Comparison between airborne remote sensing observations of an extratropical cyclone and short-term forecasts using a hierarchy of models

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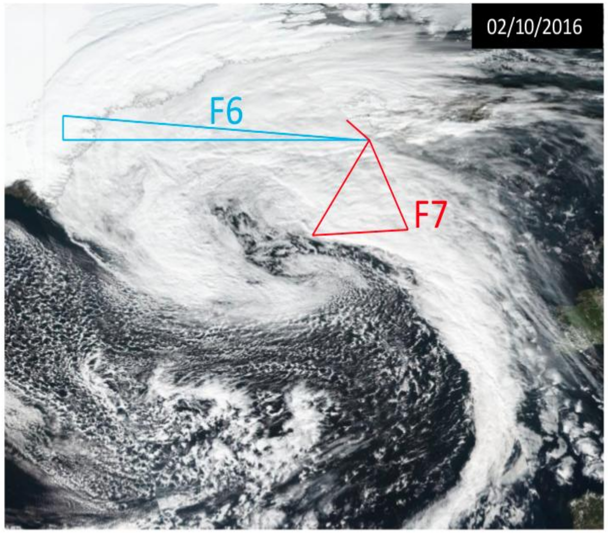


ECMWF workshop: 10-14 June 2019

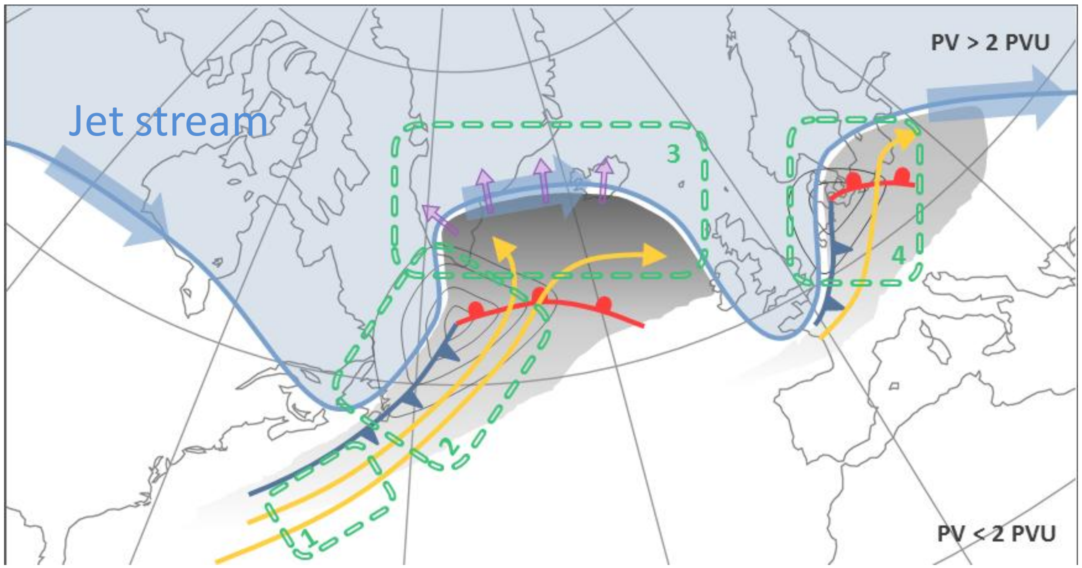
Context: the NAWDEX international field campaign

<u>Main NAWDEX hypothesis:</u> potentially misrepresentation of diabatic processes in NWP models

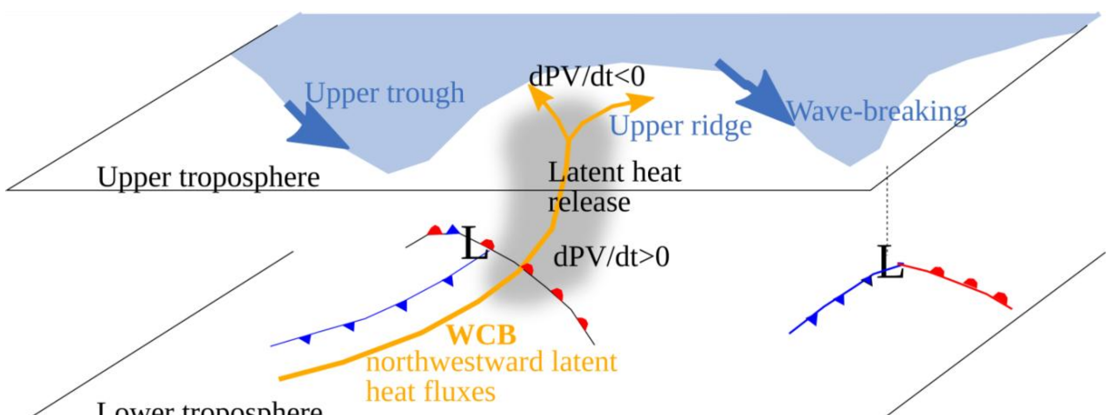
→ misrepresentation of PV gradient and jet intensity at upper levels

→ Forecast error more downstream

$$\frac{D}{Dt}PV = \frac{1}{\rho}\boldsymbol{\eta}\cdot\nabla\left(\frac{D}{Dt}\theta\right) \approx \frac{1}{\rho}\eta_z\frac{\partial}{\partial z}\left(\frac{D}{Dt}\theta\right)$$



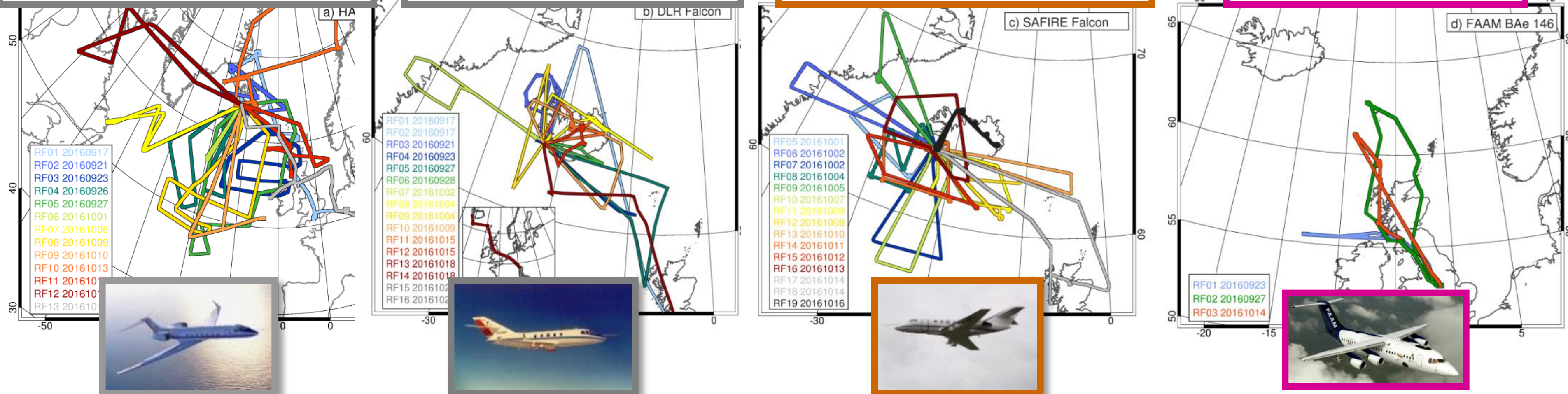
Schäfler et al. (2018)



Context: the NAWDEX international field campaign

47 research flights were conducted corresponding to 205 fight hours.

German DLR HALO | German DLR F20 | French SAFIRE F20 | FAAM BAe 146



Schafler et al. (2018)

RALI platform (cf. Presentation from J. Delanoë on Tuesday)

High spectral resolution lidar (355 nm), 532 and 1064 nm

Doppler cloud Radar (95 GHz) – 3 antennas looking down

IR radiometer CLIMAT (brightness temperature)

→ **Microphysics retrievals**

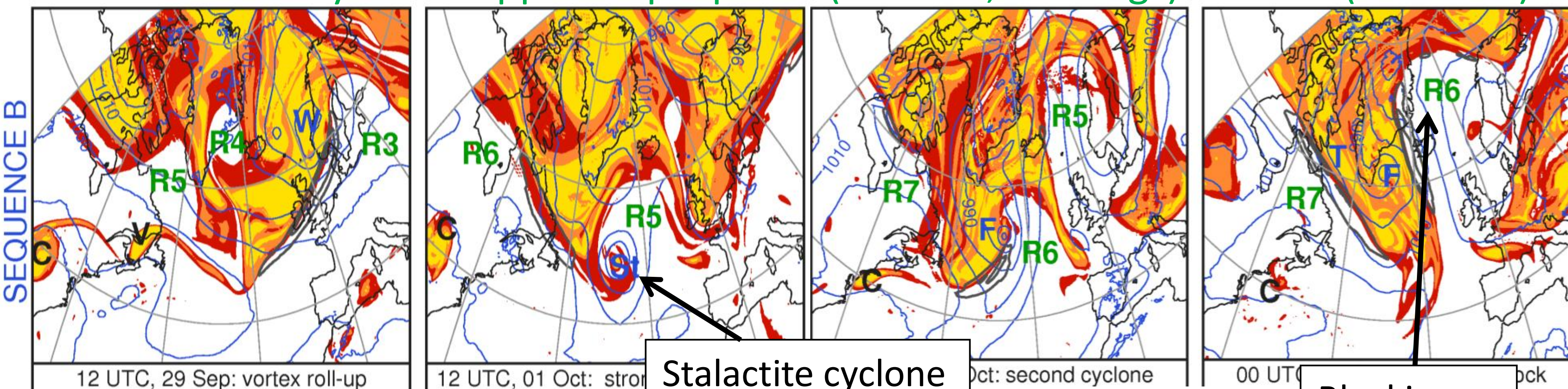
→ **3D components of the wind**

Dropsonde launching → Profiles of T, p, hum, u, v

Aircraft measurements → wind, T, p, hum at the altitude of the aircraft

NAWDEX case study: formation of a deep cyclone and Scandinavian blocking

Potential vorticity in the upper troposphere (ϴ=320K; shadings) and SLP (contours)



