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6th European Windstorm Workshop- 23 June 2017

The Role of Mesoscale Instabilities in the Sting-Jet Dynamics of Windstorm Tini

Thanks to P.Clark, S.Gray, N.Hart and O. Martinéz-Alvarado

Open questions on SJ dynamics

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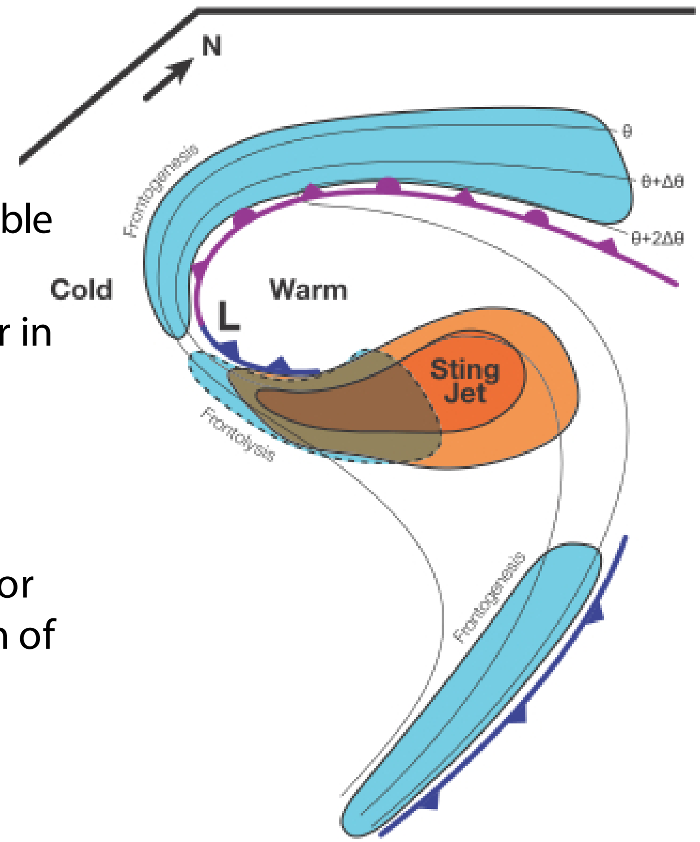
An area of general descent and acceleration

- An airstream descending out of the cloud head is associated with frontolysis connected with the frontal-fracture region (Schultz and Sienkiewicz (2013)).
- Dynamical quasi-geostrophic forcing can be largely responsible for initiating the slantwise descent (Coronel et al. (2016))
- High wind speed values are consequence of the descent of air in a low-friction environment (Slater et al. (2016))

Mesoscale mechanisms enhancing the jet strength

- The release of conditional symmetric instability (CSI), among with other atmospheric instabilities, is a plausible candidate for the origin of banding at cloud-head tip and for the generation of descending strong winds

(Baker et al. (2014), Martinez-Alvarado et al. (2014), Gray et al. (2011) among the others).



Schultz and Sienkiewicz (2013)

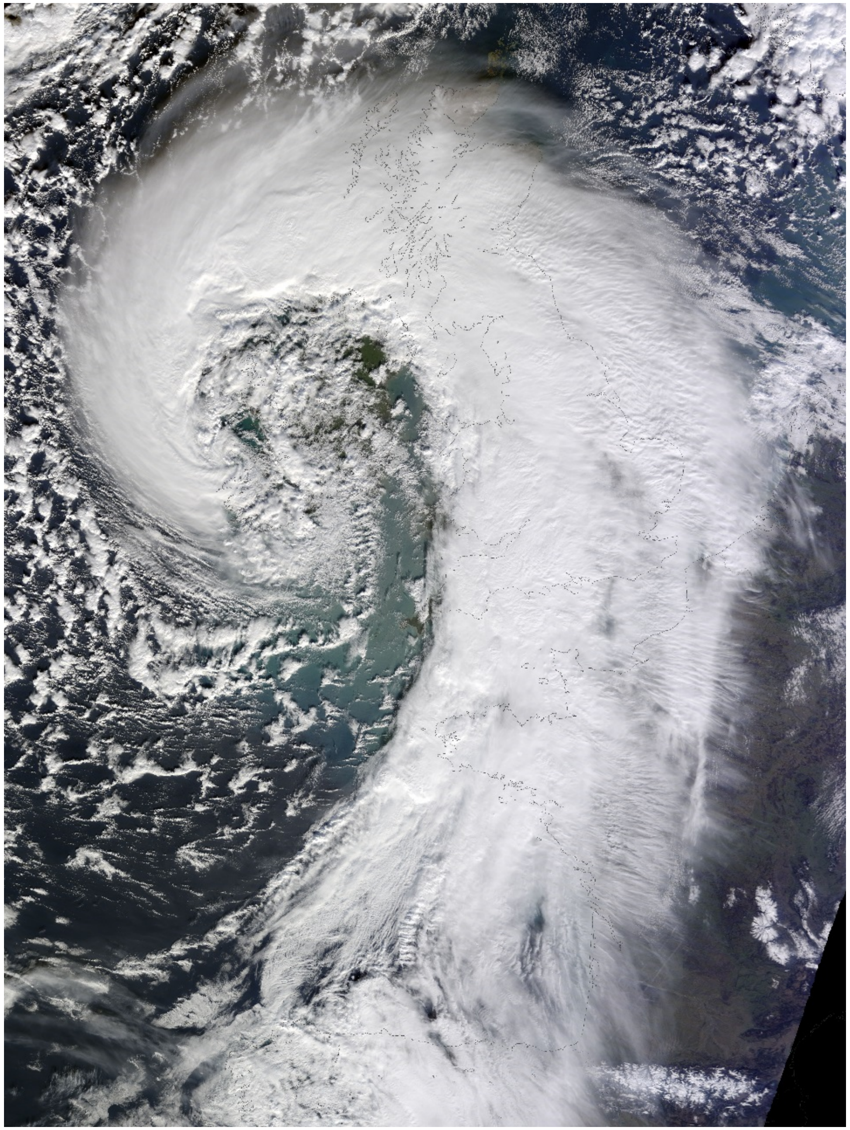
- It is particularly important to understand the link between these two aspects to clarify SJ dynamics

Here we analyse the evolution of mesoscale instabilities along the SJ in Windstorm Tini

Windstorm Tini

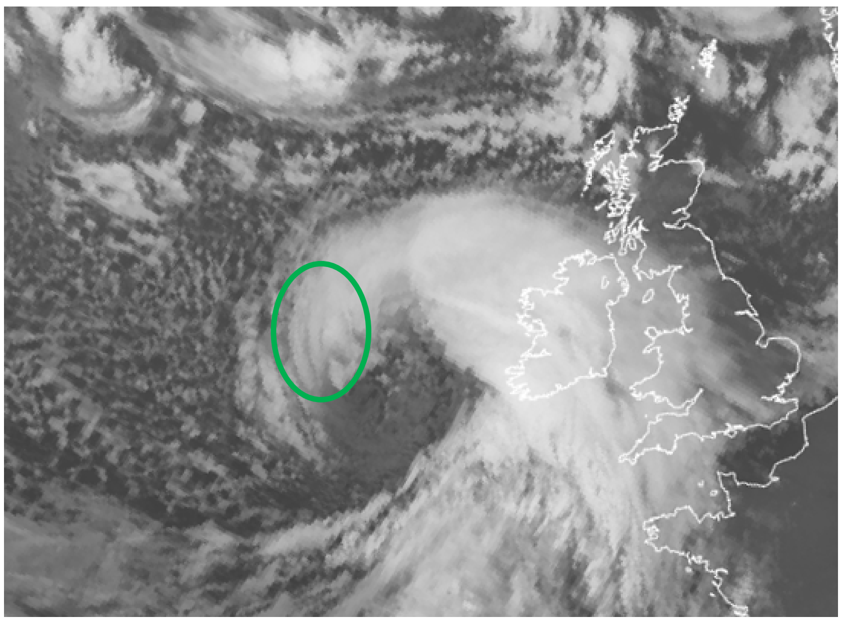
12 February 2014: Shapiro-Keyser extratropical cyclone passes over UK and Ireland with well defined bent-back front and frontal fracture

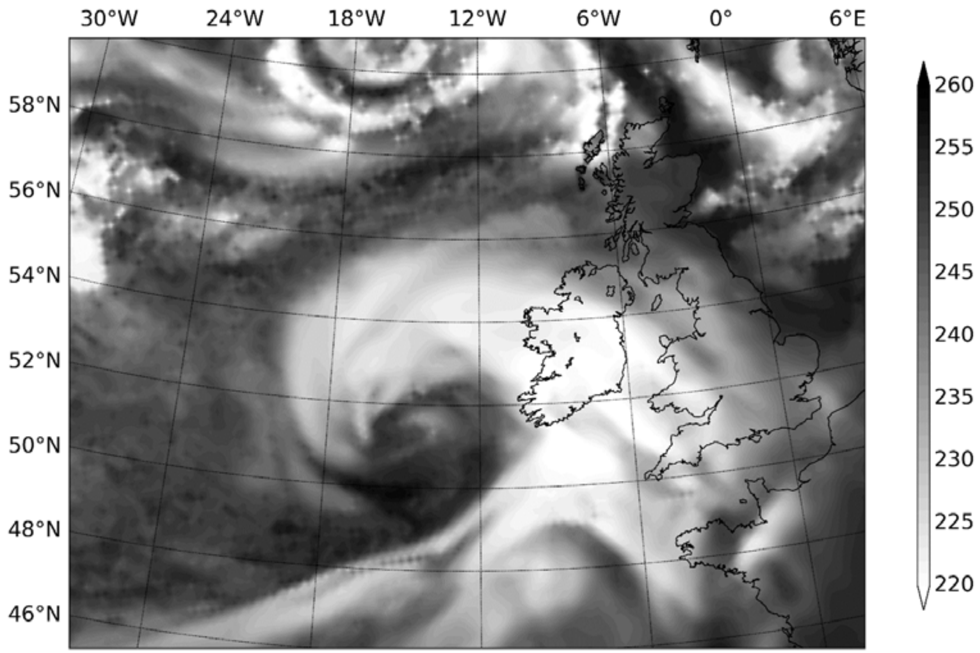
- Deep and fast cyclogenesis
- $\Delta p \sim -30$ hPa in 15 hours
- Surface gusts over 100 mph in Wales



Observations: hints of a SJ?

- Banding at cloud-head tip suggests slantwise circulations and conditional symmetric instability (CSI) release
- These features are shown also in our simulations
- Met UM vn8.2; horizontal resolution: 0.11°; vertical resolution: 70 levels (UKV)





- Meteosat infrared satellite image of windstorm Tini at 06 UTC
- Simulated-satellite image (using brightness cloud-top temperature, K)

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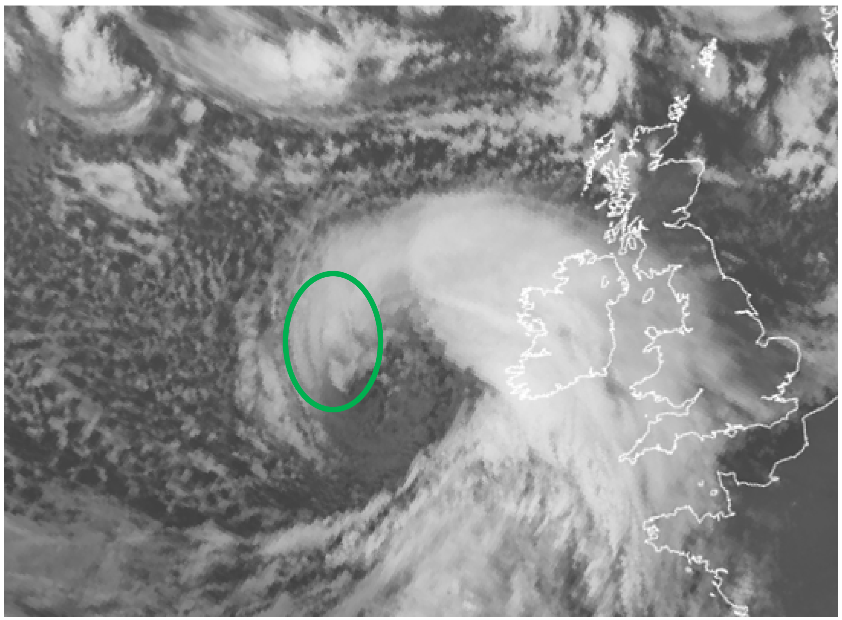
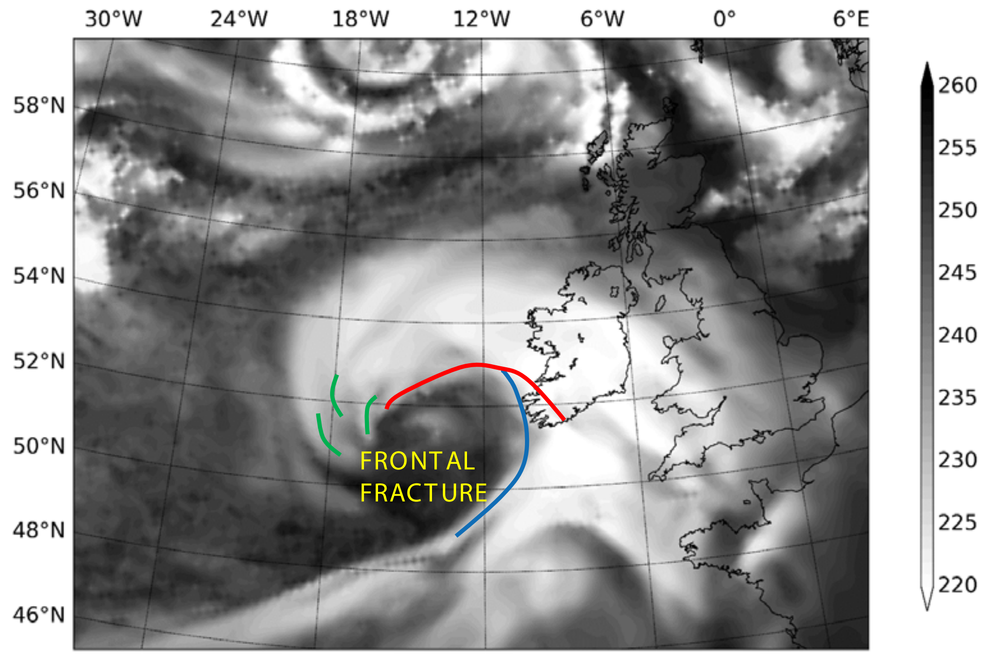


