Understanding the Variability of the Indian Monsoons - Combining Data with Model

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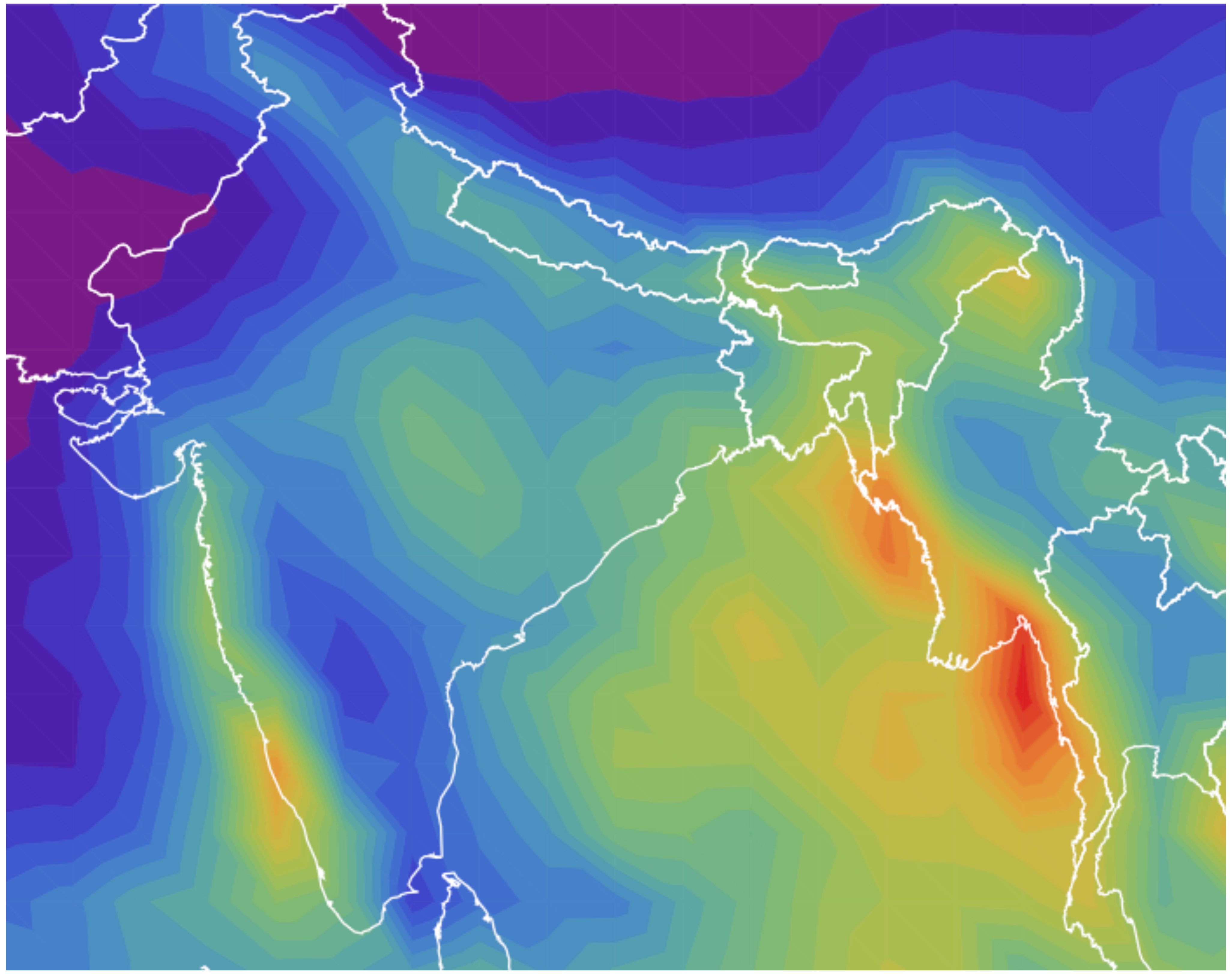
Motivations / Goals

Why do we need conceptual models?

To develop a “simple” conceptual model to gain some understanding of the dynamics of the monsoons, namely it’s **variability**.

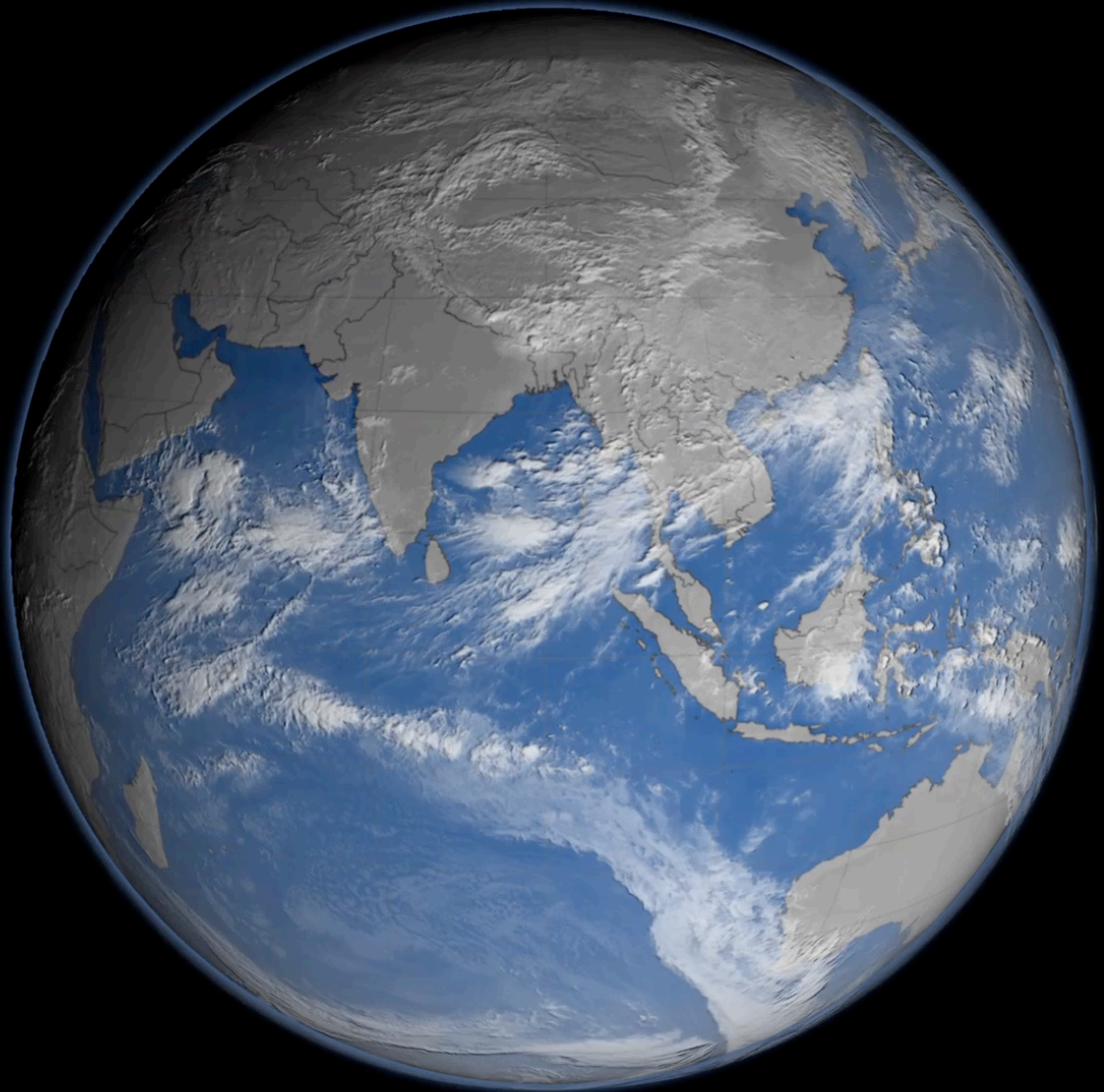
GCMs typically do a poor job in predicting monsoon rain amounts and distributions

How does global warming affect the monsoons?



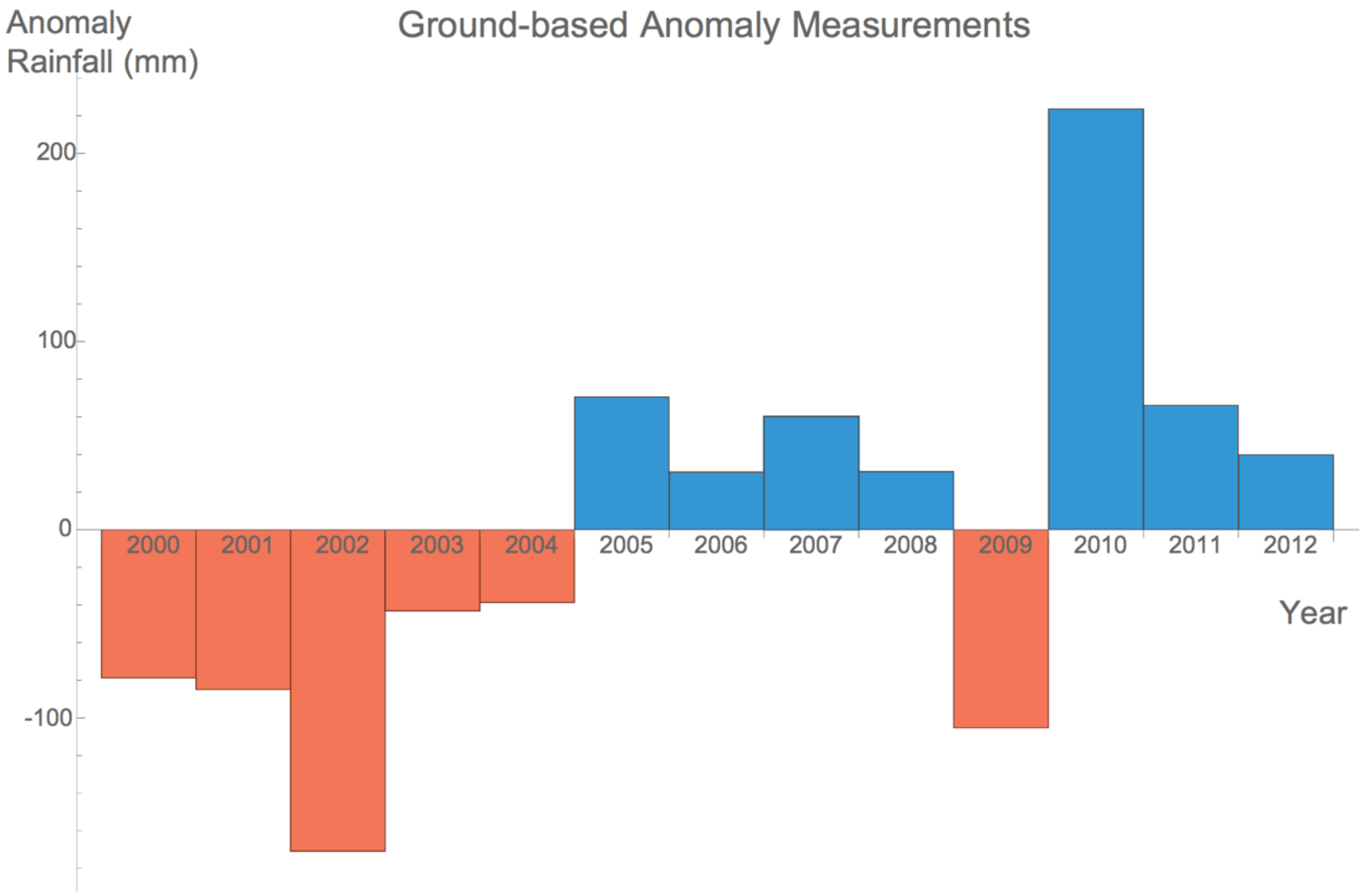
Based on TRMM Satellite data

Monsoons

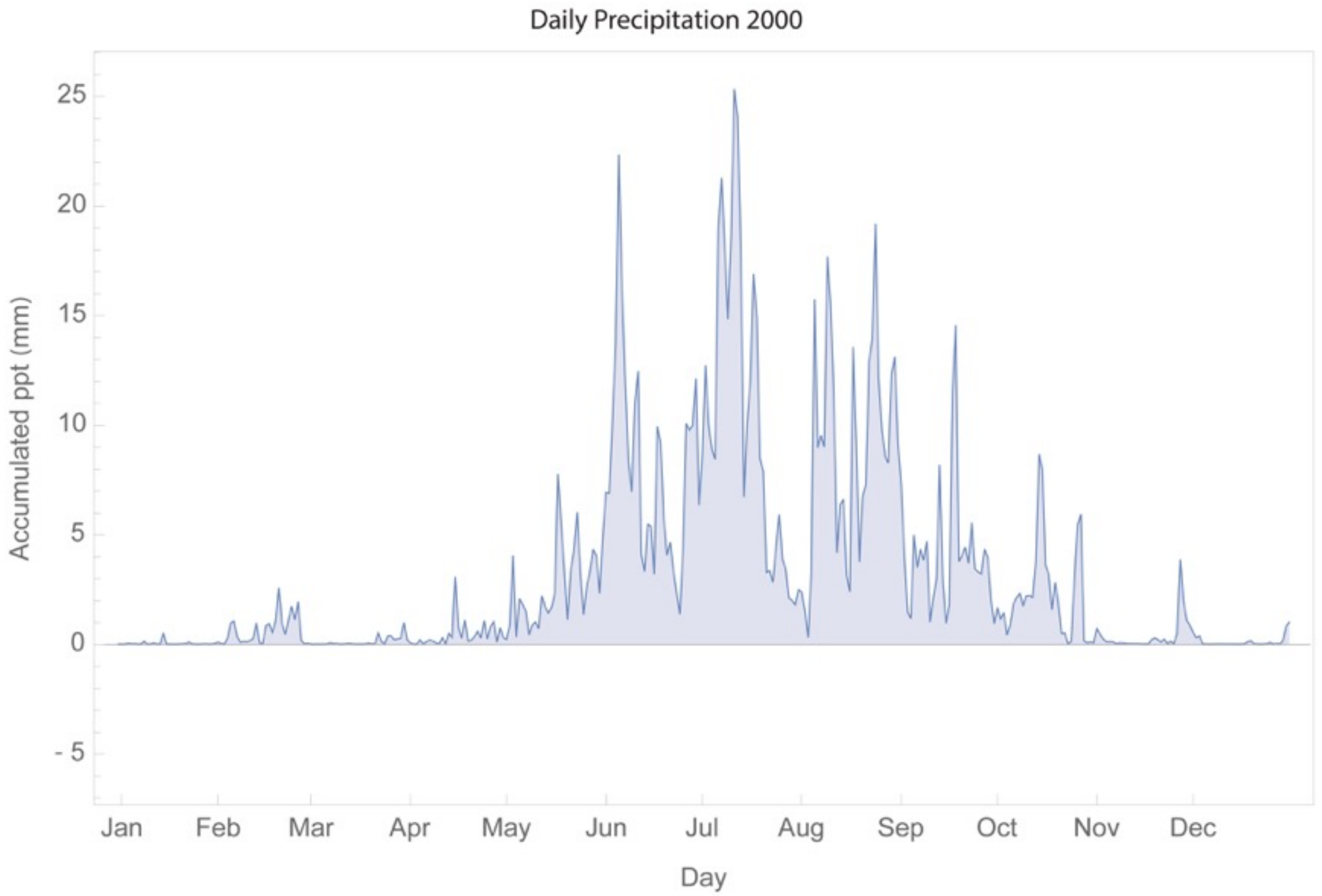


Clouds
Winds
Landslides
Rain
Snow
Temperature
Soil moisture
Floods
low high
07 Jun 2014 07:30

