

STATISTICAL DOWNSCALING FOR URBAN TEMPERATURE AT HECTOMETRIC SCALE

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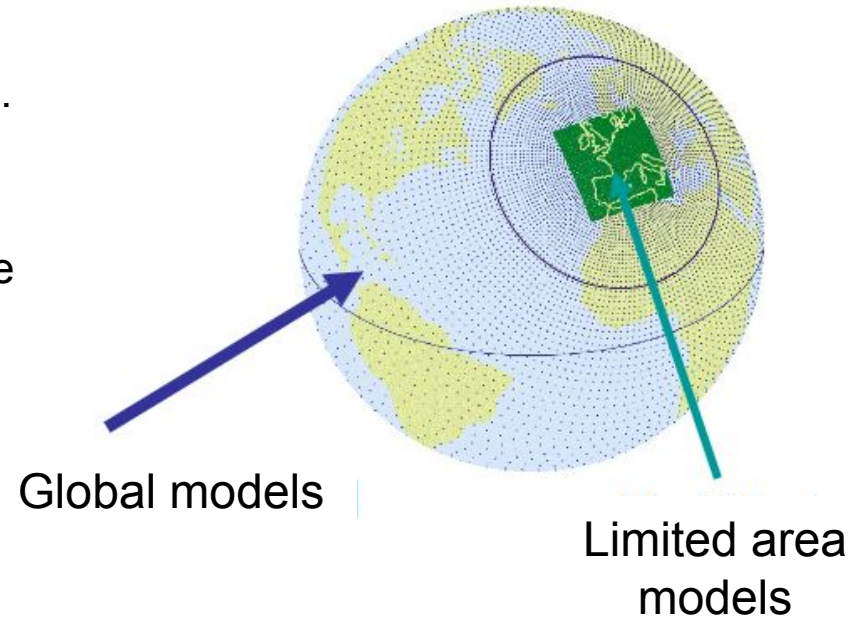
INTRODUCTION

- Urban weather forecasting:
 - +50% world's population live in cities [1].
 - Socio-economic and health impacts
- Today's forecasting:
 - Global Models: too coarse to reproduce fine scale phenomena
 - Limited Area Models: numerically expensive models



INTRODUCTION

- Urban weather forecasting:
 - +50% world's population live in cities [1].
 - Socio-economic and health impacts
- Today's forecasting:
 - **Global Models**: too coarse to reproduce fine scale phenomena (ex. ARPEGE)
 - **Limited Area Models**: numerically expensive models (ex. AROME)



STATISTICAL DOWNSCALING

- Statistical models linking large scale data to a local variable over a given domain
- Statistical relationship between the low resolution and the fine scale
- Classic statistical approaches or DL techniques

- A robust methodology is still to be built on an urban context
- Doury et al. [8] Regional Climate Emulator:
 - CNN architecture: spatial outputs
 - Adaptable to urban context

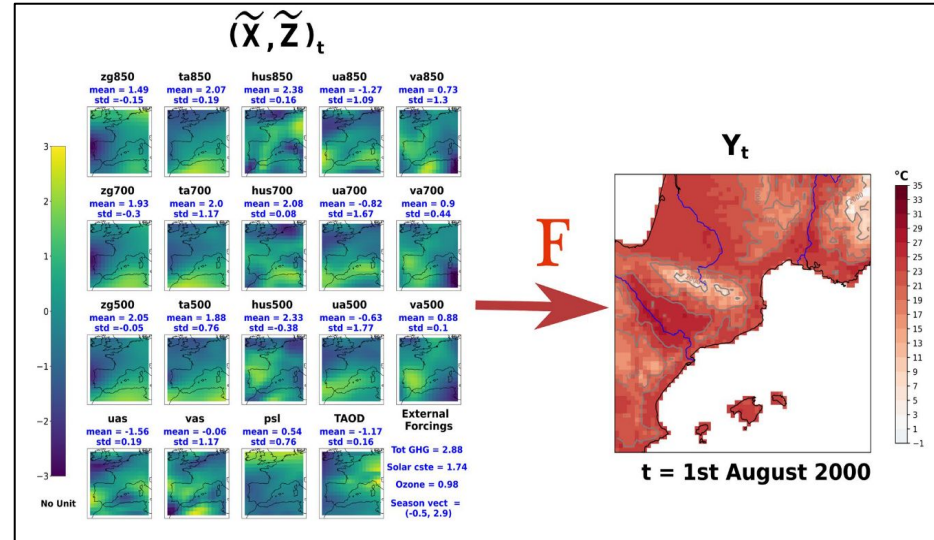
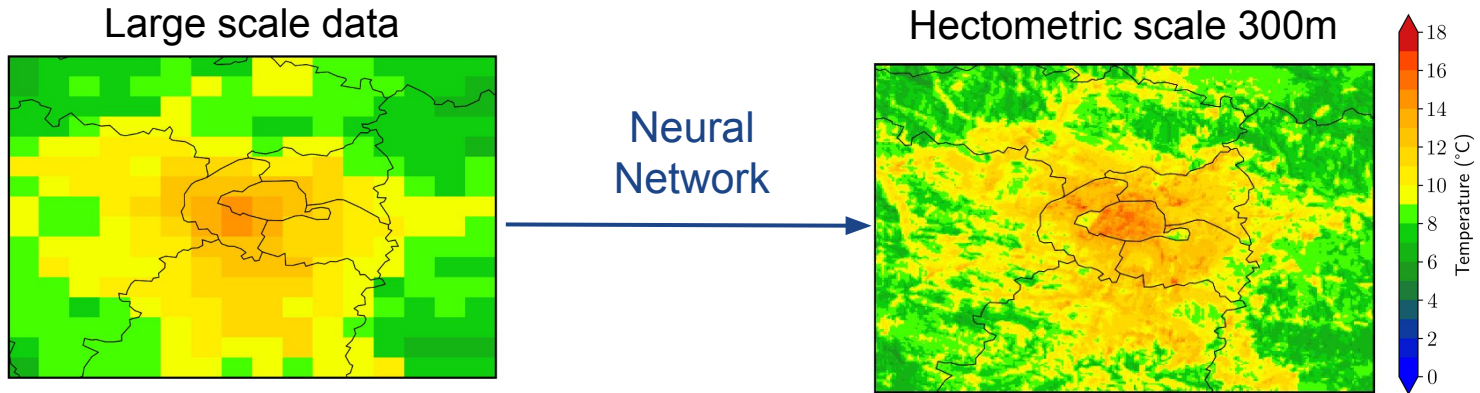


Fig. 1 Illustration of an observation for a randomly-chosen day. Left: each map represents a 2D input variables (X), on the input domain, and the blue numbers correspond to the 1D variables (Z). Right: an example of Y , the near surface temperature on the target domain Doury et al. [8]

GOAL

Build a Statistical Downscaling (SD) method that, using large-scale resolution simulations, provides the temperature field at 2 meters at a hectometric scale over Paris region.



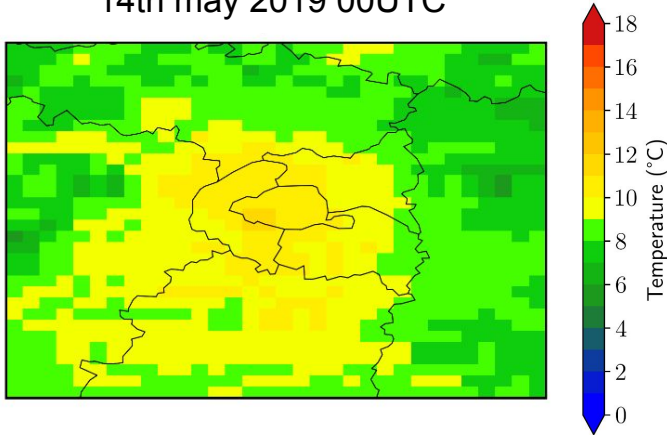
OUTLINE

1. Large scale data: AROME and ARPEGE simulations
2. Hectometric simulations
3. Downscaling over Paris
4. Downscaling over Occitanie
5. Discussion and future work

