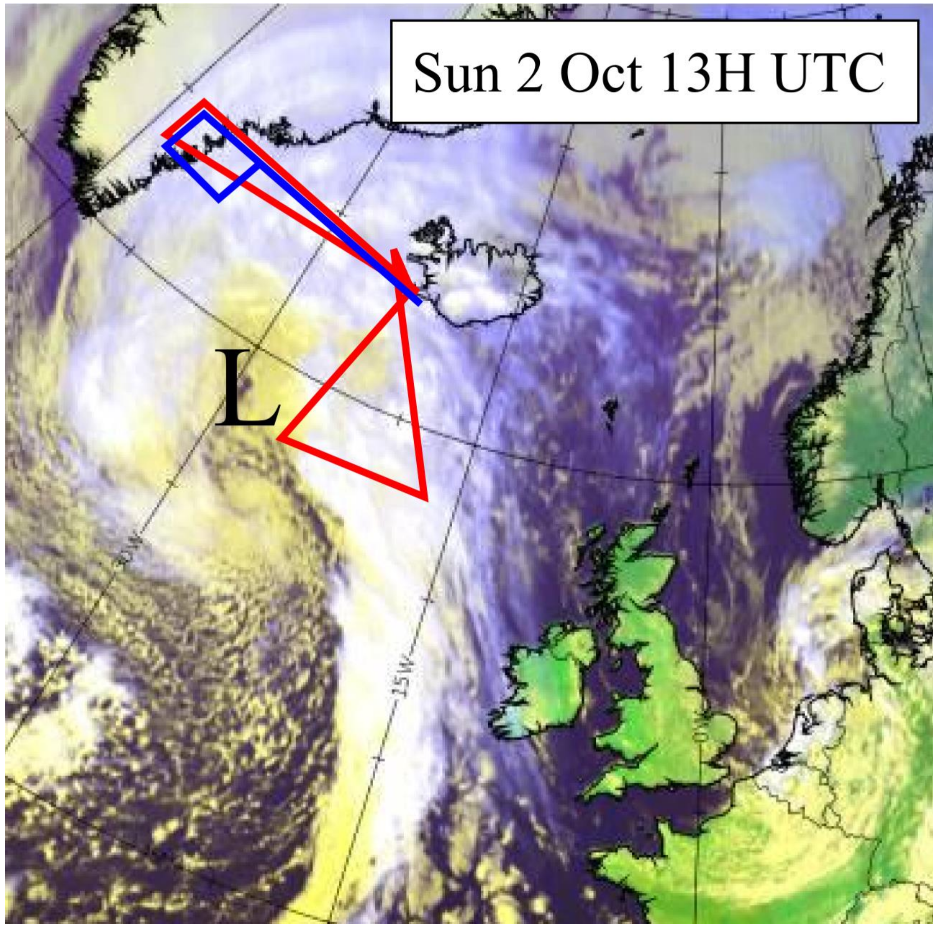
Representation of the Stalactite Cyclone in IPSL and ARPEGE Climate Models



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Cyclones in Climate Models

- Confidence is low in the projection of how cyclones will behave under climate change (Christensen et al., 2013)
- We need climate models to be able to accurately depict current cyclones to be able to determine future cyclones with any confidence
- Problems include intensity and timing
- Partly due to resolution (Willison et al., 2013)
- Can be due to parametrizations: convection, boundary layer, microphysics etc. (e.g. Trzeciak et al., 2013)

Damage from Storm Ali in Glasgow, UK (www.glasgowlive.co.uk)

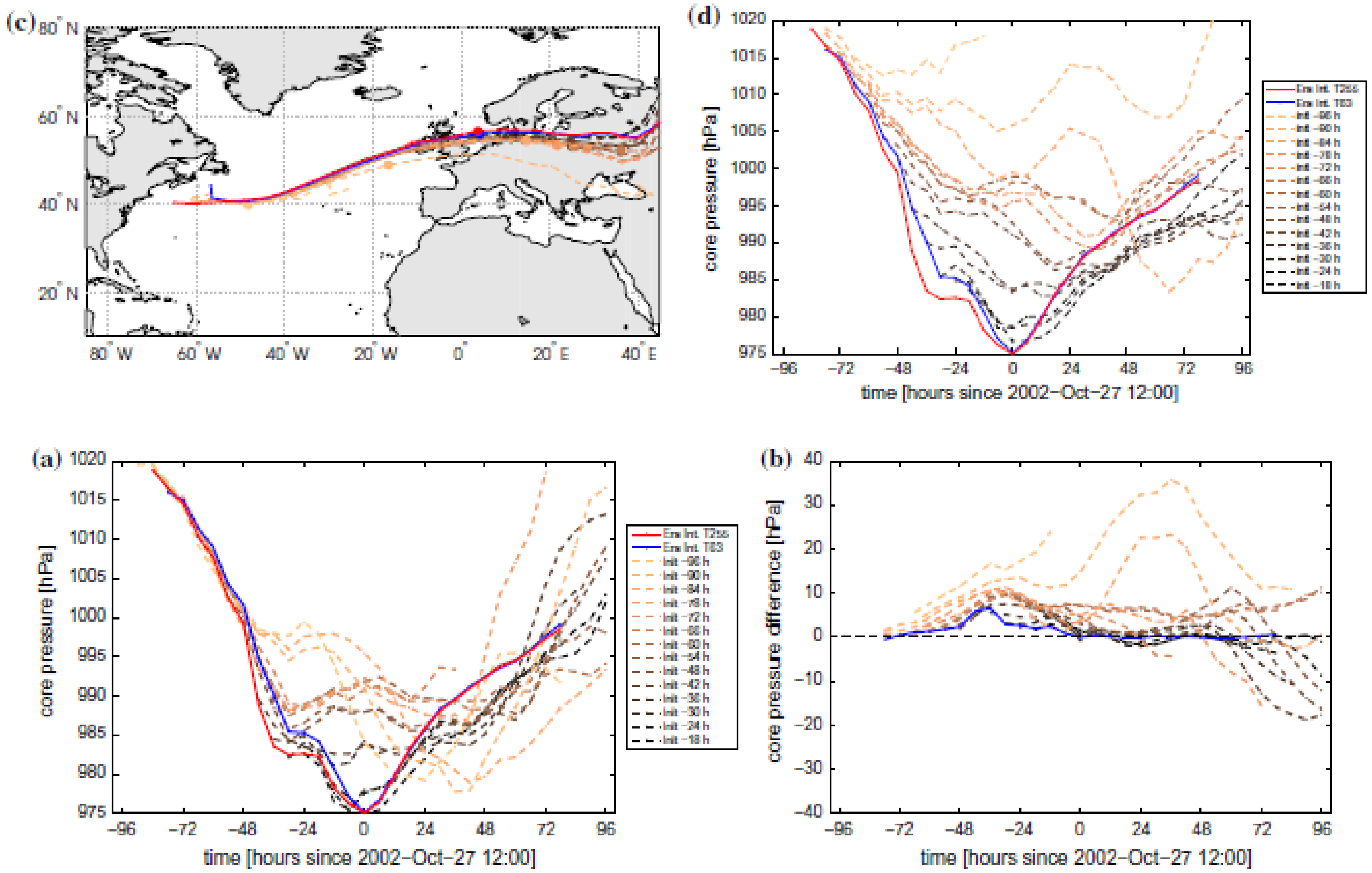
Transpose-AMIP experiments

- One method to help ‘diagnose’ problems with parametrizations in climate models.
- Run a climate model in “weather forecasting” mode (i.e. run it out for 10—15 days) and compare short-term biases with long-term biases in the ‘fast’ physics variables.
- Focus has been mainly on tropics and cloud and radiative feedbacks.
- Williams et al. (2013), Ma et al. (2014, 2015), etc.
- There can be problems with initial shock (Klocke and Rodwell, 2014).

Transpose-AMIP and Extra-Tropical Cyclones

- Models with resolution of T127 (~1.1 degrees) are able to represent cyclones (including "bomb" cyclones) and representation improves with lead time.

- Trzeciak et al. (2016)

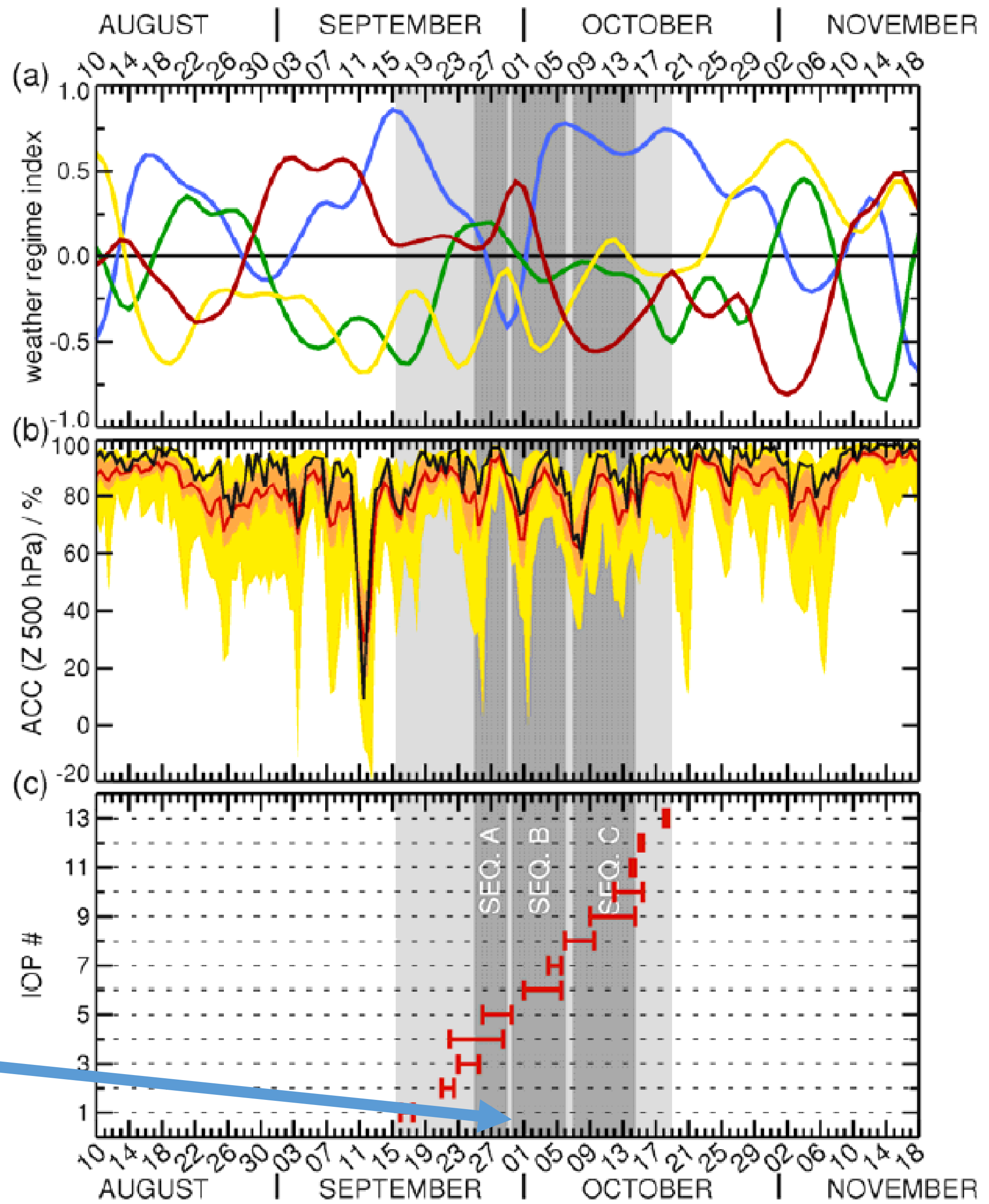


Project Aim

- Determine the relative role of diabatic and dynamical processes in the development of extra-tropical cyclones in climate models
- Detect if any short-term biases lead to long-term biases in the model
    - Use 2 climate models (IPSL and CNRM)
    - Use observations from NAWDEX field campaign

NAWDEX

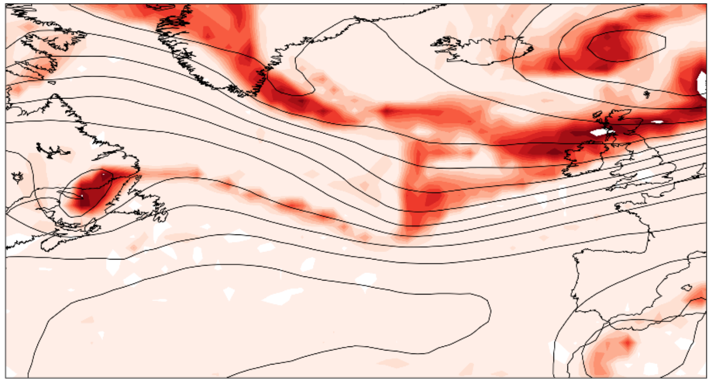
- North Atlantic Waveguide and Downstream impact Experiment
- Sept—Oct 2016
- French contingent mainly involved in the 2nd half of the field campaign
- Observations made from their SAFIRE-Falcon aircraft
- SAFIRE-Falcon made 2 flights on the Stalactite cyclone



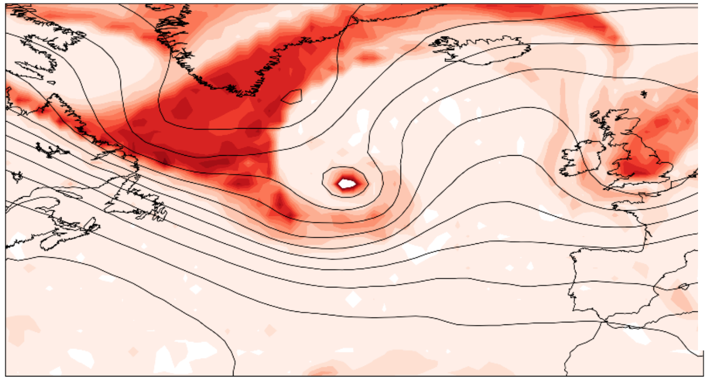
Schäfler et al (2018)

