Vortex-vortex interaction between Hurricane *Nadine* (2012) and an Atlantic cutoff dropping the predictability over the Mediterranean

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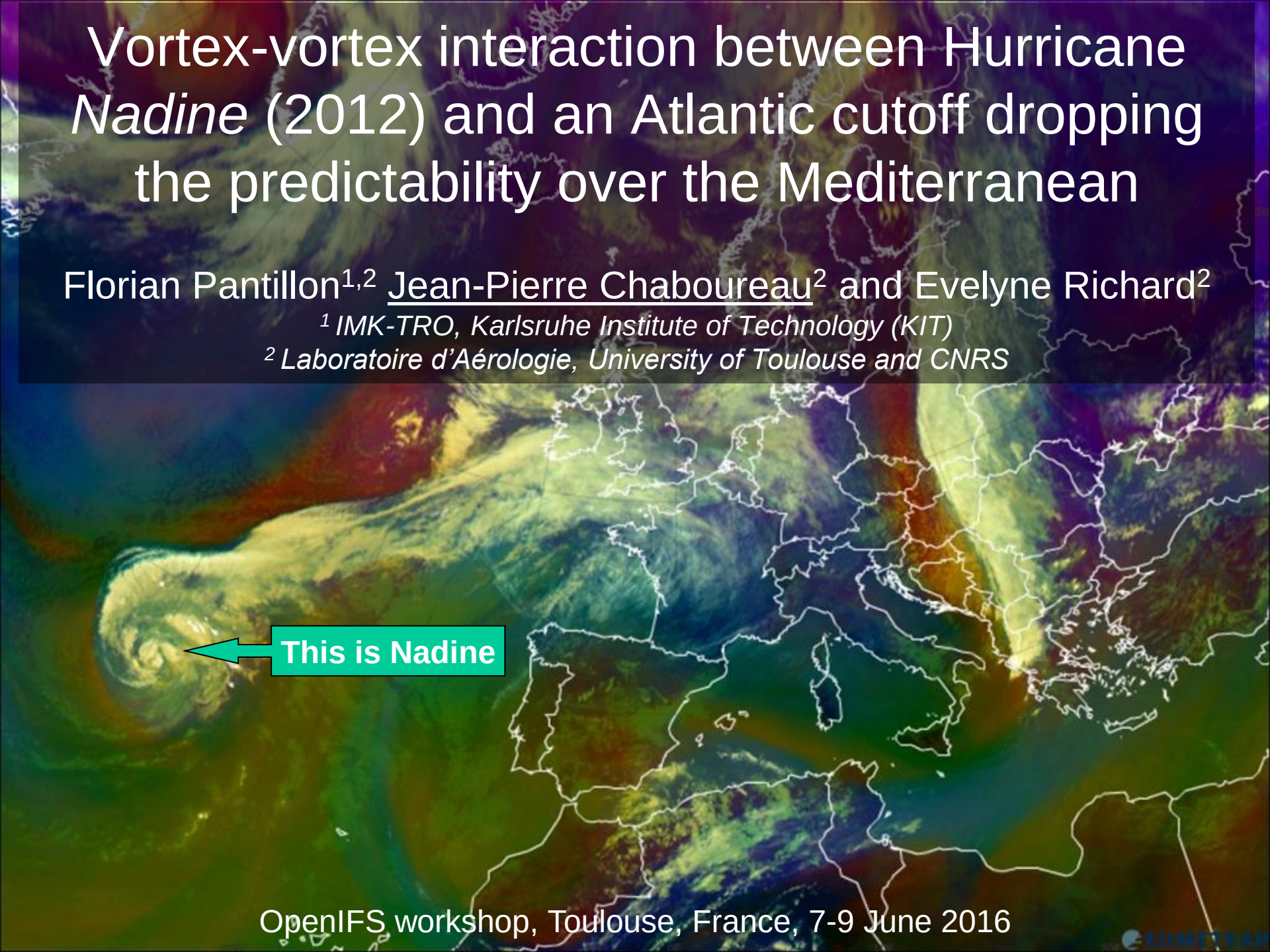
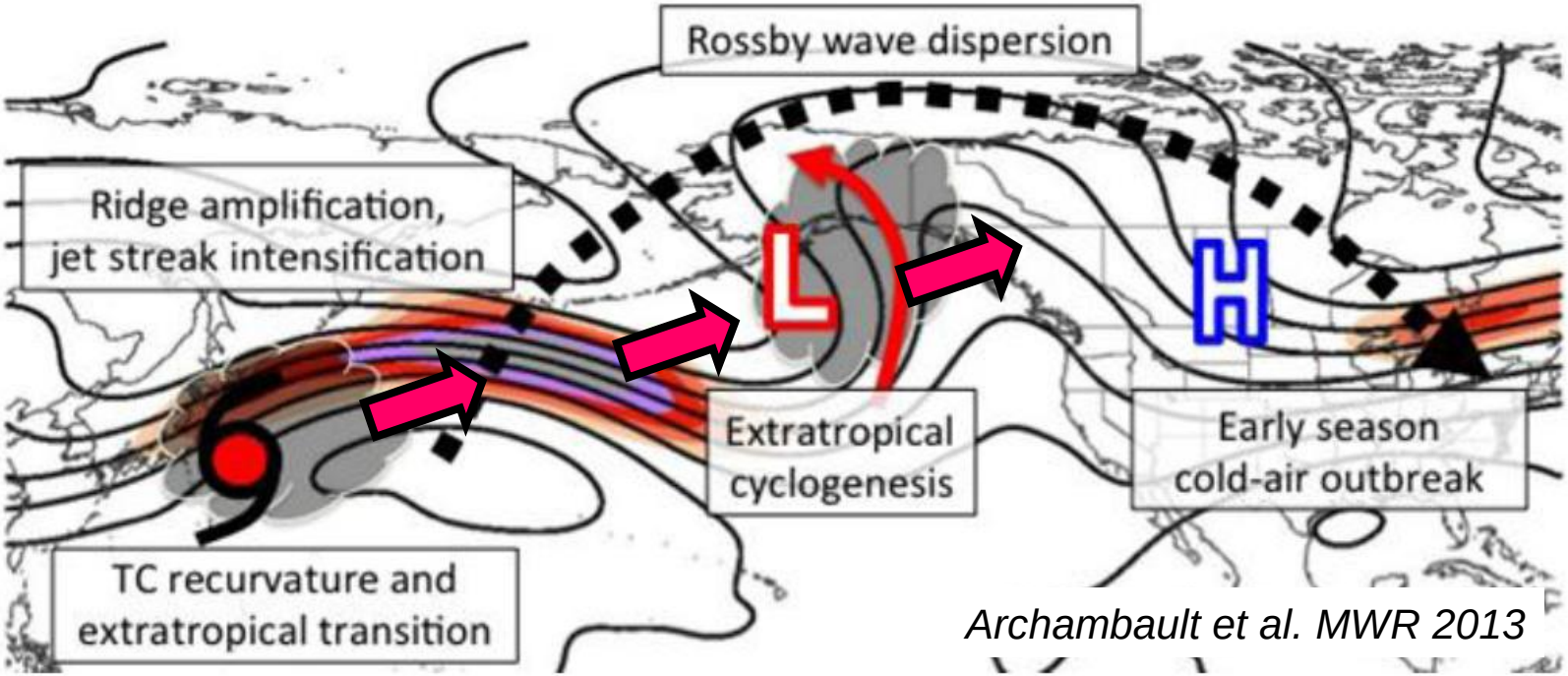


OpenIFS workshop, Toulouse, France, 7-9 June 2016

Remote impact of a hurricane

A hurricane can modify the midlatitude flow when it leaves the tropics

- the hurricane outflow accelerates an upper-level jet and builds a ridge
- the downstream trough **elongates** and triggers surface cyclogenesis
- the impact quickly propagates downstream as a **Rossby wave train**



