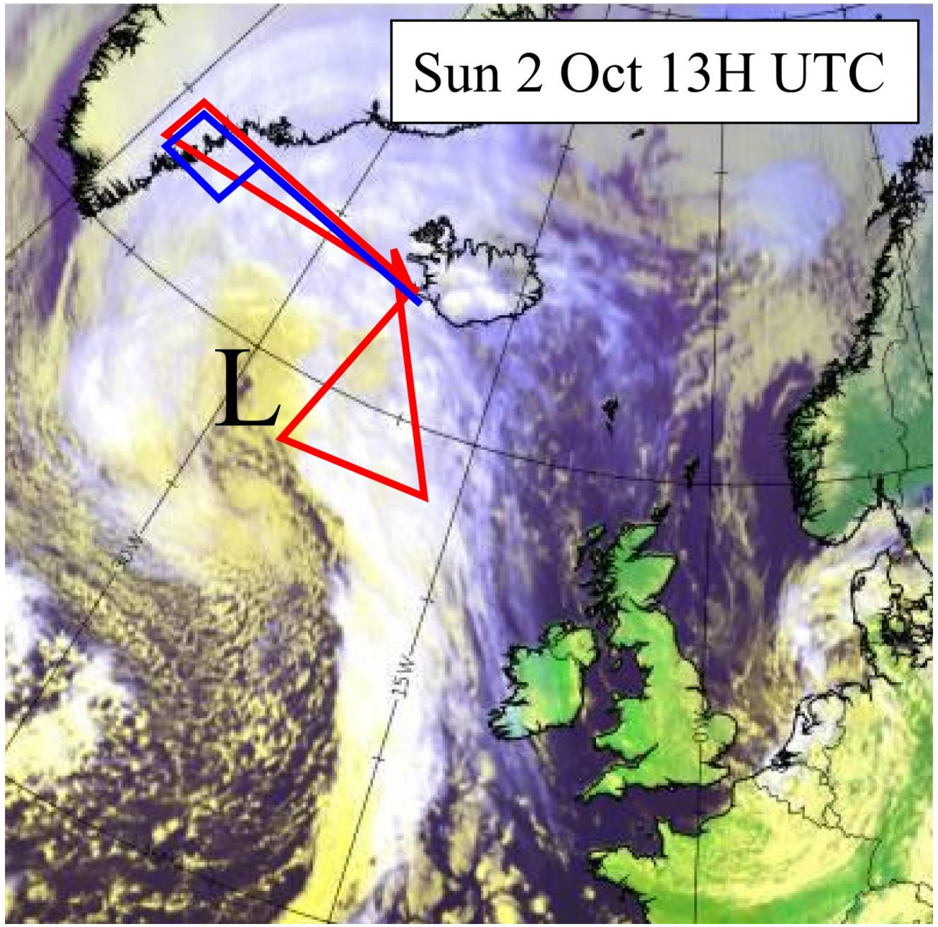
Representation of the Stalactite Cyclone by the Two French Climate Models



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4. LATMOS

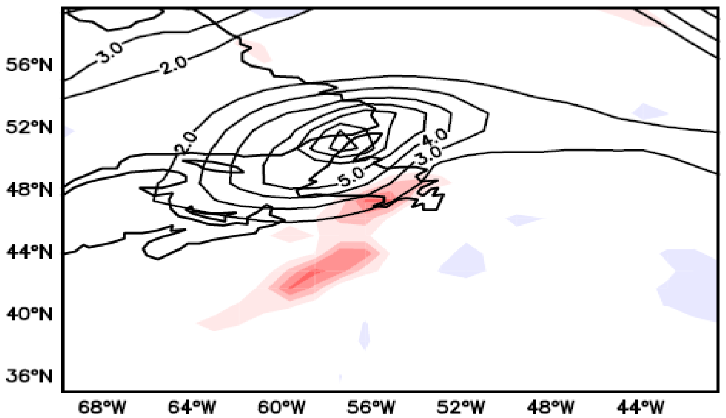
This work is funded by ANR (Agence Nationale de la Recherche) under the DIP-NAWDEX (DIabatic Processes in NAWDEX) project by grant ANR-17-CE01-0010-01

Project Questions

- How well do climate models represent the two stages of the Stalactite Cyclone?
- How do the relative roles of diabatic and dynamic processes in the development of the Stalactite Cyclone change with resolution?
- Can microphysical observations made during the field campaign give any useful information about the climate models' performance?

Cyclogenesis: A dynamical perspective

ECMWF

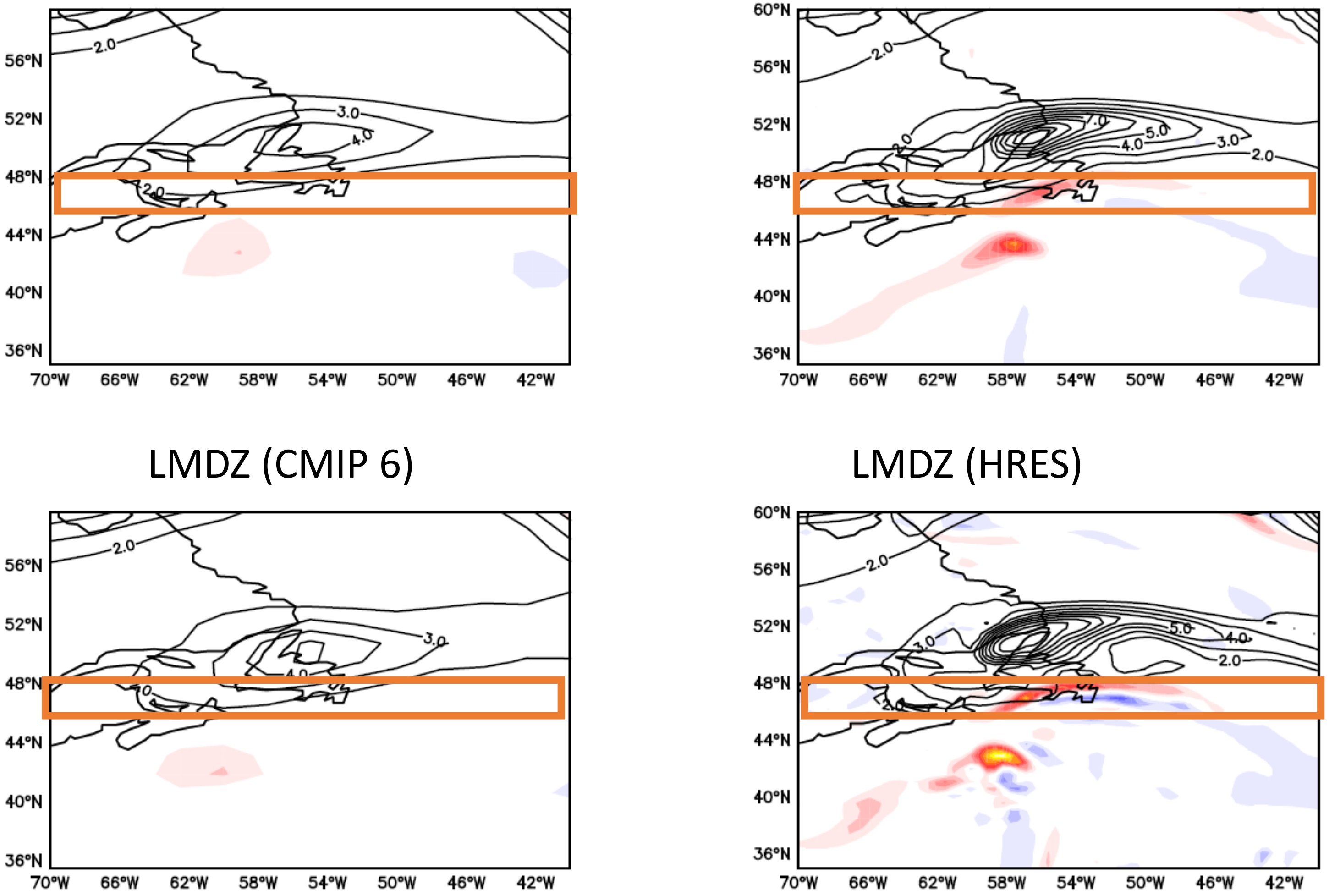


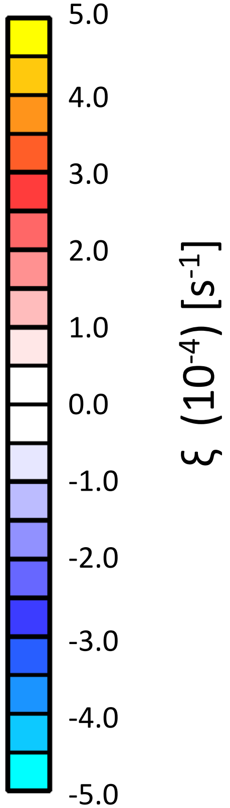
ARPEGE (CMIP 6)

ARPEGE (HRES)

LMDZ (CMIP 6)

LMDZ (HRES)