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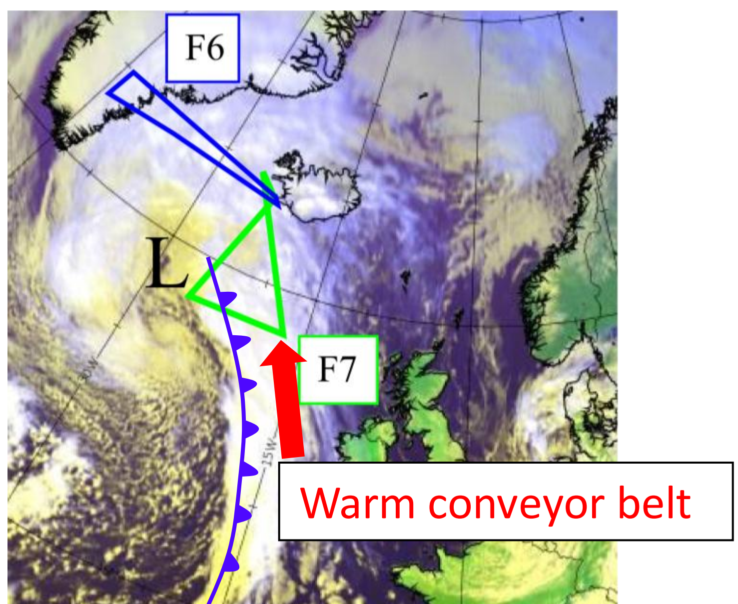


Objectives / method

Main goal: To assess the ability of the models to accurately represent diabatic processes along the warm conveyor belt of the Stalactite Cyclone.

- What are the relevant observations ?
- How to compare with model outputs ?

Use of a very broad range of models:

- Regional convection-permitting model Meso-NH at 2.5 km
  → 2 cloud microphysics scheme
- Global operational model Arpege (~10 km over the eastern North Atlantic)
  → 2 convection schemes
- Climate models (60 km resolution to CMIP6 resolution)
  → 2 models: Arpege-Climat and LMDZ/IPSL

Used observations:

- **RADAR reflectivity**
- **Ice water content** retrieval (variational algorithm; Delanoë and Hogan, 2008; Cazenave, 2019)
- **Doppler wind components**

Indirect info on the heating rate (RADAR reflectivity, ice water content)

Info on circulation (Doppler wind components)

Comparing two microphysical schemes using Meso-NH

- **Méso-NH** / 24-hour forecast

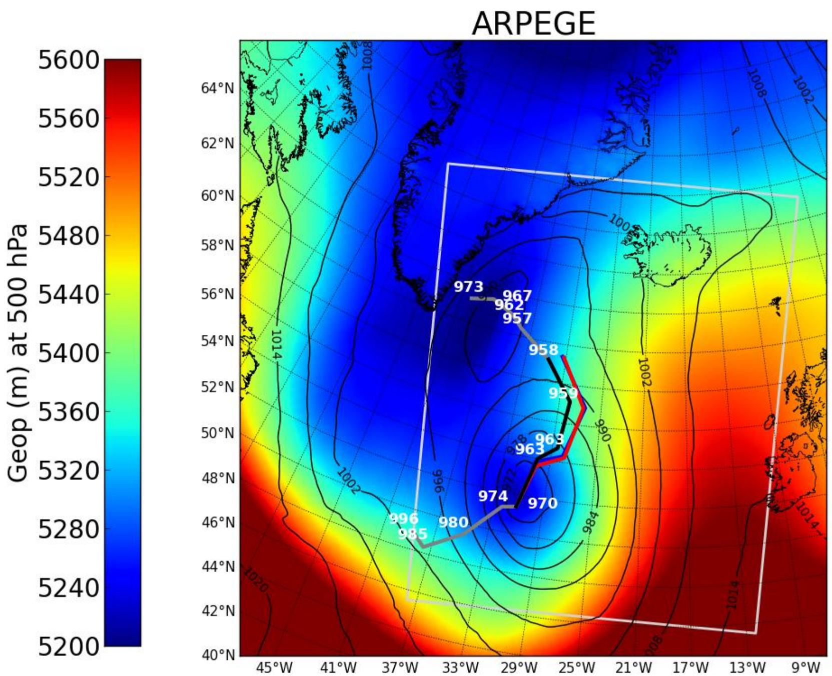
- Initial condition and forcing: global Arpege model

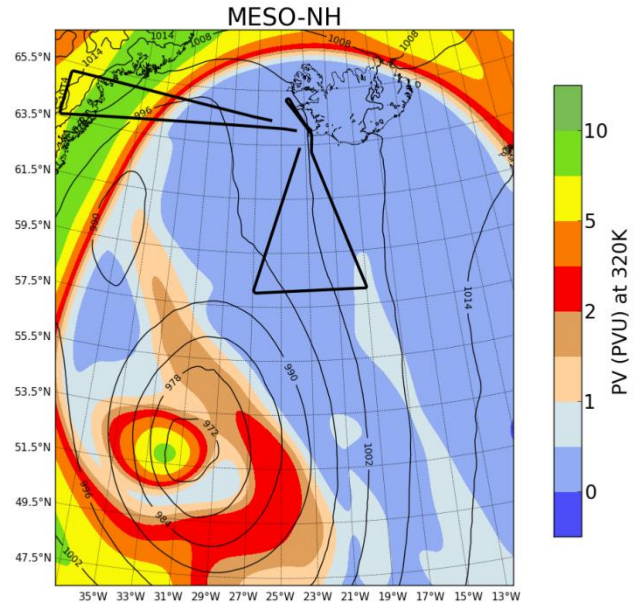
- Domain : XY → **2.5 km** x **2.5 km** 800*1000 pts (Convection resolved)
  Z → 56 verticals levels ~[0-20]km

Two microphysical schemes (droplet, rain, graupel, snow, ice)

-ICE3 One moment (r)

