Machine Learning for (Multivariate) Downscaling
A Generative Model Inspired by Forecast Evaluation

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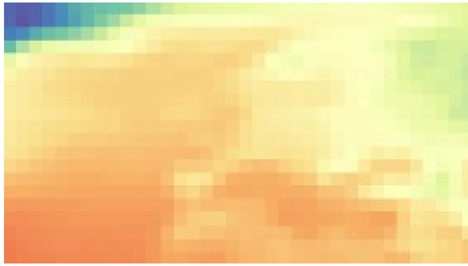
Joint work with Xinwei Shen, Maxim Samarin & Nicolai Meinshausen

EGU24

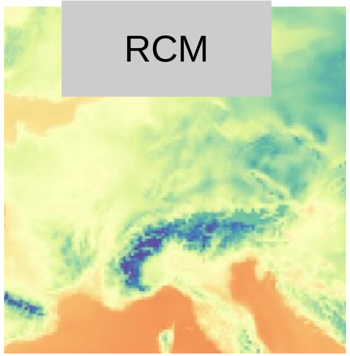
Goal: generative ML for CORDEX data

Low-res. **GCM** input

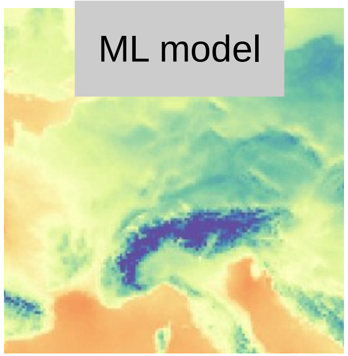


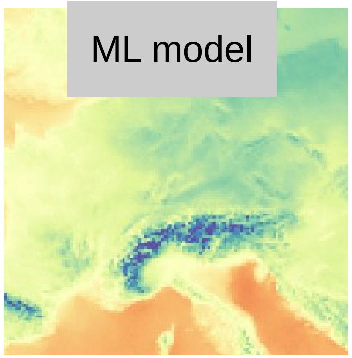
RCM

High-res. **RCM** output



Generative ML model
- easy & fast training
- flexible
- novel loss

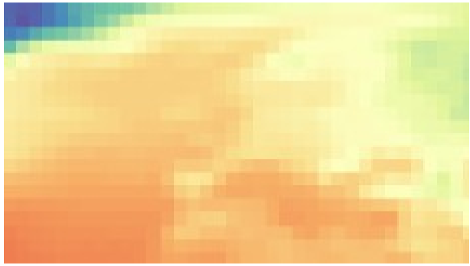




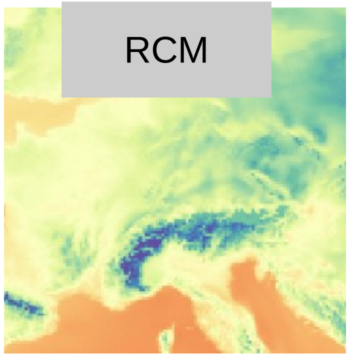
Goal: generative ML for CORDEX data

Low-res. **GCM** input

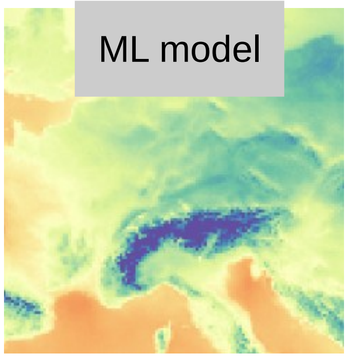
High-res. **RCM** output

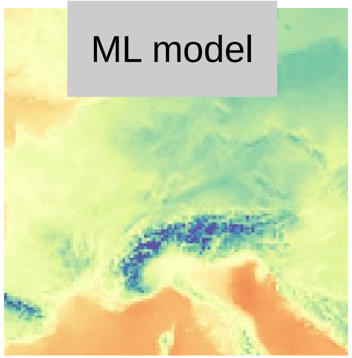


RCM



Generative ML model

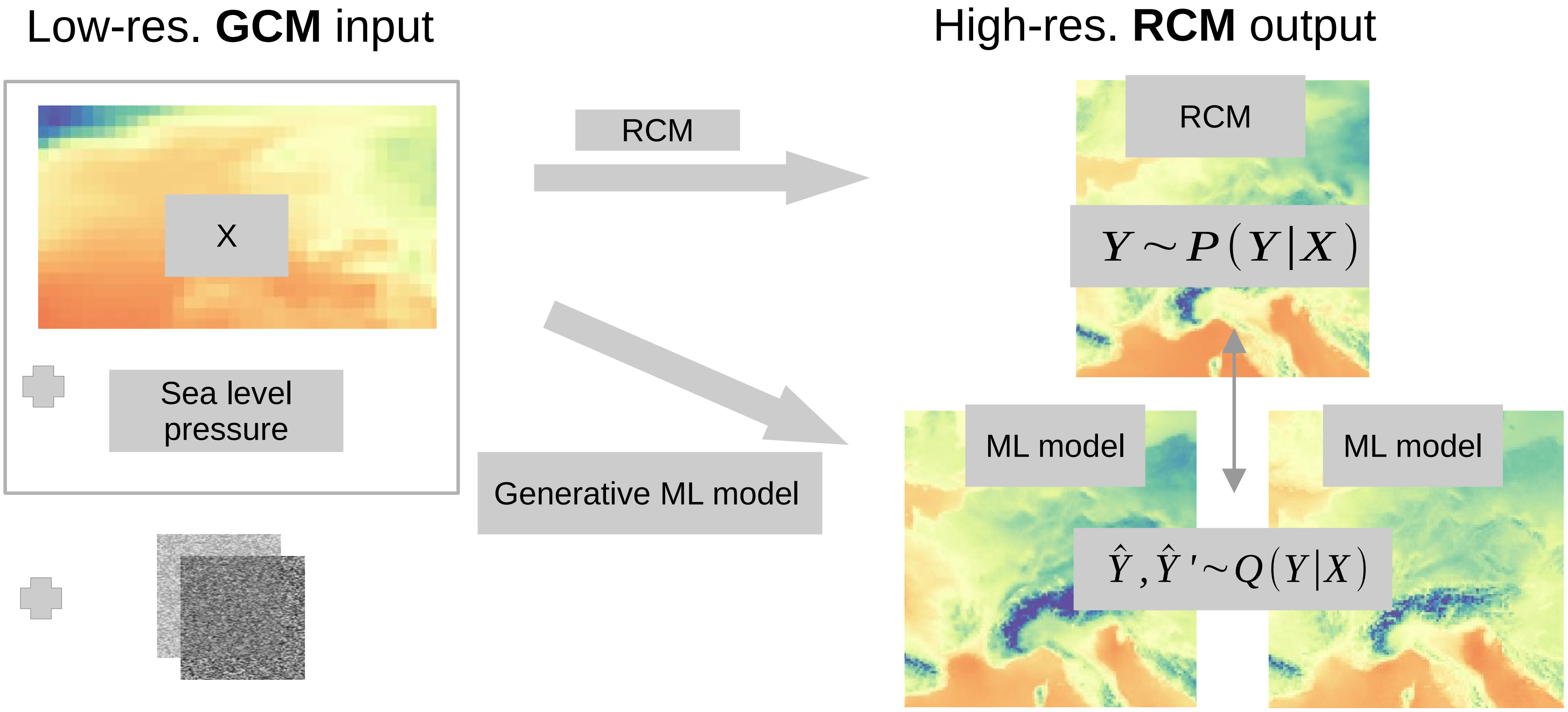




Data

- 8 GCM-RCM pairs from EURO-CORDEX
- Daily data for years 1971-2099 (RCP 8.5)
- Tas & pr

