Bow echo detection in forecasts and radar data with a U-Net

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Motivations

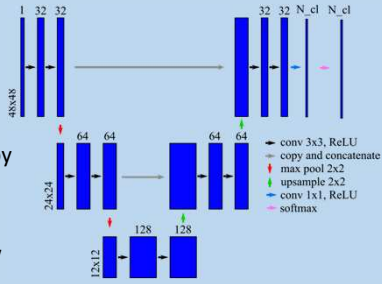
- Bow echo (BE) [1] : Mesoscale Convective System (MCS) responsible for strong wind gusts or tornadoes
- Convection-permitting ensemble prediction systems (EPS) like AROME-EPS [2] are able to explicitly simulate MCS, including bow echoes
- The aim is to develop a convolutional neural networks (CNN) which can detect bow echo directly in AROME-EPS. CNN extracts relevant information from EPS to facilitate the work of forecasters (automatic early-warning).
- AROME-EPS : 16 members, 4 runs per day, lead time up to +51h, horizontal resolution of 2.5 km

U-Net & Database

U-Net :

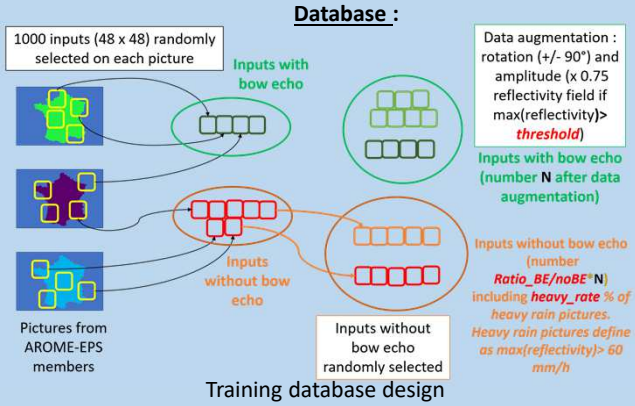
- U-Net architecture adapted from Ronneberger et al [3]
- Input : reflectivity field
- Loss function : weighted cross-entropy

5 parameters are fitted : input size, data augmentation threshold, no_BE inputs/BE inputs ratio, heavy_rate, bow class weight in loss function



U-Net architecture

Database :



Training database design

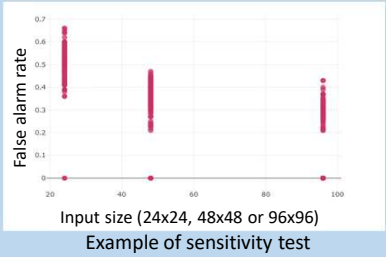
❖ 6600 pictures in training database with 550 bow echoes. 3000 in testing with 250 bow echoes. All pictures are AROME-EPS forecasts.

❖ All bow echoes are hand-labeled

Sensitivity test

Main findings :

- Best input size : 48x48 pixels (48 pixels ~ bow echo length scale)
- No BE/BE ratio : U-Net detects no bow echo if ratio is too big
- Heavy_rate : fewer false alarms for strong/heavy bow echoes
- Weights : weights depend on input size (smaller input size → smaller weights)



Example of sensitivity test

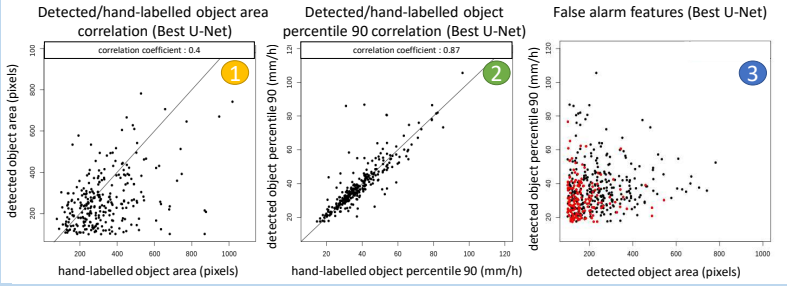
405 experiences compared to each other with MLFlow (www.mlflow.org)

References

[1] : L.Goulet. Bow Echoes :Conceptual Schemes and European Relevance. The European Forecaster. 2015
[2] : F. Bouttier, L. Raynaud, O. Nuissier, and B. Menetrier. Sensitivity of the arome ensemble to initial and surfaceperturbations during hymex.Quarterly Journal of the Royal Meteorological Society, 142(S1):390–403, 2016.doi: 10.1002/qj.2622.
[3] : O. Ronneberger, P. Fischer, and T. Brox. U-net: Convolutional networks for biomedical image segmentation.volume 9351, pages 234–241, 10 2015. doi: 10.1007/978-3-319-24574-428.

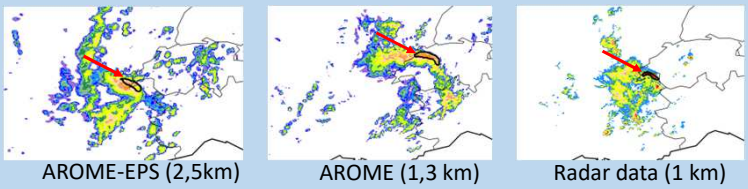
U-Net Evaluation : object-oriented approach

- The best U-Net detects 85% of bow echoes but 35% of detections are false alarms
- 2 object properties are considered :
  area (number of pixels) and percentile 90 of the reflectivity distribution within the object (high reflectivity caracteristic, in mm per hour)



- ❑ Association between detected and hand-labeled bow echoes if distance between centres of mass is smaller than 50km
- ❑ Graph 1 : Predictions of U-Net area are too small for biggest hand-labeled objects.
- ❑ Graph 2 : Percentile 90 is very well represented . Heaviest reflectivities correspond to strong gradients → the most informative part for U-Net. That's why correlation is good.
- ❑ Graph 3 : False alarms concern mainly weak and small bow echoes
- ❑ No detection features (not shown) : mainly, small bow echoes

Extension to deterministic model or radar data

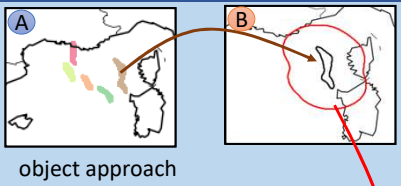

AROME-EPS (2,5km) AROME (1,3 km) Radar data (1 km)

Same U-Net has been tested with deterministic model AROME or with high resolution radar data as input without re-training. Findings are quite good even if another training could improve detections (especially for radar data)

Display tools

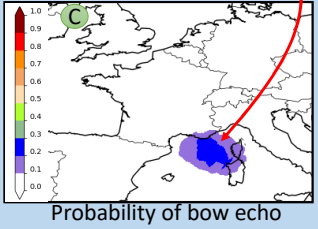
How to synthesize detections in all AROME-EPS members?

- **Object approach** A :
  1 color = 1 member and all detections are overlaid. preferred approach of forecasters.



object approach

- **Probabilistic approach** C :
  Space-time tolerance is necessary (small object).
  Space : A "risk" area of bow echo is added around each detected bow echo (red contour, picture B). The distance of this neighborhood will be fitted with evaluation of AROME-EPS.
  Time : forecasts at t-1h and t+1h are considered as forecasts at time t.



Probability of bow echo

Future work

- Evaluation of AROME-EPS (probabilistic approach + radar data detection)
- Improve radar data detection
- Same study for supercell detection (other kind of MCS)