Recent work at Météo-France's NWC department on warnings of exceptional rainfall and thunderstorm objects

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ECSS
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Outlines

2 different approaches for two different phenomena :

Based on km-scale grid point analyses :

Warnings of exceptionnal QPF at the municipal level

- **APIC :** observed exceptionnal rain rates
- **PIE :** Probabilistic QPF for threshold exceedance up to 3h

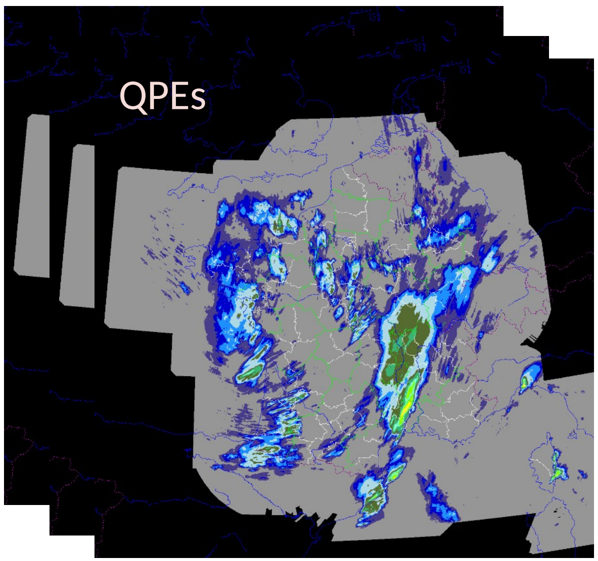
Based on objects : detection, tracking and characterization of severe storm :

- **In operation : OPIC / MIMOSA**
- **R&D on 1h forecast :**
  - of the contour by advection or by AI
  - of the level of violence of hazards

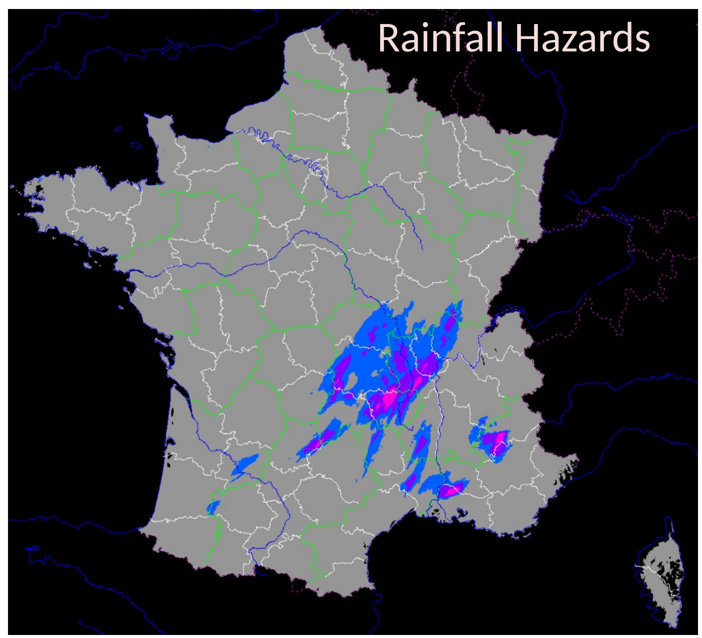
Warnings for exceptional QPE

AIGA rainfall hazards : grid point comparisons between QPEs at different depths with climatological values for different return periods. Computed over France mainland and French overseas territories, updates every 15 min

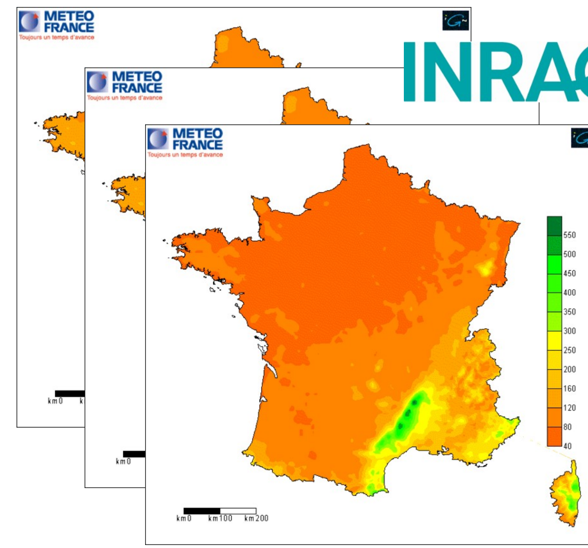
comparisons



Rain Rates
from 1 to 24h using
ANTILOPE 15 min
QPE (Radar-
Raingauges fusion)



Rainfall hazards for each depths
→ 24h summary map deduced from local maximum values



Climatological values :
2, 10 and 50 years return periods

(R. Tzanos)

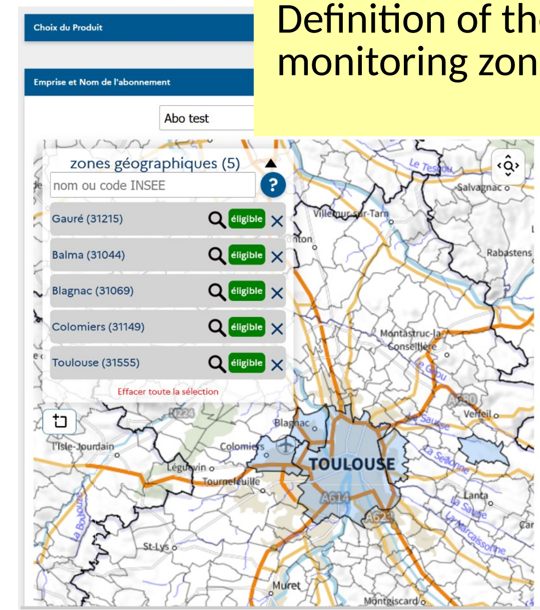
Warnings for exceptional QPE

APIC : Spatial aggregation of AIGA at the municipal level

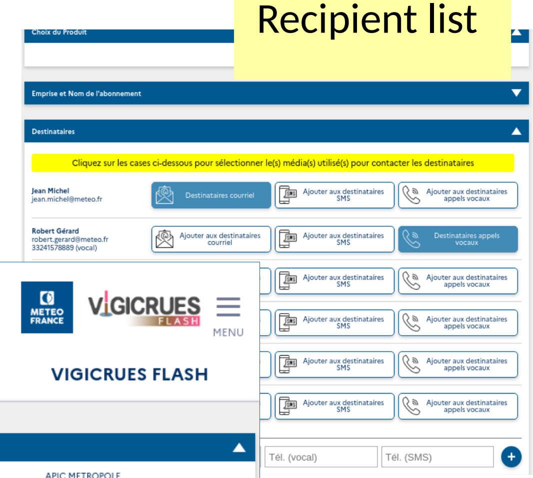
APIC-VF interfaces : Warnings broadcast to public services (more than 14 000 subscribers) and visualization ([available for the general public]) through dedicated websites

APIC is updated every 15’, together with flash flood warnings VigicruesFlash provided by the hydrological service SCP

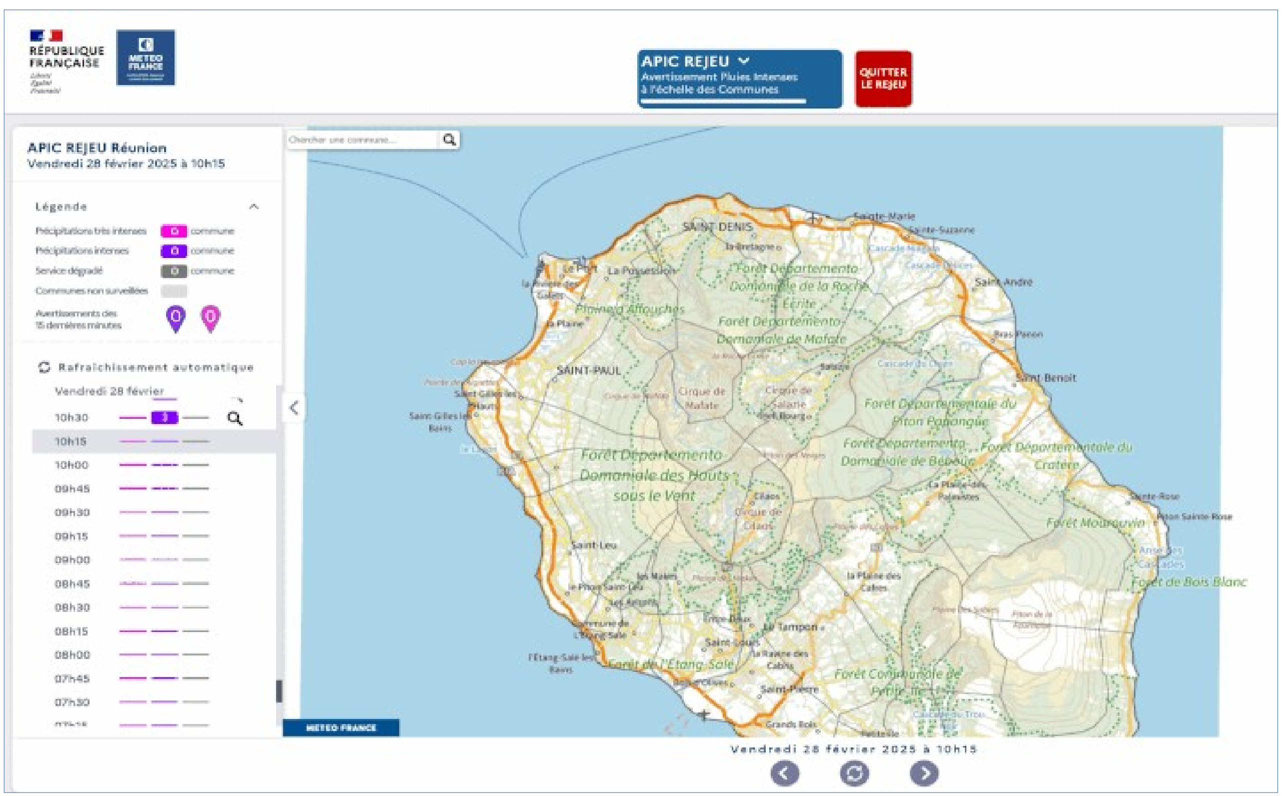
Definition of the monitoring zone



Recipient list



Available on mobile phones



Animation of APIC over the Reunion Island for the Garance cyclone in February 2025

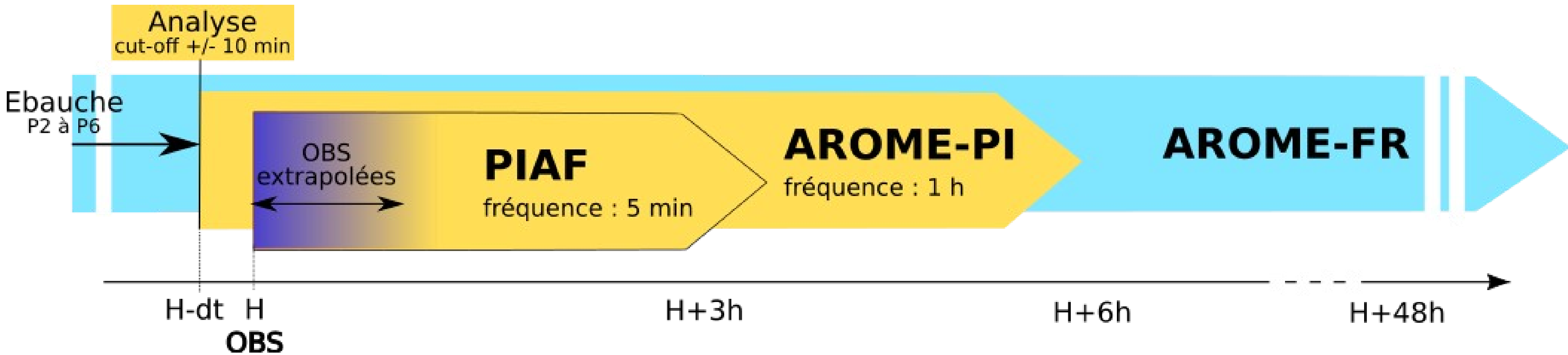
Warnings for exceptional QPF

- In addition to alerting local authorities, **APIC is very useful for identifying areas to monitor and reviewing the timing of past situations.**
- However, **its predictive capabilities are limited**, even though taking neighbouring municipalities into account in the monitoring area helps.
- One possible solution would have been to forecast the APIC for the coming hours. However, the occurrence of false alarms and, worse still, non-detections could have dramatic consequences.
- Instead, **we have chosen to provide information on the probability of additional rainfall occurring after an APIC was triggered.**

→ The aim is to determine whether rainfall will soon add to the already exceptional amounts that have fallen

→ The operational PIAF blending product is used in this context

Deterministic QPF : [0 → 3h] blending



PIAF blends images that are (i) advected and (ii) simulated by NWP. Weights depend on recent performances against the last observed images :

- Every 5 min, QPF from advection uses the 2PIR displacement field retrieved from the last 2 reflectivity images from the French ARAMIS Radar network
- Every hour, the NWP model AROME-PI provides 6h forecast after 30 min of computation (data assimilation using the most recent observations and the last AROME-France forecast)