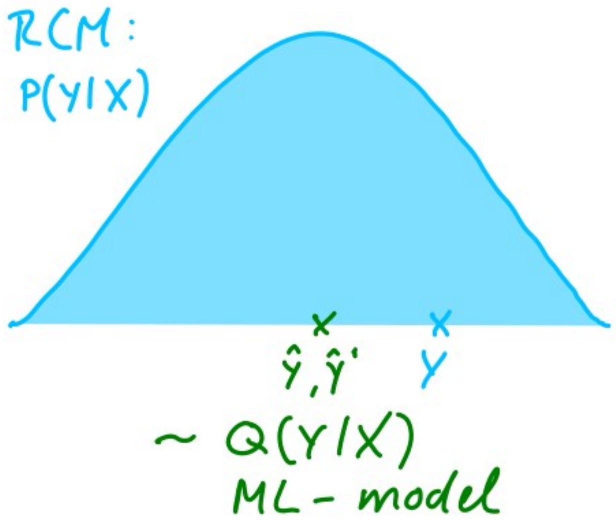
Goal: generative ML for CORDEX data



ML model: loss function & architecture

$$\text{Loss} = E[\|Y - \hat{Y}\|]$$

Prediction error

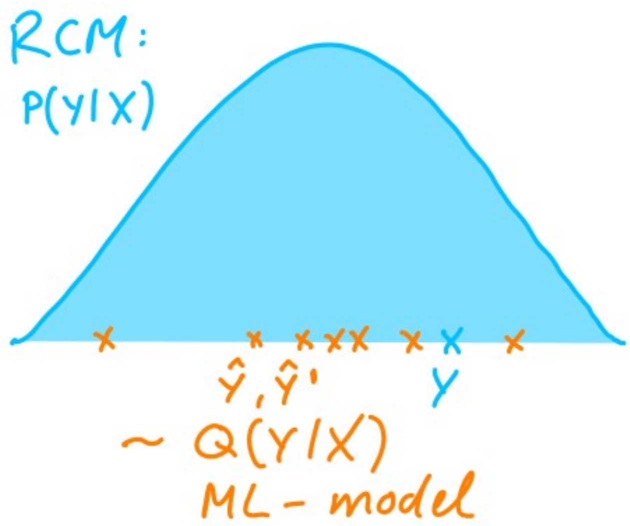


ML model: loss function & architecture

$$\text{Loss} = \underbrace{E[\|Y - \hat{Y}\|]}_{\text{Prediction error}} - \underbrace{\frac{1}{2}E[\|\hat{Y} - \hat{Y}'\|]}_{\text{Variability}}$$

Energy Score
(multivariate CRPS)

Theorem:
ES is minimal iff P = Q.



References: Gneitning 2007,
Pacchiardi 2022

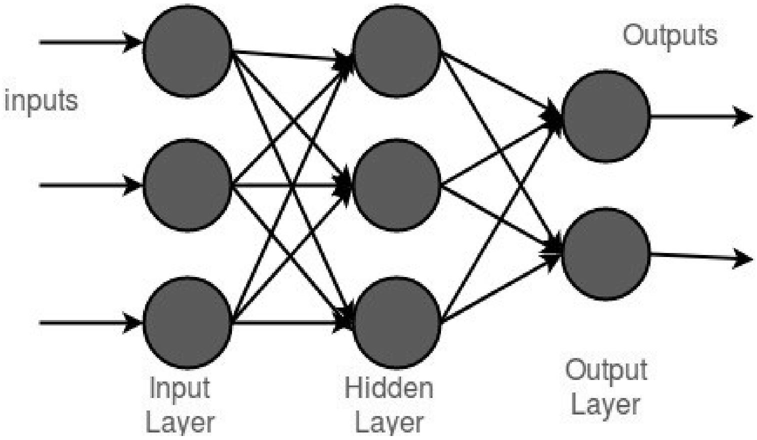
ML model: loss function & architecture

$$\text{Loss} = \underbrace{E[\|Y-\hat{Y}\|]}_{\text{Prediction error}} - \underbrace{\frac{1}{2}E[\|\hat{Y}-\hat{Y}'\|]}_{\text{Variability}}$$

Energy Score
(multivariate CRPS)

Theorem:
ES is minimal iff P = Q.