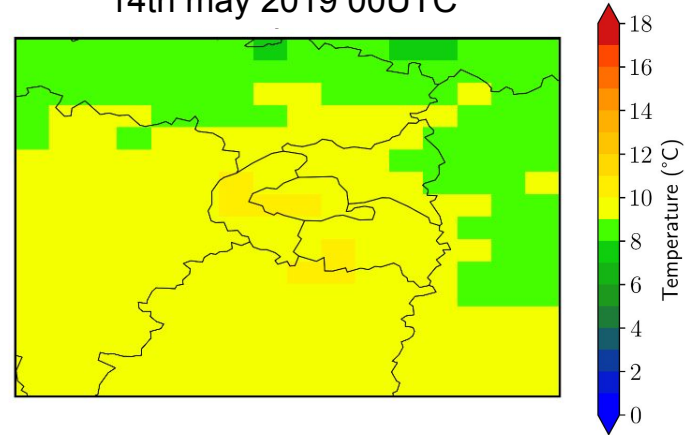
LARGE SCALE DATA: AROME 2.5km & ARPEGE 10km

- AROME and ARPEGE forecasts
- 3-hourly data during 2013-2023 period
- The urban signal disappears as the resolution gets coarser:
 - UHI effect can be still seen in AROME
 - ARPEGE data much more homogeneous

AROME 2.5km T2m,
14th may 2019 00UTC



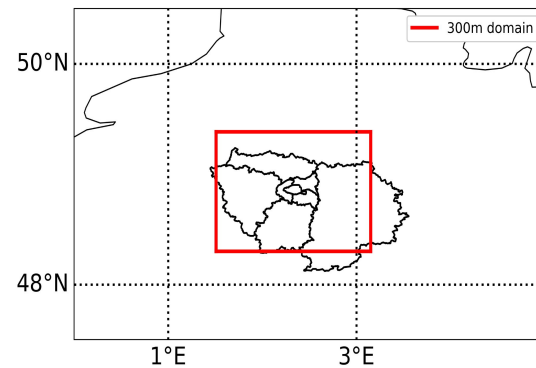
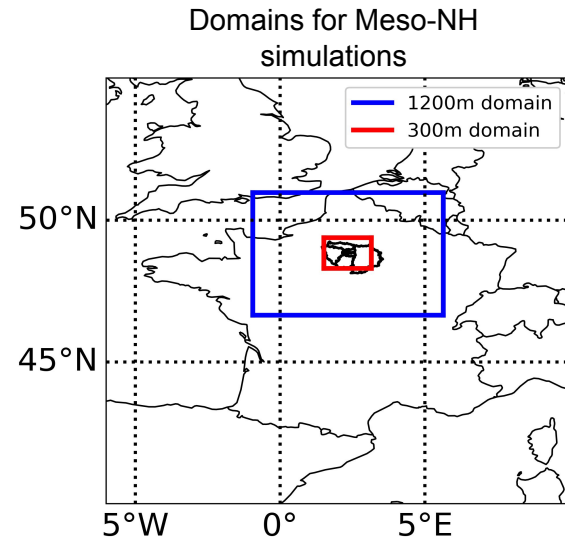
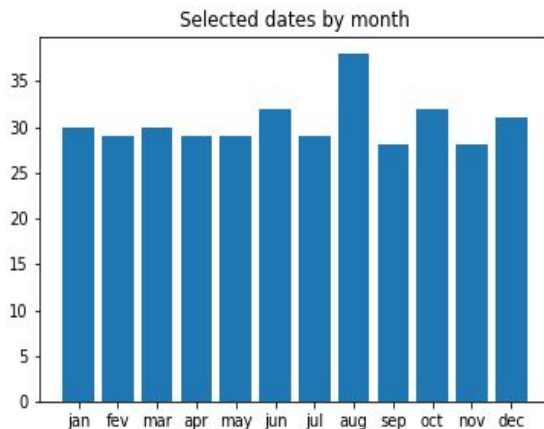
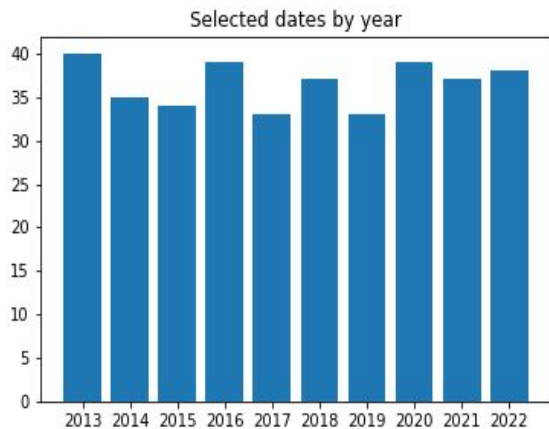
ARPEGE 5km T2m,
14th may 2019 00UTC



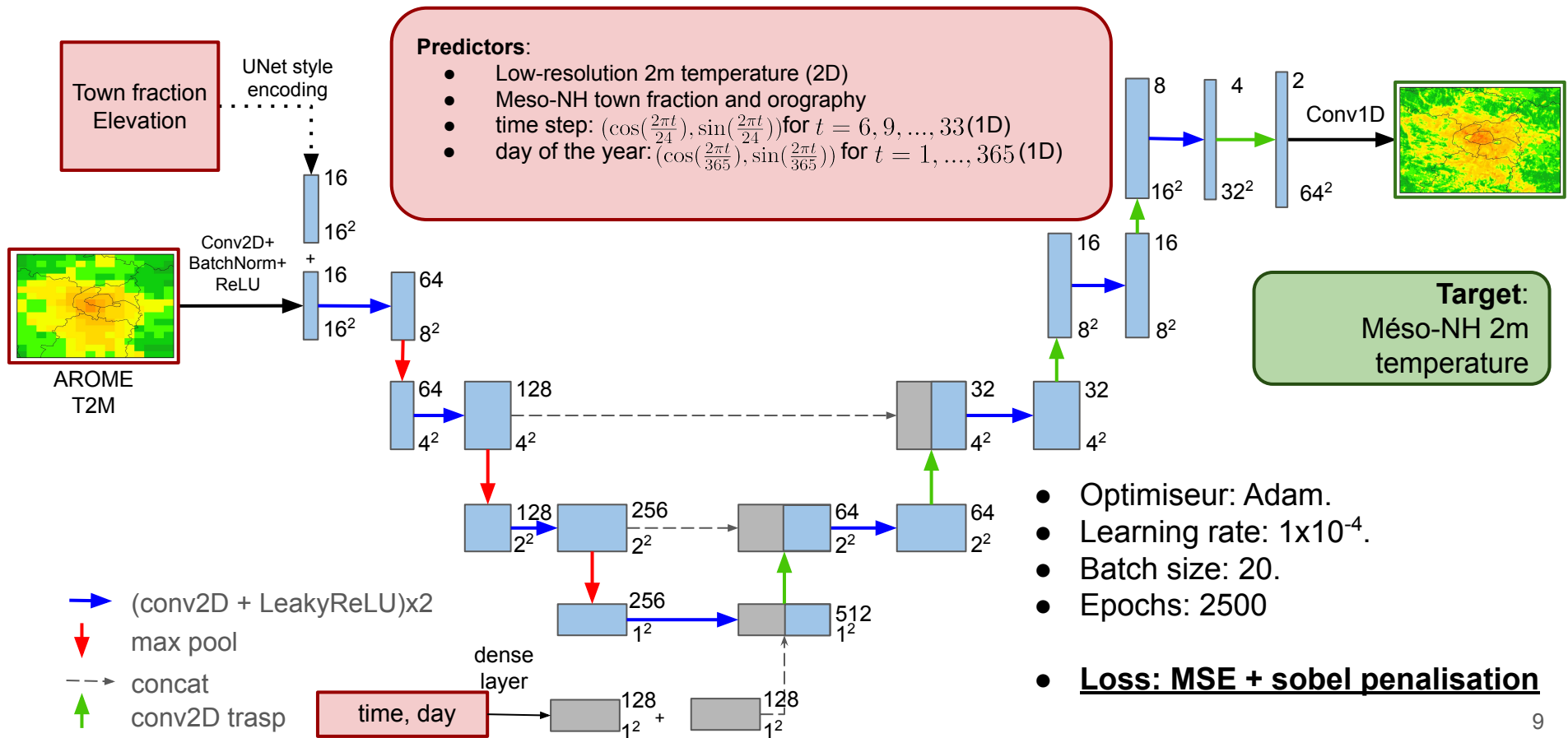
HECTOMETRIC MODEL: MESO-NH [2]

- 365 nonconsecutive days in the 2013-2023 period
- 3-hourly outputs from 9h to 33h lead time
- Train set: 90% of total dataset (~2800 fields)
- Validation set: 10% (~325 fields)

