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Diabatic processes and the structure of the warm conveyor belt

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Why study diabatic processes in ET storms?

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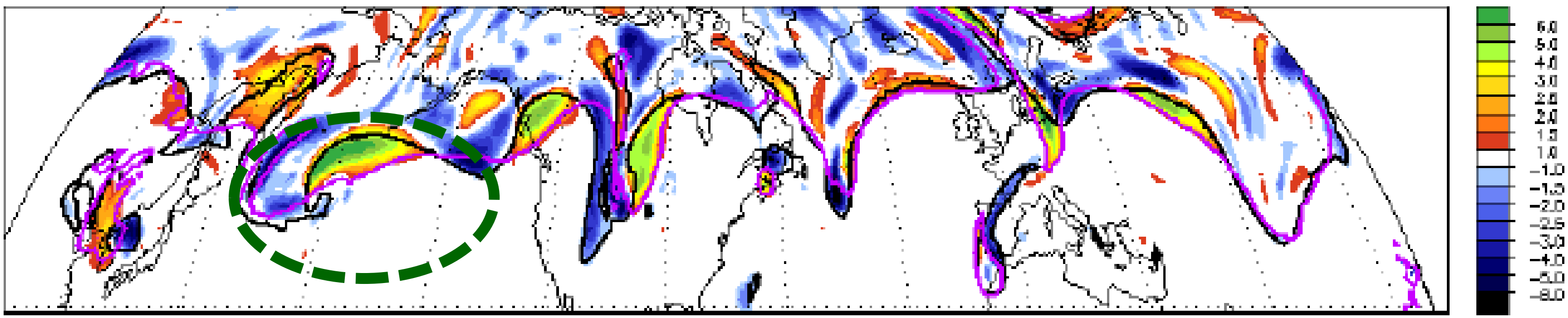
- Diabatic processes are fundamental to clouds and precipitation (i.e., weather)
- In NWP models these processes are parameterized
- The nonlinear feedback between the cloud scale and larger-scale dynamics has implications for:
  - Forecasts of heavy precipitation and high wind events
  - Assimilation of high resolution data (e.g., radar)
  - Linking forecast error to model representation of processes
  - Diabatic (heating) effects on medium-range forecasts
  - Design of perturbed physics ensembles

Diabatic PV near the tropopause



PV distribution "Forecast-Analysis" field at 320 K for a 72 h forecast to 10 October 2001, based on the ECMWF Integrated Forecast System (from Marco Didone, PhD thesis ETH Zürich).

Systematic error (PV overestimated) in medium-range weather forecasts on the downstream side of troughs.

Objectives

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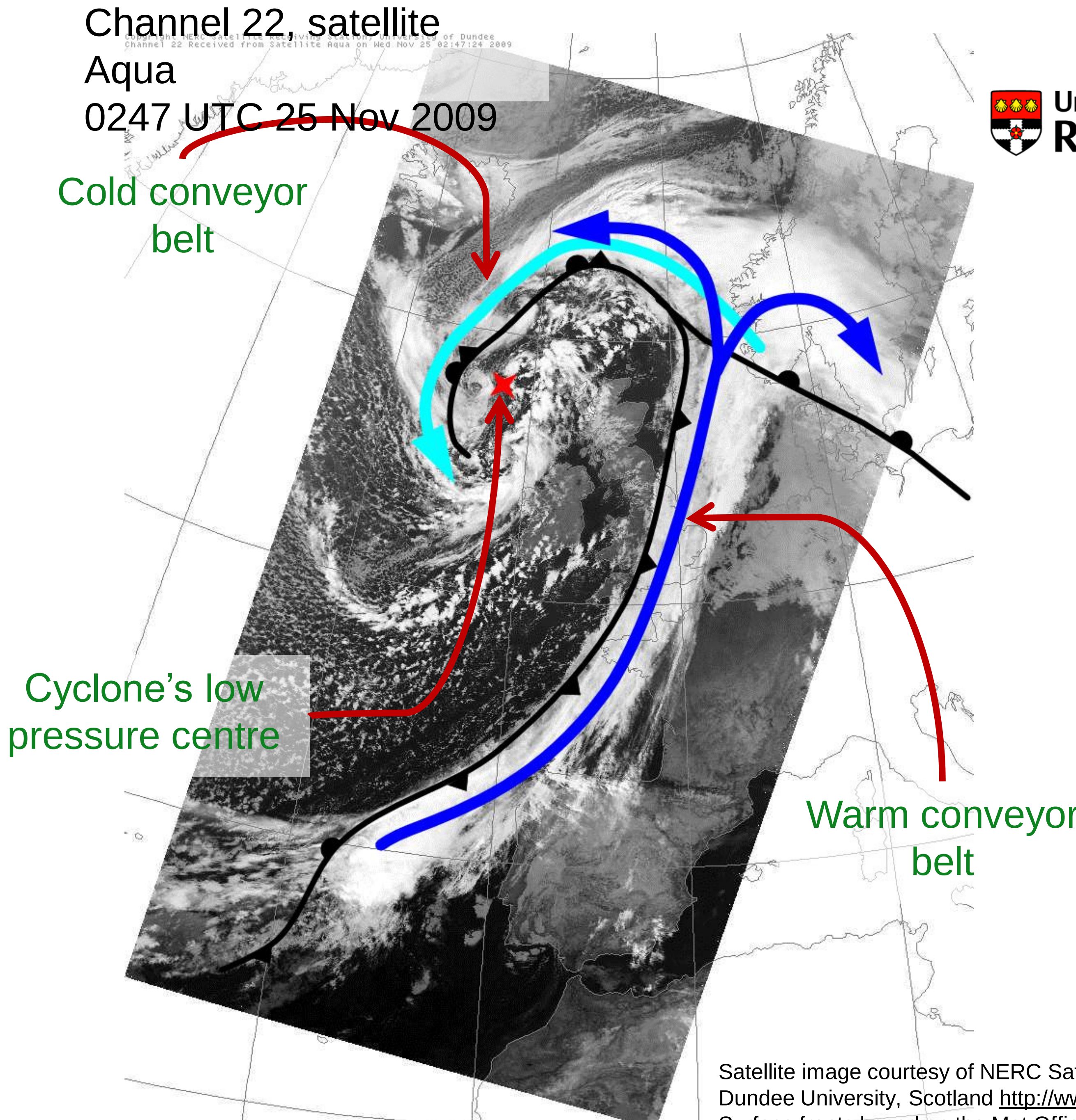
- Evaluate the accuracy of numerical models in simulating atmospheric diabatic processes
  - Extratropical cyclones and more specifically the warm conveyor belt (WCB) constitute the focus of this study
- What diabatic processes act on the WCB?
- What effect do these processes have on the WCB development?
- What are the consequences for the subsequent development of the upper-level atmospheric structure?



