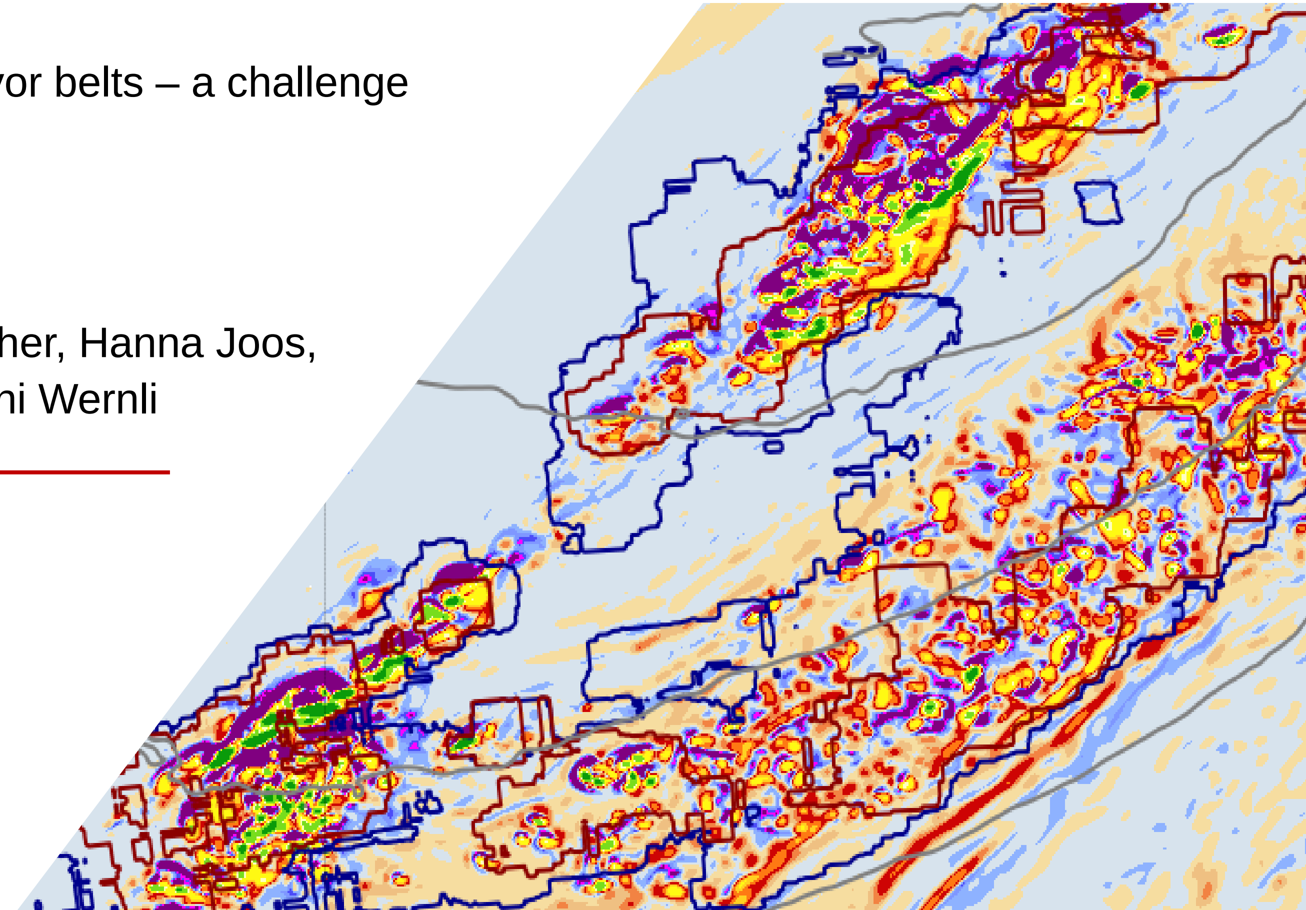
ETH
Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

Embedded convection in the warm conveyor belt of a North Atlantic cyclone and its relevance for large-scale dynamics

Workshop on warm conveyor belts – a challenge to forecasting

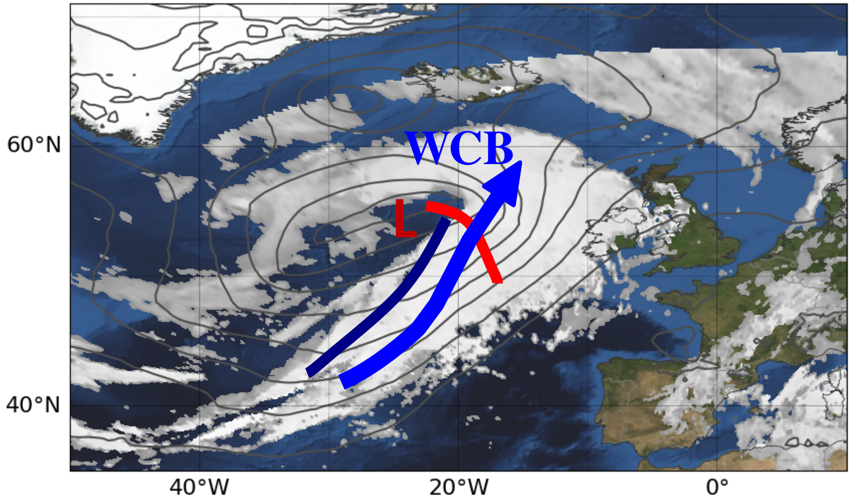
Annika Oertel, Maxi Boettcher, Hanna Joos, Michael Sprenger, and Heini Wernli

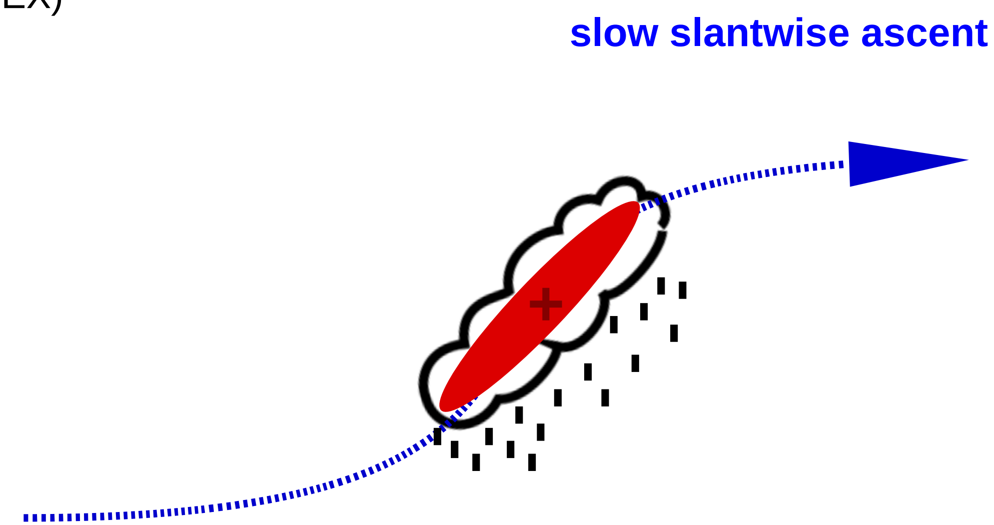


March 10, 2020

Embedded convection in WCBs

23 Sep 2016 – Cyclone *Vladiana* (IOP 3 - NAWDEX)





Embedded convection in WCBs

Satellite observations

Binder 2016, PhD thesis; Flaounas et al. 2016, QJRMS; Crespo and Posselt 2016, MWR; Flaounas et al. 2018, ClimDyn; Oertel et al. 2019, QJRMS

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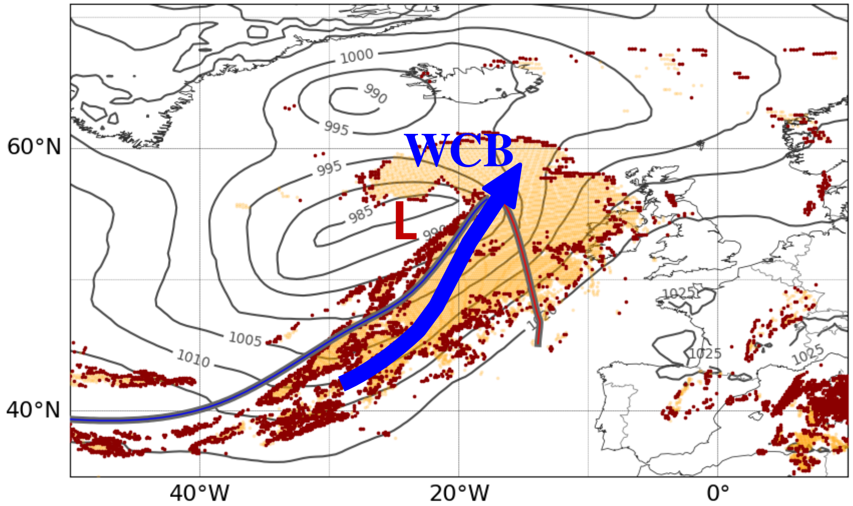
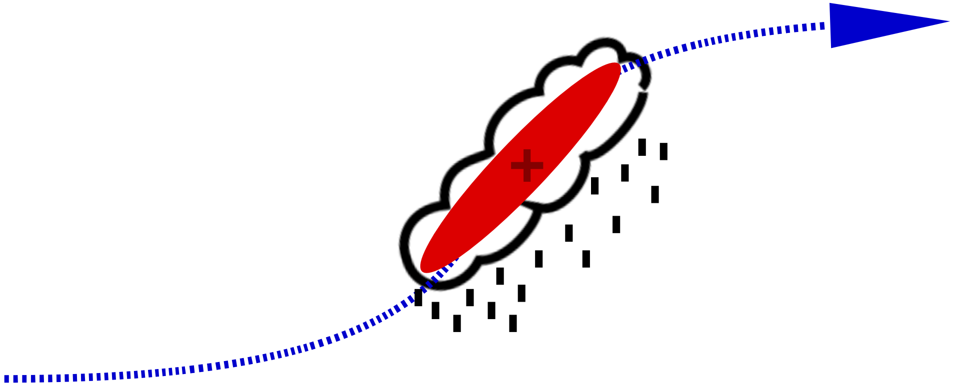


Oertel et al. 2019, QJRMS

- convective clouds
- cirrus clouds



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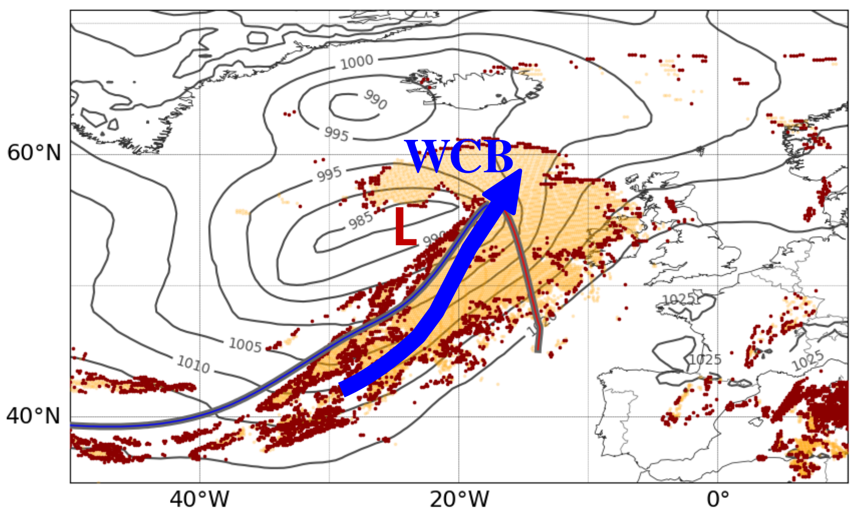

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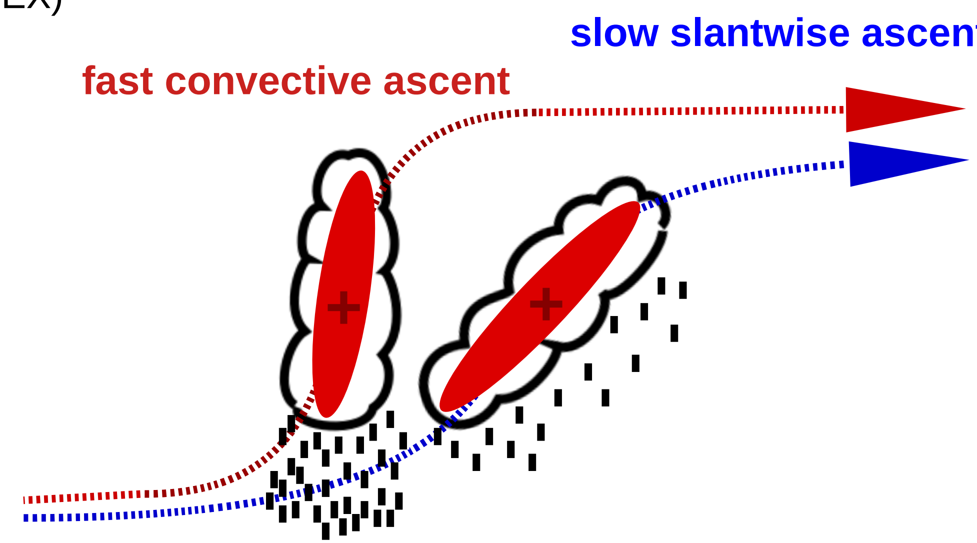

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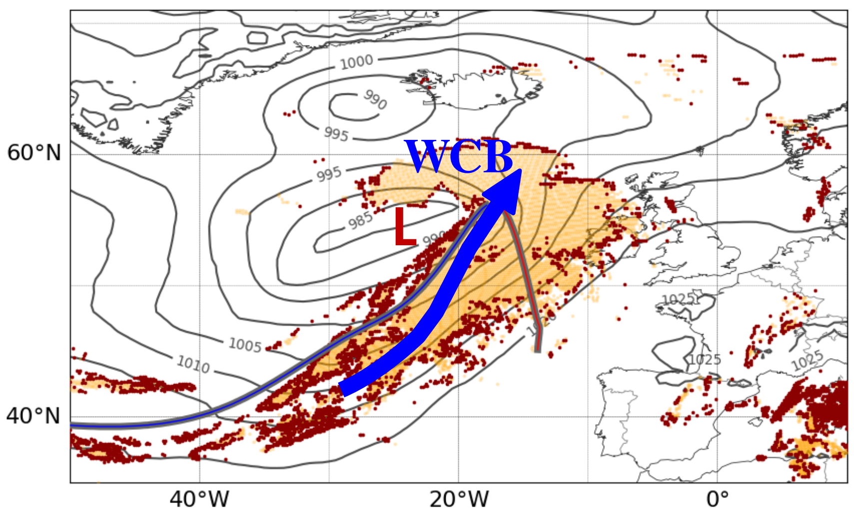

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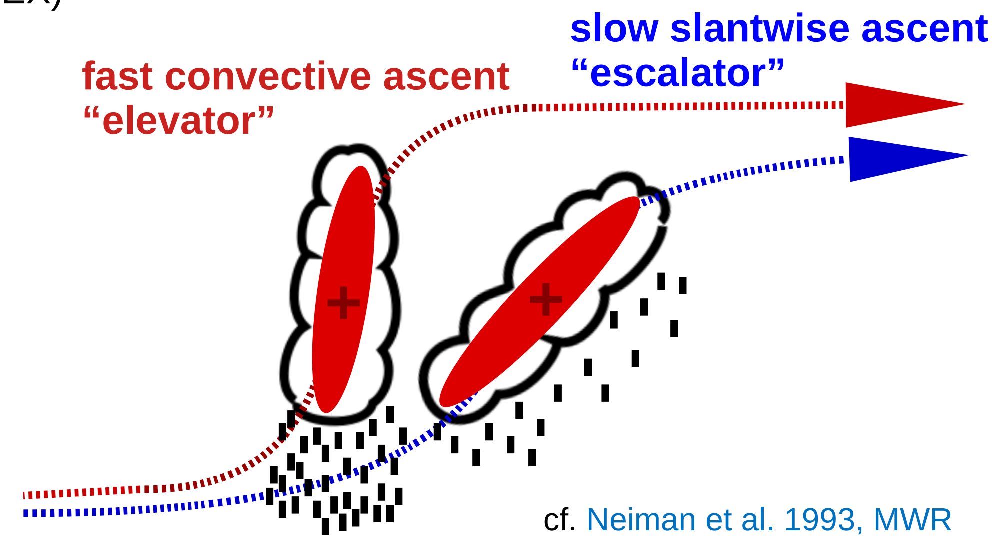

cf. Neiman et al. 1993, MWR
"escalator-elevator concept"

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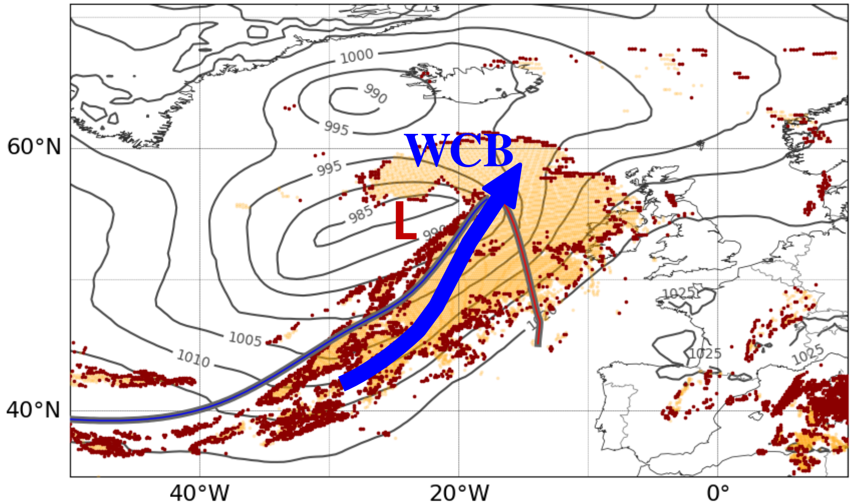

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- ● convective clouds
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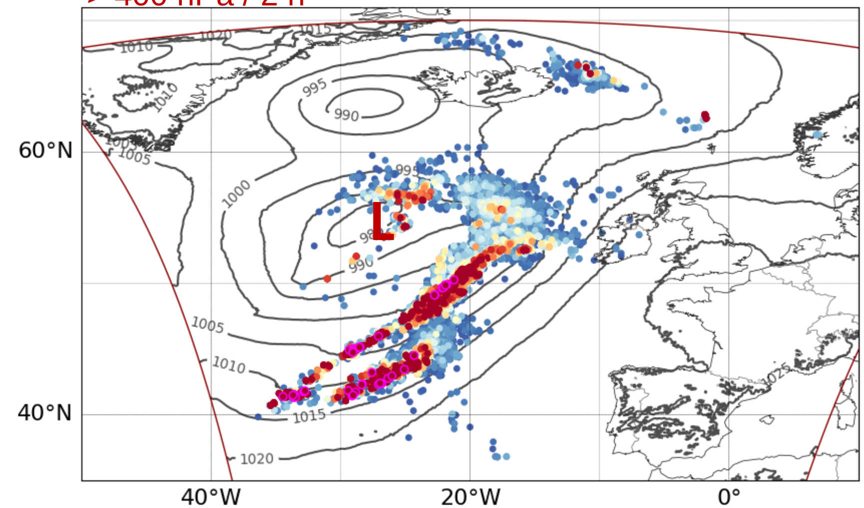
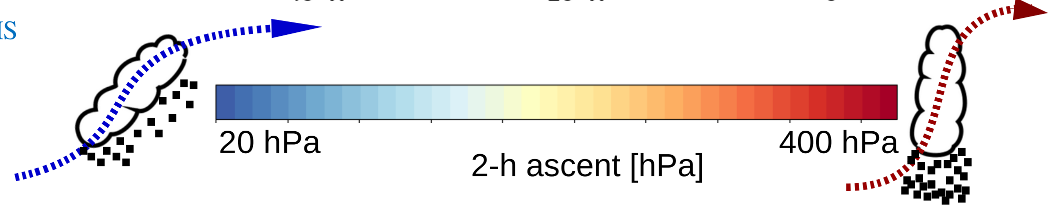
convective WCB ascent

> 400 hPa / 2 h





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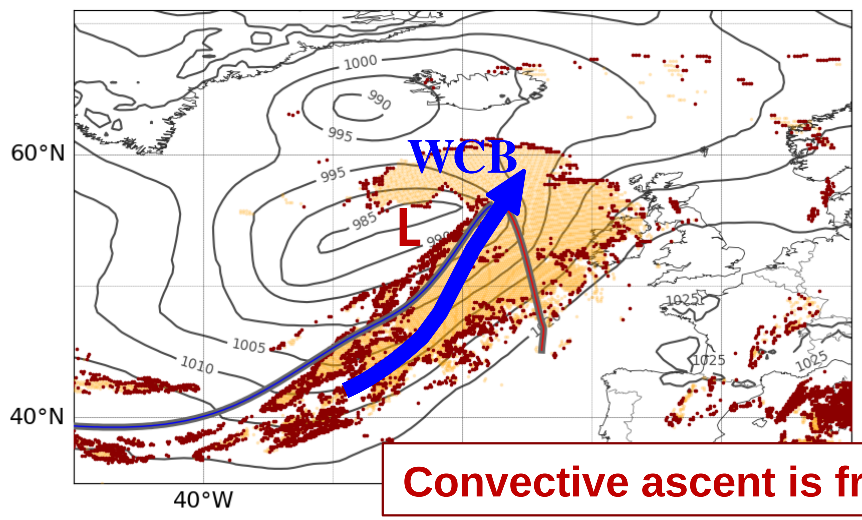

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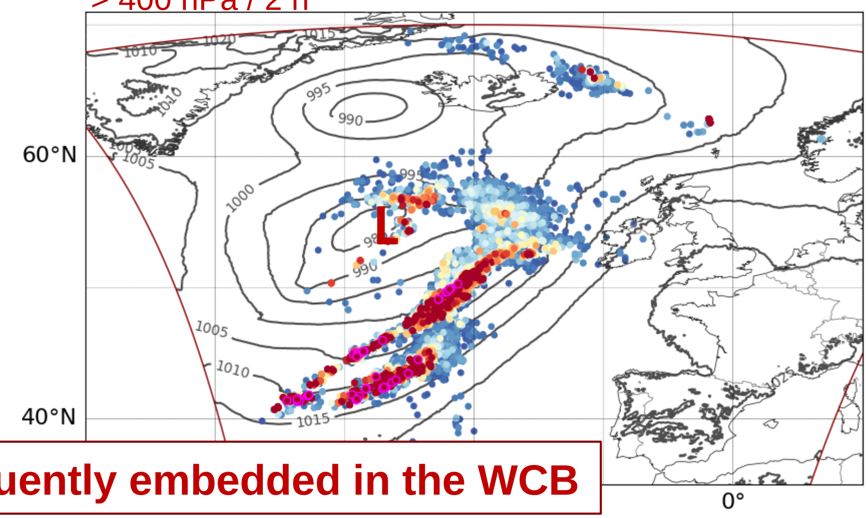

Convective ascent is frequently embedded in the WCB

Oertel et al. 2019, QJRMS

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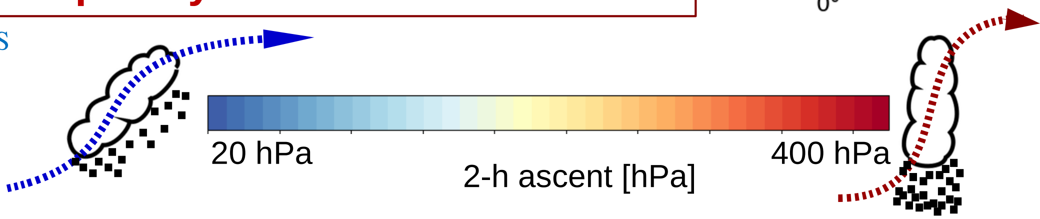


Potential vorticity (PV) framework

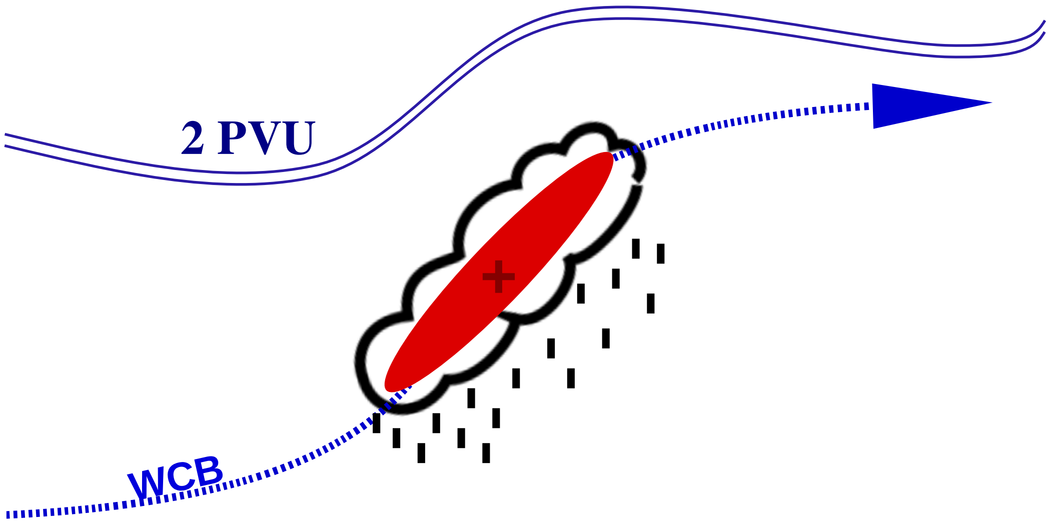
cloud diabatic processes

$$\frac{D}{Dt}PV = \frac{1}{\rho}\boldsymbol{\omega} \cdot \nabla\dot{\theta}$$

vorticity

$$PV = \frac{1}{\rho}\boldsymbol{\omega} \cdot \nabla\theta$$

potential temperature gradient



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vertical horizontal

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vorticity

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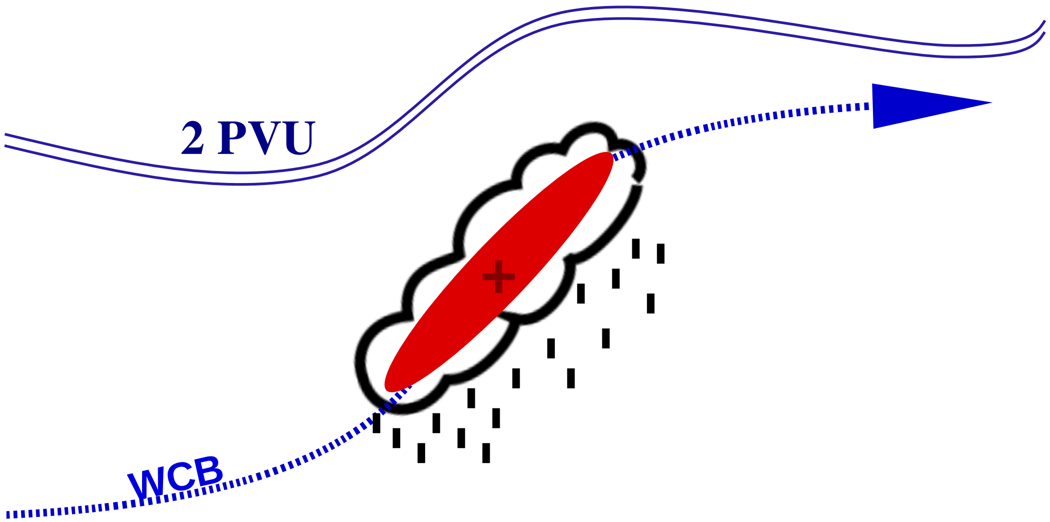

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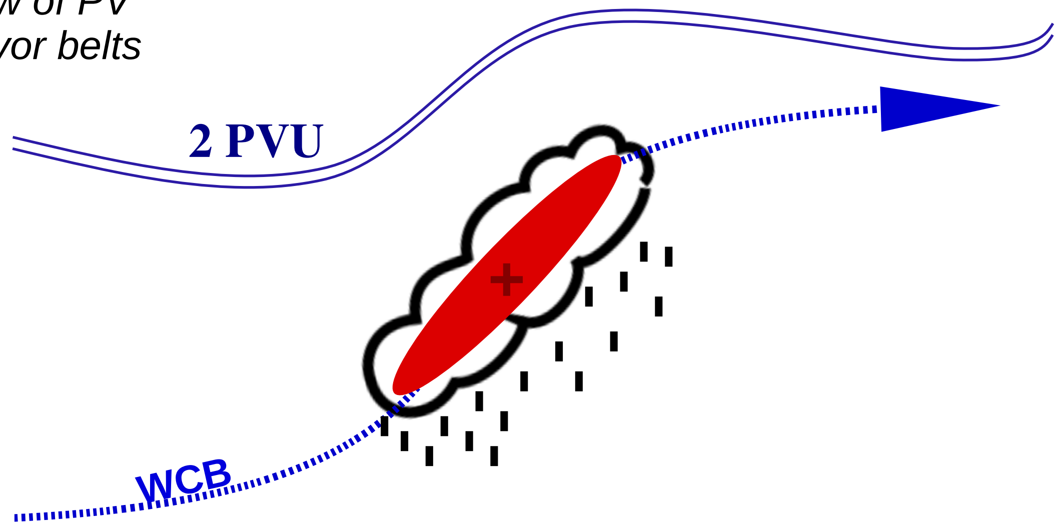
WCB ascent

e.g., Wernli and Davies 1997 QJRMS; Joos and Wernli 2012, QJRMS

cf. presentation by Ben Harvey

Revisiting the isentropic view of PV modification in warm conveyor belts



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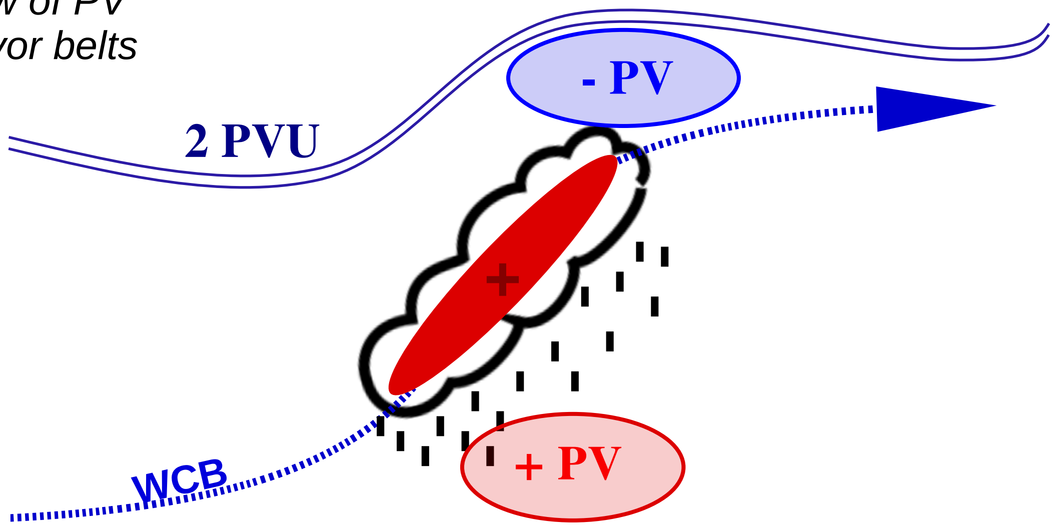