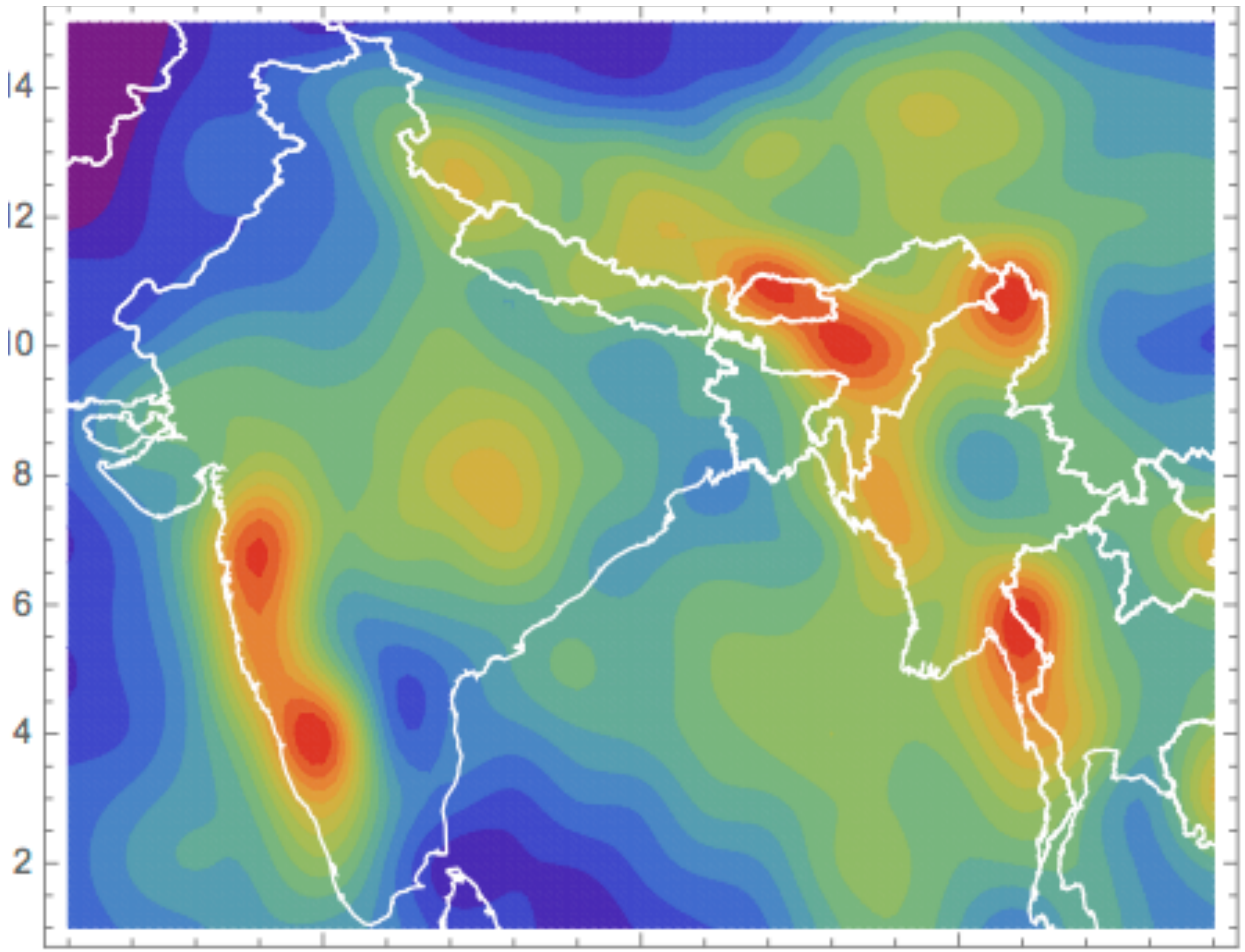
Inter-annual Variability



Intra-seasonal and spatial variability

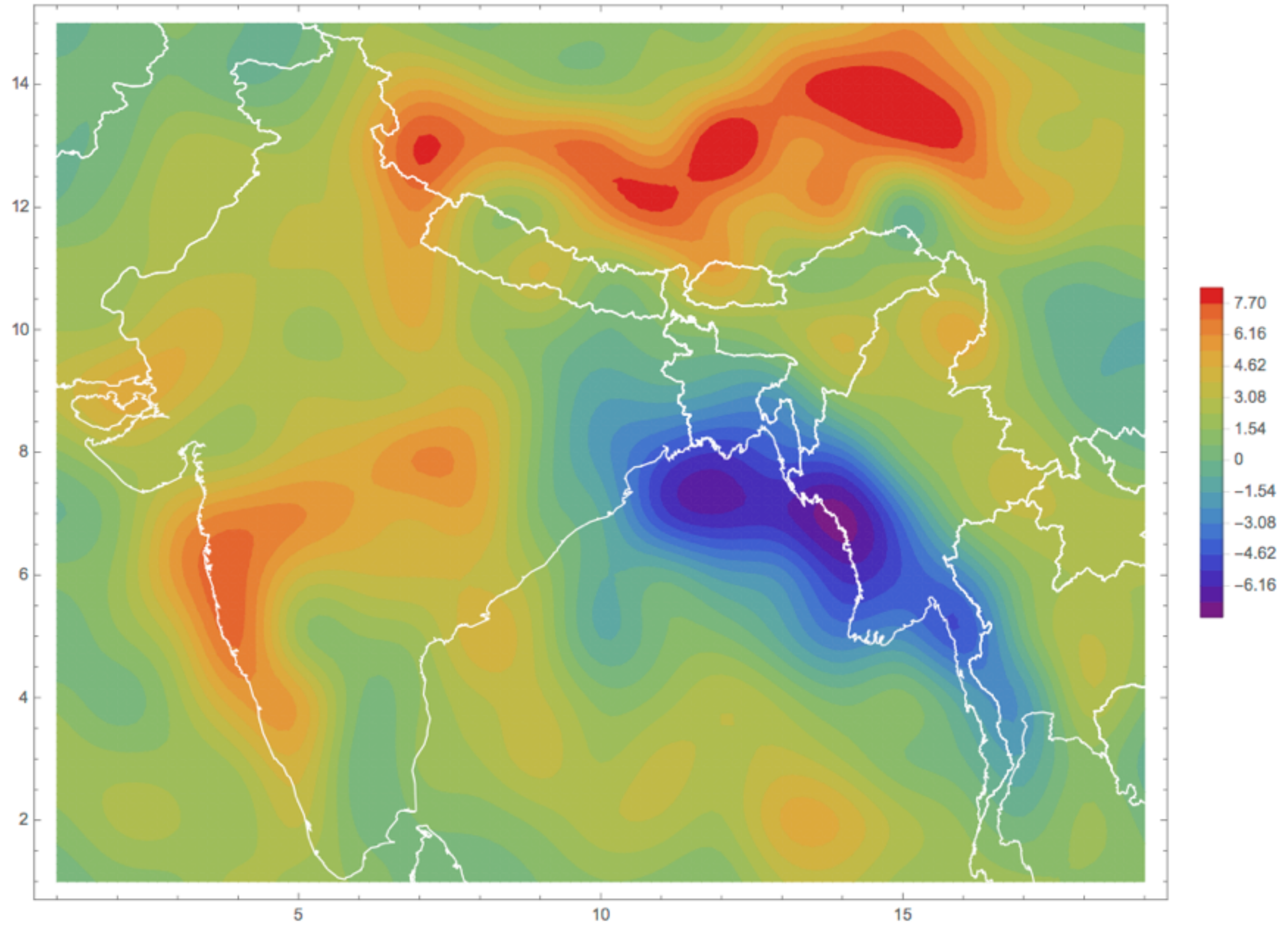


2000 June-Sept Precipitation

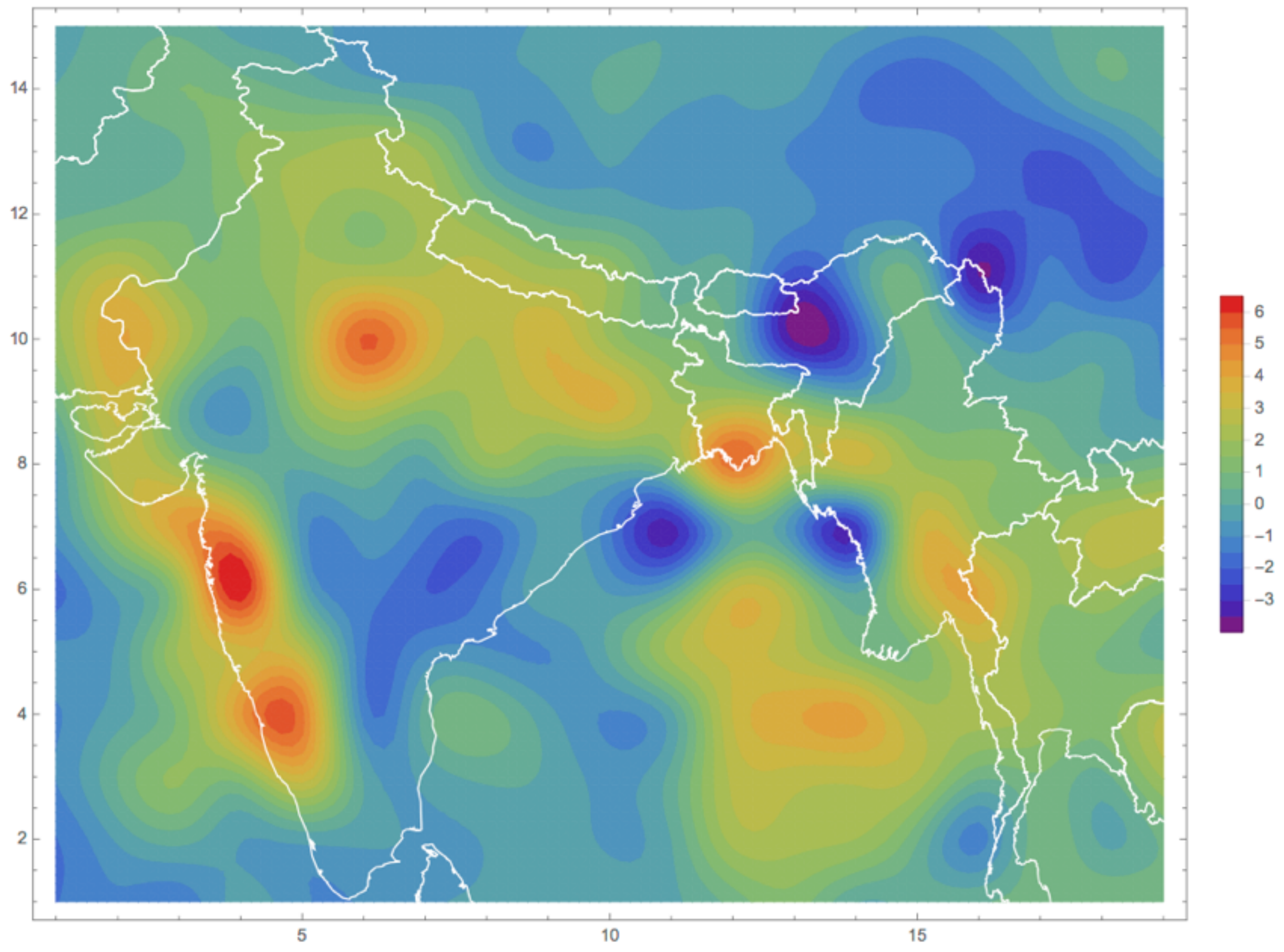


Spatial anomalies

2010 anomaly relative to 2000-2016 mean



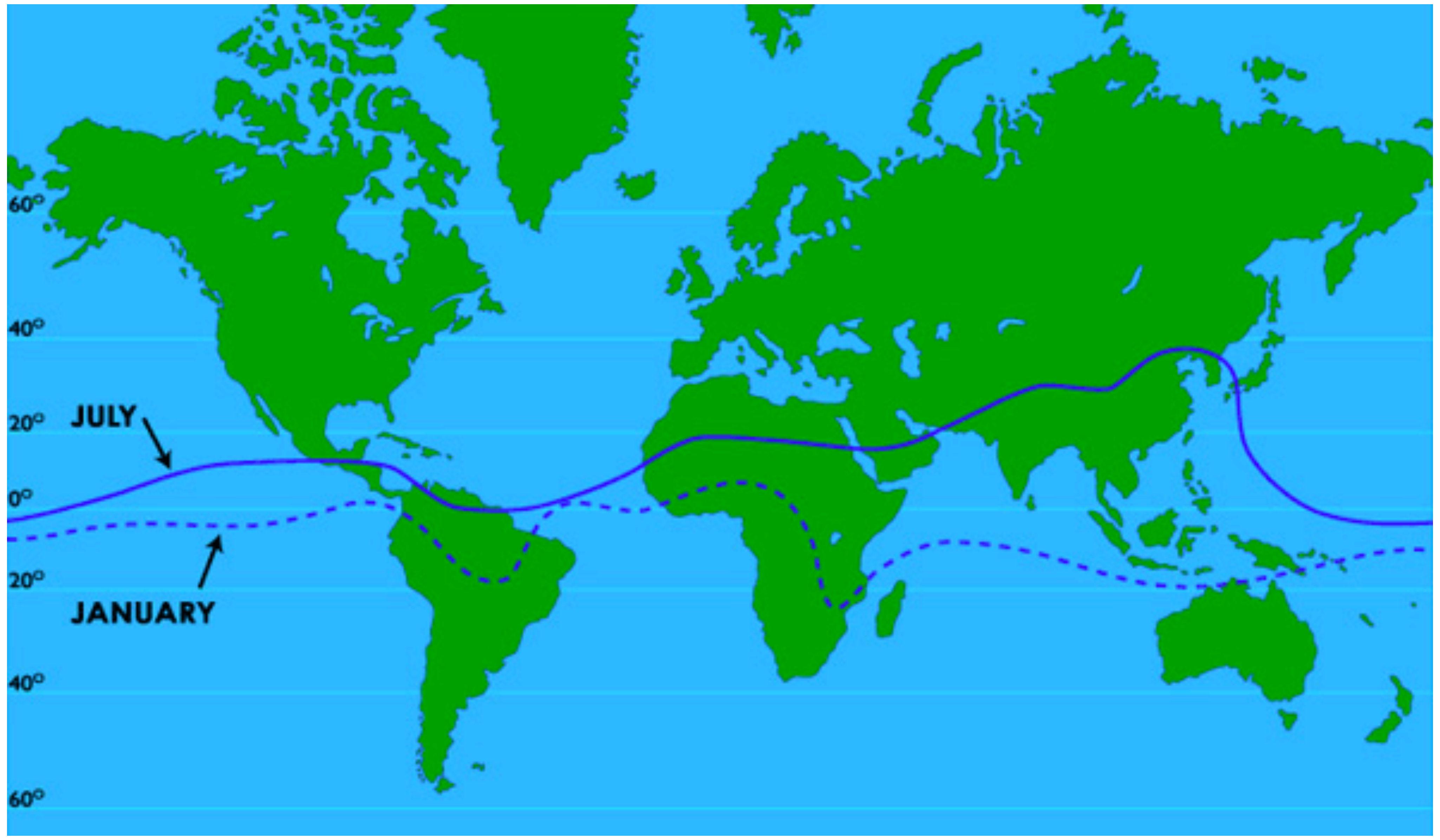
2011 anomaly relative to 2000-2016 mean



What processes are behind the variability?

