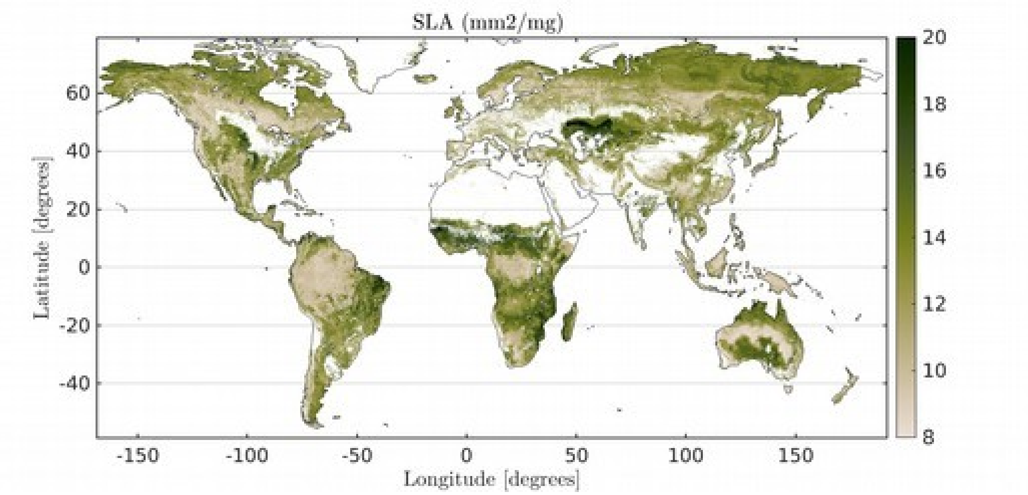
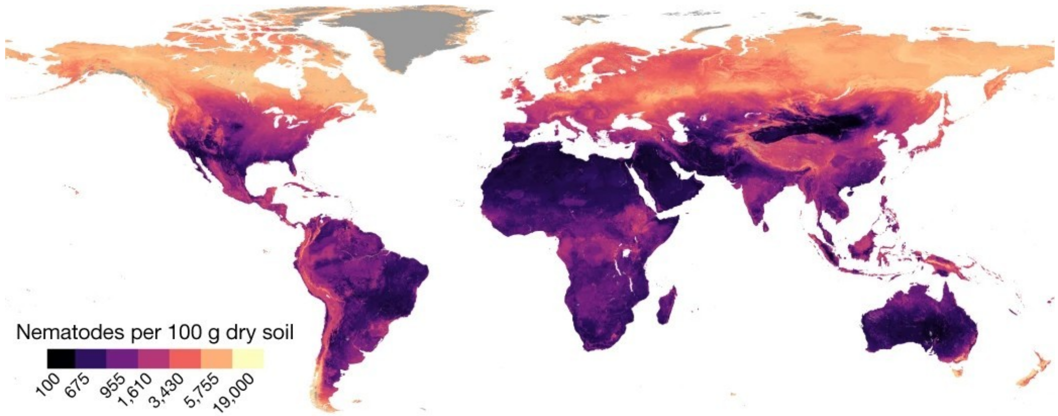
ML and EO for (global) mapping of the environment: Discussing challenges of model extrapolation and accuracy assessment

Hanna Meyer & Edzer Pebesma

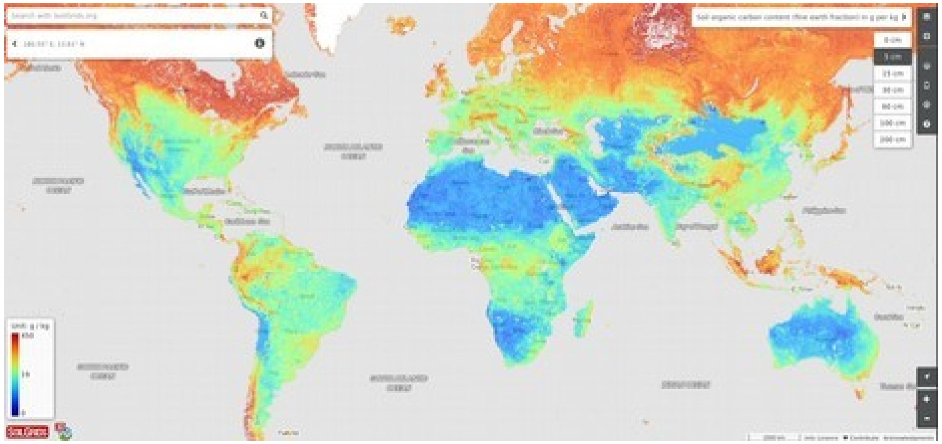
Global maps of ecological variables based on machine learning (a few of many examples)



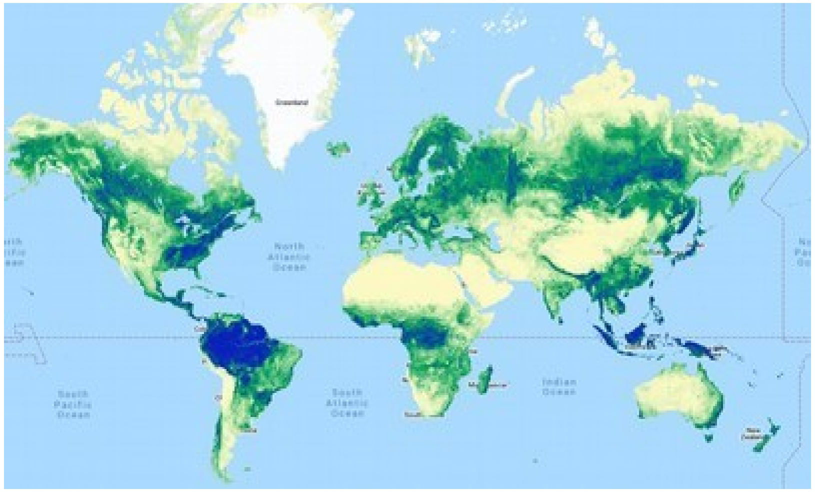
Moreno-Martínez et al., 2018



van den Hoogen et al., 2019

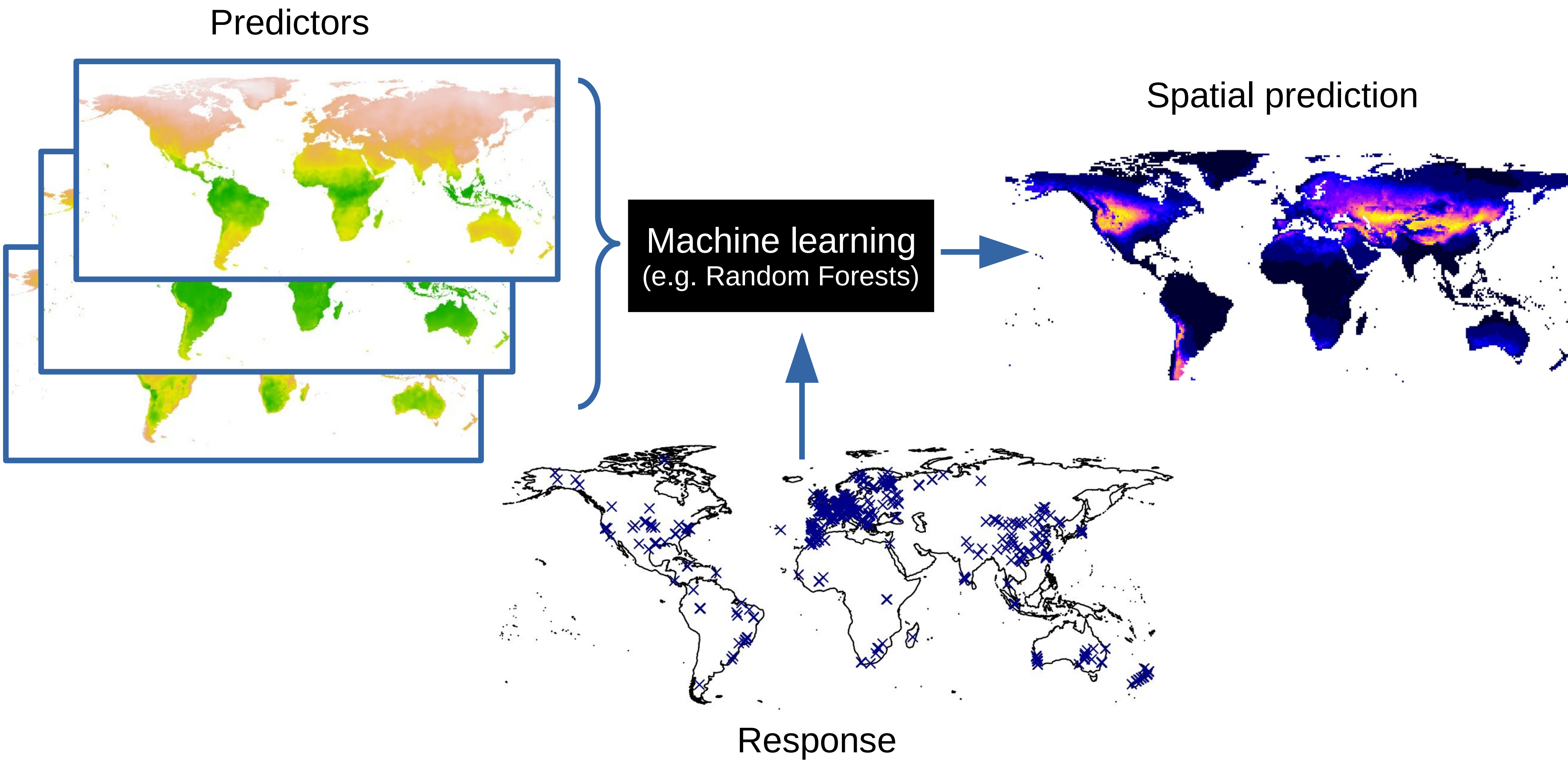


Hengl et al., 2017



Bastin et al. 2019

How do we get “maps” of ecosystem variables ?



