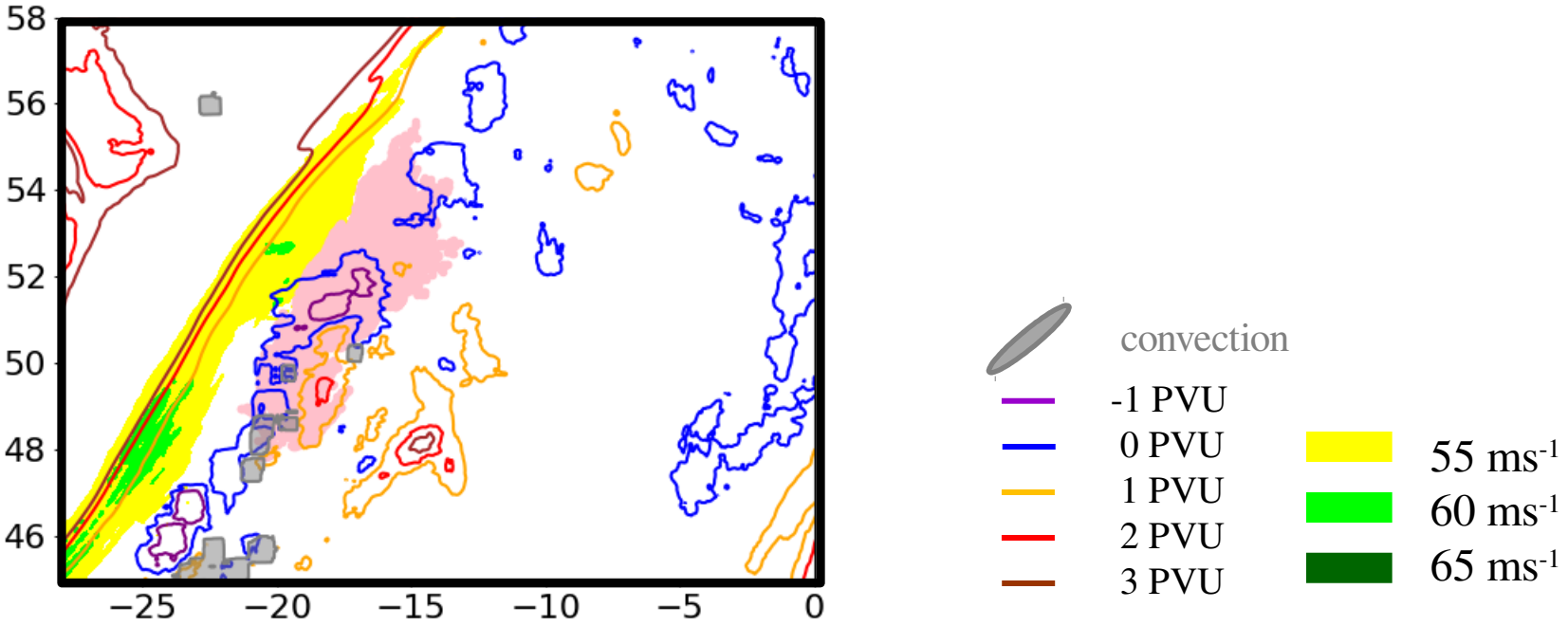

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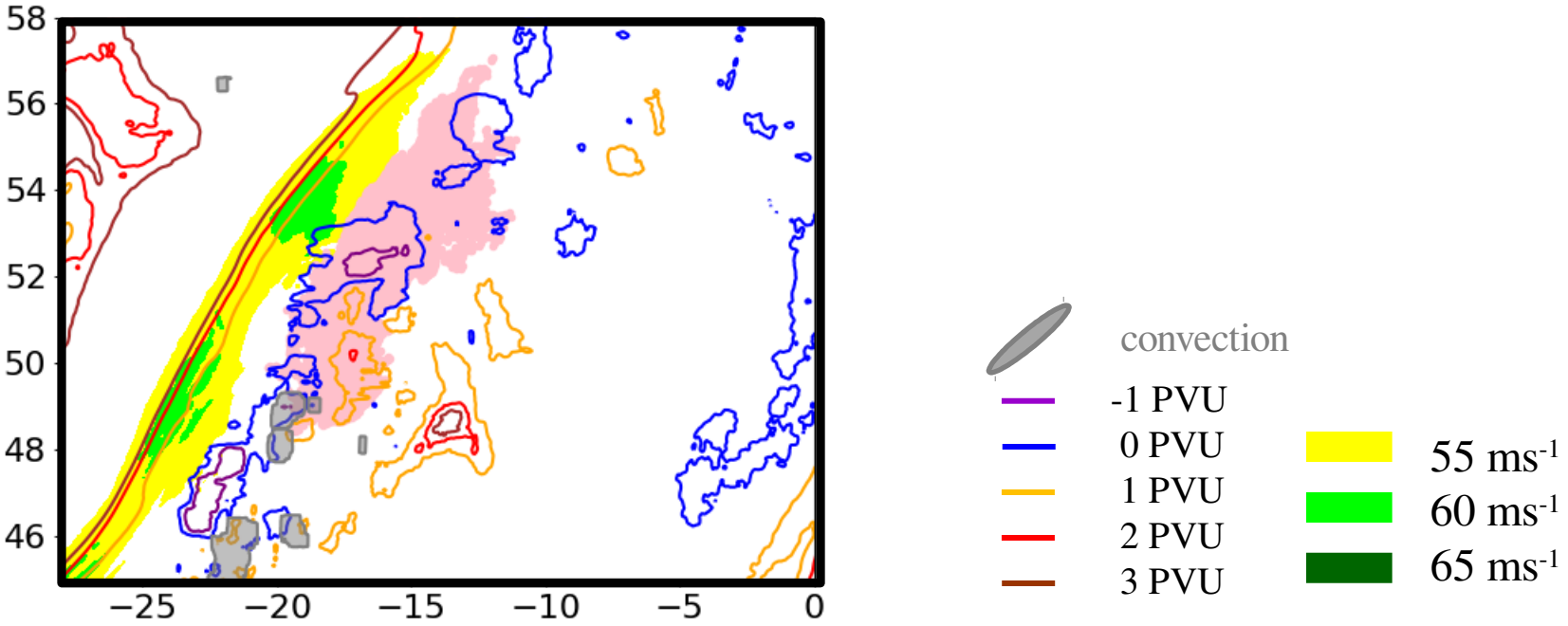

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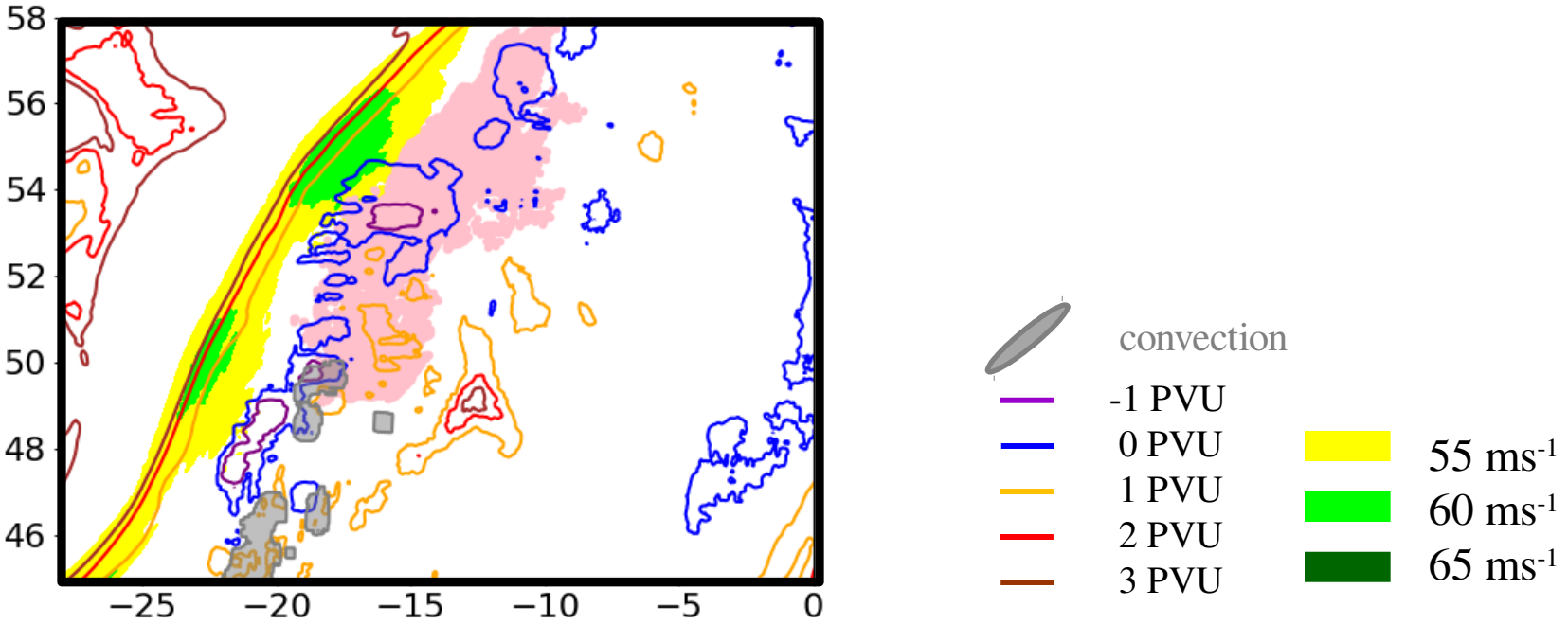

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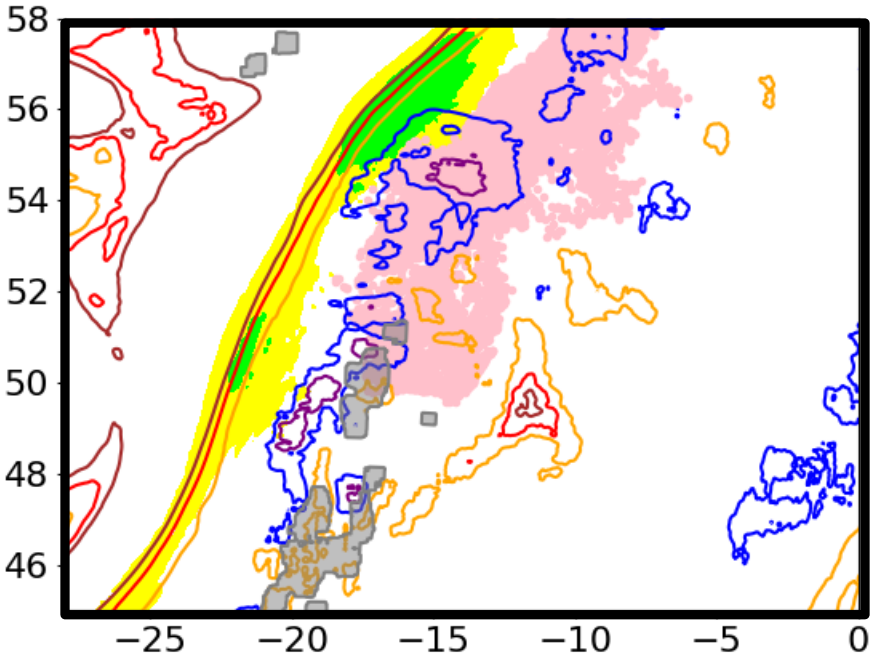

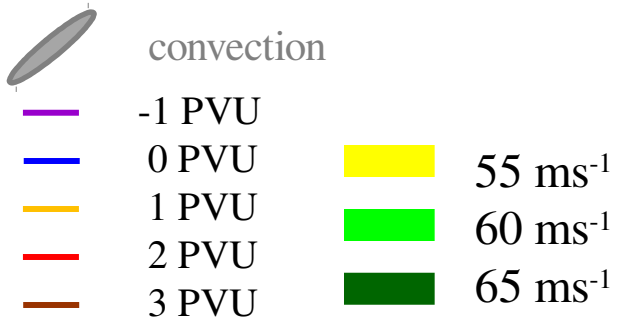

III Is embedded convection dynamically relevant?