- Madden-Julian Oscillations
- Indian Ocean Dipole
- Northward progression of the ITCZ during the summer months
- Internal feedbacks

- How does global warming affect the variability?



Approach

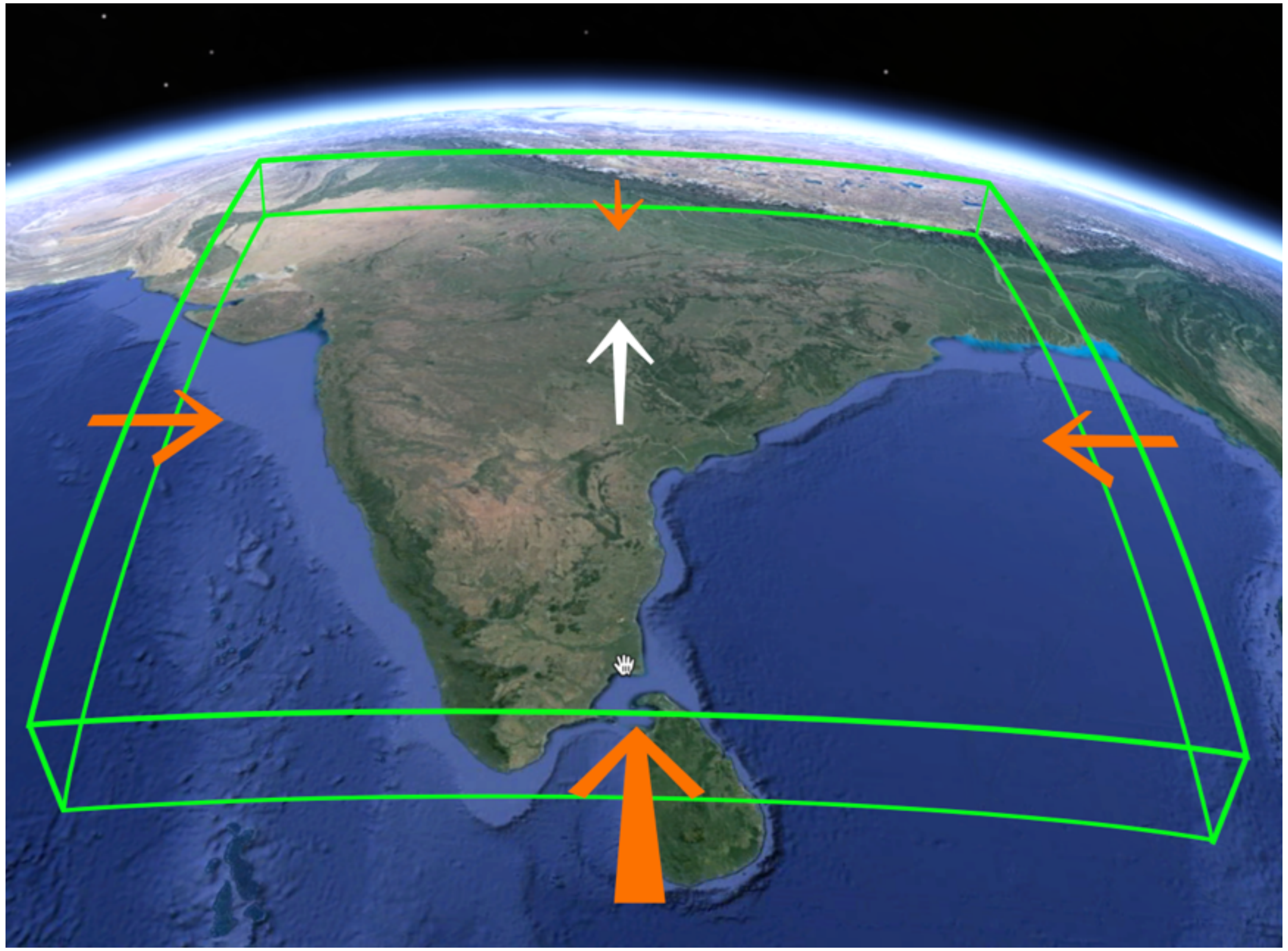
Build a “simple” model from basic physics:

Strip away all the most fundamental components of precipitation.

Reduce spatial discretization to 1 box, location and size variable.

Feed the model with real (reanalysis) boundary conditions to assess its performance.

What are the essential ingredients for explaining some of the features of the monsoons?



Model components

Basic components of the model:

Heat equation - Solar in/out, latent heats, advective transport, ground and air column heat storage

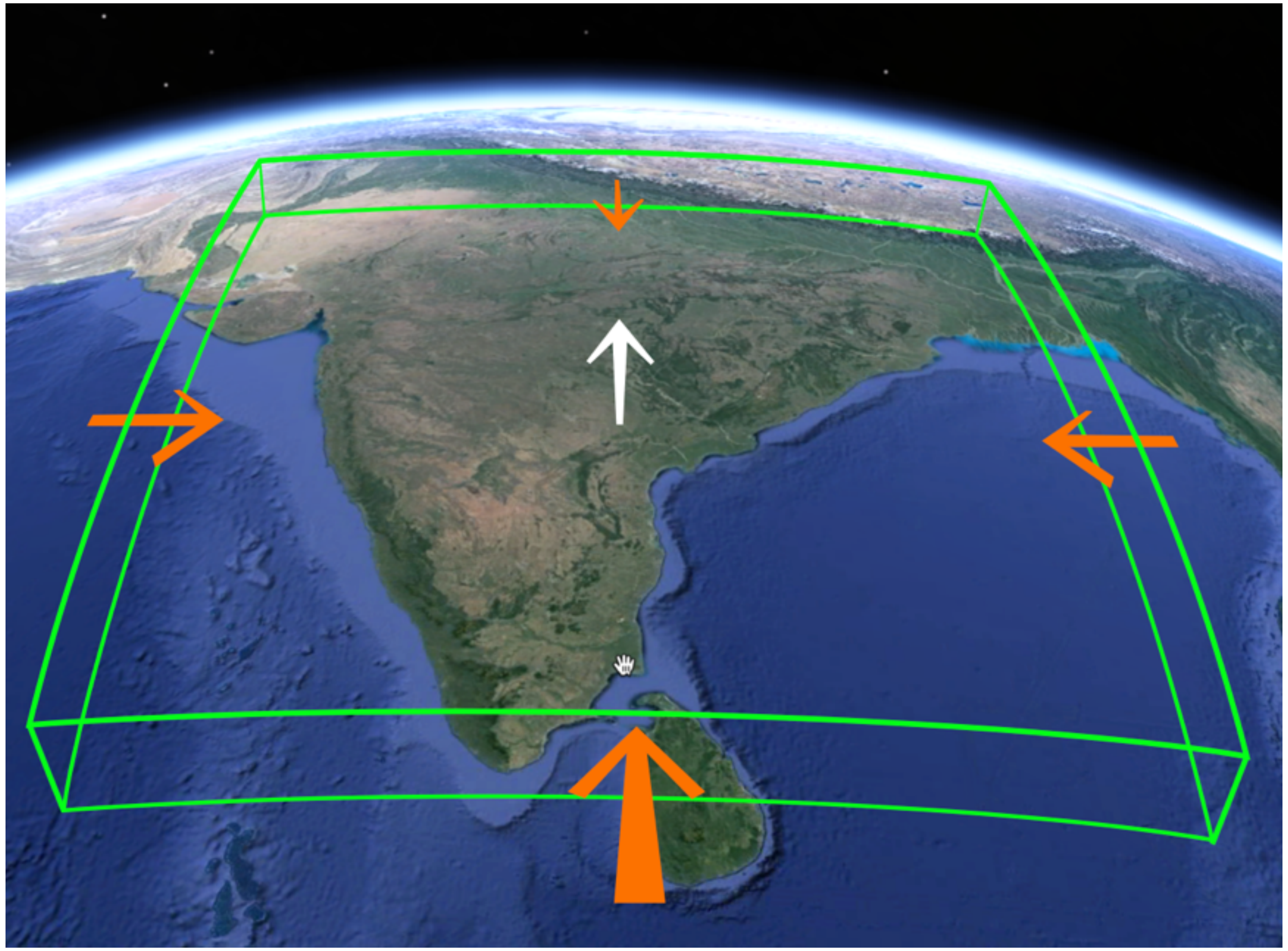
Moisture equation - Precipitation, evaporation, advective transport

Ground water - P-E, runoff

Sources: Petoukhov et.al 2000, Zickfeld 2003

Boundary inputs (NCEP/NCAR Reanalysis II):

Temperature, wind velocity, specific humidity



Model components

Basic components of the model:

Heat equation - Solar in/out, latent heats, advective transport, ground and air column heat storage

$$A_g \int_0^{H_{trop}} C_{air}\rho(z)\frac{\partial \boxed{\theta}}{\partial t}dz + m_g C_g \frac{dT_a}{dt} = I_{in}(1-\alpha(\boxed{N})) - I_{out} + L(P-E) + A_T,$$

$$\theta(z, T_a, q_a, N) = T_a - (\Gamma_0 + \Gamma_1(T_a - T_0)(1 - a_q q_a^2) - \Gamma_2 N)z + \Gamma_d z.$$

$$N = 1 - (1 - N_{cu})(1 - N_{st})$$

$$N_{cu} = \begin{cases} N_{cu}^0 tanh\left(\frac{v}{a_{1cu}}\right)\left(\frac{q_a}{a_{2cu}}\right), & \text{if } v \geq 0, \\ 0 & \text{if } v < 0. \end{cases} \qquad N_{st} = \left(\frac{q_a}{q_{sat}(T_a, p_0)}\right)^{1.5}\left(a_{1st} + a_{2st}0.5\left(\frac{v}{a_{3st}}\right)\right)$$

Model components

Basic components of the model:

Moisture equation - Precipitation, evaporation, advective transport

$$\int_0^{H_{trop}} \rho(z)\frac{\partial q(z)}{\partial t}dz = (P - E) + A_q$$

$$P = \frac{N}{\tau_p}\int_0^{H_T} \rho(z)q(z)$$

$$E = wk_e u_0 \rho_0 (q_{sat}(0, T_a) - q_a)$$

Model components

Basic components of the model:

Ground water - P-E, runoff

$$\frac{dw}{dt} = \frac{P - E - R_{off}}{f}$$

$$P = \frac{N}{\tau_p} \int_0^{H_T} \rho(z) q(z)$$

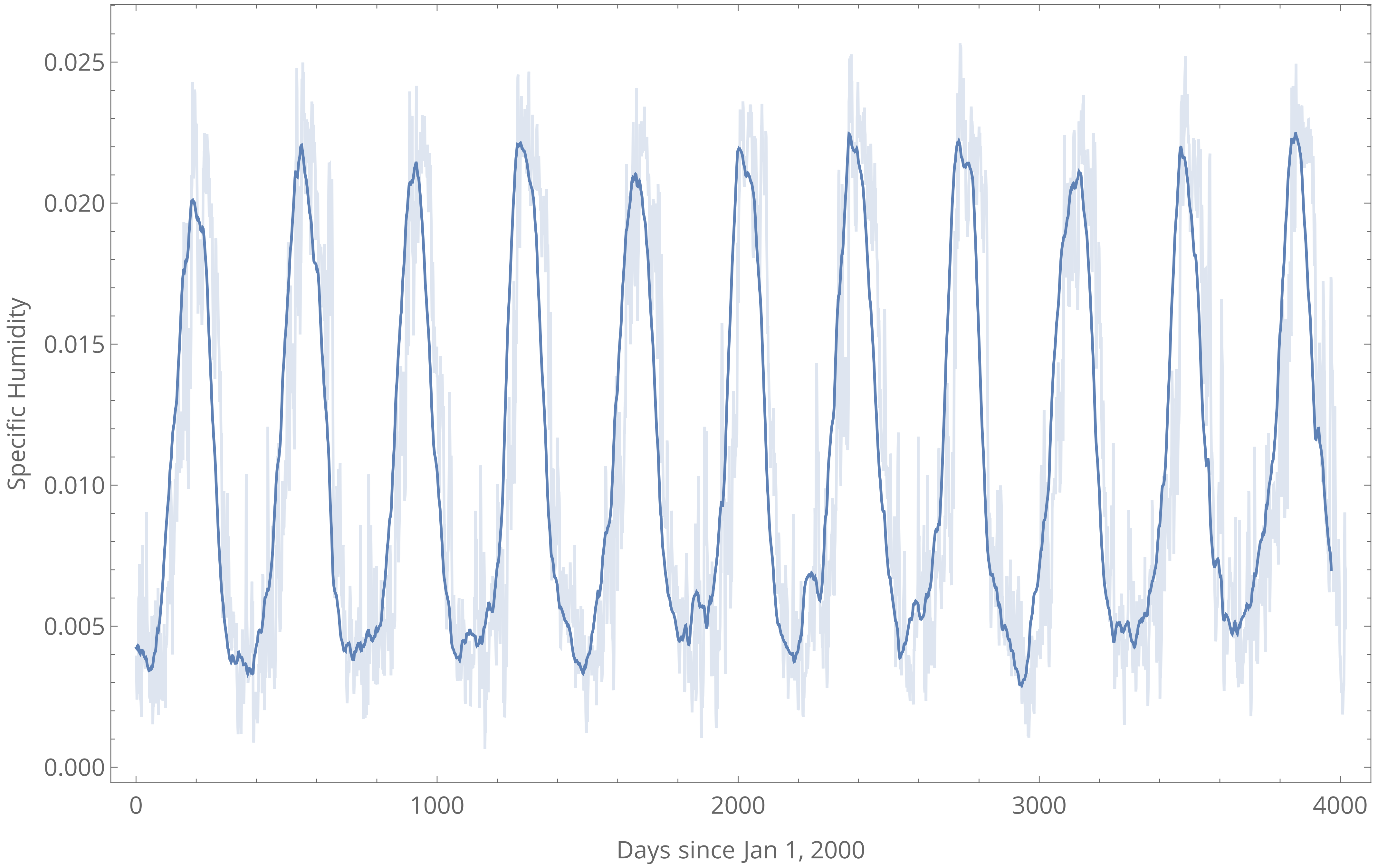
$$E = w k_e u_0 \rho_0 (q_{sat}(0, T_a) - q_a)$$

