X-band radars and QPE

Towards a better use of X-band radars in a national weather radar network

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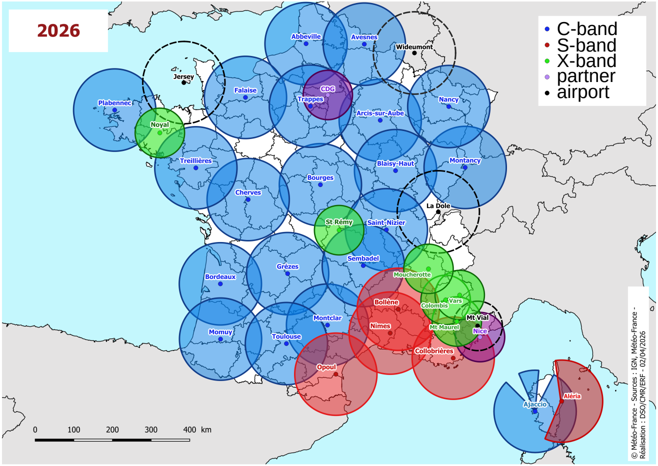
1. Context and motivation

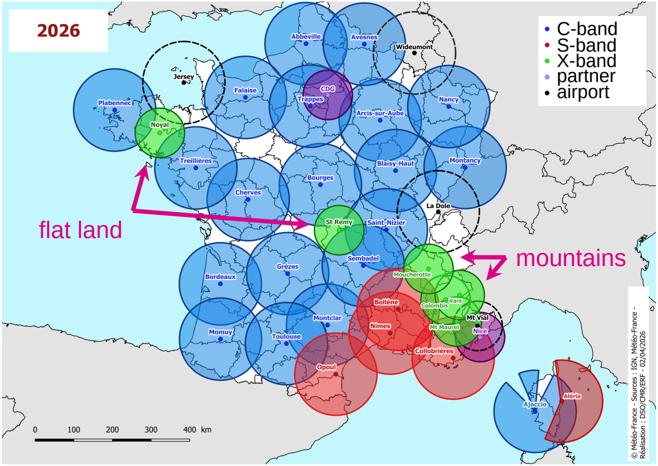
Météo-France weather radar network



Météo-France weather radar network in metropolitan France:

- 20 C-band
- 5 S-band
- 8 X-band
- 4 partner radars

Météo-France weather radar network



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- 20 C-band
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X-band radar particulars

St-Rémy radar

X-band radars in general:

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St-Rémy radar

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- small peak-power (40 kW) and antenna (1.8m):

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St-Rémy radar

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In Météo-France network:

- 4 radars are above 1700 meters of altitude

X-band radar particulars

St-Rémy radar

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In Météo-France network:

- 4 radars are above 1700 meters of altitude $\Rightarrow$ radar often within or above the bright band

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St-Rémy radar

X-band radars in general:

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In Météo-France network:

- 4 radars are above 1700 meters of altitude $\Rightarrow$ radar often within or above the bright band

At Météo-France, it was observed that X-band radars tend to be biased during severe events causing attenuation. This is particularly true if the radar is within or above the freezing level.

2. Météo-France radar QPE composition

Météo-France QPE composition in short

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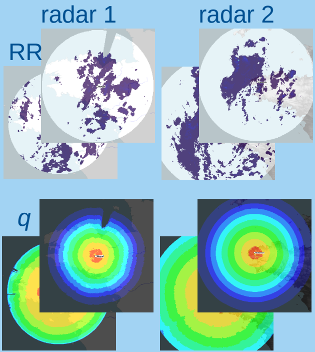
Volumetric scale



Météo-France QPE composition in short

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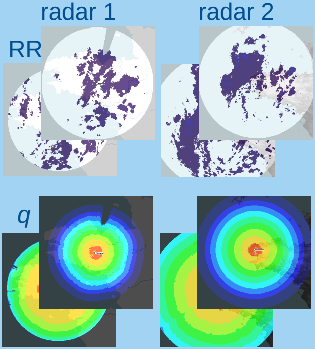
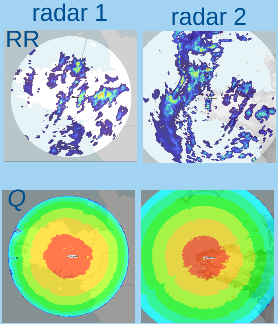