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   >> **coarse-graining** on 60 km

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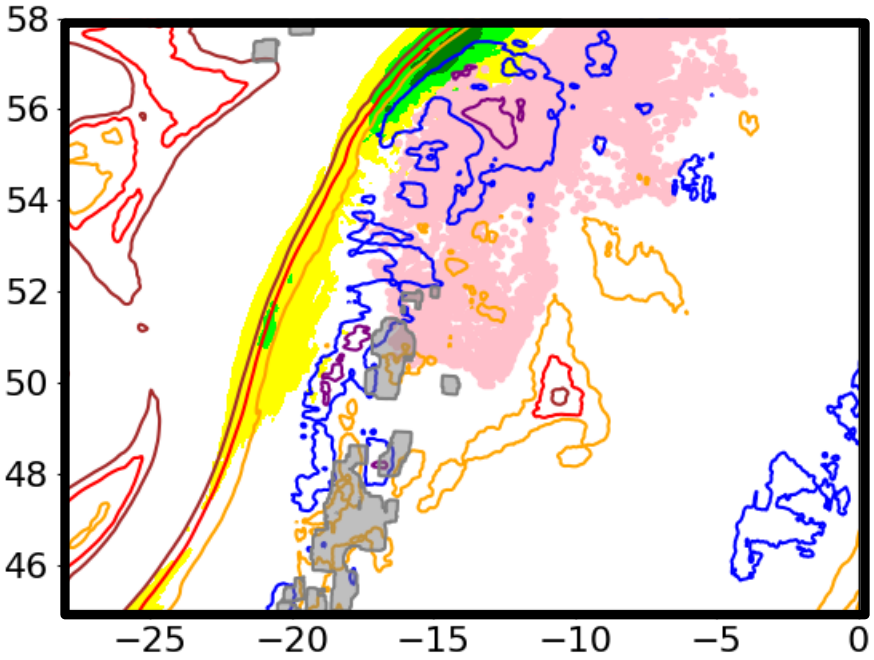

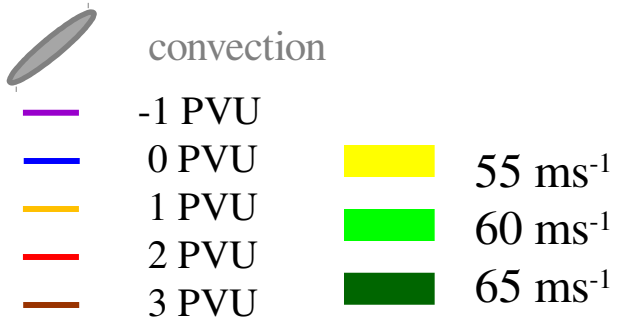

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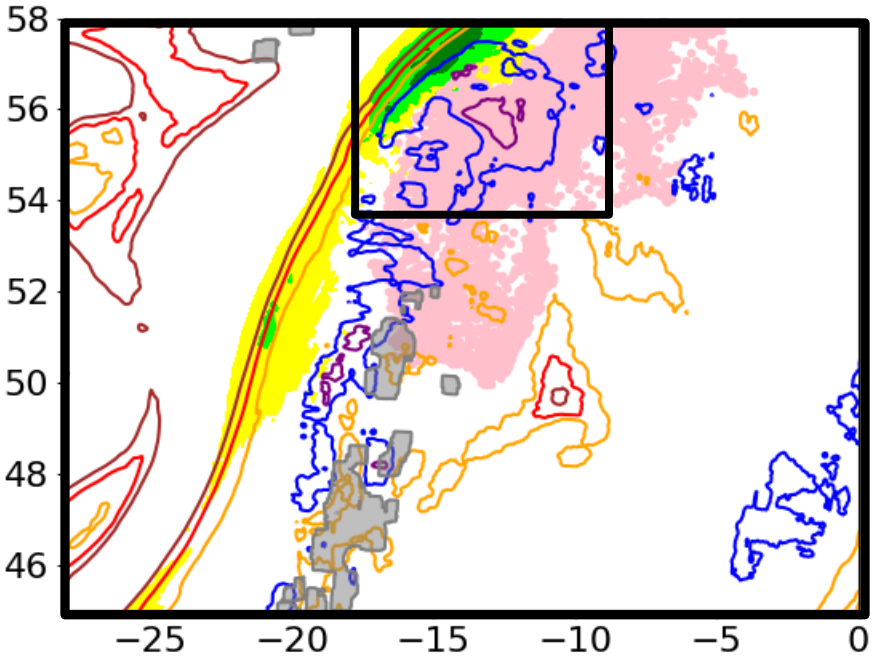

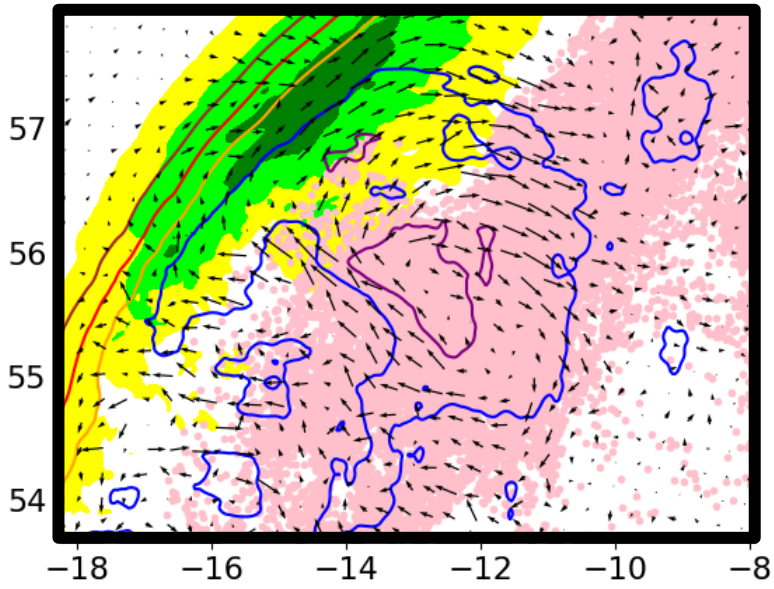

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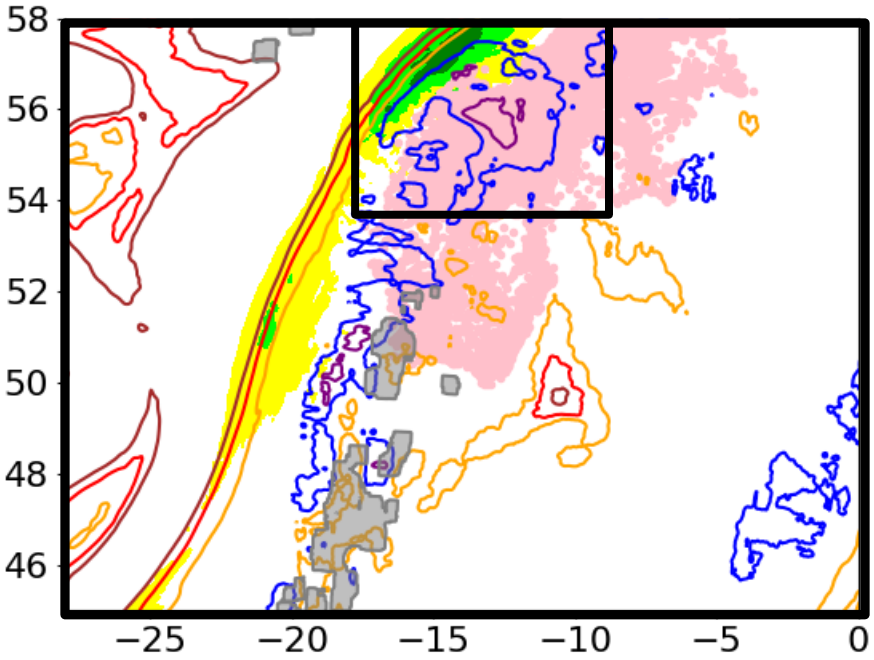
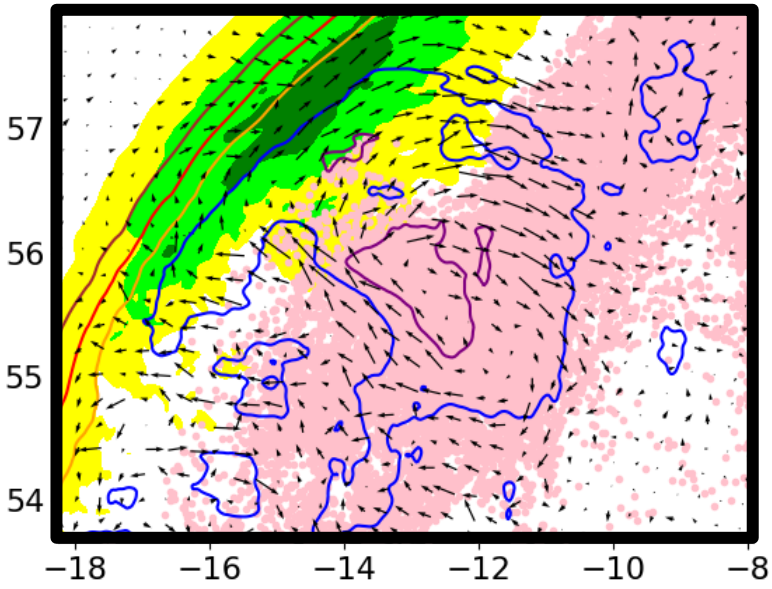
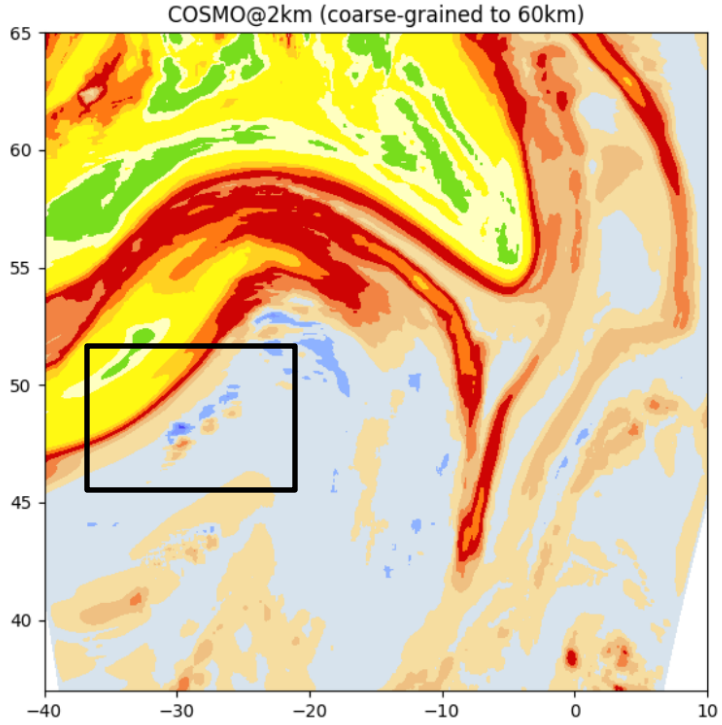


>> neg. PV has a relatively long lifetime and is advected into the ridge, where it can interact with the upper-level waveguide and result in jet streaks



III Is embedded convection dynamically relevant?

sensitivity with respect to resolution – resolved convection
COSMO@12km – COSMO@2km