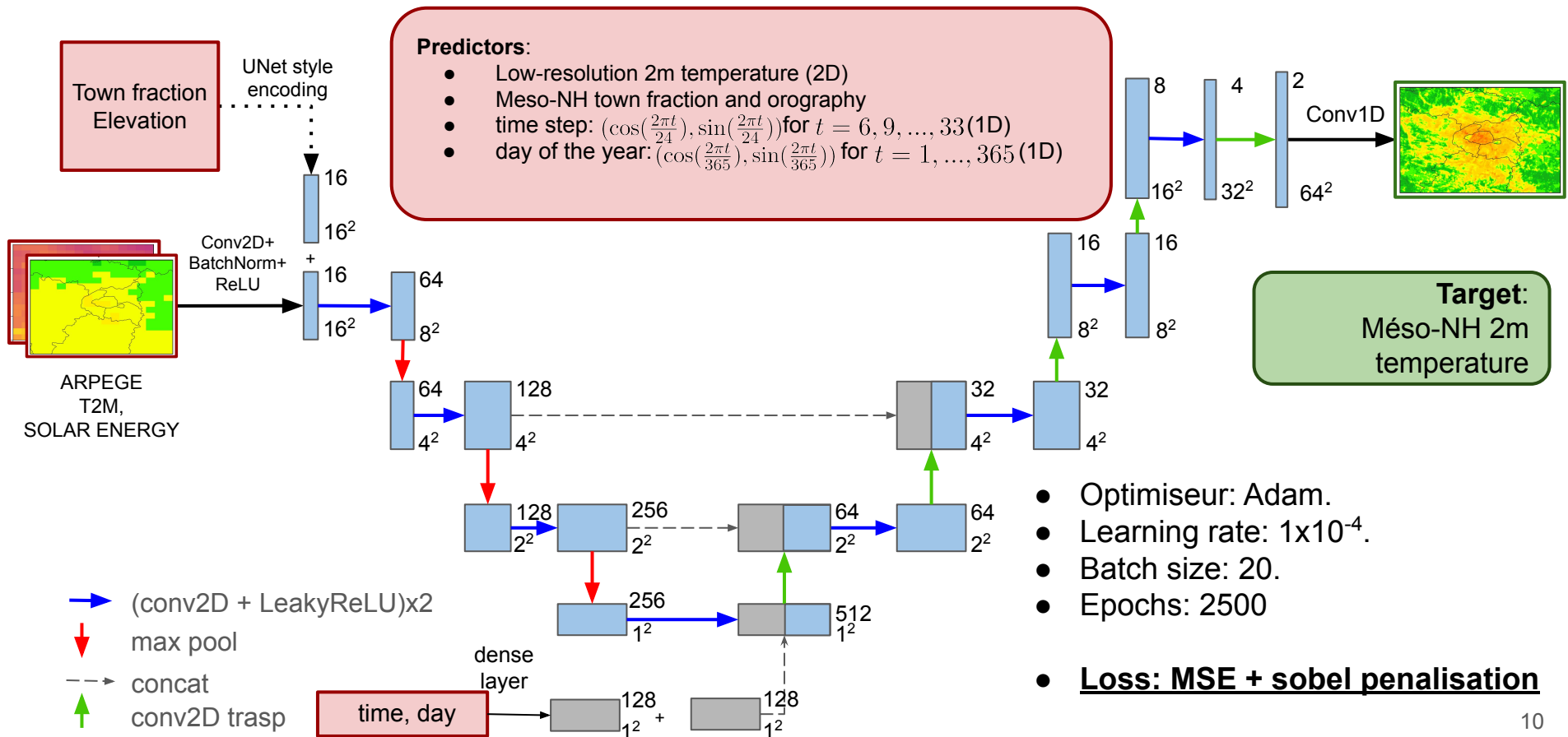
- Test set: 3 independent months (~715 fields)



UNet ARCHITECTURE [7,8]: AROME 2.5km → 300m



UNet ARCHITECTURE [7,8]: ARPEGE 10km → 300m

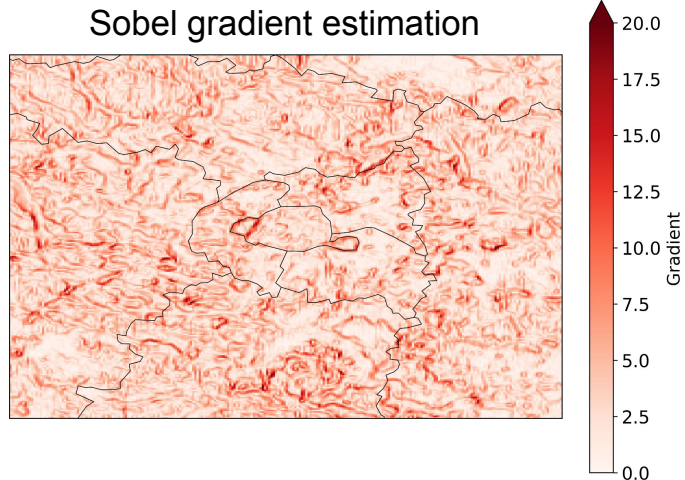
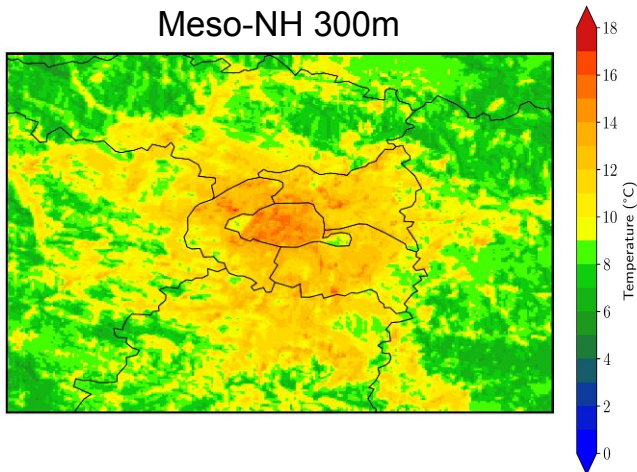


CUSTOM LOSS: SOBEL OPERATOR [9]

- Estimates the gradient's intensity among an image using two filters G_x and G_y for each direction

$$\text{Loss}(Y_{\text{pred}}, Y_{\text{true}}) = \underbrace{\text{MSE}(Y_{\text{pred}}, Y_{\text{true}})}_{\text{classic MSE term}} + \underbrace{\lambda [\text{MSE}(Y_{\text{pred}} \star G_x, Y_{\text{true}} \star G_x) + \text{MSE}(Y_{\text{pred}} \star G_y, Y_{\text{true}} \star G_y)]}_{\text{horizontal and vertical Sobel component}}$$