Radar QPE

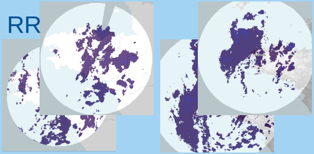


Météo-France QPE composition in short

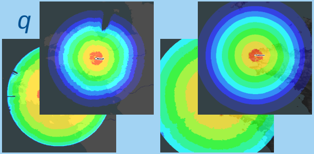
Volumetric scale

radar 1 radar 2

RR



q



Radar QPE

radar 1 radar 2

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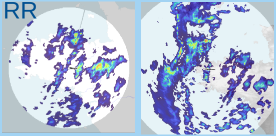

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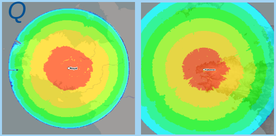
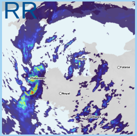
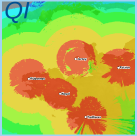


QPE composite

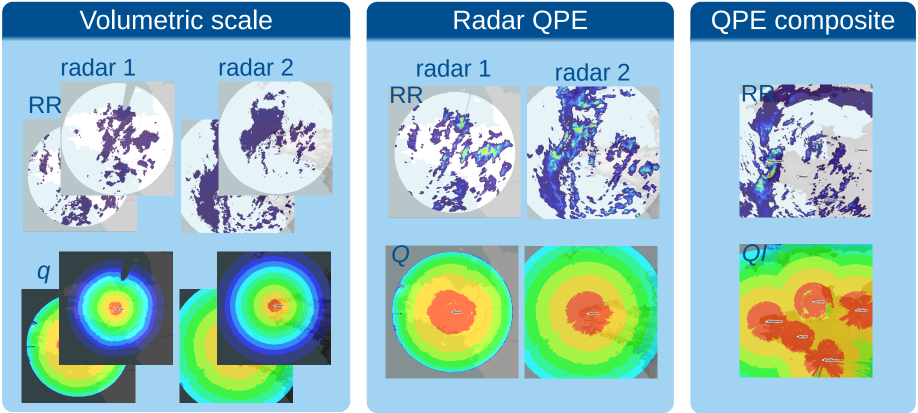
RR



QI

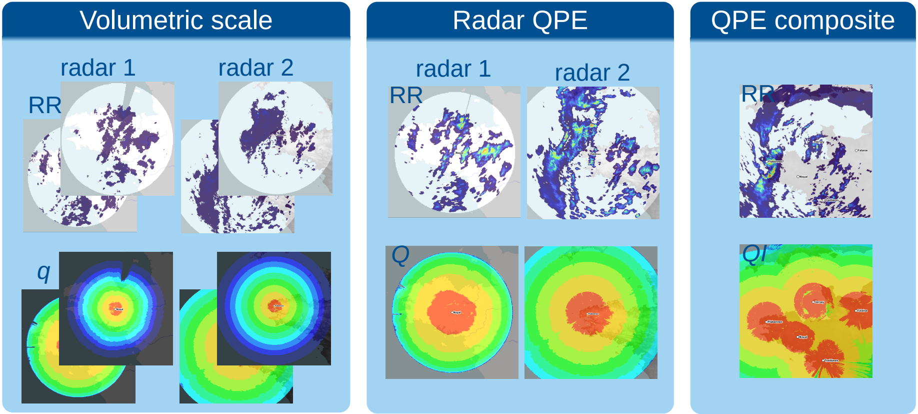


Météo-France QPE composition in short



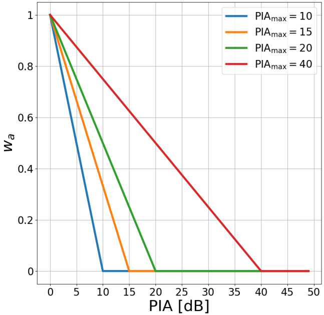
- q indexes are a product of weighting functions: $q = w_t \times w_a \times w_m \times w_h$.

Météo-France QPE composition in short



- q indexes are a product of weighting functions: $q = w_t \times w_a \times w_m \times w_h$.
- Current quality index is very static and does not adapt to situation where X-band radars don’t perform well.

Proposed update for X-band (1/3)



$$w_a = \begin{cases} 1 - \frac{\mathrm{PIA}}{\mathrm{PIA}_{max}} & \text{if } \mathrm{PIA} < \mathrm{PIA}_{max} \\ 0 & \text{otherwise} \end{cases}$$

PIA: path integrated attenuation deduced from differential phase Φ_{dp}, PIA_{max}: parameter that can be tuned.