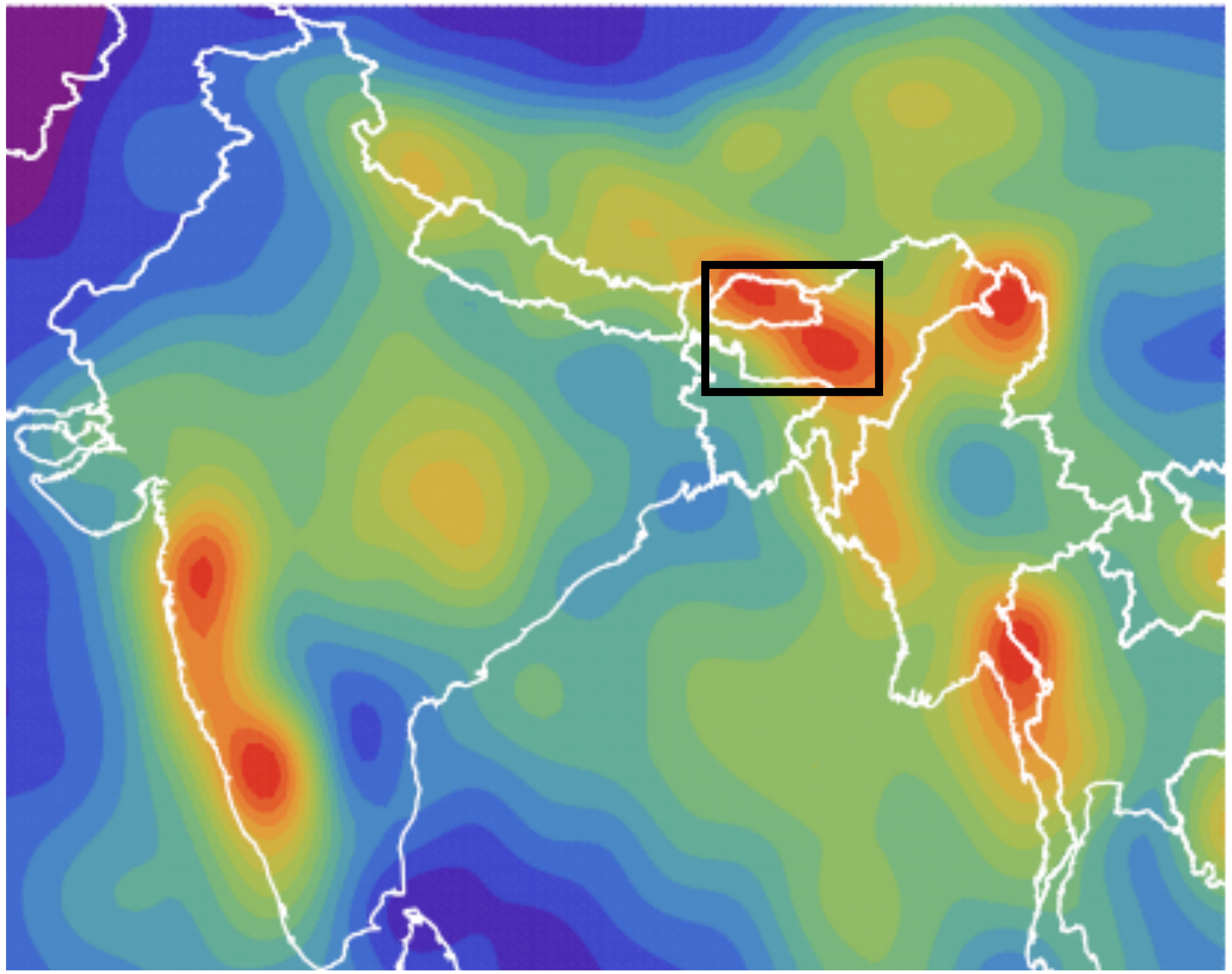
What the model does not include

- Convective motion (single box)
- Topography
- Dynamic winds
- Vegetation / ground water distribution

Inputs - Specific humidity

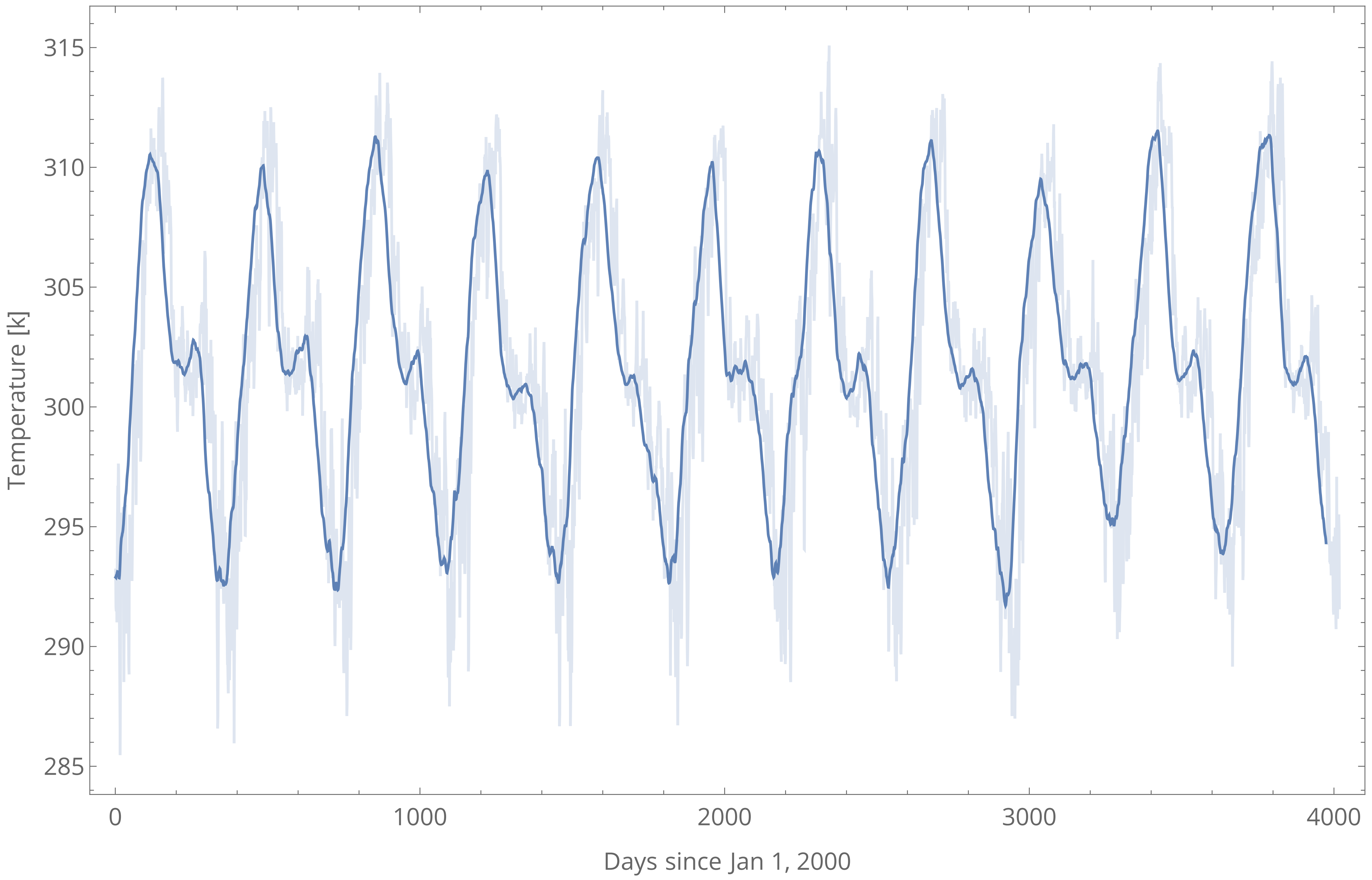
Values at the southern boundary of region