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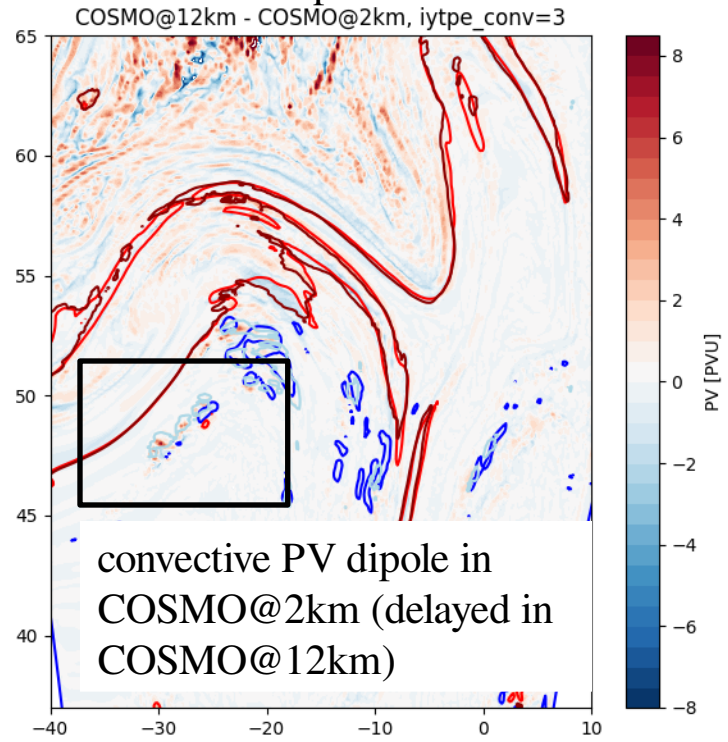
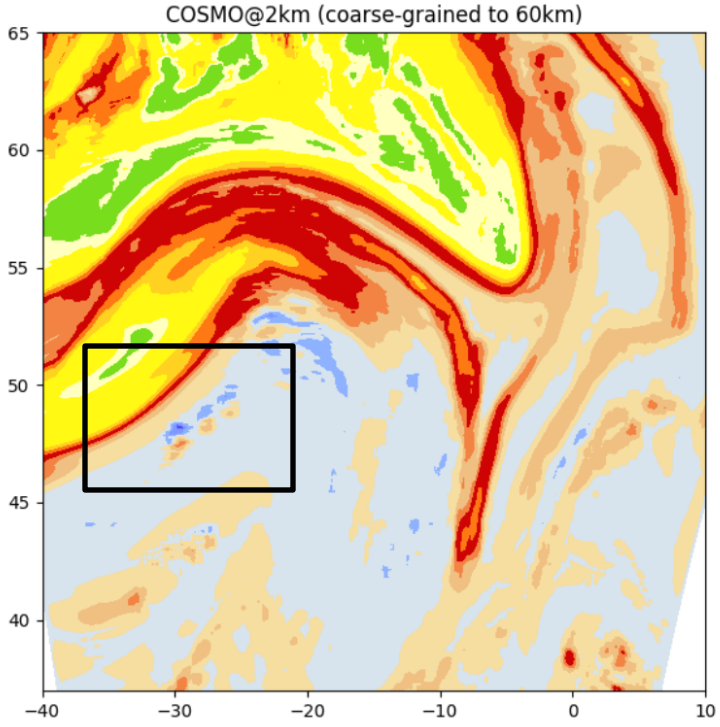
22 UTC 22 Sep





0 PVU COSMO@12km
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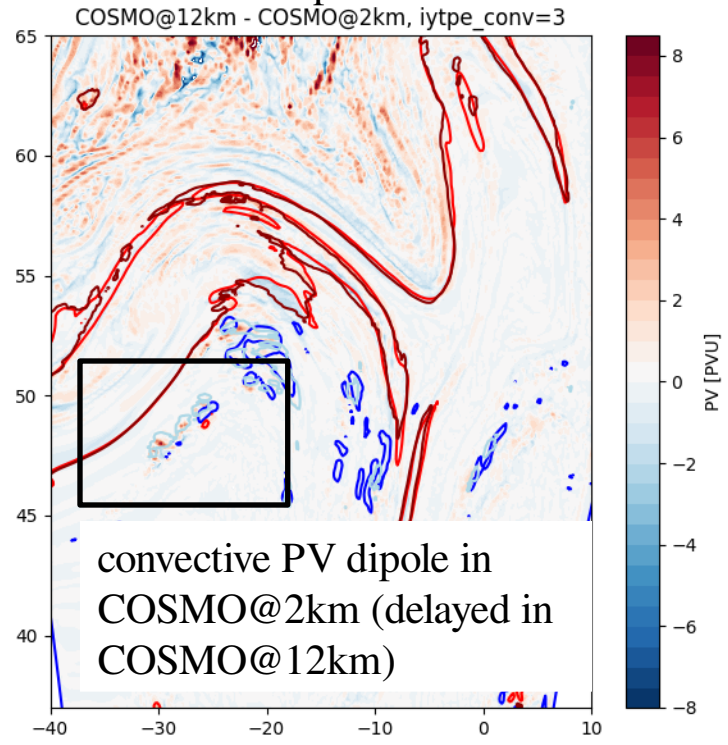
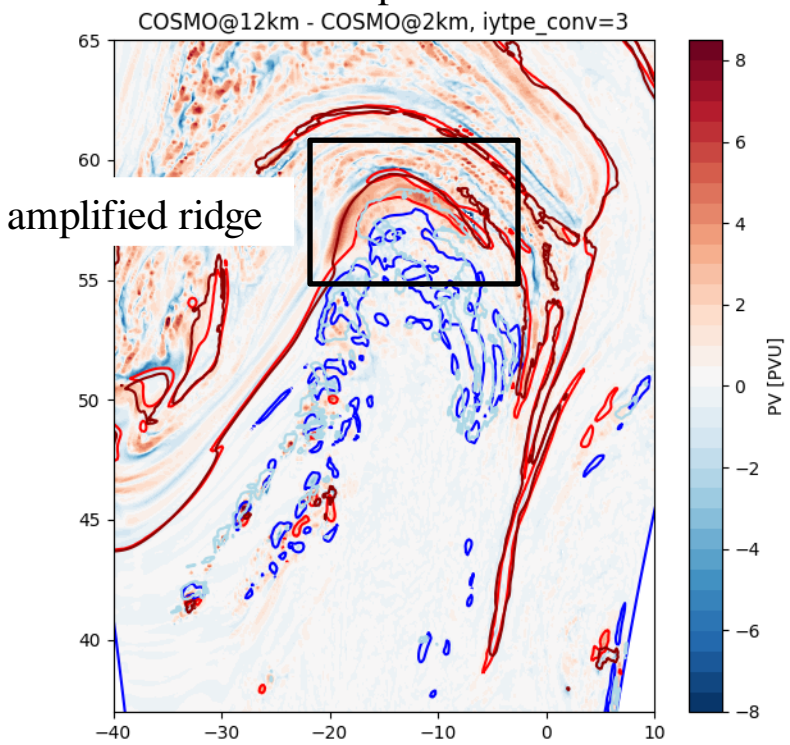


07 UTC 23 Sep



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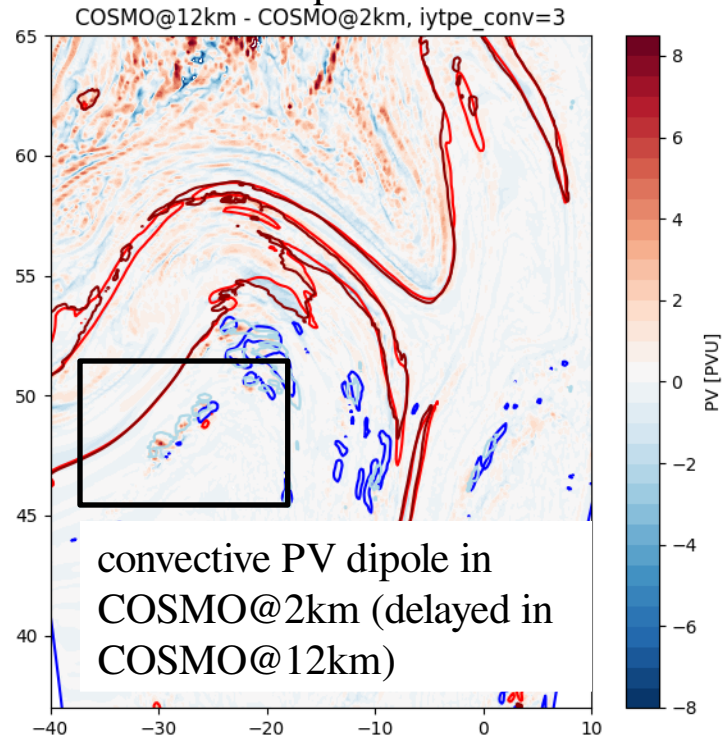

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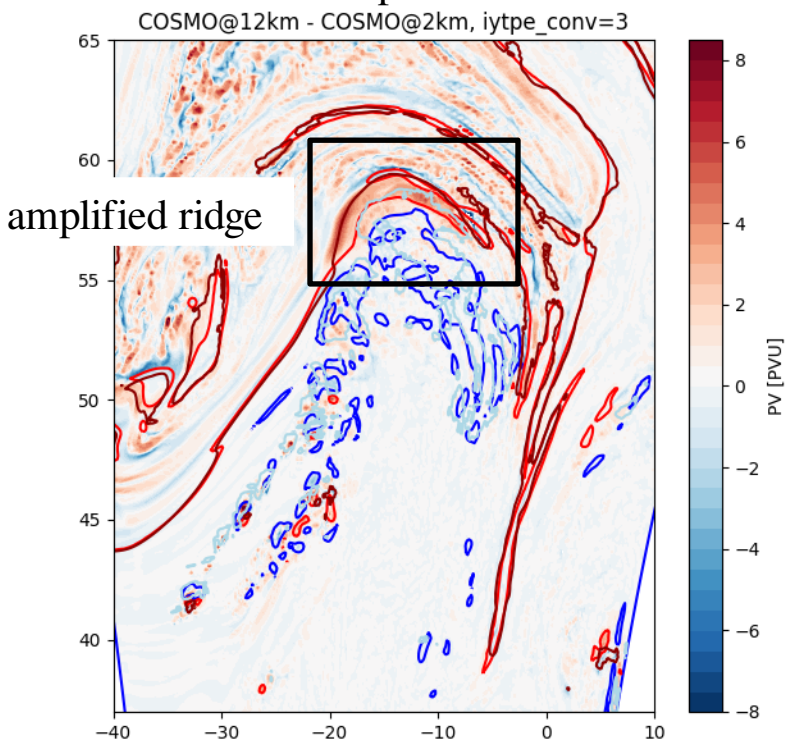

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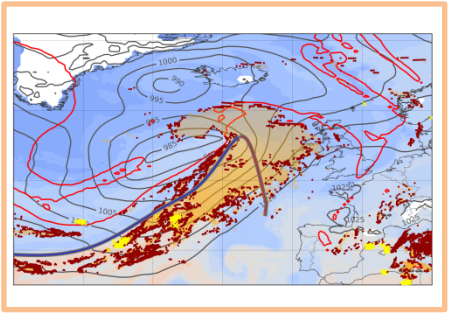
Rowe and Hitchman (2018):
inertial instability causes poleward displacement of jet maximum

Conclusions

I. convective activity is frequently embedded in the WCB of *Vladiana*

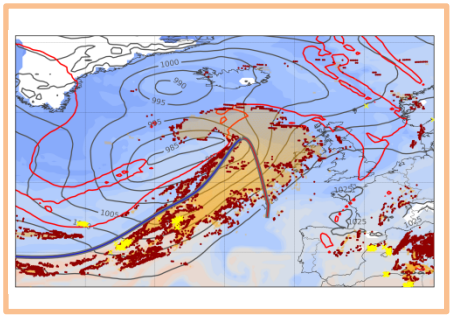


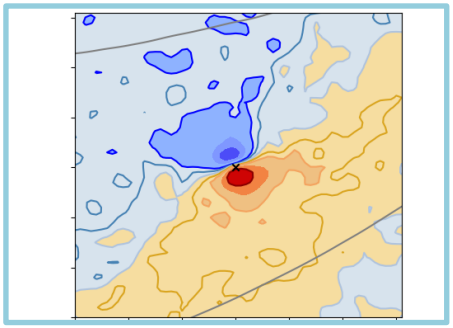
Conclusions

I. convective activity is frequently embedded in the WCB of *Vladiana*

II. embedded convection in WCBs leads to

- **stronger pos. low-level** and **neg. upper-level PV** anomalies along the ascent
- mesoscale upper-level **horizontal PV dipoles**