Architecture



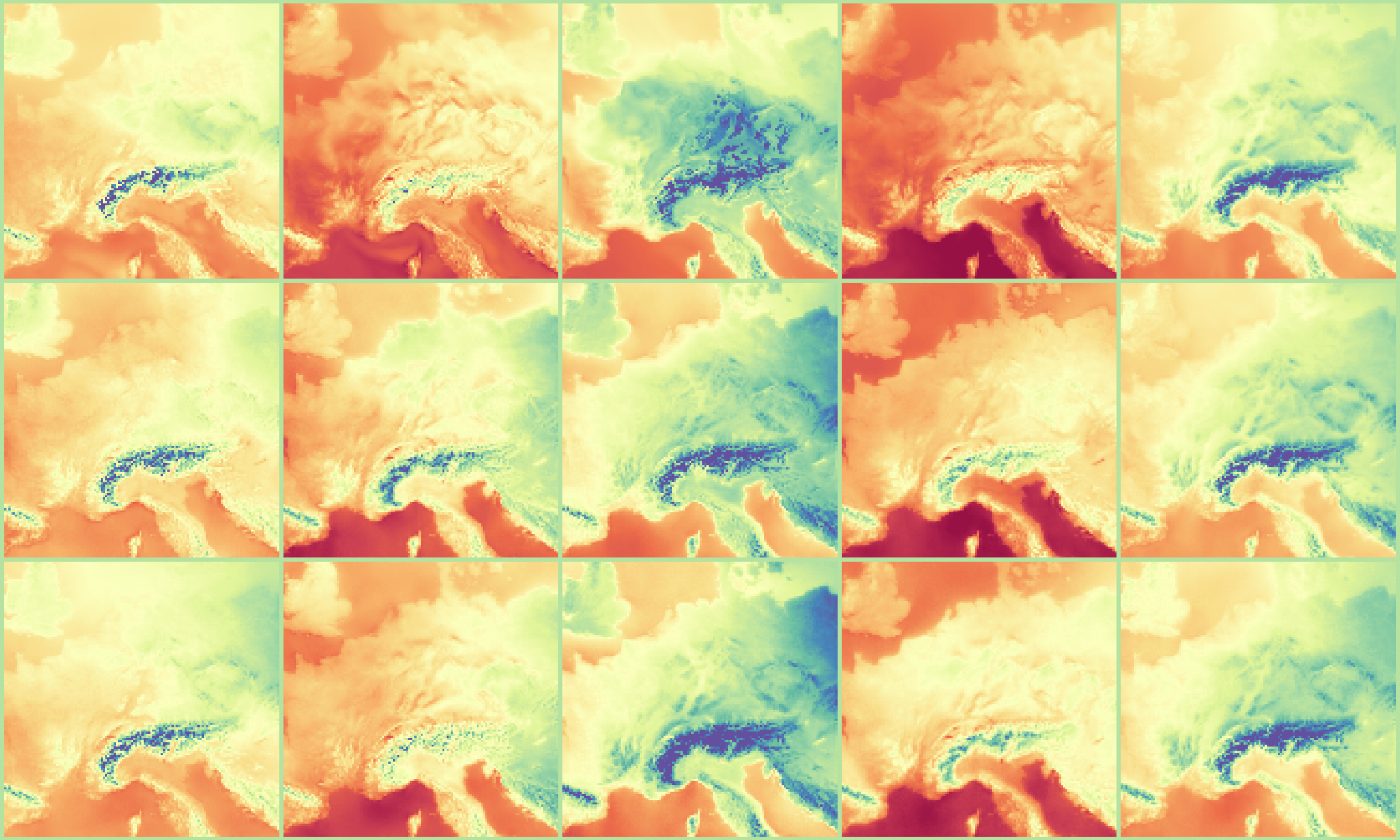
https://www.geeksforgeeks.org/multi-layer-perceptron-learning-in-tensorflow/