Machine learning as a magic tool to map everything ?

Reported performance measures are impressive but there are increasingly doubts

Wissenschaft

Wenn die KI daneben liegt

Welche Fehler drohen, wenn Forscher Wissenslücken per Computer schließen wollen, zeigen zwei aktuelle Klimastudien.

Von **Tin Fischer**

6. November 2019, 16:44 Uhr / Editiert am 9. November 2019, 17:42 Uhr / DIE ZEIT Nr. 46/2019, 7. November 2019 / 9 Kommentare

AUS DER ZEIT NR. 46/2019

DEEP TROUBLE FOR DEEP LEARNING

Nature 574, 163-166 (2019) BY DOUGLAS HEAVEN

Home / News & Opinion

Researchers Find Flaws in High-Profile Study on Trees and Climate

Four independent groups say the work overestimates the c
global forest restoration, but the authors insist their origina

Oct 17, 2019

KATARINA ZIMMER

Comment | Published: 23 August 2021

Conservation needs to break free from global priority mapping

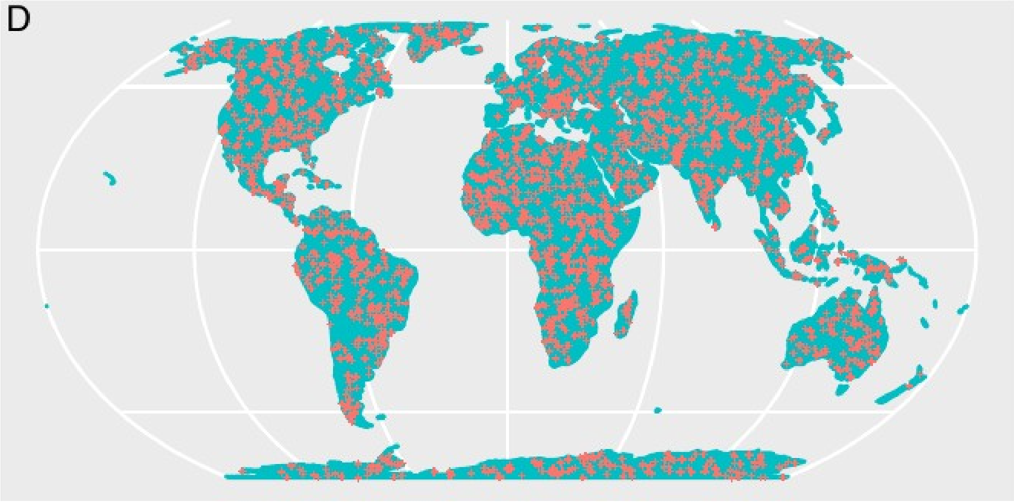
Carina Wyborn & Megan C. Evans

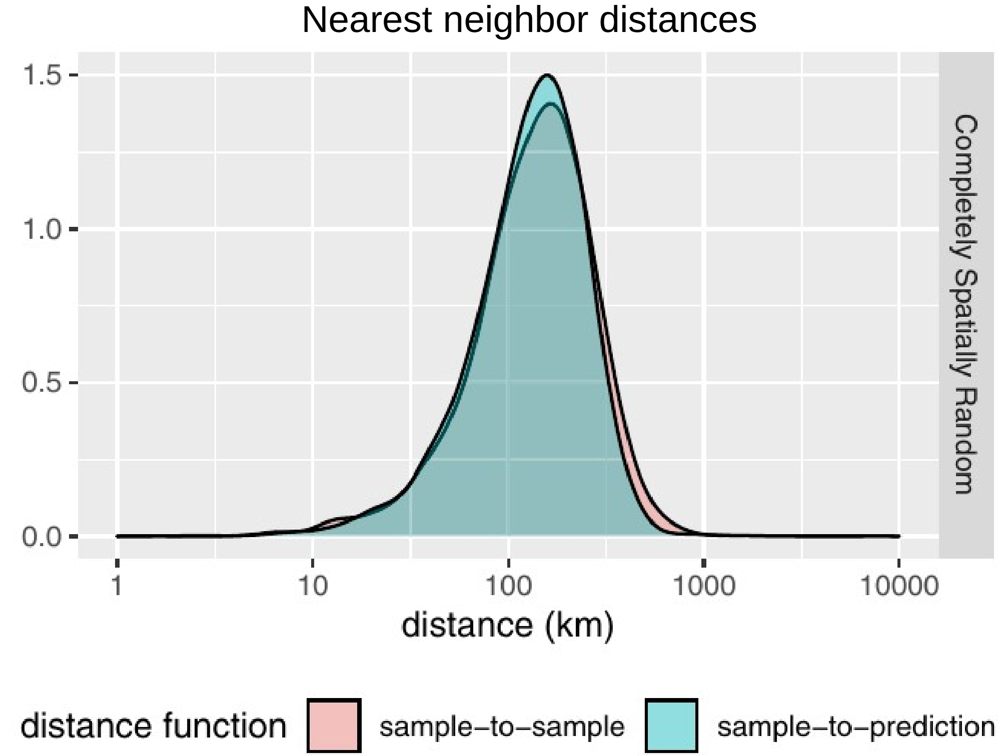
Nature Ecology & Evolution (2021) | Cite this article

Have we been too ambitious? Do our models fail ?

How do we assess the accuracy of global maps?

