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Sensitivity analyses and validation of an ENVI-met microclimate model for a greened urban study area in Cologne Südstadt under various typical weather conditions

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Motivation:

- The increasing frequency and severity of **extreme weather events** such as heat, drought or flooding is a major problem in cities and a key challenge for **urban planning.**
- **Adaptation strategies** to mitigate climate change are needed on different scales from national to local and require contributions by all parts of the society.
- To facilitate **citizen participation**, model based scenario analyses are needed.
- Measures must be based on sound scientific analyses, addressing the potentials and limits of both existing urban structures and new development.

Research Goals:

- Assessment of different **adaptation strategies** to mitigate urban heat in the small scale (16 ha) urban study area Cologne Südstadt characterized by dense development in the east as well as an urban park area in the western part using the physically-based 3D ENVI-met model. Particularly:

(1) Model assessment by **sensitivity analyses** with regard to the effects of different meteorological forcing data and **different continuous wind directions**.
(2) Model **validation** based on reference data of a densely distributed weather sensor network.

Methodological Approaches:

ENVI-met model setup: 3D model domain based on …

- Building data and urban-structural/cadastral data
- Topography, soil types and profiles, dust sources
- Ecological data: green infrastructures, greenings
- **Meteorological forcing data** for lateral boundary conditions from Campbell weather station in study area

Fig. 1: ENVI-met model domain for Cologne Südstadt

Model validation:

- Microclimatological measurements are carried out using a dense network of 33 low-cost **NETATMO weather sensors** providing 5 min. measurements of temperature, relative humidity, wind speed and wind direction within the study area (*Eingrüber et al. 2022*)
- NETATMO sensors were checked for long-term stability and consistency in the field and **under laboratory conditions.**
- Every few month, sensors are **re-calibrated** and rotated.

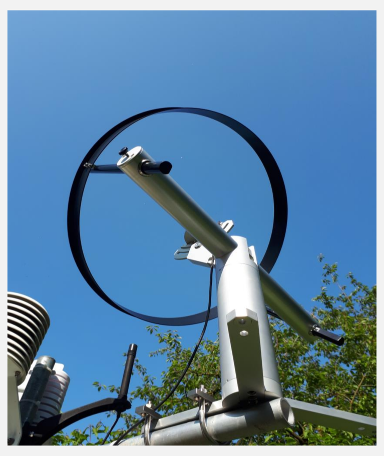
⇒ **Two-point calibration** with high accuracy reference sensor: RMSE = 0.083°C and 1.42 % relative humidity

- ENVI-met model outputs is evaluated with **statistical goodness-of-fit indicators** based upon this sensor network.

Fig. 2: A NETATMO sensor in the study area

Sensitivity Analyses:

- Comparison of model output when using i) **measured radiation** (incoming direct and diffuse shortwave radiation and incoming longwave irradiance), and ii) measurements of the **relative cloud cover** of low-level, medium-level and high-level clouds as radiative forcing.
- Radiation is measured with a **diffusometer** consisting of two pyranometers with and without a shadow ring and a **pyrgeometer** installed at our meteorological station in the urban park. The diffuse radiation is corrected by a correction factor according to DELTA OHM. The direct radiation is calculated from the global radiation minus the corrected diffuse radiation.
- Relative cloud cover for three cloud levels is derived from a close-by installed **ceilometer**.
- Comparison of the output data of model simulations for 4 different wind directions **(N, E, S, W)** when all other forcing data are kept in relation to the reference run with measured forcing data.