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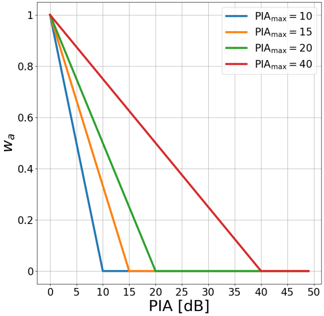

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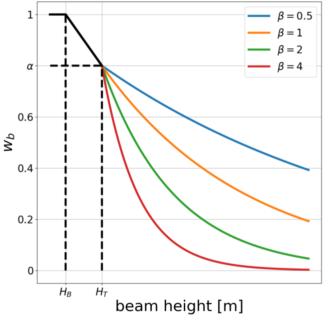
PIA: path integrated attenuation deduced from differential phase Φ_{dp}, $\mathrm{PIA_{max}}$: parameter that can be tuned.

Remarks:

- The goal here is to limit the impact of the X-band radar in case of strong precipitations.
- This is currently implemented with $\mathrm{PIA_{max}} = 40$ dB.
- Fine tuning lead to $\mathrm{PIA_{max}} = 15$ dB

Proposed update for X-band (2/3)



$$w_b = \begin{cases} 1 & \text{if } h < H_B \\ \alpha + (1-\alpha)\frac{H_T - h}{H_T - H_B} & \text{if } h \in [H_B, H_T] \\ \alpha \exp\left(-\beta \frac{1-\alpha}{\alpha} \frac{h - H_T}{H_T - H_B}\right) & \text{if } h > H_T \end{cases}$$

h: altitude of the center of the beam, H_B and H_T: bottom and top altitudes of the bright band resp. α and β: parameters that can be tuned.

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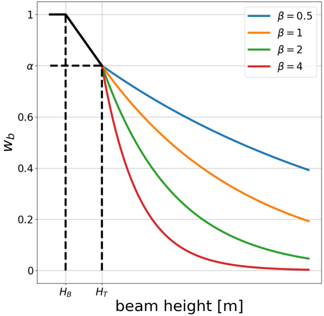

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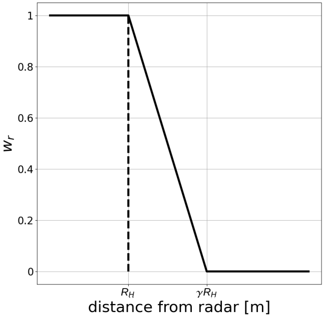
h: altitude of the center of the beam, H_B and H_T: bottom and top altitudes of the bright band resp. α and β: parameters that can be tuned.

Remarks:

- The goal here is to limit the impact of the X-band radar when the beam is within and above the bright band.
- Fine tuning lead to $\alpha = 0.8$ and $\beta = 2.5$.

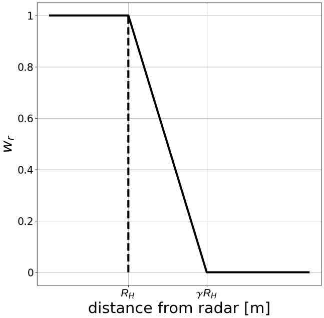
Proposed update for X-band (3/3)



$$w_r = \begin{cases} 1 & \text{if } r < R_H \\ \frac{r-\gamma R_H}{(1-\gamma)R_H} & \text{if } r \in [R_H, \gamma R_H] \\ 0 & \text{if } r > \gamma R_H \end{cases}$$

r: distance of the center of the beam from the radar, R_H: distance where the sensitivity of the radar is 0 dBZ, γ: parameter that can be tuned.

Proposed update for X-band (3/3)



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r: distance of the center of the beam from the radar, R_H: distance where the sensitivity of the radar is 0 dBZ, γ: parameter that can be tuned.

Remarks:

- The goal here is to limit the impact of the X-band radar at ranges where its sensitivity is not satisfying for QPE applications.
- Sensitivity study lead to $R_H = 100$ km and $\gamma = 1.5$

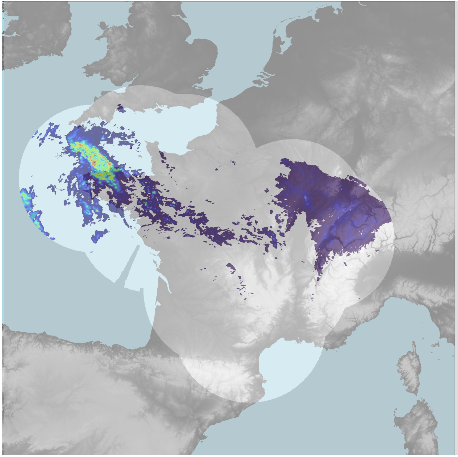
3. Results

Plain radars - Noyal (155m)

Context: due to systematic underestimation during severe events, this radar has been removed from the national QPE product in 2025.

