Characterization of the diurnal cycle of wet-bulb temperatures over South Asia

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Abstract

Recent studies have revealed a pattern of out-of-phase relation of wet bulb temperatures with the dry bulb temperatures in the diurnal timescale, which enhances during a heatwave event. This diurnal pattern can be explained in the first order by the variations in the boundary layer height and the water vapour distribution in the vertical within the column of the atmosphere up to the boundary layer height. The current work involves exploring the variations in this diurnal pattern of wet-bulb temperatures over the South Asian region using a high-resolution WRF model output to understand the controls on this diurnal pattern better robustly.

Motivation

The study by *Justine et al.(2022)* revealed that the daily wet-bulb temperature(TW) extremes over the South Asian region vary widely over the entire domain, with daily maximums occurring early in the mornings or late evenings. These timings get even more concentrated towards cooler times of the day during heat wave events. The boundary layer(BL) height and water vapour in the atmospheric column were key variables that indicated strong controls on the diurnal cycle of TW.

This study utilized a station-level dataset from HadISD for surface variables and radiosonde data from IGRA to estimate BL height and water vapour. Since the thermodynamic processes control these variables in the atmosphere, a high-resolution WRF model output is used to study the actual controls in more detail further.

Data

We are using the **WRF V4.2.1** model output with **non-hydrostatic** configuration. The model output details are as follows.

- Spatial resolution of ***3 km x 3 km(0.027º x 0.027º)*** covering the entire *South Asian* region.*(5ºN-31ºN, 65ºE-95ºE)*
- Temporal resolution of ***3 hours***.
- Vertical levels of upto ***60*** from surface(~1020 hpa) upto 5 hpa.
- Model start date ***01 March 2016***, end date ***31 June 2016***.
- This model uses *YSU Scheme* is used for the boundary layer physics, *MM5 Scheme* for the surface layer physics, *WRF Single–moment 6–class Scheme* for microphysics, *Unified Noah Land Surface Model Scheme* for land surface physics, *RRTMG Shortwave and Longwave Schemes* for radiation physics.
- This model does not use any cumulus parameterization schemes and urban parameterization schemes.

References

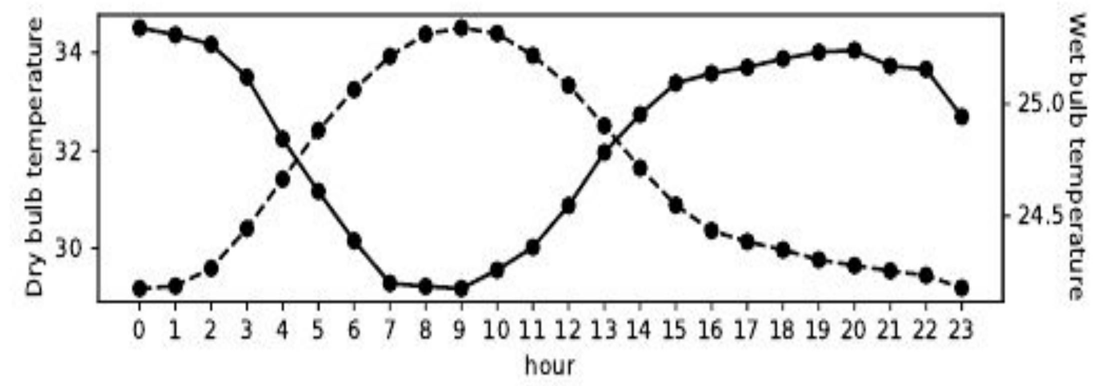
1) **The diurnal variability of wet bulb temperatures and exceedance of physiologically relevant thresholds in South Asia**, Jenix Justine, Joy M. Monteiro, Hardik Shah, Neethi Rao, 2022. (submitted)
2) **Characterization of Extreme Wet‐Bulb Temperature Events in Southern Pakistan**, Joy M. Monteiro, Rodrigo Caballero, Geophysical Research Letters, 46, 17-18, 10659-10668, 2019.
3) **Modeling tropical convergence based on the moist static energy budget**, J D Neelin, I M Held, Monthly Weather Review, 115, 1987.