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Satellite image courtesy of NERC Satellite Receiving Station, Dundee University, Scotland http://www.sat.dundee.ac.uk
Surface fronts based on the Met Office analysis at 00 UTC 25 Nov 2009 (archived by http://www.wetter3.de/fax)

Methods

- Tracers tracking changes in potential vorticity (PV) and potential temperature (θ)
- Trajectory analysis - computation of Lagrangian trajectories following air parcels subject to the model-resolved velocity field

Tracers (I)

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- The variables of interest (PV, q) are decomposed as

$$\varphi(x,t) = \varphi_0(x,t) + \sum_{i=\text{proc}} \Delta\varphi_i(x,t)$$

$$\text{proc} = \{\text{parameterised processes}\}$$

  where φ_0 represents a conserved field (redistribution by advection of the initial field) and $\Delta\varphi_i$ represents the accumulated tendency of φ due to a parameterised process.

- Parameterised processes:
  - short- and long-wave radiation
  - large-scale cloud formation
  - convection
  - boundary layer

Tracers (II)

- Thus, there are evolution equations for φ_0 and for each $\Delta\varphi_i$

$$\frac{D\varphi_0}{Dt} = \frac{\partial \varphi_0}{\partial t} + \mathbf{v}\cdot\nabla\varphi_0 = 0$$

The conserved field is affected by advection only

$$\frac{D\Delta\varphi_i}{Dt} = \frac{\partial \Delta\varphi_i}{\partial t} + \mathbf{v}\cdot\nabla\Delta\varphi_i = S_{\varphi_i}$$

Each accumulated tendency is affected by advection and by a particular source of φ given by S_{φ_i}

- The evolution equation for the relevant variables can then be written as

$$\frac{\partial \varphi}{\partial t} = -\mathbf{v}\cdot\nabla\varphi_0 - \mathbf{v}\cdot\nabla \sum_{i=\mathrm{proc}} \Delta\varphi_i + \sum_{i=\mathrm{proc}} S_{\varphi_i}$$

Total rate of change

Advection of conserved field

Advection of accumulated tendencies

Sources

Consistency between tracers and trajectories

- Theoretically, θ_0 is conserved along trajectories. In practice, this is not true mainly because we simply cannot expect a perfect match between the advection in the model and the offline computation of trajectories.
- We select those trajectories that do not depart too much from their initial θ_0 value.
- The trajectories that are rejected largely correspond to trajectories that end up in the far right-end of the theta distribution in a long trailing tail beyond the value of $\theta = 340$ K.

Numerical models and simulations

- Two numerical weather forecast models have been used
- Reading: The Met Office Unified Model (MetUM)
  - 12 km resolution
- ETH-Zürich: The COSMO (COnsortium for Small-scale Modelling) model
  - 14 km resolution
- Both simulations initialised at 0600 UTC 23 November 2009 from ECMWF operational analysis fields.

Case-study: Synoptic-scale context

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- The surface low formed in the North Atlantic on 23 November 2009 along an east-west oriented baroclinic zone
- The low deepened from 0000 UTC 23 November to 0000 UTC 25 November 2009 and moved eastward.
- By 0000 UTC 25 November, the system was occluded and had undergone “frontal fracture”.
- Precipitation was heavy and continuous along the length of the cold front during the period 23-25 November 2009. As such, this is an ideal case for examining diabatic heating in a WCB.
- The upper-level trough associated with the primary low amplified in concert with the surface low.
- The downstream ridge and downstream trough also amplified during this period.