Conclusions

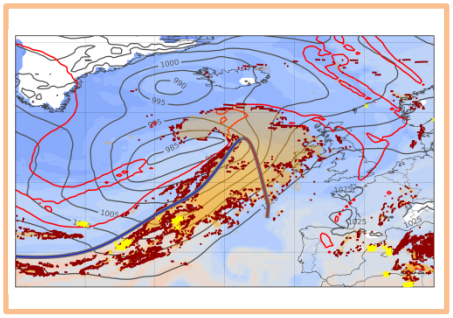
I. convective activity is frequently embedded in the WCB of *Vladiana*

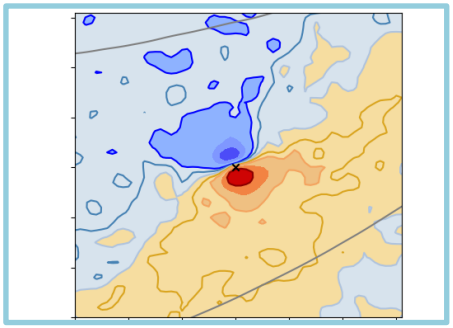
II. embedded convection in WCBs leads to

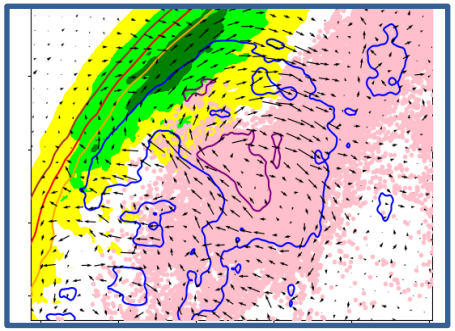
- **stronger pos. low-level** and **neg. upper-level PV** anomalies along the ascent
- mesoscale upper-level **horizontal PV dipoles**

III. on the large-scale, convectively produced PV anomalies aggregate to **elongated PV dipole bands** around elongated convective updrafts, which can

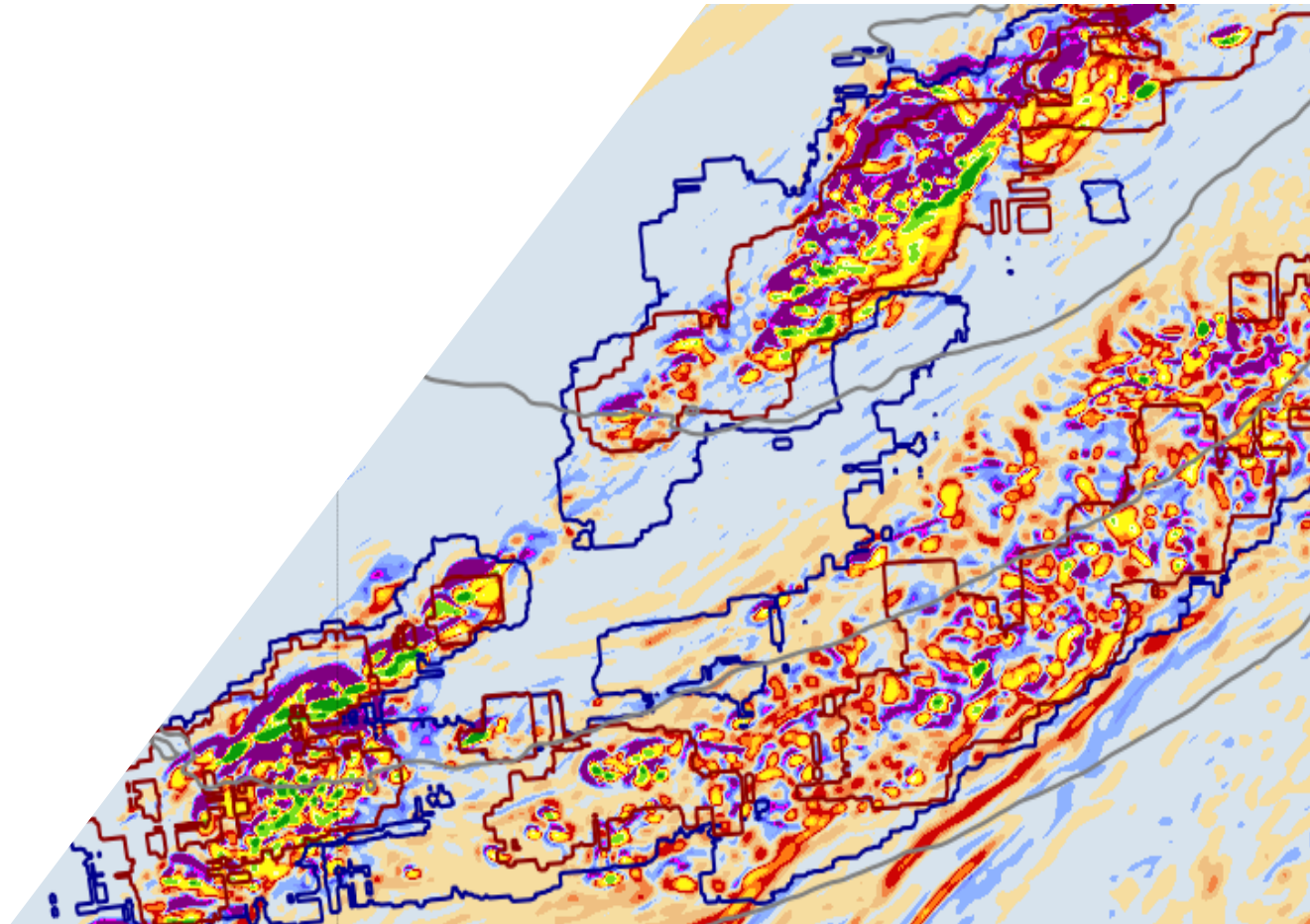
- potentially **interact with the upper-level waveguide**
- result in **jet streaks**
- strengthen the ridge amplification?





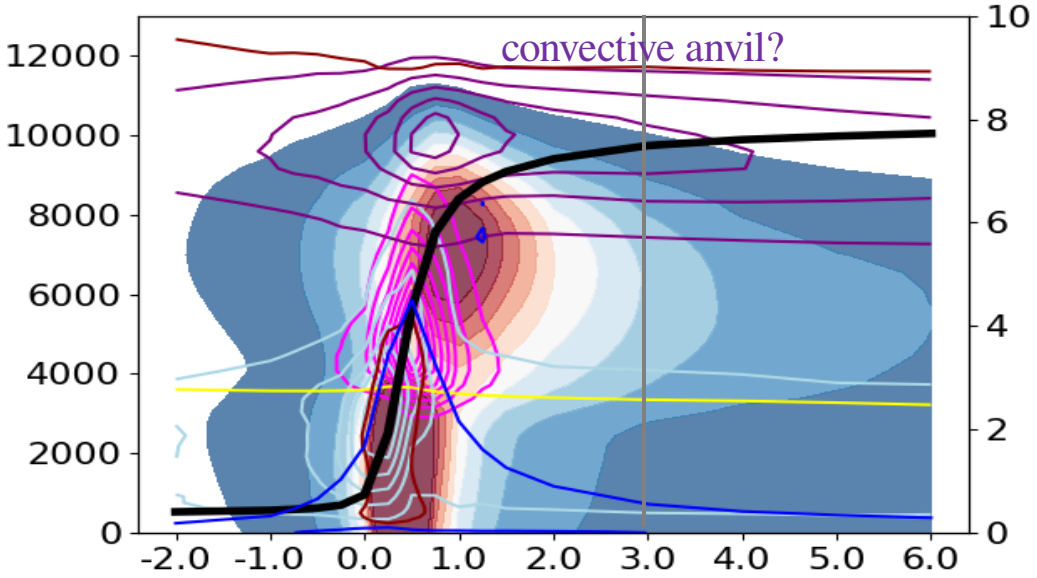


Thank you

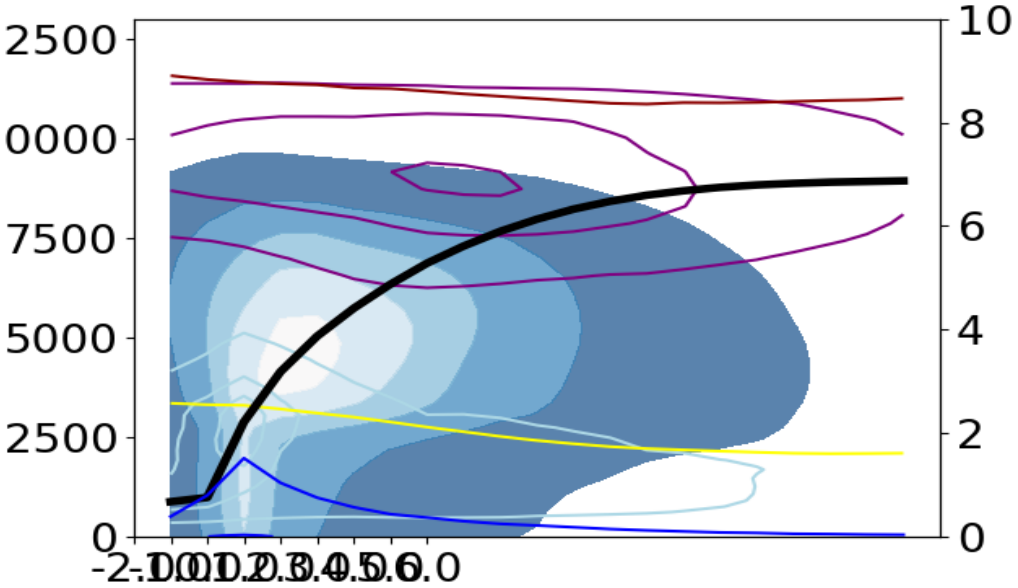


How does embedded convection in WCBs modify the *WC distribution?

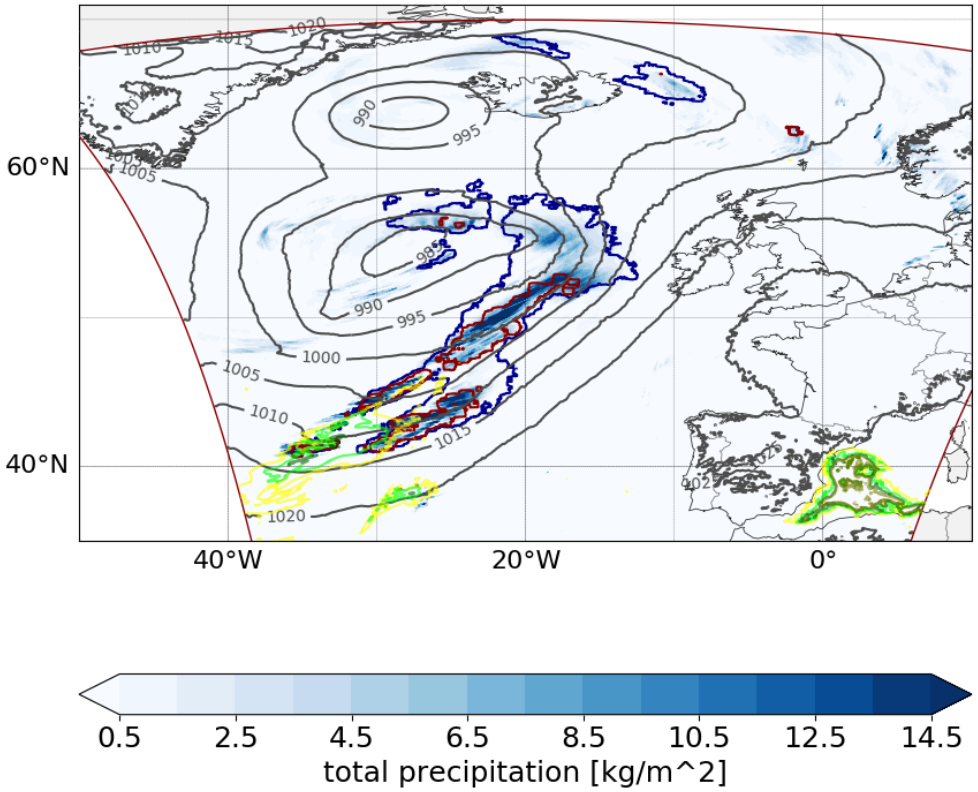
convective WCB



average WCB



Precipitation in the WCB



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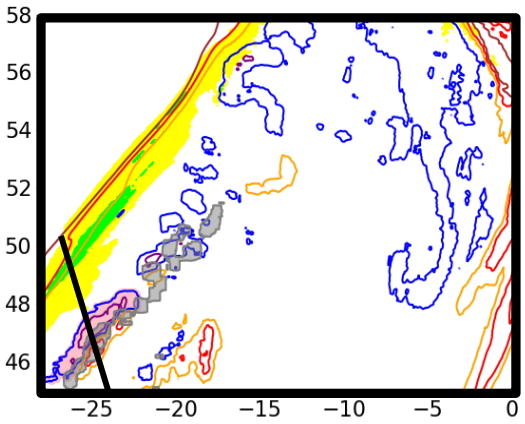