Ideal: Design-based inference using a probability sample



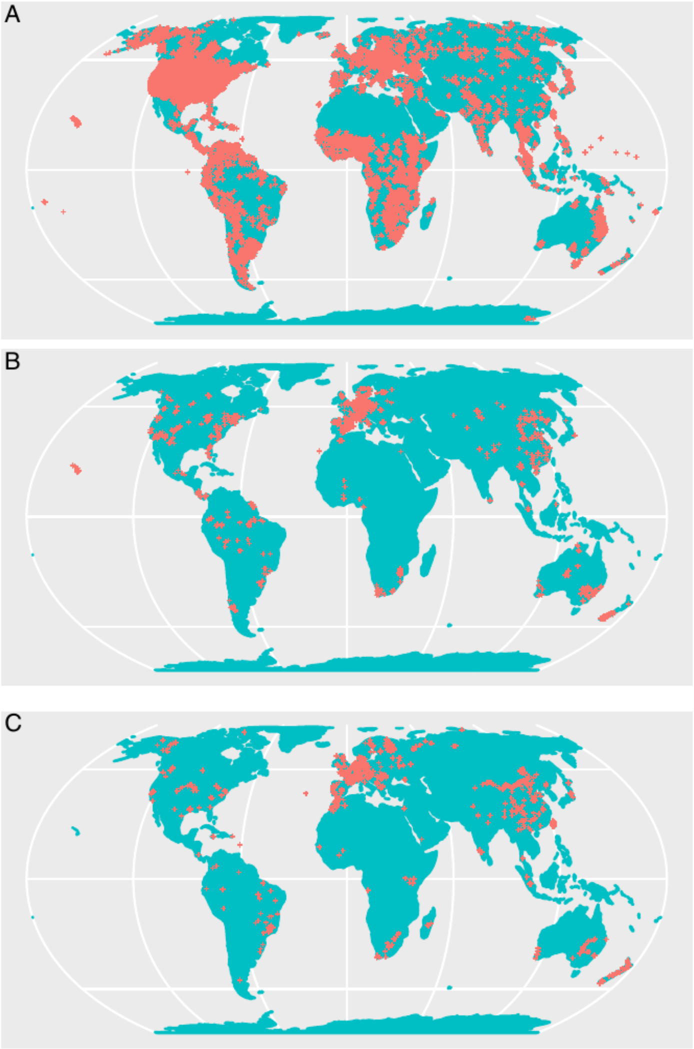


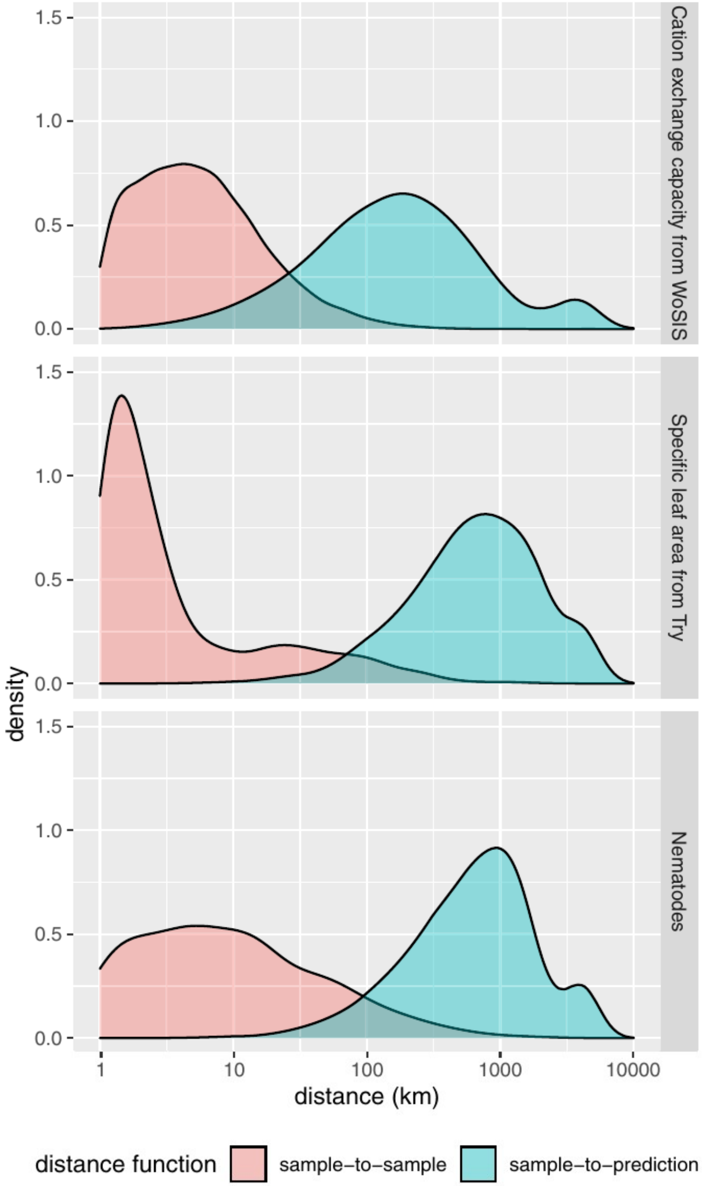
Global reference data used in machine learning applications

Soil maps

Plant traits

Nematodes

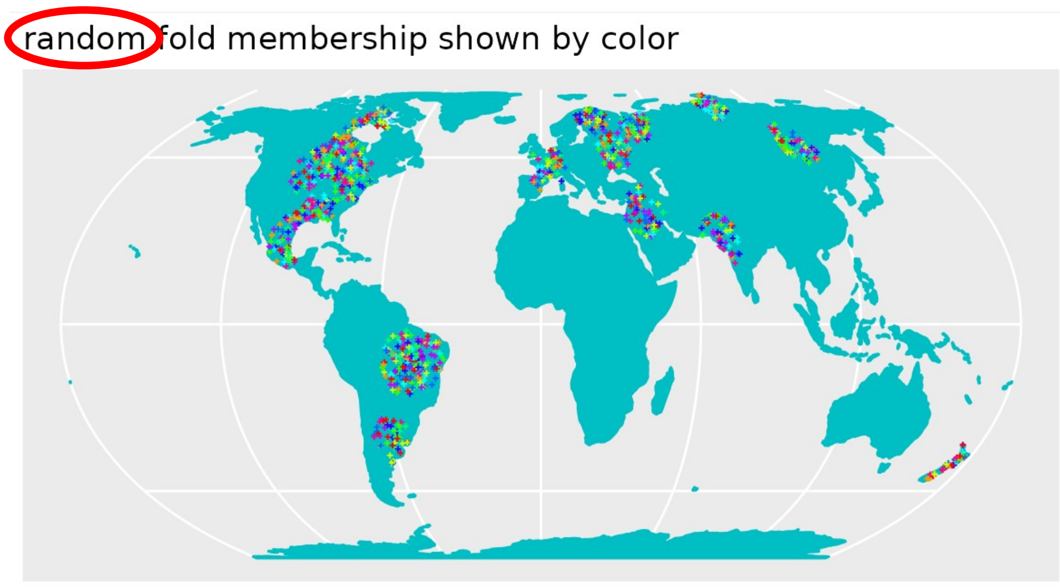




Meyer & Pebesma (2022)

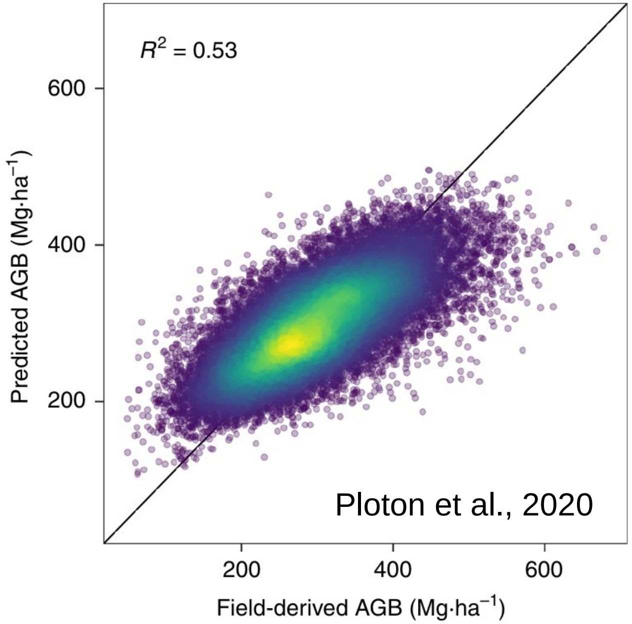
Design based approaches not possible!

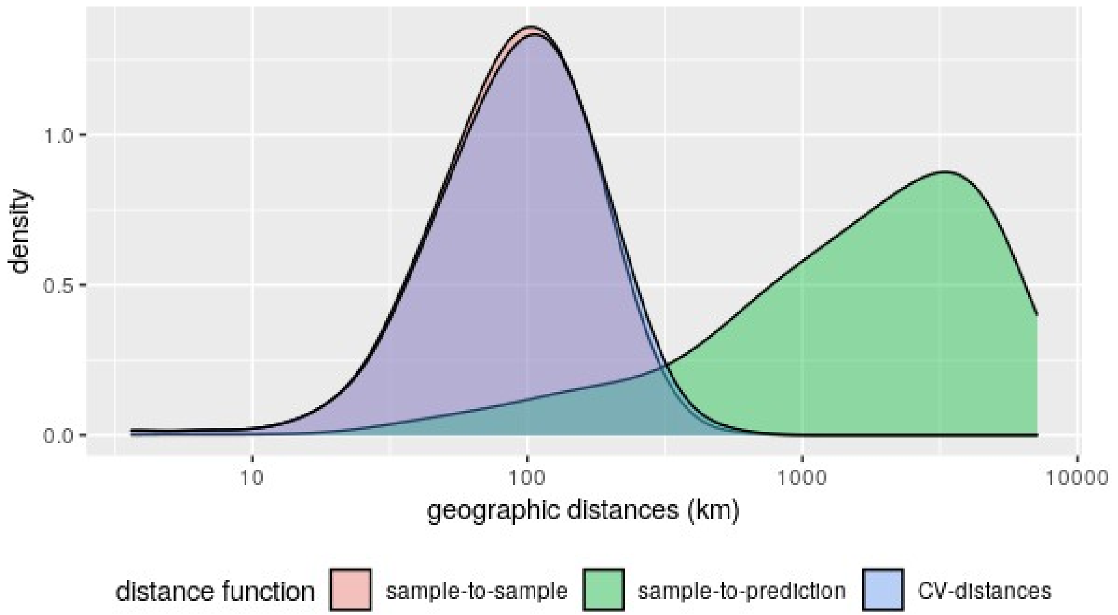
Performance assessment by default random cross-validation