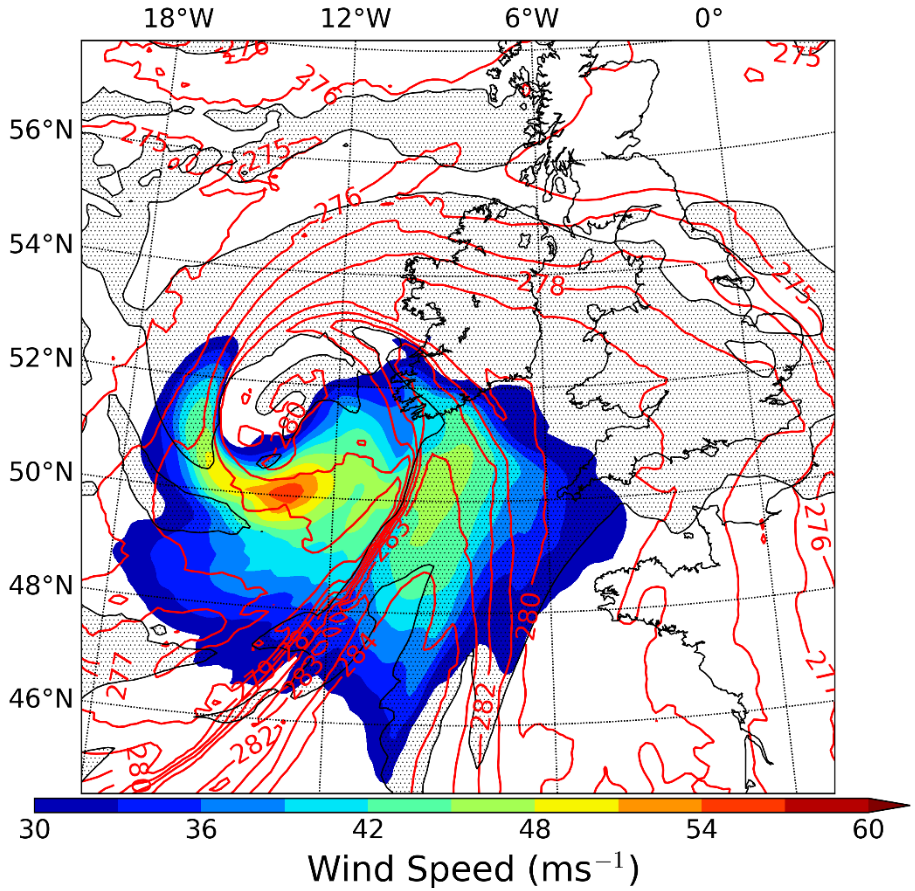


- Meteosat infrared satellite image of windstorm Tini at 06 UTC
- Simulated-satellite image (using brightness cloud-top temperature, K)

- Also: MST Radar at Aberystwyth records a low-level wind maximum just after the passage of the primary cold front (not shown)

An additional airstream

- 07 UTC – wind speed and θ_w at 850 hPa , cloud cover at 700 hPa

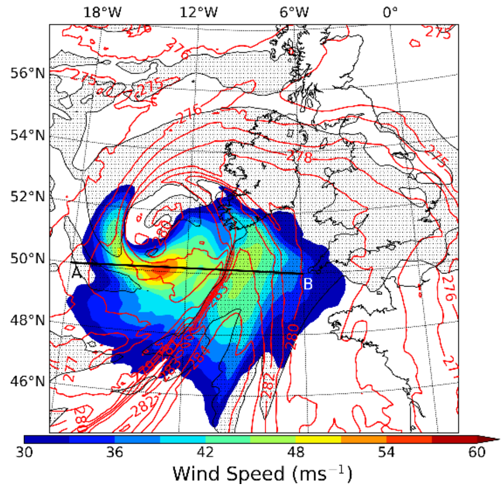


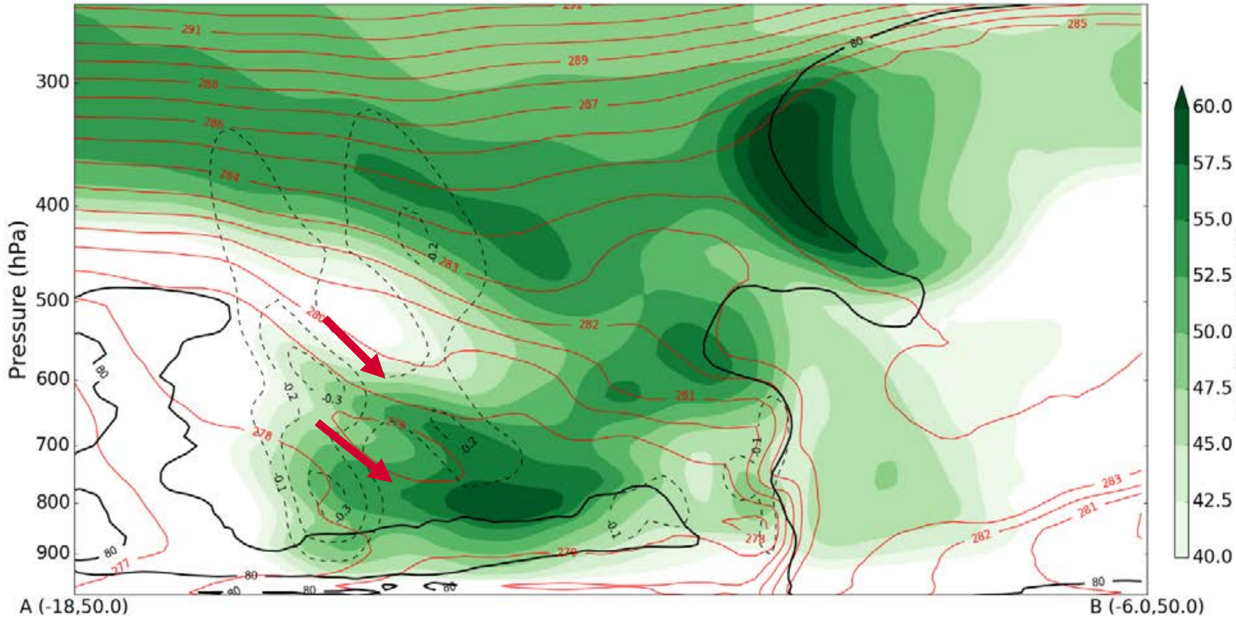
- Wind speed maximum in the frontal fracture area, where the moist isentropes spread out

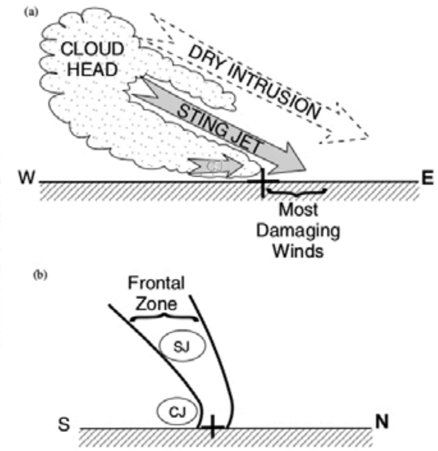
A descending airstream

Cross section along the frontal fracture shows:

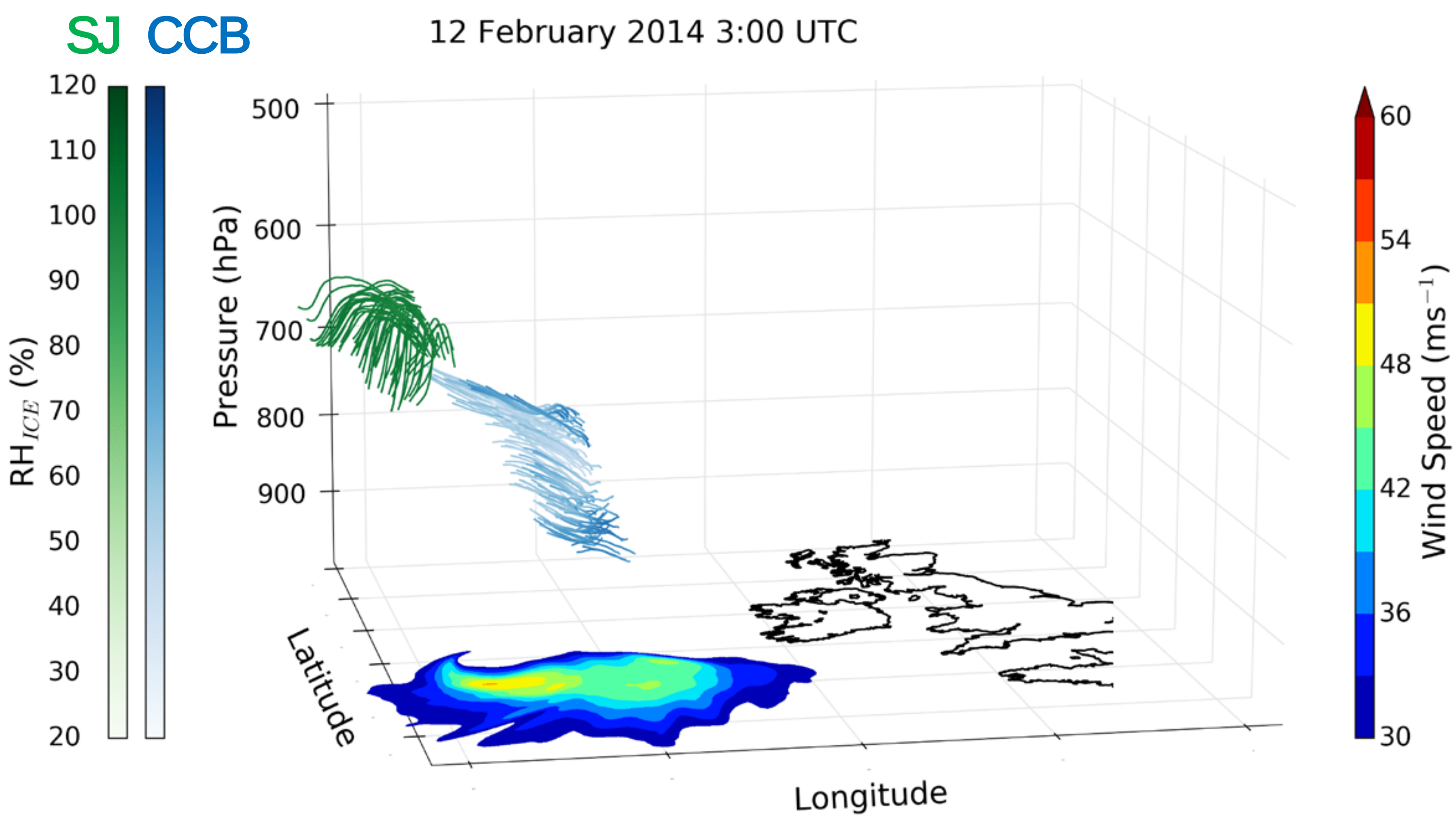
- In an area of moderate and generalised descent there are folds in wet-bulb potential temperature
- Indication of a moist-adiabatic descent of an actual airstream
- Wind speed stronger in the low-level maximum than above







A distinct airstream



- Lagrangian trajectory analysis on the identified SJ and CCB: trajectories from 22 UTC on 11 Feb to 10 UTC on 12 Feb
- SJ is a different airmass with respect to CCB, undergoing to its own evolution

“Sting-Jet ID”

