Identifying the Optimal WRF-ARW Configuration for the Wet Season in the Amazon Rainforest

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Introduction

The Amazon rainforest, located in the tropics with its deep expansive forests and bordered by the downwind Andes mountains, is the world's largest and most intense land-based convective center. It plays a significant role in shaping atmospheric dynamics and circulation patterns both within the basin and beyond. Convection in the Amazon occurs across a wide range of spatiotemporal scales and is primarily influenced by easterly waves carrying moisture from the Atlantic Ocean, as well as complex land-surface interactions. Understanding the underlying dynamics and thermodynamics of these atmospheric processes becomes challenging due to the limited temporal and spatial resolution of observational datasets. Therefore, the convection-permitting regional weather models could serve as a valuable tool for studying these phenomena.

Objectives

WRF model provides a range of parameterization options for physical processes, and the accuracy of simulating real-world environments depends on the selection of the appropriate combination of these parameterizations, grid spacing, and initial and boundary conditions for the specific locations and time periods. This study aims to evaluate the WRF model performance of various combinations of physical parameterizations during the wet season in the Amazon basin.

Weather Research & Forecasting (WRF)

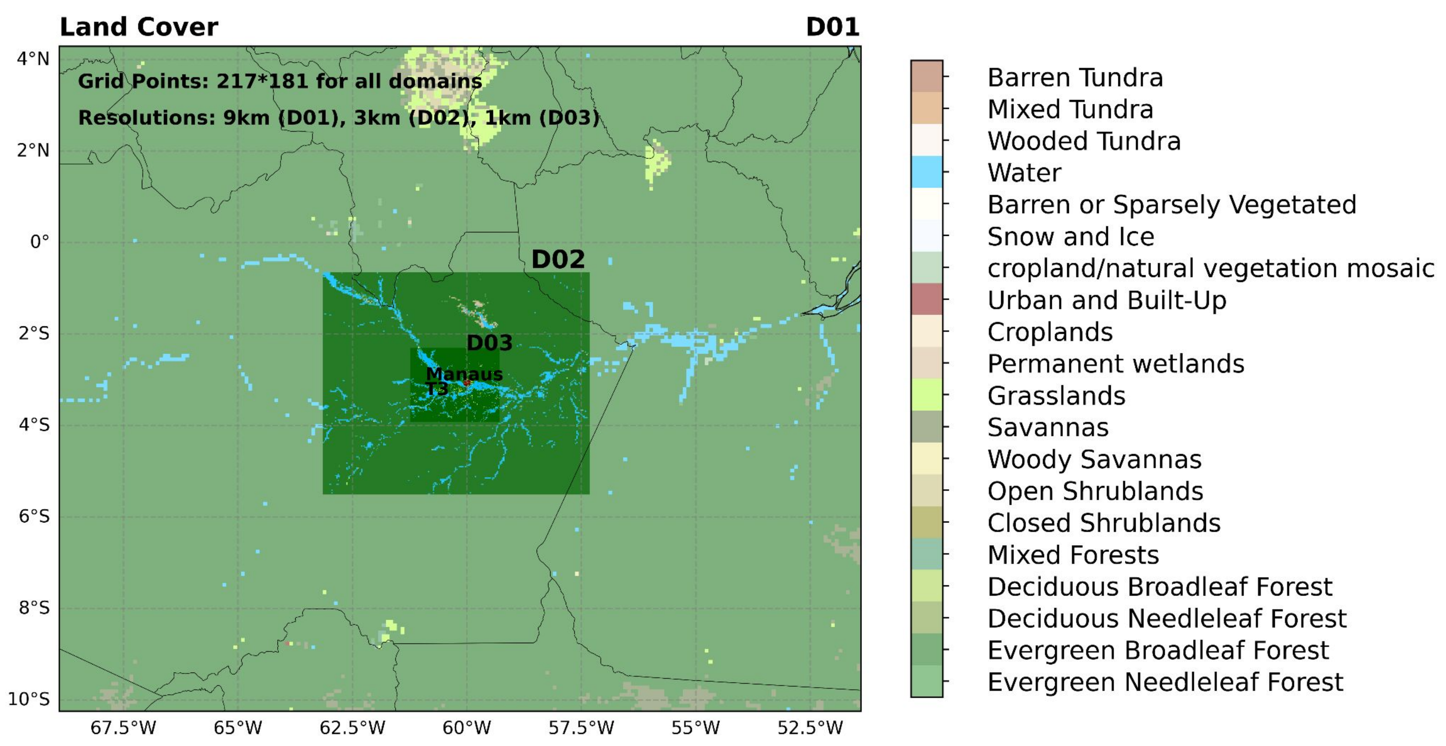
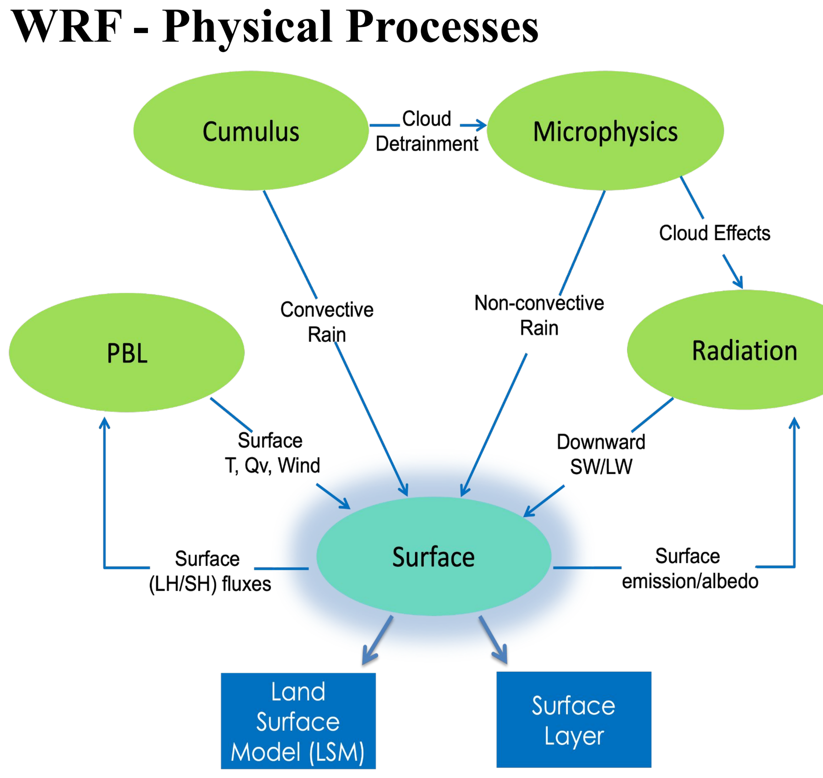
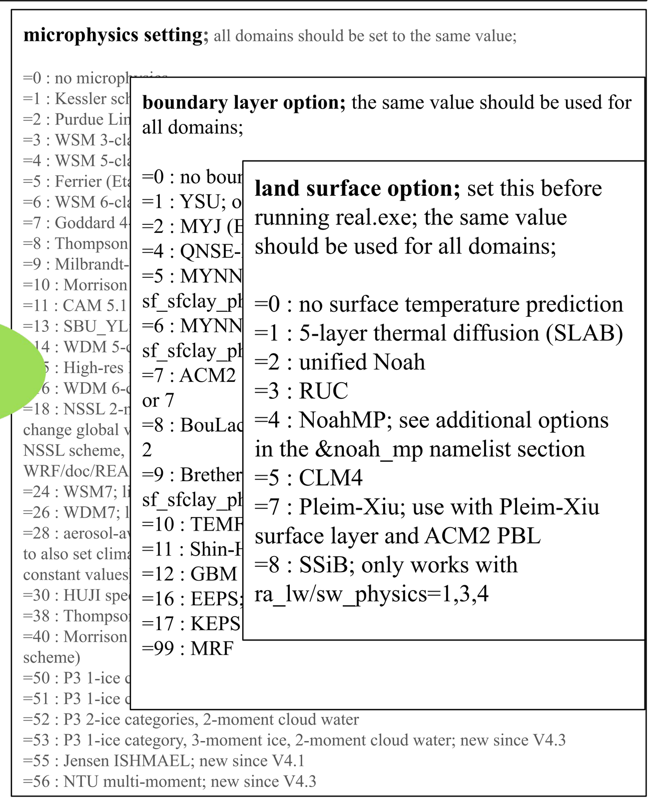


Fig: Domain Setup

- **WRF-ARW 4.4.1**
- All domains have 65 vertical levels with model top 10 hPa
- Model Output: Each 60min, 60min, and 30min
- Initial and Lateral Boundary Condition: ERA5 reanalysis, 0.25*0.25 degrees with hourly update
- Simulation period: 2014-12-11 to 2014-12-18

WRF - Physical Processes





Evaluated WRF Physical Parameterizations:

- Land Surface Model (**LSM**) : Unified Noah (Noah), NoahMP, RUC [3]
- Planetary Boundary Layer (**PBL**) : MYNN, MYJ, SH, YSU [4]
- Microphysics (**MP**) : Morrison 2-moment, Thompson, WDM, WSM6 [4]
- Cumulus (**CU**) : BMJ, G3, KF (D01 only) [3]

Optimal combination of physical schemes

$$\text{Taylor Skill Score (TSS)} = \frac{2(1+R)}{(\hat{\sigma} + \frac{1}{\hat{\sigma}})^2}$$

Where, R is correlation coefficient and $\hat{\sigma}$ is the ratio of simulated to observed (**ARMBE**) standard deviation.

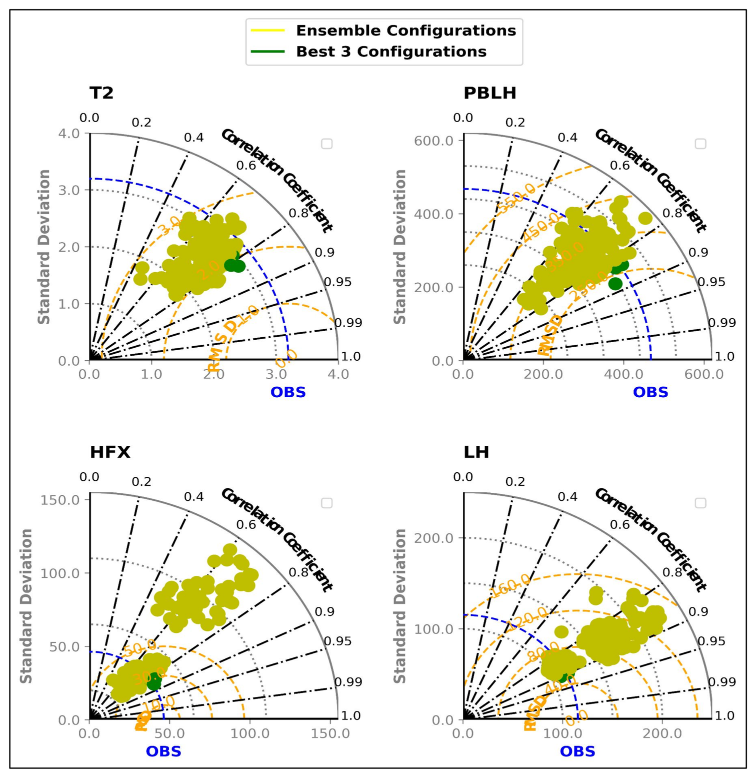


Fig. Taylor diagram for evaluated variables (D03 only). The **Green** dot represents best three configurations and **Olive** represents all ensemble configurations.

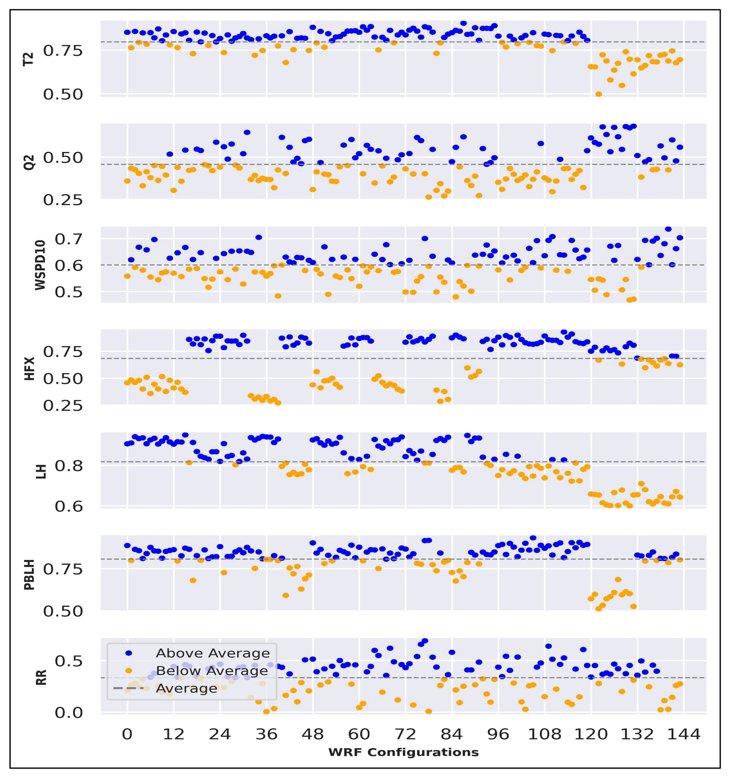


Fig: Taylor Skill Score (D03 only) for **144** ensemble experiments, from top to bottom: 2m Temperature (**T2**), 2m Humidity (**Q2**), 10m Wind Speed (**WSPD10**), Surface Sensible (**HFX**) and latent (**LH**) heat flux, Planetary Boundary Layer Height (**PBLH**), and surface Rain Rate (**RR**).

