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Biospheric Theory and Modelling

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Imprints of Evaporation and Vegetation type in Diurnal Temperature Variations

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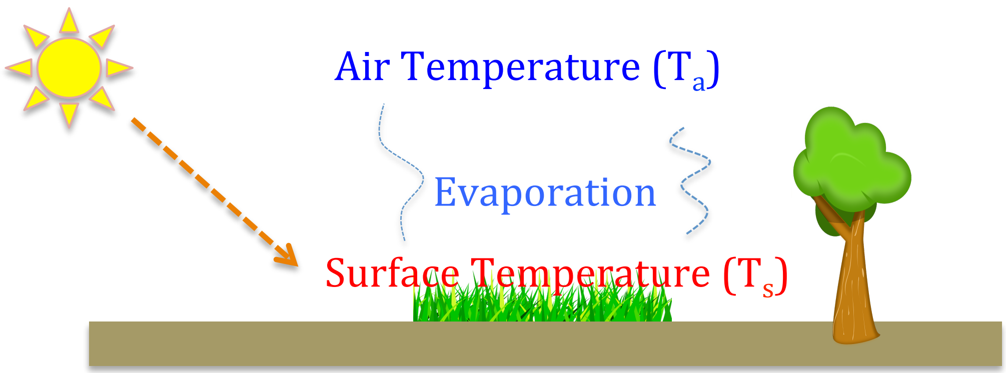
Introduction

- Diurnal variation of temperature mainly depends on solar radiation, evaporation(partitioning of turbulent heat flux) and vegetation types.



- Evaporation cools. We hypothesize that evaporative cooling dampens the diurnal warming of temperatures.

- Also, the high aerodynamic conductance of taller vegetation cools the surface by conducting heat from the surface to the atmosphere.

- **How the diurnal variation of surface and air temperature respond to changes in evaporative conditions?**

- **And, what is the role of vegetation in altering these responses?**

Warming rate

- Temperature and solar radiation peaks around the same time. Their relationship can be obtained by plotting them against each other.

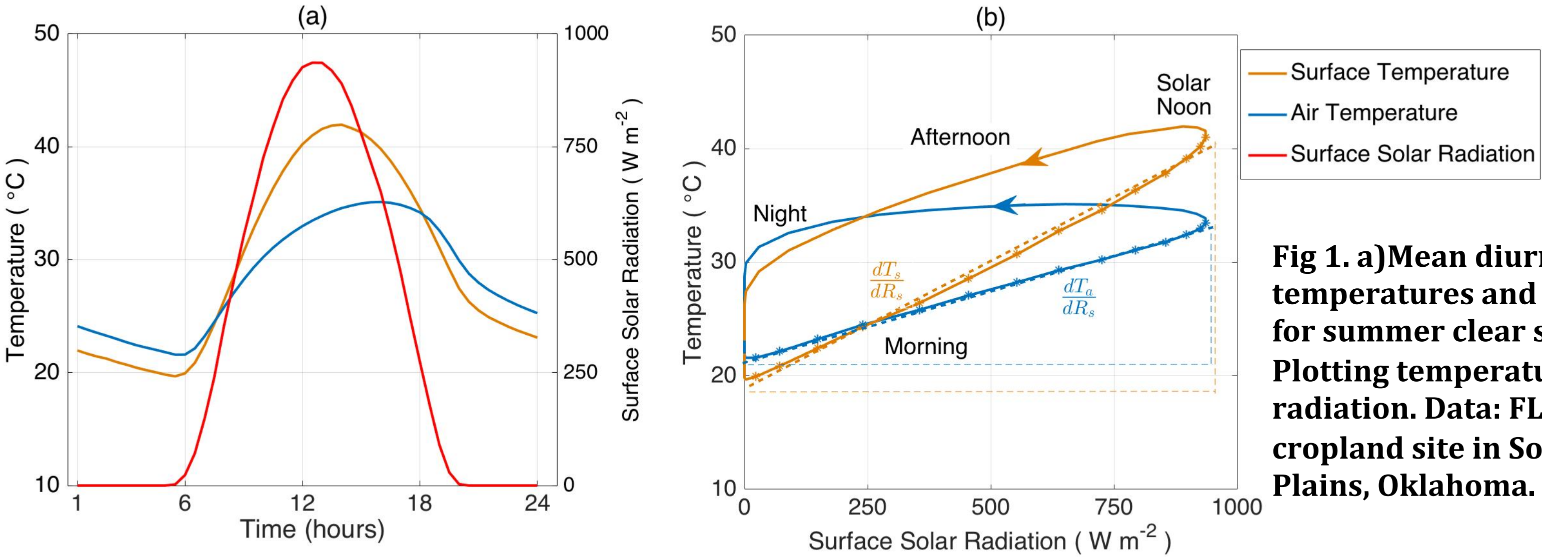


Fig 1. a)Mean diurnal cycle of temperatures and solar radiation for summer clear sky days b) Plotting temperatures against solar radiation. Data: FLUXNET data for a cropland site in Southern Great Plains, Oklahoma.