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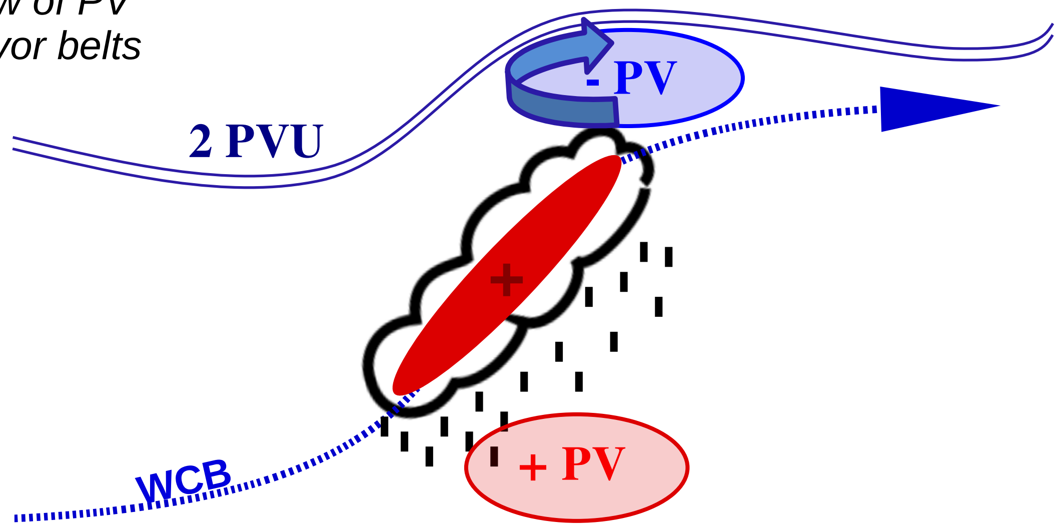
modification of the waveguide

Wernli and Davies 1997, QJRMS; Joos and Wernli 2012, QJRMS; Joos and Forbes 2016, QJRMS



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e.g., Chagnon and Gray 2009, QJRMS; Weijenborg et al. 2015 Tellus; Weijenborg et al. 2017, QJRMS; Harvey et al. 2020, QJRMS

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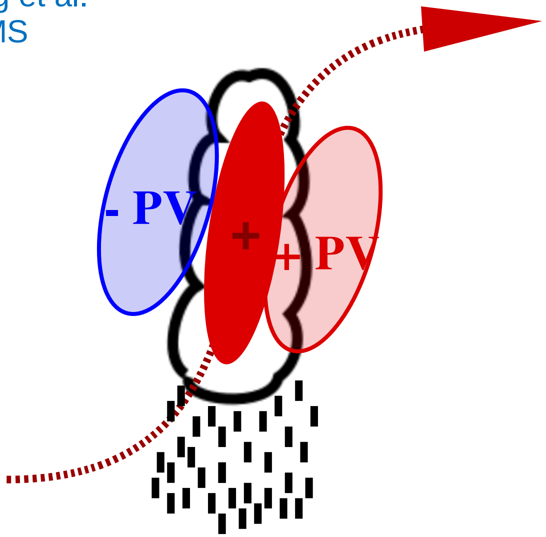

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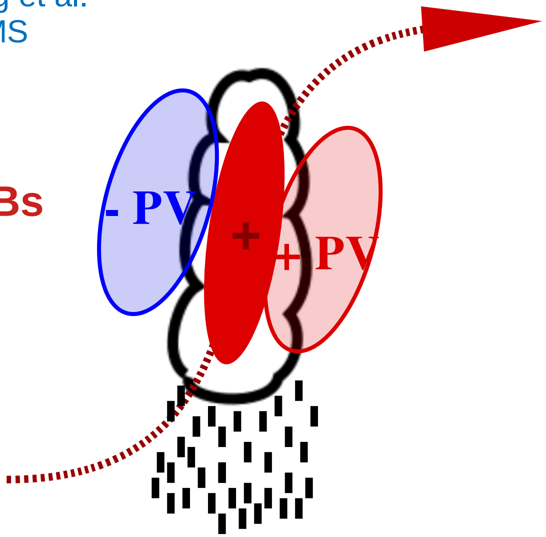

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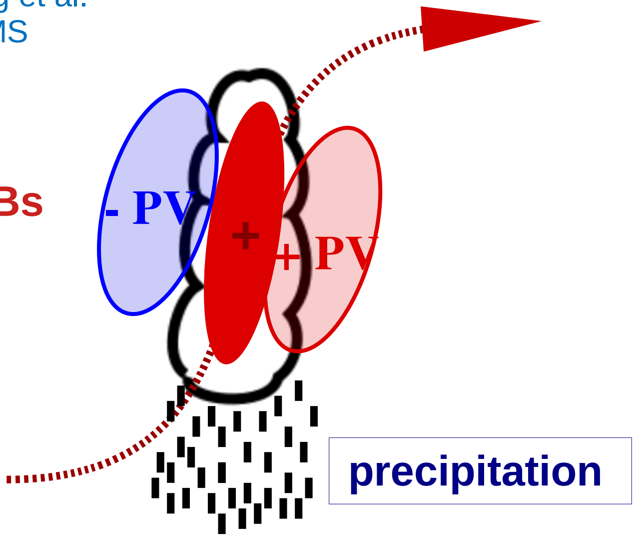

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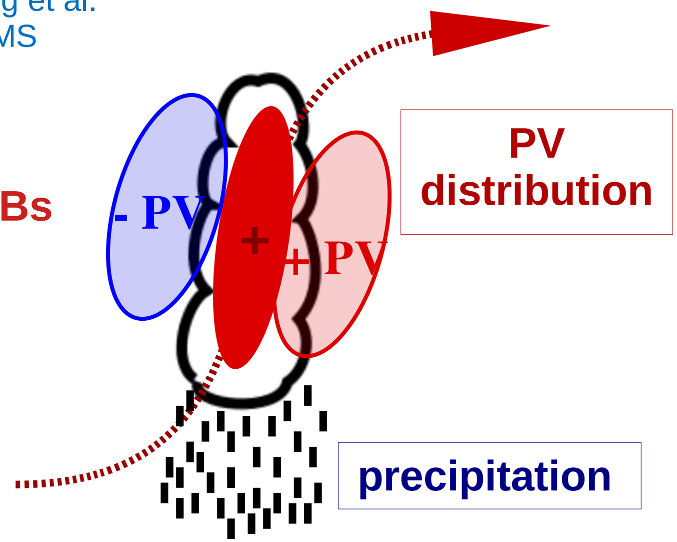

Key questions

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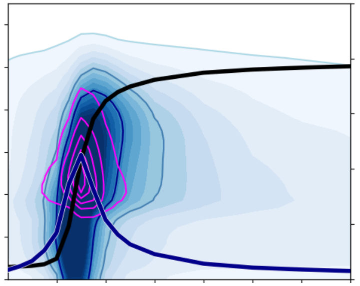

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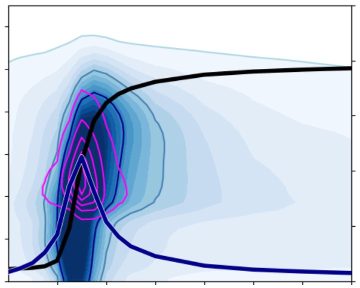
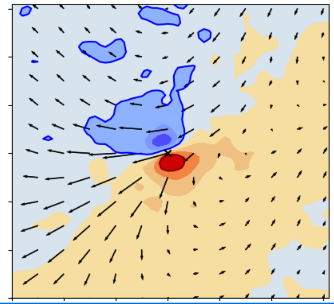


II. How does embedded convection modify the PV distribution?



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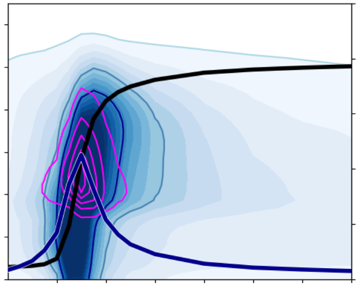

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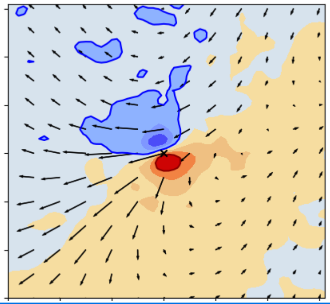
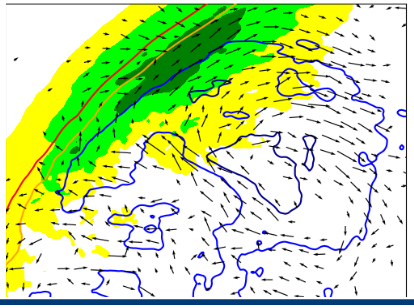


III. How does embedded convection influence the meso- and large-scale circulation?



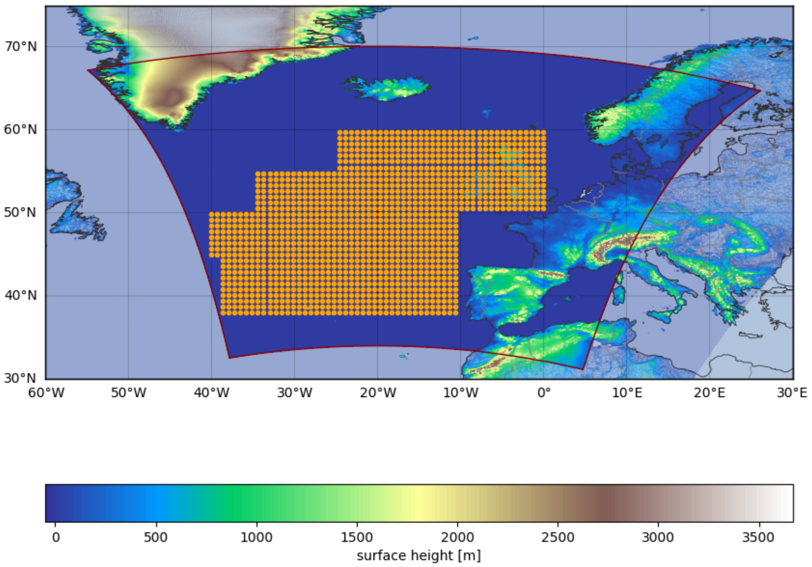
Methodology

Cyclone *Vladiana* (IOP 3 NAWDEX)

- **Convection-permitting simulation** with the non-hydrostatic model COSMO

Δlon = Δlat = 0.02° (~2 km)

limited-area model COSMO



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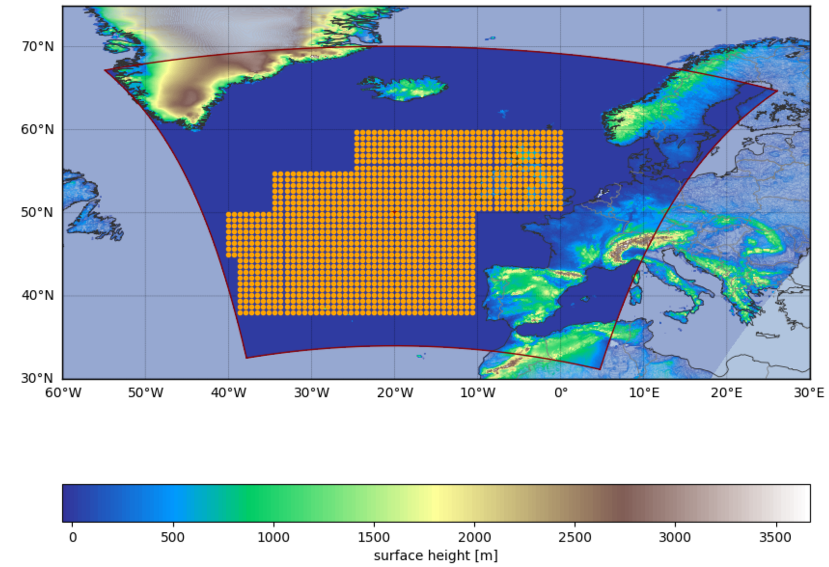

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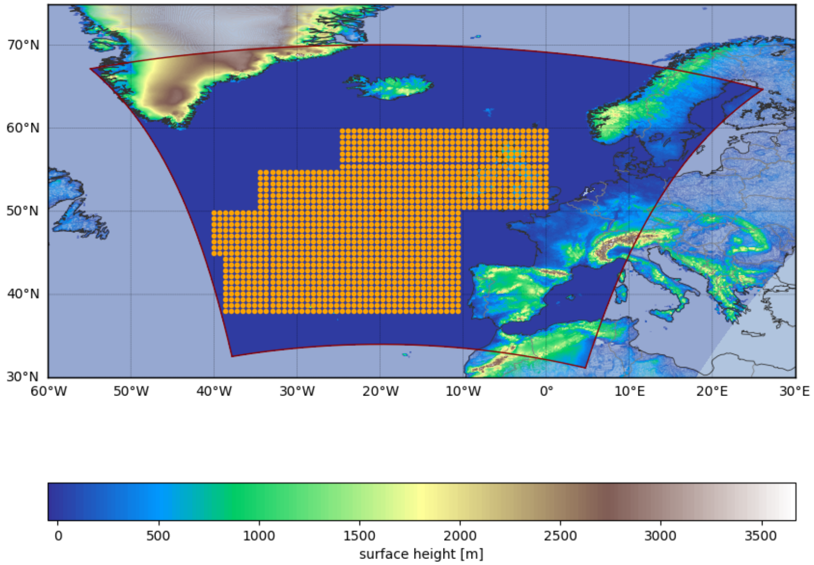

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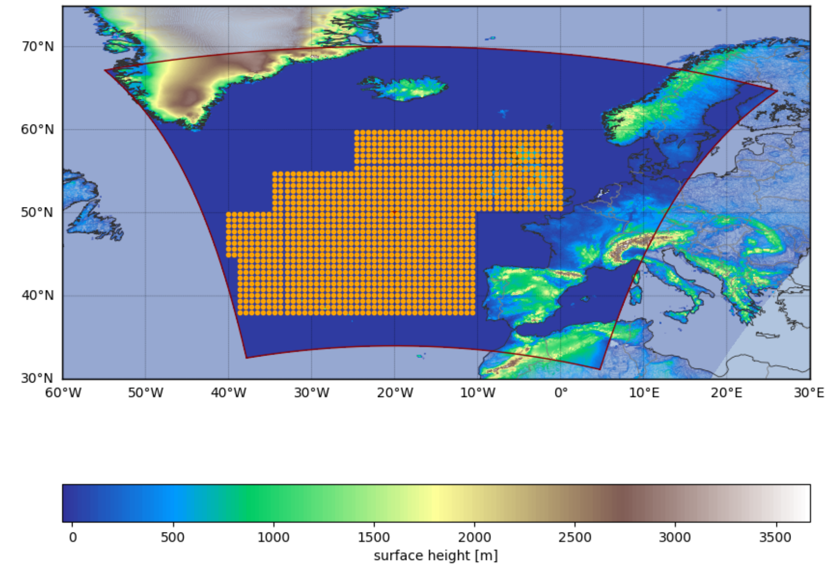

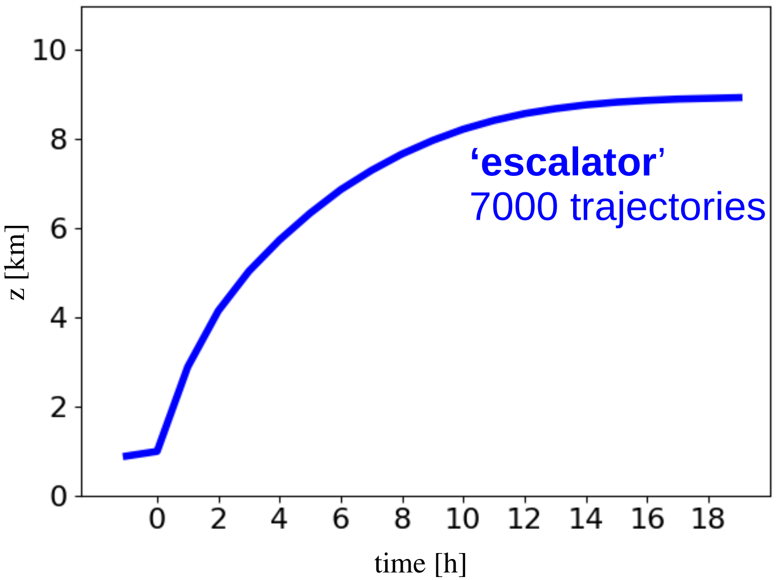

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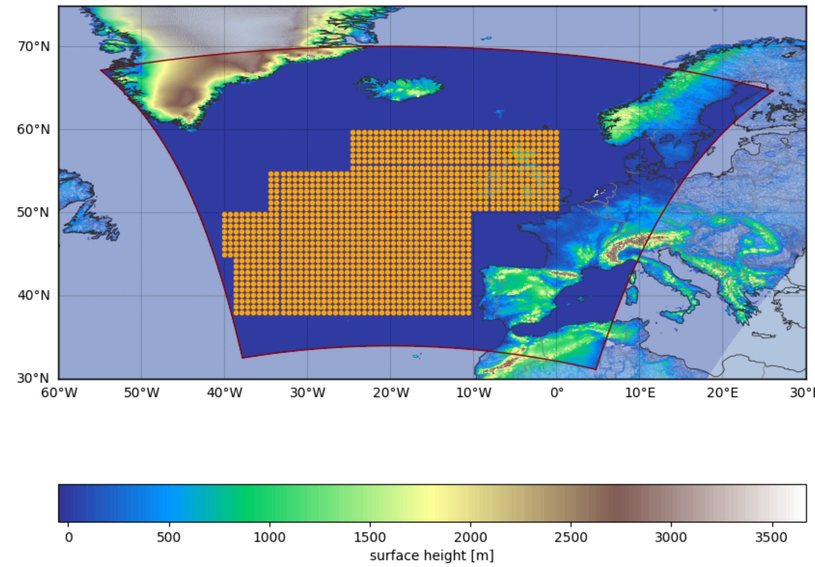
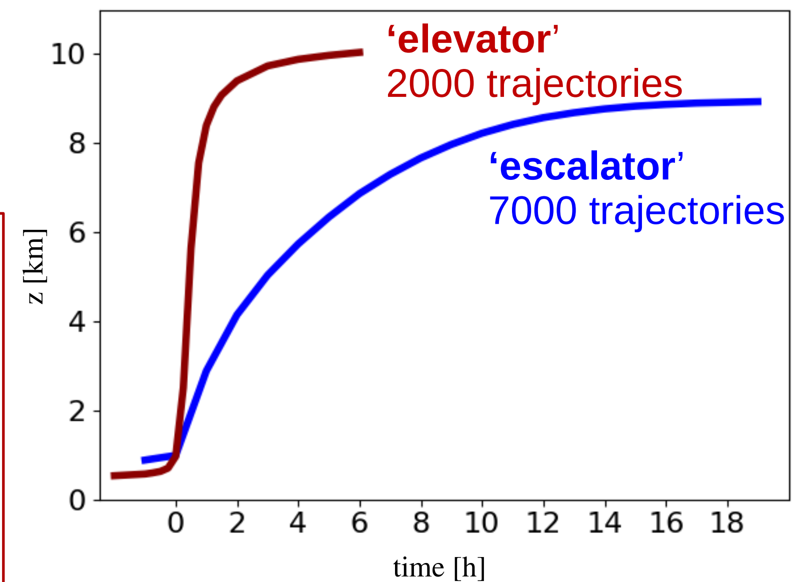
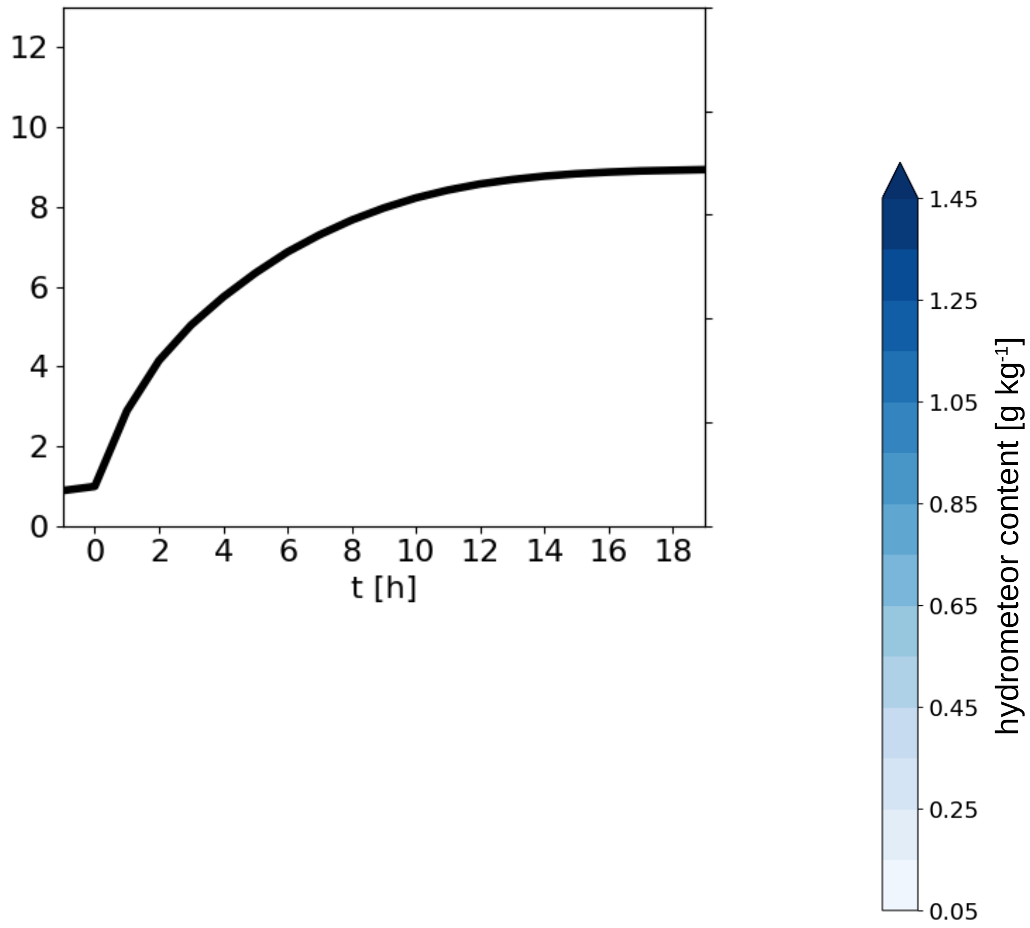




I. How does embedded convection influence the cloud structure?

Composite cloud structure



slantwise WCB
>> typical ascent

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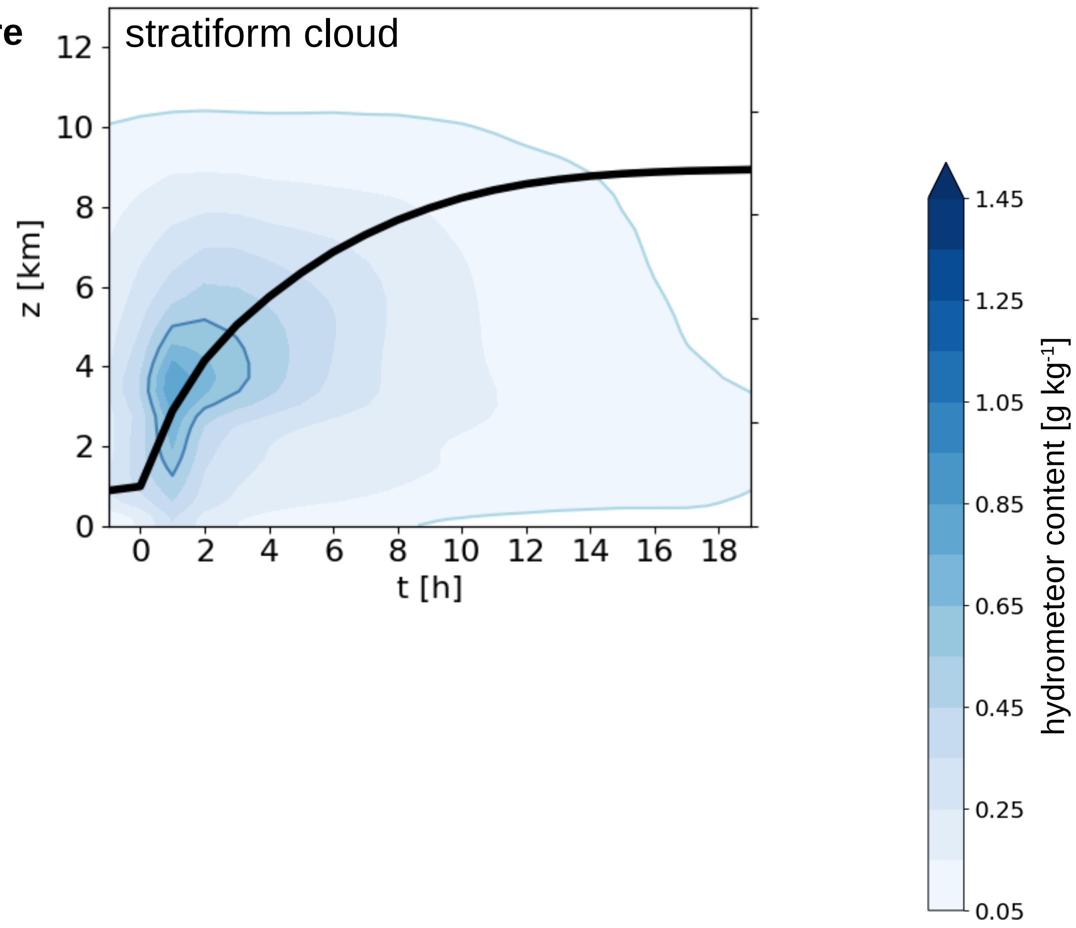

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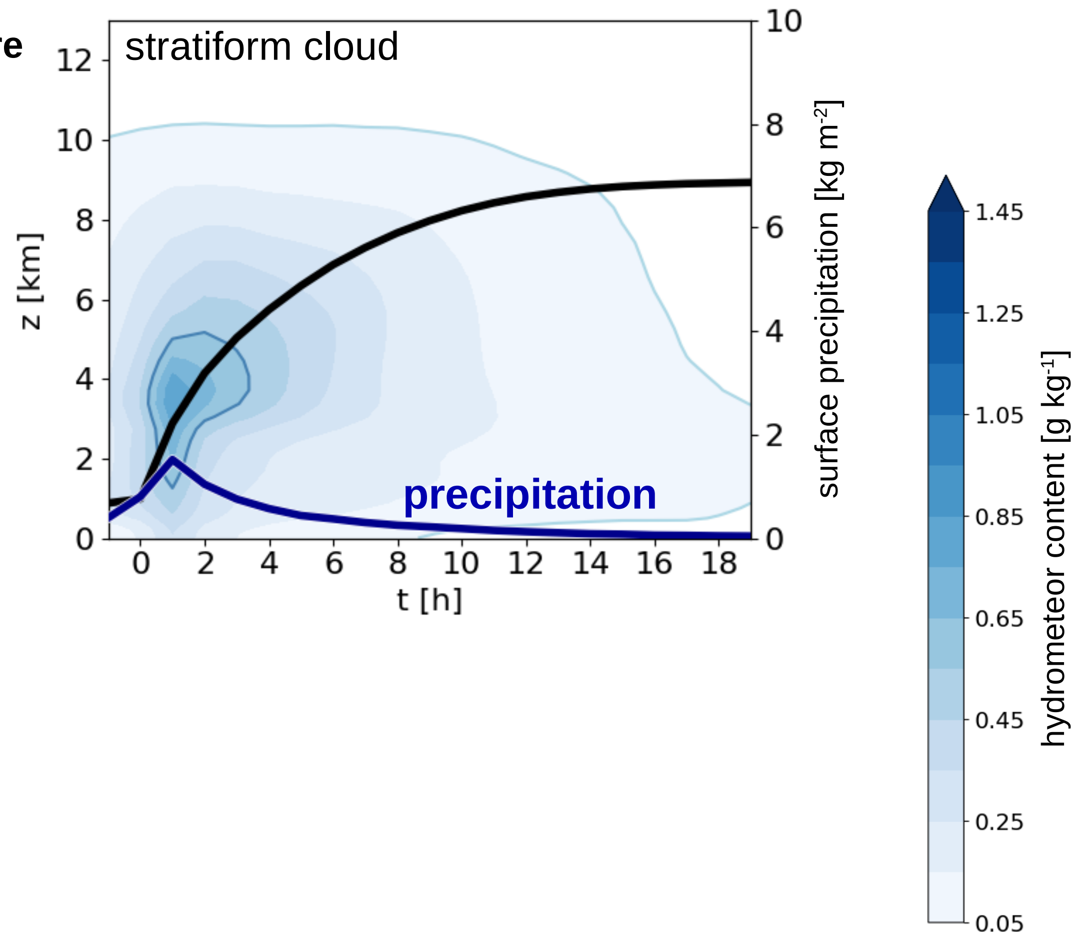

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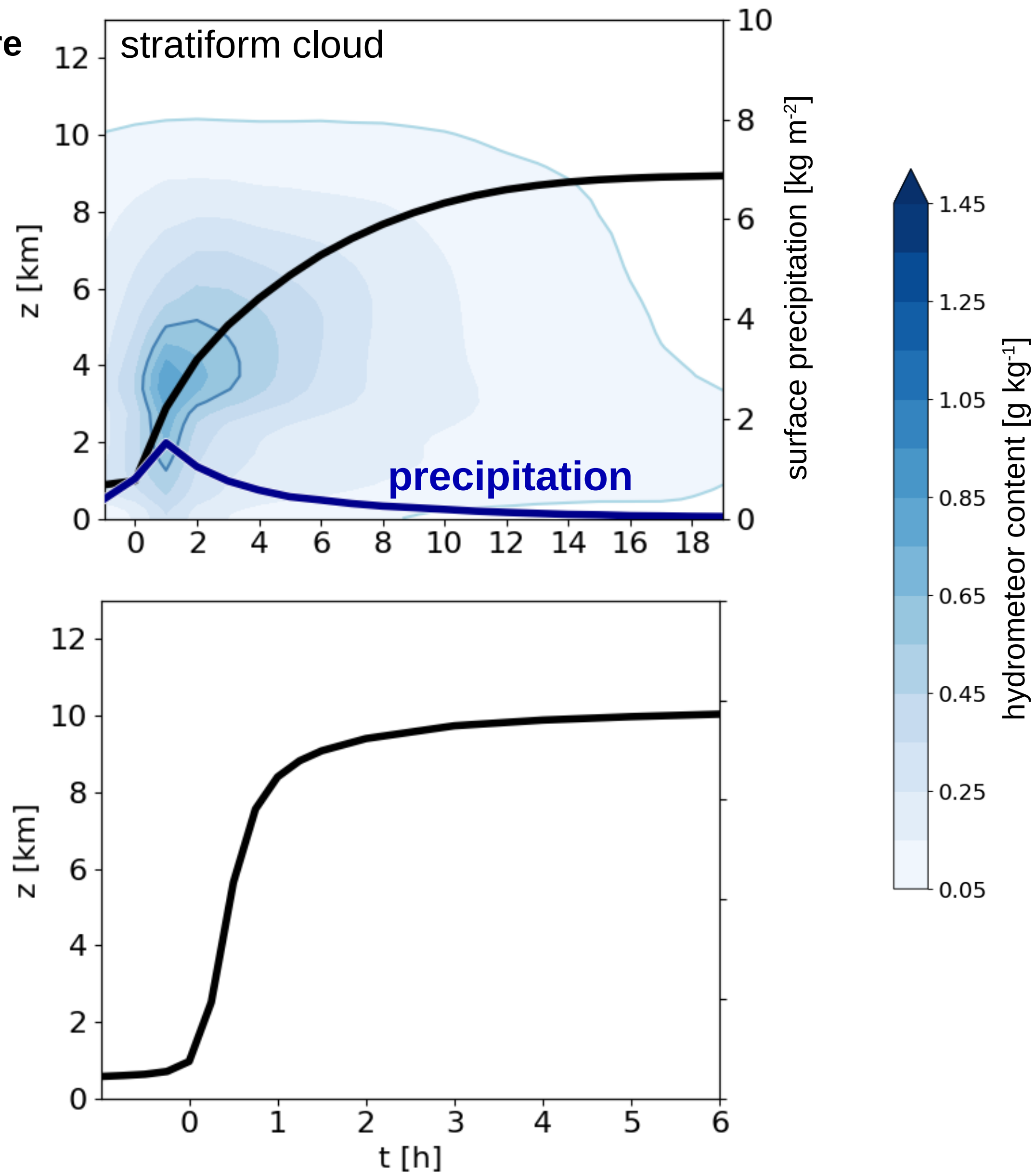