For APIC, this methodology is applied every 15 min to the 15 min ANTILOPE rain rates (fusion between Radar and raingauges), up to a 3-hour forecast

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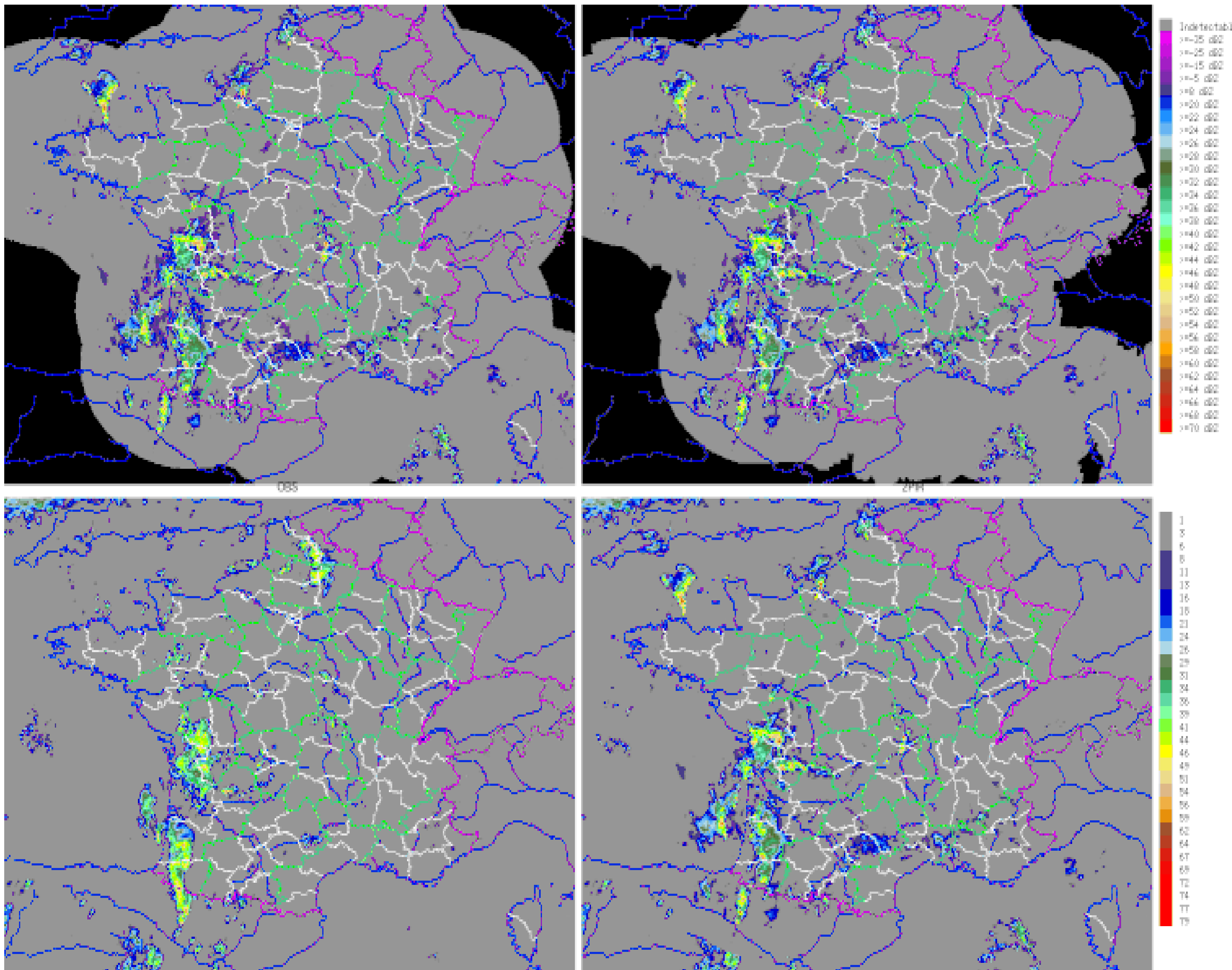
Deterministic QPF : [0→3h] blending

(I. Bernard-Bouissières)

Example of a 3h forecast, 2023/09/17 case (14h40 UTC run)

Obs *2PIR*

AROME-PI *PIAF-Z*



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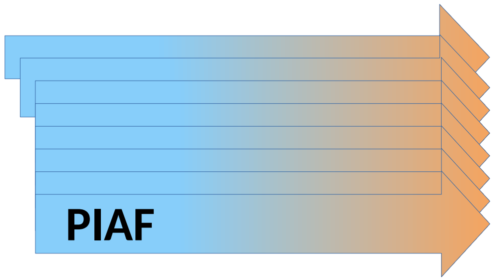
[0 → 3h] Probabilistic QPF

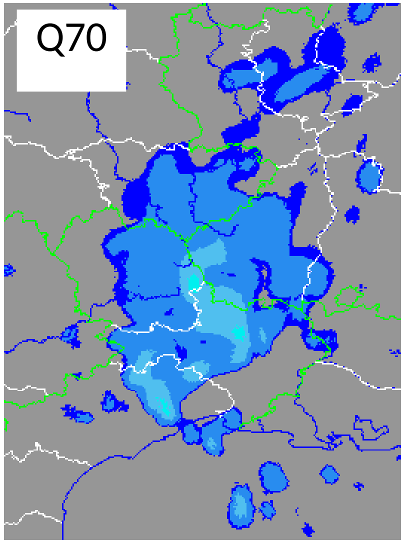
(R. Tzanos)

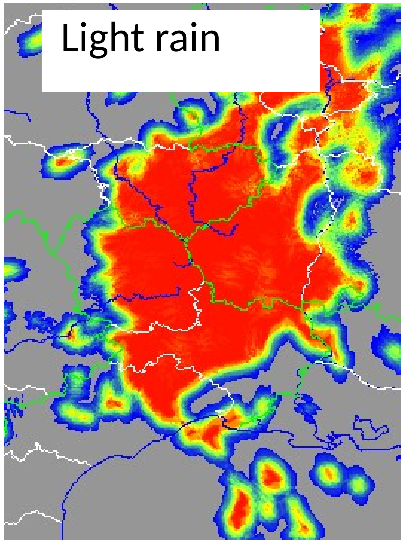


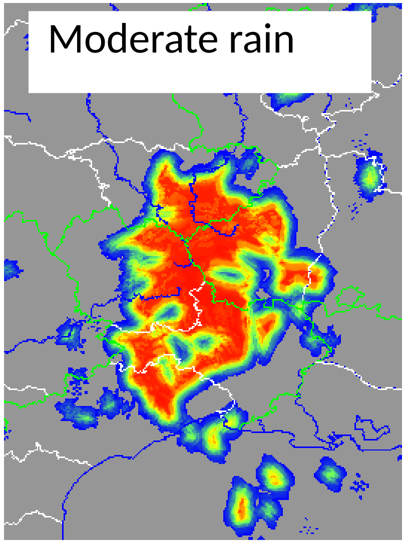
Ensemble of PIAF
(~20 members using anisotropic spatial perturbations that increase with time and time-lagging)

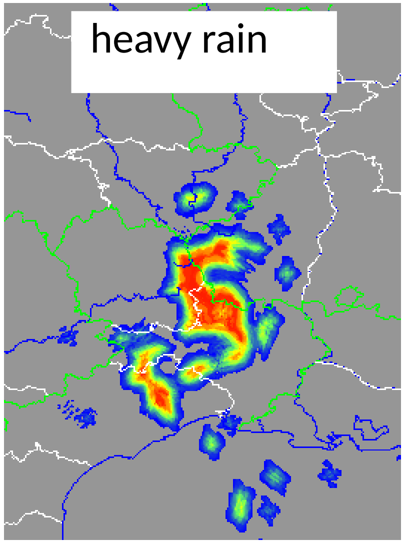
At each forecast dates, for each grid point per km²:

- Calculation of the CDF of 15min RR
- Calculation of 70th quantile
- Based on Q70, classification of the pixel as light/moderate/heavy rain, or no rain
- Calculation of the probabilities of exceeding each of the corresponding thresholds









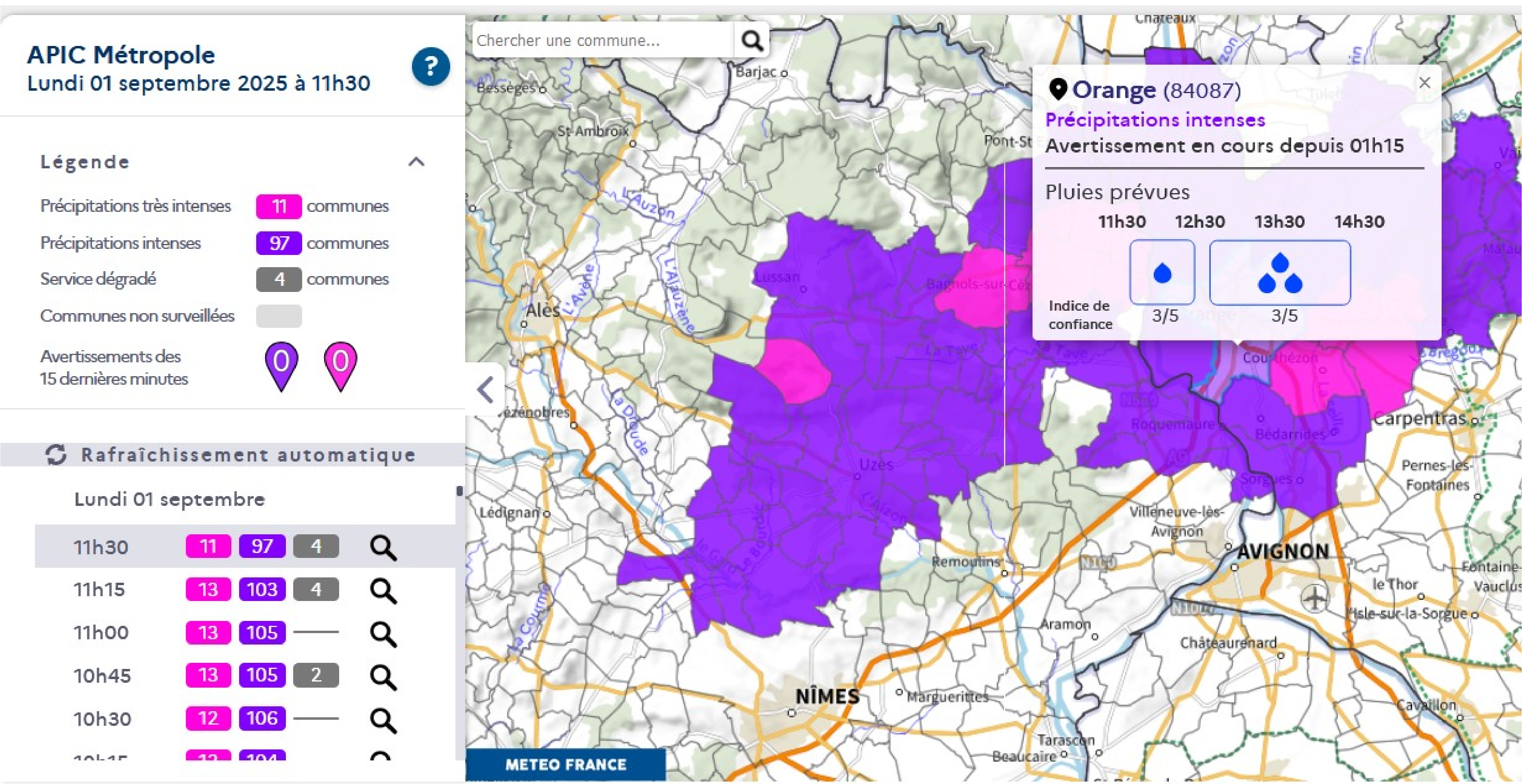
Aggregation at municipal level:

- Counting of VP15min
- Average probabilities associated with the selected VP (Preferred Value)
- Calculation of

VP1h = $\max_{H \rightarrow H+1}$(VP15min)

