An overview on the concept of Warm Conveyor Belts

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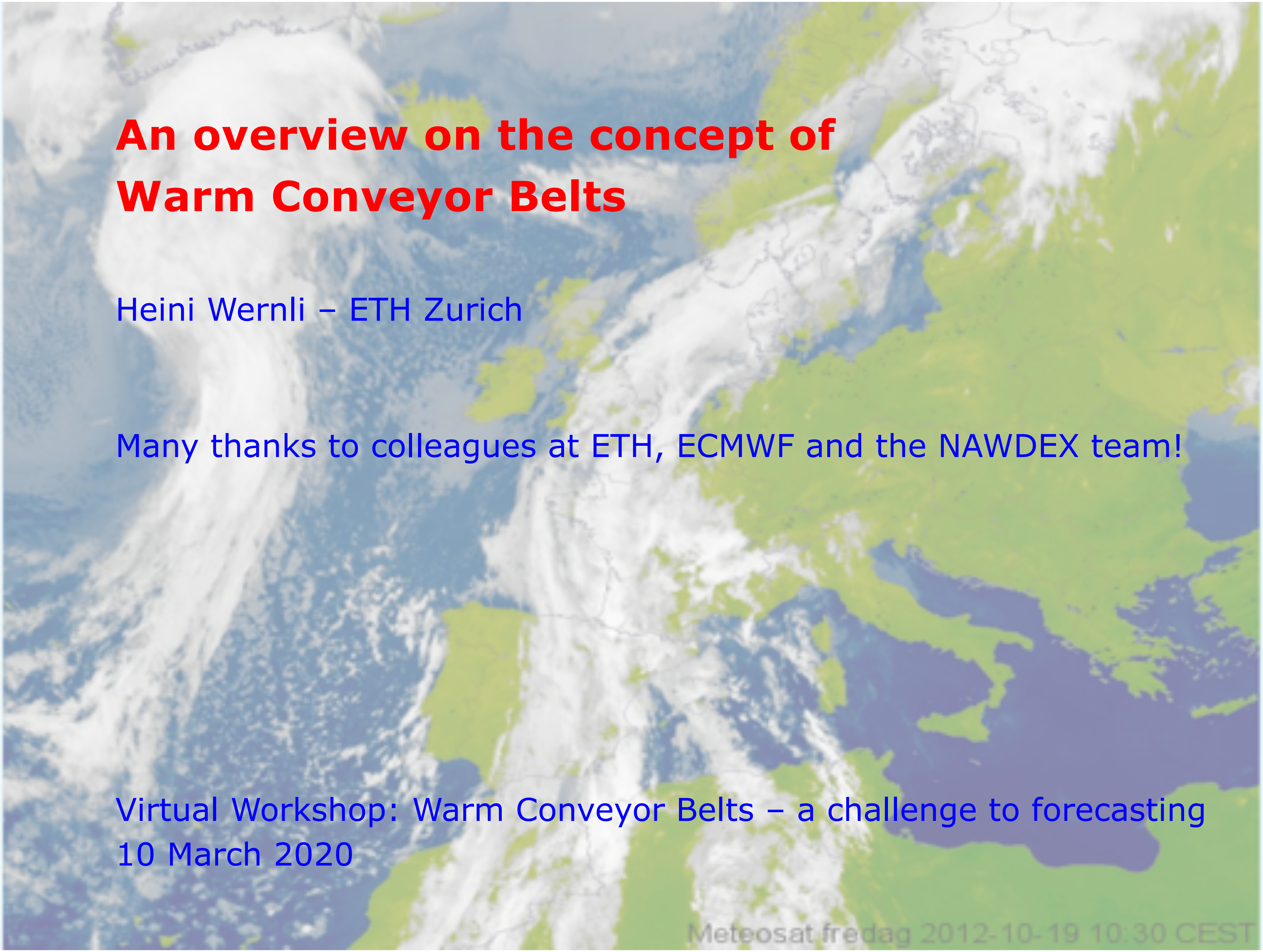
Many thanks to colleagues at ETH, ECMWF and the NAWDEX team!

Virtual Workshop: Warm Conveyor Belts – a challenge to forecasting
10 March 2020



Outline

What are WCBs? A brief historical perspective

Why are WCBs relevant and interesting?

A selection of open questions

What are WCBs? A brief historical perspective

Green et al. 1966 (QJ)

Isentropic relative-flow analysis and application of parcel theory from cumulonimbus to “large-scale convection”:

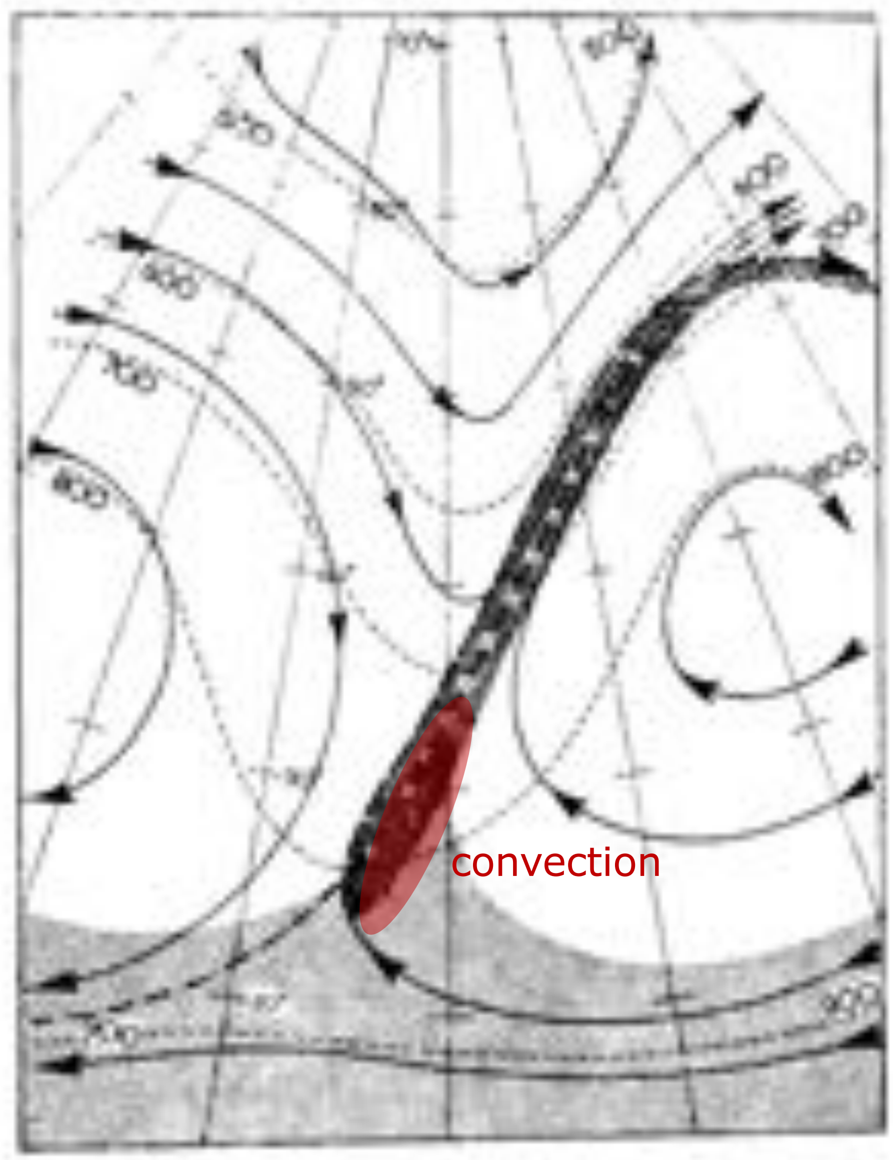
- “It appears that trade wind air may rise over a front into a jet stream …”

- “The model for the large-scale motion system is very similar to the model for the … cumulonimbus, except that the horizontal scale is very much greater.”

What are WCBs? A brief historical perspective

Green et al. 1966 (QJ)

- "The hatched area is a cloud system formed where … this air rises above the isentropic surface, producing low clouds liable to small-scale convection in the south, subsequently middle-clouds, and finally cirrus clouds near and to the right of the axis of the jet-stream …"