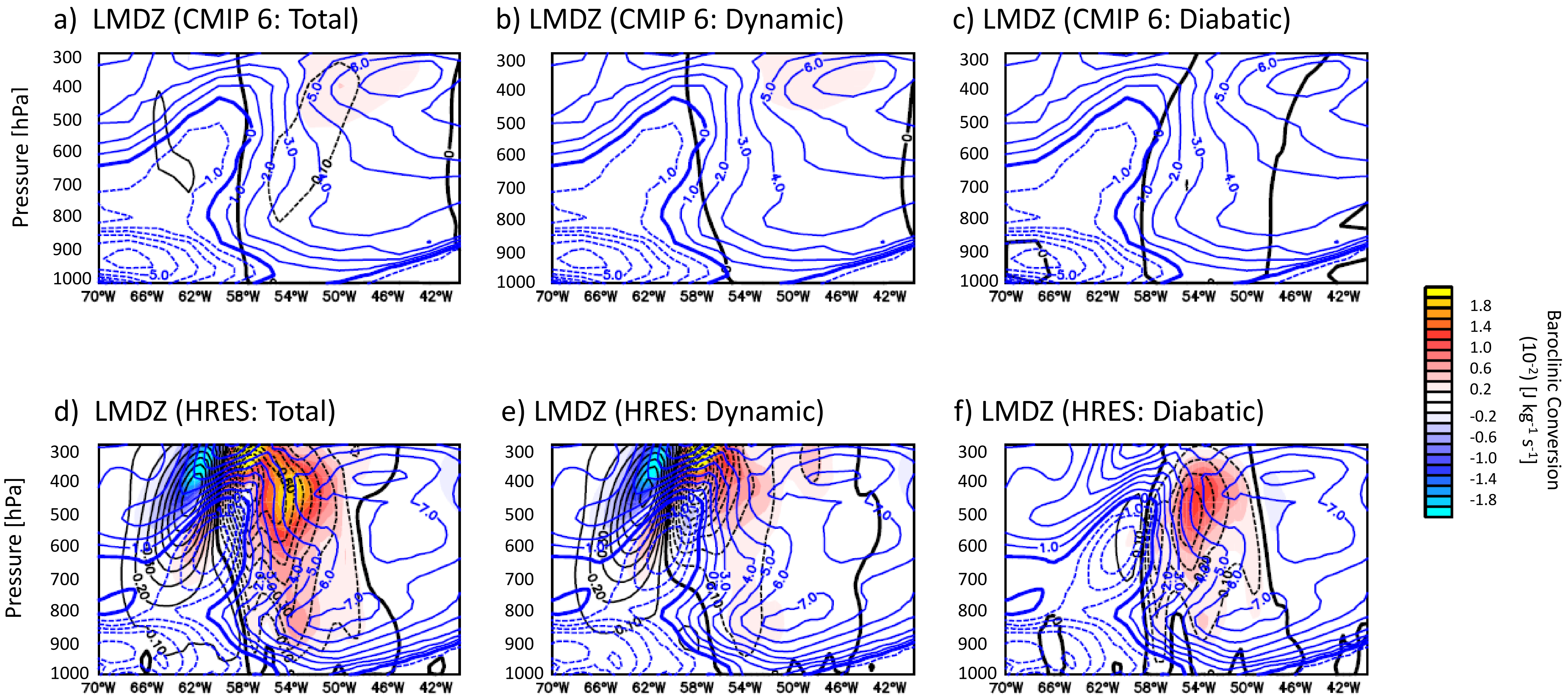




PV>2 PVU contoured

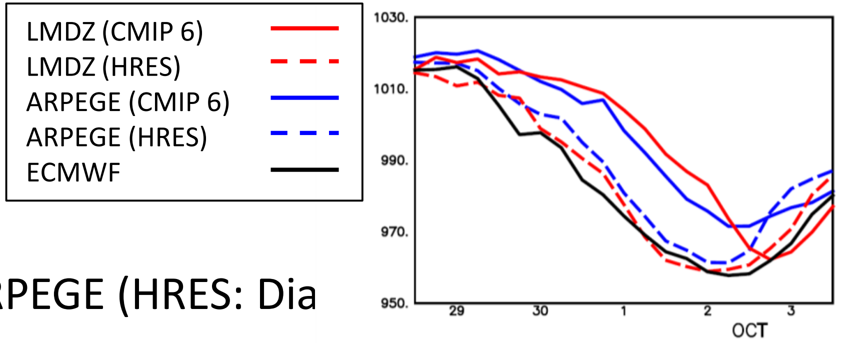
Weak surface N precursor in CMIP 6 – stronger in HRES as in ECMWF analysis

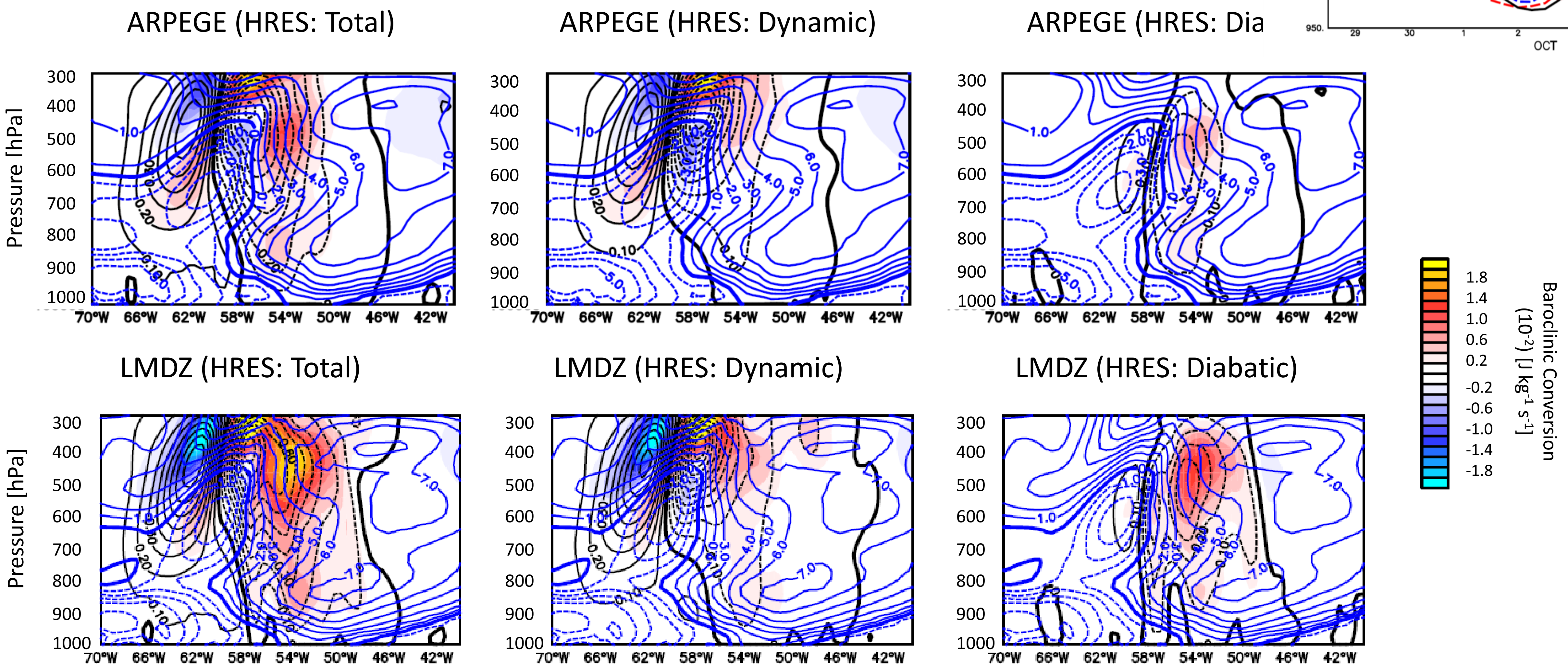
Vertical Cross-section along the Northern precursor



Dynamic forcing extends lower in atmosphere in HRES compared to CMIP 6 RES → interaction between upper and lower levels

Difference in Diabatic Heating

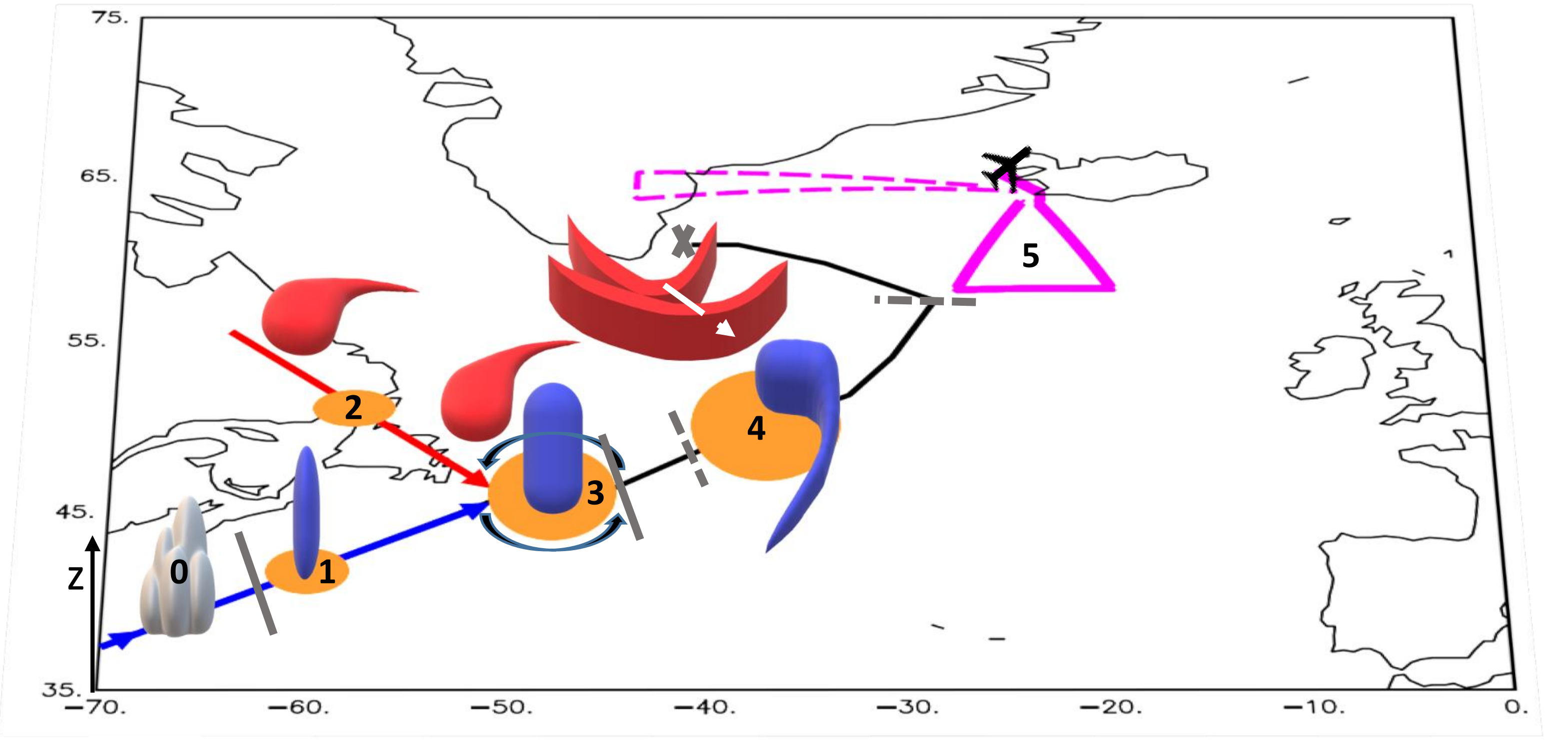




Stronger diabatic heating in LMDZ, associated with a more active model for the deepening of the cyclone