Results: realistic generated images (tas)

RCM

Sample1

Sample2



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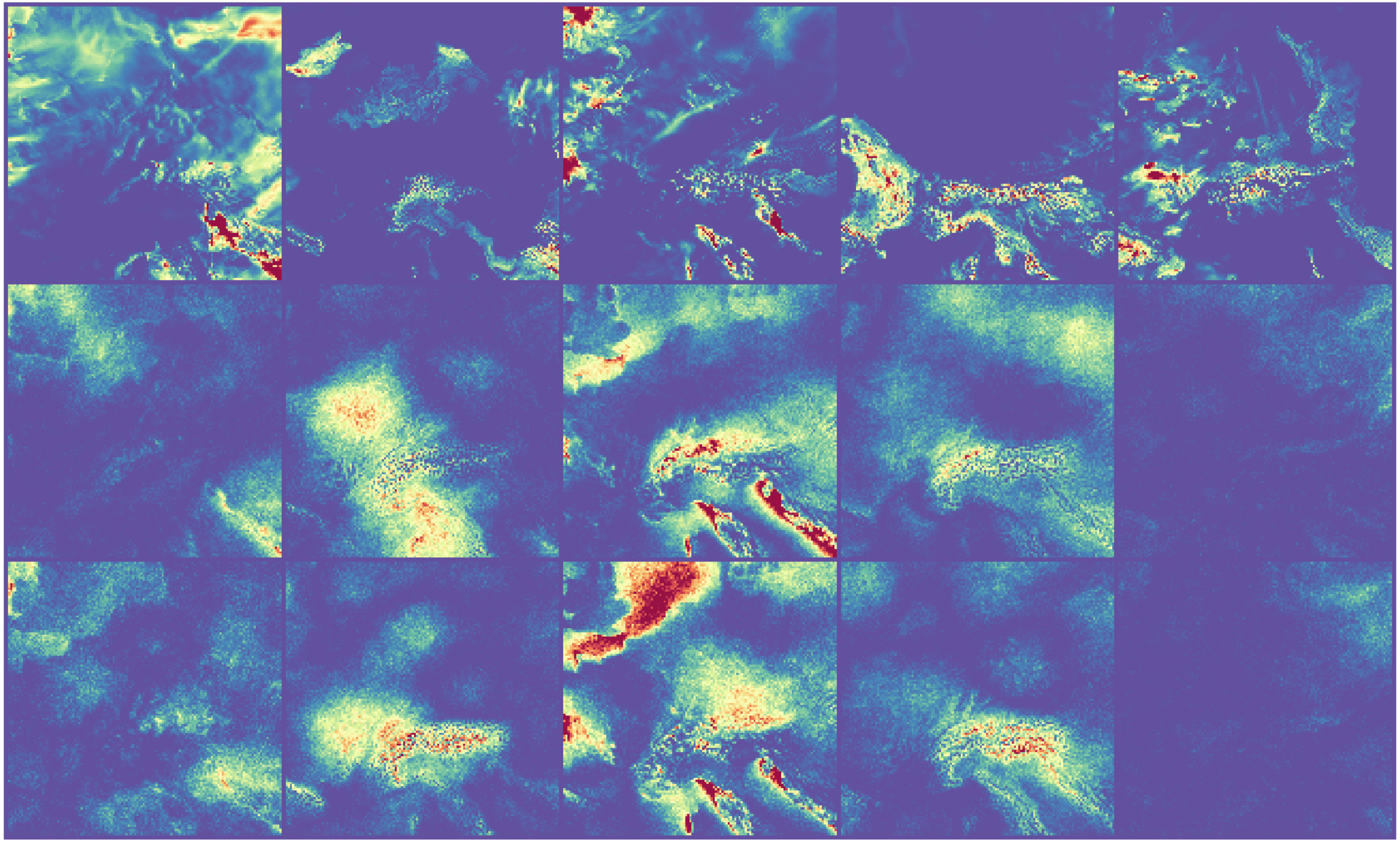


