Koninklijk Nederlands
Meteorologisch Instituut
Ministerie van Infrastructuur en Waterstaat

Multi-fidelity adaptive sampling

Towards optimal station location choice of combined official and crowd-sourced weather observation networks

Jouke de Baar & Gerard van der Schrier (KNMI)

Budapest, 11 May 2023


"Map of the Spaarne"
Pieter Bruinsz. (1584)
Hoogheemraadschap van Rijnland,
Leiden, The Netherlands
Oldest known
map that shows
iso-contour
7 foot water depth
Hoogheemraadschap
van Rijnland
Kaartverzameling
Nº A 324

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Introduction

Adding stations (NL)

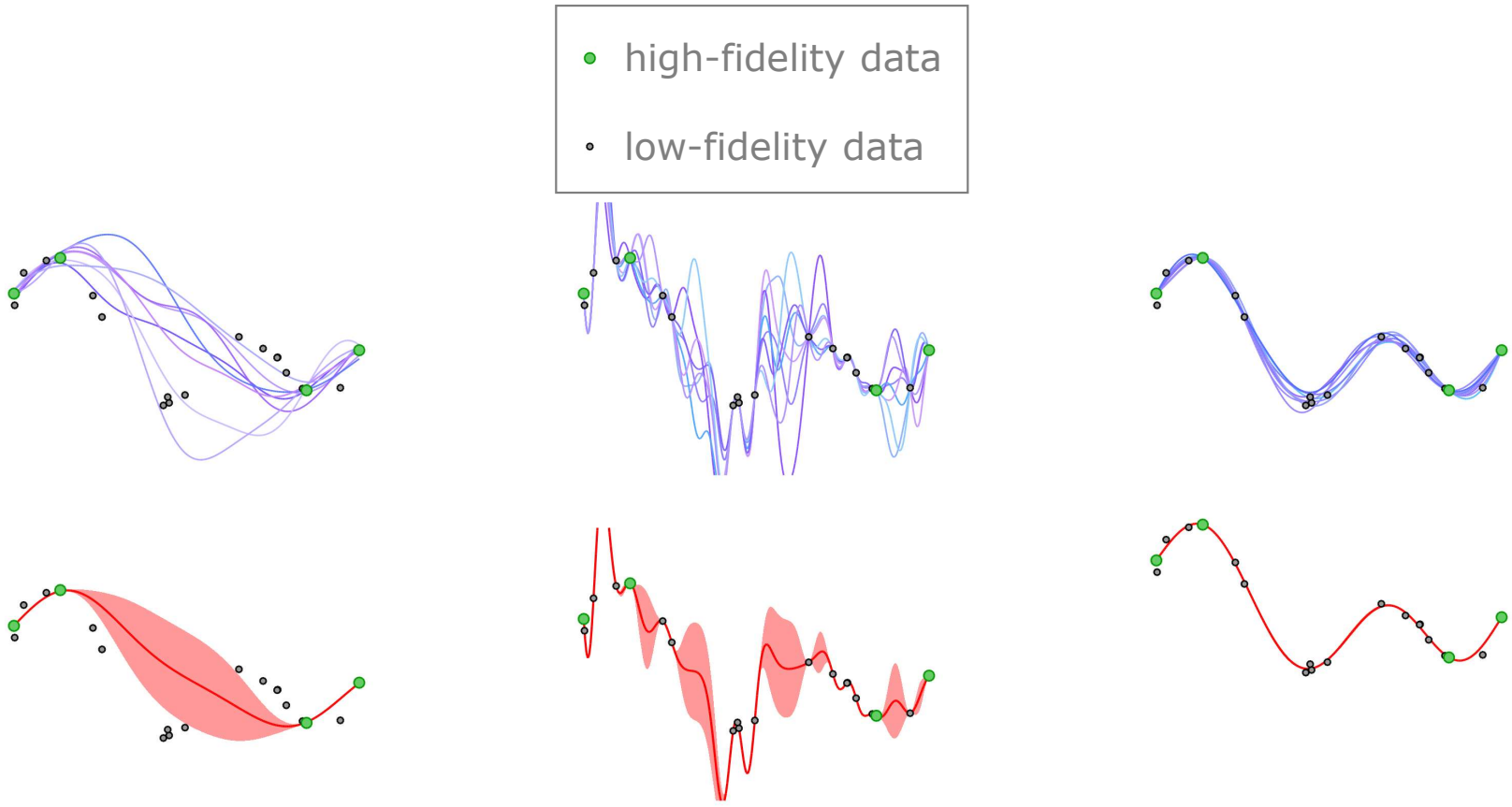
Multi-fidelity adaptive sampling (NL)

Multi-fidelity adaptive sampling (Utrecht)

Conclusions

KNMI + WOW

Multi-fidelity Gaussian process regression



ignoring low-fi data

exact interpolation

regression with noise treatment

KNMI + WOW + cov

official

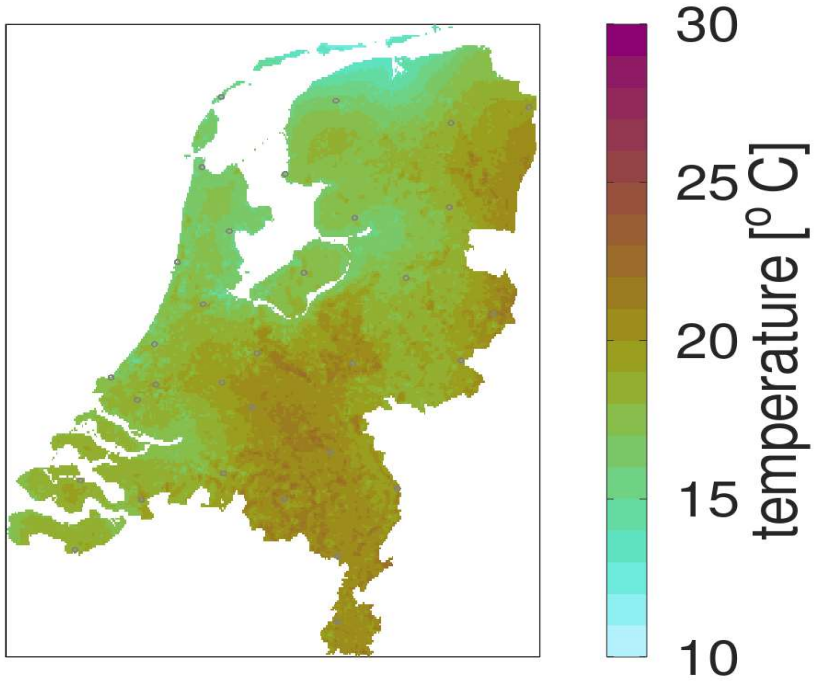
crowd-sourced

land use

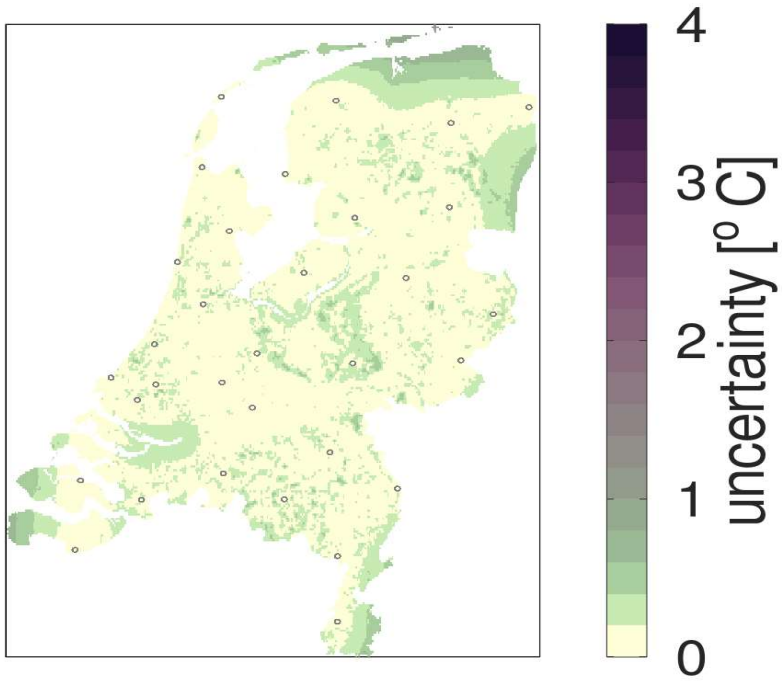
Temperature (29 June 2021, 8am-9am)

We are very grateful for all the efforts from the WOW community in providing data!