Trajectory selection

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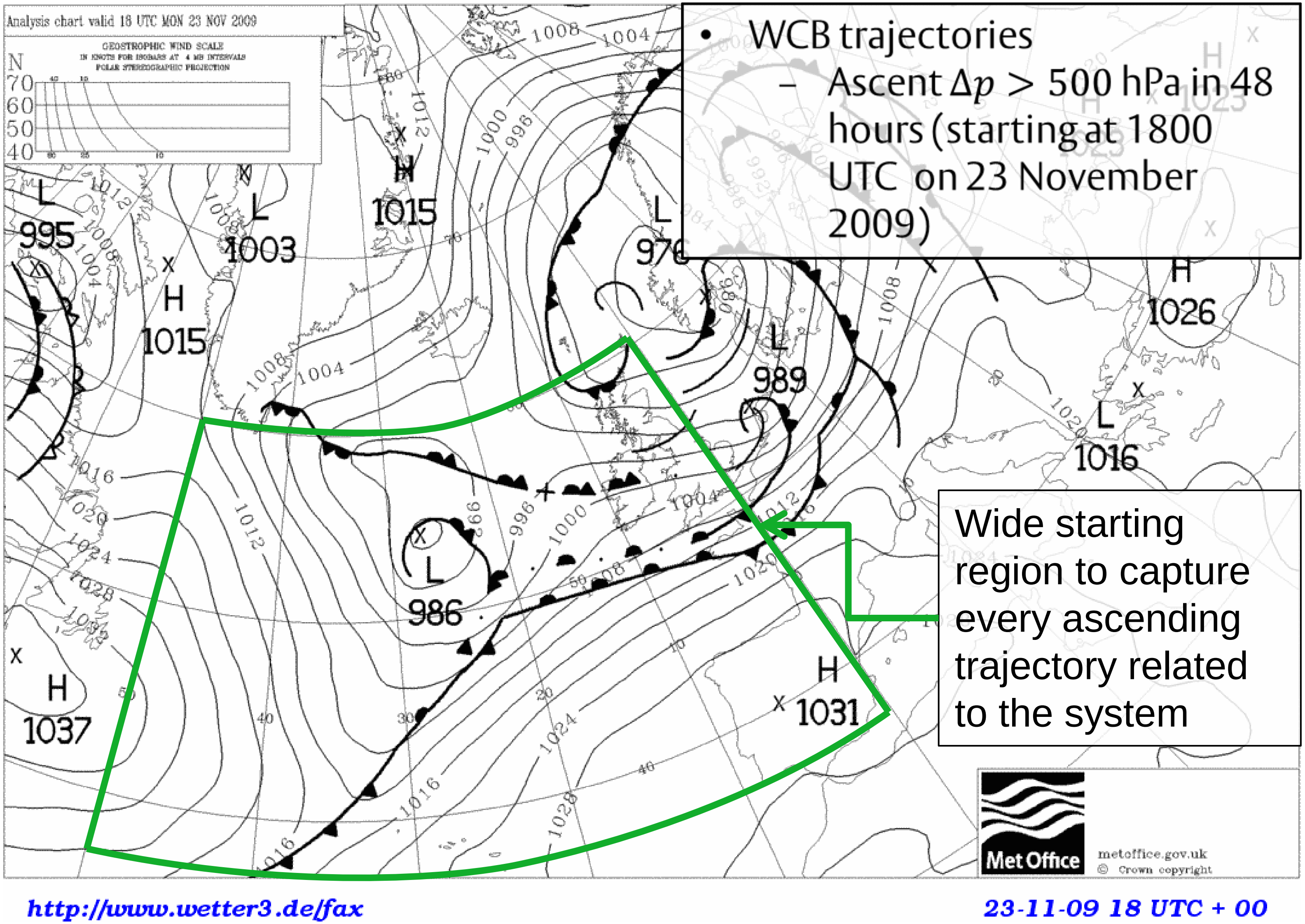
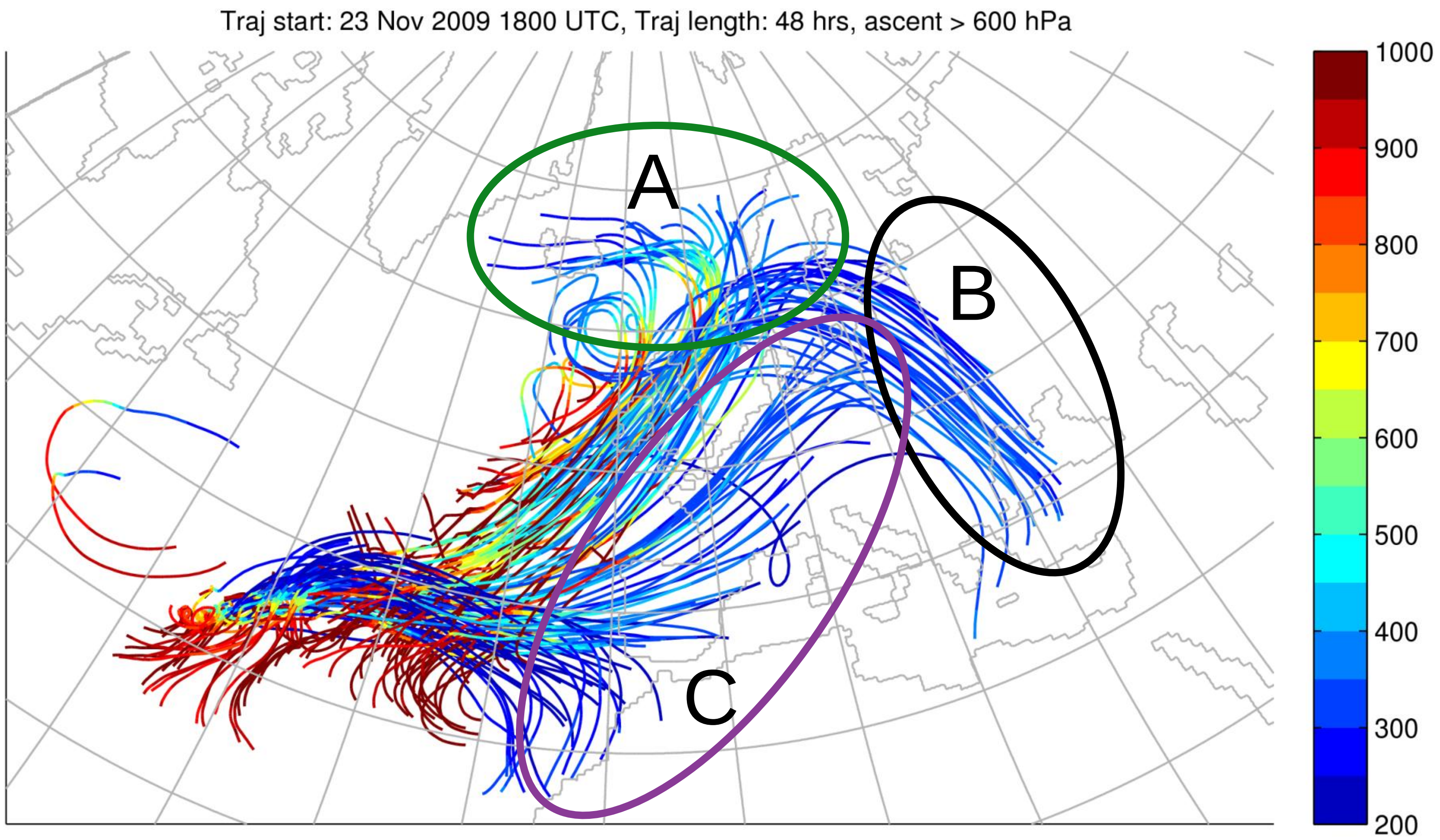