What are WCBs? A brief historical perspective

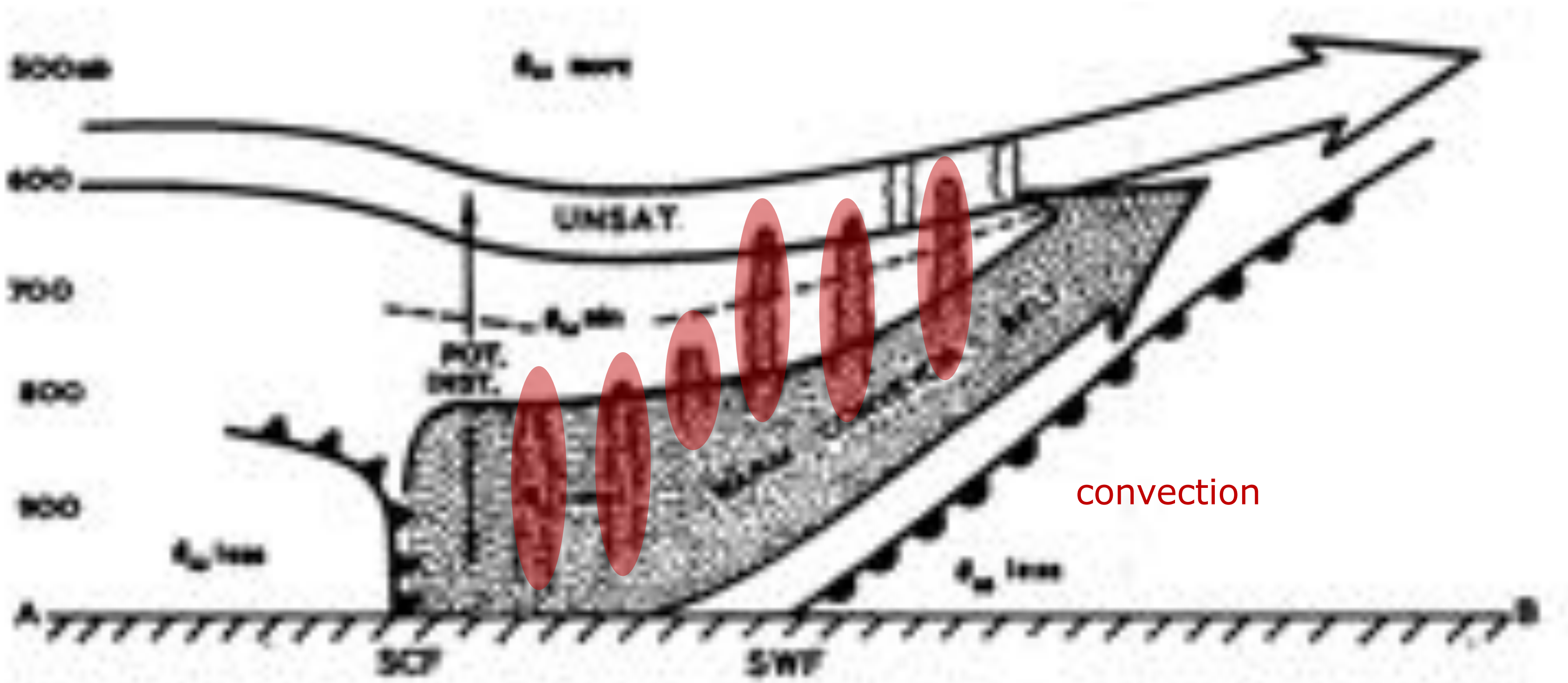
Browning 1971 (Weather)

Detailed isentropic analysis, using data from radiosondes

- "… production of frontal precipitation occurs mainly within a tongue of warm air which flows ahead of the cold front before ascending above the warm front. The extent of this flow is well defined … because of the narrowness of this flow it will be referred to as a "conveyor belt" – *footnote: This term was used in a discussion at the conference on the Global Circulation of the Atmosphere, London, 1969."*
- Large-scale ascent within the WCB is of the order of 10 cm/s *(→ 8.6 km/day)*, but this is modified by small-scale convection … often this convection is very weak with updraught velocities of about 1 m/s or less."

What are WCBs? A brief historical perspective

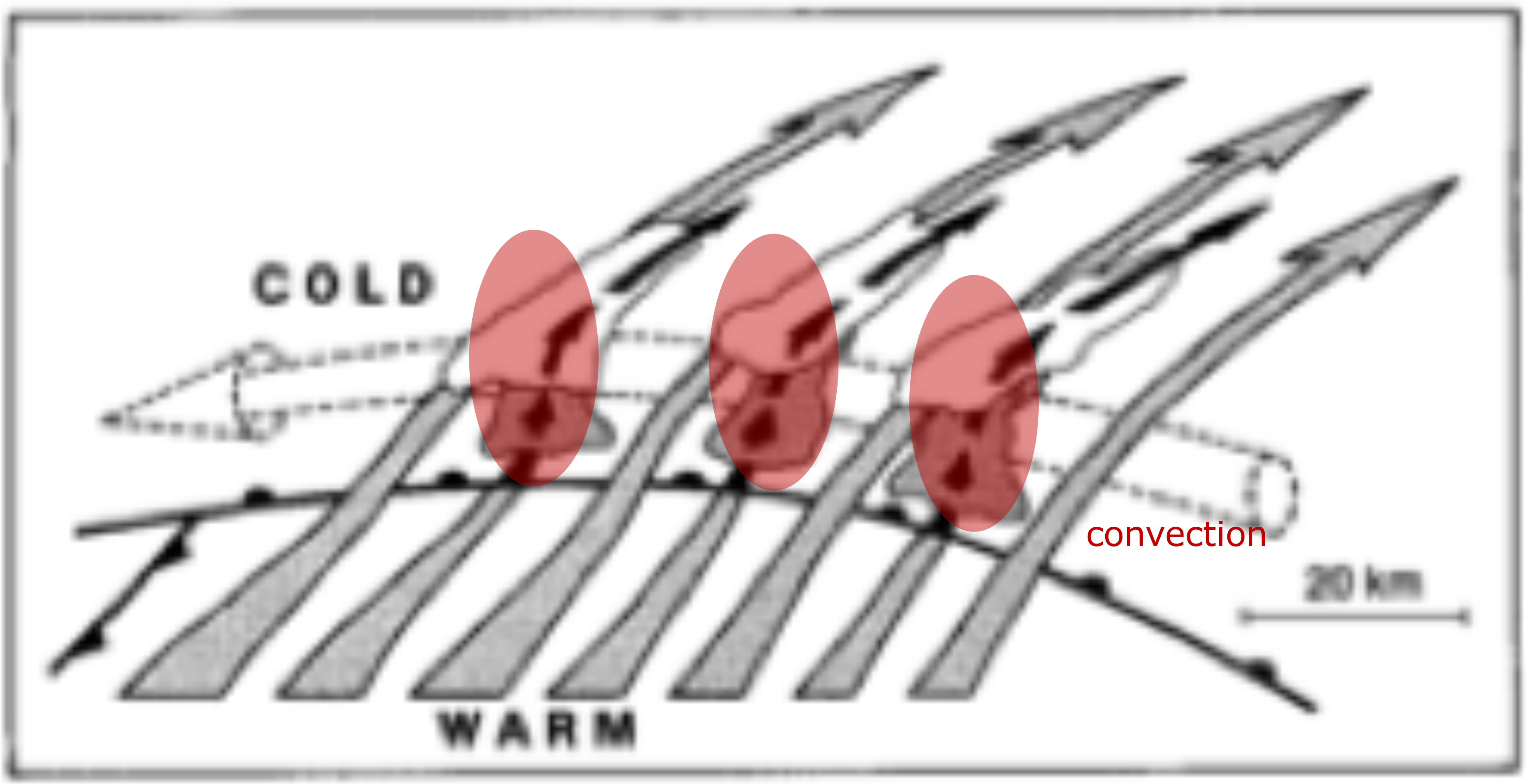
Browning 1971 (Weather) – figure redrawn from Harrold



What are WCBs? A brief historical perspective

Neiman et al. 1993 (MWR)

Slantwise ascent (“escalator”) vs. convective ascent (“elevator”)



What are WCBs? A brief historical perspective

Browning 1990 (Palmén Book)

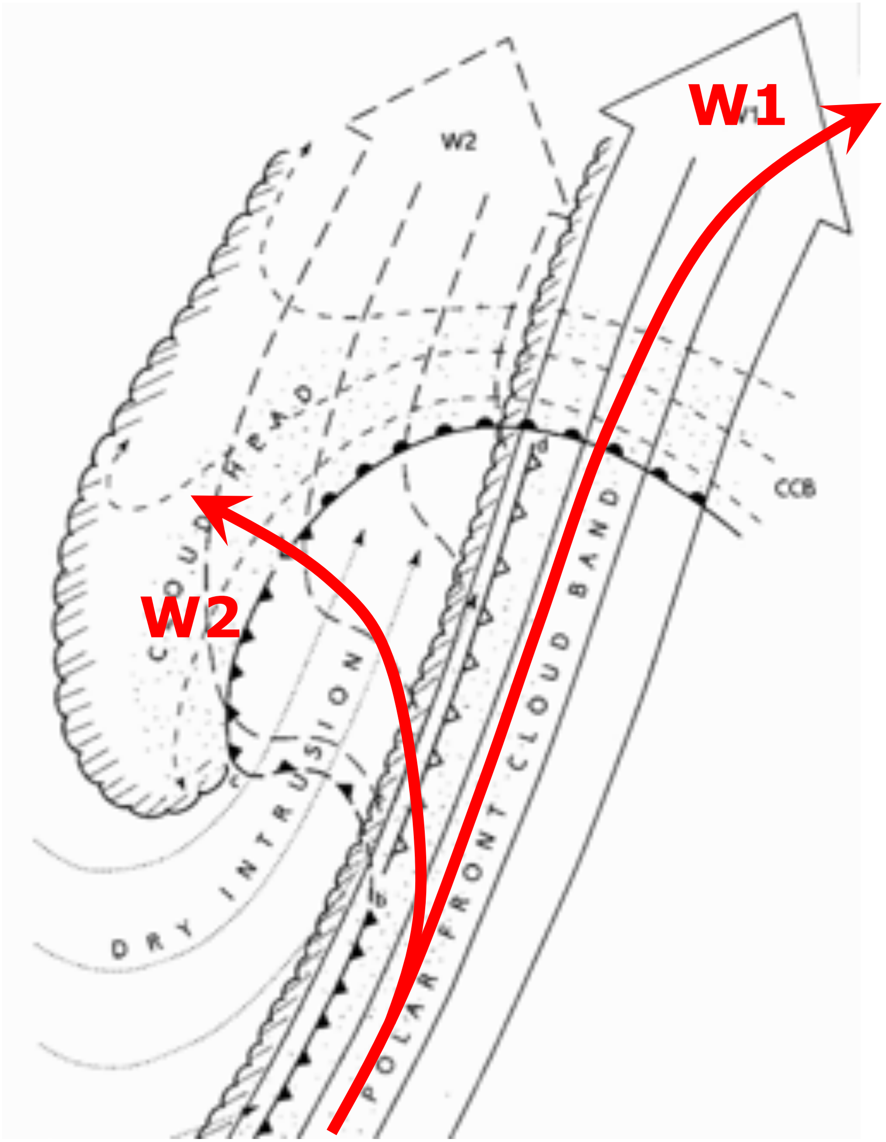
"WCB is the primary cloud- and precipitation-producing flow within extratropical cyclones"

→ WCB is airstream with max. cloud diabatic processes (e.g., maximum latent heating)

Browning 1997 (Met. App.)