Often, we focus on this map …



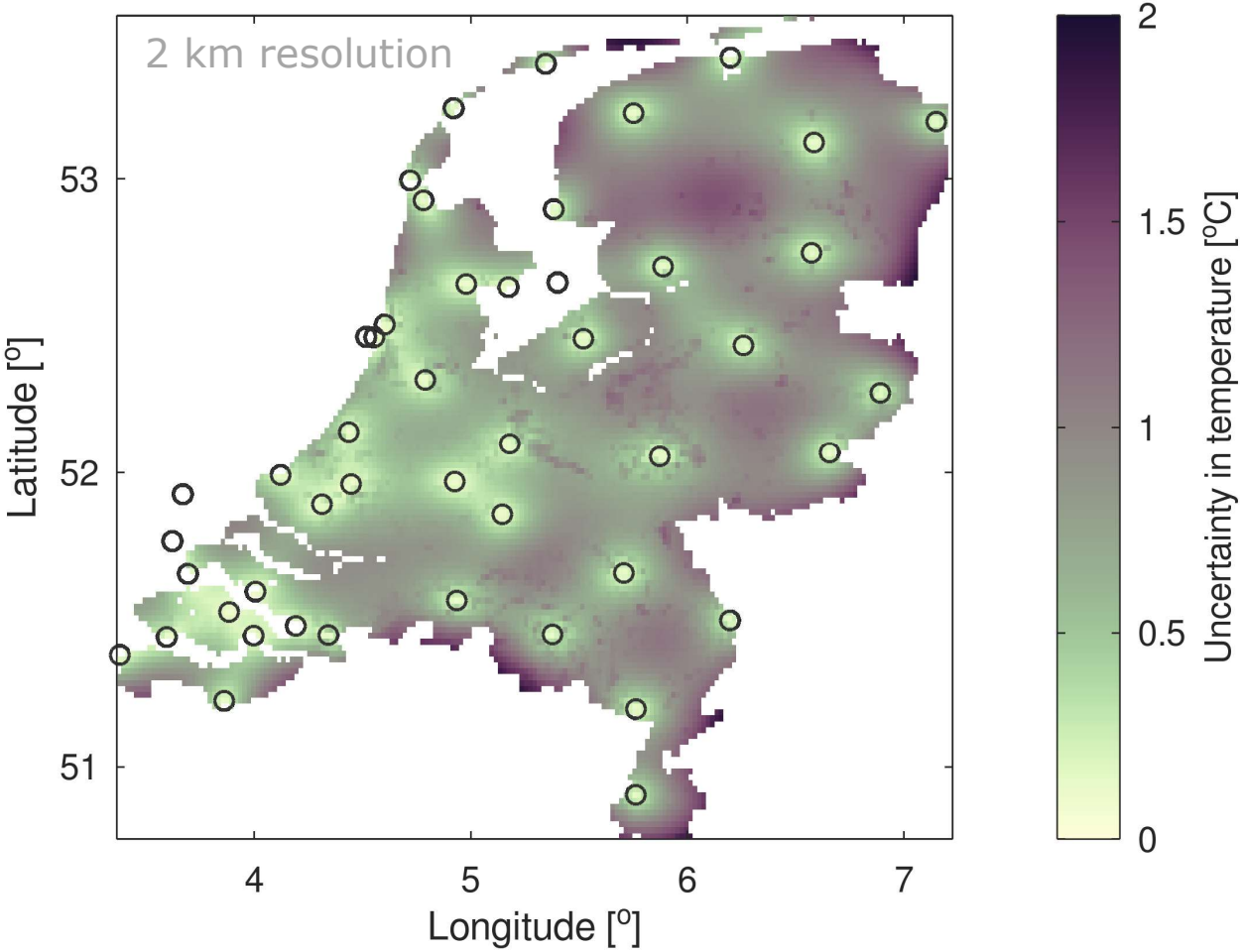
… but what can we do with this map?

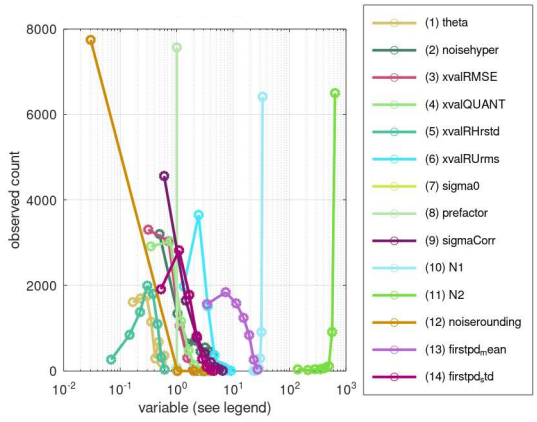


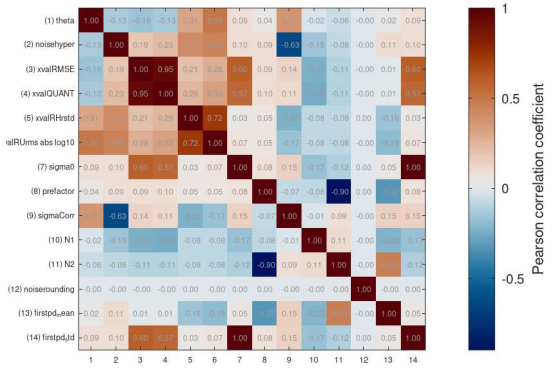
Source: De Baar, Garcia-Marti, Van der Schrier, EMS2022-53