[0→3h] Probabilistic QPF

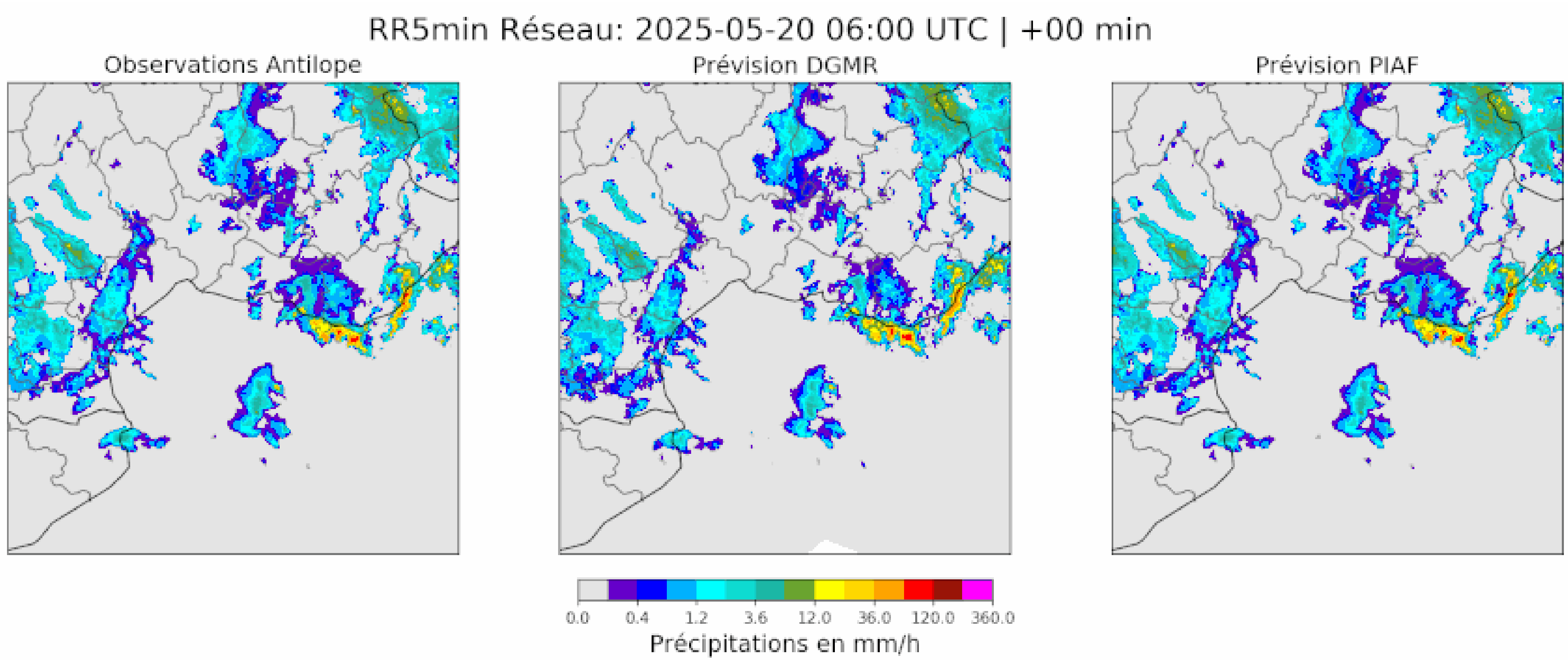
Since the 1st of october, the VP1h and VP2&3h associated with a confidence index (/5) are added to the apic-vigicruesflash.fr map and broadcasted warnings, for municipalities affected by an APIC :



R&D to improve QPF

Work is ongoing to improve the two PIAF's predictors. In order to improve on advection, several AI models have been tested over 2024 :

- DeepLabv3+ (CNN), LDCast (Diffusion), DGMR (GAN), NowCastNet (GAN)
- **Best overall scores obtained by DGRM** with a post-processing using Histogram Matching



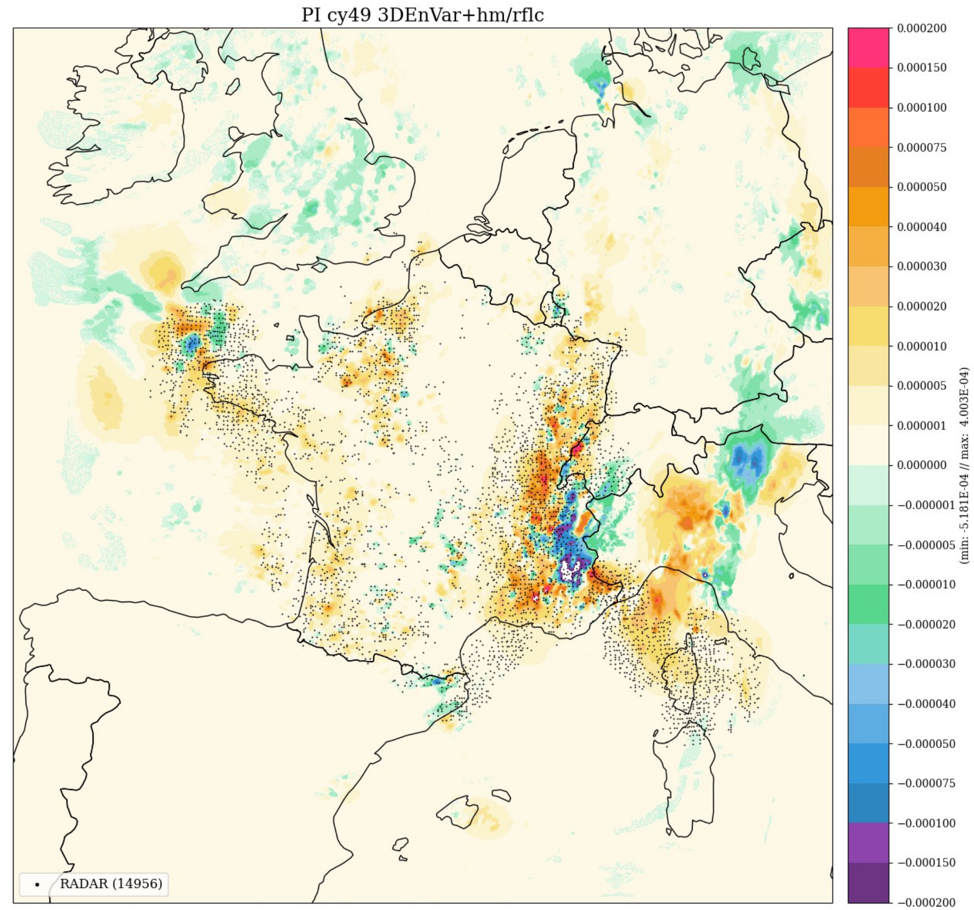
R&D to improve QPF : 3DEnVar in AROME-PI

3DVar and 3DEnVar differs by their background error covariance matrix : climatological vs. sampled from Ensemble Data Assimilation

3DEnVar, with SDL, hydrometeors in the control variable and direct assimilation of reflectivities, allows hydrometeors to be analysed :

- indirectly, through cross-covariances of background errors that project increments of 'classical' variables (Destouches et al., 2023)
- directly through the inversion of reflectivities (work by M. Martet)

→ Scheduled to become operational at the end of 2026



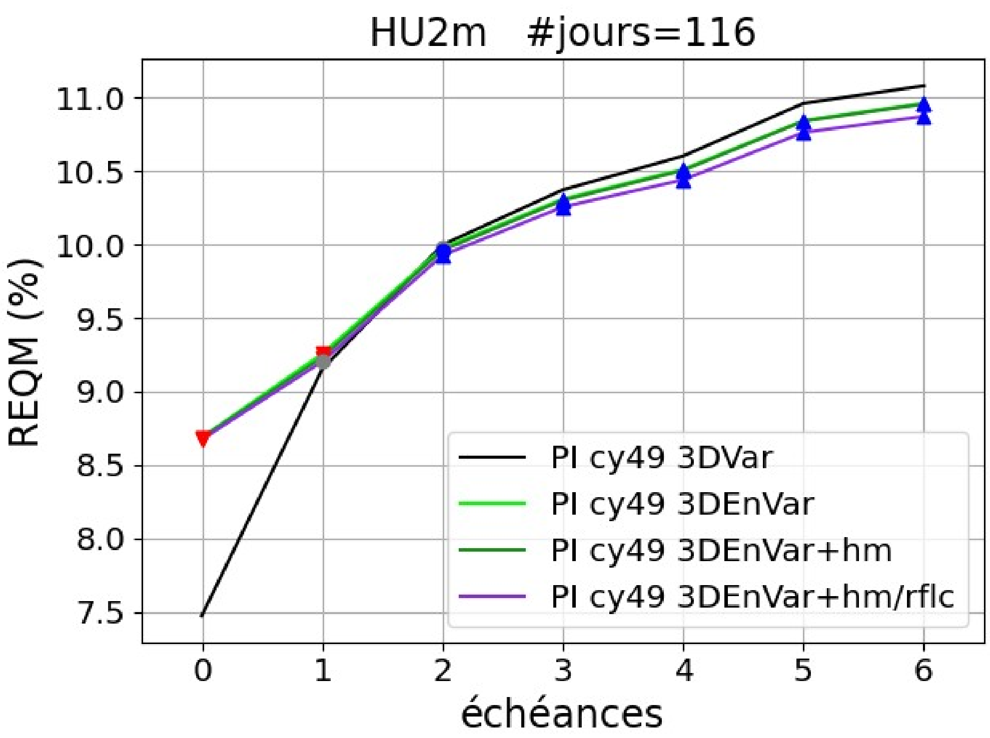
Example of specific Rain content increments (difference between analysis and backgroud) (points : active Radar obs)

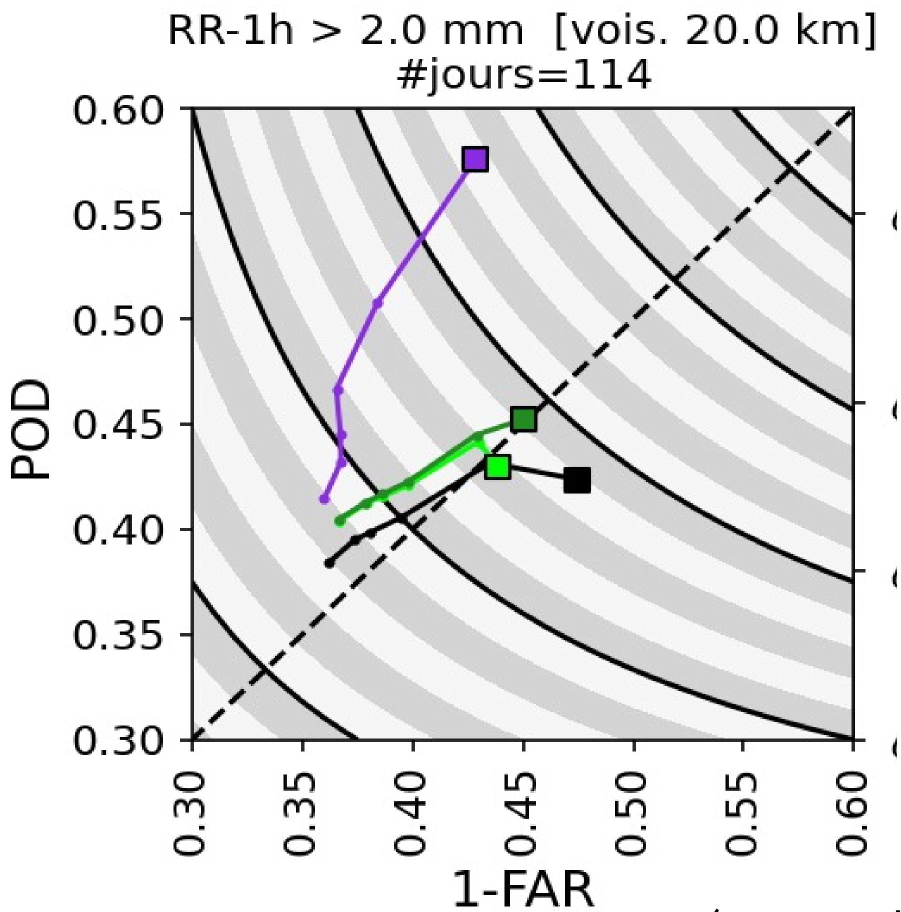
(G. Arnould)

R&D to improve QPF : 3DEnVar in AROME-PI

Forecast RR1h evaluation vs. 3DVar (11/2024 → 04/2025):

- 3DVar, 3DEnVar, 3DEnVar+Hydrometeors, 3DEnVar+Hydro+DirectZassim
- RR1h overestimated with 3DEnVars, POD improved, but more FAR
- Better REQM for Hu_{2m} after 2h lead time





(G. Arnould)

Outlines

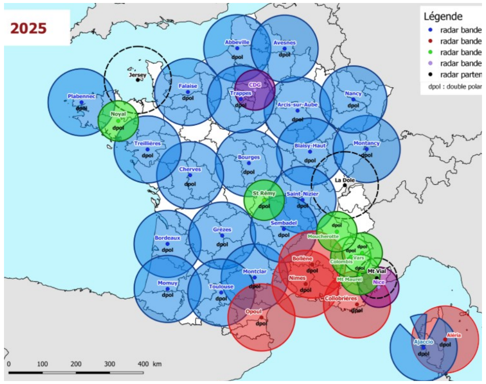
Warnings of exceptionnal rain rates at the municipal level

- **APIC :** observed exceptionnal rain rates
- **PIE :** Probabilistic QPF for threshold exceedance up to 3h

Storm objects

- **In operation : OPIC**
- **R&D on 1h forecast based on MIMOSA**
  - of the contour by advection or by AI
  - of the level of violence of hazards