WCB can have two branches

- W1 (anticyclonic)
- W2 (cyclonic)



What are WCBs? A brief historical perspective

Do trajectories confirm the existence of coherent airstreams in extratropical cyclones?

Mass and Schultz 1993 (MWR)

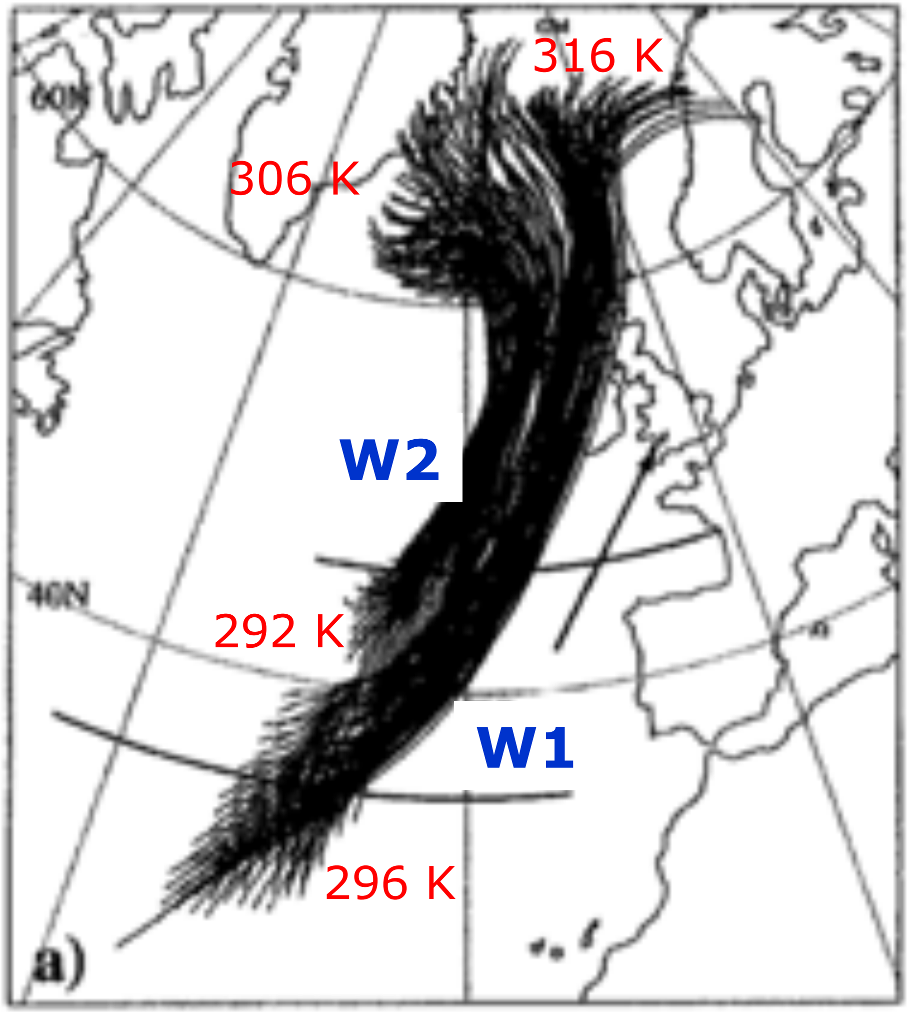
"… the rapidly rising trajectories based in the warm sector appear to fan out …. The airflow families that do exist are not belt-like in structure, but rather evidence more complex geometries."

Wernli and Davies 1997 (QJ); Wernli 1997 (QJ)

Lagrangian selection criteria (e.g., max. ascent, max. latent heat release) lead to coherent bundles of trajectories reminiscent of WCBs

What are WCBs? A brief historical perspective

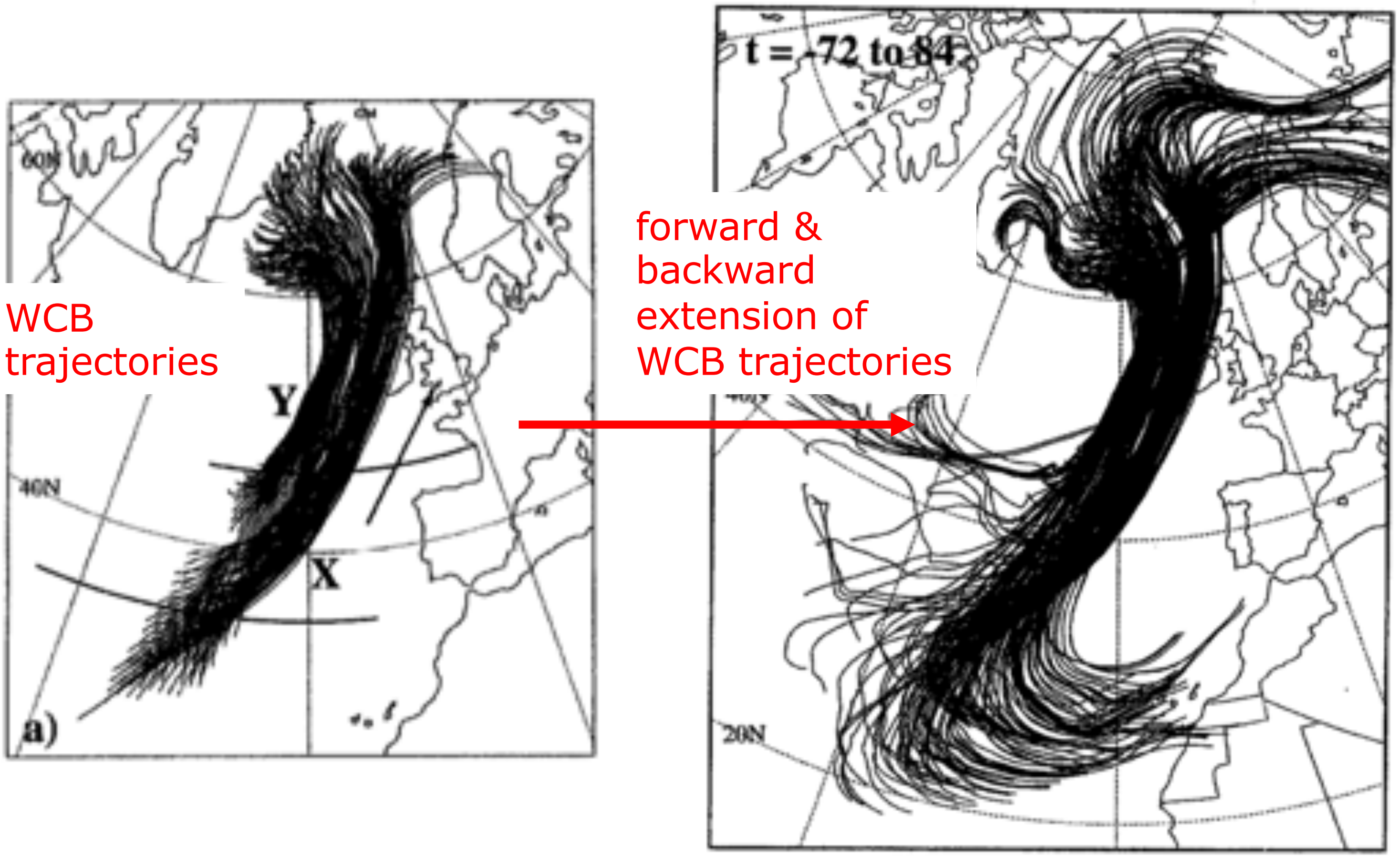
Lagrangian selection criterion of ascent > 600 hPa in 48 hours identifies (in some cases) both WCB branches



Wernli 1997 (QJ)

What are WCBs? A brief historical perspective

- Coherent phase of WCB corresponds to period of strong ascent
- Strong confluence prior to and diffluence after the ascent

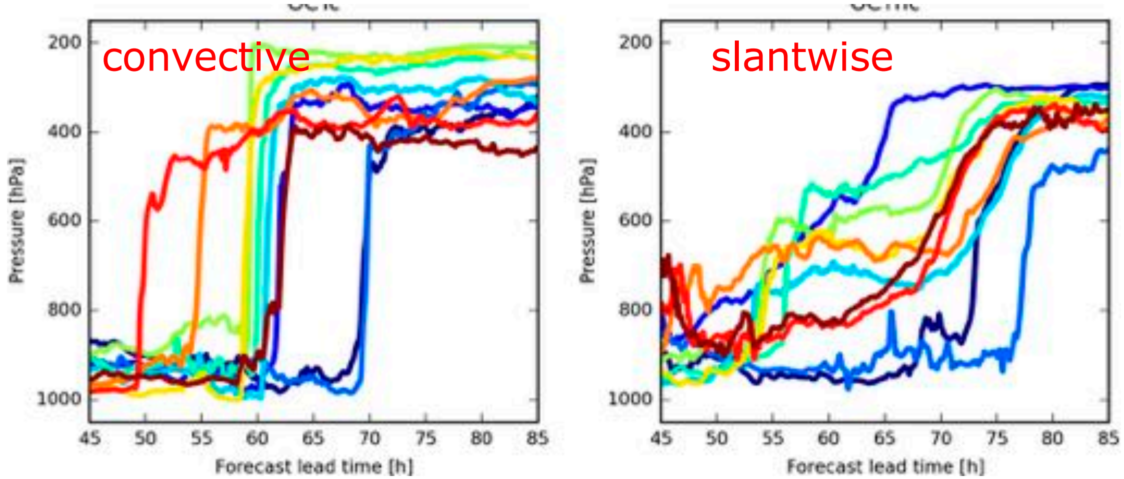


Wernli 1997 (QJ)