Warming rate: The increase in temperature with unit change in solar radiation from early morning to noon time. It is expressed in K/W m^{-2}

- Warming rate removes the dominant role of solar radiation on diurnal temperature
- Note that, warming rate is equivalent to the ratio of diurnal temperature range(DTR) and maximum solar radiation($R_{s,max}$)

Panwar et al. (2019) , GRL
https://doi.org/10.1029/2019GL082248

Warming rate and vegetation

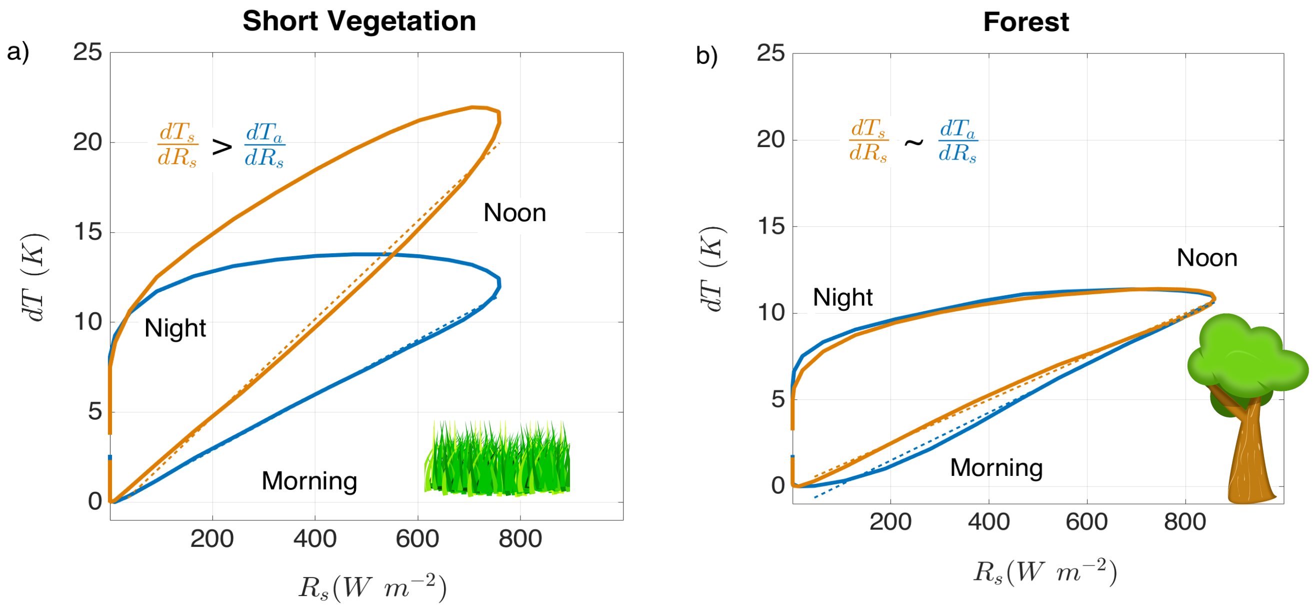


Fig 2. Demonstrating the relationship of surface(T_s) and air(T_a, ~2m) temperature warming rate for clear sky summer months of FLXUNET sites, a) Cropland site in Southern Great Plains, Oklahoma b) Forest site in Canada, Ontario

- The warming rate of surface temperature is stronger than the warming rate of air temperature for surface with short vegetation.
- The warming rates of surface and air temperature are similar for forest indicating their stronger coupling and similar diurnal warming.

> On evaporative days one might expect lower warming rates. Does evaporation dampen the diurnal warming of temperatures? Is this also true for the forests?

- To answer the unknowns, we look at observational data from 51 FLUXNET sites belonging to different vegetation types.

