Representation of the warm conveyor belt of the Stalactite Cyclone in convective-permitting simulation of Meso-NH

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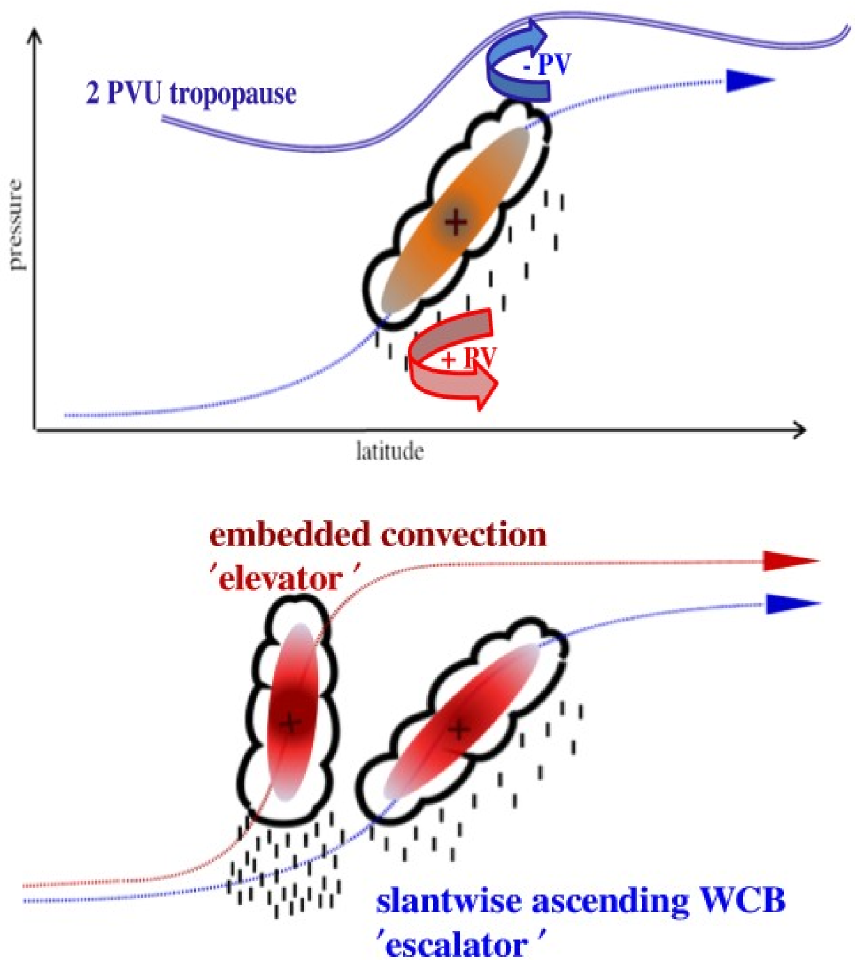
Motivation



Conceptual model by Oertel et al. (2019)

- WCBs are continously rising air masses which typically ascent 600 hPa in 48 h
  (Browning, 1986; Wernli and Davies, 1997; Madonna et al., 2014)
- Cloud diabatic processes in WCBs can impact the cyclone dynamics and the downstream large-scale circulation
  (Hoskins et al. 1985; Joos and Wernli, 2012; Binder et al. 2016, Joos and Forbes, 2016;)
- Recent studies with convection resolving models suggest the occurrence of rapid ascents embedded in some WCBs cases and can also be relevant for the large-scale dynamics
  (Rasp et al., 2016; Oertel et al., 2019a; Oertel et al., 2019b)
- Cloud processes and convection are parameterized in NWP models: suspected to be sources of forecast error growth over the Atlantic
  (Davies and Didone, 2013; Selz and Craig, 2015)

1) What are the characteristics of the ascents in the WCB of the Stalactite cyclone?

2) What are the processus leading to fast ascents?

Simulation and observations

Meso-NH mesoscale non-hydrostatic model **simulations**:

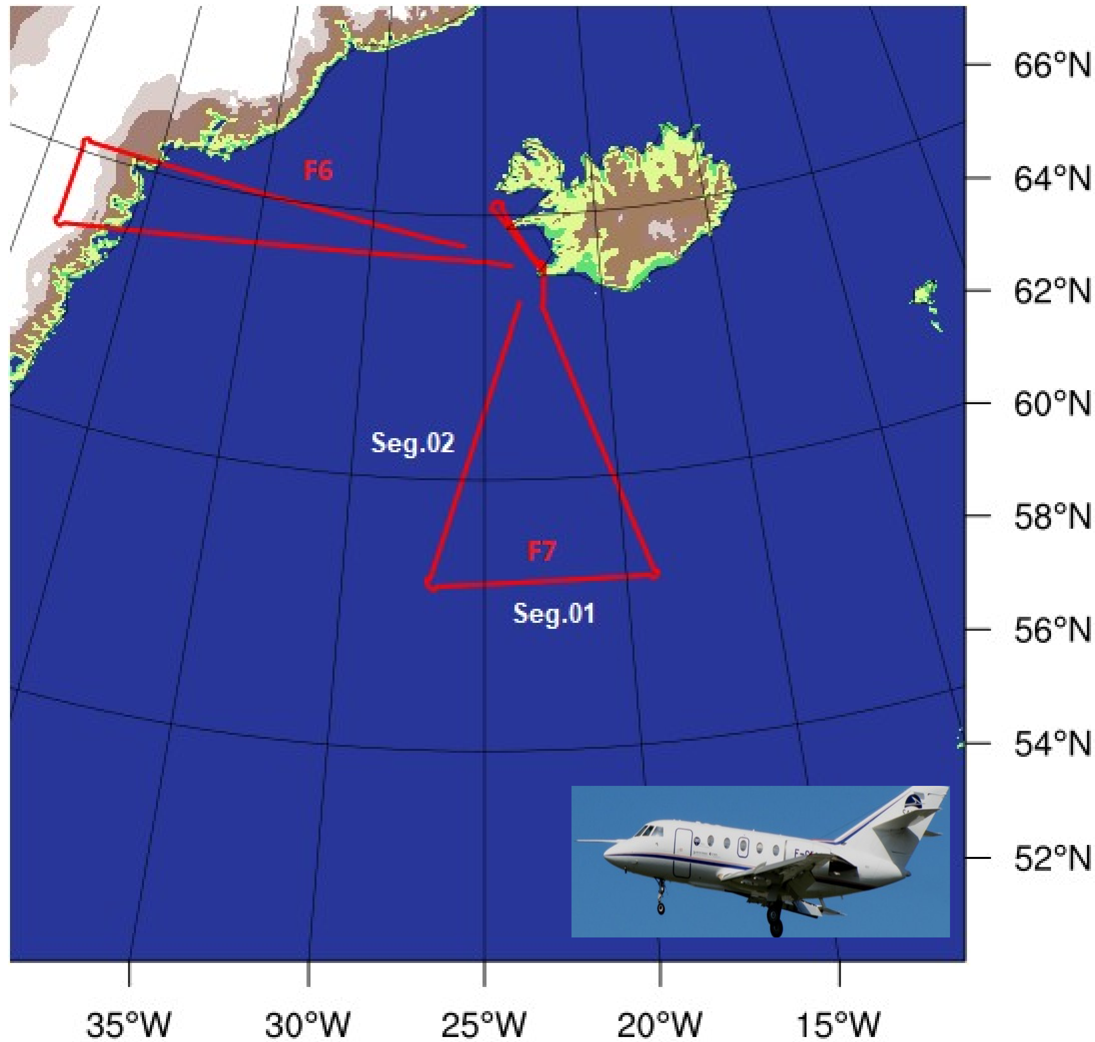
- Δx=2.5 km
  → convection permitting
- 800x800 grid points
- start at 00 UTC, 2 October 2016
  ECMWF analyses; t=36 h

WCB ascents identification in the reference simulation REF:

→ Lagrangian online trajectories calculated from 3D wind at every model time step (Δt=20 s)

→ Clustering tool in Meso-NH

Dauhut et al., 2016



Observations:

- MSG satellite images (10.8 µm)
- RASTA Doppler radar (3 mm)

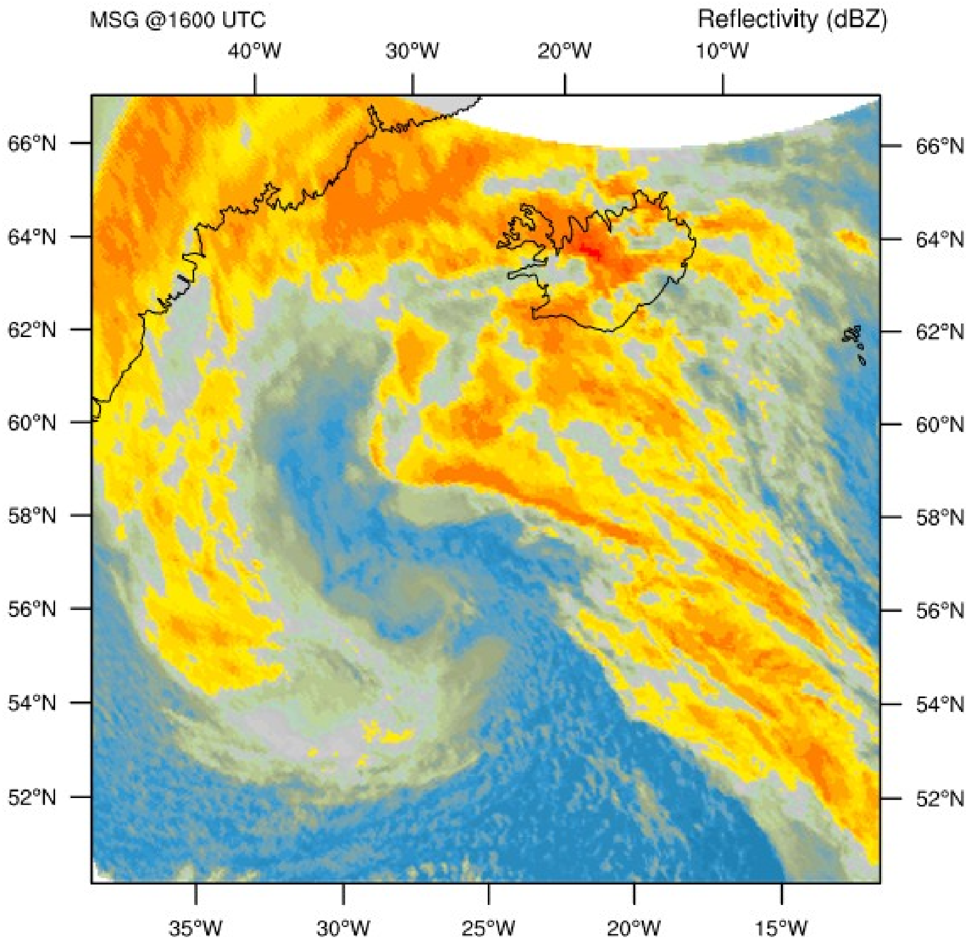
Delanoë et al., 2007

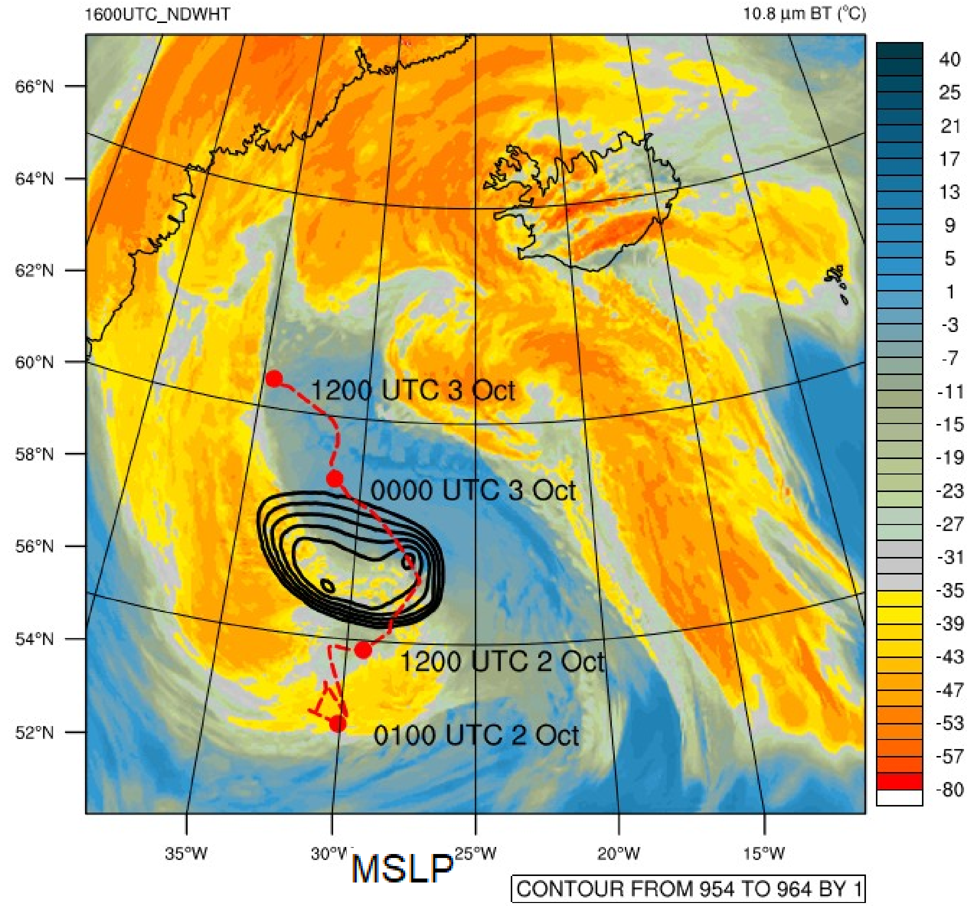
F6: 0900 UTC – 1130 UTC → WCB outflow

F7: 1300 UTC – 1600 UTC → WCB ascents

1. What are the characteristics of the ascents in the WCB of the Stalactite cyclone?

Stalactite cyclone track





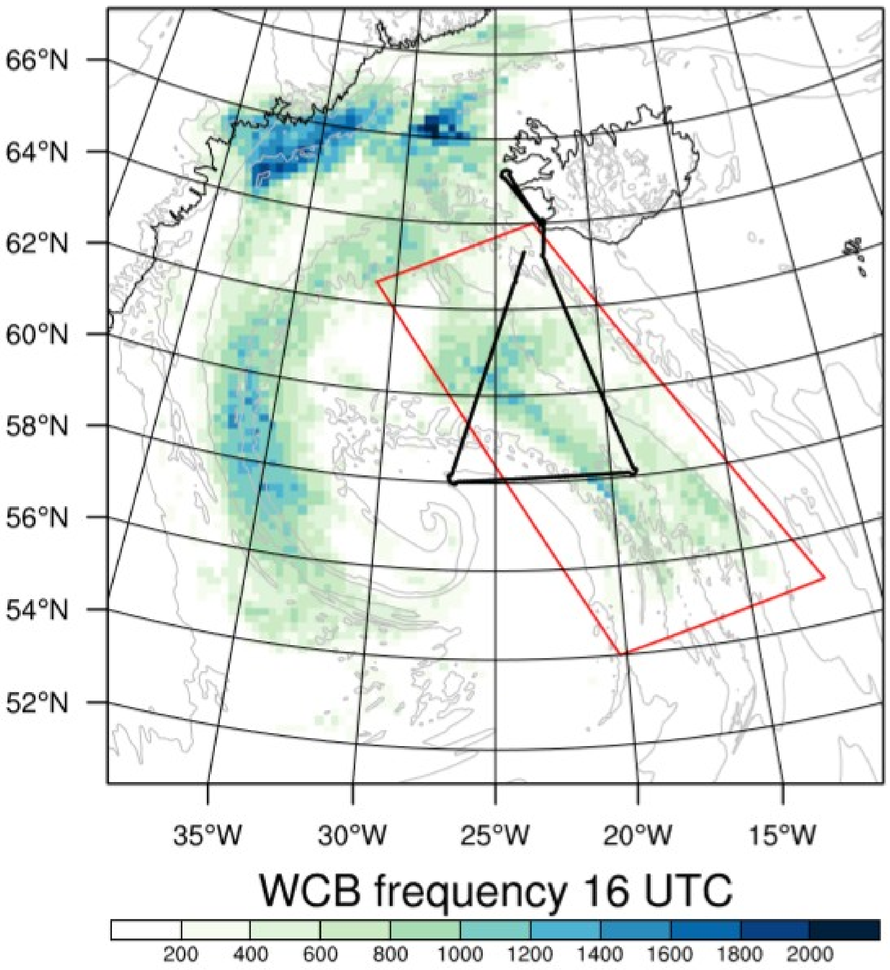
→ Track and deepening well reproduced in REF

→ Eastward shift of MSLP in REF (eg. cloud structure)

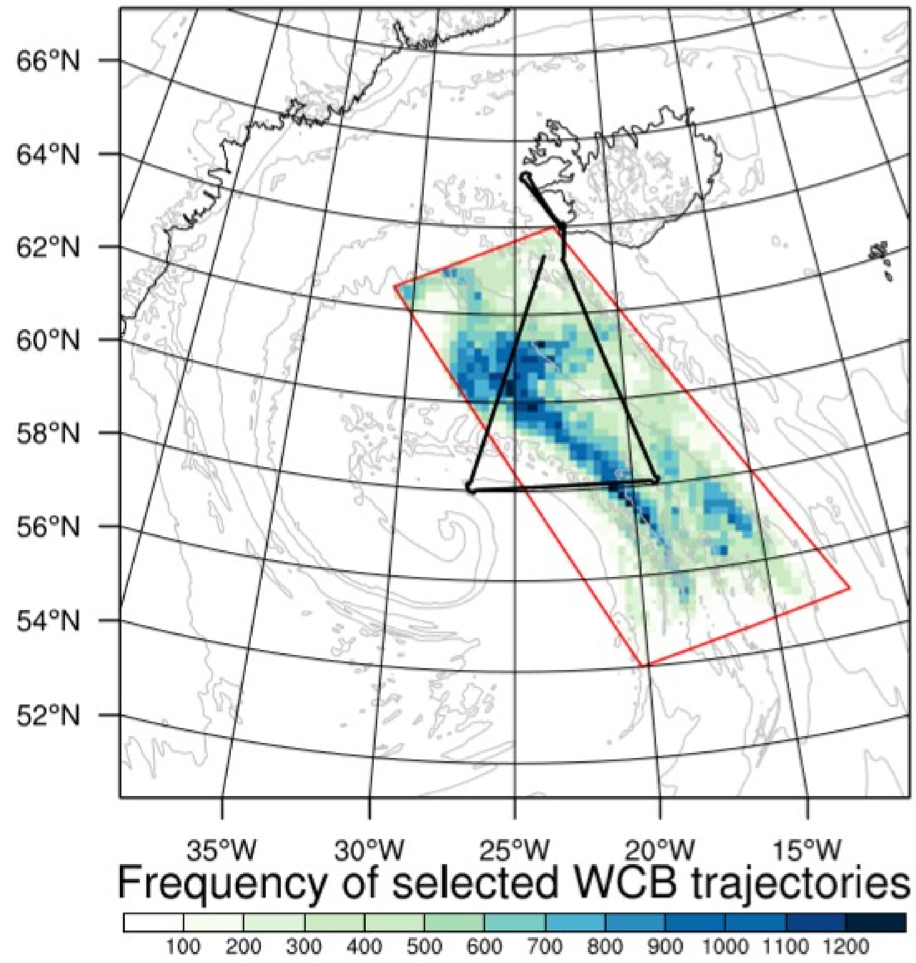
WCB identification at 1600 UTC

- **WCB:** ΔP_{12h} = pressure variation between 1000 and 2200 UTC (Oct. 2)

  $\Delta P_{12h} \leq -150$ hPa (e.g 600 hPa in 48 h ; Madonna et al. 2014)



THTE contours at z~1 km (K)



Red box : selected trajectories

→ The plane flew over the WCB

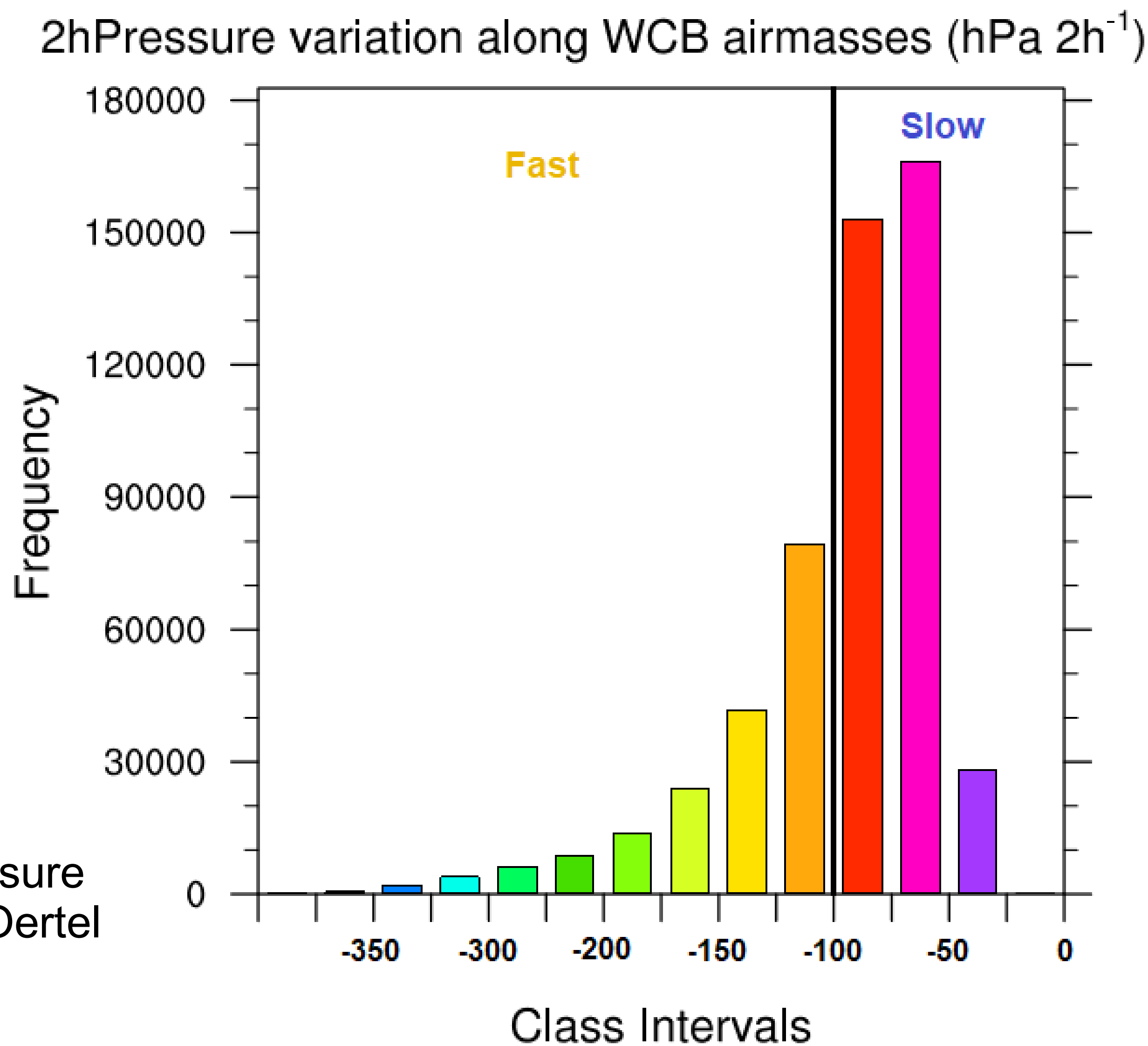
Slow - Fast ascents identification in the red box

- **WCB:** ΔP_{12h} = pressure variation between 1000 and 2200 UTC (Oct. 2)

  $\mathbf{\Delta P_{12h} \leq -150}$ **hPa** (e.g 600 hPa in 48 h ; Madonna et al. 2014)

Fast ascents:

$\Delta P_{2h} \leq -100$ hPa

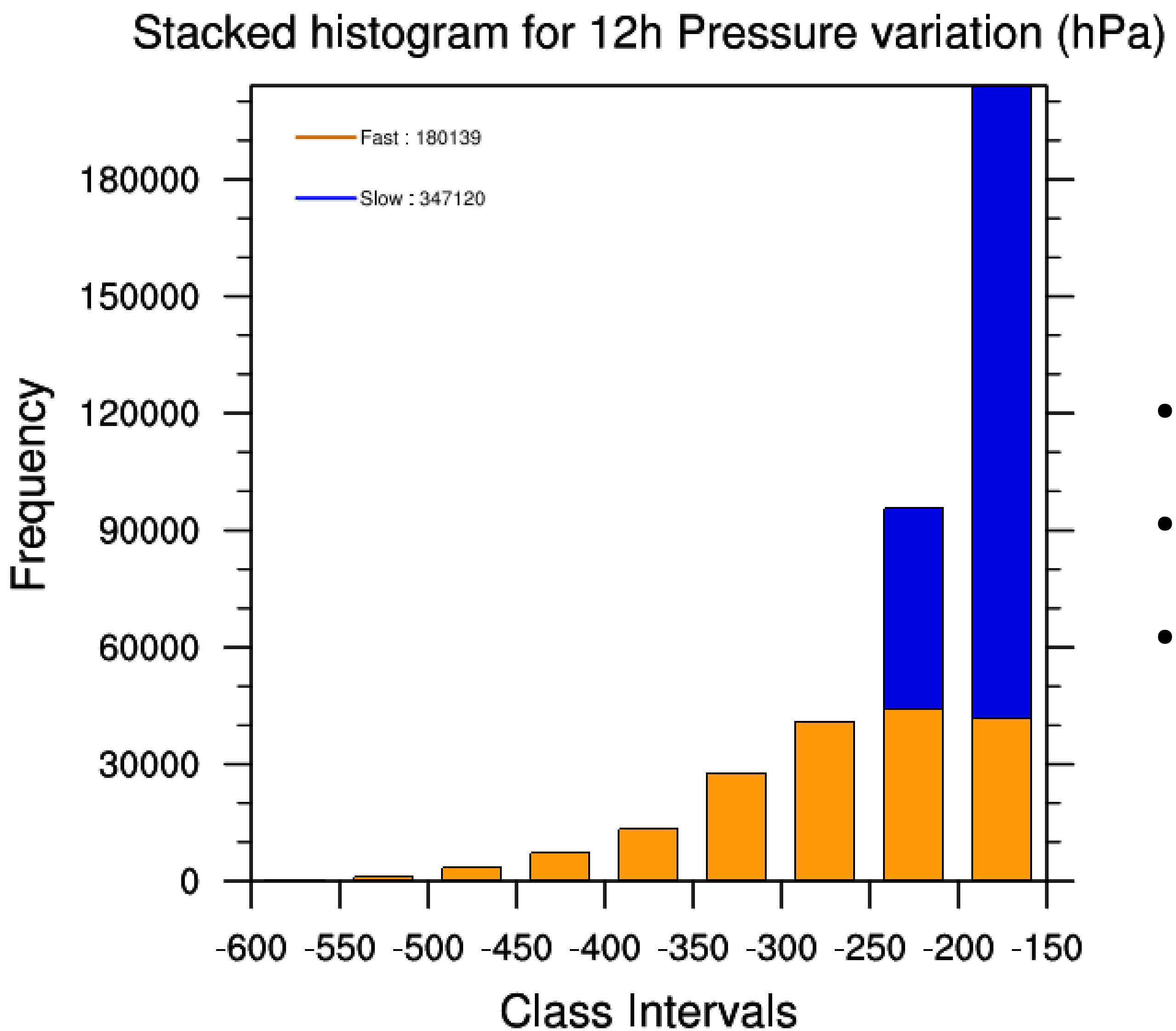


Slow ascents:

$\Delta P_{2h} > -100$ hPa

Fast ascent pressure criteria same as Oertel et al. 2019a

Slow - Fast ascents elevation in 12 h evolution

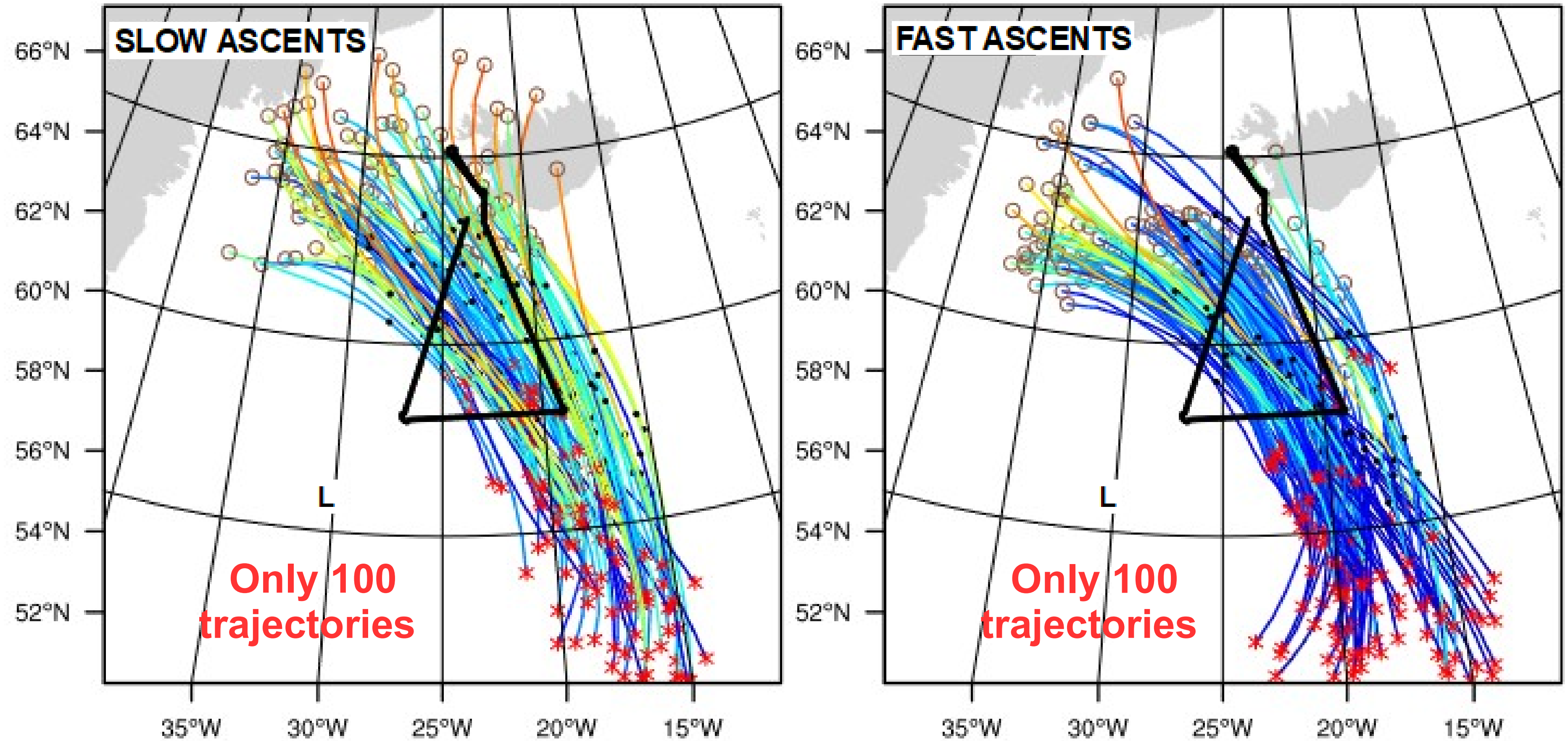


- WCB_{tot} ~530 000 trajs
- **Slow** ~2/3 WCB_{tot}
- **Fast** ~1/3 WCB_{tot}

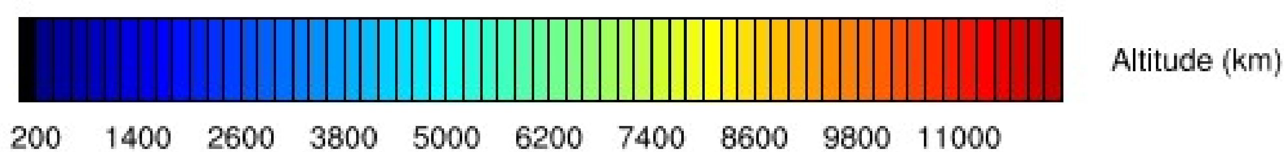
→ **Slow ascents**: -150 hPa ≤ΔP_{12h}≤ -250 hPa

→ **Fast ascents**: -150 hPa ≤ΔP_{12h}≤ -550 hPa

Air mass trajectories between 1000 – 2200 UTC



x start
● at 1600 UTC
L cyclone center



1a) **What is the location of slow and fast ascents in the WCB?**

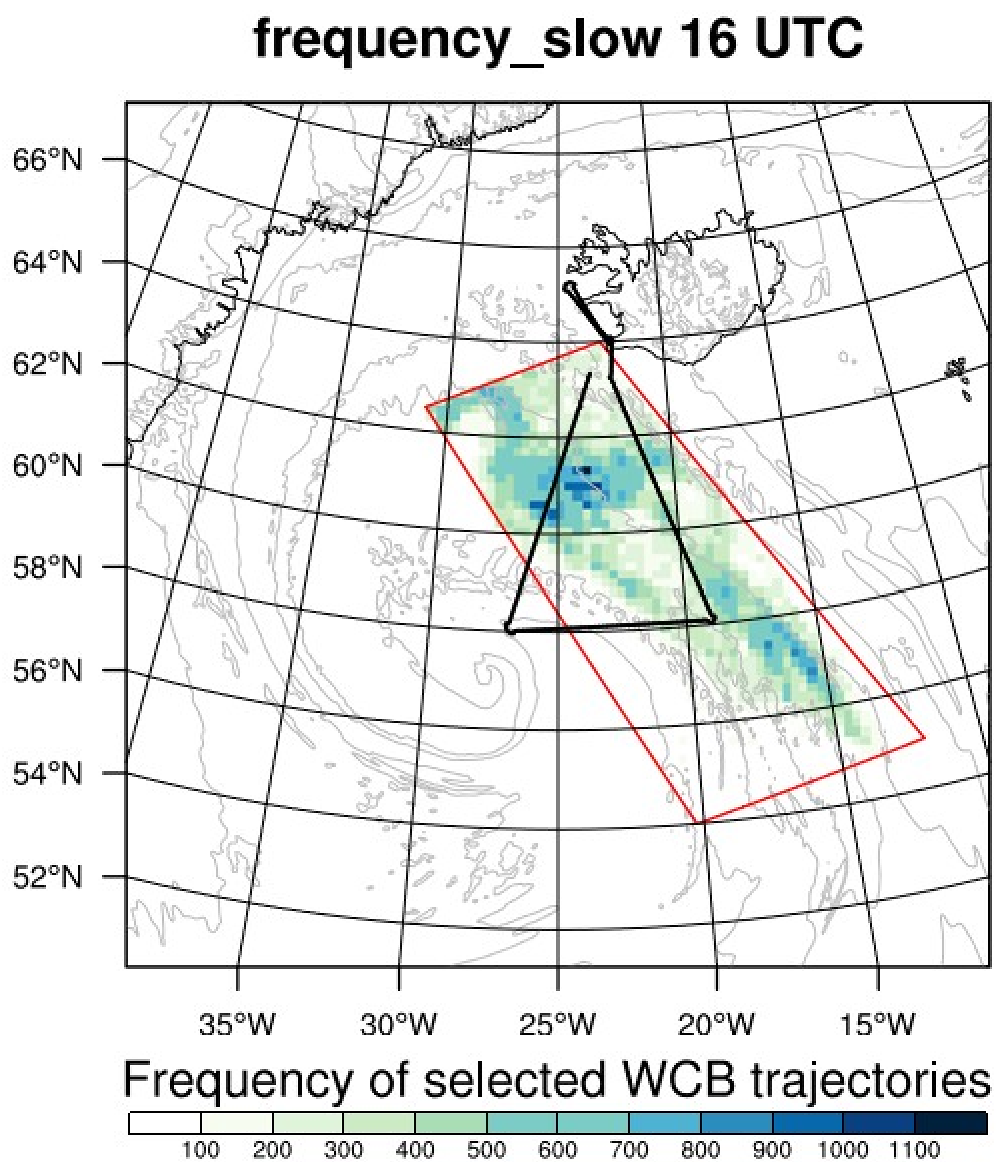
1b) **How many fast and slow ascents have a cyclonic/anticyclonic trajectory?**

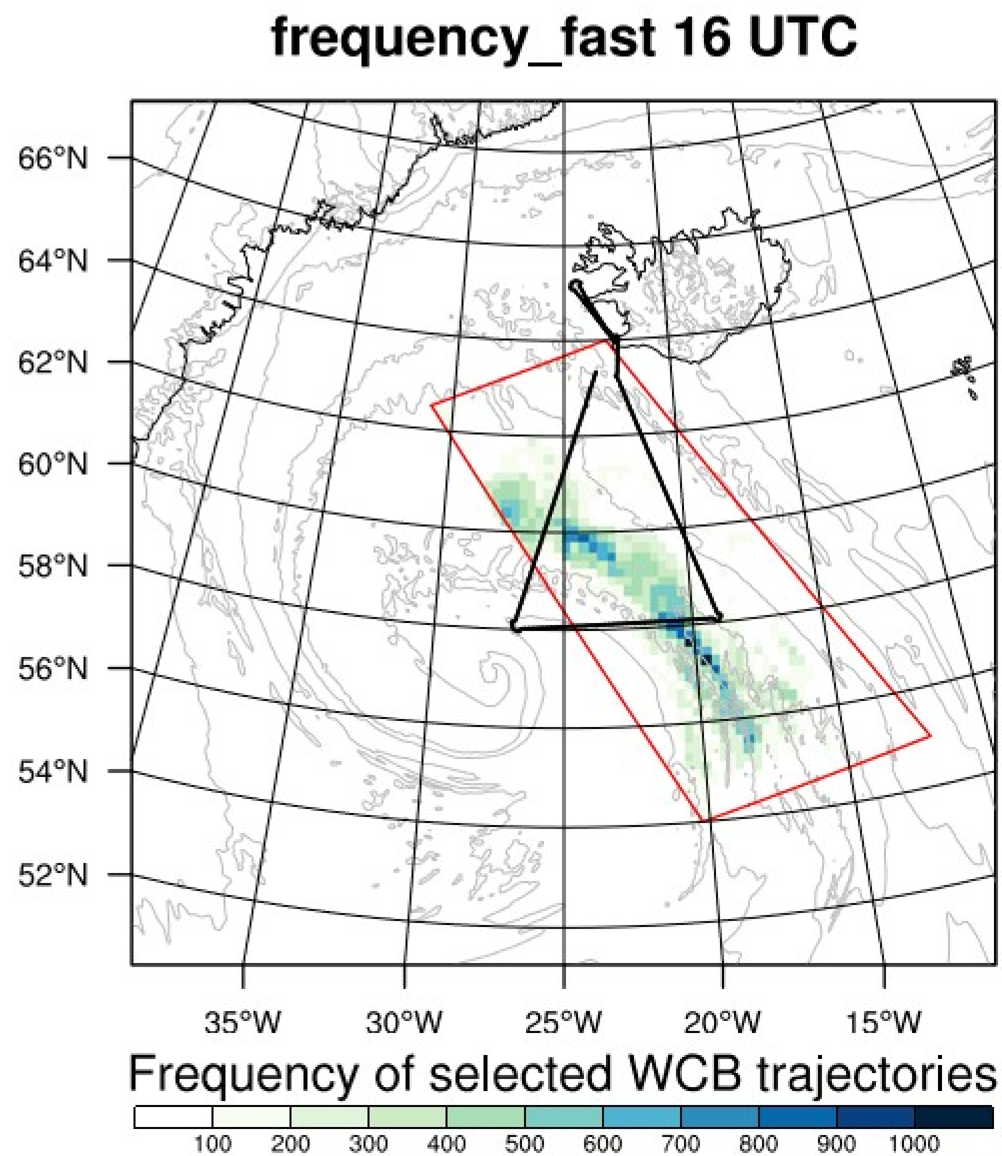
1c) **What is the altitude of fast and slow ascents?**

1a) Slow – Fast ascents location at 1600 UTC

Slow: -100 hPa < ΔP_{2h}

Fast: $\Delta P_{2h} \leq$ -100 hPa

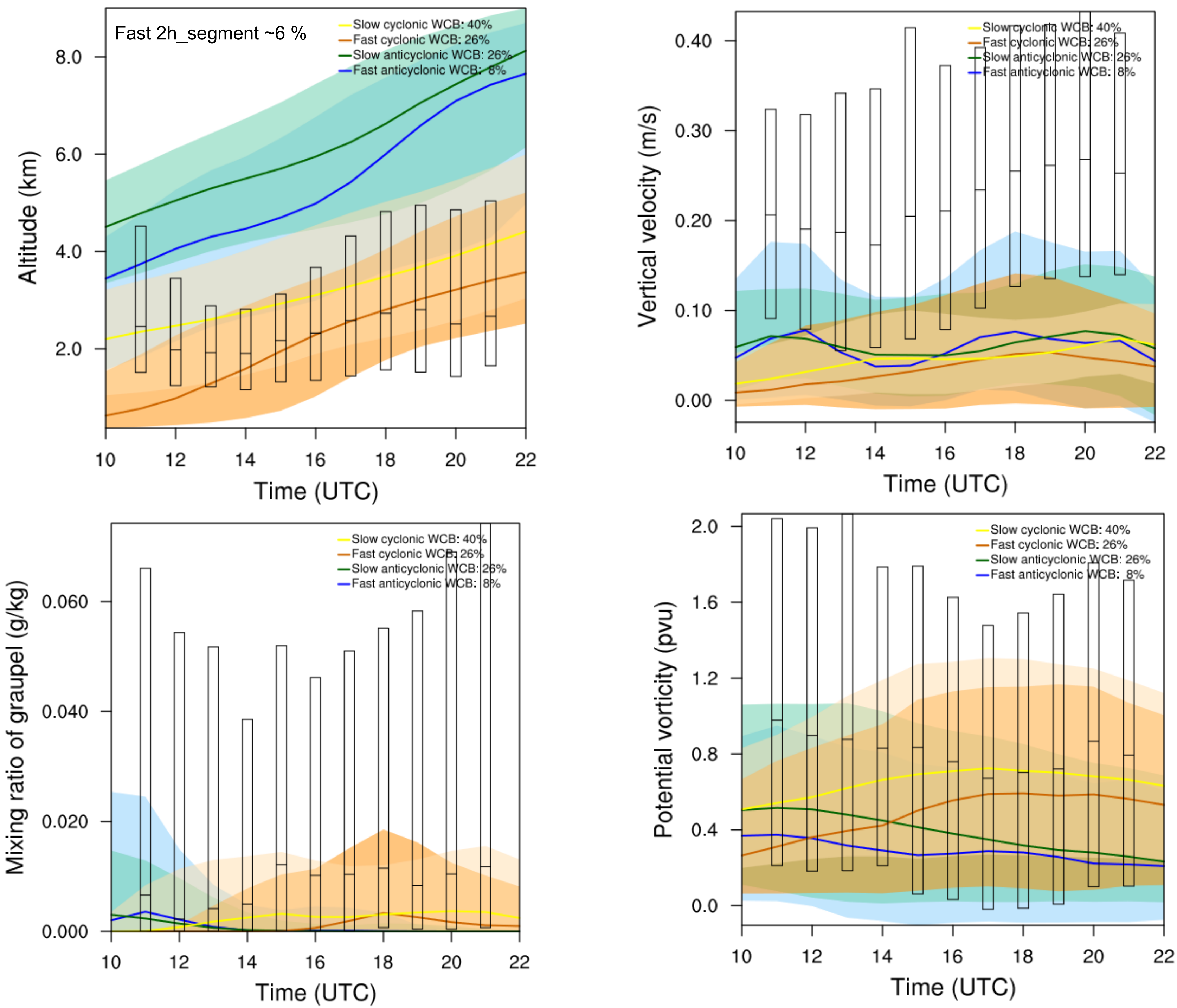




→ Slow ascents in the core of WCB

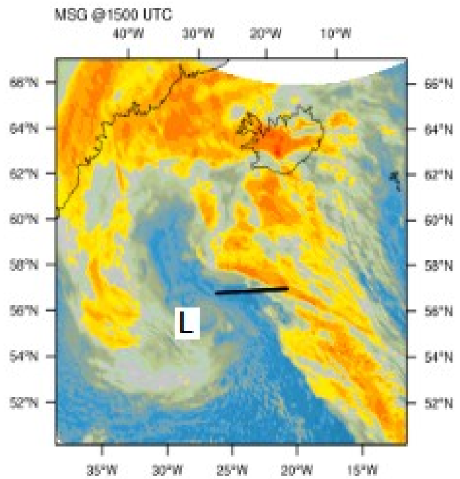
→ Fast ascents in the west side of WCB

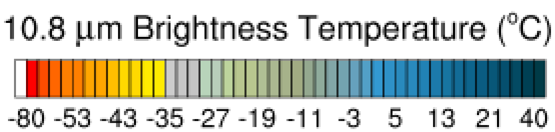
1b,c) Temporal evolution of air-mass characteristics

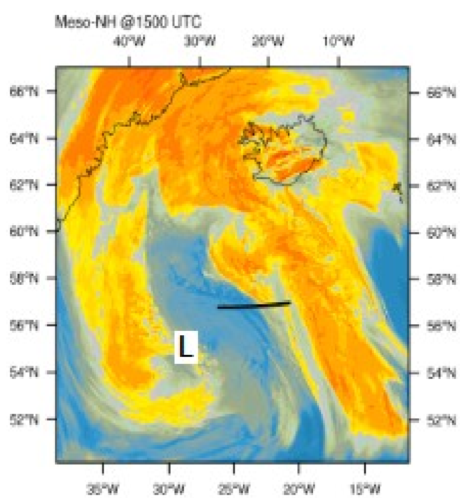


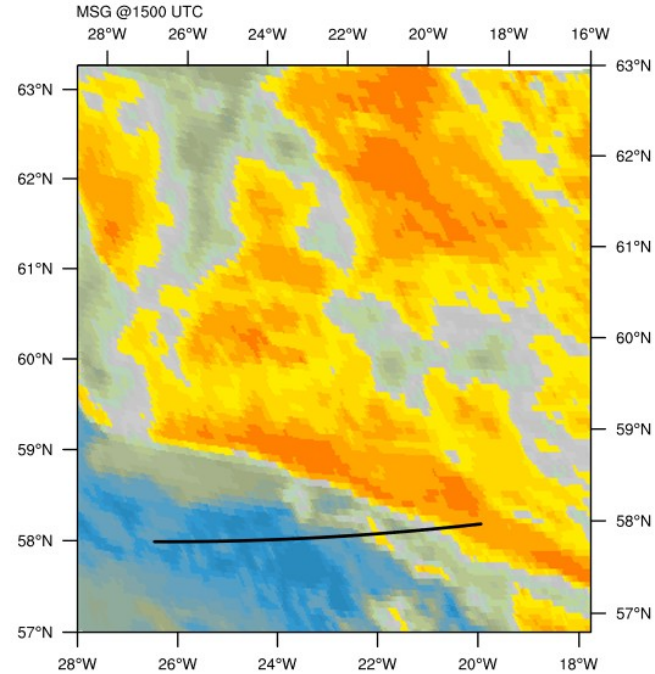
2. What are the processus leading to fast ascents?

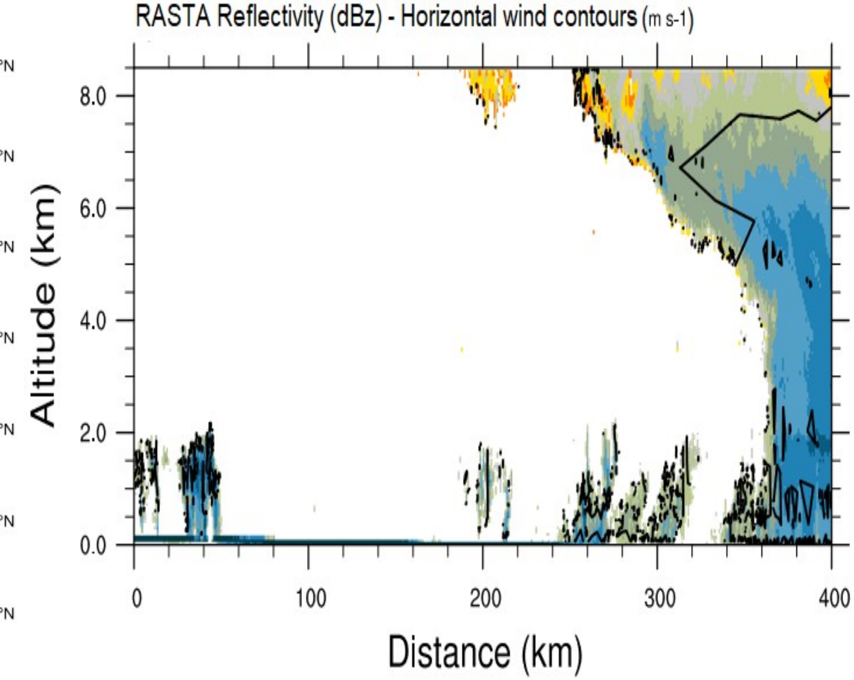
Zoom at 1500 UTC



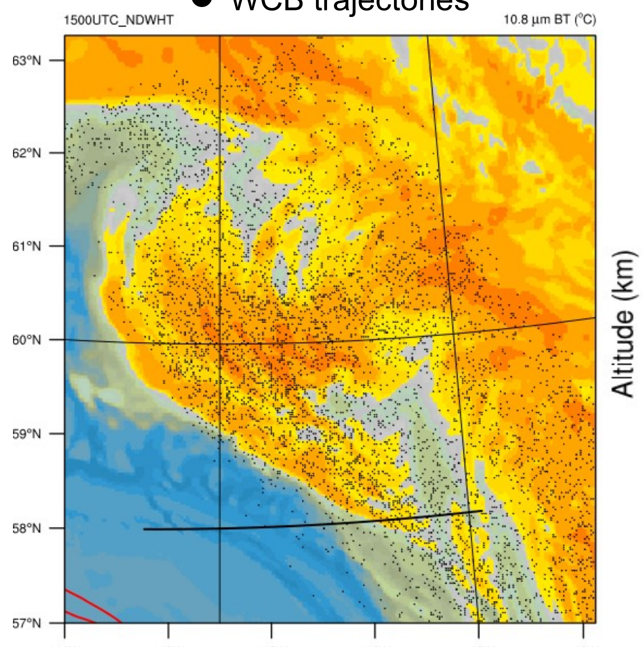




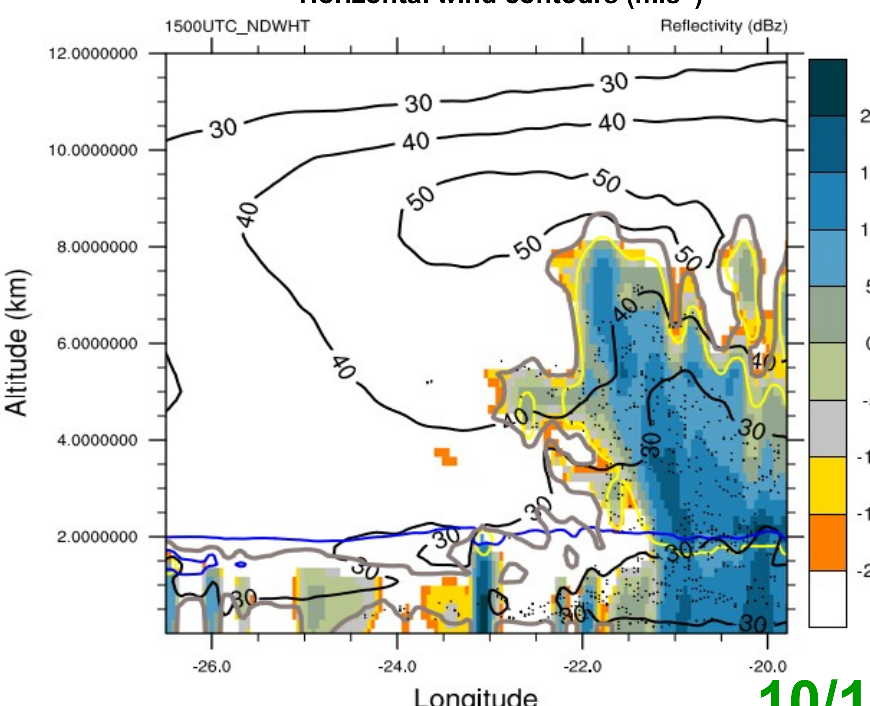




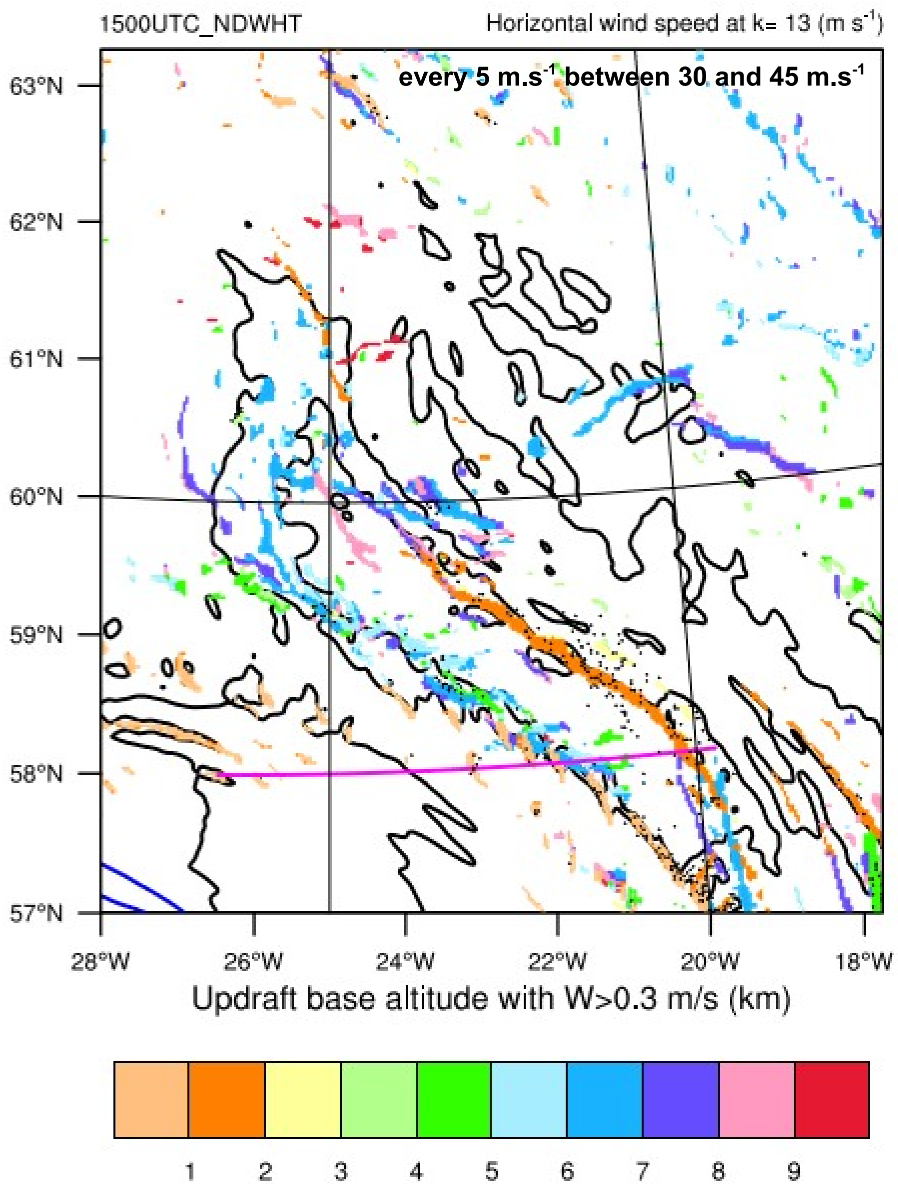
● WCB trajectories

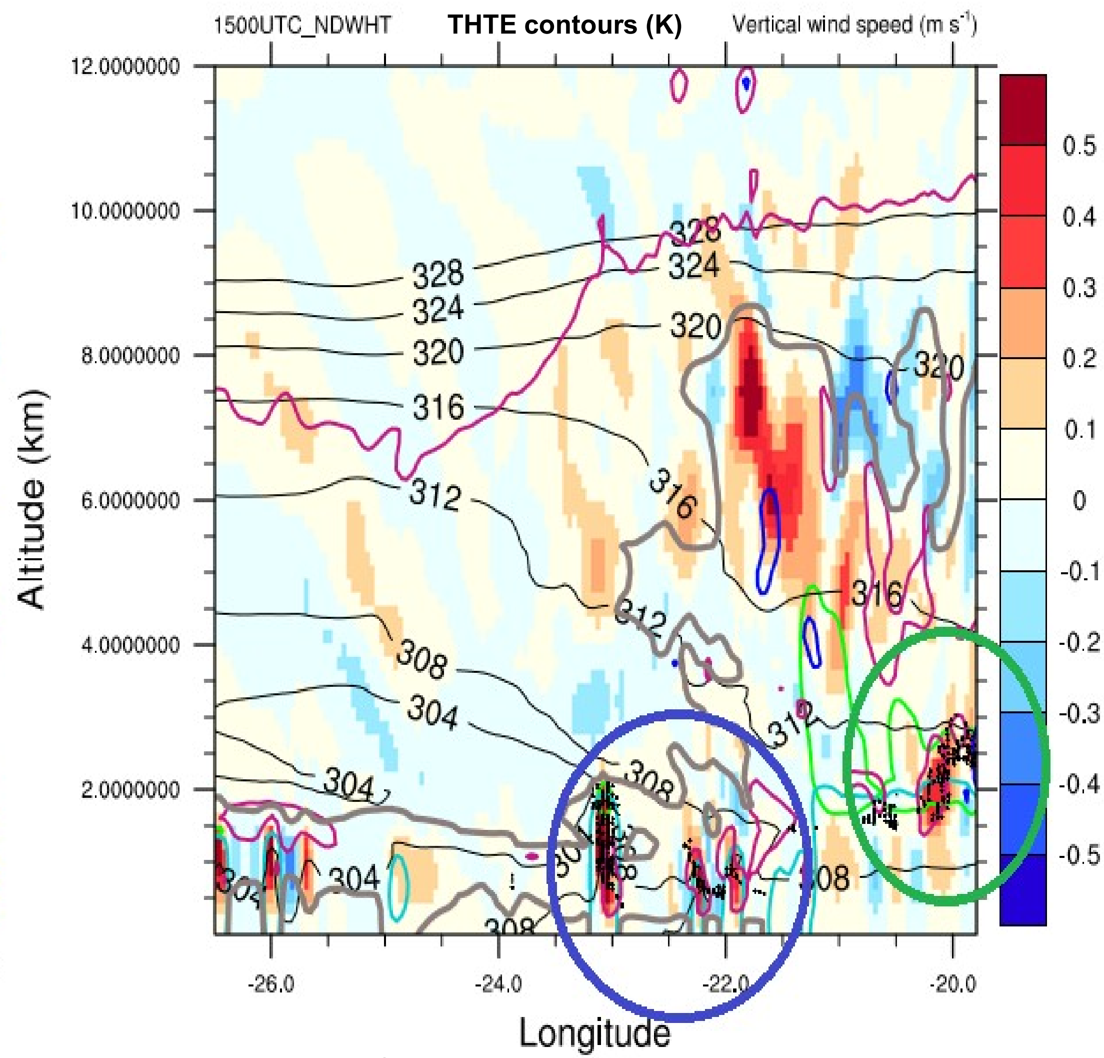


Horizontal wind contours (m.s^{-1})