-LIMA Two moments (r, N) for droplet, rain, ice

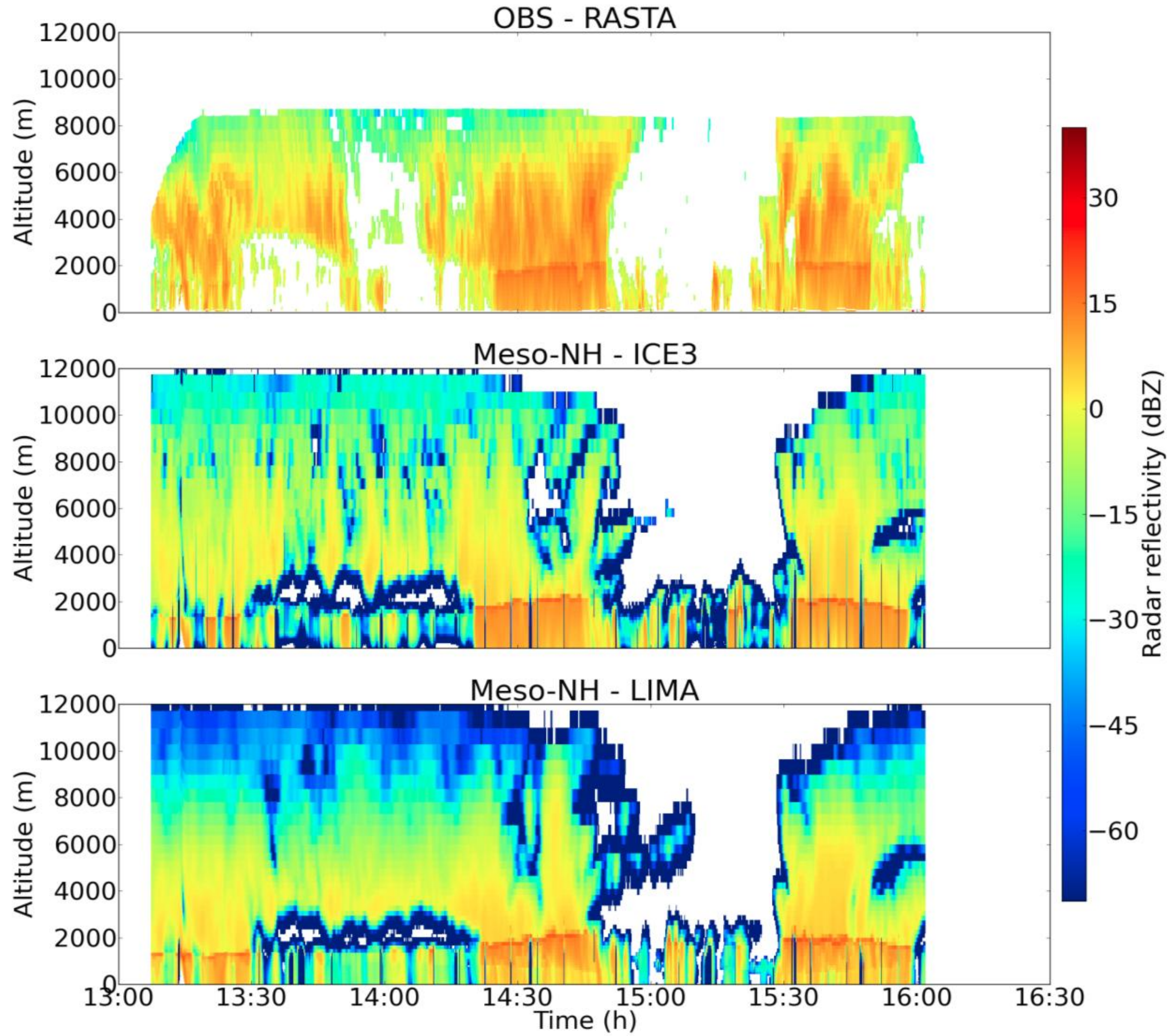




Study by M. Mazoyer

Comparing two microphysical schemes using Meso-NH

Flight F7 in the ascencing branch of the WCB

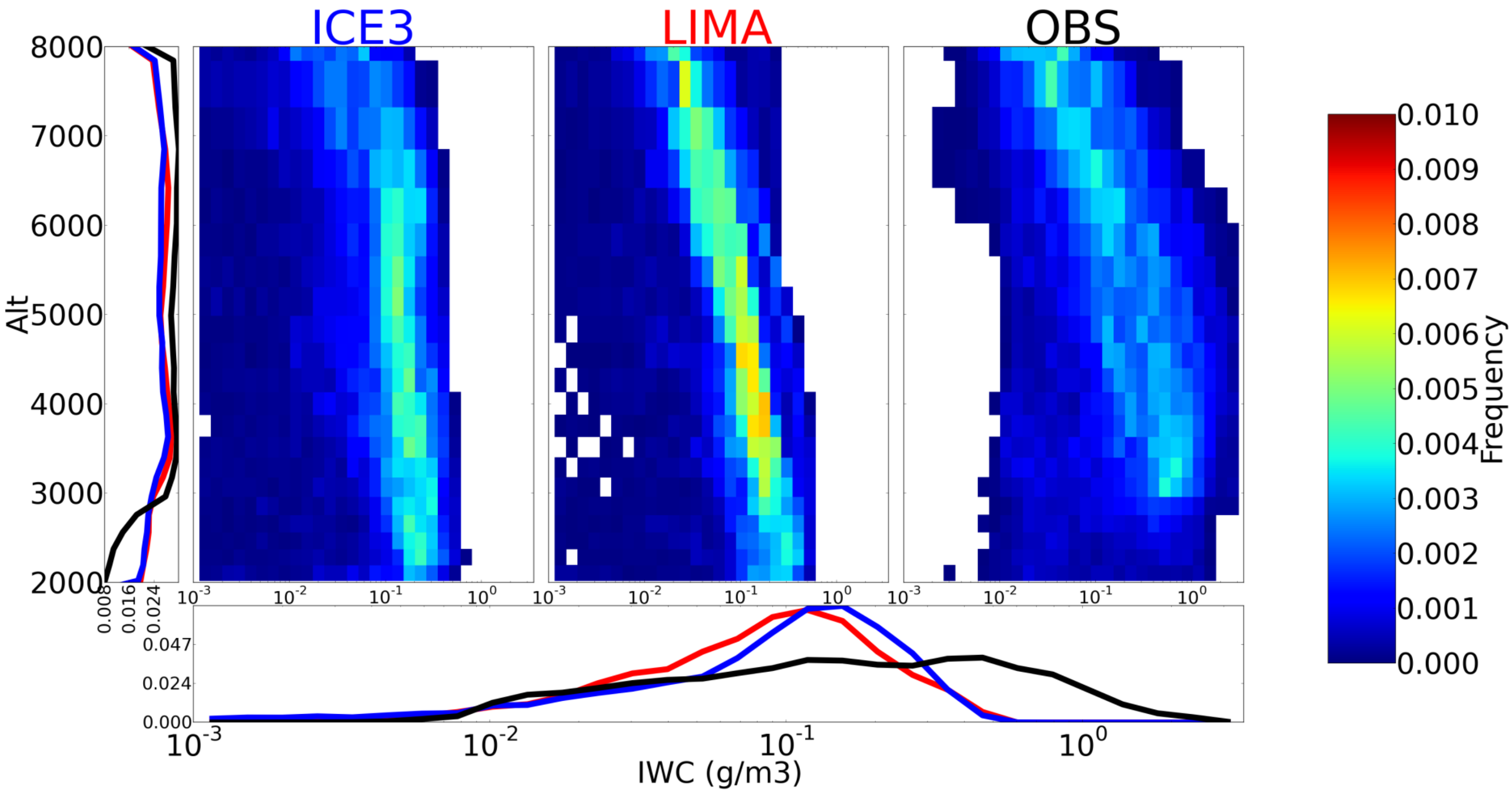


- **Very close structure** (ICE3 less diffuse)
- Melting area similar
- Strong Z underestimation
- **LIMA top clouds** have **lower reflectivies** (as satellite data)

Study by M. Mazoyer

Comparing two microphysical schemes using Meso-NH

Ice water content pdfs along the flight F7

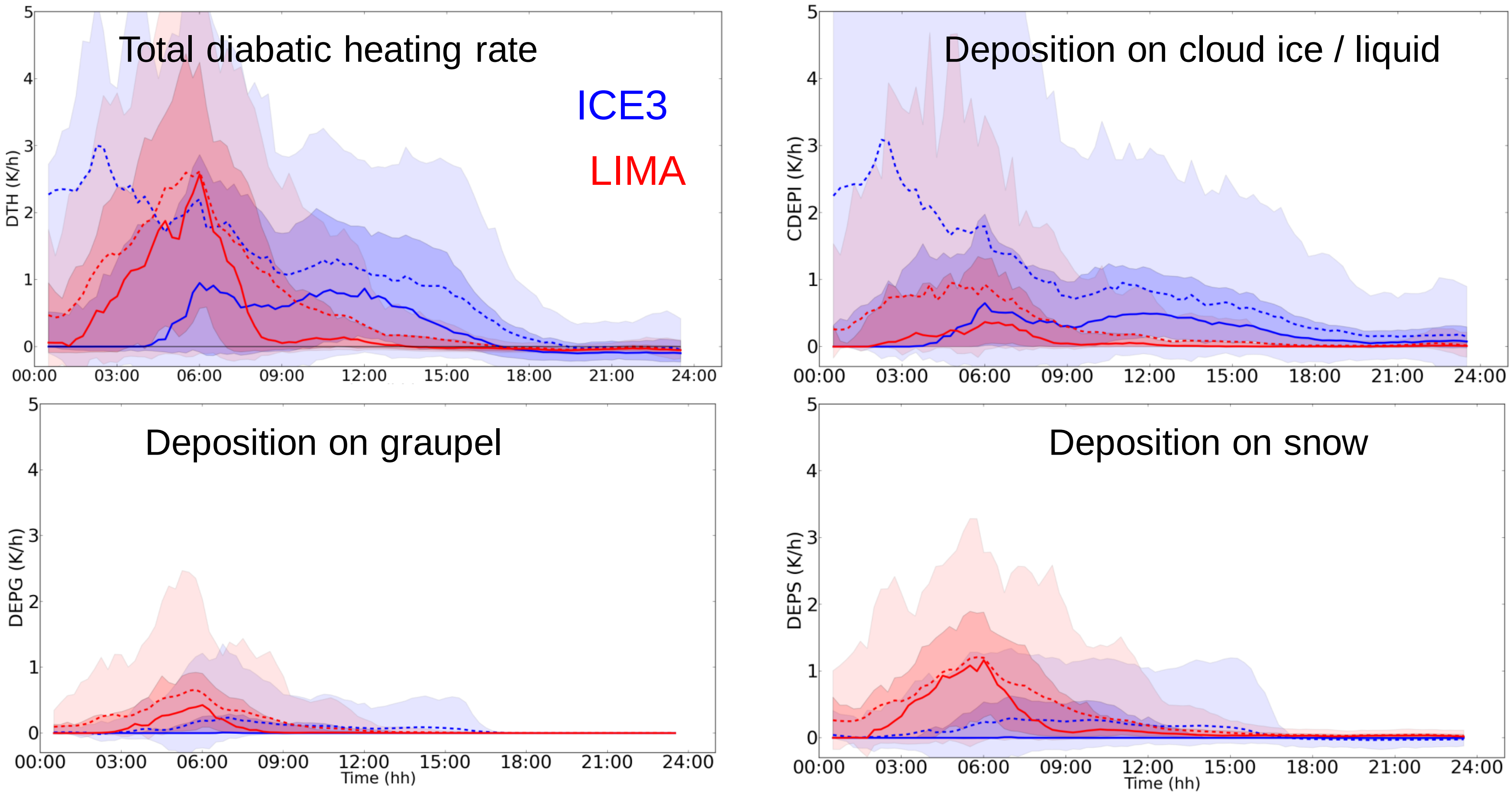


- Large underestimation of IWC in both runs.
- ICE3 is more realistic in terms of intensity while LIMA in terms of the vertical profile

Study by M. Mazoyer

Comparing two microphysical schemes using Meso-NH

Heating rate budget along WCB trajectories (ascends of 300 hPa in 24 h)