KNMI + WOW + cov

Year of *in situ* observed air temperature

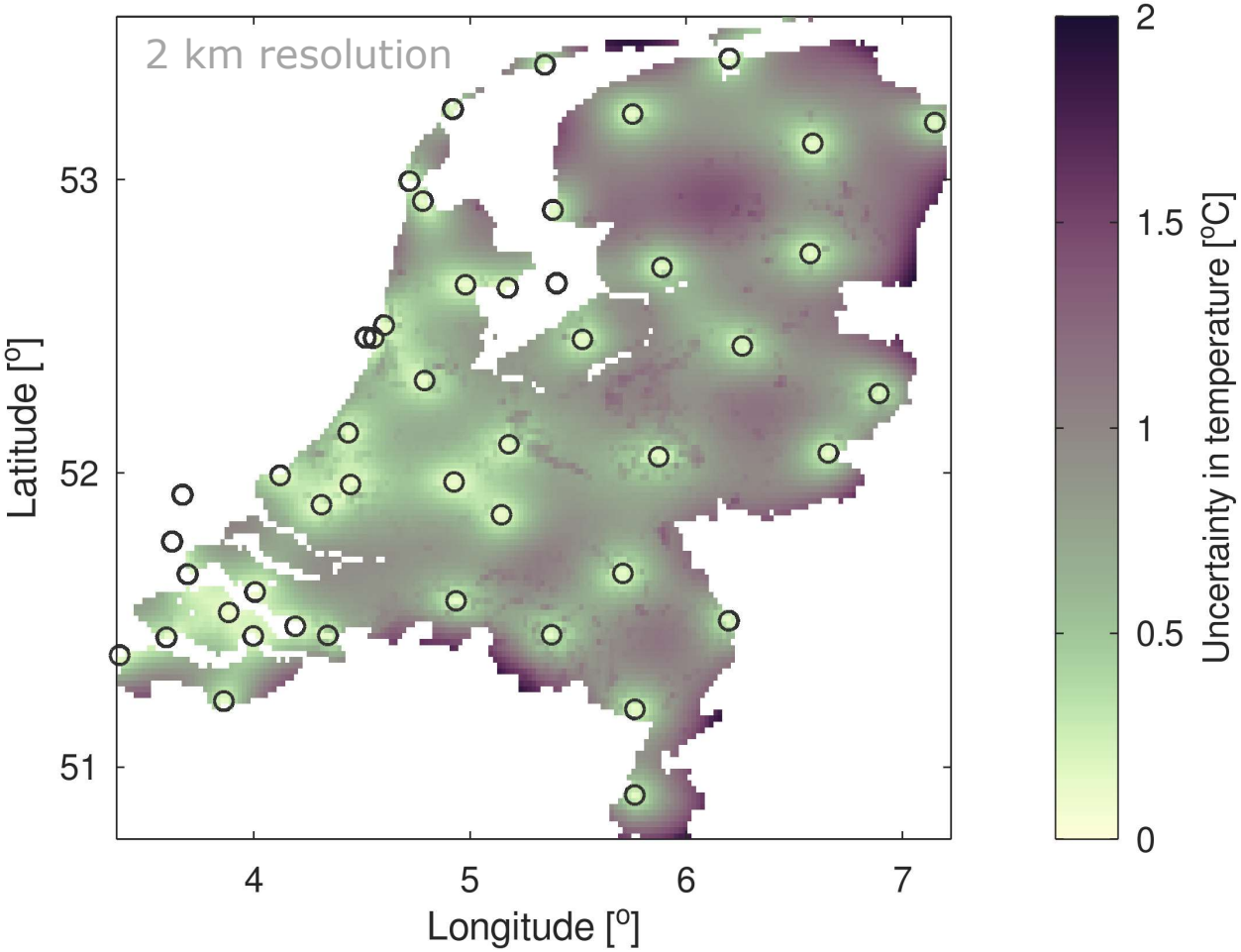






KNMI + WOW + cov

Year of *in situ* observed air temperature



- What happens to this map if we start adding stations?
- The uncertainty will be reduced, but where, and by how much?
- **Note:** compared to the estimated mean maps, the estimated uncertainty maps are still in an early stage of development!

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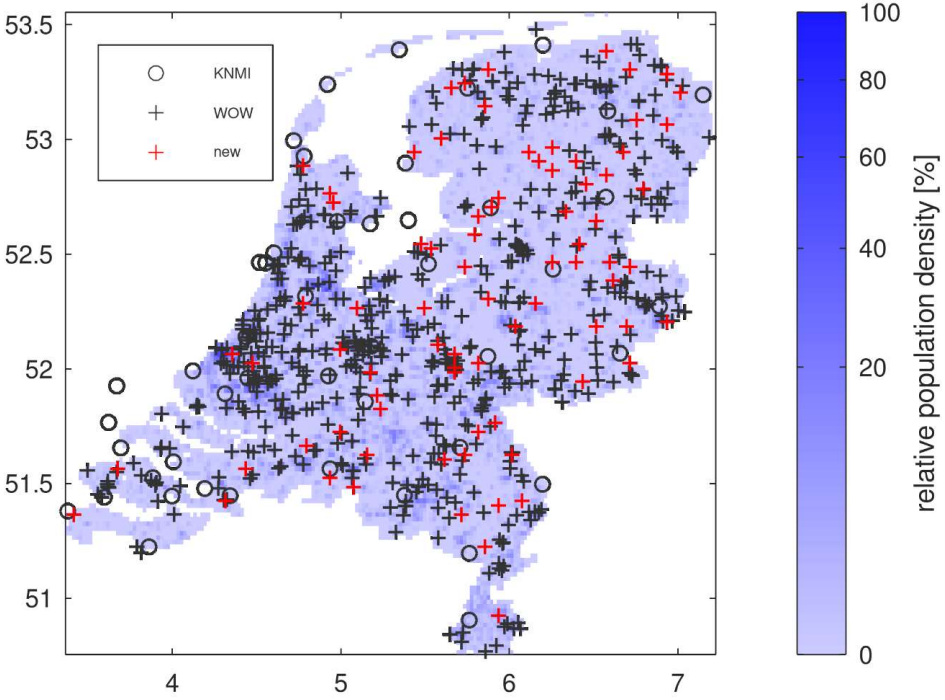
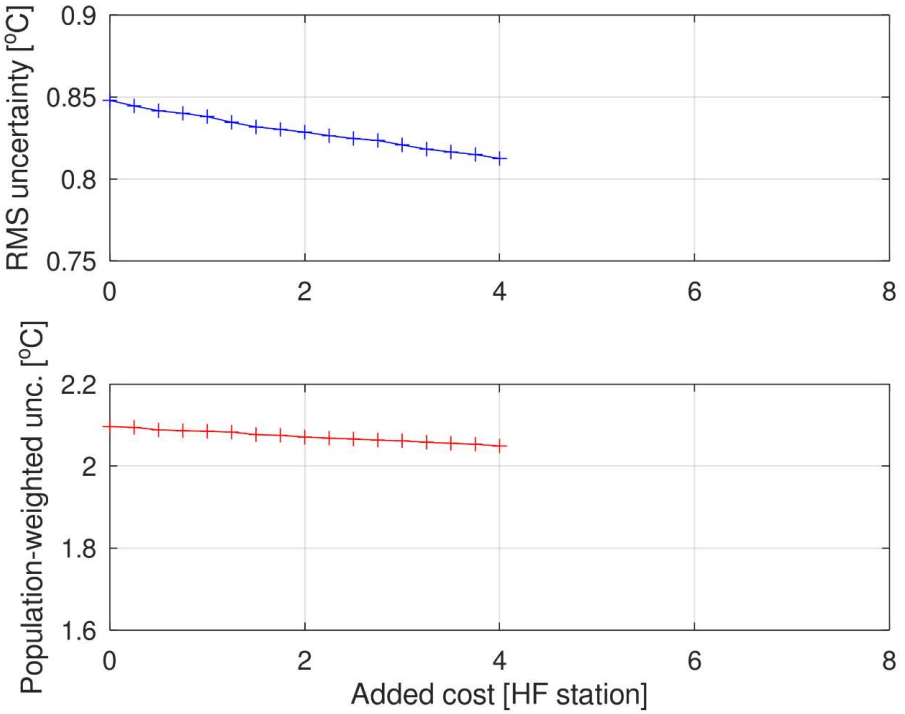
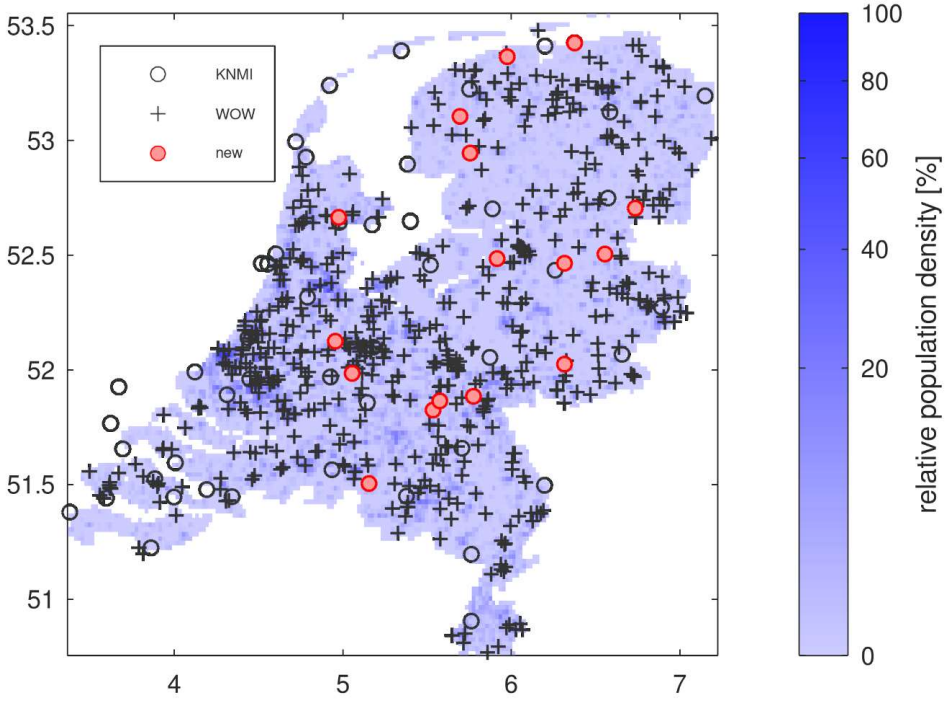


