Examining the model parameters of COSMO-CLM in 11 selected extreme events over West Bengal (WB), India

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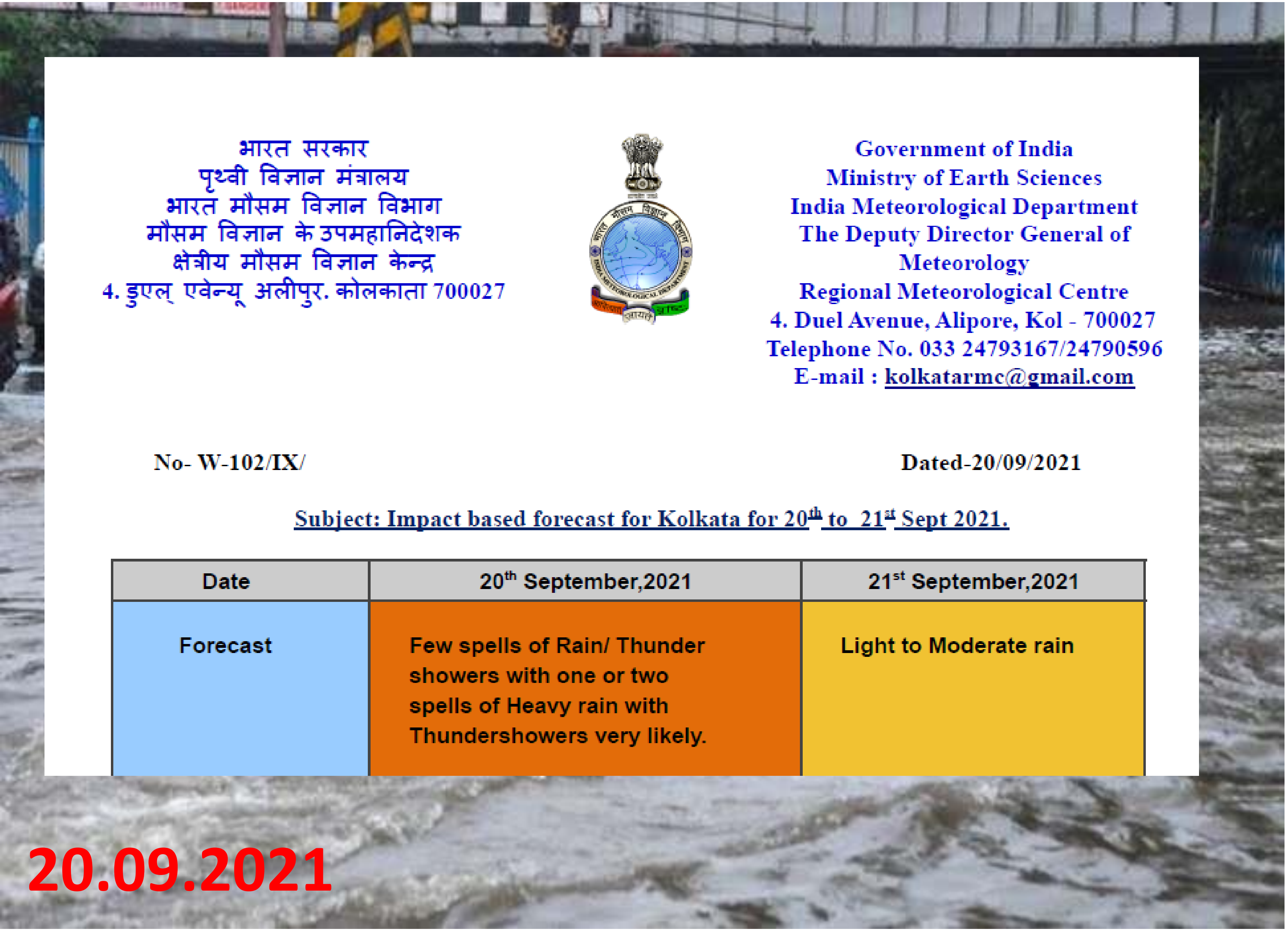

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No- W-102/IX/ Dated-20/09/2021

Subject: Impact based forecast for Kolkata for 20th to 21st Sept 2021.

Date	20th September,2021	21st September,2021
Forecast	Few spells of Rain/ Thunder showers with one or two spells of Heavy rain with Thundershowers very likely.	Light to Moderate rain

20.09.2021

Kolkata received 142 mm of rain in 24 hours till 0830 am and over 100 mm during the six-hour span from 1 am to 7 am.

Due to movement of cyclonic circulation from north-west Bay of Bengal to Gangetic West Bengal.

highest since September 25, 2007, when 174 mm rain was recorded

Motivation

Recent works

- Sensitivity studies with COSMO-CLM over the CORDEX Central Asian Domain shows remarkable deficiencies over sub-regions. In addition, parameterization related to soil and surface features are particularly sensitive. Only subset of model parameters present relevant changes in model performance. (Russo et al., 2019 & Russo et al., 2020).

- Parameter sensitivity for 5-day summer precipitation in the Greater Beijing Area with WRF reports that out of 23 model parameters only 8 are more sensitive than others. (Di et al., 2015).

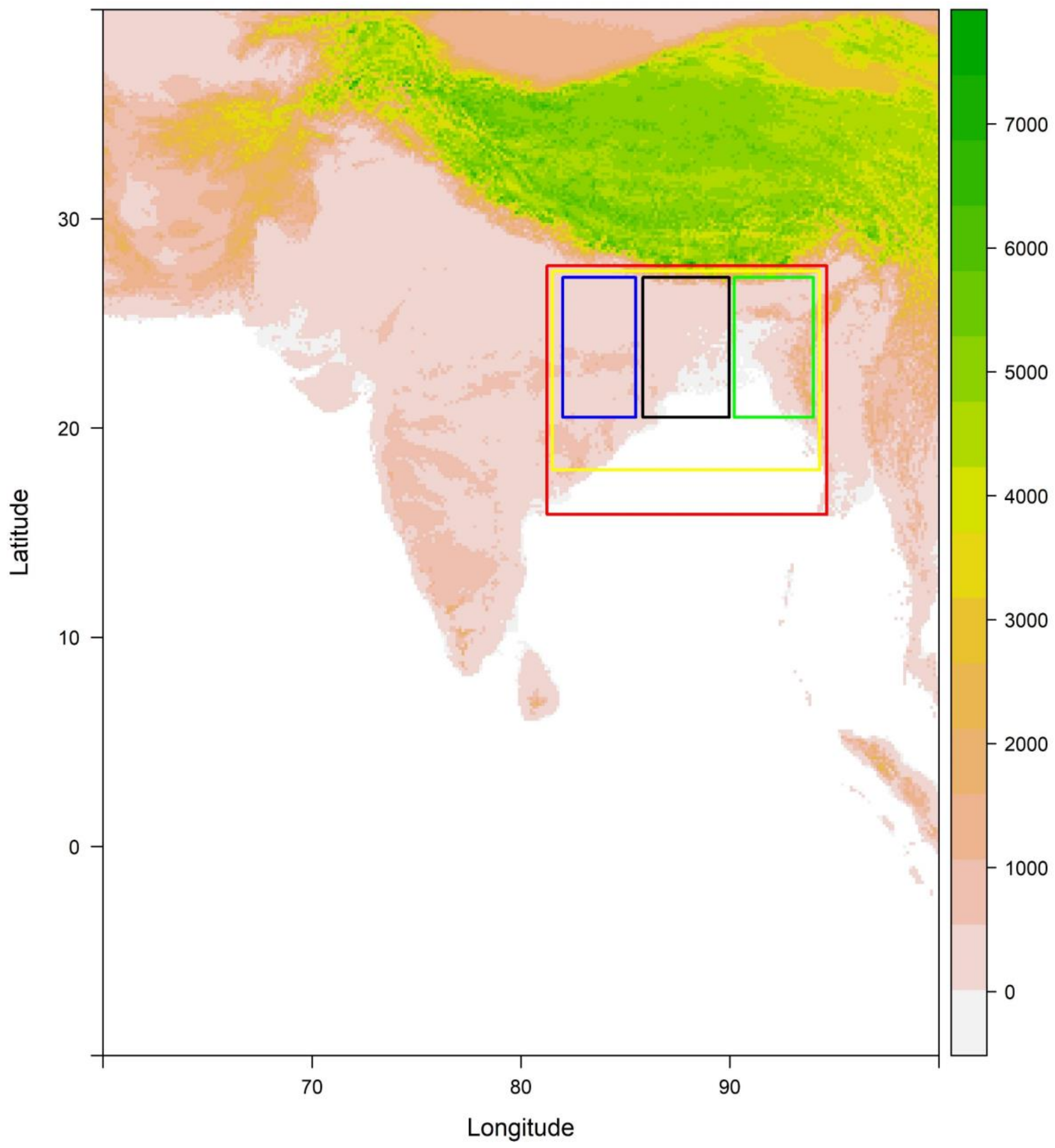
- Over the Indian region, tropical cyclones and high-intensity precipitation events were evaluated using WRF. Results from these studies suggest a subset of model parameters sensitive to model performance. (Chinta et al., 2021, Baki et al., 2021).