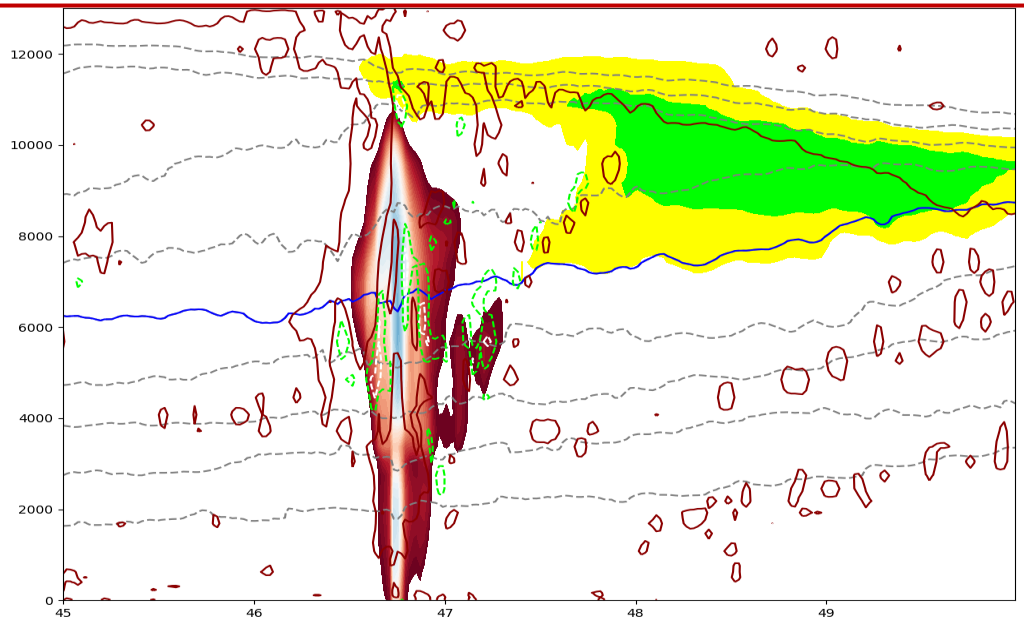

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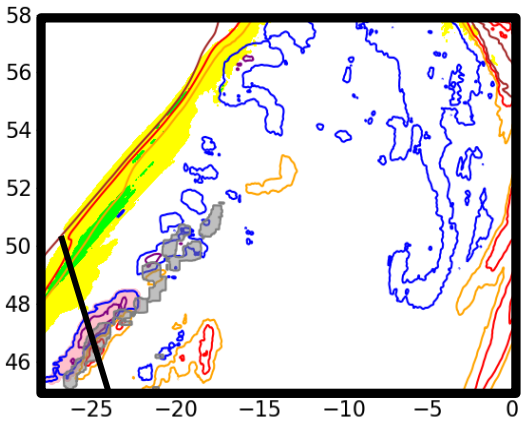

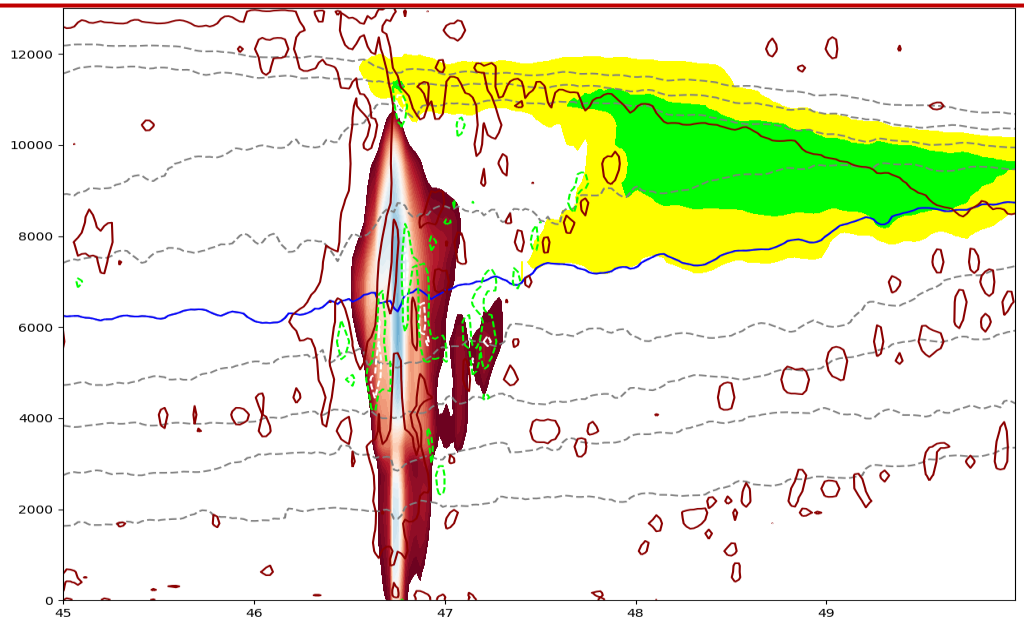

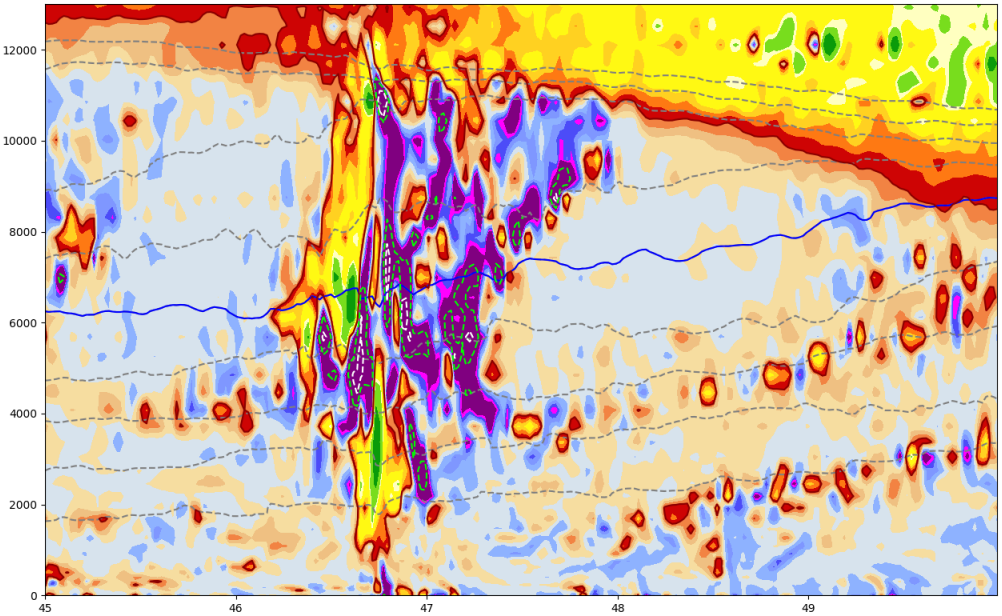

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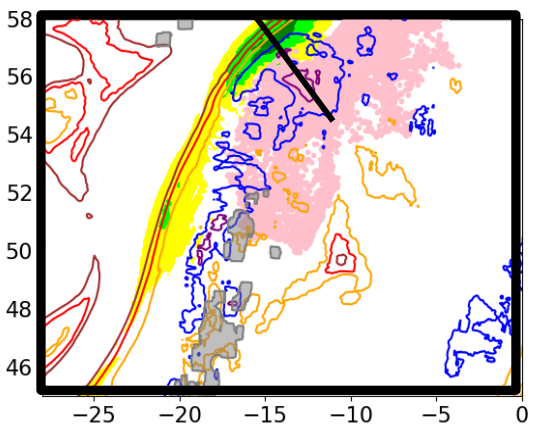