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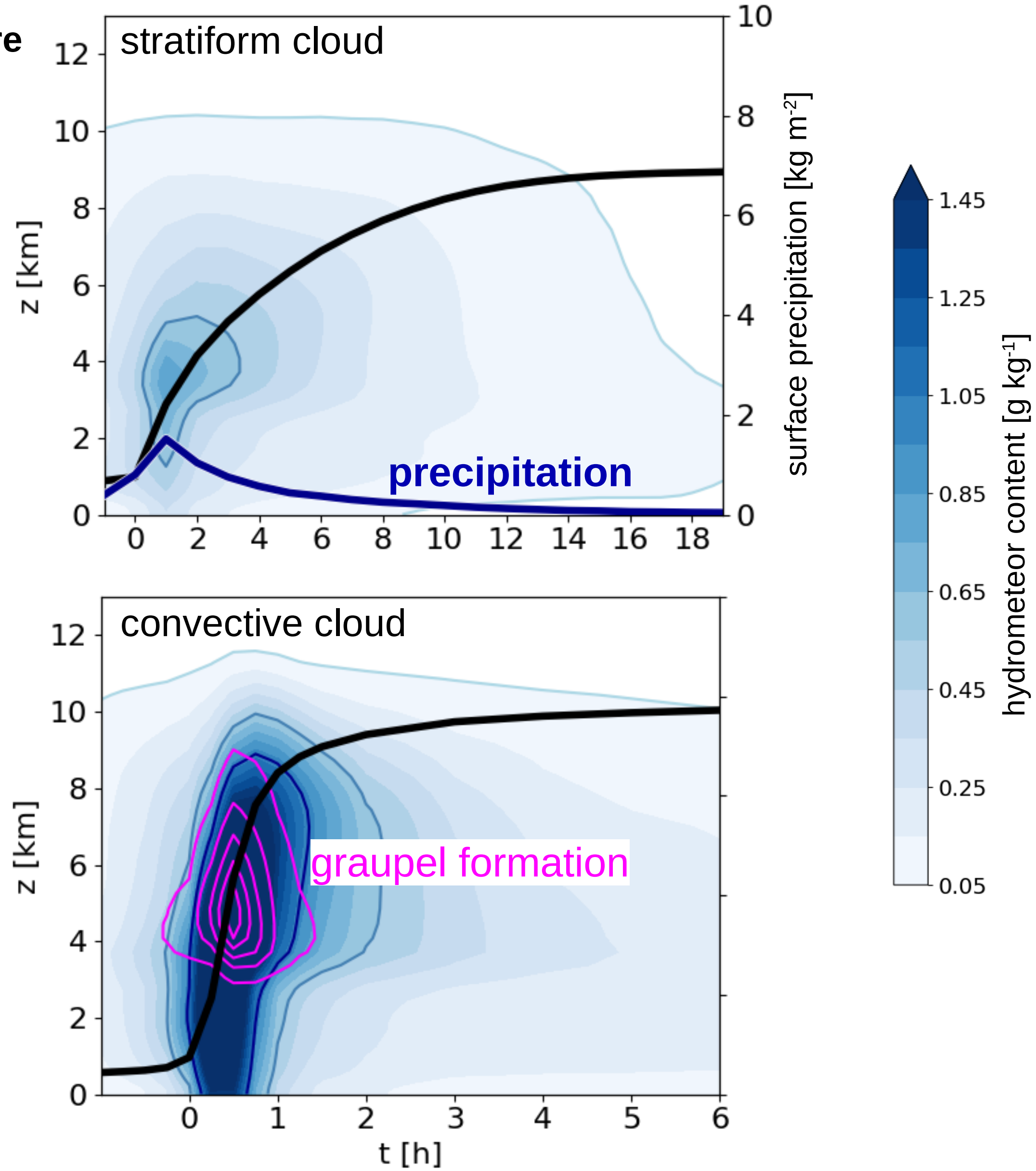
convective WCB

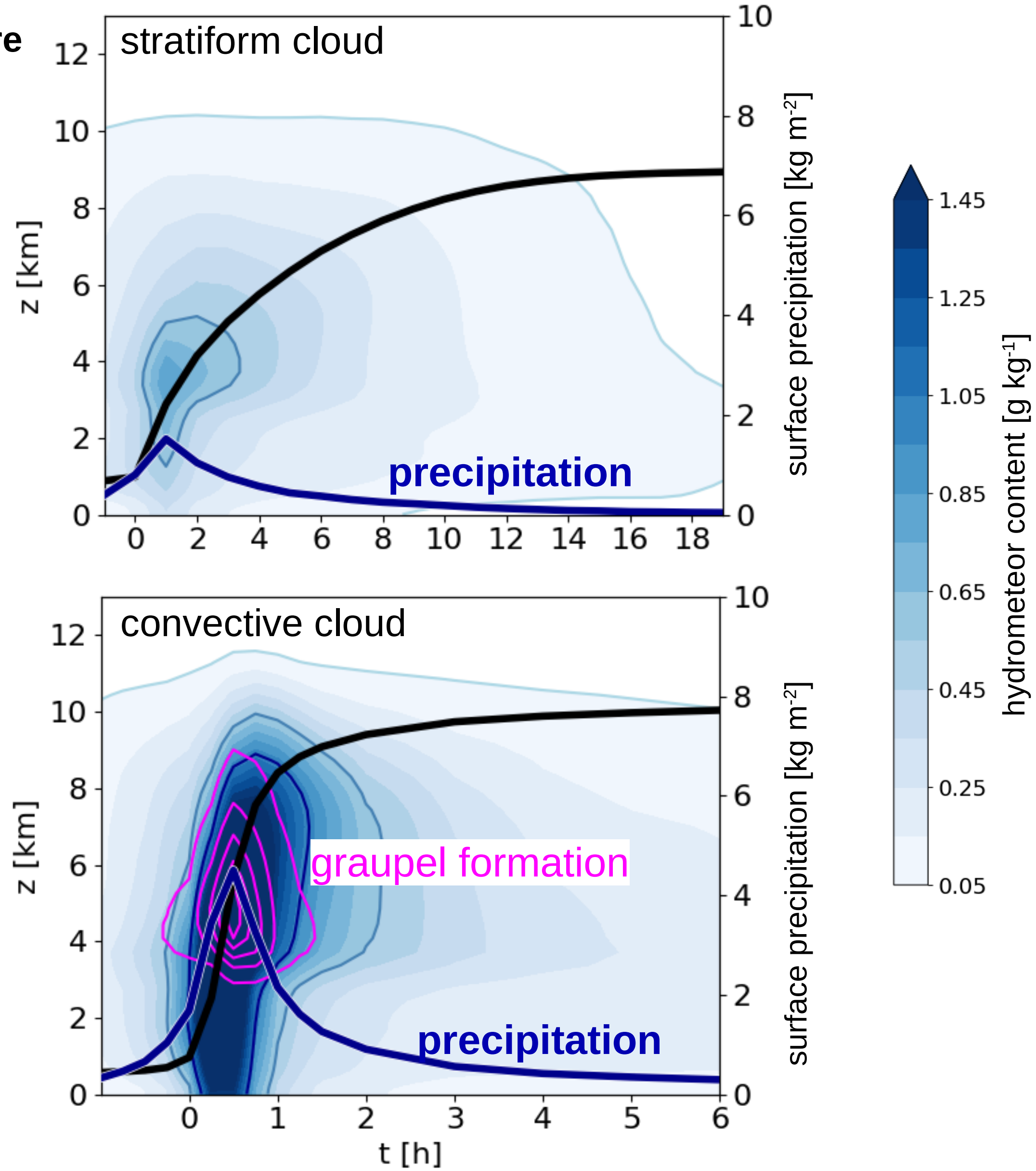


I. How does embedded convection influence the cloud structure?

Composite cloud structure

slantwise WCB
>> typical ascent

convective WCB

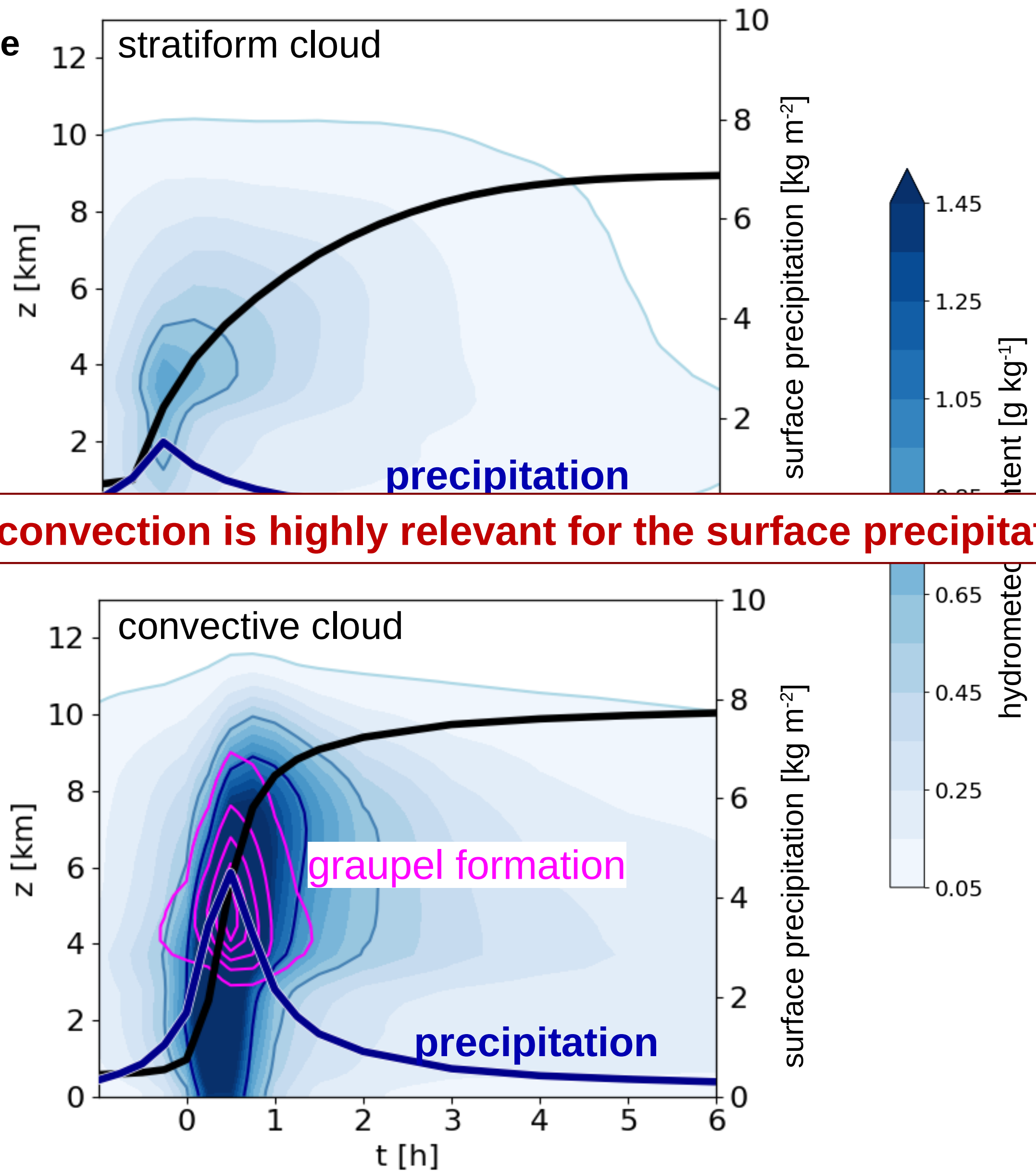


I. How does embedded convection influence the cloud structure?

Composite cloud structure

slantwise WCB
>> typical ascent

convective WCB

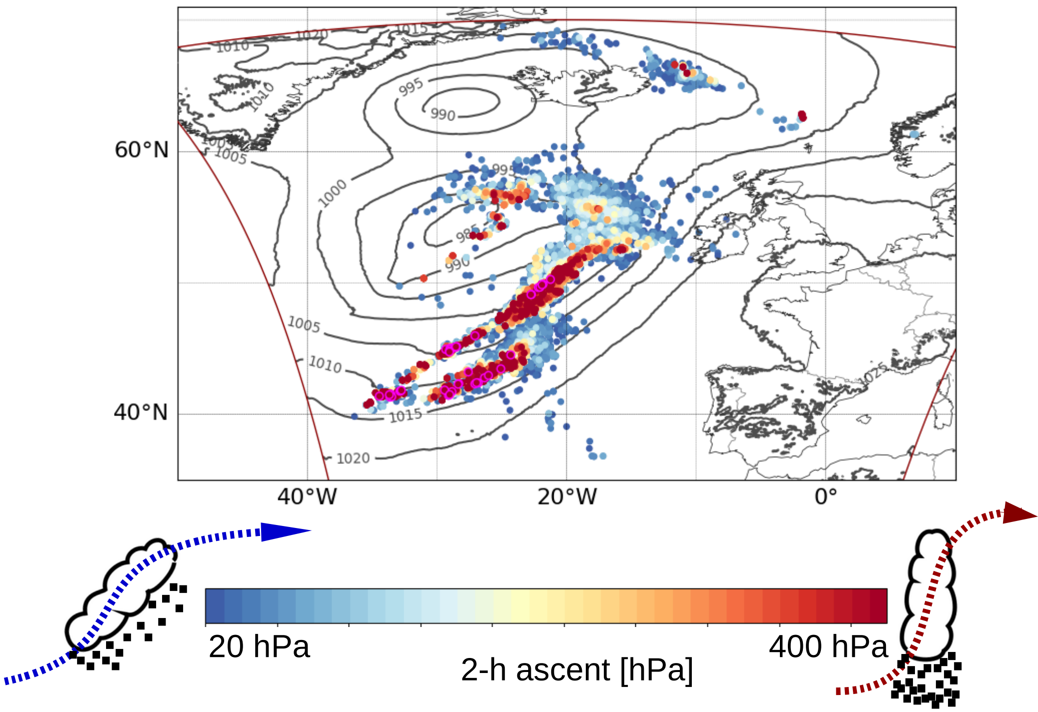


Embedded convection is highly relevant for the surface precipitation pattern

II. How does embedded convection influence the PV structure?

Online trajectories from
2 km COSMO simulation

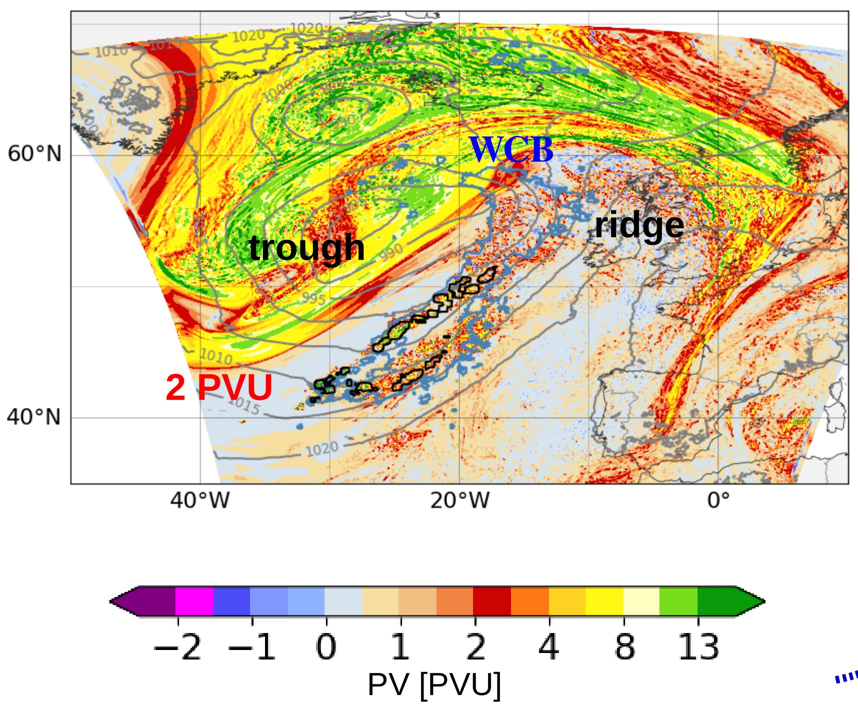
convective WCB ascent - ‘elevator’
> 400 hPa / 2 h



II. How does embedded convection influence the PV structure?

Online trajectories from
2 km COSMO simulation

PV@320K



convective WCB ascent - 'elevator'
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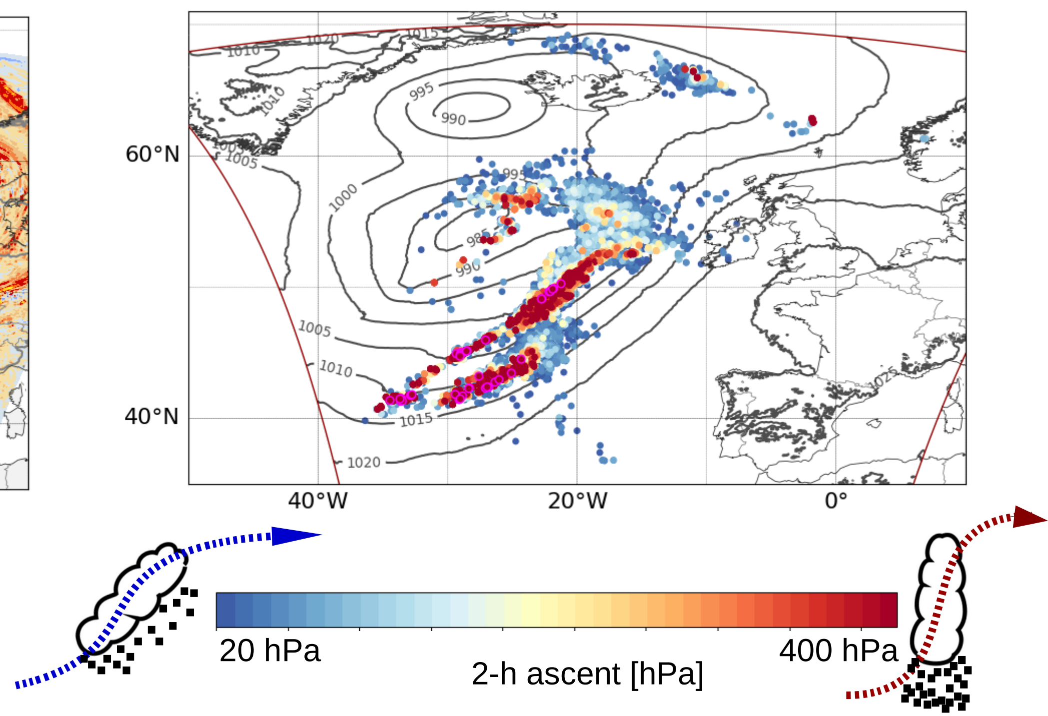
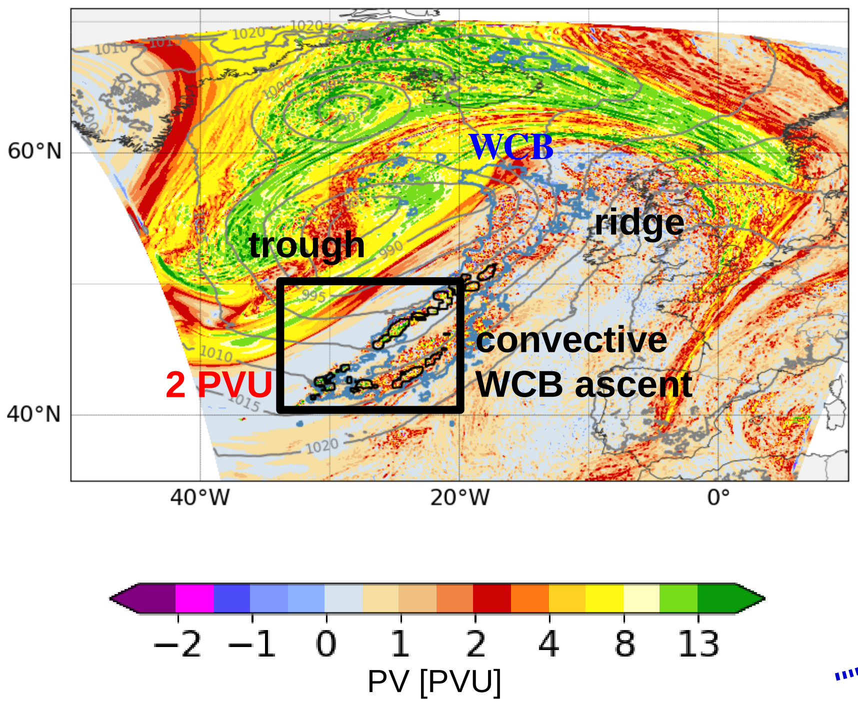


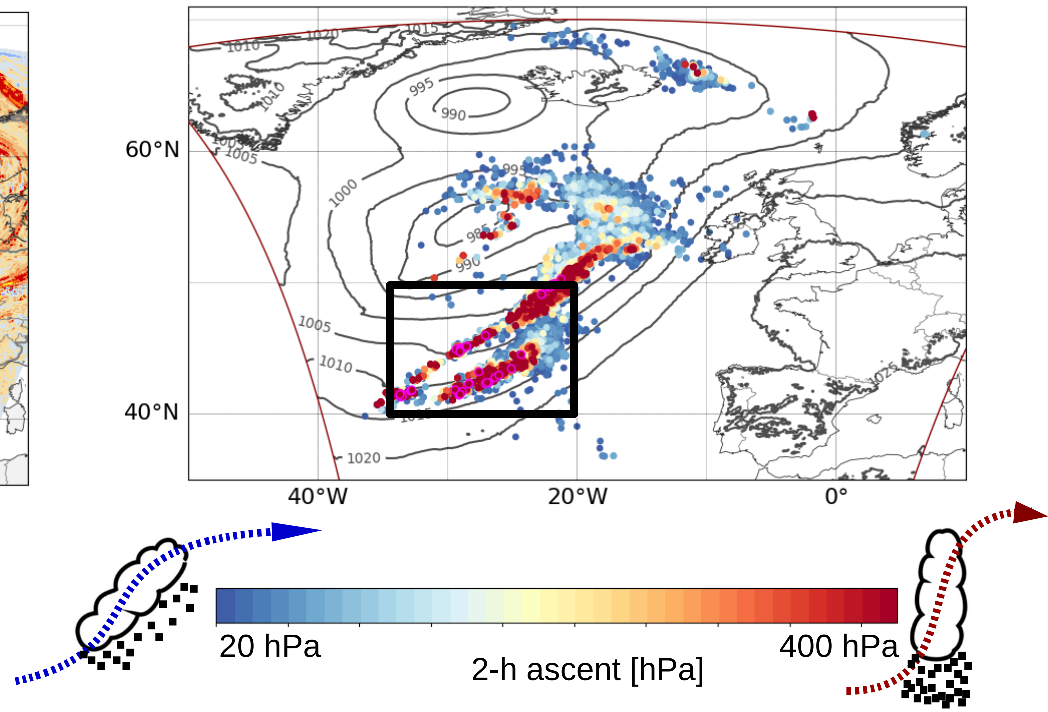
II. How does embedded convection influence the PV structure?

Online trajectories from
2 km COSMO simulation

PV@320K

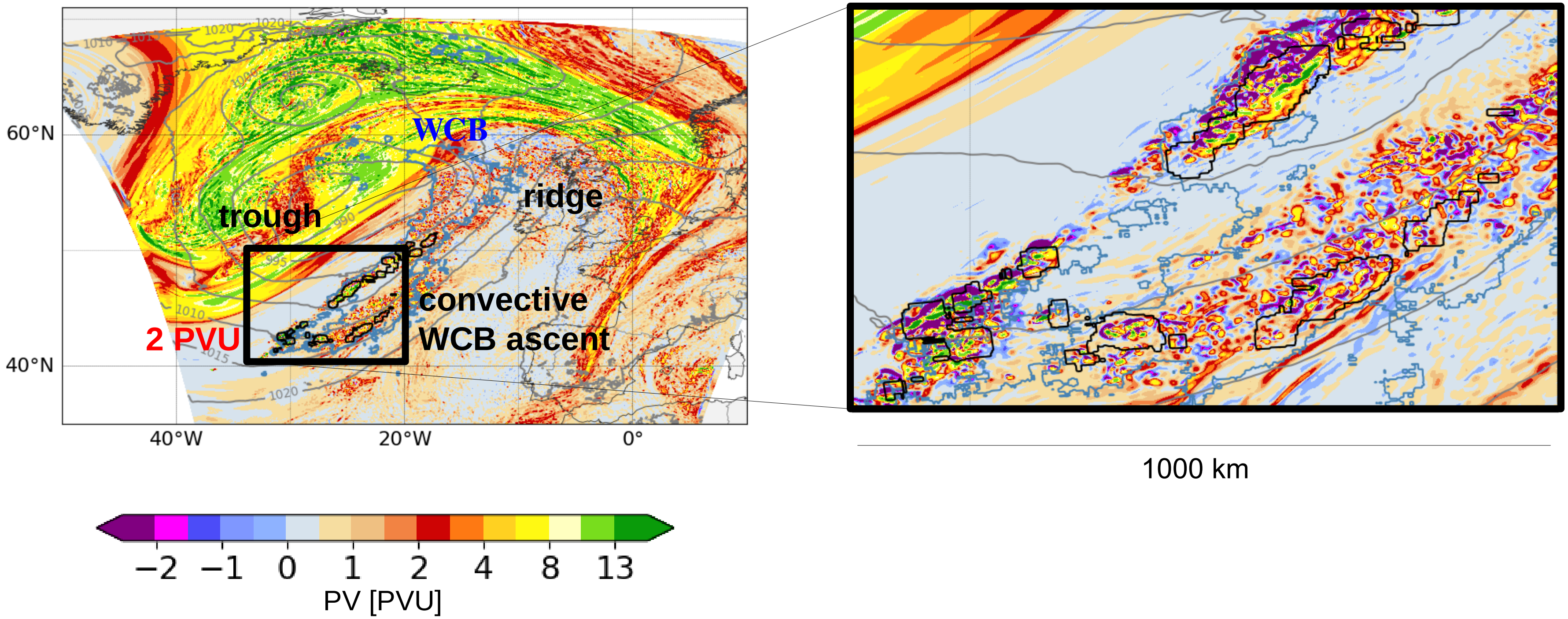


convective WCB ascent - 'elevator'
> 400 hPa / 2 h



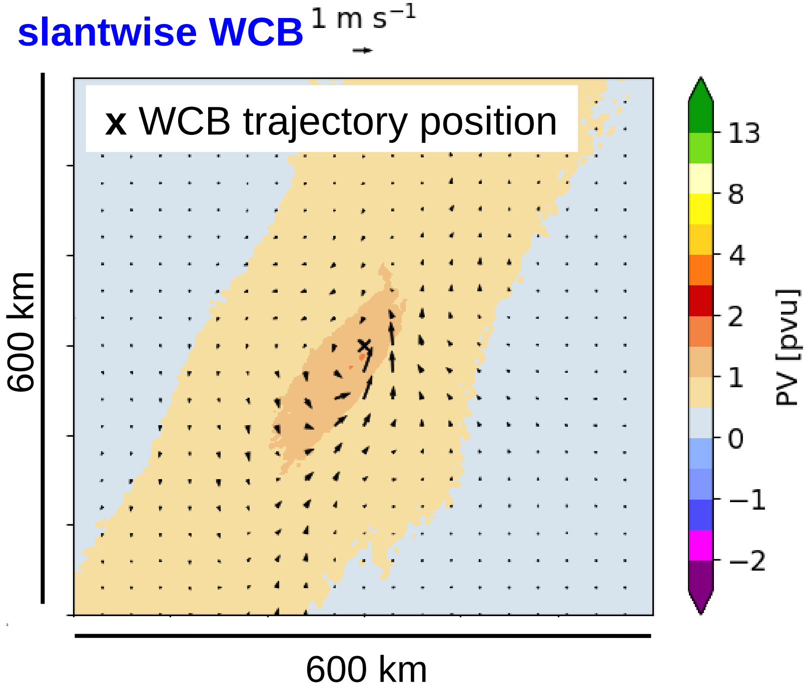
II. How does embedded convection influence the PV structure?