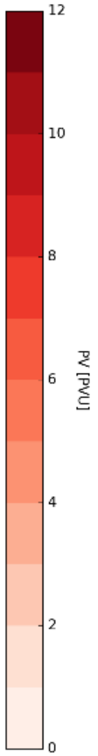
The Stalactite Cyclone

1200 UTC 29 September 2016

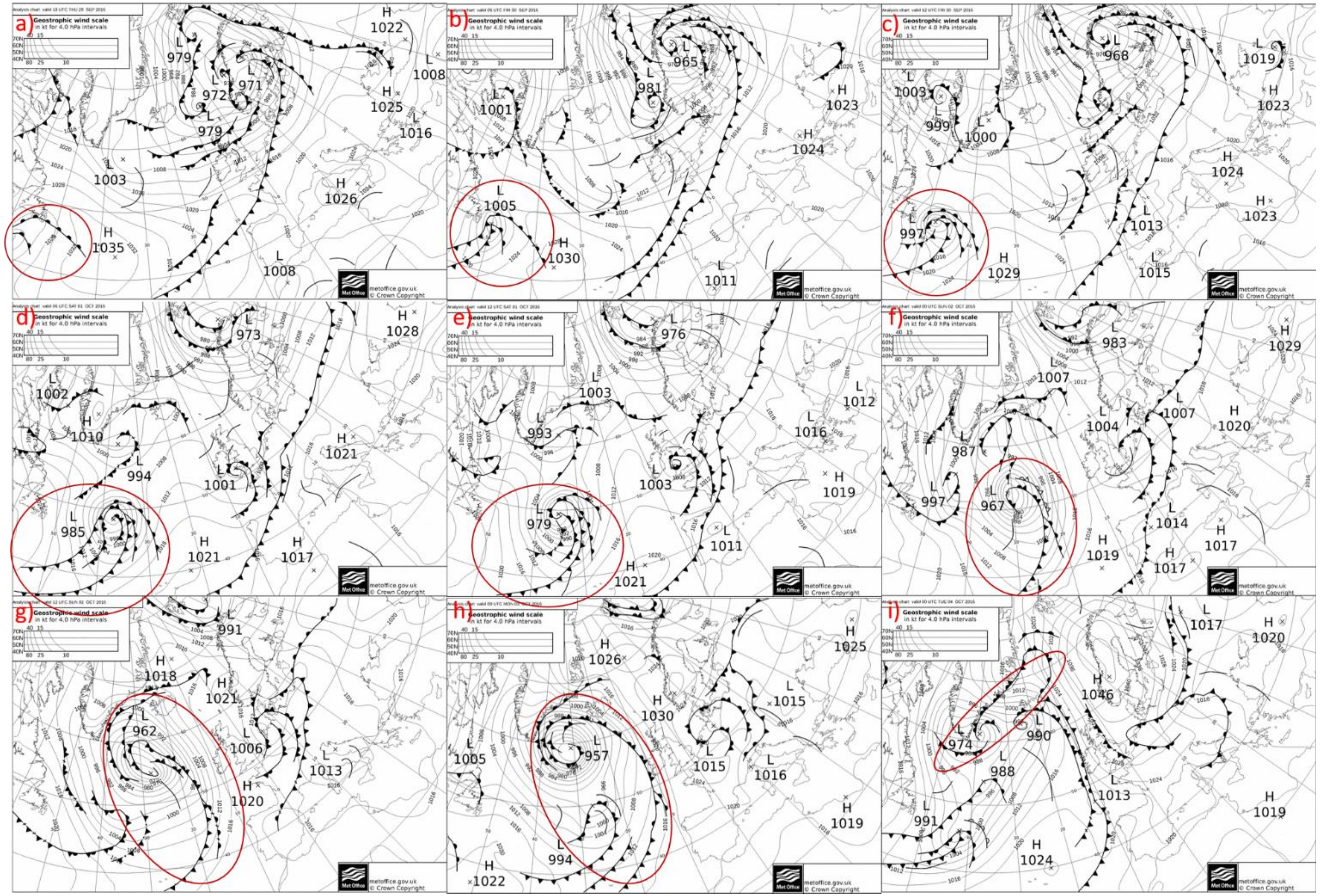


0600 UTC 2 October 2016



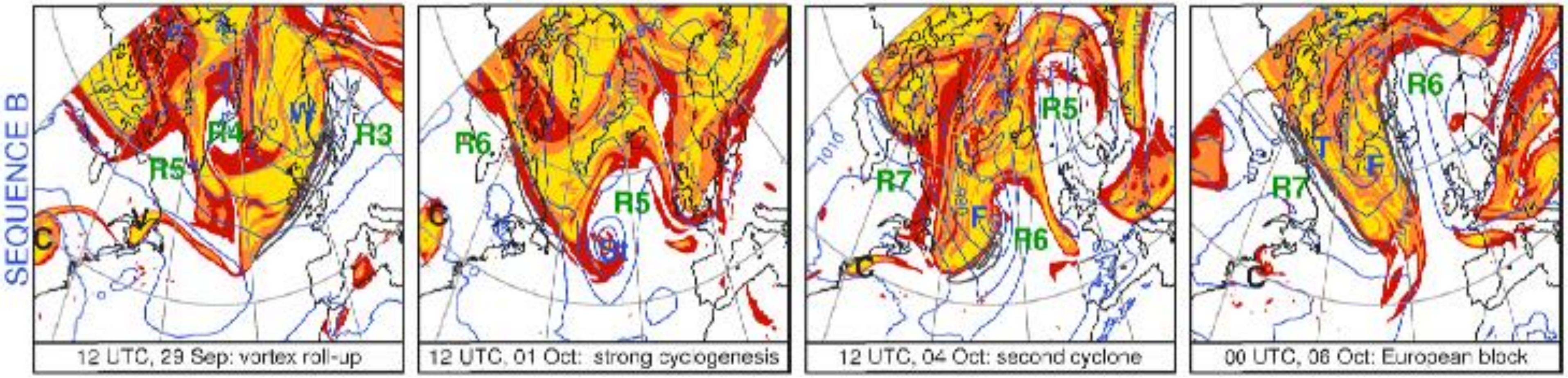


PV at 320 K and 500 hPa
Geopotential height



The Stalactite Cyclone: Key Characteristics

- 2 stages of intensification
  - Initial cyclogenesis: small-scale vortex roll-up
  - 2nd deepening stage: Interaction with large-scale upper-level trough
- Steepest decline 24.4 hPa in 24h
- Important for the setup of the Scandinavian blocking event that followed



Schäfler et al (2018)

Models

LMDZ

- 1.1 degree resolution
- Hindcasts initiated at 0000 UTC on 29 Sept and 2 Oct
- Initialised from ECMWF analysis
- Length: 10 days

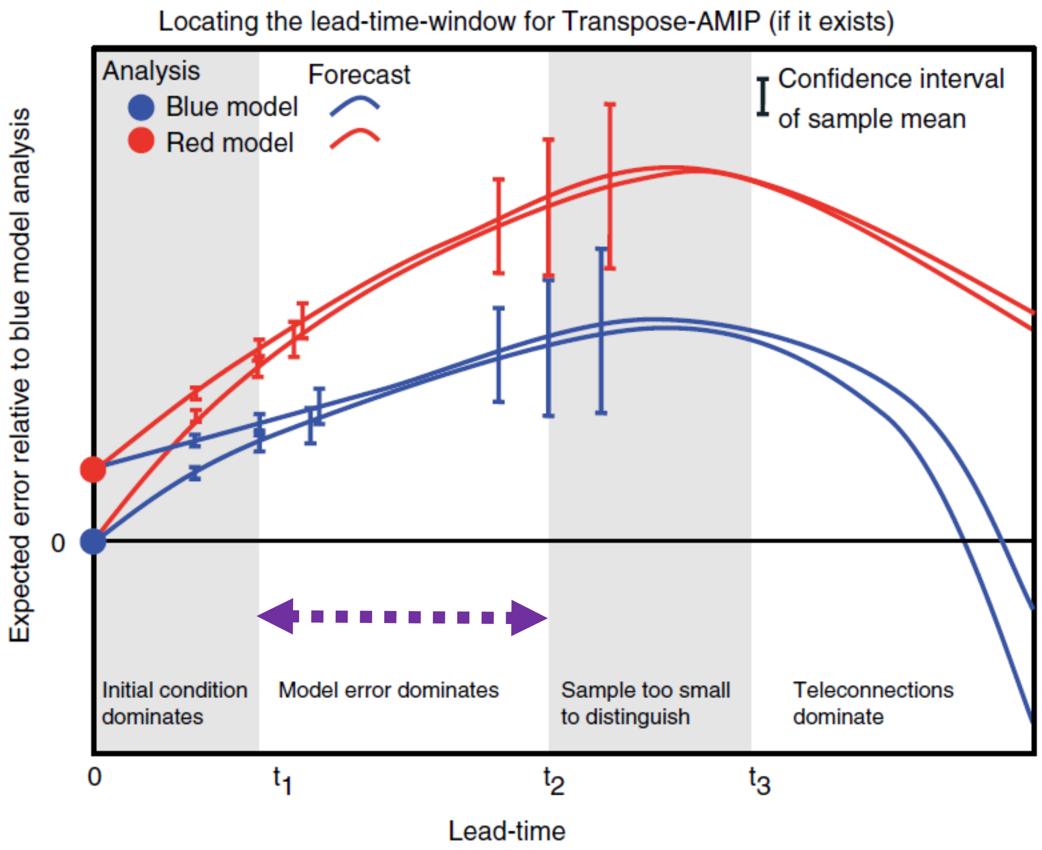
Both models used are setup as for CMIP6

ARPEGE-Climat

- T127 ~1.4 degree
- T359 ~0.5 degree
- Hindcasts initiated at 0000 UTC on 29 Sept and 2 Oct
- Initialised from ECMWF analysis and ARPEGE analysis
- Length: 10 days

Initial Shock: The Theory

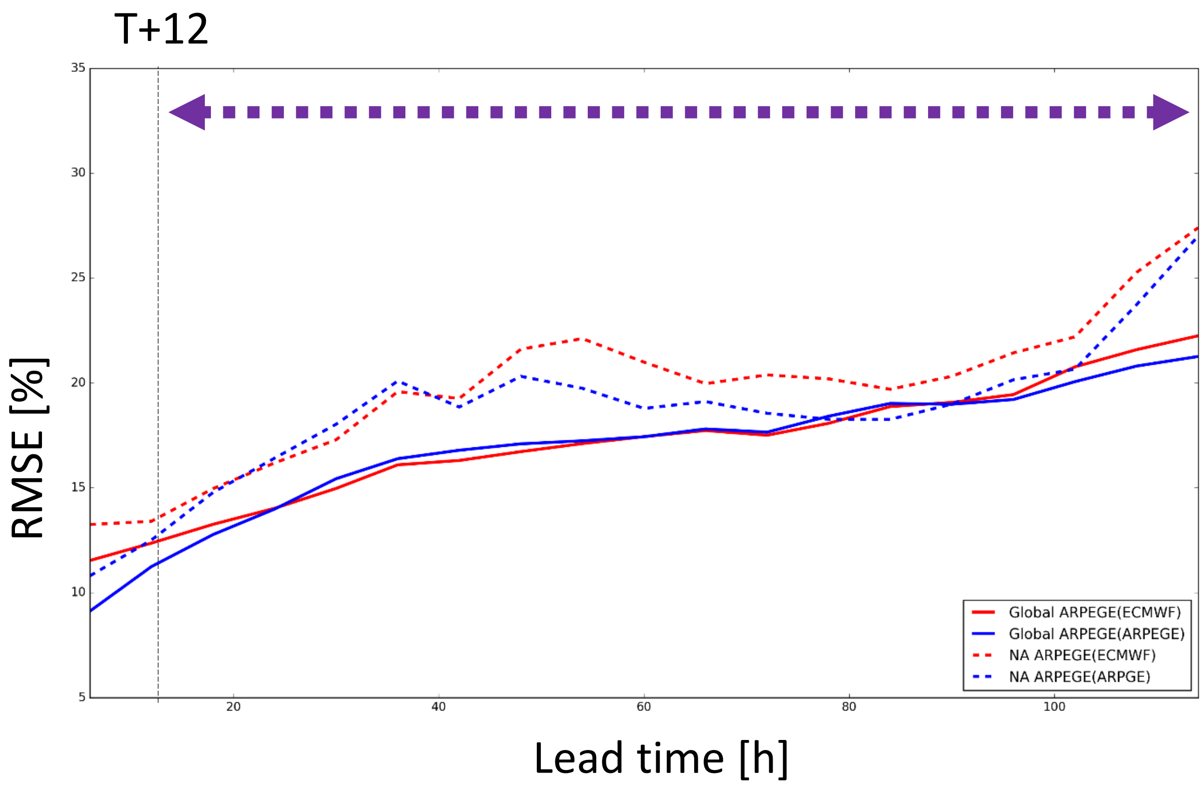
- Models initiated with a non-native initial set-up will take a while to adjust back to their own trajectory
- This adjustment is the "initial shock" and can be seen through initiation of gravity waves right at the start of the run.



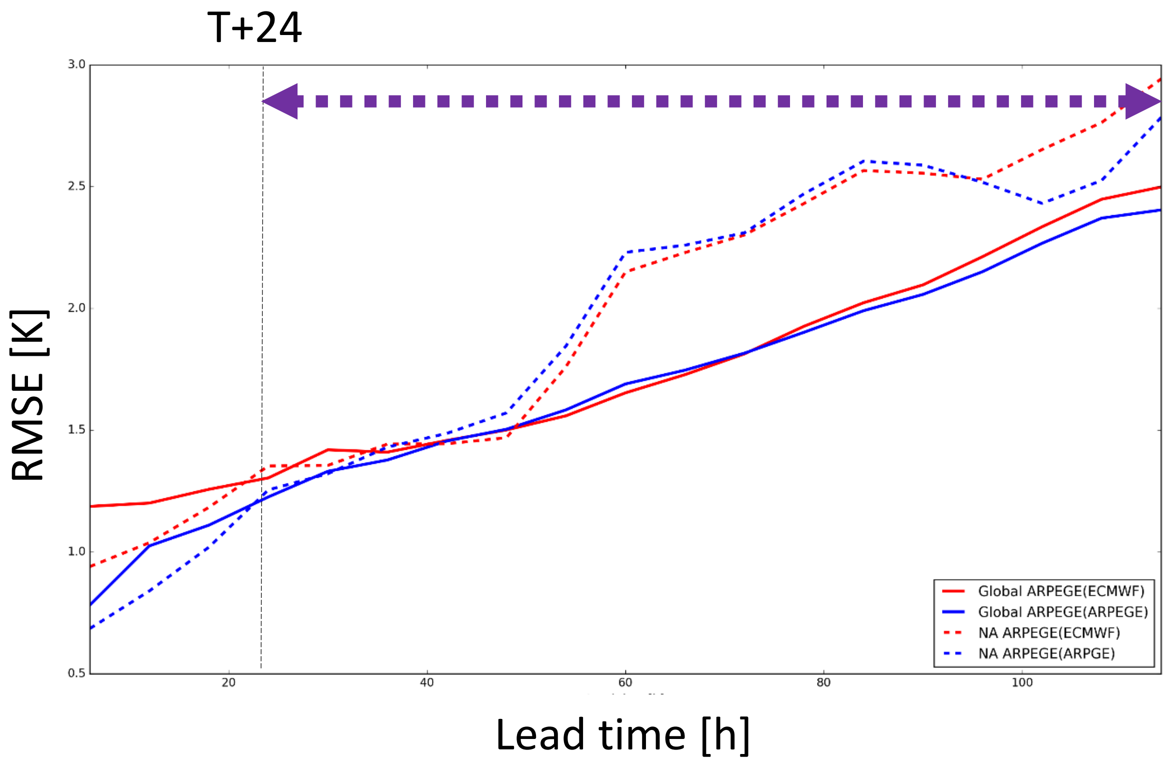
Klocke and Rodwell (2014)

Transpose-AMIP experiments are viable

Initial Shock: ARPEGE-Climat (~1.4˚)