Archambault et al. MWR 2013

Hurricanes interact with the midlatitude flow **in autumn mostly**

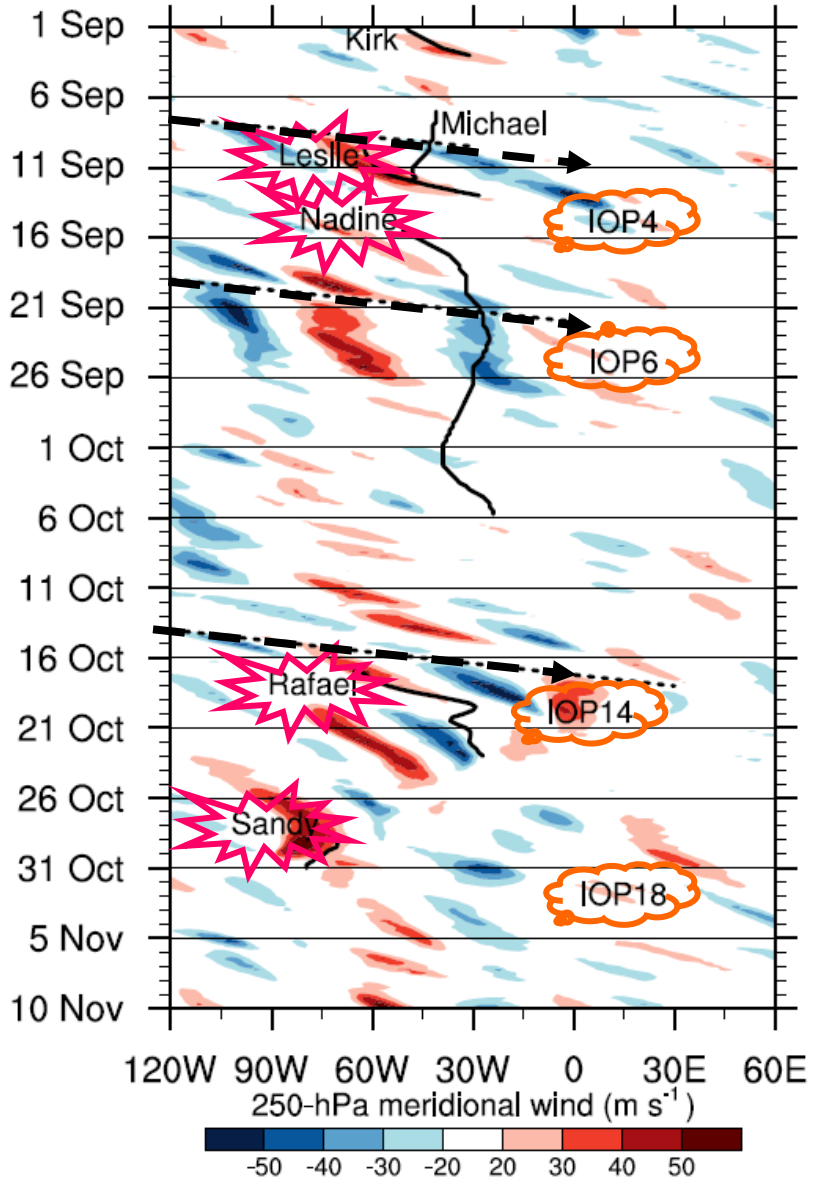
Impact of hurricanes during HyMeX SOP1

Some intense rainfall episodes were
- triggered by an elongated trough from a Rossby wave train
- located downstream of a hurricane in the midlatitudes

Hurricanes **Leslie**, **Rafael** and **Sandy** *locally* impeded the forward progression of an upstream trough, then reintensified as an extratropical cyclone. Their *remote* impact on the Mediterranean was weak or decreased the intensity of the rain

The interaction of tropical cyclones with the midlatitude flow over the western North Atlantic may be considered **a perturbation to**, rather than a source of, **downstream wave breaking** (*Pantillon et al. QJ 2015)*

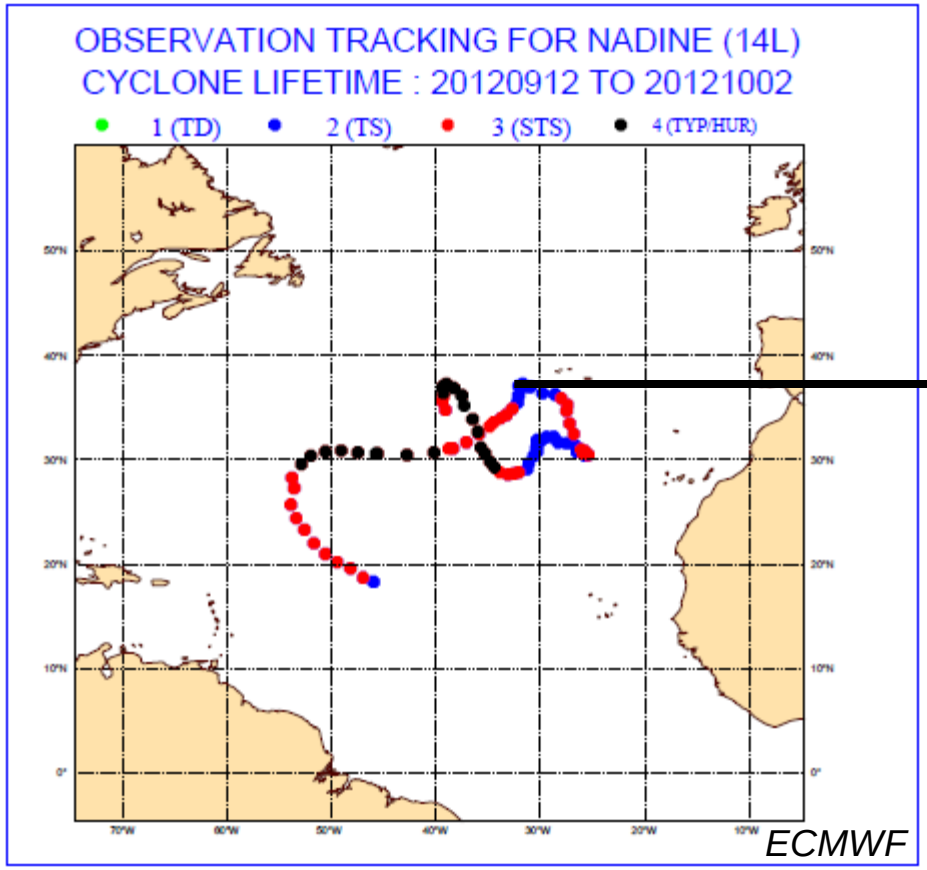
What about Hurricane **Nadine**?



The extraordinary life of Hurricane *Nadine*

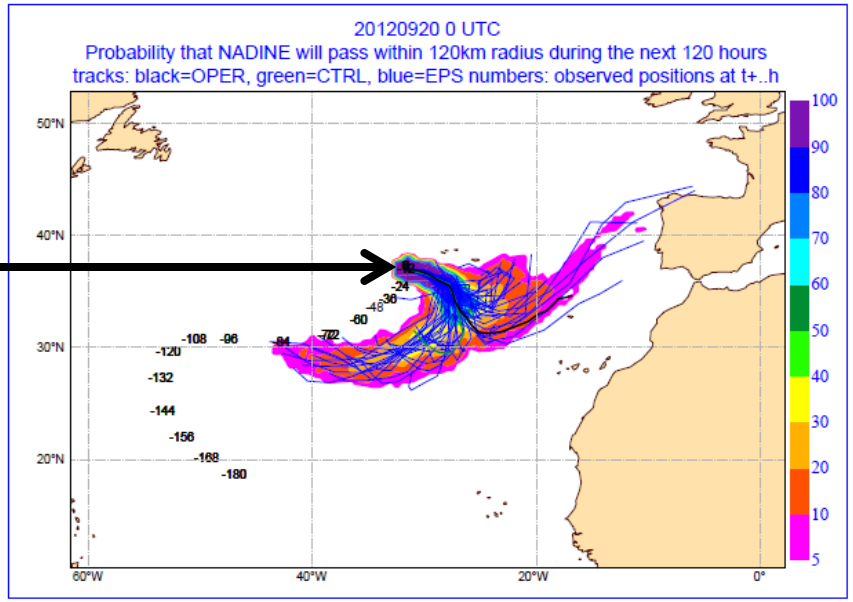
Unusual long and complex life cycle in September-October 2012

- 22 days (4th longest in history)
- Loops over the eastern Atlantic
- 2 periods with hurricane strength