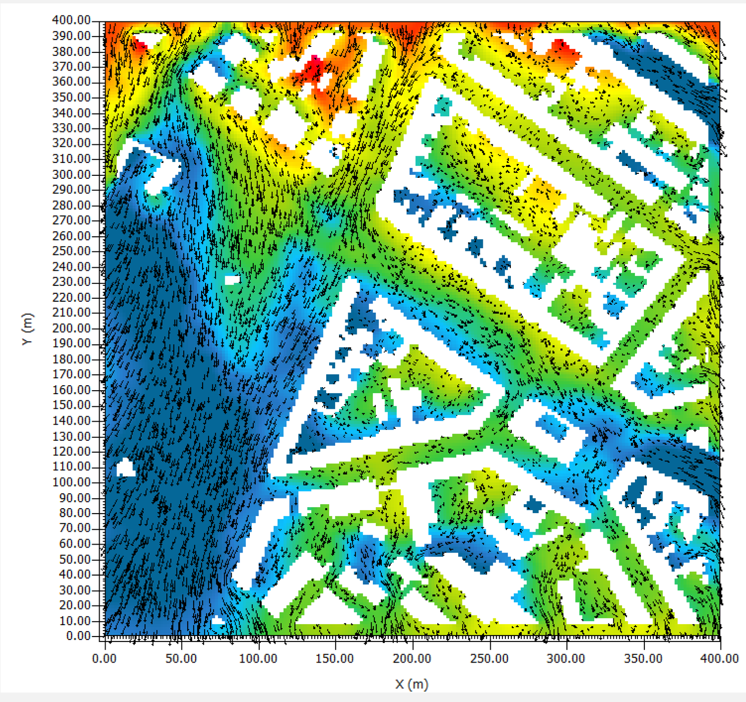
Left: Fig. 3: Diffusometer in the urban park based on two pyranometers and a shadow ring (DELTA OHM).

Top: Fig. 4: 4-component measurement system in the urban park with 2 pyrano-/pyrgeometers (KIPP & ZONEN).

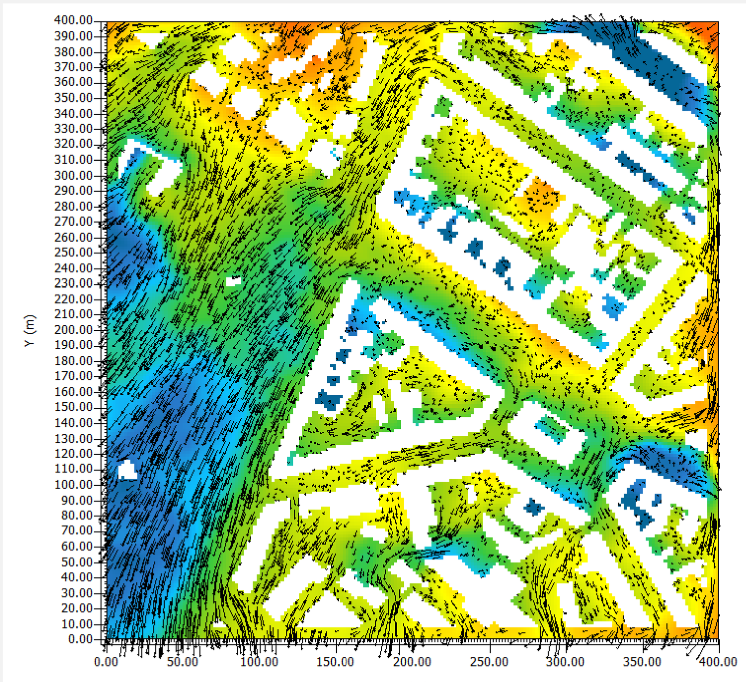
Right: Fig. 5: Ceilometer by VAISALA.

Results: for an example day in summer 2022 with low-exchange high-pressure weather conditions