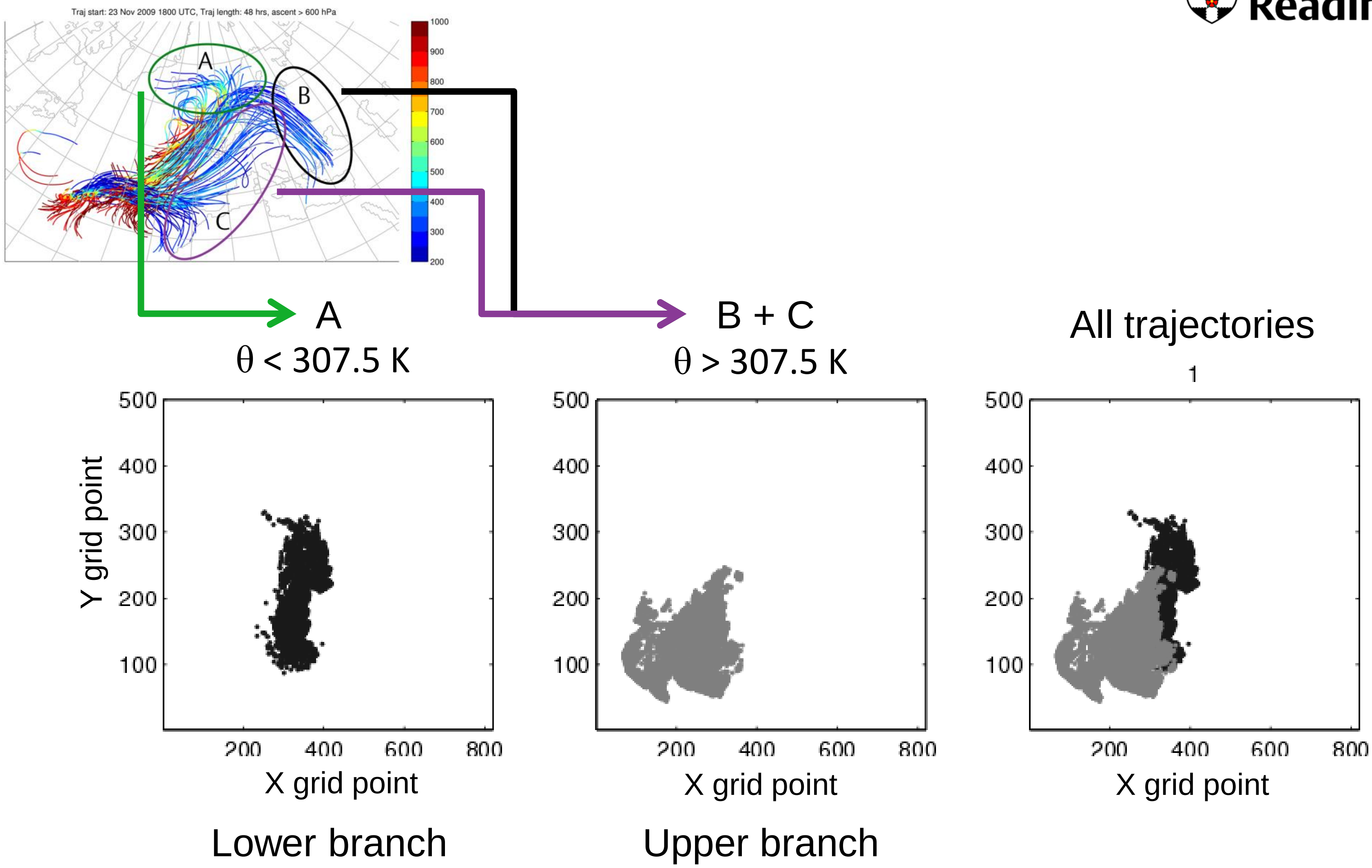
- WCB trajectories
  - Ascent $\Delta p > 500$ hPa in 48 hours (starting at 1800 UTC on 23 November 2009)

Wide starting region to capture every ascending trajectory related to the system

Trajectory bundle



Identification of sub-streams



Upper-level structure (I)