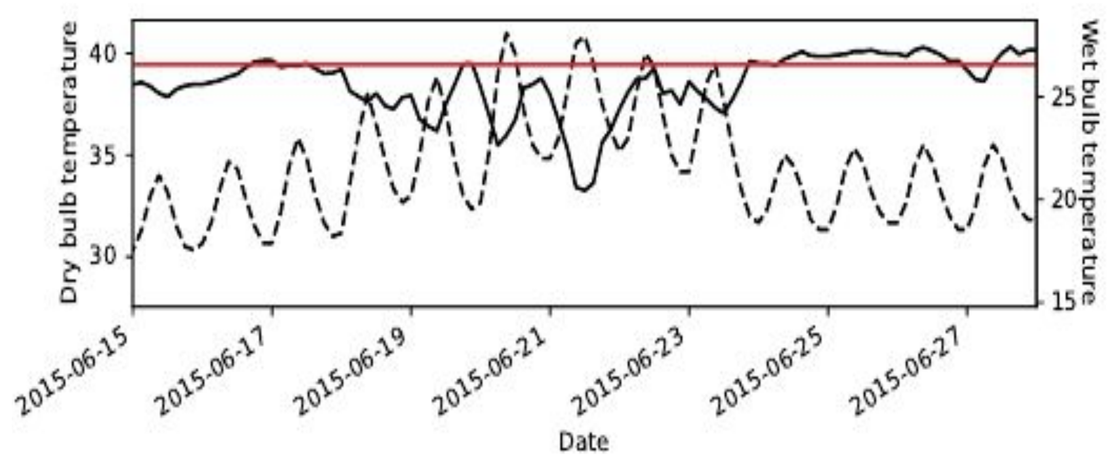
Methods

The TWs are calculated by solving an implicit equation given by

$$[c_{pd} + r^*(T_w)c_l](T - T_w) = L_v(T_w)r^*(T_w) - L_v(T)r.$$

where c_{pd} and c_l are the dry air and liquid water specific heat capacities respectively, $r^*$and r are the mixing ratios at temperatures T_w and T respectively, L_v is the latent heat of vaporization(*Monteiro & Cabellaro, 2019*). The diurnal cycle of TW and actual temperatures are shown below, as depicted in *Justine et al.(2022)*.





The surface energy fluxes that act as a bottom boundary condition for the atmosphere can be connected to variations in the moist static energy of the atmosphere through the energy balance equation for the atmosphere upto the boundary layer as follows

$$m = c_{pd}T + gz + L_v q$$

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The vertical integral of any variable 'A' from the top of the boundary layer to the bottom surface is given by

$$\langle A \rangle = \int_{pT}^{ps} A \frac{dp}{g}$$

The vertical integral form of the energy balance equation in pressure coordinate is written as follows

$$\langle \frac{Dm}{Dt} \rangle = \langle \frac{\partial m}{\partial t} \rangle + \langle V_h \cdot \nabla_h m \rangle + \langle w \frac{\partial m}{\partial p} \rangle$$