Noyal - Situation

February 18, 2026: Pedro storm.



Qualitative results

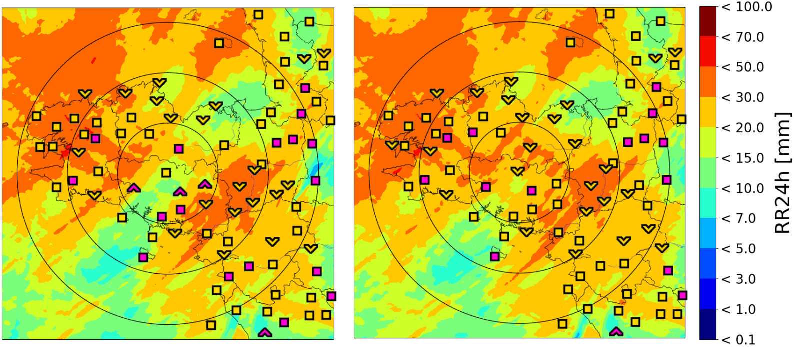
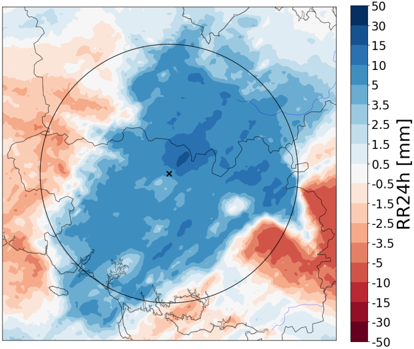


Figure: 24h cumulative precipitation (**left**) without and (**right**) with Noyal radar integration. Symbols characterize R/G ratios.

Qualitative results (cont'd)

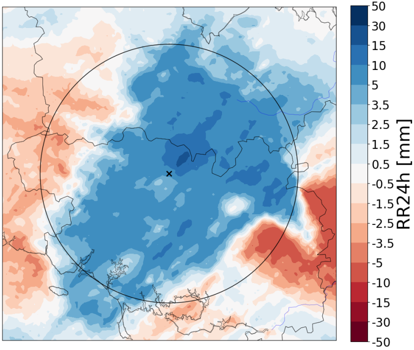
Zoom-in difference



- Increase of the QPE in its vicinity
- Reduction of the QPE close to its neighbors.

Qualitative and quantitative results

Zoom-in difference



- Increase of the QPE in its vicinity
- Reduction of the QPE close to its neighbors.

24h cumulated radar QPE and rain gauge were computed at each station (only stations with $G24h > 10$mm are considered).

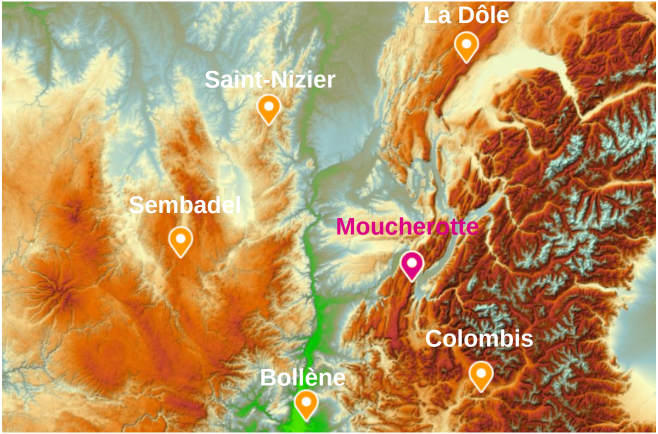
- normalized bias: $E\{R - G\}/E\{G\}$

area (km)	OPER	TEST
0 - 50	-0.036	0.123
50 - 100	0.292	0.268
100 - 150	0.143	0.161