Relative Humidity 850 hPa

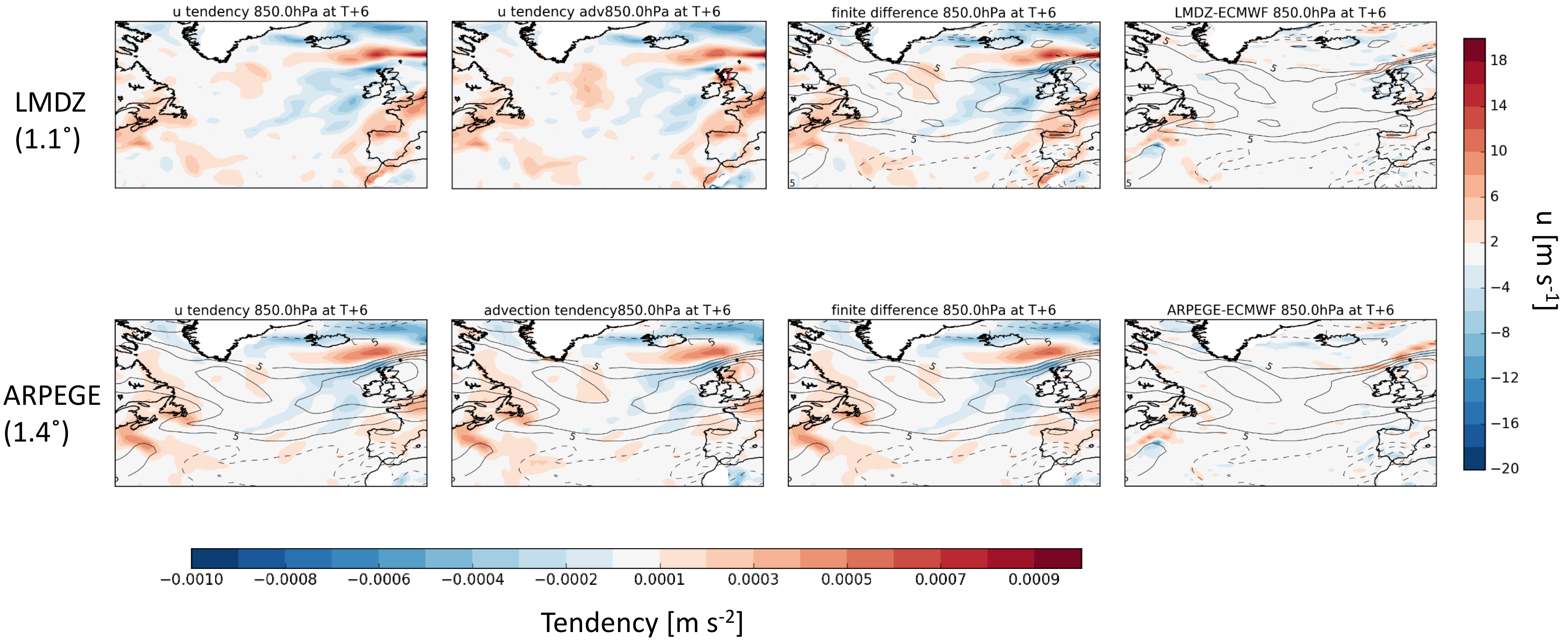


Temperature 850 hPa

Hindcasts compared against ARPEGE analysis

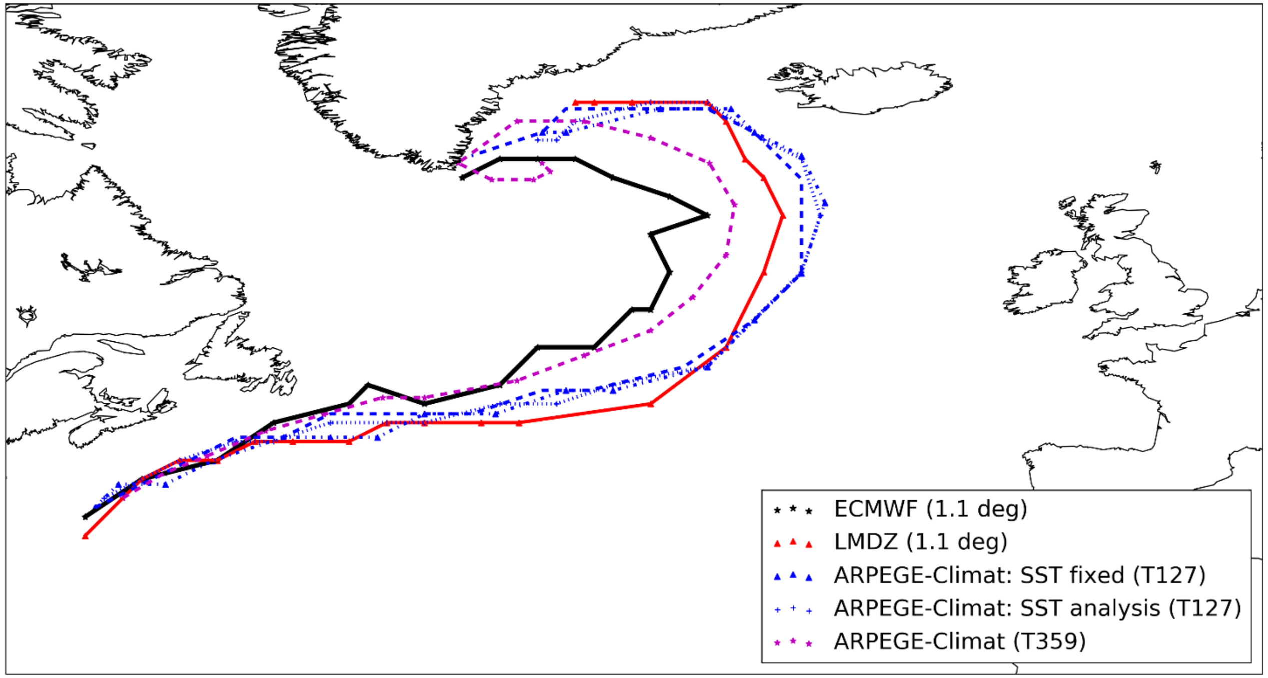
Transpose-AMIP experiments are viable

Initial Shock: LMDZ (u-850 hPa) T+6

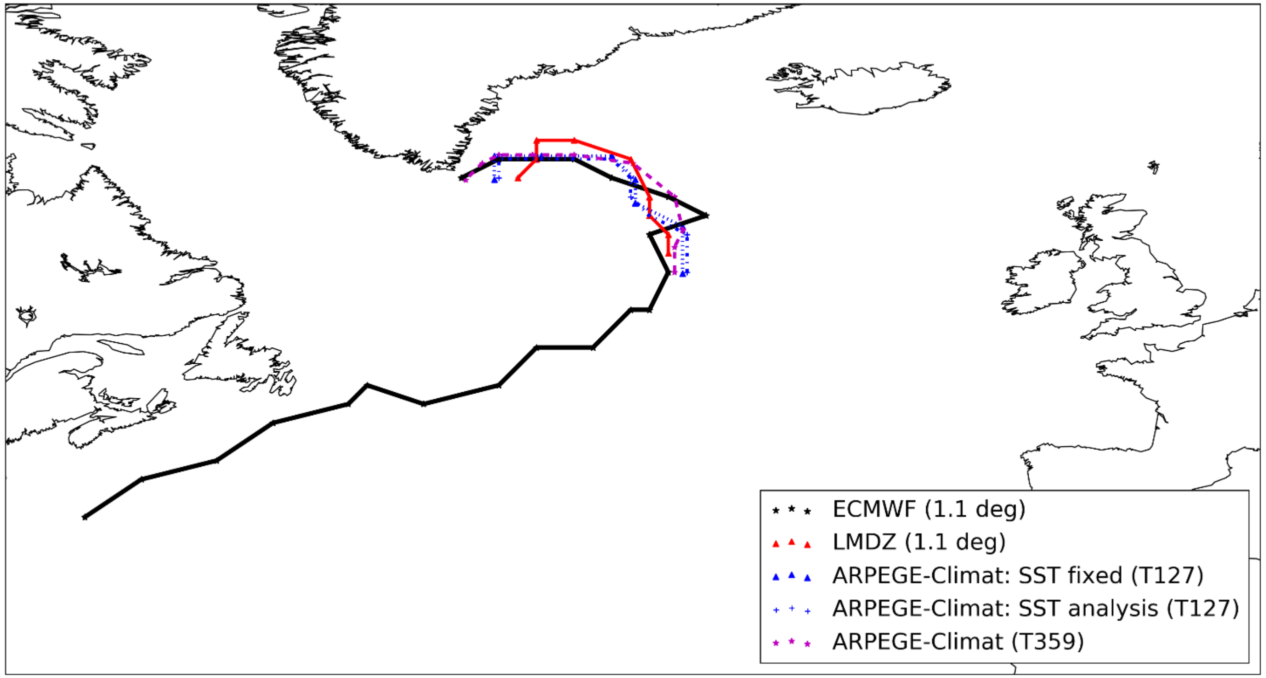


Cyclone Track

Initialised at 0000 UTC 29 September 2016

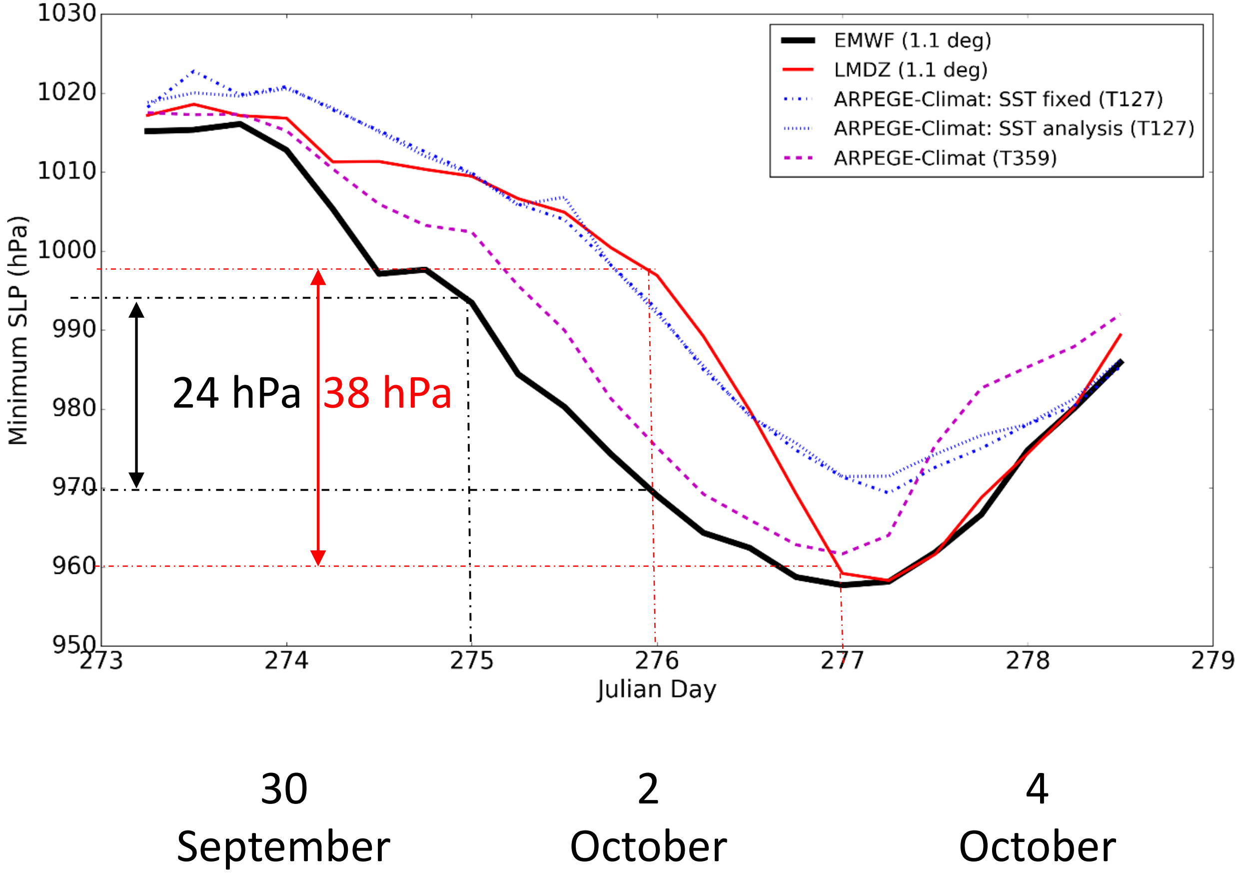


Initialised at 0000 UTC 2 October 2016

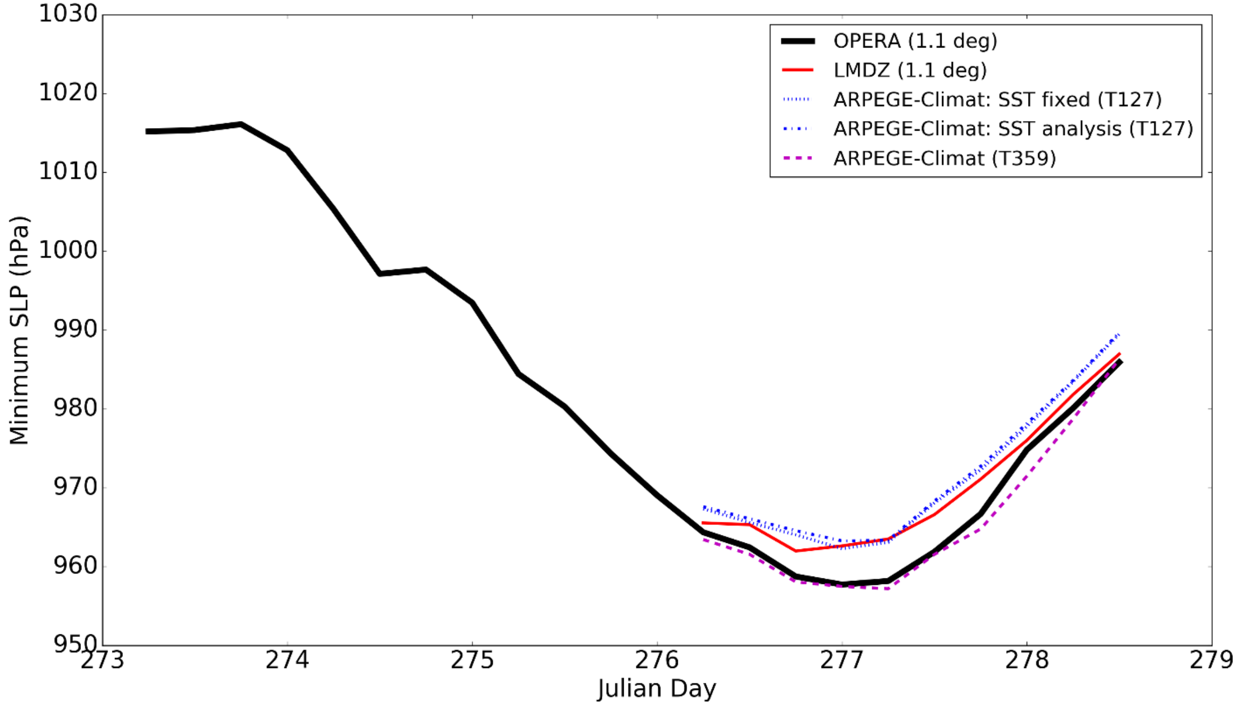


Cyclone Depth

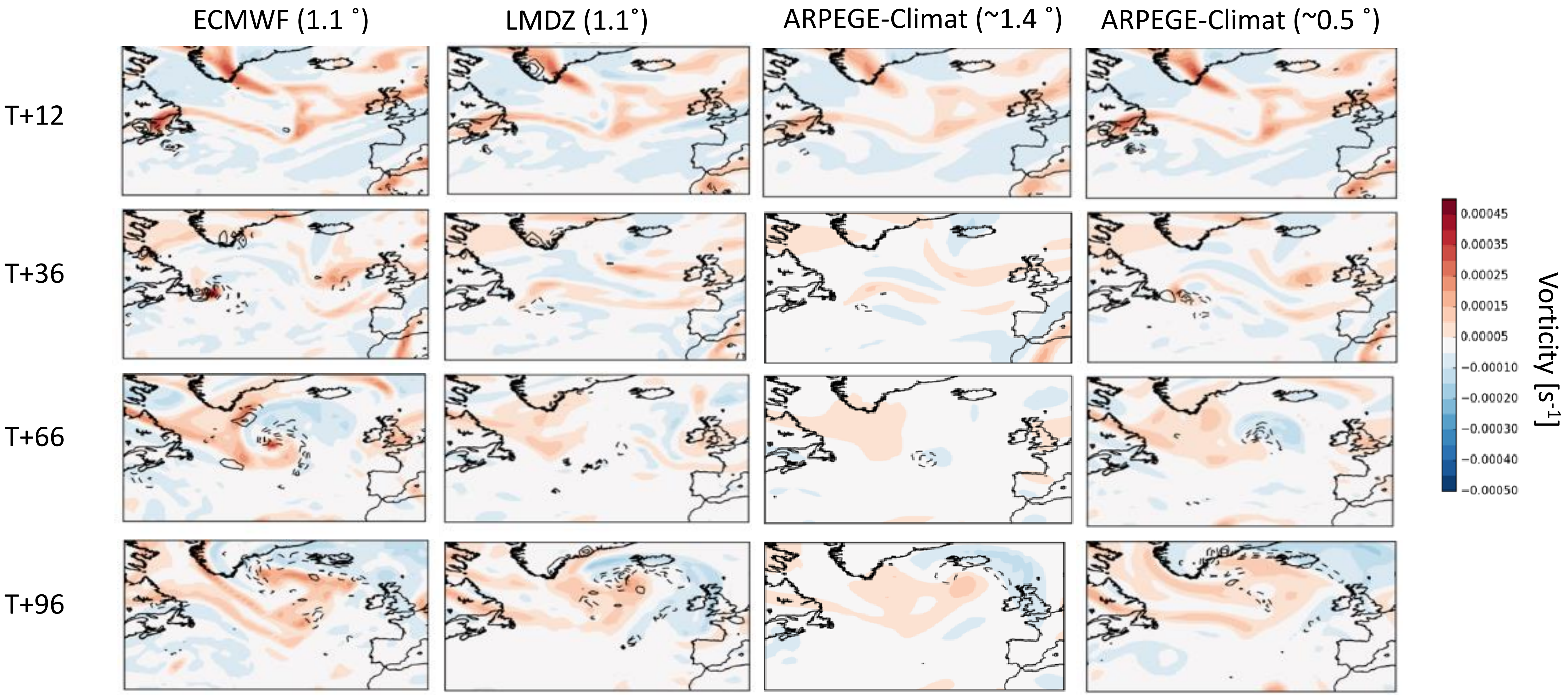
Initialised at 0000 UTC 29 September 2016



Initialised at 0000 UTC 2 October 2016



Cyclone Development: 29 September hindcast



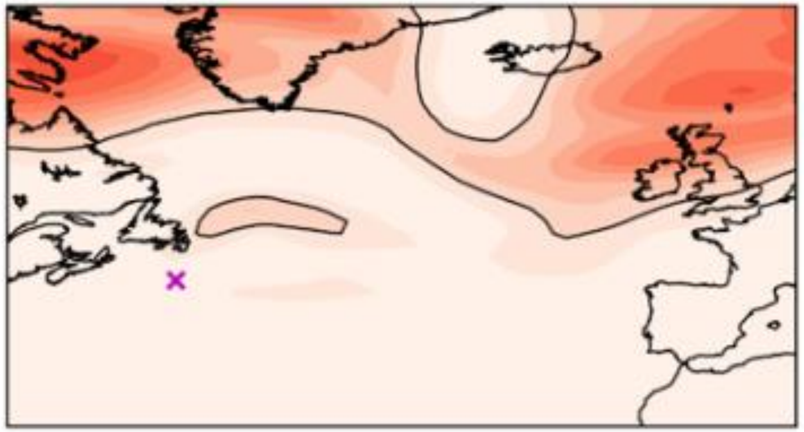
Cyclone Development: 29 September hindcast

ECMWF (1.1 ˚) | LMDZ (1.1˚) | ARPEGE-Climat (~1.4 ˚) | ARPEGE-Climat (~0.5 ˚)

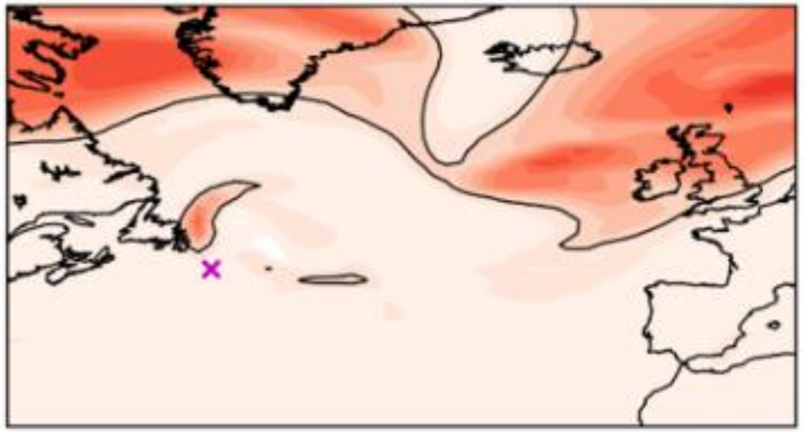
T+12

PV at T+30

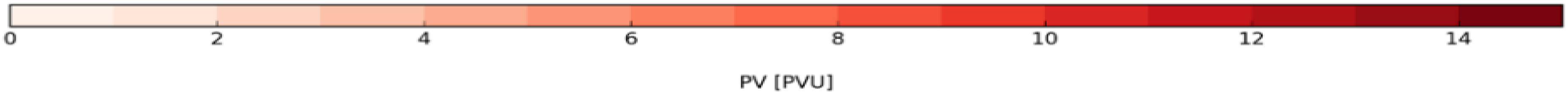
ARPEGE-Climat (~1.4 ˚)



ARPEGE-Climat (~0.5 ˚)



T+36

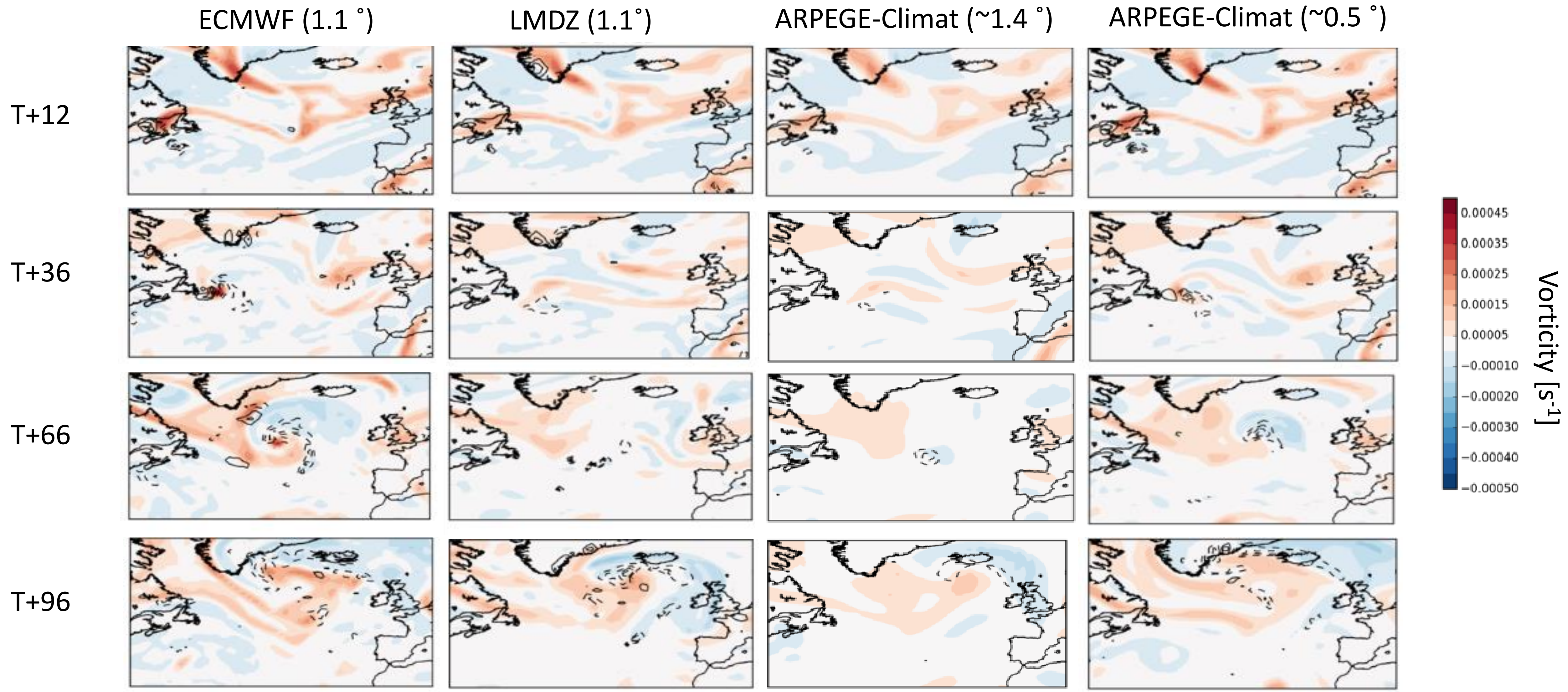


T+66

T+96

Vorticity [s^{-1}]

Cyclone Development: 29 September hindcast



ω-equation budget

$$\sigma\nabla^2\omega + f_0\frac{\partial^2\omega}{\partial p^2} = -\frac{R}{p}\left(\nabla^2\left(-\overrightarrow{u_g}.T\right) + \nabla^2 J\right) - f_0\frac{\partial}{\partial p}\left(-\overrightarrow{u_g}.\nabla\left(\xi_g + f\right)\right)$$

Writing in the form of Q vectors and diabatic terms

$$\sigma\nabla^2\omega + f_0\frac{\partial^2\omega}{\partial p^2} = -2\nabla.\vec{Q} - \frac{R}{p}\left(\nabla^2\left(\left.\frac{\partial T}{\partial t}\right|_{mp}\right)\right) - f_0\frac{\partial}{\partial p}\left(\frac{\partial}{\partial x}\left(\left.\frac{\partial v}{\partial t}\right|_{mp}\right) - \frac{\partial}{\partial y}\left(\left.\frac{\partial v}{\partial t}\right|_{mp}\right)\right)$$

where $\vec{Q} = -\frac{R}{p}\begin{pmatrix} \frac{\partial\overrightarrow{v_g}}{\partial x}.\nabla T \\ \frac{\partial\overrightarrow{v_g}}{\partial y}.\nabla T \end{pmatrix}$