Benchmarks and evaluation metrics

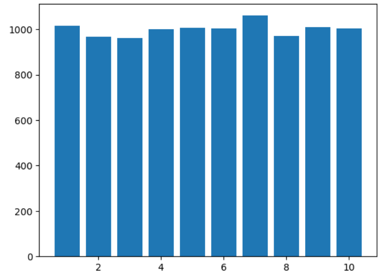
Benchmarks

- Analogues
- Linear Model
- Linear Model + EasyUQ

Metrics

- Energy score
- Quantiles
- **Rank histograms**
- …

Flat:
Correct variability



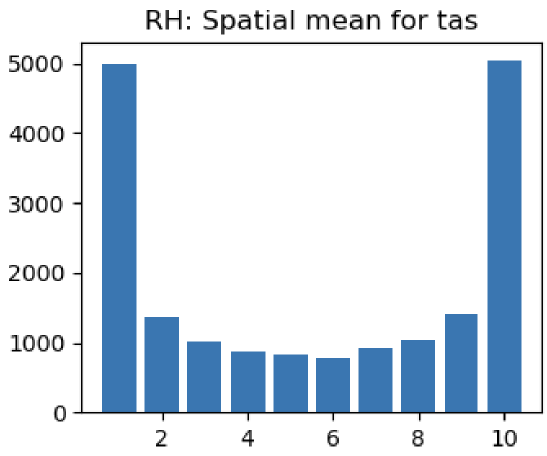
Rank

Evaluation summary

☺

☹

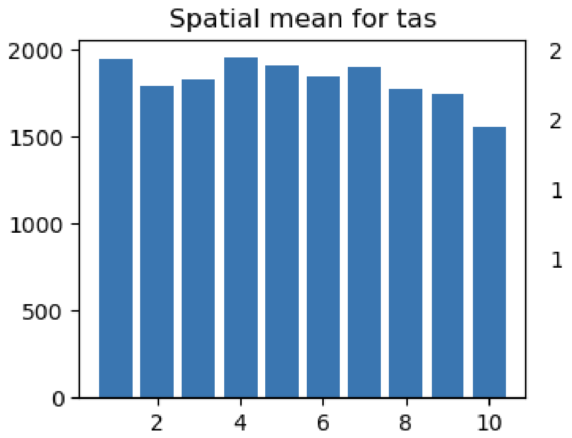
- Too little variability (overfitting!)

