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Incorporation of wheat canopy temperatures into agroecosystem models by using a meta-model

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Background & Objective

- Heat stress can significantly affect crop development and yield.
- Established agroecosystem models operating in daily time steps often use air temperature (T_{air}) based approaches to estimate the impact of heat stress.
- Nevertheless mean and maximum canopy temperatures ($T_{c,mean}$, $T_{c,max}$) are potentially more suitable than T_{air} to quantify temperature effects on yield.
- Diurnal cycles of T_{air} and canopy temperature (T_c) differ depending on meteorological conditions and soil water status.
- Therefore T_c cannot be directly derived from meteorological data and information related to soil water status is needed from dynamic models.
- We suggest a simple empirical model based on multiple linear regressions using available daily meteorological variables & output data from models operated at a daily time step to consider canopy-air temperature differences (ΔT_{mean}, ΔT_{max}) in these models.

Material & Methods

Data

- Rainout shelter experiments with wheat (*Triticum aestivum* cv. Dekan; 200 kg N/ha) conducted in Northern Germany (2010 & 2011; 3 irrigation levels: 0, 80 and 100 % of plant available soil water, PASW).

Multiple linear regression model

$$T_{c,mean} = 2.87 + 0.89T_{air} + 0.02E_{AV} - 7.17\frac{E_{act}}{ET_{pot}} - 0.37u - 0.04e_s \quad \text{adj.r}^2 = 0.96$$

$$T_{c,max} = 4.34 + 0.88T_{air} + 0.02E_{AV} - 9.96\frac{E_{act}}{ET_{pot}} - 0.52u - 0.14e_s \quad \text{adj.r}^2 = 0.94$$

$$\Delta T_{mean} = 1.86 - 0.08T_{air} + 0.01E_{AV} - 2.63\frac{ET_{act}}{ET_{pot}} + 0.12u - 0.32e_s \quad \text{adj.r}^2 = 0.77$$

$$\Delta T_{max} = 2.39 - 0.06T_{air} + 0.01E_{AV} - 2.51\frac{ET_{act}}{ET_{pot}} + 0.06u - 0.28e_s \quad \text{adj.r}^2 = 0.74$$

E_{AV}: leaf area specific available energy for sensible heat fluxes ($E_{AV} = \{R_{tot} - ET_{act}\} / \ln(LAI)$; R_{tot}: total radiation; LAI: leaf area index); E_{act}: actual evaporation; u: wind speed; e_s: saturation deficit; ET_{act}: actual evapotranspiration; ET_{pot}: potential evapotranspiration

Model Inputs

- Daily means of meteorological data between stem elongation and dough development.
- Means of canopy temperatures between sunrise+3h and sunset-3h.
- Simulated ET_{act}, ET_{pot}, E_{act}.
- The variance inflation factor (VIF) < 3 was used as benchmark to assess existing multi-collinearity of meteorological data.