No evaluation study have been reported over Eastern India by COSMO-CLM particularly in extreme events

Objective

- 11 extreme weather events over a wide eastern India are produced with the COSMO-CLM model.
- To ascertain model performances with respect to changes in model tuning parameters which are mainly related turbulence, surface, convection, microphysics, radiation, soil parametrization.
- Sensitivity analysis reduces the number of parameters to be tuned to improve the prediction of the model output variables of interest.
- To identify the most critical parameters.

Study region



Detailed definition of each domain are as follows: Simulation domain (WD): 81.25° - 94.64° E, 15.87° - 27.76° N

Inner Domain (ID):
81.50° - 94.30° E, 18° - 27.50° N

Left of West Bengal (LWB):
82° - 85.50° E, 20.52° - 27.20° N

West Bengal (WB):
85.83° - 89.96° E, 20.52° - 27.20° N

Right of West Bengal (RWB):
90.2° - 94° E, 20.52° - 27.20° N.

Mukherjee et al., 2016

List of selected extreme events simulated by COSMO-CLM

Event	Start date	End date
exp01	2013-08-15	2013-08-25
exp02	2014-06-27	2014-07-07
exp03	2015-07-05	2015-07-15
exp04	2014-04-20	2014-04-30
exp05	2014-10-05	2014-10-15
exp06	2014-05-16	2014-05-26
exp07	2015-05-18	2015-05-28
exp08	2013-10-08	2013-10-18
exp09	2018-06-13	2018-16-23

Heavy Rain
Heavy Rain
Heavy Rain
Heat wave
Cyclone Hud Hud
Heat wave
Heat wave
Cyclone Phailin
Heat wave
Heavy Rain
Heavy Rain

- **Enlisted extreme events record heavy rain, cyclone and heat waves.**
- **After identifying the keydate for each of the extreme events, COSMO-CLM was used to simulate each event for 11-day period spanning 5-day before and after the keydate.**

Model & Experiments

- **The COSMO-CLM, a three-dimensional non-hydrostatic regional model was used to evaluate the performance of the model by parameter sensitivity analysis over eastern India.**

- **Simulations were driven by the European Centre for Medium Range Weather Forecasts (ECMWF) reanalysis data sets**

- **The simulations were performed over the domain (81.25° - 94.64° E, 15.87° - 27.76° N) employing a 0.10° spatial resolution with a third order Runge-Kutta scheme for time integration with a time step of 150s. The model produces output with 3-h frequency. The Tiedtke scheme was used for the convection parameterization. The number of atmospheric vertical levels were fixed at 40. The representation of soil moisture is performed using a 9-layer soil module, TERRA-ML, having depth at 11.5 m**

- **The examined model parameters spread across plausible maximum, minimum and intermediate values. The present study considers 25 different model parameters associated with multiple processes such as sub-grid scale turbulence, land-surface, microphysics, radiation, convection and the soil scheme.**

- **All extreme event time slices were run with default values of all the model parameters coined as reference simulation. Then each extreme event window was run with 64 different parameter values one at a time. In total, this study comprises 715 simulations (64*11 +1*11).**

Model Tuning Parameters

Parameter	Description	Values
Turbulence		
tkhmin	minimal diffusion coefficients for heat	(0,**0.4**,1,2)
tkmmin	minimal diffusion coefficients for momentum	(0,**0.4**,1,2)
tur_len	maximal turbulent length scale	(100,**500**,1000)
d_heat	factor for turbulent heat dissipation	(12,**10.1**,15)
d_mom	factor for turbulent momentum dissipation	(12,15,**16.6**)
c_diff	factor for turbulent diffusion of TKE	(0,01,**0.2**,10)
q_crit	critical value for normalized oversaturation	(1,**4**,7,10)
clc_diag	cloud cover at saturation in statistical cloud diagnostic	(0.2,**0.5**,0.8)
Convection		
entr_sc	mean entrainment rate for shallow convection	(5e-5,1e-4,**3e-4**,1e-3,2e-3)

Land Surface		Values
rlam_heat	scaling factor of the laminar boundary layer for heat	(0.1,**1**,3,5,10)
rat_sea	ratio of laminar scaling factors for heat over sea and land	(1,10,**20**,50,100)
rat_can	ratio of canopy height over z0m	(0,**1**,10)
rat_lam	ratio of laminar scaling factors for vapour and heat	(0.1,**1**,10)
c_sea	surface area density of the waves over sea [1/m]	(1,**1.5**,5,10)
c_lnd	surface area density of the roughness elements over land	(1,**2**,10)
z0m_dia	roughness length of a typical synoptic station	(0.001,**0.2**,10)
pat_len	length scale of subscale surface patterns over land	(10,100,**500**,1000)
e_surf	exponent to get the effective surface area	(0.1,**1**,3)

Radiation		
uc1	parameter for computing amount of cloud cover in saturated conditions	(0.2,0.5,0.625,**0.8**)
radfac	fraction of cloud water/ice used in radiation scheme	(0.3,**0.5**,0.9)

Microphysics		
cloud_num	cloud droplet number concentration	(5e+7,**5e+8**,1e+9)
qi0	cloud ice threshold for autoconversion	(**0**,0.00001,0.0001,0.001,0.01)
v0snow	factor for fall velocity snow	(10,15,**25**)