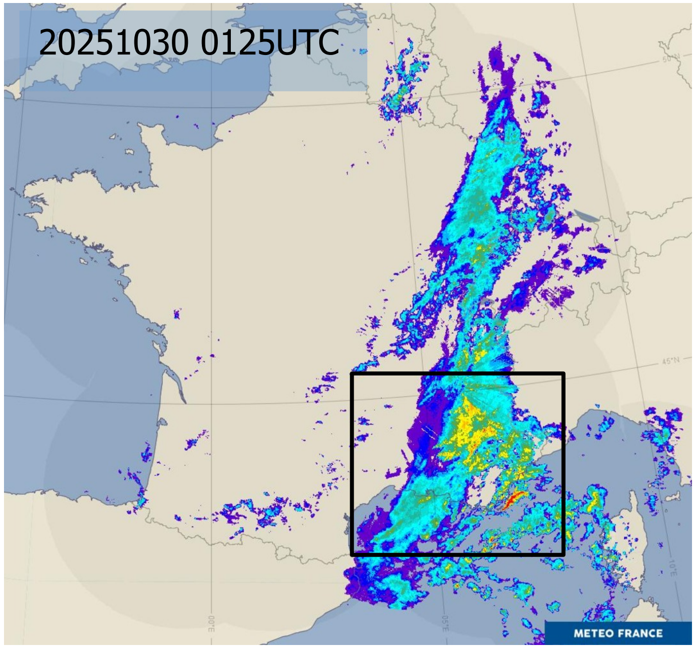
Radar storm objects : OPIC



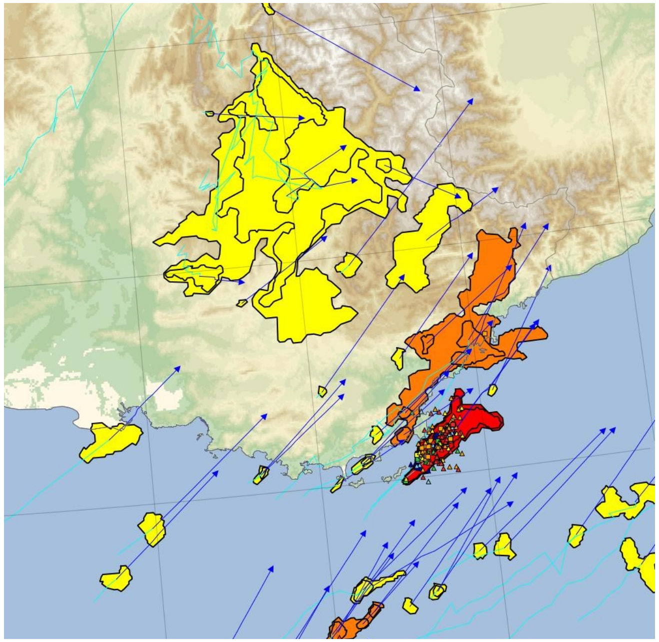
French radar network ARAMIS

1. Detection

Based on the thresholding of post-processed French reflectivity composite (Δx=1km, Δt=5min)



- Post-processing : Morphological closure, Gaussian filtering
- Image Segmentation



Operational OPIC Storm Objects :

- Detected from the 36 and 42 dBZ levels
- Gathers several attributes (morphological, diagnostics deduced from reflectivities, lightning activity, in-situ observations, rain rates)

3 levels of general severity

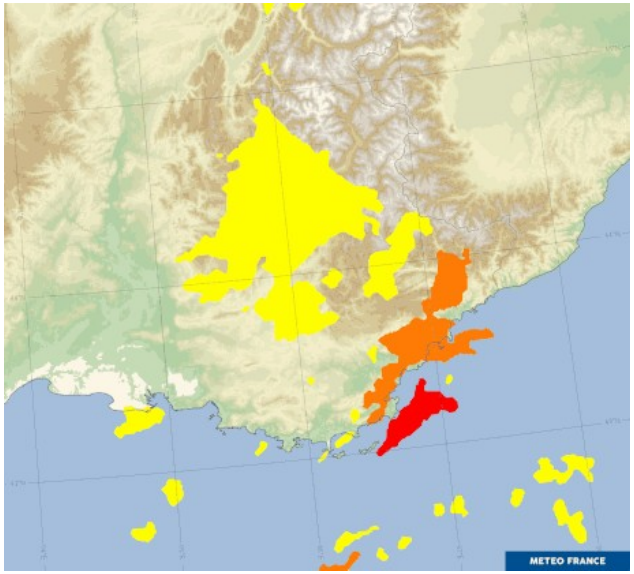
Heavy rain
Storm
Severe storm

Radar storm objects : OPIC

2. Tracking / forecast

Based on the identification of links between cells present in the last available observation (t) and in the previous image (t-5') by :

- object overlay
- cross-correlation between pixels

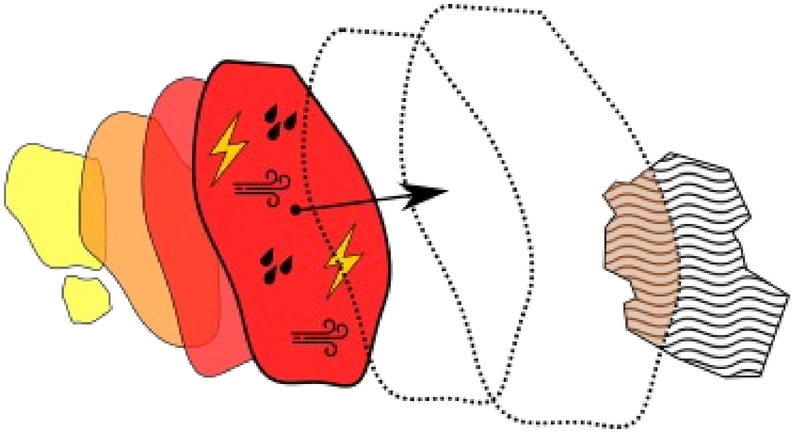


The retrieved displacement vector allows to advect the contour until 1h

To account for displacement / timing errors :

- Progressive dilatation,
- application of an encompassing polygon after 30min

Persistence of the severity level



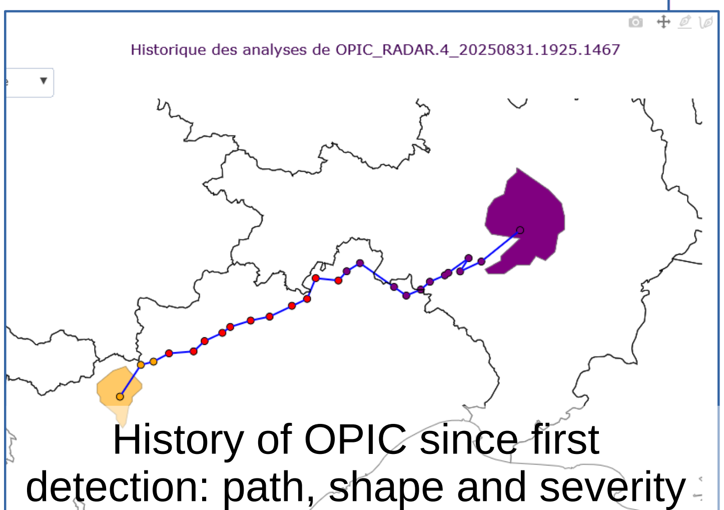
SRO commercial service :

- Broadcast of storm warning with a 1h anticipation
- Based on the overlap between forecasted OPIC and surveillance areas

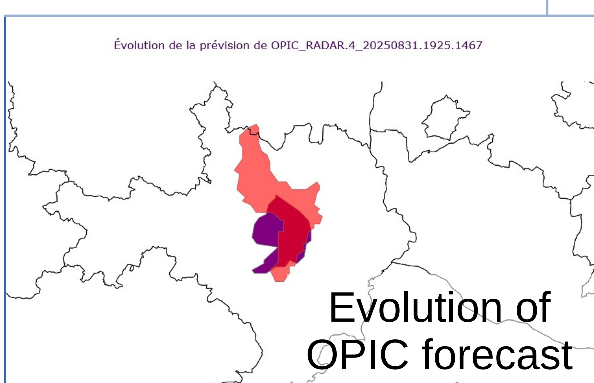
(D. Jaubert)

Radar storm objects : MIMOSA

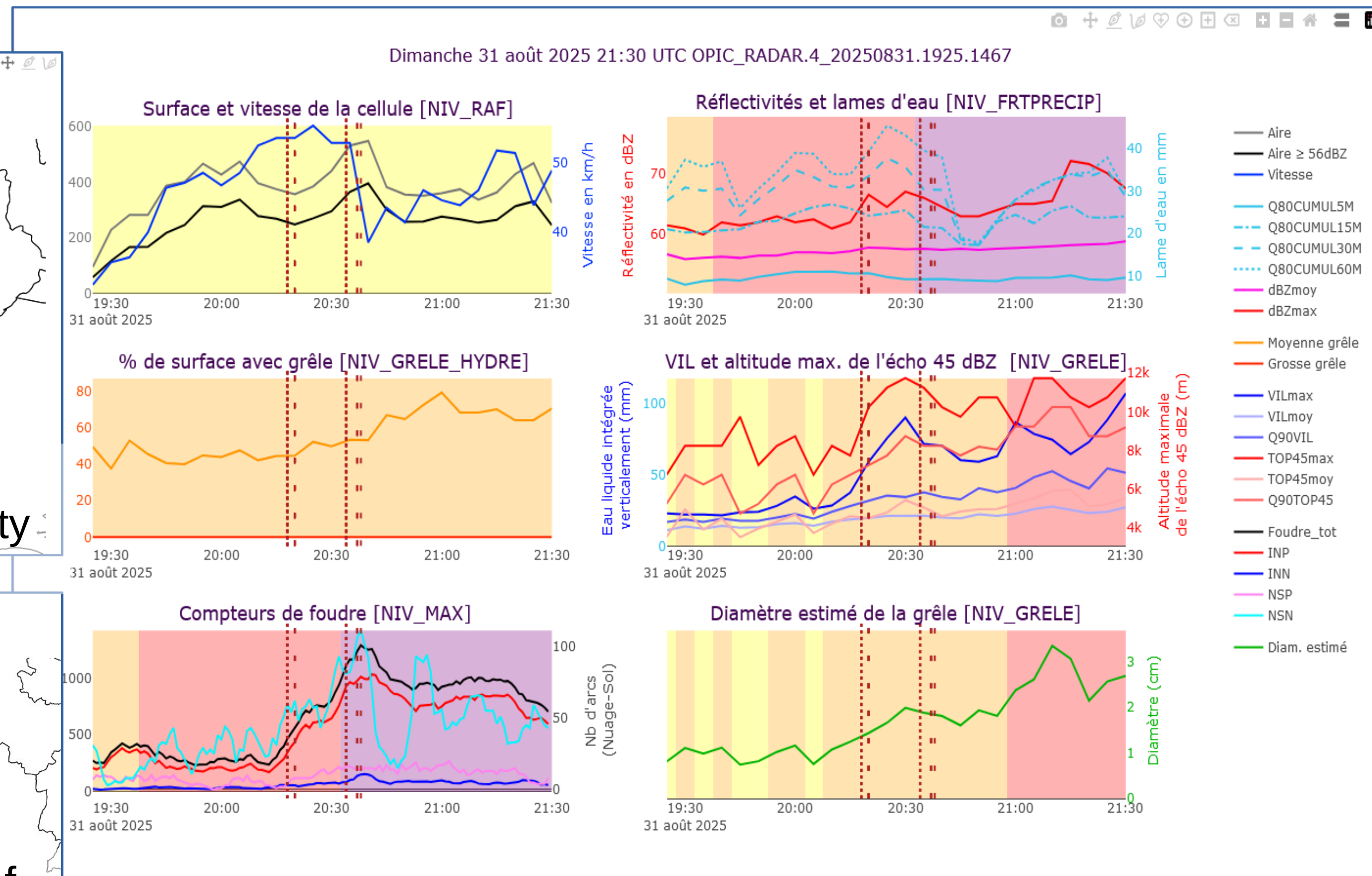
- Aims in detecting, tracking and charactering **the most violent thunderstorms**
- **Based on OPIC** at the 46, 50 and 56 dBZ reflectvity thresholds
- Go further in identifying the nature of storm severity by **focusing on hazards**
- Available through **a dedicated interface** for forecasters :