The Stalactite Cyclone

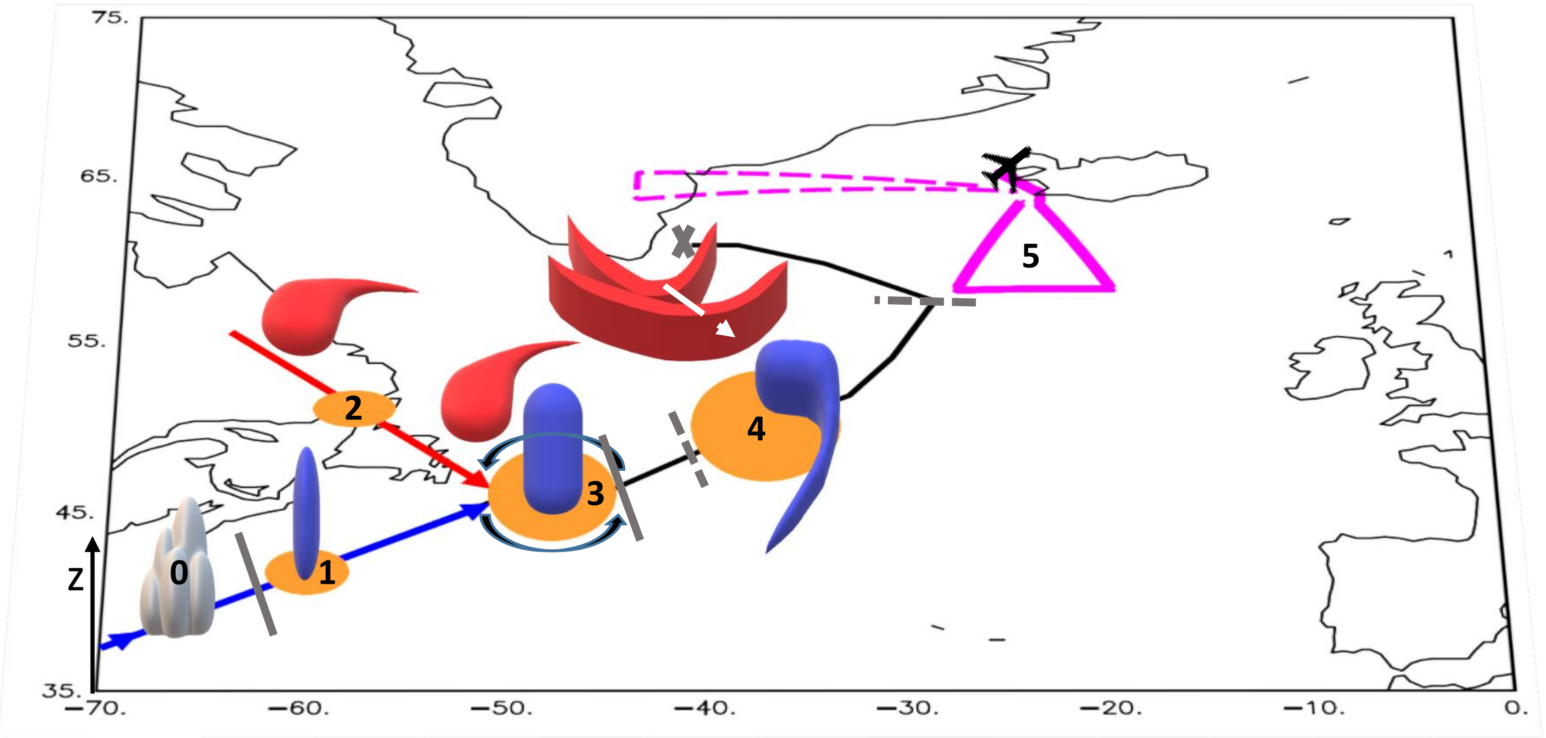
0: Mesoscale Convective System inititates diabatic Rossby wave



	Mesoscale Convective System		Diabatic heating
	Upper-level dynamical forcing		Low-level relative vorticity maximum
	ECMWF (analysis) track		Flight tracks
	Location limits of cyclogenesis phase		Location limits of explosive deepening phase
	Location of cyclolysis		Base of SAFIRE Falcon
	Vortex Roll-up		

The Stalactite Cyclone

1: Diabatic Rossby wave propagates and forms southern precursor in **all** models



	Mesoscale Convective System		Diabatic heating
	Upper-level dynamical forcing		Low-level relative vorticity maximum
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	Location limits of cyclogenesis phase		Location limits of explosive deepening phase
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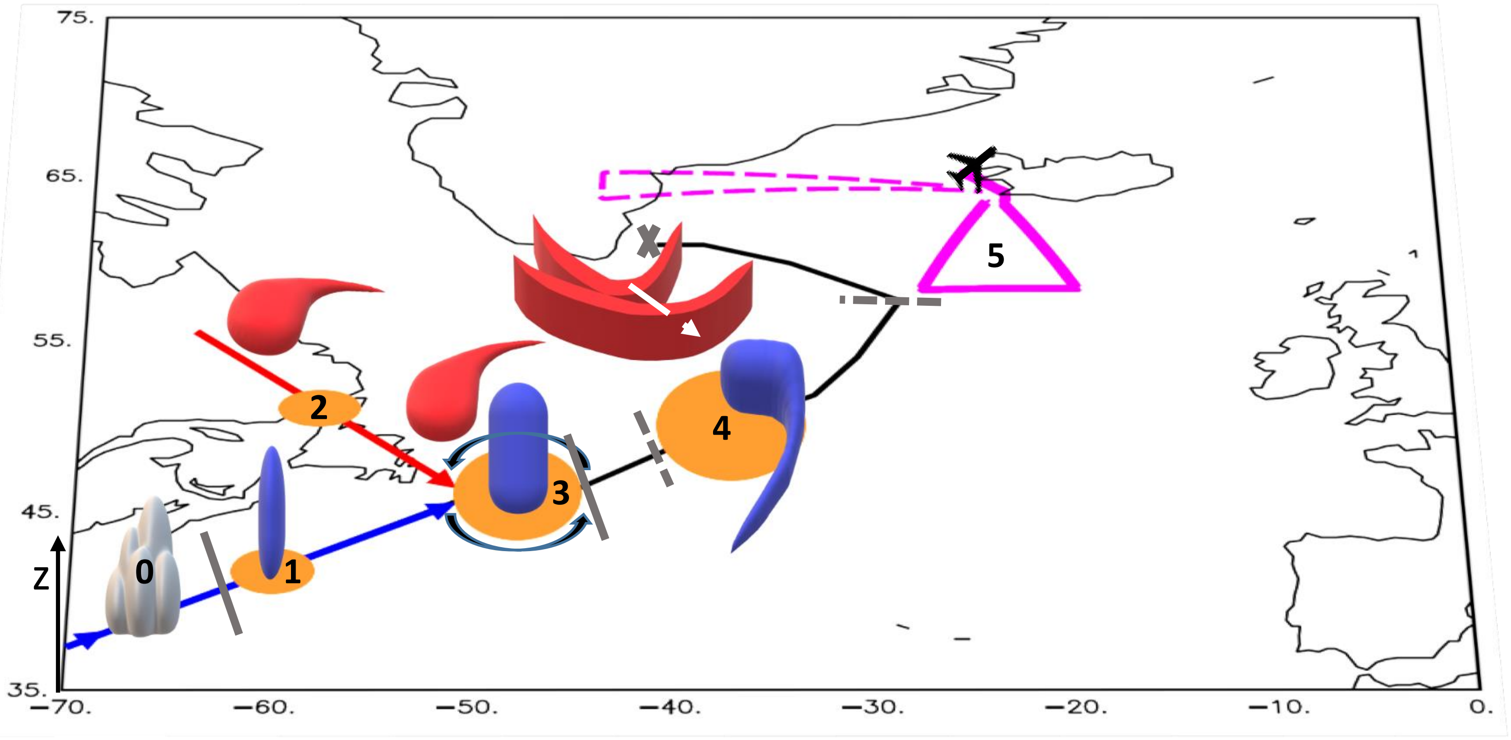
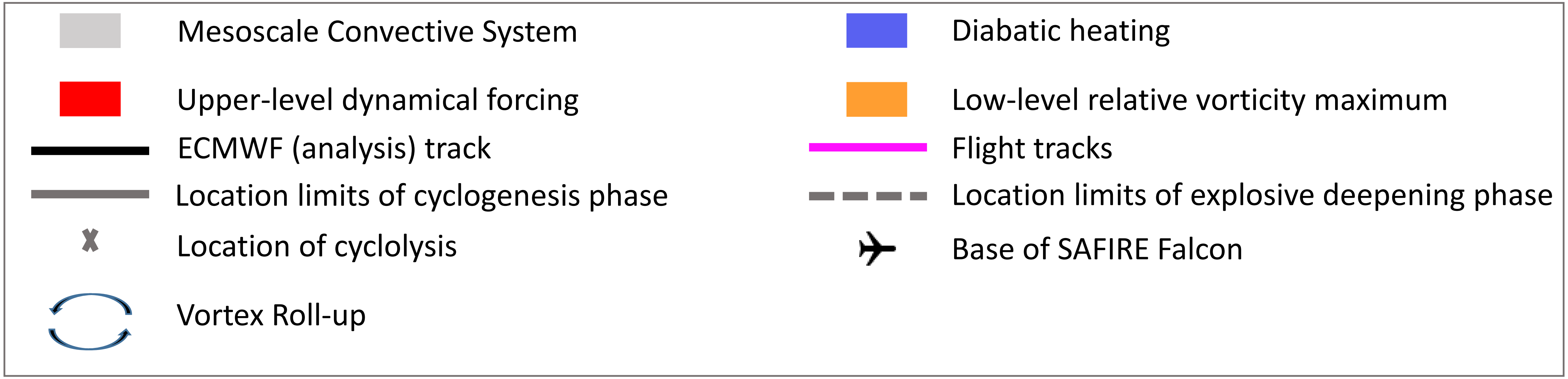
	Vortex Roll-up		

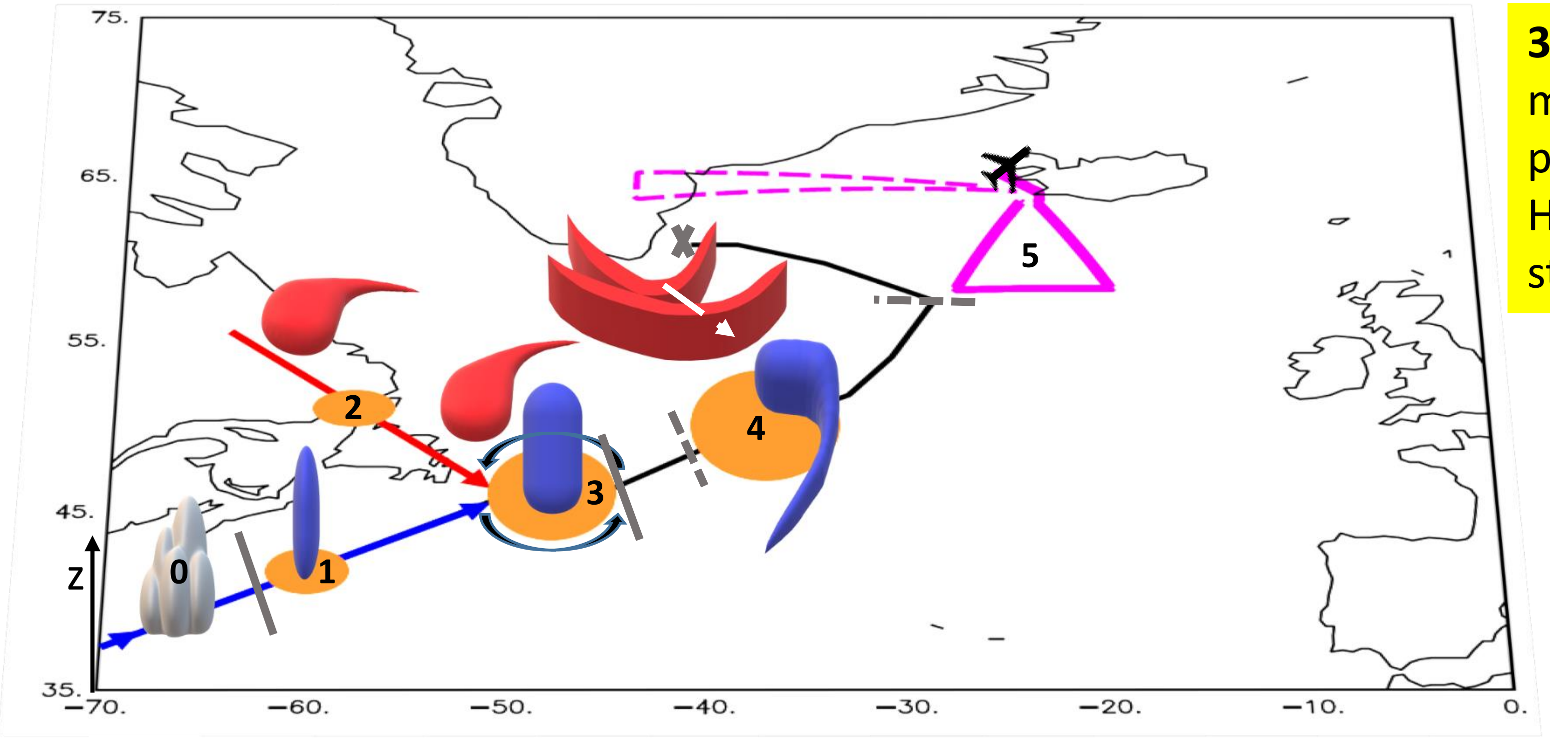
The Stalactite Cyclone

2: Upper-level PV filament acts as a northern precursor - weakly present in CMIP 6 but no surface signature