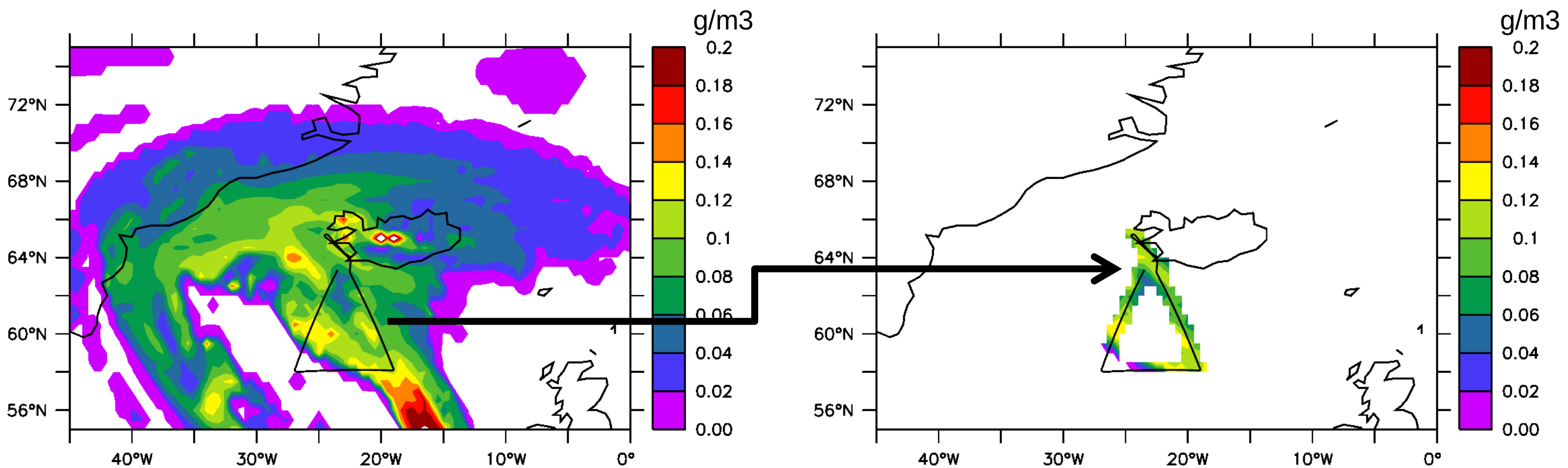
• A stronger diabatic heating rate occurs for ICE3 at upper levels due to larger deposition on cloud ice than for LIMA

Study by M. Mazoyer

Comparing two convection schemes using Arpege

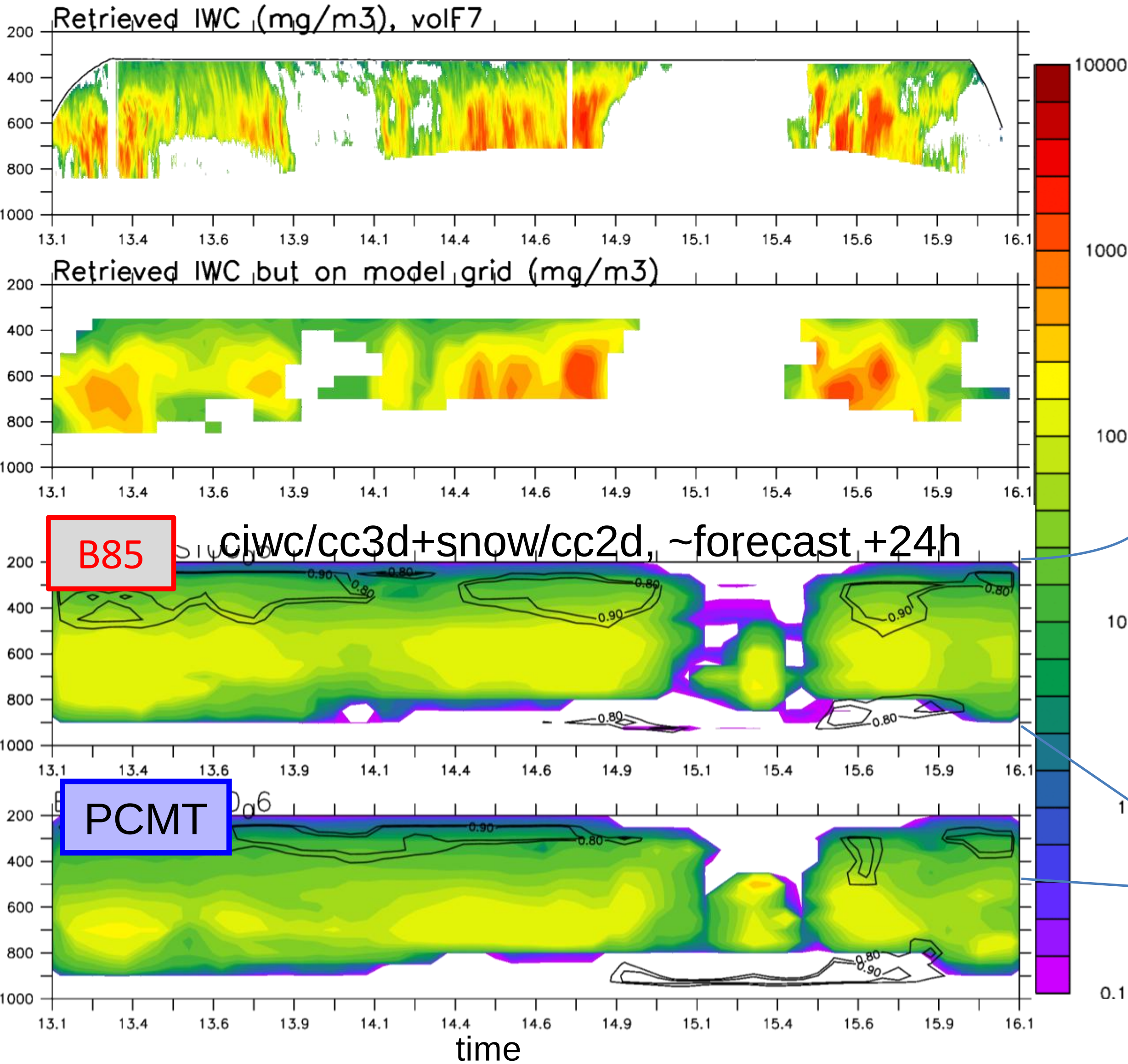
- **Arpege** / 2-3 days forecast
- Resolution: T798 with stretching → 10km over France, 20km on Iceland
- Initial condition: Arpege operational analysis (10/01/2016, 12UTC)
- Two convection schemes associated to two members:
  - → B85: Bougeault (1985): closure in humidity, used in operational NWP version.
  - → PCMT: Piriou et al. (2007) « Prognostic Condensates Microphysics and Transport »; closure in CAPE, used in Arpege climate version.
- Output resolution: lon x lat: 0.5° x 0.5° + every 15 minutes.

Cloud Ice Water content/3D cloud fraction+Snow/2D cloud fraction, ~forecast +24h

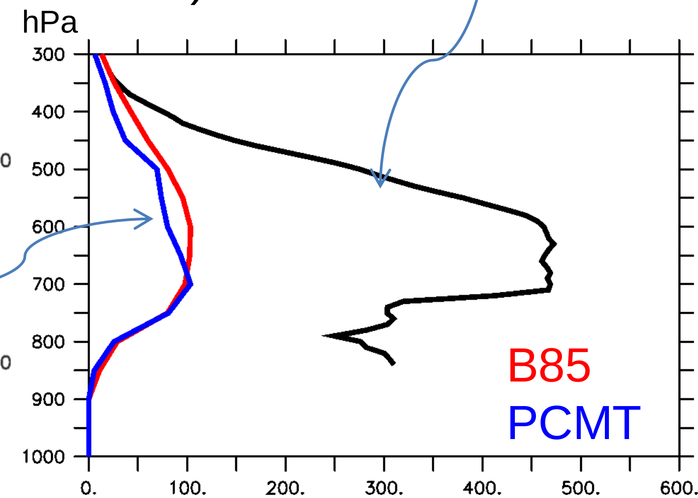


Study by G. Rivière, M. Wimmer

Comparing two convection schemes using Arpege



Obs (retreived IWC from radar/lidar; Delanoë and Hogan, 2008; Cazenave, 2018)