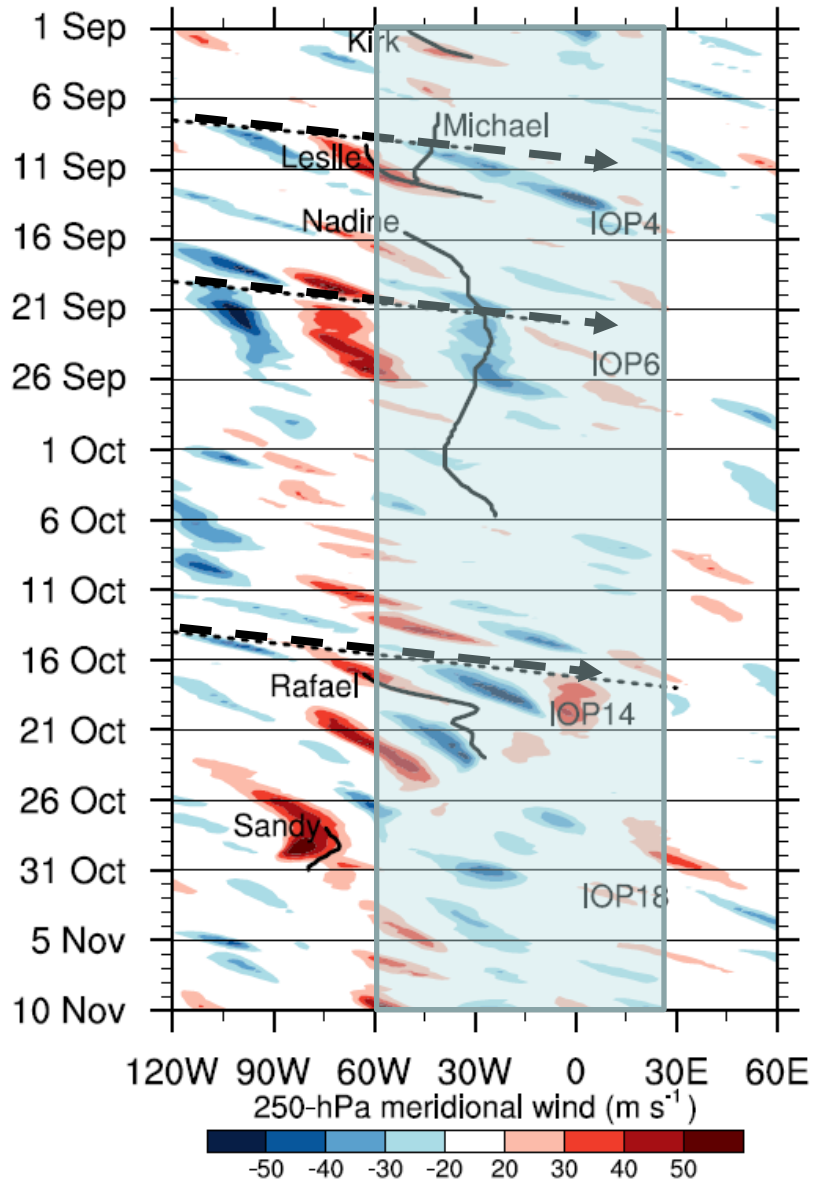
Low predictability over the eastern Atlantic

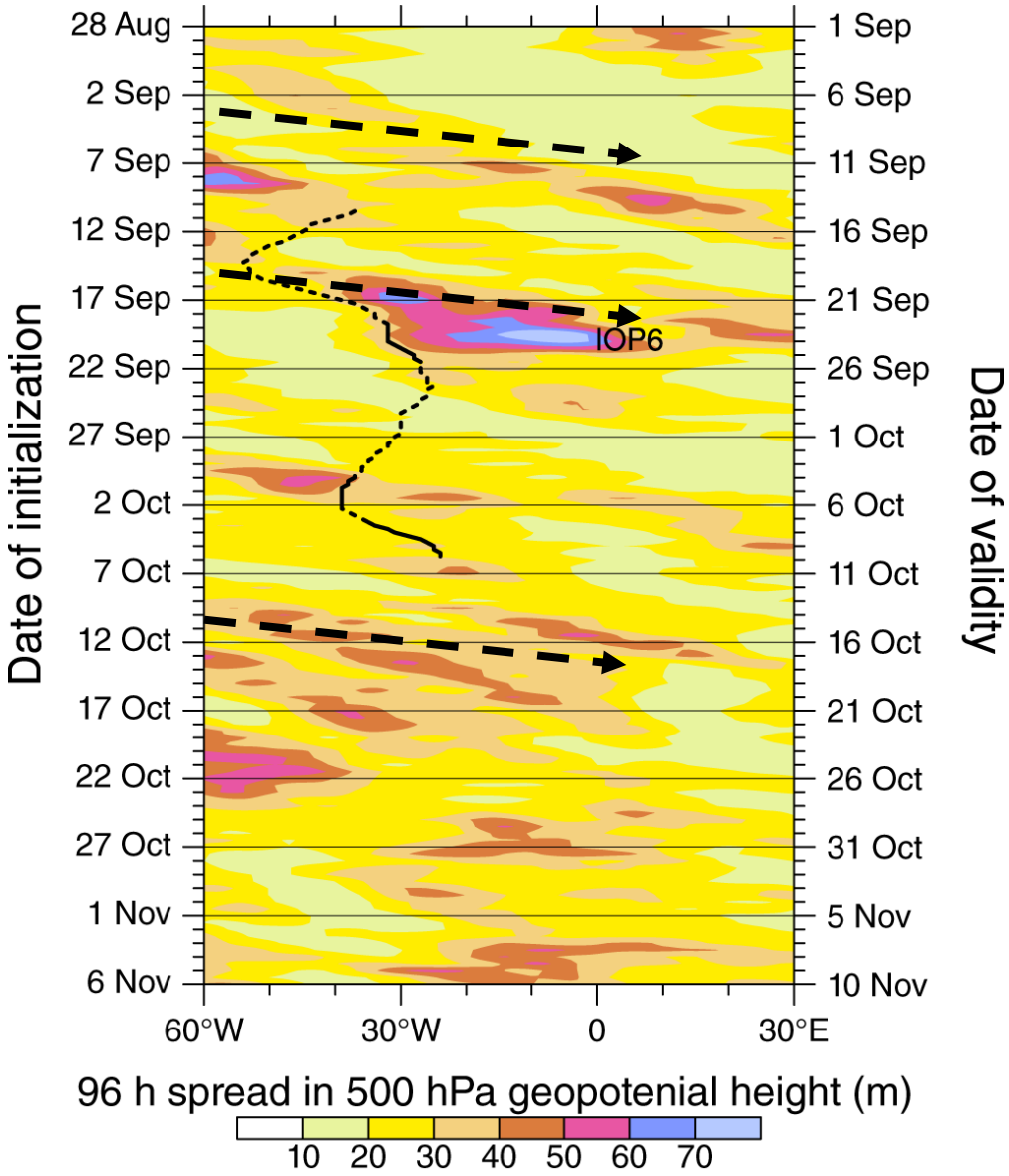
- **bifurcation** in operational forecasts between eastward and westward tracks
- similar to bifurcation in cyclone tracks during interaction with upper-level trough *(Scheck et al. 2011, Grams et al. 2013, Pantillon et al. 2013, Riemer and Jones 2013)*