What are WCBs? A brief historical perspective

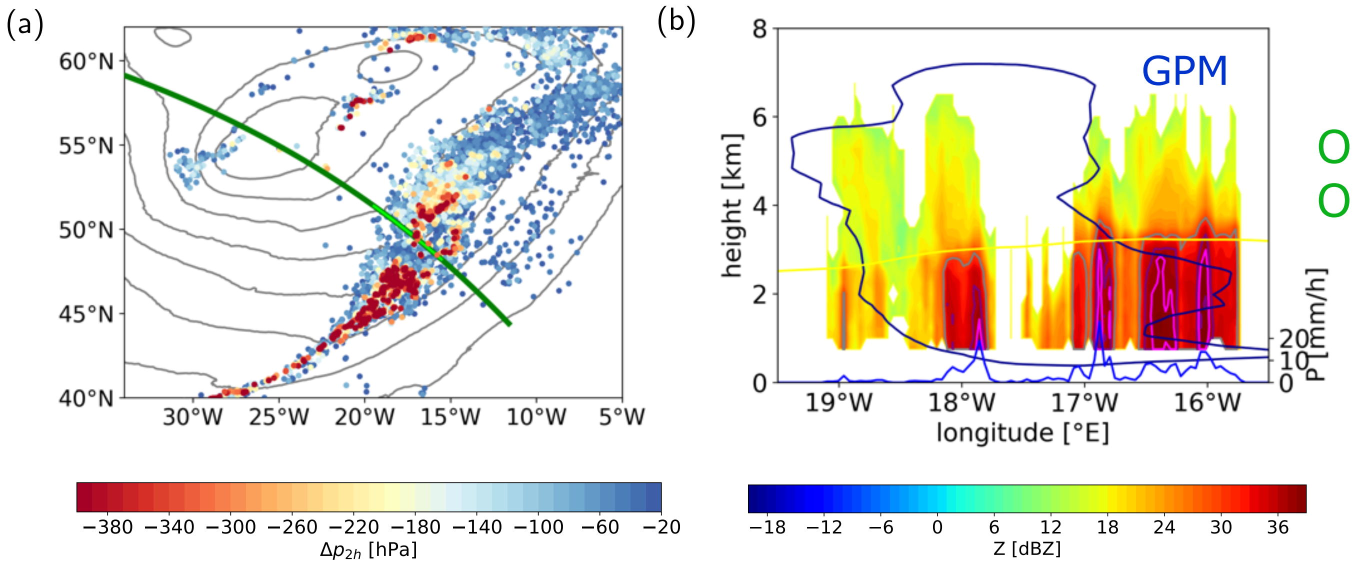
Convective vs. slantwise ascent in WCBs?

→ km-scale simulations with explicit convection reveal both types



Rasp et al. 2016 (MWR)

→ good agreement between km-scale simulations and radar observations



Oertel 2019 (PhD thesis)
Oertel et al. 2019 (QJ)

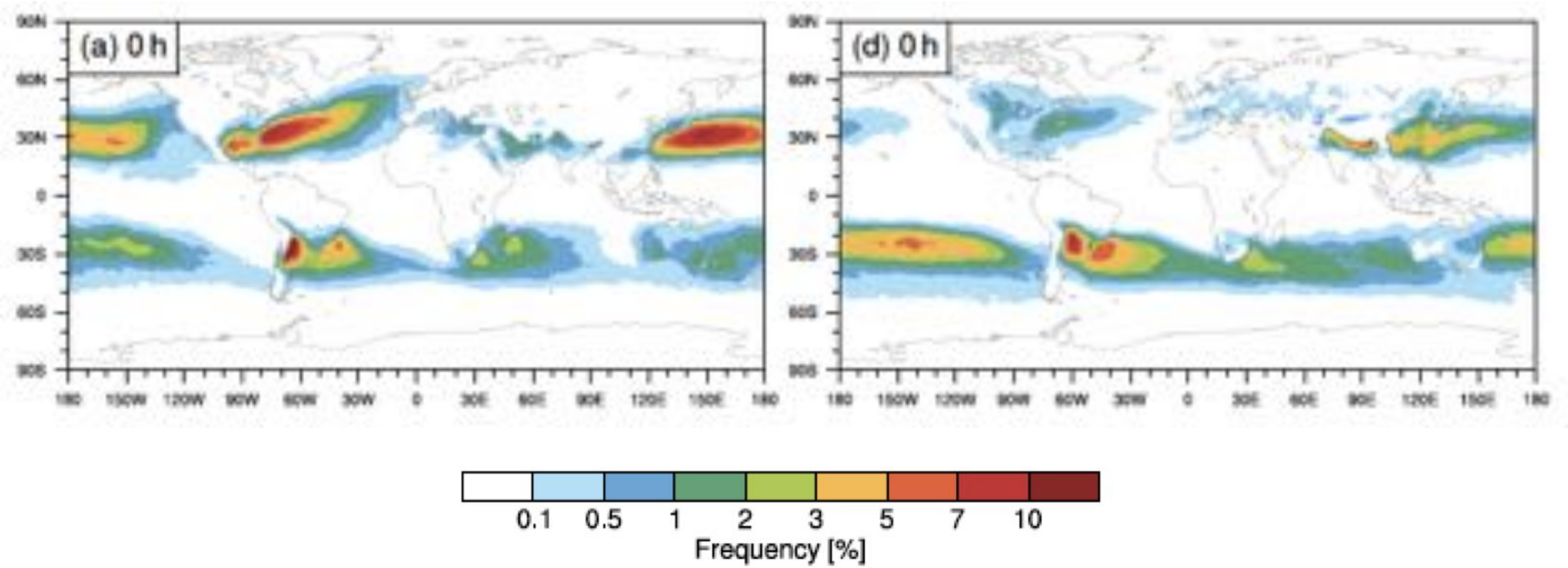
What are WCBs? A brief historical perspective

How often do they occur? → Climatologies based on reanalyses

Eckhardt et al. 2004 (J Clim); Madonna et al. 2014 (J Clim)

Frequency of WCB starting points for 1979-2014 based on ERA-Interim

DJF JJA



Binder 2016 (PhD thesis), update from Madonna et al. 2014 (J Clim)

Why are WCBs relevant and interesting?

- (Extreme) **precipitation** in mid-latitudes
- Intense **latent heating** → cloud-circulation coupling
- Diabatic PV production at low levels → **cyclone intensification**
- Cross-isentropic transport of low-PV air → **jet interaction, ridge-building, blocks, weather regimes**
- **Complex cloud system** involving all microphysical process (warm phase, mixed phase, cirrus, below-cloud processes) and slantwise vs. convective ascent
- Strong **cloud radiative forcing** → climate dynamics
- WCBs can lead to **reduced predictability / busts**

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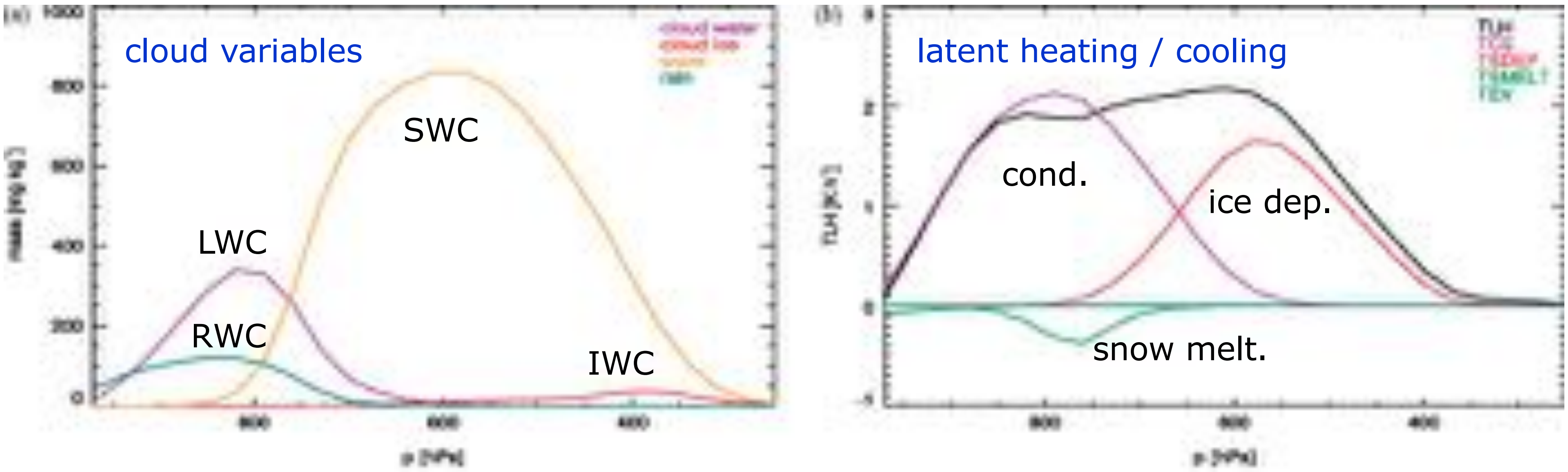
These – and other – asepcts will be addressed by talks and posters during this workshop

Open questions (1)

How well constrained are microphysical processes along WCB ascent? How realistic are cloud variables and latent heating in WCBs in models? Which processes are most uncertain?