ω-equation budget

$$\sigma\nabla^2\omega + f_0\frac{\partial^2\omega}{\partial p^2} = -\frac{R}{p}\left(\nabla^2(-\overrightarrow{u_g}.T) + \nabla^2 J\right) - f_0\frac{\partial}{\partial p}\left(-\overrightarrow{u_g}.\nabla(\xi_g + f)\right)$$

Writing in the form of Q vectors and diabatic terms

$$\sigma\nabla^2\omega + f_0\frac{\partial^2\omega}{\partial p^2} = \underbrace{-2\nabla.\vec{Q}}_{\text{Dynamical contribution}} \underbrace{- \frac{R}{p}\left(\nabla^2\left(\left.\frac{\partial T}{\partial t}\right|_{mp}\right)\right) - f_0\frac{\partial}{\partial p}\left(\frac{\partial}{\partial x}\left(\left.\frac{\partial v}{\partial t}\right|_{mp}\right) - \frac{\partial}{\partial y}\left(\left.\frac{\partial v}{\partial t}\right|_{mp}\right)\right)}_{\text{Diabatic contribution from the model physics tendencies}}$$

Dynamical contribution

Diabatic contribution from the model physics tendencies
For temperature: microphysics, convection, radiation, turbulence, drag
For velocity: convection, turbulence, orography and gravity wave drag

ω-equation budget

$$\sigma\nabla^2\omega + f_0\frac{\partial^2\omega}{\partial p^2} = -\frac{R}{p}\left(\nabla^2\left(-\overrightarrow{u_g}.T\right) + \nabla^2 J\right) - f_0\frac{\partial}{\partial p}\left(-\overrightarrow{u_g}.\nabla\left(\xi_g + f\right)\right)$$

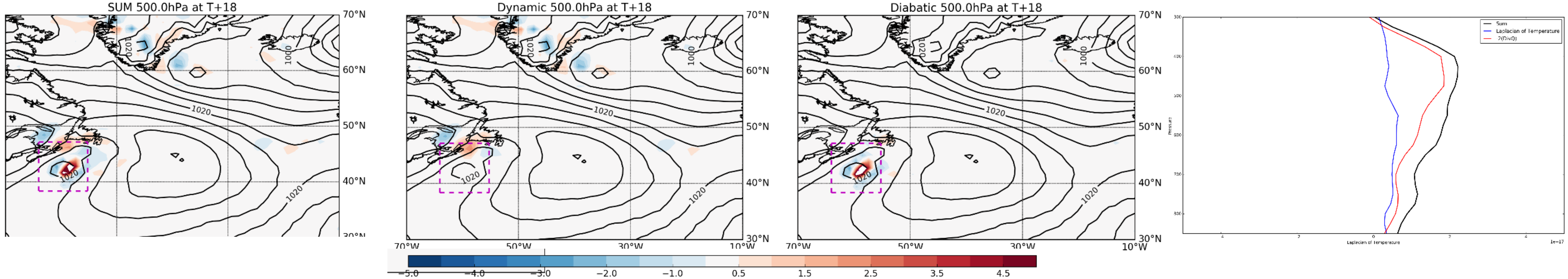
Writing in the form of Q vectors and diabatic terms

$$\sigma\nabla^2\omega + f_0\frac{\partial^2\omega}{\partial p^2} = \underbrace{-2\nabla.\vec{Q}}_{\text{Dynamical contribution}} - \underbrace{\frac{R}{p}\left(\nabla^2\left(\left.\frac{\partial T}{\partial t}\right|_{mp}\right)\right)}_{\text{Diabatic contribution from the model physics tendencies microphysics, convection, radiation, turbulence, drag}} - f_0\frac{\partial}{\partial p}\cancel{\left(\frac{\partial}{\partial x}\left(\left.\frac{\partial v}{\partial t}\right|_{mp}\right) - \frac{\partial}{\partial y}\left(\left.\frac{\partial v}{\partial t}\right|_{mp}\right)\right)}$$