Panwar et al. (HESSD)
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Data

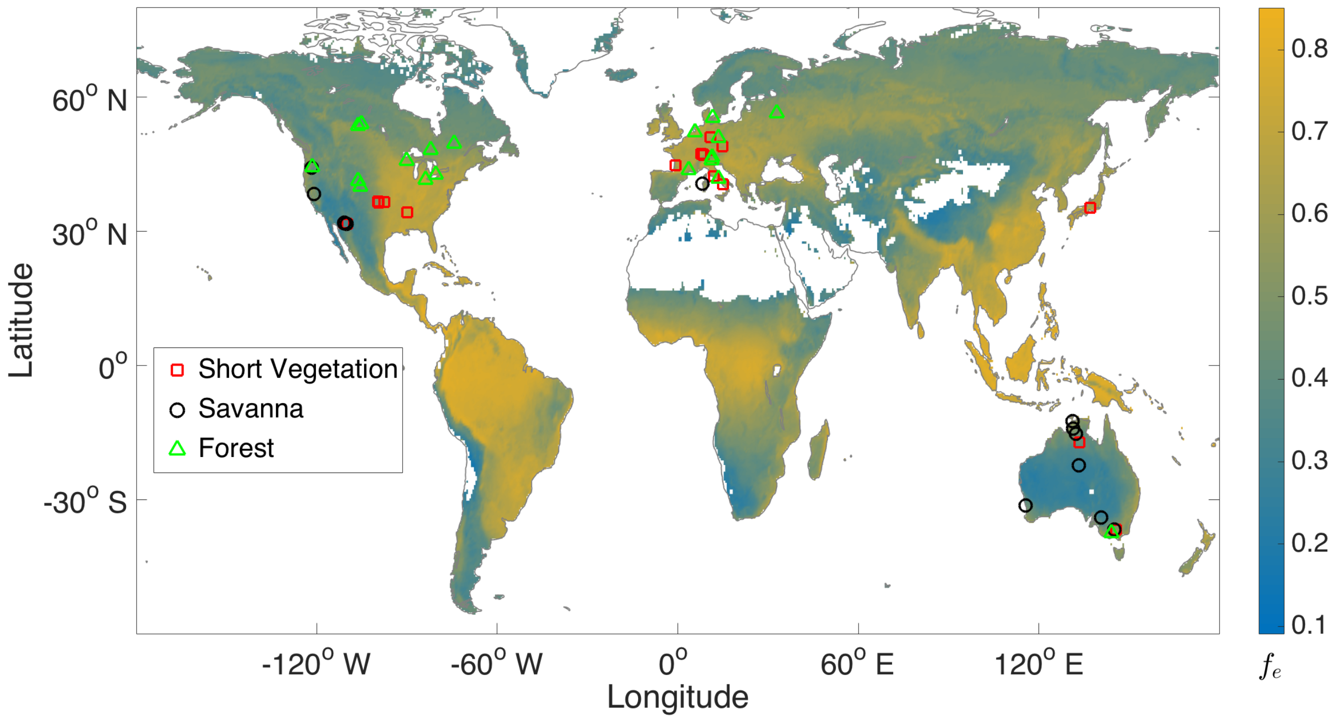

Fig 3. Location of 51 FLUXNET sites chosen for this study. Color bar: Mean summer time evaporative fraction(f_e) obtained from FLUXCOM data

- Only summer clear sky days
- Evaporative condition expressed by term evaporative fraction(f_e)= LE/(LE+H)
- Daily f_e is assumed constant

  Shuttleworth et al. (1989)
- Days are segregated as per their daily evaporative fraction
- Surface temperature is obtained from Stefan Boltzmann law ($R_{l,out} = \sigma T^4$)
- The aerodynamic conductance (g_a) of vegetation is obtained form $g_a = (u_*)^2 / u$

  Verma (1989)

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Warming rate: Surface versus air temperature