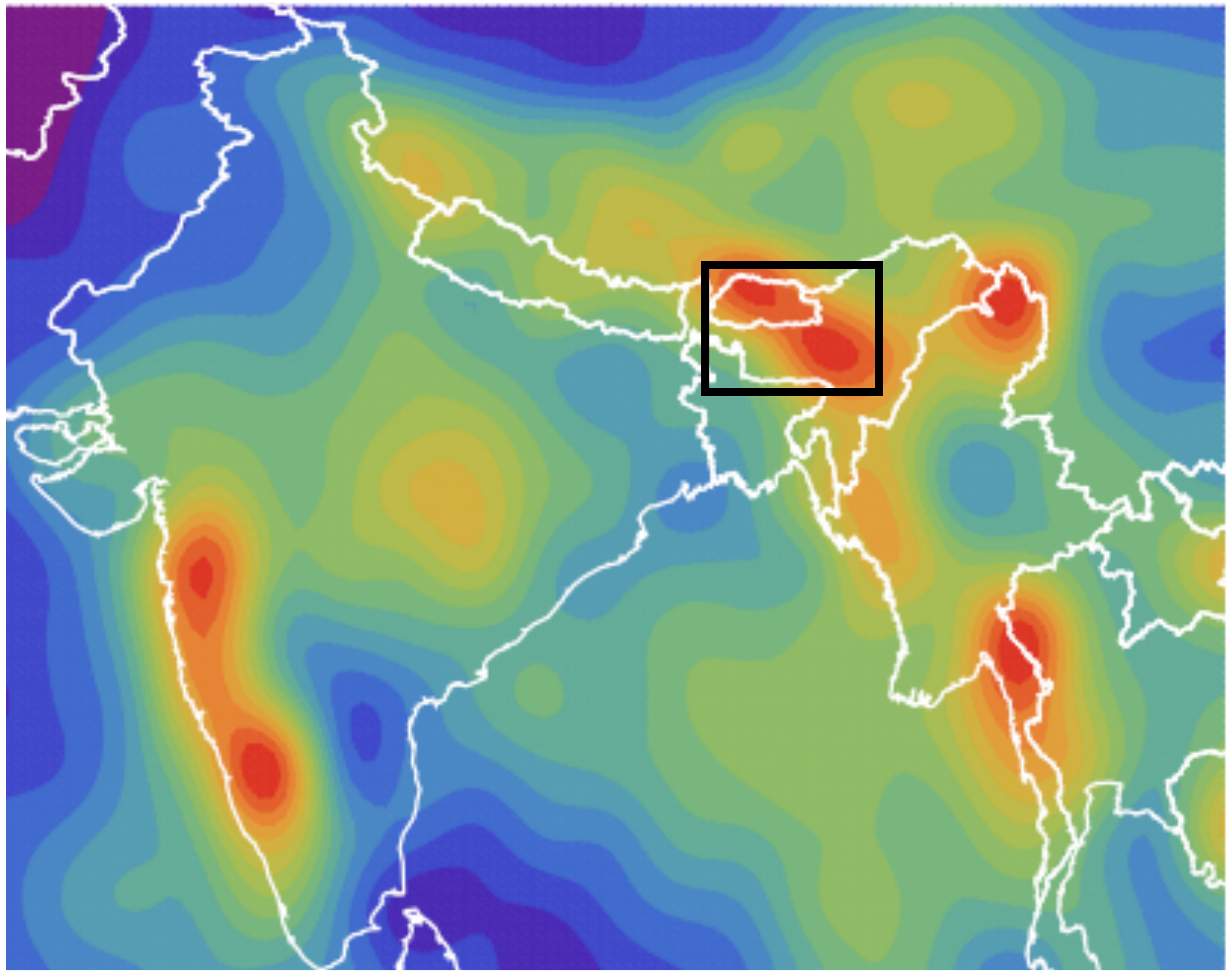




Inputs - Temperature

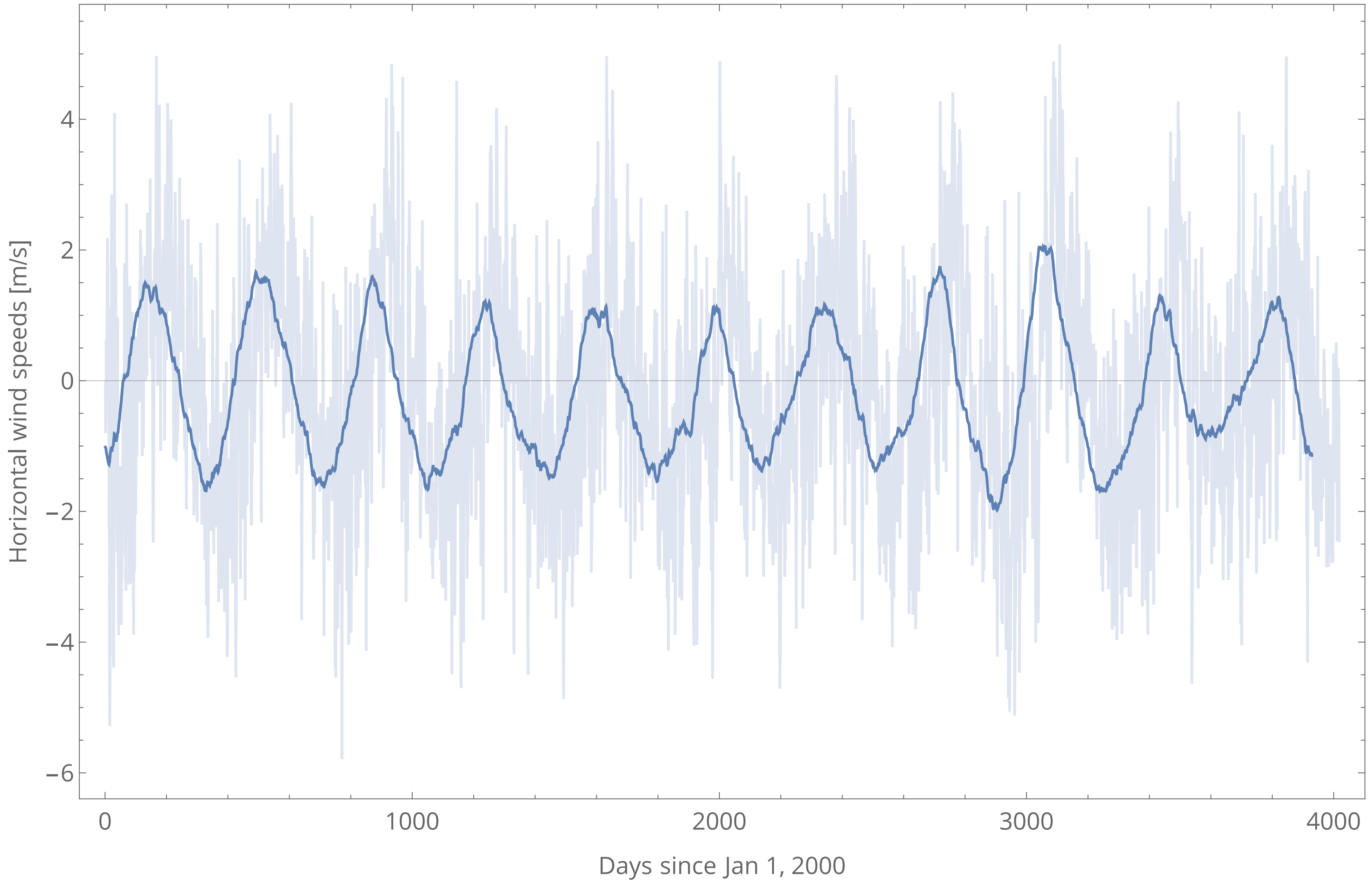
Values at the southern boundary of region