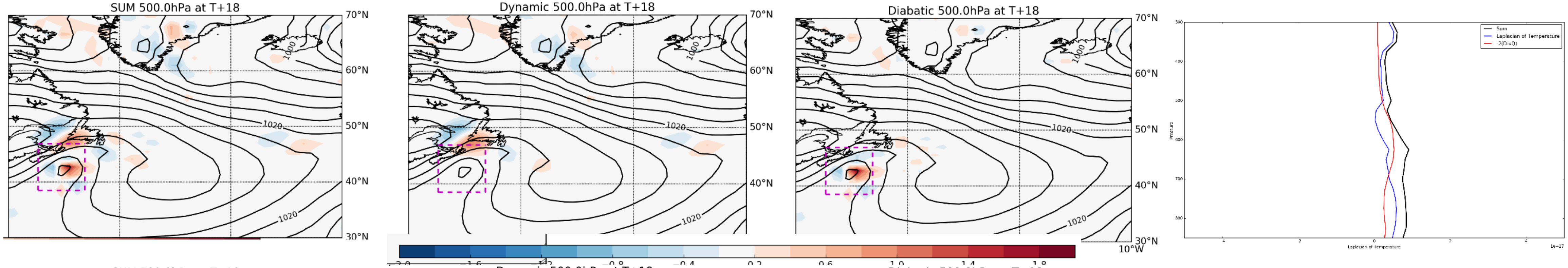
Neglected as 10 times smaller than other terms

ω-equation budget (T+18)

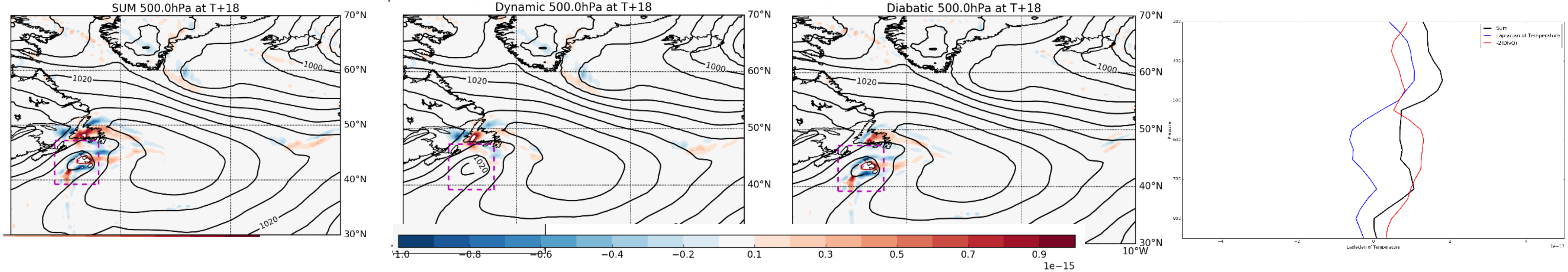
LMDZ



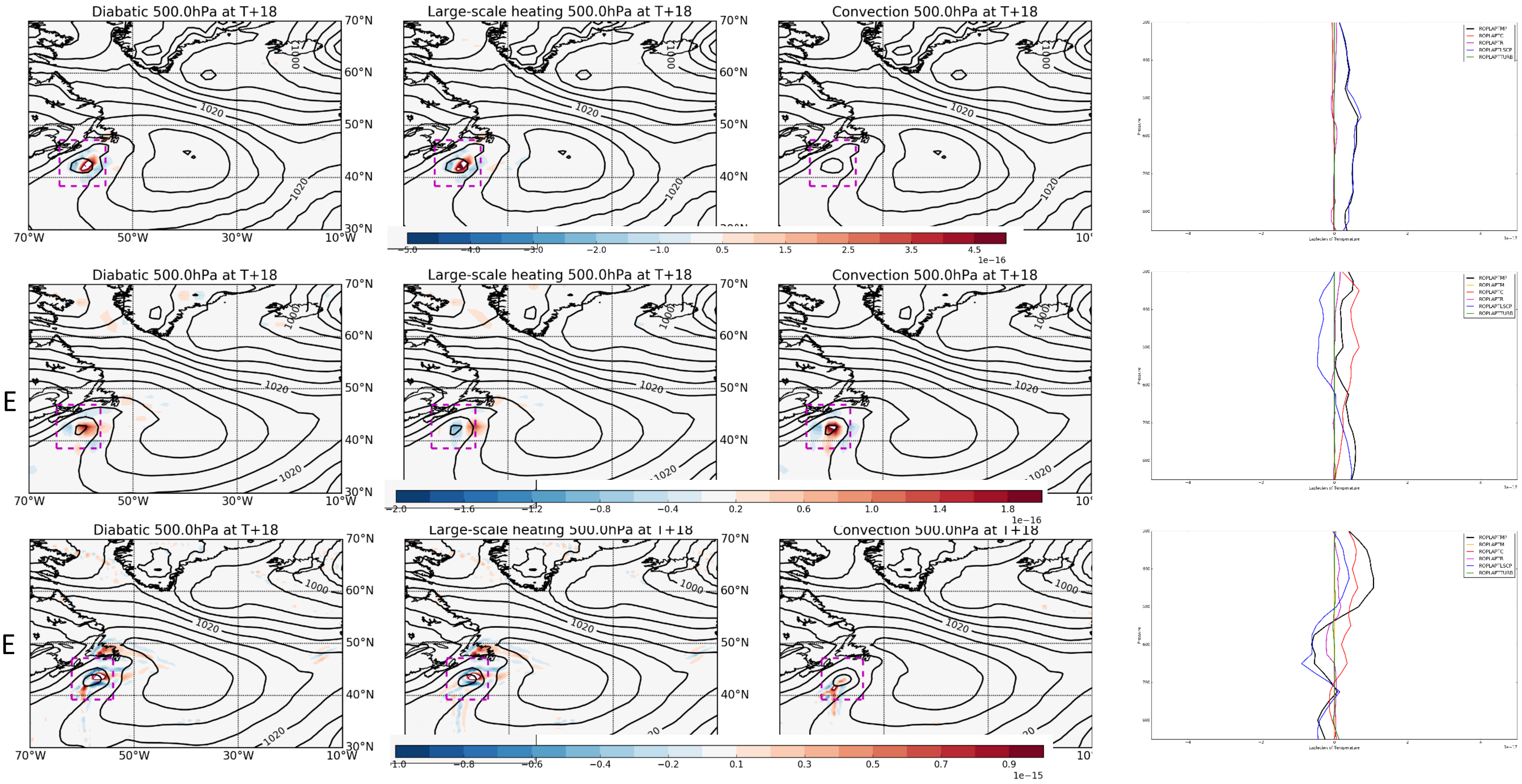
ARPEGE
(1.4)



ARPEGE
(0.5)



Laplacian of the temperature – breakdown (T+18)



LMDZ

ARPEGE (1.4)

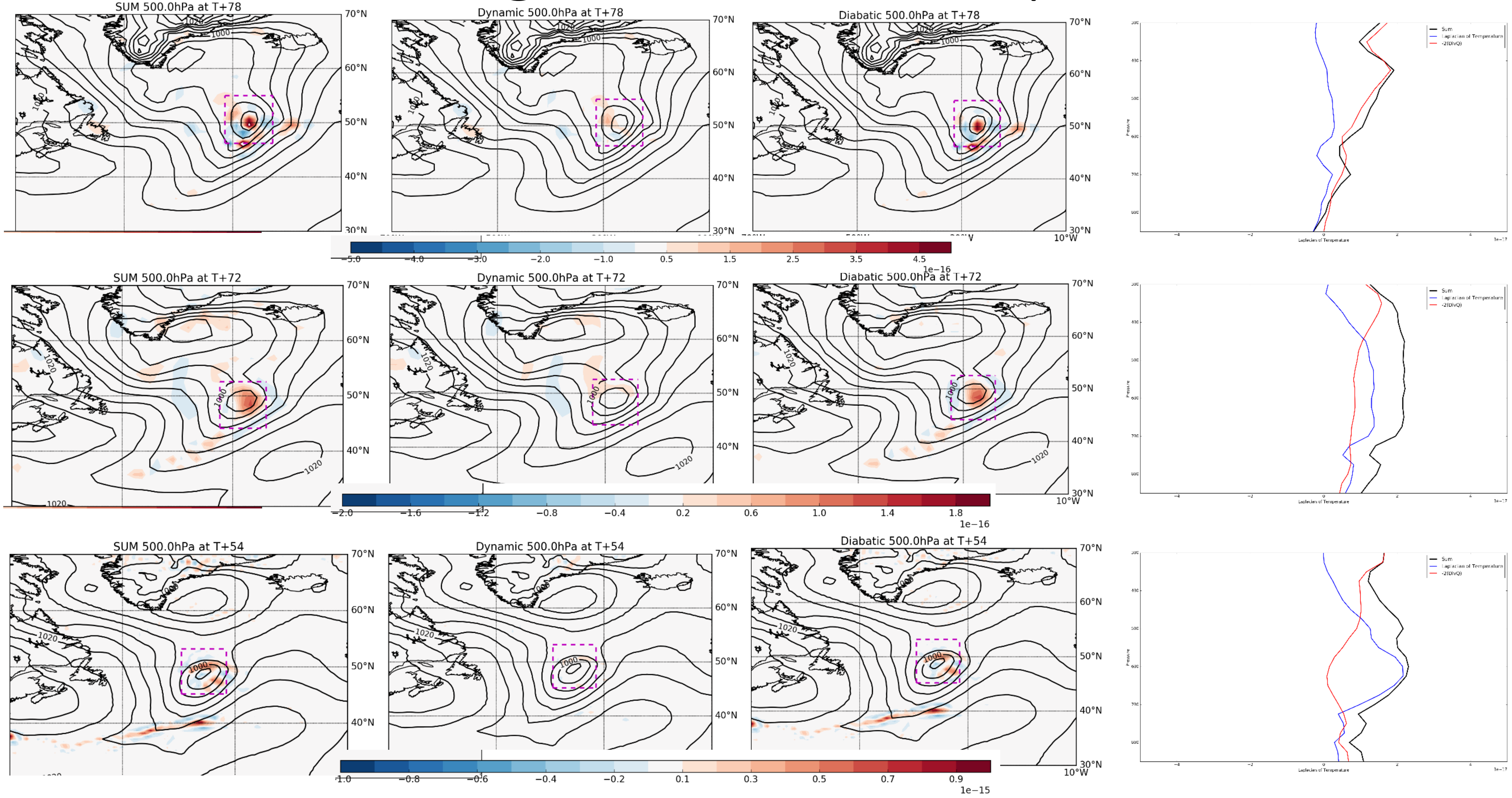
ARPEGE (0.5)