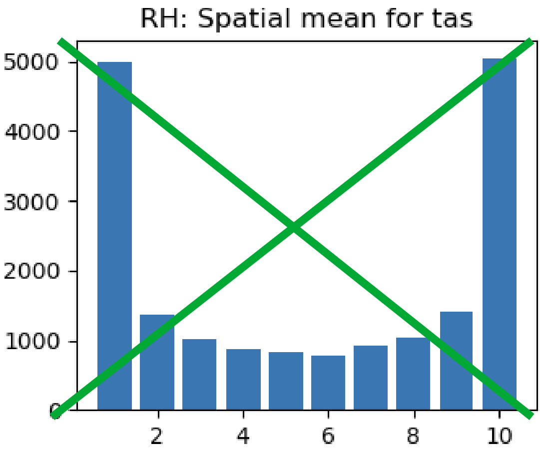


Evaluation summary

- ~~Spatial structure good~~
- Correct variability

- ~~Too little variability (overfitting!)~~
- Worse spatial structure

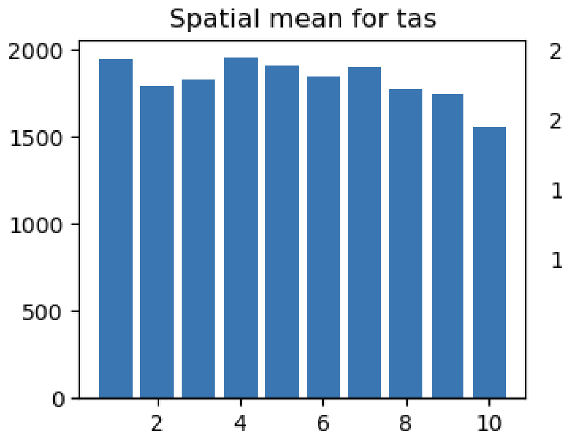


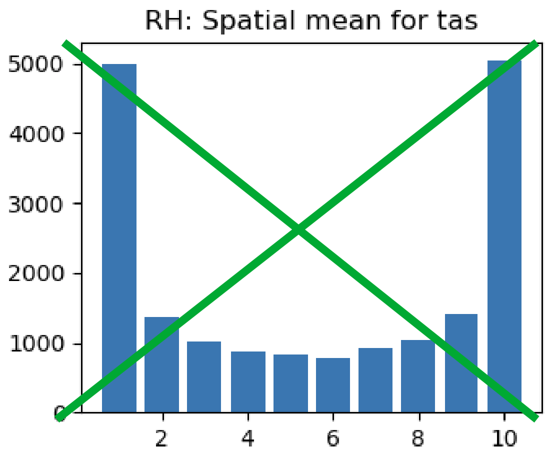


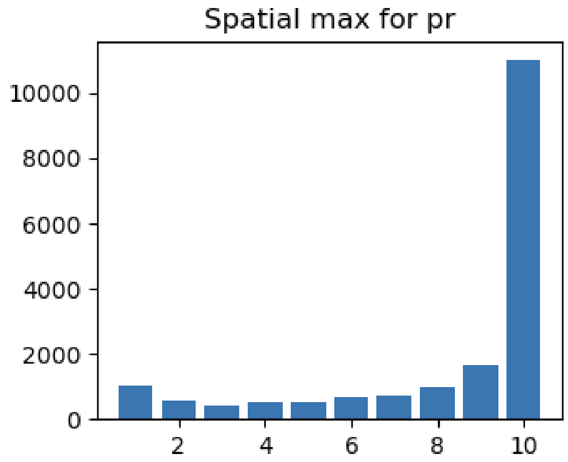
Evaluation summary

- ~~Spatial structure good~~
- Correct variability

- ~~Too little variability (overfitting!)~~
- Worse spatial structure
- Underestimate high precipitation