Soil		
soilhyd	multiplication factor for hydraulic conductivity and diffusivity	(**1**,1.62,6)
fac_rootdp2	uniform factor for the root depth field	(0.5,**1**,1.5)

Methodology

$$PERFORMANCE\ INDEX\,(PI) = \frac{1}{n_v \times n_r \times n_h \times n_e} \sum v \sum r \sum h \sum e \left[\frac{\sqrt{(F_{v,r,h,e} - O_{v,r,h,e})^2}}{\sigma_{O_{v,r,h,e}}} \right]$$

Where n_v correspond to the examined number of climate variables, n_r is the number of regions and n_h is the number of hours considered in the entire simulation. COSMO-CLM field value $F_{v,r,h,e}$ is for a variable v, over the region r at some time h against the observation $O_{v,r,h,e}$ for the same variable v, same region r and at the same time h for a given experiment e. σ_o is the standard deviation estimated from the observations corresponding over the entire duration of the simulation for each event. Here $n_v = 3$, $n_r = 5$, $n_h = 88\ timesteps$, $n_e = 11$

$$Performance\ Score\ (PS) = e^{(-0.5PI^2)}$$

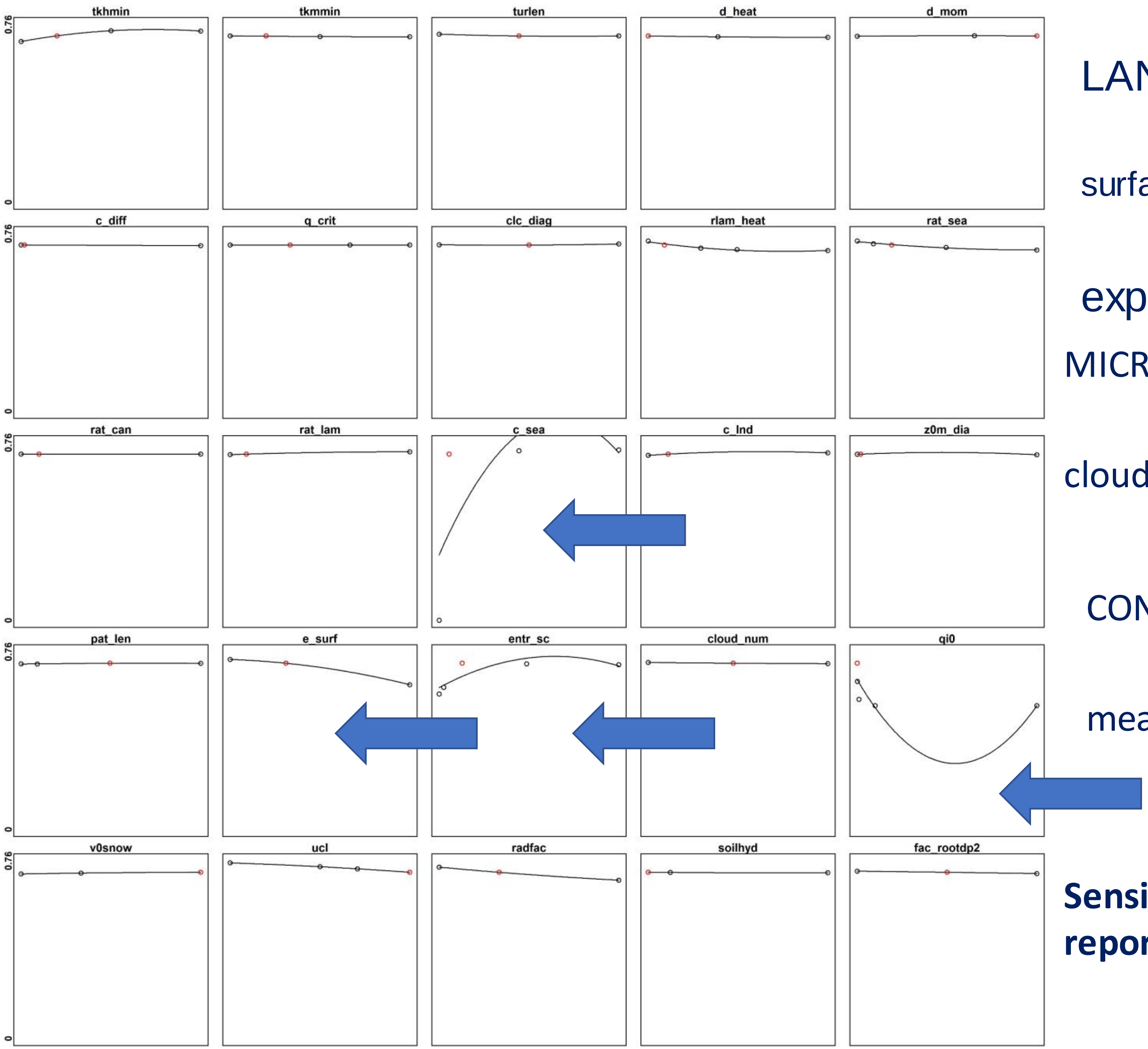
Russo et al., (2020) & Bellprat et al, (2012)

$$Skill\ Score(SS) = \left(1 - \frac{PI_{sim}}{PI_{ref}}\right).$$

Here PI_{sim} and PI_{ref} stands for PI value of a simulation for a given variable and region and PI value for default model configuration respectively

MERRA (Modern Era Representative analysis for Research and Applications) was employed for model evaluation. Simulated 2m-temperature (2TM), precipitation (PR), and cloud cover (CC) were validated against the MERRA gridded data sets.

PS computed for all the considered variables



Most Sensitive Parameters

LAND SURFACE

surface area density of the waves over sea [1/m] (c_sea)

exponent to get the effective surface area (e_surf)

MICROPHYSICS

cloud ice threshold for autoconversion (qi0)