- normalized RMSE: $\sqrt{E\{(R-G)^2\}}/E\{G\}$

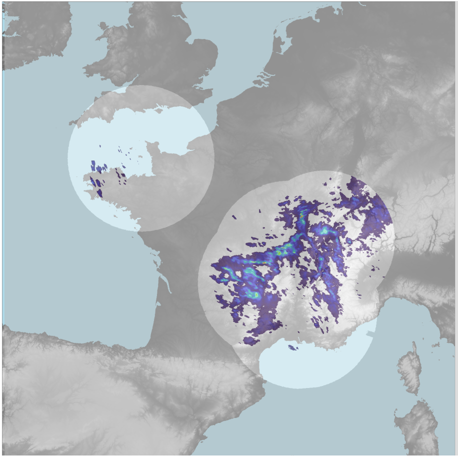
area (km)	OPER	TEST
0 - 50	0.228	0.208
50 - 100	0.374	0.343
100 - 150	0.253	0.266

Mountain radars - Moucherotte (1913m)



Moucherotte - Situation

February 19, 2026



Qualitative results

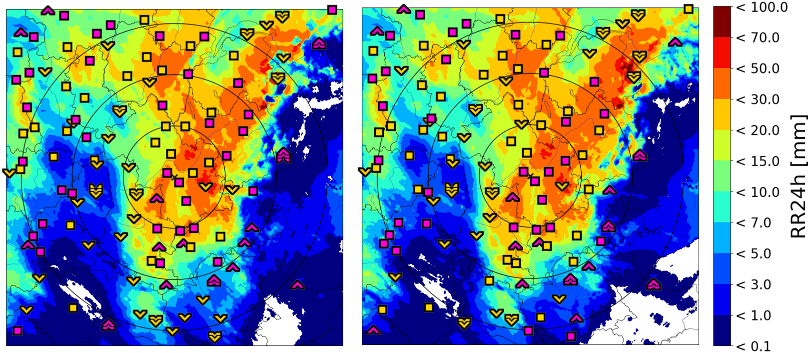
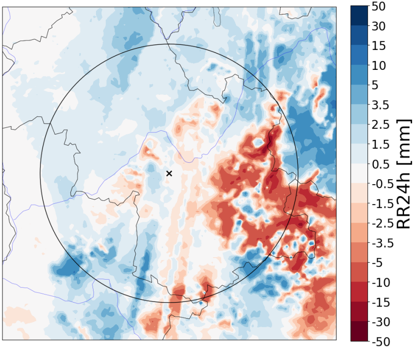


Figure: 24h cumulative precipitation (**left**) with old and (**right**) with proposed weights implemented in Moucherotte radar. Symbols characterize R/G ratios.

Quantitative results

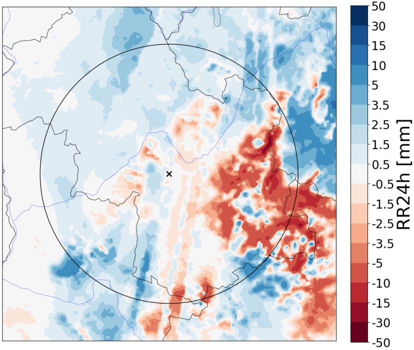
Zoom-in difference



- QPE reduction over the mountains.
- Increase of the QPE in the valleys.

Quantitative results

Zoom-in difference



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- Increase of the QPE in the valleys.

24h cumulated radar QPE and rain gauge were computed at each station (only stations with $G24h > 10$mm are considered).

- normalized bias: $E\{R-G\}/E\{G\}$

area (km)	OPER	TEST
0 - 50	-0.058	-0.081
50 - 100	0.018	0.115
100 - 150	0.047	0.160

- normalized RMSE: $\sqrt{E\{(R-G)^2\}}/E\{G\}$

area (km)	OPER	TEST
0 - 50	0.428	0.420
50 - 100	0.285	0.296
100 - 150	0.351	0.418

4. Conclusions and perspectives

Conclusions

- In order to better exploit X-band radars for QPE present in Météo-France network, a first study based on dynamic weights and quality indexes has been done.
- For radars that were not integrated in the national QPE composite (Noyal and St-Rémy), their data have been shown to improve the overall quality of the composite in their vicinity without degrading when other radars are closer. This positive result was confirmed by a test over 4 weeks in operational conditions.
- For radars in the Alps, already used in the national QPE composite, the proposed approach has a similar impact on the case study. The important take-away being that it does not strongly affect the overall quality of the composite.