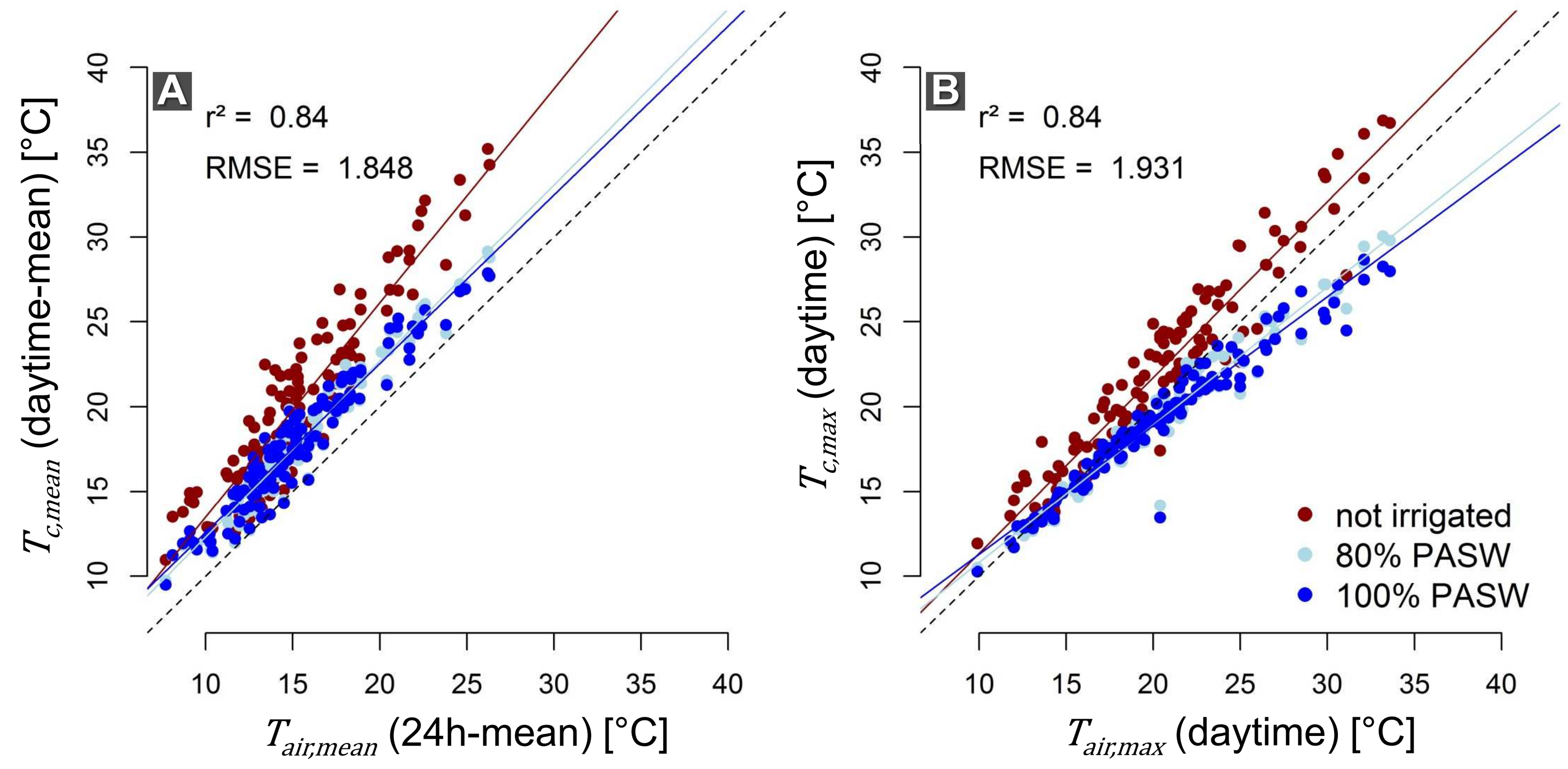

Fig. 1: Linear regression between measured $T_{air,mean}$(24h-mean) and $T_{c,mean}$(daytime) (A) and between measured $T_{air,max}$ and $T_{c,max}$ (B) in 2010 and 2011 (statistics of the overall regression fit are shown; colored solid lines indicate linear model fits for the different irrigation treatments; dashed black line: line of identity)