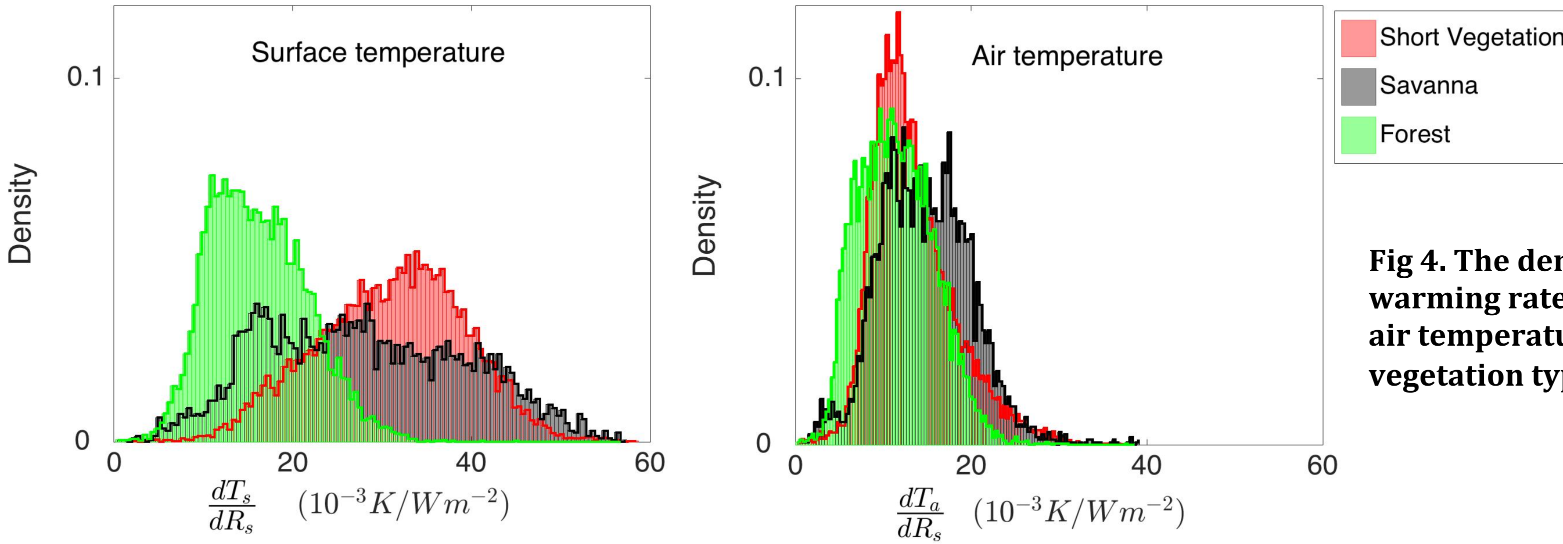

Fig 4. The density plot for the warming rate of surface and air temperature for three vegetation types.

- Surface temperature warming rate of short vegetation is higher(median= 31.4 x 10^{-3} K/W m^{-2}) than that of forest(median= 15.5 x 10^{-3} K/W m^{-2}).
- Savanna is heterogeneous covering a broad range in surface temperature warming rate.
- Surprisingly, unlike surface temperature, air temperature warming rate are found similar for all the vegetation types.

Diurnal variation of surface temperature carries imprints of vegetation types but the diurnal variation of air temperature does not.

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Warming rate response to evaporation

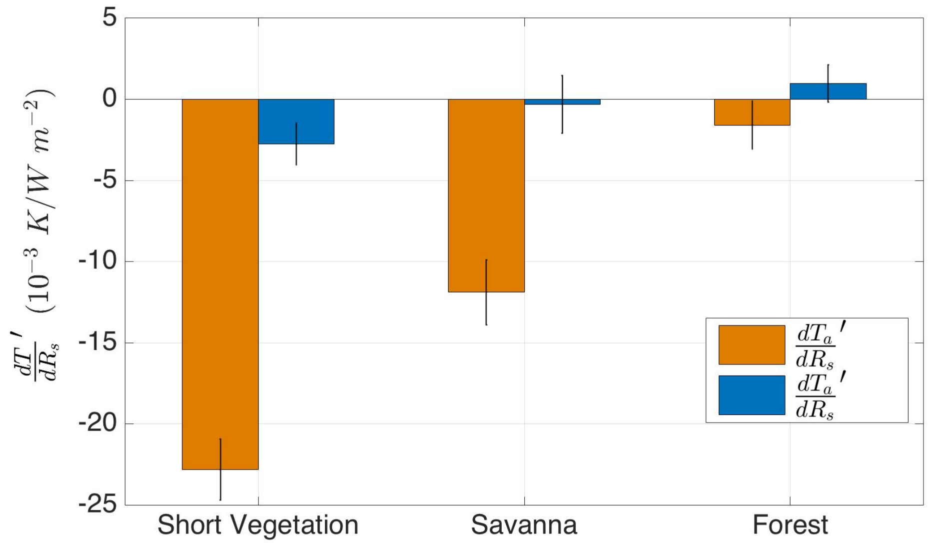

Fig 5. Bar plot of the mean response of surface and air temperature warming rate to changes in evaporative fraction(0 to 1). Error bars represent the standard error of mean.