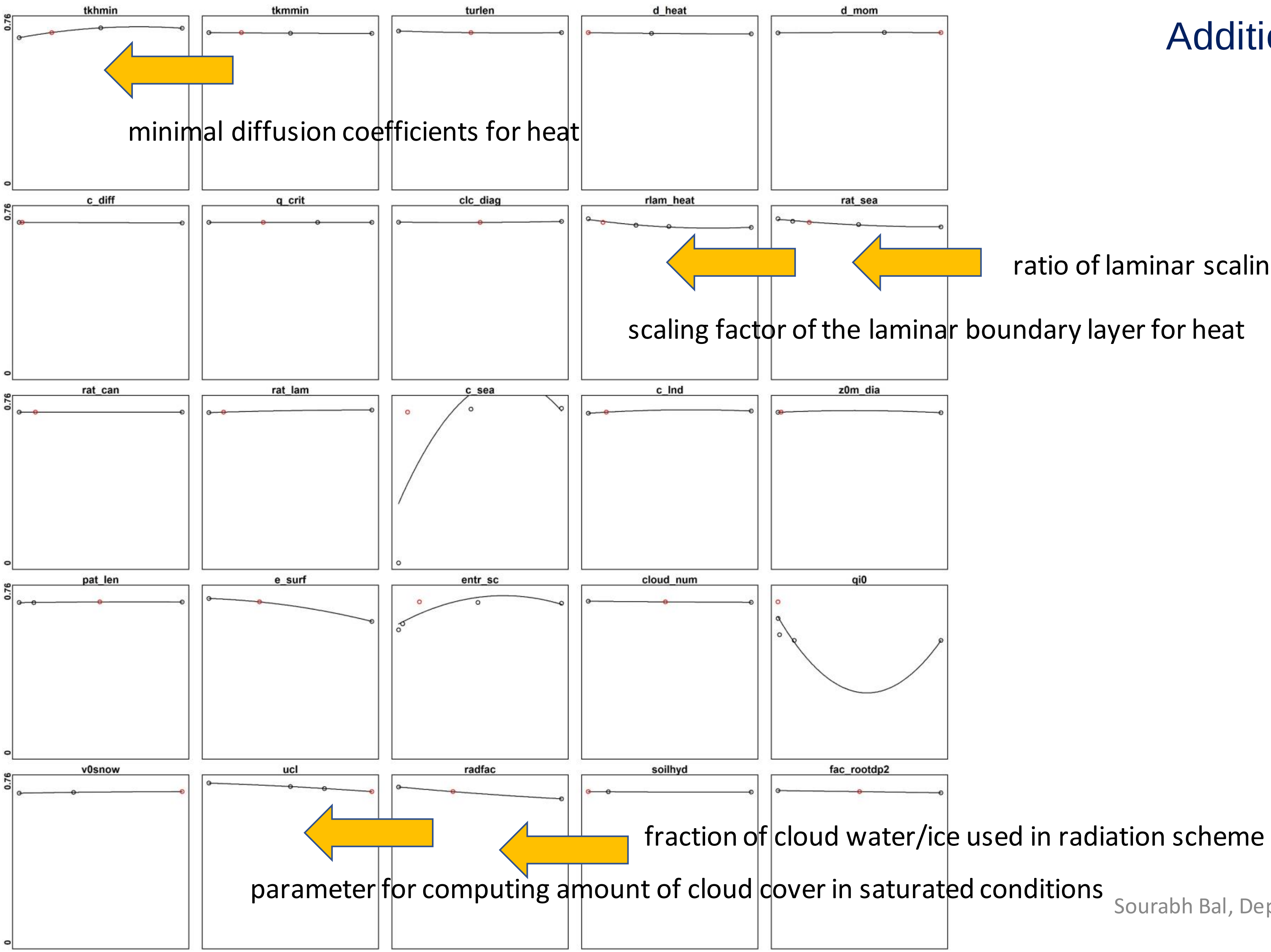
CONVECTION

mean entrainment rate for shallow convection (entr_sc)

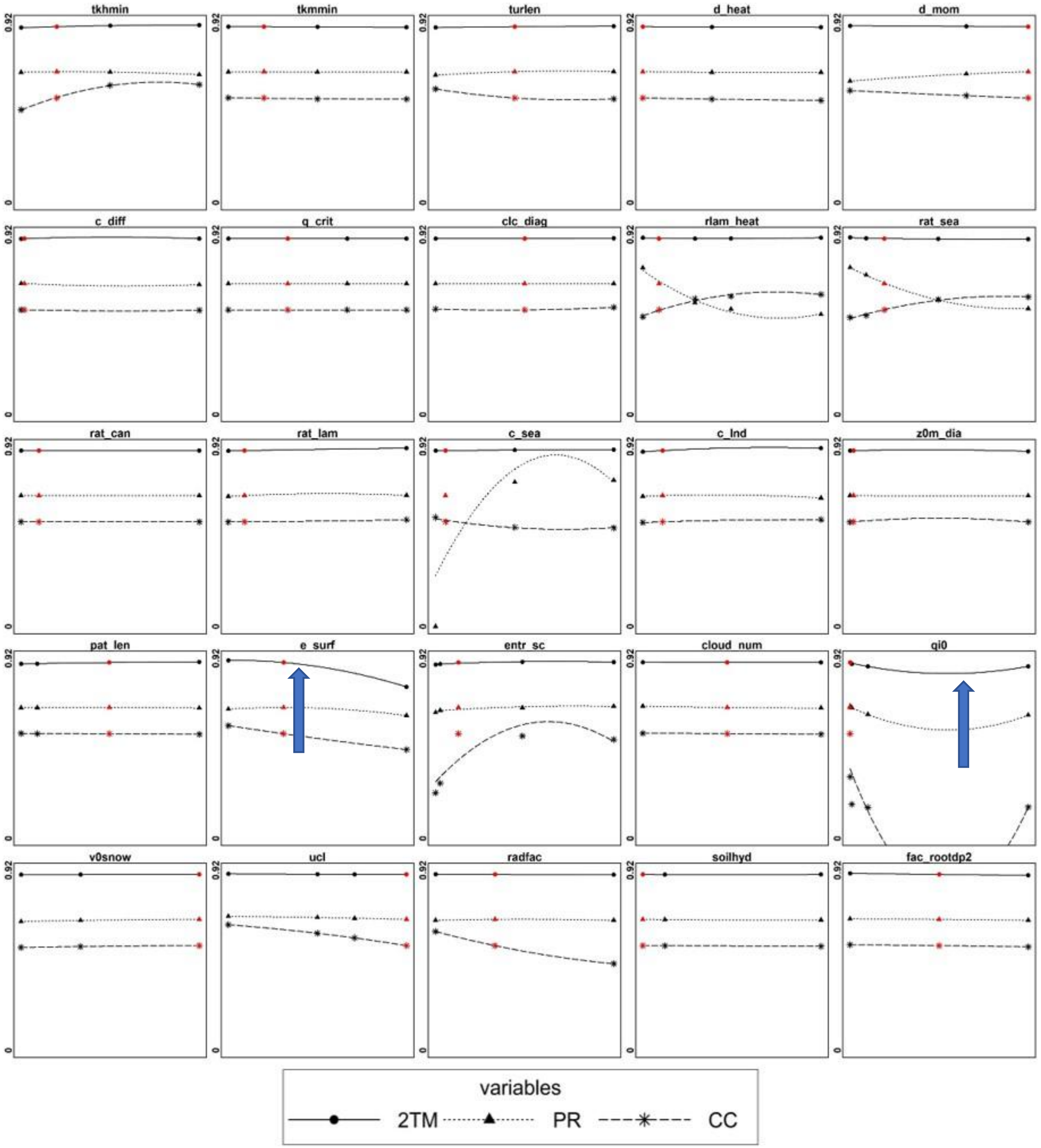
Sensitive parameters identified in this study has also been reported by Russo et al., 2020