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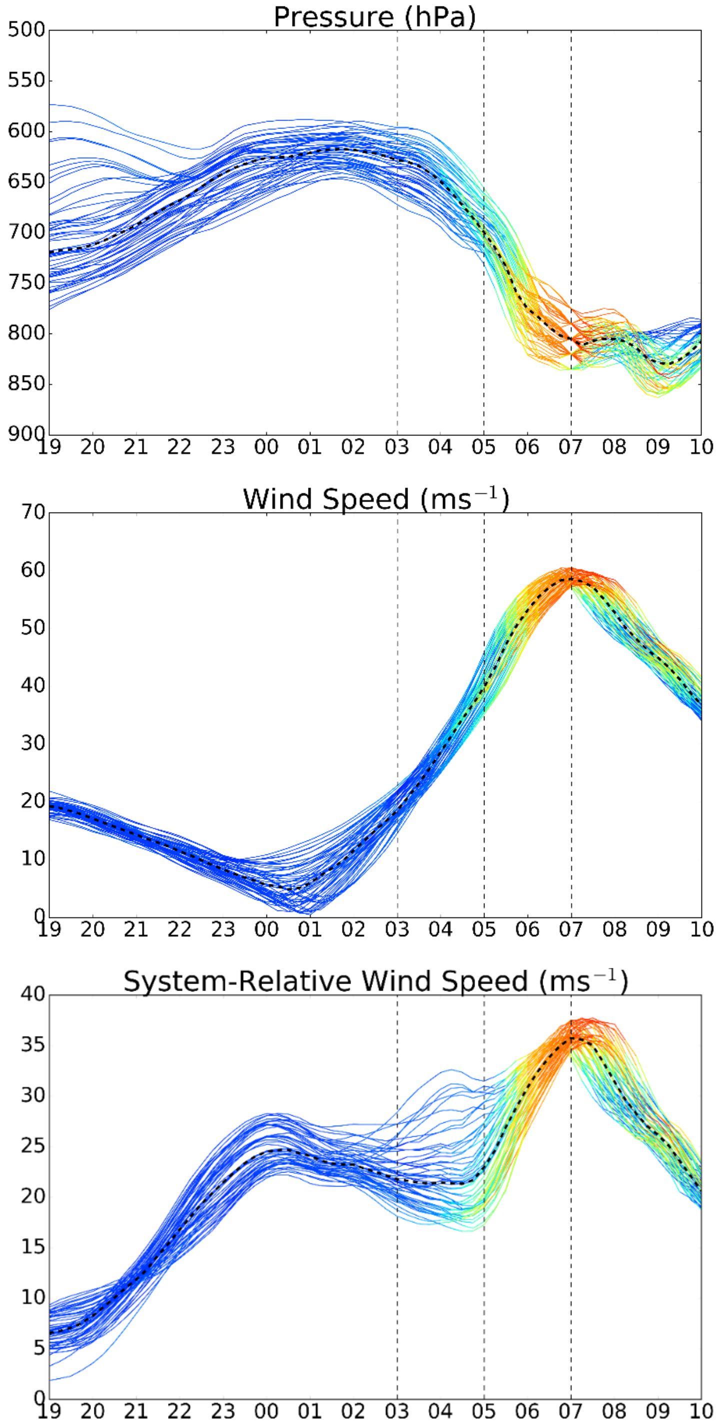

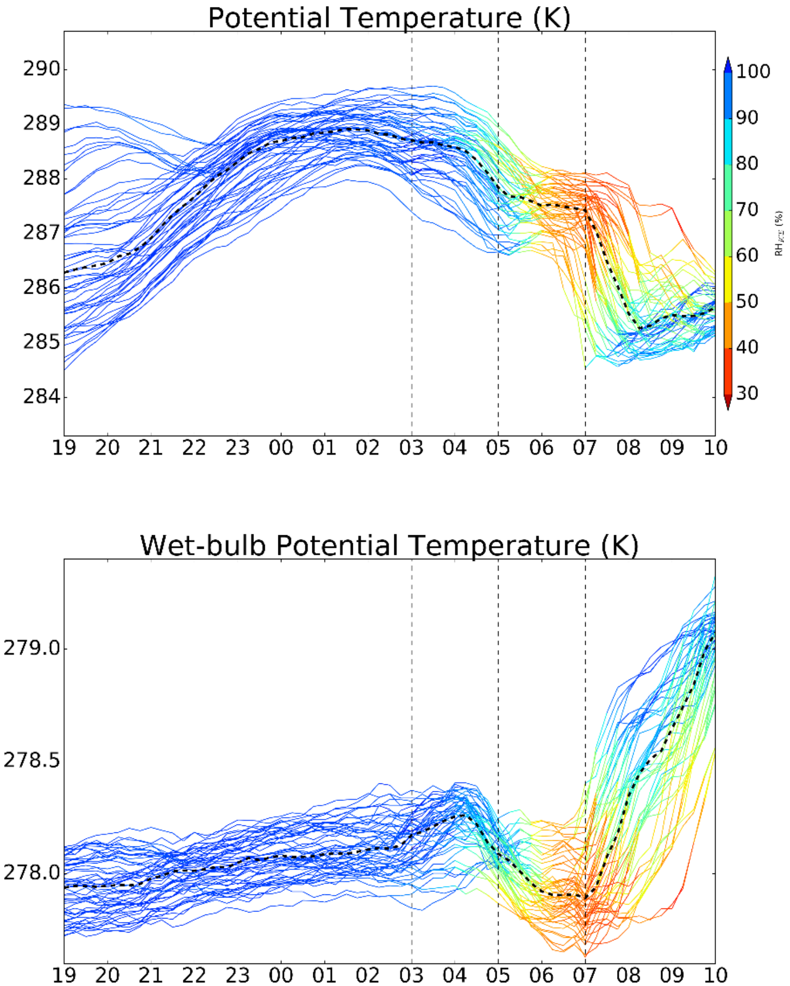

Instabilities on trajs

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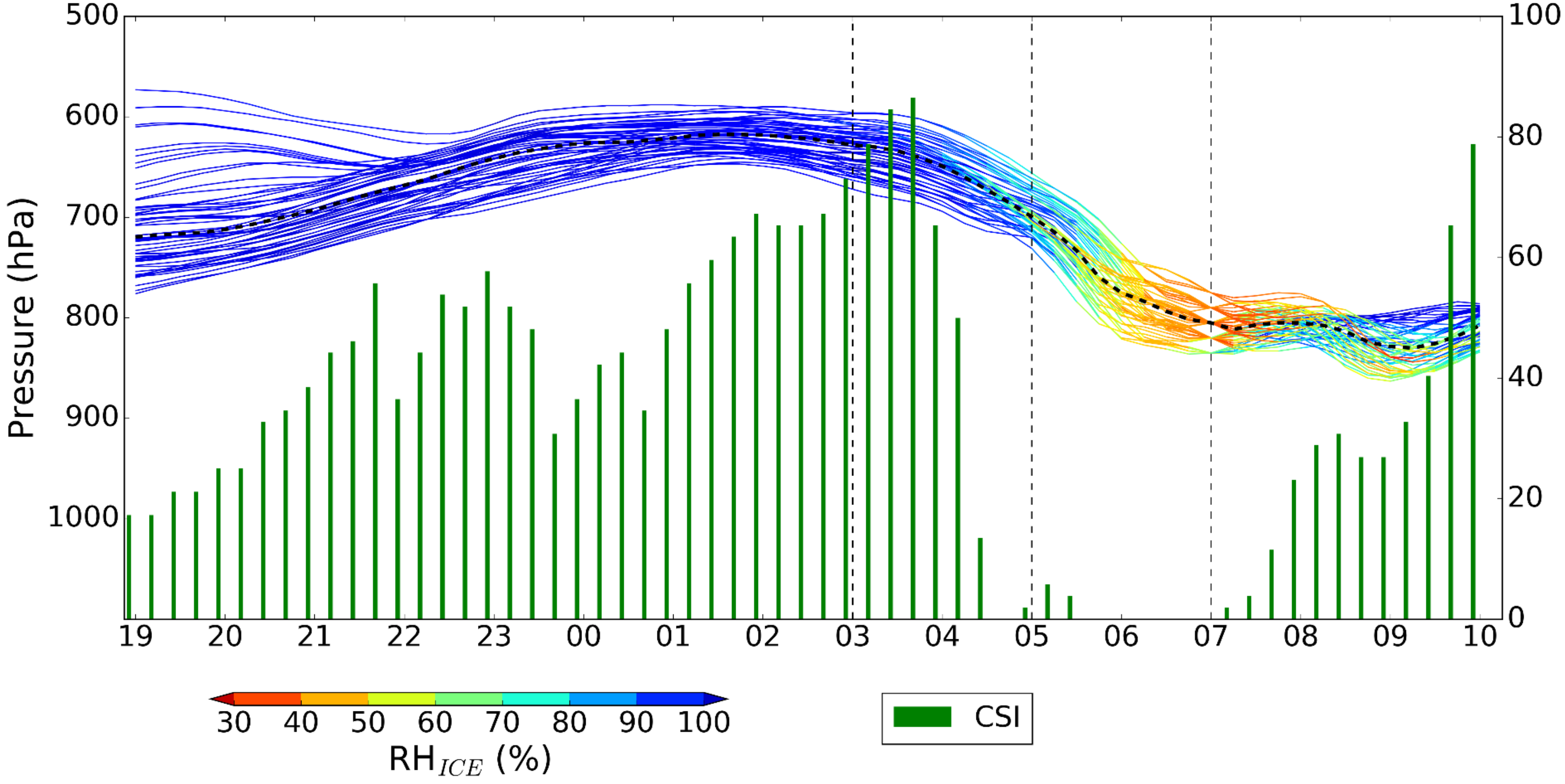
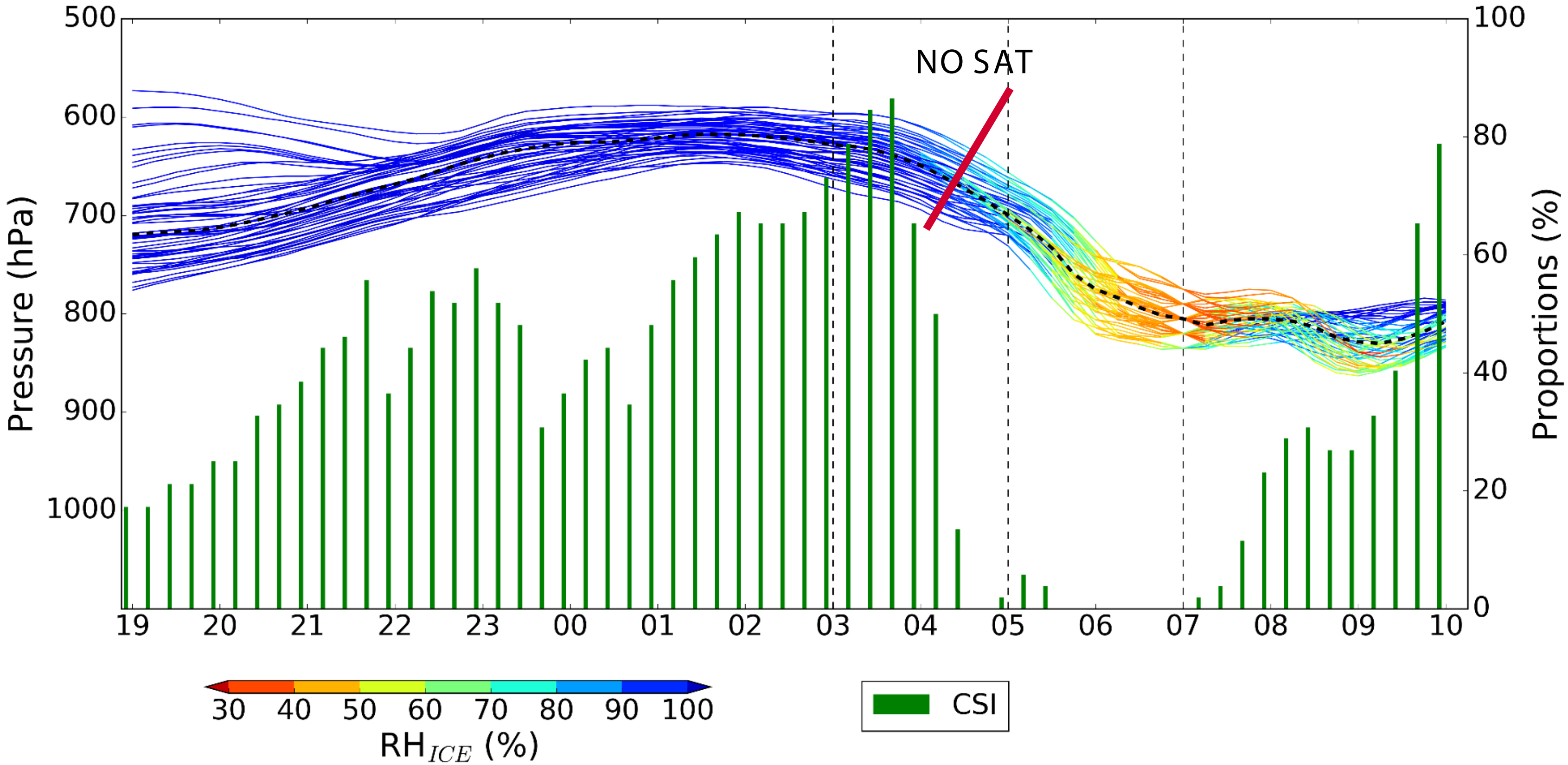