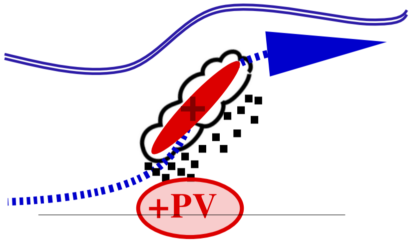
PV@320K



Composite low-level PV structure (at 800 m)

slantwise WCB

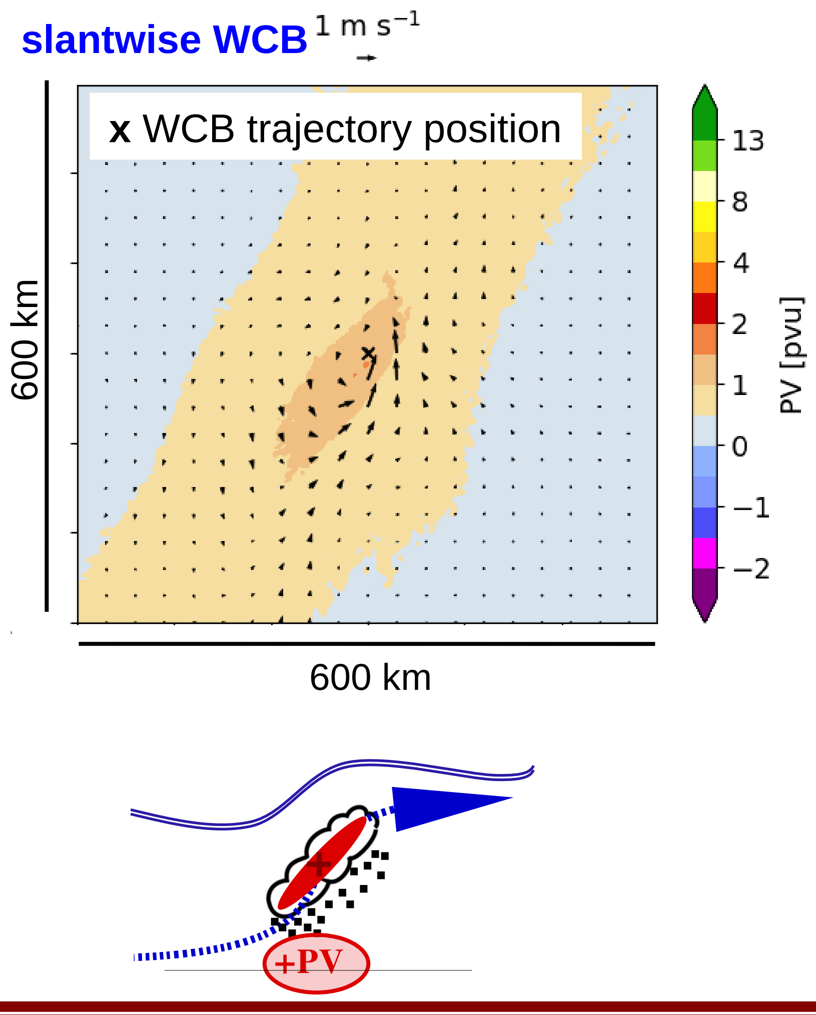




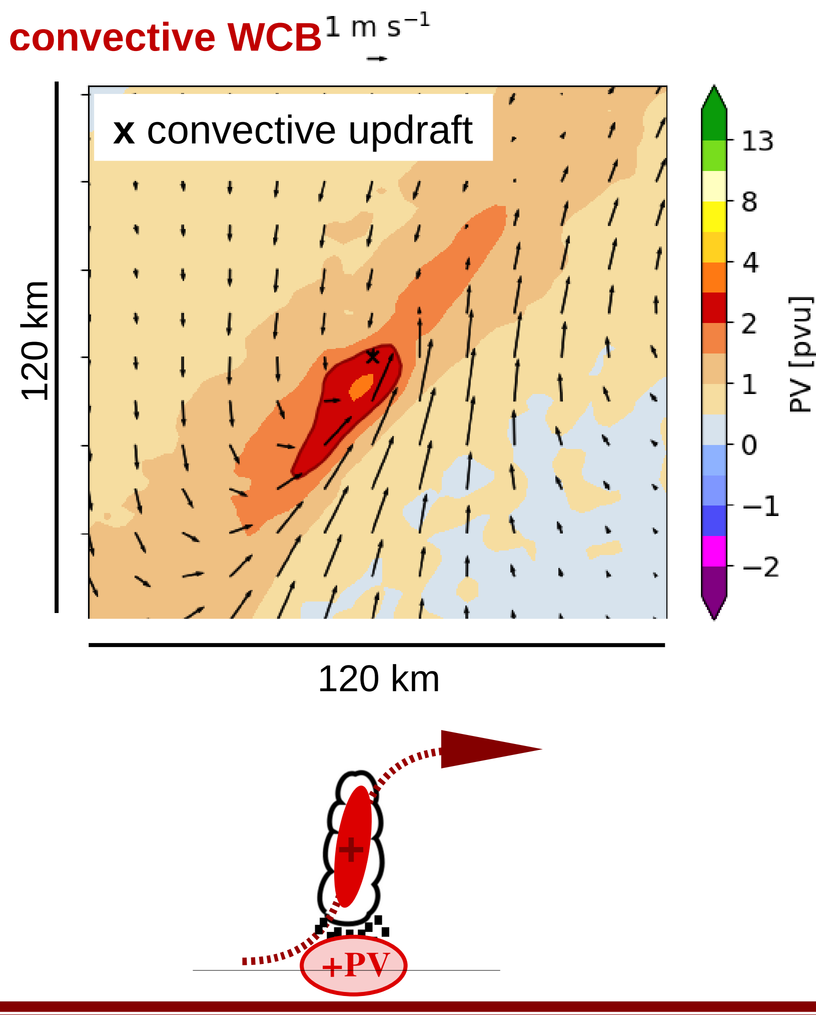
II. How does embedded convection influence the PV structure?

Composite low-level PV structure
(at 800 m)

slantwise WCB



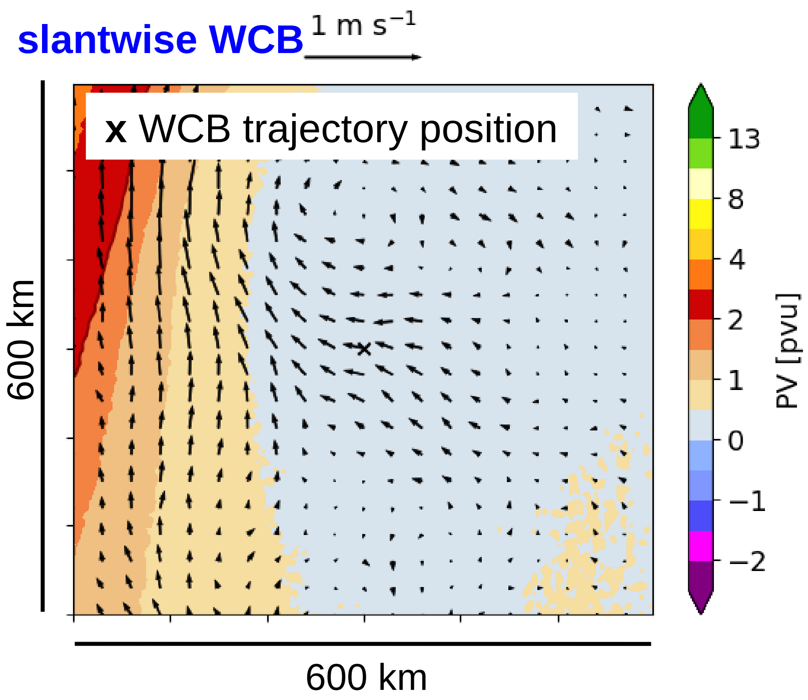
convective WCB

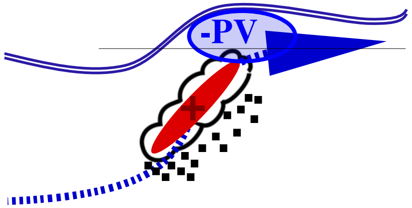


II. How does embedded convection influence the PV structure?

Composite upper-level PV structure (at 320 K)

slantwise WCB

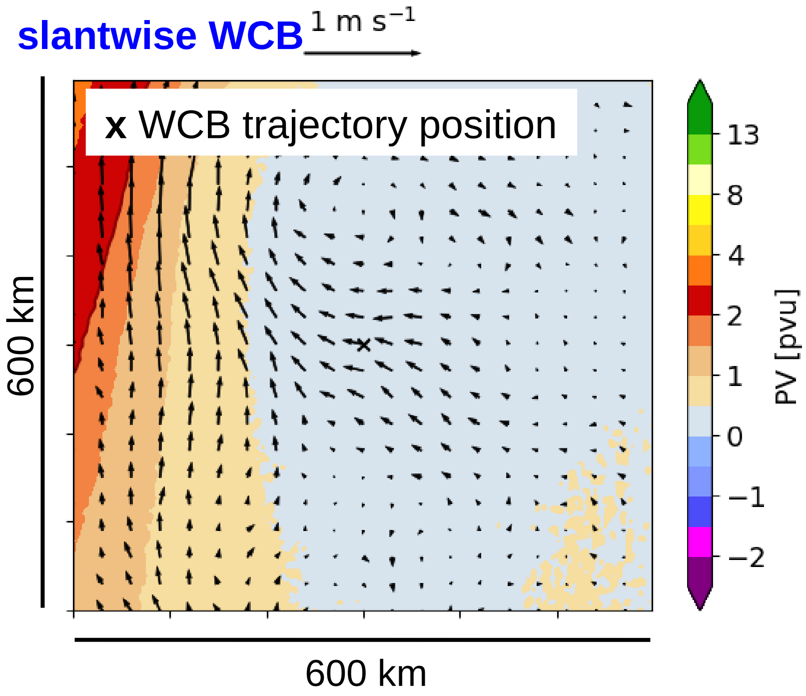


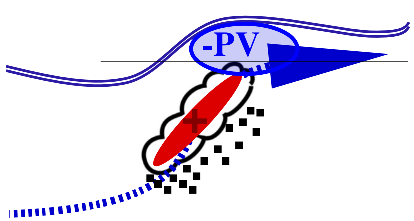


II. How does embedded convection influence the PV structure?

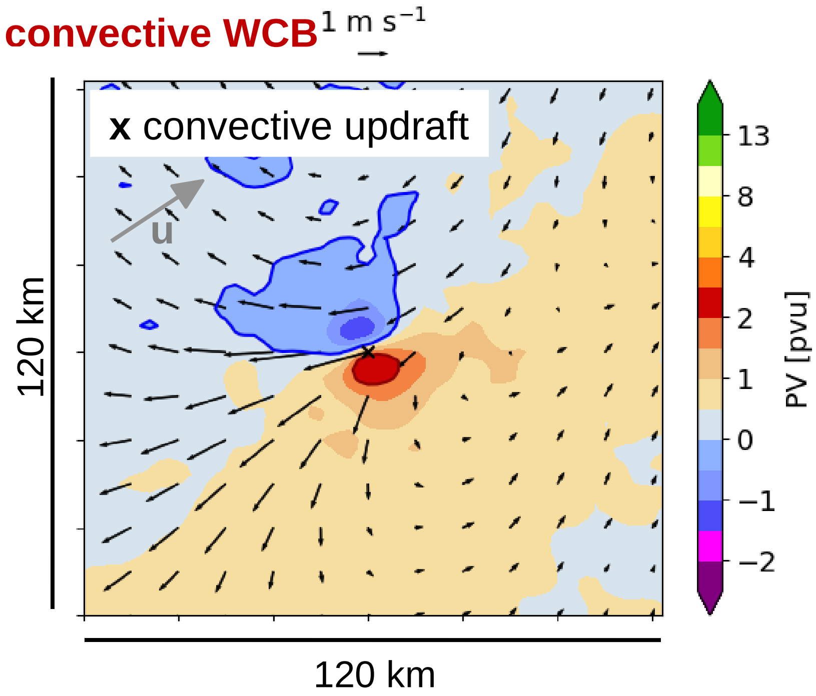
Composite upper-level PV structure
(at 320 K)

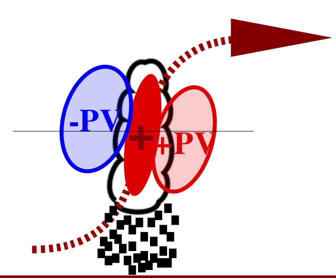
slantwise WCB





convective WCB

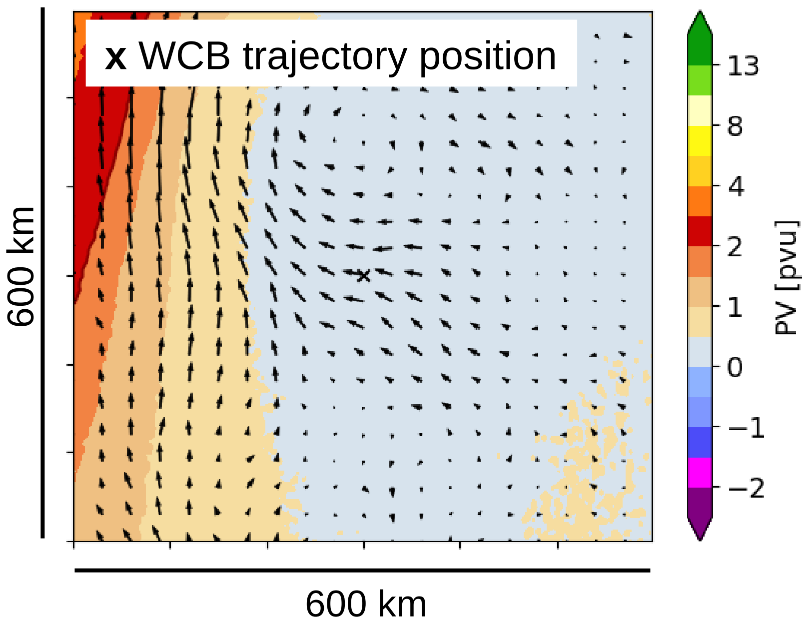




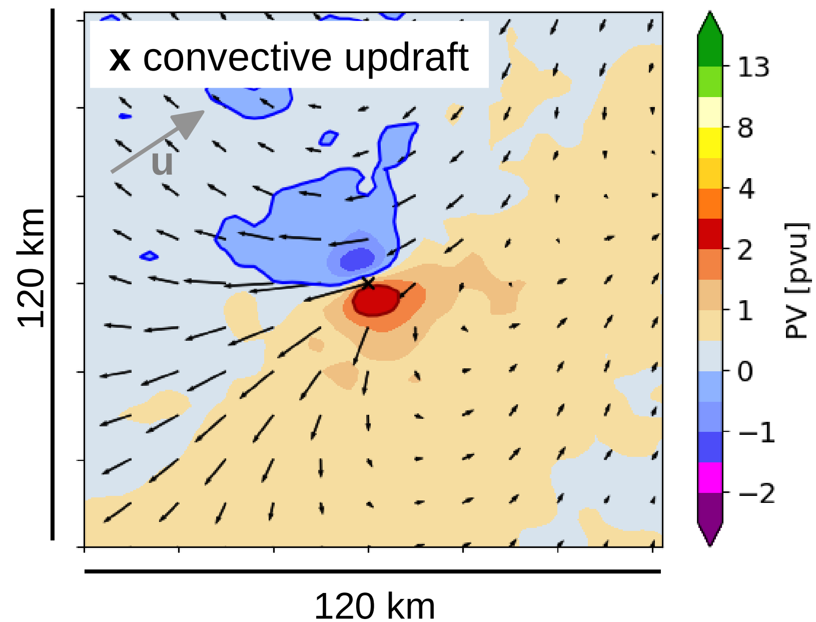
II. How does embedded convection influence the PV structure?

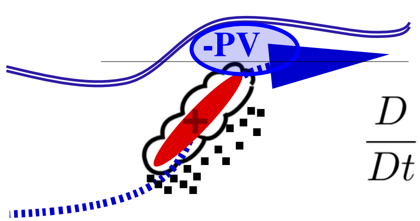
Composite upper-level PV structure
(at 320 K)

slantwise WCB

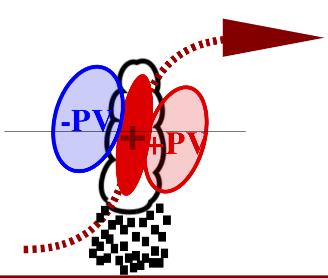


convective WCB





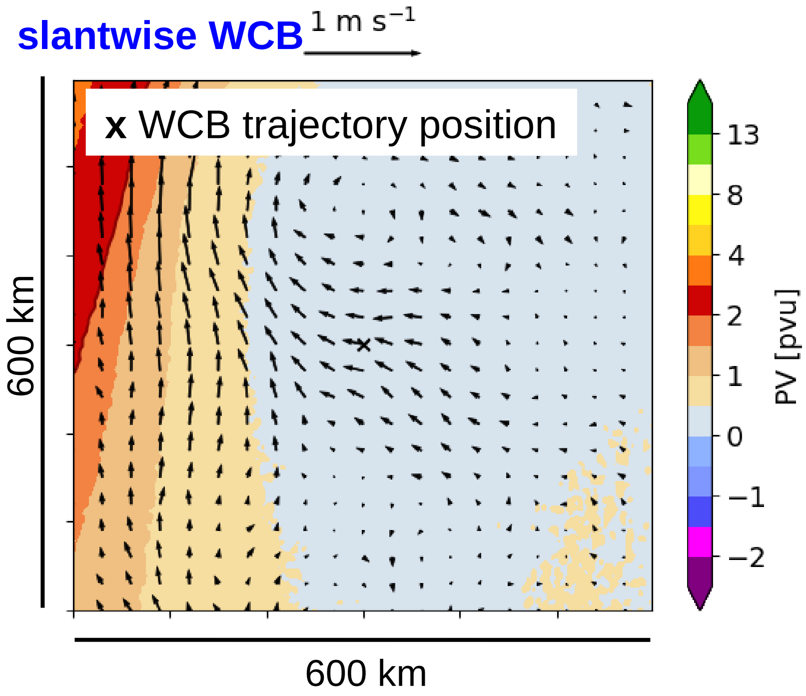
$$\frac{D}{Dt}PV = \frac{1}{\rho}\left[(f+\zeta)\frac{\partial\dot{\theta}}{\partial z} + \boxed{\boldsymbol{\omega}_h \cdot \nabla_h \dot{\theta}}\right]$$



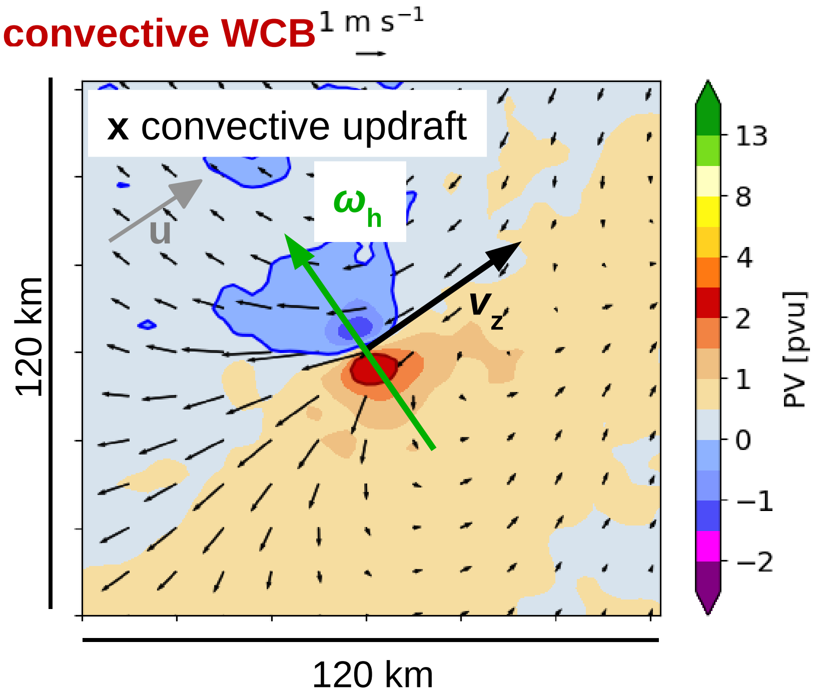
II. How does embedded convection influence the PV structure?

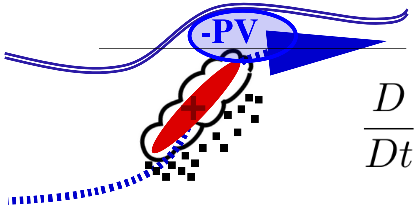
Composite upper-level PV structure
(at 320 K)

slantwise WCB



convective WCB





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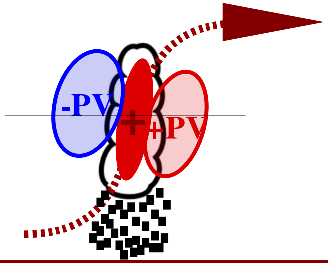
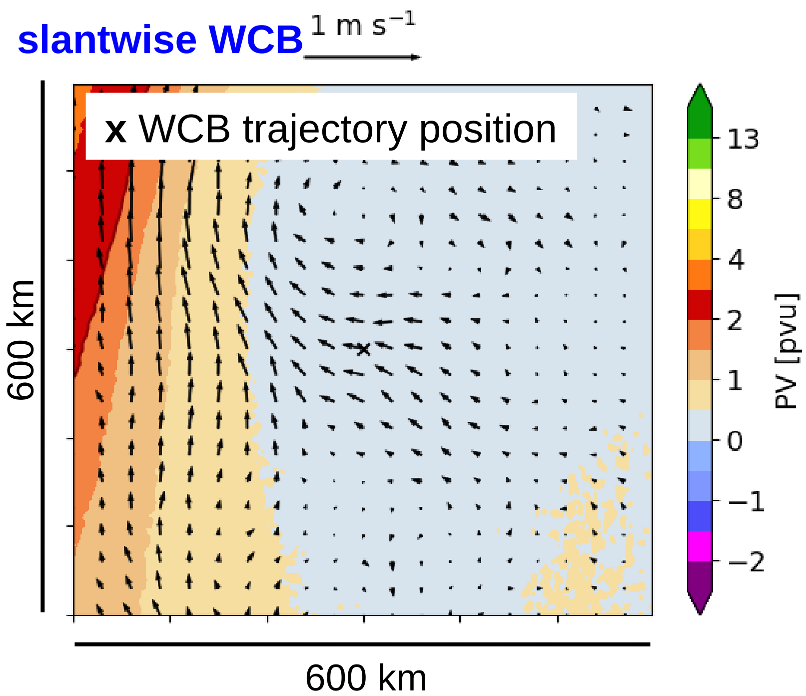
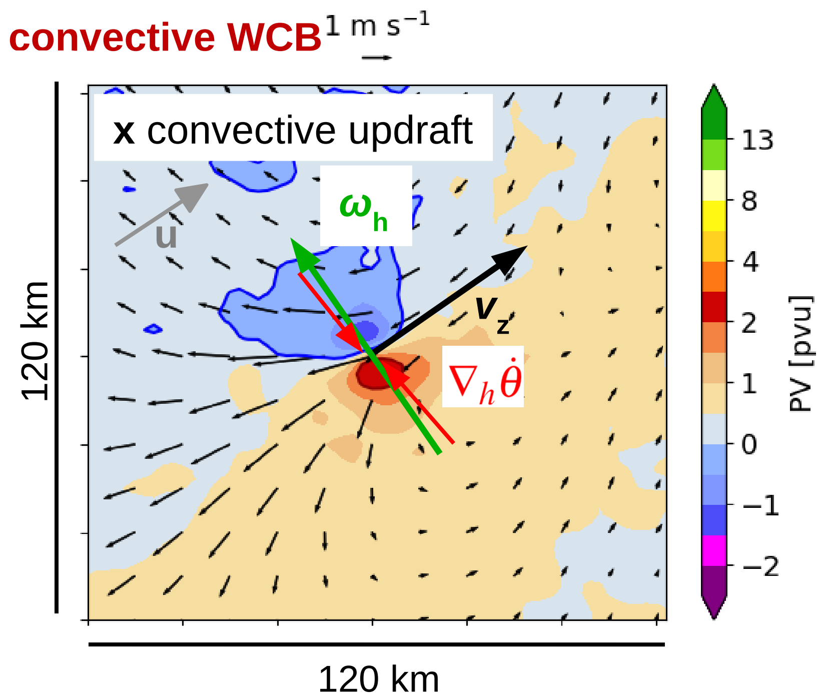
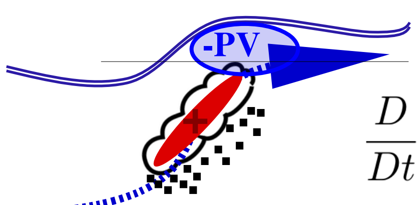


Composite upper-level PV structure
(at 320 K)







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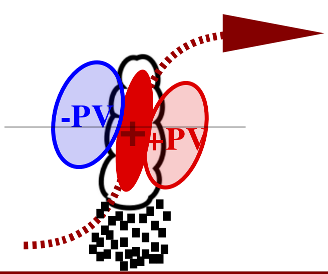
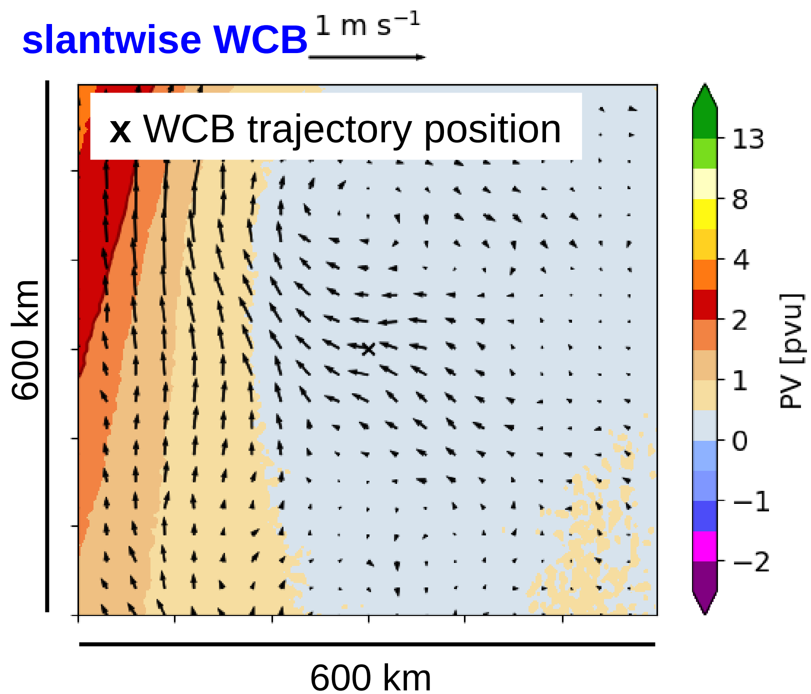
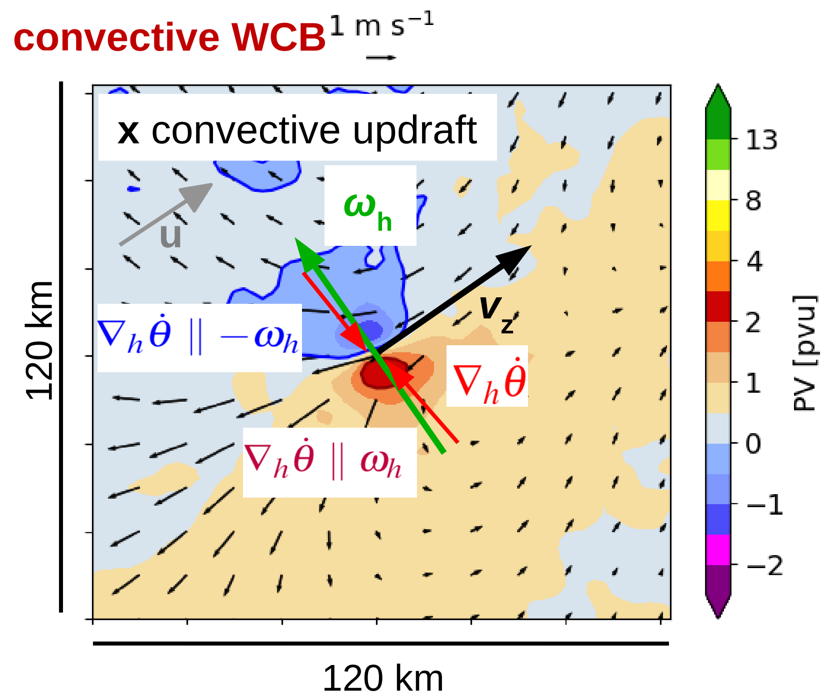
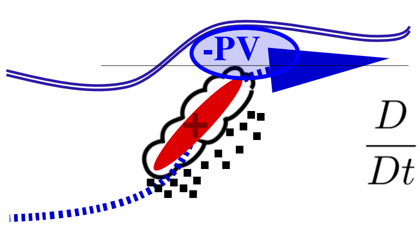


Composite upper-level PV structure (at 320 K)







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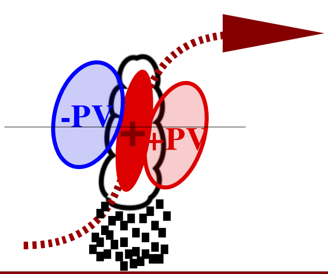
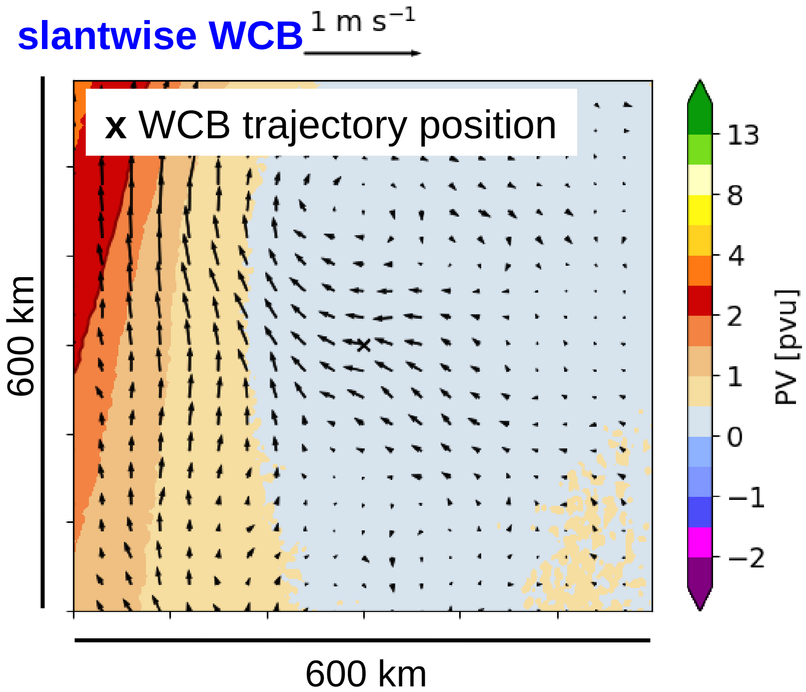


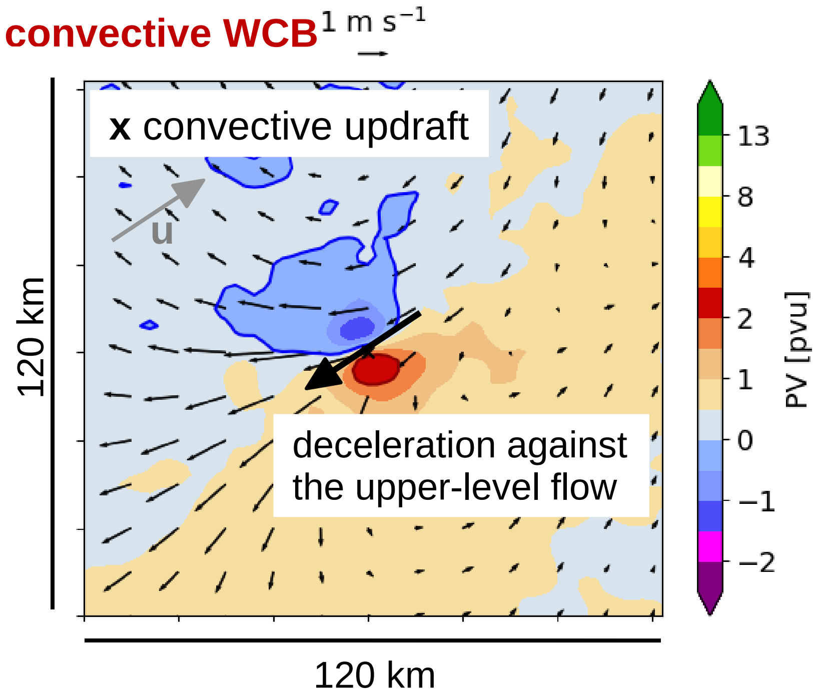
II. How does embedded convection influence the PV structure?