History of OPIC since first detection: path, shape and severity



Evolution of OPIC forecast



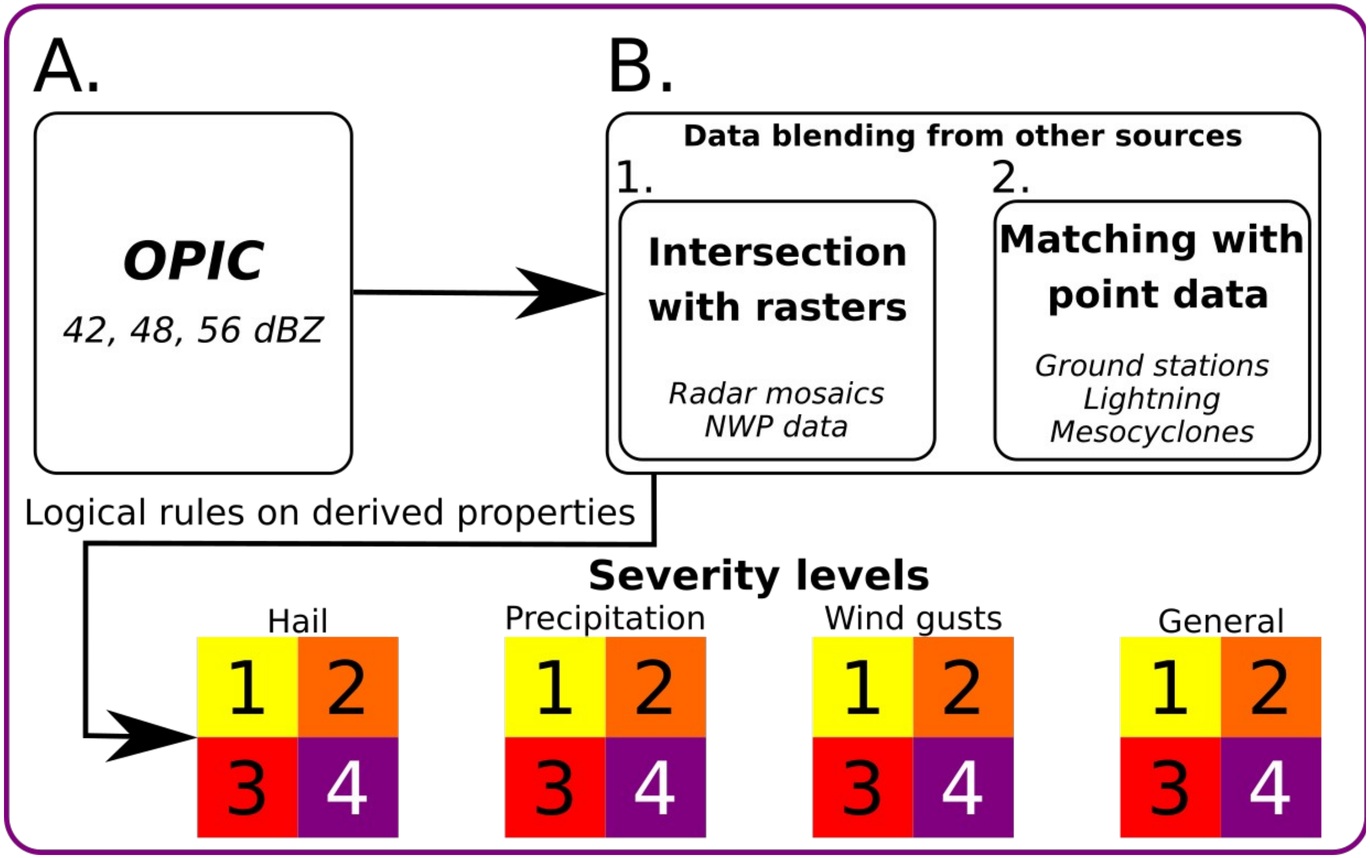
Interactive evolution graphs for OPIC properties

Radar storm objects : MIMOSA analysis

Based on several additional attributes :

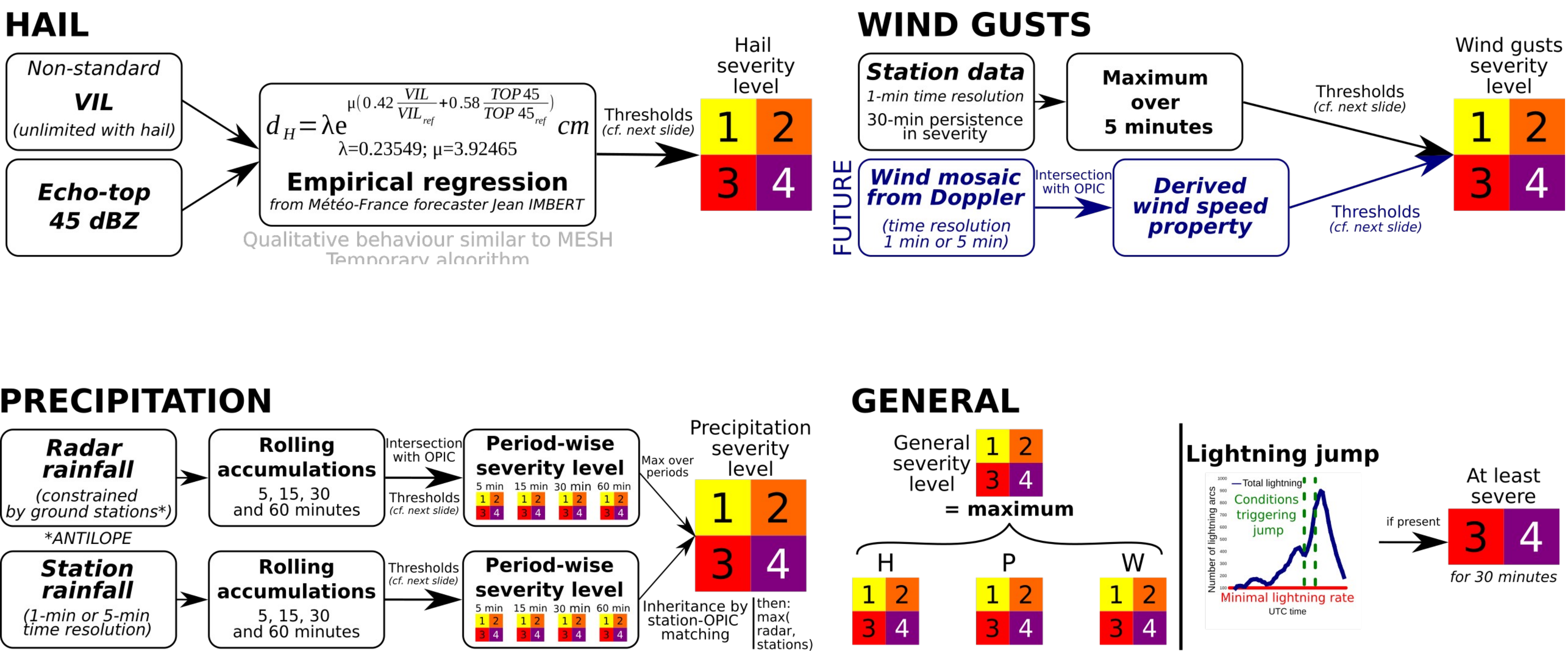
- Reflectivity, lightning, ground stations, radar rainfall, VIL, echo-top 45 dBZ,
- R&D : NWP (environment), DOW, satellite BT, mesocyclones, buoys…

3 Hazard used to compute a general severity level : Hail, Precipitation, Wind Gust :



Radar storm objects : MIMOSA analysis

Methods for analysing severity levels :



Radar storm objects : MIMOSA analysis

Thresholds used for severity level determination

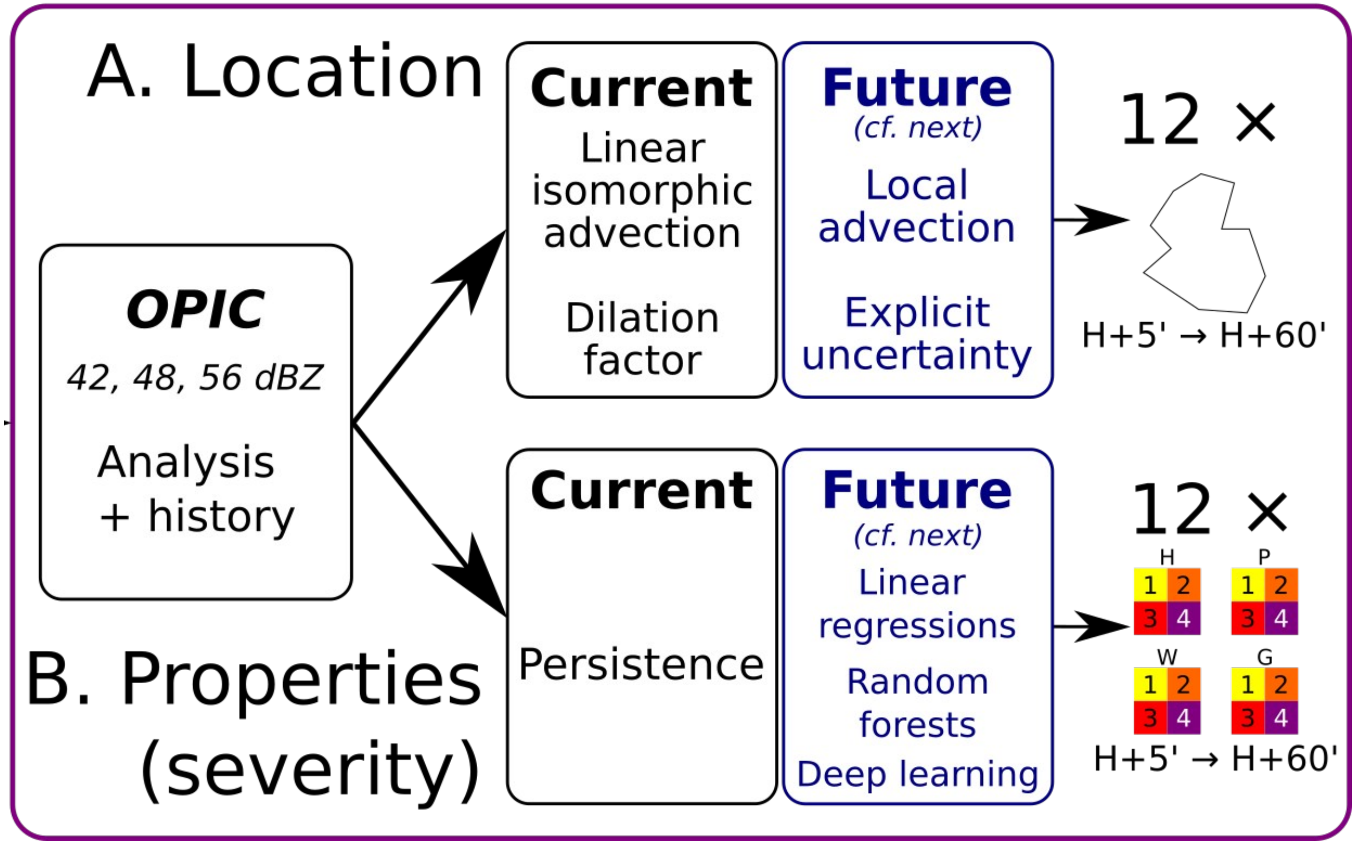
- Determined from experience and forecaster feedback,
- No regional modulation, nor explicit area vulnerability awareness,
- Further tuning would require a large study with impact input and climatological-like approach.

Severity level	**5' rainfall** (mm)	**15' rainfall** (mm)	**30' rainfall** (mm)	**60' rainfall** (mm)	**Hail** ⌀ (cm)	**Wind gusts** (km/h)
Moderate	< 5	< 12	< 20	< 30	< 1	< 60
Strong	5 – 10	12 – 25	20 – 35	30 – 45	1 – 2	60 – 90
Severe	10 – 15	25 – 35	35 – 45	45 – 55	2– 5	90 – 120
Very severe	> 15	> 35	> 45	> 55	> 5	> 120

Radar storm objects : MIMOSA forecasts

MIMOSA provides two kind of forecasts up to 60 min :

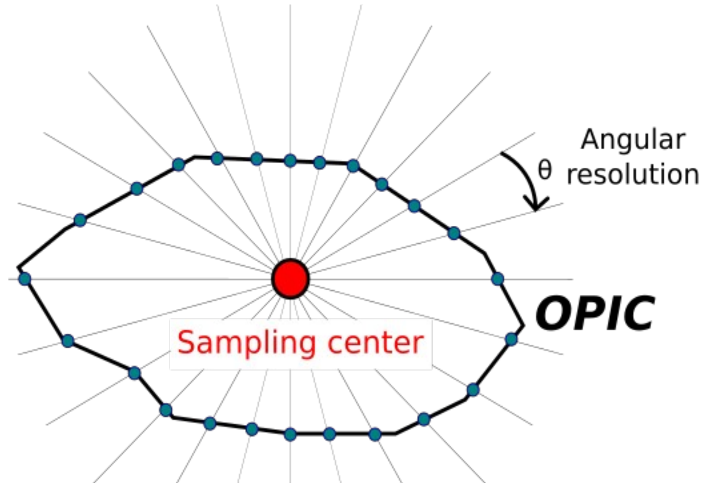
- **Location of the contour** : same method as OPIC, without dilatation
- **Severity level**

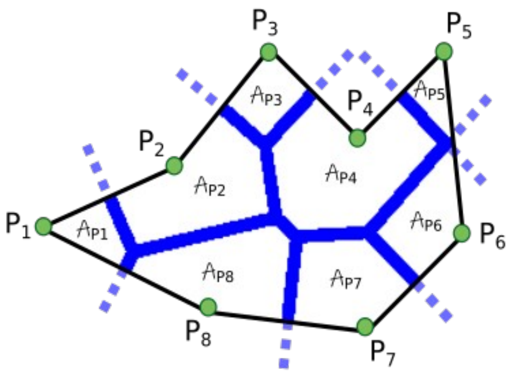


Radar storm objects : MIMOSA forecasts

Towards local advection for OPICs

- Angular sampling of the contour
- Tracking of the points
- Local speed computation for points with the same angle in the last two images