ω-equation budget – start of deepening

LMDZ
T+78

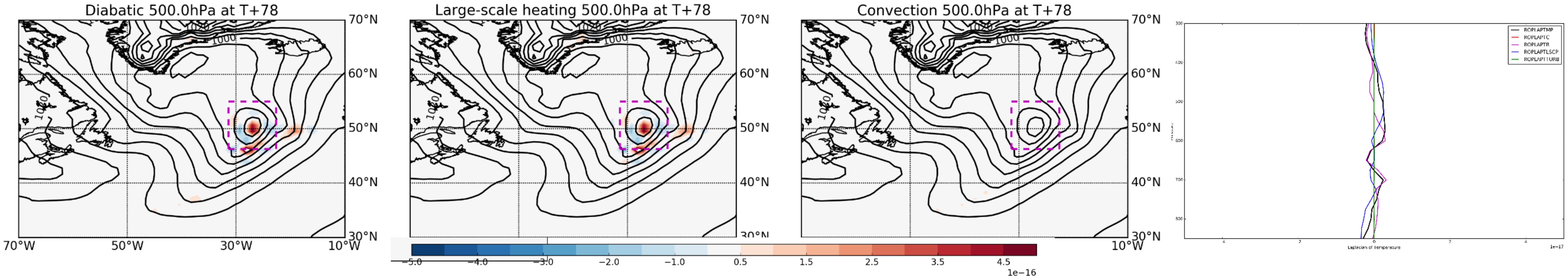
ARPEGE
(1.4)
T+72

ARPEGE
(0.5)
T+54

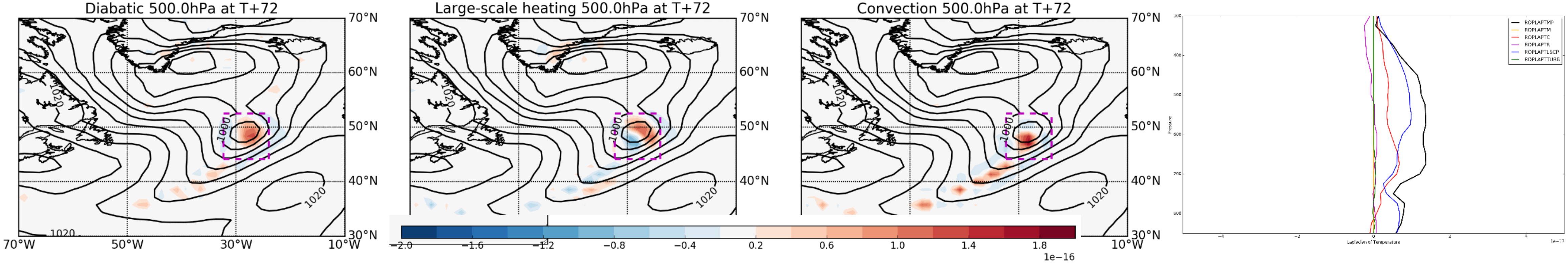


Laplacian of the temperature - breakdown

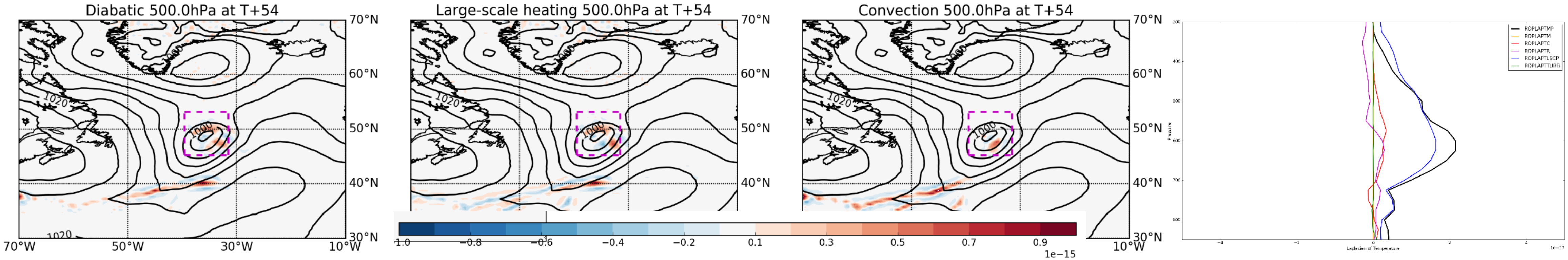
LMDZ
T+78



ARPEGE
(1.4)
T+72



ARPEGE
(0.5)
T+54

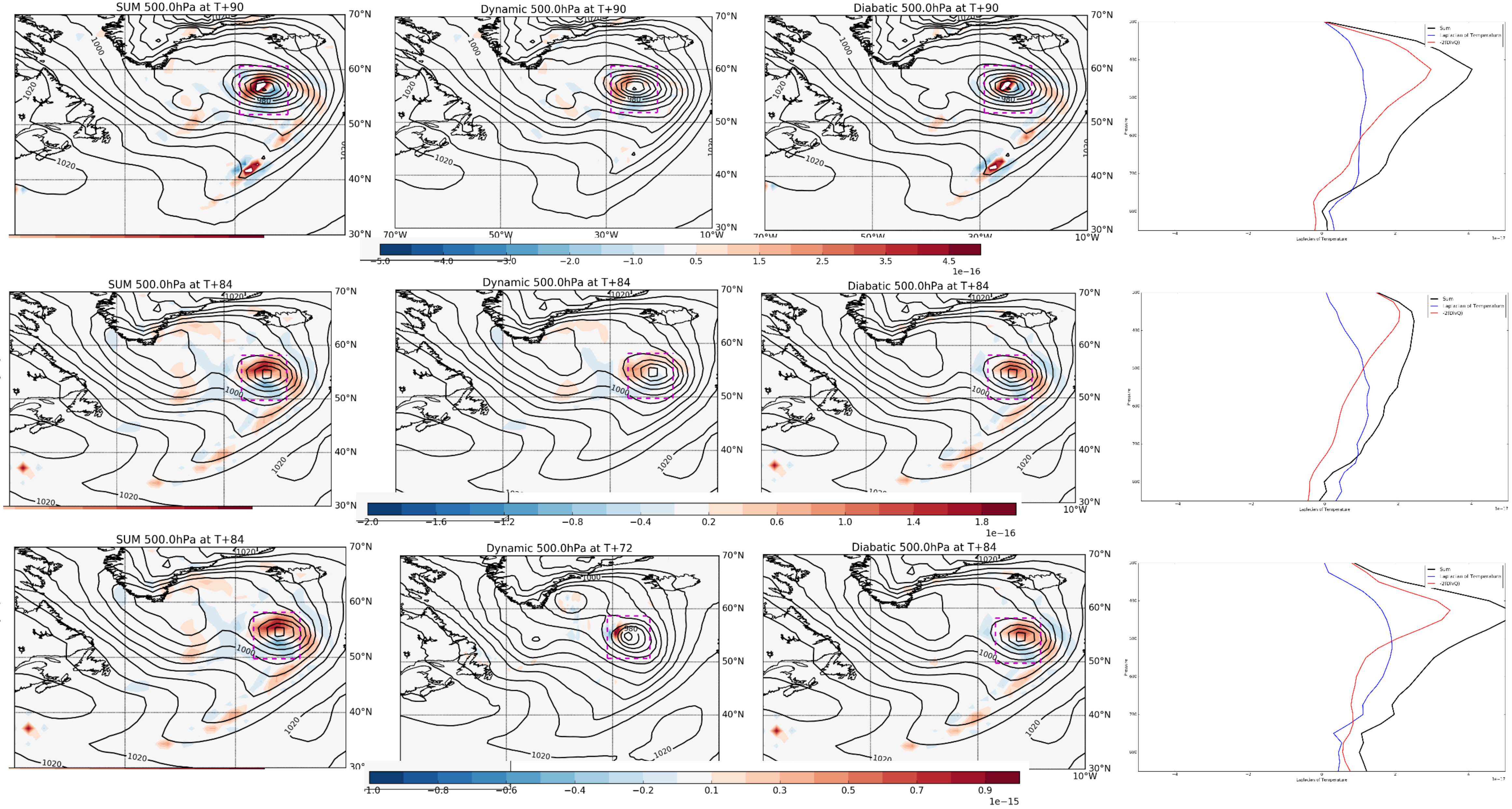


ω-equation budget – mature stage

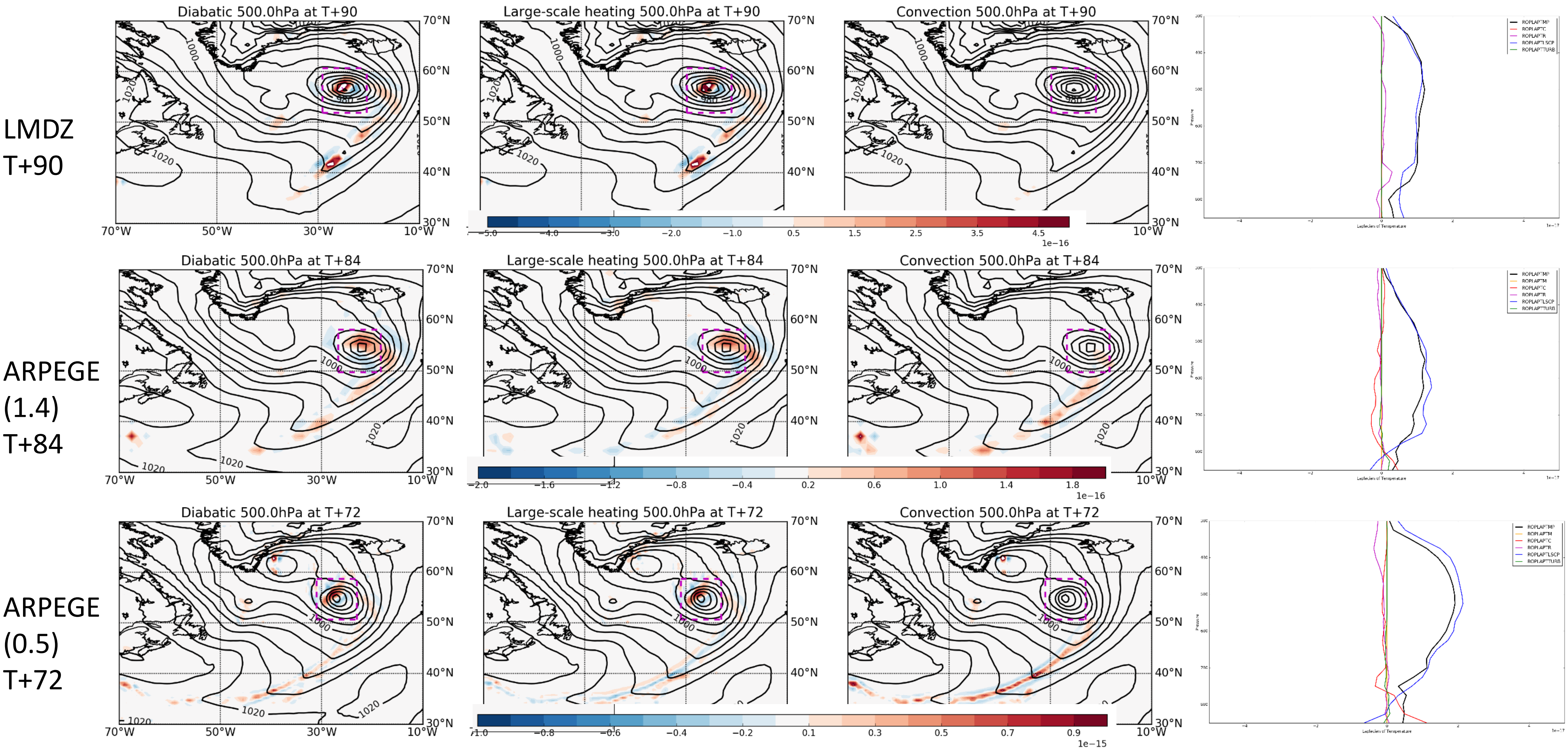
LMDZ
T+90

ARPEGE
(1.4)
T+84

ARPEGE
(0.5)
T+72

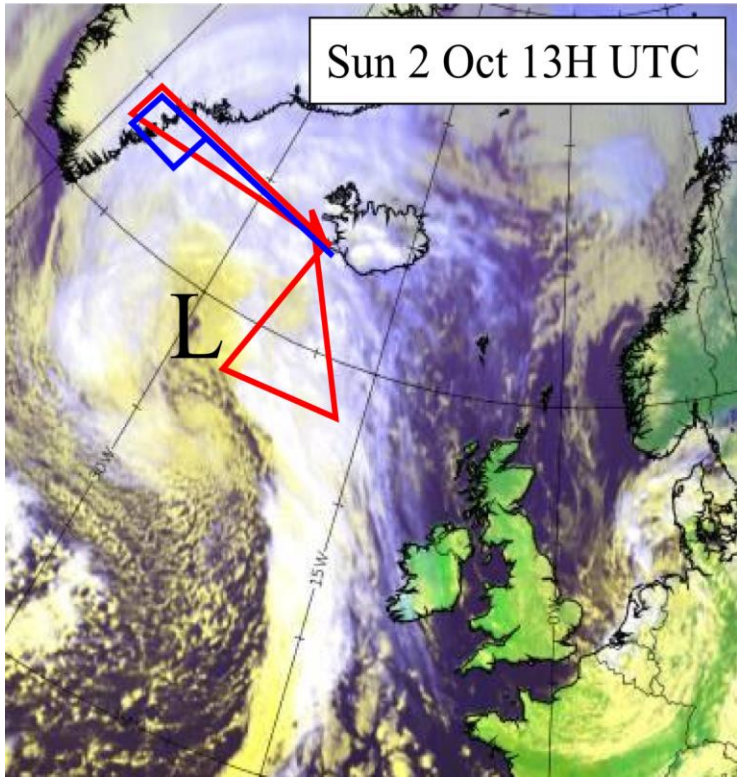


Laplacian of the temperature - breakdown

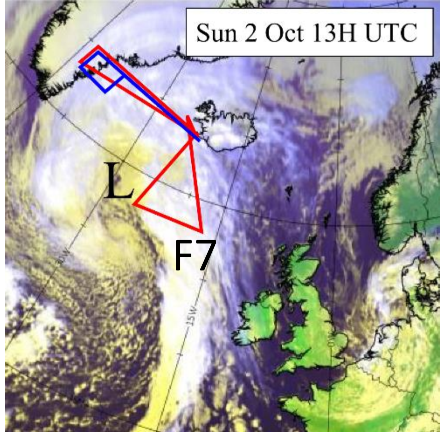


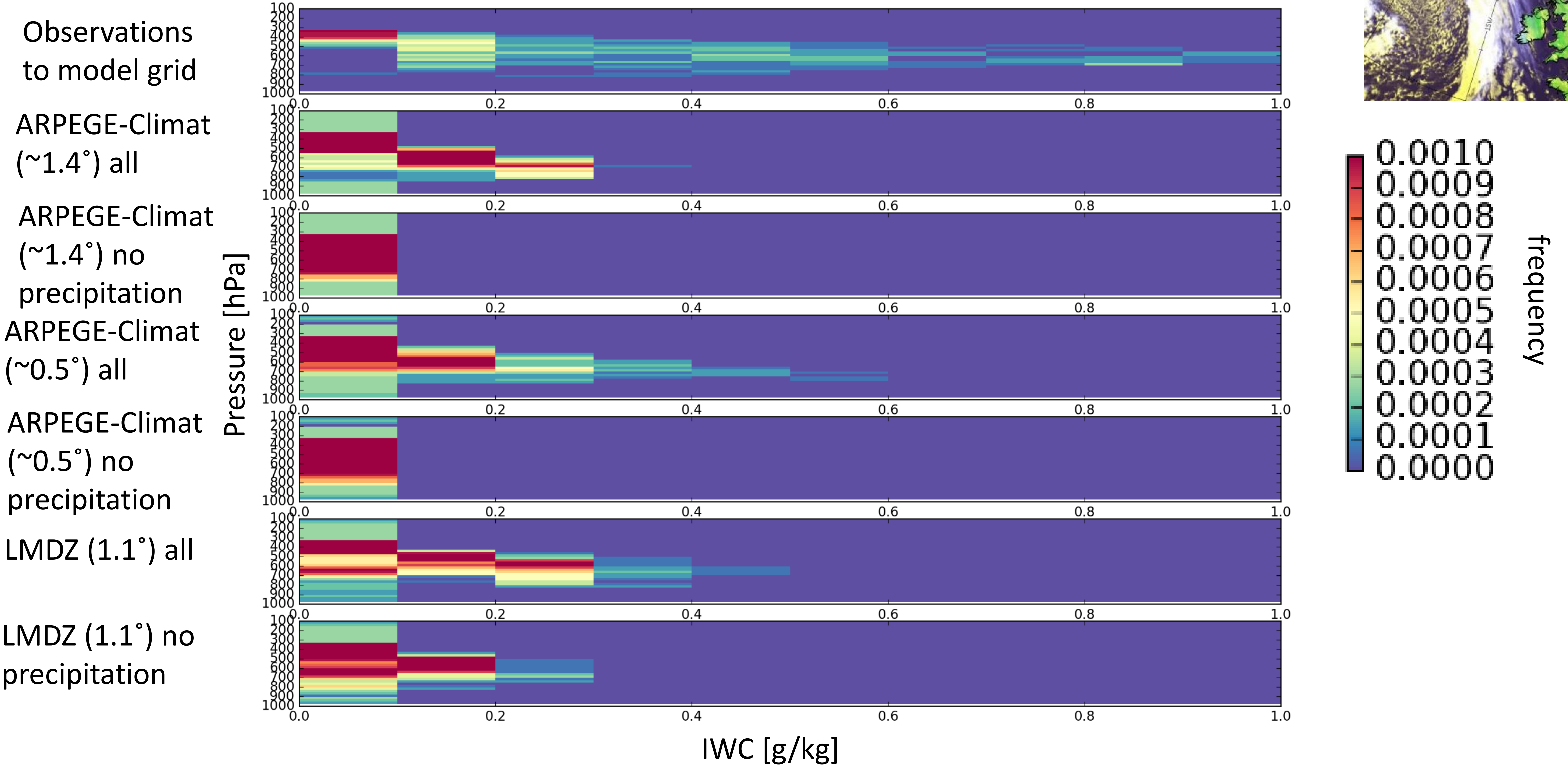
Observations

- Focus on ice water content for flight 7

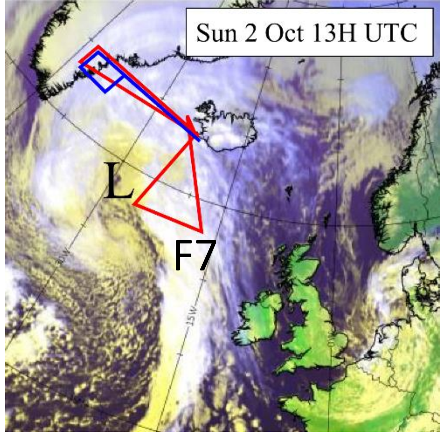


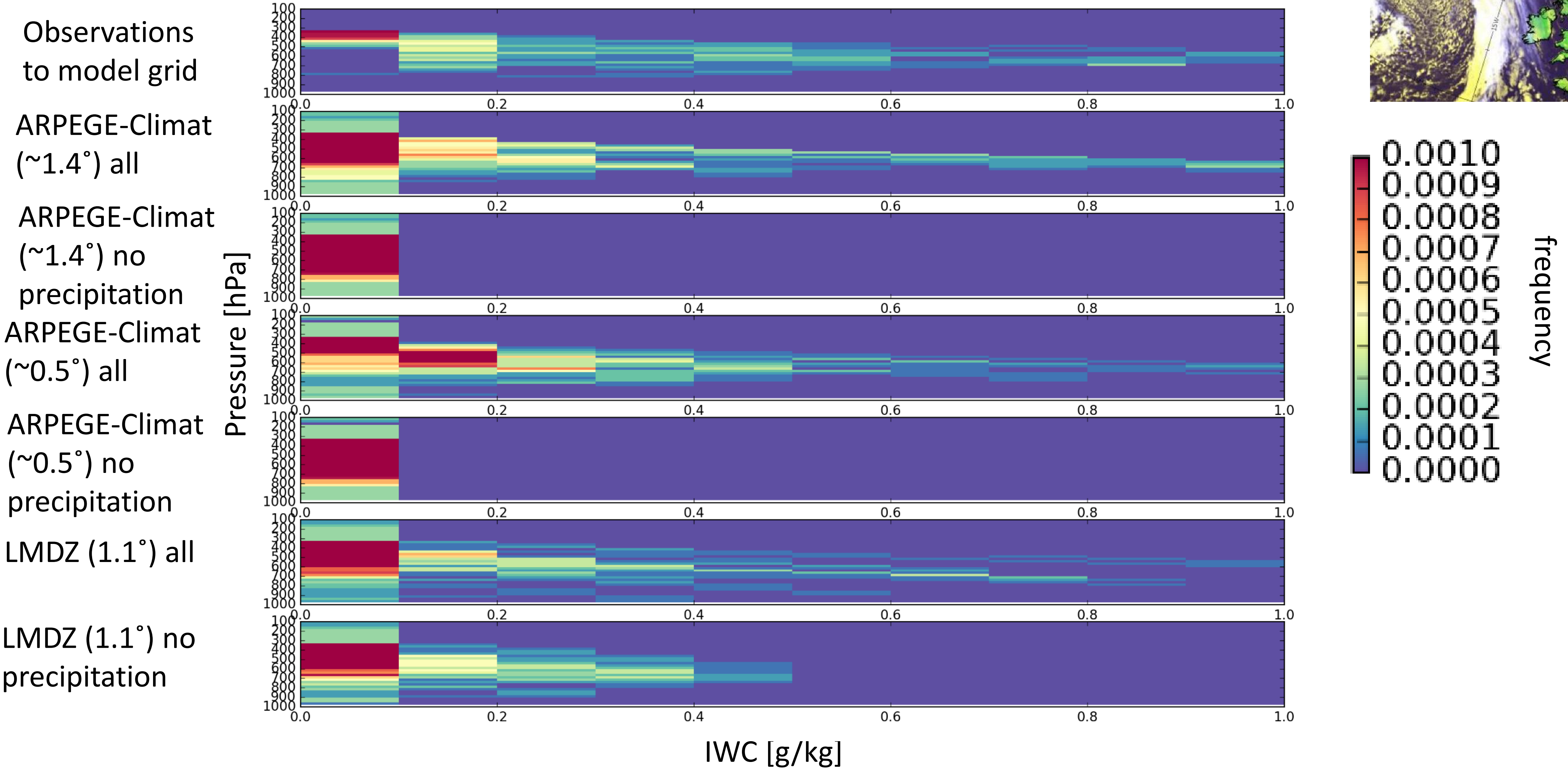
Ice Water Content: Flight7 (2 Oct run)





Ice Water Content: Flight7 (29 Sept run)





2D consideration of Ice Water Content 29 September – all on 1.1˚ grid

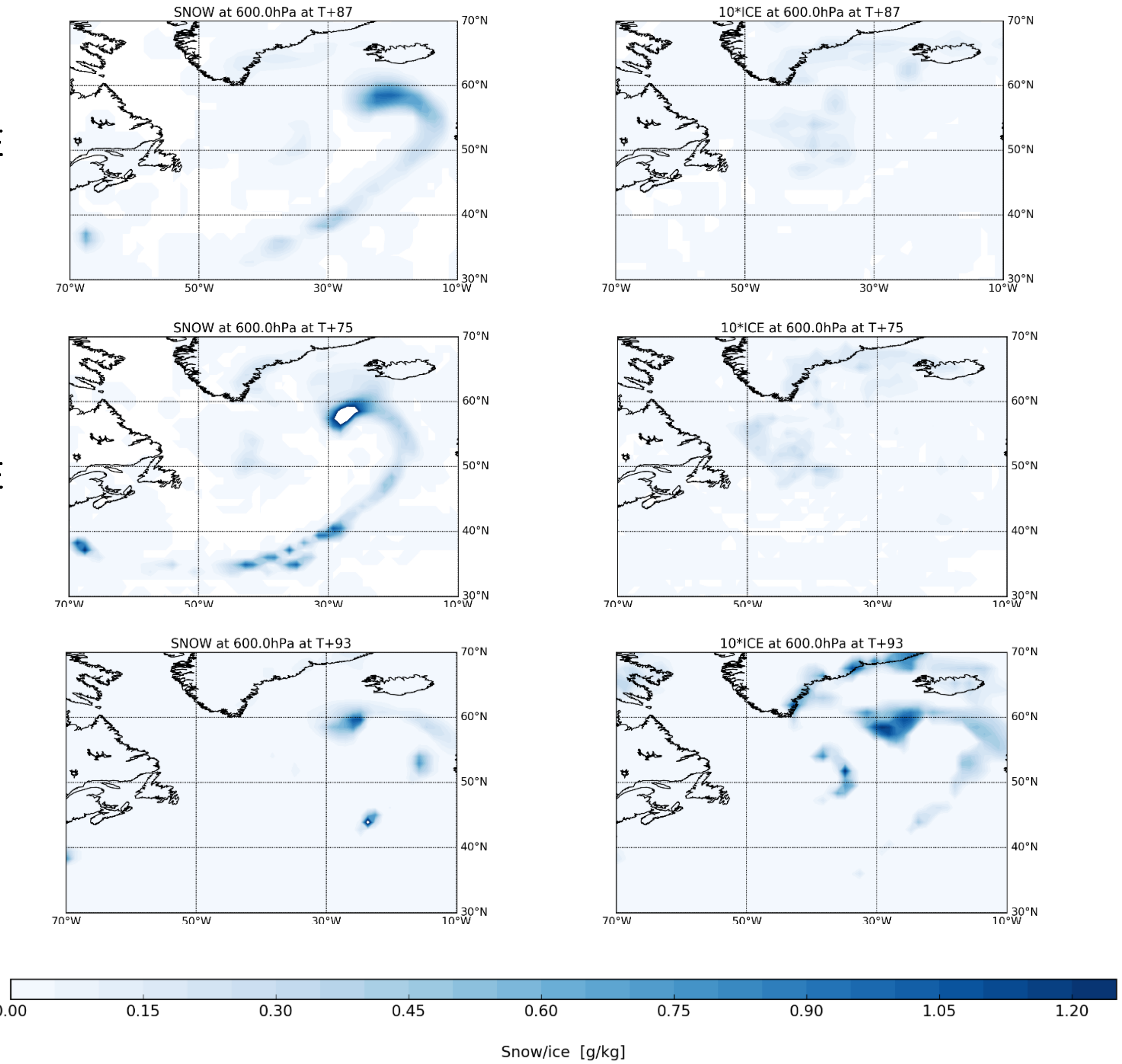
All ICE values have been multiplied by 10

All climate models produce large amounts of snow

LRES ARPEGE

HRES ARPEGE

LMDZ



Summary

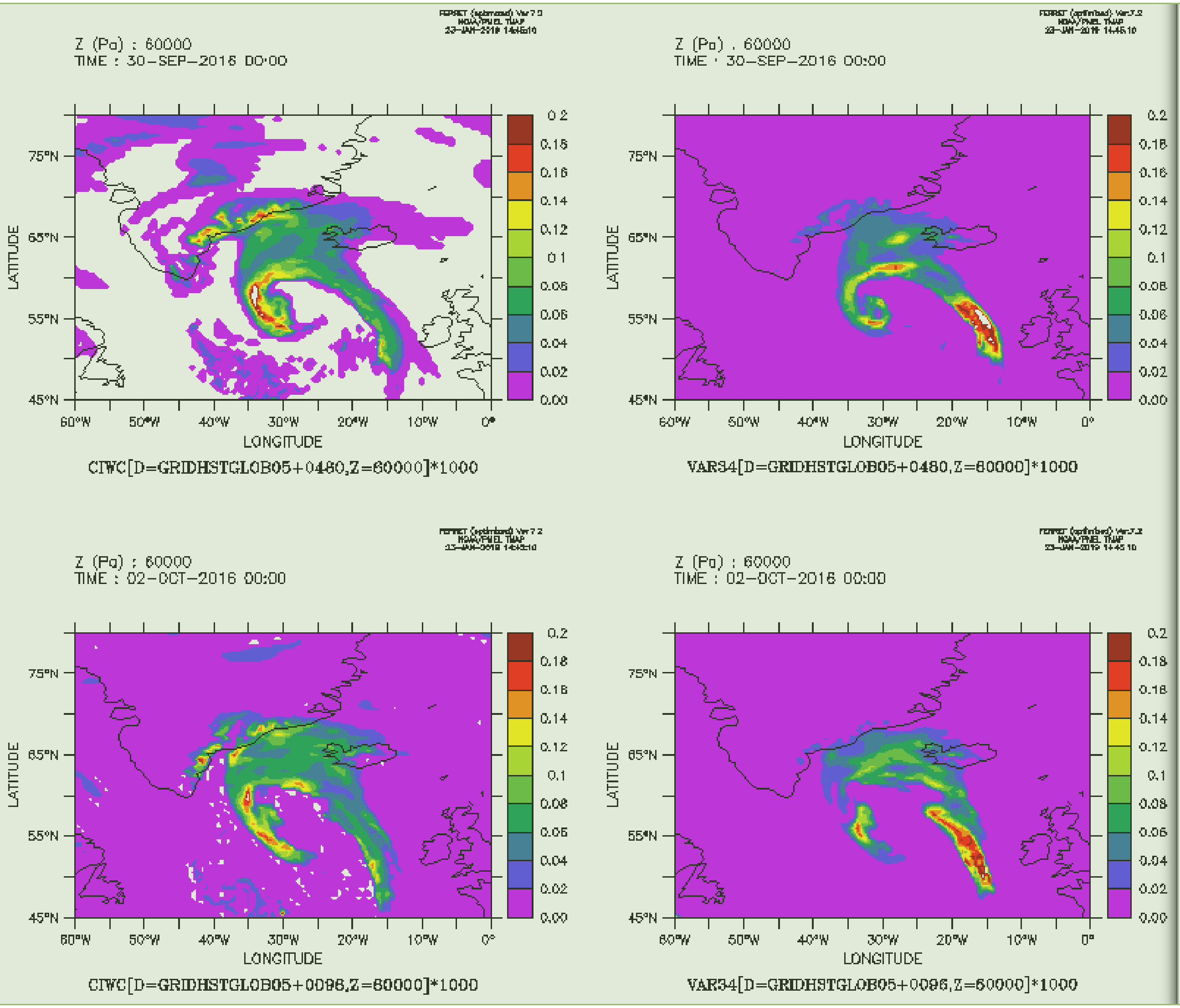
- Initial shock is not a problem