Randomly adding WOW stations

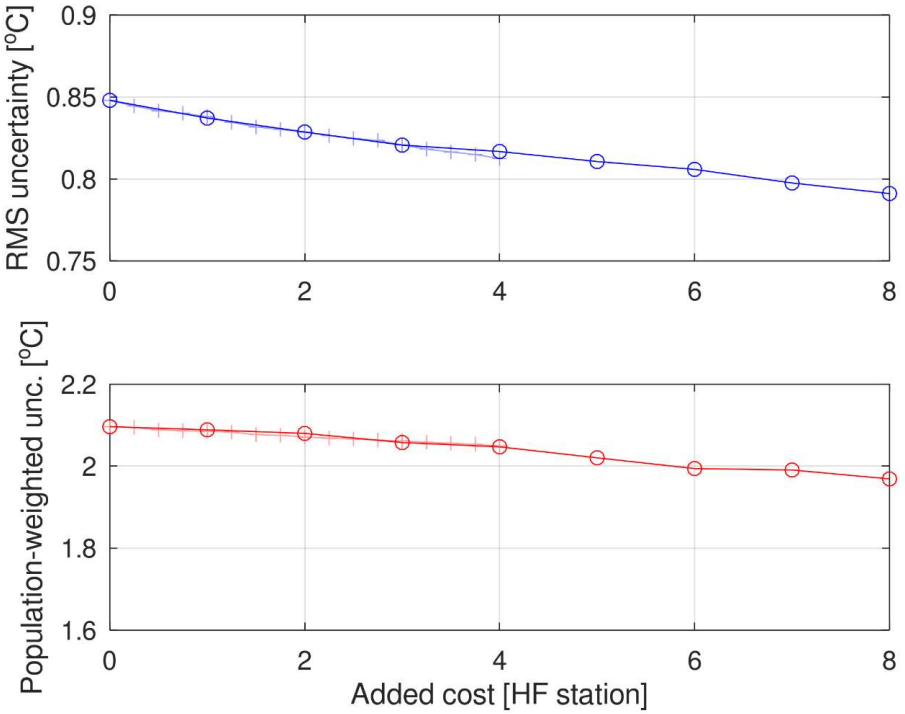


assuming WOW station cost
is 5 % of KNMI station cost

Adding stations



Randomly adding KNMI stations



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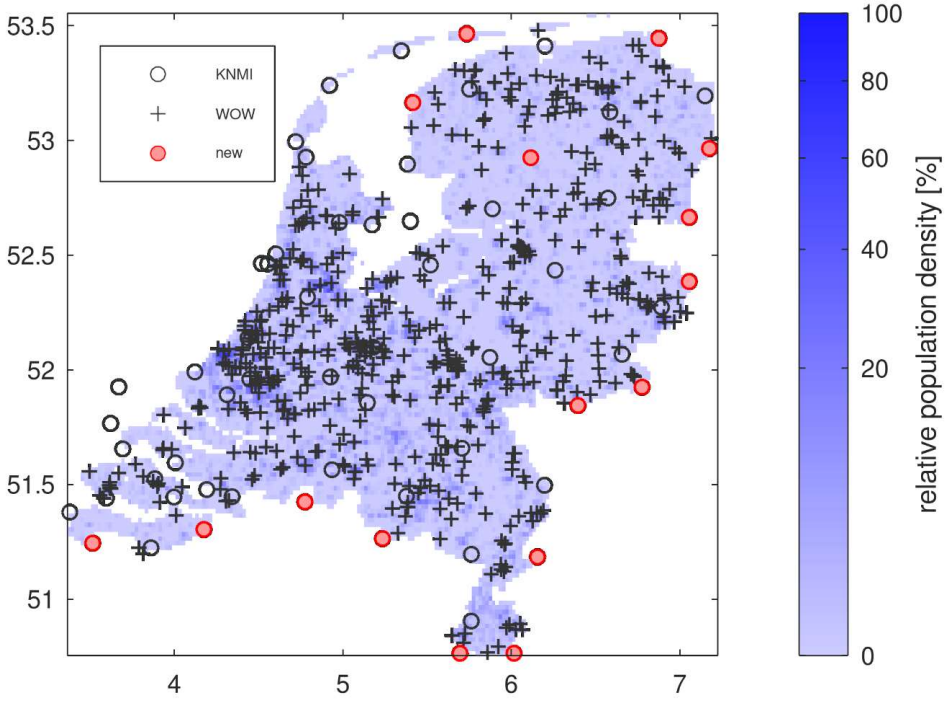
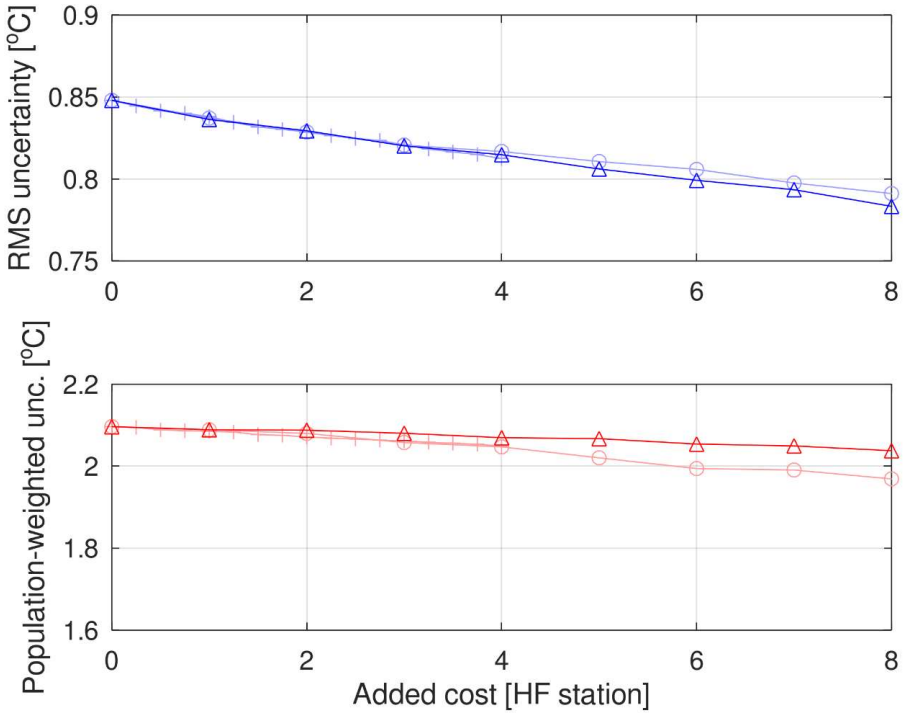