penalty weight: 0.2

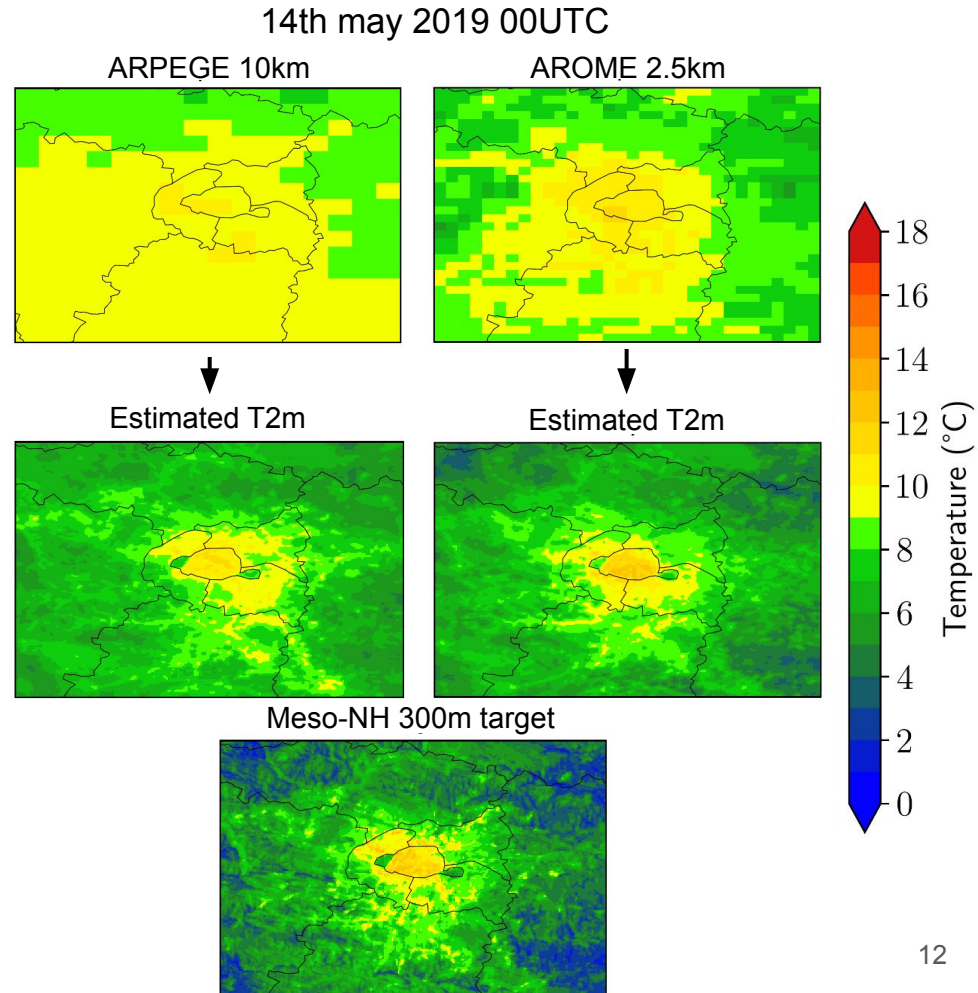


DOWNSCALING RESULTS



Very different physics between ARPEGE-AROME-Meso-NH:

- Systemic biases on the downscaling fields compared to Meso-NH
- **But Meso-NH (research) isn't necessarily better than ARPEGE/AROME (optimized for NWP)**
- Need to evaluate against observations

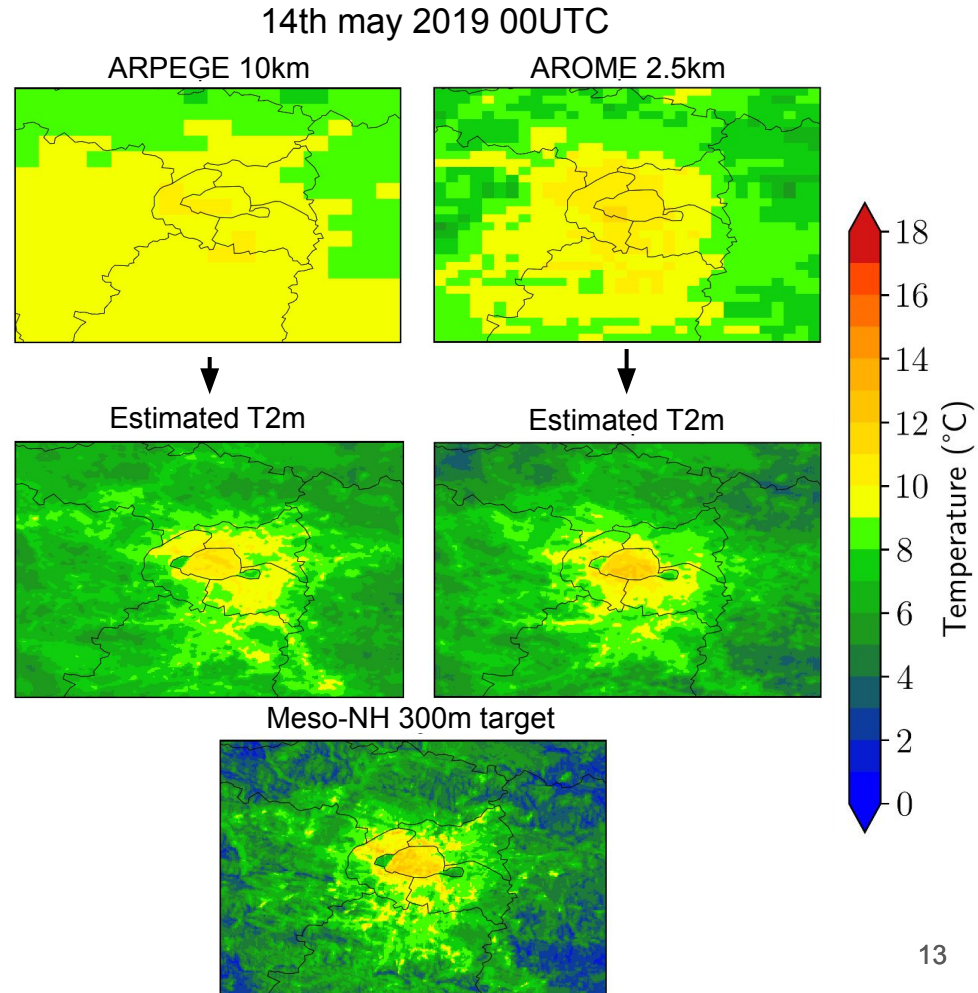


DOWNSCALING RESULTS



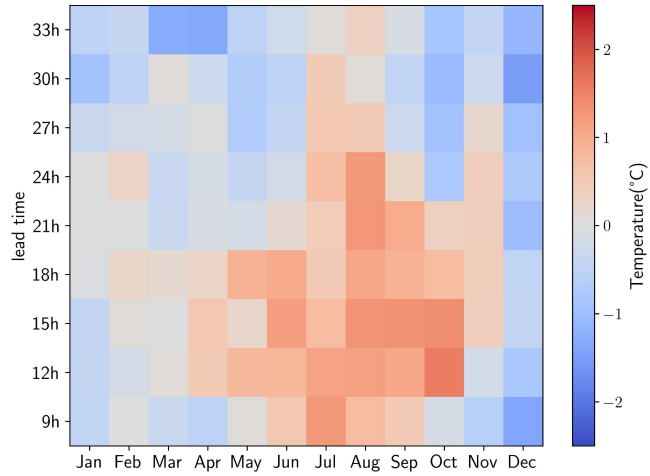
Very different physics between ARPEGE-AROME-Meso-NH:

- Systemic biases on the downscaling fields compared to Meso-NH
 - **But Meso-NH (research) isn't necessarily better than ARPEGE/AROME (optimized for NWP)**
 - Need to evaluate against observations
- The temperature intensity is well estimated over the city center
 - The cooling effect of green zones is well captured
 - On the Urban Heat Island (UHI) shape:
 - ARPEGE: a mean UHI over all cases
 - AROME: follows better the Meso-NH pattern
 - Warmer temperatures on the countryside