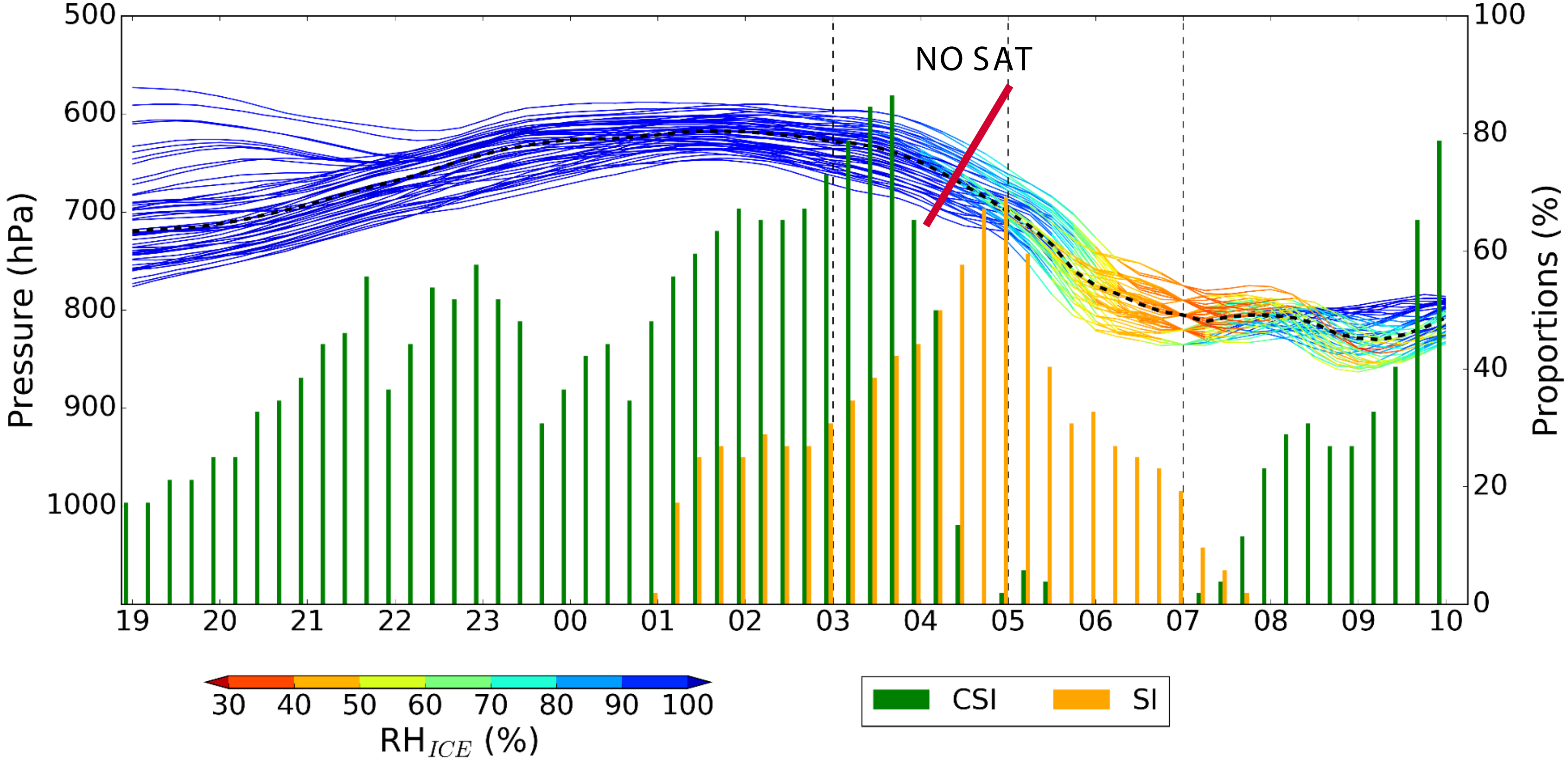
- Large portion of trajectories unstable to CSI before jet starts descending: consistent with previous studies

Instabilities on trajs



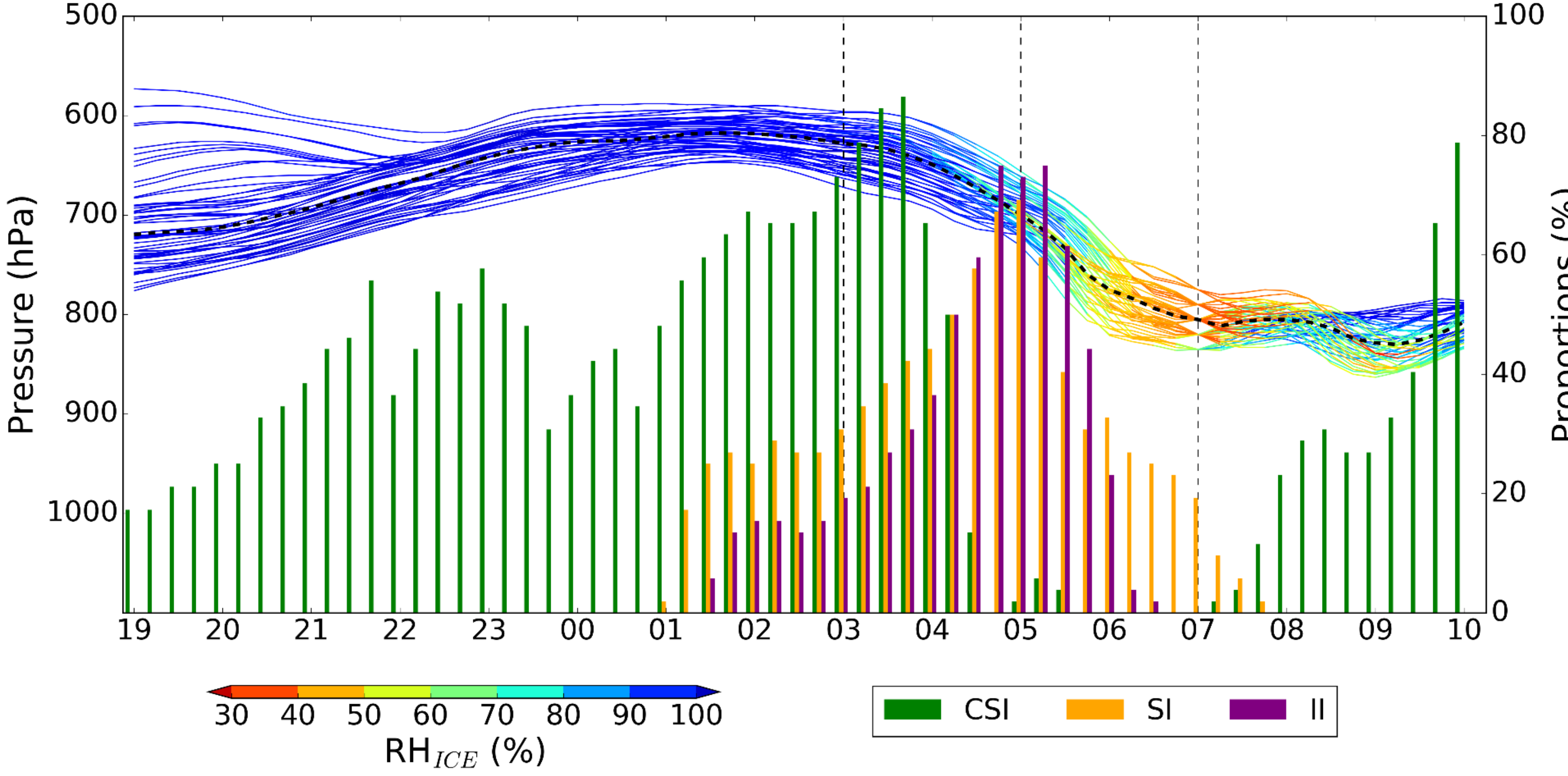
- Large portion of trajectories unstable to CSI before jet starts descending: consistent with previous studies
- CSI needs saturated environment to be released so it cannot be released out of the cloud

Instabilities on trajs



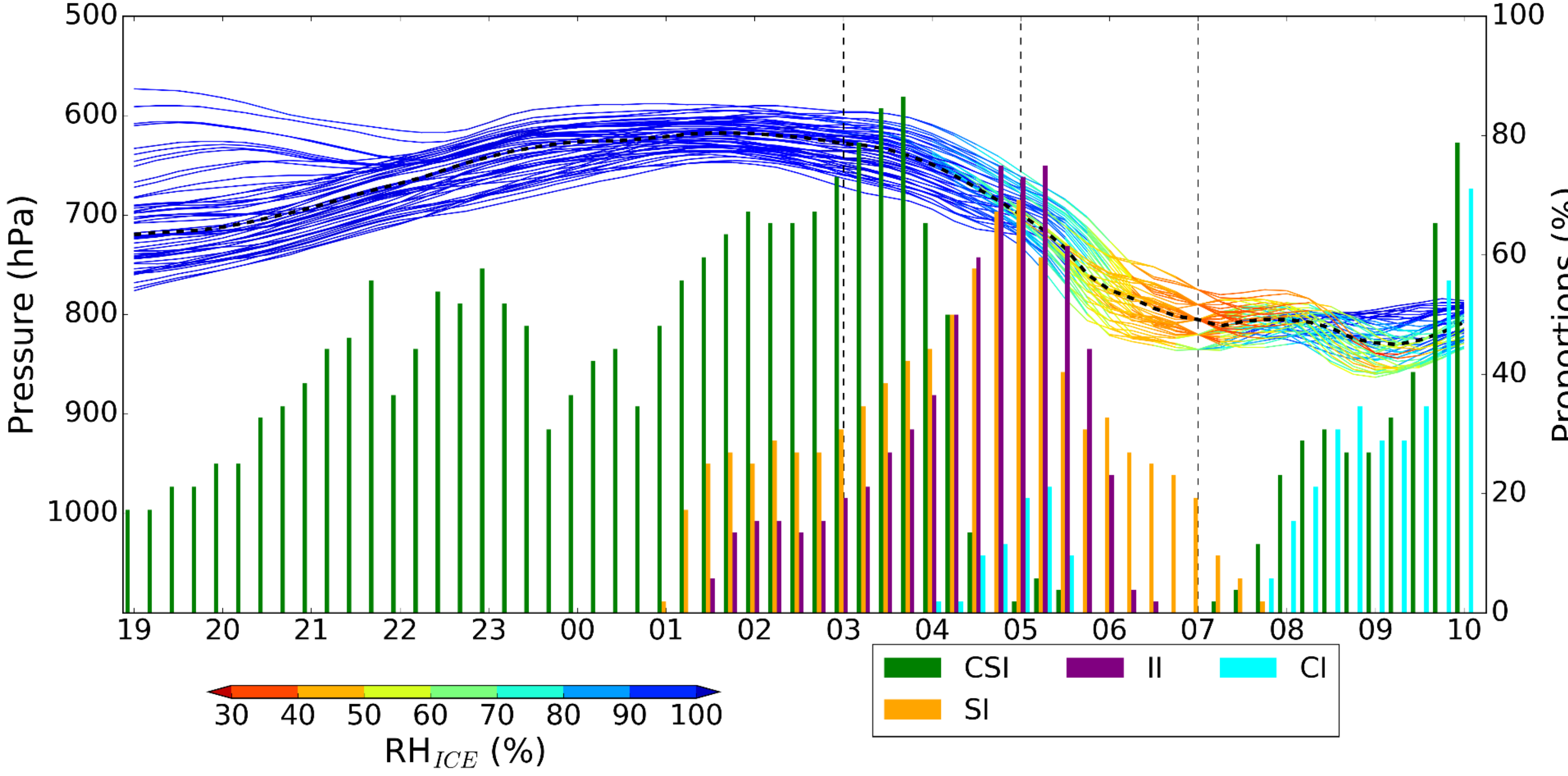
- During the descent rapid growth and subsequent drop of dry symmetric instability (SI)
- Diabatic processes are changing PV on the trajectories
- The release of a dry instability can explain why the SJ continues to accelerate even when not saturated