Adding KNMI station at location of heighest uncertainty



assuming WOW station cost is 5 % of KNMI station cost

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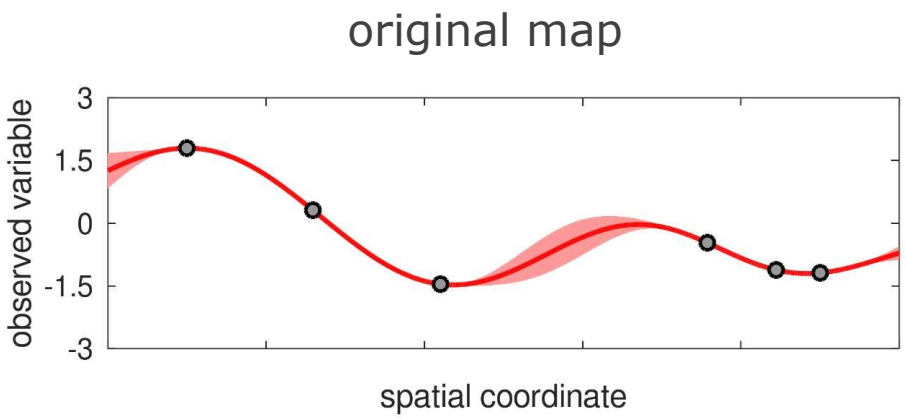
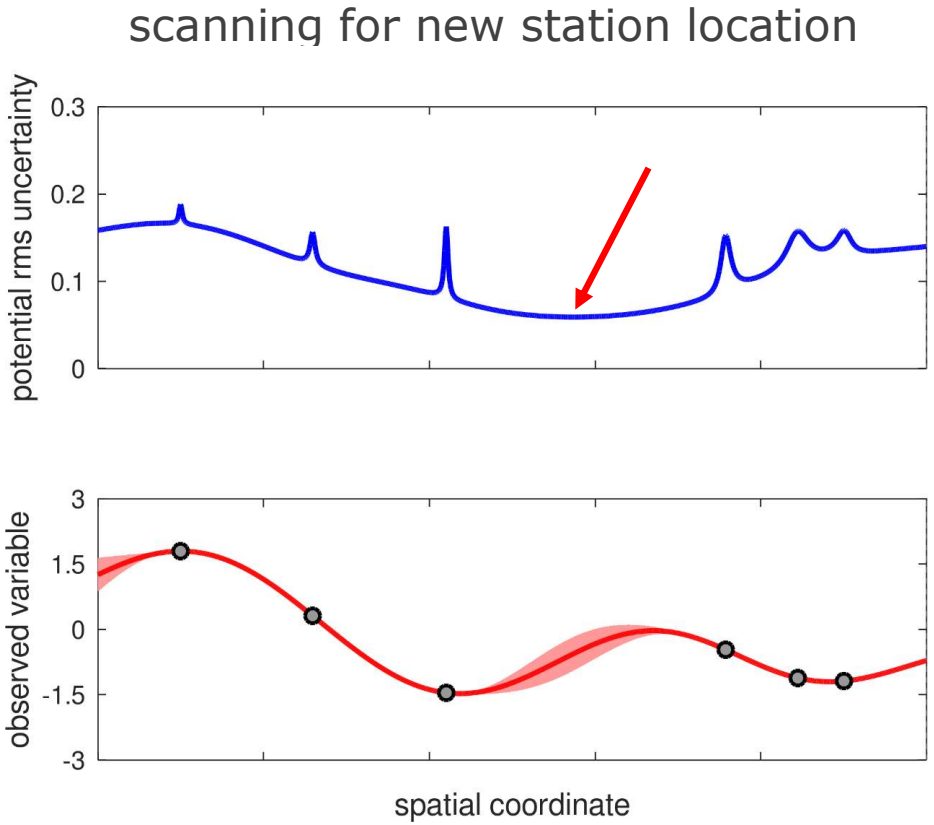
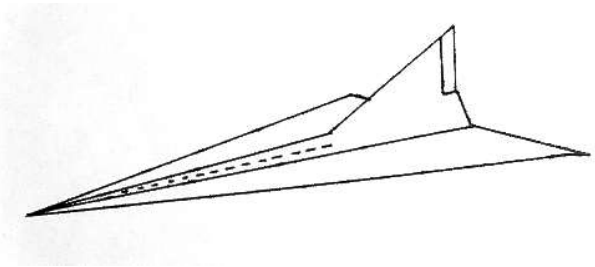
Explicit multi-fidelity adaptive sampling



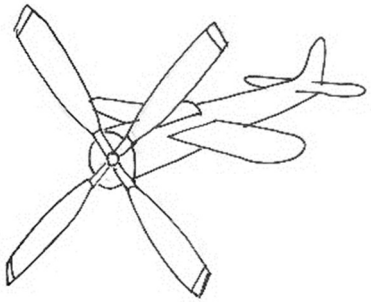


Adding stations

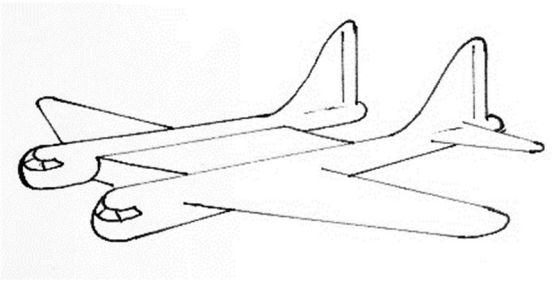
Don’t optimize for single objective!