Fast ascents at 1500 UTC





● Fast Lag. trajs. at 1500 UTC
(every 20 trajectories)

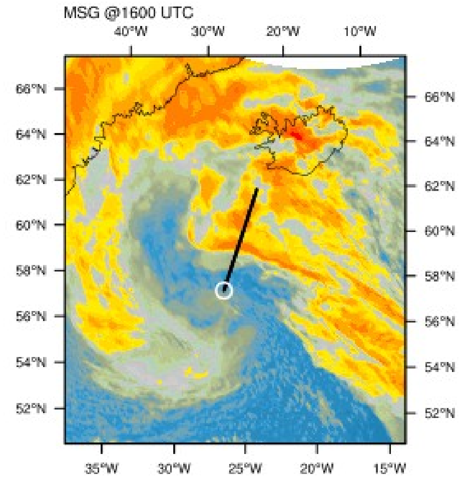
→ Good accordance between the location of Fast Lagrangian trajectories and the Updrafts base

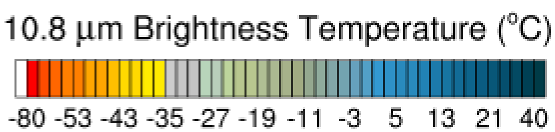
→ **Extended low-level jet** (LLJ)

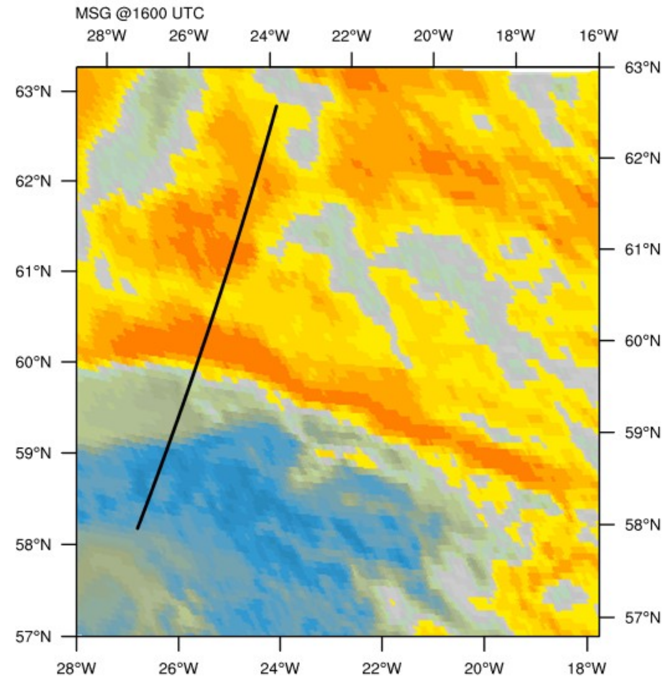
→ **Isolated shallow convection** located close to the cold front, at the west of the WCB and LLJ

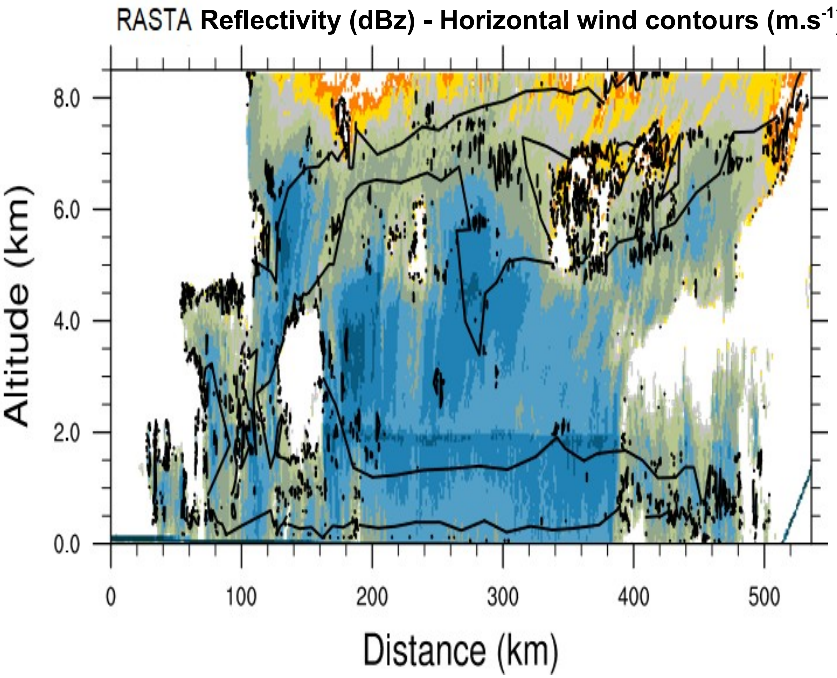
→ **Organized low-level convection** located in the core of the WCB, at the east of LLJ

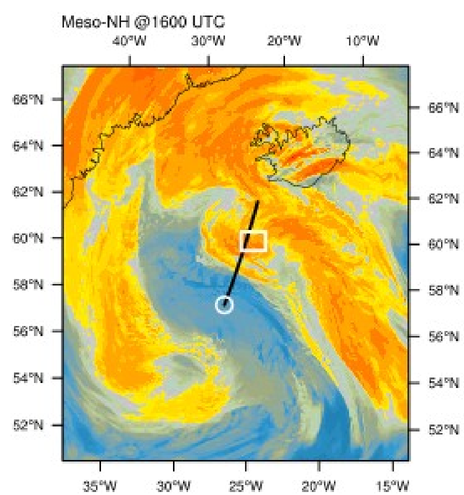
Zoom at 1600 UTC

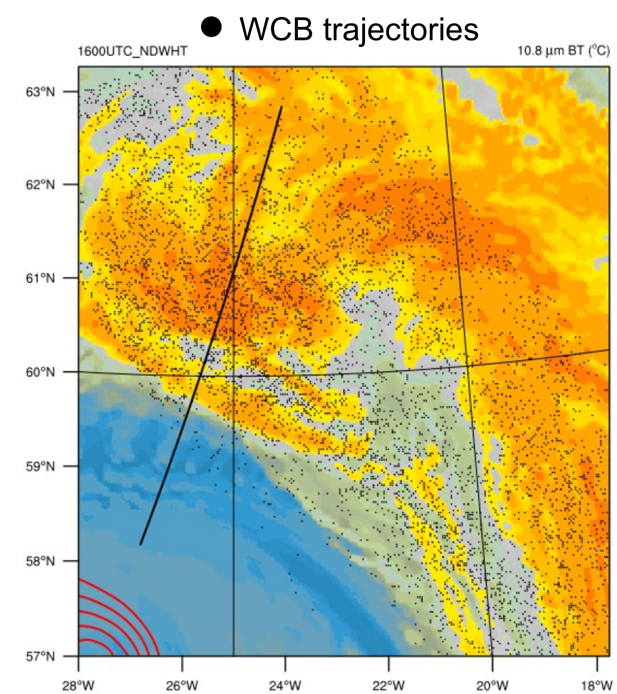


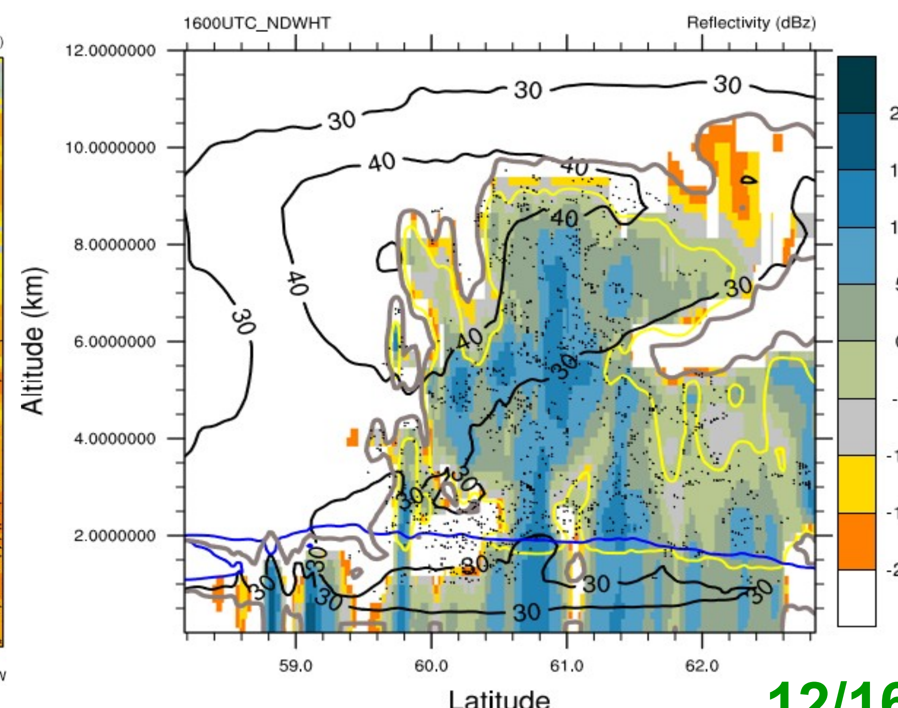




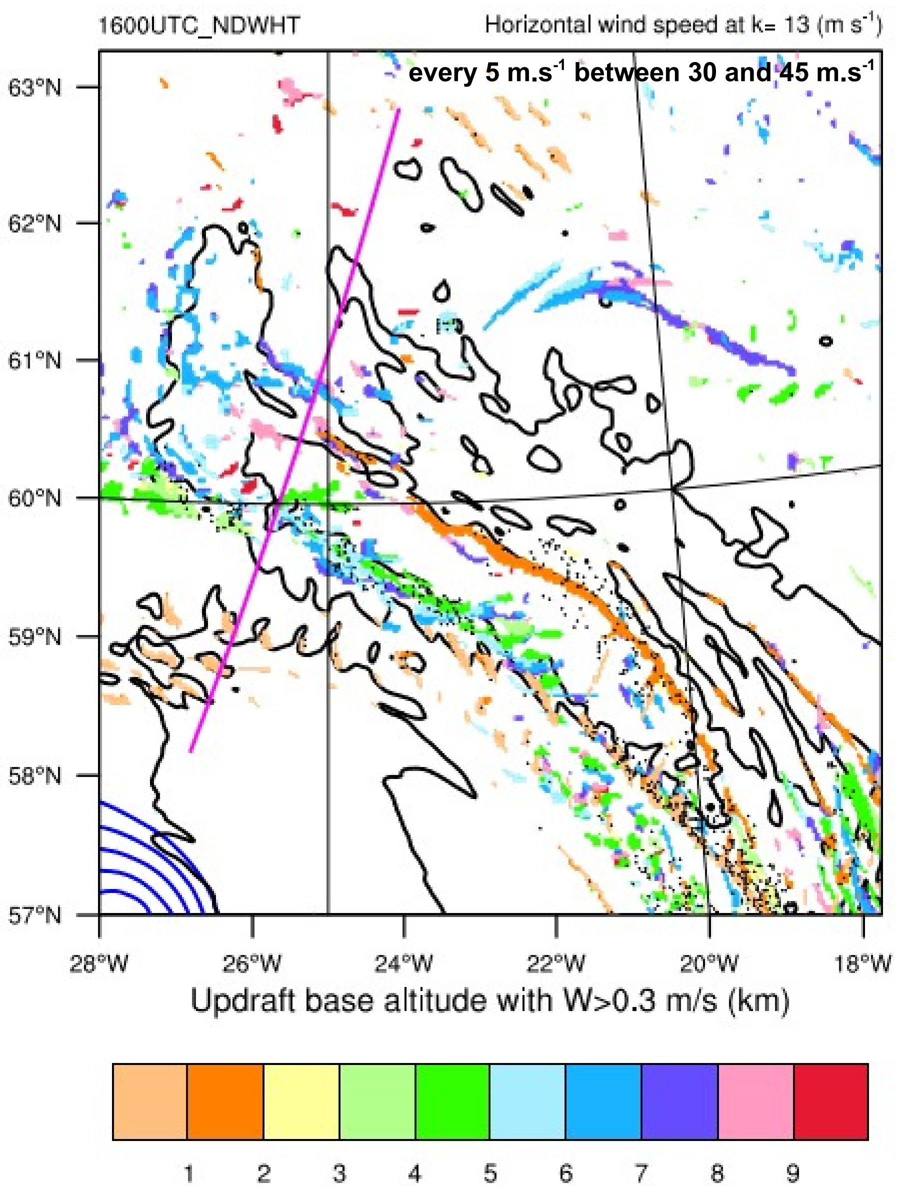


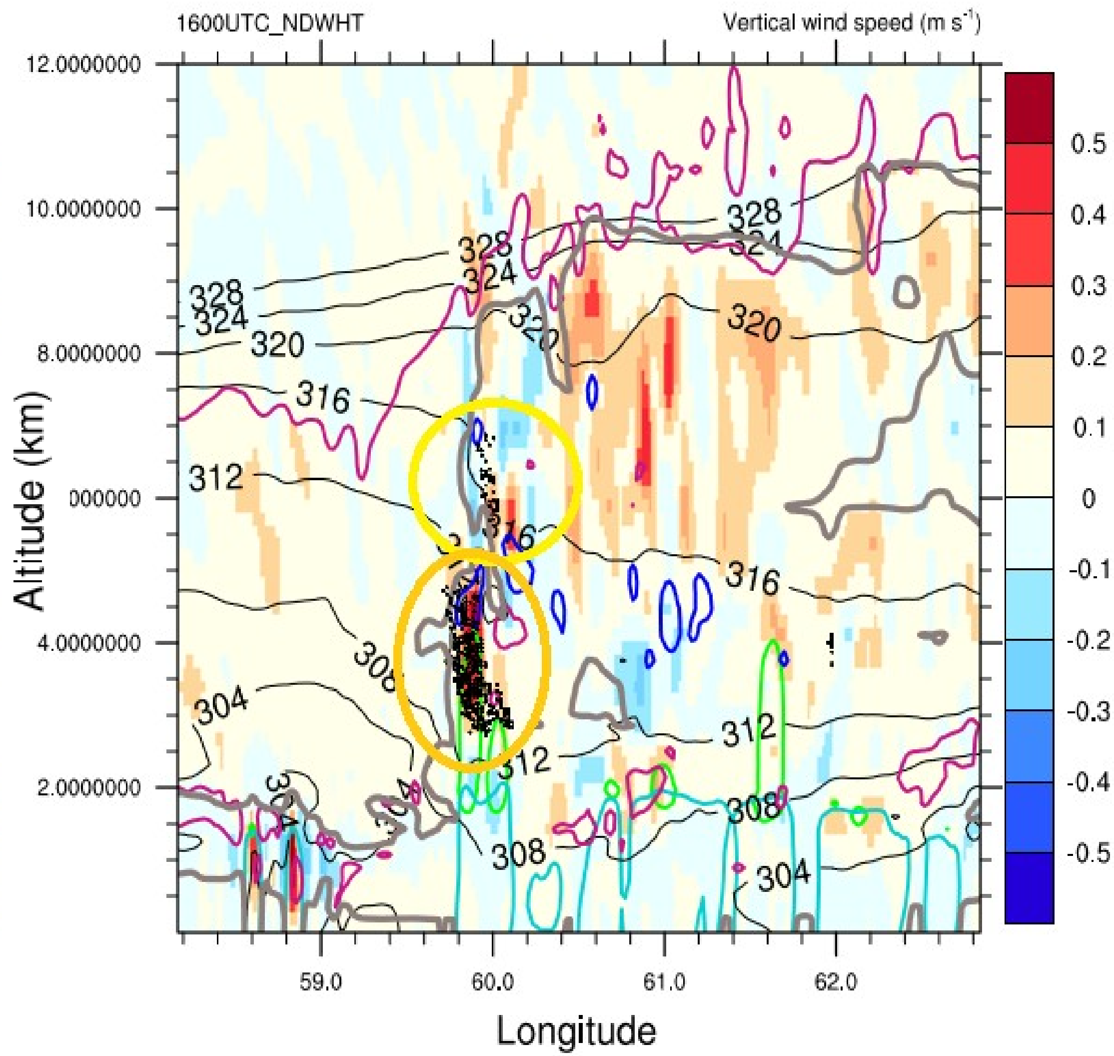






Fast ascents at 1600 UTC





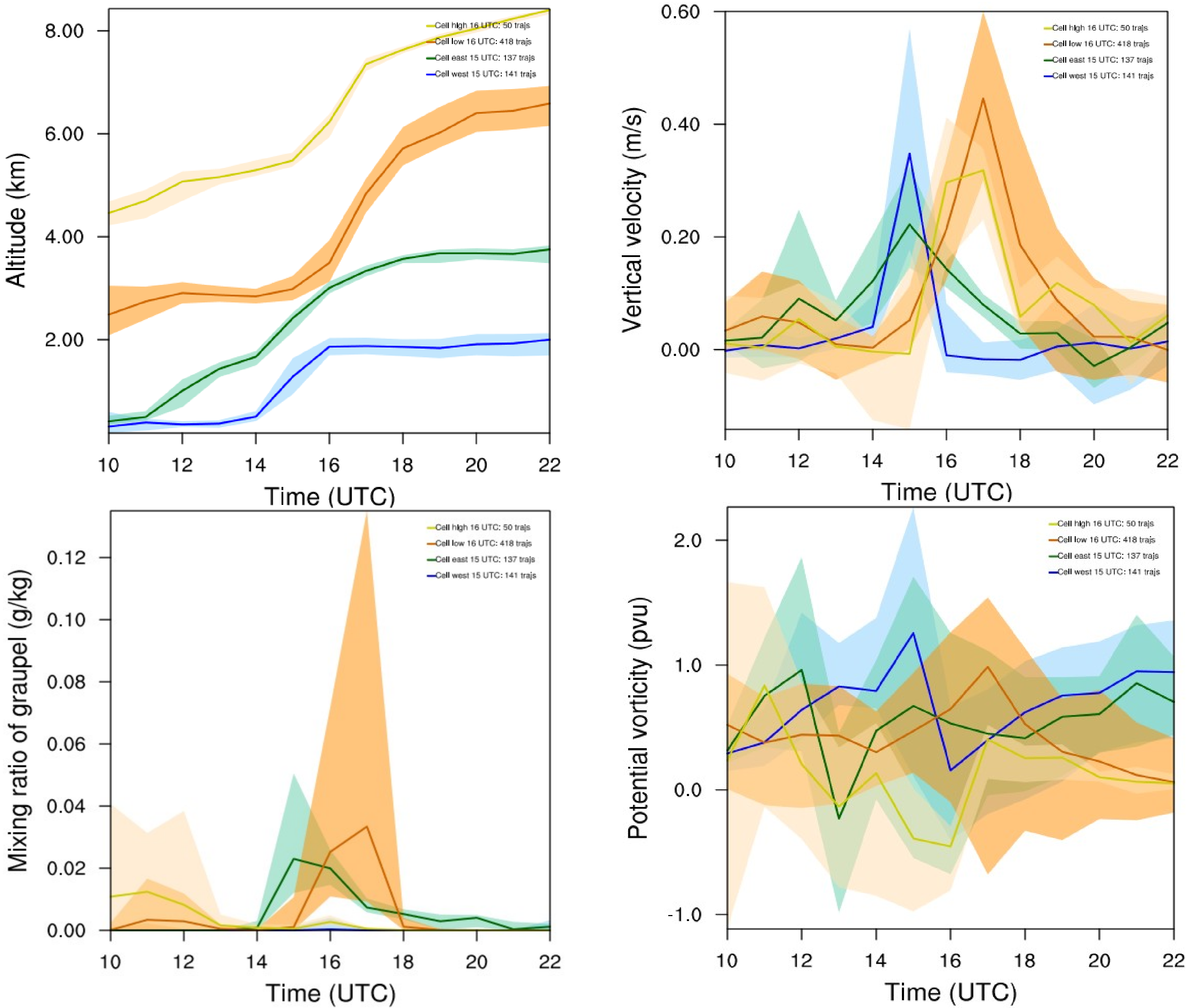
• **Fast Lag. trajs. at 1500 UTC (every 20 trajectories)**

→ Good accordance between the location of Fast Lagrangian trajectories and the Updrafts base

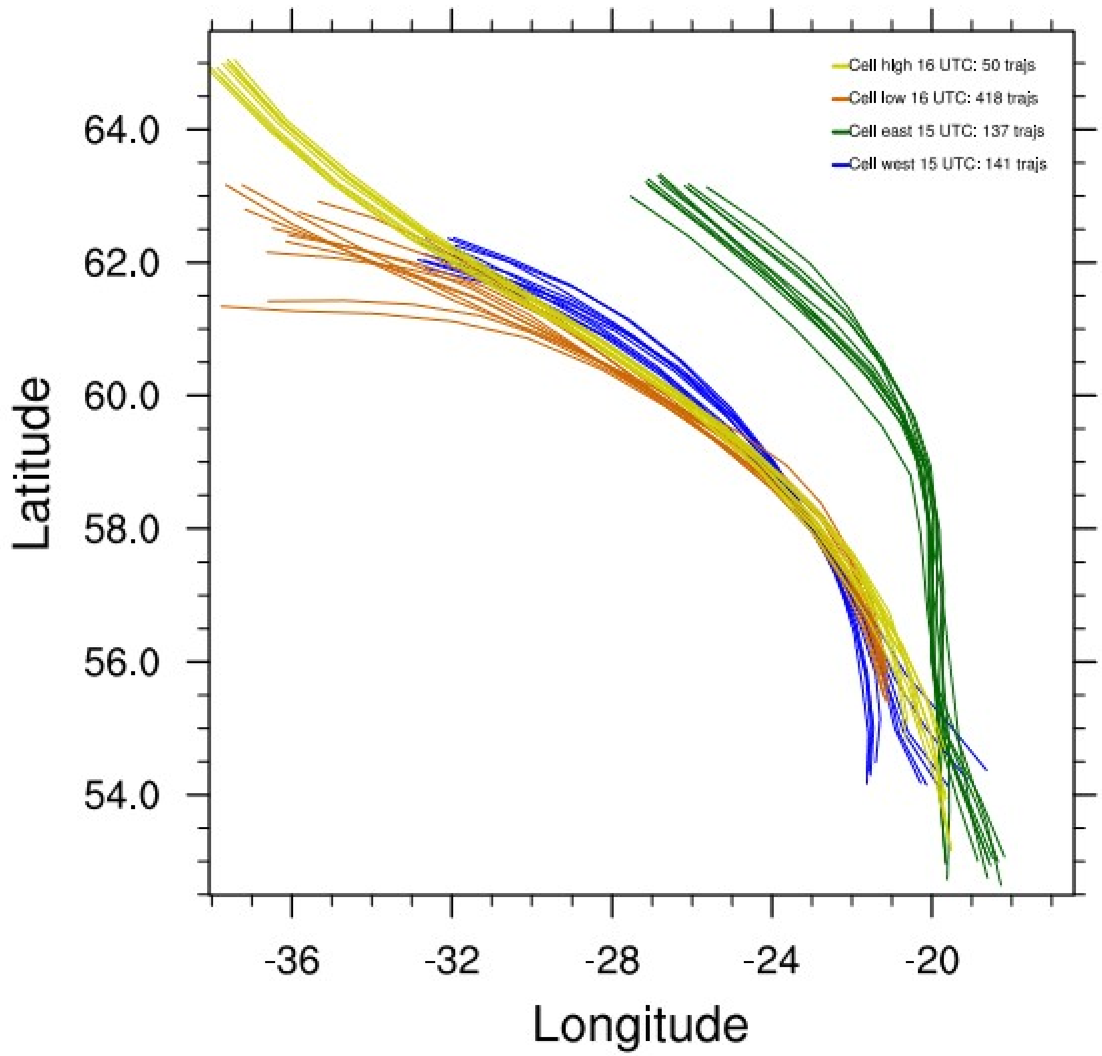
→ **Extended low-level jet** (LLJ)

→ **Isolated Mid-level** (high/low) **convection** located to the west of the WCB and of the LLJ

Temporal evolution of 4 identified convection cells



Trajectories of 4 identified convection cells (10-22 UTC)



→ Différence d'altitude de z=2 km pour les trajectoires rapides identifiées à 1600 UTC font qu'elles empruntent une tournure cyclonique ou anticyclonique en fin de trajectoire

Conclusions

1. **What are the characteristics of the ascents in the WCB of the Stalactite cyclone?**

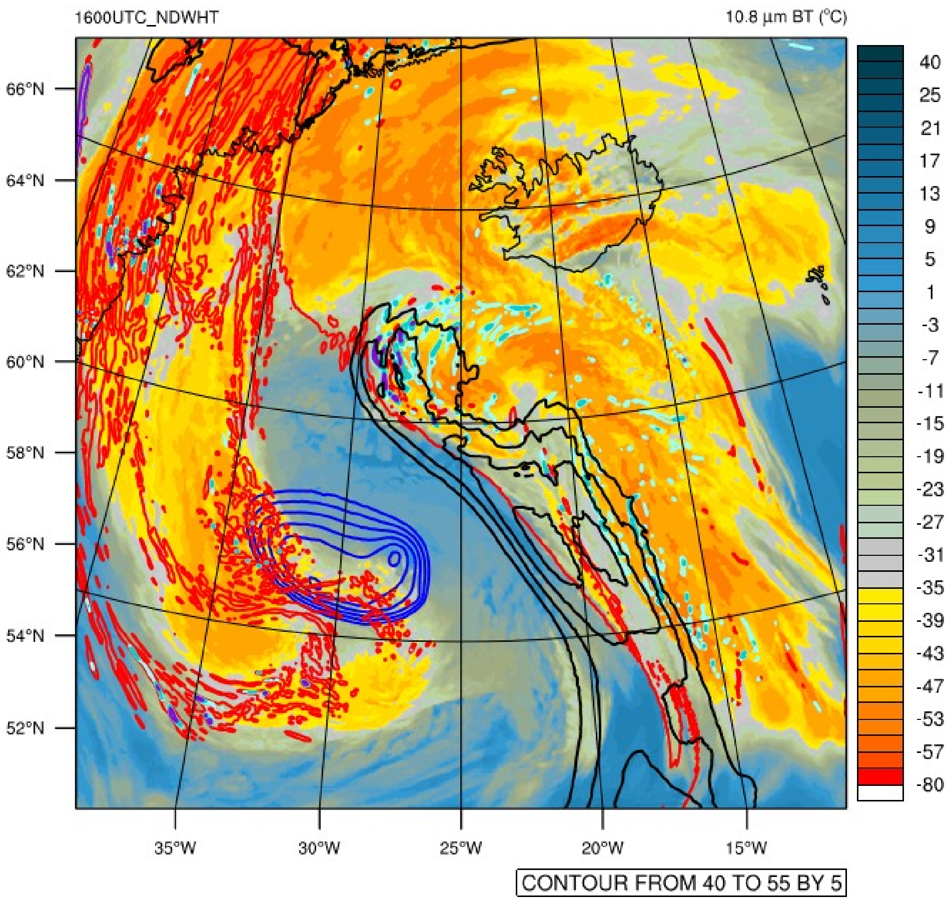
- **1/3 of fast ascents** (-100 hPa ≥ ΔP_{2h}) embedded in the slantwise WCB ascents
- **2/3 of cyclonic trajectories, 3/5 for slow ascents** and **4/5 for fast ascents**
- **anticyclonic ascents located at highers altitude than cyclonic ascents**
- slow ascents in the core of WCB and fast ascents in its west side, close to the cold front

2. **What are the processus leading to fast ascents?**

- **Isolated shallow convection** : west of the WCB and LLJ, low-layer (500 m<z<2 km), cyclonic trajectory, $PV_{mediane}$ > 0 PVU
- **Organized low-level convection** : WCB core at 500 m<z<4 km, east of the LLJ, graupel, cyclonic trajectory, $PV_{mediane}$ > 0 PVU mainly
- **Isolated Mid-level (*high* / low) convection :** WCB at 2 km<z<8 km, graupel, *anticyclonic*/cyclonic trajectories, $PV_{mediane}$ ~0 PVU with **negative values**

Perspectives : negative PV bands in the cloud head !