Instabilities on trajs



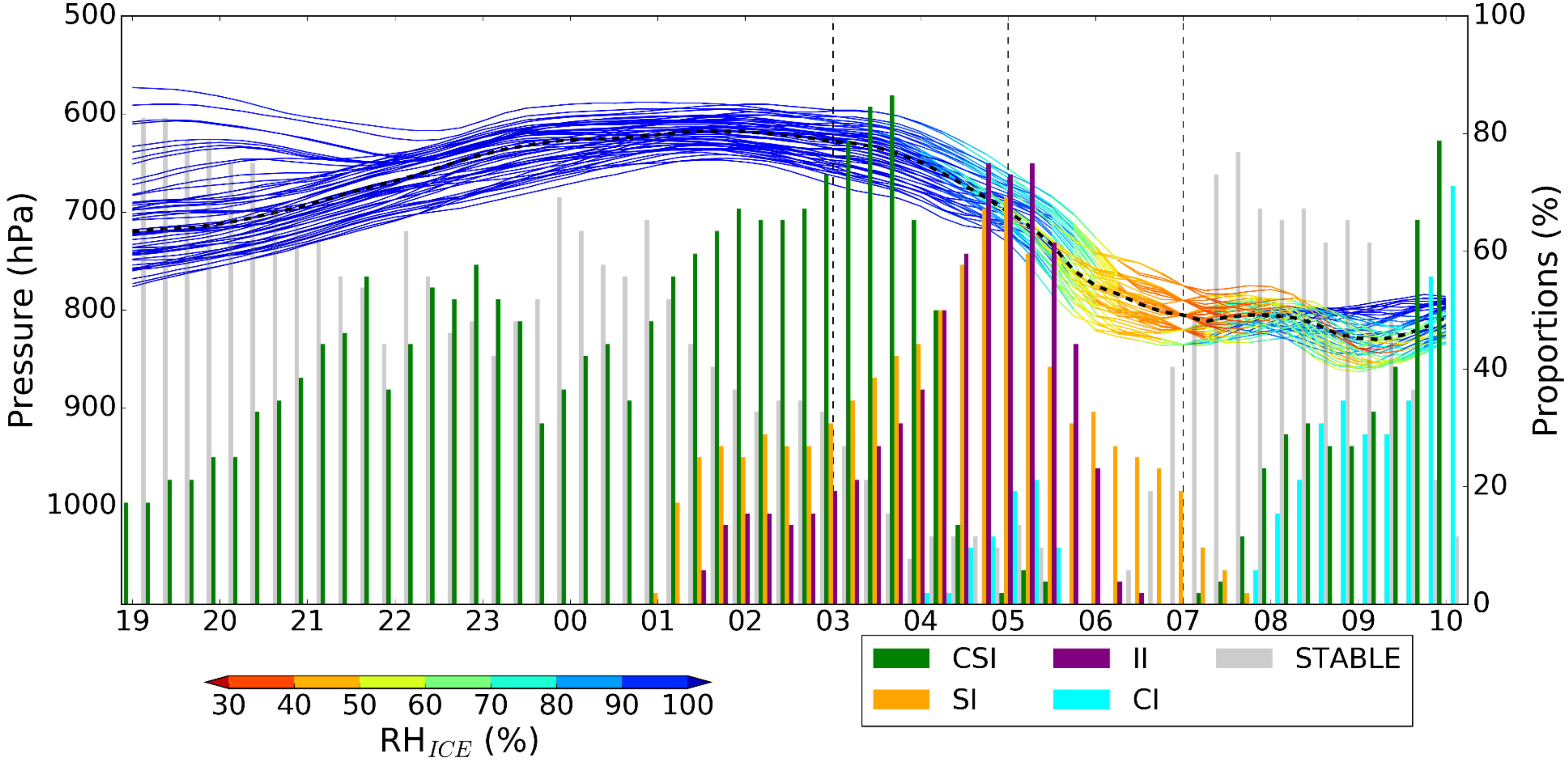
- At the same time a large portion of the airstream gets also unstable to II
- Vertical component of absolute vorticity gets negative

Instabilities on trajs



- The situation is definitely more complex than just CSI release
- Very little conditional instability

Instabilities on trajs



- The parcels that get unstable to CSI at first then get unstable to dry mesoscale instabilities
- Single process of destabilisation and subsequent release of mesoscale instability on the airstream

Evolution of vorticity

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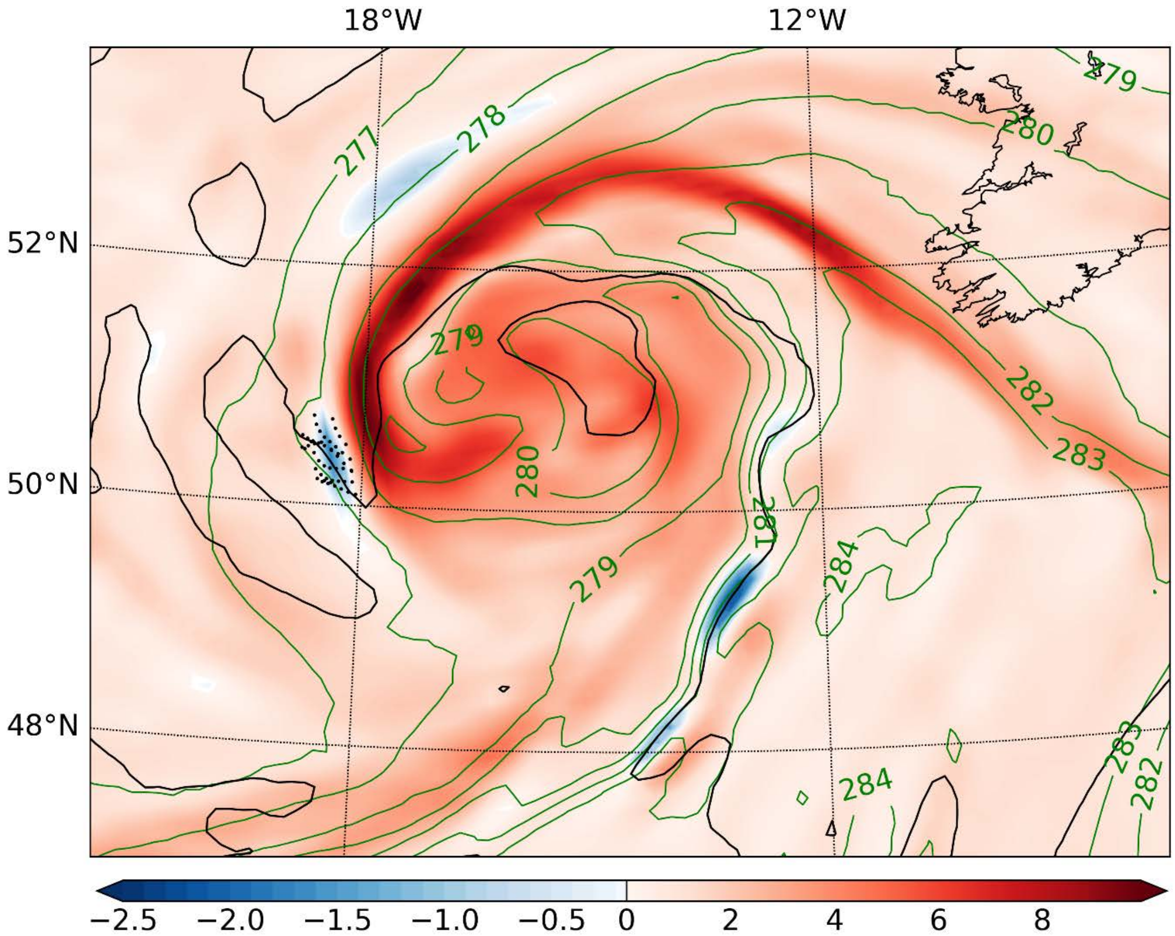
- The SJ gets more and more unstable while exiting from the cloud head, up to the point that the vertical component of absolute vorticity becomes negative (condition for II)
- How does the jet get to this unstable condition?



Absolute vorticity ($10^{-4}\ s^{-1}$) computed at 700 hPa at 05 UTC

Evolution of vorticity

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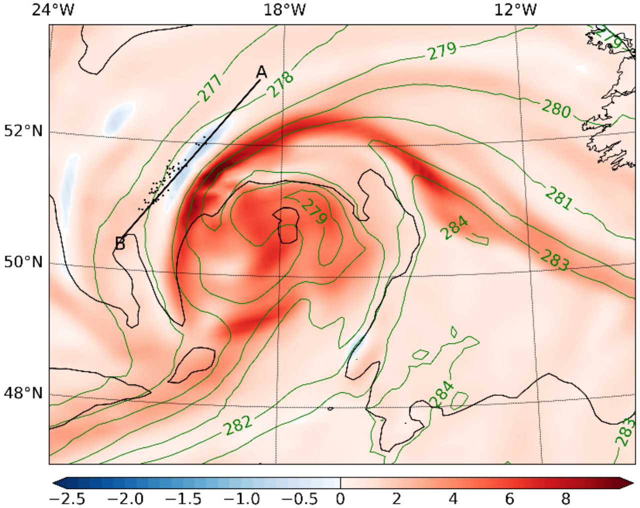
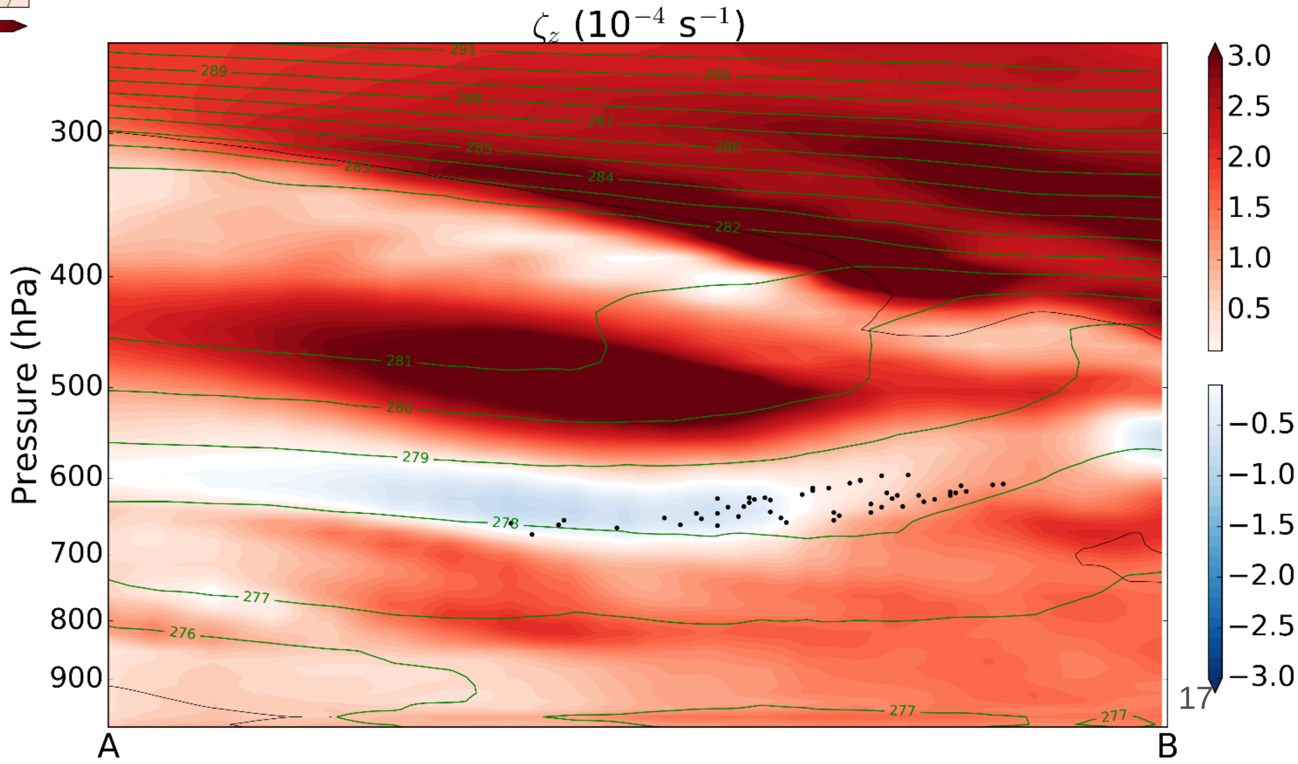