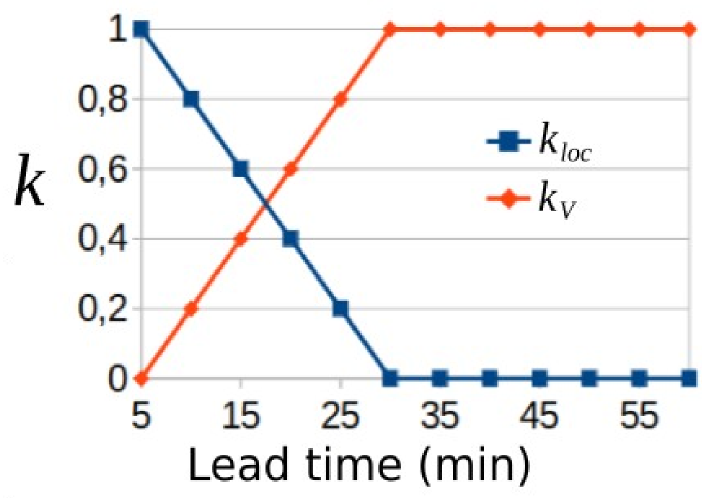




Voronoi regions providing weighting factor

- Building global speed from individual ones : use of a Voronoi distance

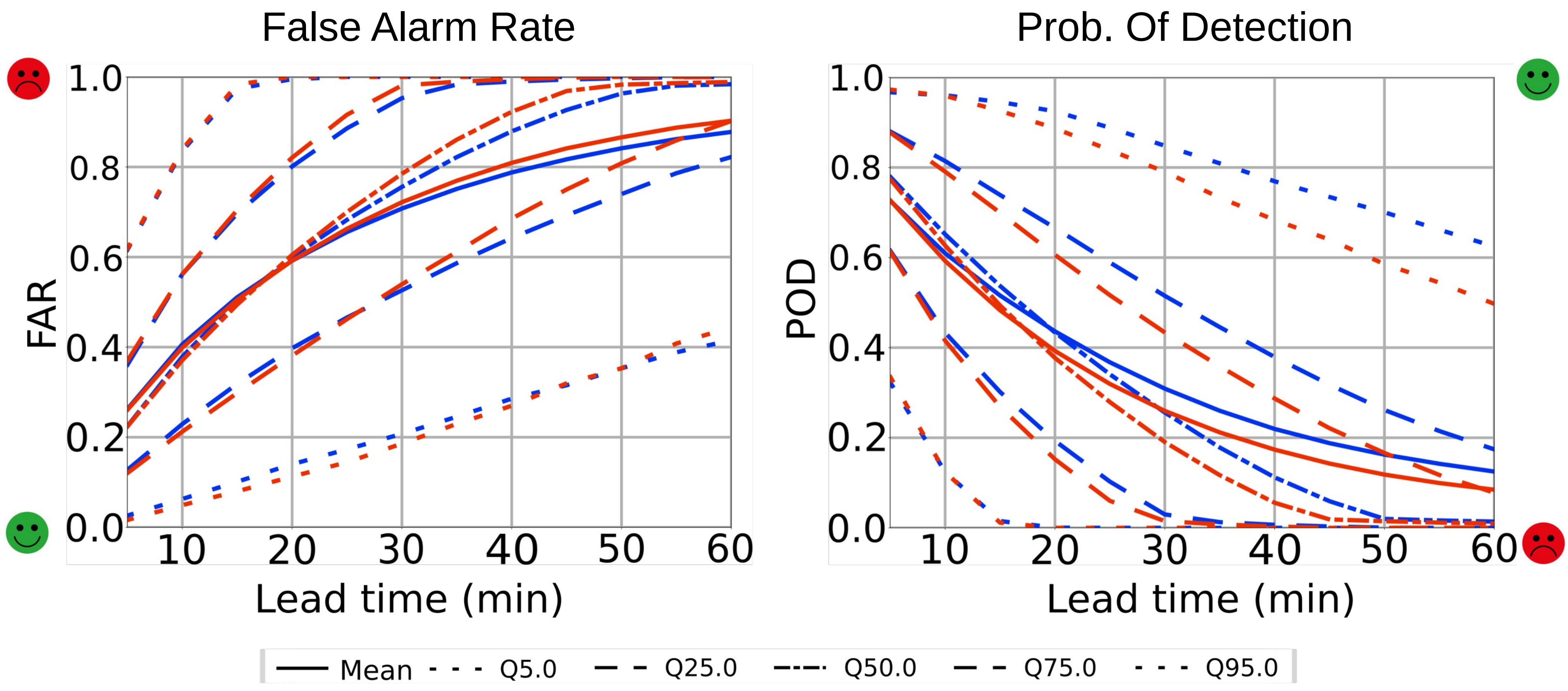
- Combining both speeds using a linear combination with weights that impose a linear transition from local speed to global from t to t+30 min



Radar storm objects : MIMOSA forecasts

Towards local advection for OPICs : angular sampling

Contingency Scores computed for June 2023



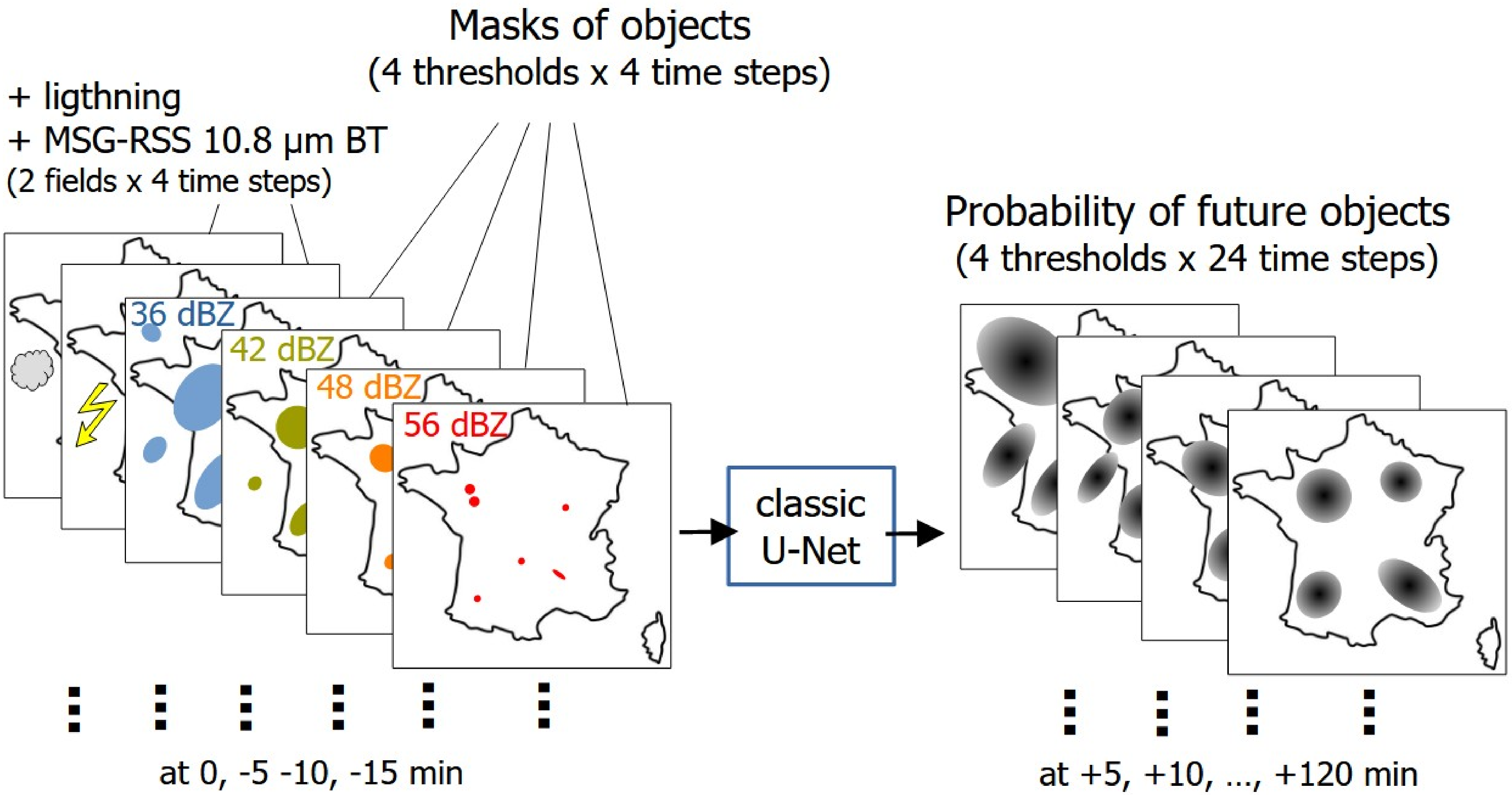
Reference : linear isomorphic advection

Local advection based on angular sampling

(M. Laval)

Radar storm objects : MIMOSA forecasts

Using a U-Net for 2-hours objects location forecast

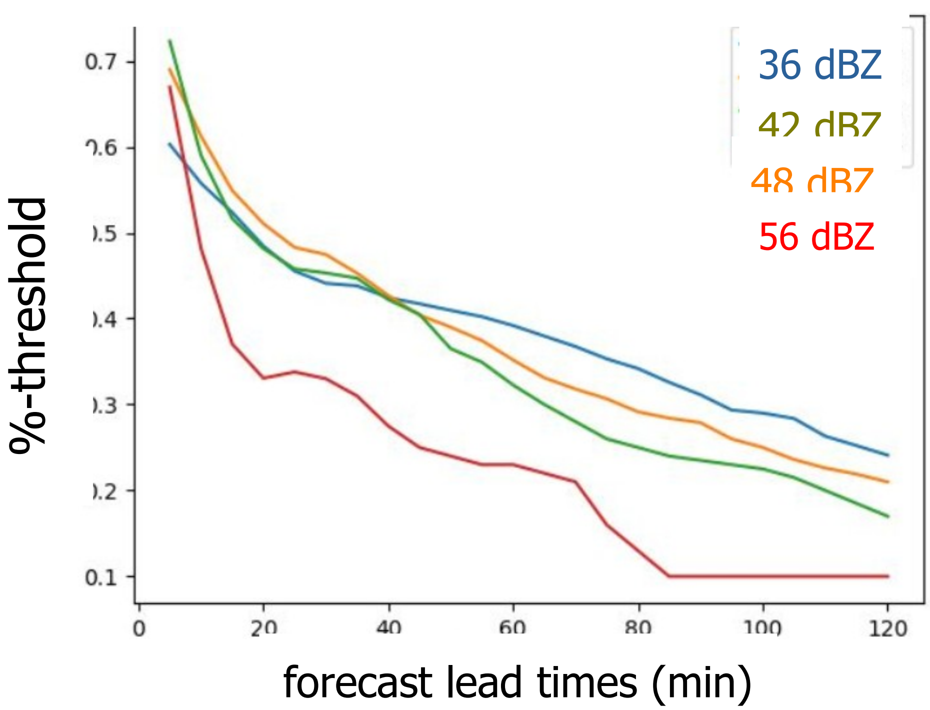


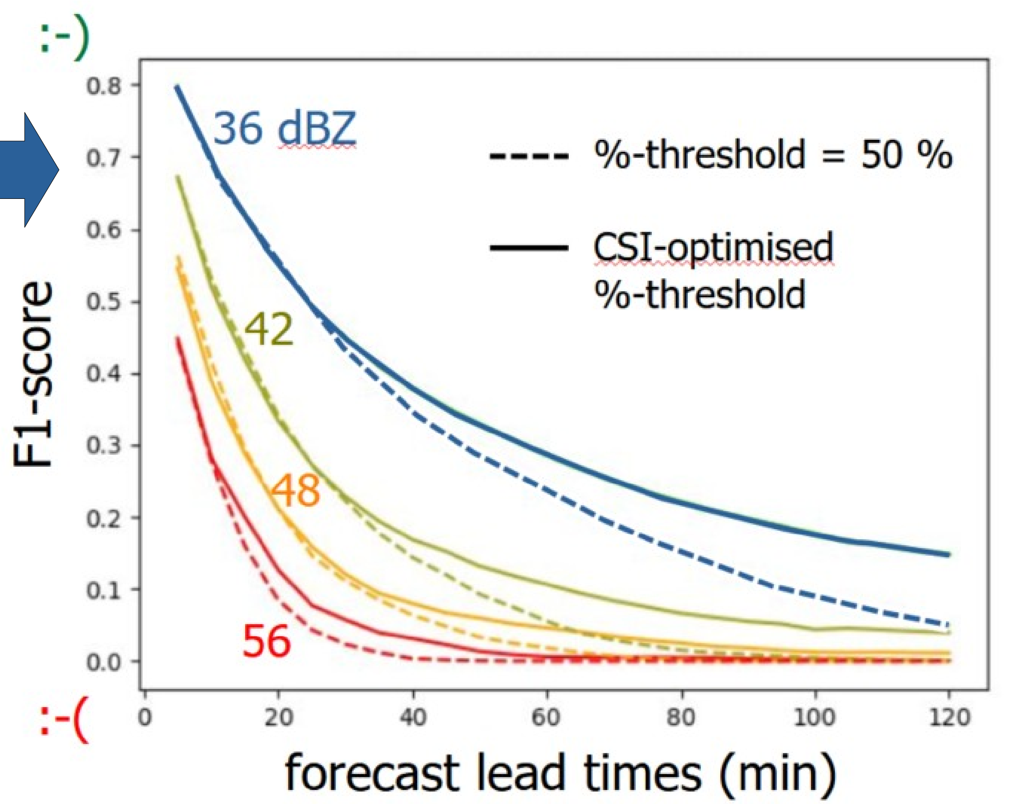
Radar storm objects : MIMOSA forecasts

Using a U-Net for 2-hours objects location forecast

Use of the CSI score to objectively impose the best % threshold to the forecasted probabilities :