Evaporative cooling dampens the diurnal warming of surface temperature but only for surface with short vegetation

- Surface temperature warming rate decreases strongly by 23 x 10^{-3} K/W m^{-2} from dry(f_e~0) to wet(f_e~1). The weaker response of air temperature warming rate to evaporation is due to compensating role of boundary layer development, see Panwar et al.(2019)

- Similarly, in savanna surface temperature warming rate decreases by 12 x 10^{-3} K/W m^{-2} but air temperature warming rate remains almost constant.

- In forest, both, surface and air temperature warming rate remains unaffected from any changes in evaporative fraction.

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Aerodynamic conductance and its sensitivity to evaporation

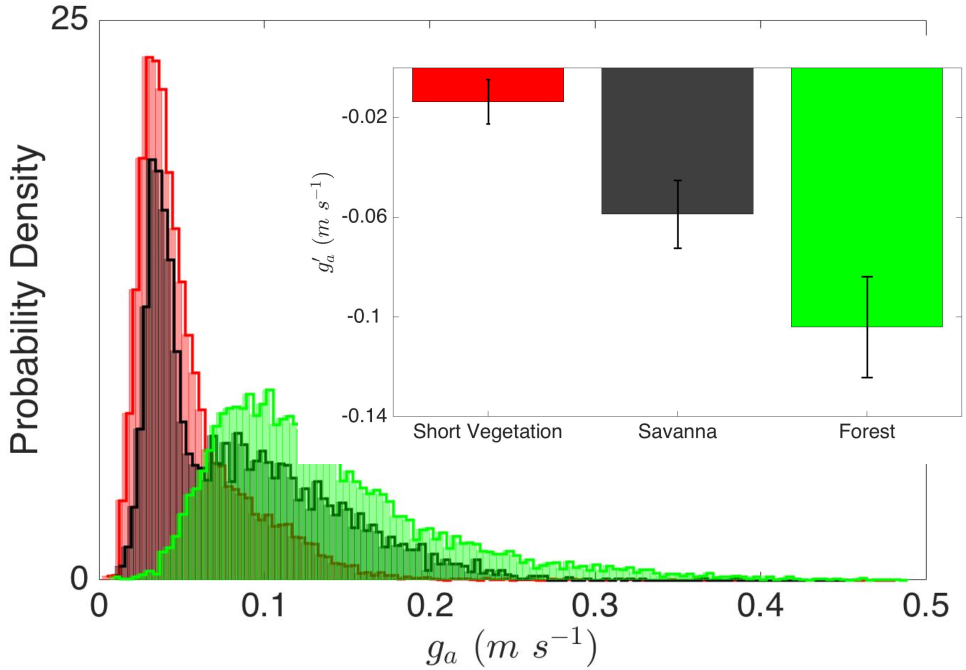

Fig 6. Density distribution of the aerodynamic conductance for three vegetation types. The inset plot shows the mean sensitivity of aerodynamic conductance to evaporative fraction with the error bar representing the standard error of the mean.

- Generally tall vegetation like forests have higher aerodynamic conductance than the short vegetation.
- The aerodynamic conductance increases on dry days, that is relatively stronger and significant for the forest compared to short vegetation

What is the role of high aerodynamic conductance of forest in dampening the response of warming rate to evaporation? To understand this we develop a simple model…

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Model: Warming rate relationship to evaporative fraction and aerodynamic conductance of vegetation

We develop an expression of surface temperature warming rate using surface energy balance to quantify the significance of vegetation and evaporation in shaping the diurnal temperature

$$R_s = R_{l,net} + LE + H + G$$

$$R_s = R_o + k_r\,(T_s - T_{ref}) + LE + H + G$$

$$\frac{dT_s}{dR_s} = \frac{(1 - f_e) + c_p\,\rho\,g_a\,(dT_a/dR_s)}{k_r\,(1 - f_e) + c_p\,\rho\,g_a}$$

$$\frac{dT_s}{dR_s} = \frac{(1 - f_e)}{c_p\,\rho\,g_a} + \frac{dT_a}{dR_s}$$

Warming rate

$$\frac{dT_s{}'}{dR_s} = -\frac{1}{c_p\,.\,\rho\,.\,g_a^2}\,.\,(\,g_a + g_a'\,(1 - f_e)\,) + \frac{dT_a{}'}{dR_s}$$