03 UTC – 640 hPa



Evolution of vorticity

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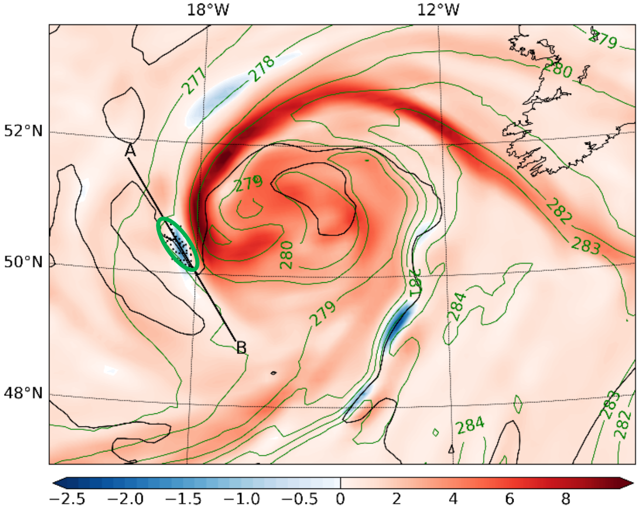
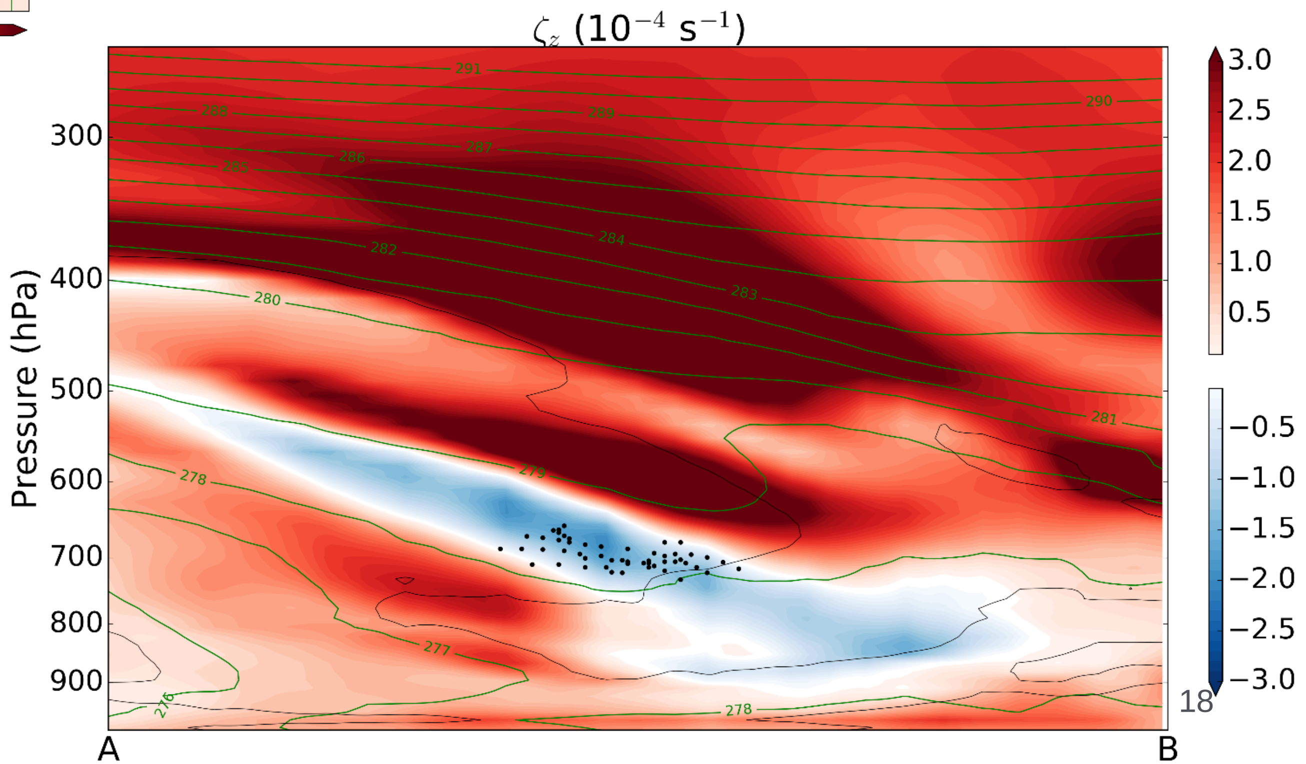
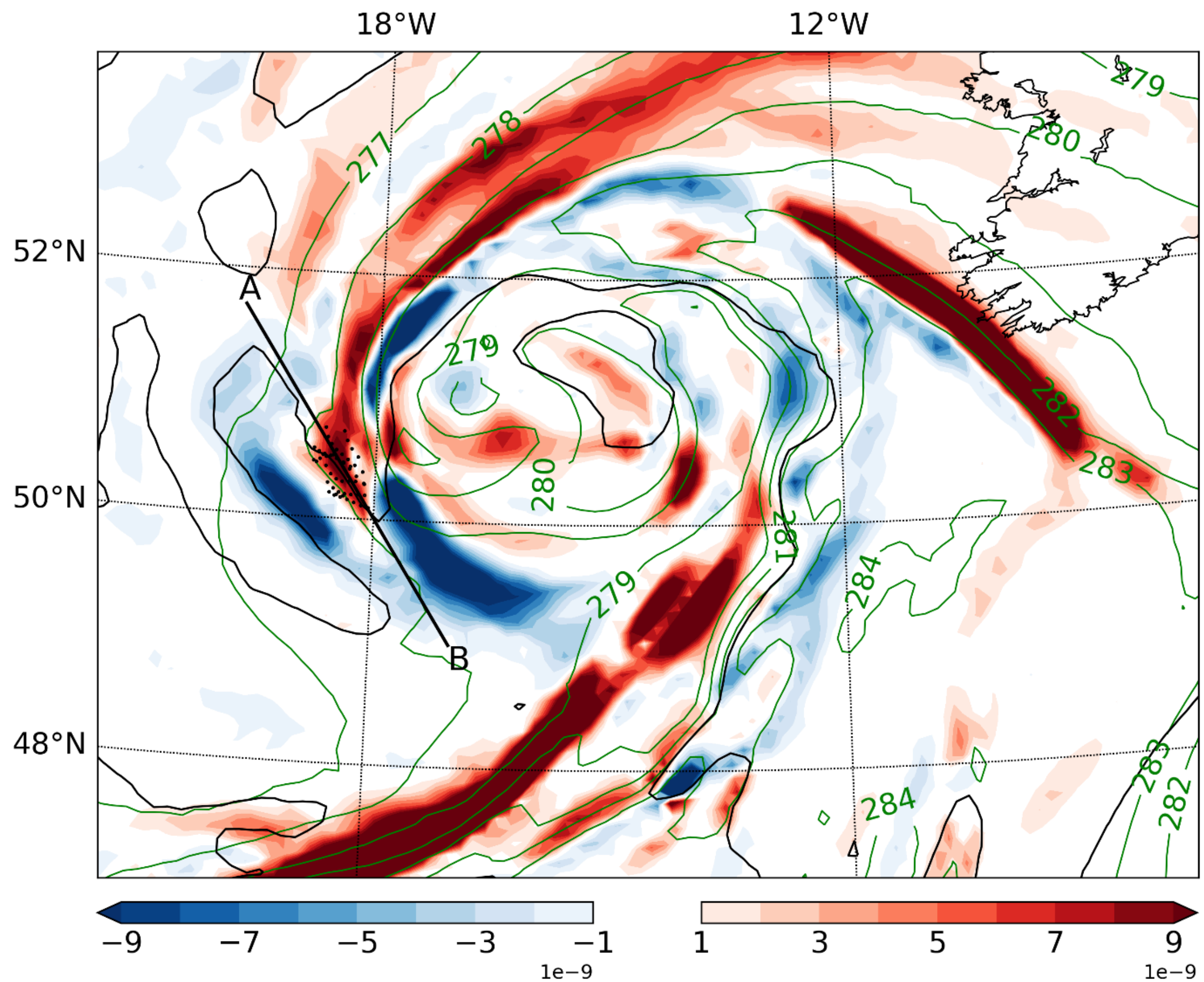




Evolution of frontogenesis

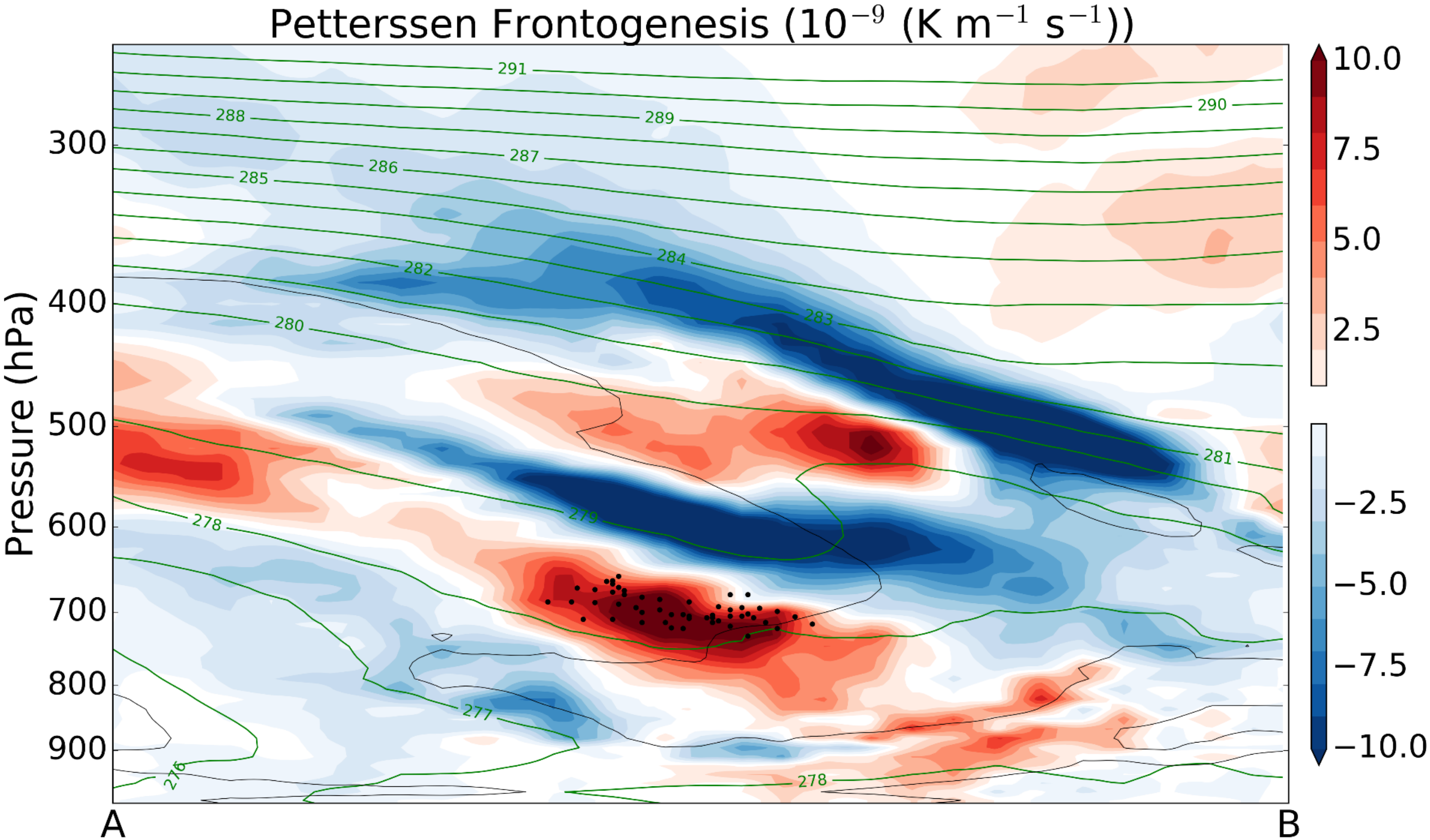
- We showed mesoscale instabilities evolving on the airstream
- What is the associated frontogenesis pattern?
- There is more structure than in the results of Schultz and Sienkiewicz (2013)



Petterssen Frontogenesis (K m^{-1} s^{-1}) computed at 700 hPa at 05 UTC

Evolution of frontogenesis

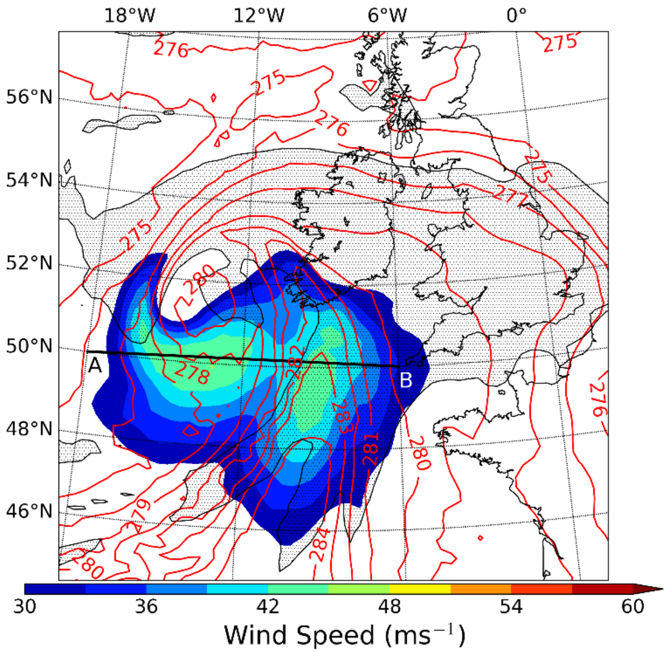
- Evident vertical banding, consequence of the distortion of theta gradient operated by the slantwise motions
- SJ is located in a frontogenetic region for most of its descent