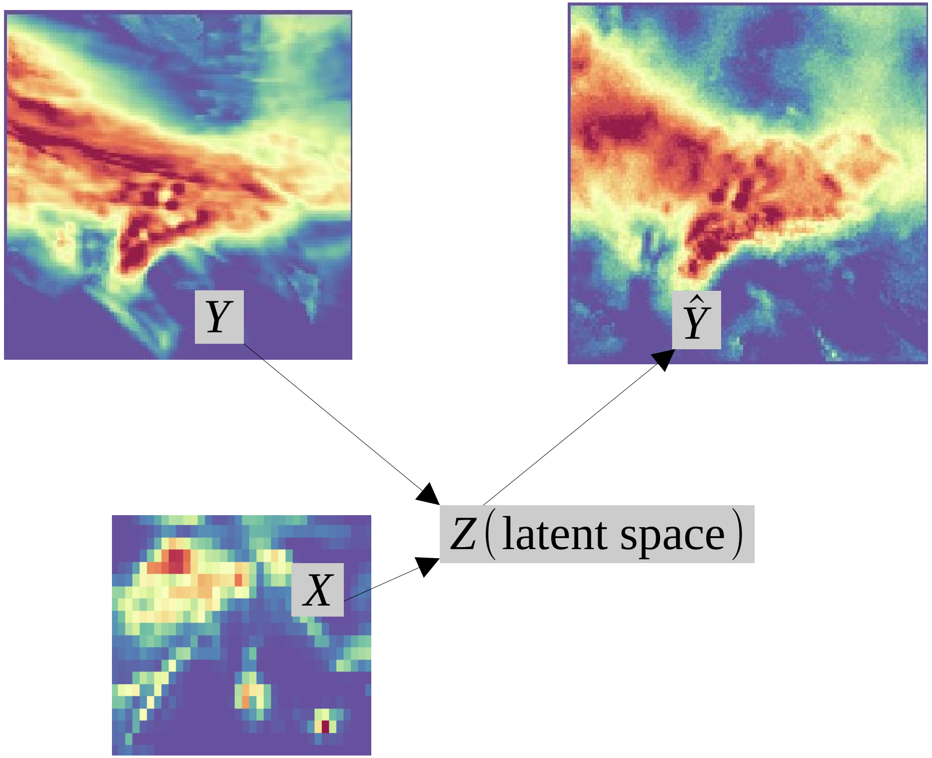




Work in progress: dimension reduction

- Multivariate downscaling
- Bias-correction to observational data

Dimension reduction

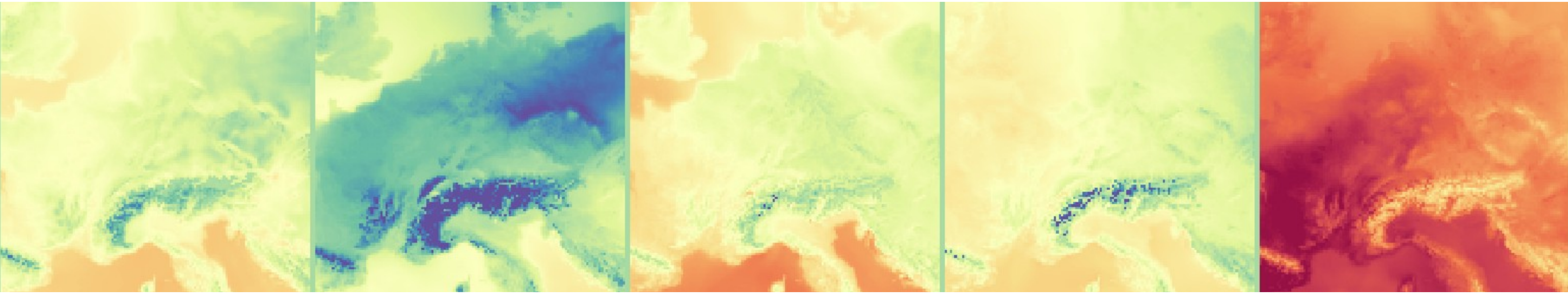


Take Home Messages

1. Generative models with scoring rules are an easy-to-use and flexible tool.

2. Open questions, e.g. around multivariate versions and bias-correction.

3. Current results for downscaling seem promising.



Thank you! Questions? Feedback?

Appendix

References

Data

EURO-CORDEX Community, 2016: EURO-CORDEX simulation list, maintained by H. Truhetz (contact: heimo.truhetz@uni-graz.at); accessed 13.12.2016. http://www.euro-cordex.net/imperia/md/content/csc/cordex/20160204a-eurocordex-simulations.pdf

C. Spirig and E. Zubler (2016): New observational datasets: Documentation and recommendation; https://wiki.c2sm.ethz.ch/pub/CH2018/WebHome/CH2018_obs_data.pdf

Jacob, D.; Petersen, J.; Eggert, B.; Alias, A.; Christensen, O. B.; Bouwer, L. M.; Braun, A.; Colette, A.; Déqué, M.; Georgievski, G.; Georgopoulou, E.; Gobiet, A.; Menut, L.; Nikulin, G.; Haensler, A.; Hempelmann, N.; Jones, C.; Keuler, K.; Kovats, S.; Kröner, N.; Kotlarski, S.; Kriegsmann, A.; Martin, E.; van Meijgaard, E.; Moseley, C.; Pfeifer, S.; Preuschmann, S.; Radermacher, C.; Radtke, K.; Rechid, D.; Rounsevell, M.; Samuelsson, P.; Somot, S.; Soussana, J.-F.; Teichmann, C.; Valentini, R.; Vautard, R.; Weber, B. & Yiou, P. EURO-CORDEX (2014): new high-resolution climate change projections for European impact research Regional Environmental Changes. Vol. 14, Issue 2, pp. 563-578., https://doi.org/10.1007/s10113-013-0499-2

References

General

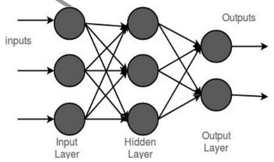
Jieyu Chen, Sebastian Lerch, and Tim Janke. “Generative machine learning methods for multivariate ensemble post-processing”. In: EGU General Assembly 2022, Vienna, Austria, 23–27 May 2022 Ml (2022). url: https://lens.org/189-140-183-158-58X.