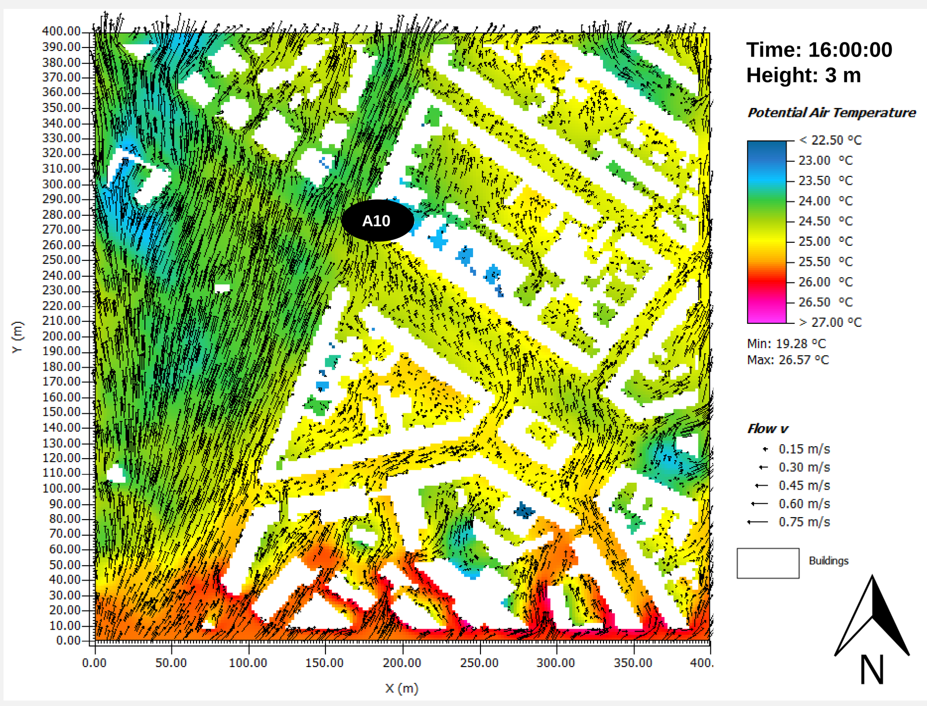
North Wind, Forcing by Radiation Data



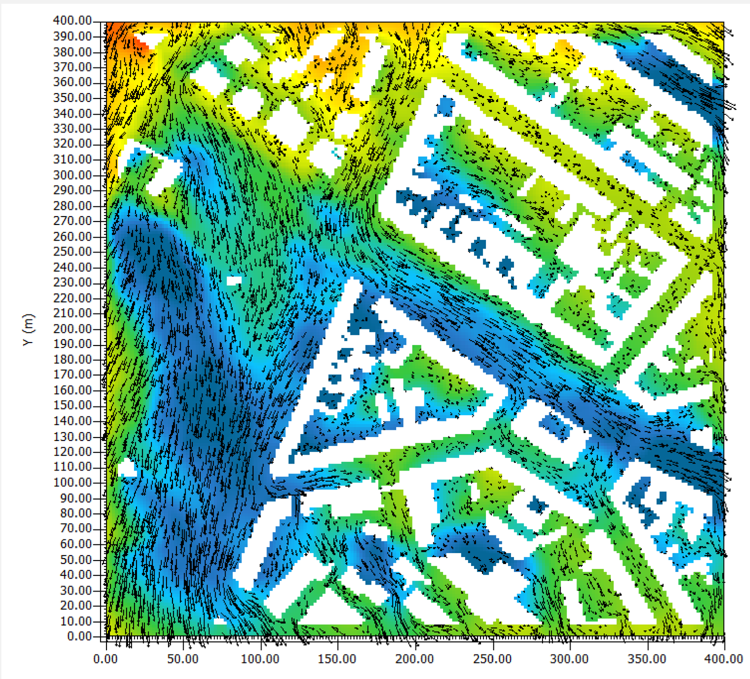
East Wind, Forcing by Radiation Data



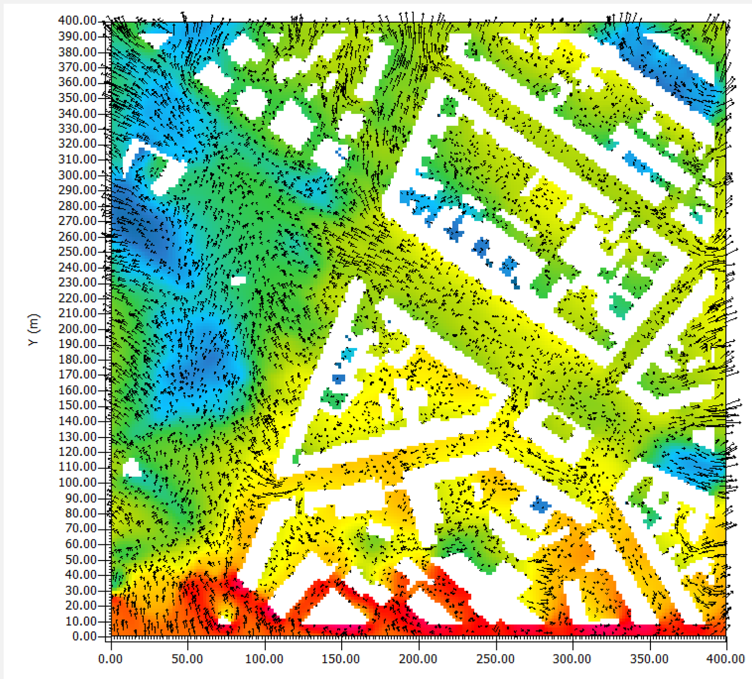
Measured Wind (SW), Forcing by Radiation Data