Perspectives

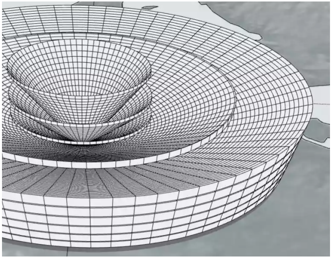
- The proposed approach will be tested over next winter in order to be validated in conditions where the mountain radars will often be located above the freezing level.
- Another lead to improve the use of X-band data in the national QPE composite is to work on the calibration procedure, recent work involving spatial calibration look promissing and might help X-band radar as they tend to generated biased QPE.
- Finally, a complete overhaul of X-band radars processing chain (attenuation, VPR, precipitation phase, etc.) is planned for the coming months.


Хвала пуно!

References I

Tabary, P. (2007). "The new French operational radar rainfall product. Part I: Methodology". In: *Wea. Forecasting* 22.3, pp. 393–408.

backup: Volumetric quality index



Weather data are first processed at the volumetric level.

(image extracted from Met.3D)

A quality index $q_k^{(i)}$ associated to the pixel at location k of the PPI i is first evaluated (Tabary 2007).

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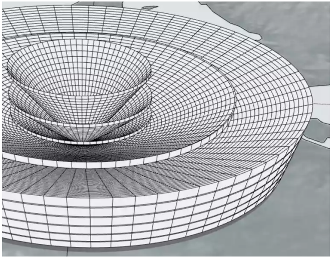

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initialization of quality indexes based on fuzzy logic: $q_k^{(i)} = 0$ if ground clutter, and $q_k^{(i)} = 1$ otherwise.

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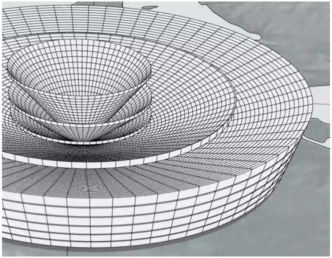

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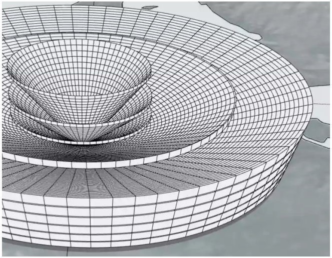
For X-band only: signal attenuation correction: $q_k^{(i)} = q_k^{(i)} * (1 - \mathrm{PIA}/\mathrm{PIA}_{max})$, $\mathrm{PIA}_{max} = 40$ dB.

backup: Volumetric quality index



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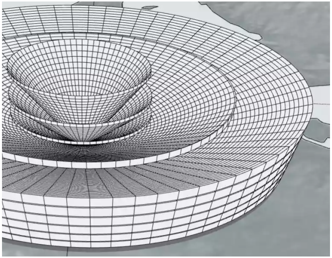

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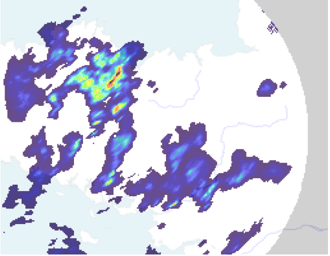
Mask correction (if mask $< 70\%$): $q_k^{(i)} = q_k^{(i)} * (1 - \text{mask}/100)$.

PVR correction: $q_k^{(i)} = q_k^{(i)} * \exp(-H_{\text{beam}}/H_0)$, $H_0 = 500$ m.

backup: Radar QPE quality index

When evaluating the rain rate $R_k^{(r)}$ for a given radar r, a associated quality index $Q_k^{(r)}$ is also computed.



Radar QPE is then obtained by aggregation of volumetric data.

(image extracted from Météo-France SERVAL software)

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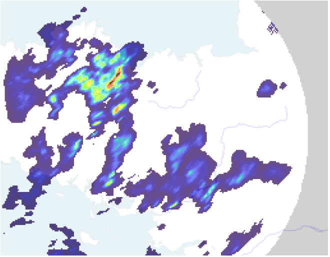

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(image extracted from Météo-France SERVAL software)

When evaluating the rain rate $R_k^{(r)}$ for a given radar r, a associated quality index $Q_k^{(r)}$ is also computed.