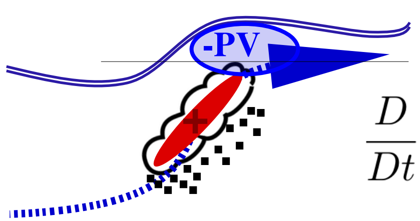
Composite upper-level PV structure
(at 320 K)

slantwise WCB

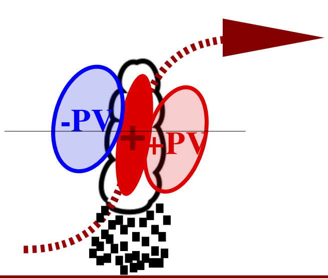


convective WCB



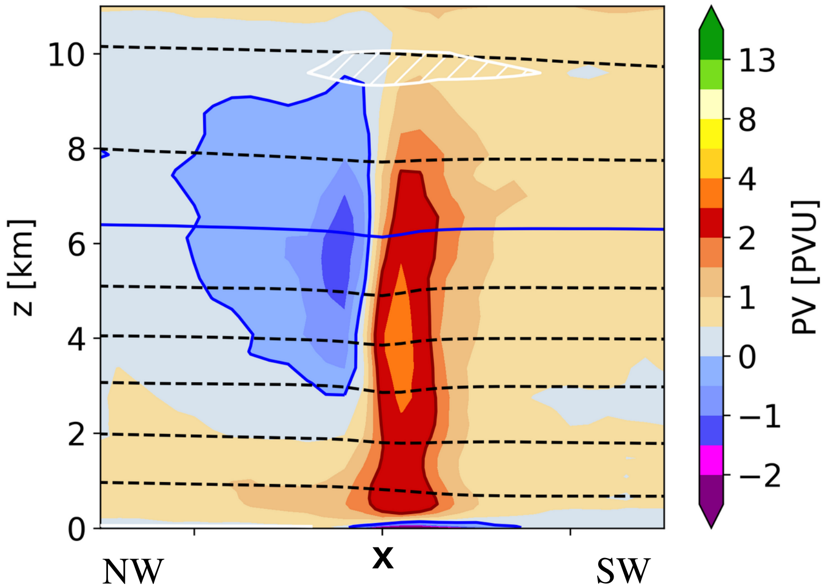


$$\frac{D}{Dt}PV = \frac{1}{\rho}\left[(f+\zeta)\frac{\partial\dot{\theta}}{\partial z} + \boldsymbol{\omega}_h \cdot \nabla_h \dot{\theta}\right]$$

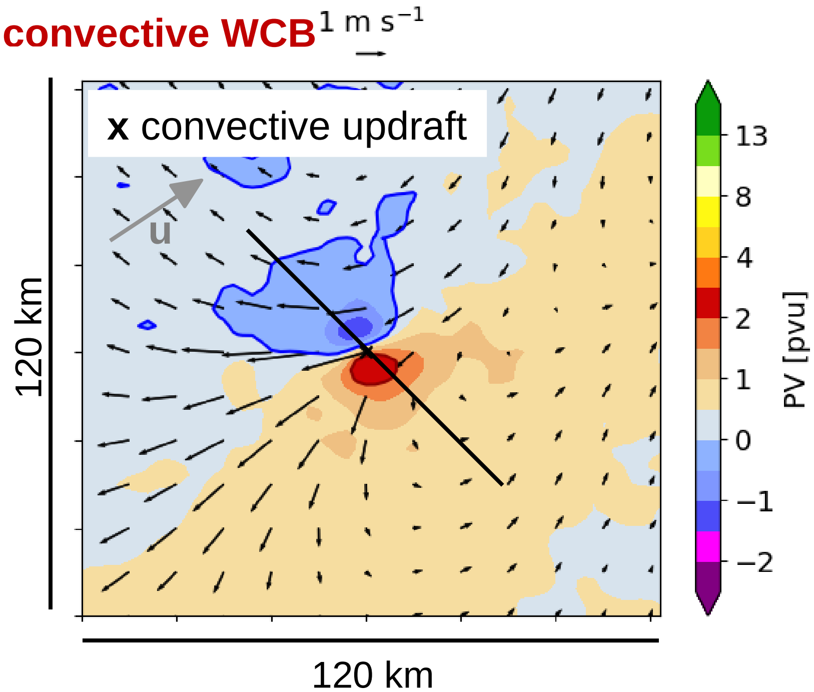


II. How does embedded convection influence the PV structure?

Composite upper-level PV structure
(at 320 K)



convective WCB



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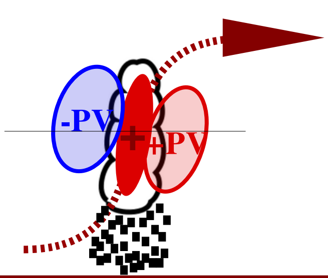
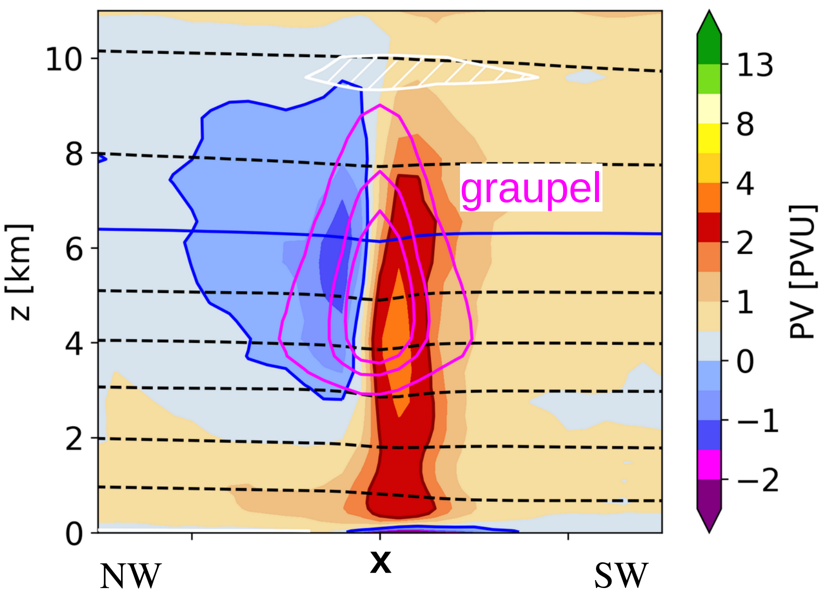
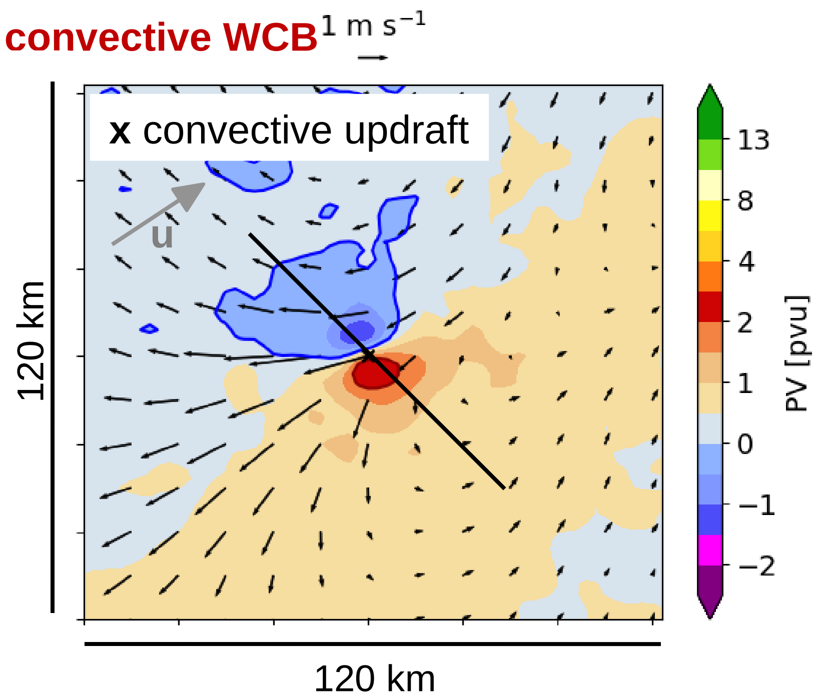


II. How does embedded convection influence the PV structure?

Composite upper-level PV structure (at 320 K)





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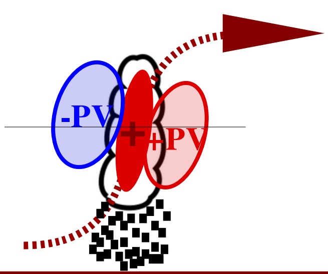
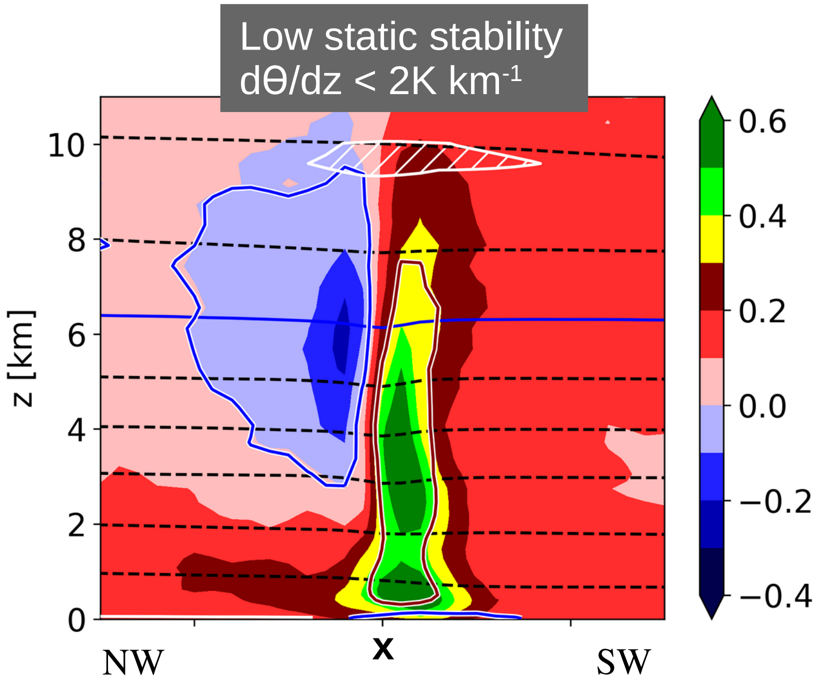
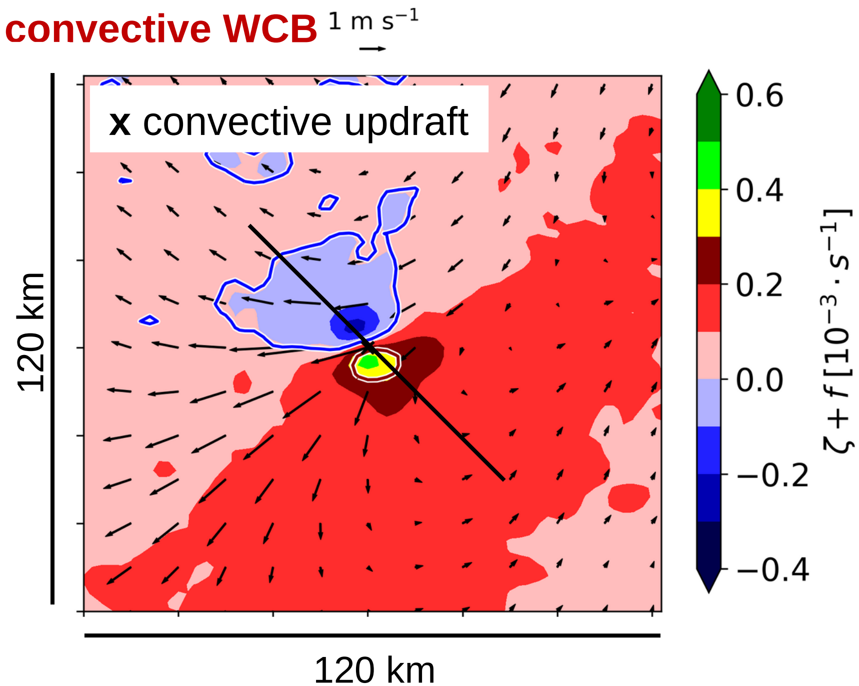


II. How does embedded convection influence the PV structure?

Composite upper-level vertical vorticity structure (at 320 K)





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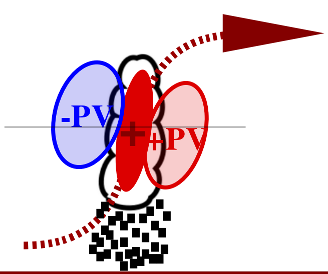
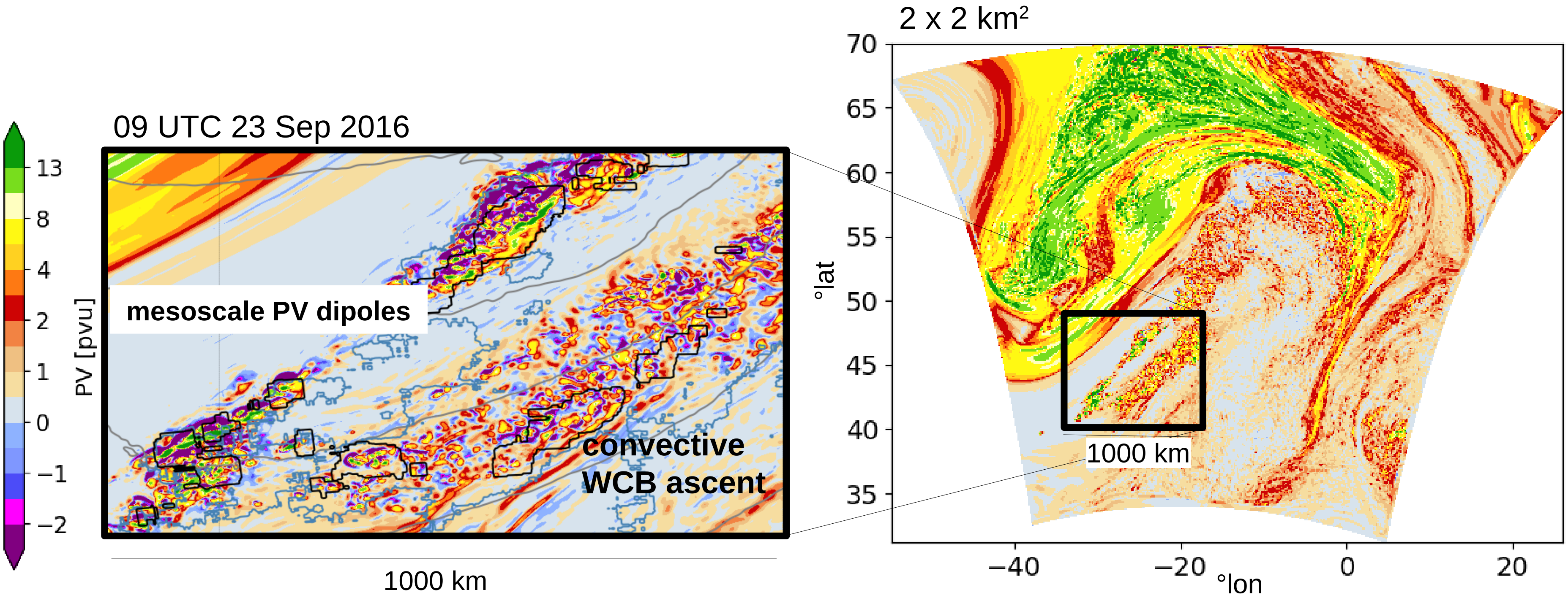


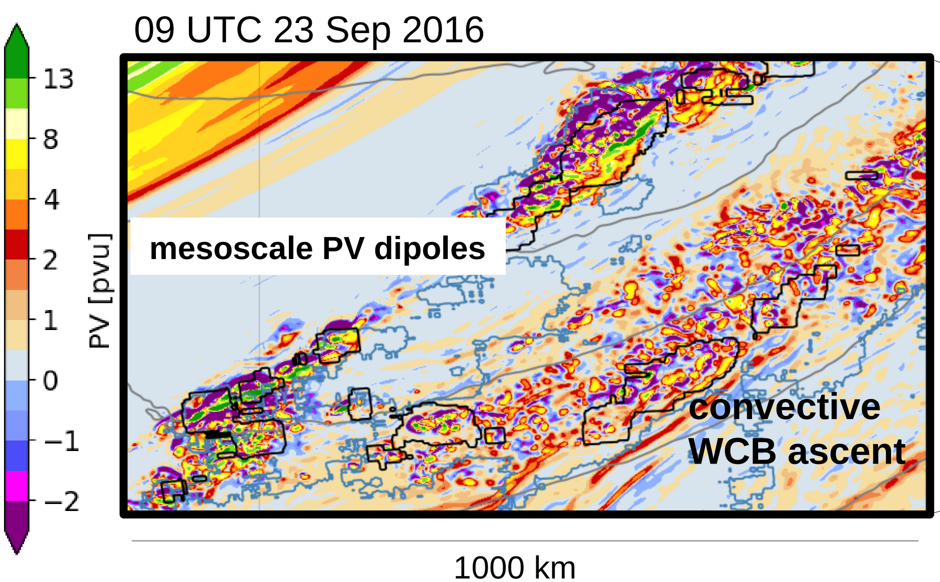
II. How does embedded convection influence the PV structure?

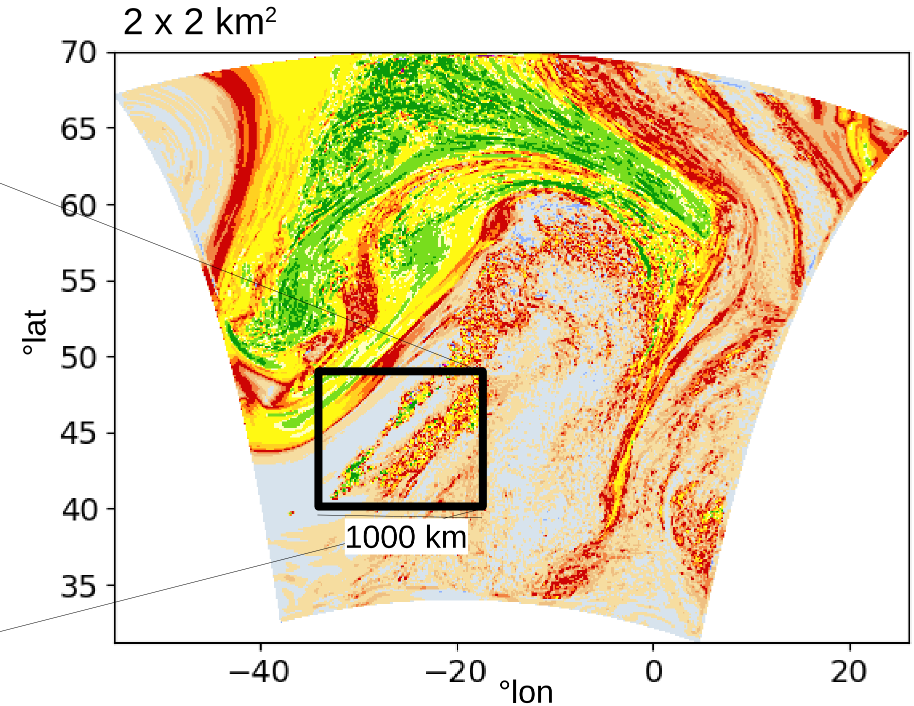
Embedded convection forms mesoscale PV dipoles



III. How does embedded convection influence the large-scale circulation?

1) existence of PV anomaly on a larger-scale
>> **coarse-graining** to 60 km





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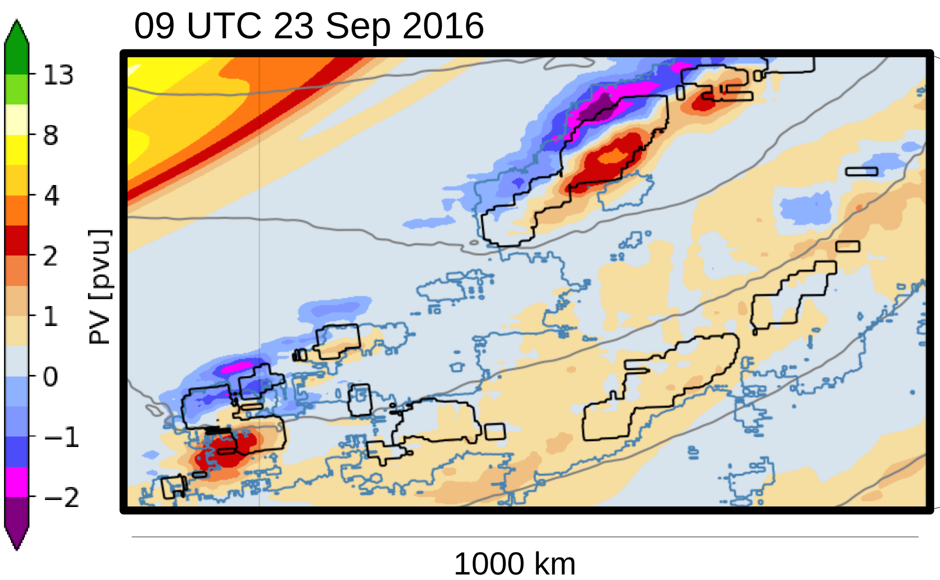
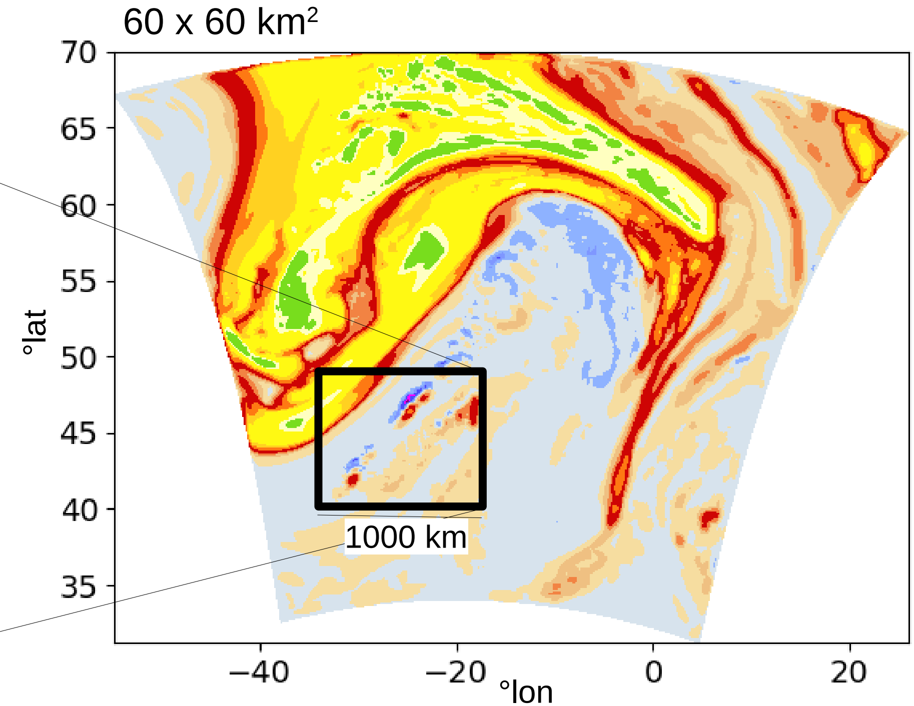
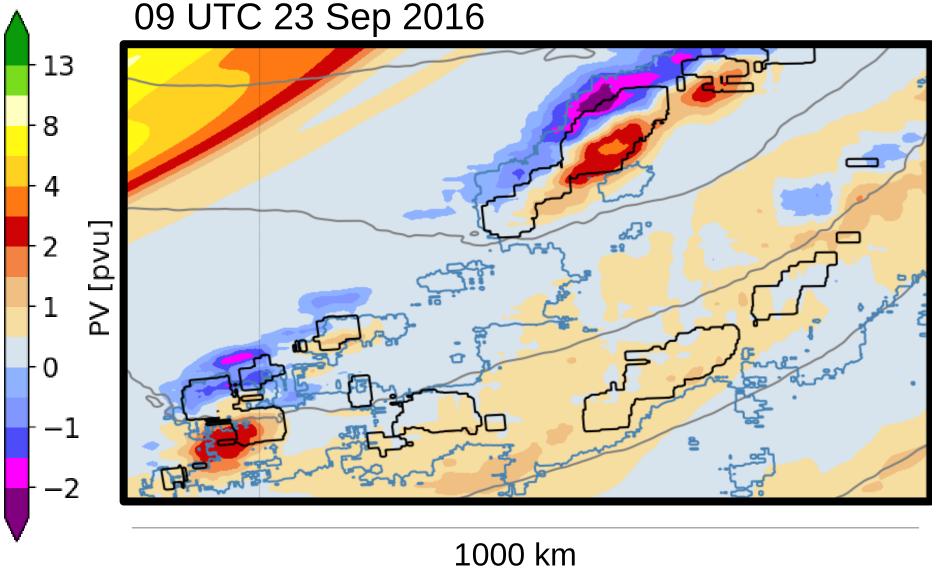




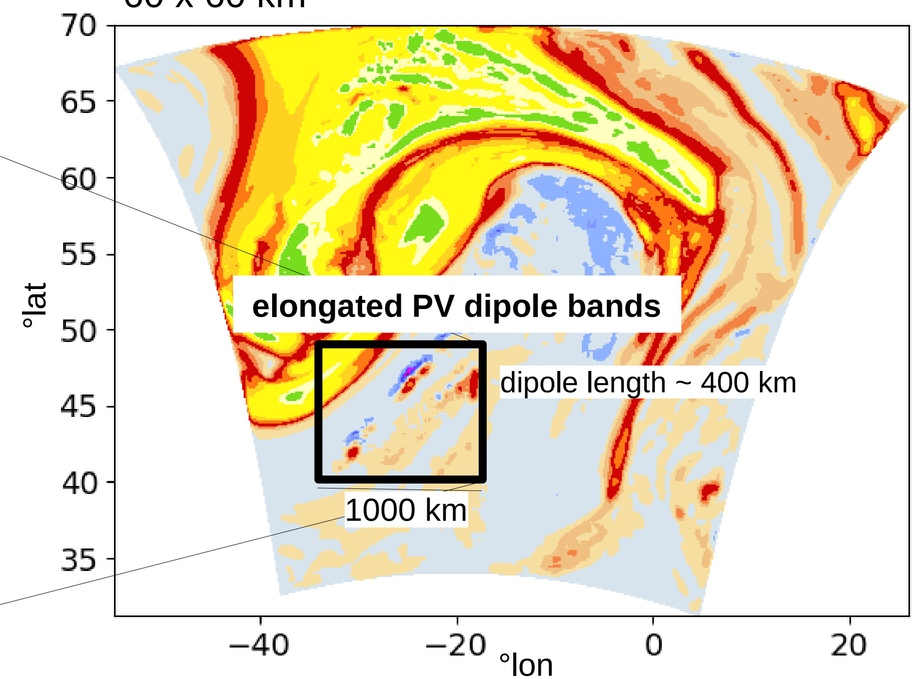
III. How does embedded convection influence the large-scale circulation?