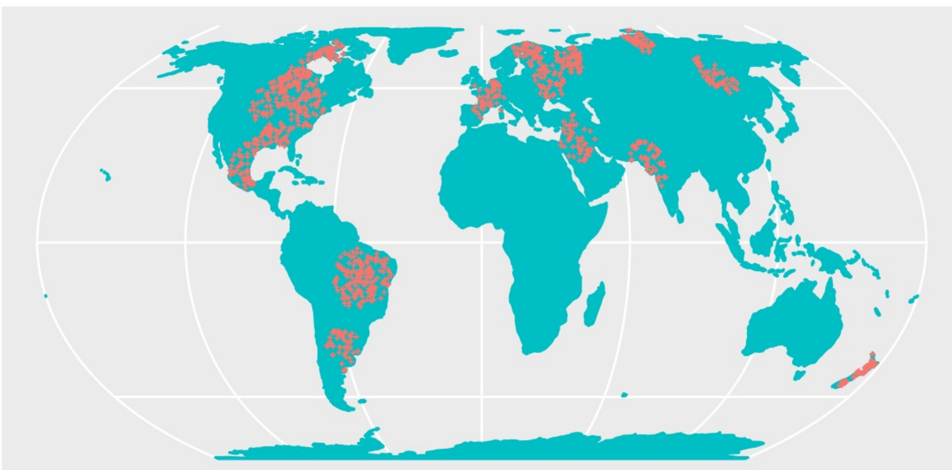
Cross-validation in general:
- Divide data into k folds
- Repeatedly train models on k-1 fold
- Test on held back data

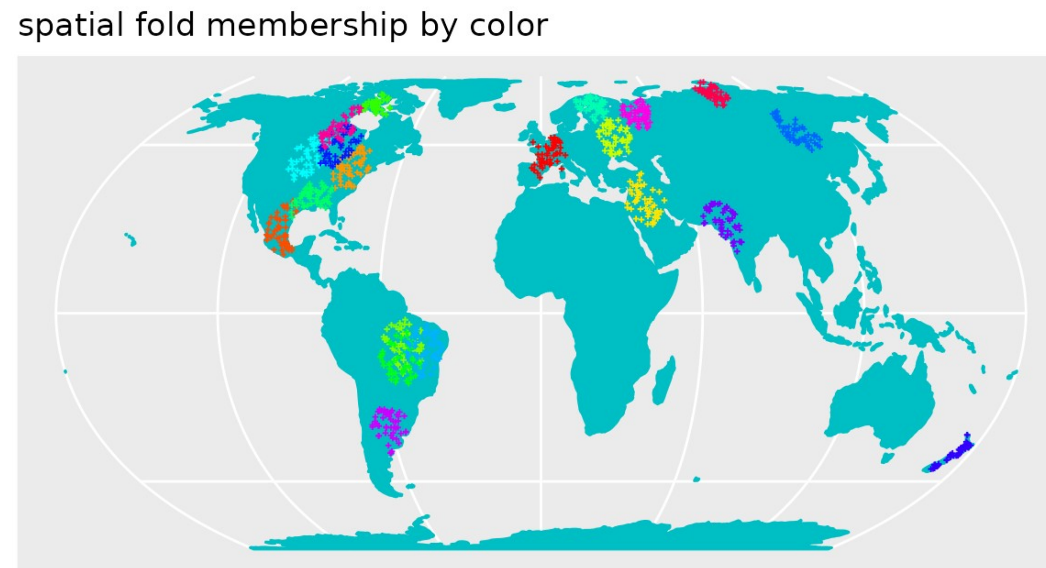
Random CV indicates here how well we can **reproduce** the training data

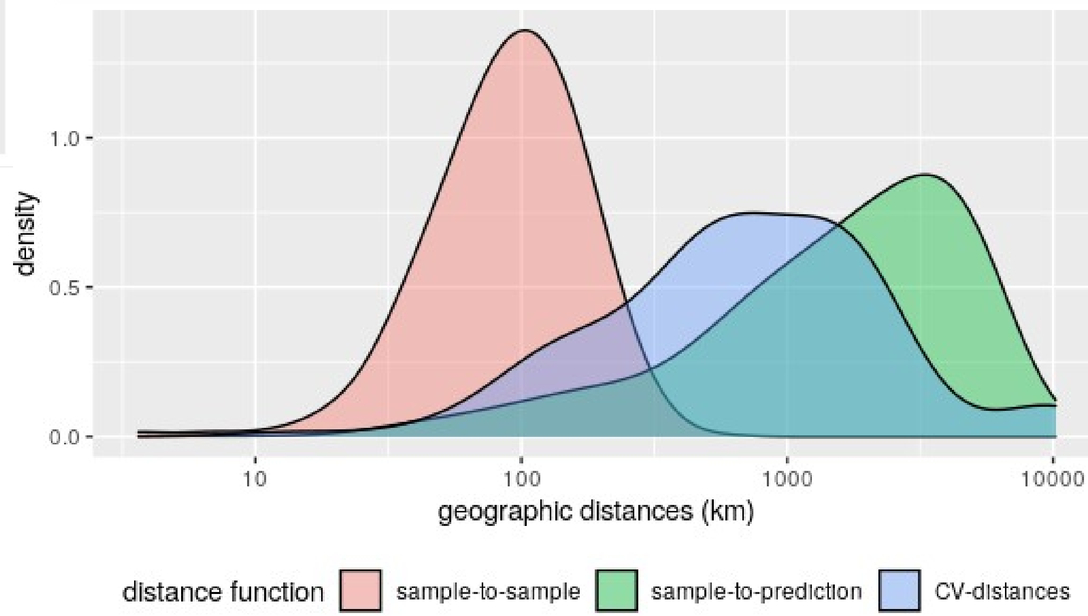




Performance assessment by a simple spatial cross-validation







Indicates how well we can make spatial **predictions !**

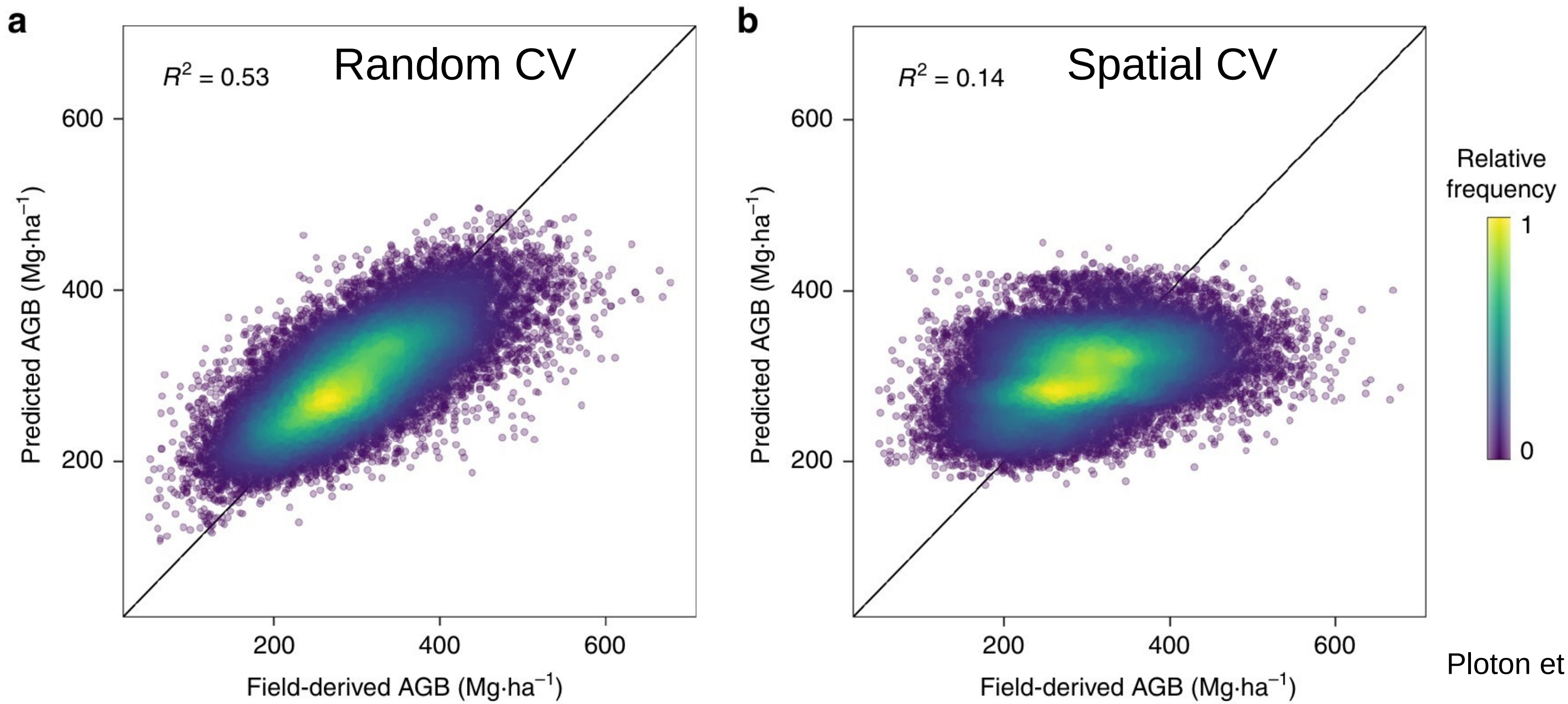
Reproduce figures:
https://hannameyer.github.io/CAST/articles/cast04-plotgeodist.html