$$\boxed{\langle \frac{Dm}{Dt} \rangle + SHF + LHF + \epsilon = 0}$$

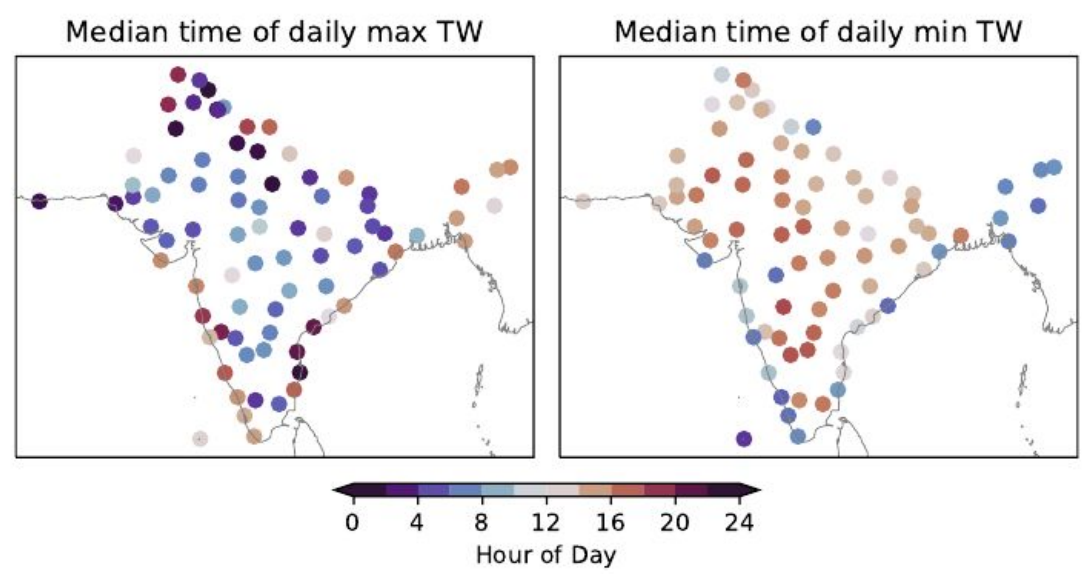
Here *m* is moist static energy, *SHF* is the net upward sensible heat flux, *LHF* is the net upward latent heat flux at the surface, $V_h$is the horizontal component of velocity and ϵ is the residual energy.

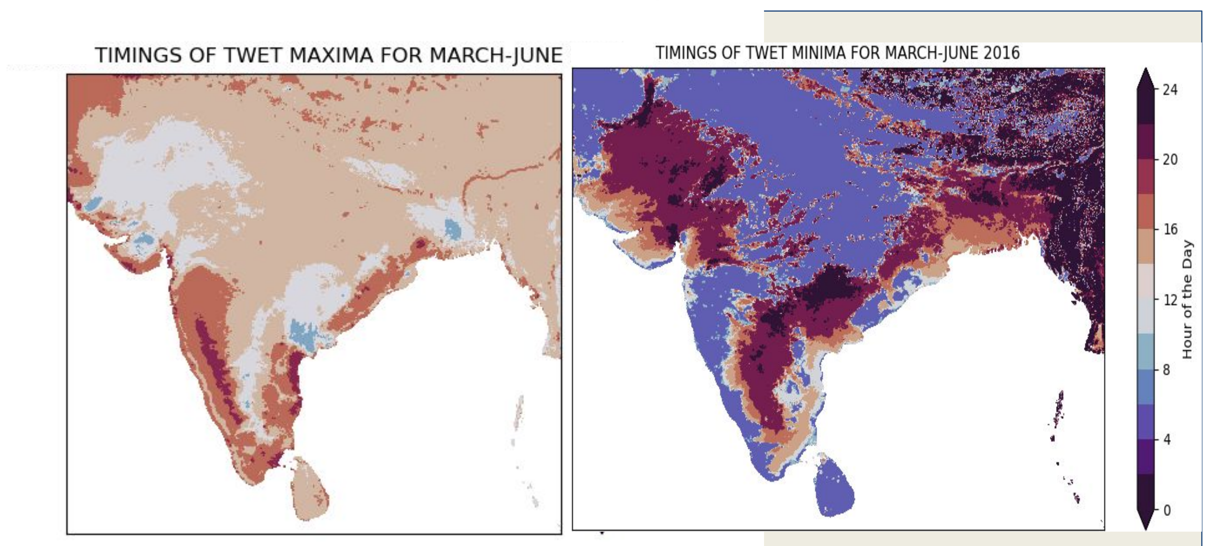
Current work involves supplementing the results obtained by *Justine et al.(2022)* from the observations with the WRF model output data to explore the controls on the diurnal variations in wet-bulb temperatures using the moist static energy variations in the atmospheric column below the planetary boundary layer.

Results

- The median daily extremes of TW from the observations and the model output are compared below.