Warming rate response to evaporative fraction

- The warming rate of surface temperature is inversely proportional to the aerodynamic conductance
- Warming rate of surface temperature is directly proportional to($1\text{-}f_e$)

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Model: Warming rate sensitivity to evaporation and vegetation

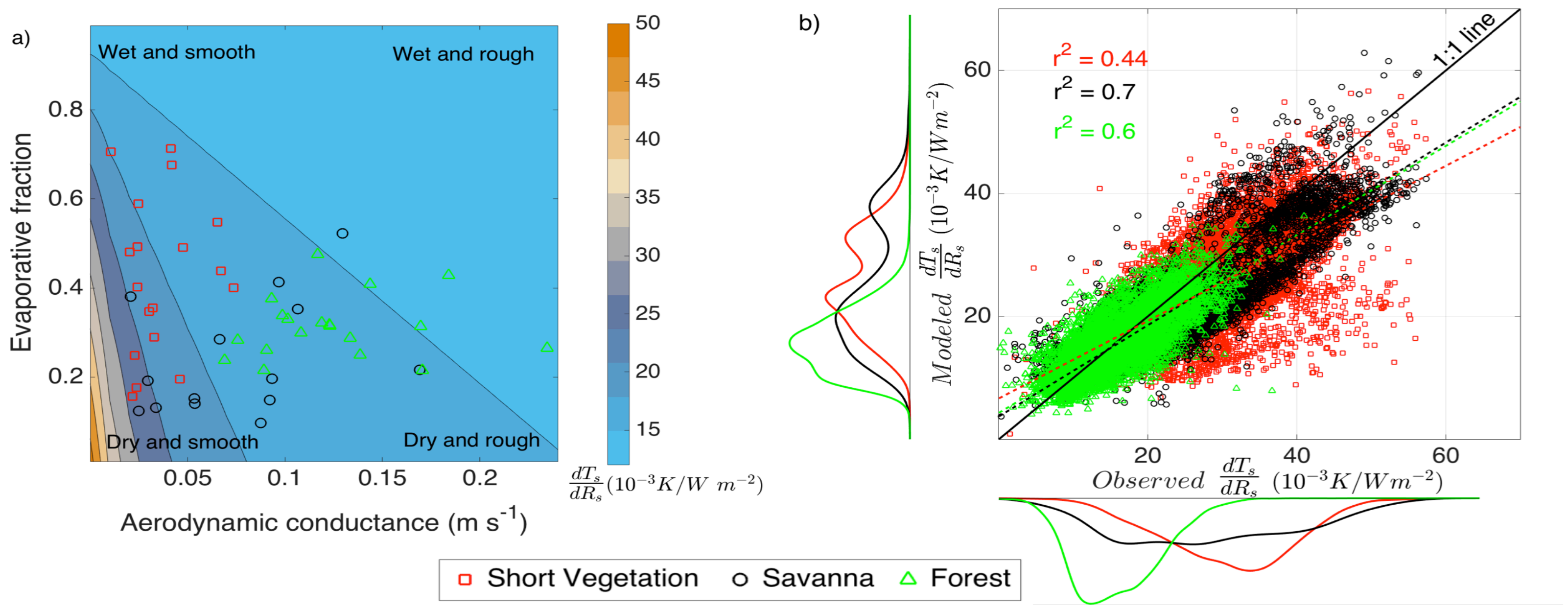

Fig 7. a) Modeled surface temperature warming rate for different aerodynamic conductance and evaporative fraction, b) Comparison of modeled and observed daily warming rates

- The warming rates are more sensitive to evaporation for lower aerodynamic conductance (short vegetation)
- Our model reproduces the surface temperature warming rate significantly

The diurnal variation of temperature can be simply reproduced from evaporative fraction and the aerodynamic conductance

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Model: Role of vegetation in altering the response of warming rate to evaporation