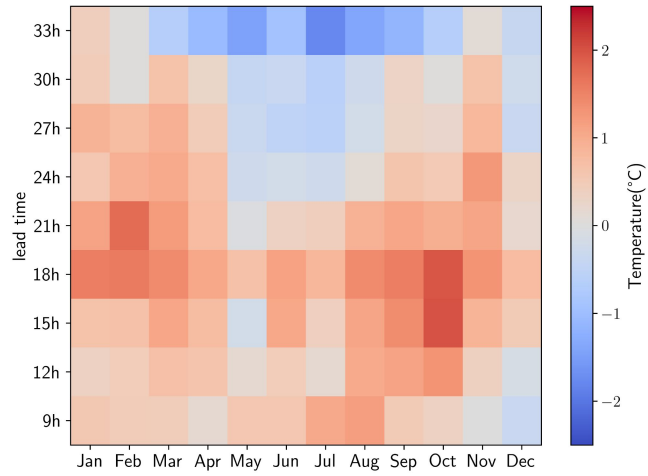


Mean error of downscaled fields by month and lead time over test set

SD from AROME

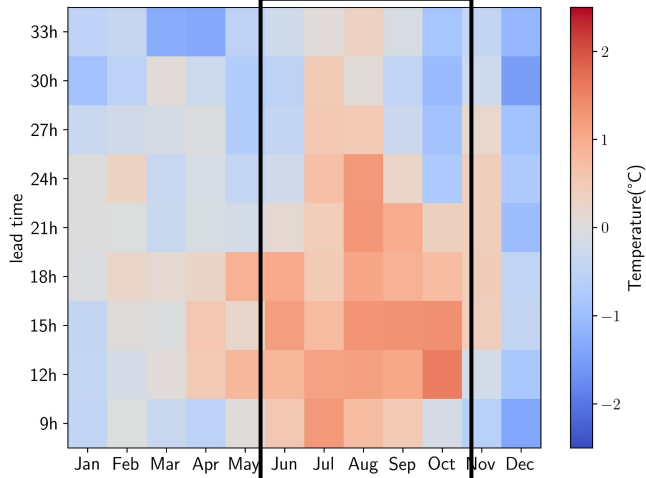


SD from ARPEGE

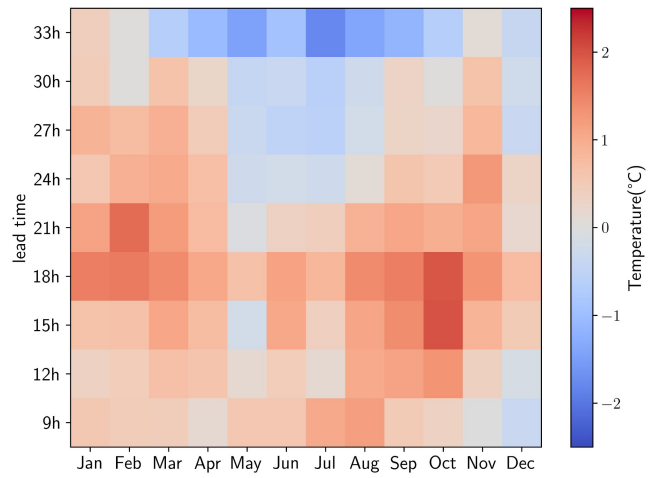


Mean error of downscaled fields by month and lead time over test set

SD from AROME



SD from ARPEGE

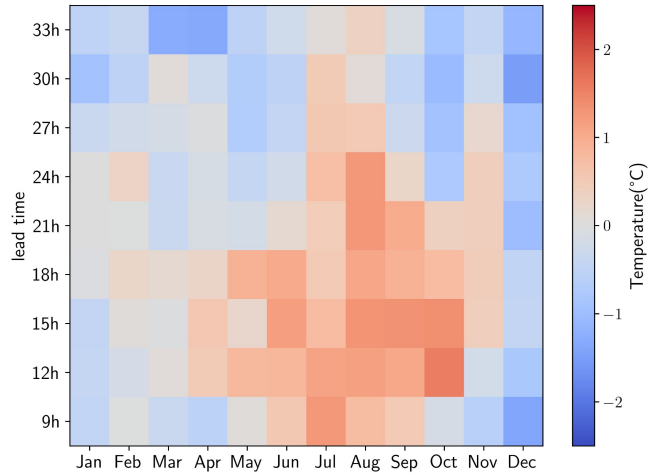


Seasonal behaviour of the errors:

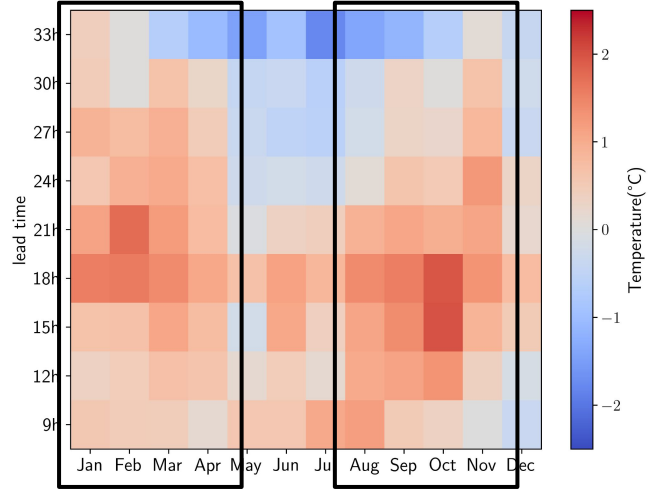
- Over estimation during summer
- Under estimation during winter

Mean error of downscaled fields by month and lead time over test set

SD from AROME



SD from ARPEGE

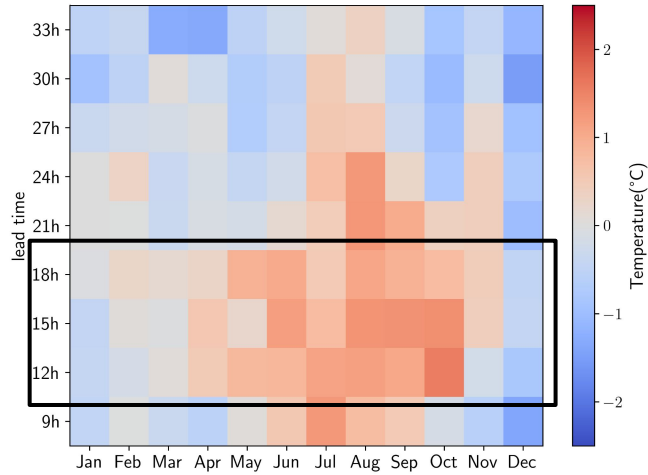


Seasonal behaviour of the errors:

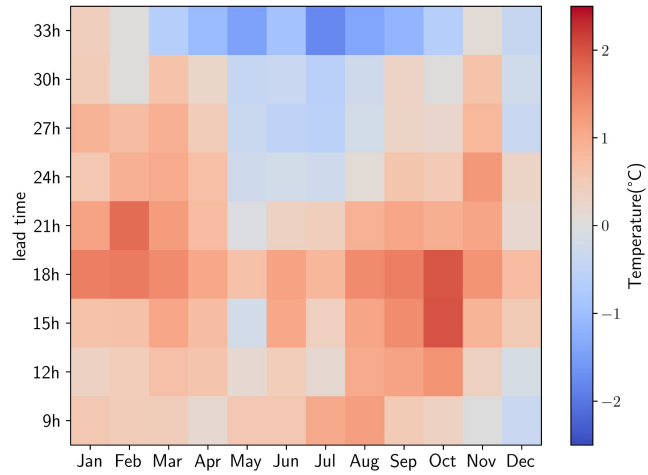
- Solar energy adds some information for UHI during summer
- Still other physical processes that need to be taken into account

Mean error of downscaled fields by month and lead time over test set

SD from AROME



SD from ARPEGE

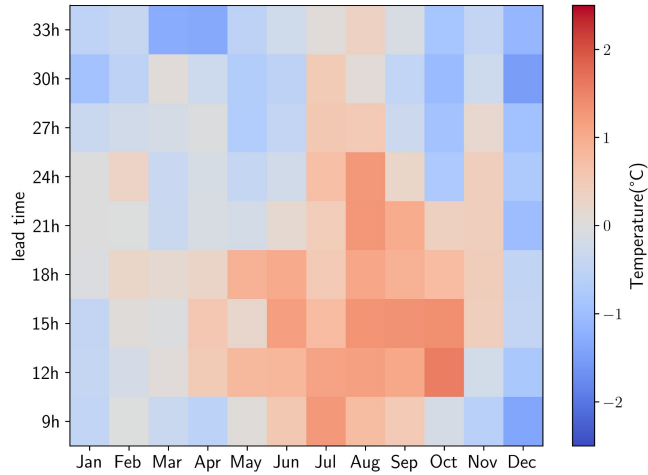


Diurnal behaviour of the error:

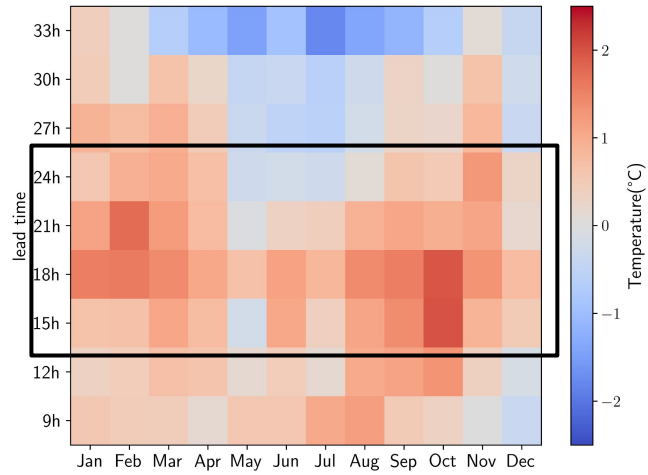
- Over estimation during peaking temperature lead times