1600 UTC



At θ=320 K

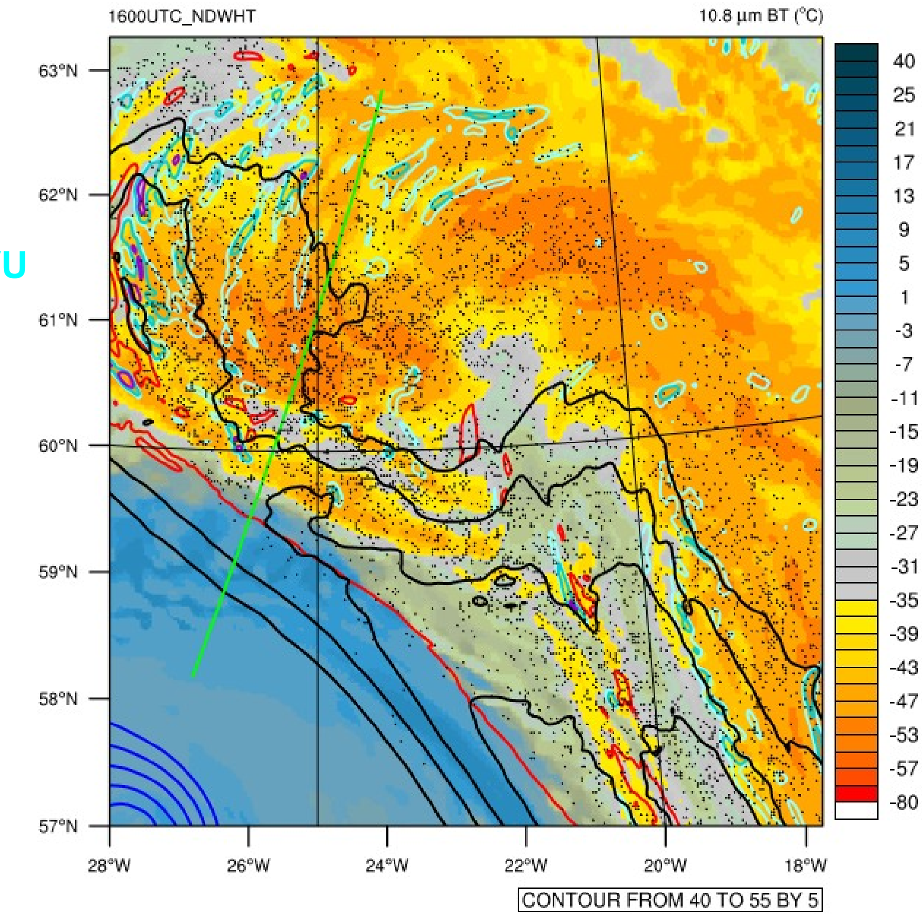
+2 PVU

-0.5 / -1 PVU

-2 PVU

MSLP

1600 UTC



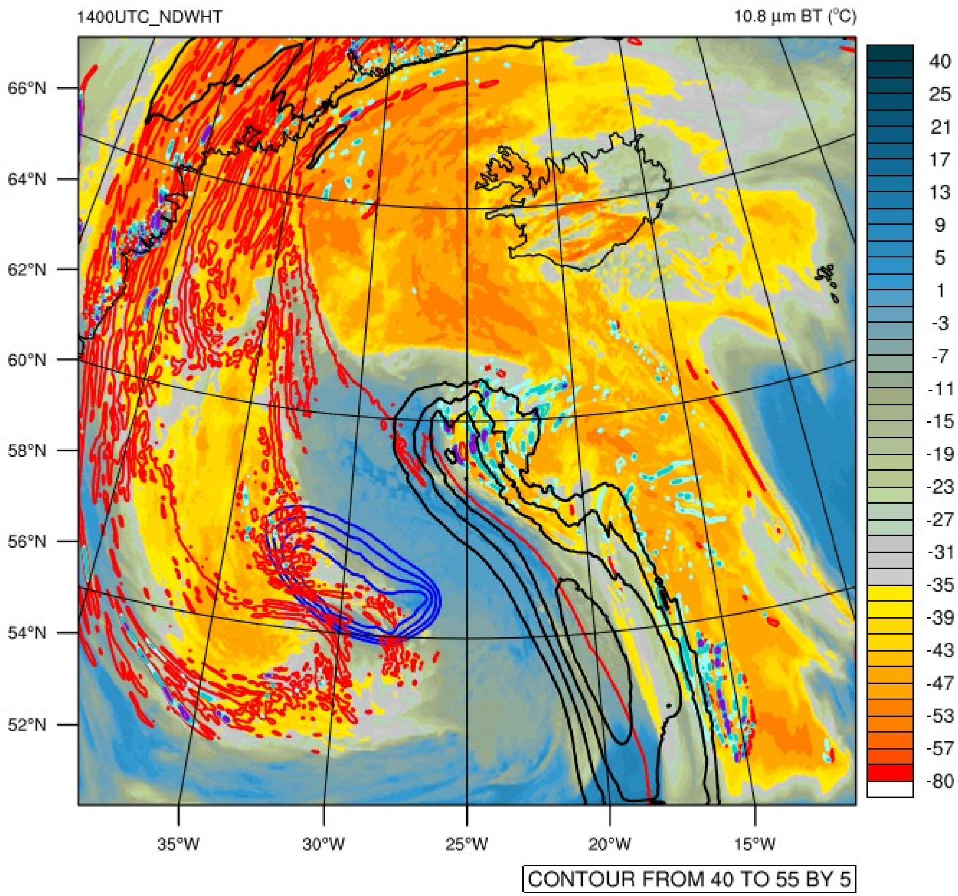
Horizontal wind speed contours
every 5 $m.s^{-1}$ between 40 and 55 $m.s^{-1}$

→ Negative PV bands follow the *cloud head* structure as well as the Jet Stream

→ Jet Stream is locally intensified by the PV gradient

Origin of the negative PV bands?

1400 UTC **At θ=320 K** **1400 UTC**

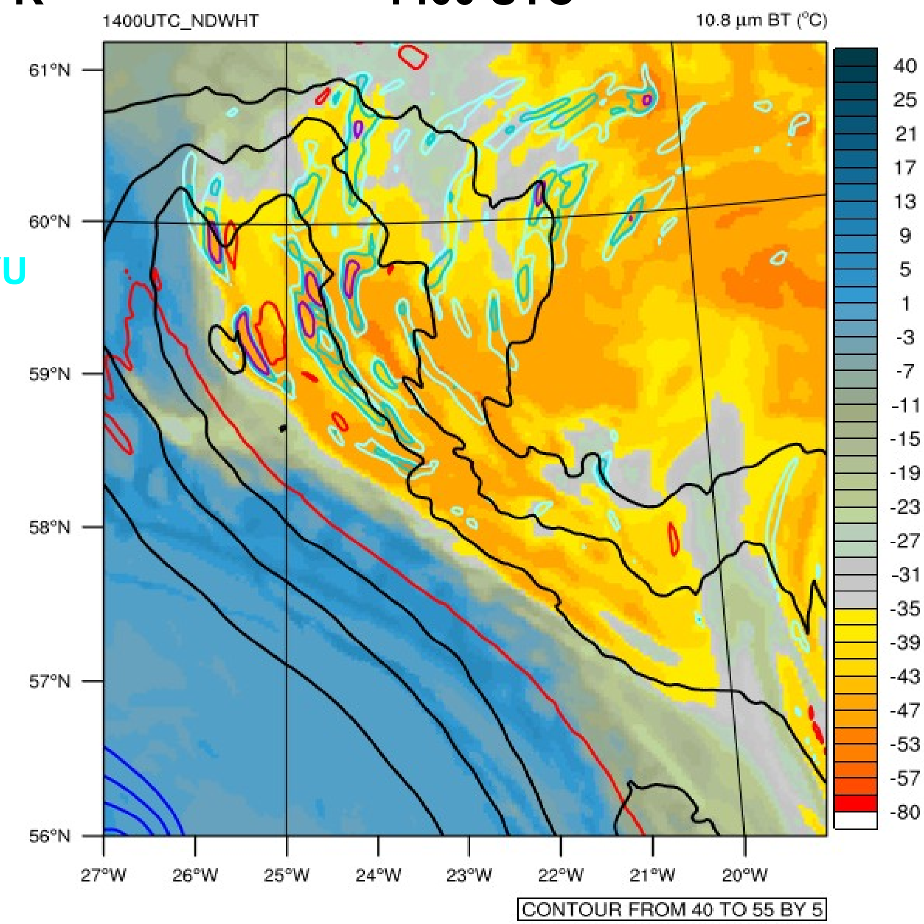


+2 PVU

-0.5 / -1 PVU

-2 PVU

MSLP



Horizontal wind speed contours
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→ Negative PV bands follow the *cloud head* structure as well as the Jet Stream

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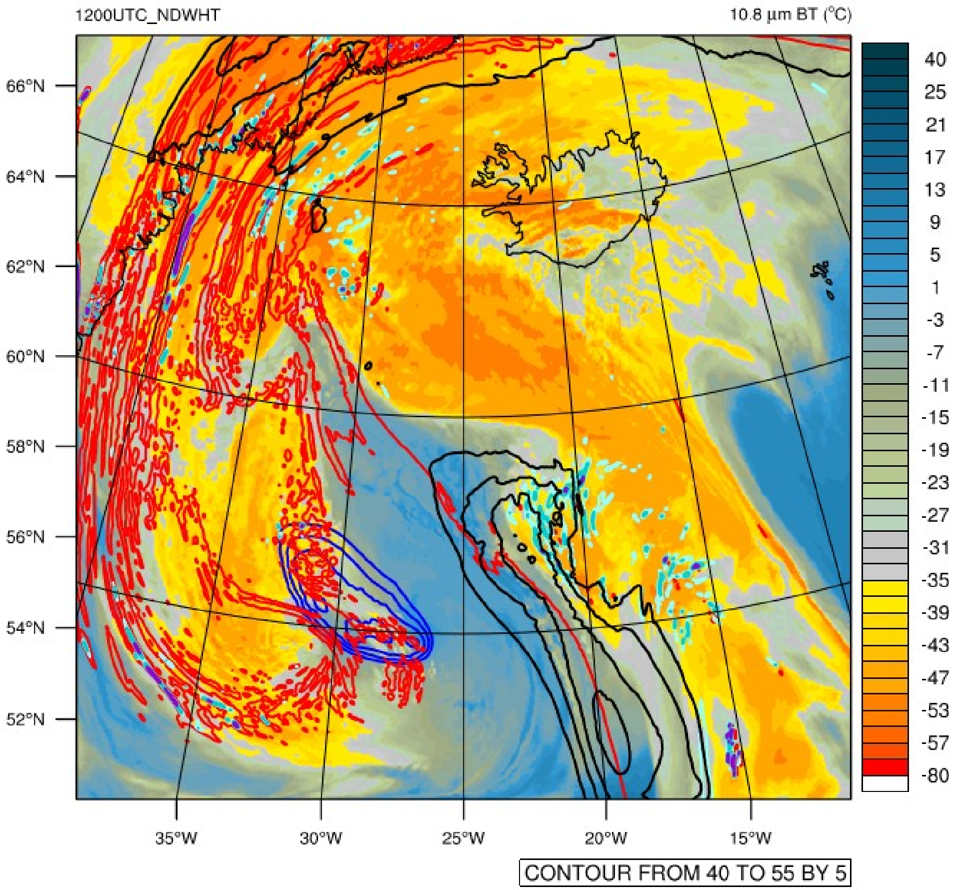
Origin of the negative PV bands?

1200 UTC **At θ=320 K**



+2 PVU

-0.5 / -1 PVU

-2 PVU

MSLP

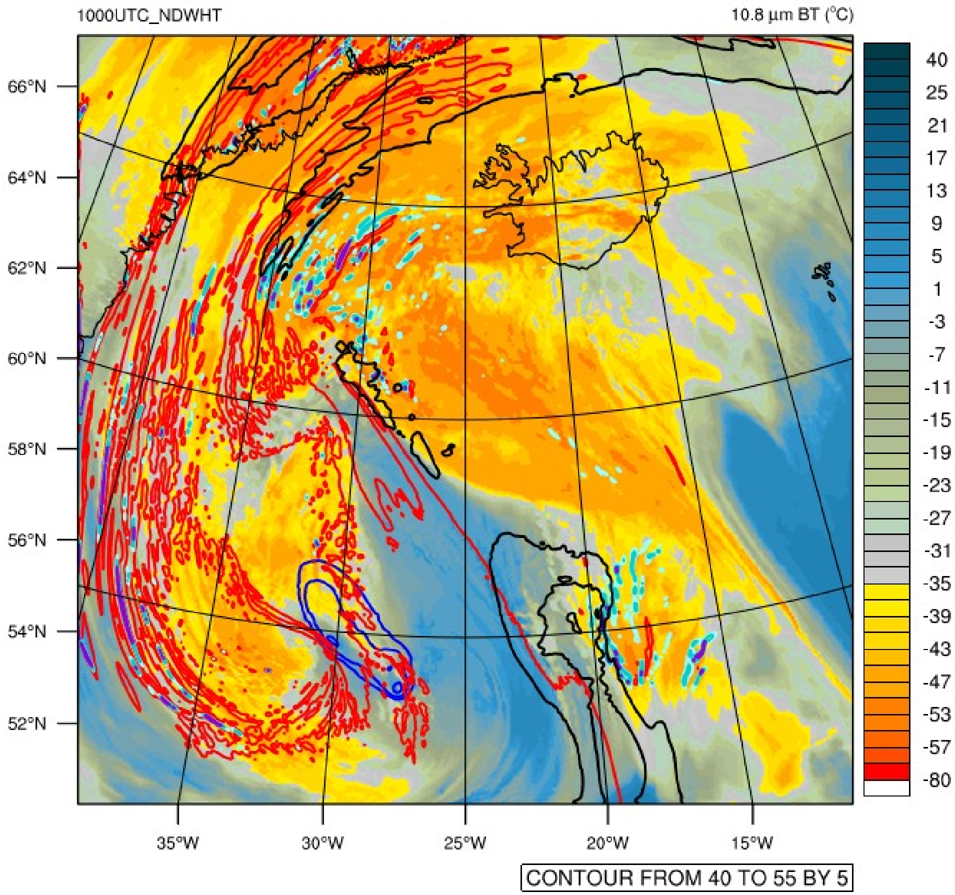
→ Negative PV bands persist with time...

Horizontal wind speed contours every 5 m.s^{-1} between 40 and 55 m.s^{-1}

→ Negative PV bands follow the *cloud head* structure as well as the Jet Stream

Origin of the negative PV bands?

1000 UTC **At θ=320 K** **1000 UTC**

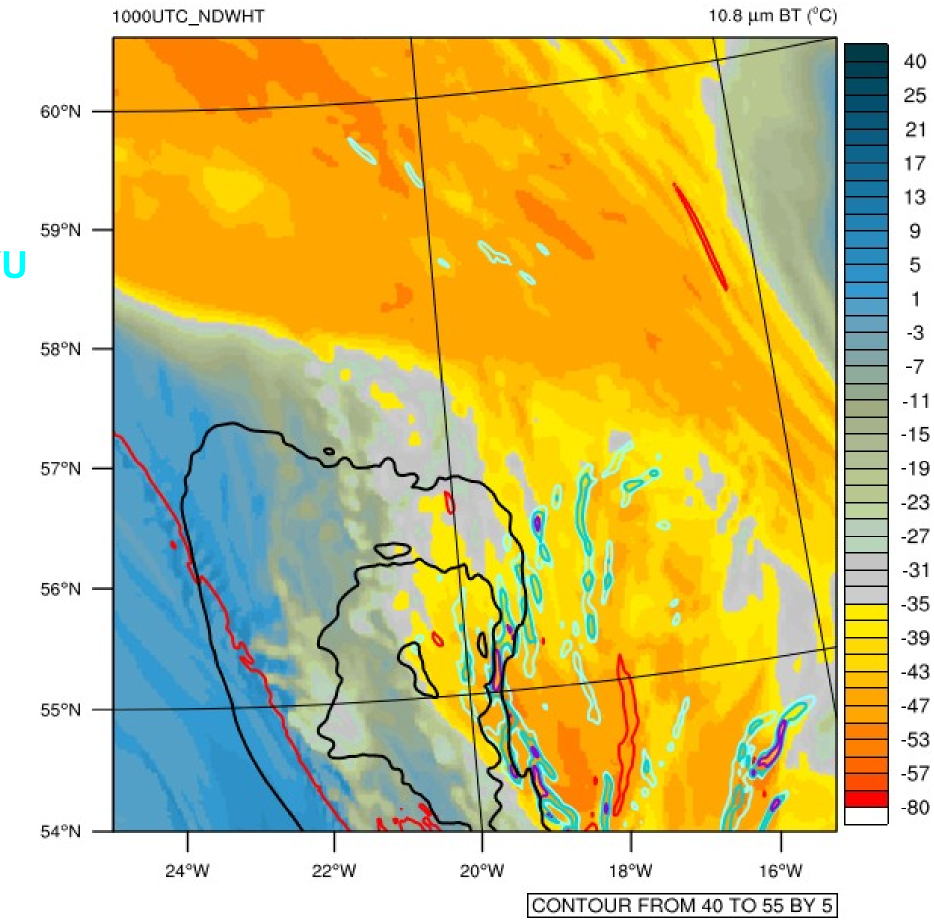


+2 PVU

-0.5 / -1 PVU

-2 PVU

MSLP

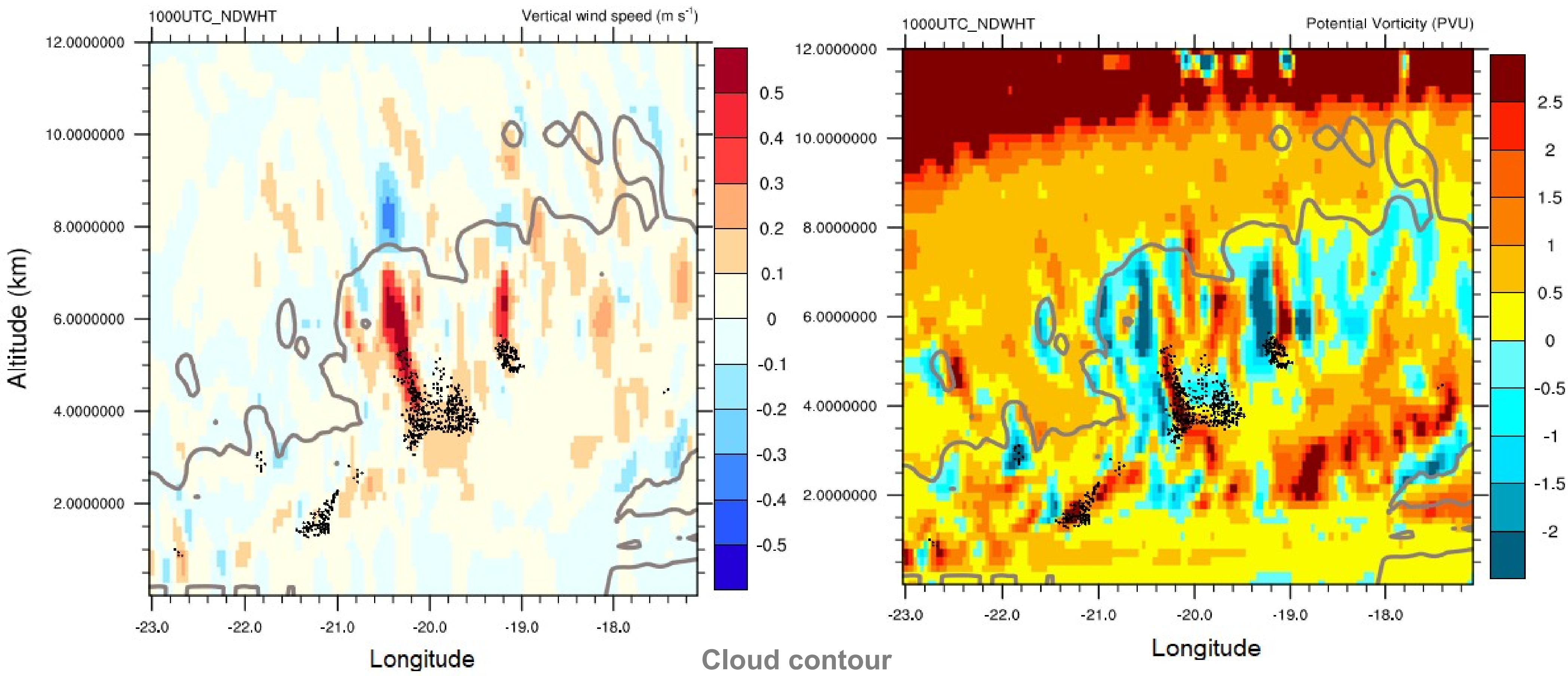


Horizontal wind speed contours
every 5 $m.s^{-1}$ between 40 and 55 $m.s^{-1}$

→ Negative PV bands follow the *cloud head* structure as well as the Jet Stream

→ Negative PV bands formation

Vertical cross section at 1000 UTC

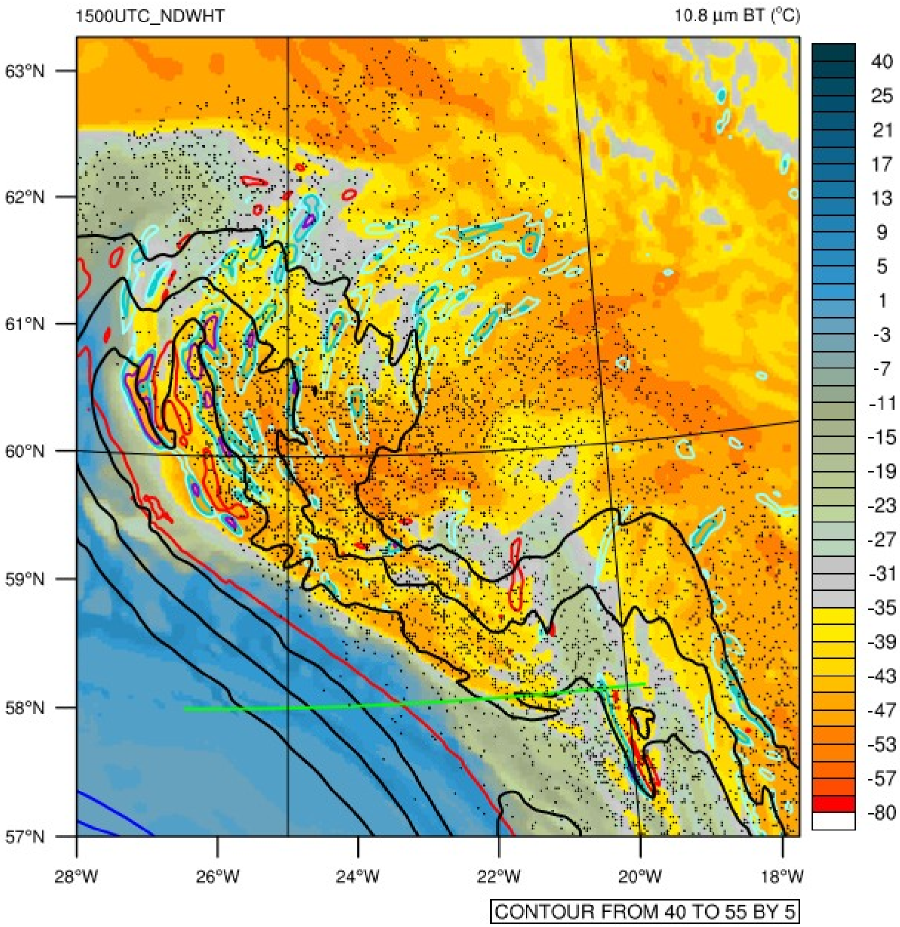


→ Fast Lagrangian trajectories in mid-level convective regions

→ **Negative PV** in altitude located in these regions

ANNEXES

Jet Stream and PV at θ_320K

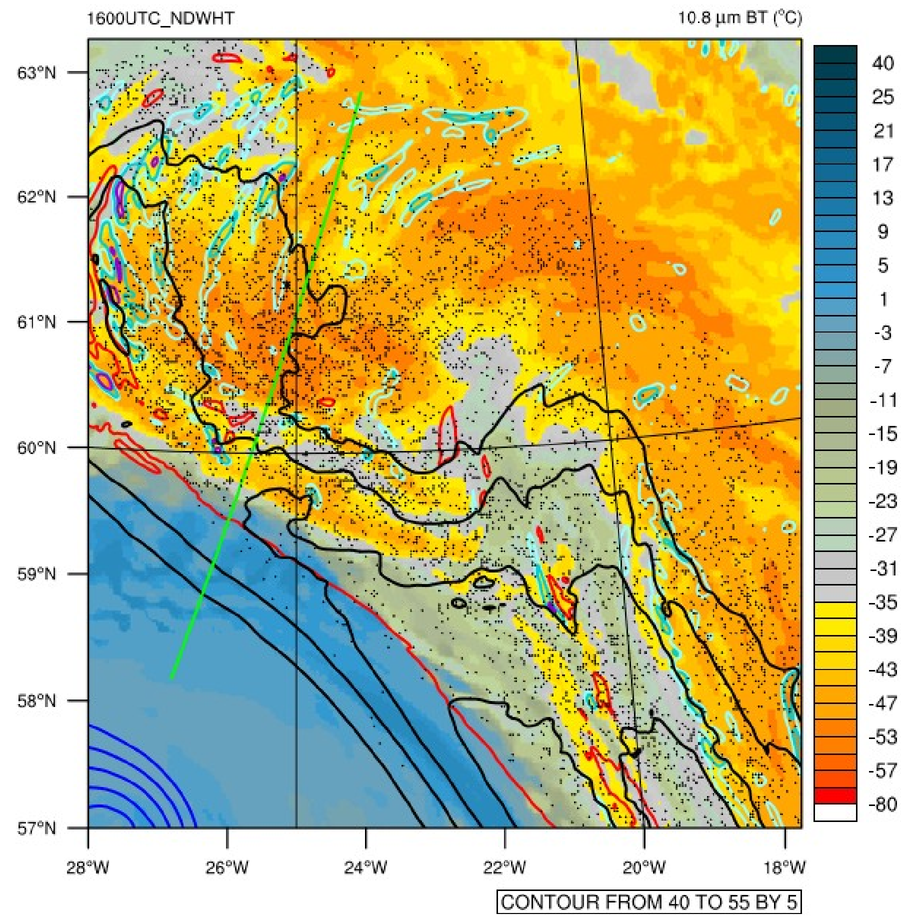


+2 PVU

-0.5 / -1 PVU

-2 PVU

MSLP



Horizontal wind speed contours every 5 $m.s^{-1}$ between 40 and 55 $m.s^{-1}$

→ Negative PV bands follow the *cloud head* structure as well as the Jet Stream

→ Jet Stream is locally intensified by the PV gradient

→ What is the origin of the negative PV bands?