Performance assessment using different CV strategies

Spatial validation reveals poor predictive performance of large-scale ecological mapping models

Pierre Ploton, Frédéric Mortier, Maxime Réjou-Méchain, Nicolas Barbier, Nicolas Picard, Vivien Rossi, Carsten Dormann, Guillaume Cornu, Gaëlle Viennois, Nicolas Bayol, Alexei Lyapustin, Sylvie Gourlet-Fleury & Raphaël Pélissier

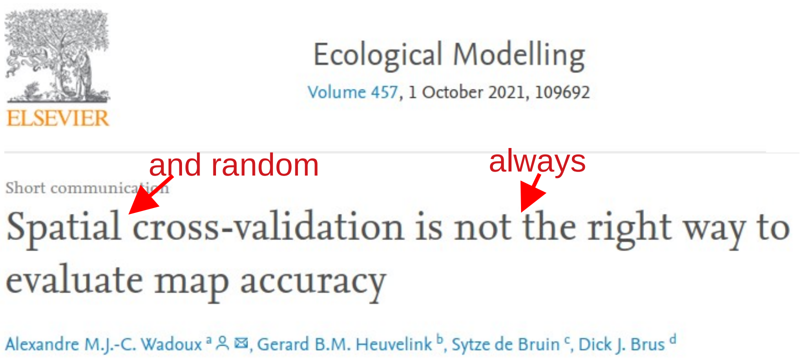
Nature Communications **11**, Article number: 4540 (2020) | Cite this article



Ploton et al., 2020

….but spatial CV methods are still under discussion...

...but spatial CV has also been blamed to be too pessimistic. Why ?


Ecological Modelling
Volume 457, 1 October 2021, 109692

Short communication

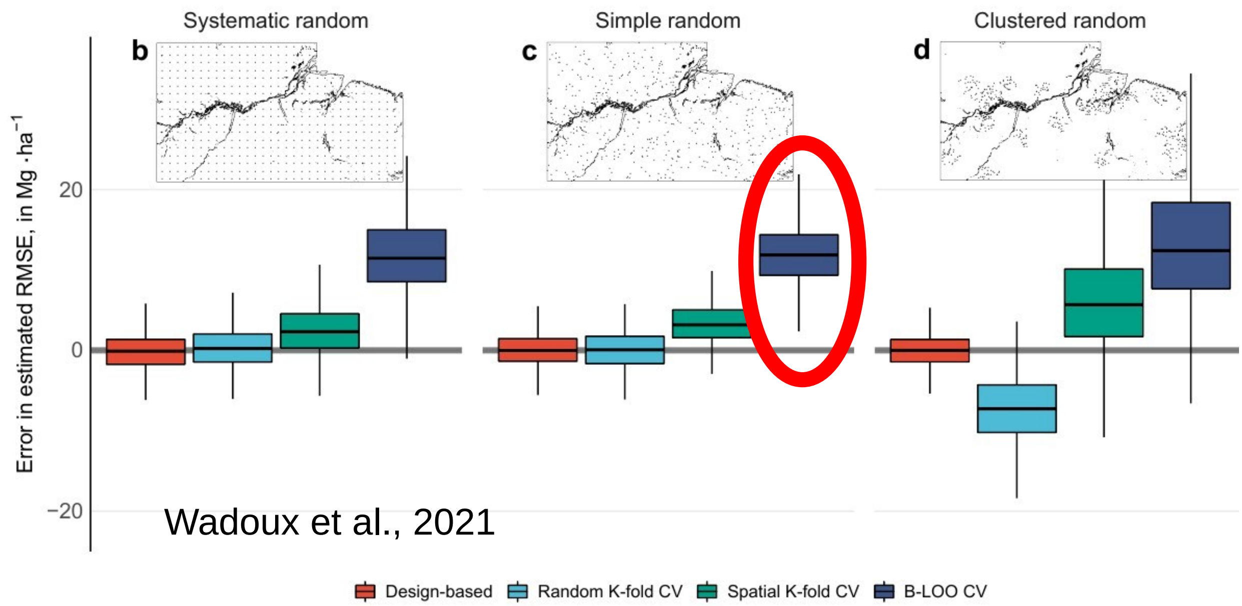
Spatial cross-validation is not the right way to evaluate map accuracy

Alexandre M.J.-C. Wadoux [a], Gerard B.M. Heuvelink [b], Sytze de Bruin [c], Dick J. Brus [d]

and random

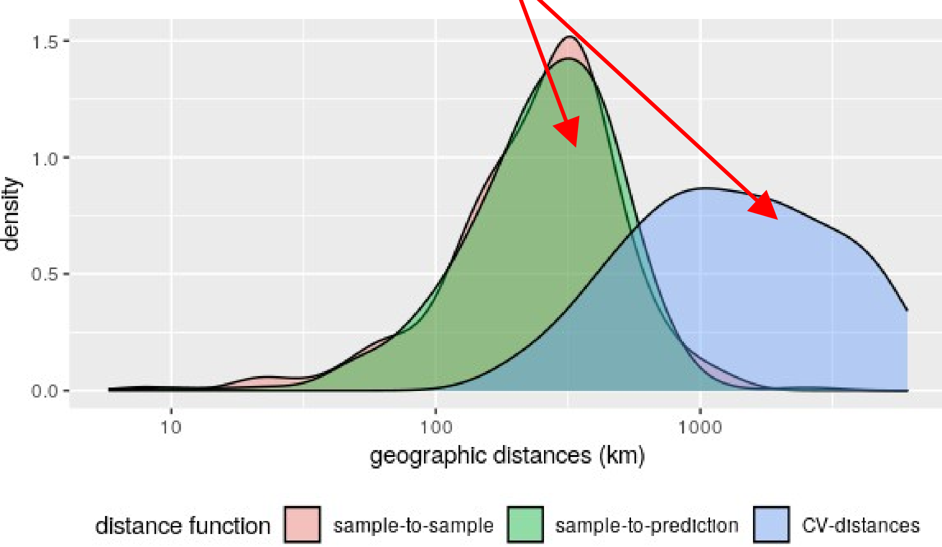
always

CV predictions are harder than the actual prediction task



Wadoux et al., 2021

It’s obviously NOT the right way here. Why?



Prediction situations created during CV need to resemble those encountered while predicting the global map from the reference data

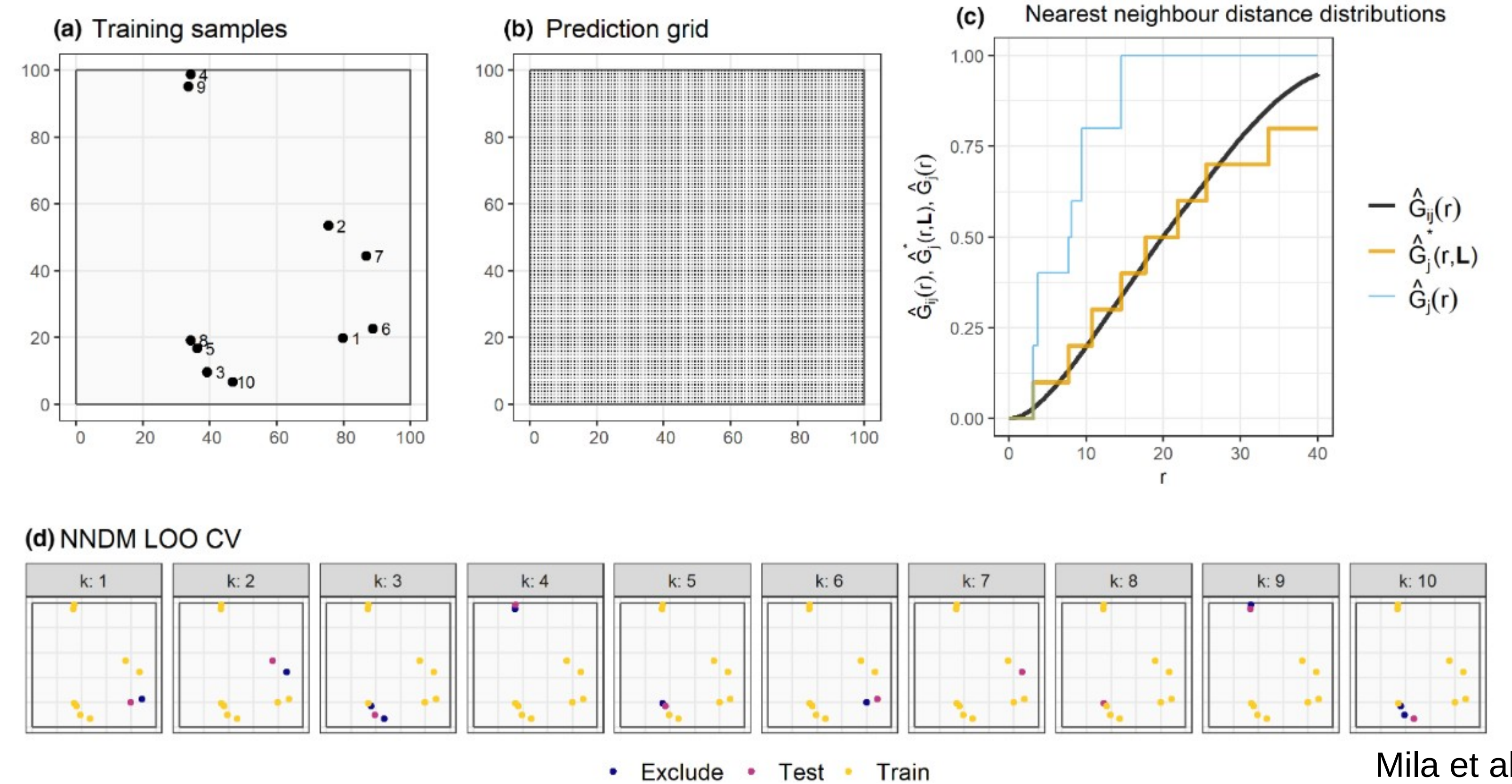
Suggestion of a nearest neighbor distance matching LOO CV