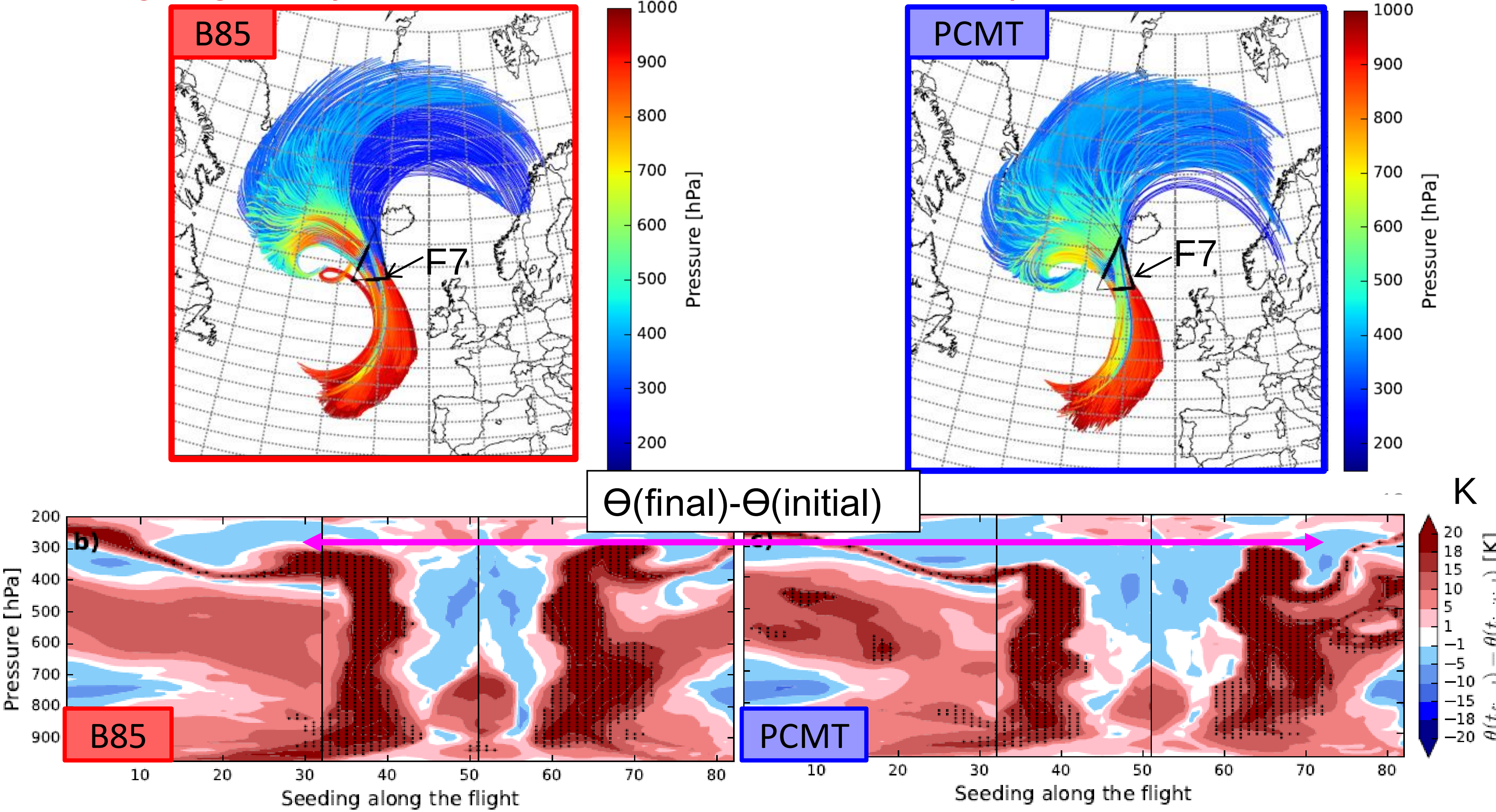
Units: mg/m3

3 hours flight: 12 forecasts separated by 15 min

Study by G. Rivière, M. Wimmer

Comparing two convection schemes using Arpege

Lagrangian trajectories: ascent 300hPa in 24h + initial pressure >850hPa



The heating rate reaches higher levels in B85 than in PCMT, consistent with IWC differences!

Study by M. Wimmer

Comparing two convection schemes using Arpege

- B85
  - More ice phase heating
  - Upper heating
  - WCBs reach higher heights
  - Stronger ridge building

- PCMT
  - More liquid phase heating
  - Lower and earlier heating
  - WCBs reach lower heights
  - Weaker ridge building

The higher ice water content in B85 compares better with the retrieved IWC even though the comparison is hard because of the strong underestimation of the simulated contents !

Study by M. Wimmer

Representation of the Stalactite Cyclone in climate models

Context: transpose AMIP experiment: run a climate model in « weather forecasting » mode to eventually detect short-term model biases

Caution should be taken: models initiated with a non-native initial set-up will take a while to adjust back to their own trajectory (Klocke and Rodwell, 2014)

Two models are used :

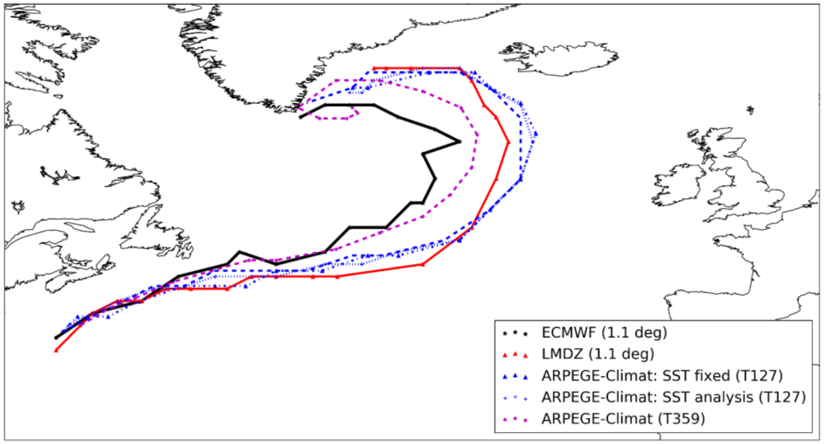
→ Arpege-Climat with two resolutions T127 (CMIP6 version) and T358~0.5 degree. Initialized from ECMWF analysis and Arpege analysis

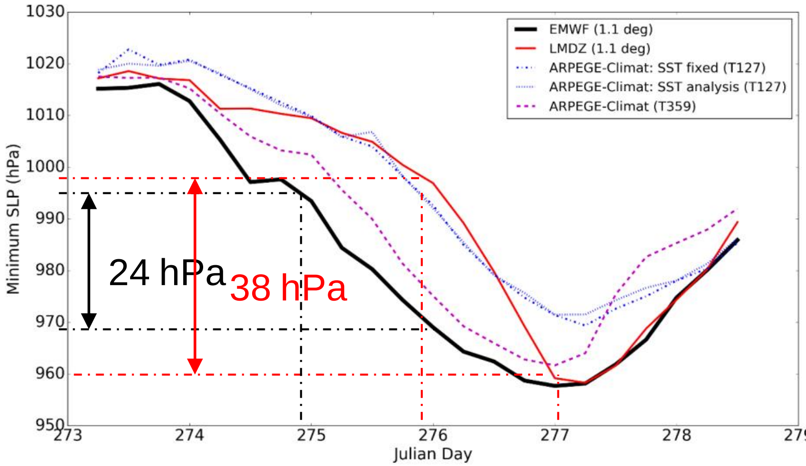
→ LMDZ: initialised from ECMWF analysis. CMIP6 physics but at higher resolution (1.1 degree)

Study by D. Flack

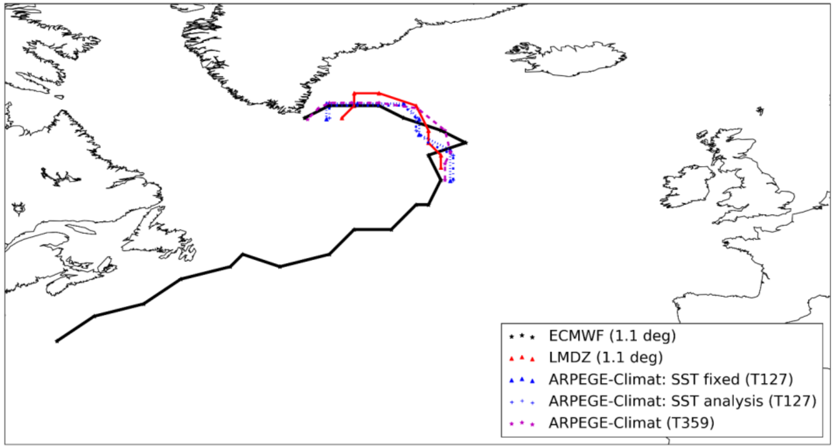
Representation of the Stalactite Cyclone in climate models

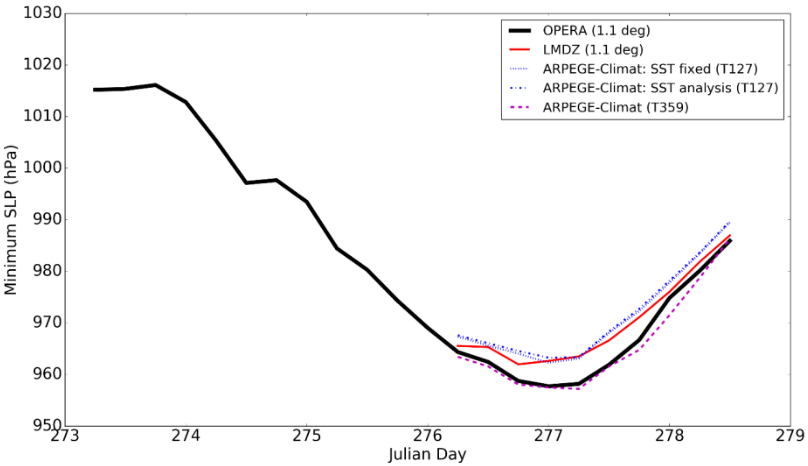
Initialised at 0000 UTC 29 September 2016