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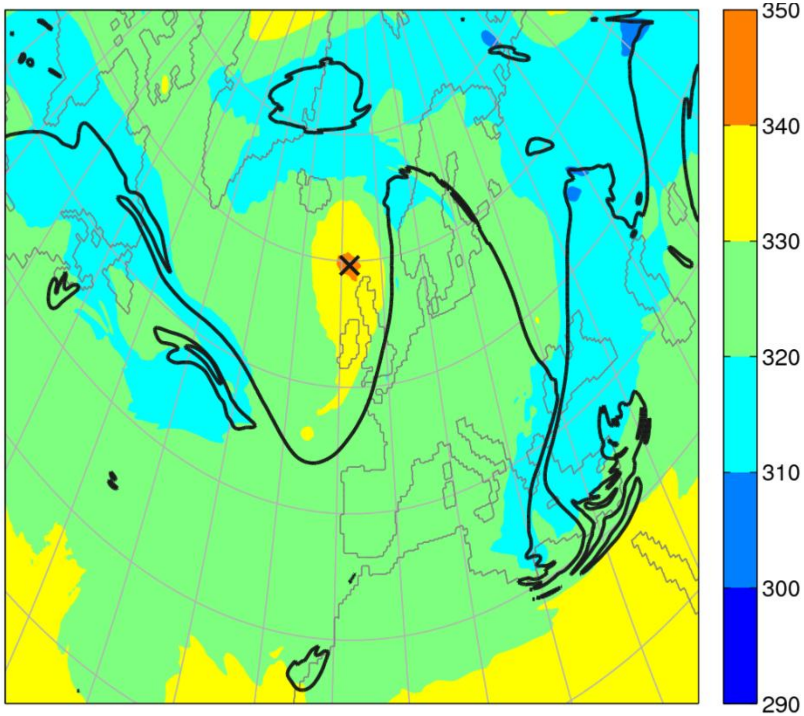
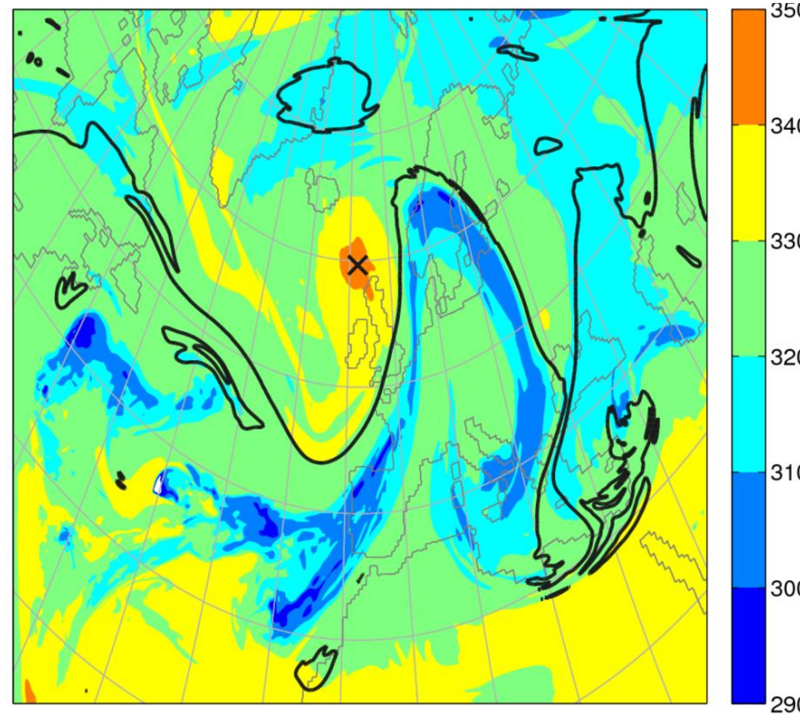
Potential temperature (K)



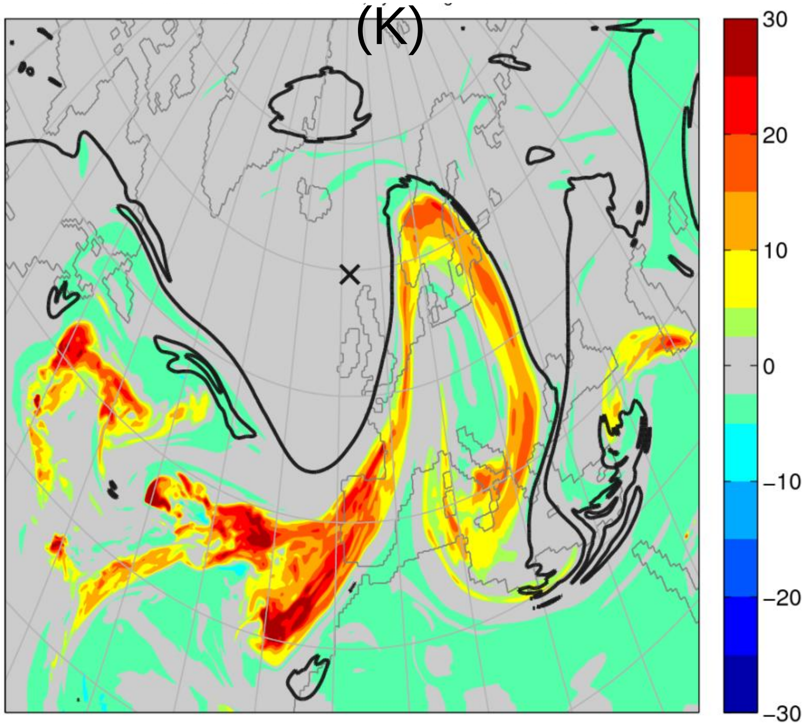
Potential temperature conserved component (K)