PS computed for all the considered variables

Additional Sensitive Parameters



PS computed for each variable separately

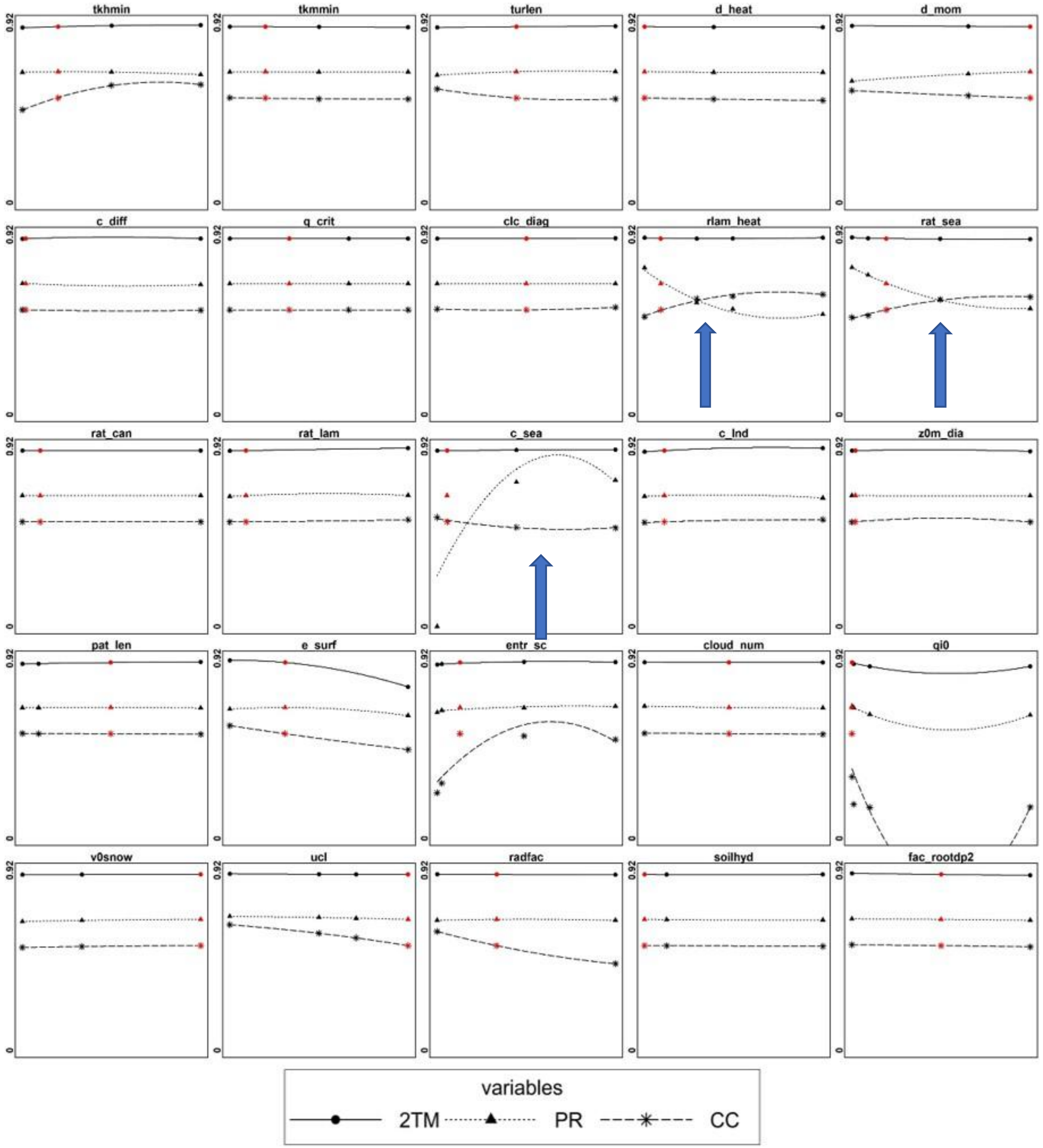


Common model parameters with the largest variation in PS for each variable separately are

e_surf -> exponent to get the effective surface (Land Surface)

qi0 -> cloud ice threshold for auto conversion (Microphysics)

PS computed for each variable separately



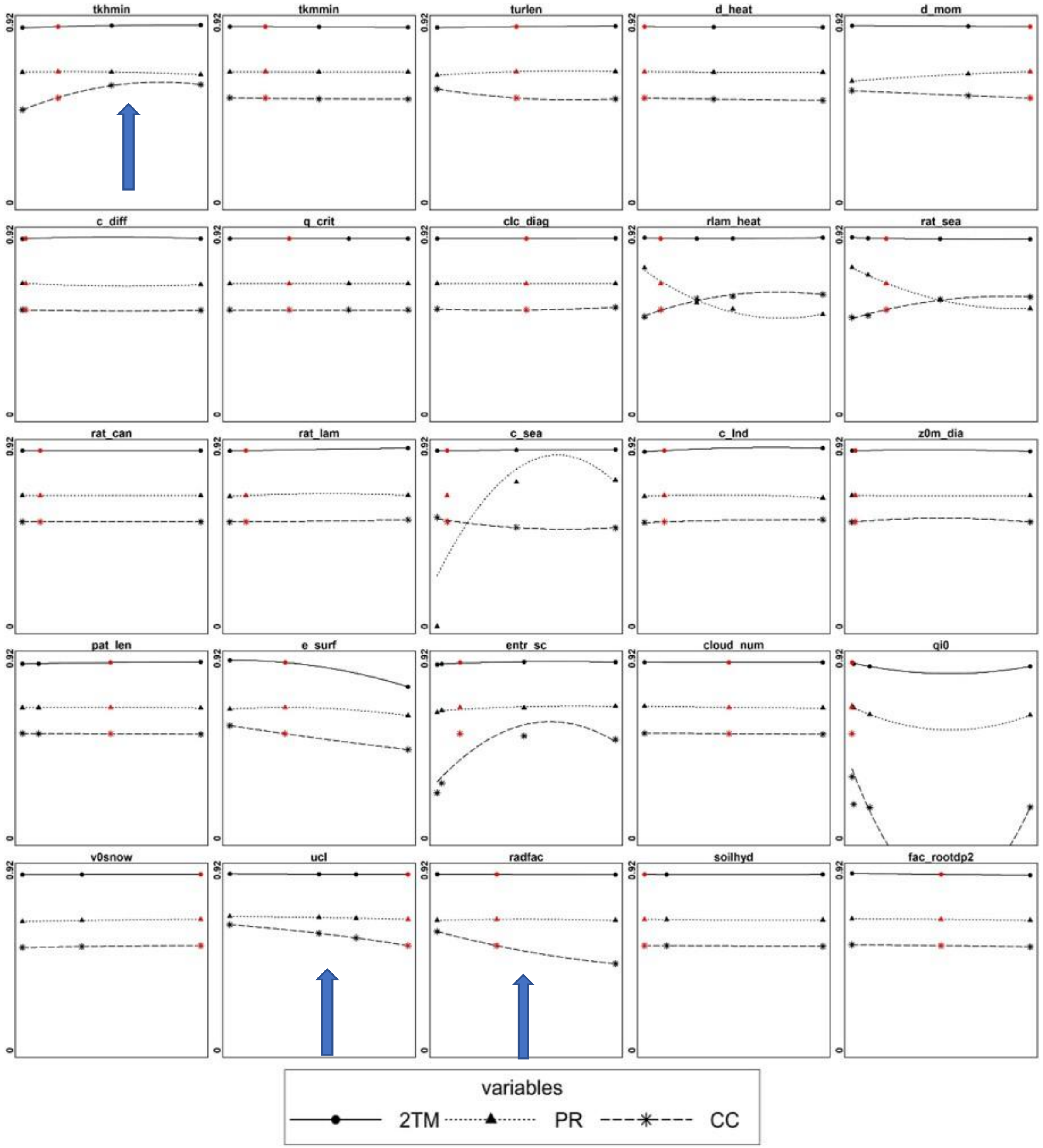
Common sensitive parameters for Precipitation and Cloud Cover Separately studied

rlam_heat -> scaling factor of the laminar boundary layer for heat (Land Surface)

rat_sea -> ratio of laminar scaling factors for heat over sea and land (Land Surface)

c_sea -> surface area density of the waves over sea (Land Surface)