Origin of the negative PV bands?

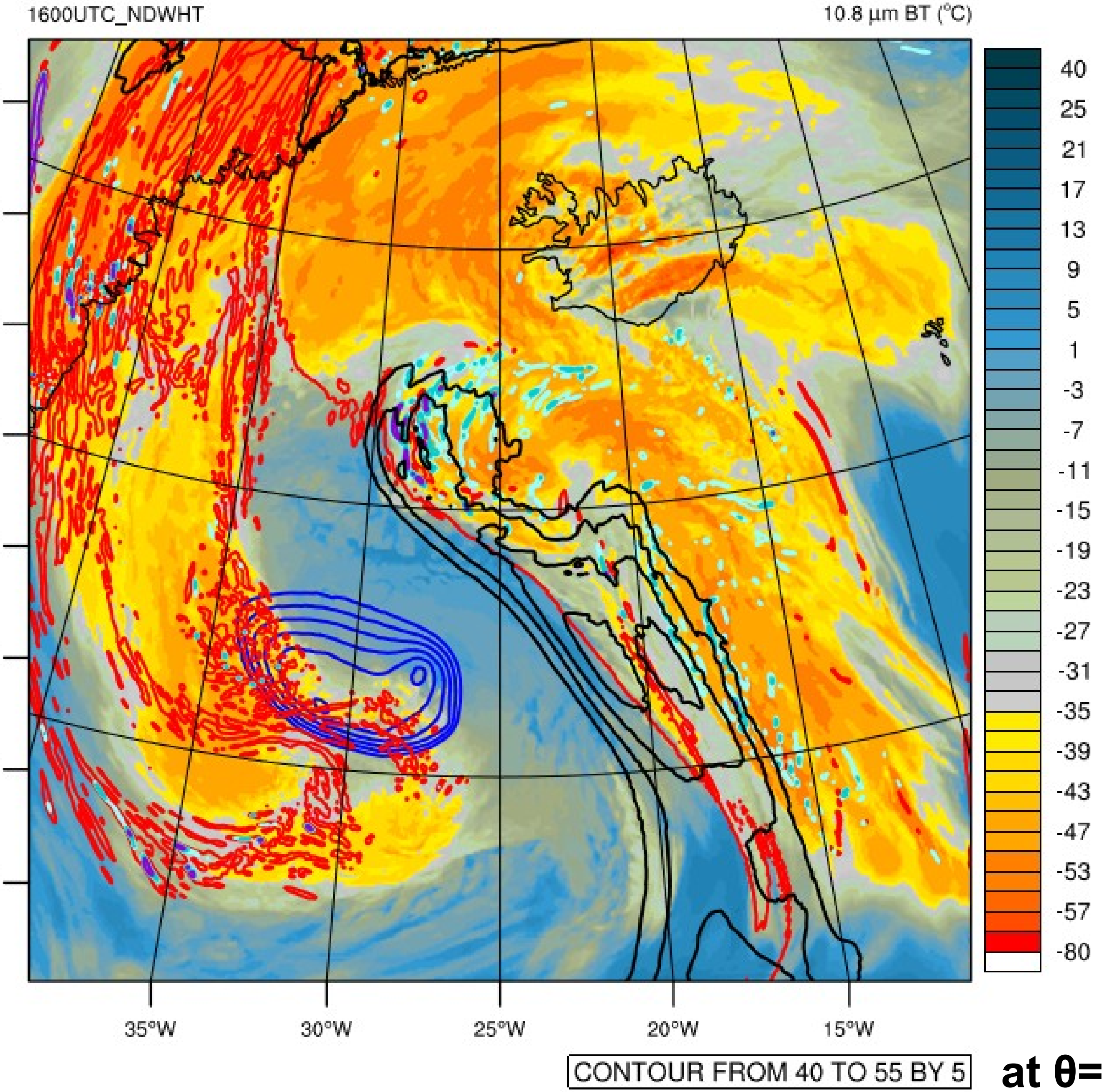
1600 UTC

+2 PVU

-0.5 / -1 PVU

-2 PVU

MSLP



at θ=320 K

Origin of the negative PV bands?

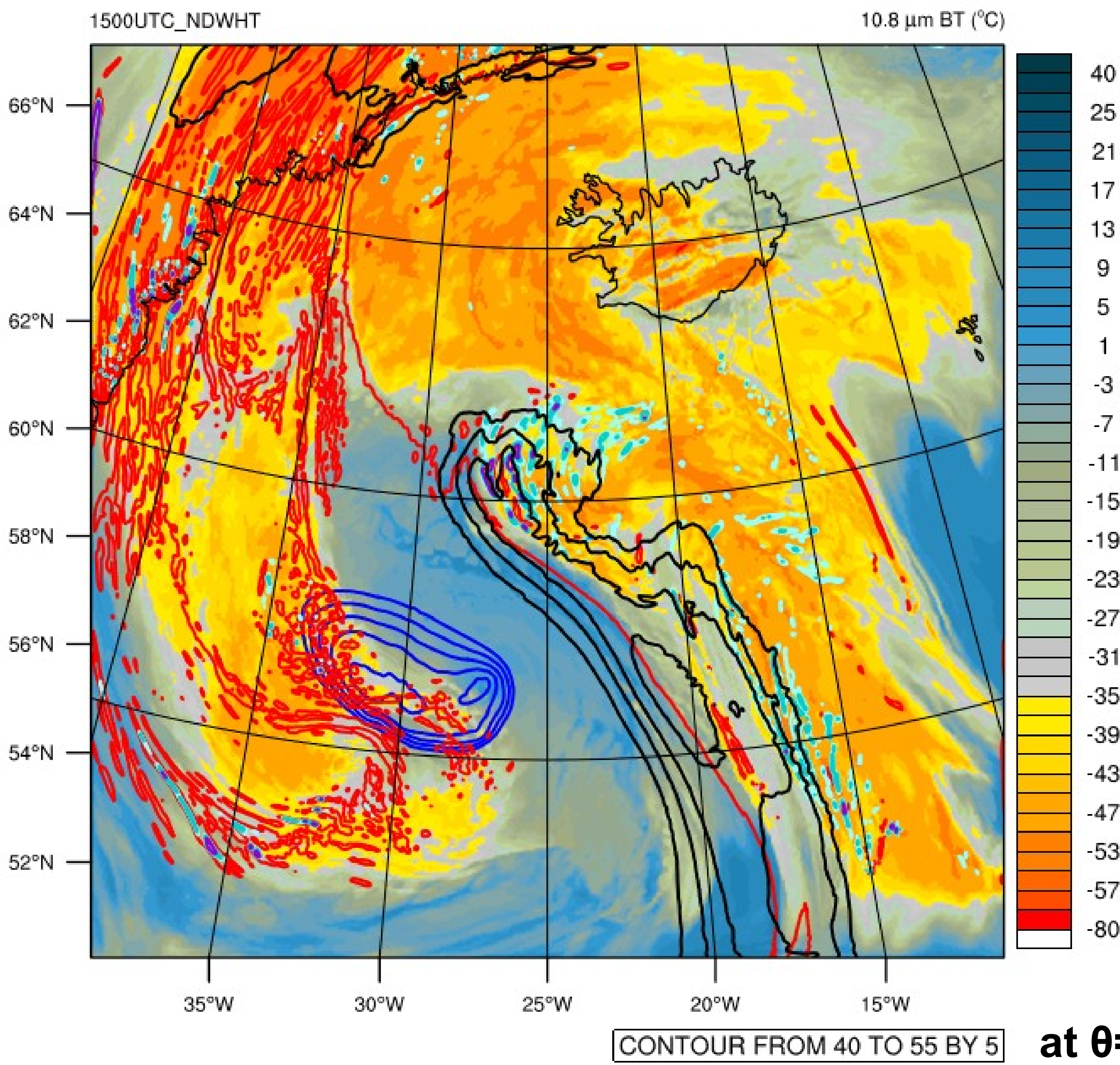
1500 UTC

+2 PVU

-0.5 / -1 PVU

-2 PVU

MSLP



Negative PV bands follow the *cloud head* structure observed at 1600

at θ=320 K

Origin of the negative PV bands?

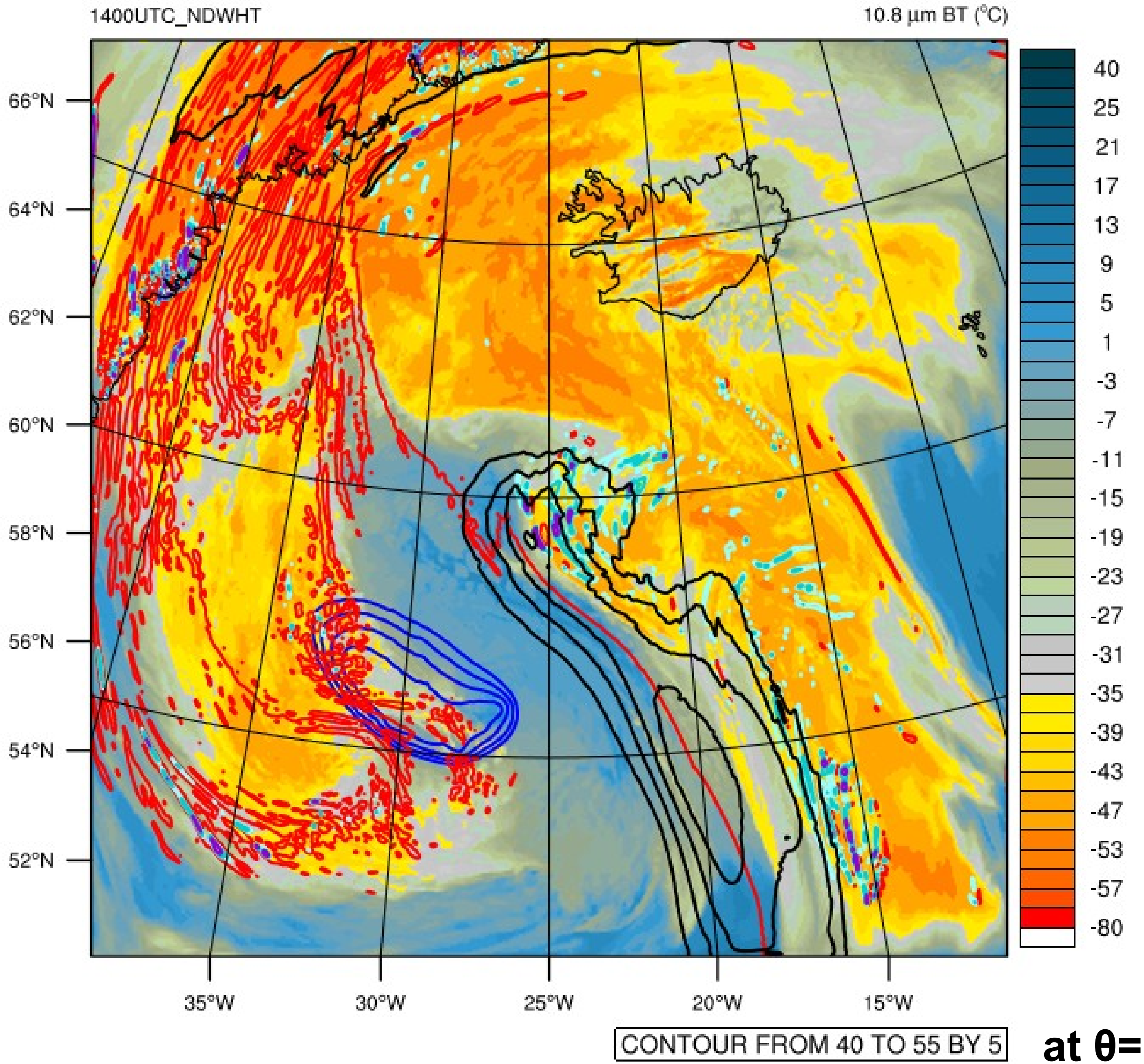
1400 UTC

+2 PVU

-0.5 / -1 PVU

-2 PVU

MSLP



at θ=320 K

Origin of the negative PV bands?

1400 UTC

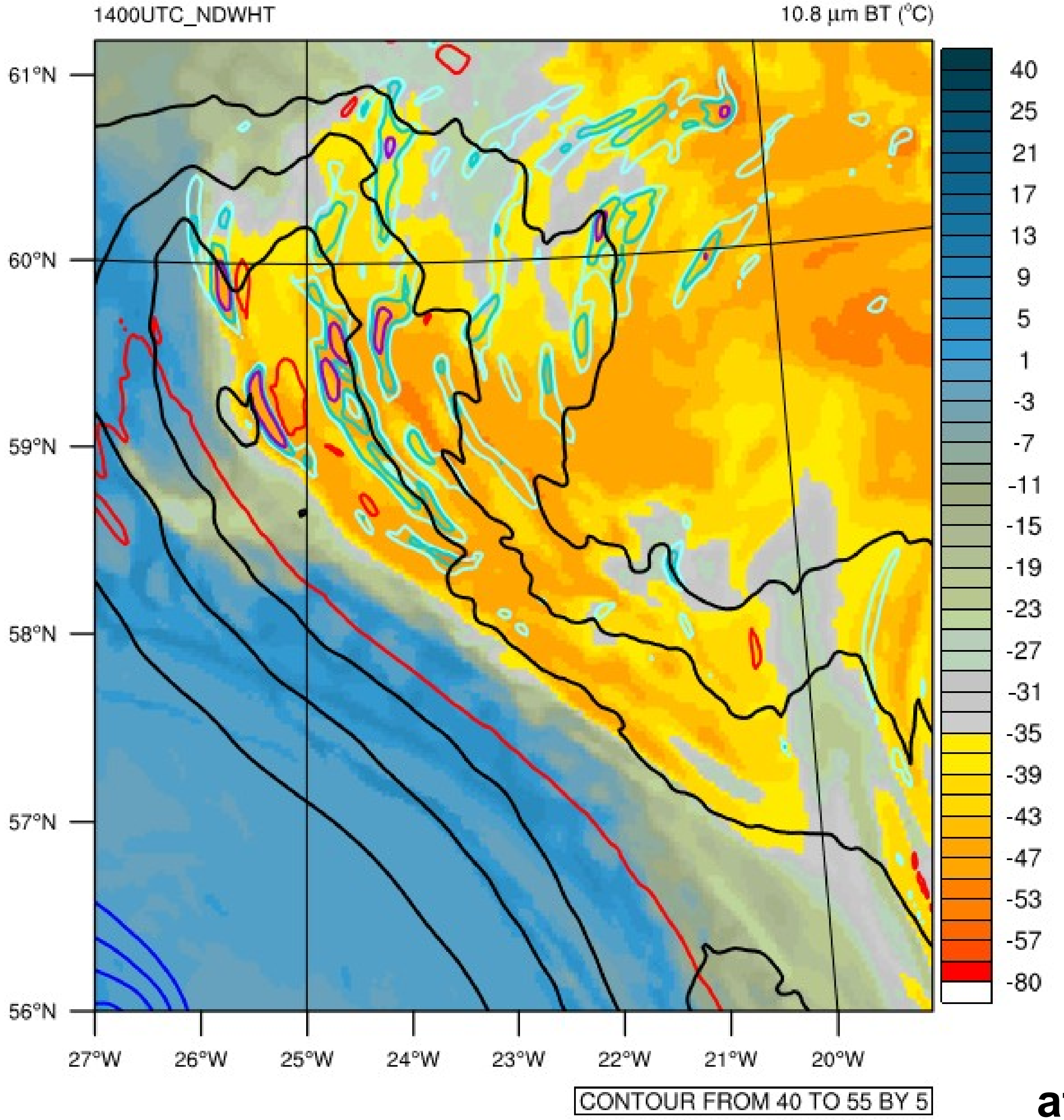
Zoom

+2 PVU

-0.5 / -1 PVU

-2 PVU

MSLP



Jet Stream is locally intensified by the PV gradient

at θ=320 K

Origin of the negative PV bands?

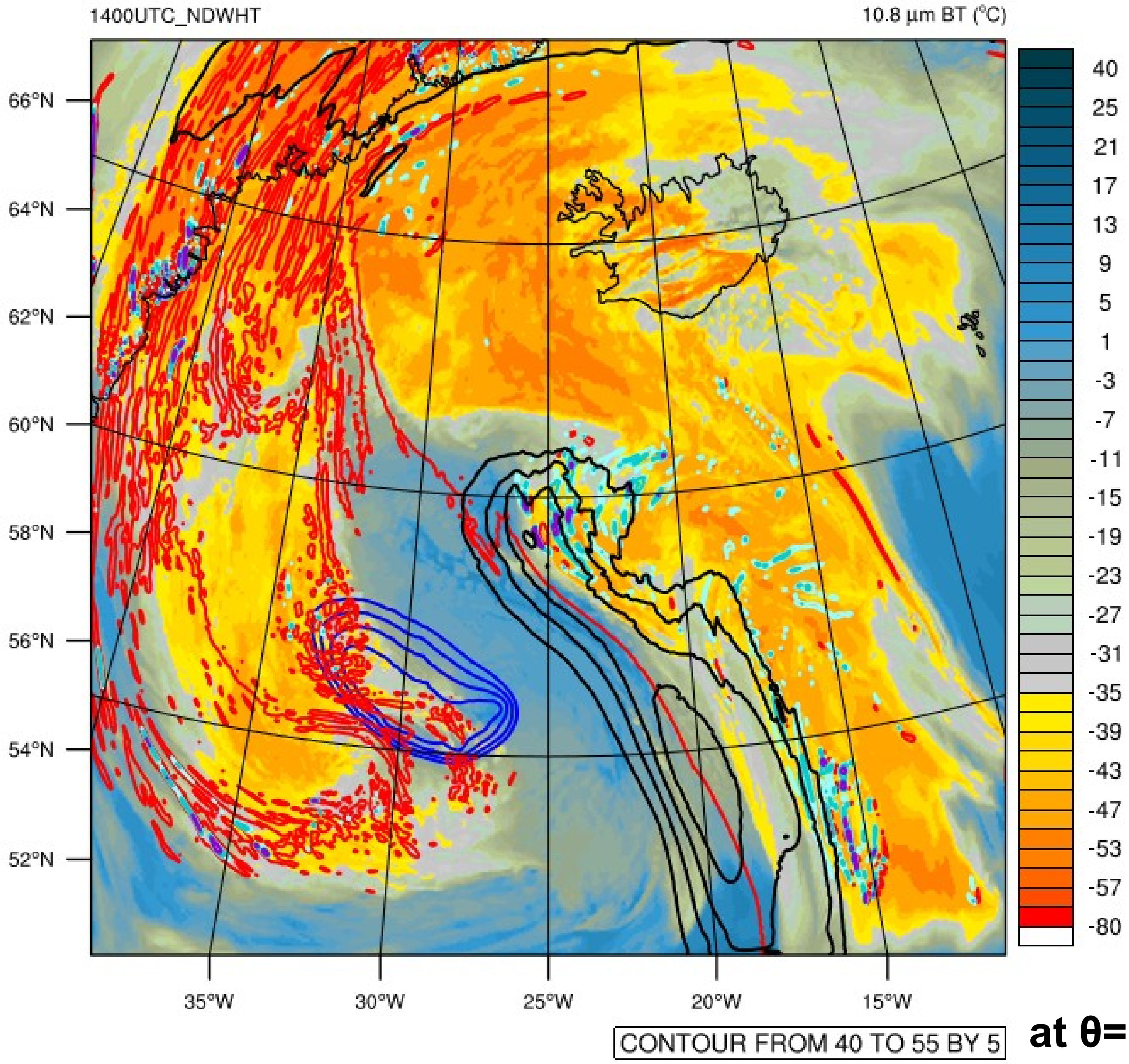
1400 UTC

+2 PVU

-0.5 / -1 PVU

-2 PVU

MSLP



at θ=320 K

Origin of the negative PV bands?

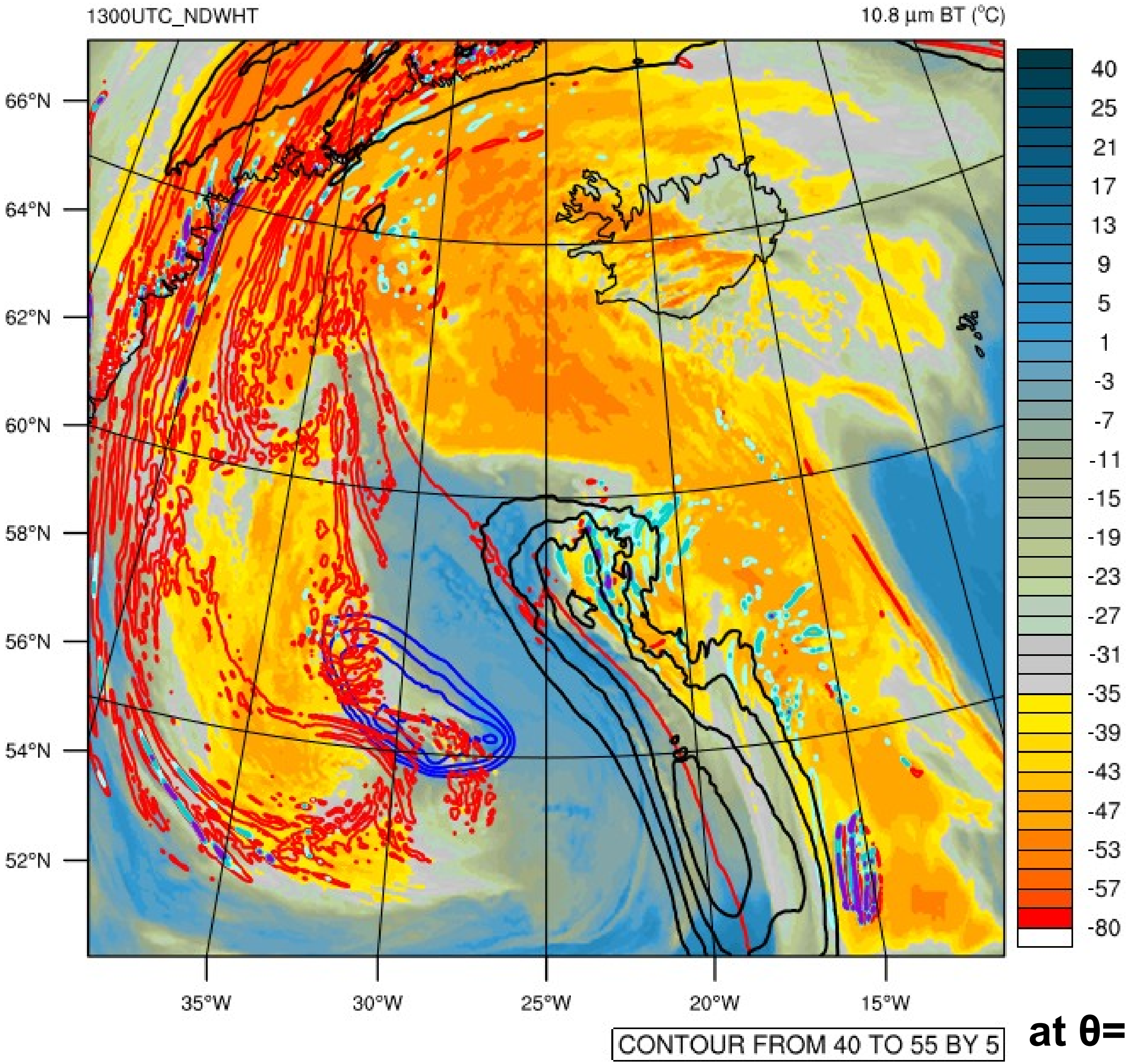
1300 UTC

+2 PVU

-0.5 / -1 PVU

-2 PVU

MSLP



at θ=320 K

Origin of the negative PV bands?

1200 UTC

Negative PV bands persist with time

+2 PVU

-0.5 / -1 PVU

-2 PVU

MSLP

at θ=320 K

Origin of the negative PV bands?

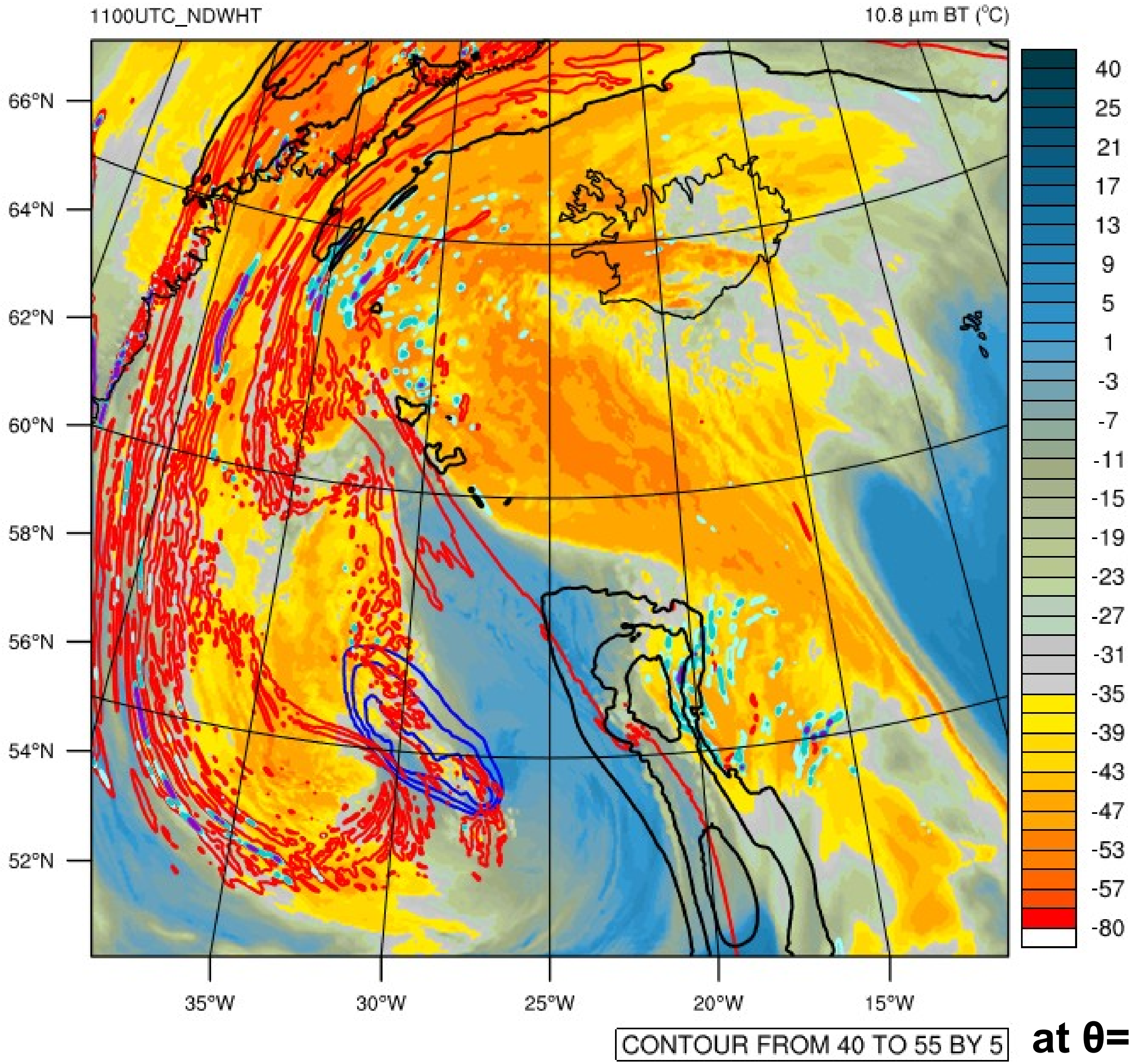
1100 UTC

+2 PVU

-0.5 / -1 PVU

-2 PVU

MSLP



at θ=320 K

Origin of the negative PV bands?

1000 UTC

Negative PV bands formation

+2 PVU

-0.5 / -1 PVU

-2 PVU

MSLP

at θ=320 K

Origin of the negative PV bands?