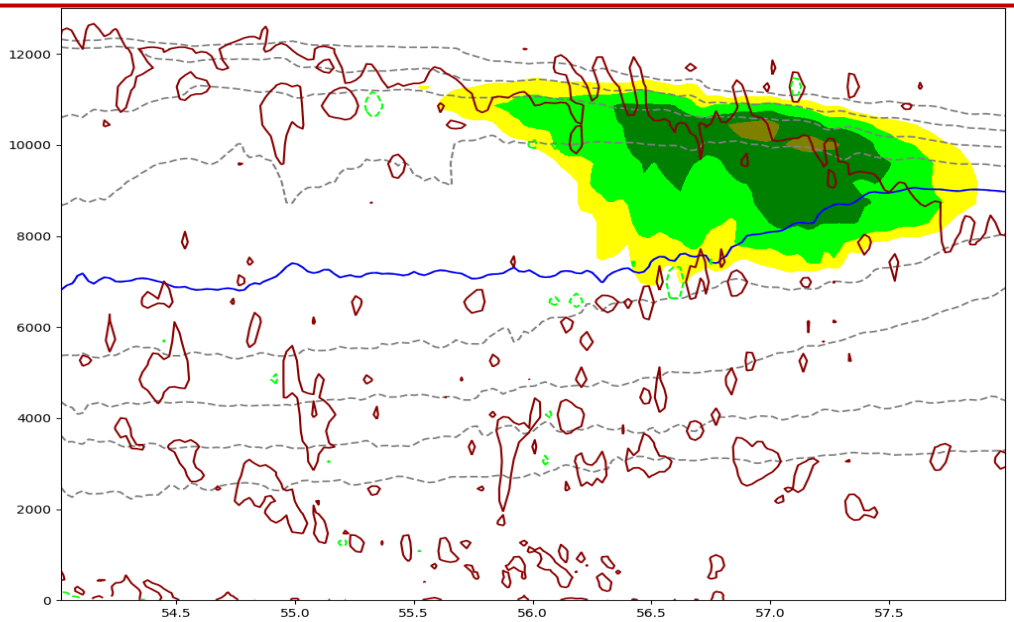

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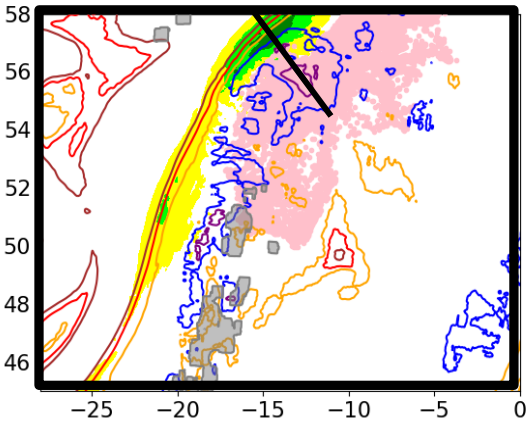
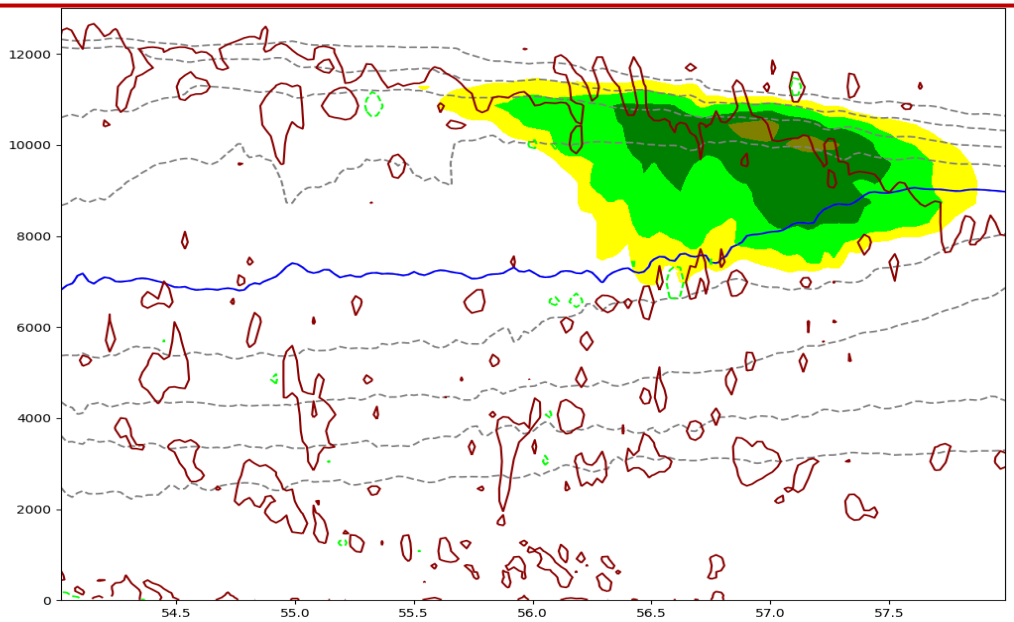
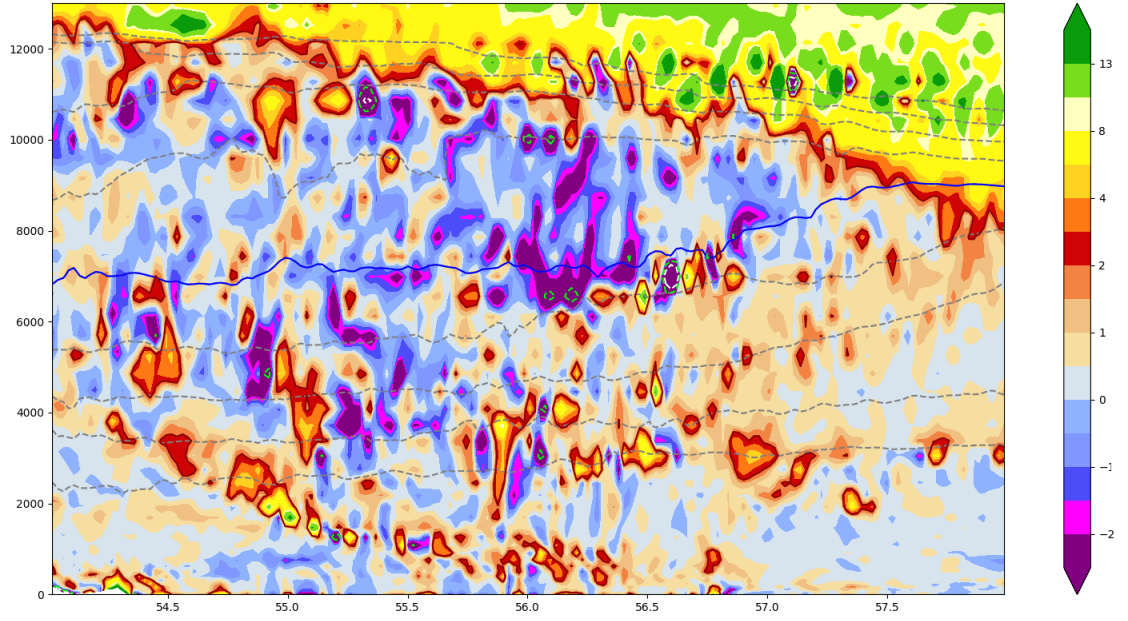






Background and Motivation

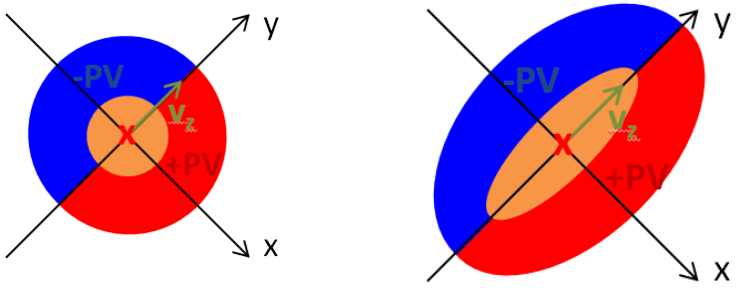
$$\frac{DPV}{Dt} = \frac{1}{\rho}\eta \cdot \nabla\dot{\Theta} + \frac{1}{\rho}\nabla\Theta \cdot (\nabla \times F)$$

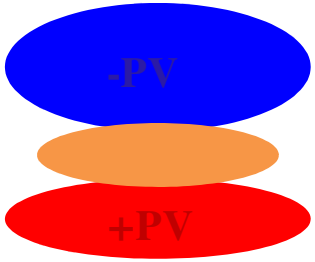
in x-direction:

$PV_x \sim (w_y - v_z) \cdot \Theta_x$

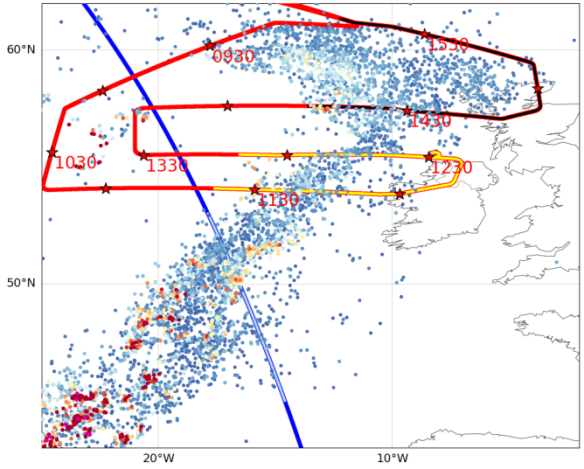
in z-direction:

$PV_z \sim (v_x - u_y) \cdot \Theta_z$





I What are typical characteristics of embedded convection?

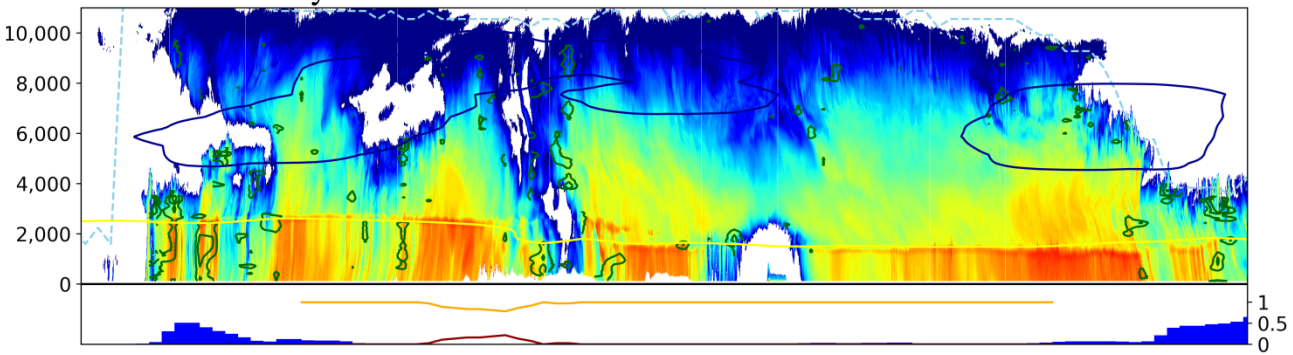


Indications for embedded convection:

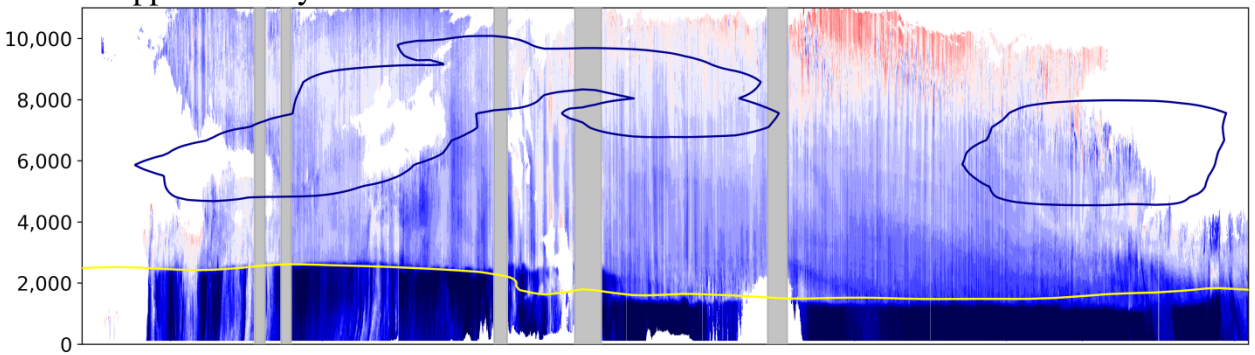
- increased heterogeneity of radar reflectivity
- decreased (and more heterogeneous) Doppler velocity >> increased updraft velocity