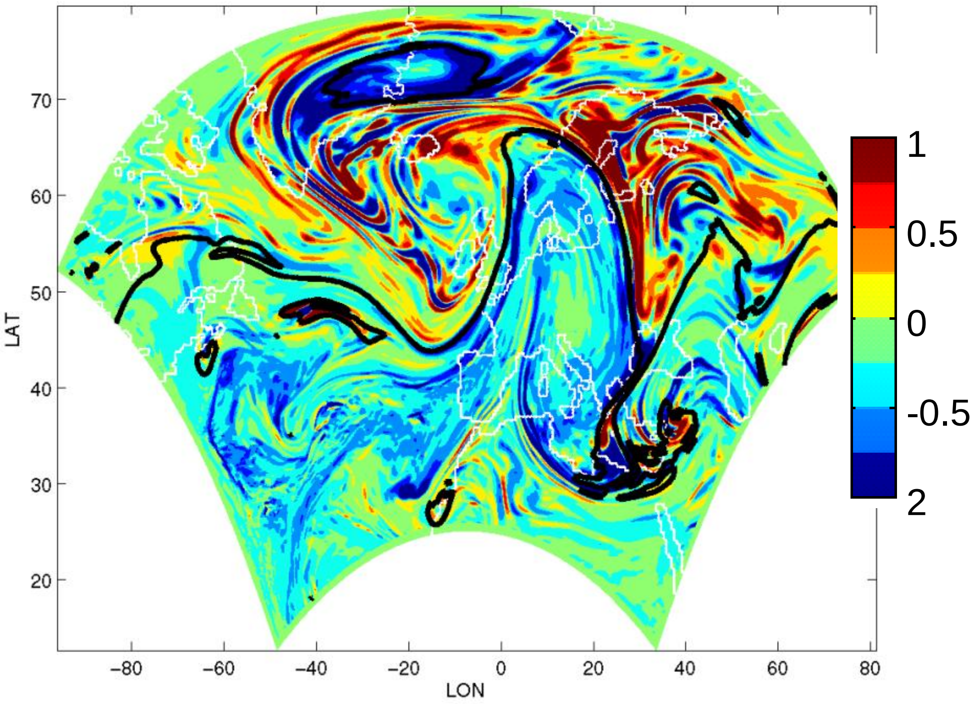
Model level at 9.68 km

Upper-level structure (II)

Diabatic potential temperature (K)



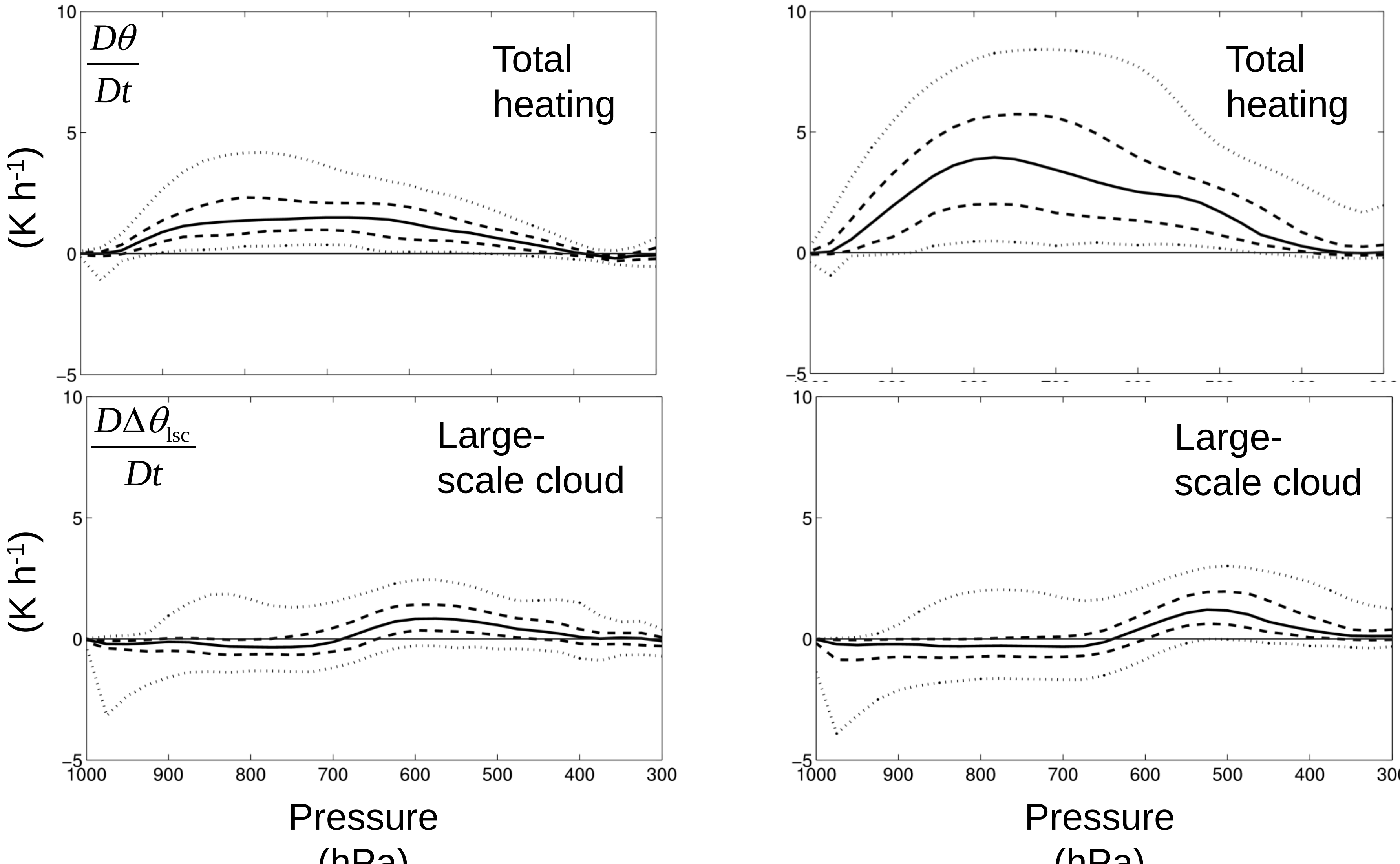
Diabatic potential vorticity (PVU)