Comparison with global model

- Global simulation of Tini on a ~25km horizontal grid spacing domain

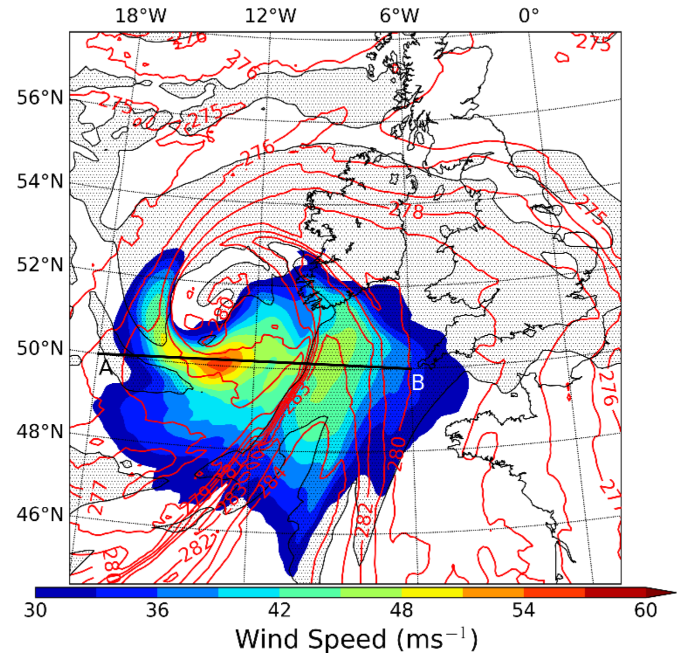
25km



WCB ~ 42 m/s

SJ ~ 45 m/s

12km



WCB ~ 48 m/s

SJ ~ 60 m/s

- Wind speed and wet bulb potential temperature at 850 hPa (07 UTC)
- The broad structure is the same but wind weakening in SJ area is evident

Comparison with global model

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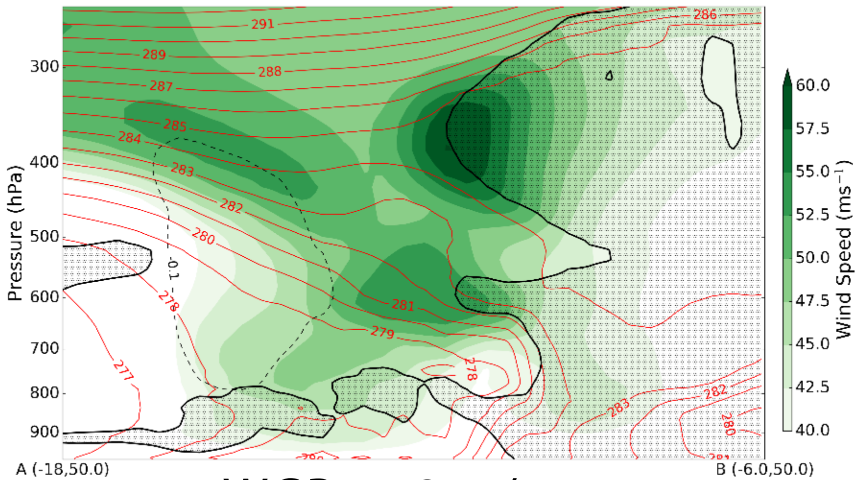
25km



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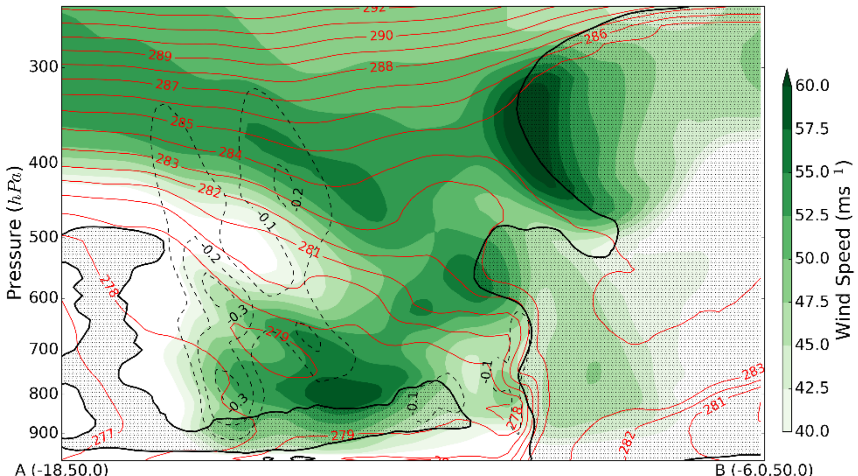


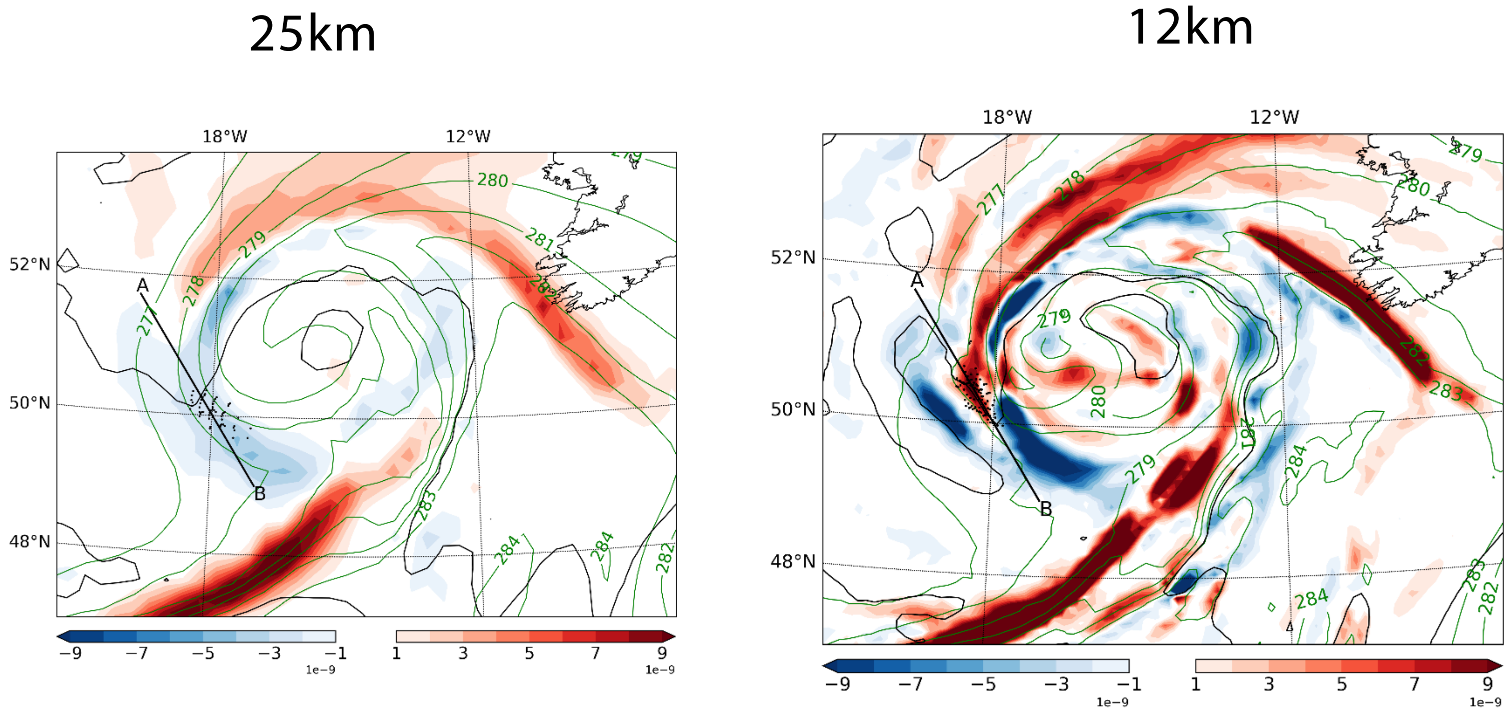
WCB ~ 48 m/s
SJ ~ 60 m/s

- High- and mid-troposphere wind fields are similar with both resolutions

In the 25km:

- Significant weakening of wind speed at low levels in the frontal fracture area
- Descending motions much weaker and no folding in θ_w

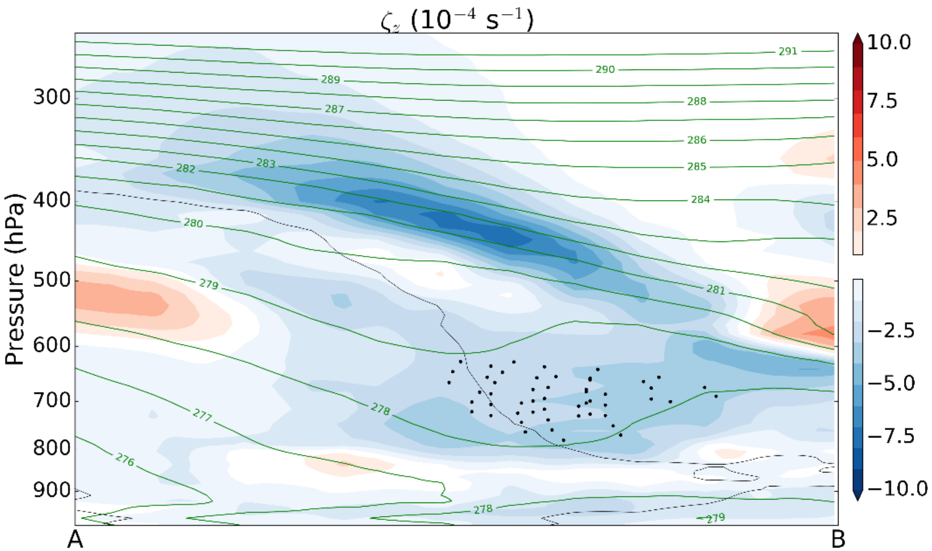
Comparison with global model



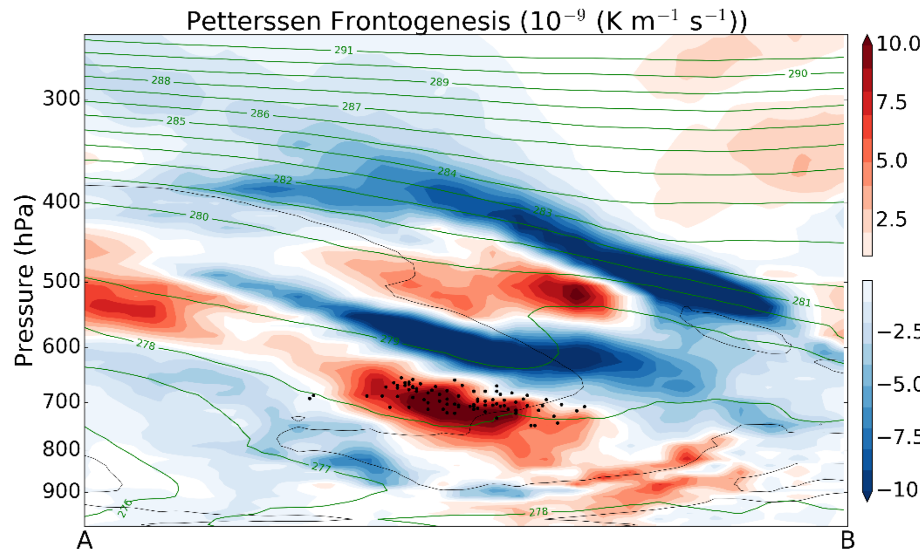
- Same broad structure in frontogenesis, smaller magnitude in the 25km
- Pattern closely resembles Schultz and Sienkiewicz(2013)
- No finer-scale structure