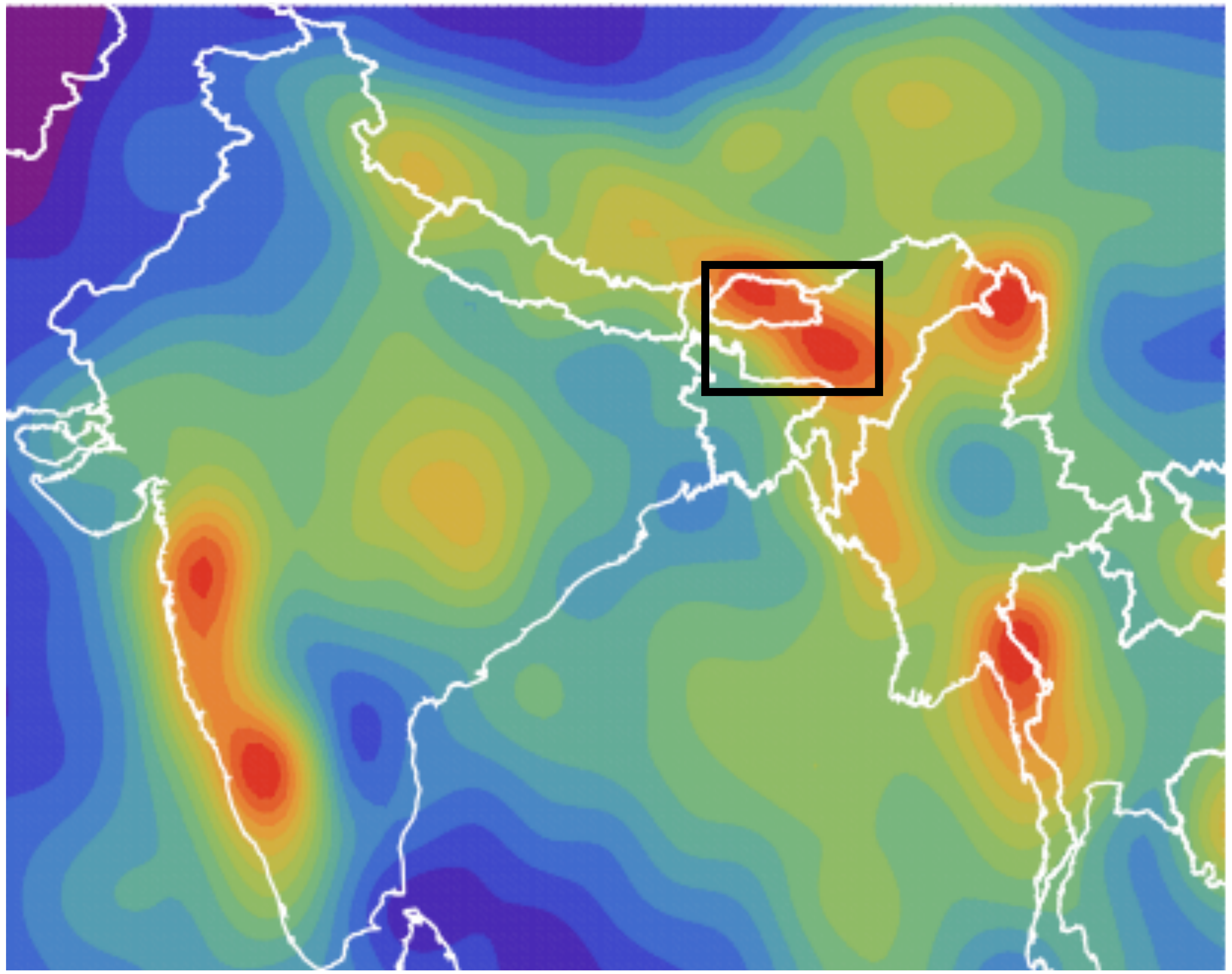




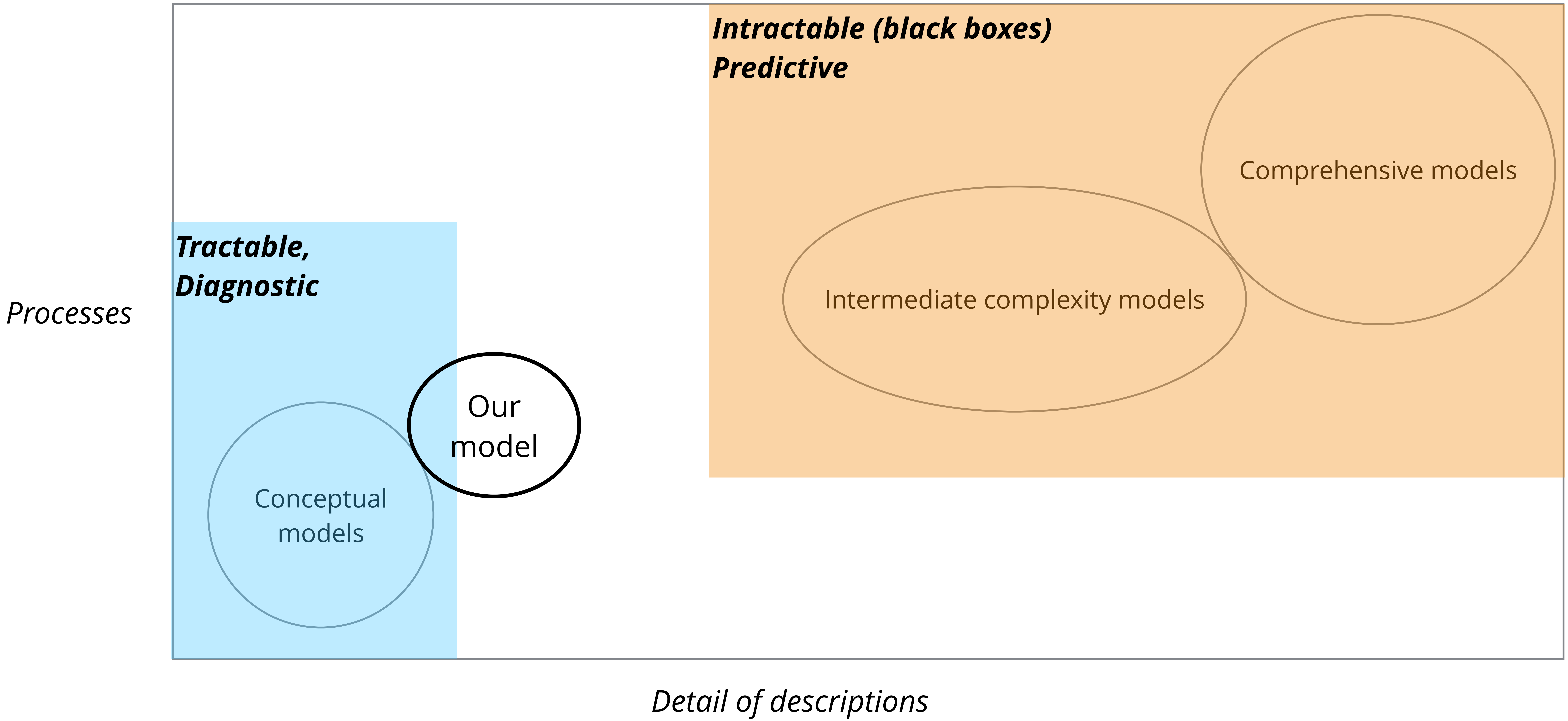
Inputs - Wind speeds

Values at the southern boundary of region



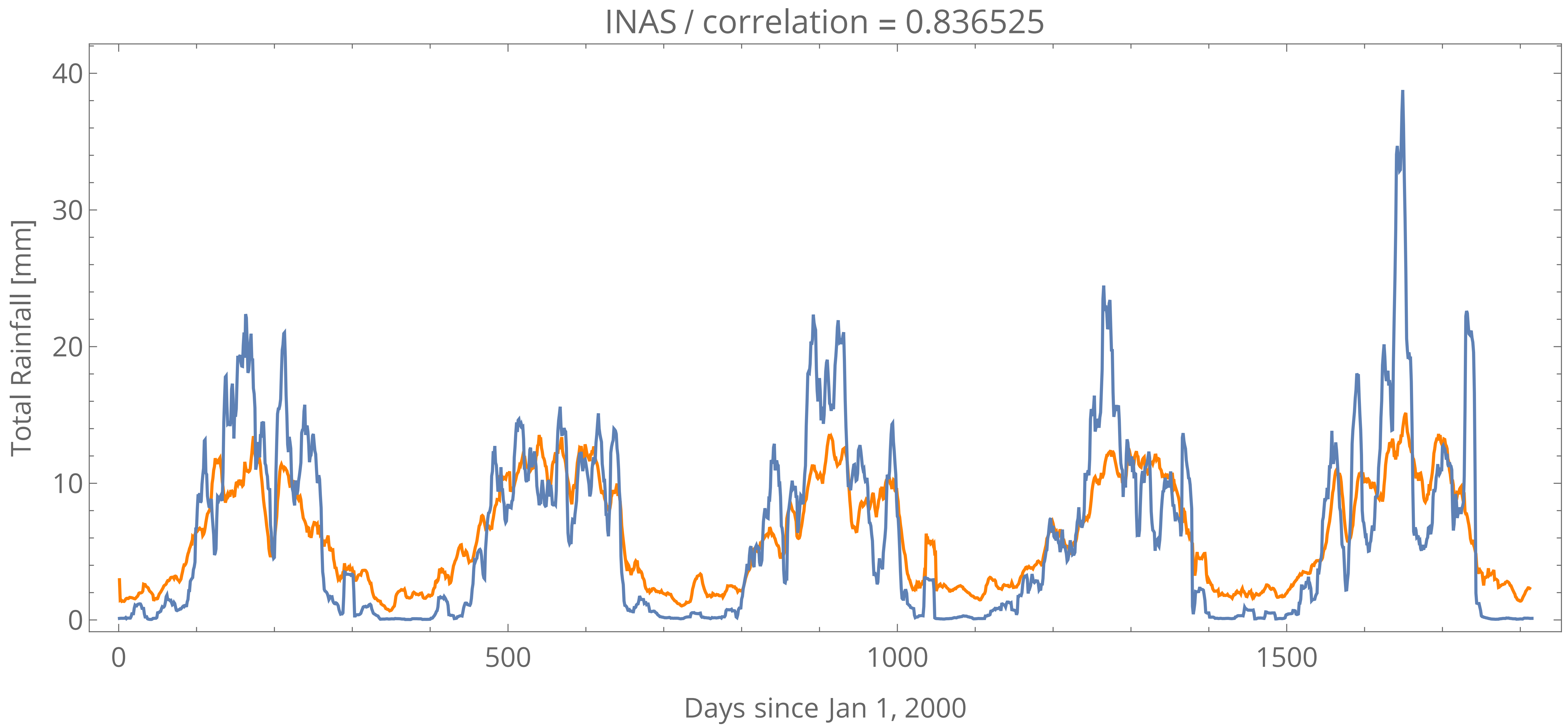


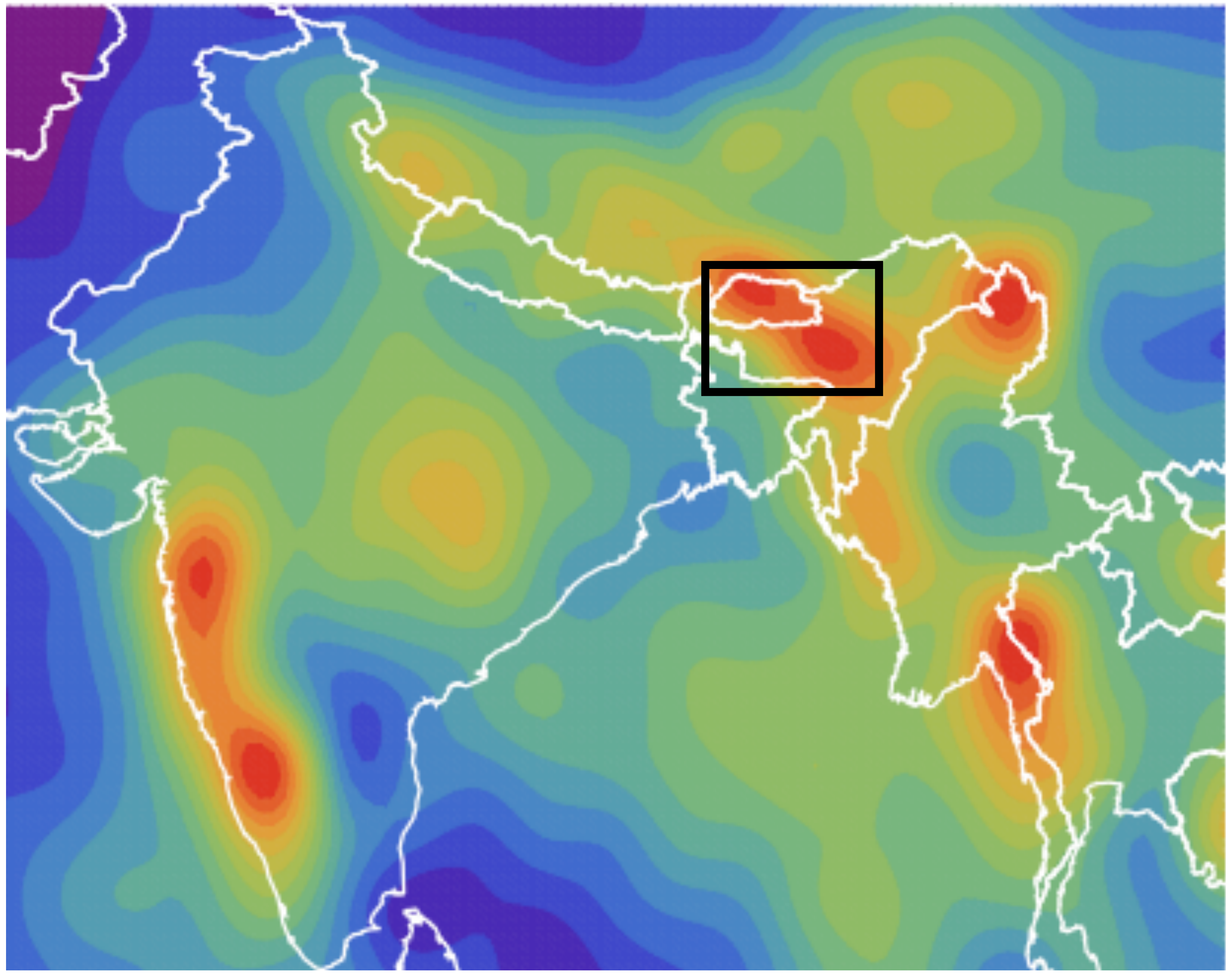
In the hierarchy of models...



Outputs

Total rainfall in region, moving average of 20 days.
Blue: Actual (TRMM)
Orange: Model output





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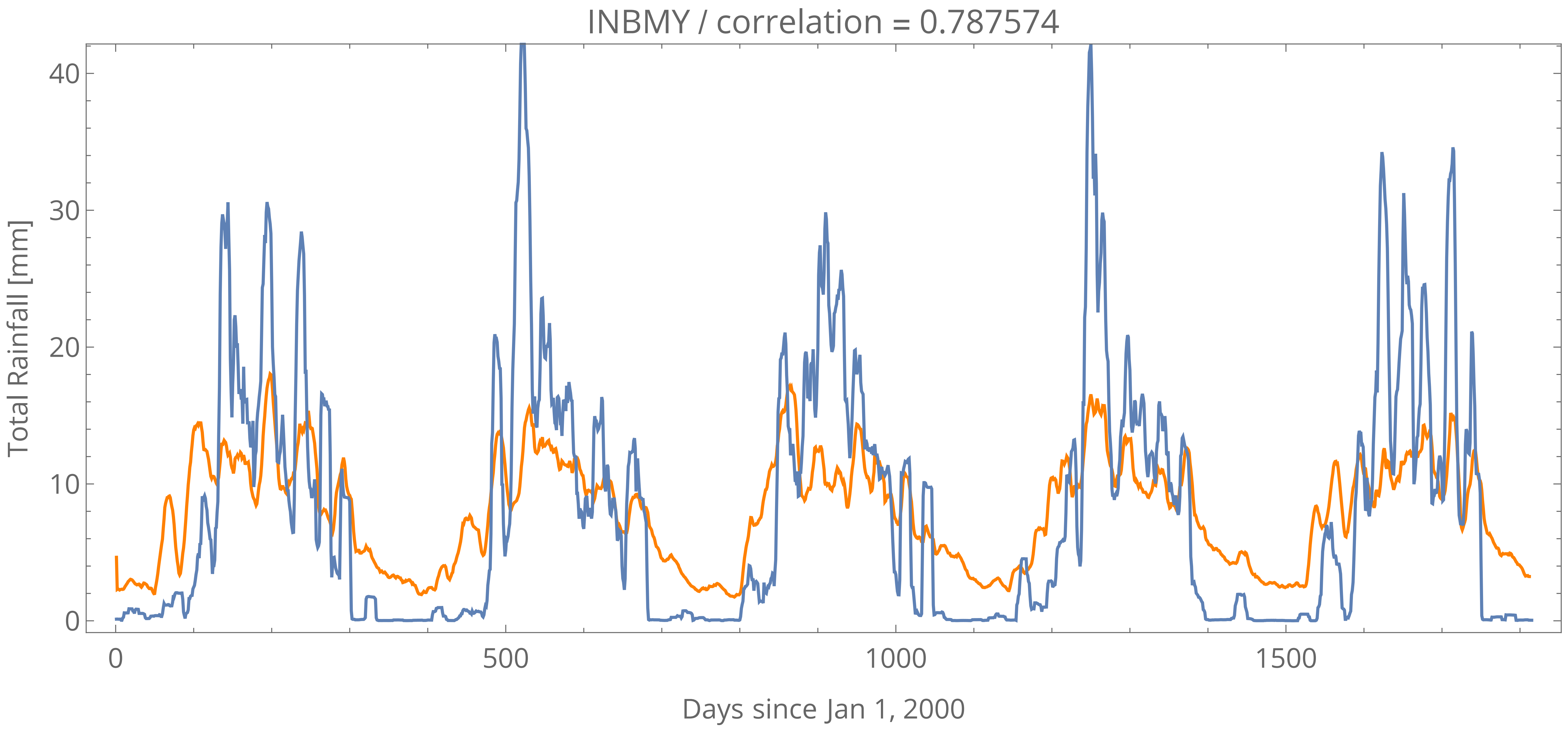

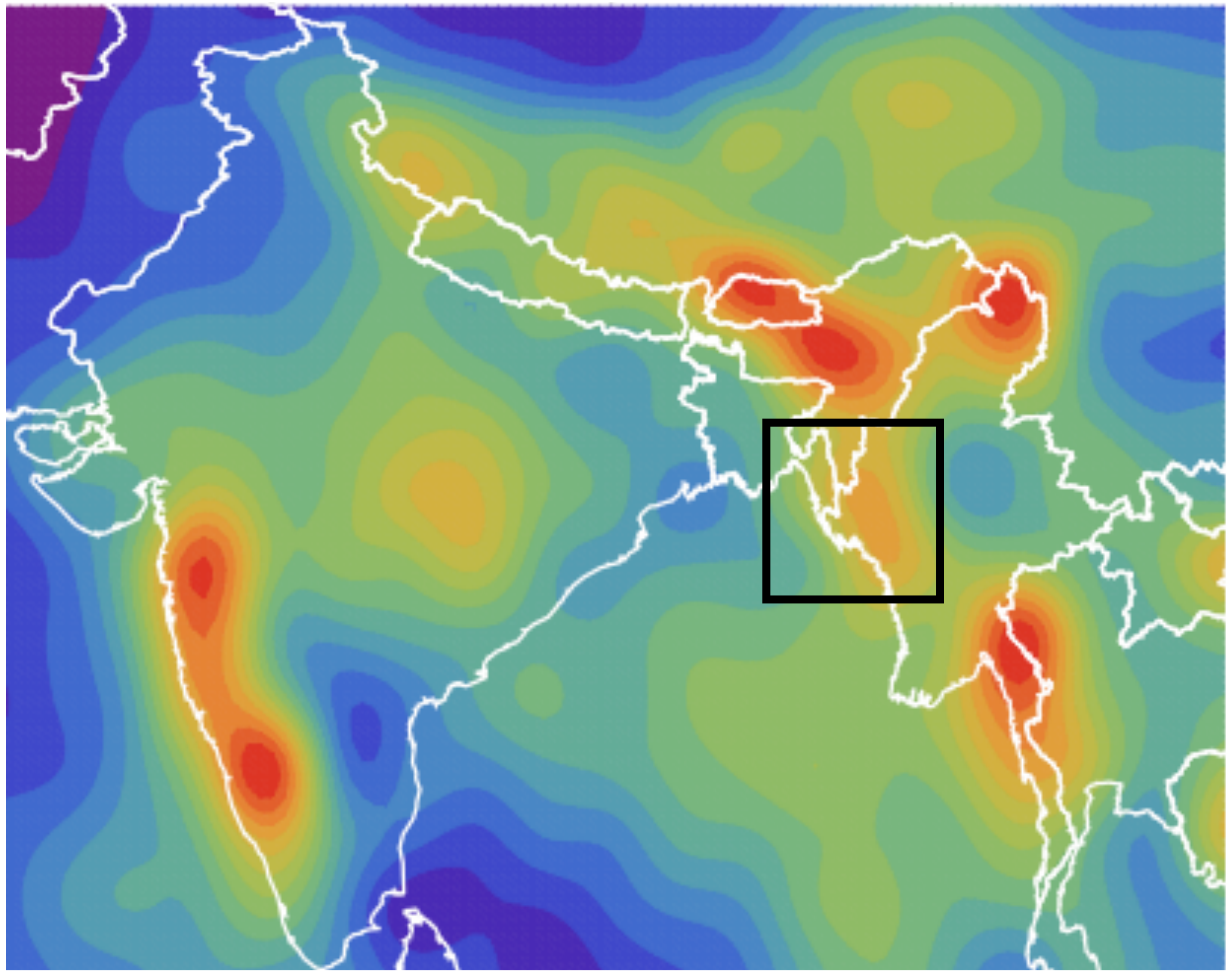

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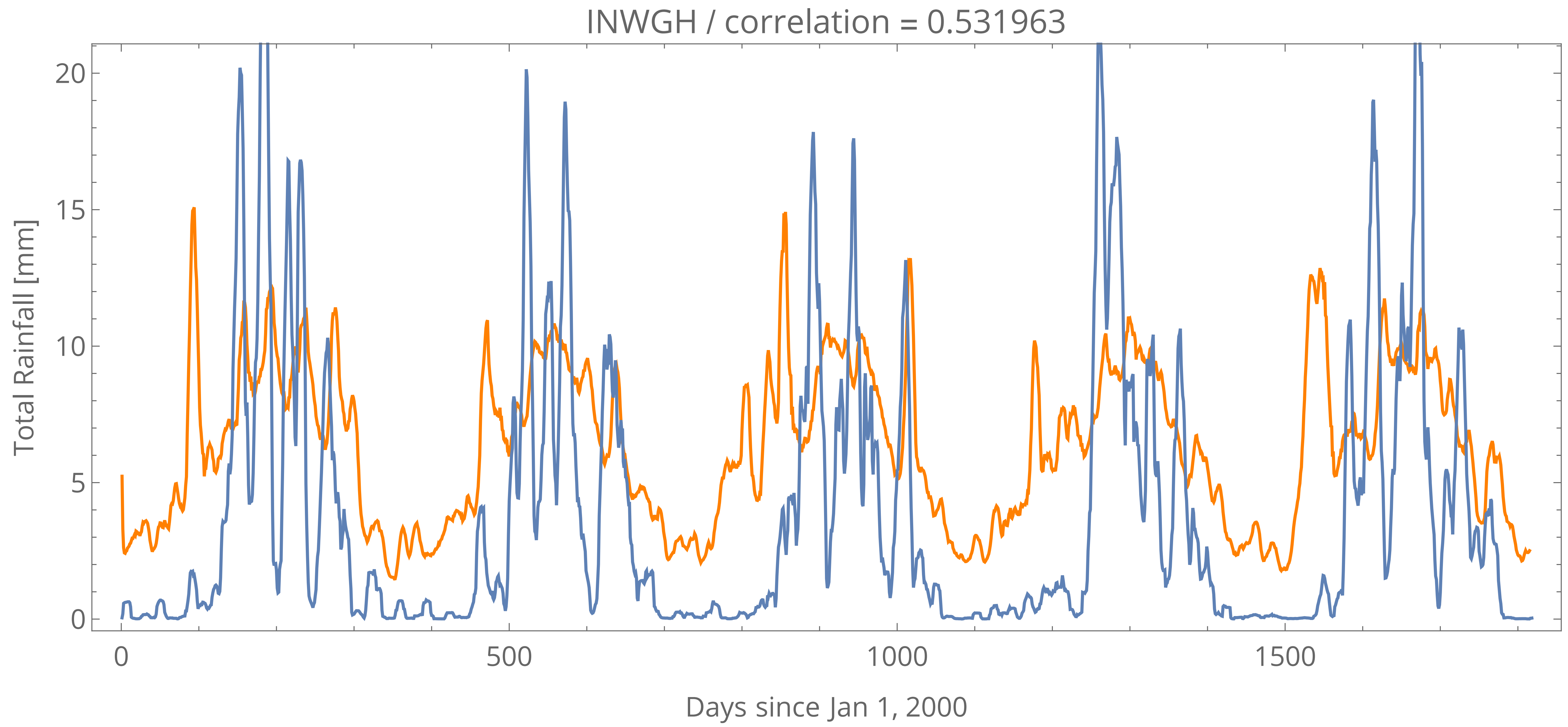