Model level at 9.68 km

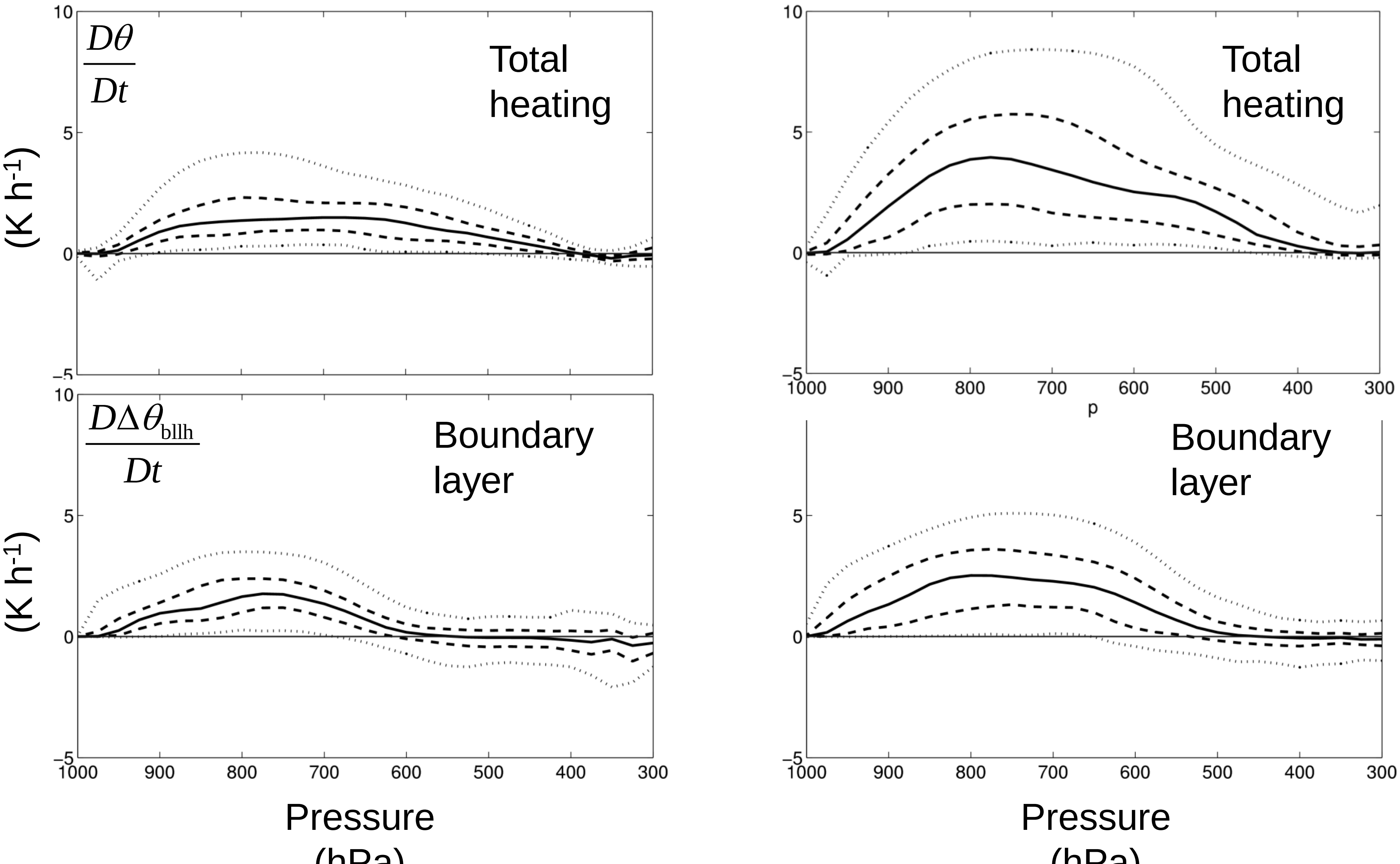
Heating rates – MetUM (I)

A | B + C



Heating rates – MetUM (II)