PS computed for each variable separately



Parameters sensitive to improve Cloud Cover only are

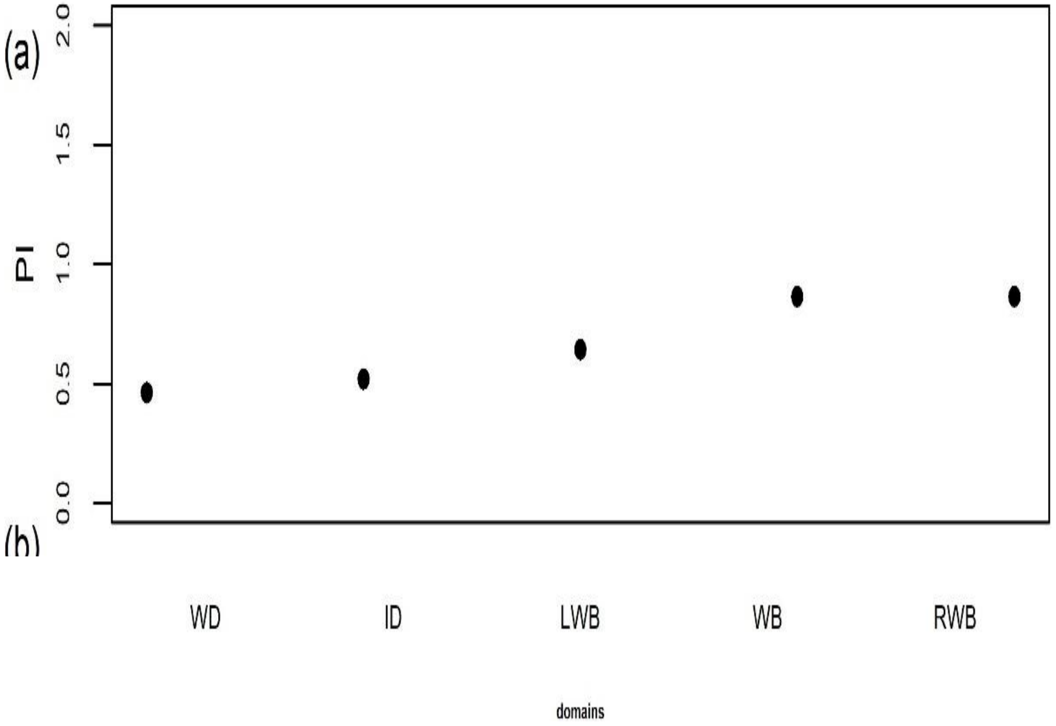
tkhmin -> minimal diffusion coefficients for heat (Turbulence)

uc1-> parameter for computing amount of cloud cover in saturated conditions (Radiation)

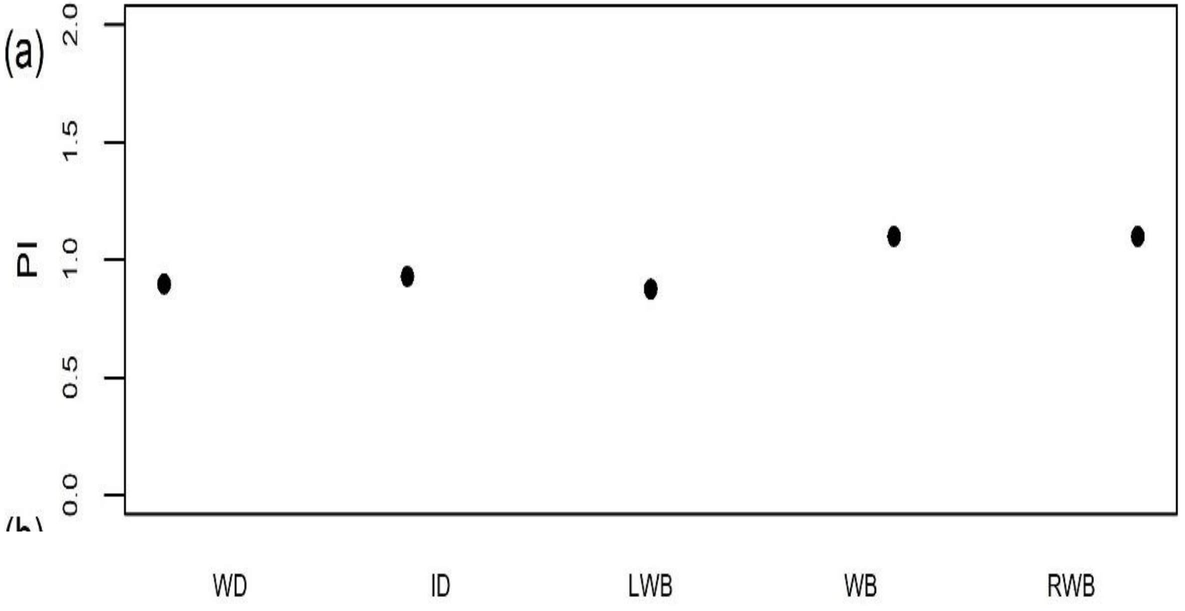
radfac-> fraction of cloud water/ice used (Radiation)