1000 UTC

Zoom

+2 PVU

-0.5 / -1 PVU

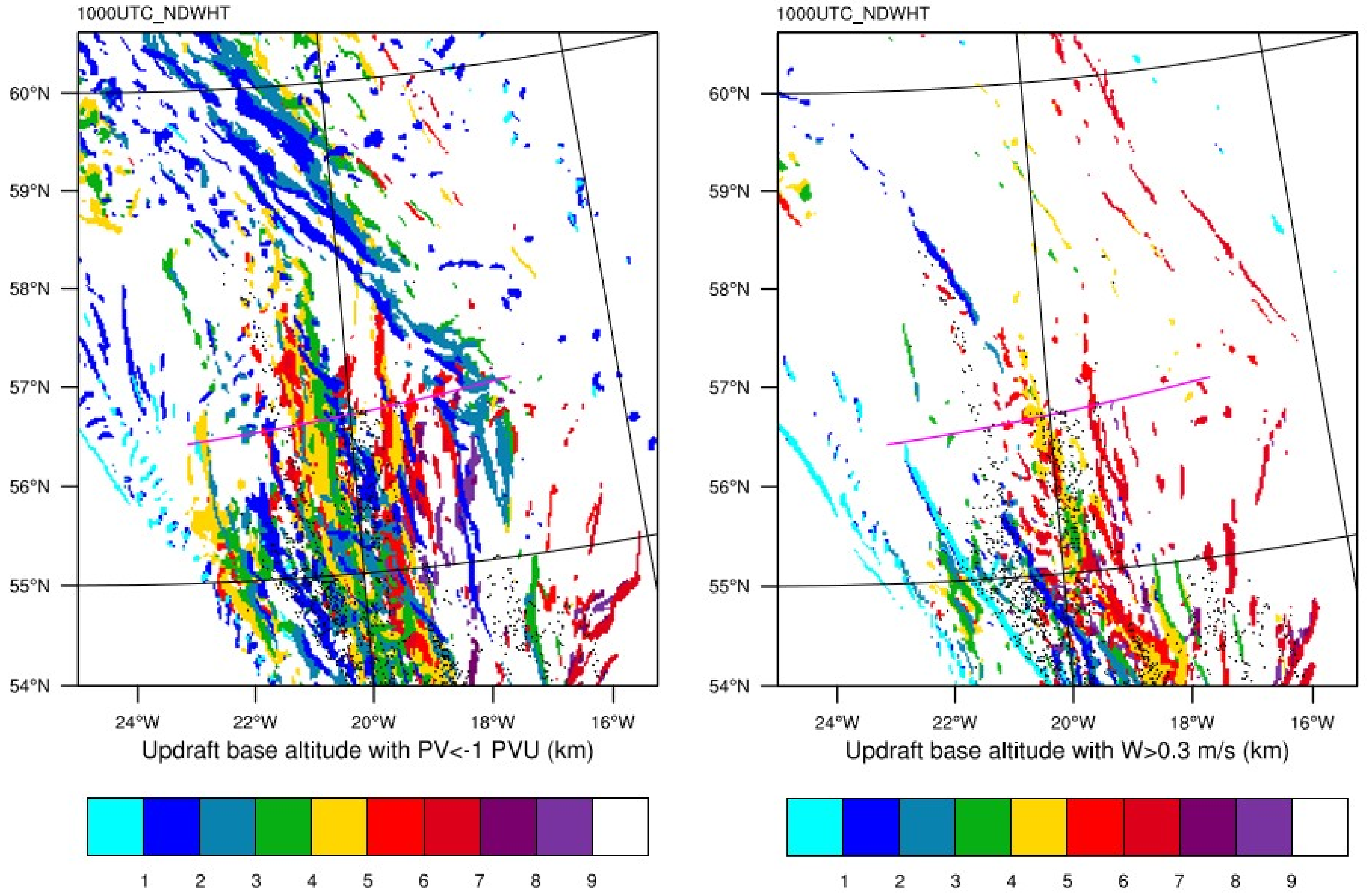
-2 PVU

MSLP

Negative PV bands formation

at θ=320 K

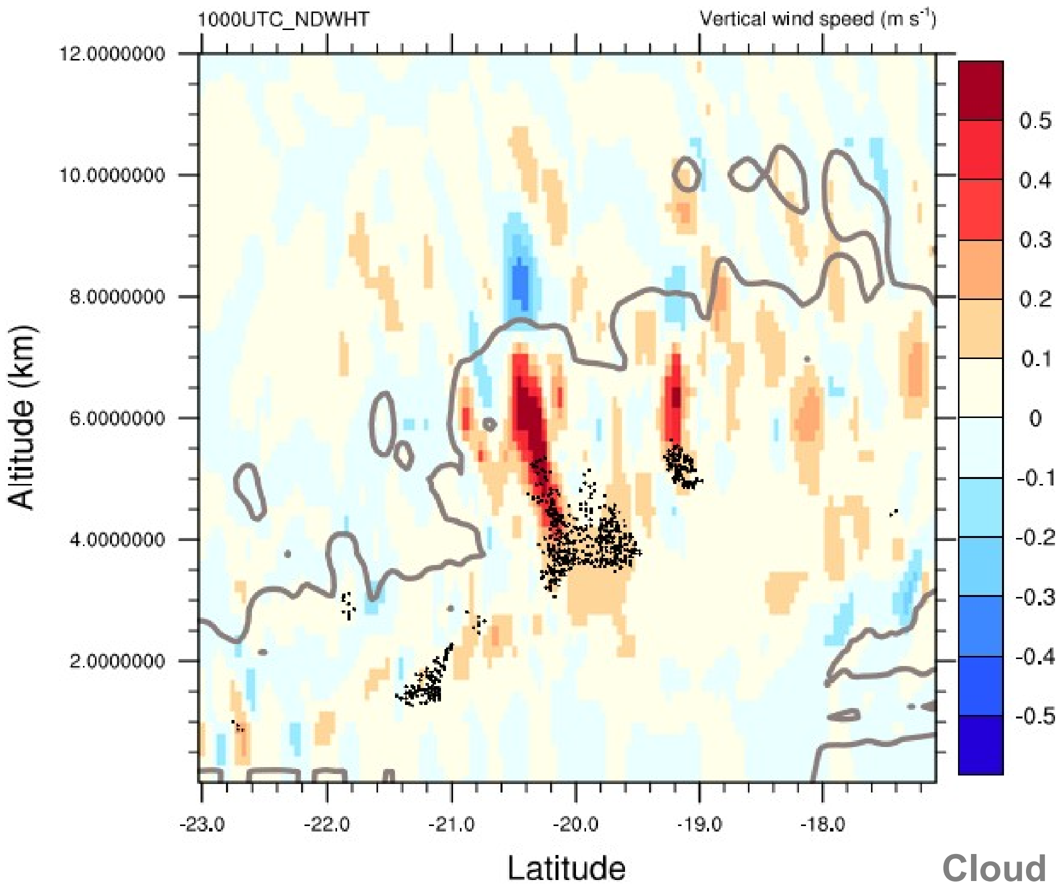
Negative PV bands at 1000 UTC

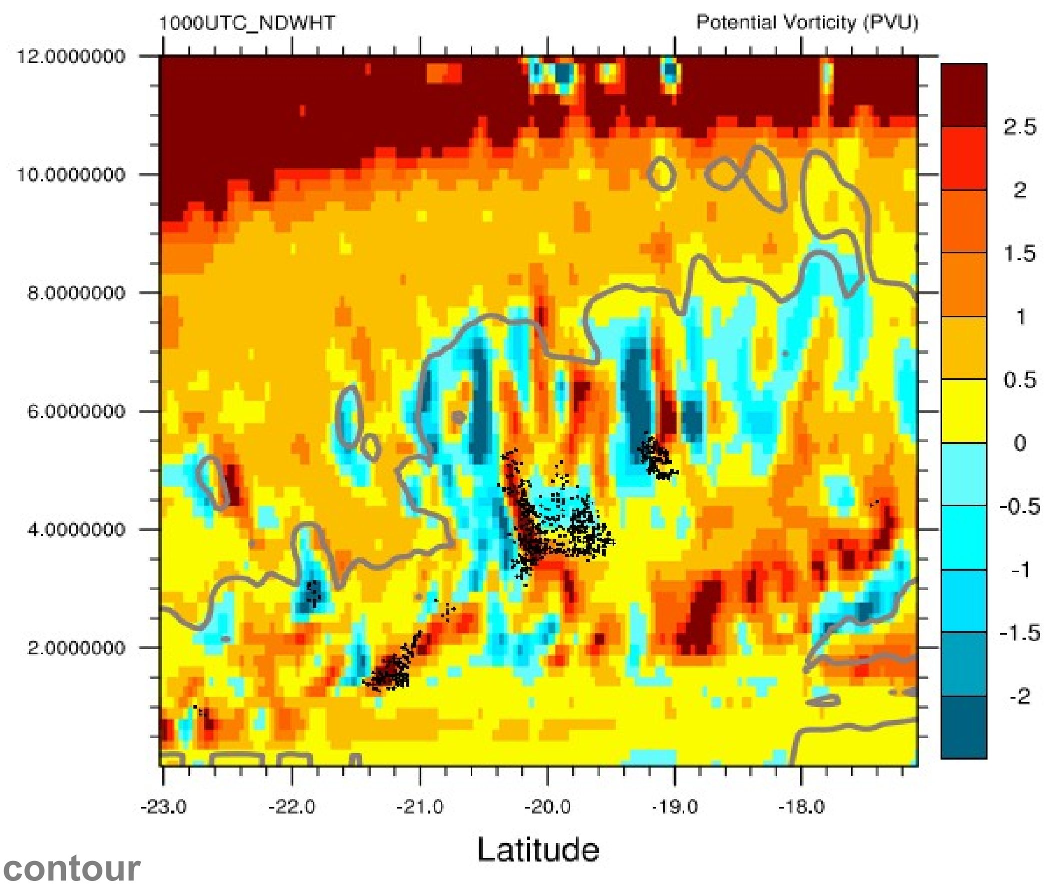


Altitude and location of negative PV bands correspond to those of Updrafts z~5 km

Fast Lagrangian trajectories (every 20 trajs) located on Updrafts bases

Vertical cross section at 1000 UTC





Cloud contour

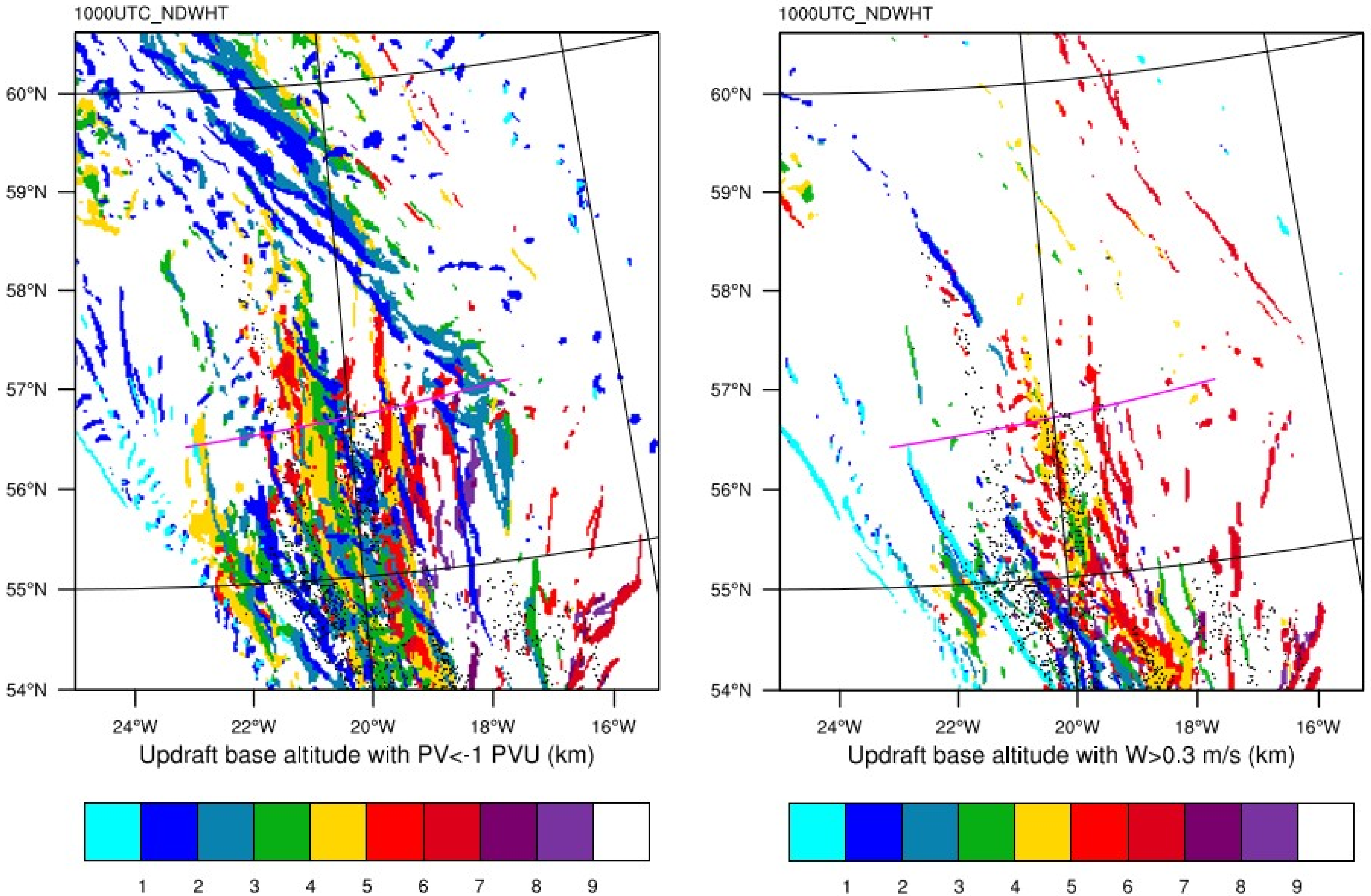
Fast Lagrangian trajectories located close to Updrafts regions (W>0.3 m.s^{-1})

→ Mid-level / High-level convection

PV dipoles located in regions of strong vertical movements

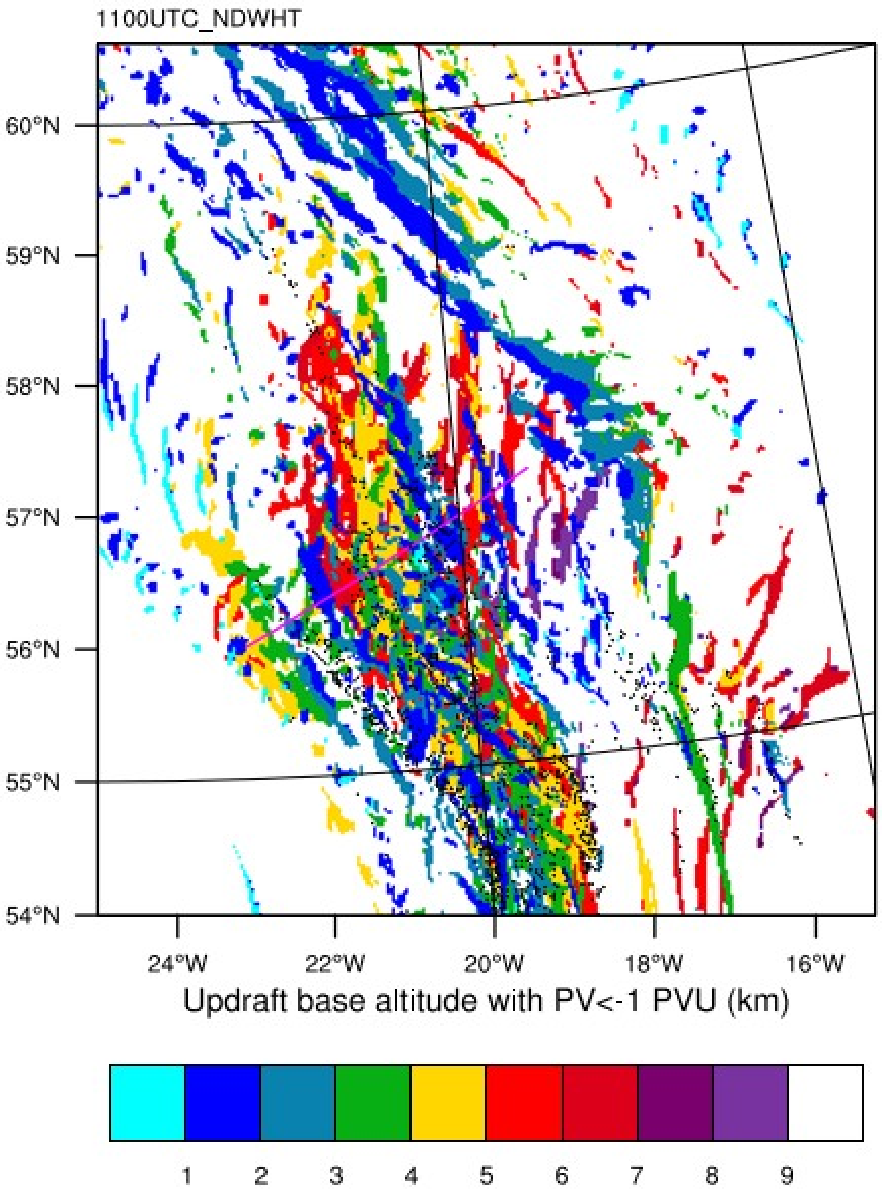
→ Diabatic production of PV dipoles?

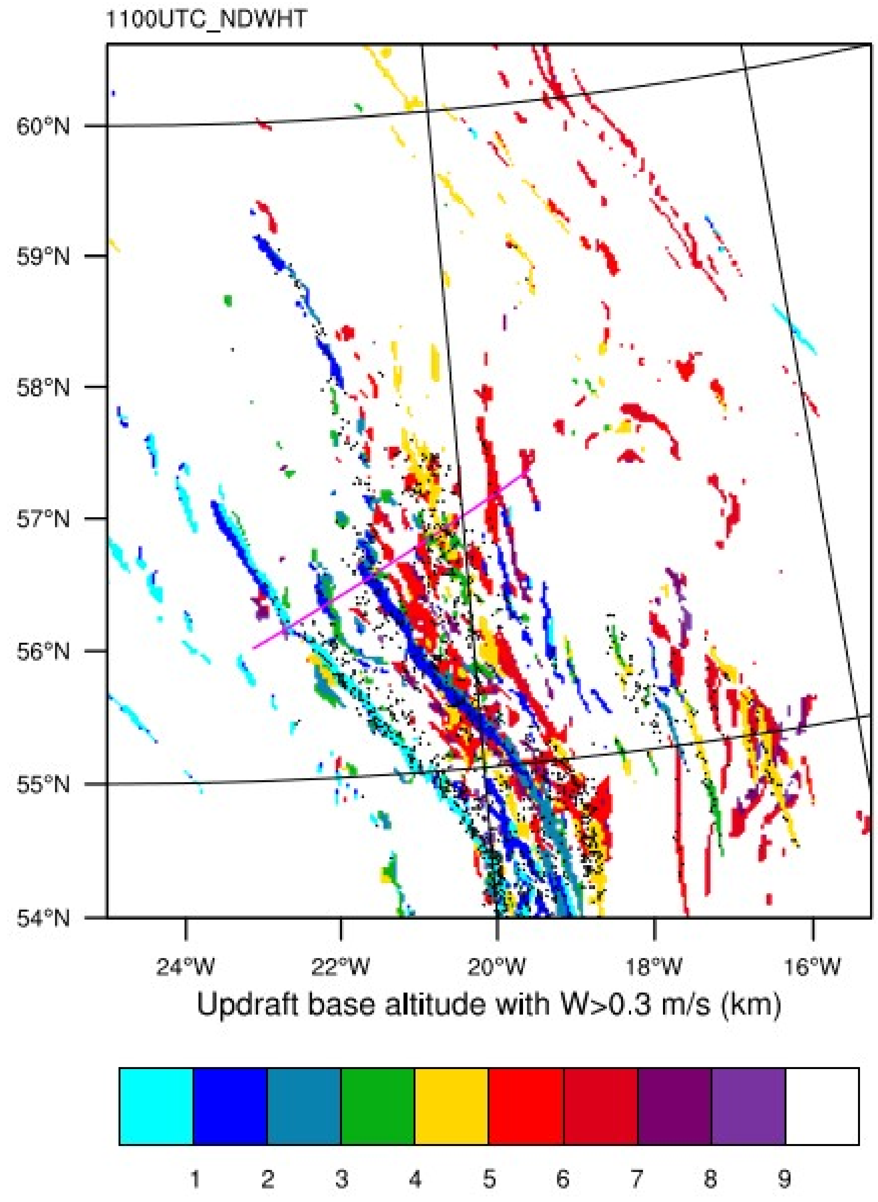
Negative PV bands at 1000 UTC



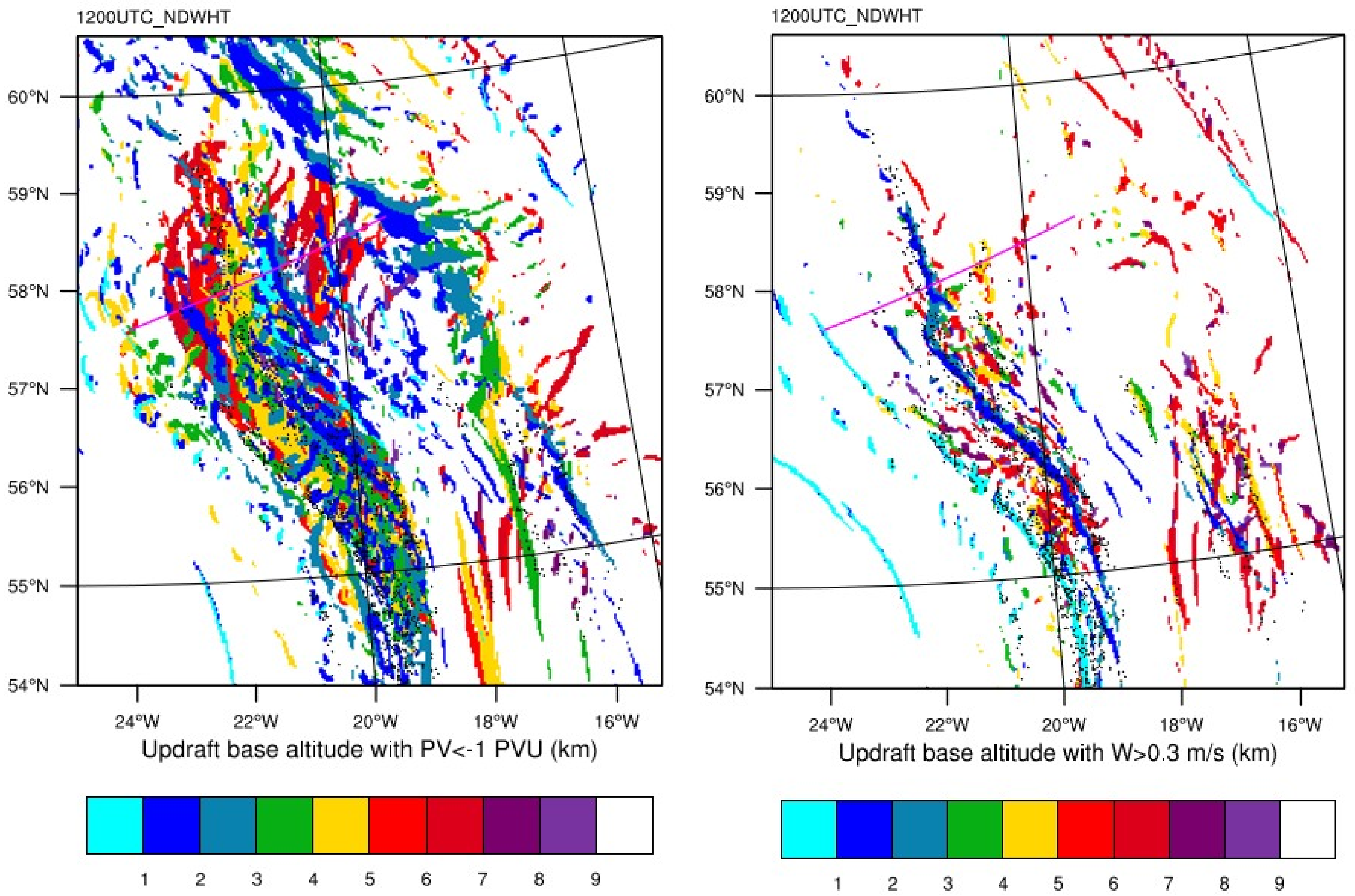
Narrow negative PV bands base located at ~5 km of altitude
as well as Updrafts base

Negative PV bands at 1100 UTC



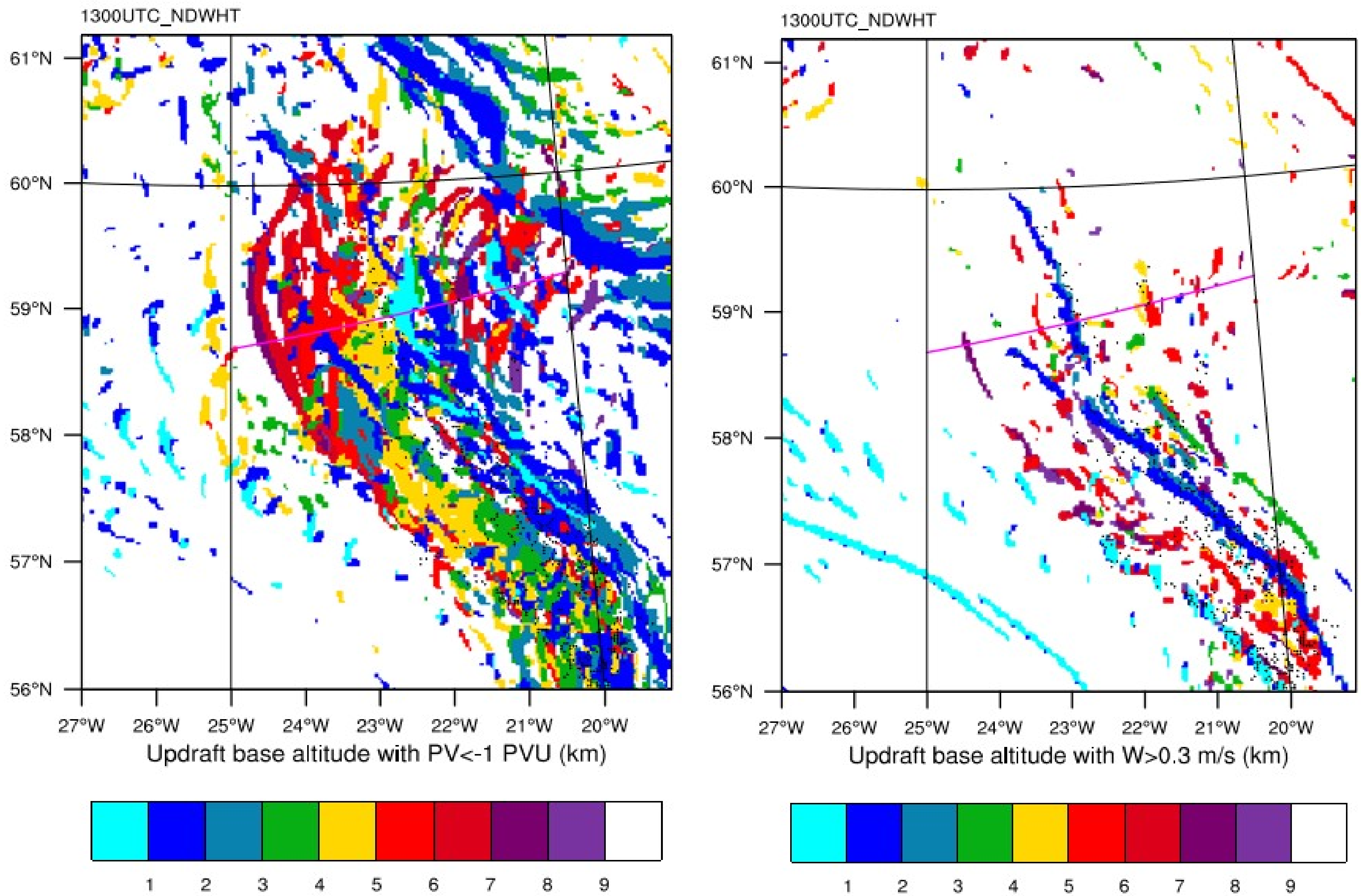


Negative PV bands at 1200 UTC



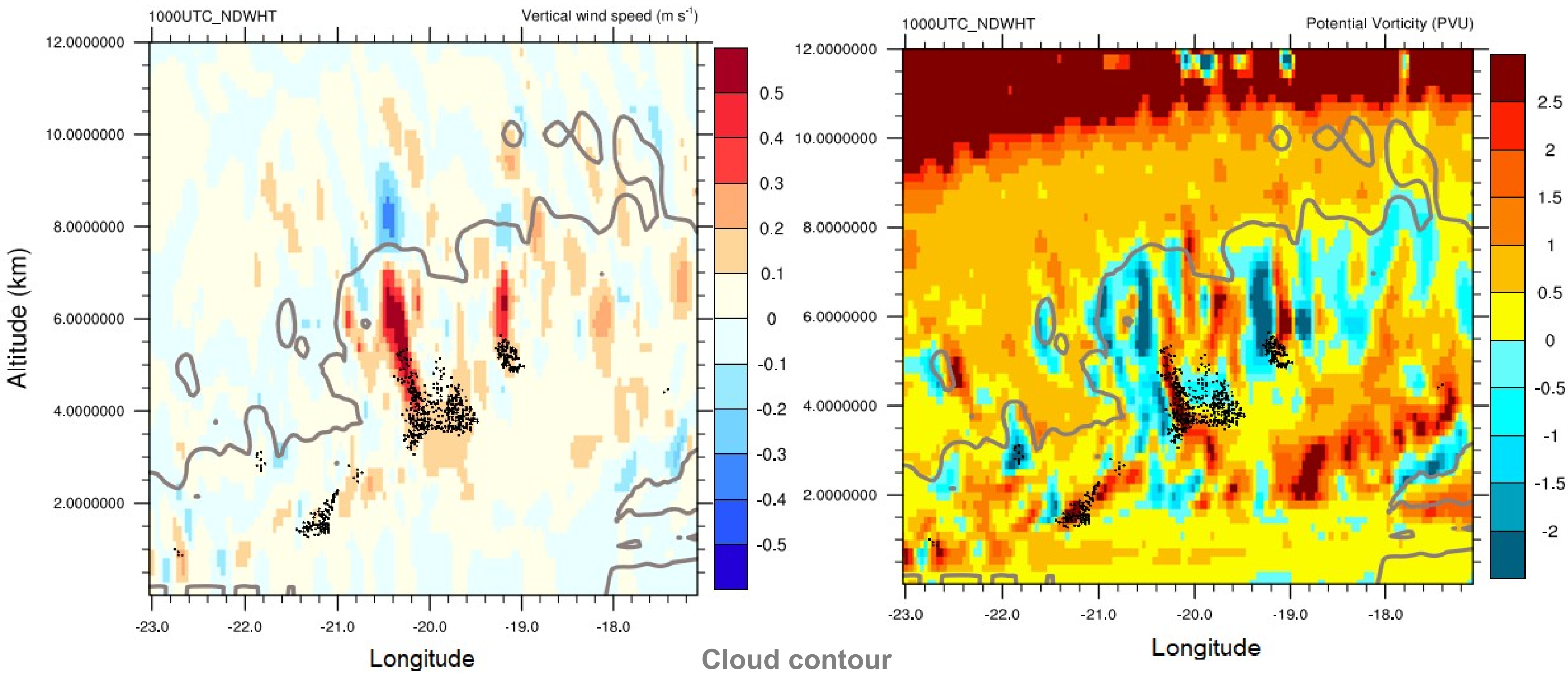
Negative PV bands base located between 5 and 6 km of altitude