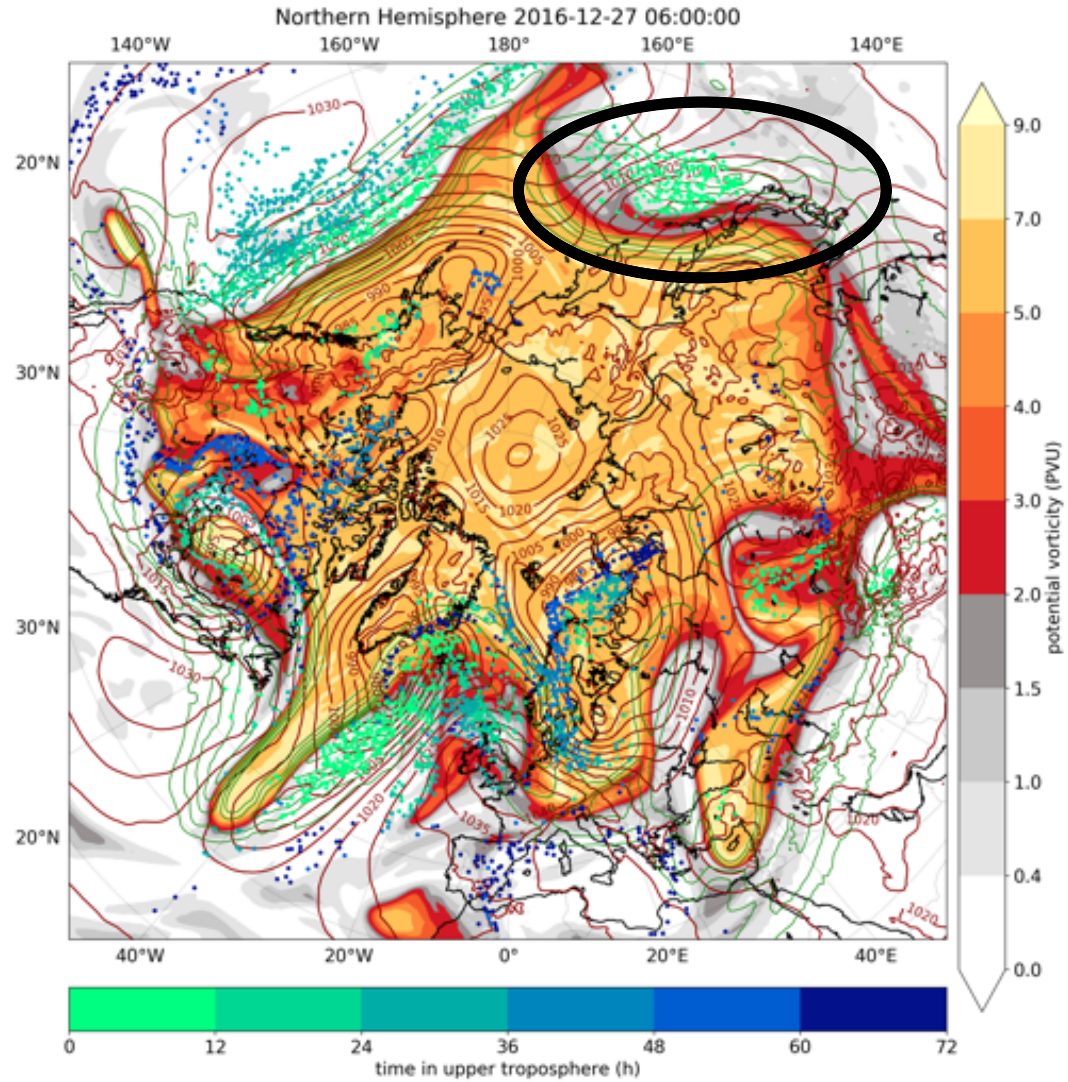
Example from COSMO model:



Joos and Wernli 2012 (QJ)

Open questions (2)

What determines WCB–jet interactions? When is interaction weak (WCB dispersed along jet) vs. strong (formation of block)?



Example:

- explosive cyclogenesis in North Pacific
- intense WCB outflow
- formation of downstream block

from Christopher Rausch

Open questions (2)

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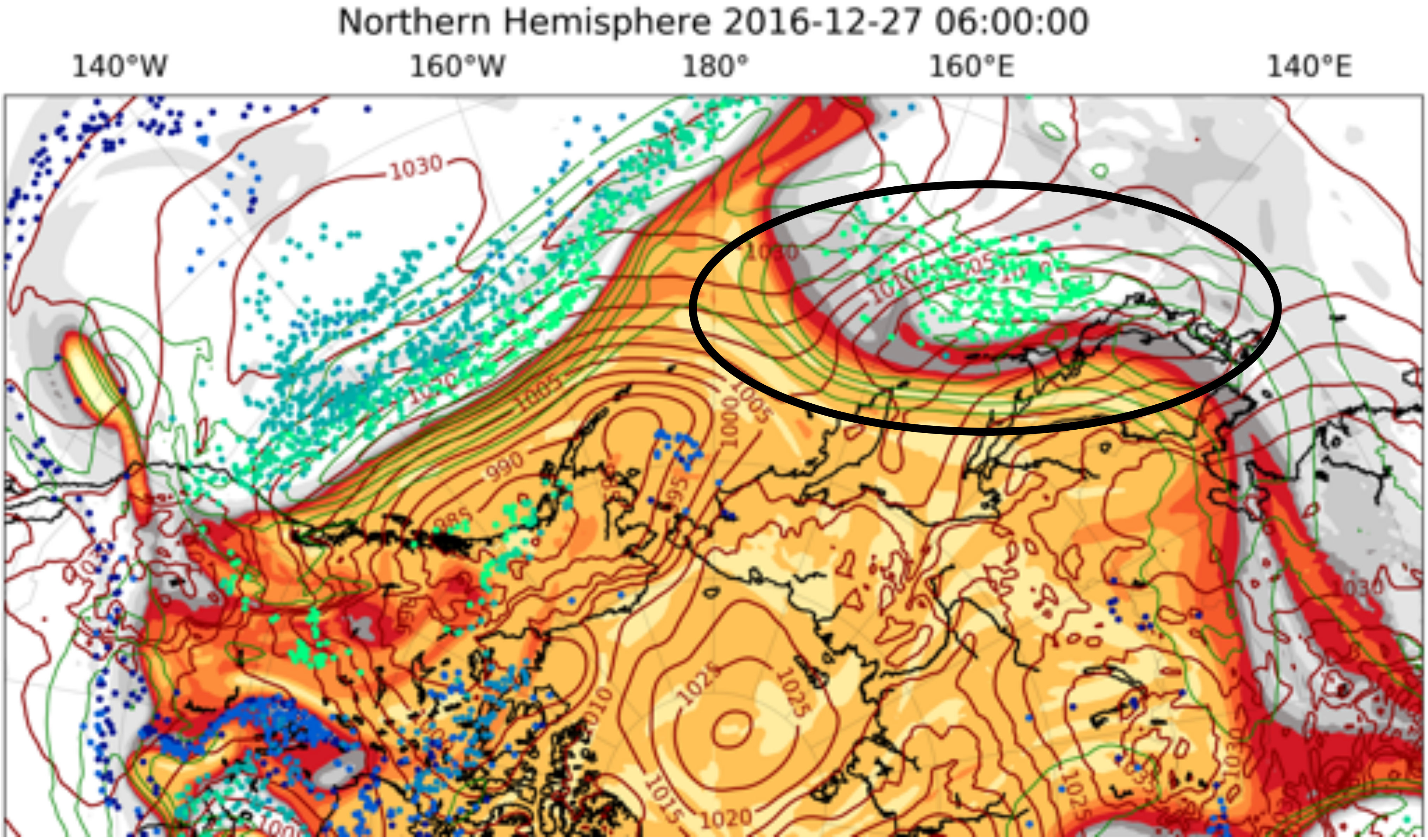

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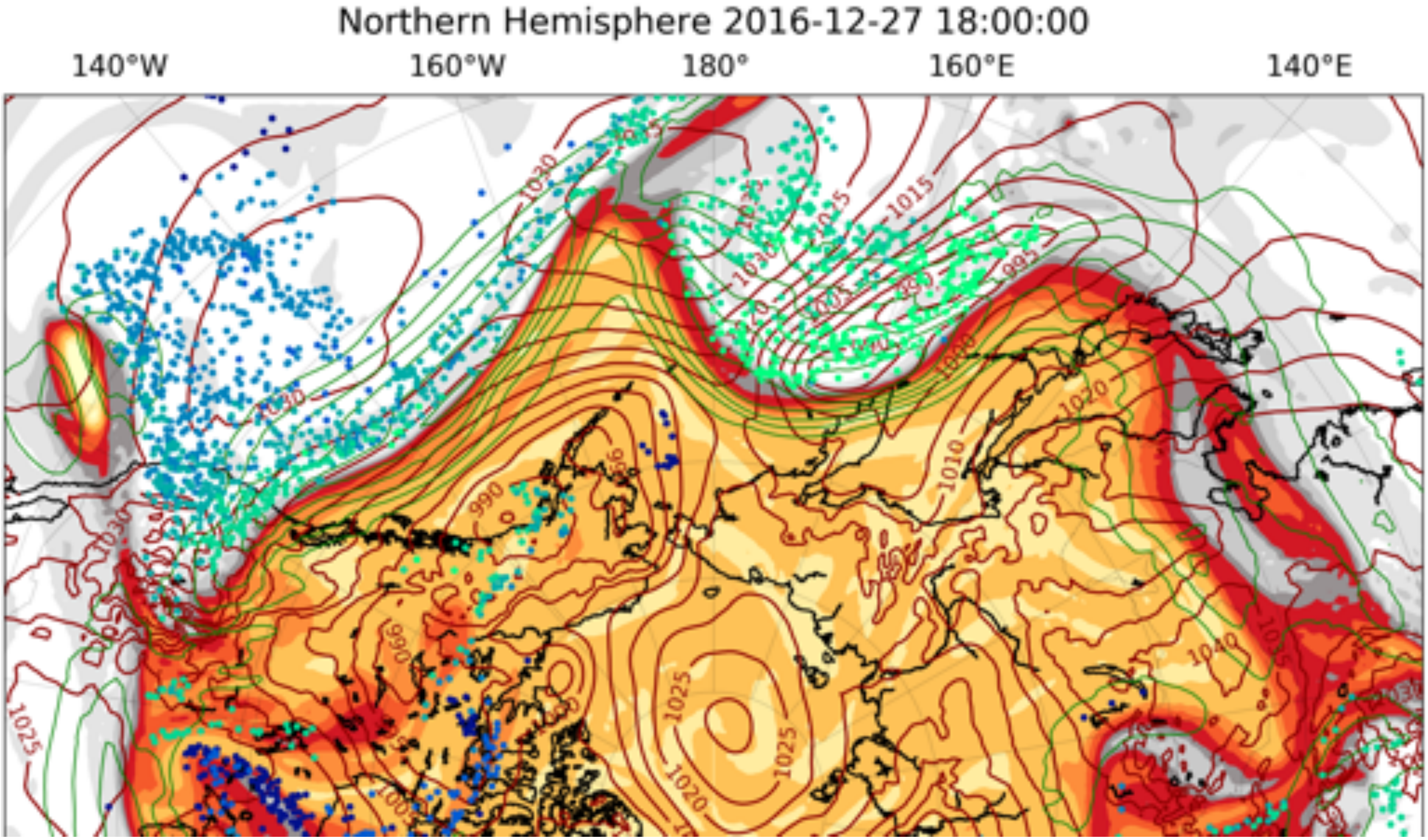