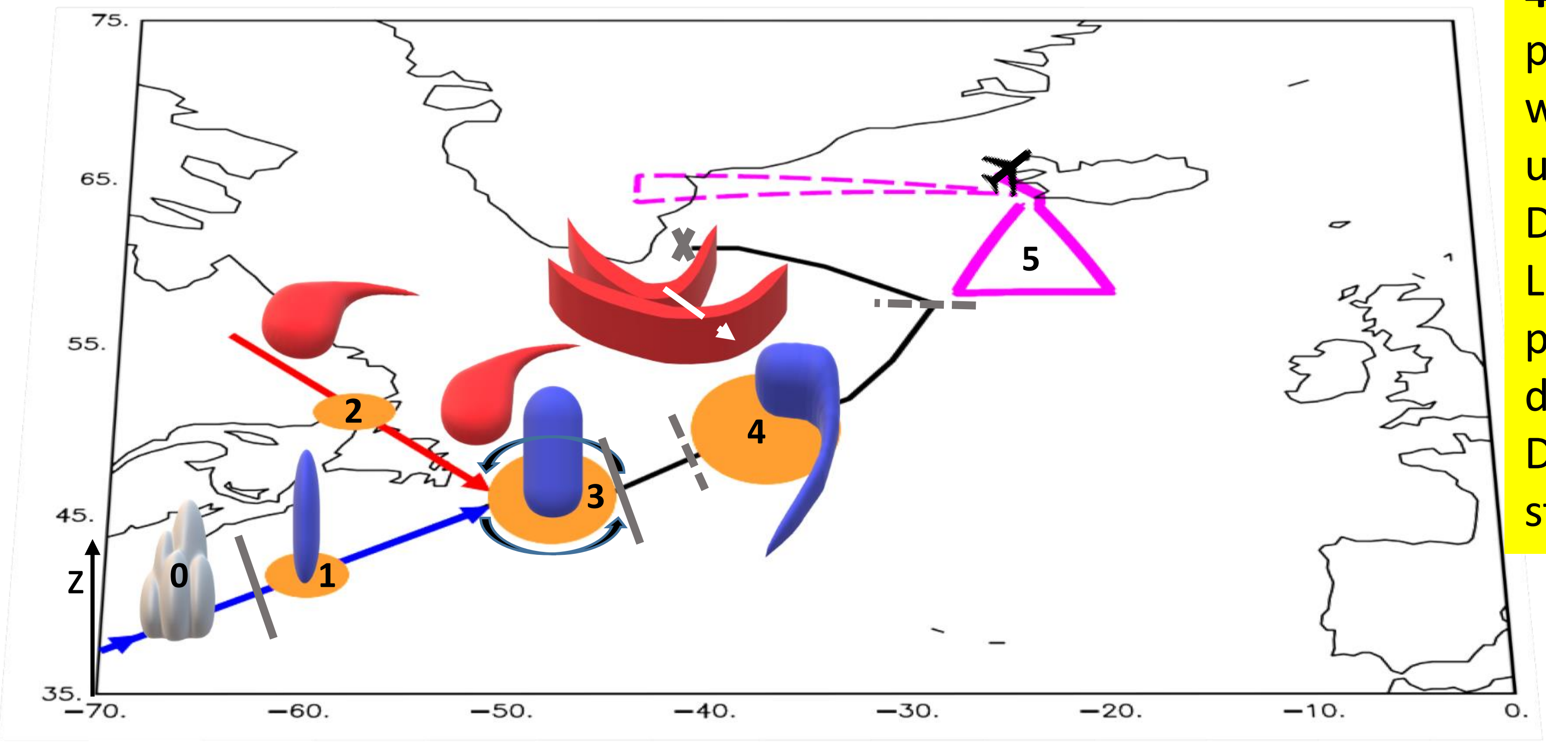
The Stalactite Cyclone



3: Vortex roll-up as merging of both precursors. Delayed in HRES and more strongly in CMIP 6

	Mesoscale Convective System		Diabatic heating
	Upper-level dynamical forcing		Low-level relative vorticity maximum
	ECMWF (analysis) track		Flight tracks
	Location limits of cyclogenesis phase		Location limits of explosive deepening phase
	Location of cyclolysis		Base of SAFIRE Falcon
	Vortex Roll-up		

The Stalactite Cyclone



4: Maximum deepening phase from interaction with a succession of upper-level trough. Deepening strongest in LMDZ but both models produce explosively deepening cyclone. Diabatic heating strongest in LMDZ.

Mesoscale Convective System

Upper-level dynamical forcing

ECMWF (analysis) track

Location limits of cyclogenesis phase

Location of cyclolysis

Vortex Roll-up

Diabatic heating

Low-level relative vorticity maximum

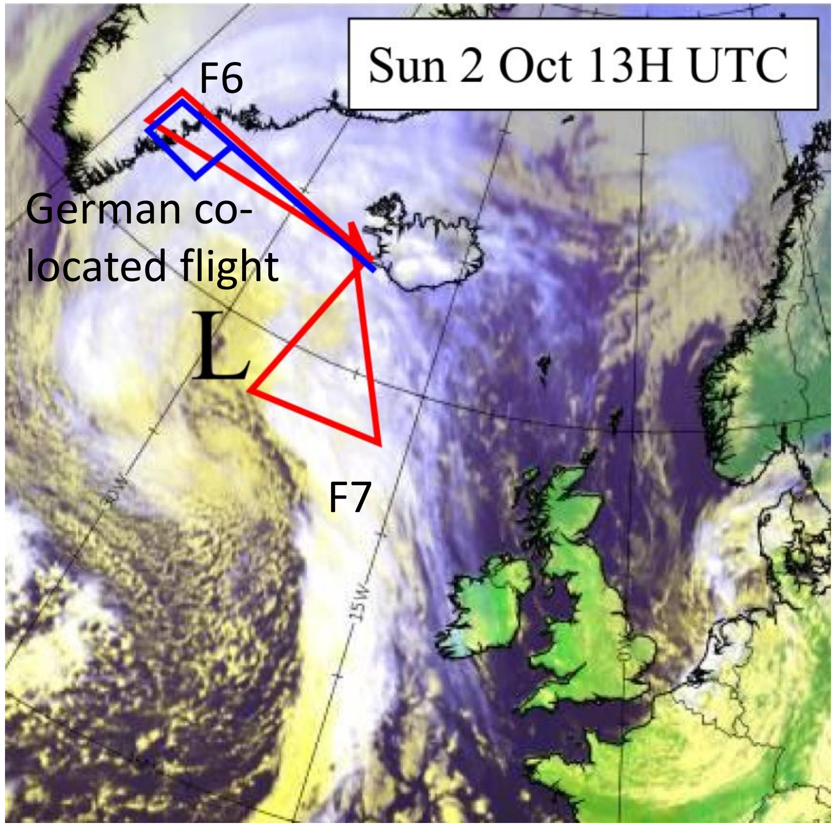
Flight tracks

Location limits of explosive deepening phase

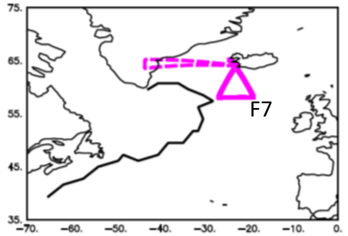
Base of SAFIRE Falcon

Comparison with Observations

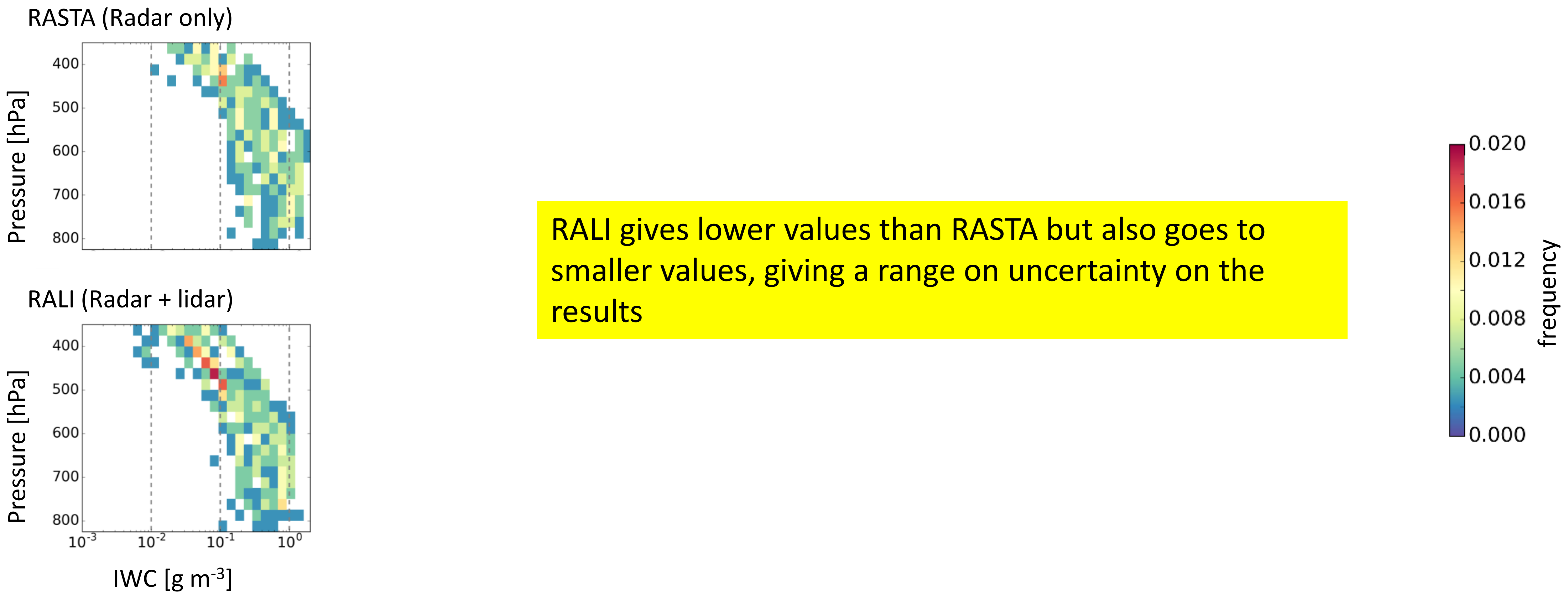
- The dynamical factors can be easily compared with the analysis but diabatic processes cannot
- Can we infer anything about diabatic heating by comparing the model with observations of microphysical properties?