Aggregation of the observations from all the available PPI:

$$R_k^{(r)} = \sum_{i=1}^{N_{\mathrm{PPI}}} q_k^{(i)} R_k^{(i)} / \sum_{i=1}^{N_{\mathrm{PPI}}} q_k^{(i)}$$

$$Q_k^{(r)} = \max_i q_k^{(i)}$$

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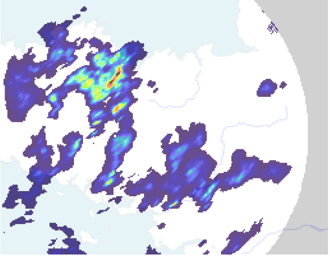

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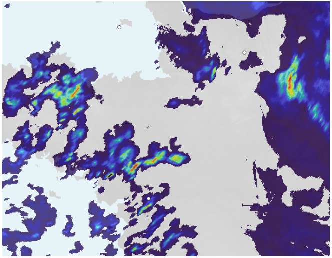
$$Q_k^{(r)} = \max_i q_k^{(i)}$$

Advection-based filling: some pixels are deduced from advection of prior observation: $Q_k = Q_k * \exp(-\text{obs. age}/T_0)$, $T_0 = 20$ mn.

backup: QPE composition procedure

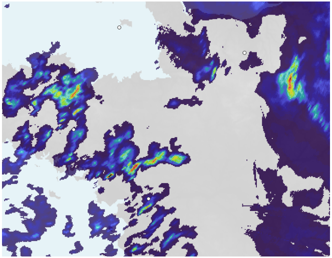


Composition of different radar QPE is finally obtained by weigthing data with quality indexes.

(image extracted from Météo-France SERVAL software)

The global QPE composition is done by comparing overlapping radar data. The final rain rate estimate *RR* and its corresponding quality index *QI* are then computed.

backup: QPE composition procedure



Composition of different radar QPE is finally obtained by weigthing data with quality indexes.

(image extracted from Météo-France SERVAL software)

The global QPE composition is done by comparing overlapping radar data. The final rain rate estimate *RR* and its corresponding quality index *QI* are then computed.

Linear combination of available data:

$$RR_k = \sum_{r \in \text{radar}} = Q_k^{(r)} R_k^{(r)} / \sum_{r \in \text{radar}} Q_k^{(r)}$$

$$QI_k = \max_r Q_k^{(r)}$$

backup: Metrics

In this study, one of the metrics used was the radar QPE to raingauge ratio R/G. This ratio located at a weather ground station, can be graphically represented as follows:

Radar over-estimation

$R/G \in (1, 1.2)$

$R/G \in (1.2, 1.5)$

$R/G \in (1.5, 2)$

$R/G > 2$

Radar under-estimation

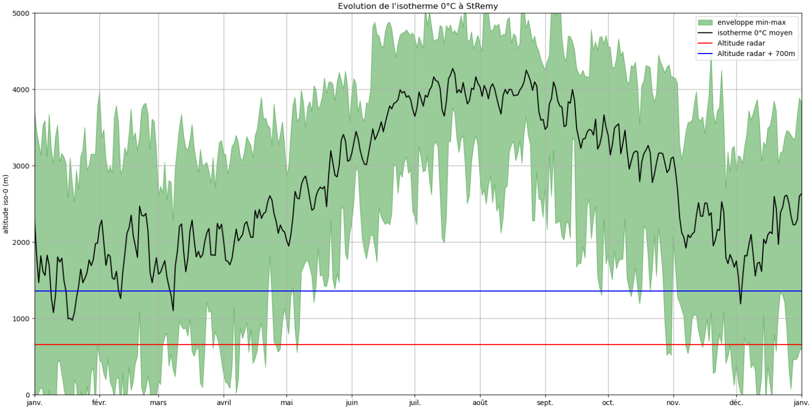
$R/G \in (0.8, 1)$

$R/G \in (0.5, 0.8)$

$R/G \in (0.25, 0.5)$

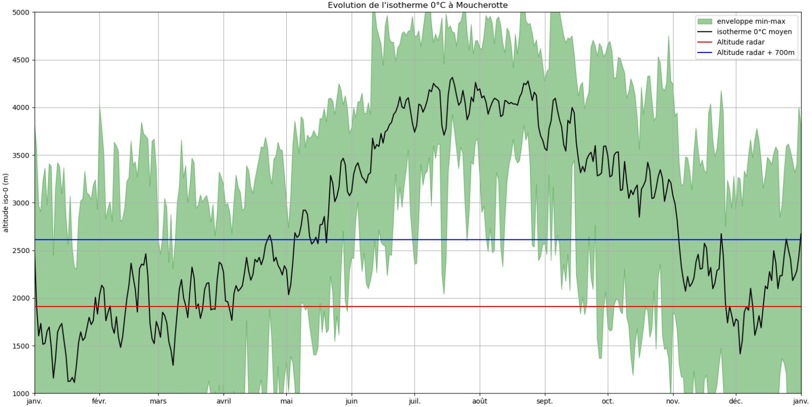
$R/G < 0.25$

backup: Bright band height example 1/2



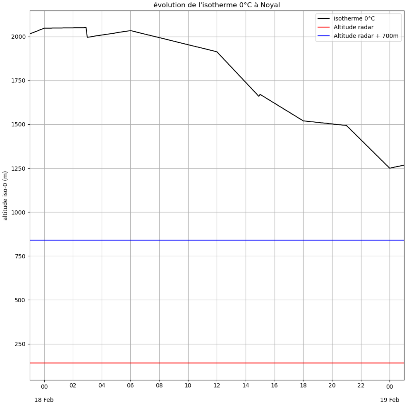
Freezing level yearly evolution based on model from 2016 to 2023 at St-Rémy radar location (altitude: 660m).

backup: Bright band height example 2/2



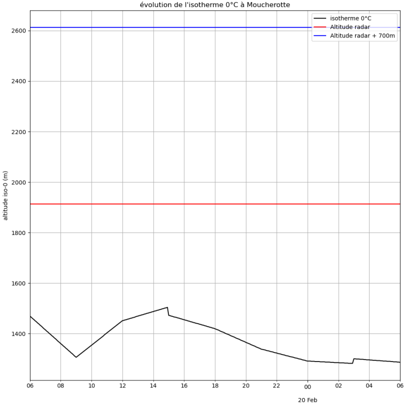
Freezing level yearly evolution based on model from 2016 to 2023 at Moucherotte radar location (altitude: 1913m).

backup: Freezing level for Noyal



Freezing level during Noyal case study on February 18, 2026.

backup: Freezing level for Moucherotte



Freezing level during Moucherotte case study on February 19, 2026.

backup: Global scores

radar	area (km)	Bias		RMSE	
		OPER	TEST	OPER	TEST
NOYA	0 - 50	-3.48	-1.51	5.58	6.38
	50 - 100	1.67	1.18	6.22	6.17
	100 - 150	0.91	0.86	5.82	5.79
STRE	0 - 50	-5.34	-4.84	7.14	6.27
	50 - 100	-4.24	-4.63	9.45	9.39
	100 - 150	-1.85	-1.87	7.89	7.88
MOUC	0 - 50	-1.77	-4.01	8.72	8.43
	50 - 100	-0.27	-1.1	7.37	8.02
	100 - 150	-0.67	-0.72	7.39	8.18
MAUR	0 - 50	-1.69	-2.71	7.09	7.11
	50 - 100	-1.37	-2.65	9.49	9.91
	100 - 150	-0.24	-2.55	8.48	8.37
CLMB	0 - 50	1.08	1.81	5.82	6.32
	50 - 100	1.29	3.31	8.38	8.60
	100 - 150	-1.84	-1.46	9.08	9.36

backup: Hour-based calibration scheme

At Météo-France, a QPE hour-based calibration, noted CC_H at instant H, is implemented on all radars. This scheme is based on the most recent observations between each radar and its surrounding stations. It's definition is as follows:

$$CC_H = \frac{\sum_{i=0}^{M} w_i P_{H-i} + C_r}{\sum_{i=0}^{M} w_i R_{H-i} + \frac{C_r}{CC_M}},$$

where,

- P_{H-i} is the cumulative rain gauge observations at instant $H - i$ (for rain gauges located in areas where the QPE quality index is larger than 84%),
- R_{H-i} is the corresponding radar QPE at instant $H - i$,
- $w_i = 2^{-i/T}$ is a weighting function that gets smaller as the observation gets older,
- C_r, M and T are parameters that tune the dynamics of CC_H (especially when there is no more rain.
- CC_M is the QPE month-based calibration.

backup: quantitative results

RR24h is computed at each station and compared with the QPE. Only stations with $G24h > 10$mm and $CQ > 84$ are considered.

For Noyal episode:

- $\%$ of ratios within $[0.8, 1.25]$:

area (km)	N_S	**OPER**	**TEST**
0 - 50	6	50.00	66.67
50 - 100	36	36.11	33.33
100 - 150	30	63.33	63.33

For Moucherotte episode:

- $\%$ of ratios within $[0.8, 1.25]$:

area (km)	N_S	**OPER**	**TEST**
0 - 50	16	31.25	37.50
50 - 100	19	47.37	47.37
100 - 150	26	50.00	50.00