Received: 20 September 2021 | Accepted: 8 March 2022
DOI: 10.1111/2041-210X.13851
Methods in Ecology and Evolution BRITISH ECOLOGICAL SOCIETY
RESEARCH ARTICLE

Nearest neighbour distance matching Leave-One-Out Cross-Validation for map validation

Carles Milà[1] | Jorge Mateu[2] | Edzer Pebesma[3] | Hanna Meyer[4]

Aim: Prediction situations created during CV resemble those encountered while predicting the map



Mila et al., 2022

Suggestion of a nearest neighbor distance matching?

Received: 20 September 2021 | Accepted: 8 March 2022
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Methods in Ecology and Evolution BRITISH ECOLOGICAL SOCIETY

RESEARCH ARTICLE

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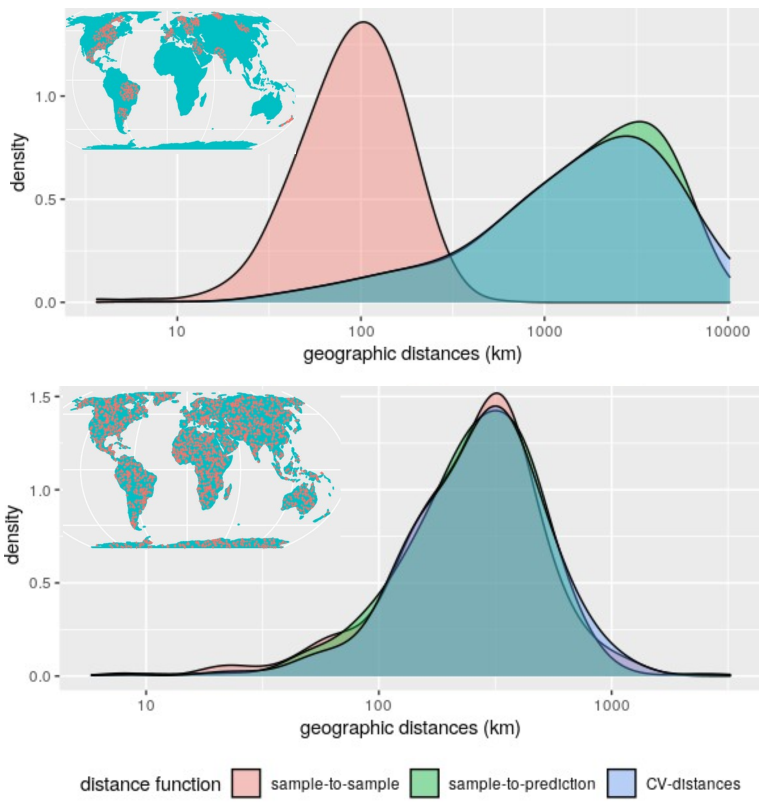
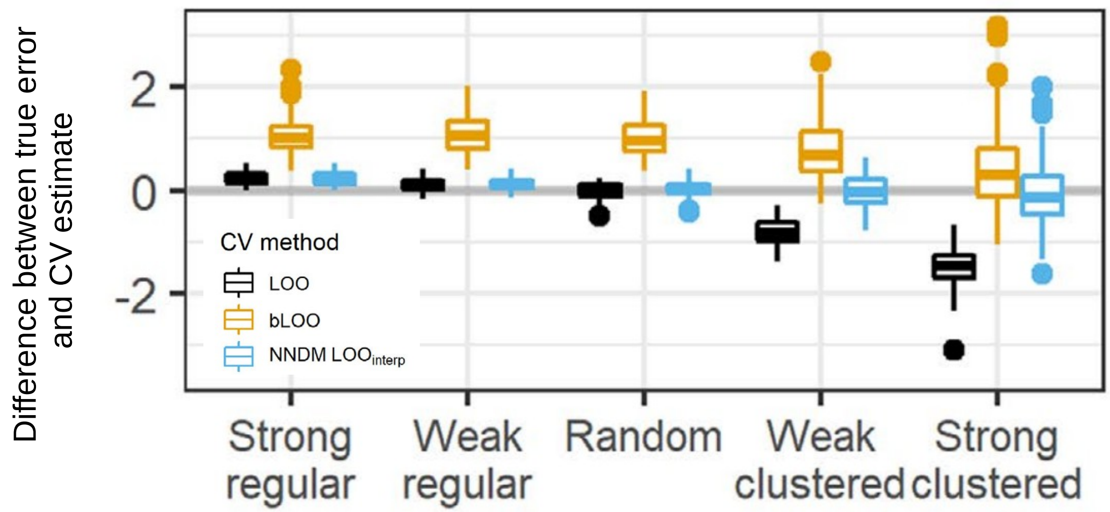


Aim: Prediction situations created during CV resemble those encountered while predicting the global map



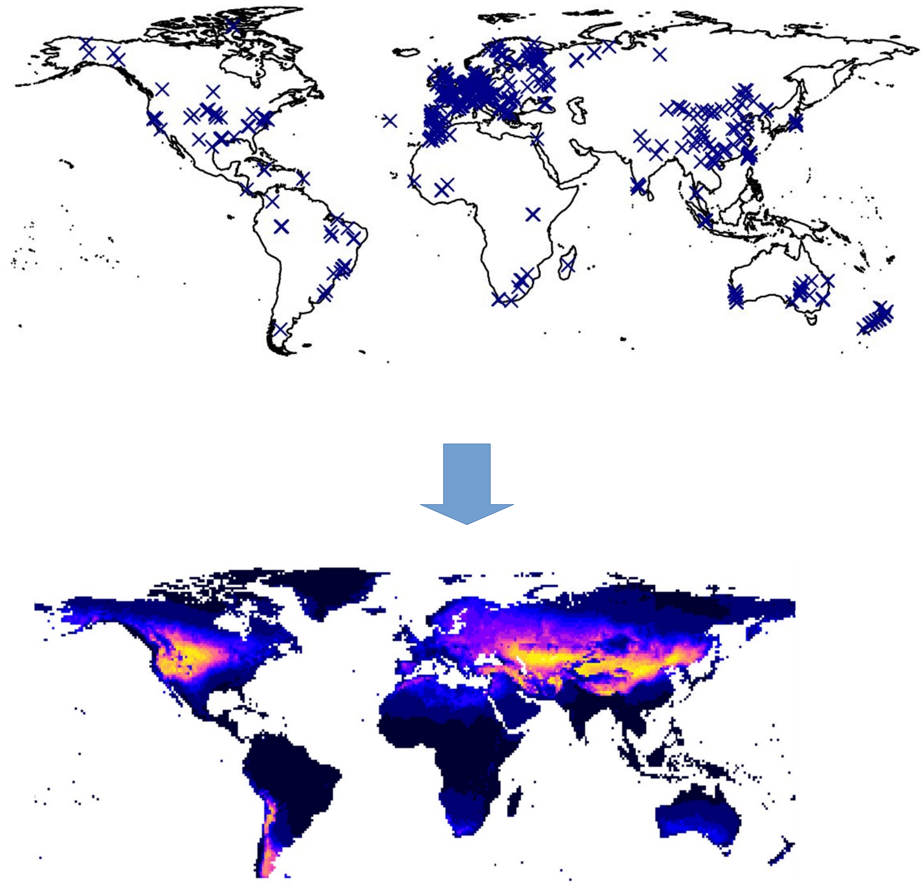
Mila et al., 2022

Relevance of choosing a suitable CV strategy

- Cross-validation strategy affect:
  - Performance estimate
  - Selected hyperparameters
  - Variable selection
- Consequences of using a unsuitable CV:
  - Unreliable performance estimates
  - Models that can well reproduce but not necessarily predict
- Hence, CV strategies that fit the prediction task are required!