Initialised at 0000 UTC 2 October 2016





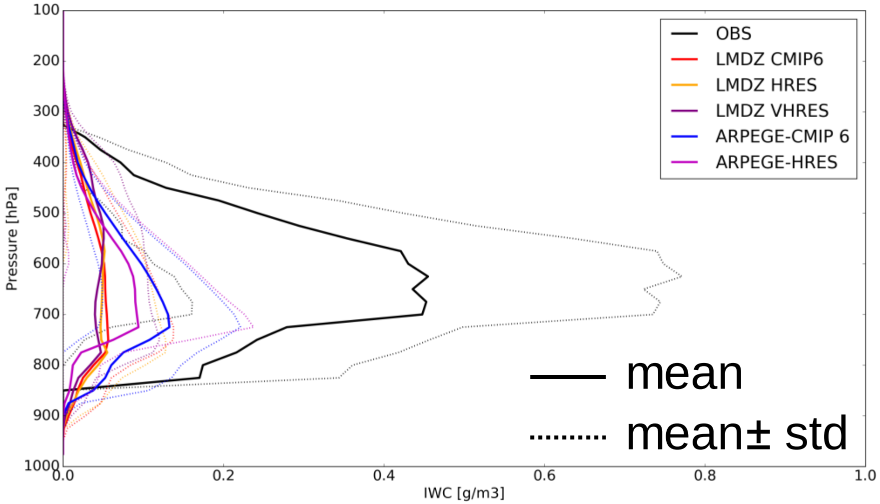
- The highest resolution (~50 km) is able to capture the main stages of the real cyclone but the lowest resolution is able to create a very strong deepening
- The eastward shift bias is also seen in NWP operational forecasts

Study by D. Flack

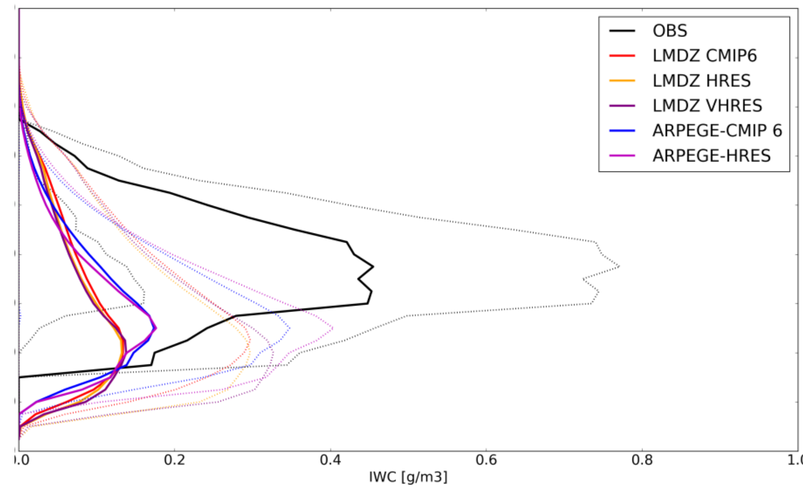
Representation of the Stalactite Cyclone in climate models

Averaged IWC (cloud ice + snow)

Along the flight track



Over a box encircling the cyclone center



- The peaks of IWC are around 700-800 hPa in the models and 600-700 hPa in the observations.
- IWC strongly depends on snow fall speed but a smaller fall speed leads to a peak at lower levels than in the observations !

Study by D. Flack

Conclusions

- **All types of models underestimate the retrieved ice water content and/or reflectivity** along the flight tracks. This underestimation is **more obvious in the upper troposphere** and varies between a factor 2 to 5.

- **Despite a strong underestimation of the intensity, the convection permitting simulations show realistic structures** of reflectivity and IWC.

- The simulated ice water content increases by **decreasing the ice and snow fall speeds** but this **is never enough to correctly represent the observed content** in the upper troposphere.

- **The retrieved IWC and observed reflectivity are not better represented by the more recently developped / more elaborated schemes** (convection scheme for Arpege and cloud microphysics scheme for Meso-NH)

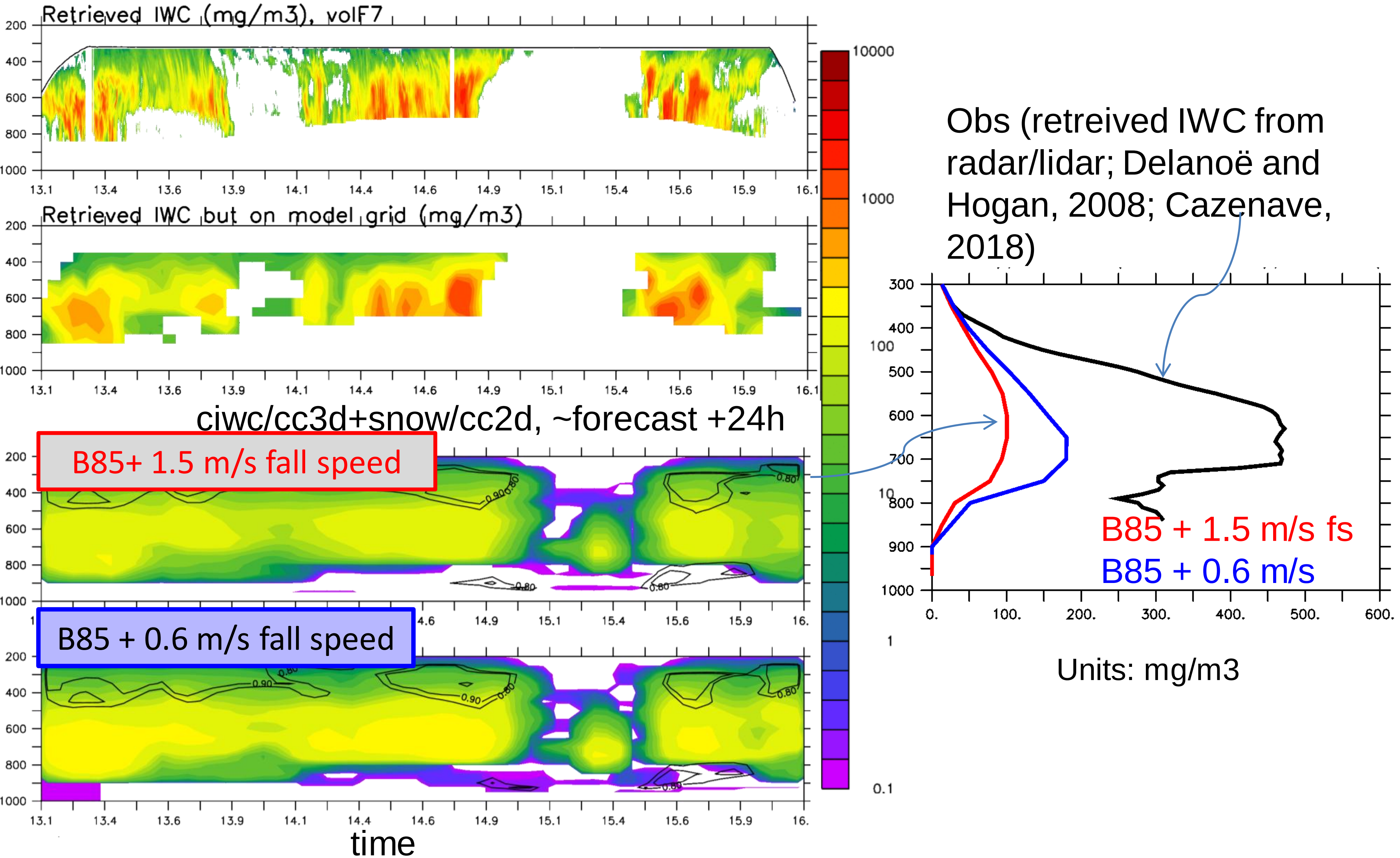
- **Caution should be taken when deducing information from the retrieved ice water content to address the NAWDEX scientific questions**: a difference in IWC does not necessarily correspond to a difference in latent heating !

Outlook

- Analysis of the dozen of SAFIRE flights to confirm the above results.
- Same analysis for ECMWF forecasts.
- Similar approach is currently made for the wind representation (comparison with radar Doppler wind)
- Use of dropsondes data to compare observed and simulated temperature profiles

Additional slides

Sensitivity to the snow terminal fall speed



Strong underestimation of the IWC even for the slowest snow fall speed (factor 2.5)

Representation of the Stalactite Cyclone in climate models

Context: transpose AMIP experiment: run a climate model in « weather forecasting » mode to eventually detect short-term model biases

- Two models are used :

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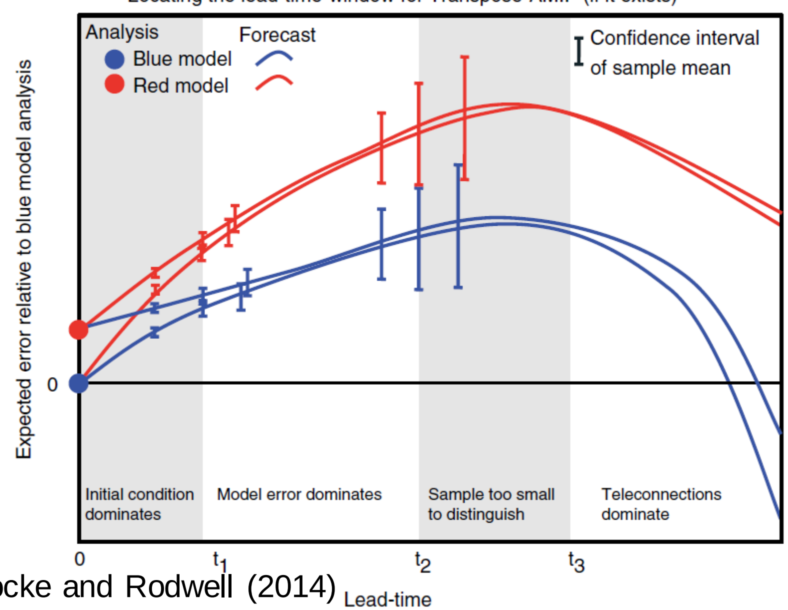
→ LMDZ: initialised from ECMWF analysis. CMIP6 physics but at higher resolution (1.1 degree)