Tilmann Gneiting and Adrian E. Raftery. “Strictly proper scoring rules, prediction, and estimation”. In: Journal of the American Statistical Association 102.477 (2007), pp. 359–378. issn: 01621459. doi: 10.1198/016214506000001437.

Lorenzo Pacchiardi et al. “Probabilistic Forecasting with Generative Networks via Scoring Rule Minimization”. In: (Dec. 2021). URL: http://arxiv.org/abs/2112.08217.

Bias-correction: idea

$X(\text{Low-res}) \xrightarrow{\text{physical model}} Y_{RCM} \sim P_{RCM}(Y|X)$



Minimise dist

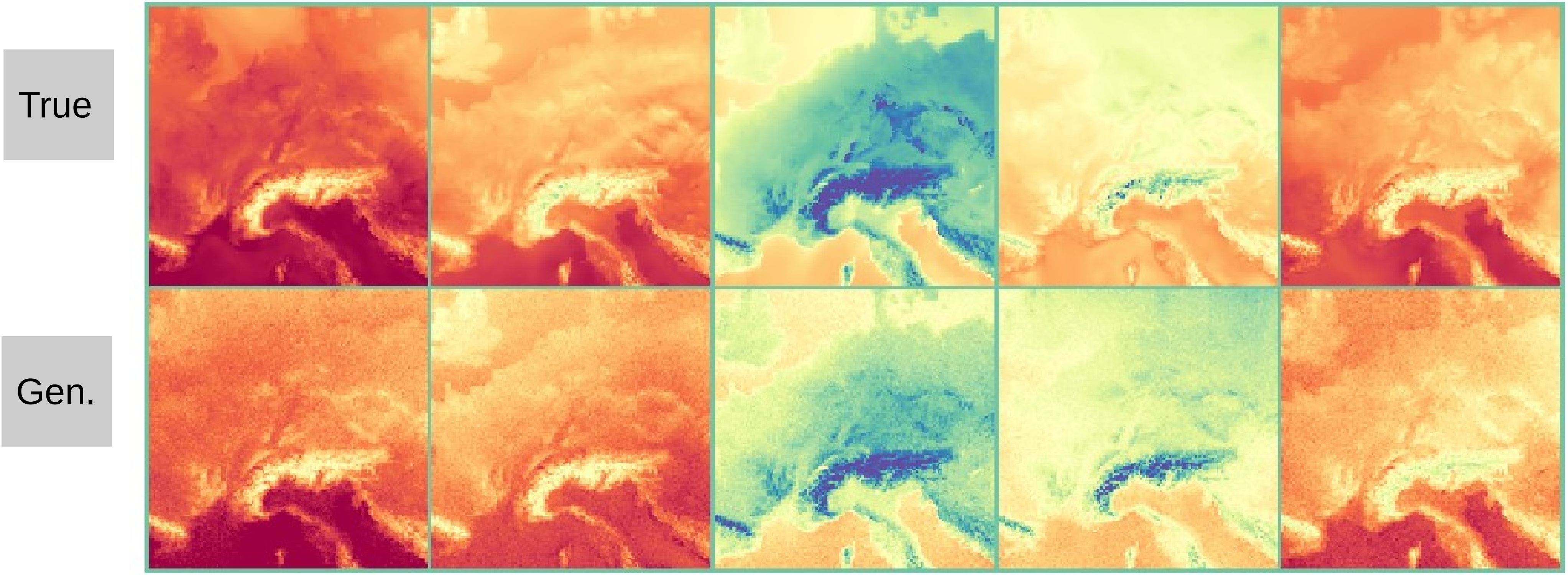
$Y_{Obs}, Y'_{Obs} \sim Q_{Obs}(Y|X)$

$Q_{Obs}(Y)$ should match marginal observational distribution $P_{Obs}(Y)$

Idea:

minimise $\mathrm{ES}(P_{RCM}(Y|X), Q_{Obs}(Y|X))$
subject to: $P_{obs}(Y) = Q_{Obs}(Y)$

Results: examples with other architecture (tas)



Results: examples with other architecture (pr)

Truth

Sample1

Sample2