West Wind, Forcing by Radiation Data



South Wind, Forcing by Radiation Data



Measured Wind, Forcing by Clouds

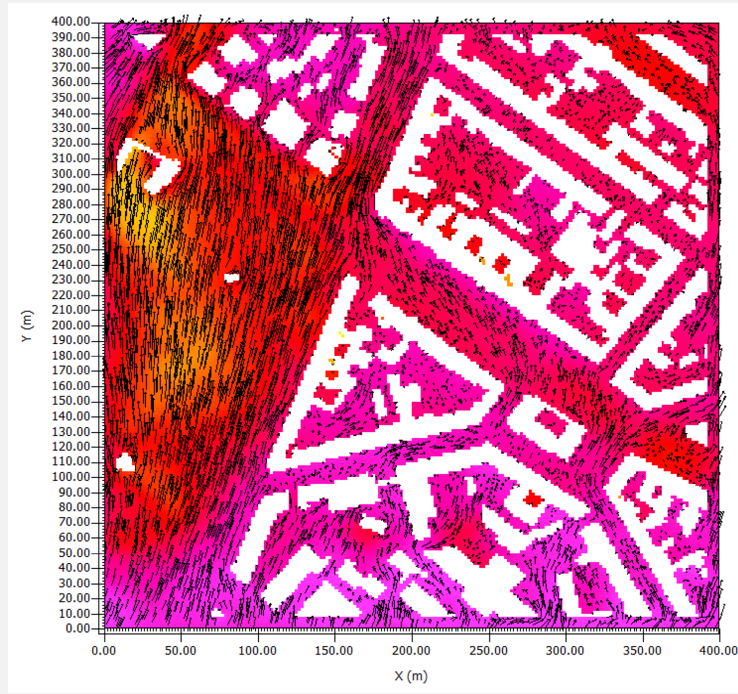
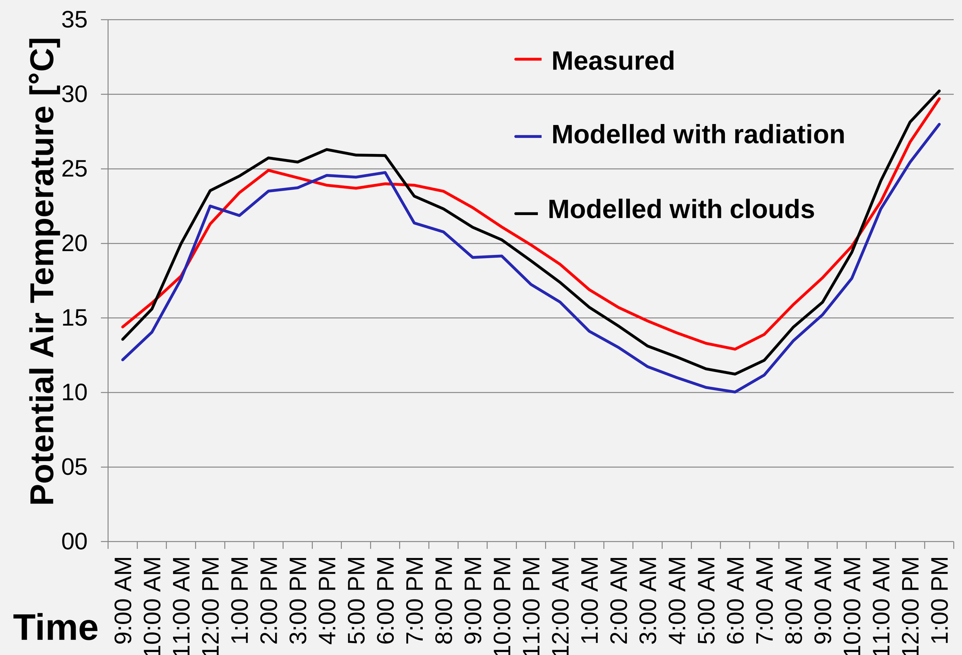