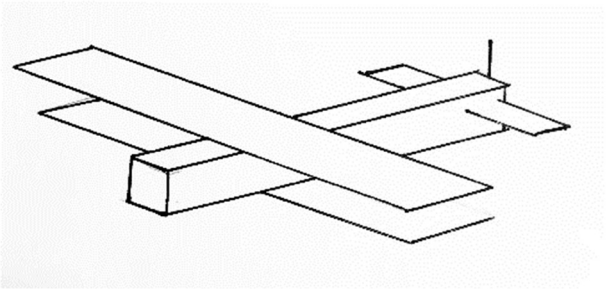
aerodynamics team



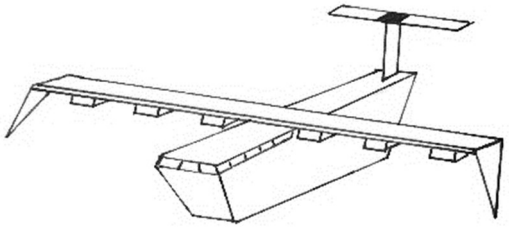
propulsion team



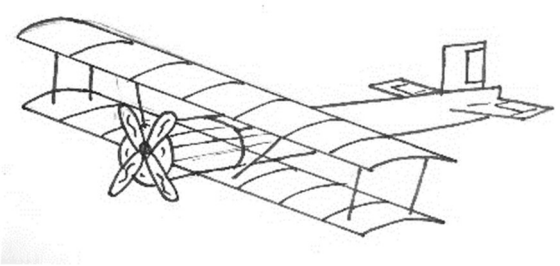
fuselage team



assembly team



cargo team

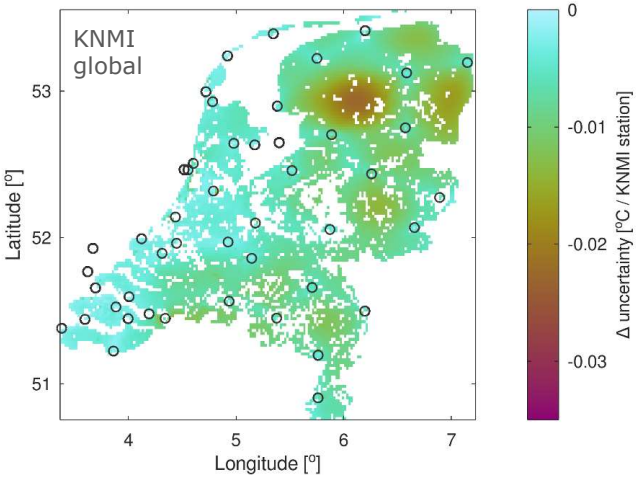


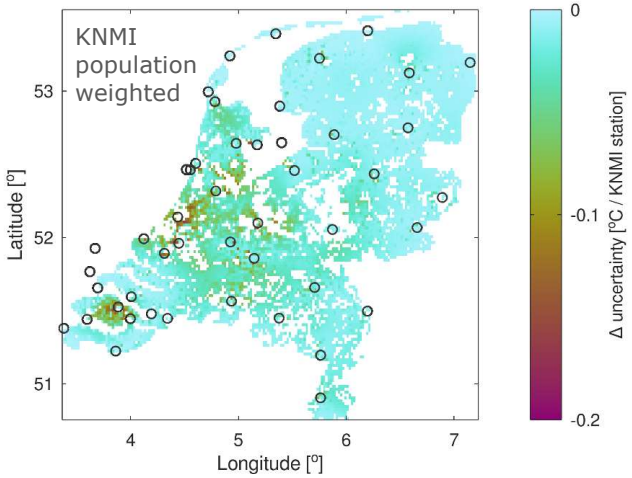
weight team

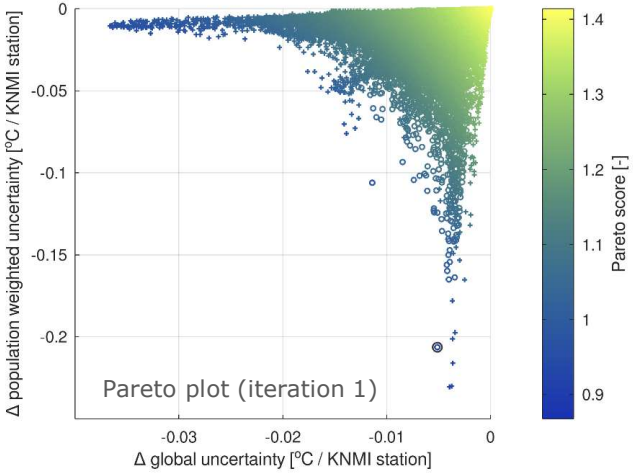
Drawings: Adriaan van Dijk

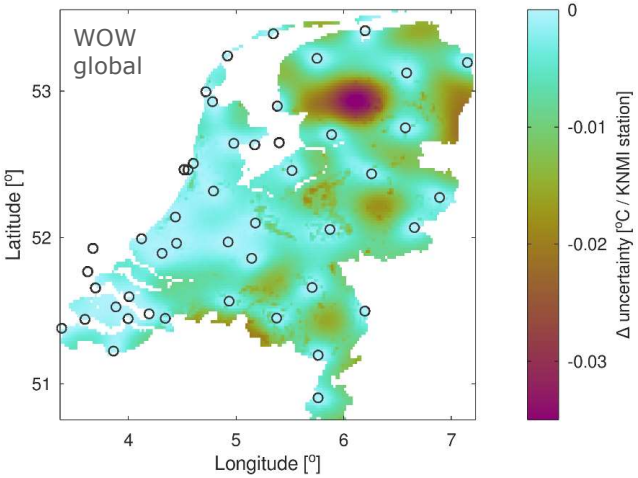
Results: Iteration 1

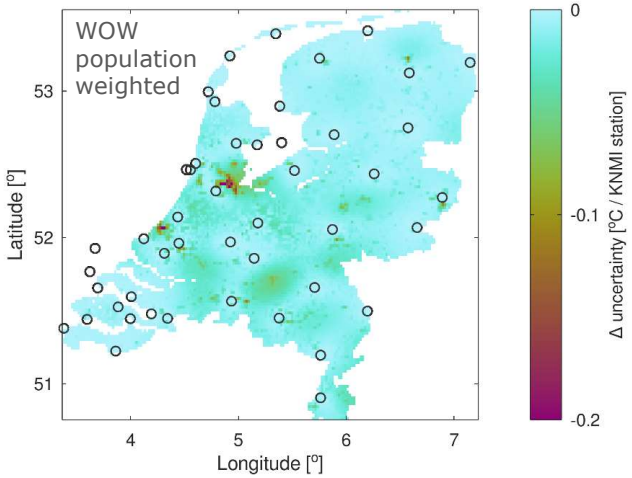
Explicit multi-fidelity adaptive sampling









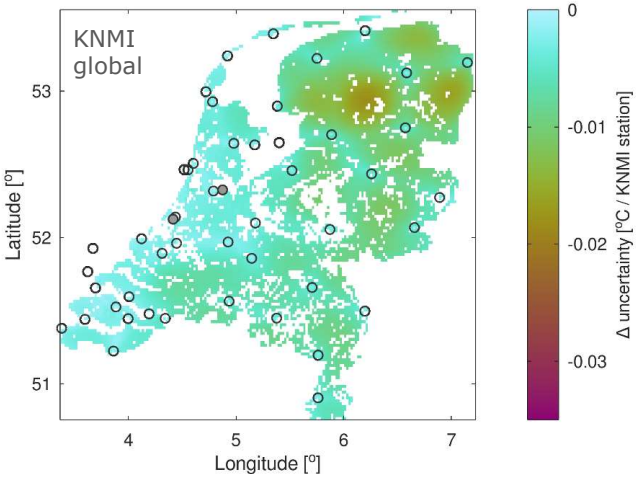


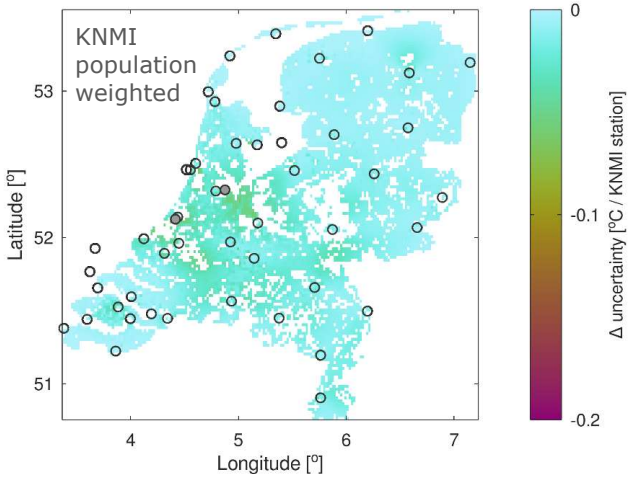
Need to make assumption about cost of WOW station

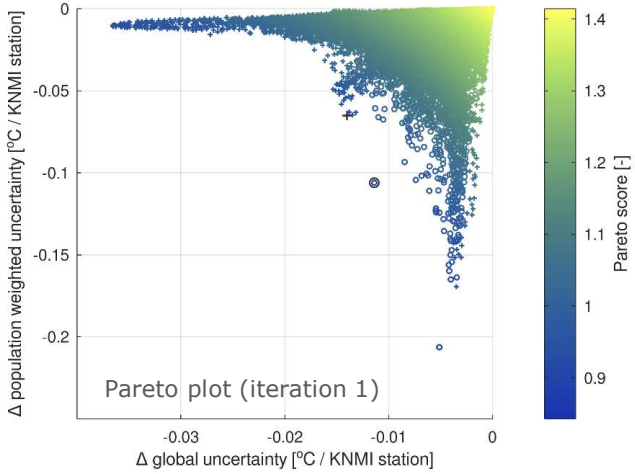
Assumption:
WOW cost = 5 % KNMI cost

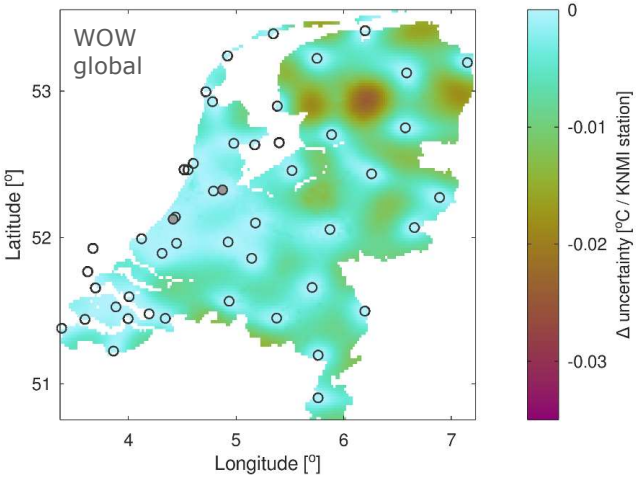
Results: Iteration 12

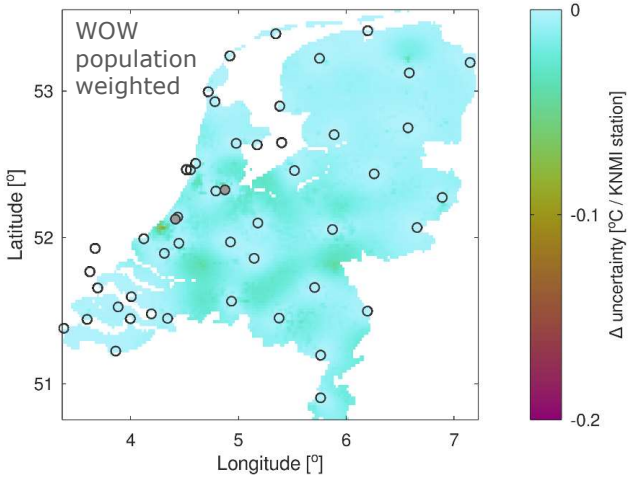
Explicit multi-fidelity adaptive sampling