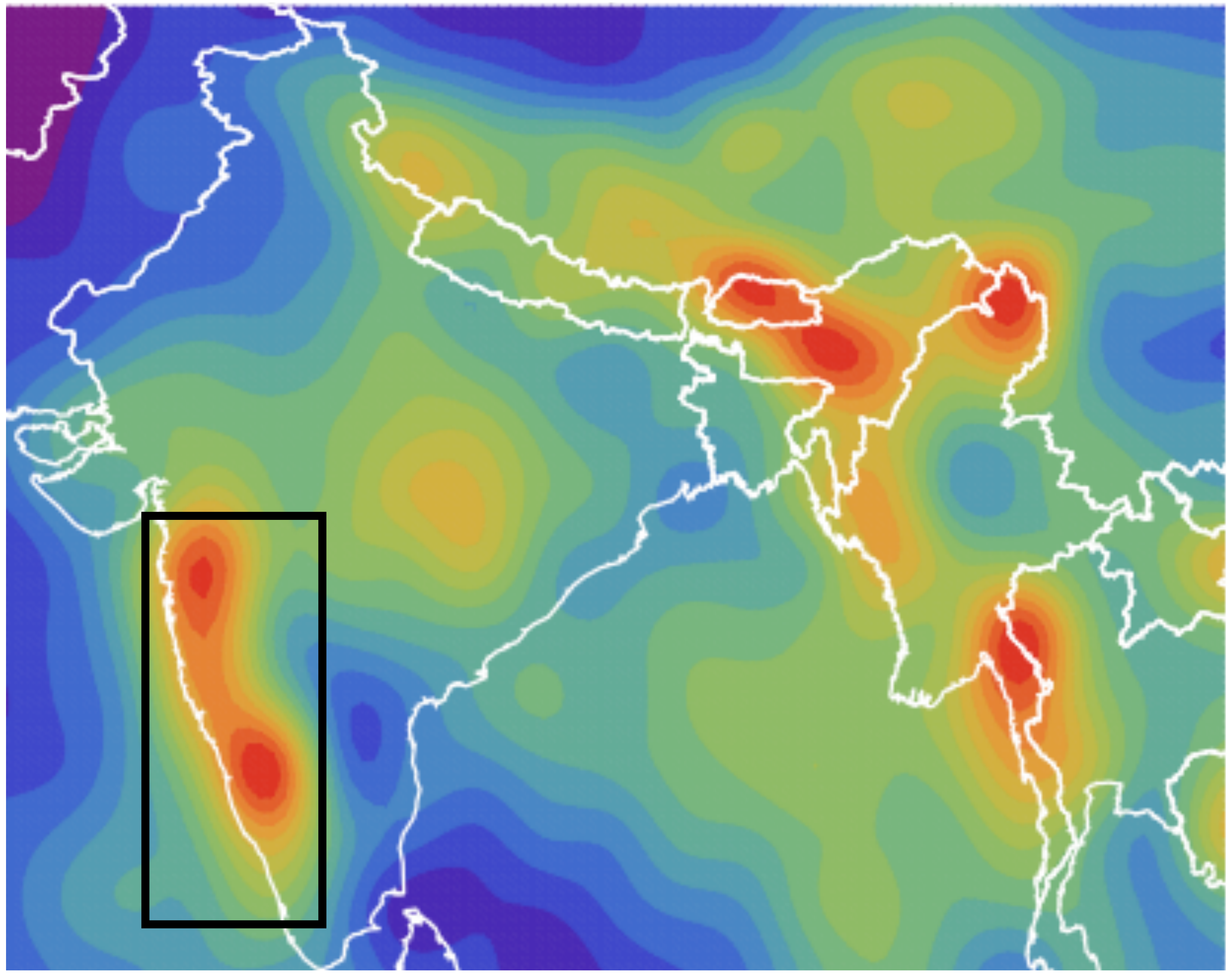

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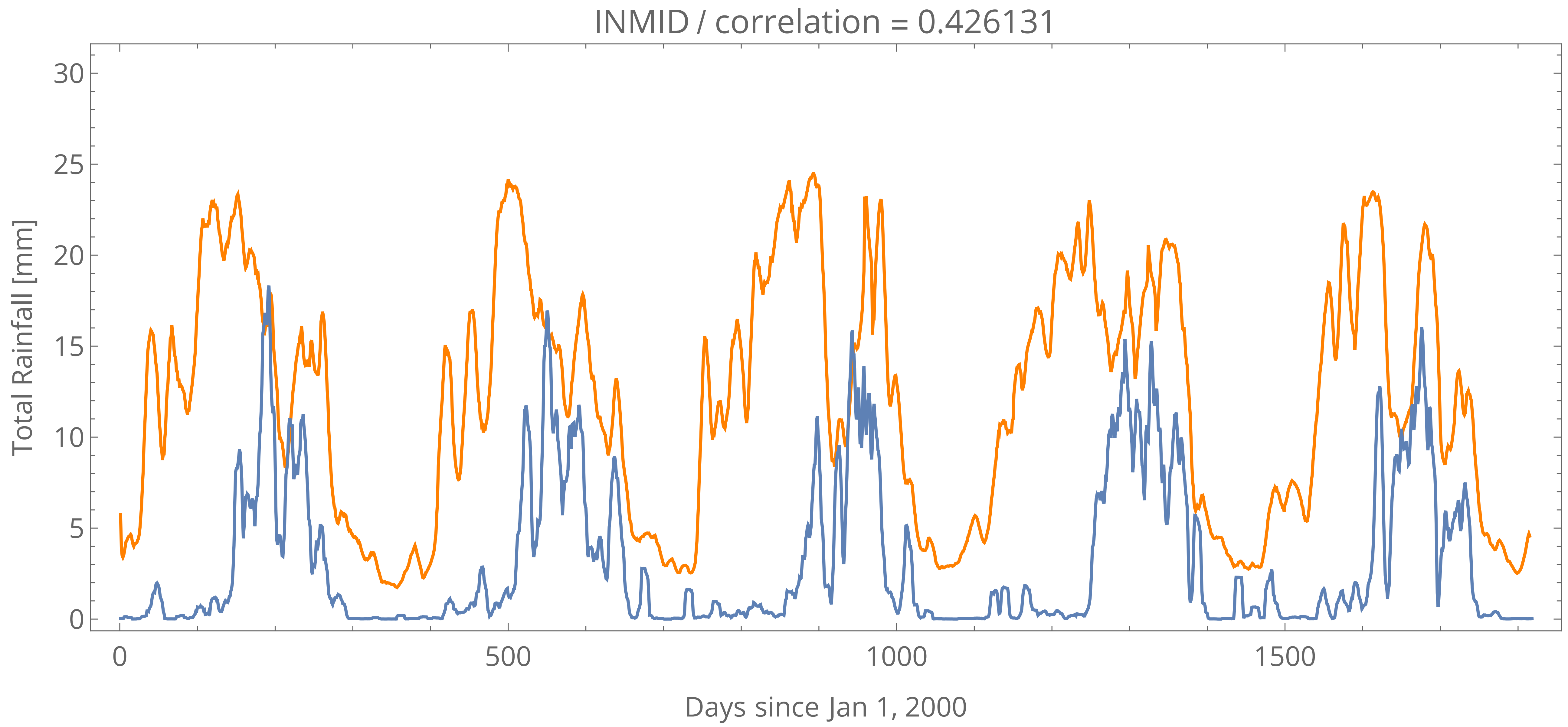

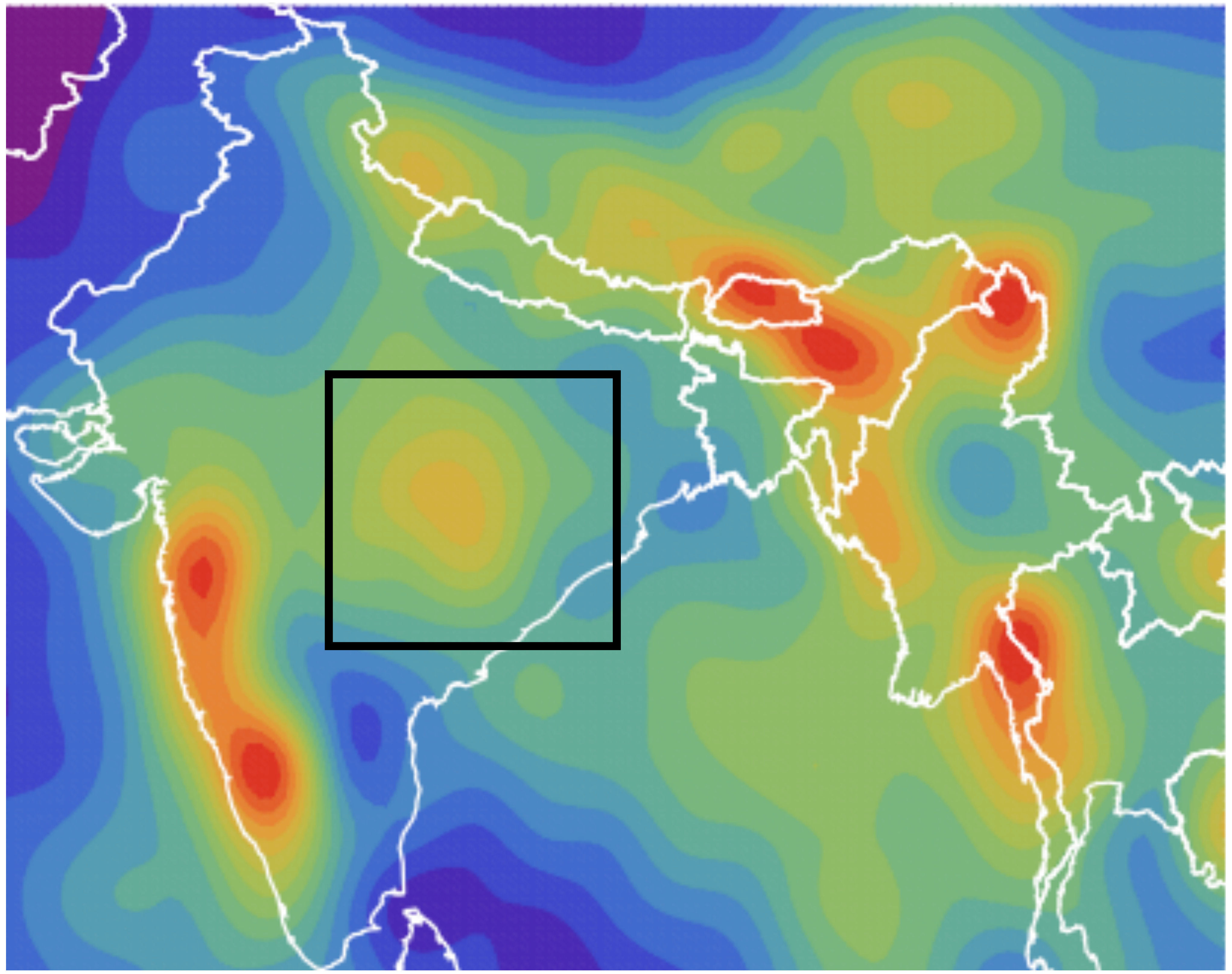

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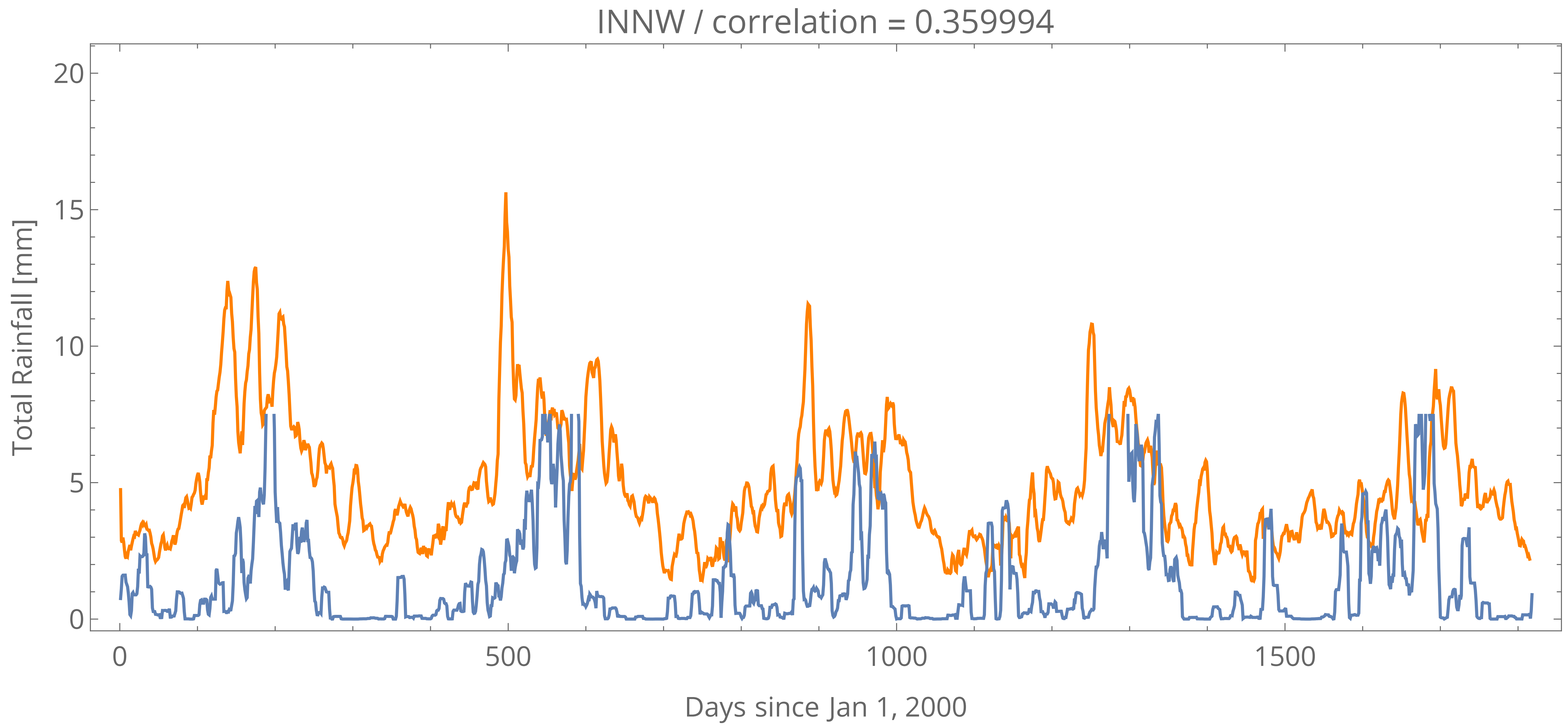
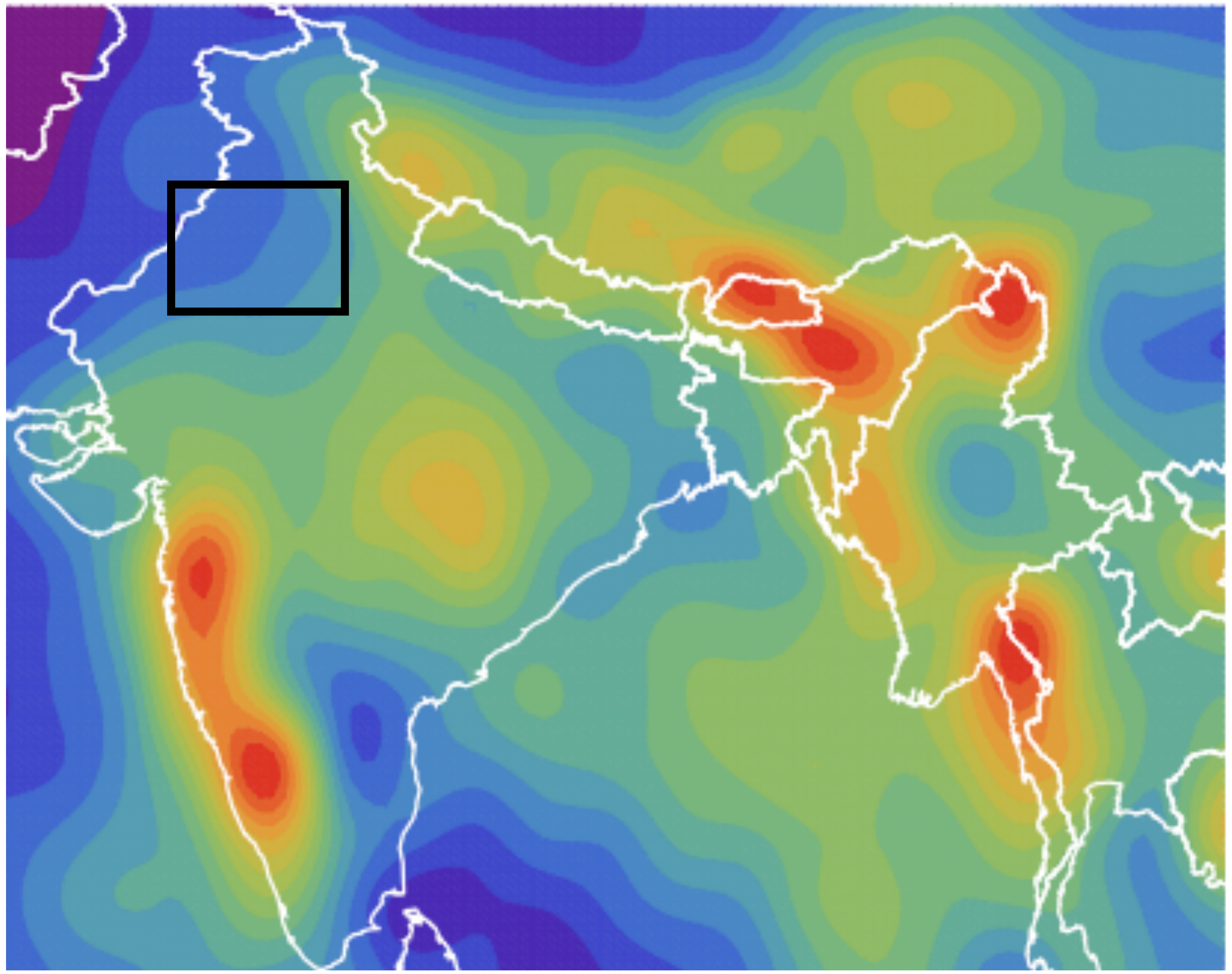