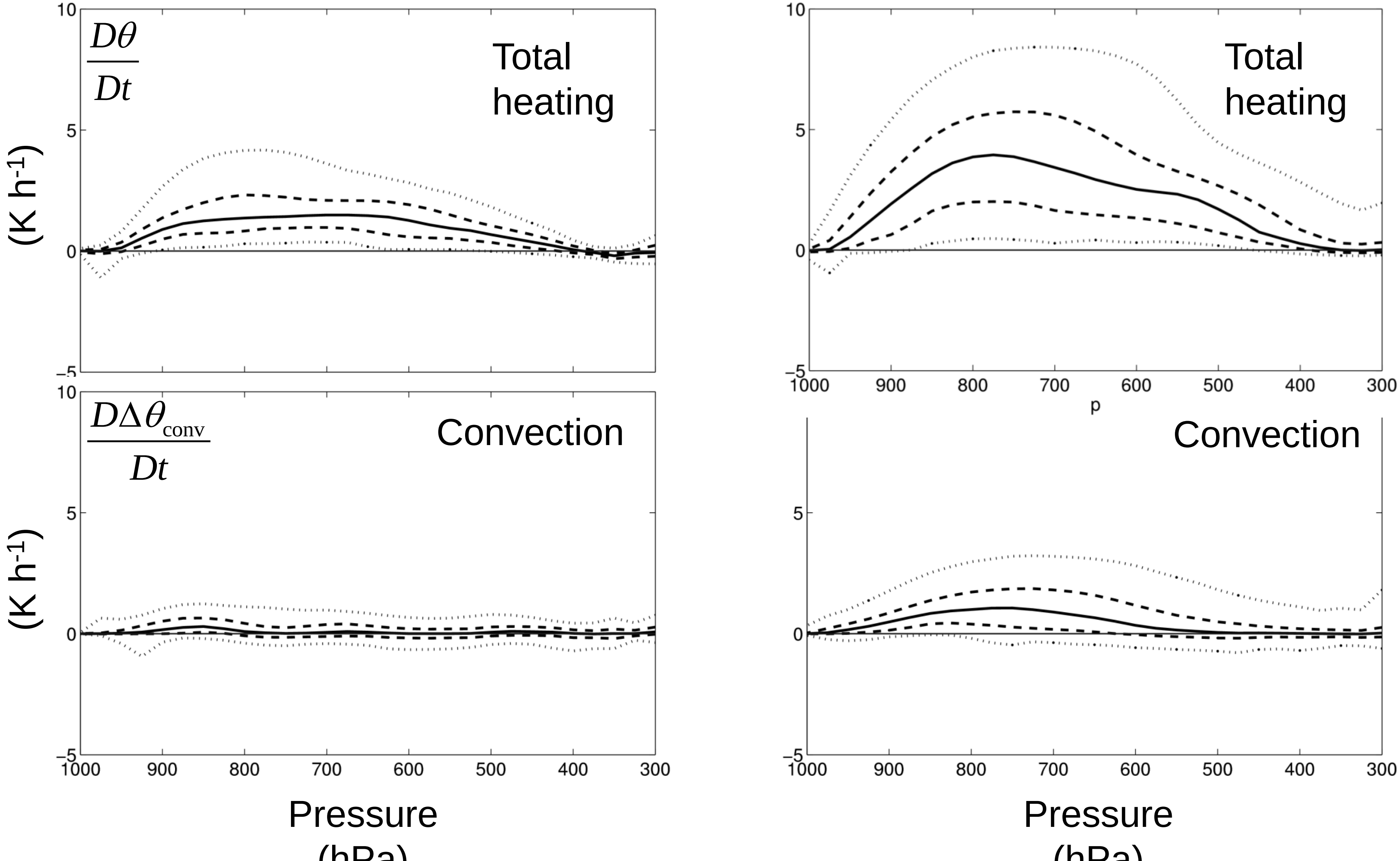
A | B + C



Heating rates – MetUM (III)

A

B + C



Heating rates – COSMO model

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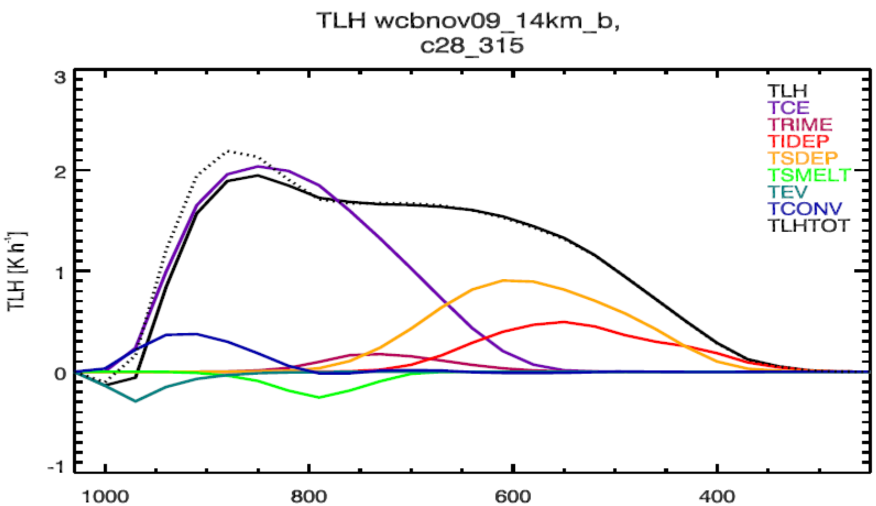
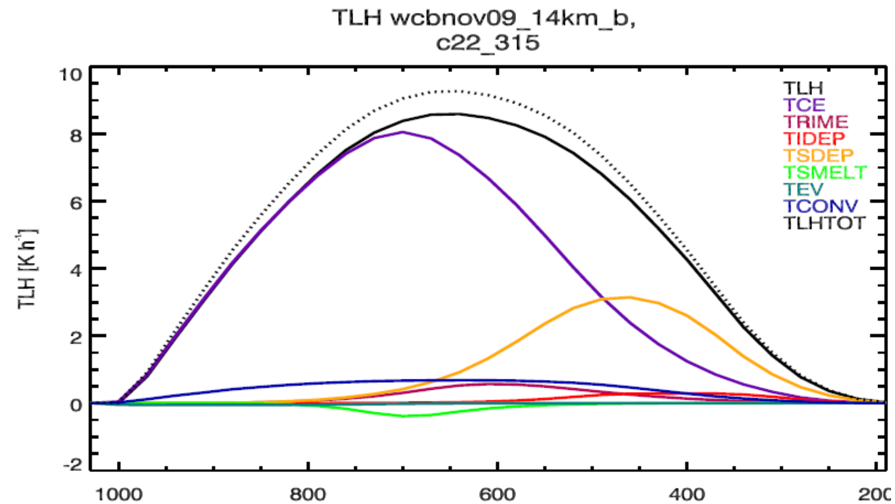
A + B



Pressure (hPa)

C



Pressure (hPa)

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Summary and conclusions

- The WCB splits in two branches in its outflow region
- The upper-level structure reflects and is affected by this split
- Diabatic processes act differently over these two branches
- The upper-level structure is modified by these diabatic processes (through the WCB split)

Future work

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- Complete a systematic comparison between the two models
  - Further integrate the diabatic decomposition techniques at both research centres
- The formation of a streamer at the tip of the downstream ridge over North Africa may be noteworthy? Did this lead to heavy precipitation downstream in the eastern Med?
  - A MetUM forecast of the upper-level trough and ridge structure only departed from the analysis in one noteworthy respect -- the downstream ridge extended too far northwards .
  - A second MetUM forecast was also performed but not discussed here. This forecast, which was initialised 30 hours earlier, was much less accurate than the one presented here (e.g., the downstream ridge was not elongated and did not lead to streamer formation)

References

- Grams, C. M., Wernli, H., Bötcher, M., Čampa, J., Corsmeier, U., Jones, S. C., Keller, J. H., Lenz, C.-J. and Wiegand, L. (2011) The key role of diabatic processes in modifying the upper-tropospheric wave guide: a North Atlantic case-study. *Q. J. R. Meteorol. Soc.* **137**: 2174–2193.
- Joos, H. and Wernli, H. (2011) Influence of microphysical processes on the potential vorticity development in a warm conveyor belt: a case-study with the limited-area model COSMO. *Q. J. R. Meteorol. Soc.* **138**: 407–418