1) existence of PV anomaly on a larger-scale
>> **coarse-graining** to 60 km

09 UTC 23 Sep 2016



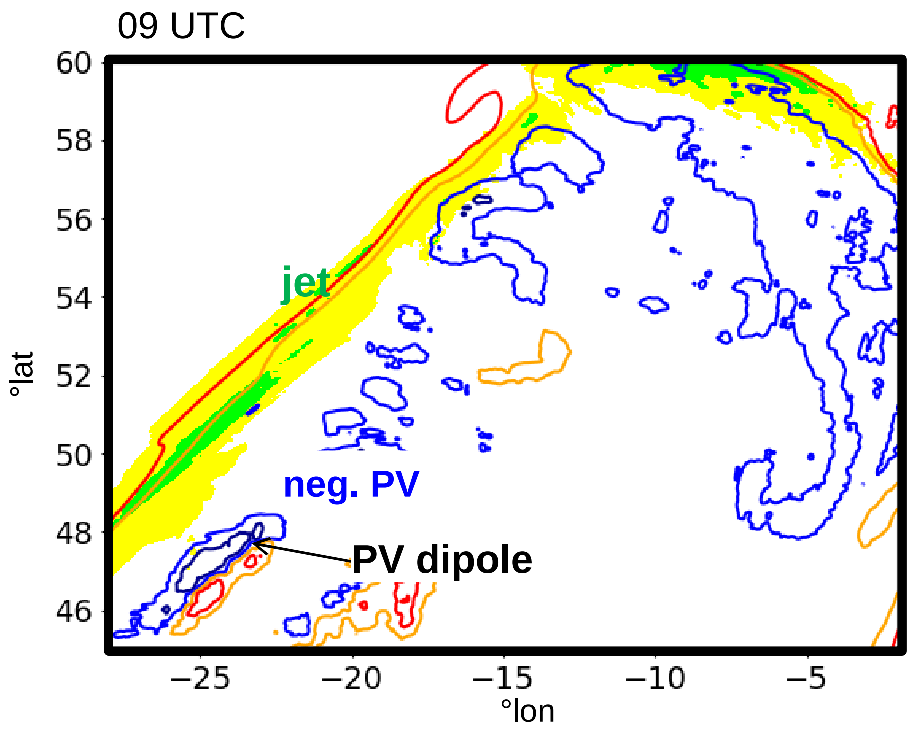
60 x 60 km^2

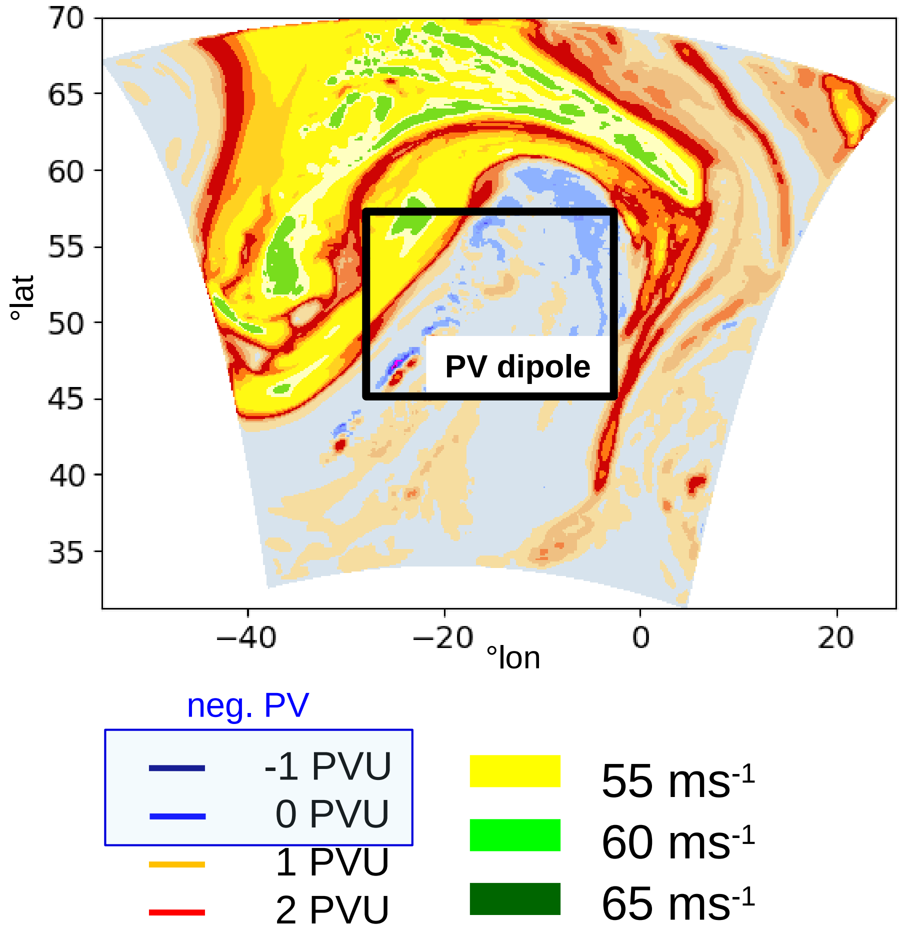


III. How does embedded convection influence the large-scale circulation?

1) existence of PV anomaly on a larger-scale
   >> **coarse-graining** to 60 km

2) Temporal evolution of **negative PV**





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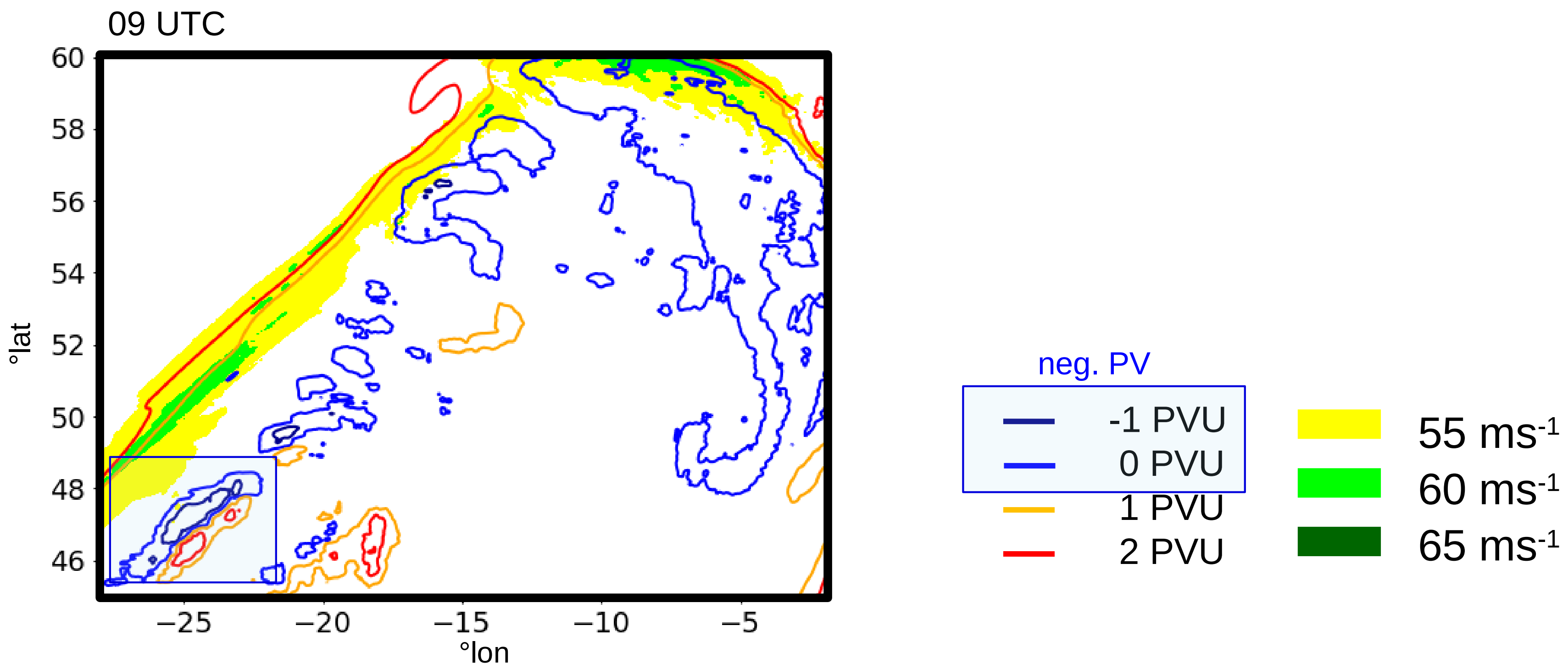

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   >> **coarse-graining** to 60 km

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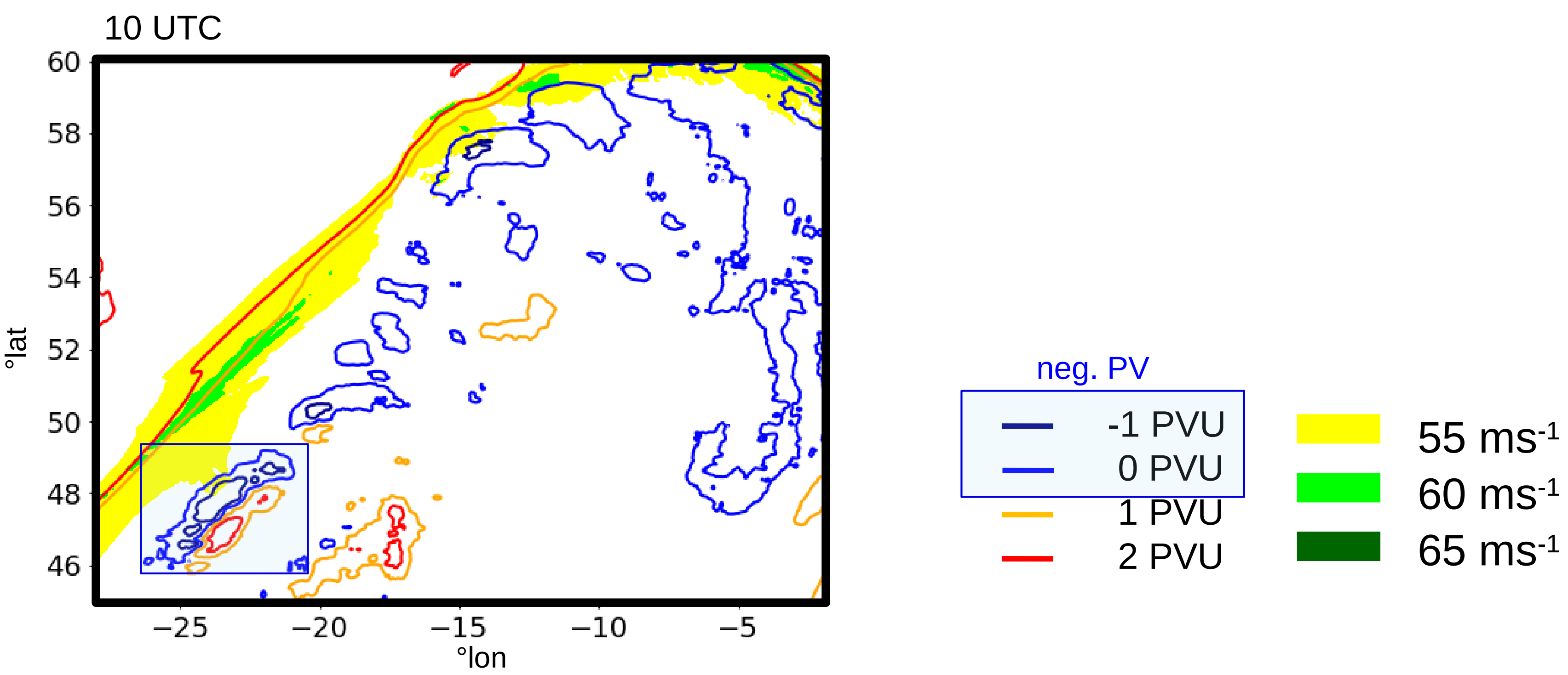

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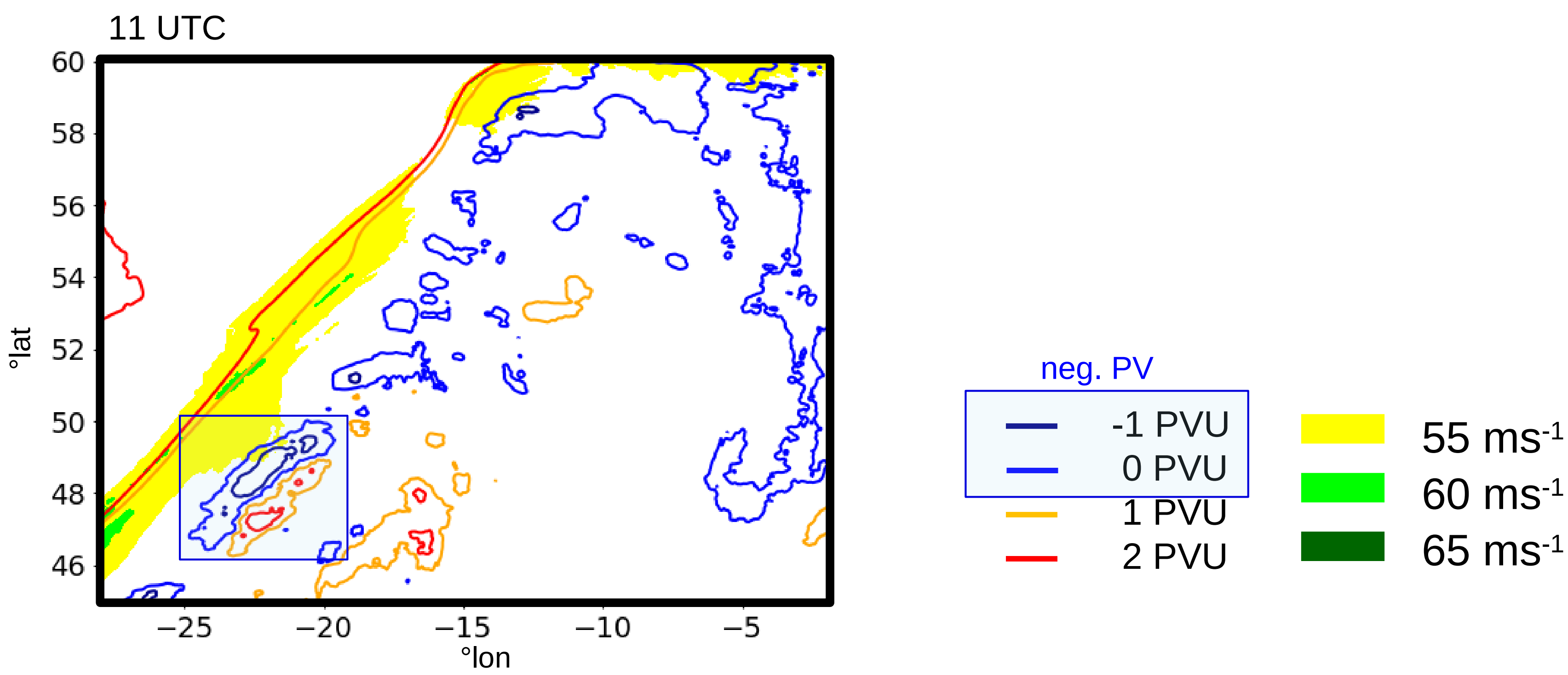

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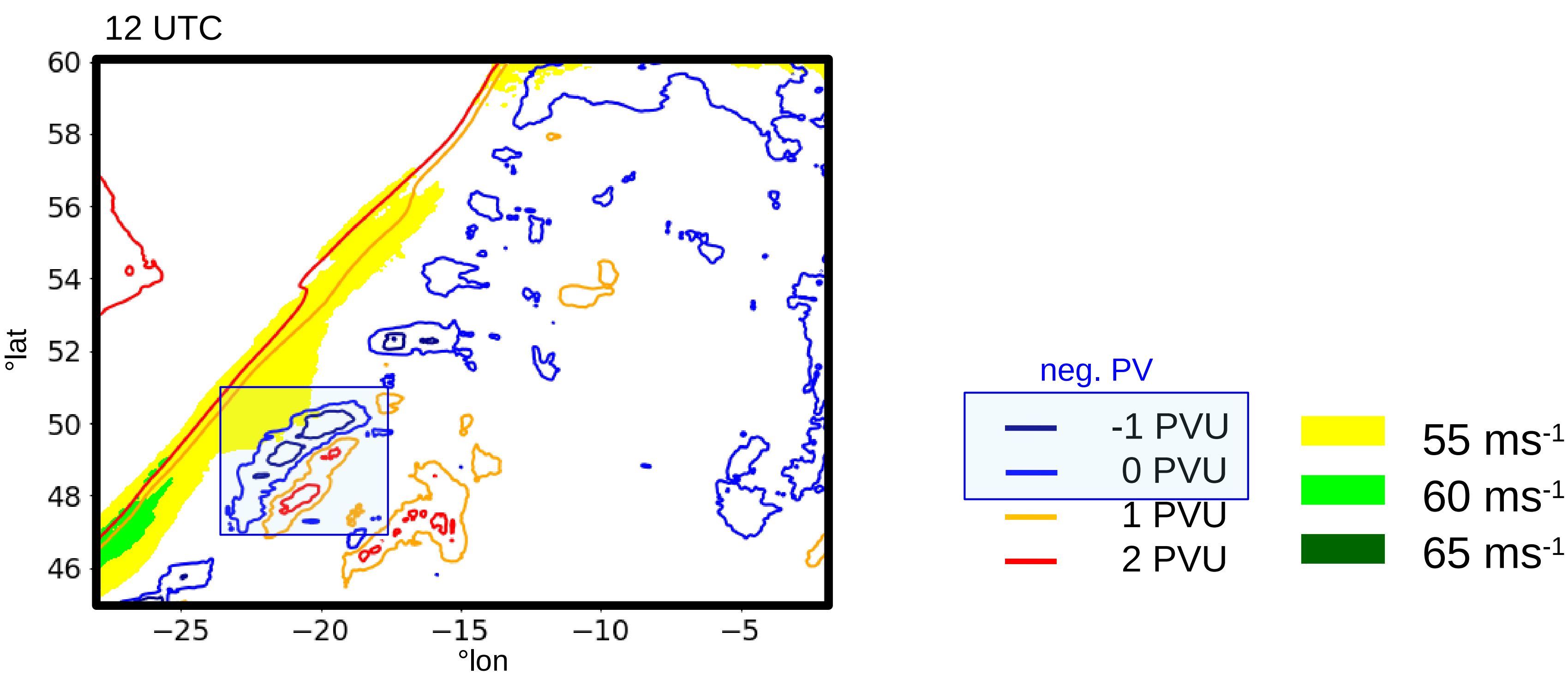

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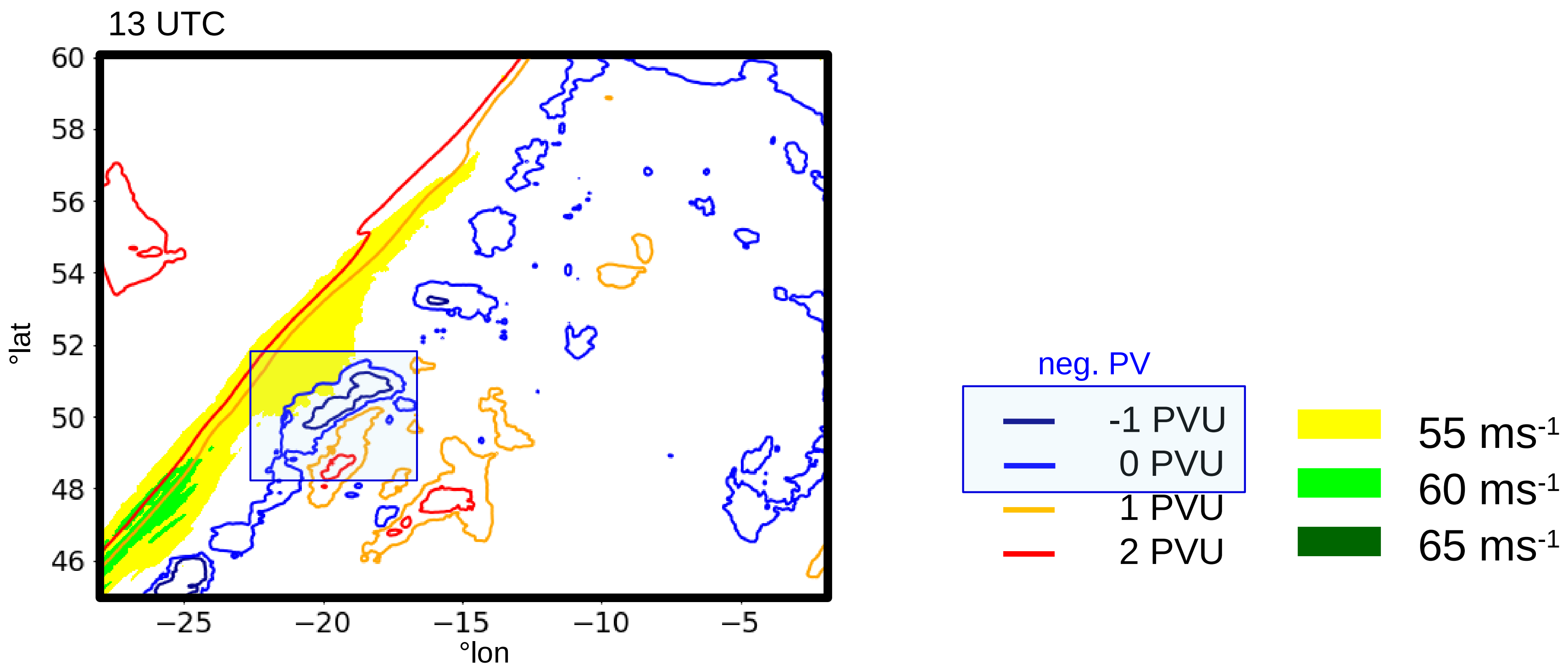

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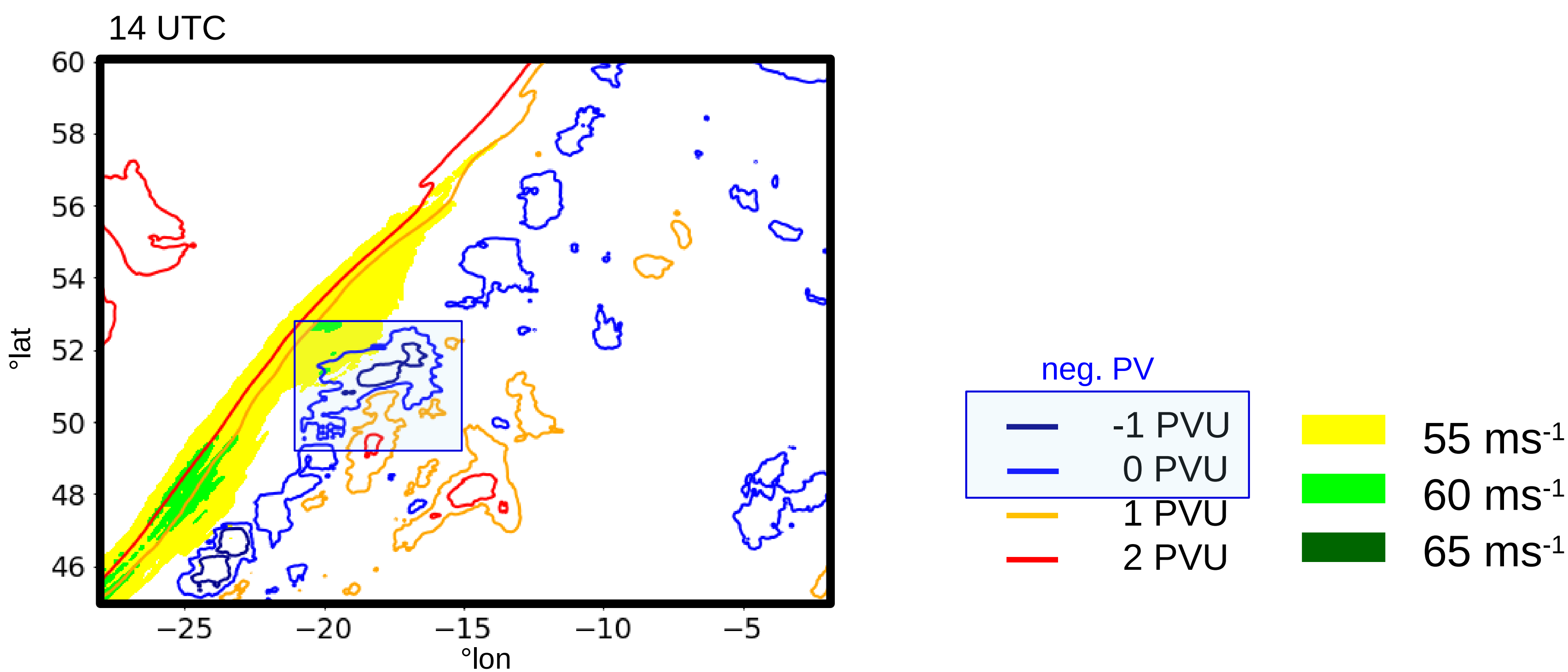
>> **coarse-graining** to 60 km

2) Temporal evolution of **negative PV**



III. How does embedded convection influence the large-scale circulation?

1) existence of PV anomaly on a larger-scale
   >> **coarse-graining** to 60 km

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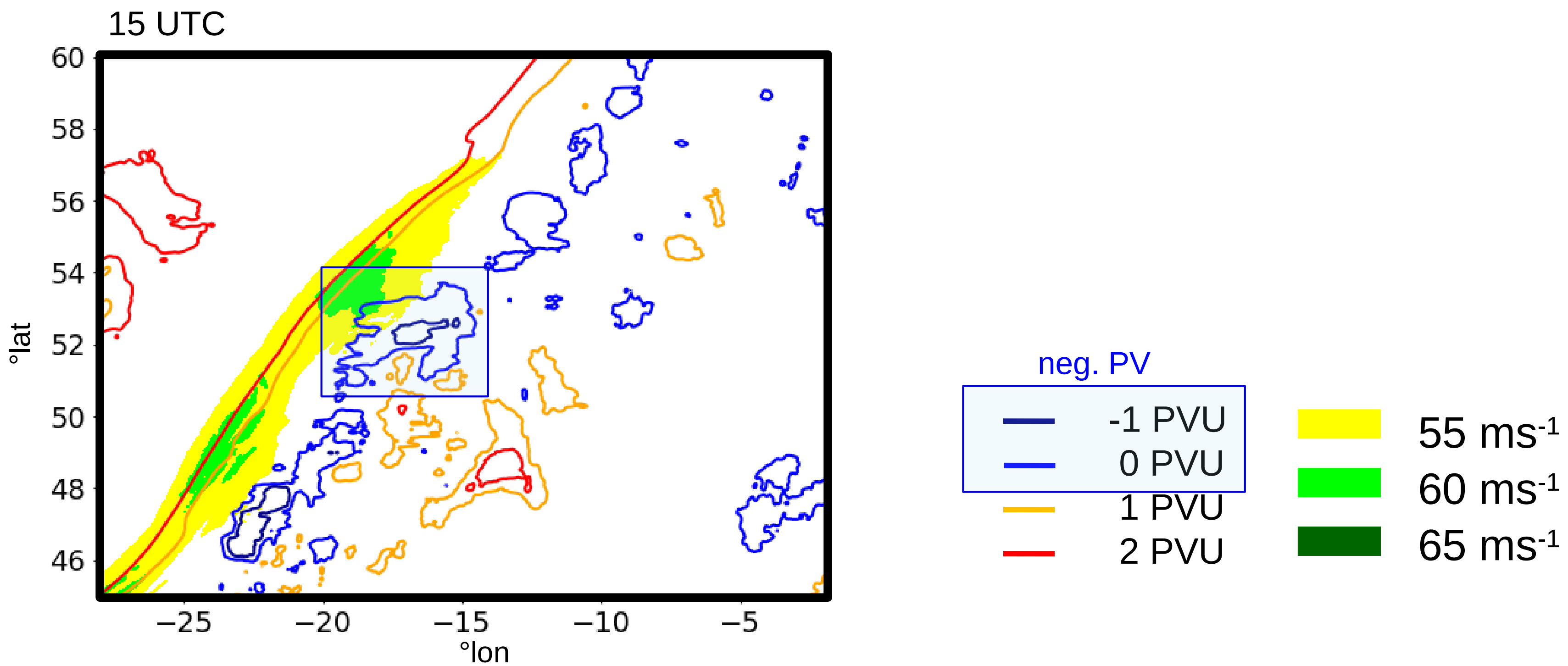

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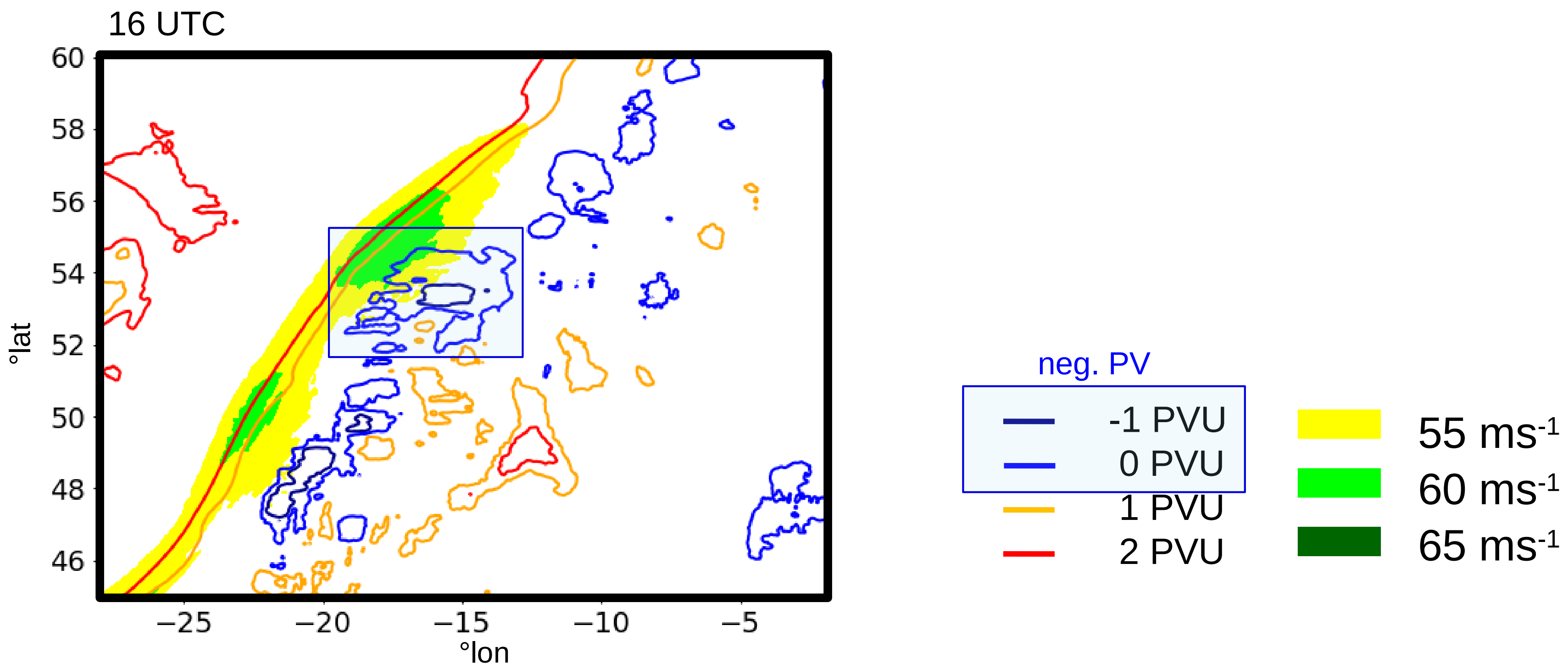

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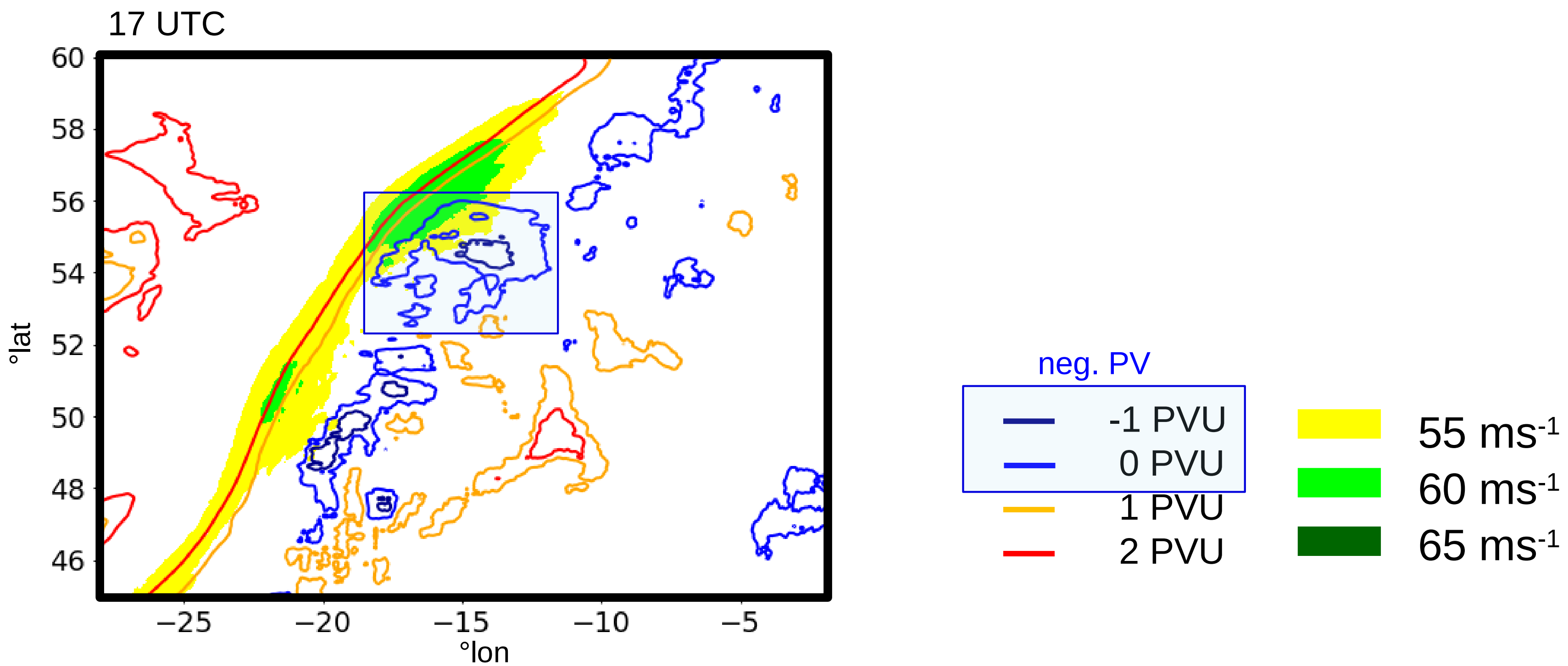