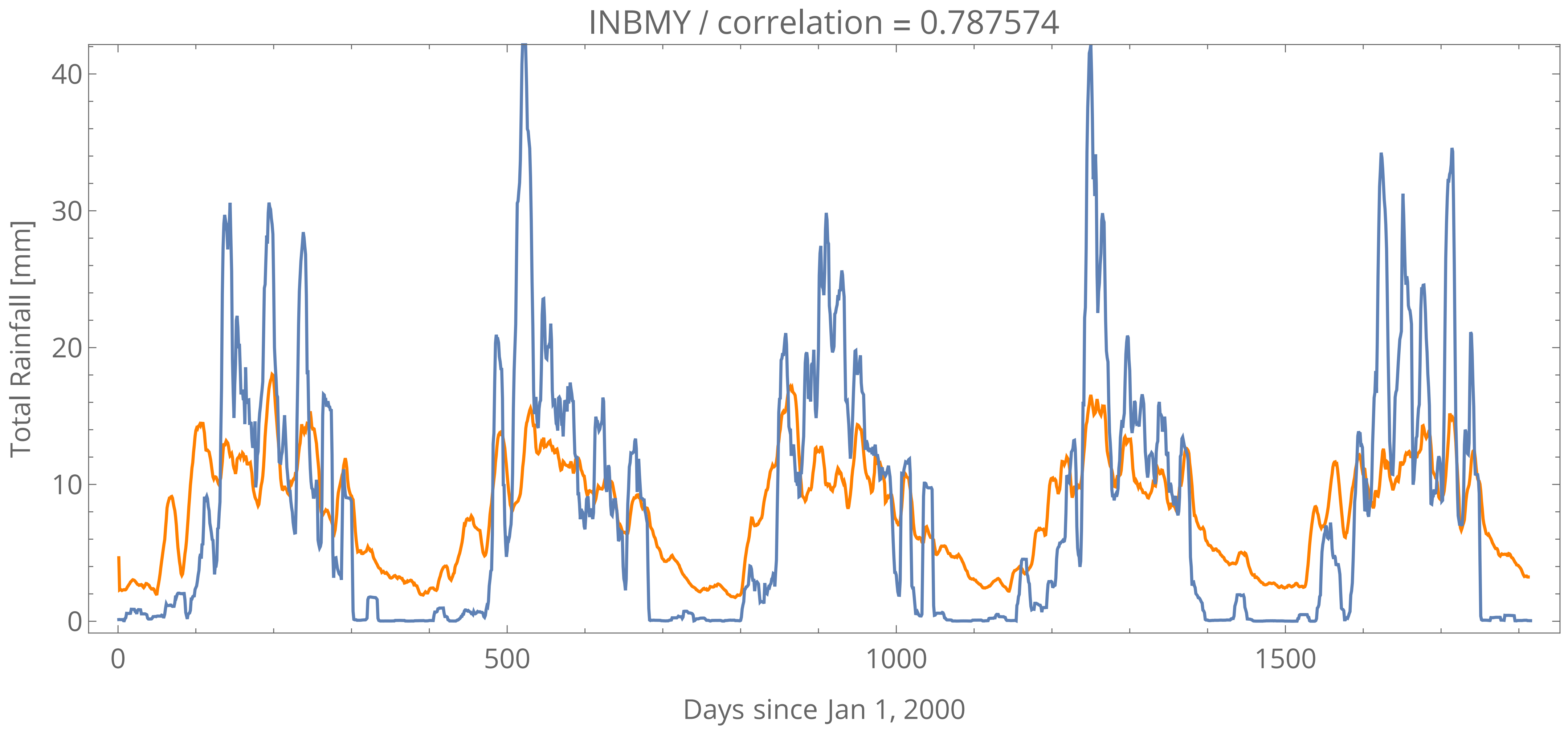


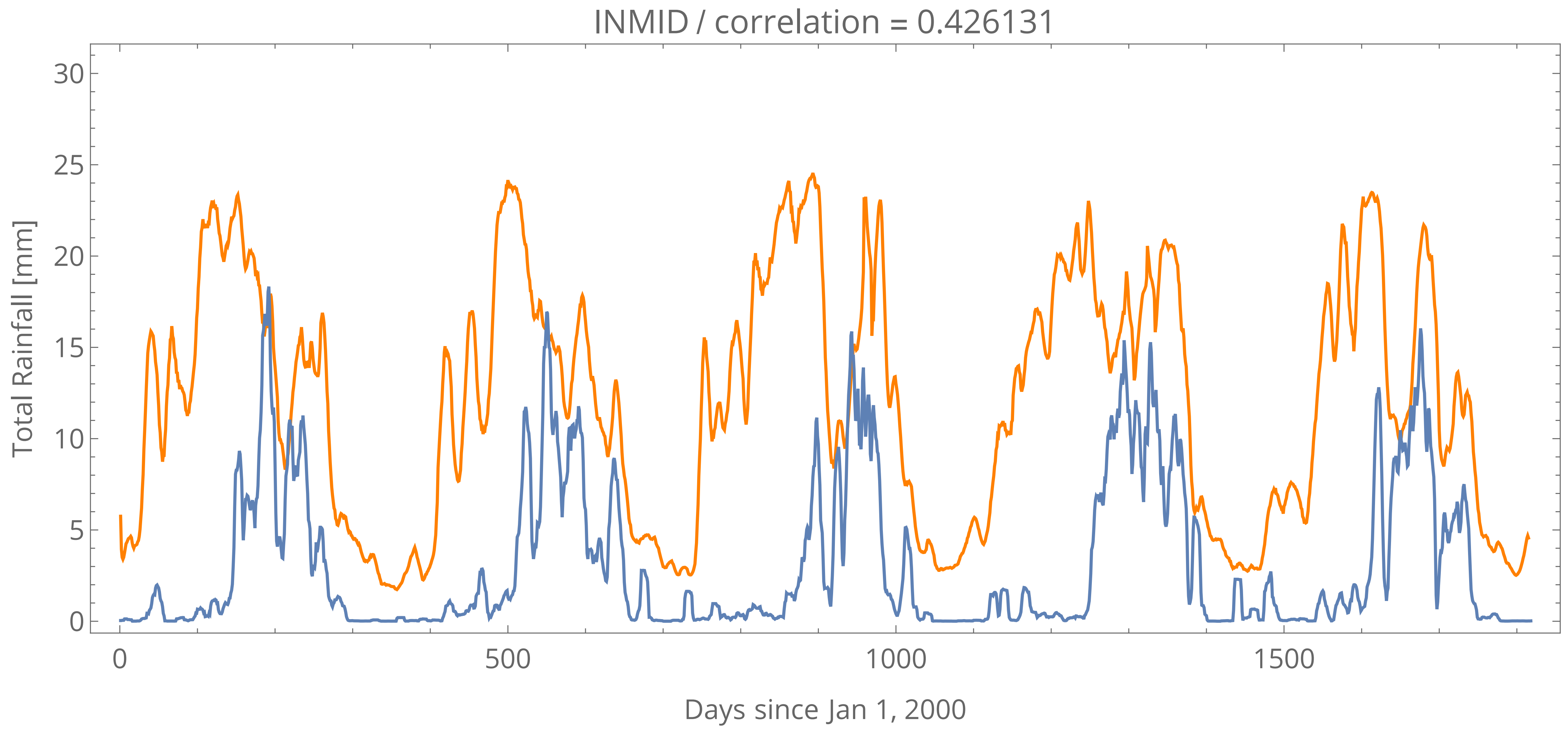
Observations

- Scale and variability well reproduced in certain regions - Bay of Bengal
- Peaks are underestimated in those regions
- Precipitation in interior regions are overestimated
- Abruptness of onset not reproduced well
- Ground water does not play a significant role

What processes / feedbacks are missing?

- Convective motion
- (concentrated) ground/surface water evapotranspiration
- Surface albedo changes due to moisture and vegetation
- Dynamic winds



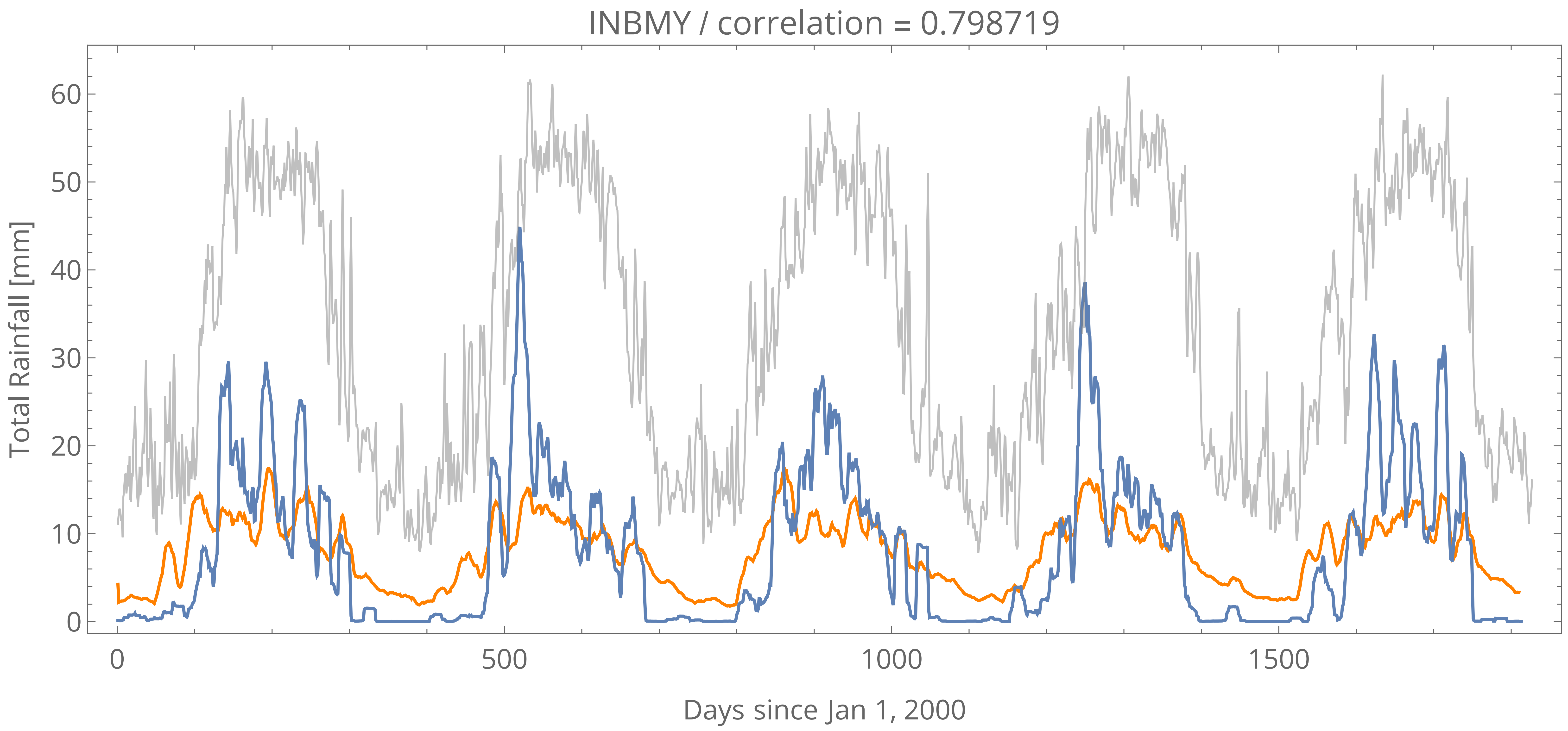


Acknowledgements

- The study was partly funded by the Mathematics and Climate Research Network (MCRN) and Faculty development Grant from Bates College.

- Collaborators, Amit Apte, Rama Govindarajan and Wade Rosko.

- Chris Jones


INBMY / correlation = 0.798719
Total Rainfall [mm]
Days since Jan 1, 2000
0
10
20
30
40
50
60
0
500
1000
1500

CPC June-July soil moisture