ECMWF ensemble forecast initialised at 00 UTC 20 Sep

The lowest predictability for IOP6



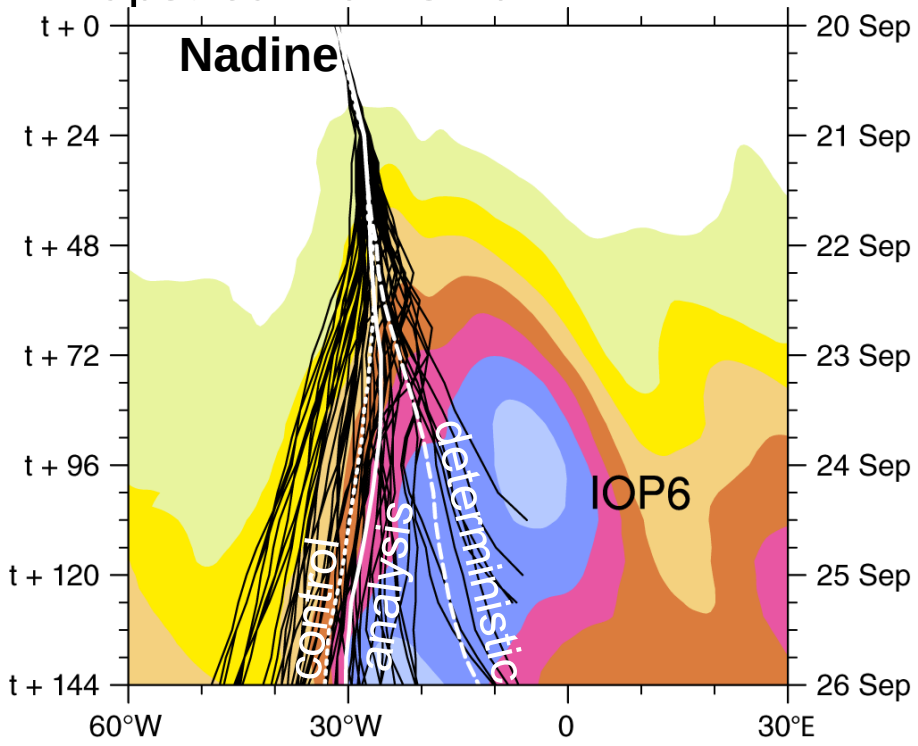


Pantillon et al., Quart. J. Roy. Meteor. Soc.. 2016

The lowest predictability for IOP6

The lowest predictability in ensemble forecast on 24 September

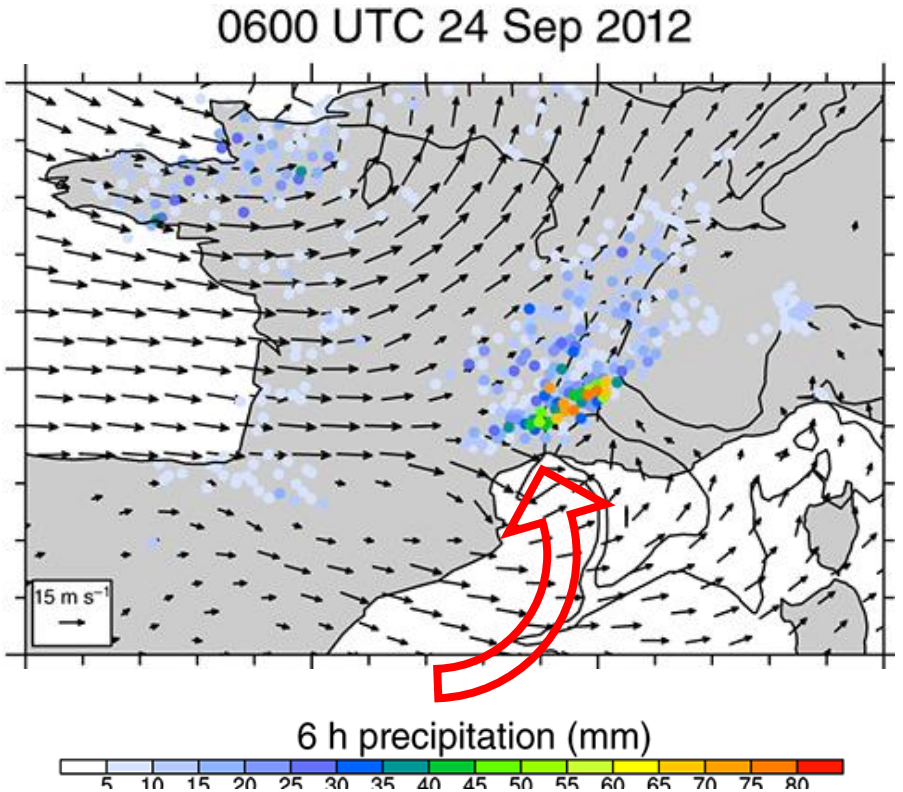
1. downstream of Hurricane Nadine
2. upstream of IOP6 HPE



ECMWF ensemble forecast initialised at 00 UTC 20 Sep

Convective line on 24 September

- >70mm/6h over the Cévennes
- 184mm over northeastern Italy

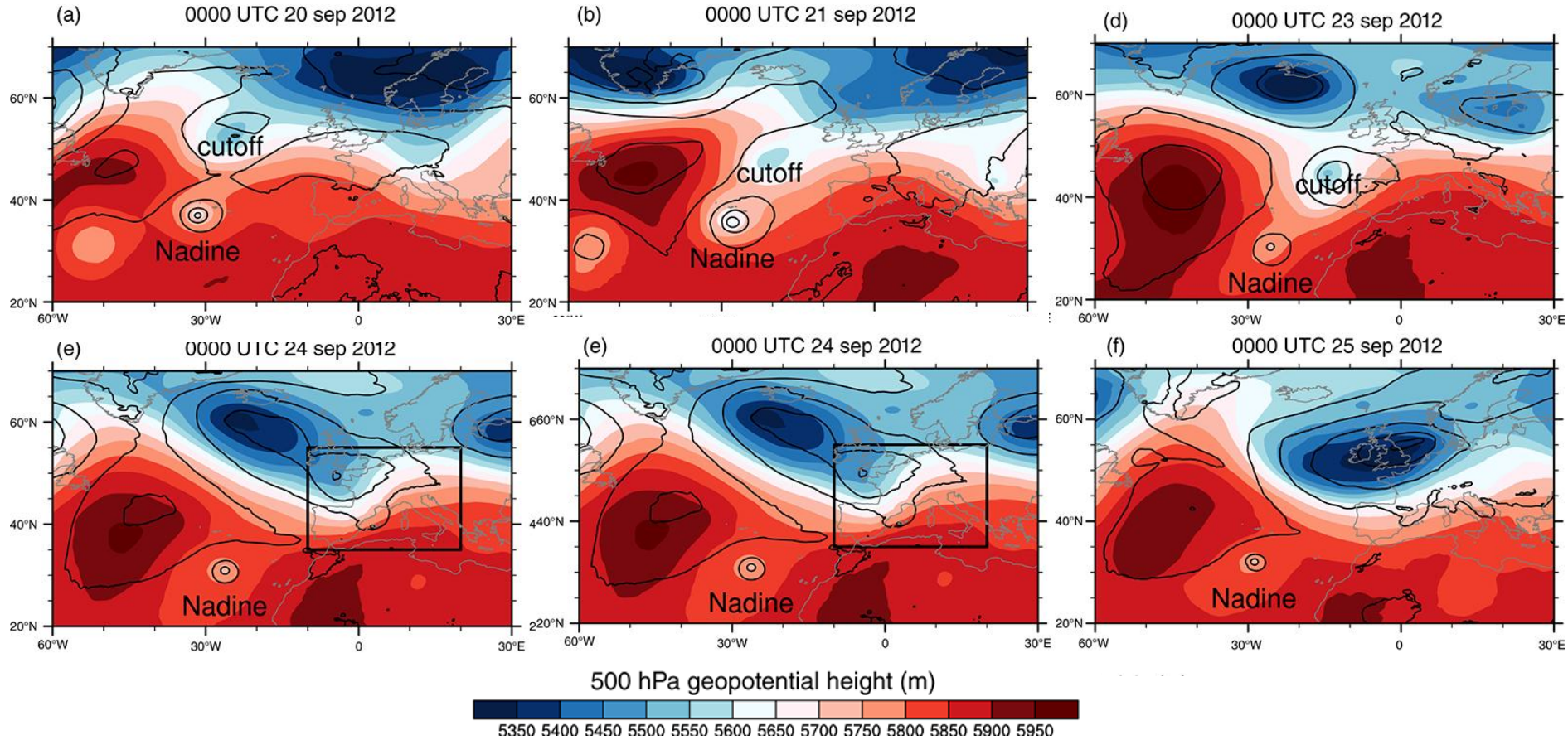


Precipitation observation from HyMeX database
500-hPa geopotential and 925-hPa wind from ECMWF

Synoptic evolution on 20-25 September

Track of post-tropical storm Nadine over the eastern North Atlantic

- Nadine moves slowly while a cut-off approaches from the north
- The cut-off is steered by a trough and moves eastward
- Nadine is steered by a ridge and turns westward



Pantillon et al., Quart. J. Roy. Meteor. Soc.. 2016

Understanding the forecast uncertainty

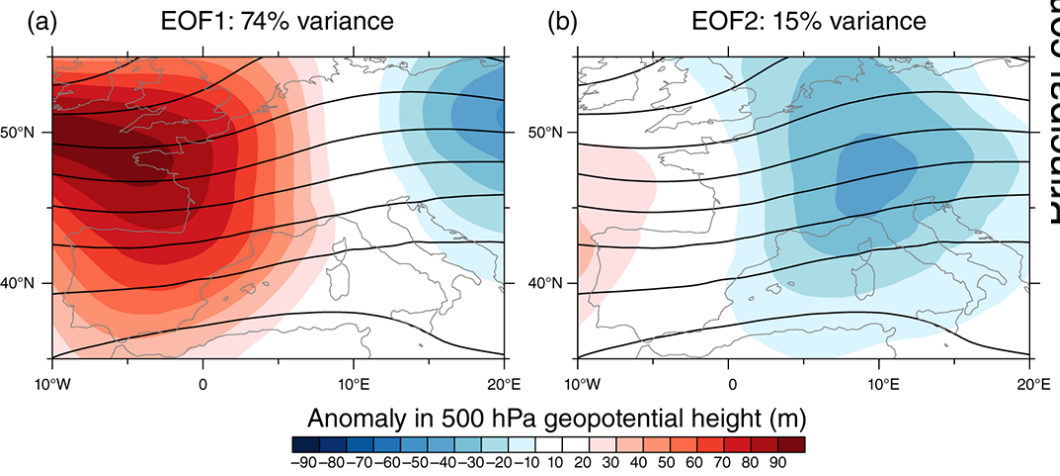
ECMWF ensemble forecast (Δx=30km)

initialized at 00 UTC 20 September

- 50 perturbed members + 1 control
- Initial perturbations: singular vectors
- Also perturbed physics during run