PI value for reference simulation

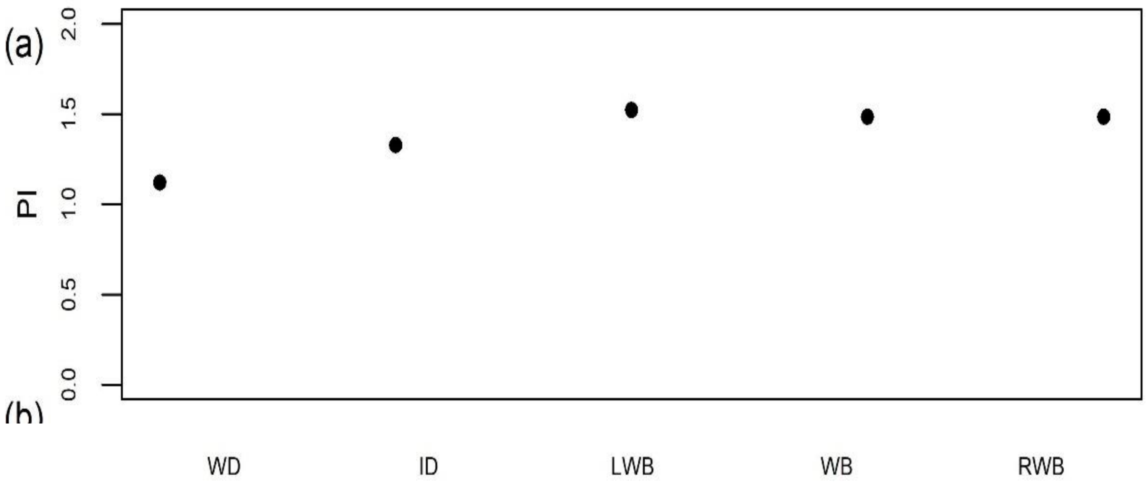
2m-Temperature



Precipitation

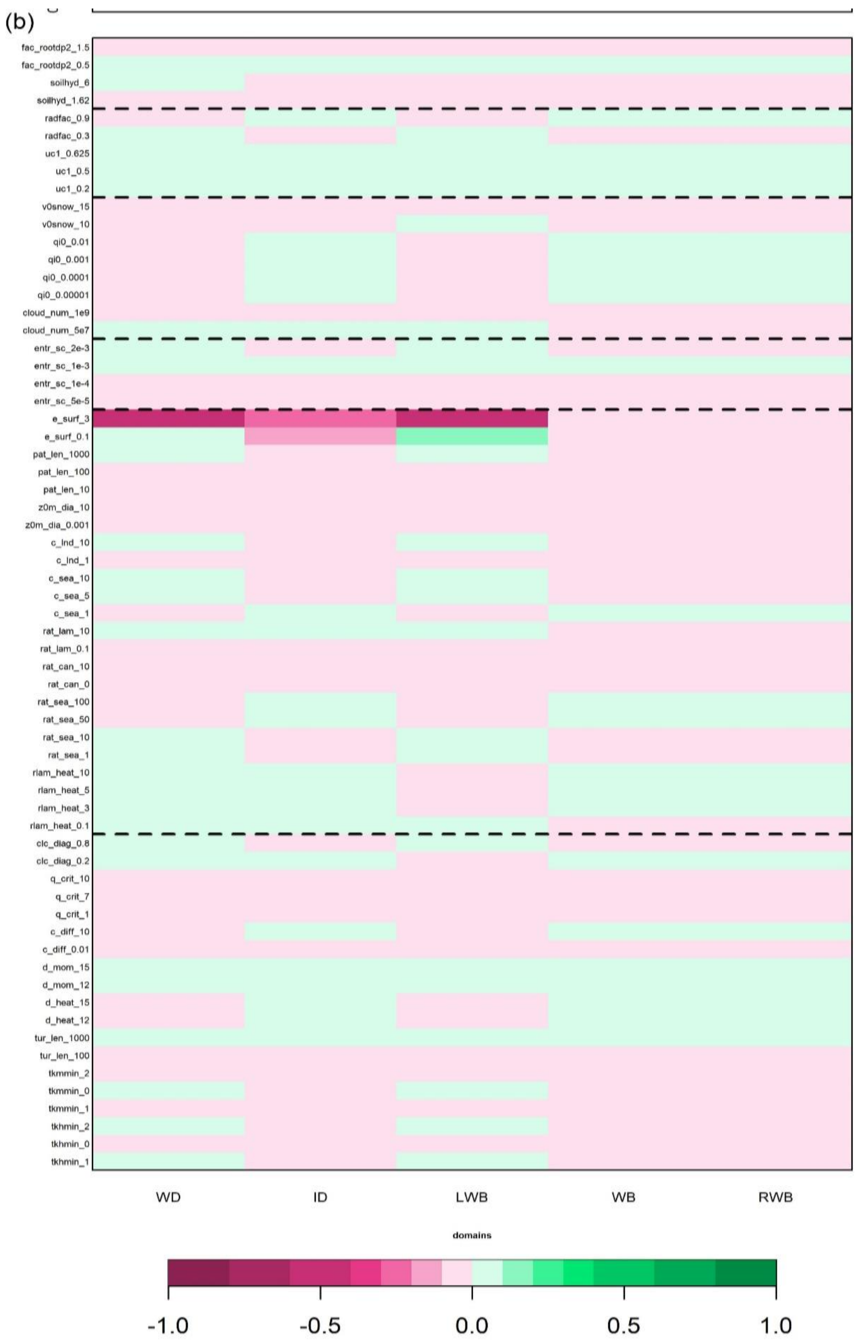


Cloud Cover



- The magnitude of the PI value suggests that the model performs best in simulating 2m-Temperature followed by Precipitation and Cloud Cover.
- Model performs slightly better in whole domain than in sub-domains is evident for 2m-Temperature and Cloud Cover.

Skill Score for 2m-Temperature



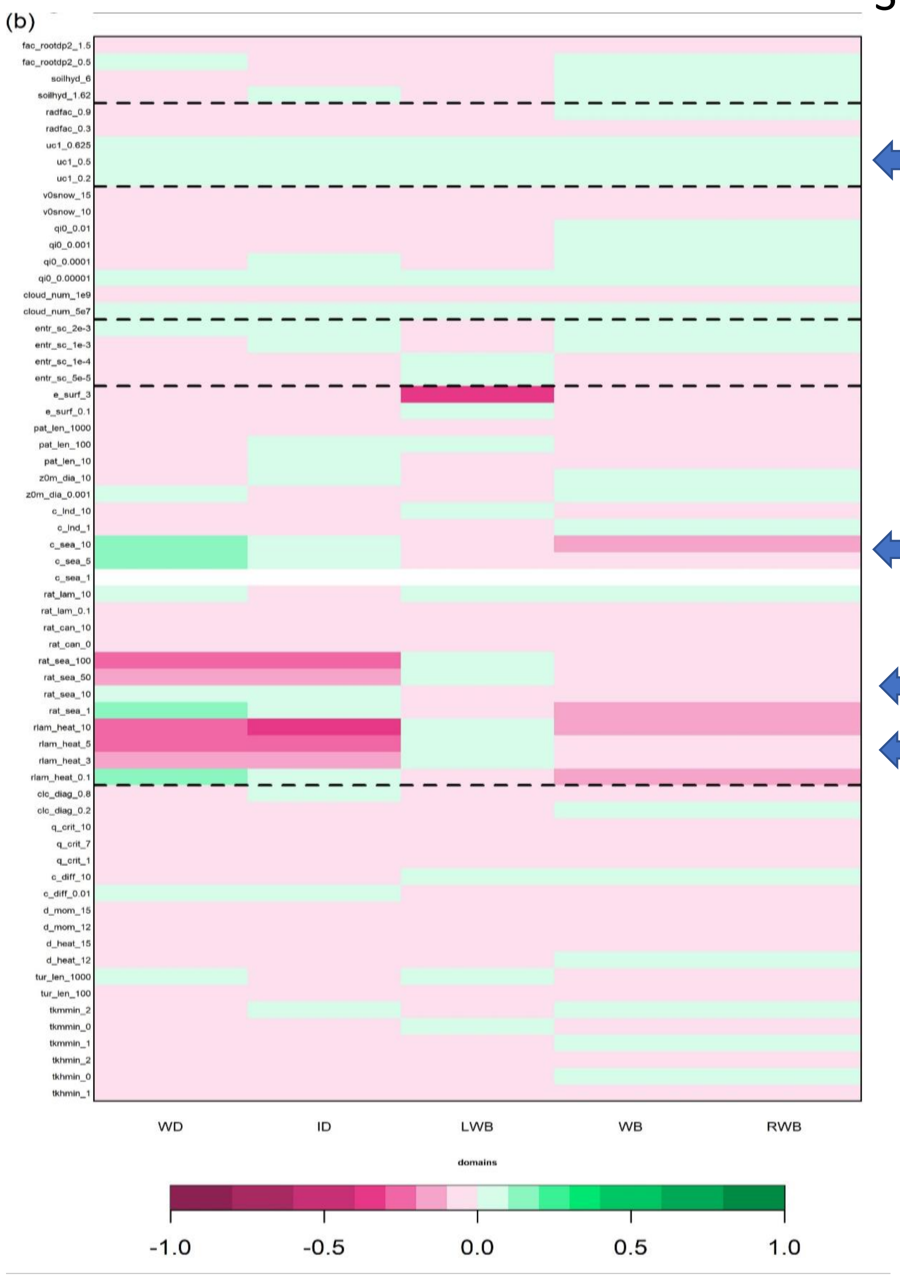
parameter for computing amount of cloud cover in saturated conditions (uc1)