Negative PV bands at 1300 UTC



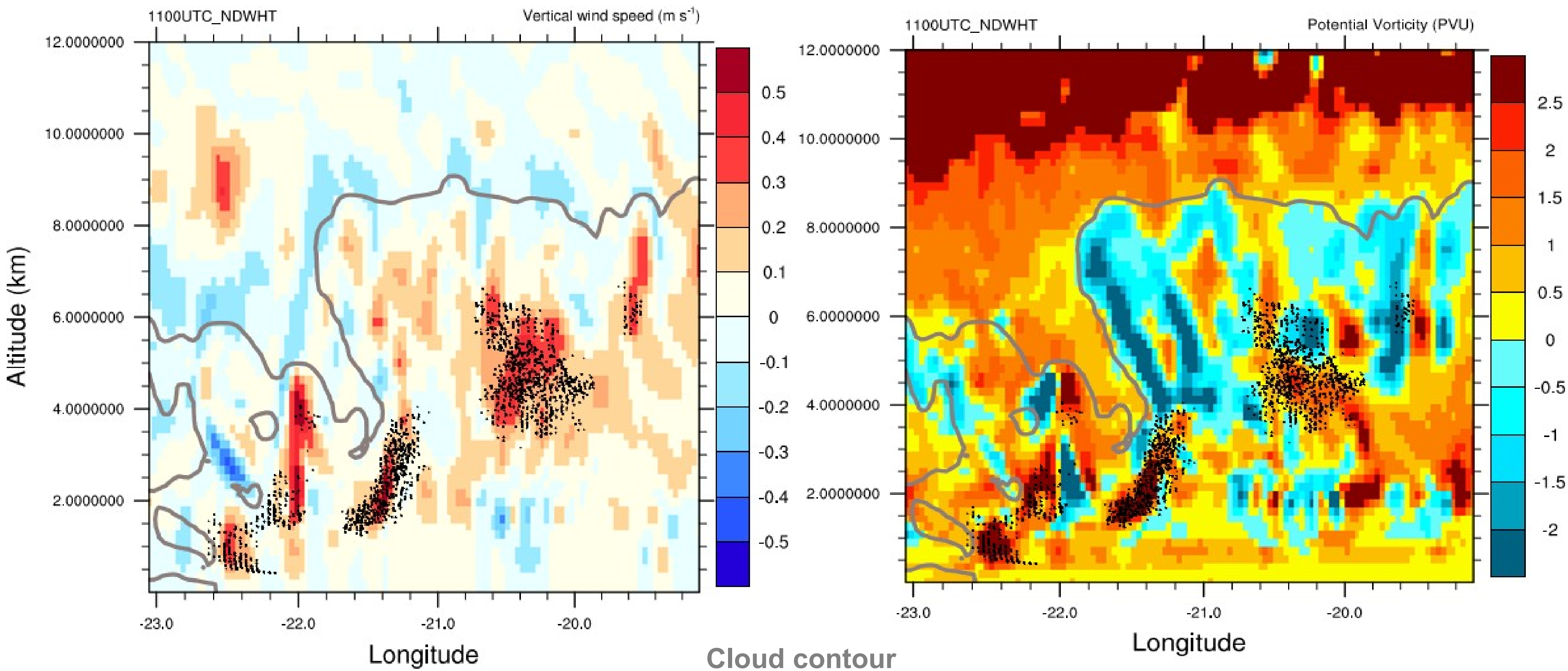
Negative PV bands base located between 6 and 7 km of altitude
as well as Updrafts base

Vertical cross section at 1000 UTC



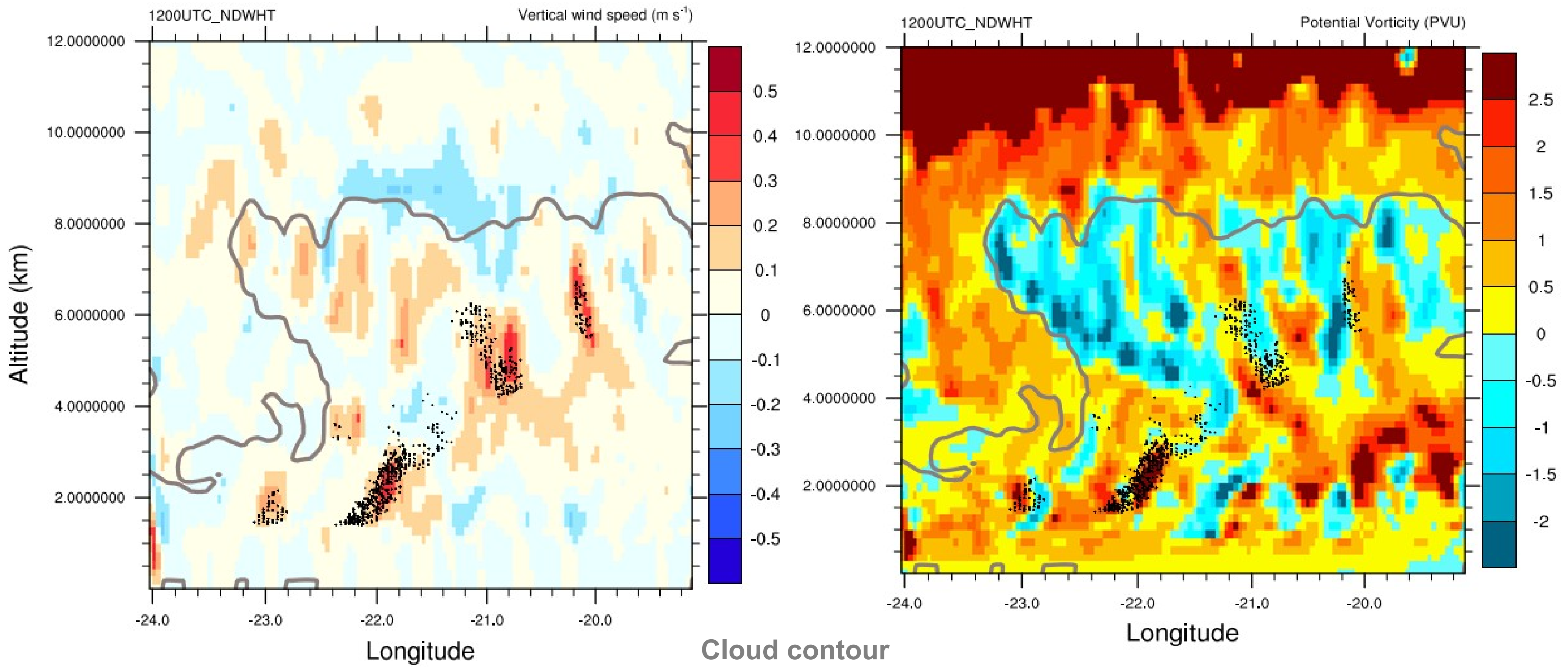
- Cloud top at z~8 km
- **Negative PV** in altitude located in mid-level convection regions
- Other PV dipoles in convection regions within the cloud

Vertical cross section at 1100 UTC



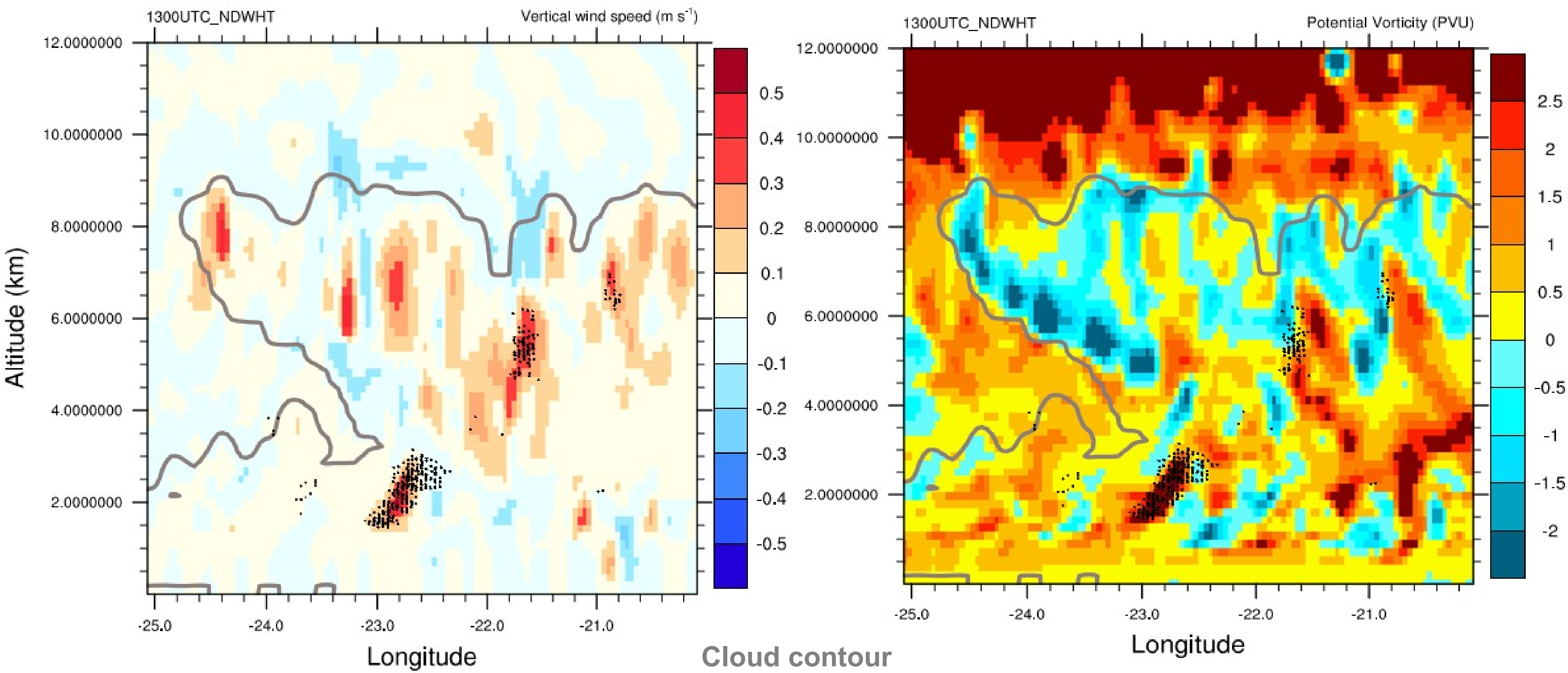
- Cloud top at z~8.5 km
- **Vertically elongated negative PV band** (advected) close to the edge of the cloud
- Other PV dipoles in Updrafts regions within the cloud
- **Strong positive** PV>2 PVU in low-layers, in Updrafts regions

Vertical cross section at 1200 UTC



- Cloud top at z~8.5 km
- **Horizontally elongated** negative PV band (advected) close to the edge of the cloud
- **A priori disconnected from Updrafts regions**
- **Strong positive PV>2 PVU in low-layers, in Updrafts regions**

Vertical cross section at 1300 UTC



- Cloud top at z~8.5 km
- **Horizontally elongated** negative PV band close to the edge of the cloud
- **A priori disconnected from Updrafts regions?**
- **Strong positive PV>2 PVU in low-layers, in Updrafts regions**

End of the negative PV bands?

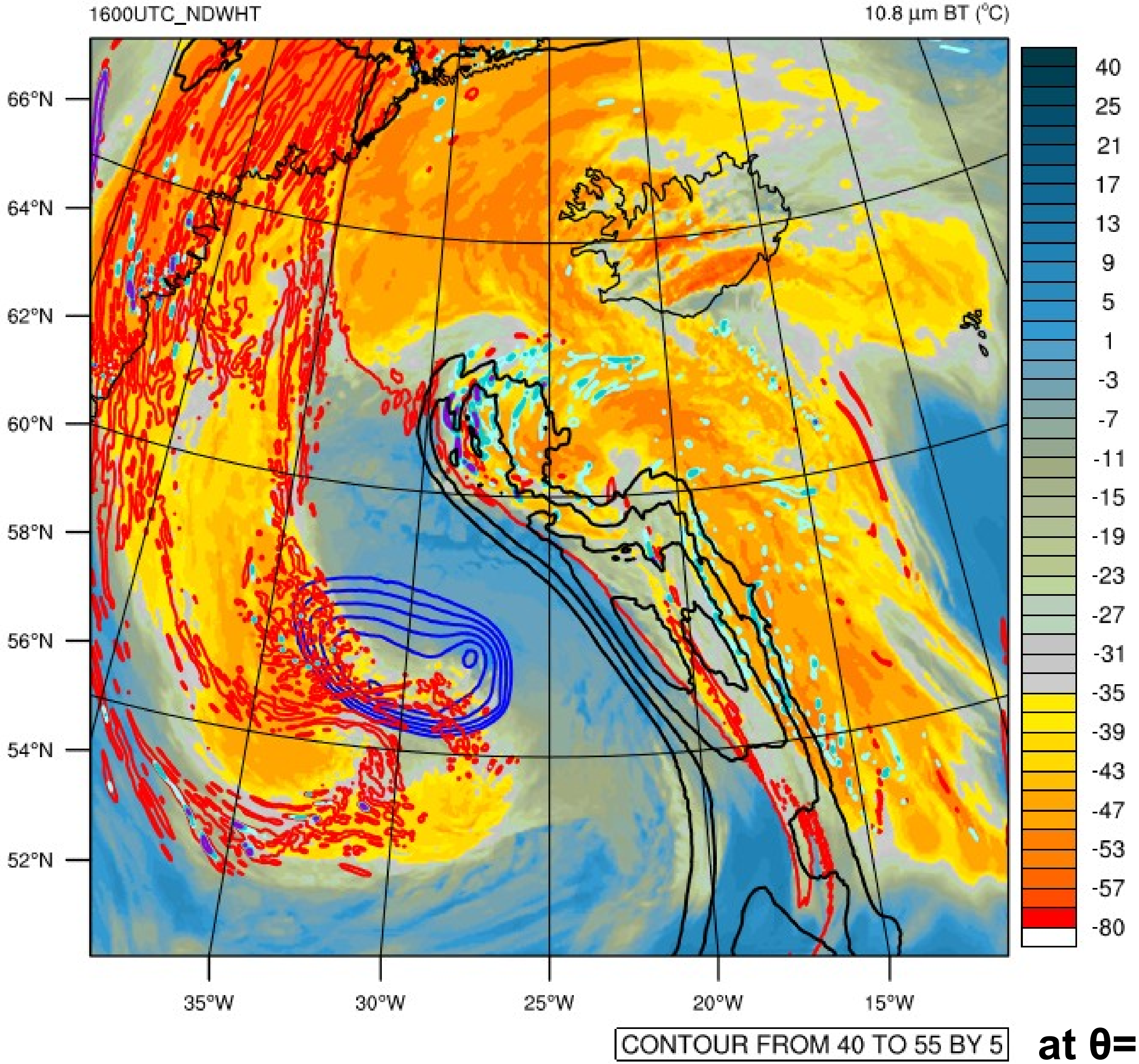
1600 UTC

+2 PVU

-0.5 / -1 PVU

-2 PVU

MSLP



at θ=320 K

End of the negative PV bands?

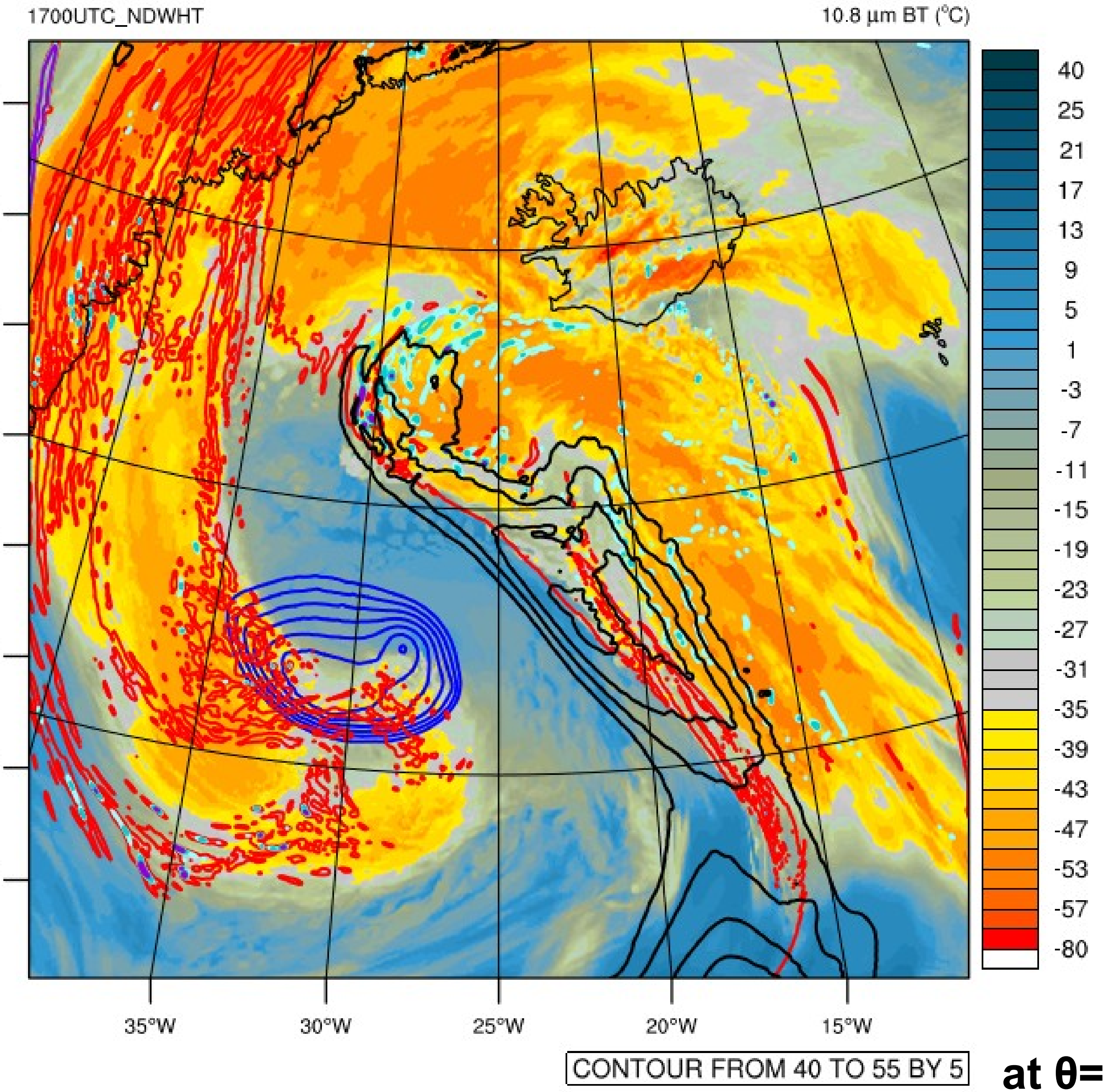
1700 UTC

+2 PVU

-0.5 / -1 PVU

-2 PVU

MSLP



Jet Stream still follow the *cloud head* structure

at θ=320 K

End of the negative PV bands?

1700 UTC

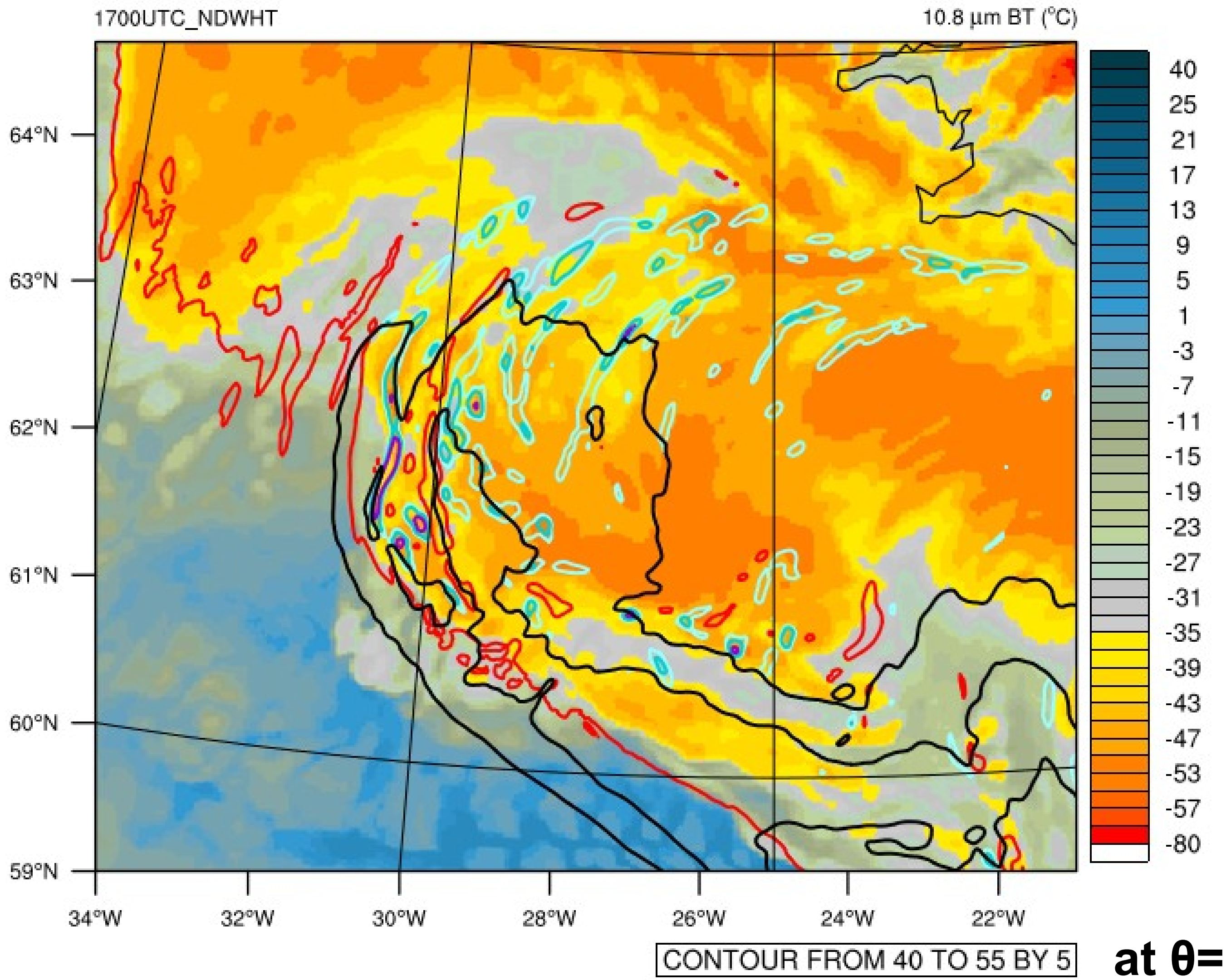
Zoom

+2 PVU

-0.5 / -1 PVU

-2 PVU

MSLP



Jet Stream is locally intensified by the PV gradient

at θ=320 K

End of the negative PV bands?

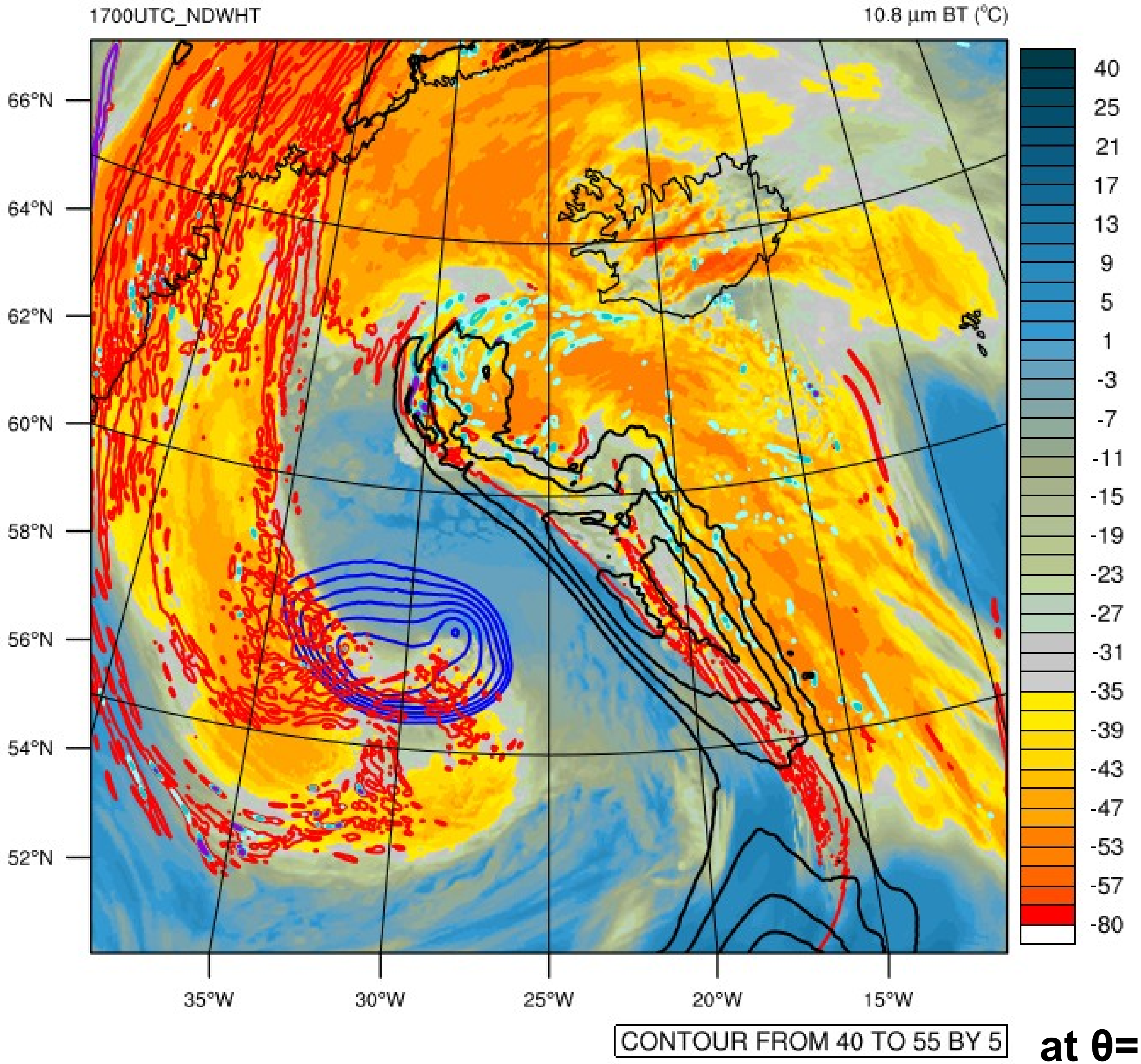
1700 UTC

+2 PVU

-0.5 / -1 PVU

-2 PVU

MSLP



Jet Stream still follow the *cloud head* structure

at θ=320 K

End of the negative PV bands?

