Vortex-vortex interaction between Hurricane 

*Nadine* (2012) and an Atlantic cutoff dropping 
the predictability over the Mediterranean

Florian Pantillon\(^1,2\) Jean-Pierre Chaboureau\(^2\) and Evelyne Richard\(^2\)

\(^1\) IMK-TRO, Karlsruhe Institute of Technology (KIT)
\(^2\) Laboratoire d’Aérologie, University of Toulouse and CNRS

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

Hurricanes interact with the midlatitude flow in autumn mostly

Archambault et al. MWR 2013
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
The lowest predictability for IOP6

The lowest predictability in ensemble forecast on 24 September

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

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
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

(a) 0000 UTC 20 sep 2012

(b) 0000 UTC 21 sep 2012

(c) 0000 UTC 22 sep 2012

(d) 0000 UTC 23 sep 2012

(e) 0000 UTC 24 sep 2012

(f) 0000 UTC 25 sep 2012

500 hPa geopotential height (m)
Understanding the forecast uncertainty

ECMWF ensemble forecast ($\Delta x=30\text{km}$)
- 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…

---

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.

<table>
<thead>
<tr>
<th>Name</th>
<th>Lateral boundaries</th>
<th>Initial shift of Nadine (km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CTRL-AN</td>
<td>ECMWF analysis</td>
<td>0</td>
</tr>
<tr>
<td>SH100-AN</td>
<td>ECMWF analysis</td>
<td>100</td>
</tr>
<tr>
<td>SH200-AN</td>
<td>ECMWF analysis</td>
<td>200</td>
</tr>
<tr>
<td>CTRL-FC</td>
<td>ECMWF deterministic forecast</td>
<td>0</td>
</tr>
<tr>
<td>SH100-FC</td>
<td>ECMWF deterministic forecast</td>
<td>100</td>
</tr>
<tr>
<td>SH200-FC</td>
<td>ECMWF deterministic forecast</td>
<td>200</td>
</tr>
</tbody>
</table>

Assessment using Meso-NH experiments

- **Analysis 00 UTC 22 Sep:** distance > 1000 km
- **Control run t+48:** distance > 1000 km
- **Sensitivity run t+48:** distance < 1000 km

- **Analysis 00 UTC 23 Sep:** weak interaction
- **Control run t+72:** weak interaction
- **Sensitivity run t+72:** strong interaction

330 K Potential Vorticity (PVU)

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

(a) lateral boundaries: deterministic forecast

(b) lateral boundaries: analysis

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)