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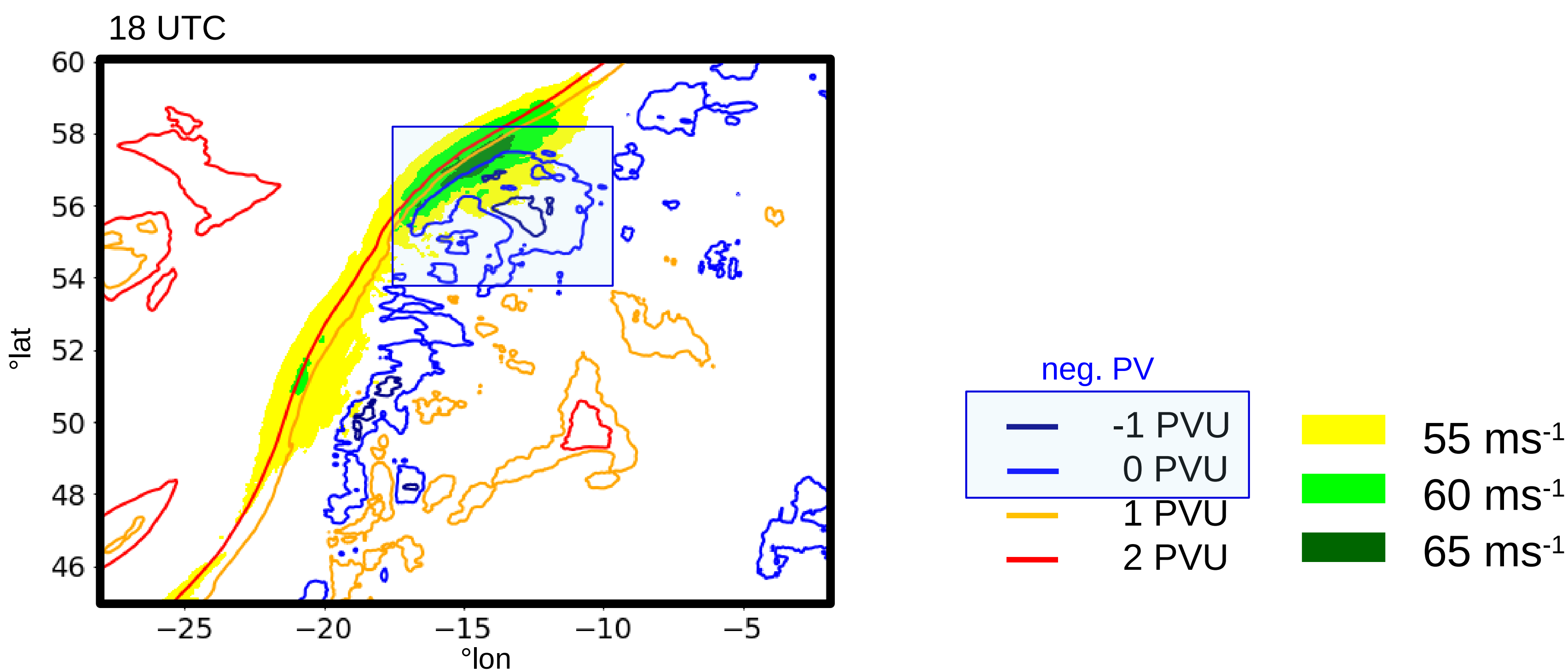
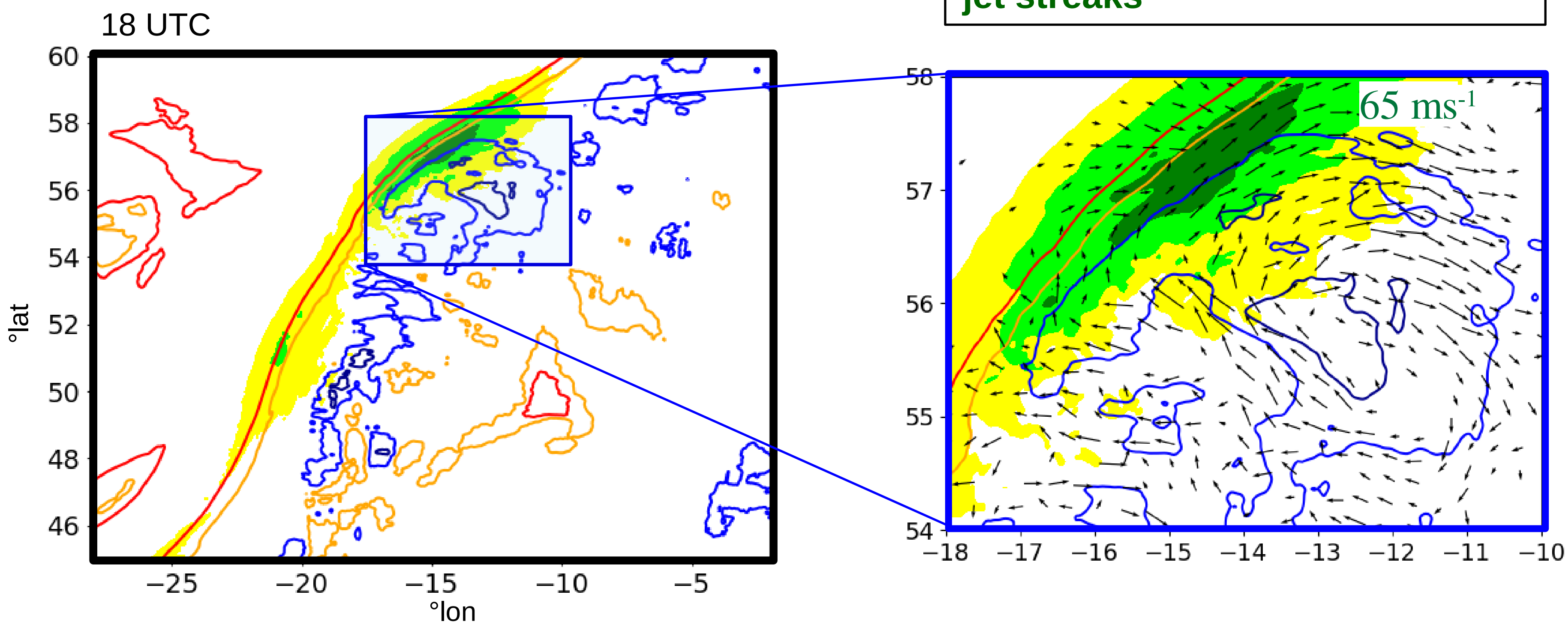


III. How does embedded convection influence the large-scale circulation?

1) existence of PV anomaly on a larger-scale
>> **coarse-graining** to 60 km

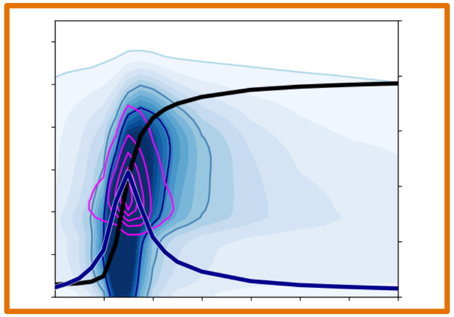
2) Temporal evolution of **negative PV**

>> neg. PV has a relatively long lifetime, can interact with the upper-level waveguide and form **jet streaks**



Conclusions

I. Embedded convective ascent in WCBs forms a denser cloud with **higher hydrometeor** content and more **intense surface precipitation**



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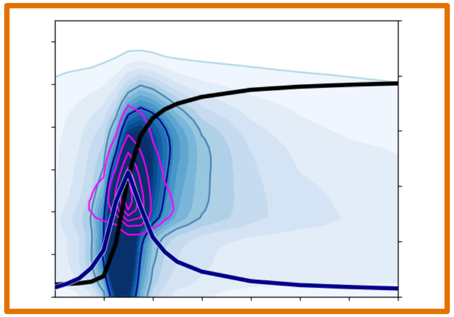
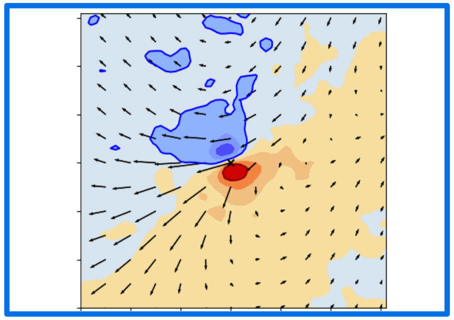


II. Embedded convection in WCBs leads to

- **stronger pos. low-level PV** anomalies
- mesoscale upper-level **horizontal PV dipoles**



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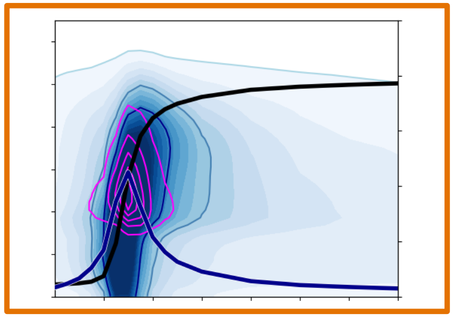

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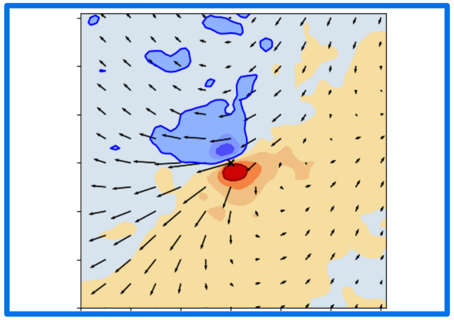
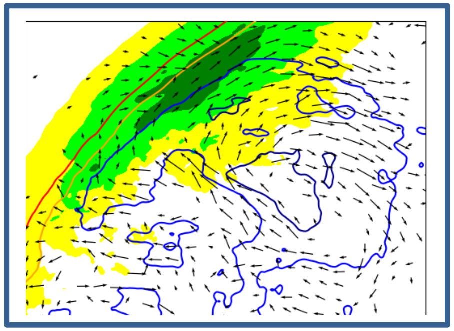
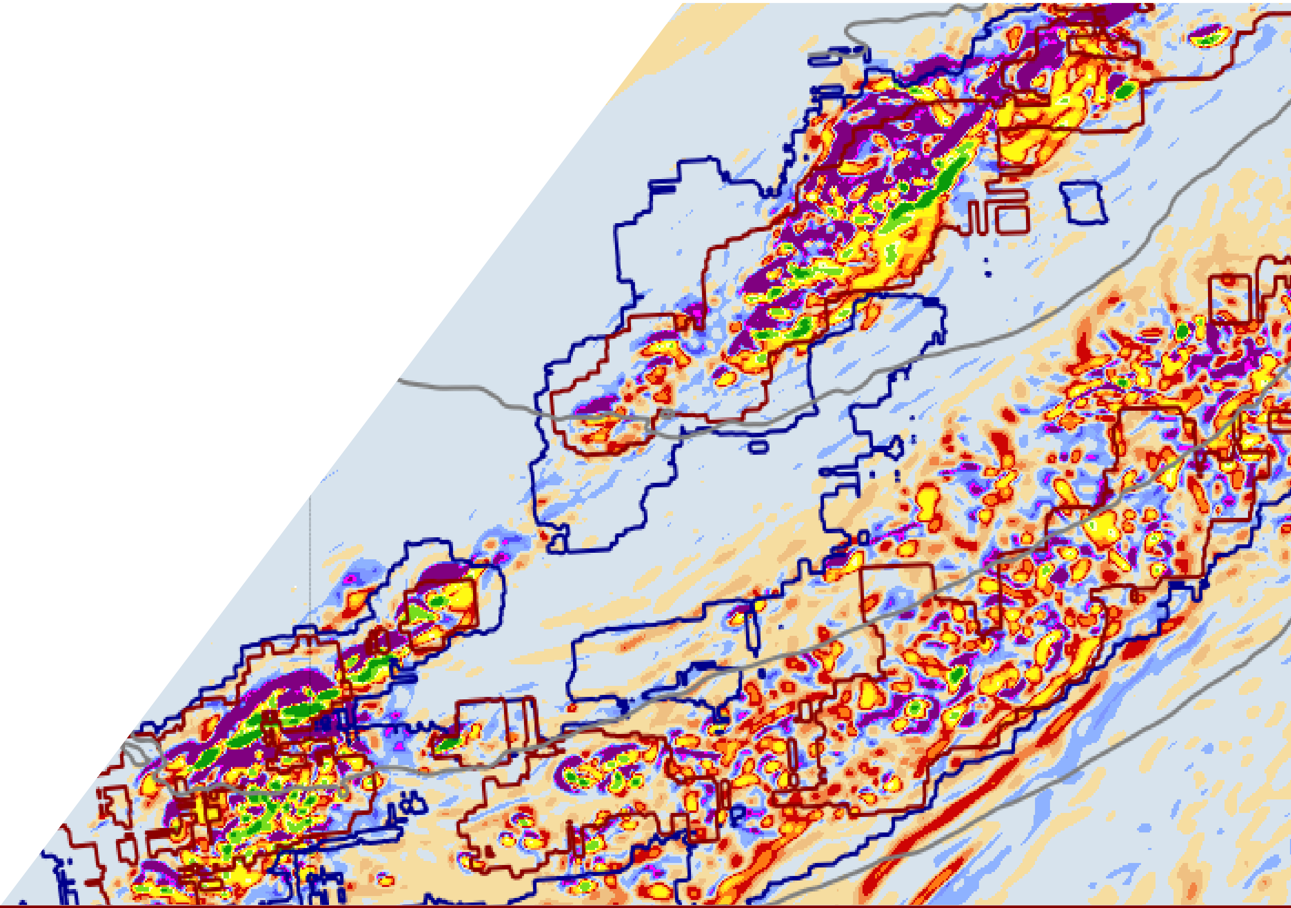


III. On the larger-scale, convectively produced PV anomalies aggregate to **elongated PV dipole bands** around elongated convective updrafts, which can

- **interact with the upper-level waveguide**
- strengthen the **isentropic PV gradient**
- result in **jet streaks**



Thank you



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Weijenborg, C., P. Friederichs, and A. Hense, 2015: Organisation of potential vorticity on the mesoscale during deep moist convection. Tellus, 67, 25 705, doi:10.3402/tellusa.v67.25705.

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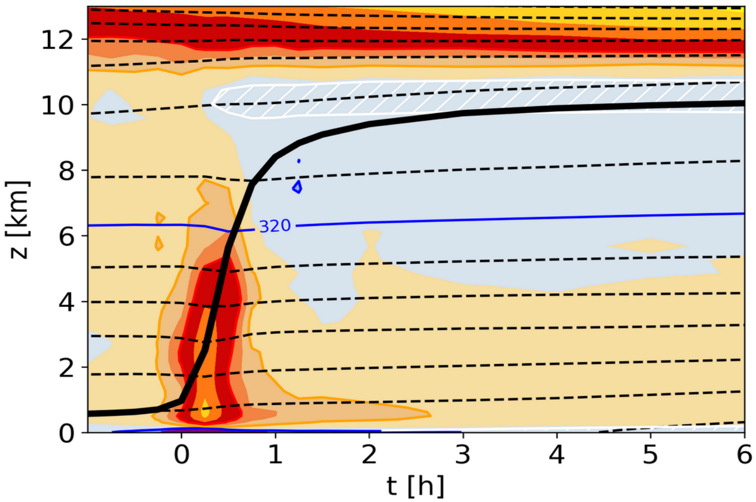
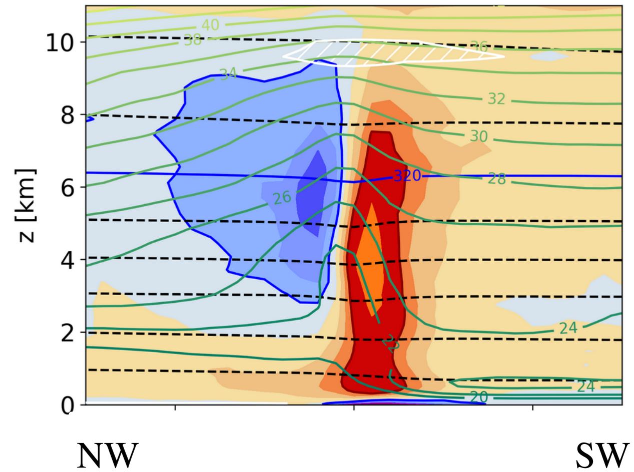
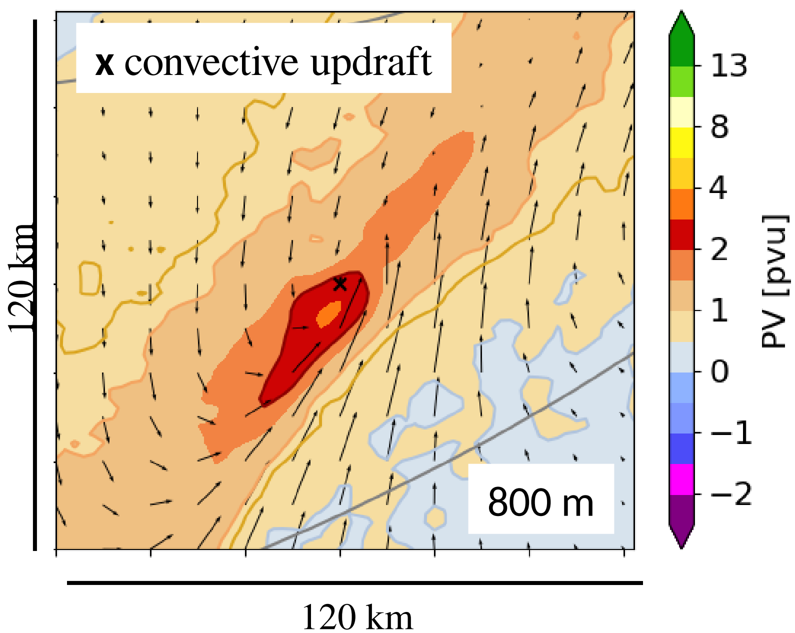
PV structure

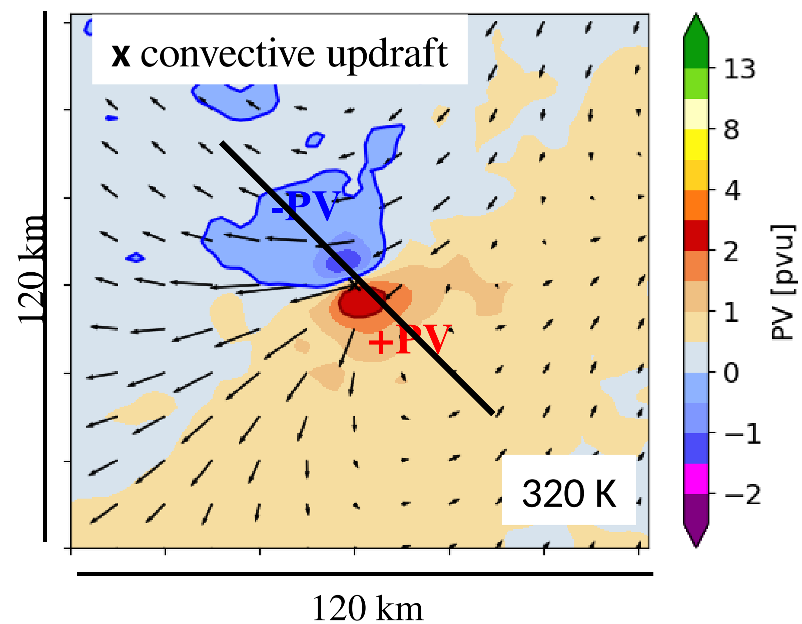




low-level positive PV anomaly



upper-level PV dipole

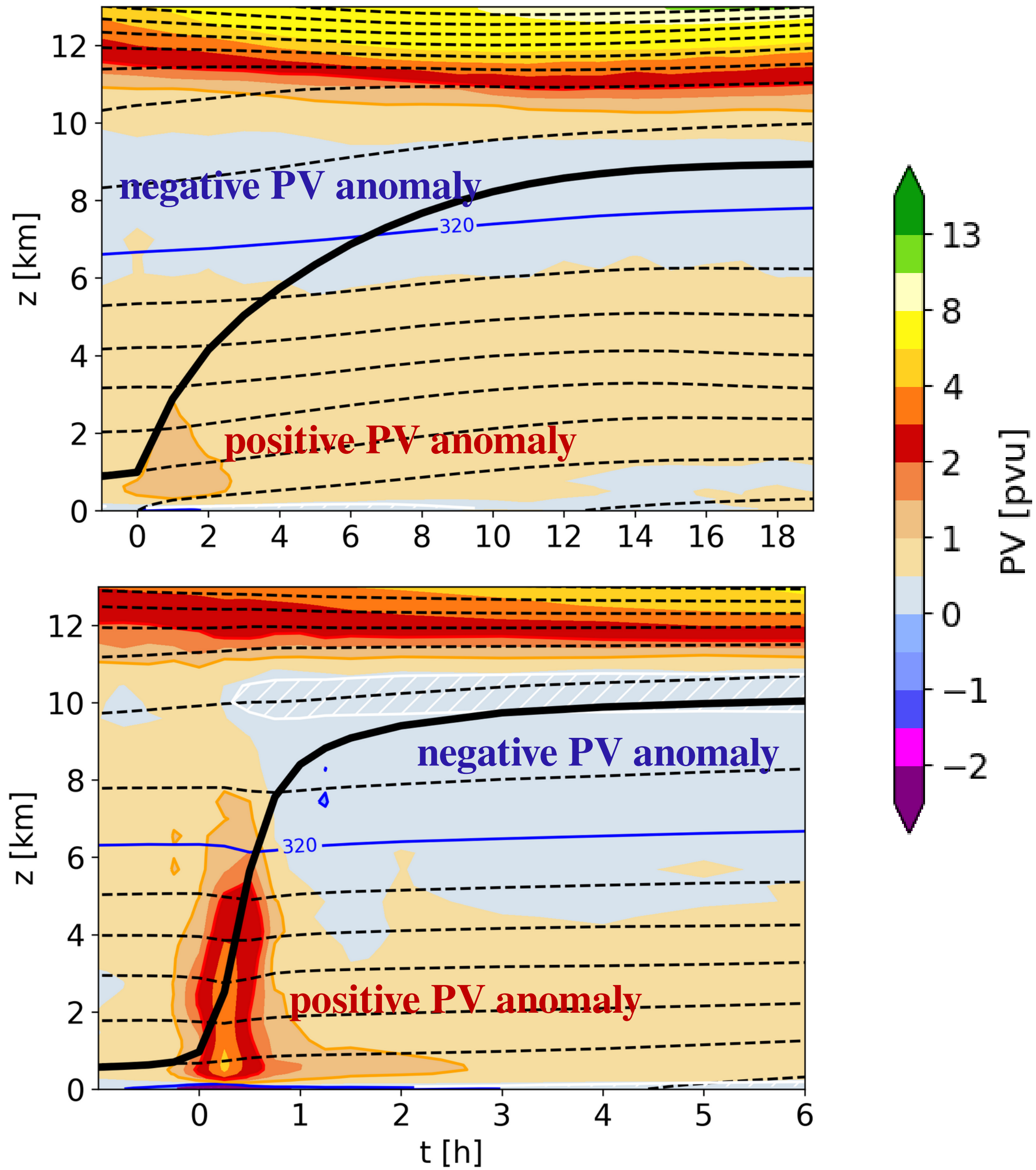


II. How does embedded convection influence the PV structure?

Composite PV structure

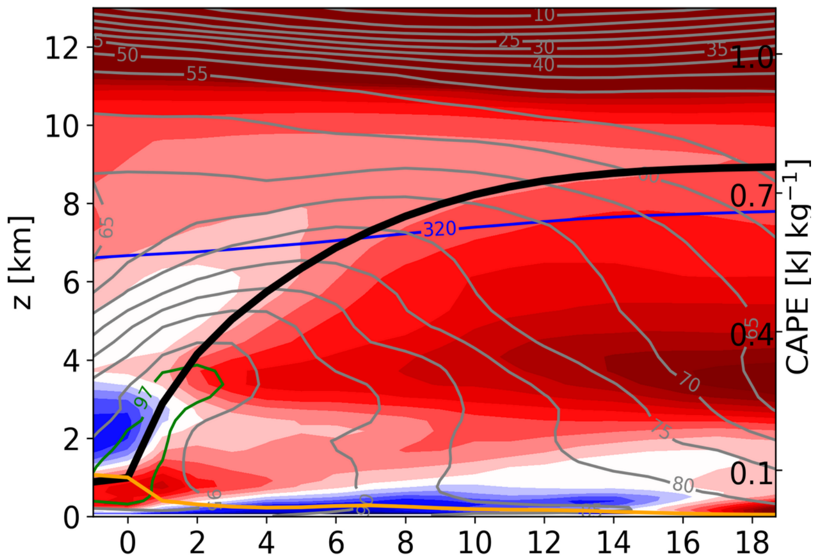
slantwise WCB
>> typical ascent

convective WCB

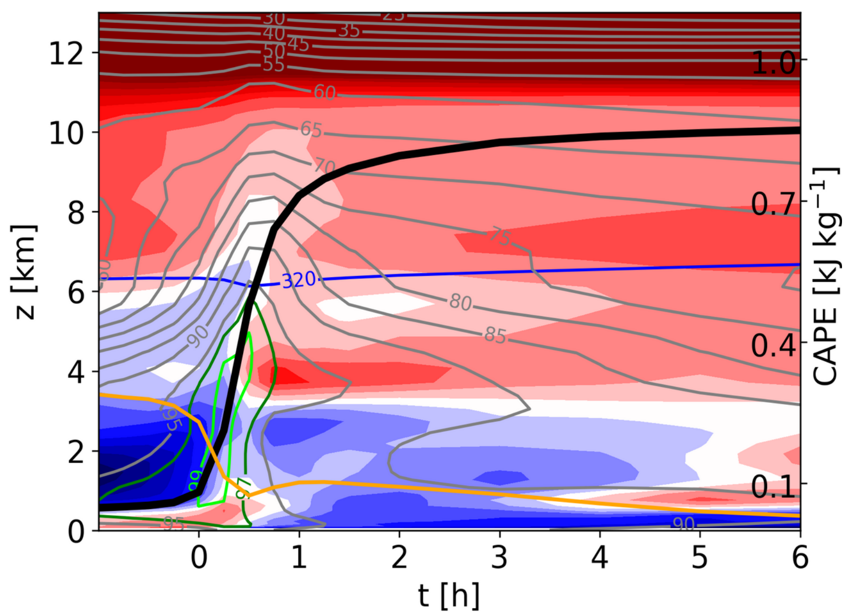


Potential (in-)stability ($d\theta_e/dz$)