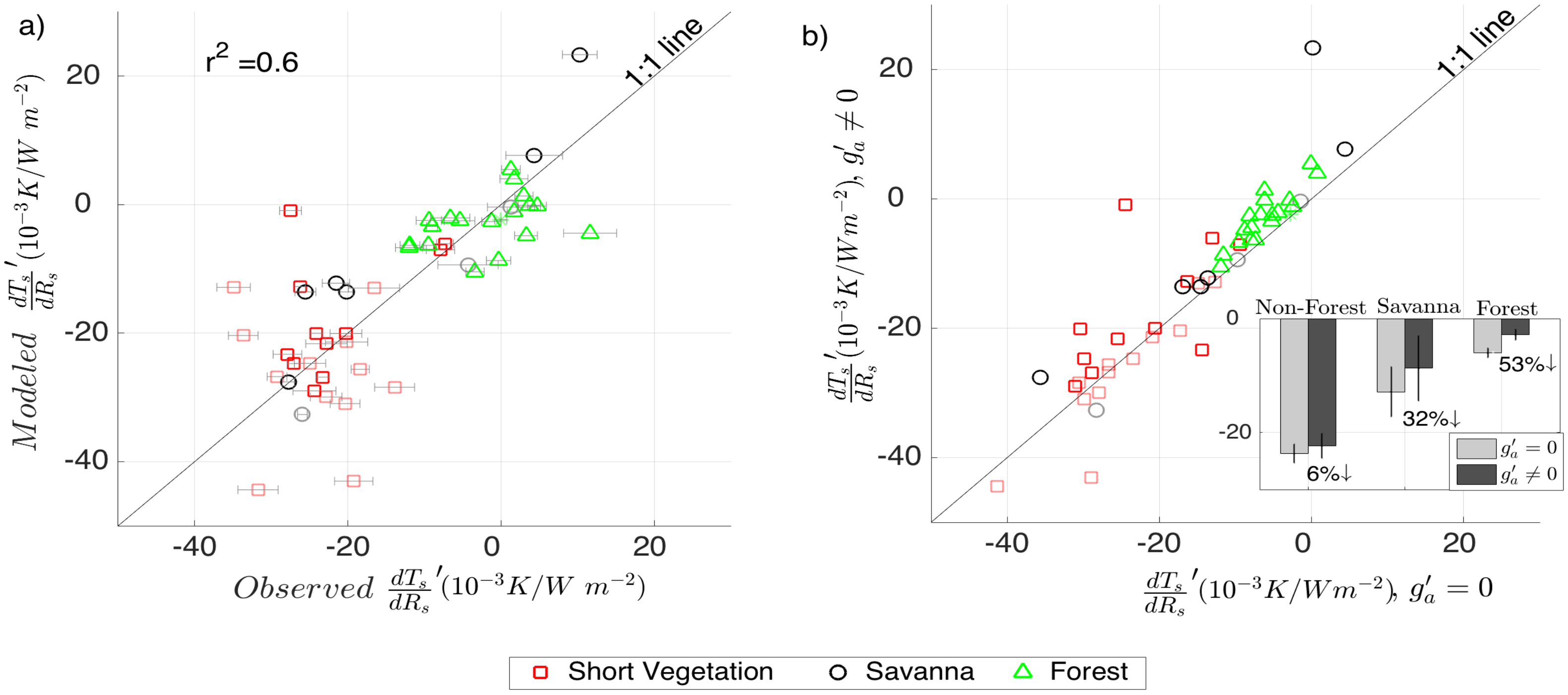

Fig 8. a) Model evaluation of the response of surface temperature warming rate to evaporative fraction, b)Comparison of modeled response for two cases , the first case assumes the aerodynamic conductance to be insensitive to evaporative fraction and the second case includes the sensitivity of aerodynamic conductance to evaporative fraction

The aerodynamic conductance increases on dry days, specially in forests. Overall, it is the high aerodynamic conductance of forest that overshadows the evaporative cooling of temperatures.

Panwar et al. (HESSD)
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Significance of solar radiation, evaporation and vegetation for diurnal temperature variation