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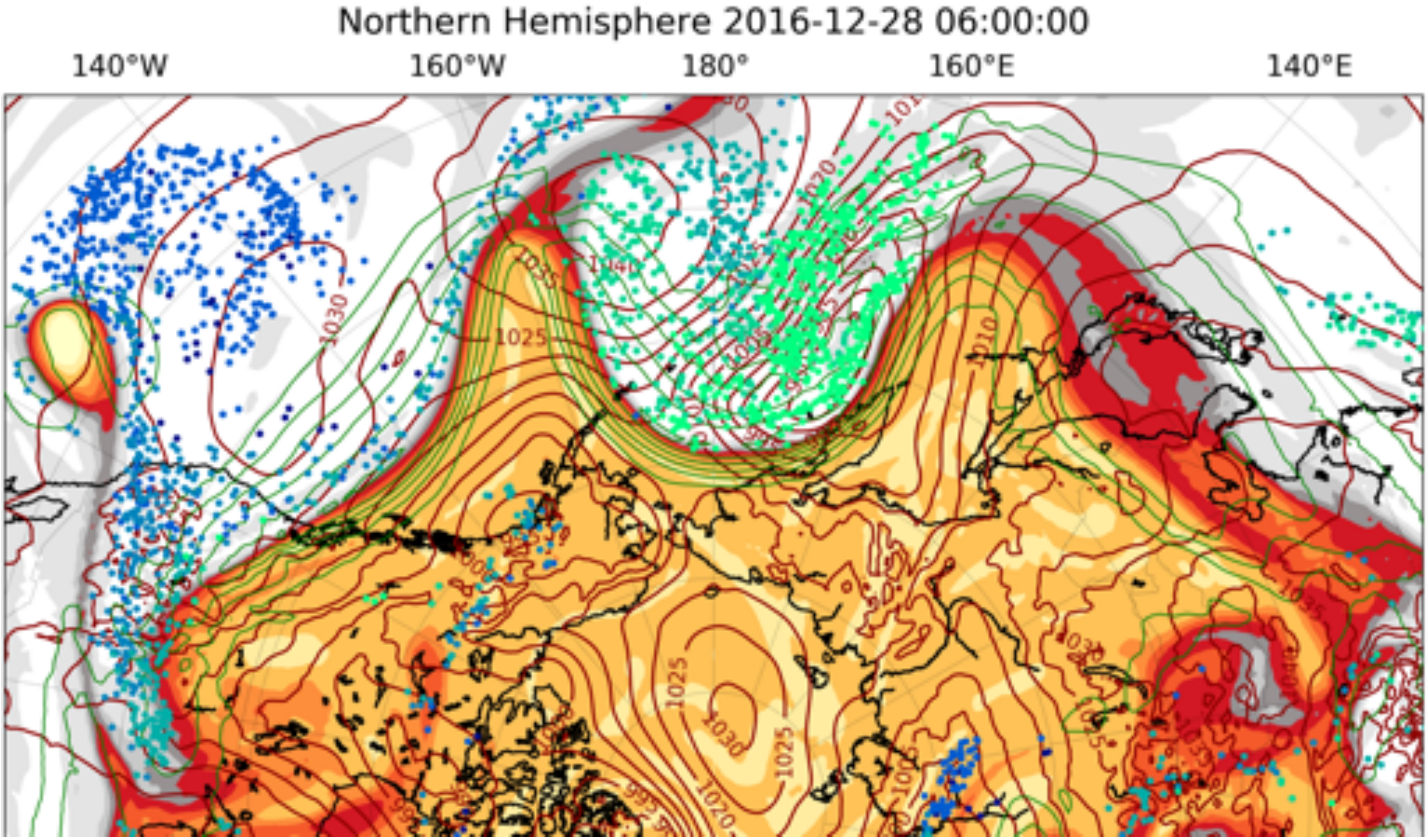

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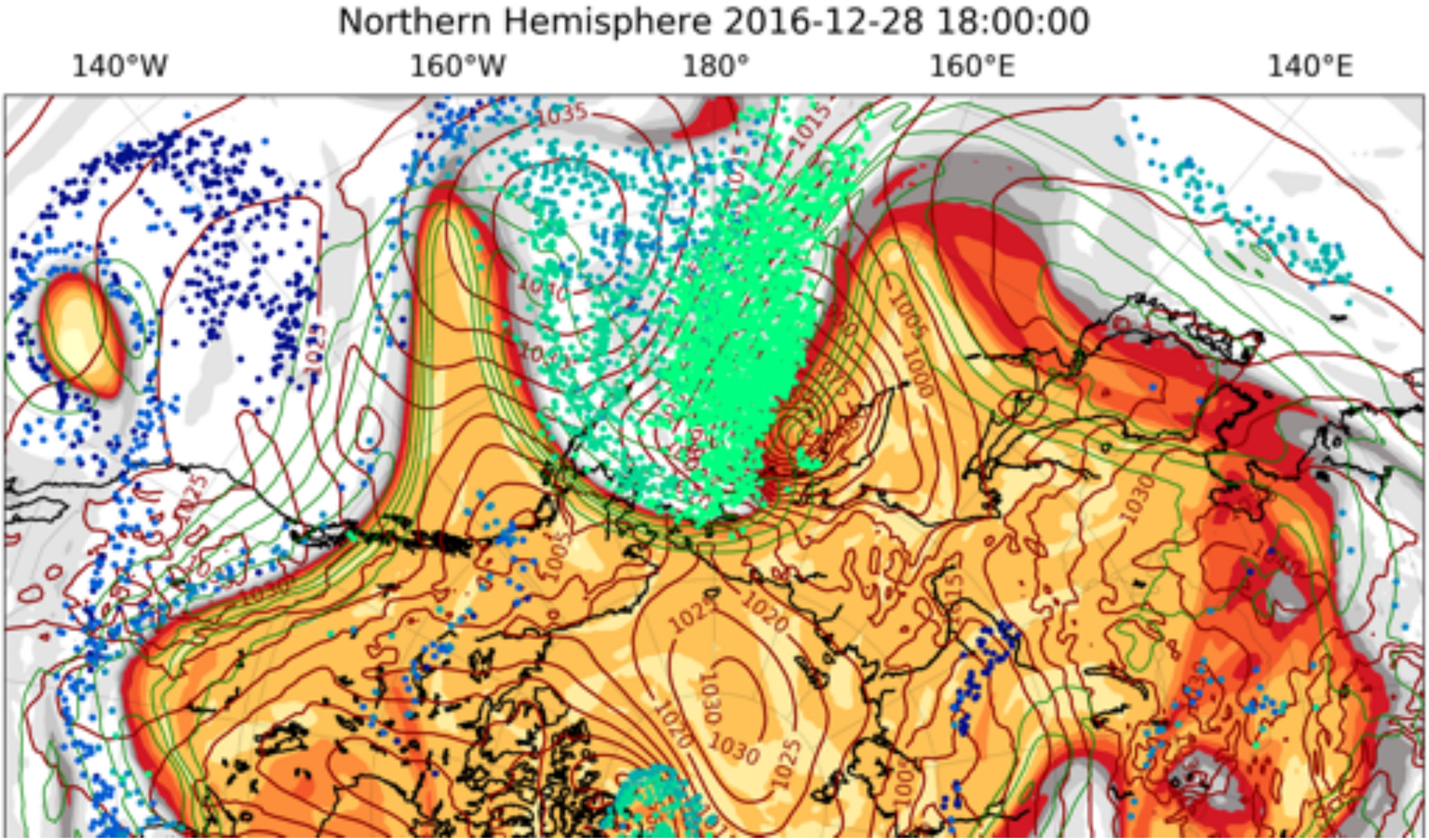