Comparison with global model

25km

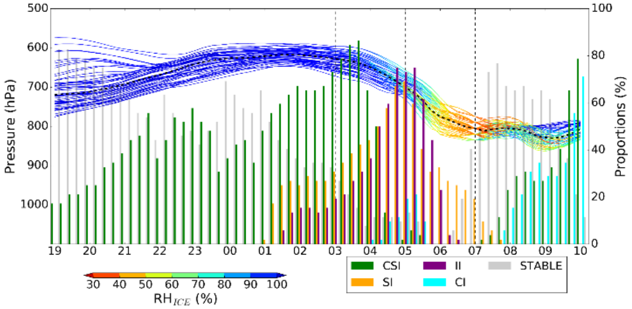


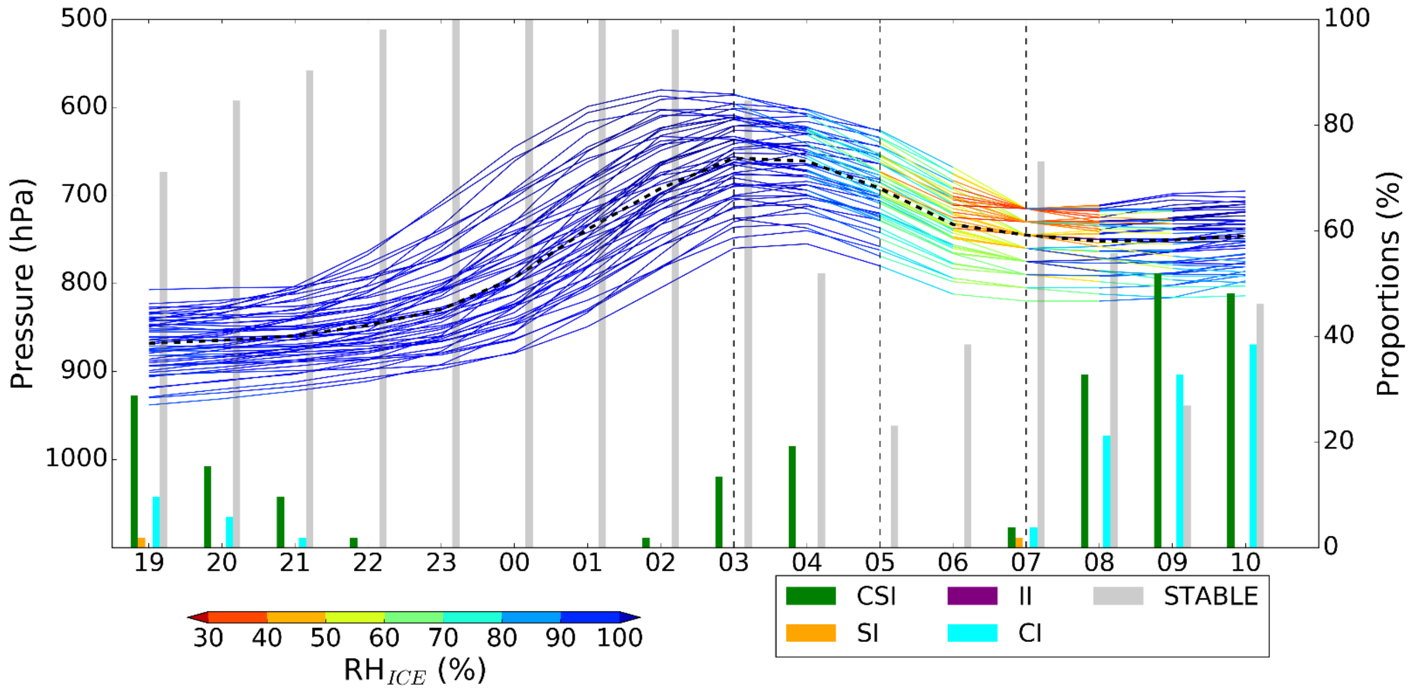
12km



- Mesoscale bandings at the tip of the cloud head are absent

Coarser resolution





- The build-up and release of mesoscale instabilities driving the SJ descent in the hi-res simulation is almost absent in a coarser-resolution one, resulting in weaker winds

Summary

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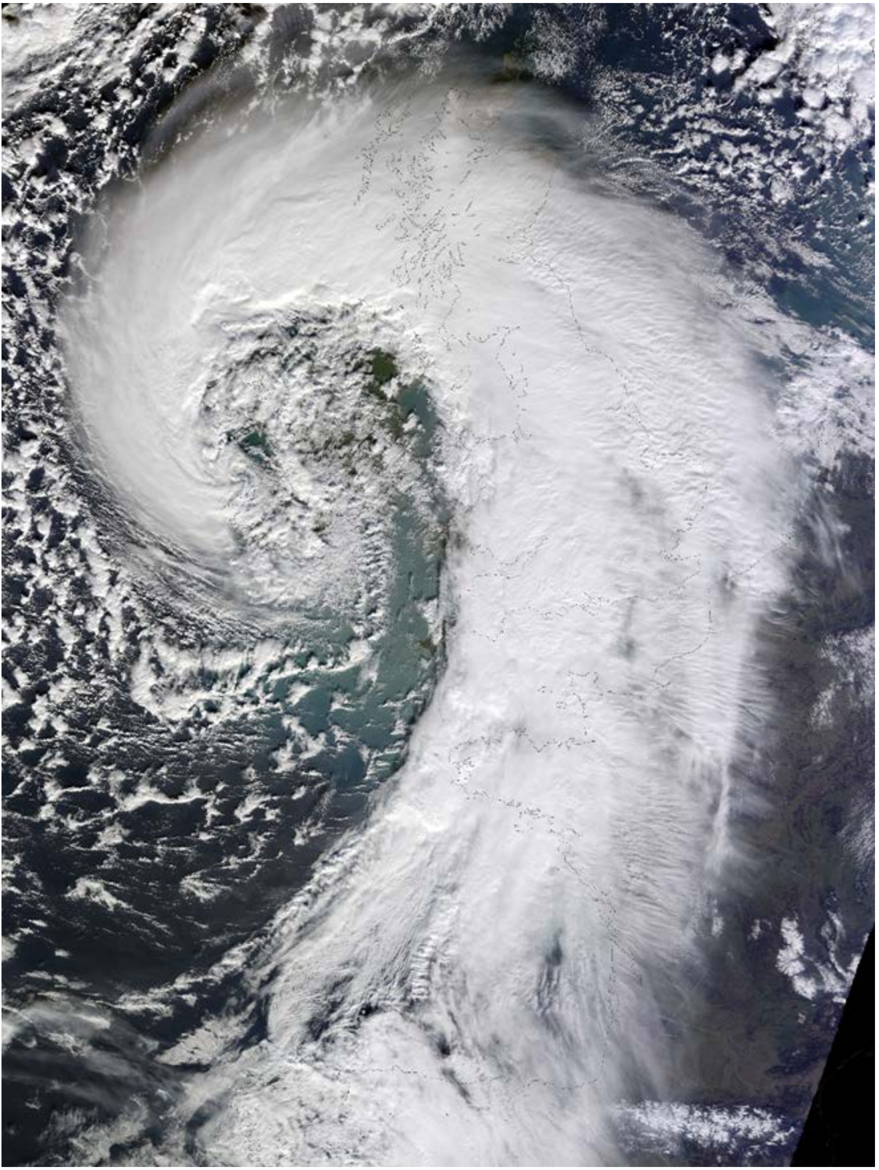
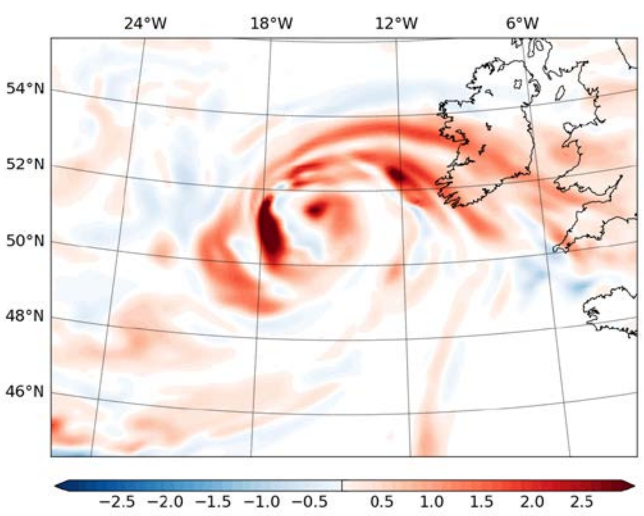


- Dynamics of SJ is still debated, particularly on the relative importance of larger-scale cyclone dynamics and mesoscale instabilities
- Simulations of windstorm Tini show the presence of a SJ as a distinct airstream
- This airstream becomes at first largely unstable to CSI and then also to other dry mesoscale instabilities driving its descent.
- The same destabilisation does not occur in a coarser-resolution simulation, resulting in a weaker wind jet in the frontolytic region.
- This dynamics does not contradict a large-scale paradigm connecting strong winds in that area with the frontal fracture dynamics. Rather, the analysis reveals the synergy between cyclone dynamics and mesoscale instabilities in SJ formation.

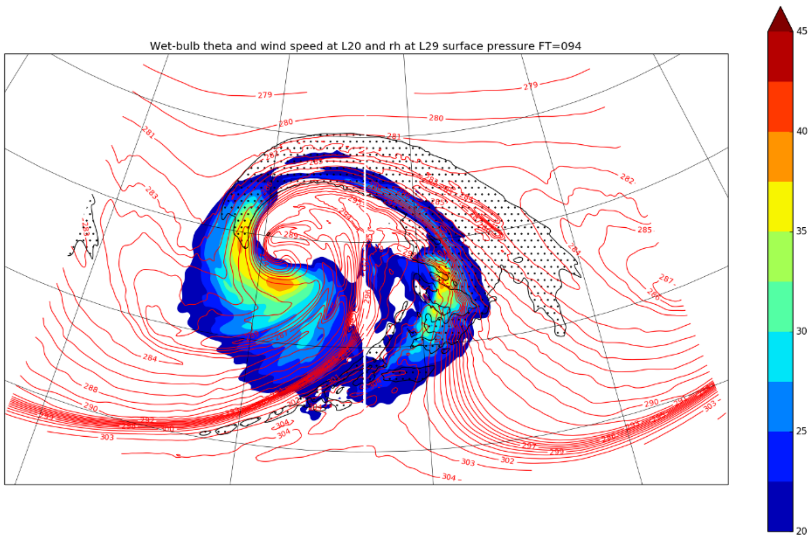
And now?

- The results of this case study suggest that the SJ undergoes to a process of destabilisation that enhances its descent and acceleration, adding up to the strong winds already generated by the larger-scale cyclone dynamics.
- We need now to identify the processes driving these dynamics to get a complete picture of the SJ.
- To put it simply, the research focus has to widen from *how* a SJ forms and evolves to *when*, *where* and *why* it evolves and to include the effects of future climate change.

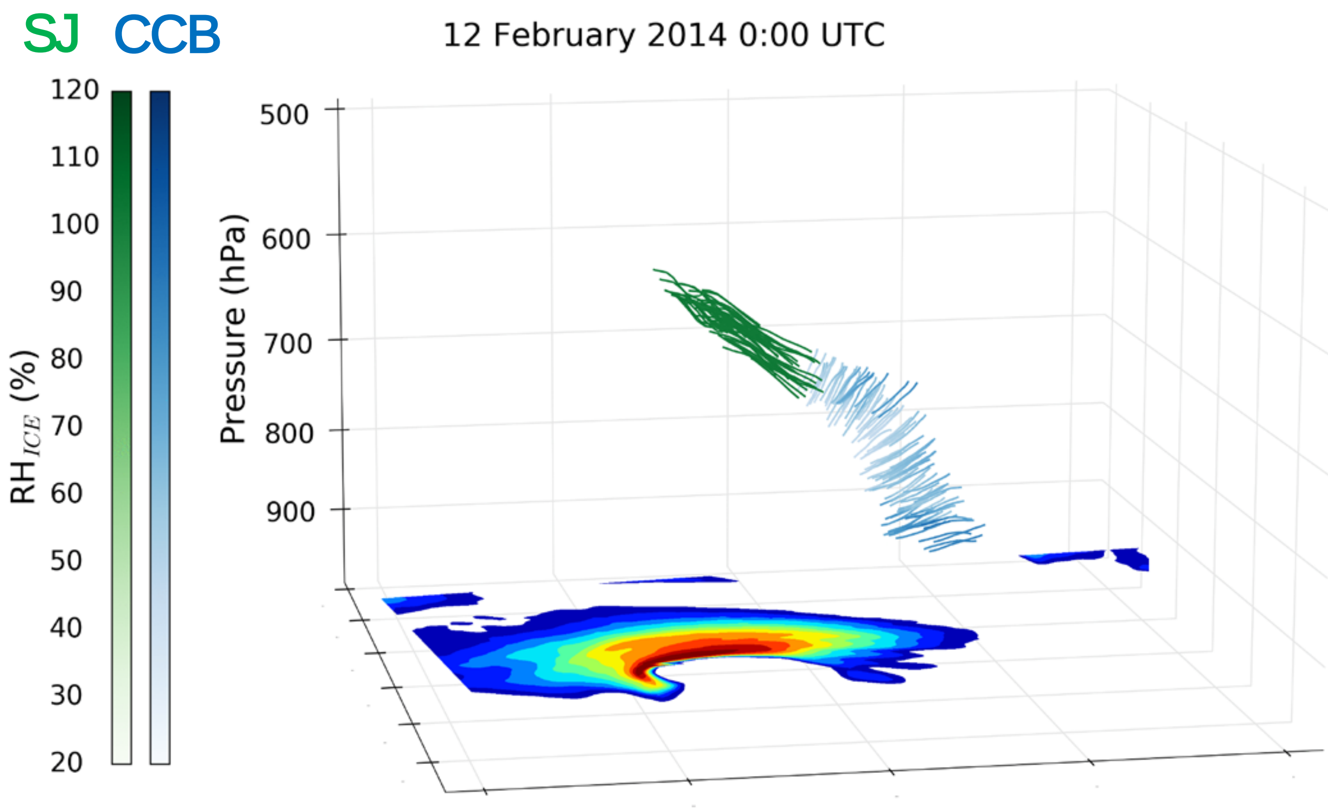
PV tracers



Idealised simulations



Thanks for the attention!



- System-relative reference frame