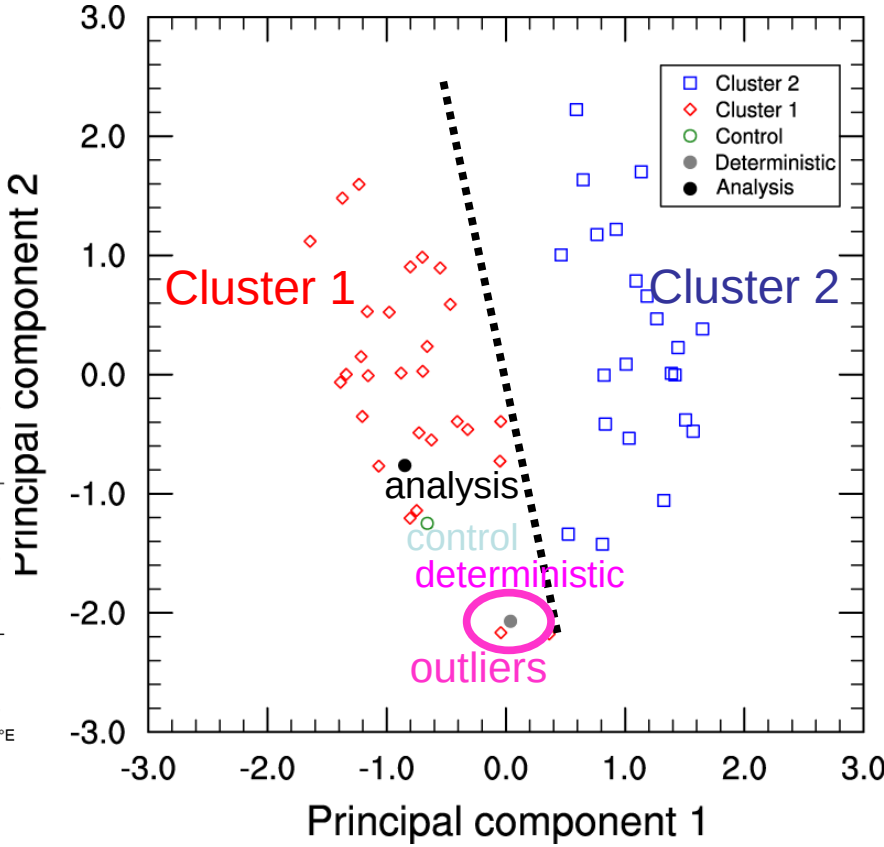
Principal Component Analysis

- Target: 00 UTC 24 September (t+96)
- Field: 500-hPa geopotential height
- Area: northwestern Mediterranean

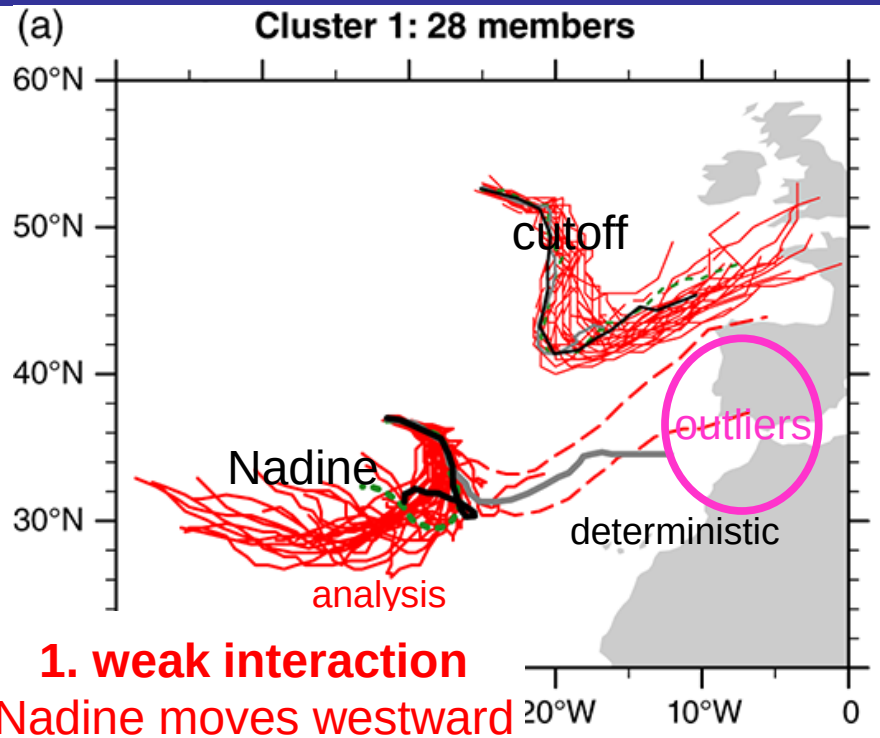


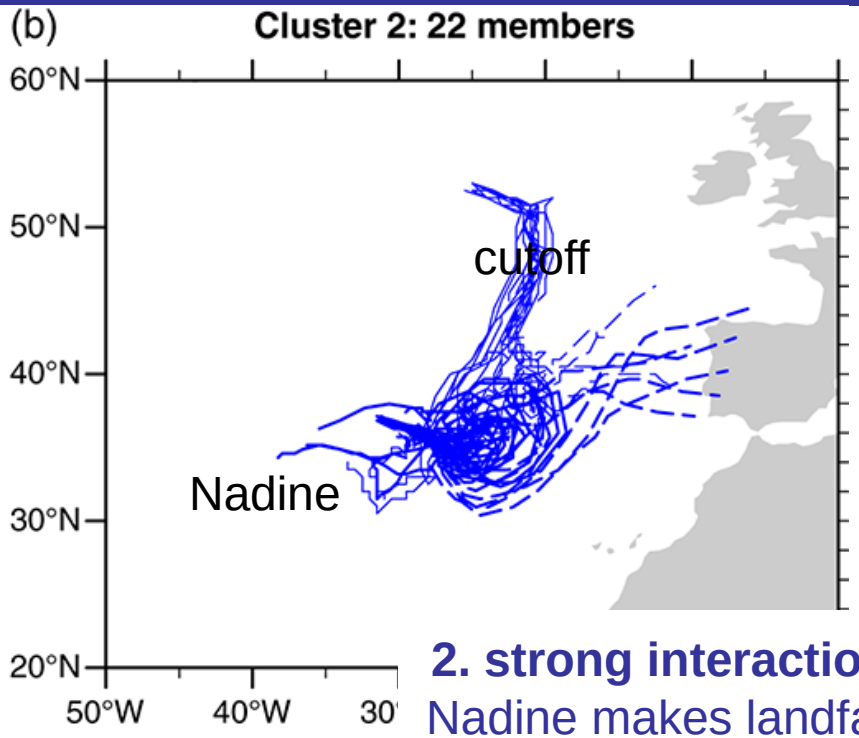
Clustering of 50 ensemble members

- projection on 2 principal components
- ascending hierarchical classification
- number of clusters = 2 (arbitrary)



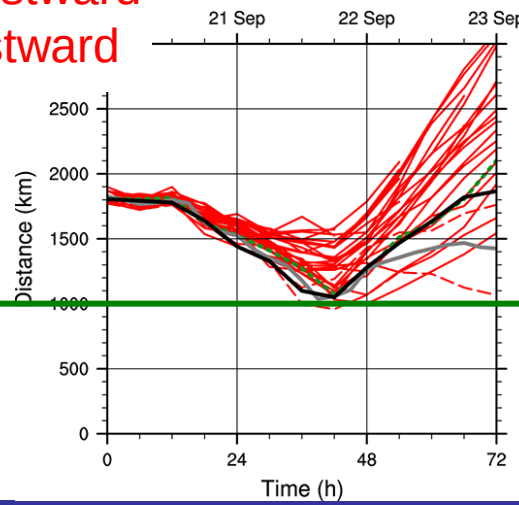
Two scenarios for Nadine-cutoff interaction

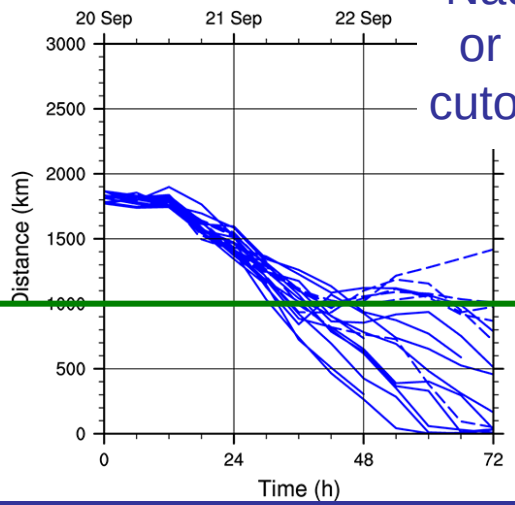




1. weak interaction
Nadine moves westward
cutoff moves eastward

2. strong interaction
Nadine makes landfall
or merges with cutoff
cutoff moves southward