- different from (isolated) deep convective systems

Radar reflectivity



Doppler velocity



Oertel et al. 2019, QJRMS

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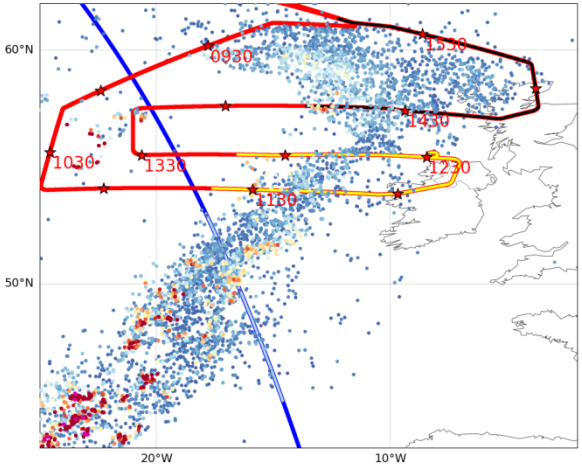
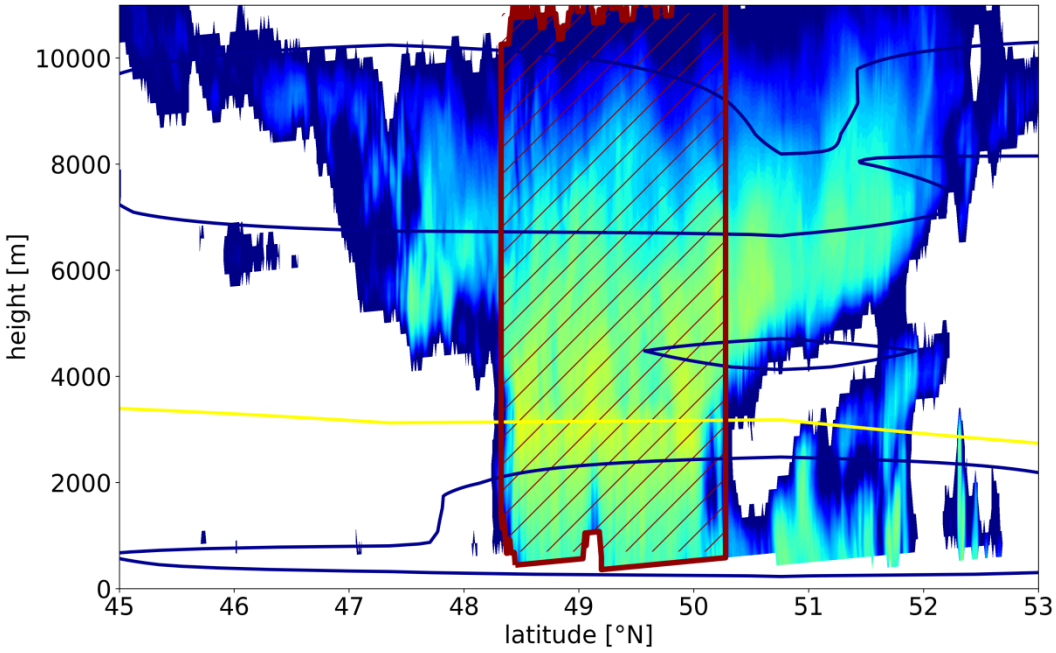
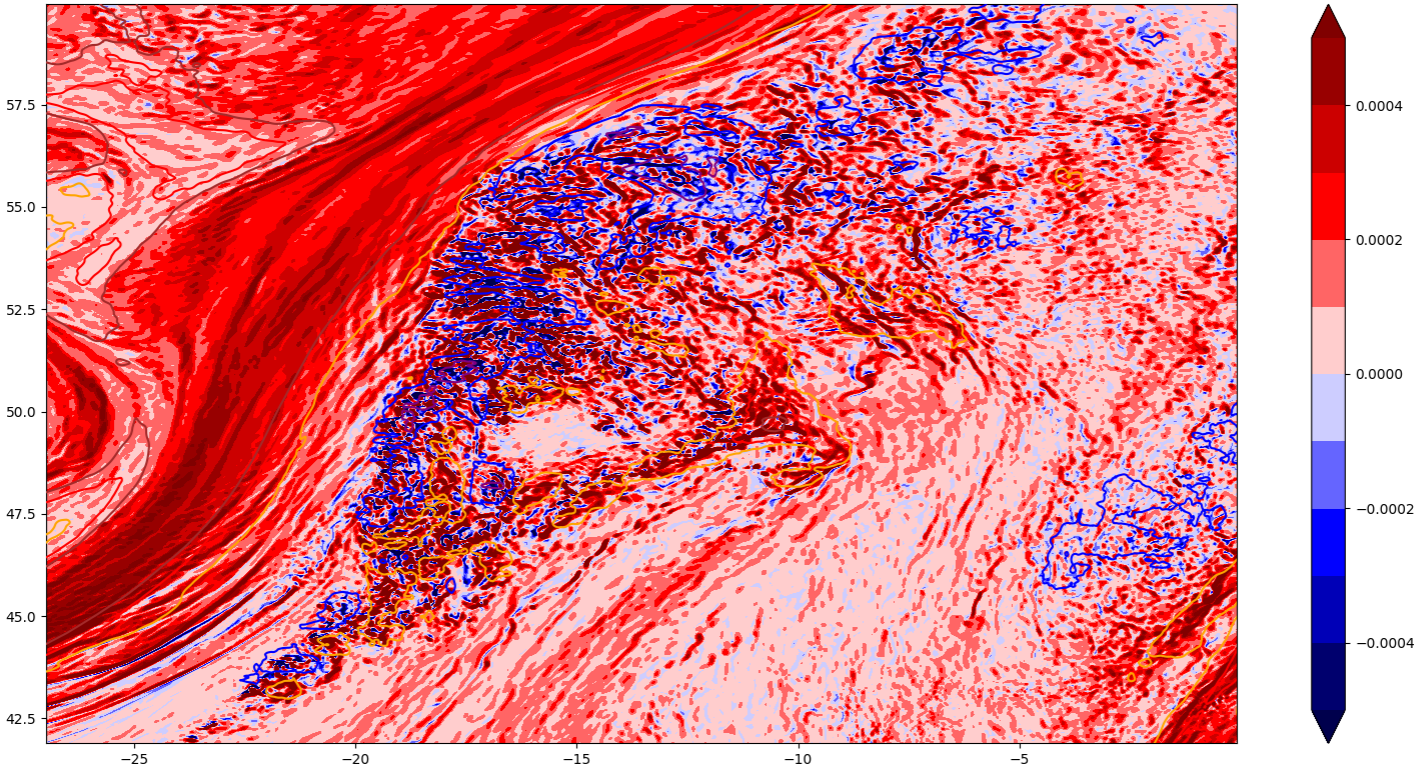
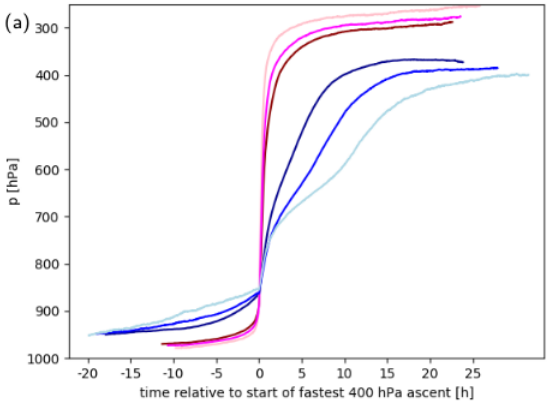


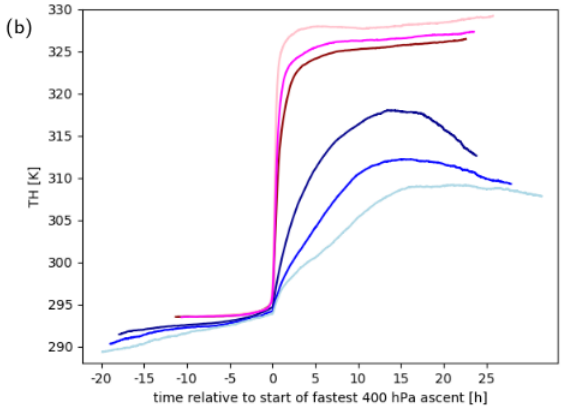


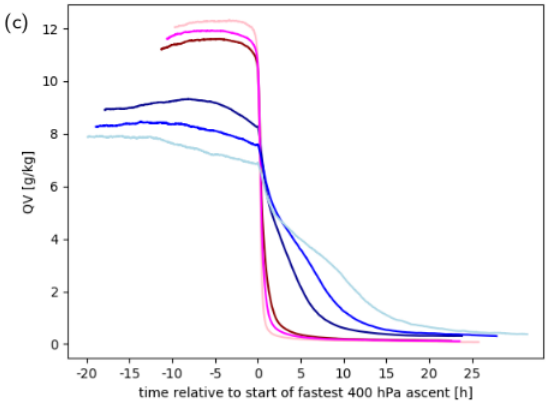
Vertical absolute vorticity

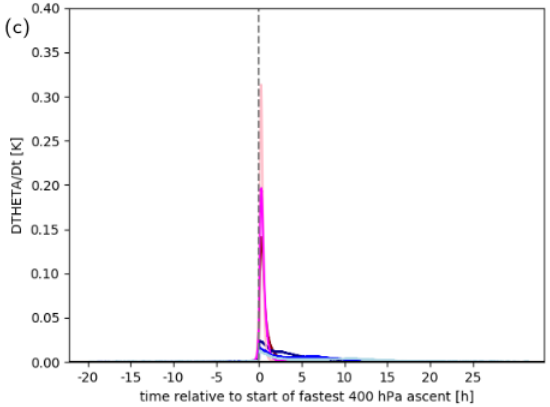


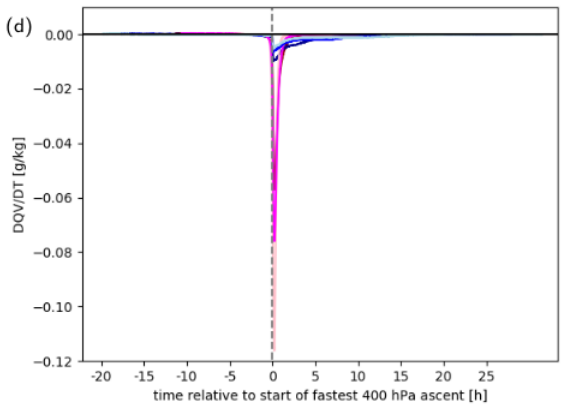
Ascent characteristics

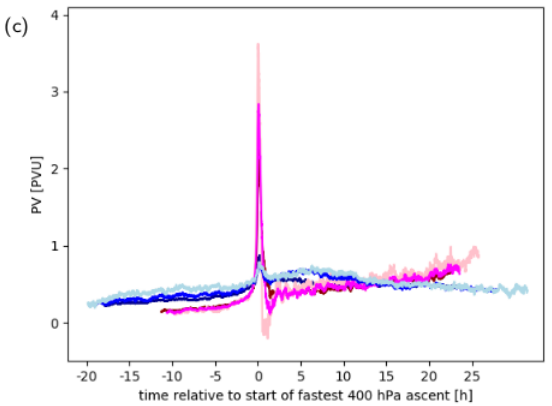












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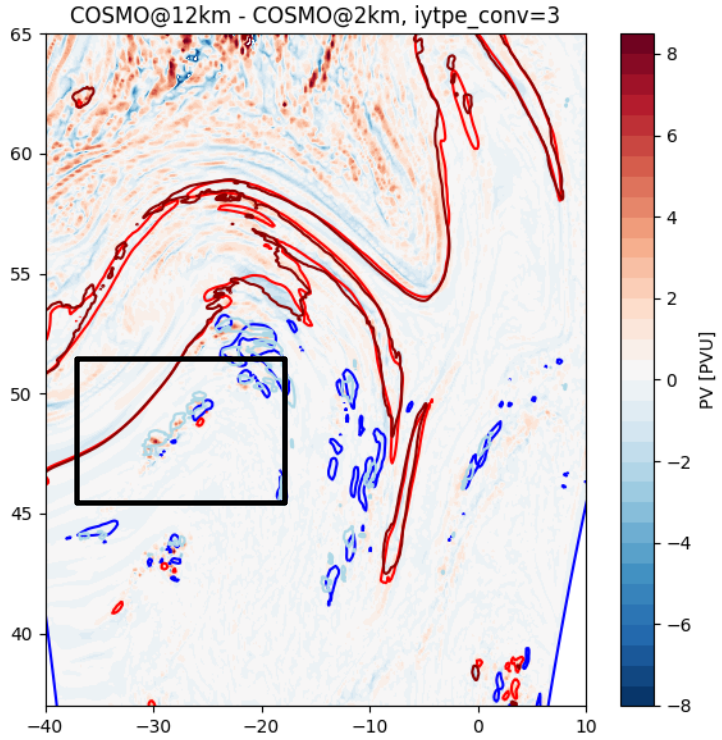

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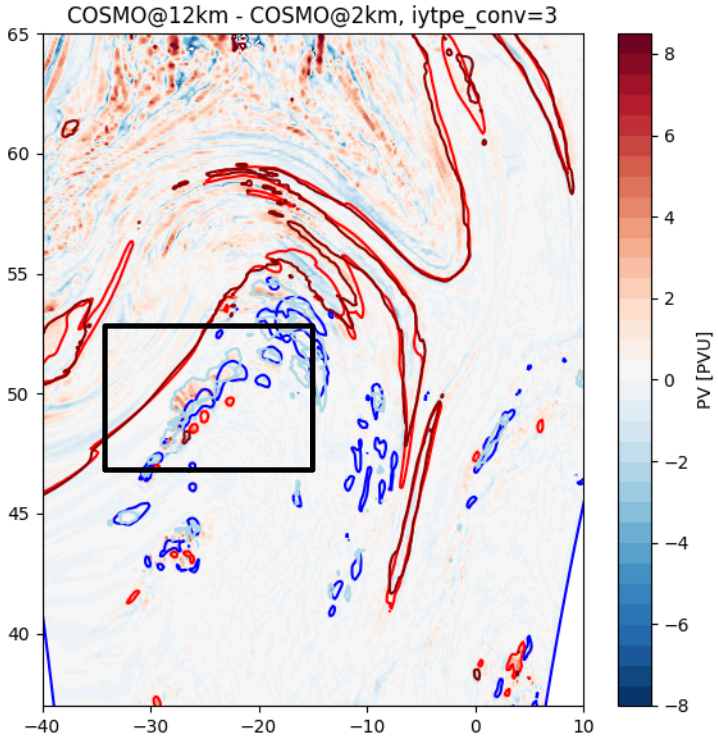