But is this sufficient for reliable global mapping ?

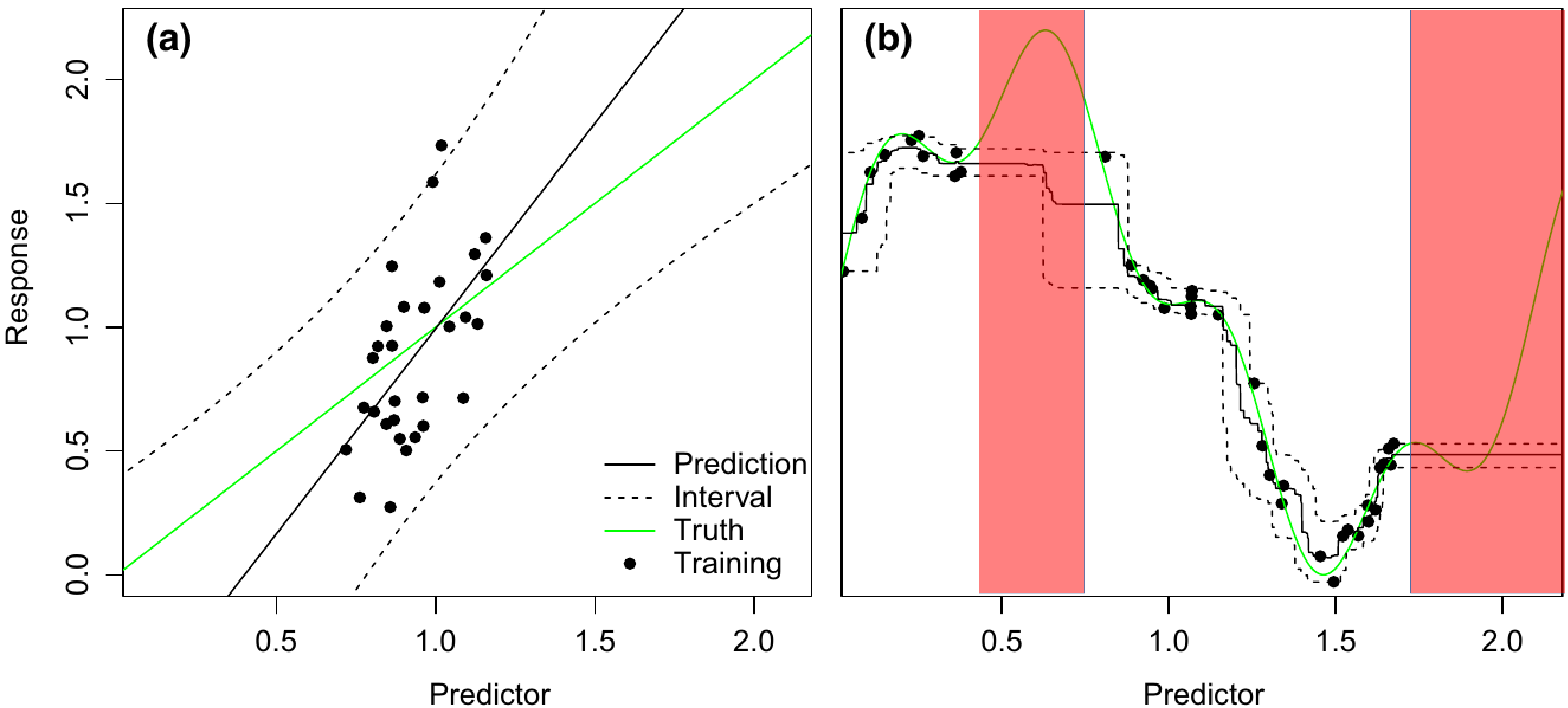
Limits to accuracy assessment



- Mapping requires prediction far beyond clustered reference data
- Transfer to new space required
- New space might differ in environmental properties

...but what happens if the model has never “seen” such new predictor properties?

Predictions and common uncertainty measures are unreliable beyond training data



Meyer & Pebesma 2021

Shouldn’t we avoid predictions into “unknown space”?

Suggestion: Area of Applicability (AOA)

Methods in Ecology and Evolution | BRITISH ECOLOGICAL SOCIETY

RESEARCH ARTICLE | Open Access

Predicting into unknown space? Estimating the area of applicability of spatial prediction models

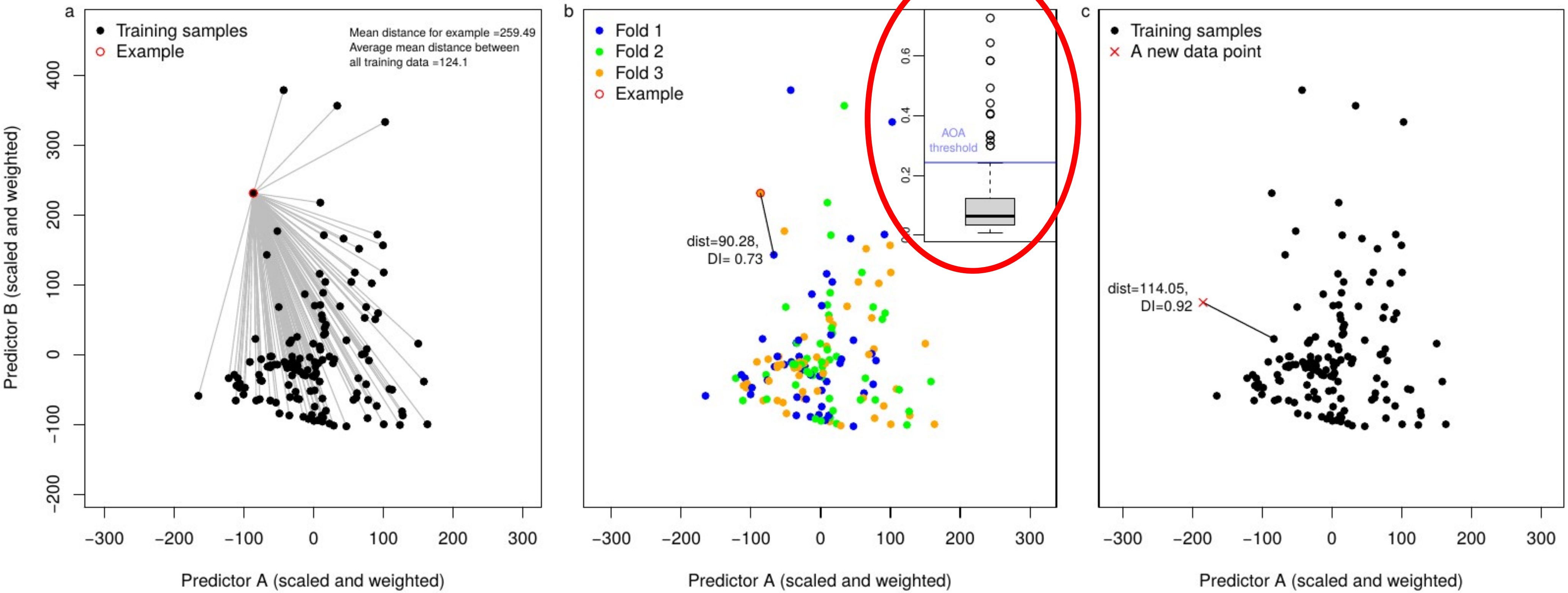
Hanna Meyer, Edzer Pebesma

We try to derive the area...