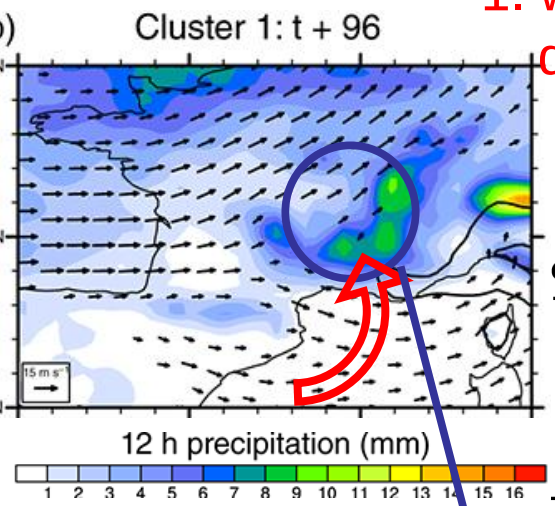
Critical distance
1000 km

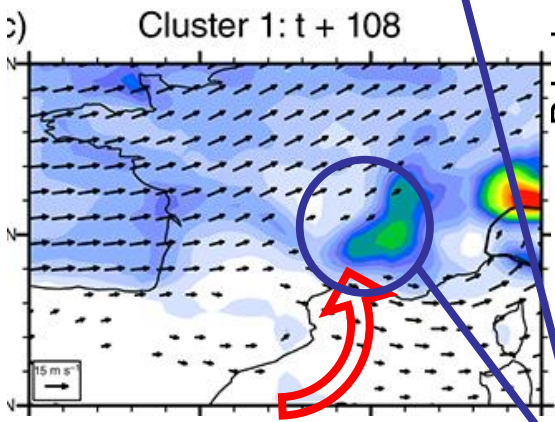
Strong impact on precipitation predictability

12-24 UTC 23 Sep

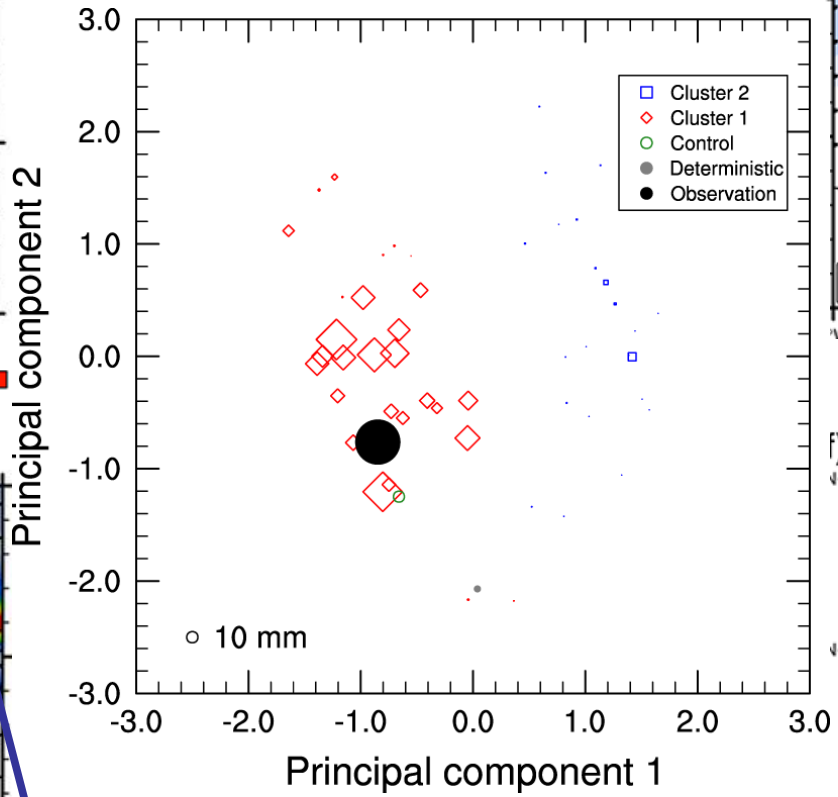
1. weak interaction
delayed cutoff

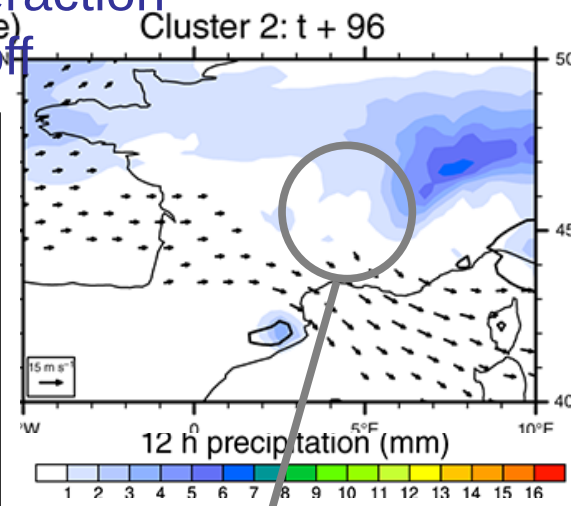
2. strong interaction
no cutoff

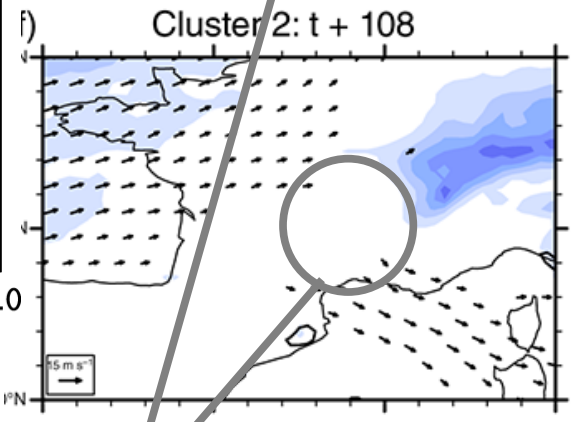




00-12 UTC 24 Sep





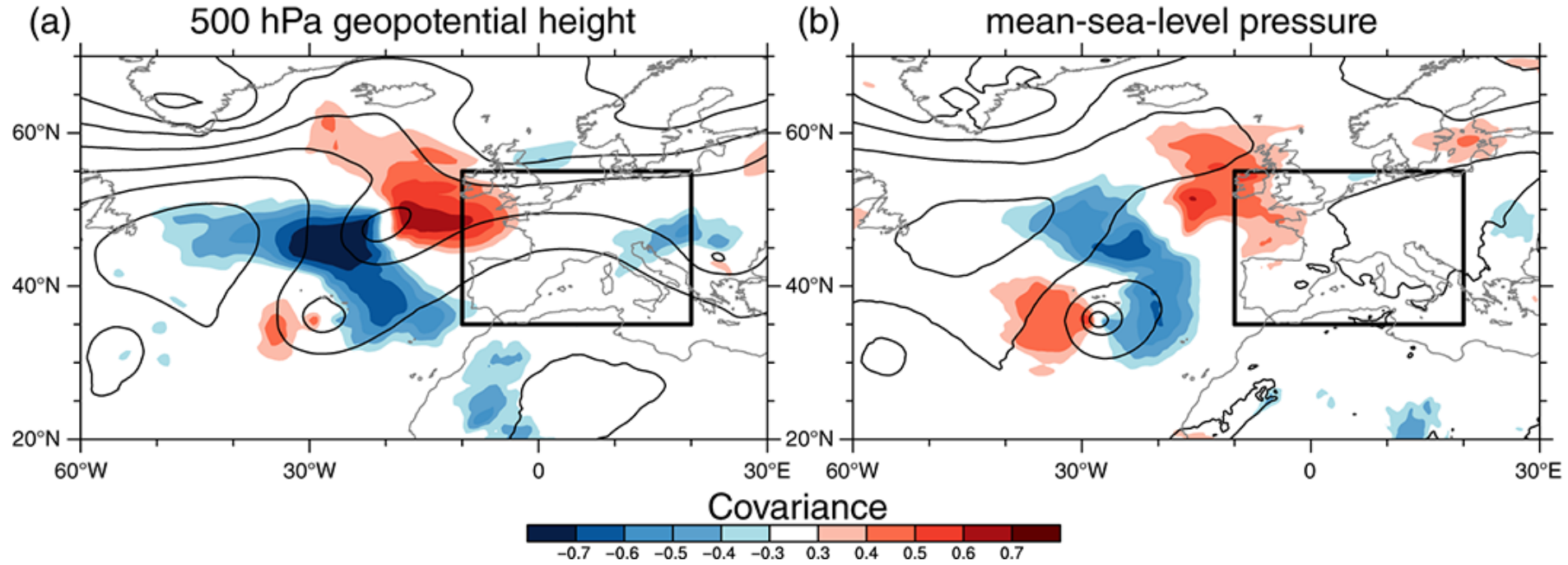


Precipitation over the Cévennes

No precipitation over the Cévennes

Sources of forecast uncertainty

Linear error growth: Ensemble sensitivity tracked back in time *(Torn and Hakim 2008, Chang et al. 2013)* *ensemble sensitivity* defined in each point as correlation among 50 members between 500-hPa geopotential and Principal Component