Mean error of downscaled fields by month and lead time over test set

SD from AROME



SD from ARPEGE

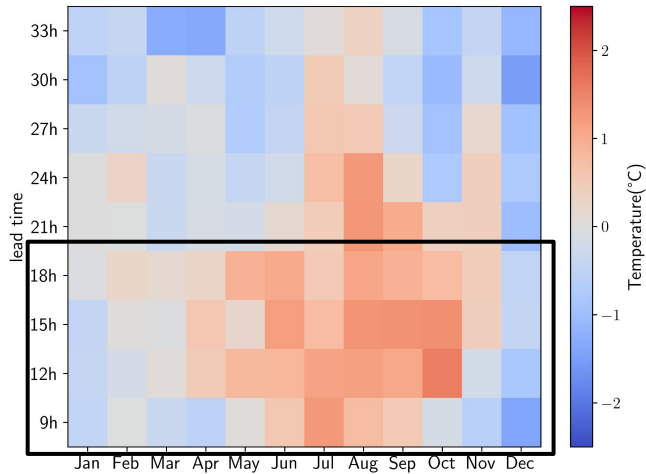


Diurnal behaviour of the error:

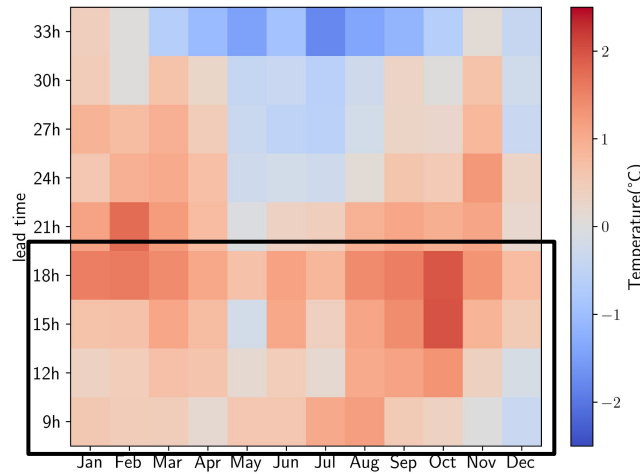
- Over estimation during peaking temperature lead times
- Transition between day/night

Mean error of downscaled fields by month and lead time over test set

SD from AROME

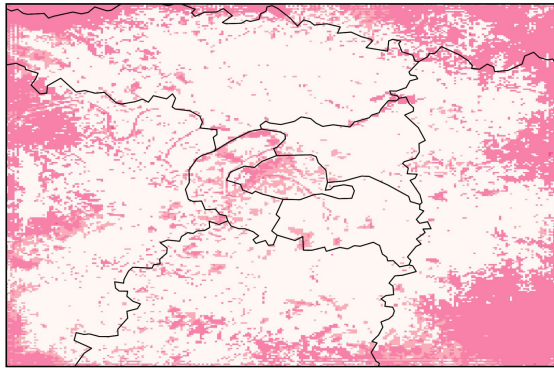


SD from ARPEGE

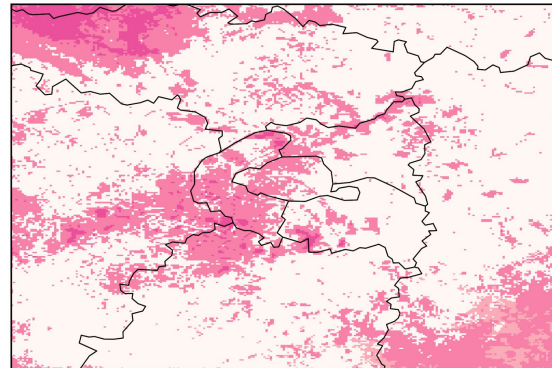


Mean of absolute errors higher than the 90th quantile

SD from AROME



SD from ARPEGE

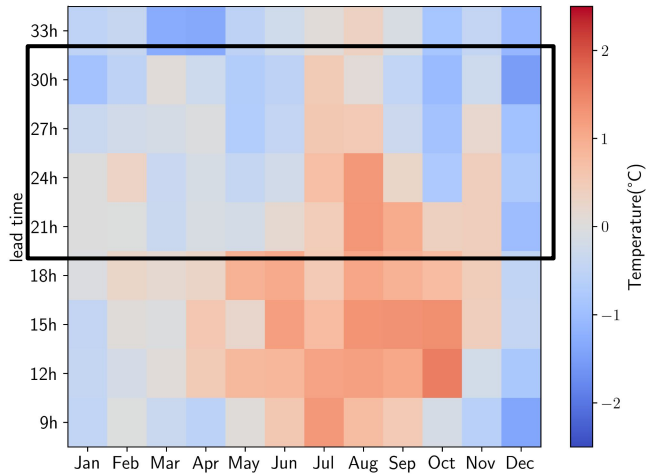


During daytime:

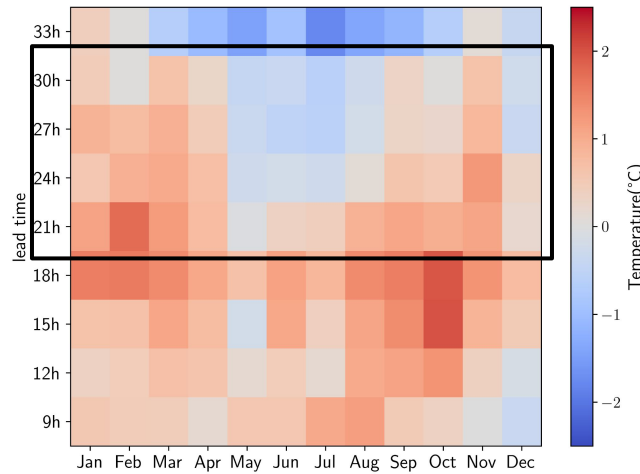
- More intense errors for ARPEGE downscaling
- More intense errors over the north of Paris
- Other errors due to the synoptic differences

Mean error of downscaled fields by month and lead time over test set

SD from AROME

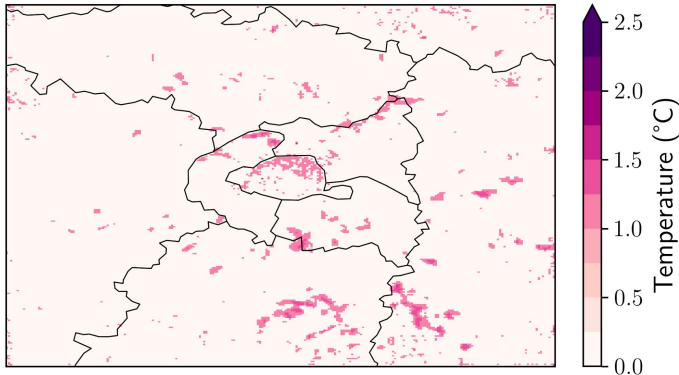


SD from ARPEGE

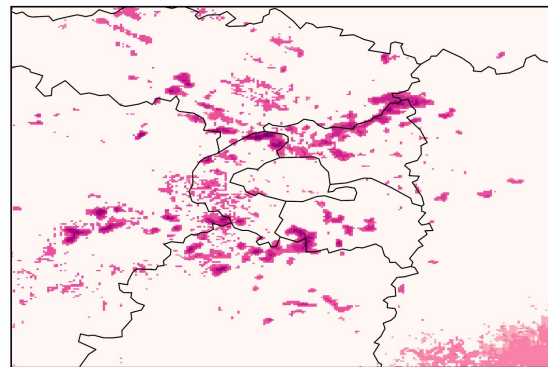


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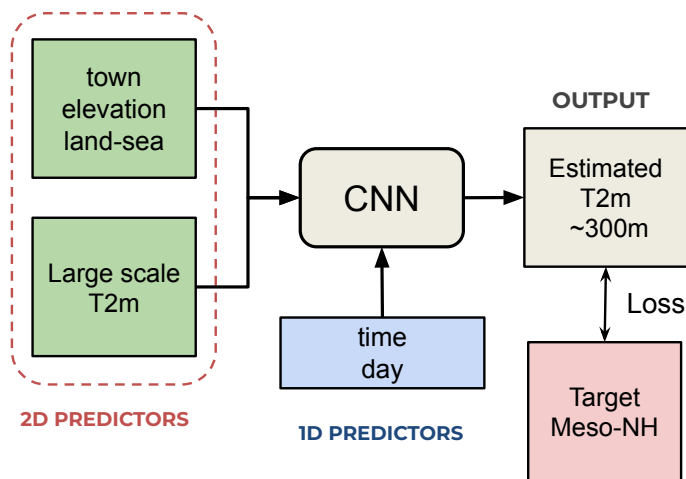
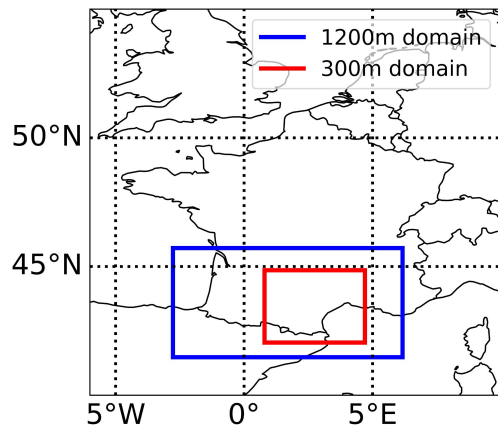


During night time:

- More intense errors for ARPEGE downscaling
- Small structures over city center: small urban parks
- Spatial patterns over mineralized but not urban zones (roads, airports, industrial zones...)