Fig. 6 (a) – 6 (f): Simulated potential air temperatures and wind vectors in a pedestrian height level of 3 meters at 4 pm.

Fig. 7: Comparison of measured and modelled air temperatures at the sensor site A10:



Tab. 1 (a) + 1 (b): Model Validation: Goodness-of-fit indicators and absolute differences of descriptive statistical parameters between ENVI-met modelled temperatures (forcing by radiation or clouds) and measured NETATMO data of the sensor A10 for the test period:

Index	Radiation	Clouds
MAE [°C]	1.99	1.35
RMSE [°C]	2.18	1.46
R^2	0.96*	0.96*
NSE	0.83	0.93
Willmott (d)	0.95	0.98

* = significant (p < 0.05)

Abs.Difference	Radiation	Clouds
Average [°C]	1.76	0.17
Stan. Dev. [°C]	0.79	1.07
Maximum [°C]	1.71	0.52
Minimum [°C]	2.87	1.67
Amplitude [°C]	1.15	2.19

Tab. 2: Modelled and measured potential air temperatures [°C] for the grid cell of the NETATMO sensor A10 at 4 PM and 1 day means:

Radiation driver:	from cloud cover	measured radiation	measured radiation	measured radiation	measured radiation	measured radiation	NETATMO data
Wind direction:	Measured (SW)	Measured (SW)	North	East	South	West	from sensor A10
Temp. at A10 at 4:00 PM [°C]	24.56	26.30	24.33	24.62	24.59	24.13	23.90
1 day mean temperature [°C]	19.85*	18.24	16.57*	16.88*	17.13*	14.93*	19.90*

* = significant difference to measured (SW) wind direction and forcing by radiation measurements (p < 0.05)

Conclusions and Discussion:

- Daily cycles and magnitudes of air temperature are well represented by the uncalibrated ENVI-met model.
- **Cooling effects** of green infrastructures like the urban park or the street trees in the avenue can be identified.

(1) The **sensitivity analyses** showed that **significant differences** in the potential air temperature can be identified at the sensor site for the simulations with forcing by radiation or cloud cover, and with forcing by the constant **wind directions** N, E, S, W in relation to measured direction (SW).
(2) The **model validation** showed a better model fit **(NSE = 0.93)** to the measurements for forcing by cloud cover. Forcing by radiation data significantly underestimates the measurements.

⇒ Differences could occur due to partial diffusometer shadowing.

Further Materials and References:

- **Eingrüber, N., Korres, W., and Schneider, K.: Microclimatic field measurements to support microclimatological modelling with ENVI-met for an urban study area in Cologne, Adv. Sci. Res., 19, 81–90, https://doi.org/10.5194/asr-19-81-2022, 2022.**
- **Eingrüber, N., Korres, W., and Schneider, K.: Pathways for climate change adaptation in urban areas - first results from field measurements and ENVI-met modeling, EMS Annual Meeting 2021, online, 6–10 Sep 2021, EMS2021-374, https://doi.org/10.5194/ems2021-374, 2021.**
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Outlook:

- Further research will use this validated ENVI-met model to simulate and analyse the effects and potentials of various hypothetical climate change adaptation measures in urban areas (e. g. by facade/roof greenings, green infrastructures, light surfaces, shadow effects, urban water bodies, …) taking into account climate change projections until 2099 of GCMs.
- Comparison of different scenarios in order to mitigate future heat stress in cities and improve the urban microclimate and thermal outdoor comfort.

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