- to which the model can be applied because it has been enabled to learn about relationships
- where the estimated performance holds
- for which uncertainty measures can be interpreted

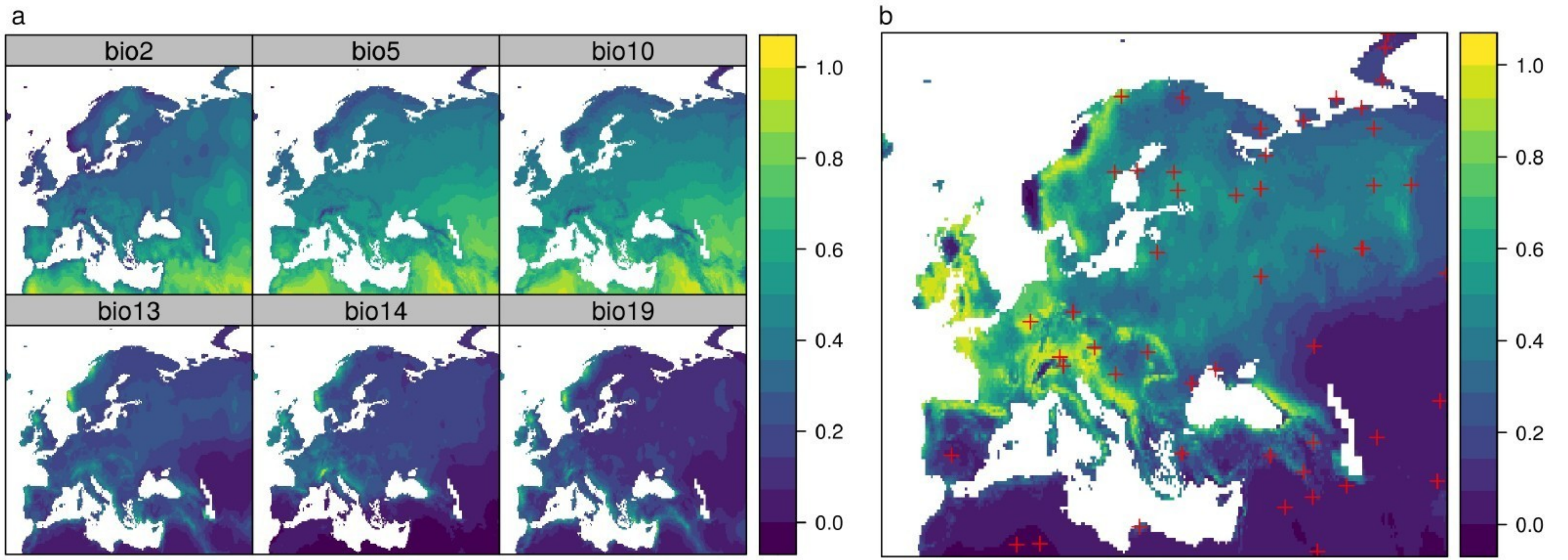
Suggestion of a method to derive the AOA

Calculation of a
Dissimilarity Index (DI)



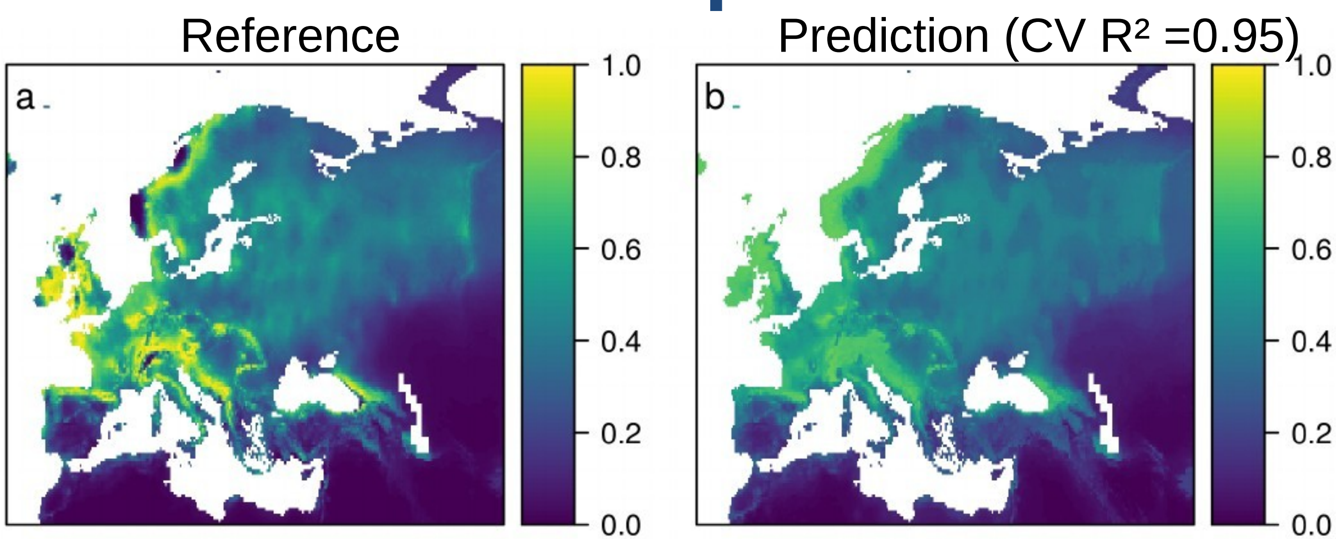
Meyer & Pebesma (2021)

Simulated example: Predictors and response

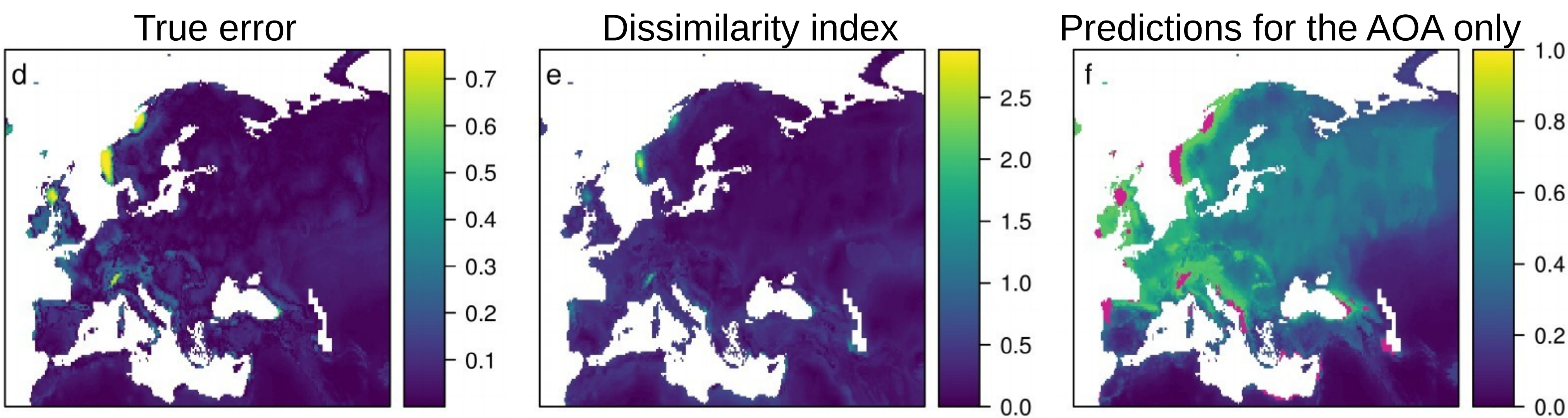


Meyer & Pebesma (2021)

Simulated example: Results



Reproduce example:
github.com/HannaMeyer/
MEE_AOA



Meyer & Pebesma (2021)

Conclusions & Discussions

- Results are not just nice maps but used for subsequent modeling, nature conservation, risk assessment,…
- We think that predictions should only be made for the AOA (accept gaps!?)
- We (= producers of the maps) are responsible for clearly indicating usage of maps, don’t leave it to the user
- Methods suggested here are implemented in the R package CAST
- We have to work on methods to better assess the prediction performance and uncertainties, especially local performance estimates

References

- Bastin et al. 2019: The global tree restoration potential. Science. Vol. 365, Issue 6448, pp. 76-79.
- Batjes, N. H., Ribeiro, E. & van Oostrum, A. Standardised soil profile data support global mapping and modelling (wosis snapshot 2019). Earth Syst. Sci. Data 12, 299–320 (2020).
- Hengl et al. (2017): SoilGrids250m: Global gridded soil information based on machine learning. PloS one 12(2): e0169748.
- Van den Hoogen, J., Geisen, S., Routh, D. et al. (2019): Soil nematode abundance and functional group composition at a global scale. Nature 572, 194–198.
- Kattge, J. et al. TRY plant trait database – enhanced coverage and open access. Glob. Change Biol. 26, 119–188 (2020).
- Meyer, H. & Pebesma, E. Predicting into unknown space? Estimating the area of applicability of spatial prediction models. Methods Ecol. Evol. 12, 1620–1633 (2021).
- Meyer H, Pebesma E. 2022. Machine learning-based global maps of ecological variables and the challenge of assessing them. Nature Communications 13.
- Milà, C., Mateu, J., Pebesma, E. & Meyer, H. Nearest neighbour distance matching Leave-One-Out Cross-Validation for map validation. Methods in Ecology and Evolution. 00, 1–13 (2022).
- Moreno-Martinez, A. et al. A methodology to derive global maps of leaf traits using remote sensing and climate data. Remote Sens. Environ. 218, 69–88 (2018).
- Ploton, P. et al. (2020): Spatial validation reveals poor predictive performance of large-scale ecological mapping models. Nat. Commun. 11, 4540.
- Wadoux, A. M.-C., Heuvelink, G. B., de Bruin, S. & Brus, D. J. Spatial cross-validation is not the right way to evaluate map accuracy. Ecol. Modell. 457, 109692 (2021).