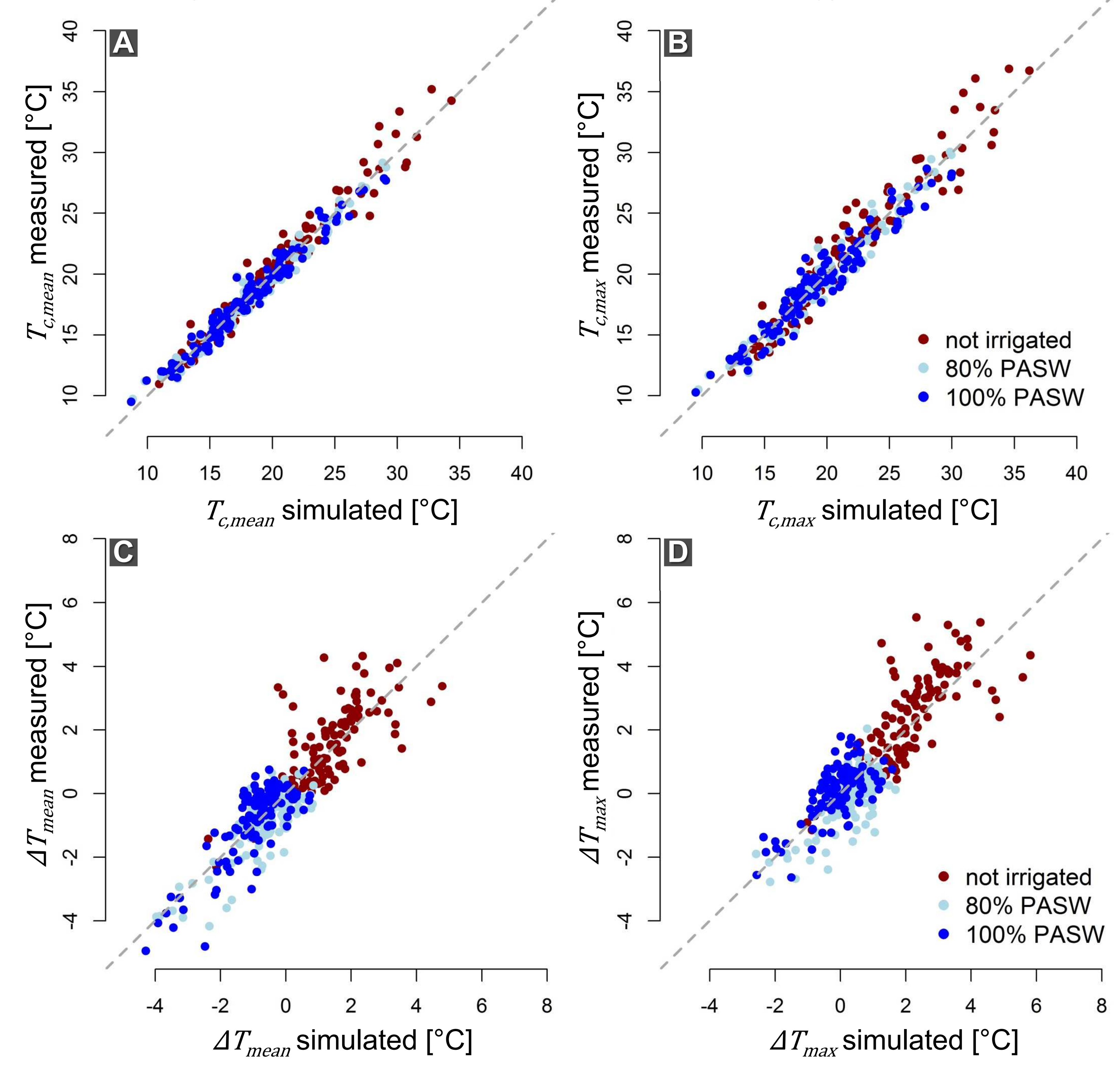

Fig. 2: Scatterplots between simulated and measured $T_{c,mean}$(A), $T_{c,max}$(B), ΔT_{mean}(C) and ΔT_{max}(D) for the years 2010 and 2011 (dashed gray line: line of identity)

Preliminary Results

- T_c differs from T_{air} with systematic deviation due to water status (Fig.1).
- Goodness of fit of the multiple linear regression model:
  - Realistic canopy temperatures with an RMSE of < 1°C for $T_{c,mean}$ and ~1 – 1.4°C for $T_{c,max}$ (Fig. 2 A, B).
  - Realistic canopy-air temperature differences (ΔT_{mean}, ΔT_{max}) with an RMSE of ~0.8 °C which can be used as an indicator for crop response to water stress (Fig. 2 C, D).

Discussion and Outlook

- Observed high canopy temperatures could have a strong impact on wheat productivity and models should strive to predict them accurately especially if critical temperature thresholds are used.
- This regression model is a first step to develop the aspired meta-model.
- In order to obtain a more universal algorithm longer time series data and non-linear responses of canopy temperatures to environmental conditions need to be included.

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