the %-thresholds defining forecast objects optimise CSI-score



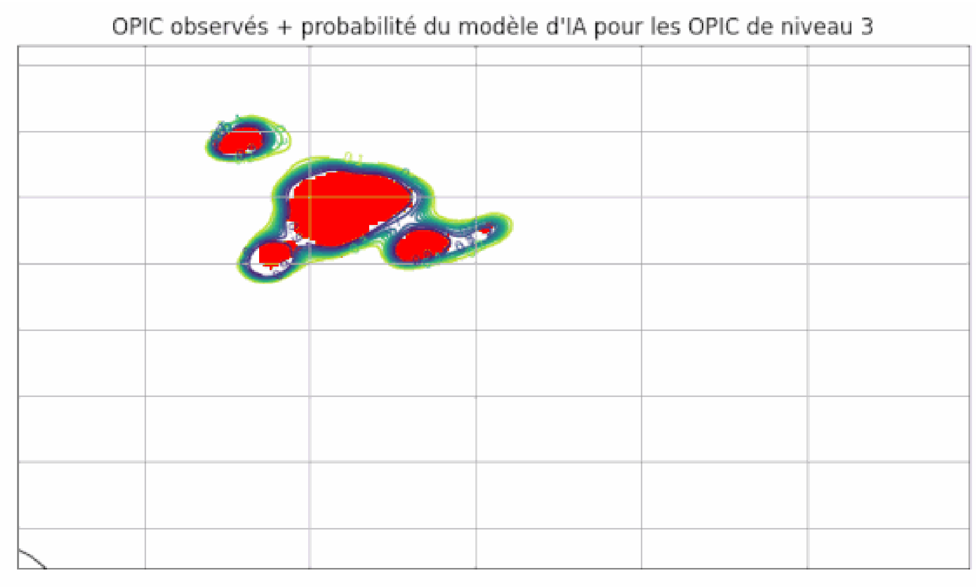


(R. Rohr)

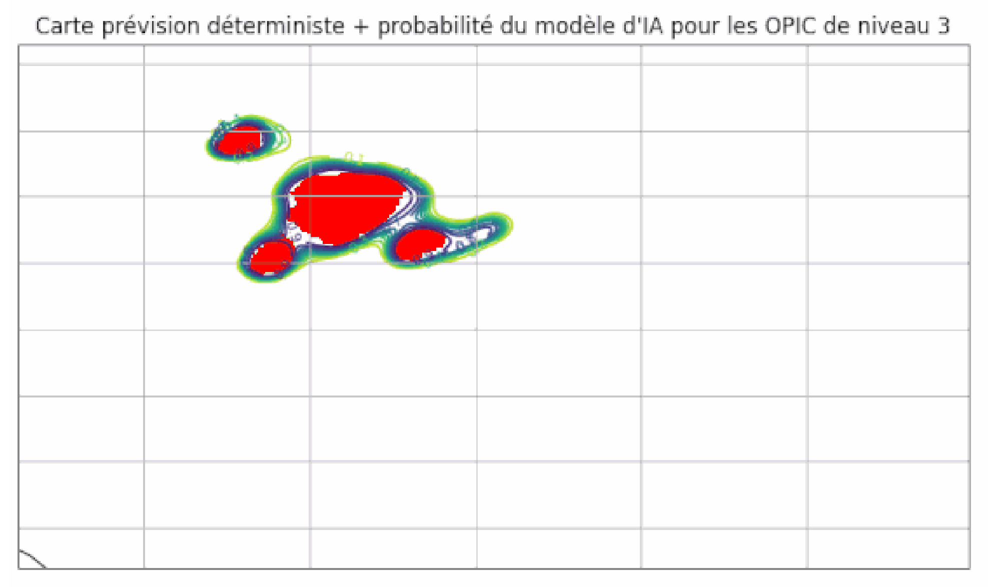
Radar storm objects : MIMOSA forecasts

Illustration of the different approaches

- Forecasted objects at longer lead times are statistically less probable => we need to interpret them as risk areas
- probabilistic and deterministic approaches look complementary



1h U-Net forecasts of the probability of level 3 OPIC occurrence (contours), compared to the observed OPIC (in red)

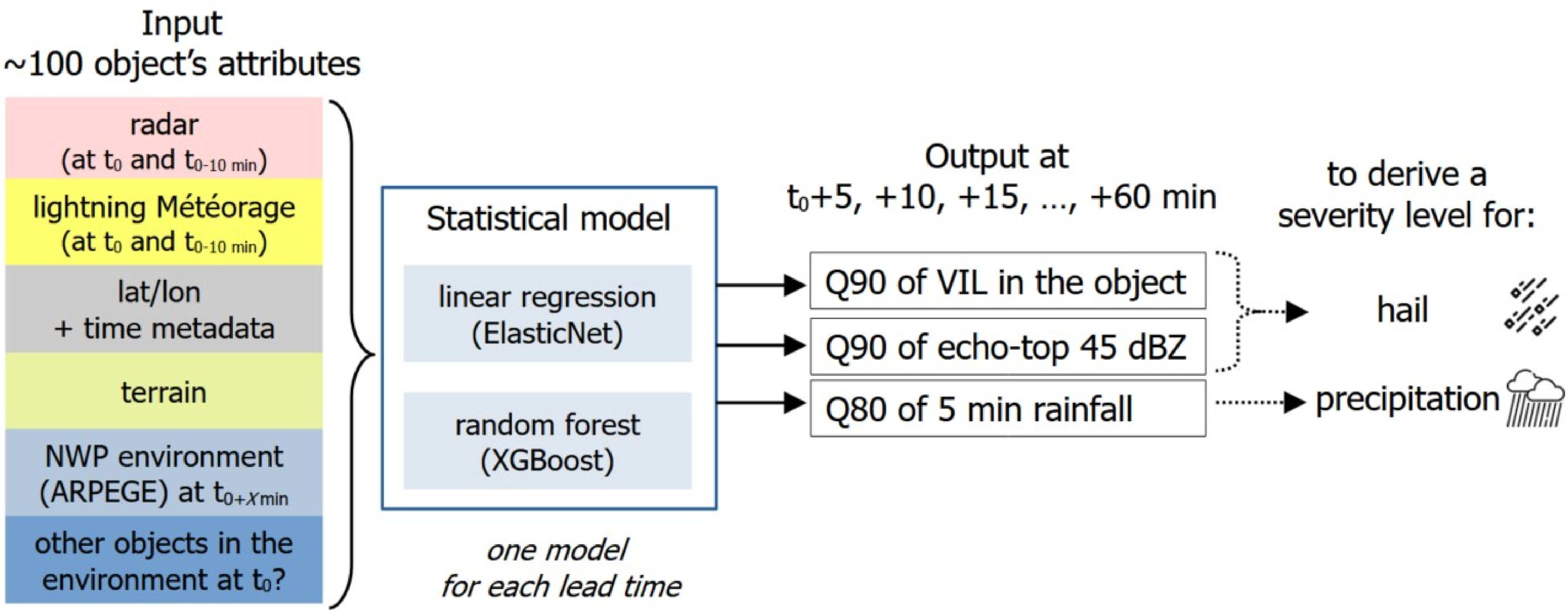


1h U-Net forecasts of the probability of level 3 OPIC occurrence (contours), compared to the forecast by Local advection (in red)

Radar storm objects : MIMOSA forecasts

1-hour forecast of storm attributes

Methodology :

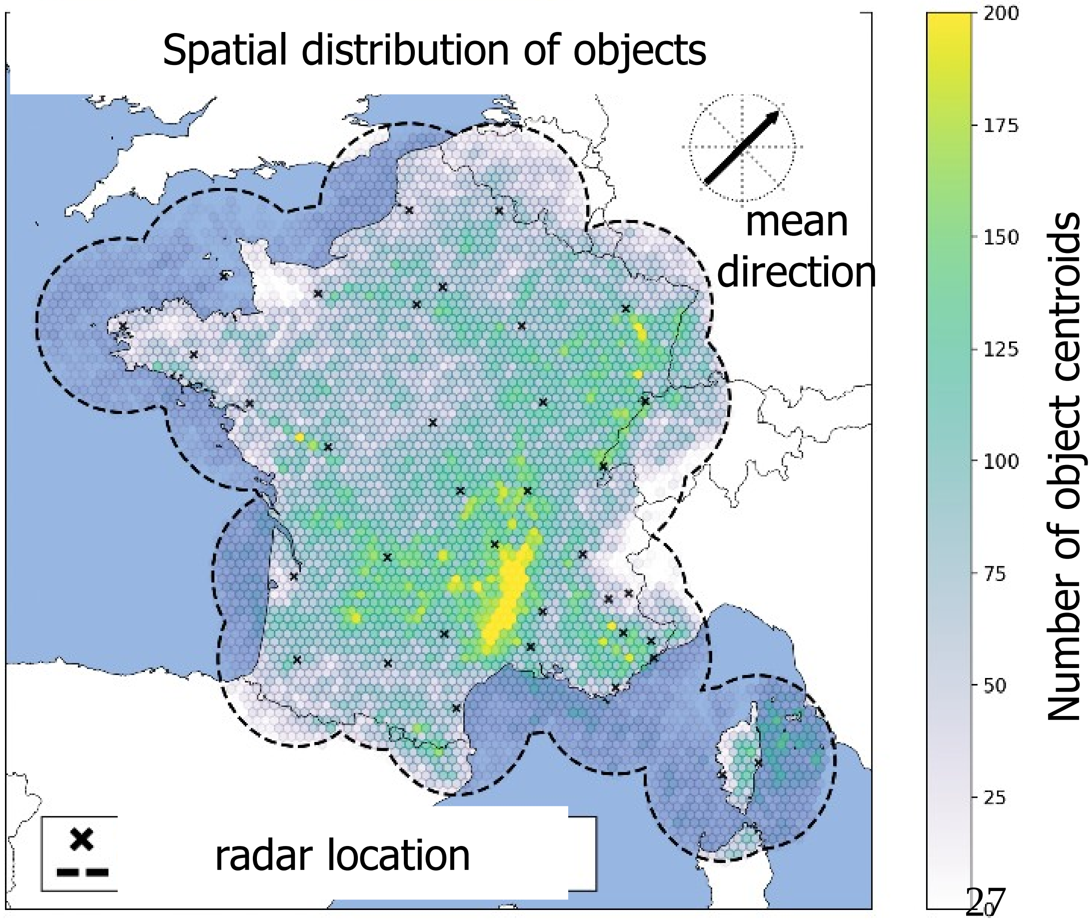


(E. Pottez)

Radar storm objects : MIMOSA forecasts

1-hour forecast of storm attributes

Dataset analysis: ~200 000 48-dBZ objects in April-October 2024



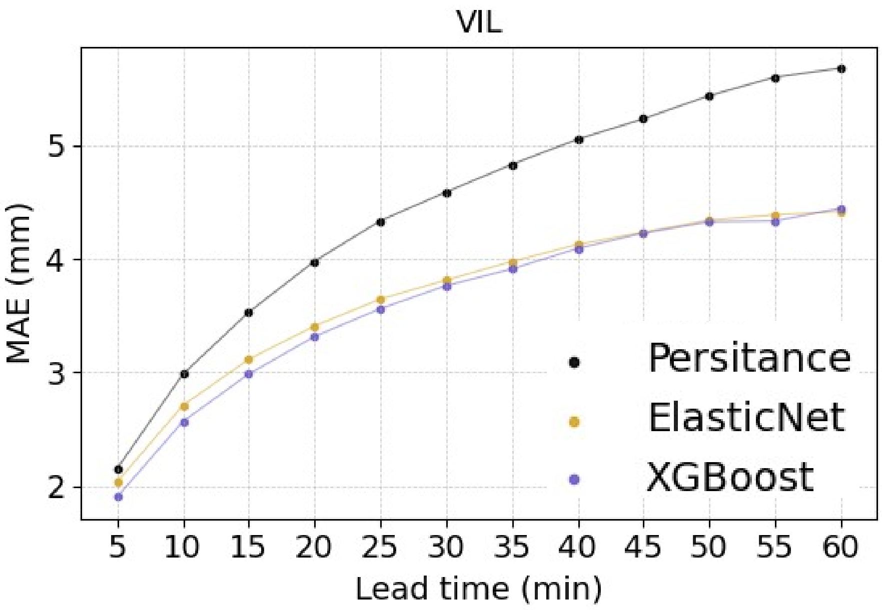
(E. Pottez)