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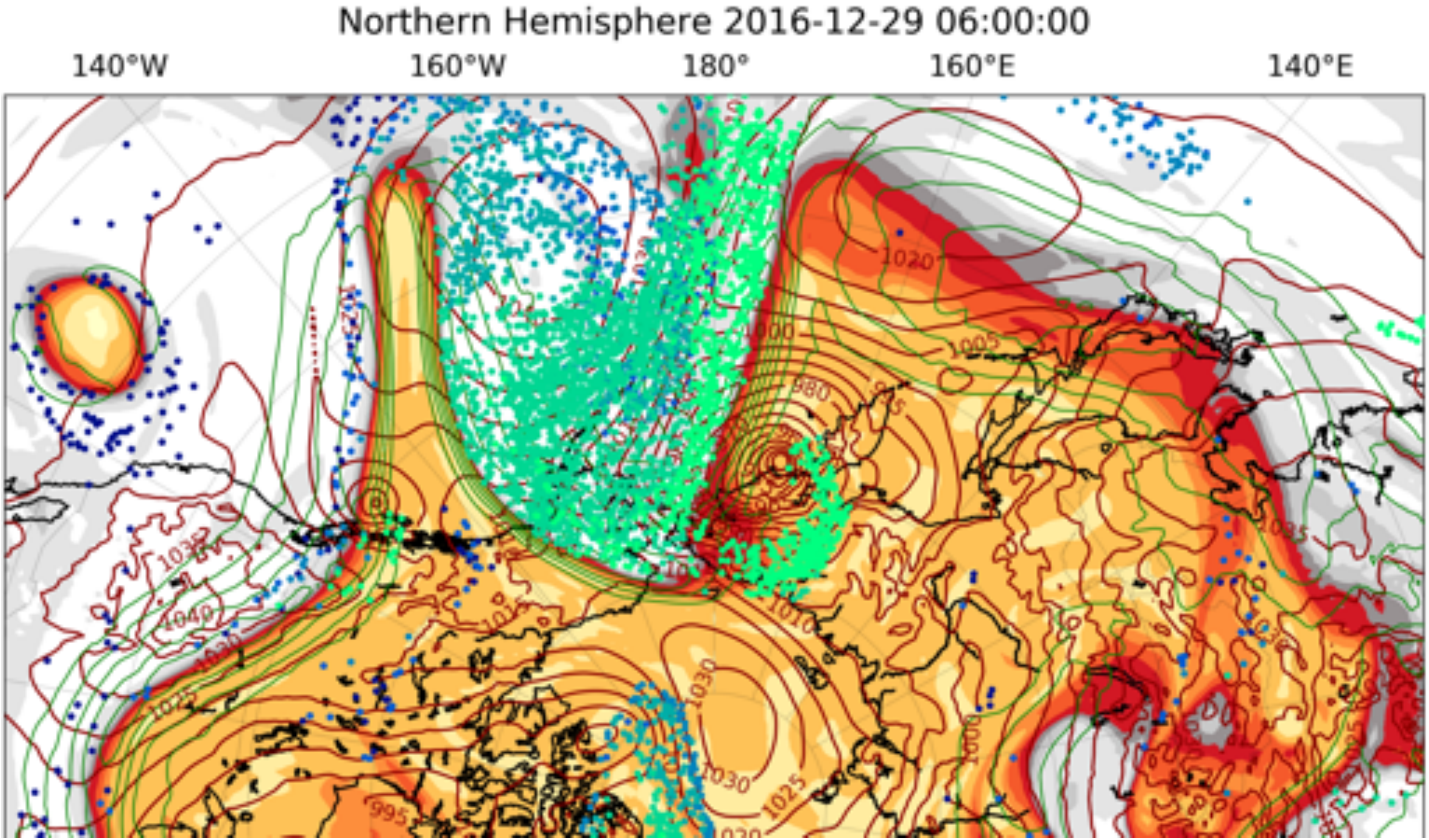

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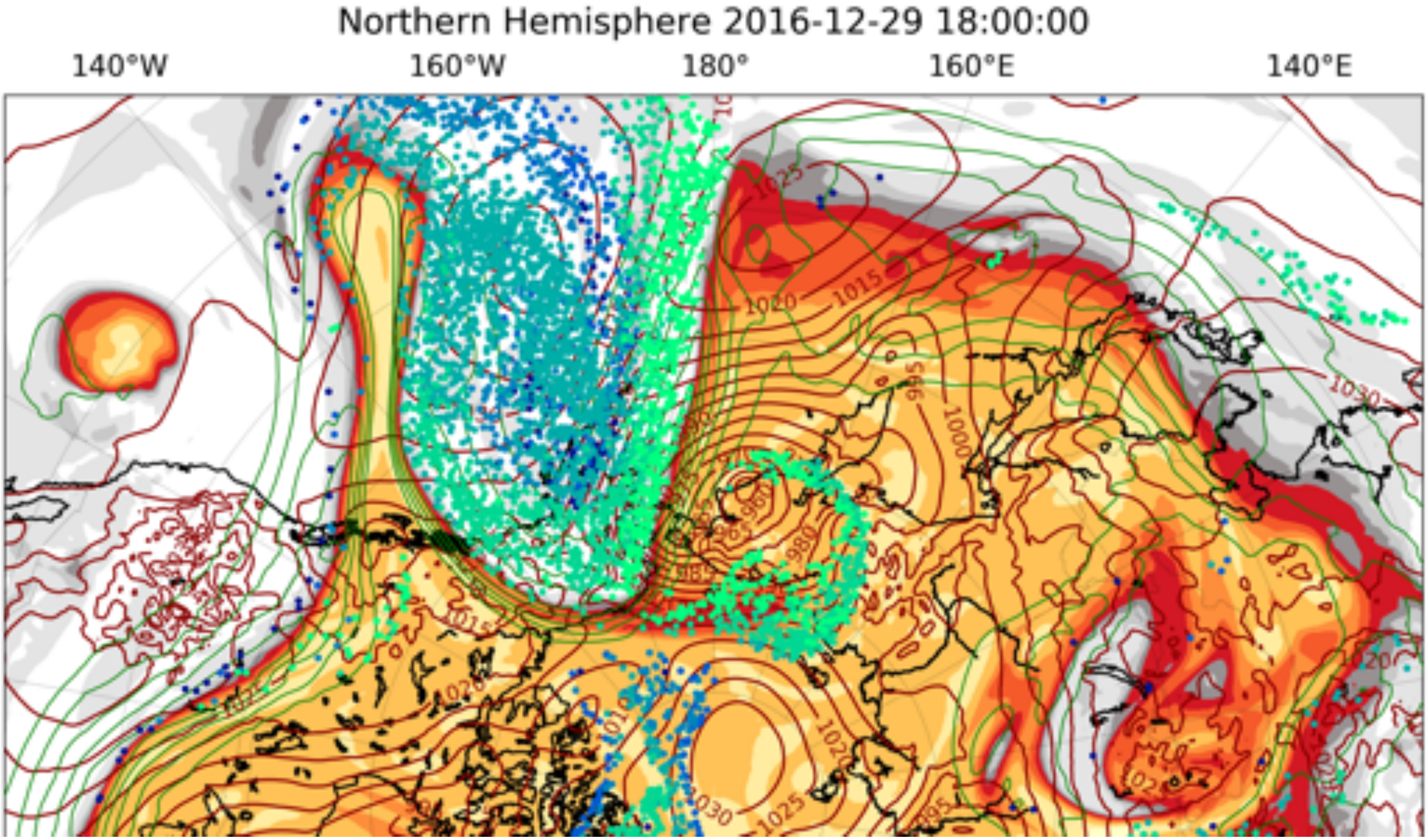

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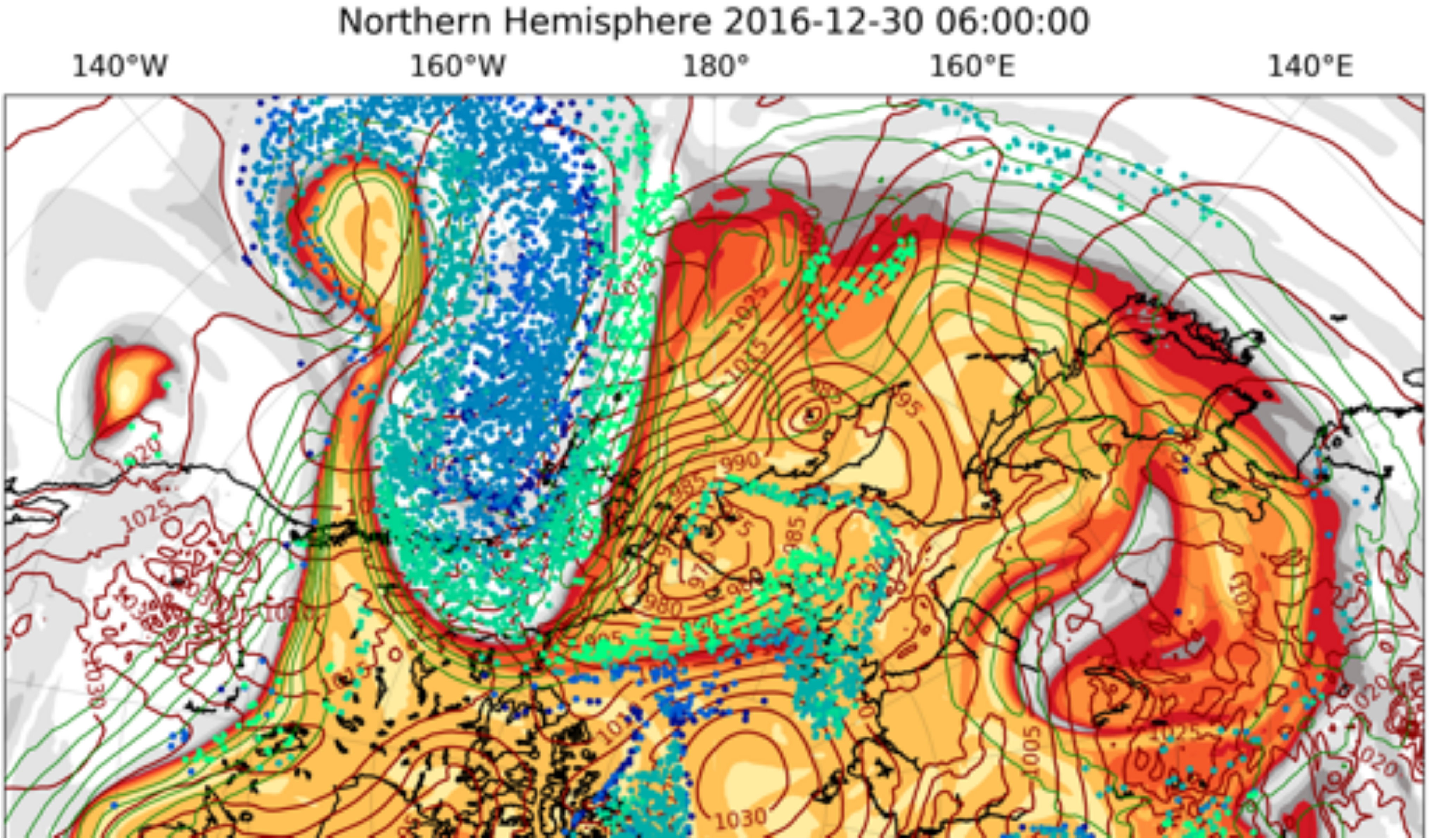