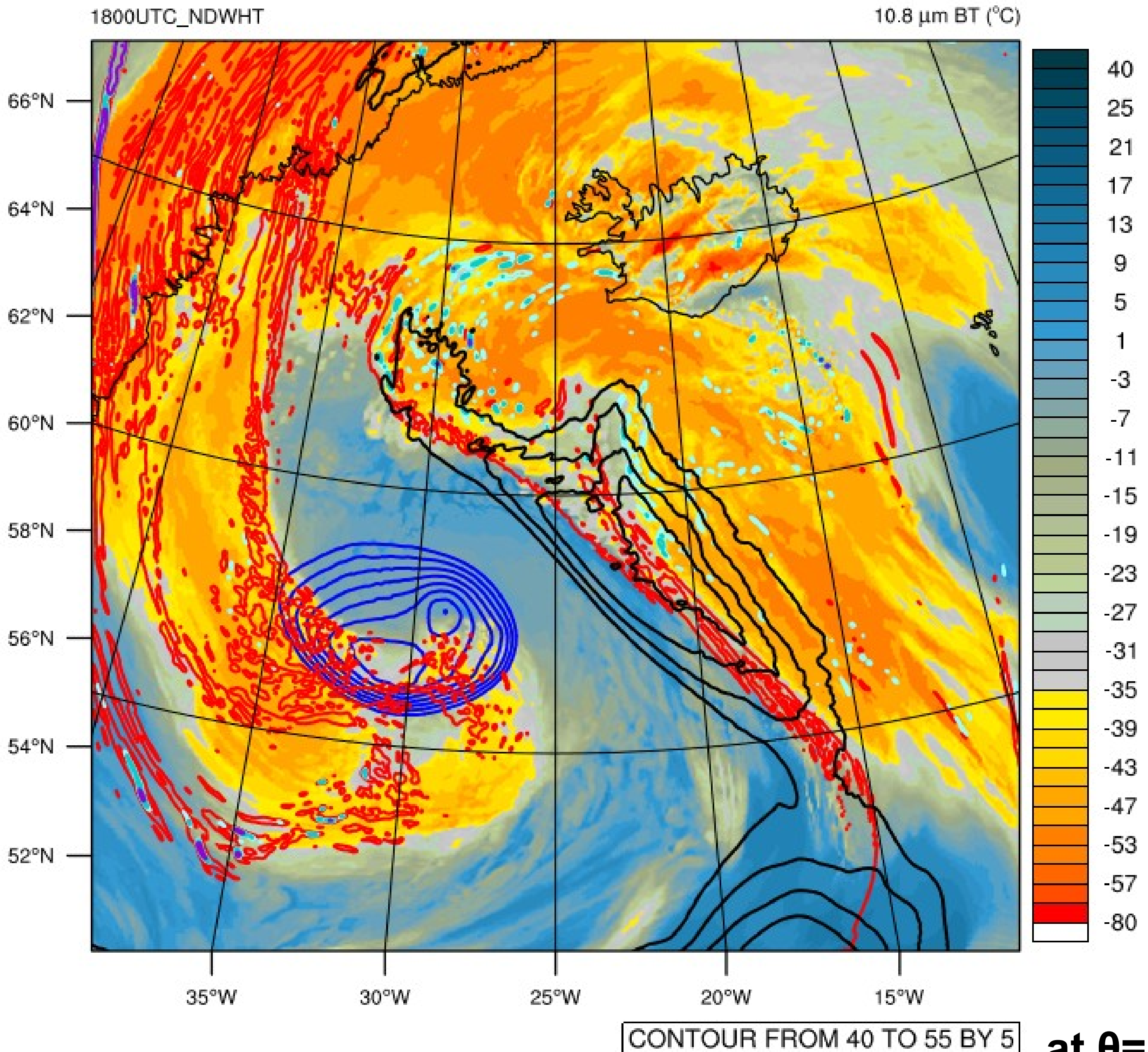
1800 UTC

+2 PVU

-0.5 / -1 PVU

-2 PVU

MSLP



at θ=320 K

End of the negative PV bands?

1800 UTC

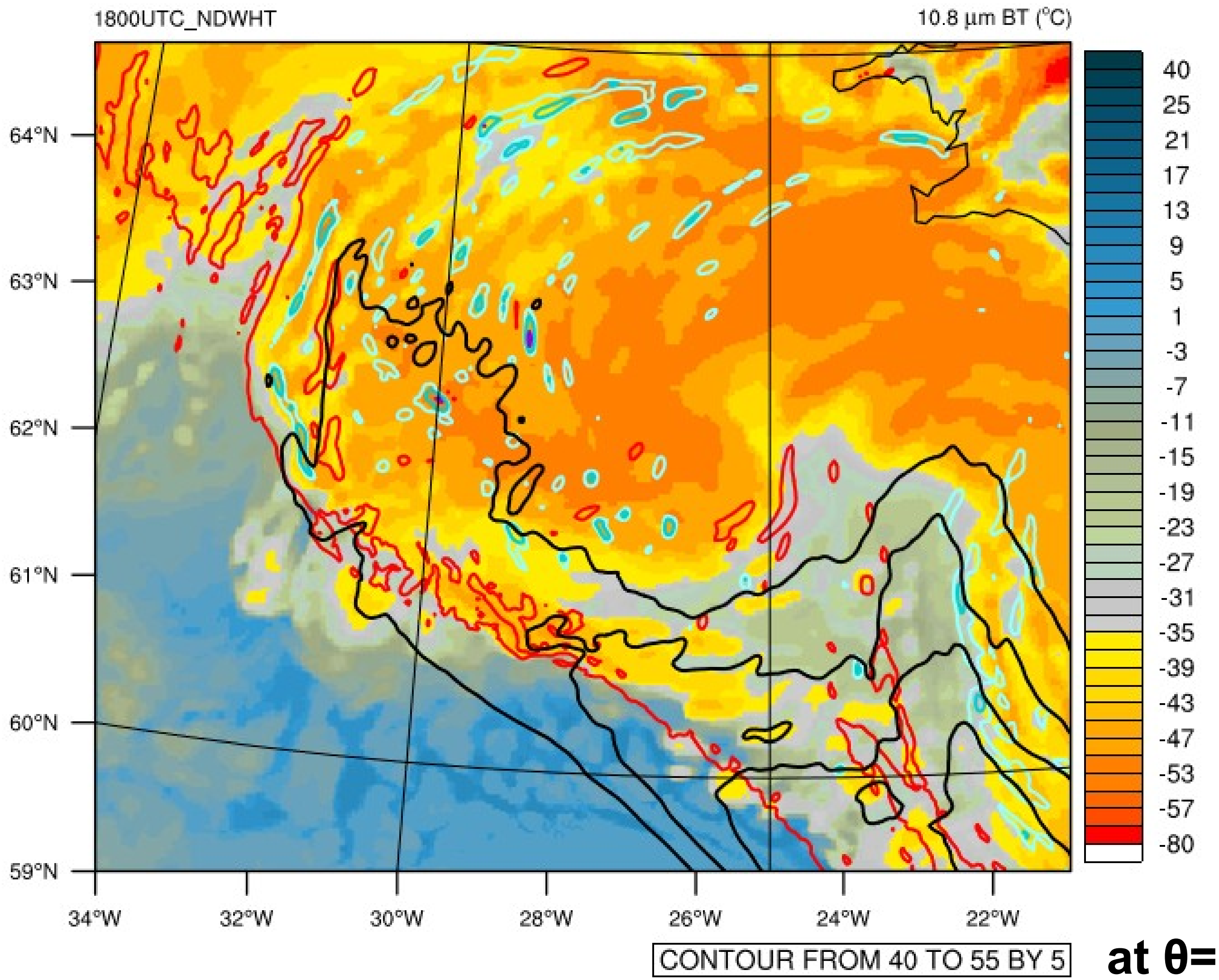
Zoom

+2 PVU

-0.5 / -1 PVU

-2 PVU

MSLP



Discontinous negative PV bands

at θ=320 K

End of the negative PV bands?

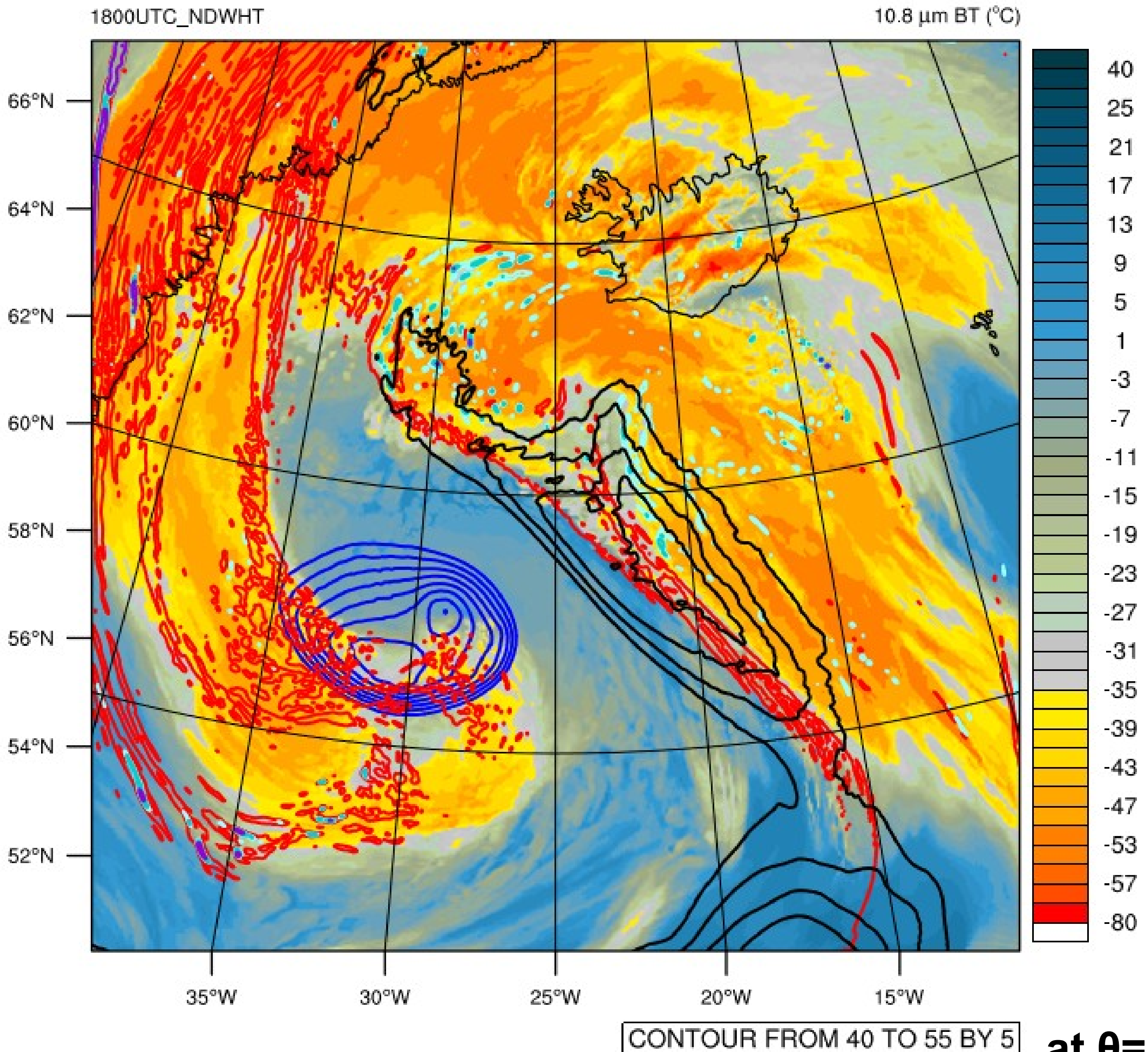
1800 UTC

+2 PVU

-0.5 / -1 PVU

-2 PVU

MSLP



at θ=320 K

End of the negative PV bands?

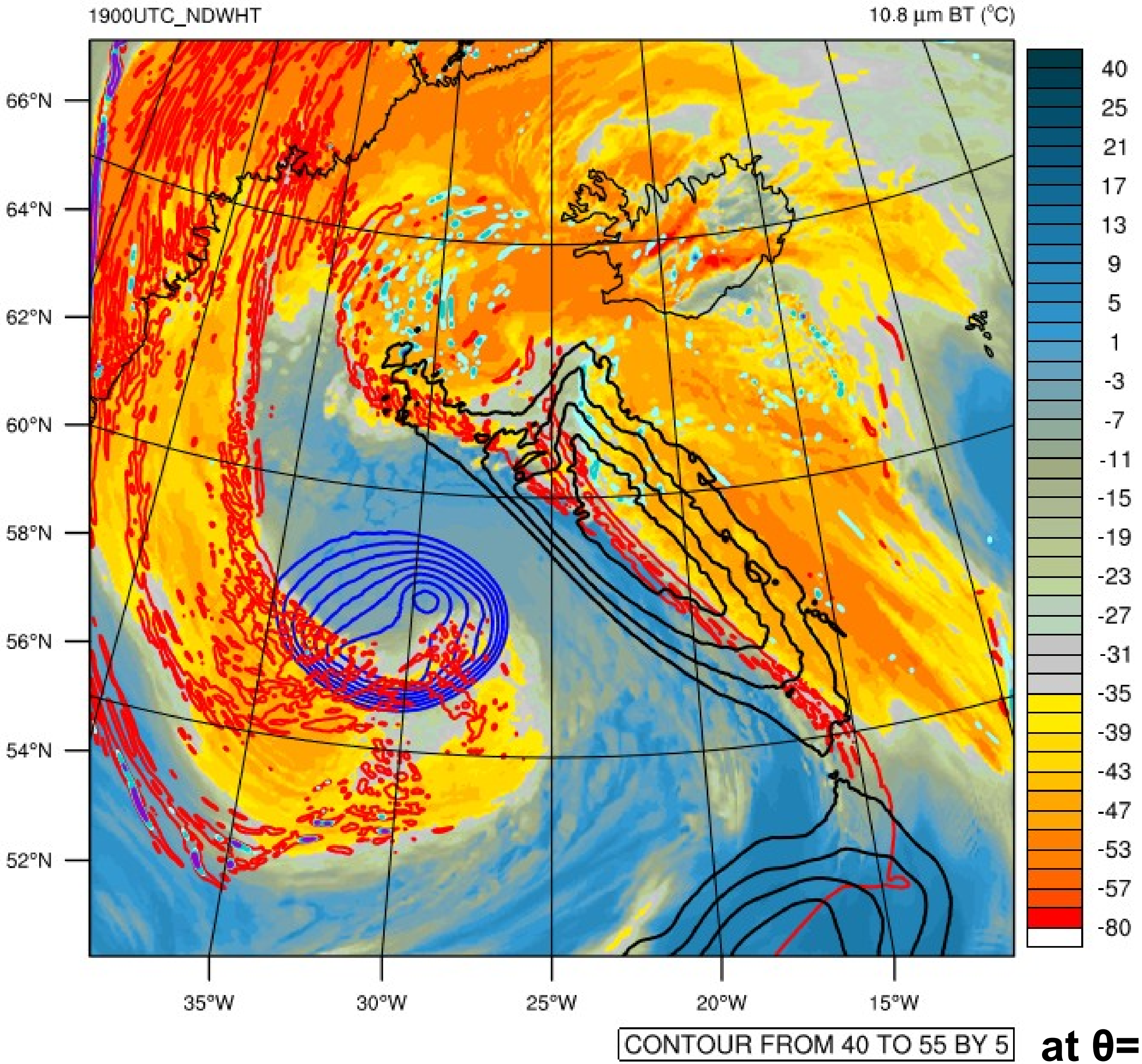
1900 UTC

+2 PVU

-0.5 / -1 PVU

-2 PVU

MSLP



North part of the Jet Stream disappears because of the cloud head and negative PV bands advection

at θ=320 K

End of the negative PV bands?

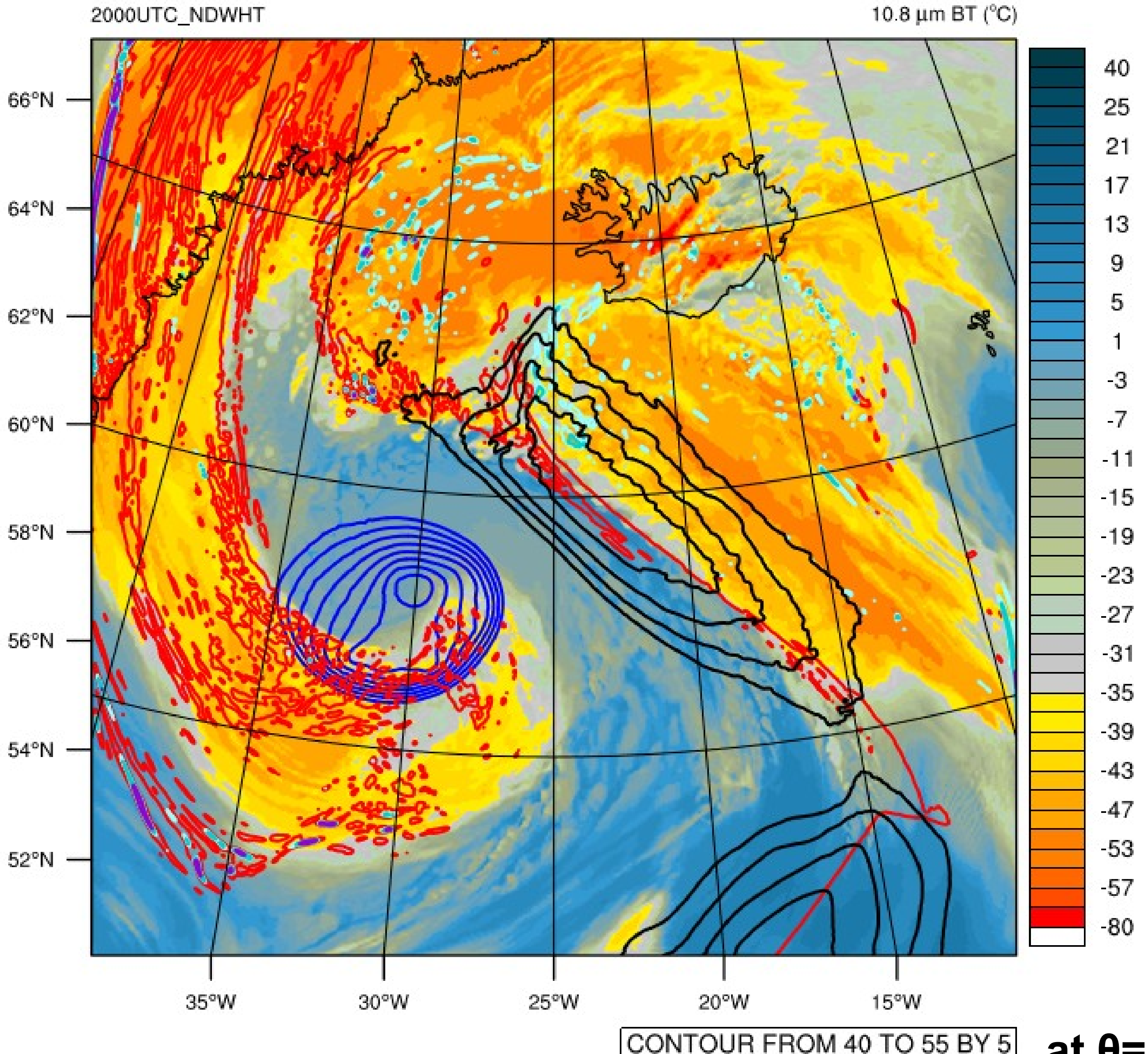
2000 UTC

+2 PVU

-0.5 / -1 PVU

-2 PVU

MSLP



Dispersion of elongated negative PV bands

at θ=320 K

End of the negative PV bands?

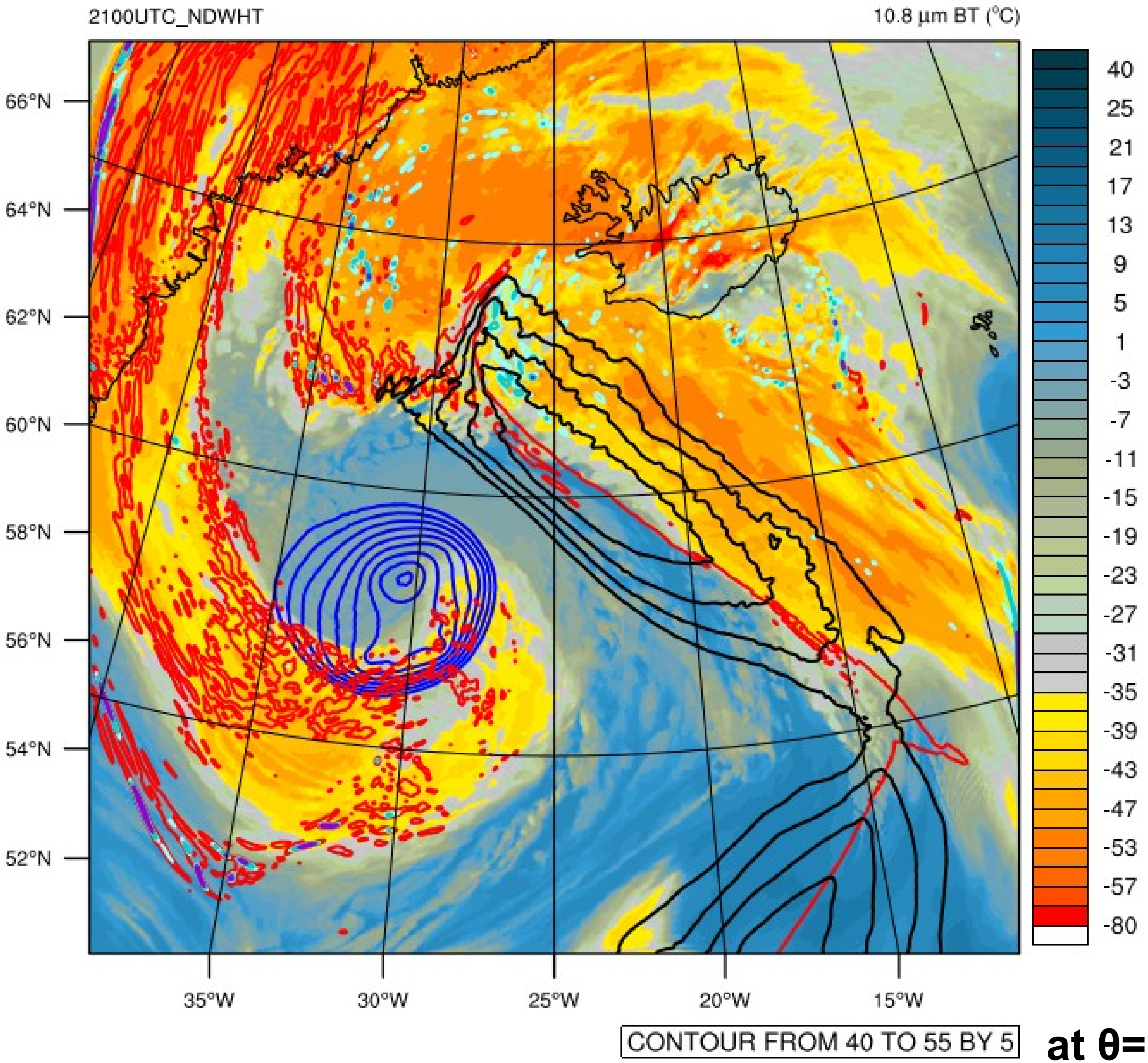
2100 UTC

+2 PVU

-0.5 / -1 PVU

-2 PVU

MSLP



Negative PV in anticyclonic flow

/

Negative PV within cloud head in cyclonic flow

at θ=320 K

End of the negative PV bands?

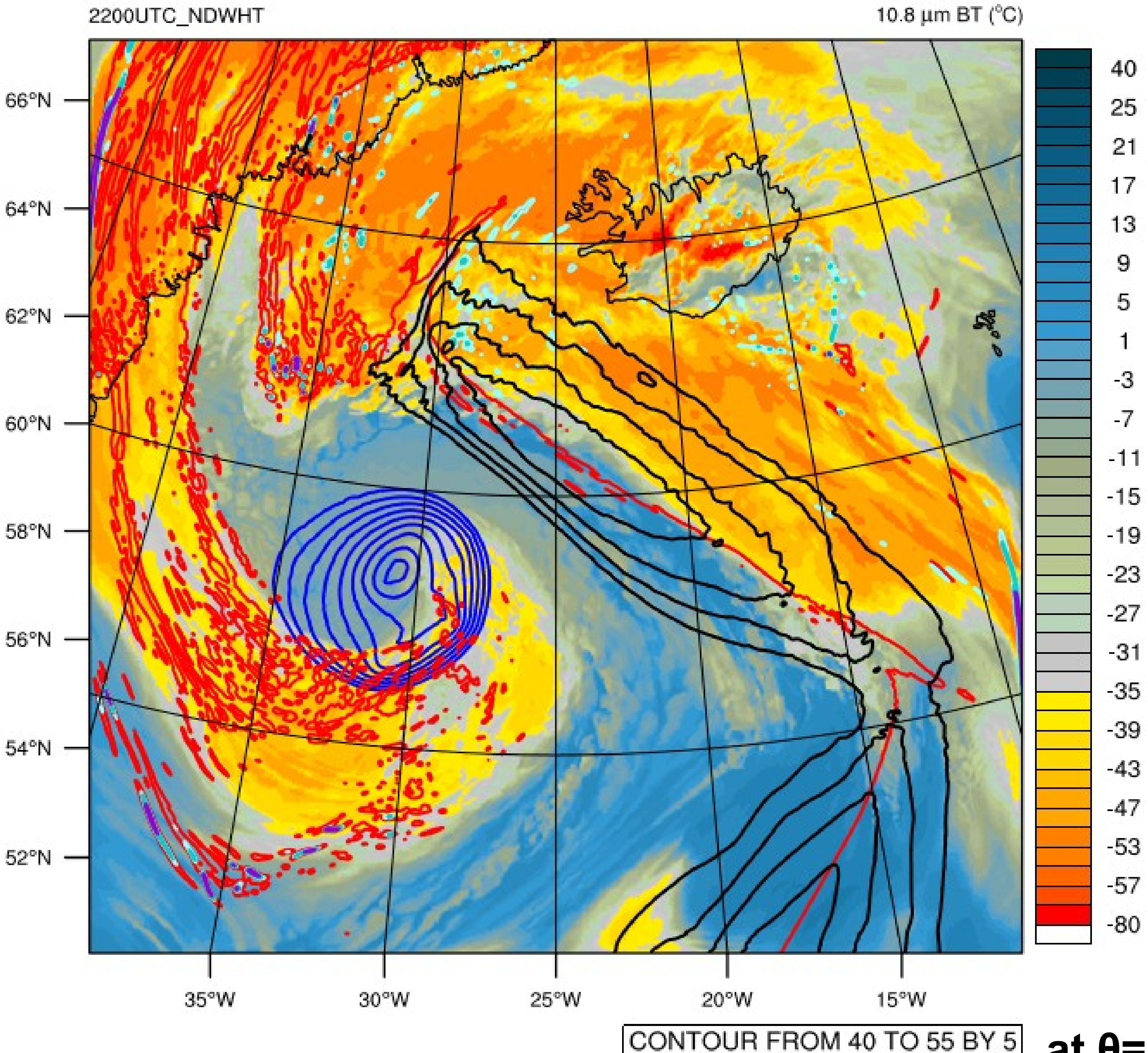
2200 UTC

+2 PVU

-0.5 / -1 PVU

-2 PVU

MSLP



Negative PV disappears

at θ=320 K