but based on linear assumptions…

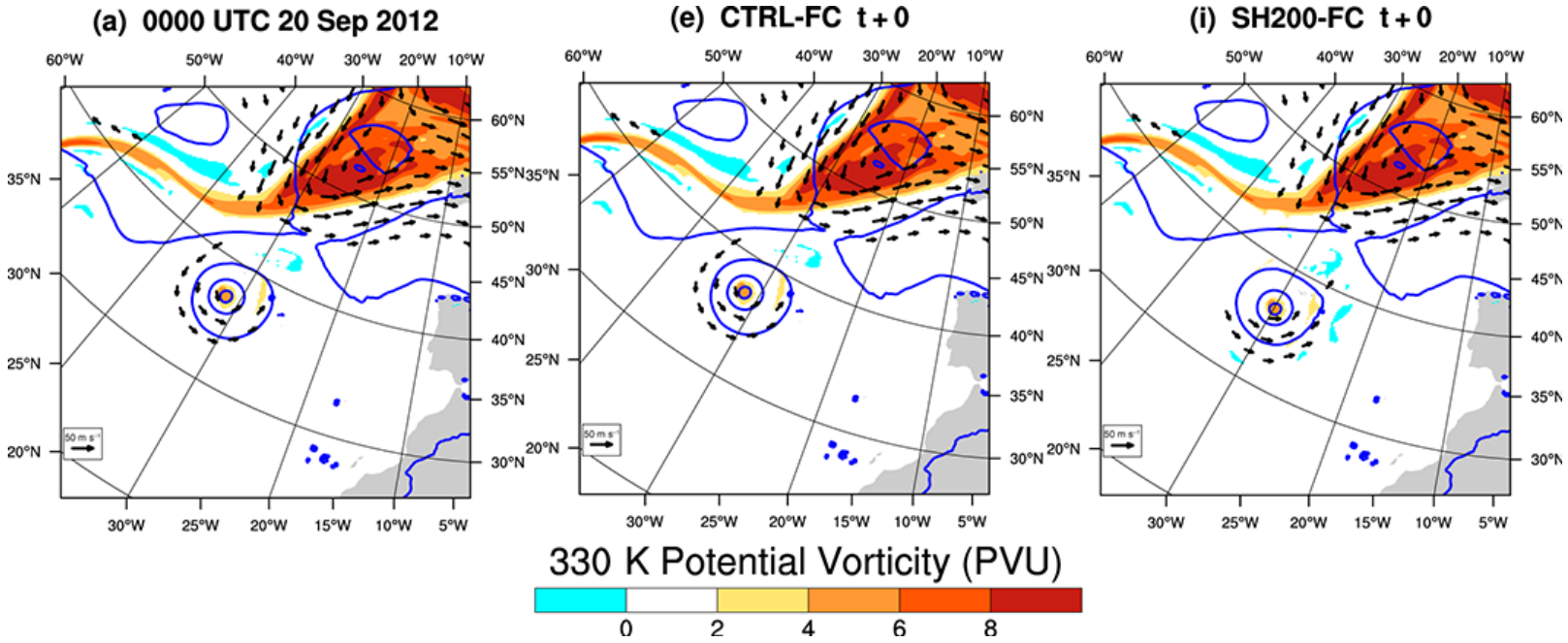
Sensitivity experiments with Meso-NH

mesoscale non-hydrostatic model

Non-linear error growth:
sensitivity experiments with Meso-NH by shifting the initial location of Nadine by 100 and 200 km eastward in the direction of the motion of Nadine – corresponding to a 6 and 12 h delay of Nadine

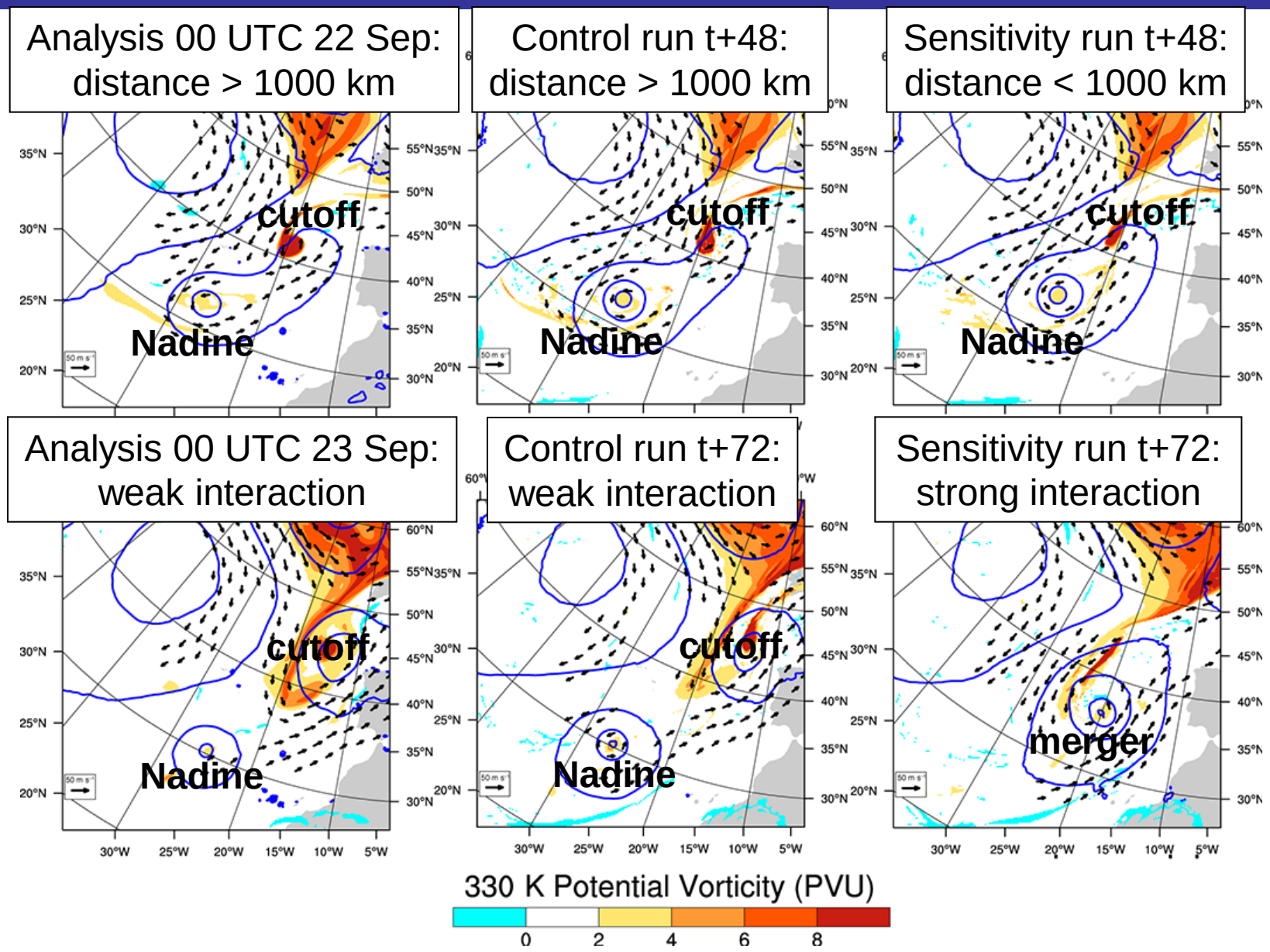
Table 1. Essential characteristics of Meso-NH numerical experiments.