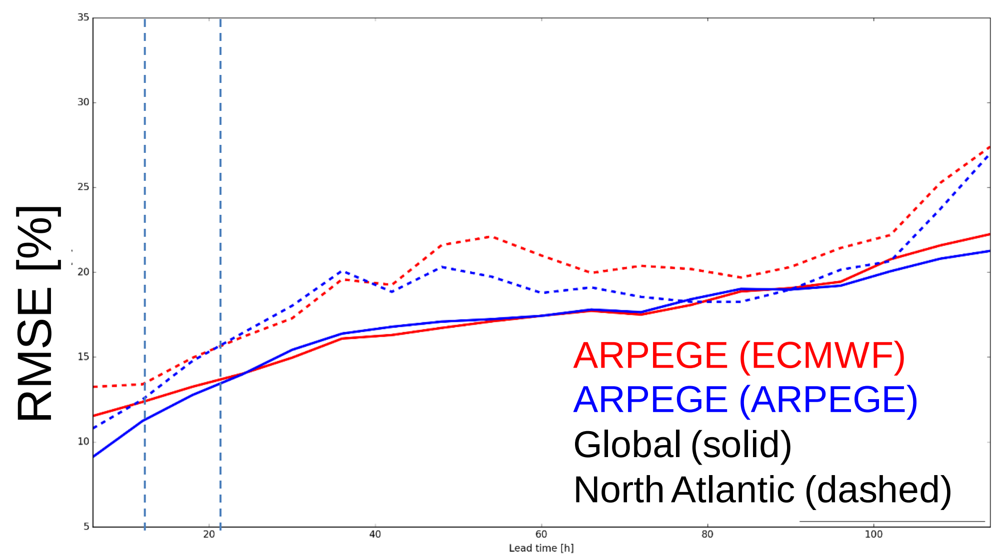
Models initiated with a non-native initial set-up will take a while to adjust back to their own trajectory

Locating the lead-time-window for Transpose-AMIP (if it exists)



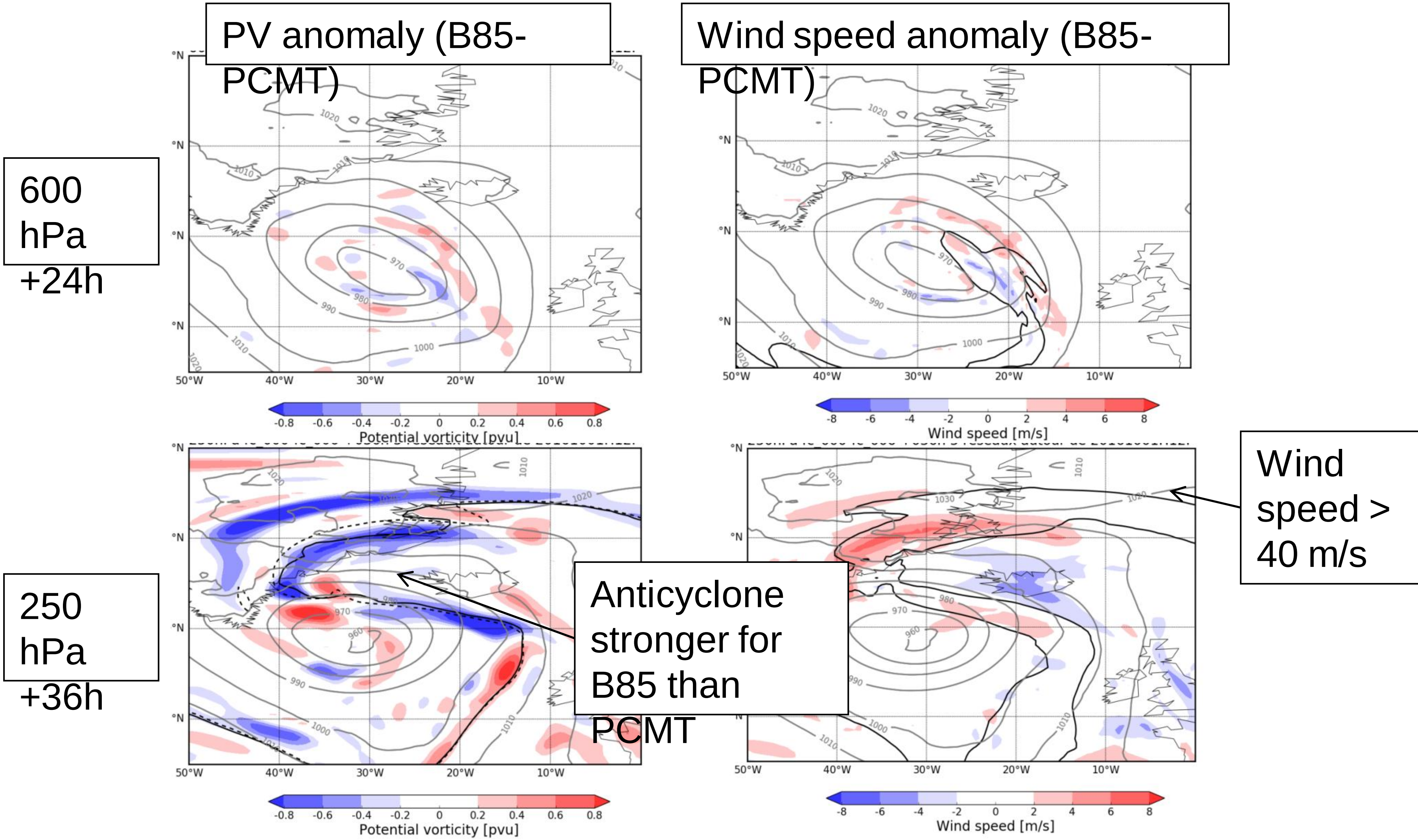
Klocke and Rodwell (2014)