exponent to get the effective surface area (e_surf)

- **The largest positive changes in SS is obtained for e_surf in LWB on the other hand poor performance by the model in other domains by e_surf.**
- **A small amplitude positive changes in SS observed for uc1 and d_mom for all domains.**

factor for turbulent momentum dissipation (d_mom)

Skill Score for Precipitation



parameter for computing amount of cloud cover in saturated conditions (uc1)

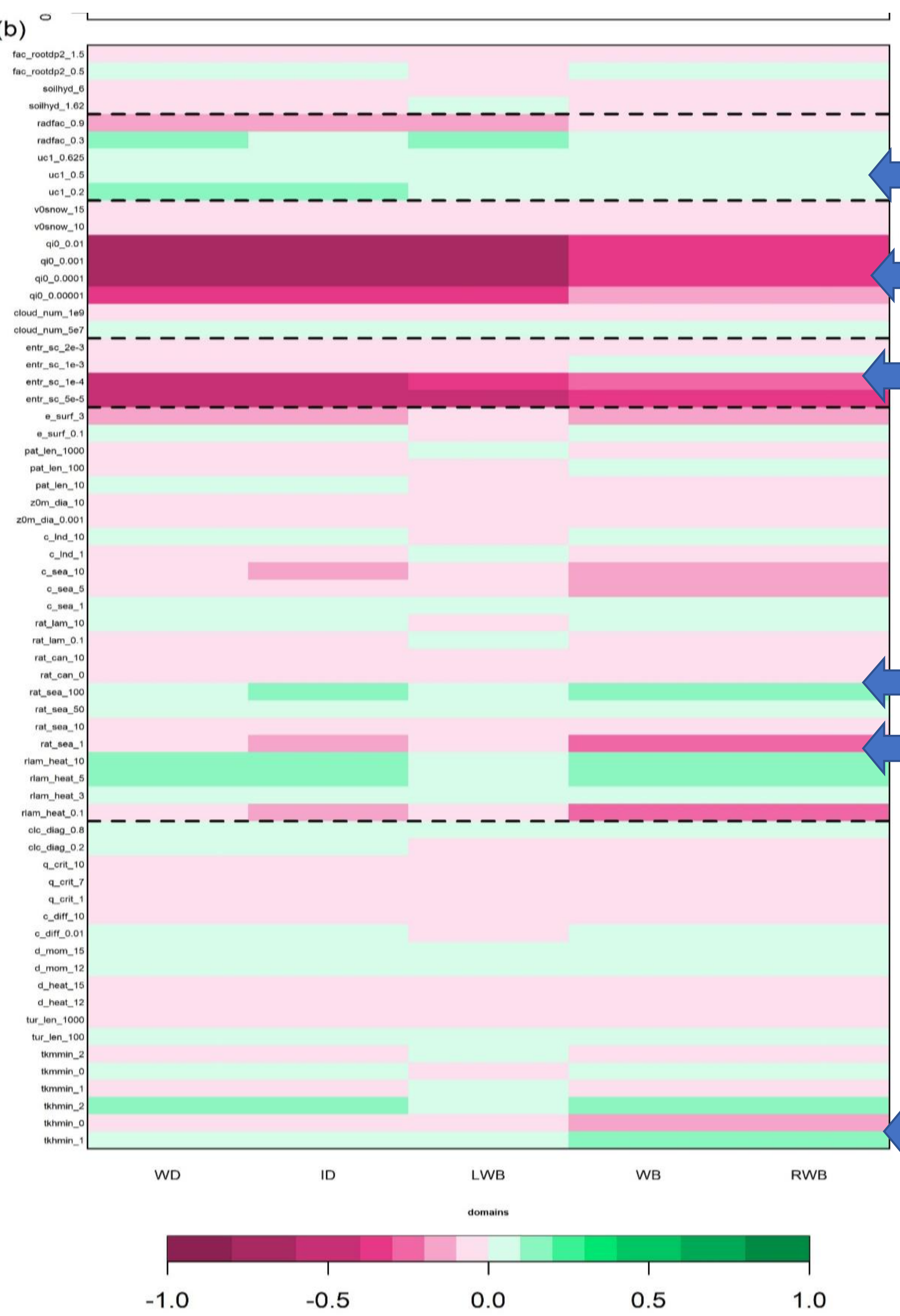
surface area density of the waves over sea [1/m] (c_sea)

ratio of laminar scaling factors for heat over sea and land (rat_sea)

scaling factor of the laminar boundary layer for heat (rlam_heat)

- **Model performance in simulating precipitation can enhance by properly choosing parameter value of c_sea, rat_sea, rlam_heat.**
- **uc1 shows positive SS changes for all the domains for precipitation.**

Skill Score for Cloud Cover



parameter for computing amount of cloud cover in saturated conditions (uc1)

cloud ice threshold for autoconversion (qi0)

mean entrainment rate for shallow convection (entr_sc)

ratio of laminar scaling factors for heat over sea and land (rat_sea)

scaling factor of the laminar boundary layer for heat (rlam_heat)

- **negative SS changes is confirmed by qi0 and e_surf**
- **chance to improve model performance can be achieved by tkhmin, uc1, d_mom, rat_sea, rlam_heat**

minimal diffusion coefficients for heat (tkhmin)

Conclusions

- The cloud ice threshold for auto conversion (**qi0**) and exponent to get the effective surface area (**e_surf**), and mean entrainment rate for shallow convection (**entr_sc**) are the most sensitive parameters in simulating all the three variables inferred from PS.

- The next set of additional sensitive parameters are **tkhmin, rlam_heat, rat_sea, c_sea, radfac, and uc1.**

- Model reliability estimated from PI is low for cloud cover compared to 2m-temperature and precipitation when model parameters are set to default values (reference simulation).

- There is no strong indication of better performance by the model w.r.t the model with default parameter values in simulating 2m-temperature. Among the model parameters employed, **uc1** (computing amount of cloud cover in saturated conditions) shows positive skill score for all the domains and variables.

- Soil parameterization scheme does not play any key role at least in this study

Thank you