DOWNSCALING TEMPERATURE OVER OCCITANIE

- Domain covering the Occitanie region at 300m resolution
- Additional stakes: mountains, sea ...
- Hourly Meso-NH simulations over the 2019-2025 period:
 - 365 non-consecutive days selected for train/val
 - 90 non-consecutive days selected for test
- Same training strategy:
 - Predictors:
 - AROME 2.5km T2m
 - Static predictors: town, land-sea mask and elevation
 - Time predictors: day and hour
 - Target: Meso-NH 300m T2m
 - **Loss: (MSE + sobel term) with sea-land mask**



SOME PRELIMINARY RESULTS

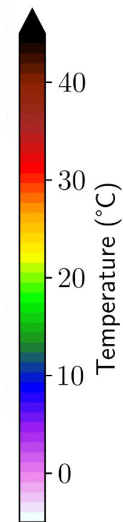
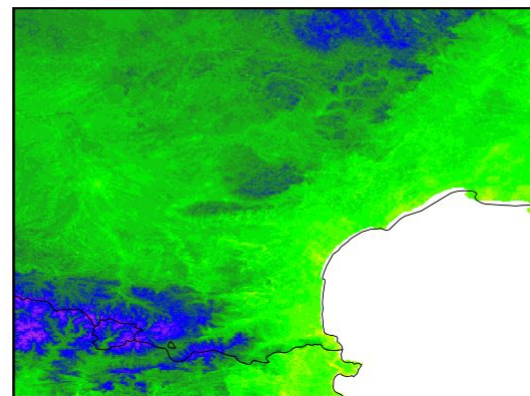
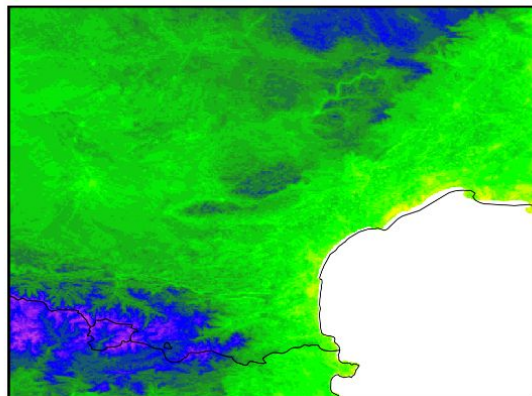
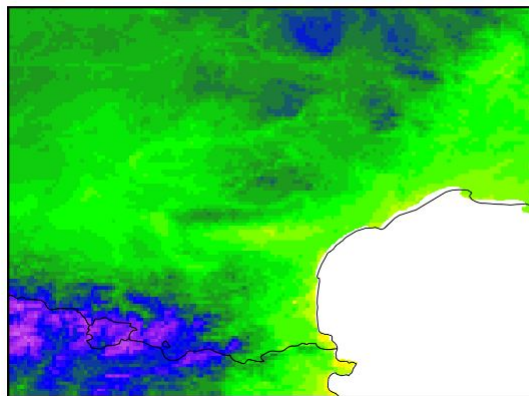
- Running time: train ~8 days, inference ~1min
- Some urban information seems to be present in the downscaled field
- Training focuses especially in temperature variations related to elevation
- More evaluation is needed to further improve the methodology
- How to adapt the method to take more into account the urban pixels (0.12% domain): modify loss?

Downscaling exemple for the T2m on the 25th september 2021 23UTC

AROME 2.5KM

Downscaled T2m

Meso-NH 300m



DISCUSSION AND FUTURE WORK

- On the SD from AROME over Paris:
 - Only SD of T2m but methodology could be extended to other variables (wind, humidity)
 - Need to compare results to observations to better assess performance
 - Outlook: building a high-resolution climatology is now possible!
- On the SD from ARPEGE over Paris:
 - Find proper inputs to estimate UHI intensity
 - Temperature intensity and fine scale patterns are however well recovered
 - Outlook: SD could be significantly benefit from ARPEGE 2.5km (with TEB)
- On the Occitanie downscaling:
 - Need to define proper scores to evaluate the method
 - How to balance urban and non-urban pixels?

	CSI	FBI
DS ARPEGE	0.63	1.16
DS AROME	0.62	0.89
AROME	0.22	0.22

REFERENCES

- [1] Population Division (2019) United Nations, Department of Economic {and} Social Affairs. World urbanization prospects the 2018 revision.
- [2] Lac et al. 2018. Overview of the meso-NH model version 5.4 and its applications. Copernicus GmbH, 11(5):1929–1969.
- [3] Masson et al. 2013. The SURFEXv7.2 land and ocean surface platform for coupled or offline simulation of earth surface variables and fluxes. Copernicus GmbH, 6(4):929–960.
- [4] Masson et al. 2002. Evaluation of the town energy balance (TEB) scheme with direct measurements from dry districts in two cities. American Meteorological Society, Section: Journal of Applied Meteorology and Climatology, 41(10):1011–1026.

- [5] Bueno et al. 2012. Development and evaluation of a building energy model integrated in the TEB scheme. *Geoscientific Model Development*, 5(2):433–448.
- [6] Bocher et al. 2021. Geoclimate: a geospatial processing toolbox for environmental and climate studies. *Journal of Open Source Software*, 6(65):3541.
- [7] Ronneberger et al. 2015. U-net: Convolutional networks for biomedical image segmentation. *Medical Image Computing and Computer-Assisted Intervention*, 234–241.
- [8] Doury et al. 2022. Regional climate model emulator based on deep learning: concept and first evaluation of a novel hybrid downscaling approach. *Climate Dynamics*, 60(5):1751–1779.
- [9] Ebert-Uphoff et al. 2021. CIRA guide to custom loss functions for neural networks in environmental sciences.
- [10] Blunn et al. 2024. Machine learning bias correction and downscaling of urban heat wave temperature predictions from kilometre to hectometre scale. *Meteorological Applications*.

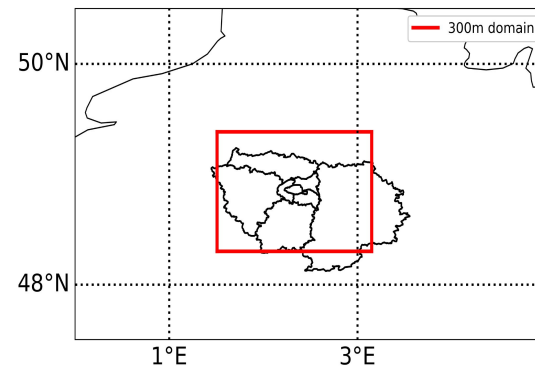
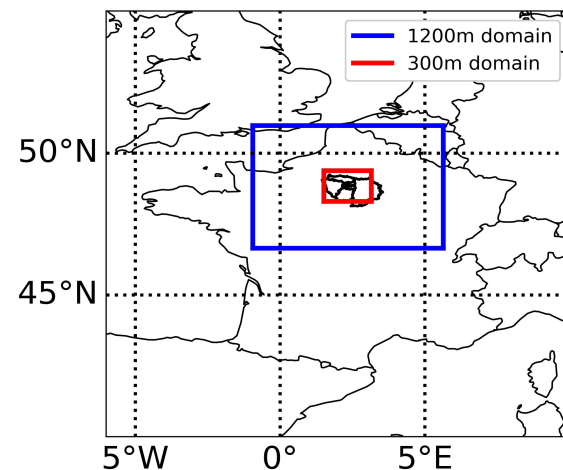
HECTOMETRIC MODEL: MESO-NH [2]

Parameter	Meso-NH 300m domain	Meso-NH 1200m domain
Domaine size (km)	120x120	480x480
Time step (s)	5*	10
Land model	Surfex v9 [3], TEB [4] with BEM [5]	
Land-use	Geoclimate-OSM [6]	ECOCLIMAP-SG
Turbulence scheme	3D	1D
Model dynamics	WENO3 scheme	