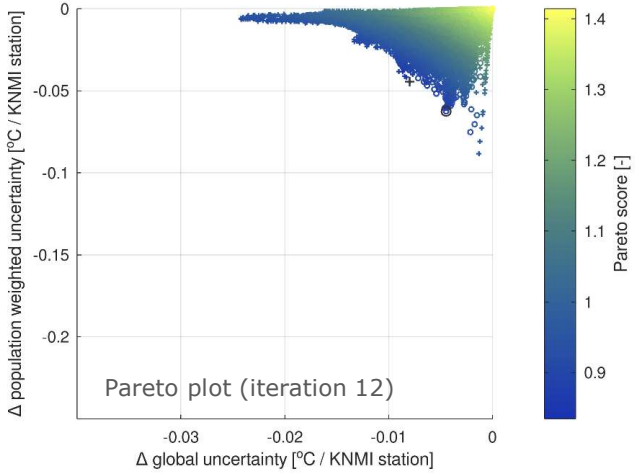




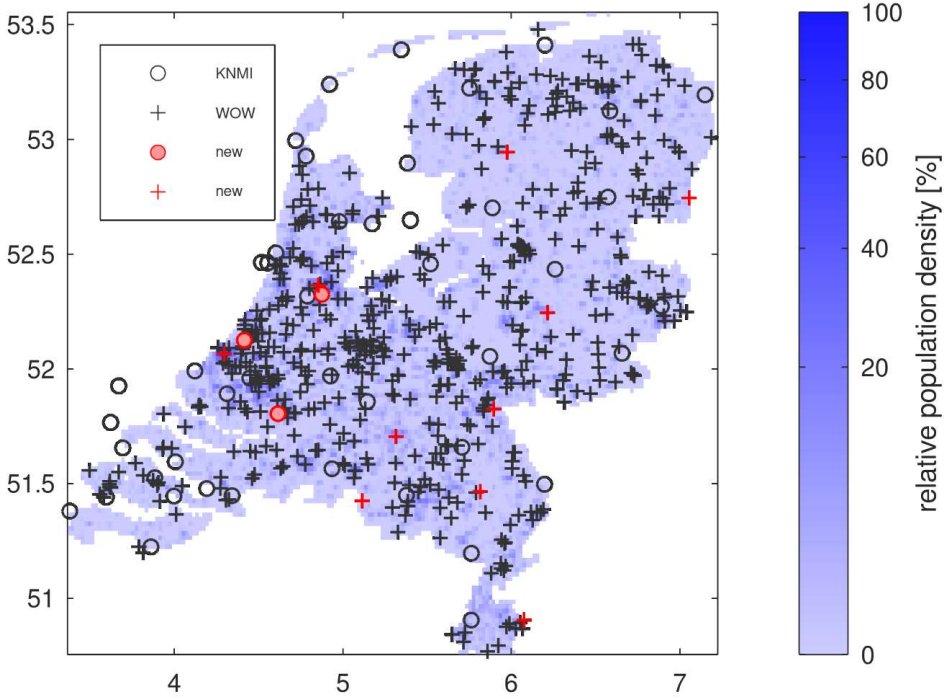




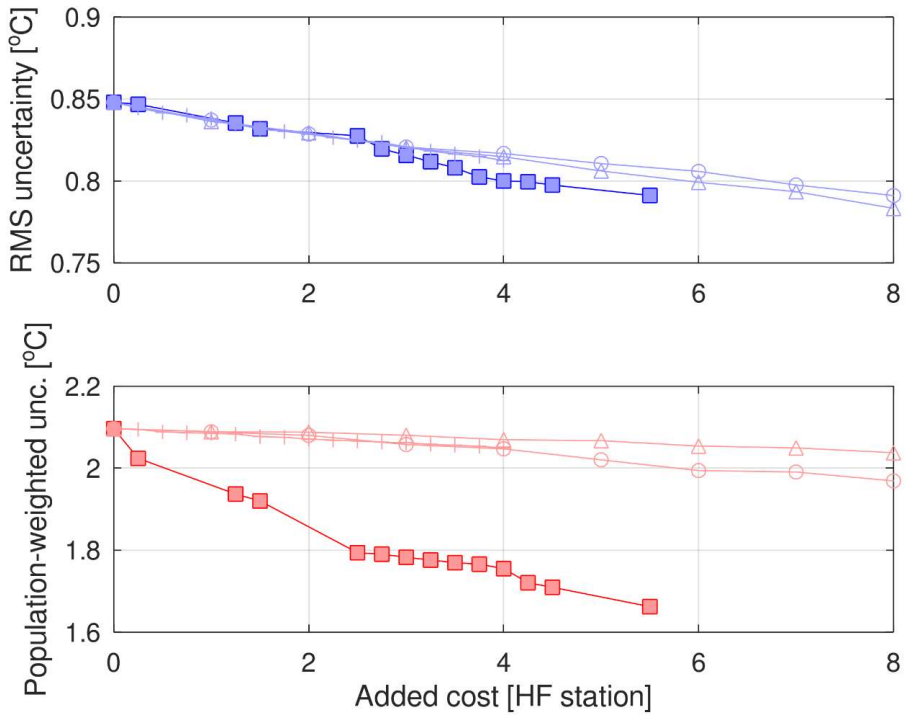




Adding stations



Explicit multi-fidelity adaptive sampling



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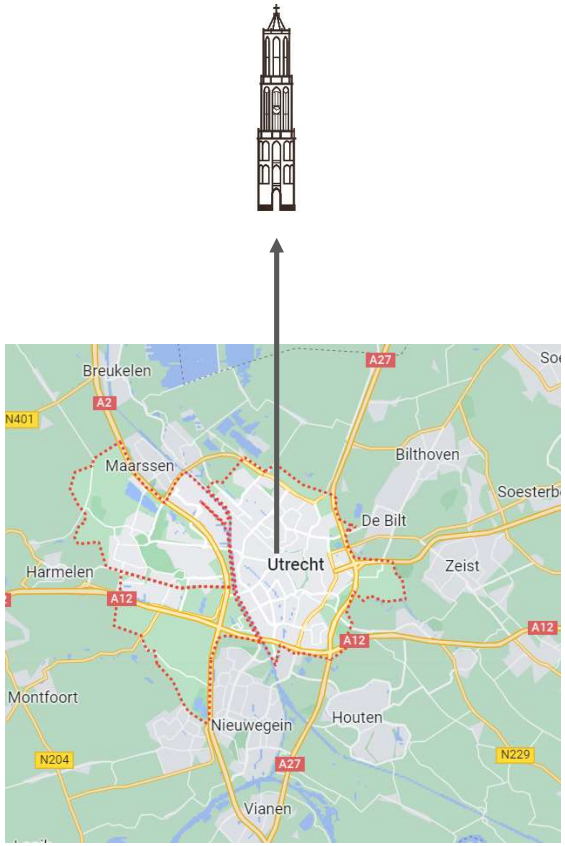
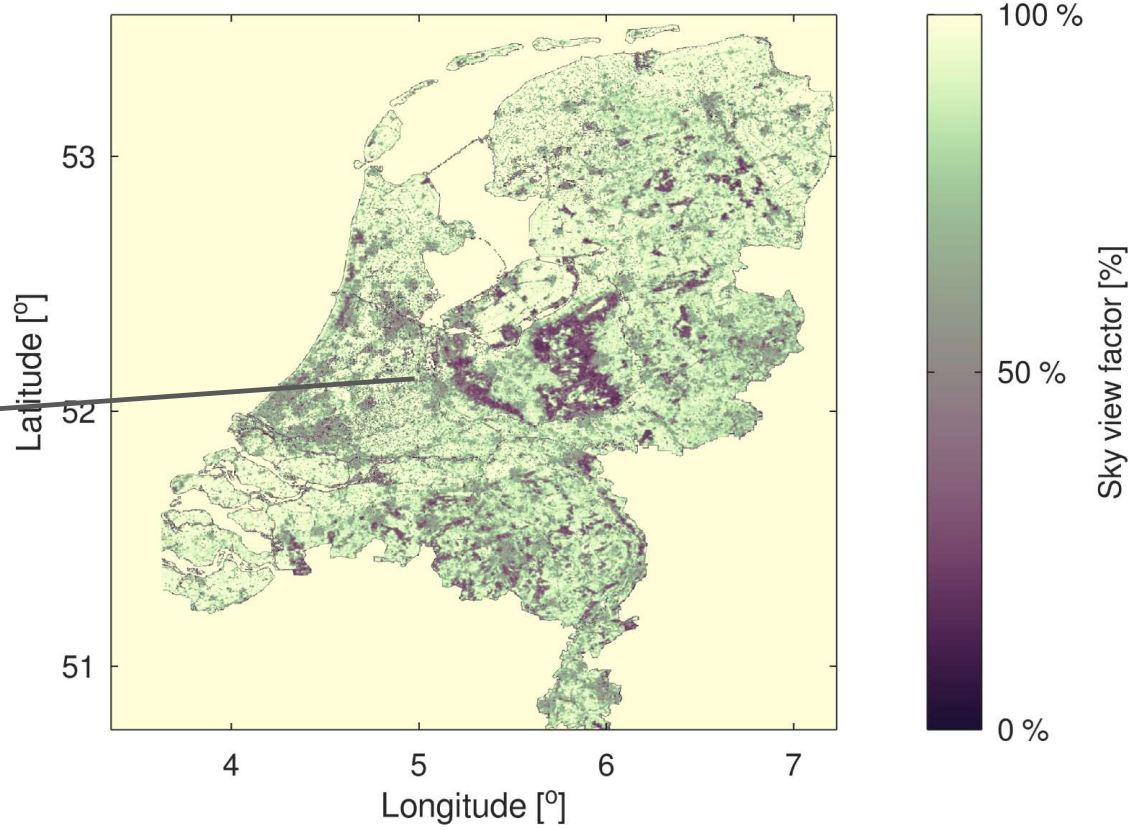
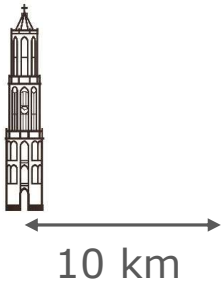
Adding stations: Utrecht city area