- Eastward shift in the cyclone tracks in both models.
- Representation of the Stalactite Cyclone is improved with resolution in ARPEGE-Climat.
  - There is closer interaction of the upper-level vortex and the surface cyclone allowing the initial deepening to occur.
- All agree on vertical structure and roles of diabatic vs. dynamic processes by the mature stage of their cyclones
  - There are limited differences between LRES and HRES ARPEGE in terms of the ratios for the relevant diabatic vs. dynamic processes
  - LMDZ is dominated by dynamic processes during the rapid deepening
- Ice water content structure is well represented in both models, and is dominated by stratiform snow.
  - The climate models represent the ice water content better than the operational model for 29 September!

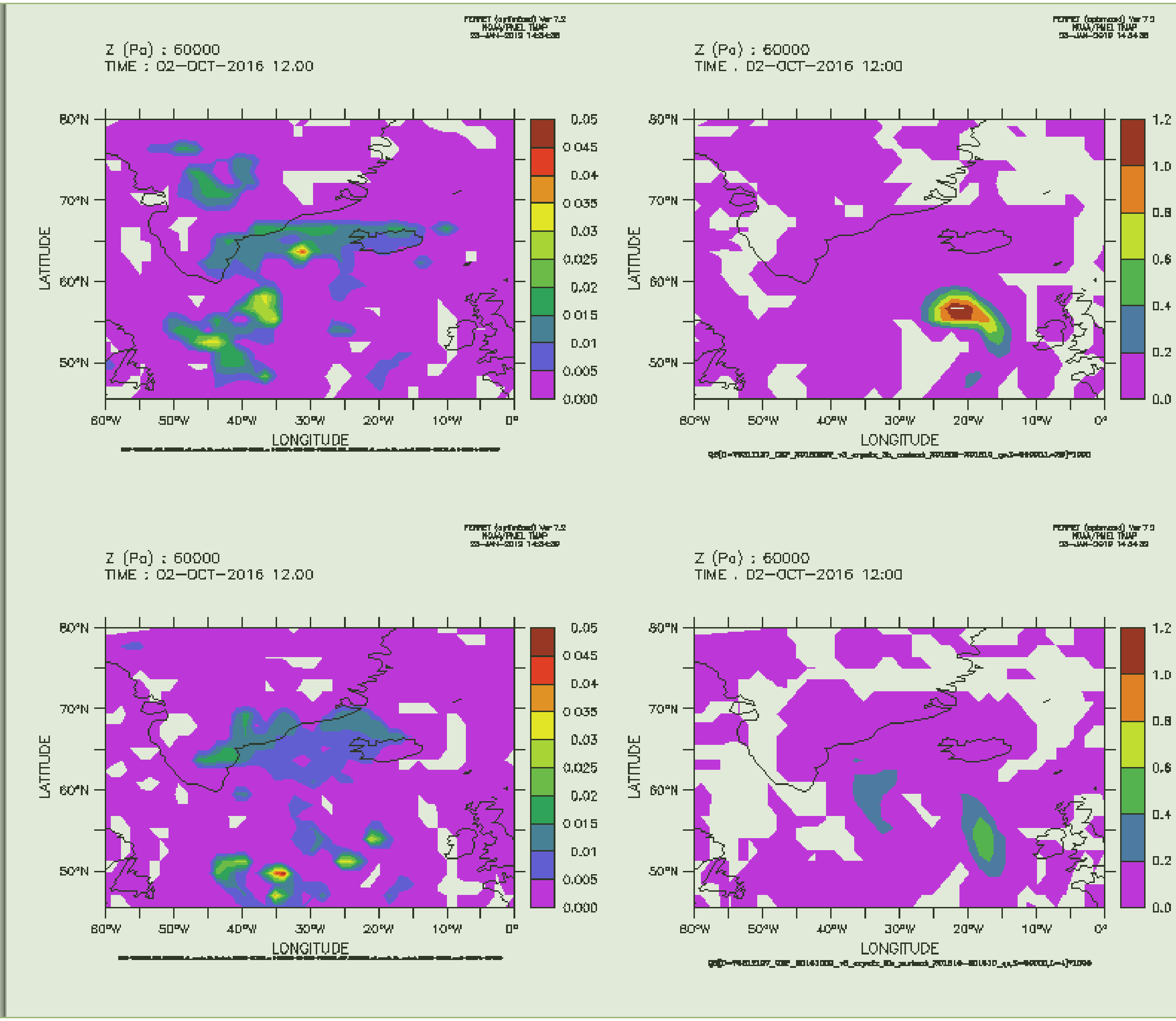
Future Work

- More analysis into observations
- More analysis into the strong deepening in LMDZ and vertical motion budget
- Analyse more runs of the Stalactite cyclone at different lead times to see if the results are consistent or improve/degrade with lead time.
- Analyse runs of similar (two-stage intensification) cyclones throughout the NAWDEX field campaign to check results are consistent.