- 365 nonconsecutive days in the 2013-2023 period
- 3-hourly outputs from 9h to 33h lead time
- Train set: 90% of total dataset (~2800 fields)
- Validation set: 10% (~325 fields)

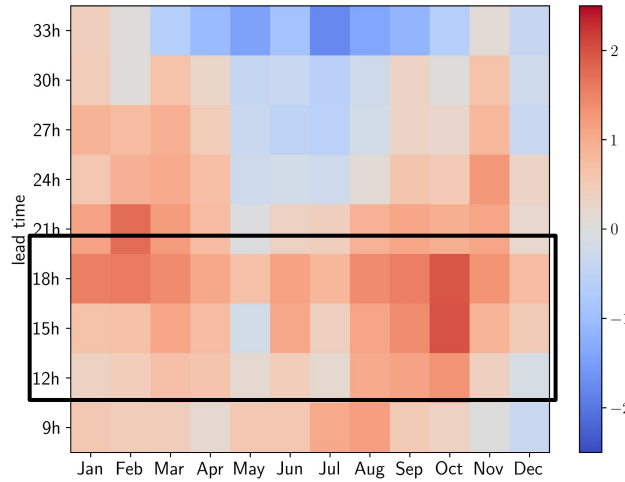
- Test set: 3 independent months (~715 fields)

Domains for Meso-NH simulations

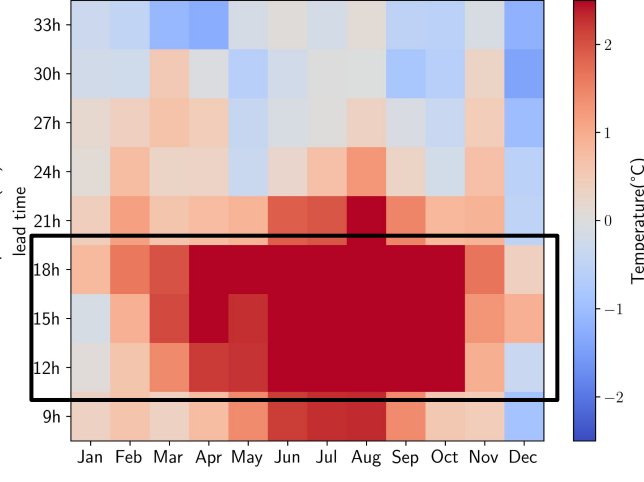


Mean error of downscaled fields by month and lead time

SD from ARPEGE (t, fls)

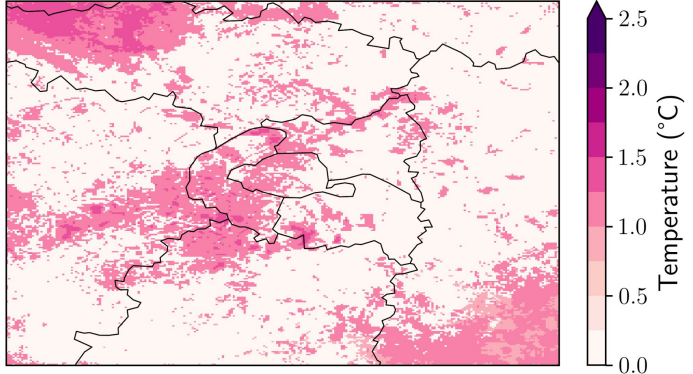


SD from ARPEGE (t)

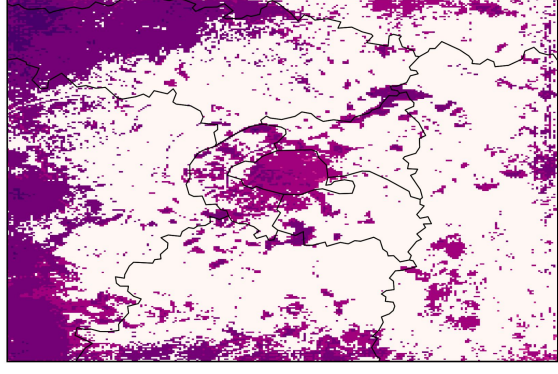


Mean of absolute errors higher than the 90th quantile (day time)

SD from ARPEGE (t, fl)

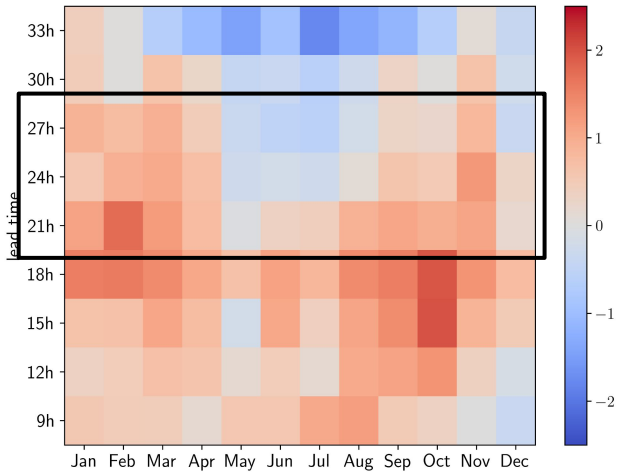


SD from ARPEGE (t)

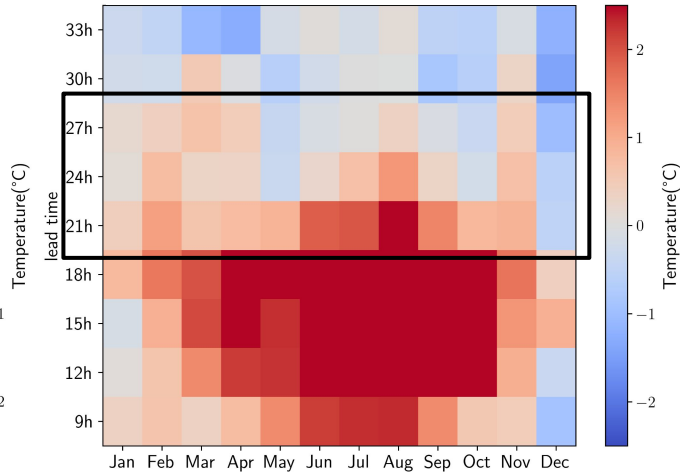


Mean error of downscaled fields by month and lead time

SD from ARPEGE (t, fls)



SD from ARPEGE (t)



Seasonal behaviour of the errors:

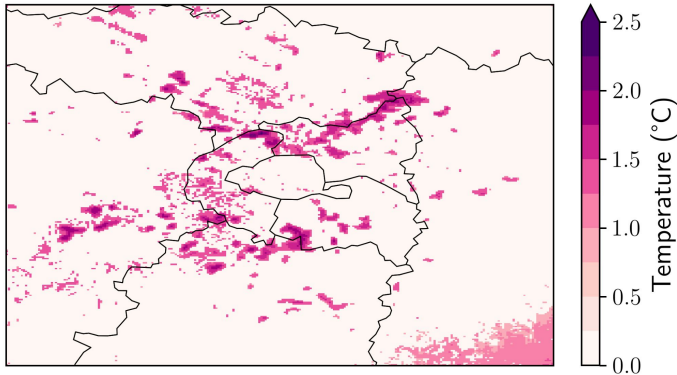
- Over estimation during summer
- Under estimation during winter

Diurnal behaviour of the errors:

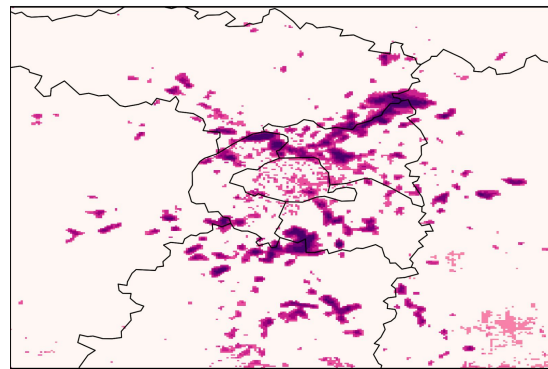
- Over estimation during the peaking temperature lead times.

Mean of absolute errors higher than the 90th quantile

SD from ARPEGE (t, fls)



SD from ARPEGE (t)



During night time:

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- Small structures over city center: small urban parks
- Spatial patterns over mineralized but not urban zones (roads, airports, industrial zones...)