Observations: Ice Water Content: F7

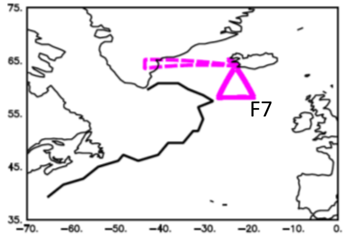


Ice Water Content retrieved from radar/lidar using the variational algorithm of Delanoë and Hogan (2008) with adaptations from Cazenave (2019).



RALI gives lower values than RASTA but also goes to smaller values, giving a range on uncertainty on the results

Observations: Ice Water Content: F7



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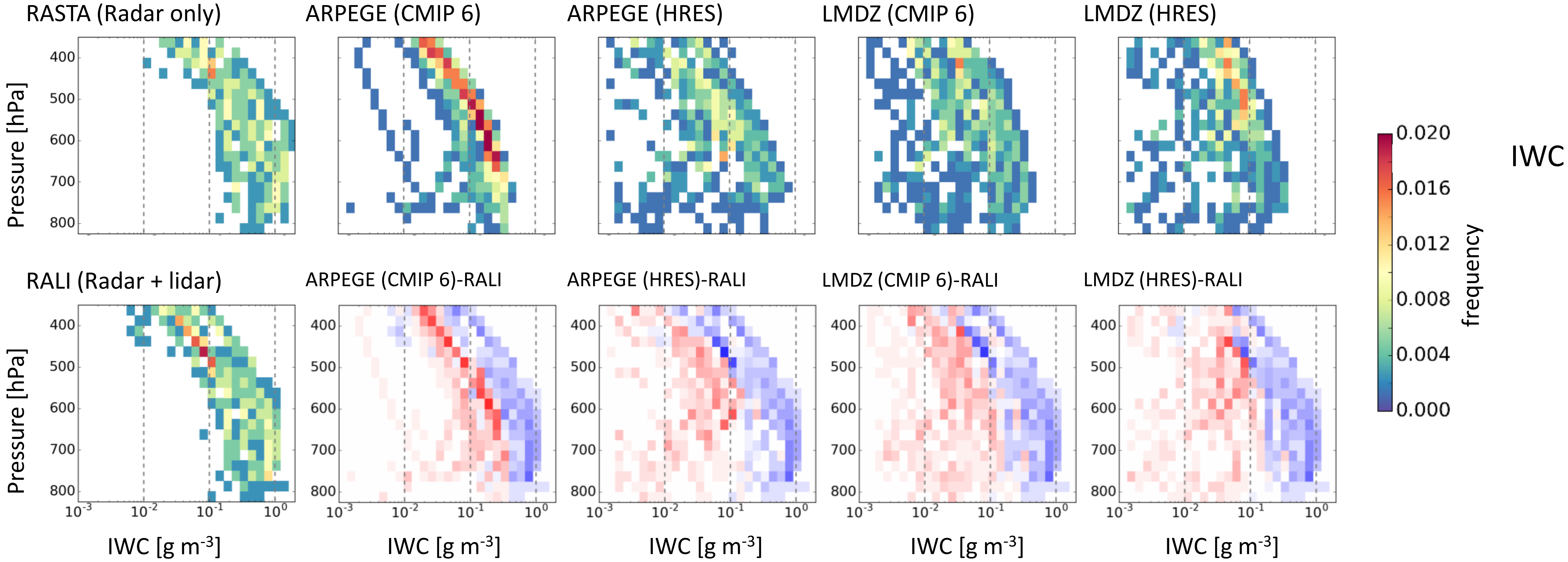
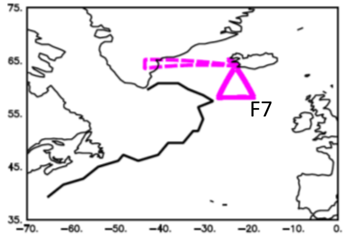


There is an underestimation in all models of the IWC

Observations: Ice Water Content: F7



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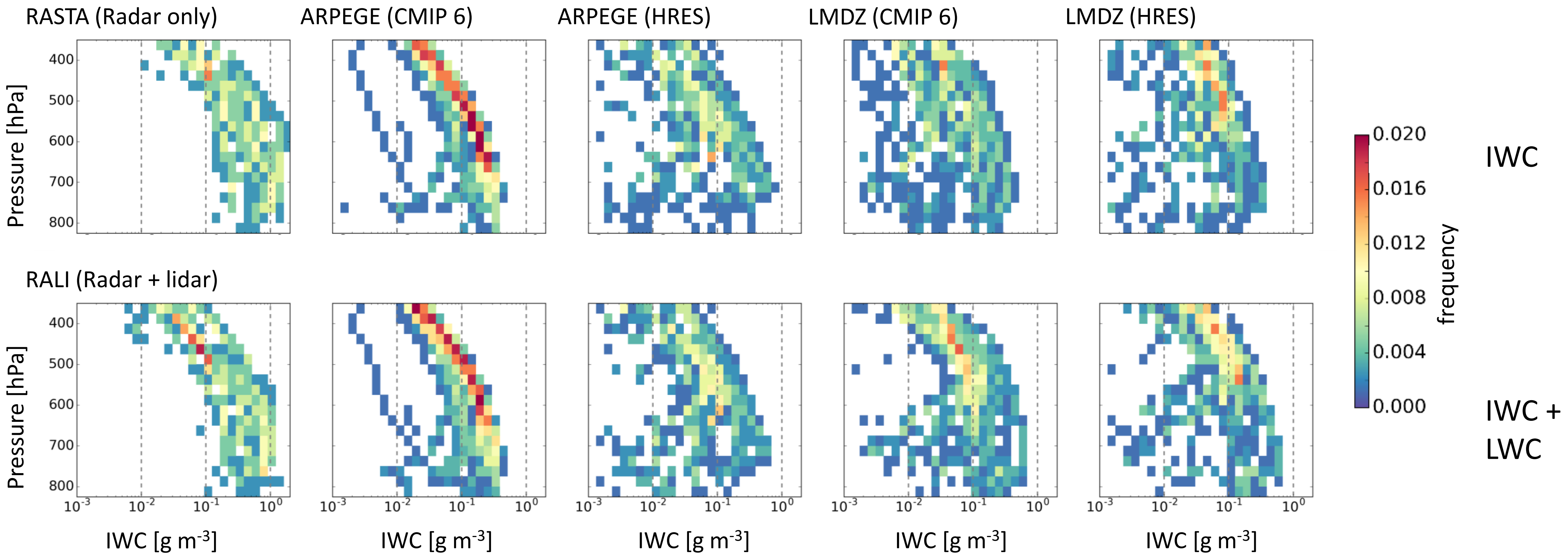
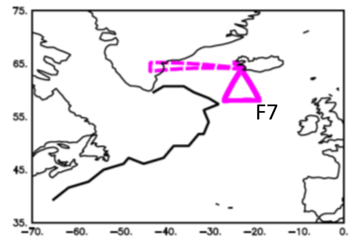


Ice content is larger at upper levels in LMDZ in both resolutions, and +LWC helps improve the shape