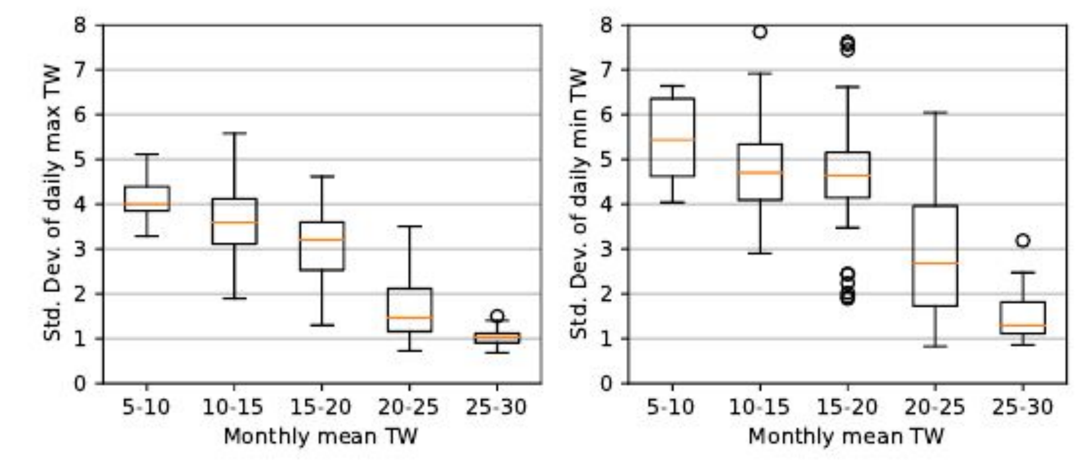
Source: Justine et al.(2022)

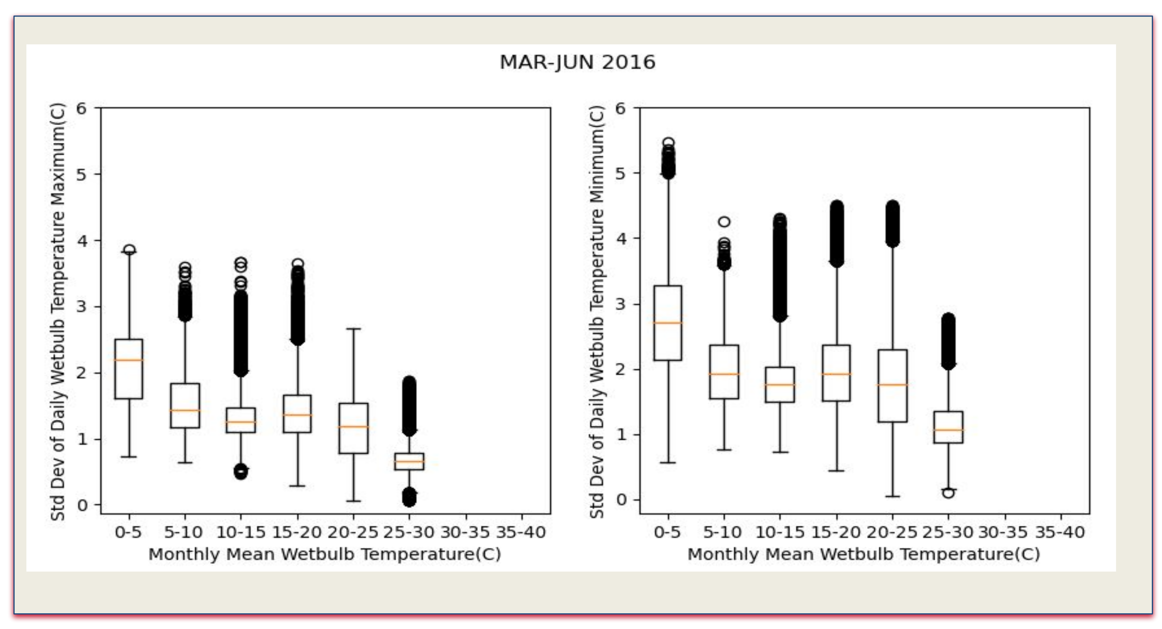




- The deviation of daily extreme TW values from the monthly mean are shown below for the observations and the model output.

Source: Justine et al.(2022)





- A representation of a typical diurnal cycle over land for some important variables.