T+12-T+24 Relative Humidity 850 hPa



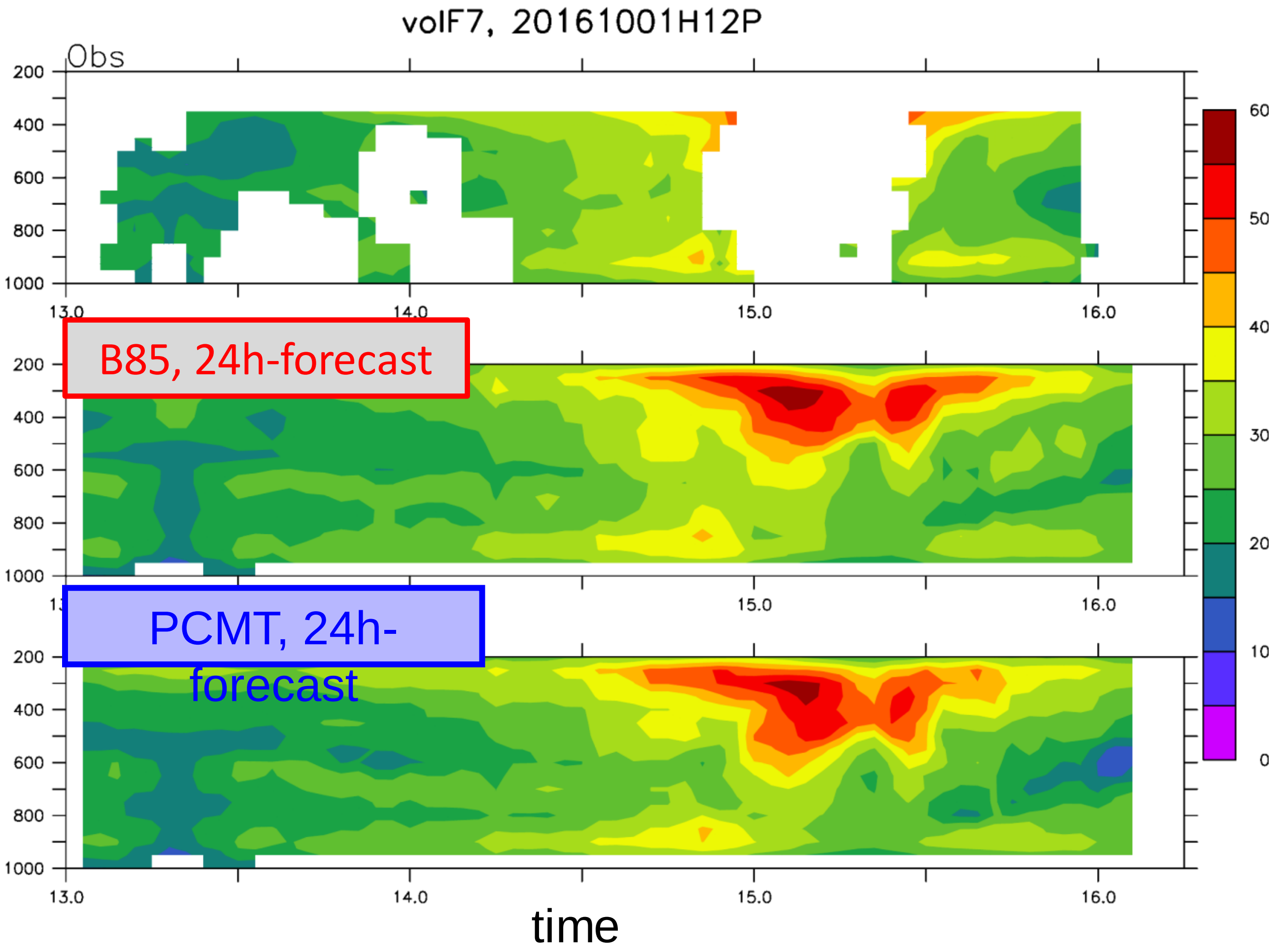
Study by D. Flack

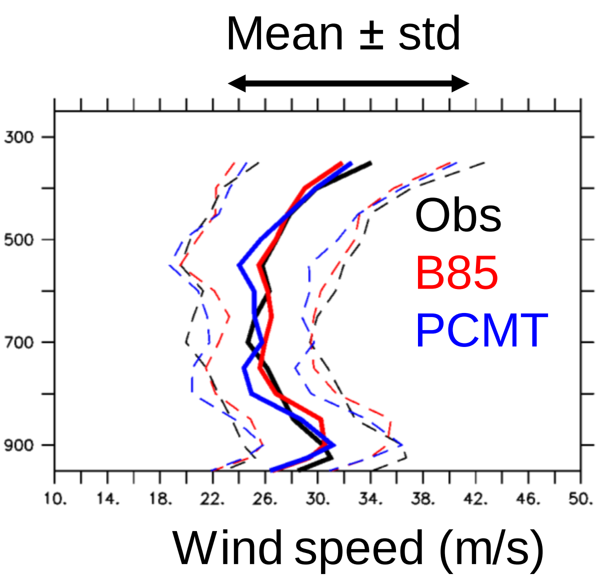
Recall of Meryl's results on Stalactite Cyclone



More positive PV anomalies at 600 hPa due to more heating during liquid transition and less heating during ice transition

Comparison between « observed » wind speed and simulated wind speed





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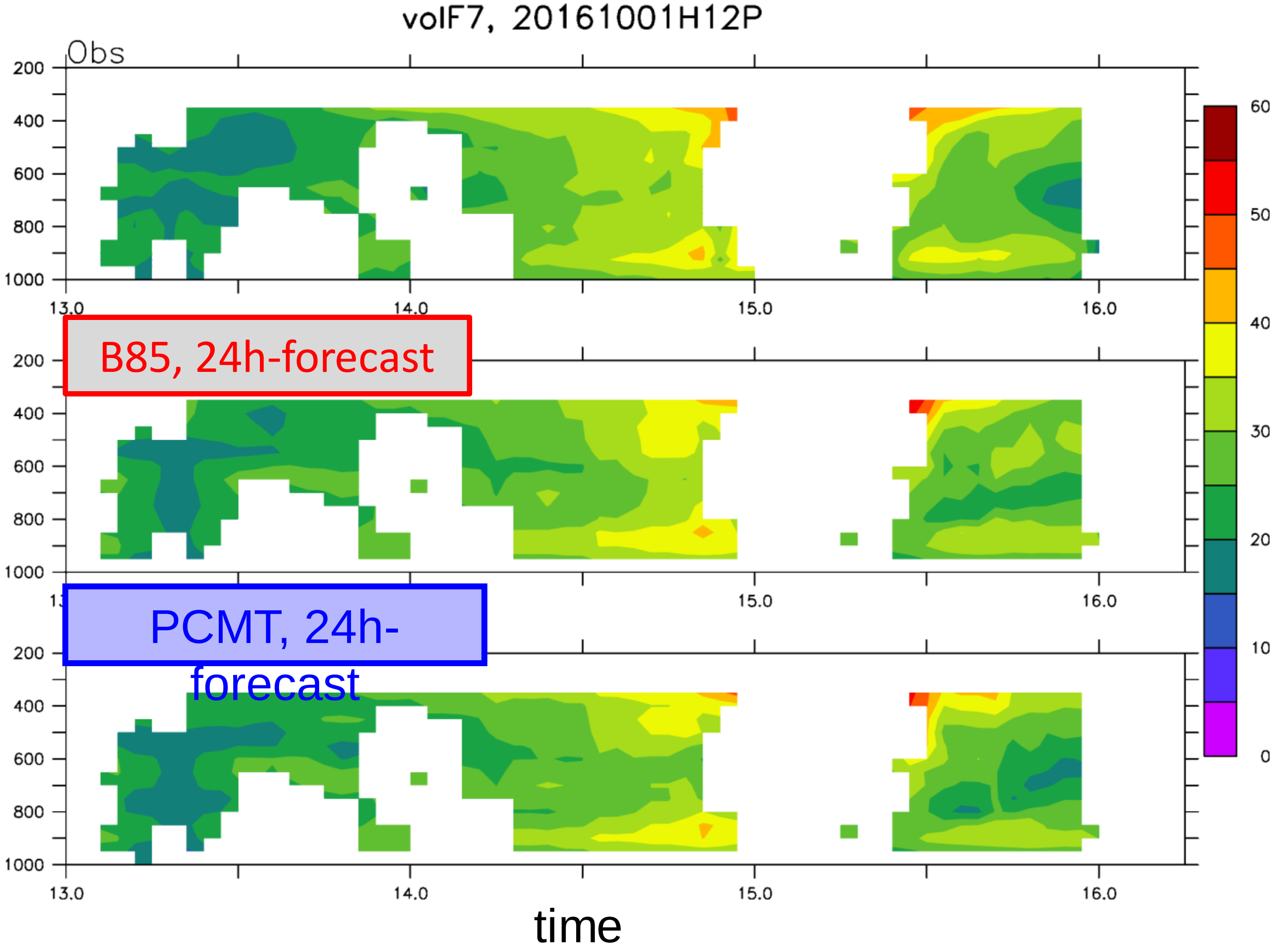
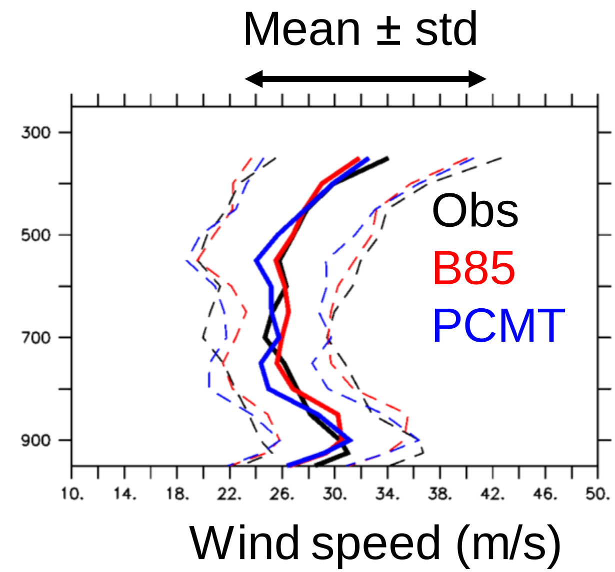
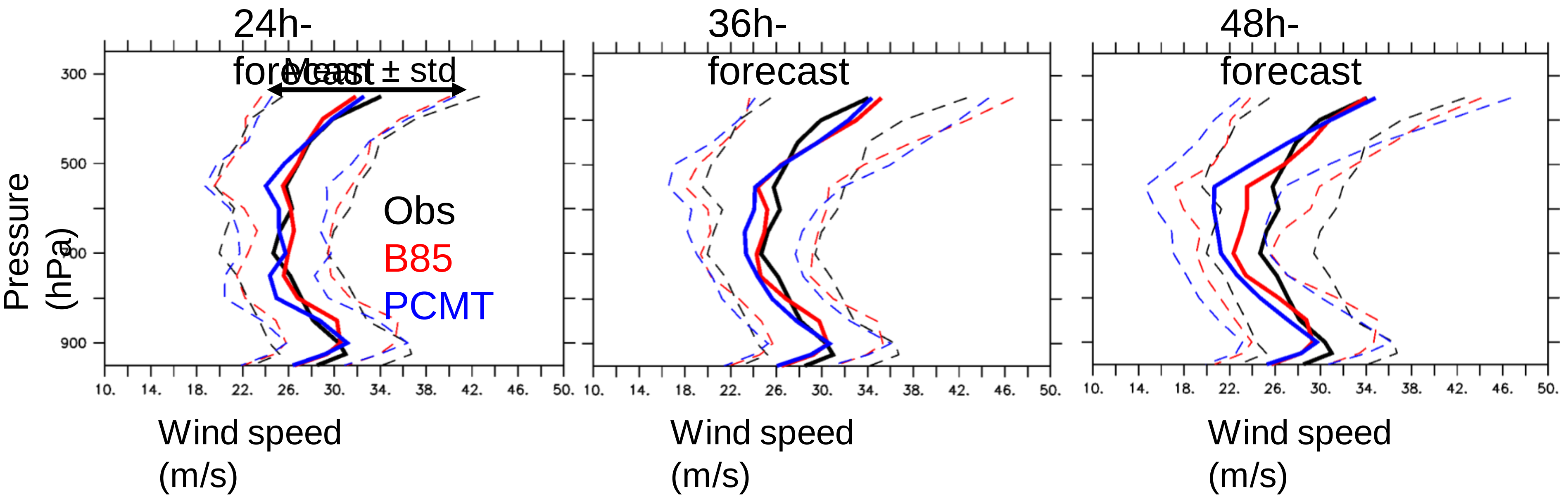




Wind speed differences for F7 as function of lead time



- Wind speed underestimation between mid- and low levels (500-850hPa), more obvious after 48 hours.
- Stronger underestimation for PCMT scheme.