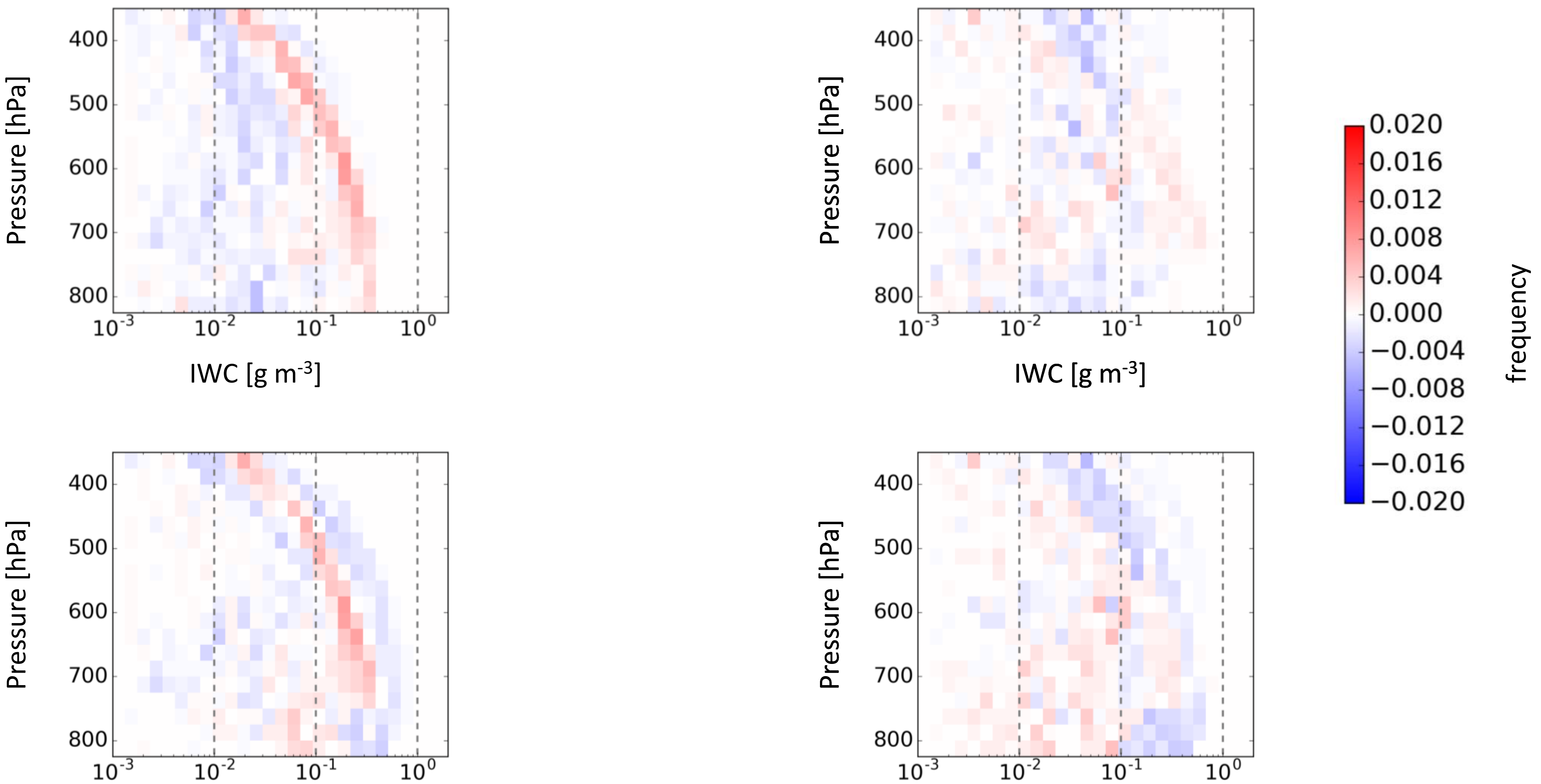
IWC differences: ARPEGE - LMDZ: F7

CMIP 6

HRES

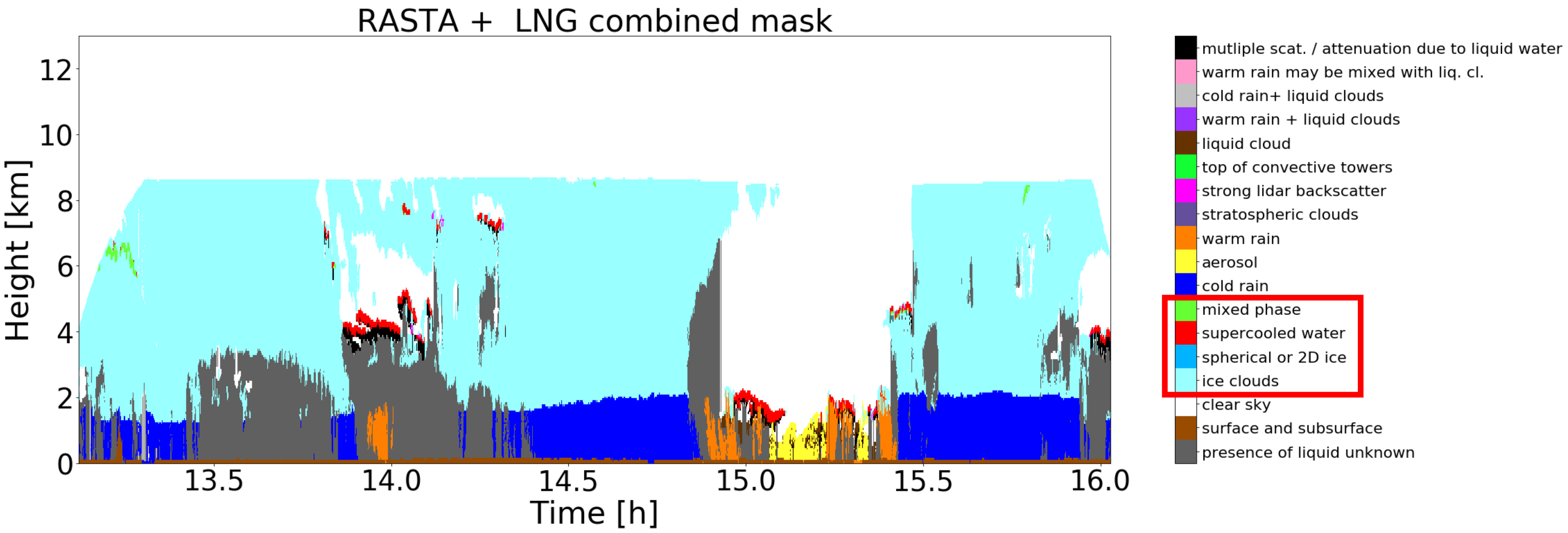
IWC

IWC+LWC



More ice LMDZ is associated with stronger diabatism at all resolutions

With RALI data we can determine if the particles are ice, super-cooled liquid and mixed phase



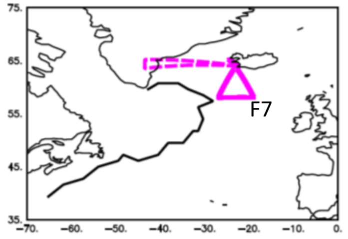
Ice Water fraction compared to Liquid Water fraction

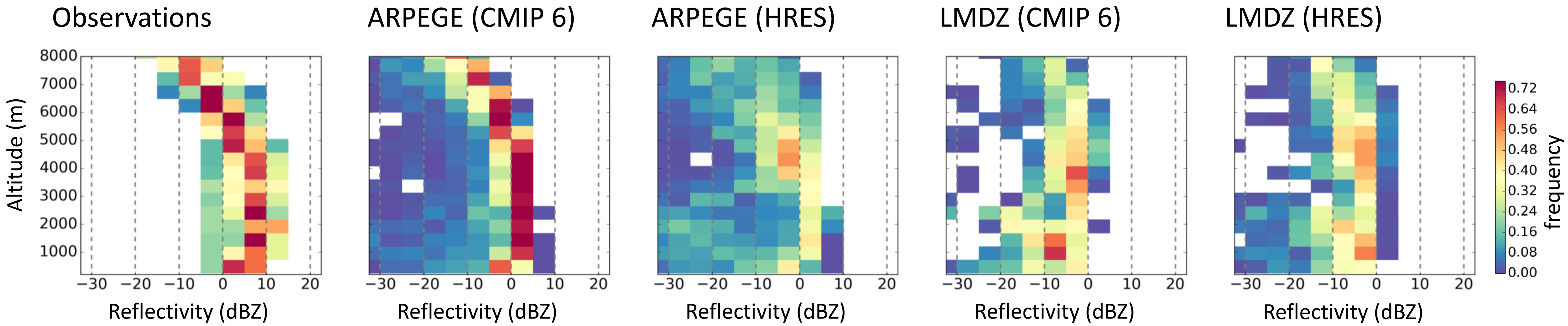
There is less water in ARPEGE compared to LMDZ, and too much water in LMDZ compared to the observations, regardless of threshold used to identify ice

	Observations	LMDZ CMIP 6	LMDZ HRES	ARPEGE CMIP 6	ARPEGE HRES
Super-cooled liquid [LWC > 0.99(TOTAL)]	1.5	1.2	0.5	0.0	0.0
Mixed phase [0.01(TOTAL) < LWC < 0.99(TOTAL)]	0.2	72.8	79.7	41.4	61.6
Ice [LWC < 0.01(TOTAL)]	98.3	26.0	19.8	58.6	38.4
combined Super-cooled liquid	1.7	74.0	80.2	41.4	61.6
combined Ice	98.5	98.8	99.5	100.0	100.0

Where
TOTAL = ICE + SNOW + LIQUID
Combined Super-cooled liquid = Super-cooled liquid + Mixed phase
Combined Ice = Ice + Mixed phase

Radar CFADs: F7

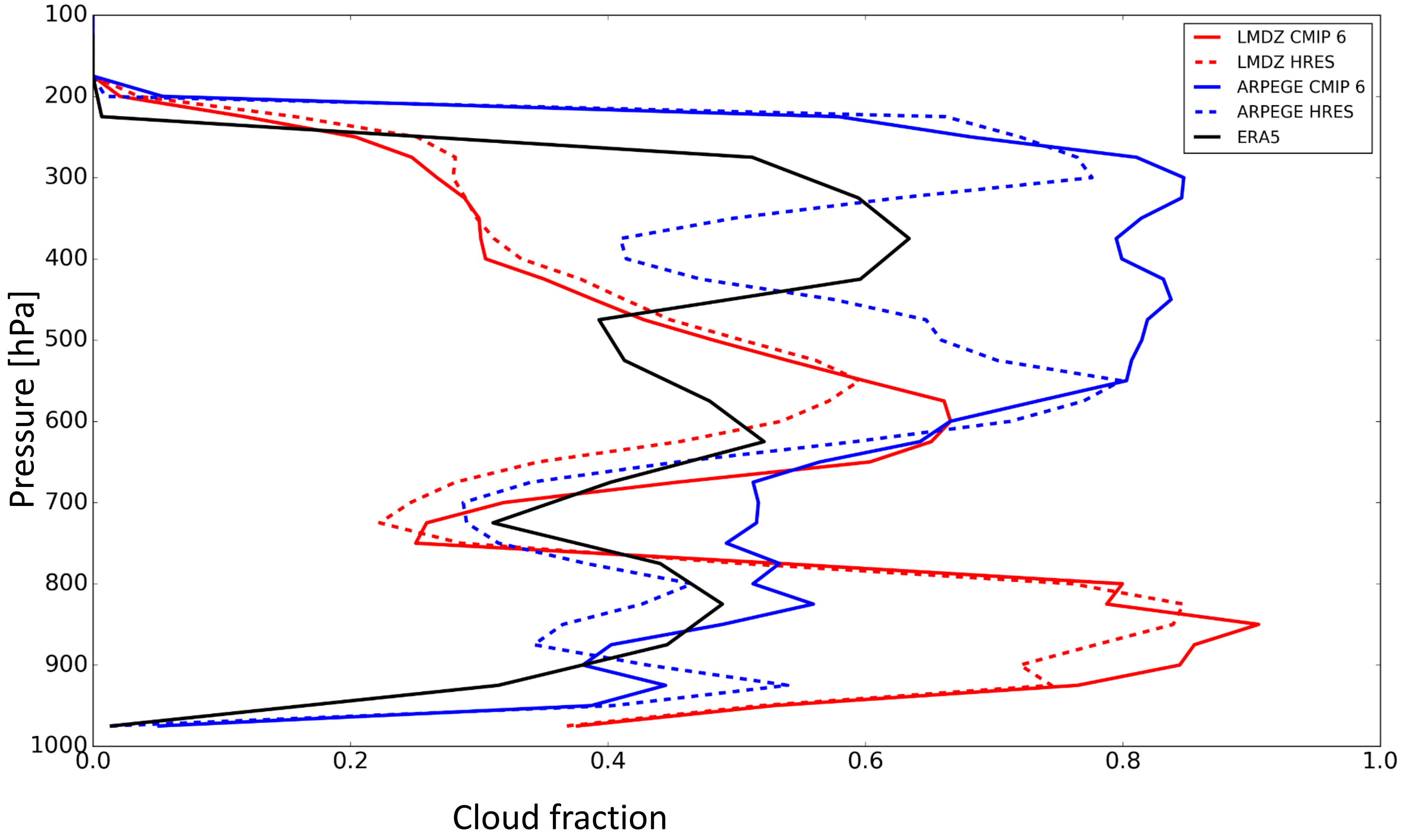




ARPEGE has better representation of reflectivity as it is more sensitive to the larger ice particles compared to the smaller liquid particles which are more numerous in LMDZ

Ice content is larger at upper levels in LMDZ but there is less cloud!