Radar storm objects : MIMOSA forecasts

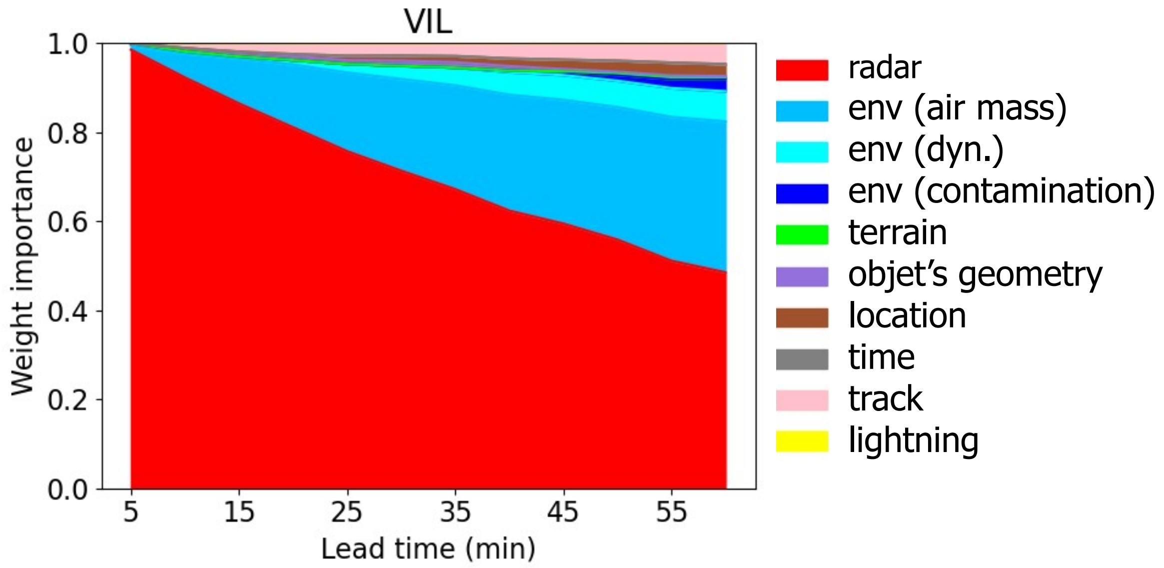
1-hour forecast of storm attributes

Scores on a test dataset for VIL :

(E. Pottez, G. Arnould)



Predictors importance for ElasticNet



- statistical models improve persistance
- machine learning (XGBoost) does not improve linear regression (ElasticNet)
- radar attributes have more weight but NWP environment is more relevant at longer lead times

(similar conclusions for echo-top 45 dBZ and 5 min rainfall)

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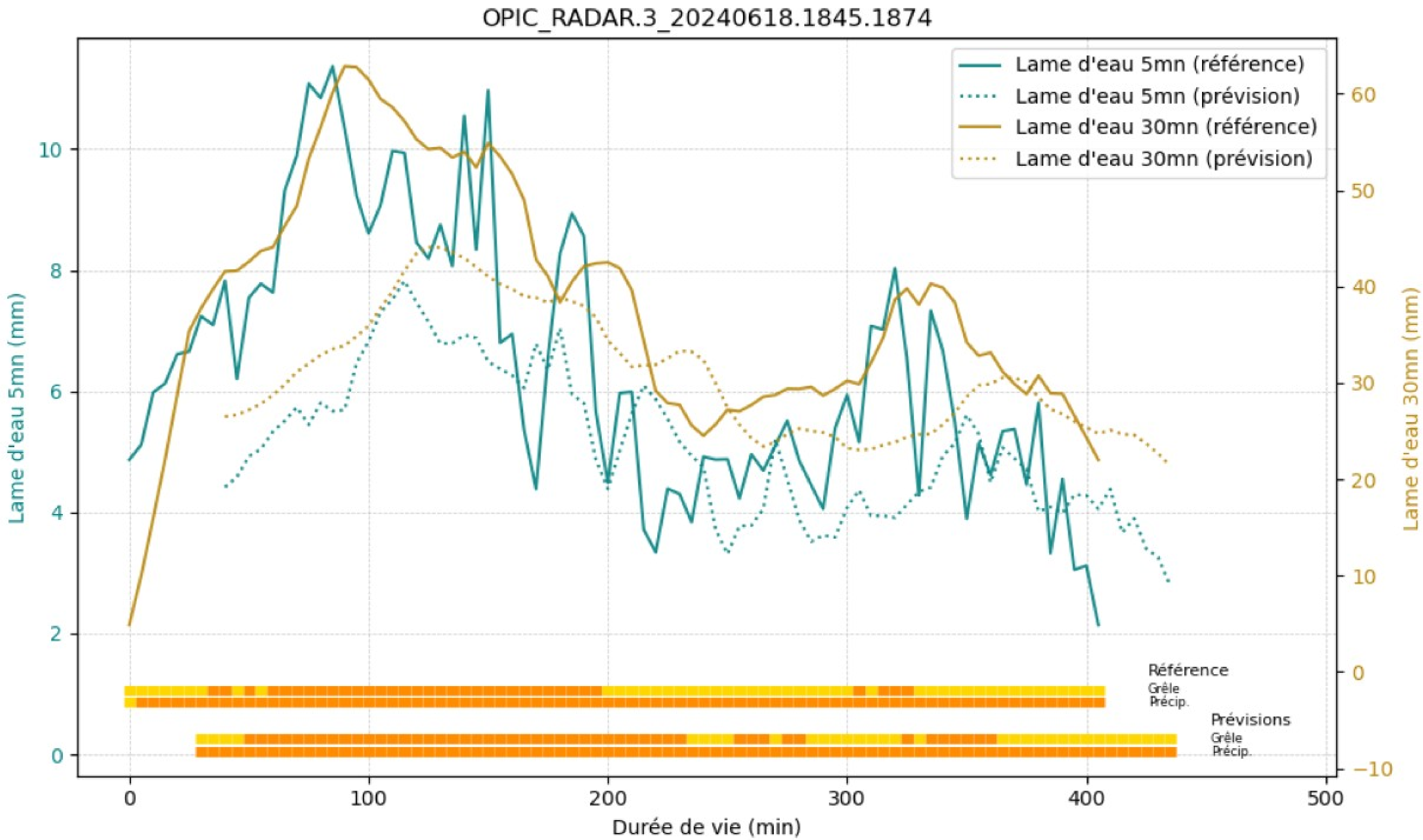


(a) Valeurs des lames d'eau sur 5 mn et 30 mn prévues (traits pointillés) et observées (traits pleins).

Conclusions

- In France, local authorities are warned for exceptional rain rates at the commune level by APIC, with a 15 min update
- This service has been recently completed by a probabilistic forecast of precipitation threshold exceedence up to 3h, provided only where an APIC is triggered
- This forecast is deduced from an ensemble of PIAF forecasts, that blends image extrapolation and AROME-PI, an optimized version of AROME-France for NWC purposes
- Warning for thunderstorm is based on the OPIC objects, the MIMOSA interface allowing to go further in terms of severity and hazards diagnostics
- Work is ongoing to improve the forecasts of the contour and of the severity up to 1h
- These developments aim :
  - to provide synthetic informations and visual warnings to forecasters
  - To build an automatic warning system, build upon the actual one, but with much more flexibility

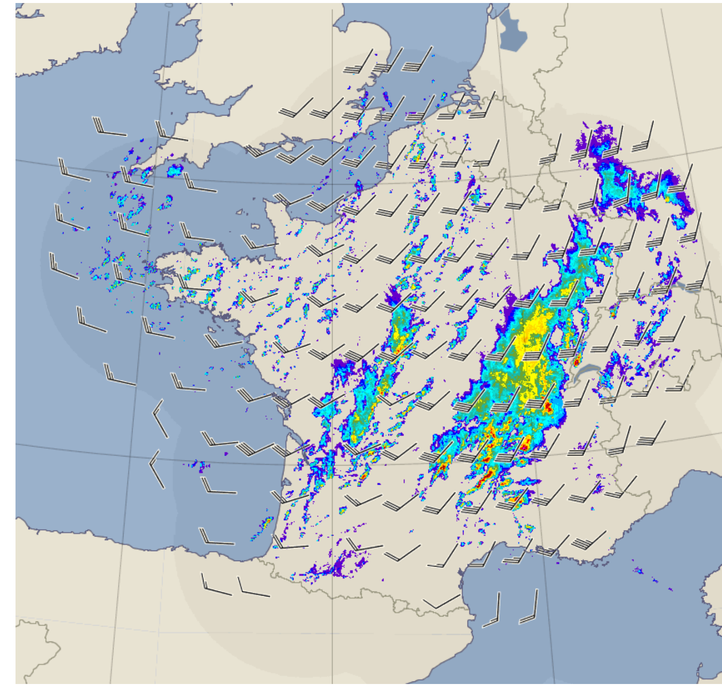
References

Caron J.-F., Michel Y., Montmerle T and Arbogast E.: 2019 : Improving Background-Error Covariances in a 3D Ensemble-Variational Data Assimilation System for Convective Scale NWP. Monthly Weather Review, DOI:10.1175/mwr-d-18-0248.1.

Destouches M., Montmerle T., Michel Y., and Ménétrier B : 2021. Estimating optimal localization for sampled background error covariances of hydrometeor variables. QJRMS, pages 1–20. DOI 10,1002/qj.3906.

Destouches M., Montmerle T., Michel Y. and J.-F. Caron, 2022 : Impact of hydrometeor control variables in a convective-scale 3DEnVar data assimilation scheme. QJRMS, 1-24. DOI: 10.1002/qj.4426

Deterministic QPF



1. 2PIR Displacement field retrieval

Iterative computation of cross-correlations to account the different scales of the reflectivity pattern

2. Advection by the displacement field

- Pixels of the last available image are advected up to 70’ forecast with outputs every 5’

Available at meteofrance.com and on mobile phones

- Same displacement is used to advect the 5’ QPE
- One application of the latter is “rain in the next hour” public product (after aggregation at the municipal level)

Limitations in case of :

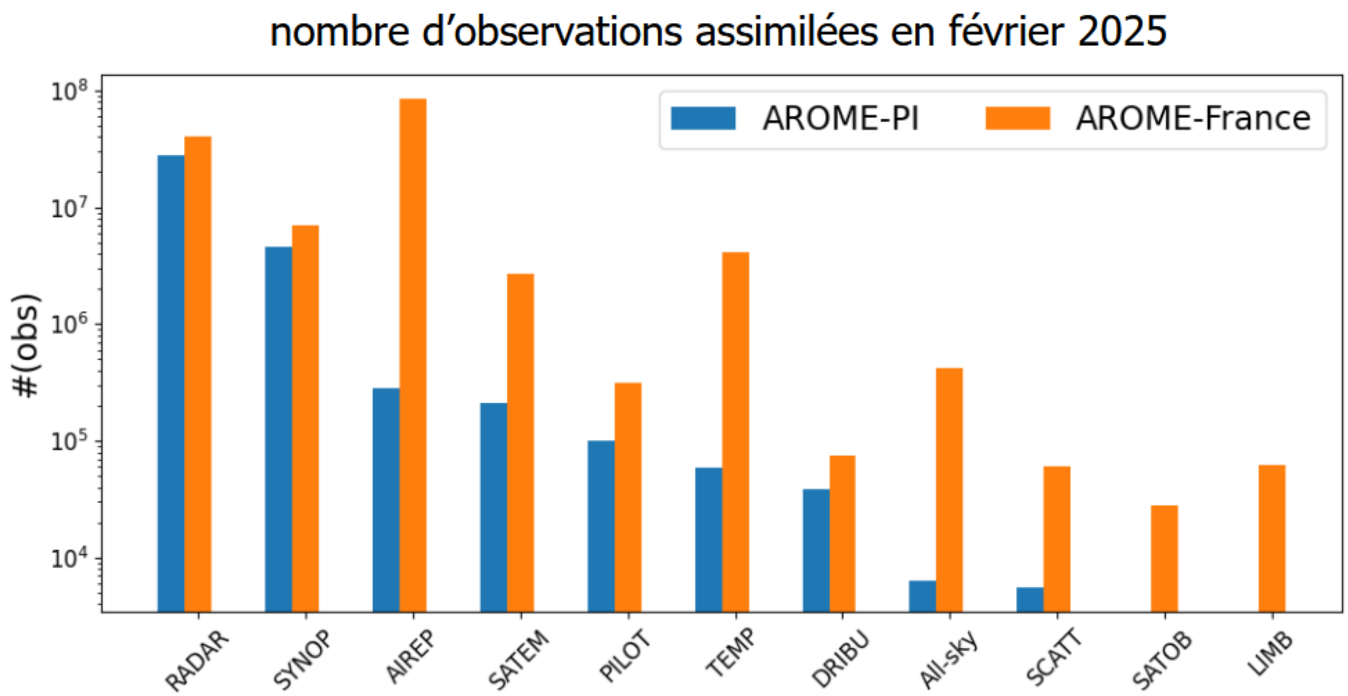
- radar data of poor quality, strong orography
- Strong convection (where traj of convective cells may differ from the large scale flow)

AROME-PI : NWP tuned for NWC

After ~1.5–2 hours, extrapolation shows its limitations : NWP is needed within short lead times and with regular, frequent outputs.

→ AROME-PI : **Update of the latest AROME-France forecast**, using assimilation of the most recent observations using 3DVar (oper) or 3DEnVar (e-suite)

→ Forecasts up to 6h ahead with 15min outputs, available every hour at H+30 min.



A-posteriori differences with AROME-FR come from the shorter cut-off (10')

(G. Arnould)

Volumetric radar data (Z and DOW) remain by far the most widely used observations