slantwise WCB
>> typical ascent

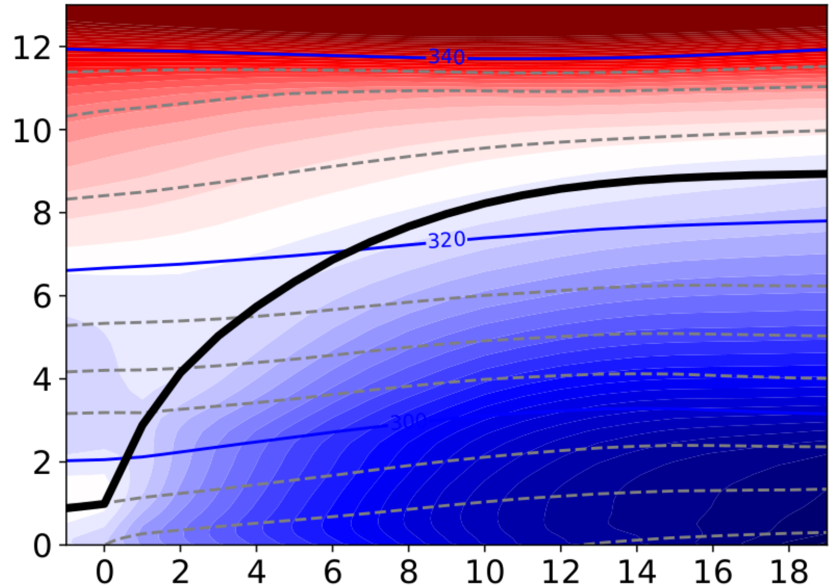


convective WCB

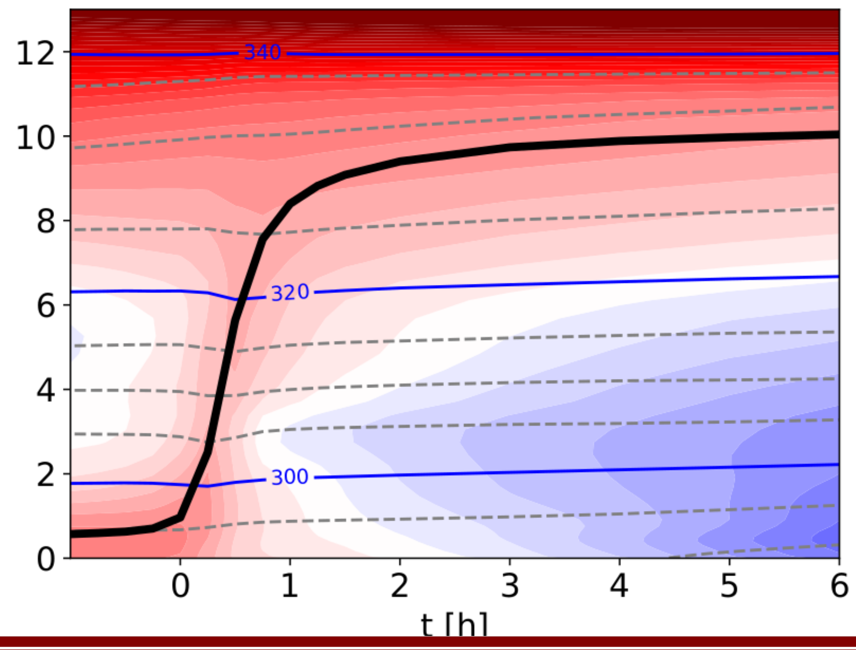


Equivalent potential temperature

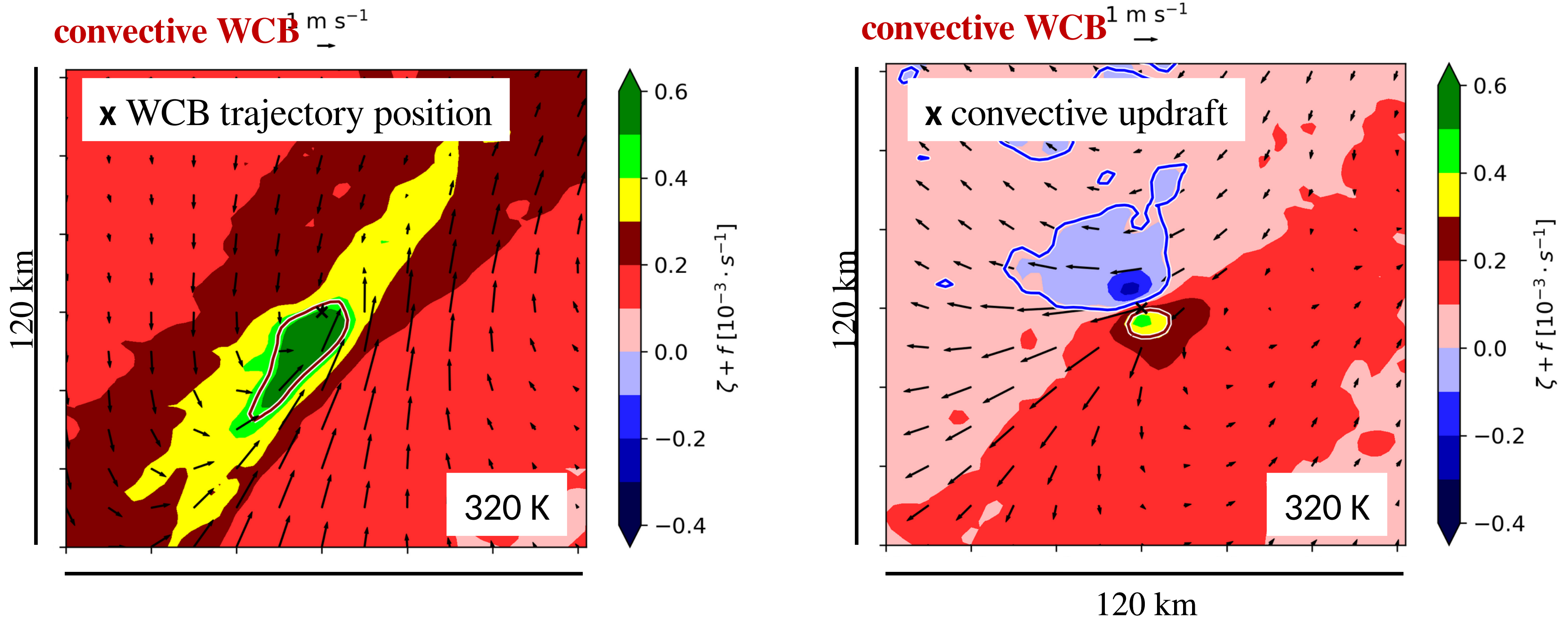
"average" WCB
>> typical ascent



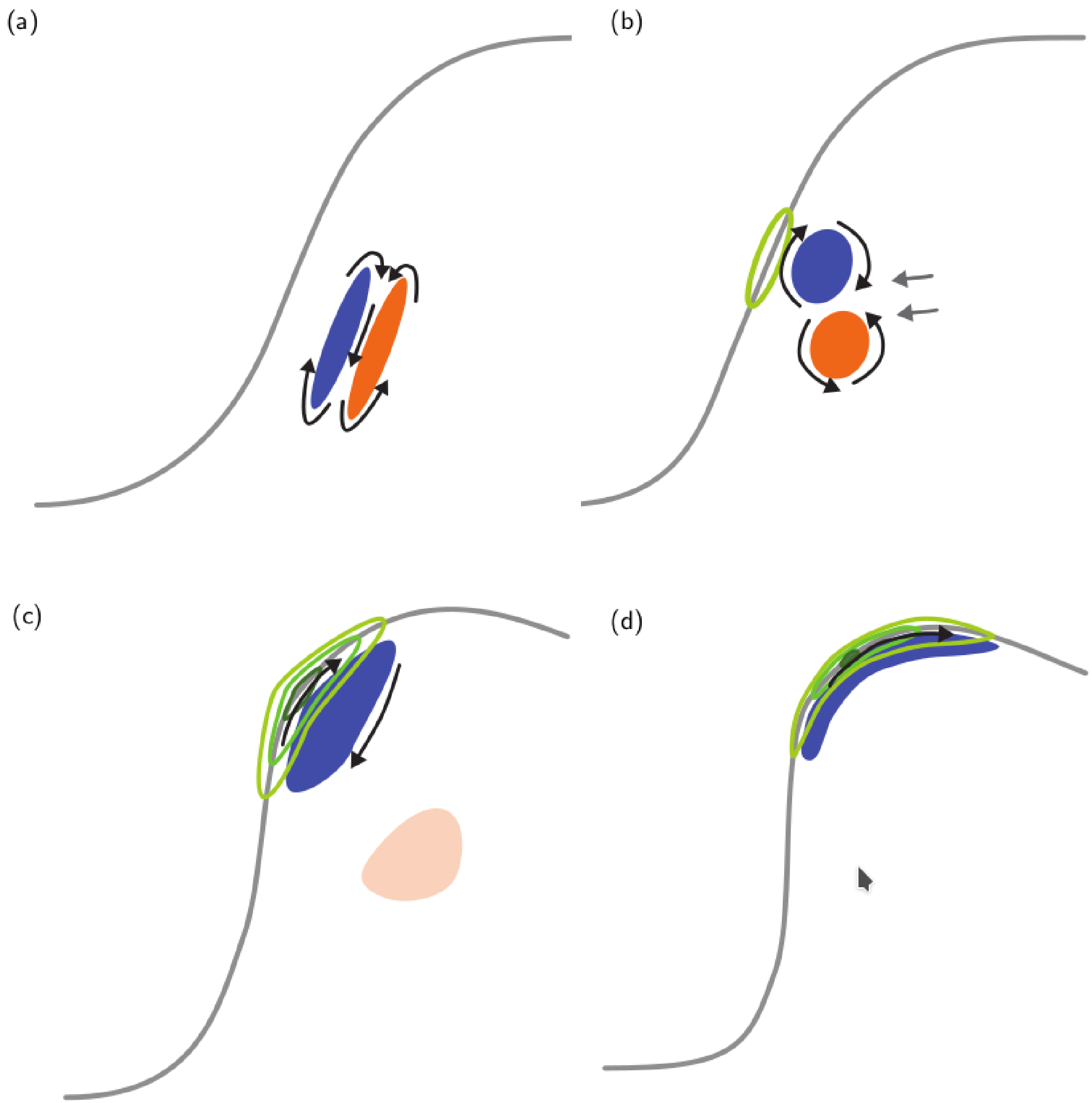
convective WCB



Vertical vorticity

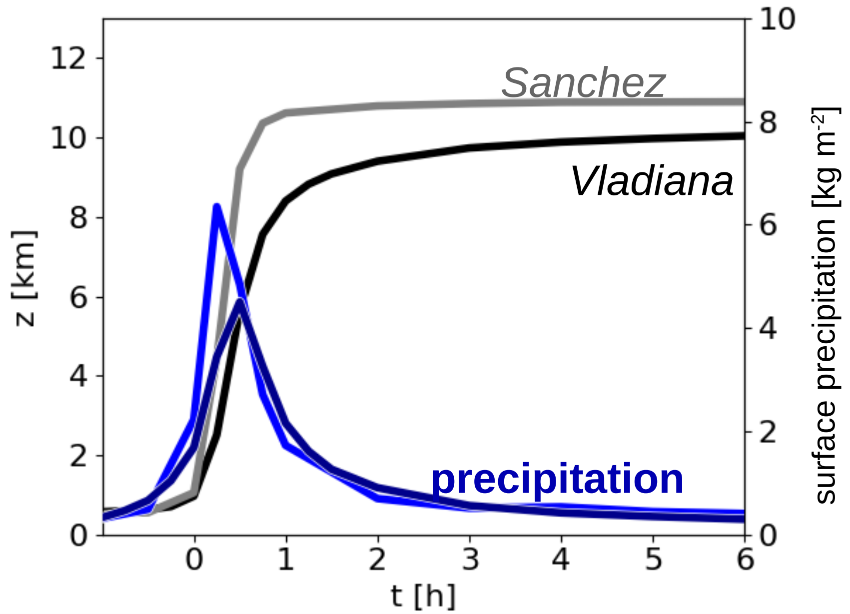


Different stages of convectively generated PV



Comparison of cyclones *Vladiana* and *Sanchez*

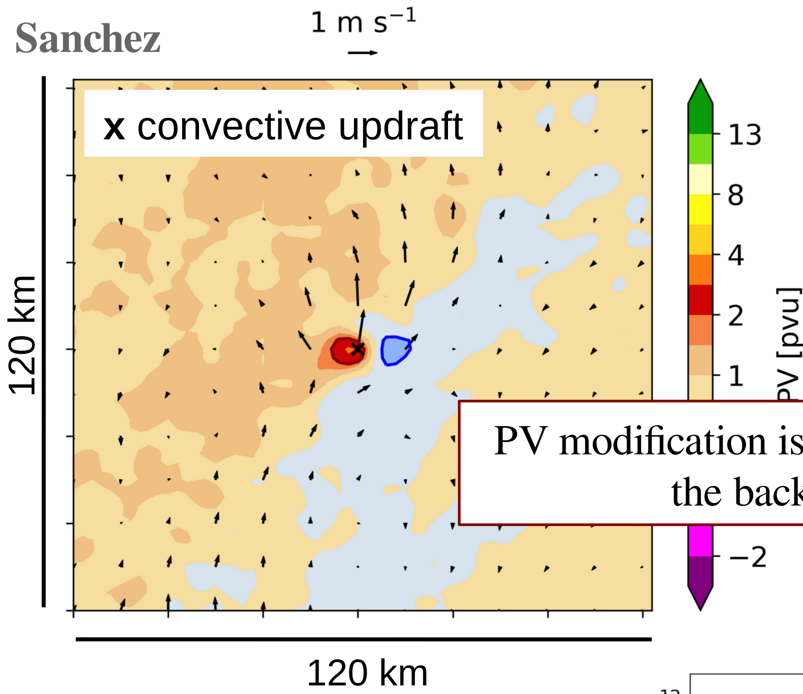
embedded convection of
Vladiana and *Sanchez*

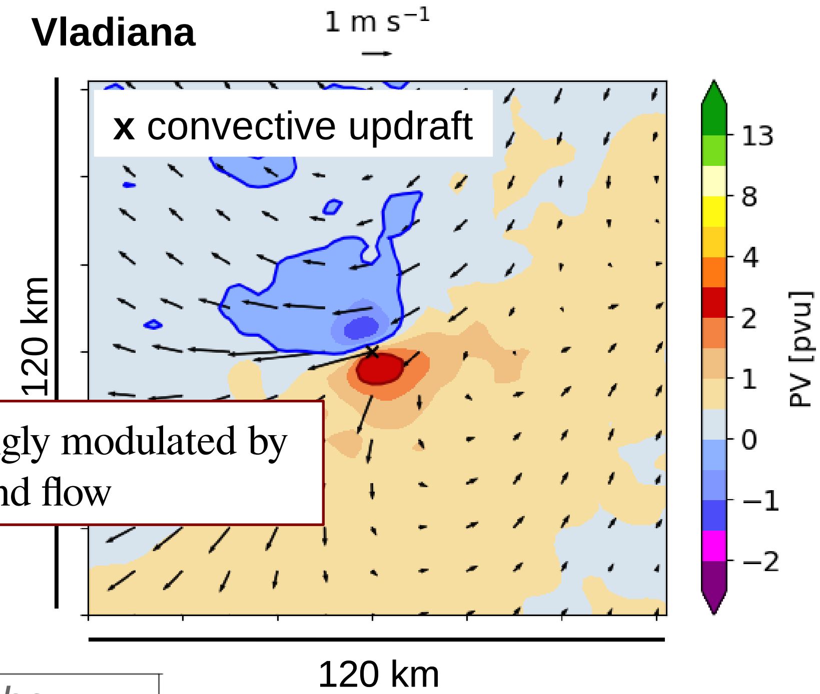


convective WCB

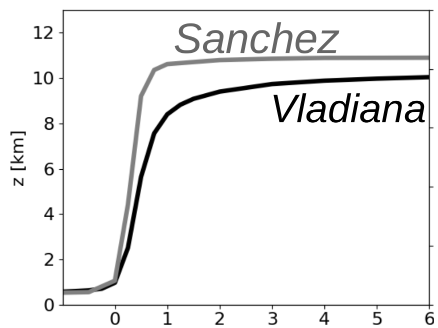
Comparison of cyclones *Vladiana* and *Sanchez*

Composite upper-level PV structure
(at 320 K)



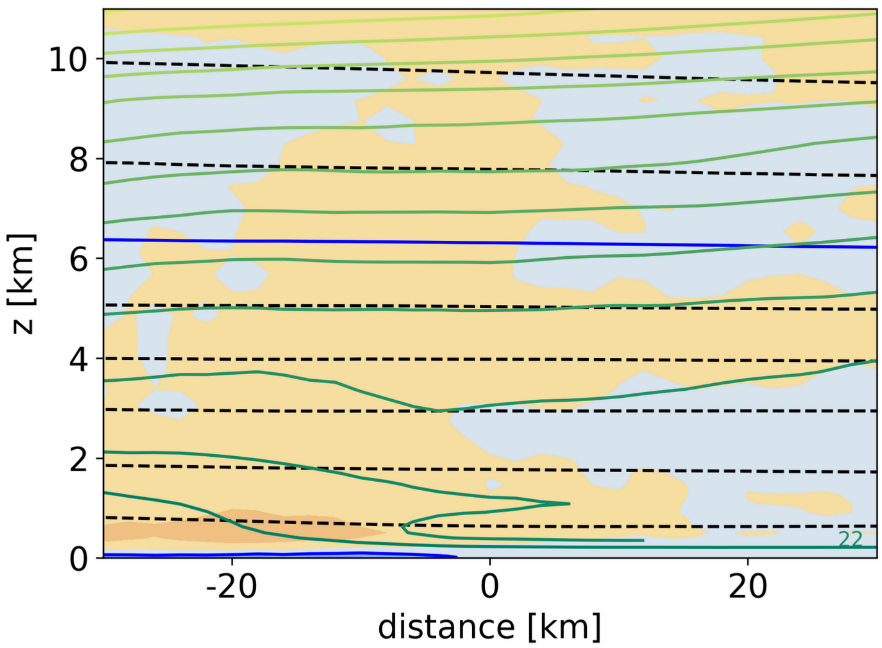


PV modification is strongly modulated by the background flow



PV structure and CAPE

convective WCB – 1h prior to ascent



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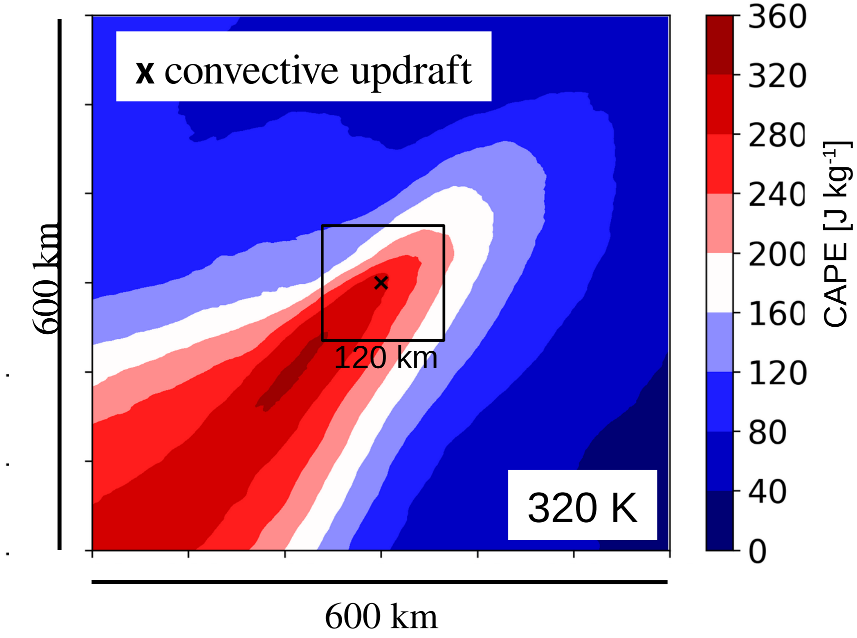
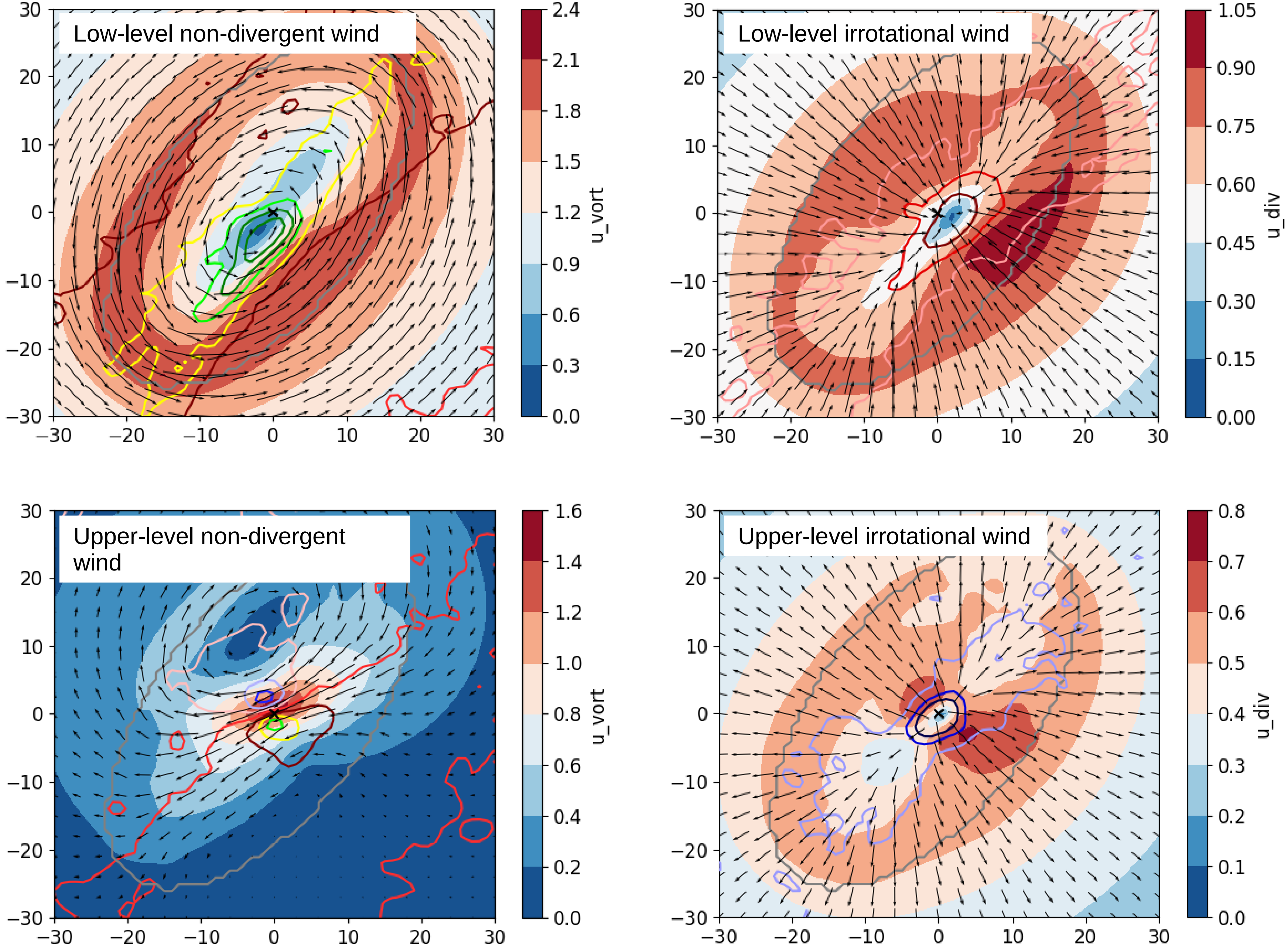
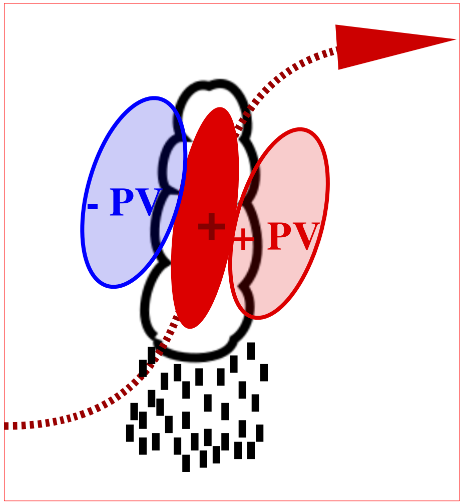


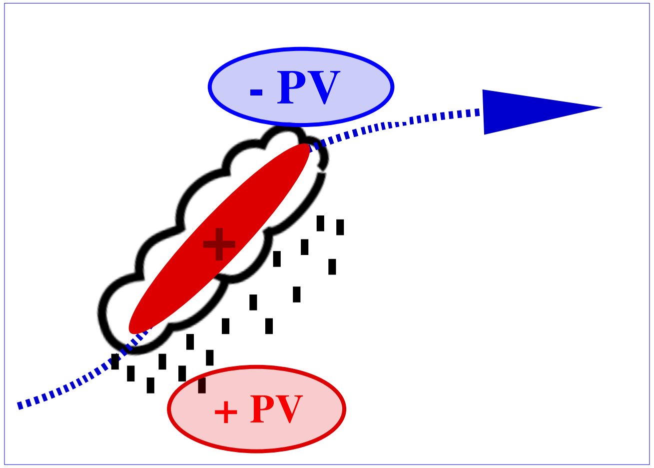
Flow attribution



PV modification

$$\frac{D}{Dt}PV \approx \frac{1}{\rho}\left[\zeta\frac{\partial\dot{\theta}}{\partial z} + \omega_h \cdot \nabla_h\dot{\theta}\right]$$



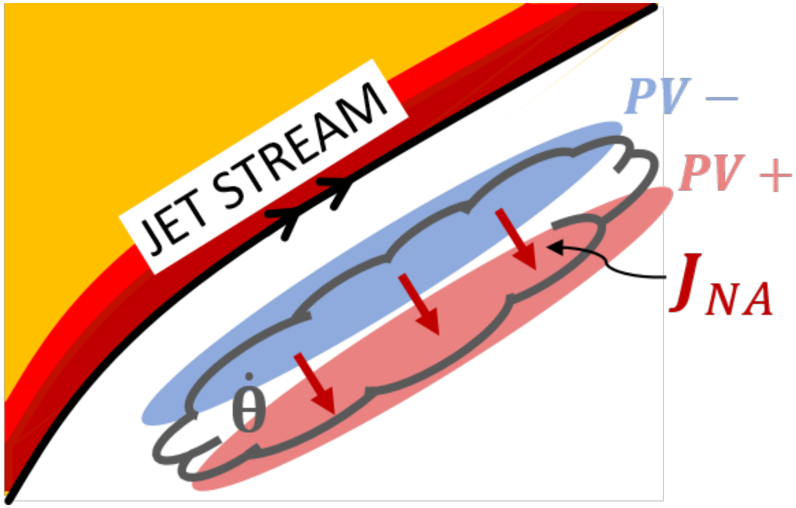


Harvey et al.2020, QJR

diabativ mass flux divergence

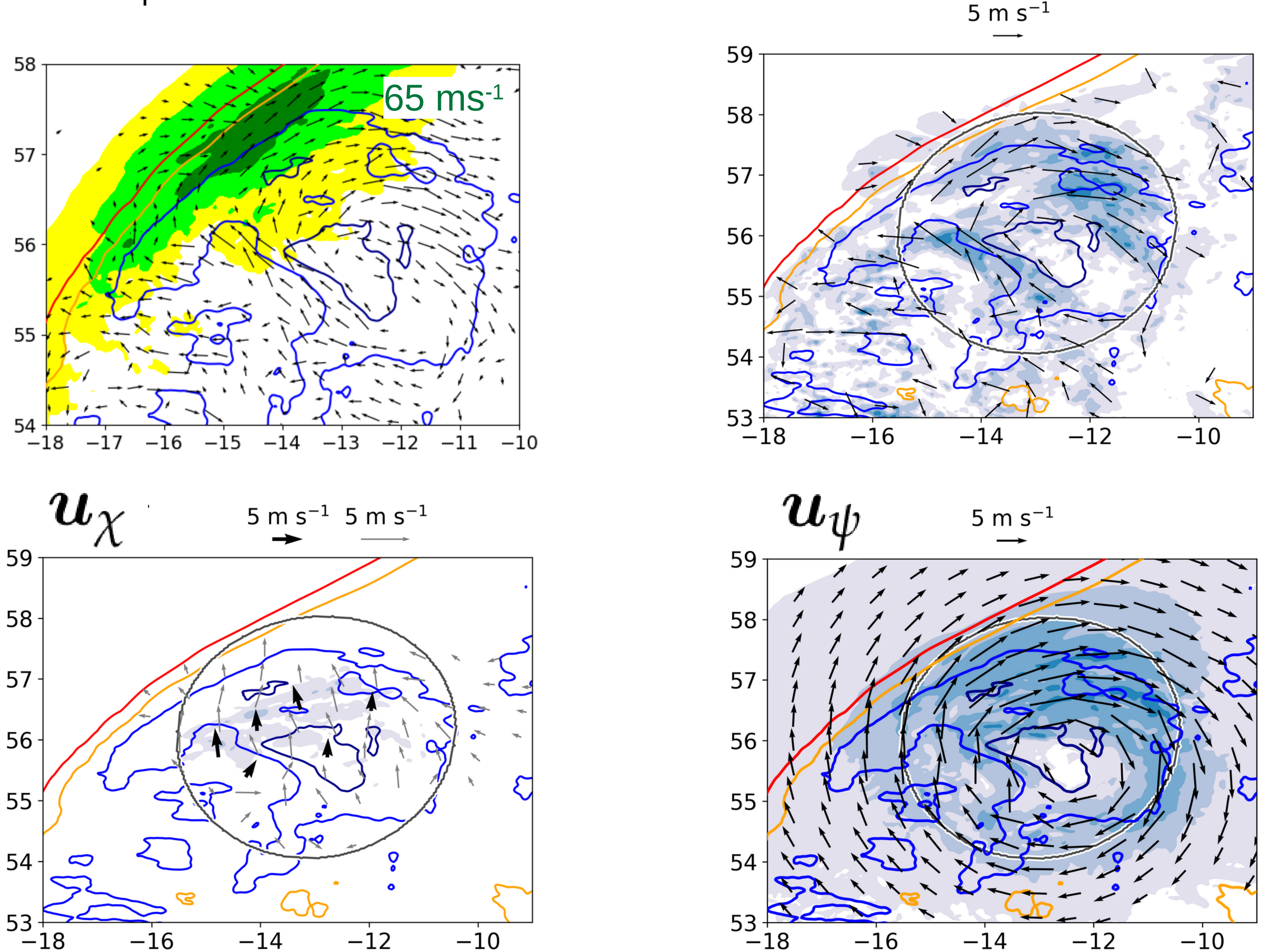
non-advective PV flux

$$\rho\frac{\tilde{D}P}{Dt} = P\nabla\cdot(\rho\mathbf{u}_D) + \nabla\cdot\left(\zeta_{//}\dot{\theta}\right) - \nabla\cdot(\mathbf{F}\times\nabla\theta)$$

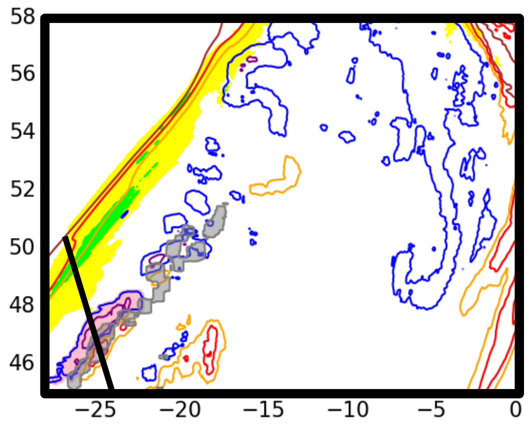


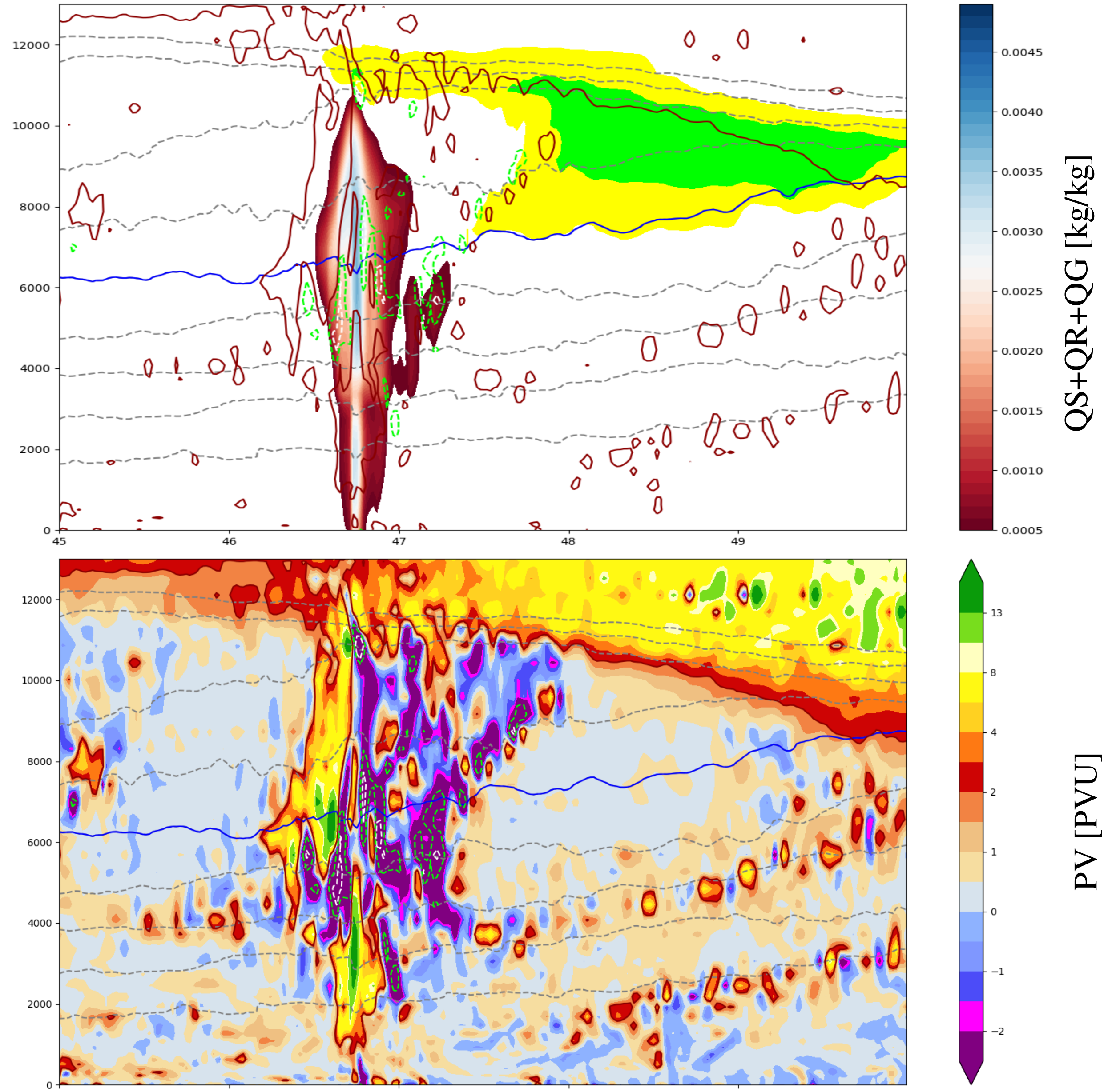
Jet acceleration

18 UTC 23 Sep 2016



Vertical cross-section





Vertical cross-section