Cloud Fraction

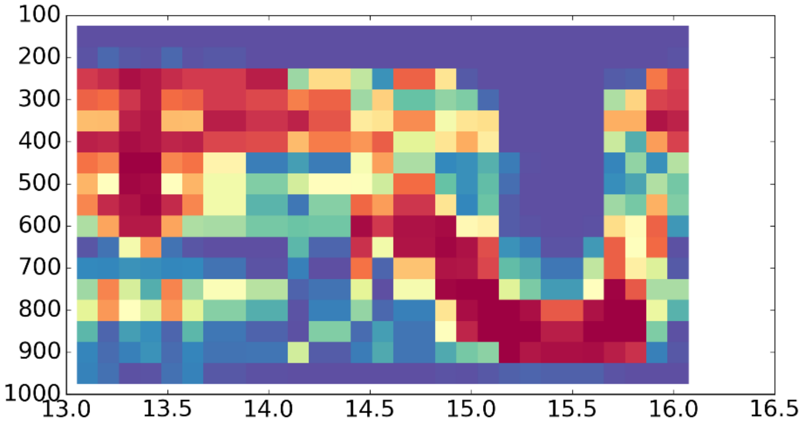


Cloud Fraction Cross-sections along F7

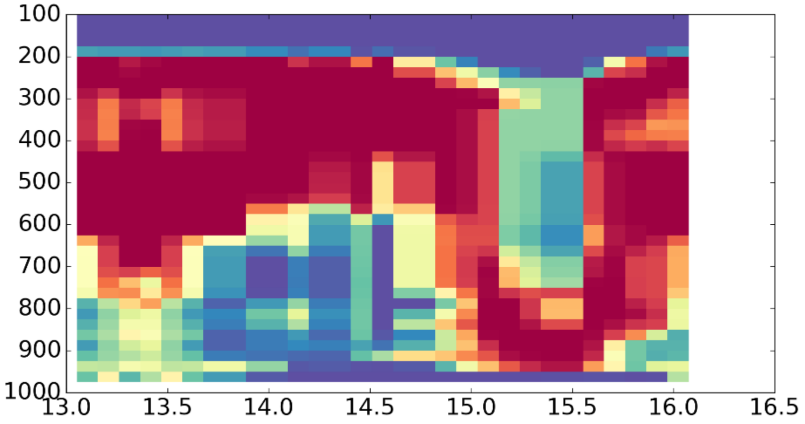
Red=1.0; green/yellow=0.5;blue=0.0

Cloud is more concentrated to lower levels in LMDZ

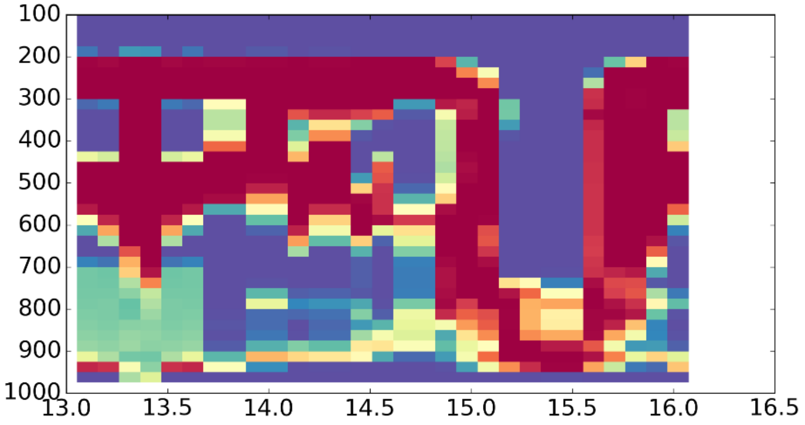
ERA 5



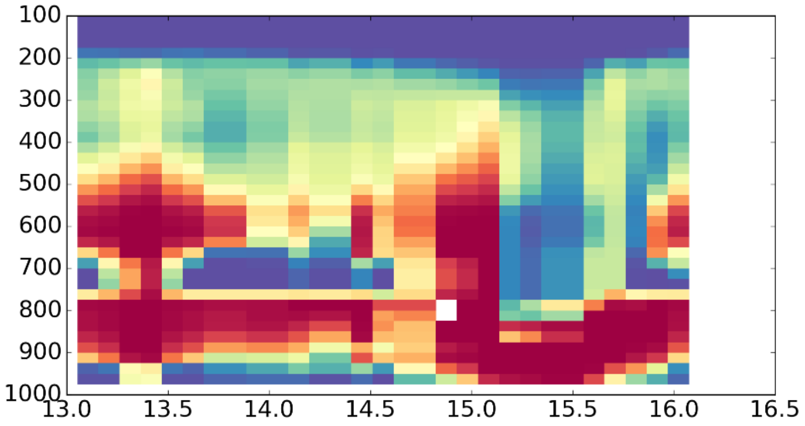
ARPEGE
CMIP6



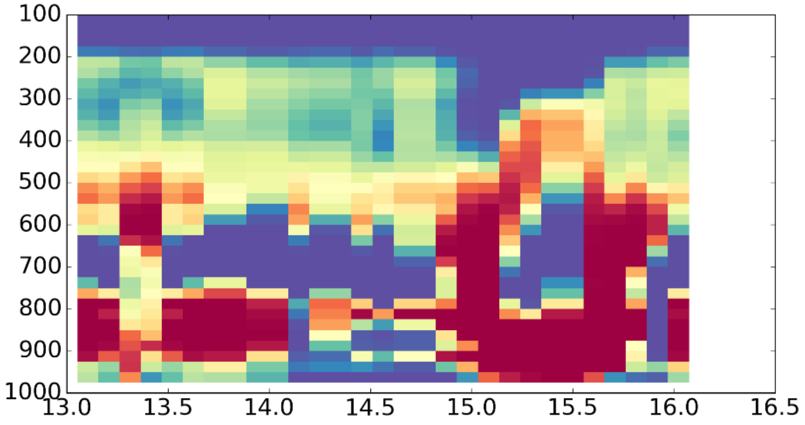
ARPEGE
HRES



LMDZ
CMIP6



LMDZ
HRES



Questions

- Why does LMDZ have less cloud at altitude given that it has more ice at higher atlitudes?
- Why do the models appear to over-estimate the amount of super-cooled liquid water in the atmosphere?
- How reliable are the observation splitting into ice, mixed phase, super-cooled liquid water?

Summary

- How well do climate models represent the two stages of the Stalactite Cyclone?
  - 0.5° (HRES) can represent the dyanmics well
  - CMIP 6 can do the mature stage but not cyclogenesis
- How do the relative roles of diabatic and dynamic processes in the development of the Stalactite Cyclone change with resolution?
  - Diabatic heating does not increase in relative importance with increasing resolution unlike previous studies (e.g. Willison et al., 2013; Trezciak et al., 2016)
- Can microphysical observations made during the field campaign give any useful information about the climate models' performance?
  - Some information is gained, but it is not complete