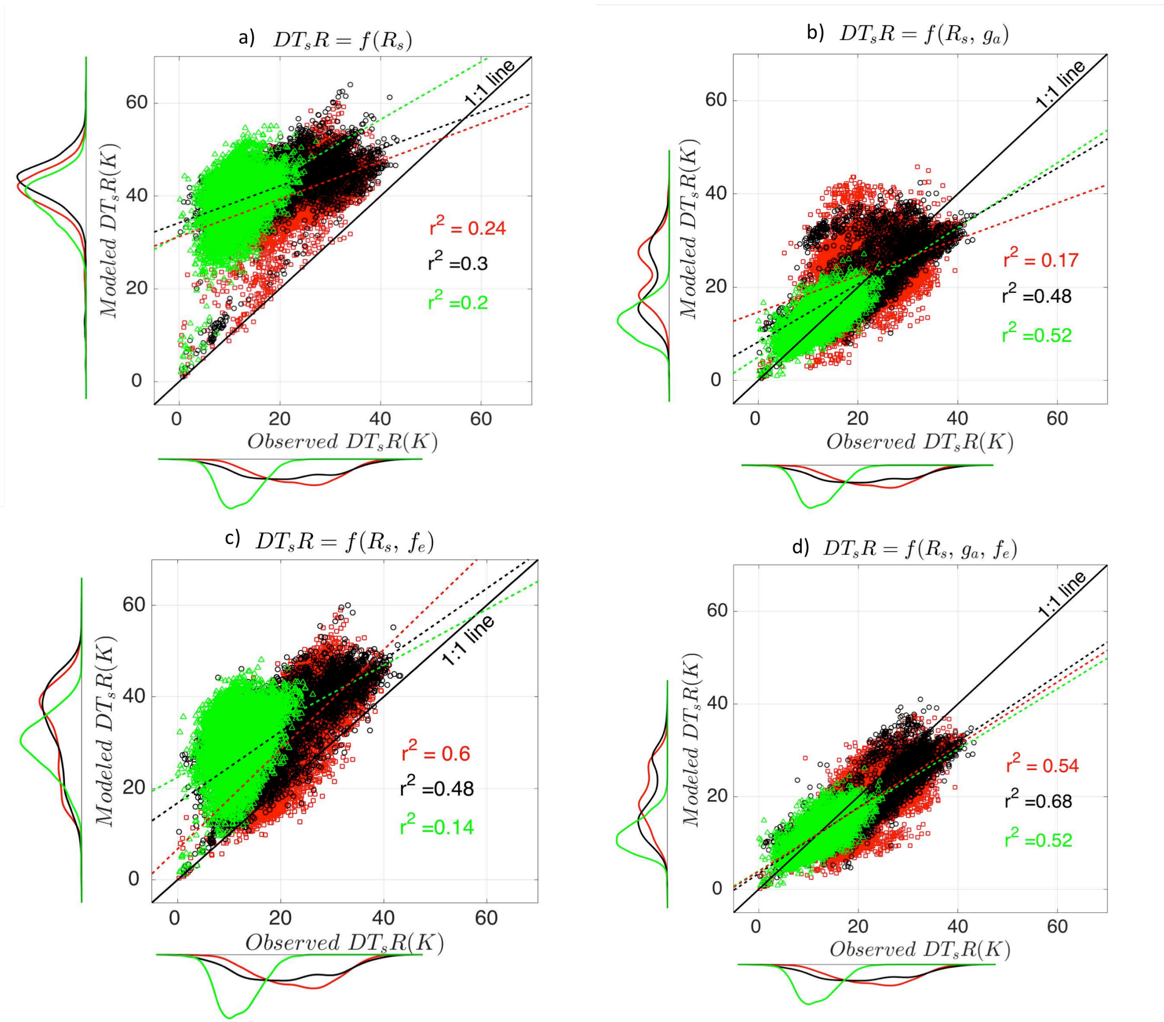

Fig 9. Comparison of model estimates of DT_sR for four conditions, a) only solar radiation, b) solar radiation and vegetation, c)solar radiation and evaporation, and d) solar radiation, vegetation and evaporation.

- We obtain diurnal surface temperature range (DT_sR) by multiplying maximum solar radiation to the warming rate of surface temperature
- **Solar radiation** alone **overestimate** the DTsR.
- Both **evaporation and vegetation** properties **reduce** the DTsR
- **Evaporative cooling** of DT_sR is more **significant for short vegetation** compared to the forest

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Conclusion

- **Diurnal air temperature** carries **no information of evaporation** in all vegetation type. See the explanation in *Panwar et al. (2019) , GRL* *https://doi.org/10.1029/2019GL082248*

- **Diurnal surface temperature** of short vegetation carries **stronger imprints of evaporation**

- Absence of evaporation imprints in diurnal temperature variation in **forests** is majorly due to their **high aerodynamic conductance**. Also, aerodynamic conductance of forest **enhances on dry days** which furthermore contributes to weaker imprints of evaporation.

Future outlook

- Interpreting the global pattern of diurnal temperature range to understand how solar radiation, evaporation and vegetation effect the temperature in diurnal scale.

Thank you

Detailed information on this work is present in the mentioned manuscripts. If you have any interesting **thoughts, questions, opportunities in related research and ideas for collaboration**, you can contact me (apanwar@bgc-jena.mpg.de)

Please **cite** the work (given doi) incase you use the scientific material from this document