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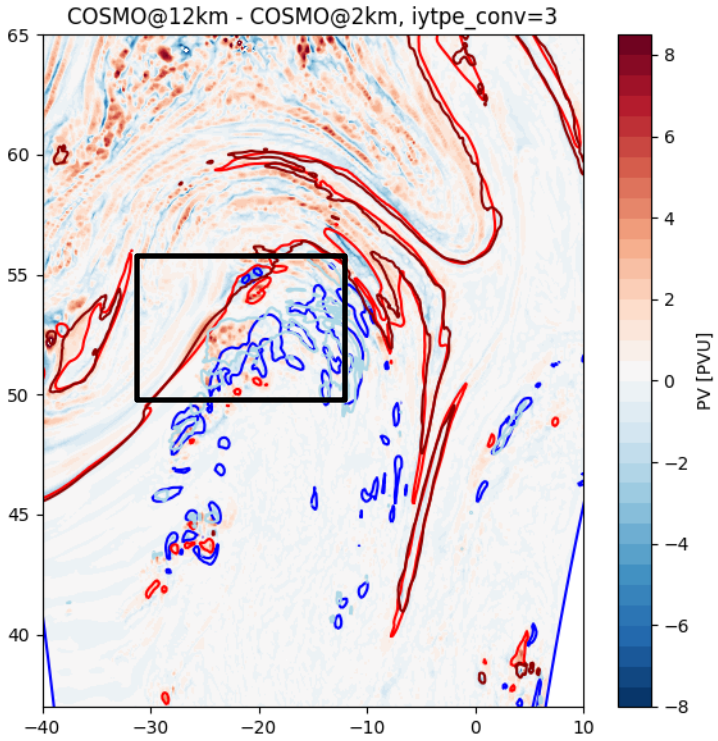

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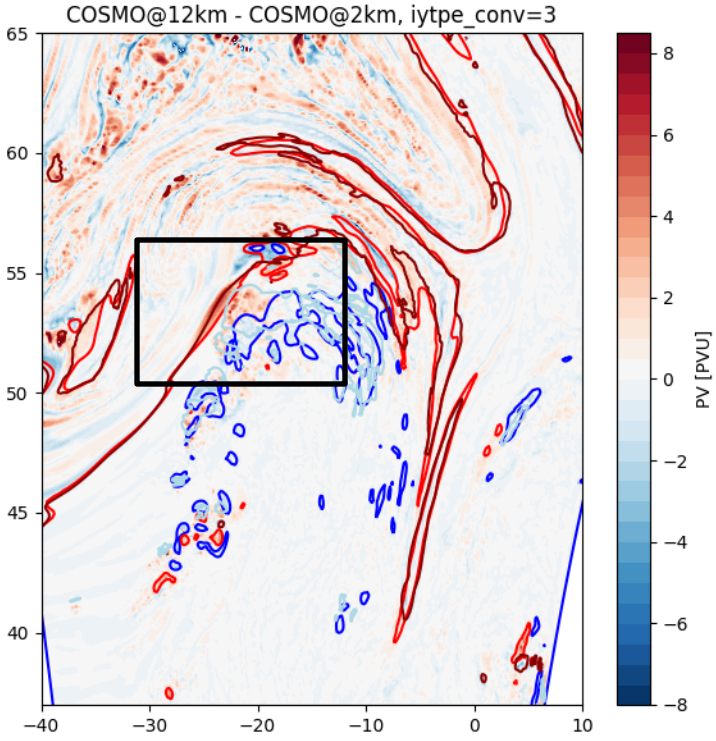

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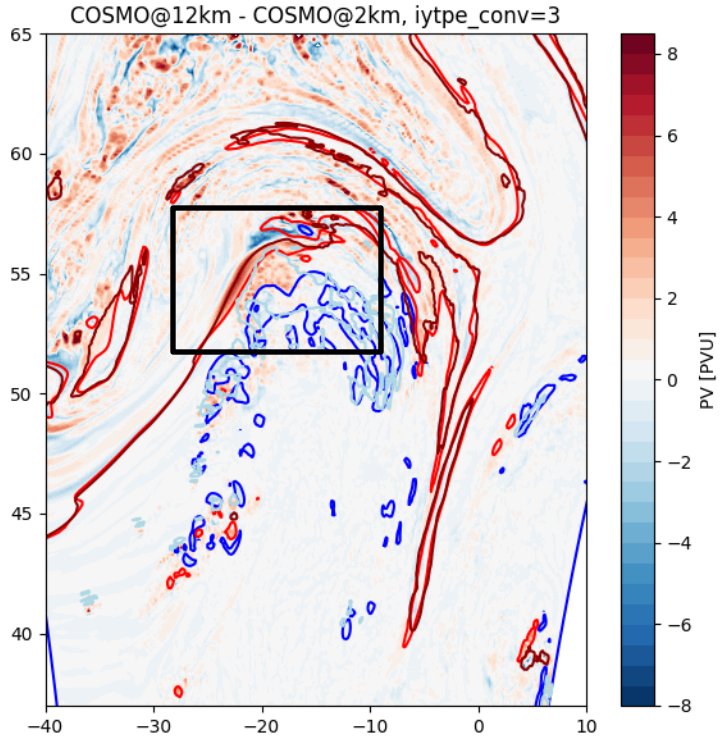
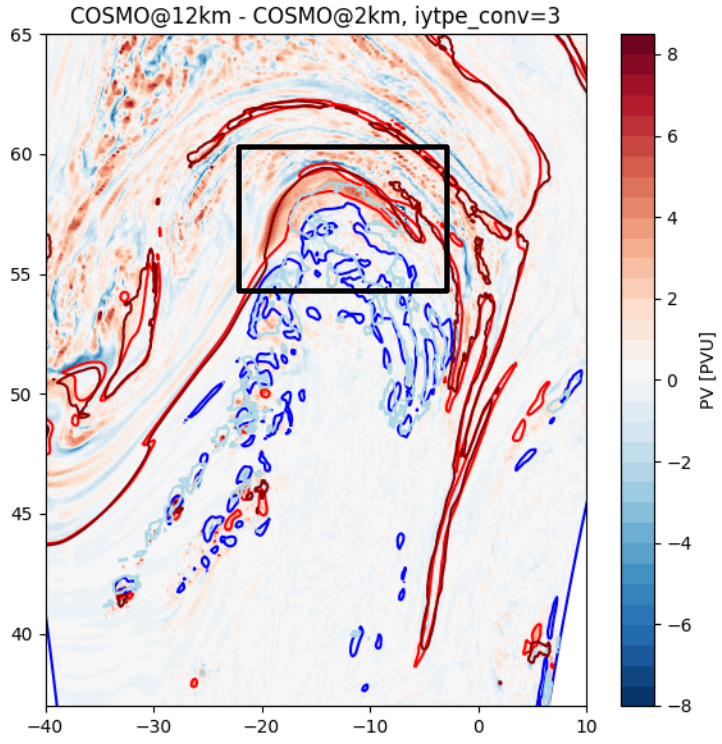
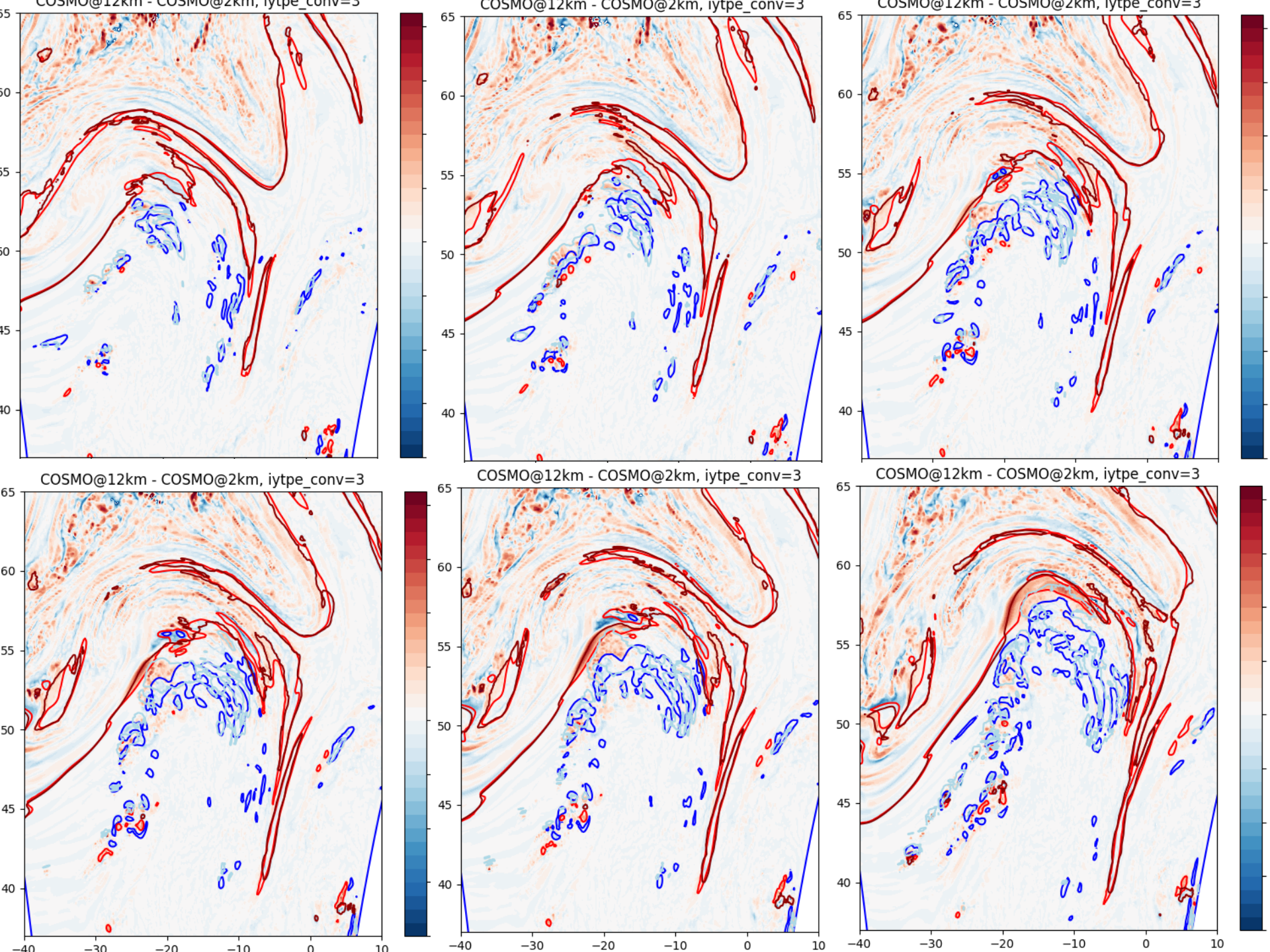


III Is embedded convection dynamically relevant?




COSMO@12km - COSMO@2km, iytpe_conv=3
COSMO@12km - COSMO@2km, iytpe_conv=3
COSMO@12km - COSMO@2km, iytpe_conv=3
COSMO@12km - COSMO@2km, iytpe_conv=3
COSMO@12km - COSMO@2km, iytpe_conv=3
COSMO@12km - COSMO@2km, iytpe_conv=3
65
60
55
50
45
40
−40
−30
−20
−10
0
10