Supplementary Slides

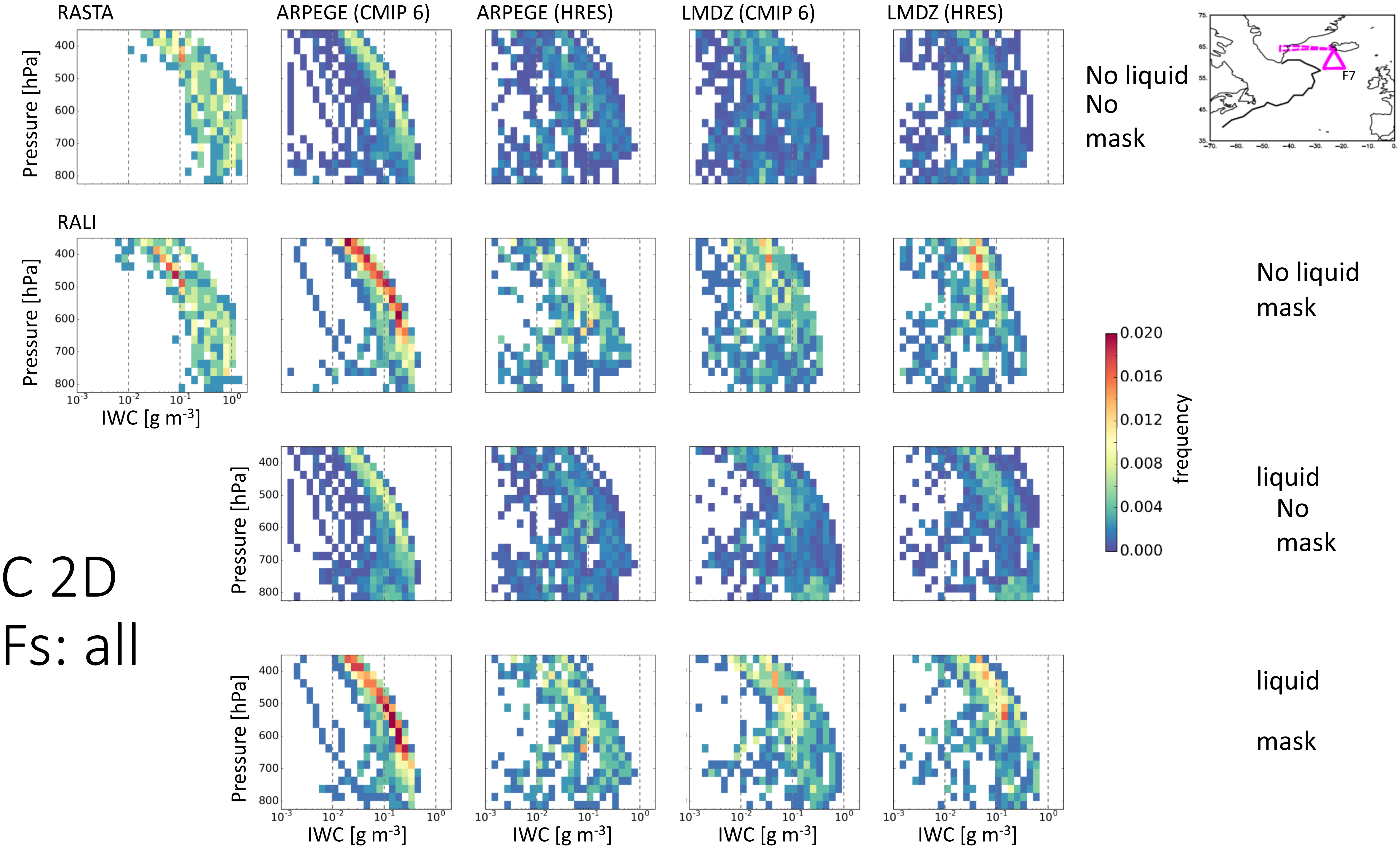
- F6 comparisons
- Model details

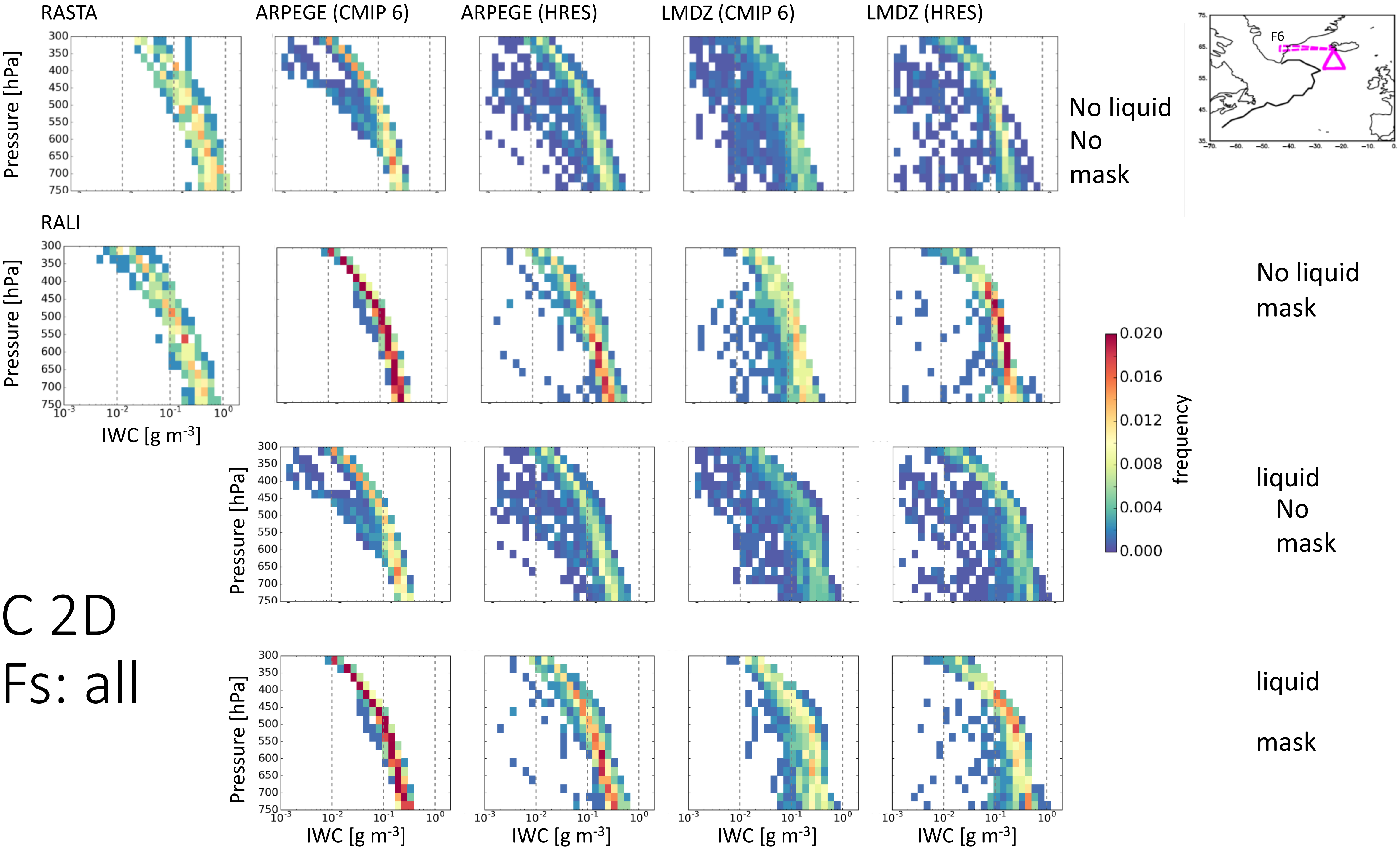
Climate Models

	ARPEGE-Climat	**LMDZ**
CMIP 6	T127 (~1.1°)	2.5° x 1.7°
HRES	T359 (~0.5°)	zoom to 0.5° over N Atlantic; rest of domain 1.1°
Physics	CMIP 6	CMIP 6
Hindcast initiation dates	27,28,**29 September** and 1,2 October 2016	27,28,**29 September** and 1,2 October 2016
Hindcast initiation time	00 UTC	00 UTC
Hindcast length	10 days	10 days
Vertical output	Pressure levels every 25 hPa	Pressure levels every 25 hPa
Temporal output	3 h	3 h
Initial Conditions	ECMWF analysis	ECMWF analysis
Data considered after	T + 18 h	T + 18 h

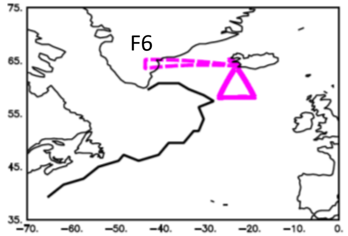
Observations; **entire lifecycle**

IWC 2D PDFs: all F7





IWC 2D PDFs: all F6



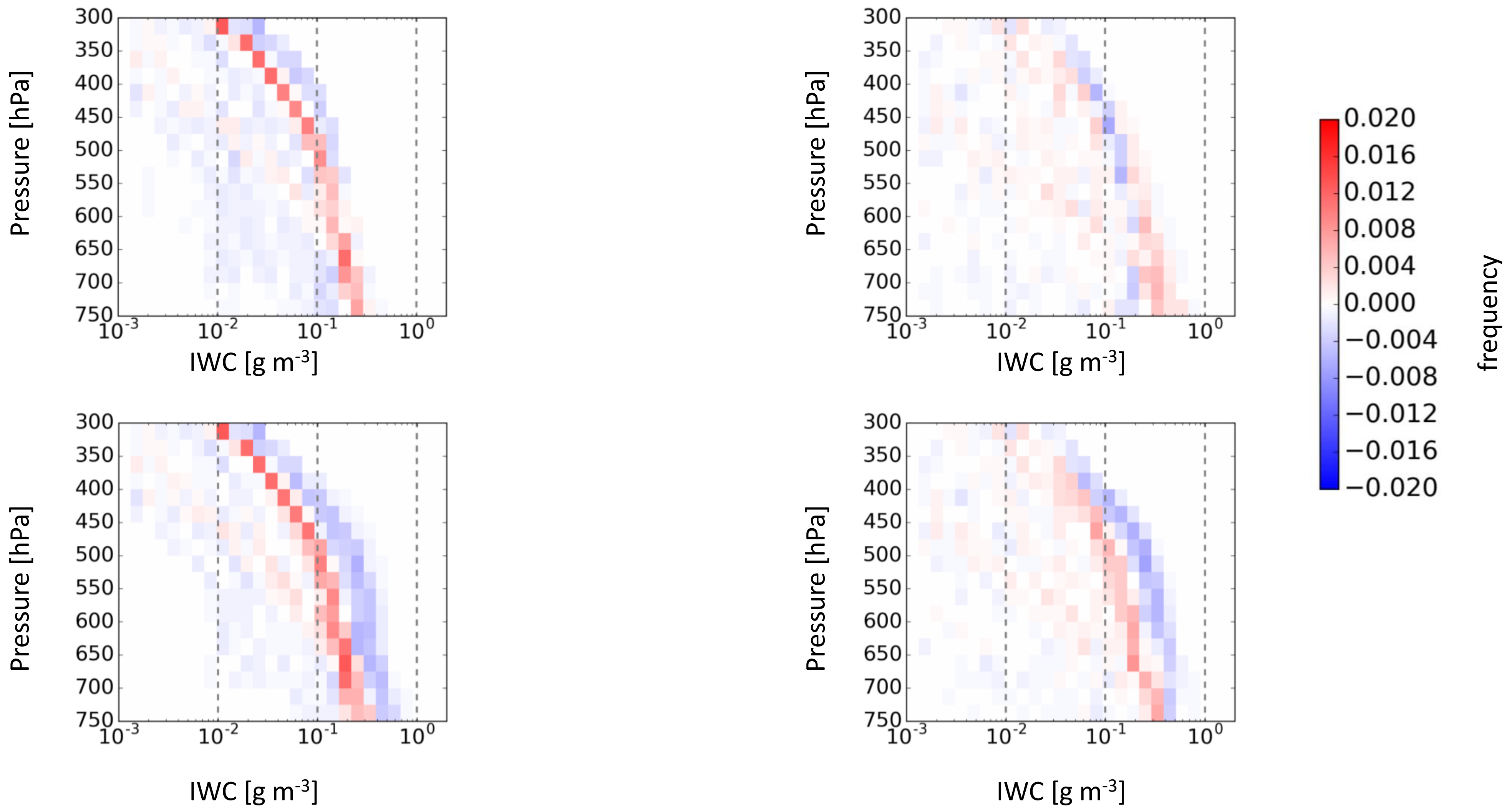
IWC Differences: F6

CMIP 6

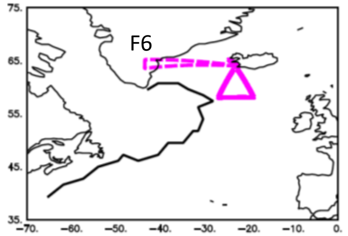
HRES

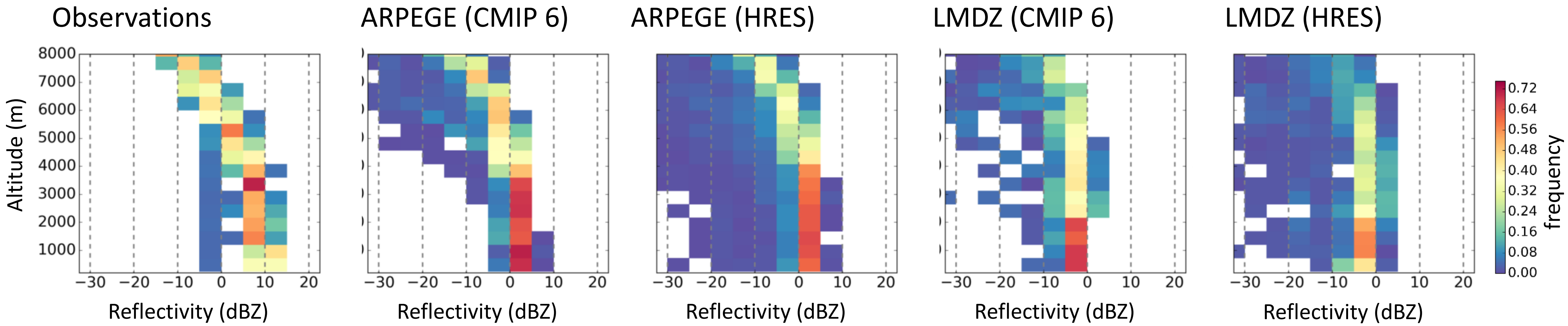
IWC

IWC+LWC



Radar CFADs: F6





Sensitivity to LWC/IWC definitions

	Observations	LMDZ CMIP 6	LMDZ HRES	ARPEGE CMIP 6	ARPEGE HRES
Super-cooled liquid [LWC > 0.95(TOTAL)]	1.5	3.2	1.7	0.0	0.2
Mixed phase [0.05(TOTAL) < LWC < 0.95(TOTAL)]	0.2	67.7	75.5	8.7	36.2
Ice [LWC < 0.05(TOTAL)]	98.3	29.1	22.8	91.3	63.6
combined Super-cooled liquid	1.7	70.9	77.2	8.7	36.4
combined Ice	98.5	96.8	98.3	100.0	99.8

Where
TOTAL = ICE + SNOW + LIQUID
Combined Super-cooled liquid = Super-cooled liquid + Mixed phase
Combined Ice = Ice + Mixed phase

Sensitivity to LWC/IWC definitions

	Observations	LMDZ CMIP 6	LMDZ HRES	ARPEGE CMIP 6	ARPEGE HRES
Super-cooled liquid [LWC > 0.9(TOTAL)]	1.5	5.3	2.9	0.0	0.3
Mixed phase [0.1(TOTAL) < LWC < 0.9(TOTAL)]	0.2	60.7	70.5	0.9	21.3
Ice [LWC < 0.1(TOTAL)]	98.3	34.0	26.6	99.1	78.4
combined Super-cooled liquid	1.7	66.0	73.4	0.9	21.6
combined Ice	98.5	94.7	97.1	100.0	99.7

Where
TOTAL = ICE + SNOW + LIQUID
Combined Super-cooled liquid = Super-cooled liquid + Mixed phase
Combined Ice = Ice + Mixed phase

Sensitivity to LWC/IWC definitions

	Observations	LMDZ CMIP 6	LMDZ HRES	ARPEGE CMIP 6	ARPEGE HRES
Super-cooled liquid [LWC > 0.75(TOTAL)]	1.5	9.9	7.7	0.0	2.2
Mixed phase [0.25(TOTAL) < LWC < 0.75(TOTAL)]	0.2	42.3	56.3	0.3	8.2
Ice [LWC < 0.25(TOTAL)]	98.3	47.8	36.0	99.7	89.6
combined Super-cooled liquid	1.7	52.2	64.0	0.3	10.4
combined Ice	98.5	90.1	92.3	100.0	97.8

Where
TOTAL = ICE + SNOW + LIQUID
Combined Super-cooled liquid = Super-cooled liquid + Mixed phase
Combined Ice = Ice + Mixed phase