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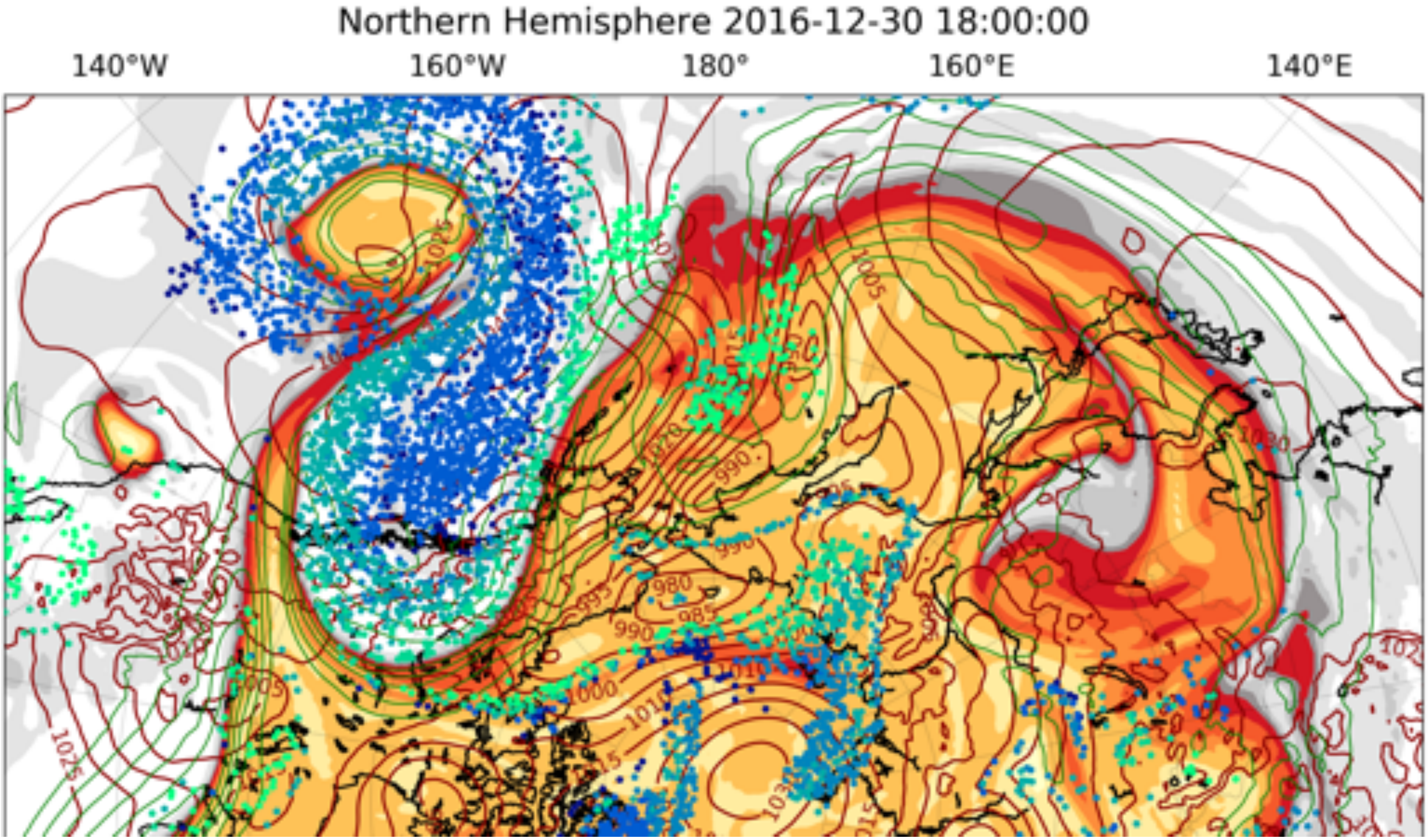
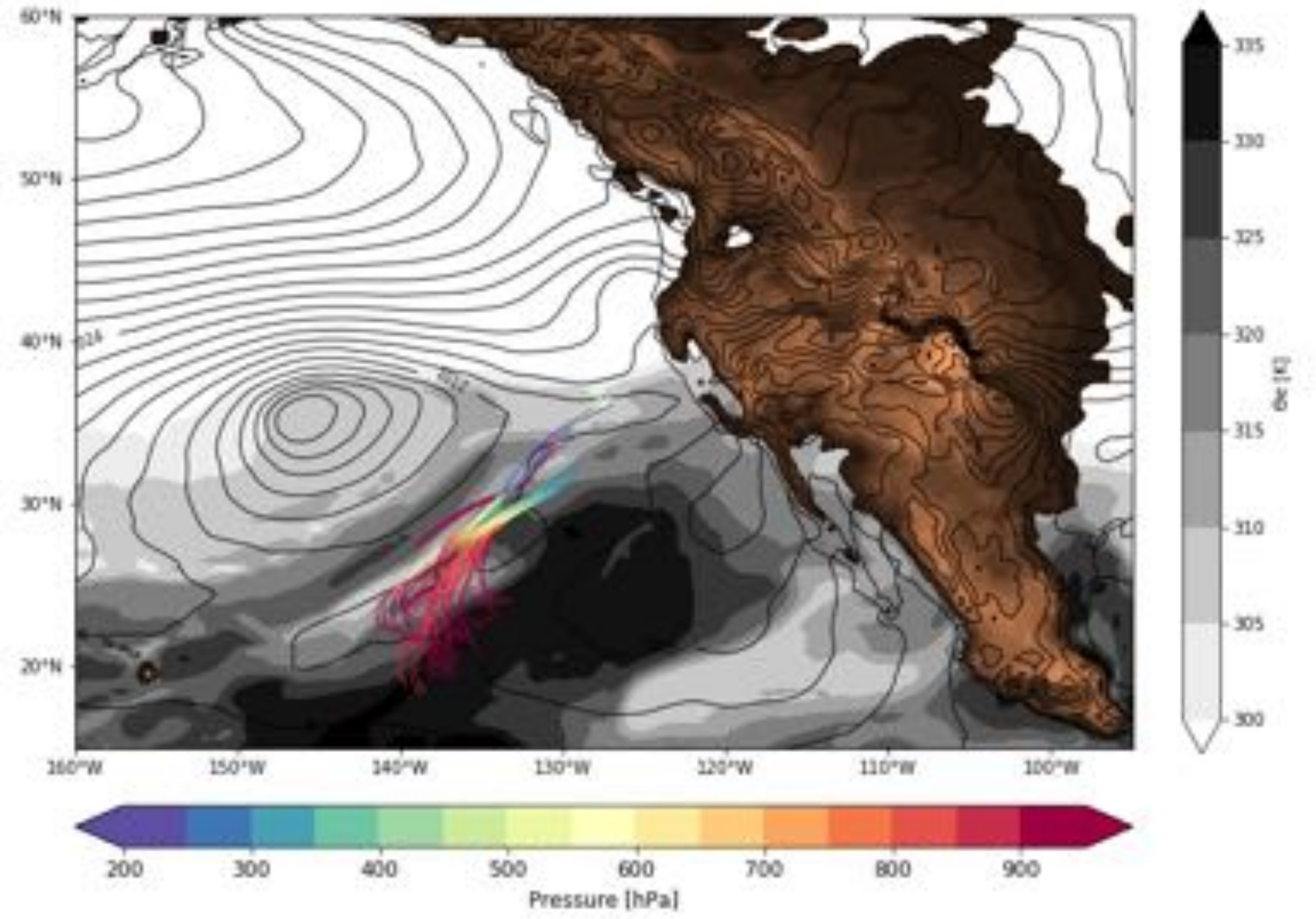


Open questions (3)

How do WCBs interact with orography? What is link to ARs?

Case study winter storm *Iras* (5-9 Jan 2017)



from Livia Näf

Open questions (4)

- How often are WCBs involved in forecast busts? And why?
- How do WCBs affect ensemble reliability?
- How can observations (routine and from field campaigns) be used to reduce forecast uncertainty related to WCBs?
- How frequent is embedded convection in WCBs? How well is it captured by IFS with parameterized convection?
- How important is interaction with dry intrusions, e.g., above WCB inflow / underneath WCB ascent?
- How well do we understand processes near WCB outflows (cirrus, turbulence, strat-trop exchange)?
- How do WCBs look like in km-scale global simulations with explicit convection?
- How is WCB climatology influenced by climate change?

Summary

WCB research has >50 years of history and is facing new challenges and opportunities

- solid general understanding of the phenomenon …
- … but still important set of open questions
- unique observations from NAWDEX, AR reconnaissance, …
- new opportunities given by ensemble prediction systems, convection-resolving models, and refined microphysical schemes
- fruitful collaboration between ECMWF, research institutes and universities (this workshop, projects like waves-to-weather, new field campaigns …)


Thank you very much for your attention and thanks to
ECMWF for organizing this workshop!