Name	Lateral boundaries	Initial shift of *Nadine* (km)
CTRL-AN	ECMWF analysis	0
SH100-AN	ECMWF analysis	100
SH200-AN	ECMWF analysis	200
CTRL-FC	ECMWF deterministic forecast	0
SH100-FC	ECMWF deterministic forecast	100
SH200-FC	ECMWF deterministic forecast	200



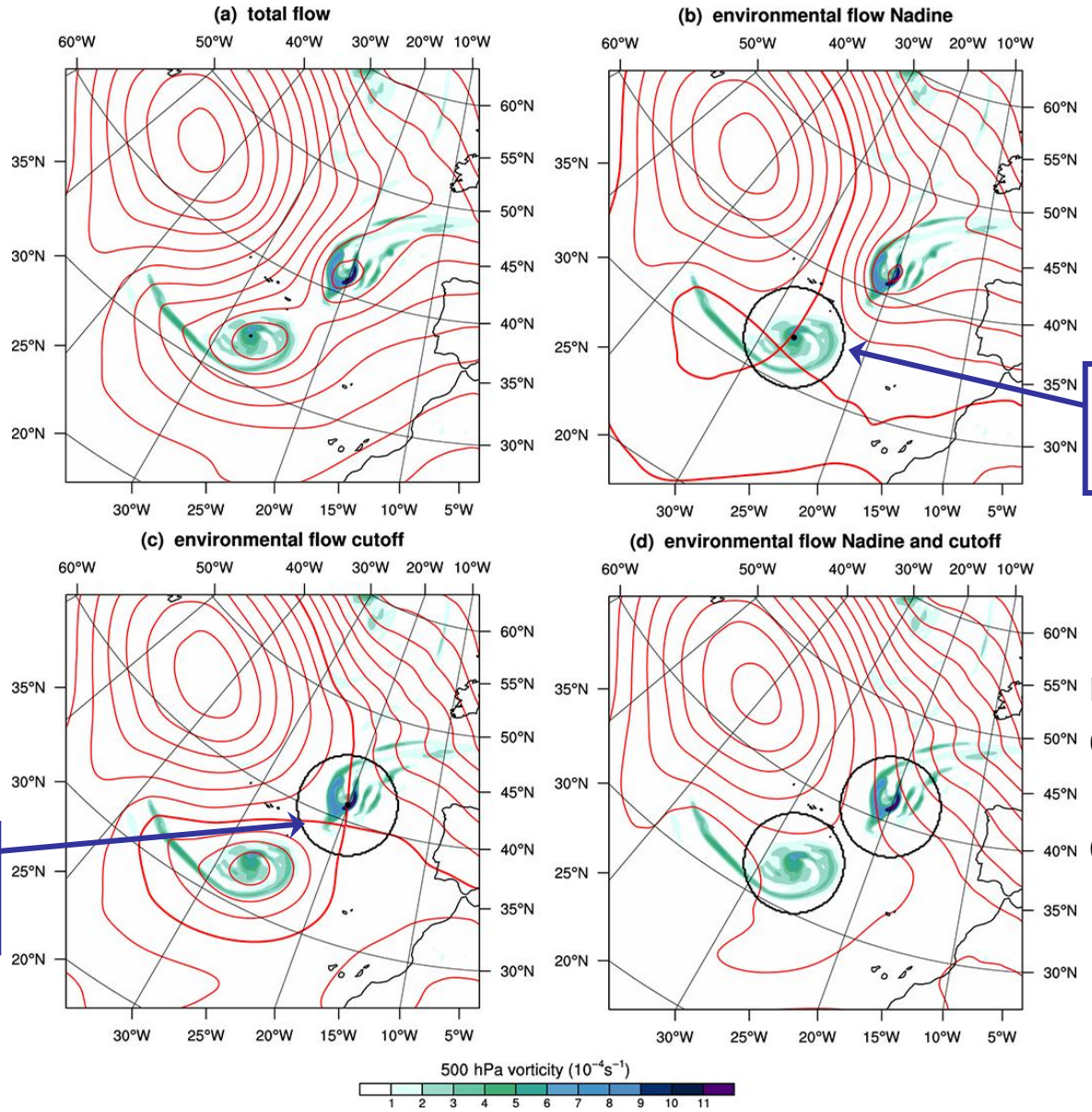
Assessment using Meso-NH experiments

Meso-NH mesoscale non-hydrostatic model



Vortex-vortex interaction

Separation of the total flow by an attribution technique



Flow after removing the one due to Nadine

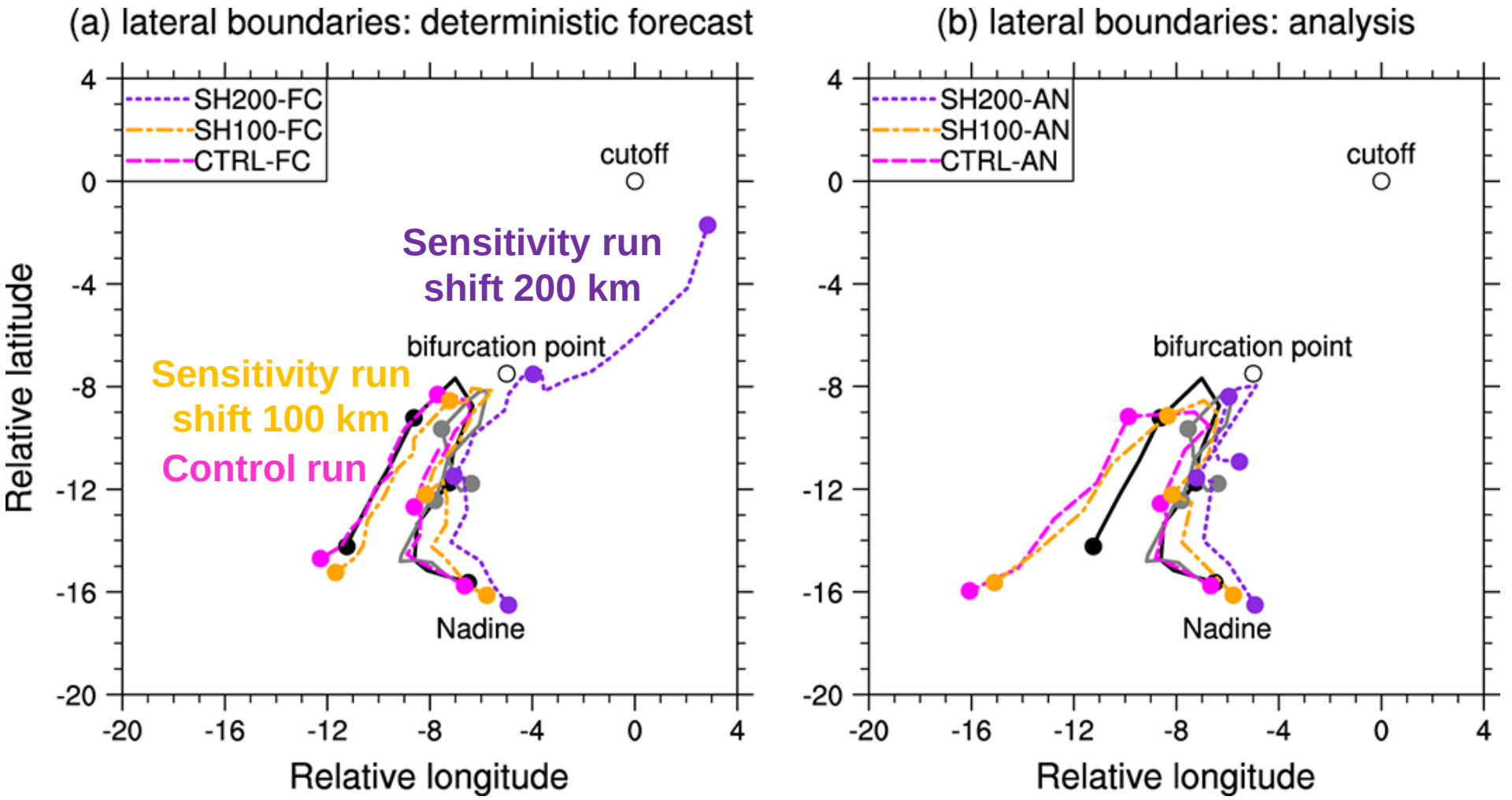
Nadine in a saddle point

Flow after removing the one due to the cutoff

Cutoff in a saddle point

Flow after removing the ones due to Nadine and the cutoff

Existence of a bifurcation point



Conclusions

Double predictability issue related to Nadine during HyMeX SOP1

✓ **Uncertainty track** of Nadine with possible landfall over Iberian Peninsula

✓ **Uncertain synoptic conditions** over western Europe downstream

Clustering ECMWF ensemble forecast + Meso-NH sensitivity experiments

✓ **Two scenarios** of weak vs. strong interaction between Nadine and cutoff

✓ **Critical distance** ~1000 km and **bifurcation point** in relative position

→ Matches **vortex-vortex interaction** between two tropical cyclones

The landfall of Nadine did not occur, does it belong to the model world only?

- Landfall possible as tropical cyclone (Vince 2005) or after ET (Gonzalo 2014)
- Landfall hurricanes more likely in future climate (Haarsma et al. 2013)