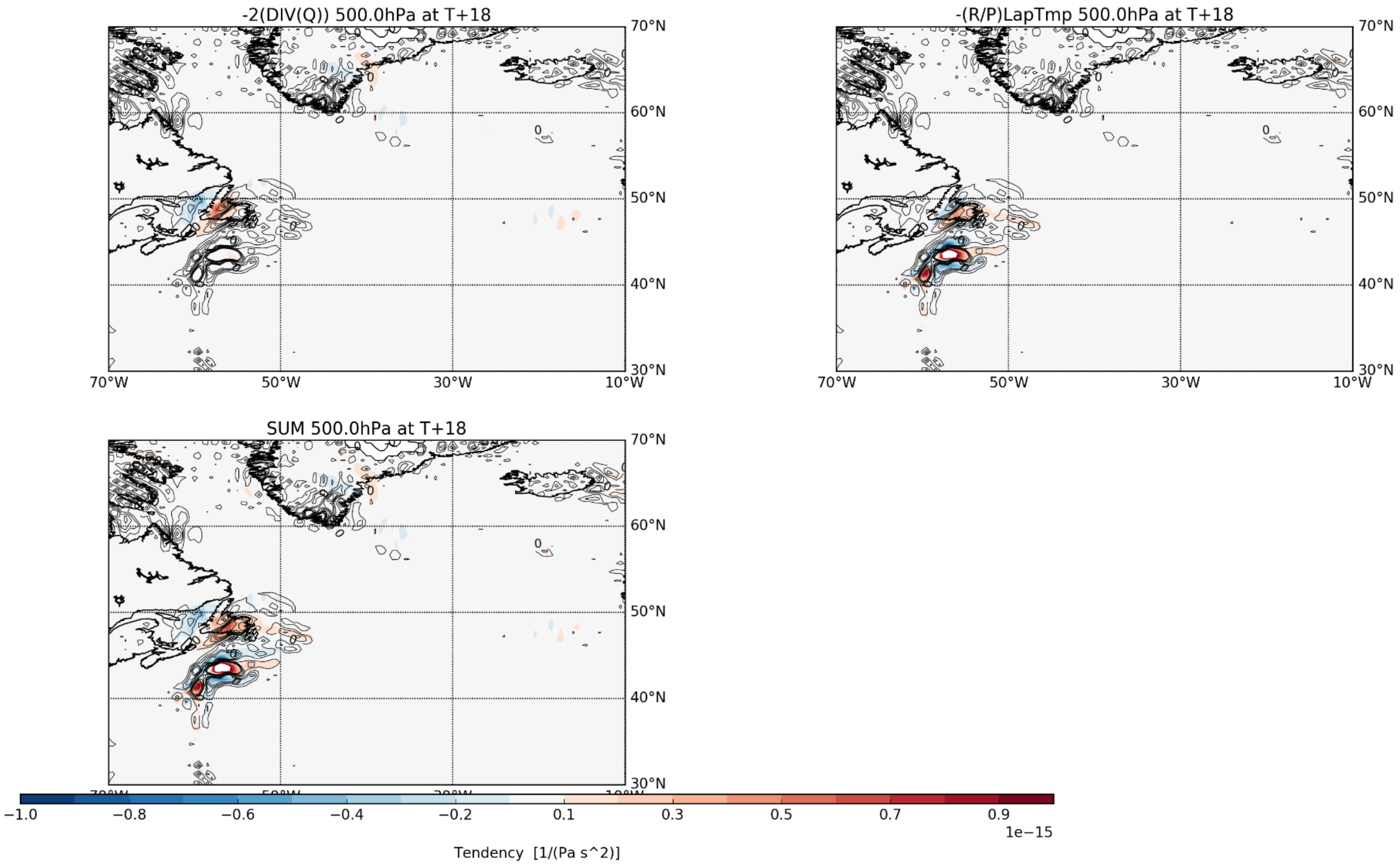
Extra Slides if required

Ice Water Content – raw output from models

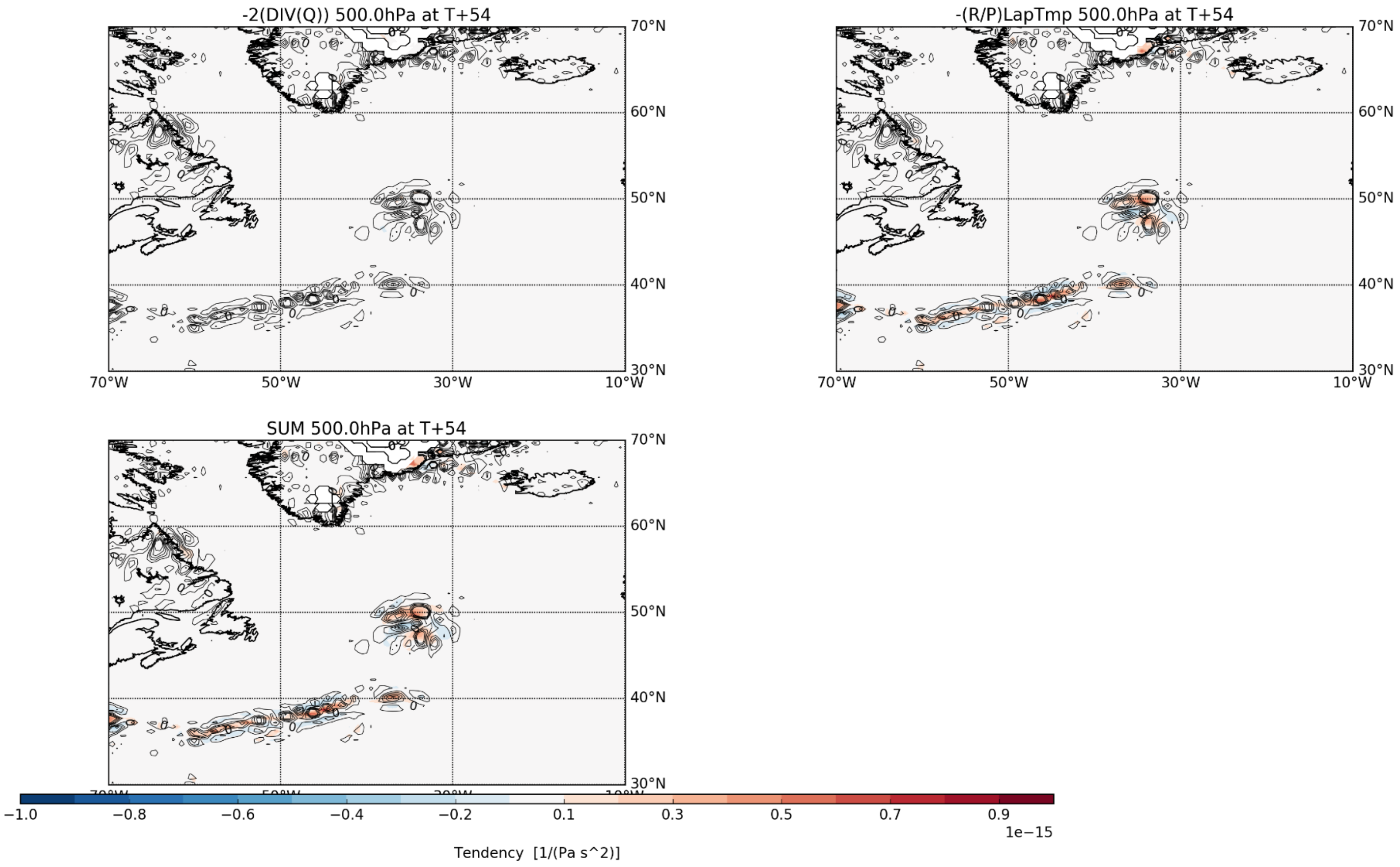




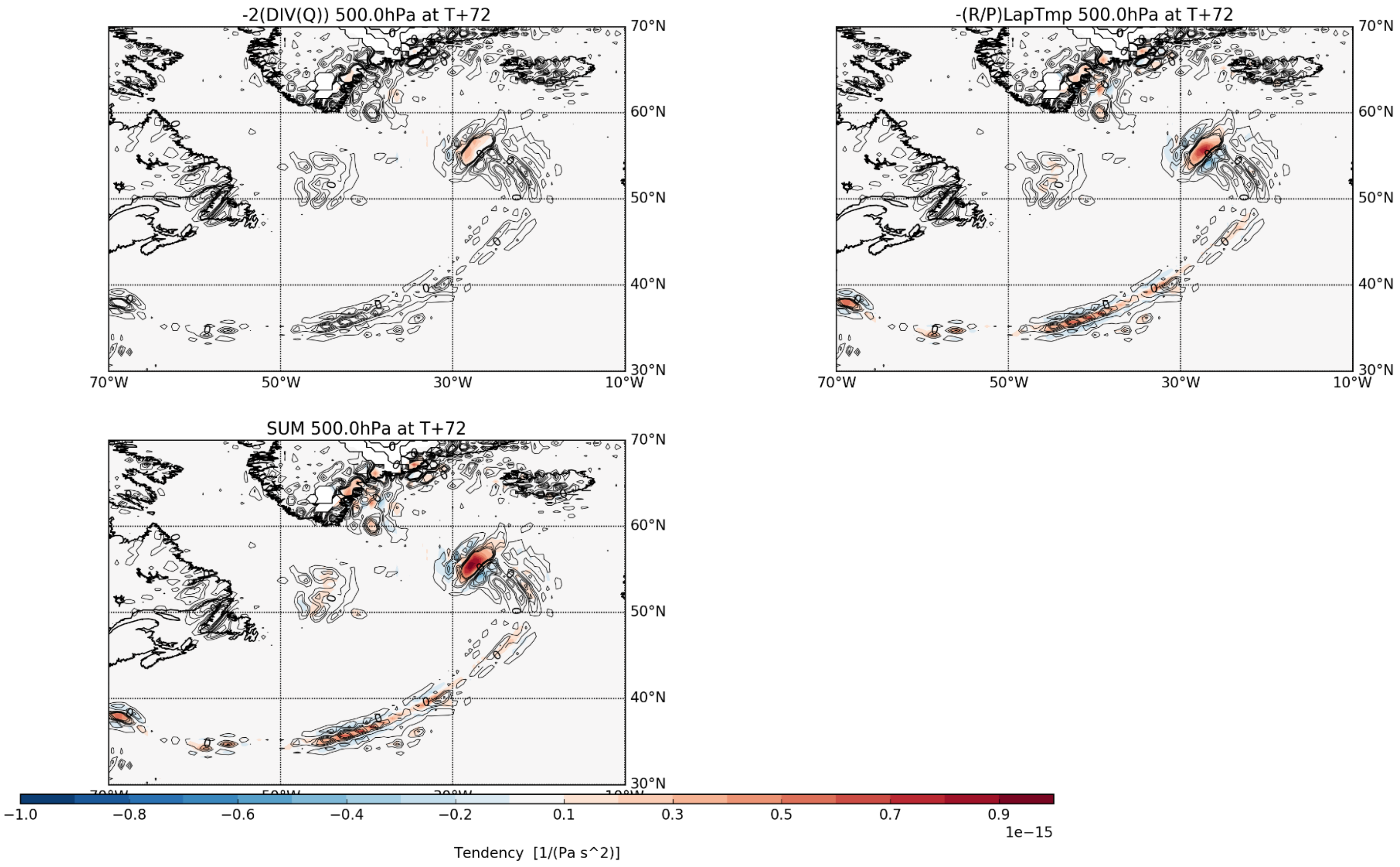
Tendencies with 2D Laplacian of vertical motion HRES ARPEGE only



Tendencies with 2D Laplacian of vertical motion HRES ARPEGE only

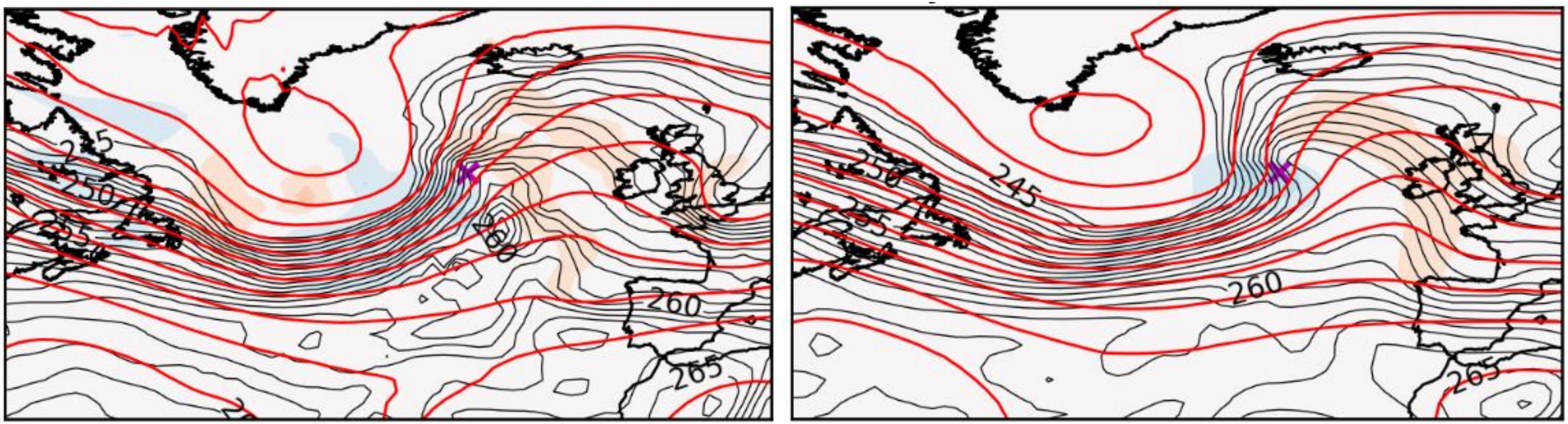


Tendencies with 2D Laplacian of vertical motion HRES ARPEGE only



LMDZ vs. LRES ARPEGE deepening

LMDZ T+84 | ARPEGE T+84



Tighter Geopotential height gradient in LMDZ compared to ARPEGE