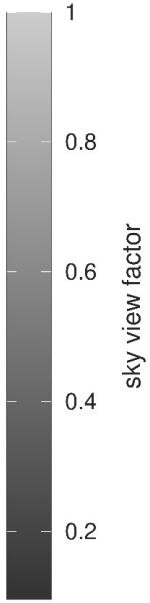
Currently working on this





Adding stations: Utrecht city area





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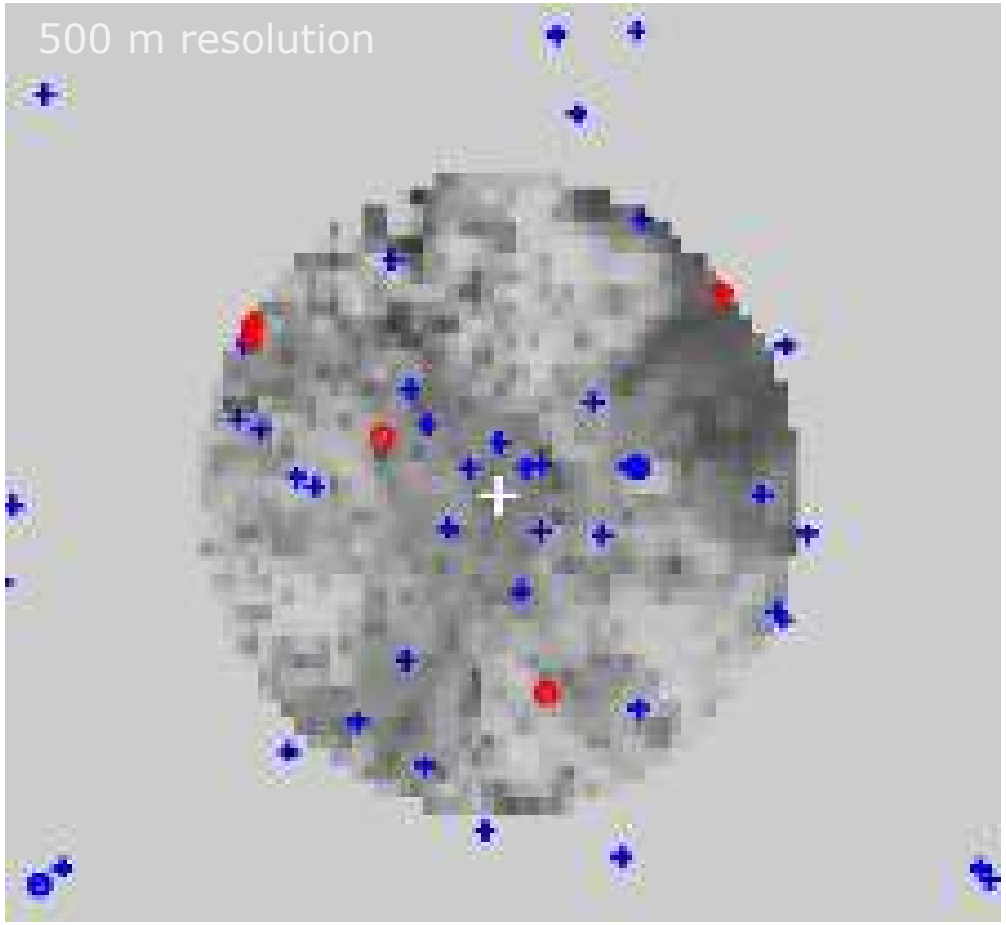

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Conclusions

Developed and implemented a method for **multi-fidelity adaptive sampling**

However, before it can be used in real life, we first need to learn more about the approach and reliability of uncertainty of weather maps!

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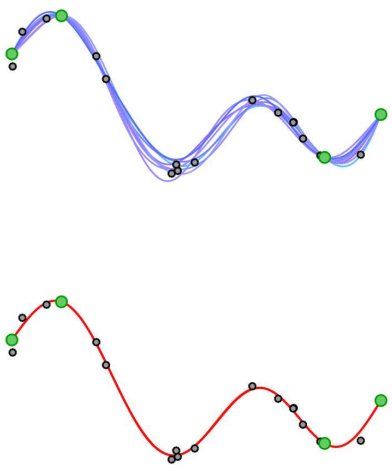
Thank you very much for your kind attention

Jouke de Baar & Gerard van der Schrier (KNMI)

Budapest, 11 May 2023 (online)

Question & answer slide

Equations



regression with noise treatment

Prior $$p(\boldsymbol{X}) = \mathcal{N}(Q\hat{\boldsymbol{\beta}}_Q, P)$$

Likelihood $$p(\boldsymbol{Y}|\boldsymbol{x}) = \mathcal{N}(H\boldsymbol{x} + B\boldsymbol{\beta}_B, R)$$

$$\sqrt{R} = N\hat{\boldsymbol{\beta}}_N I_{n\times n}$$

Posterior $$p(\boldsymbol{X}|\boldsymbol{y}) = \mathcal{N}(\hat{\boldsymbol{x}}, \hat{C})$$

Source: De Baar, Garcia-Marti, Van der Schrier, EMS2022-53 / Proceedings asr-2023-5

Question & answer slide

Equations

Standard GPR

$$E[f(x)] = m(x) + k(x,\mathbf{x'},\theta)\, K(\mathbf{x'},\mathbf{x'},\theta)^{-1} \{ \mathbf{y} - \mathbf{m}(\mathbf{x'}) \},$$

$$var[f(x)] = k(x,x,\theta) - k(x,\mathbf{x'},\theta)^{T}\, K(\mathbf{x'},\mathbf{x'},\theta)^{-1}\, k(x,\mathbf{x'},\theta),$$

With external drift

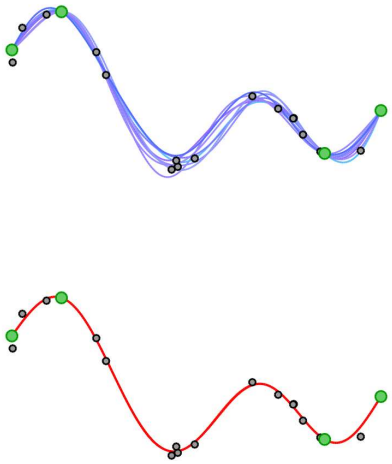
$$E[f(x)] = M(x)\,\boldsymbol{\beta} + k(x,\mathbf{x'},\theta)\, K(\mathbf{x'},\mathbf{x'},\theta)^{-1} \{ \mathbf{y} - \mathbf{M}(\mathbf{x'})\,\boldsymbol{\beta} \},$$

$$var[f(x)] = k(x,x,\theta) - k(x,\mathbf{x'},\theta)^{T}\, K(\mathbf{x'},\mathbf{x'},\theta)^{-1}\, k(x,\mathbf{x'},\theta) + C_M(x,x,\theta,\boldsymbol{\beta}),$$

With bias and noise

$$E[f(x)] = M(x)\,\boldsymbol{\beta} + k(x,\mathbf{x'},\theta) \{ K(\mathbf{x'},\mathbf{x'},\theta) + R(\mathbf{x'},\mathbf{x'},\boldsymbol{\varepsilon}) \}^{-1} \{ \mathbf{y} - \mathbf{M}(\mathbf{x'})\,\boldsymbol{\beta} \},$$

$$var[f(x)] = k(x,x,\theta) - k(x,\mathbf{x'},\theta)^{T} \{ K(\mathbf{x'},\mathbf{x'},\theta) + R(\mathbf{x'},\mathbf{x'},\boldsymbol{\varepsilon}) \}^{-1}\, k(x,\mathbf{x'},\theta) + C_M(x,x,\theta,\boldsymbol{\beta}).$$



regression with noise treatment

Source: De Baar, Garcia-Marti, NATO STO-MP-AVT, 2022, Varna