- The T2, LH, and PBLH shows highest TSS in average, whereas RR and Q2 show lowest.
- The optimal combinations of physical schemes vary with the variable of interest.

Optimization of parameterization for all evaluated variables:

$$\text{Aggregated Weighted TSS} = \sum_{v=1}^{v} w_v T_v \quad \text{where, } w_v = \frac{1-\bar{T}_v}{\sum_{v=1}^{v}(1-\bar{T}_v)}, \quad \bar{T}_v \text{ is}$$

average TSS for vth evaluation variable, and $\sum_{v=1}^{v} w_v = 1$.

SN	Configuration	Agg. TSS
1.	ERA5_MM5_NOAH_YSU_Morrison_G3	0.692355
2.	ERA5_MM5_NOAH_YSU_Thompson_G3	0.689488
3.	ERA5_MM5_NOAH_YSU_WSM6_G3	0.663904
4.	ERA5_MM5_RUC_YSU_Morrison_G3	0.661634
5.	ERA5_MM5_NOAH_SH_WSM6_G3	0.659852
6.	ERA5_MYJ_NOAH_MYJ_Morrison_G3	0.645367
7.	ERA5_MYJ_NOAH_MYJ_WSM6_BMJ	0.644557
8.	ERA5_MM5_NOAH_SH_Thompson_G3	0.644544
9.	ERA5_MYJ_NOAH_MYJ_Morrison_BMJ	0.642519
10.	ERA5_MYNN_NOAH_MYNN_Morrison_BMJ	0.640825

Table 1: Top 10 configurations for simultaneous variables based on aggregated weighted TSS.

- When evaluating the top ten configurations across all variables, the NOAH scheme for LSM, YSU for PBL, Morrison for MP, and the G3 scheme for CU dominate.

Sensitivity of variables to physical processes

The higher the mean square value, the greater the variable's sensitivity.

- T2, HFX, and LH are highly sensitive to LSM compared to other physical processes.
- PBLH shows significant sensitivity to PBL physics.
- RR is significantly sensitive to MP physics.
- WSPD10 seems sensitive to LSM, PBL, and CU physics.

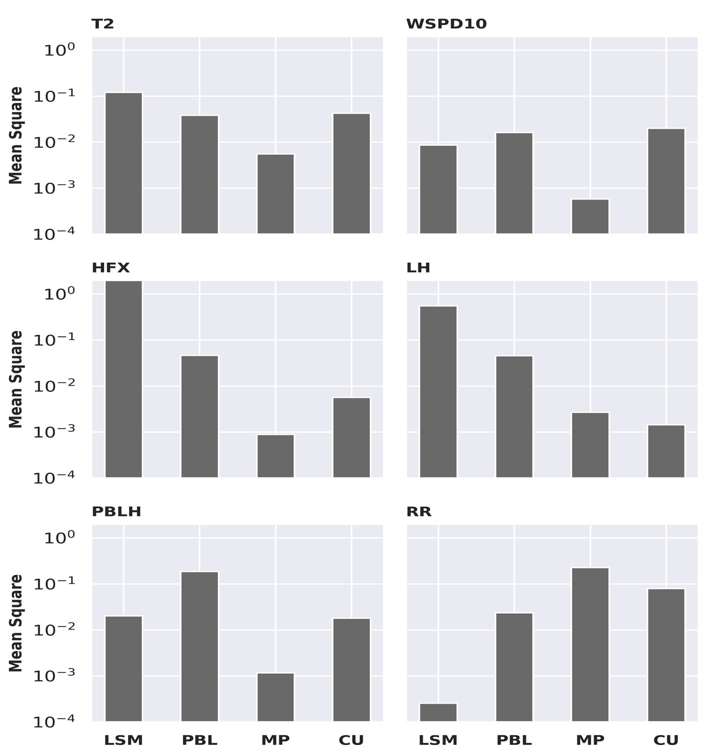


Fig. Bar plot showing the mean square values of each physical process for the evaluated variables.

Relevance of physical schemes for the evaluated variables

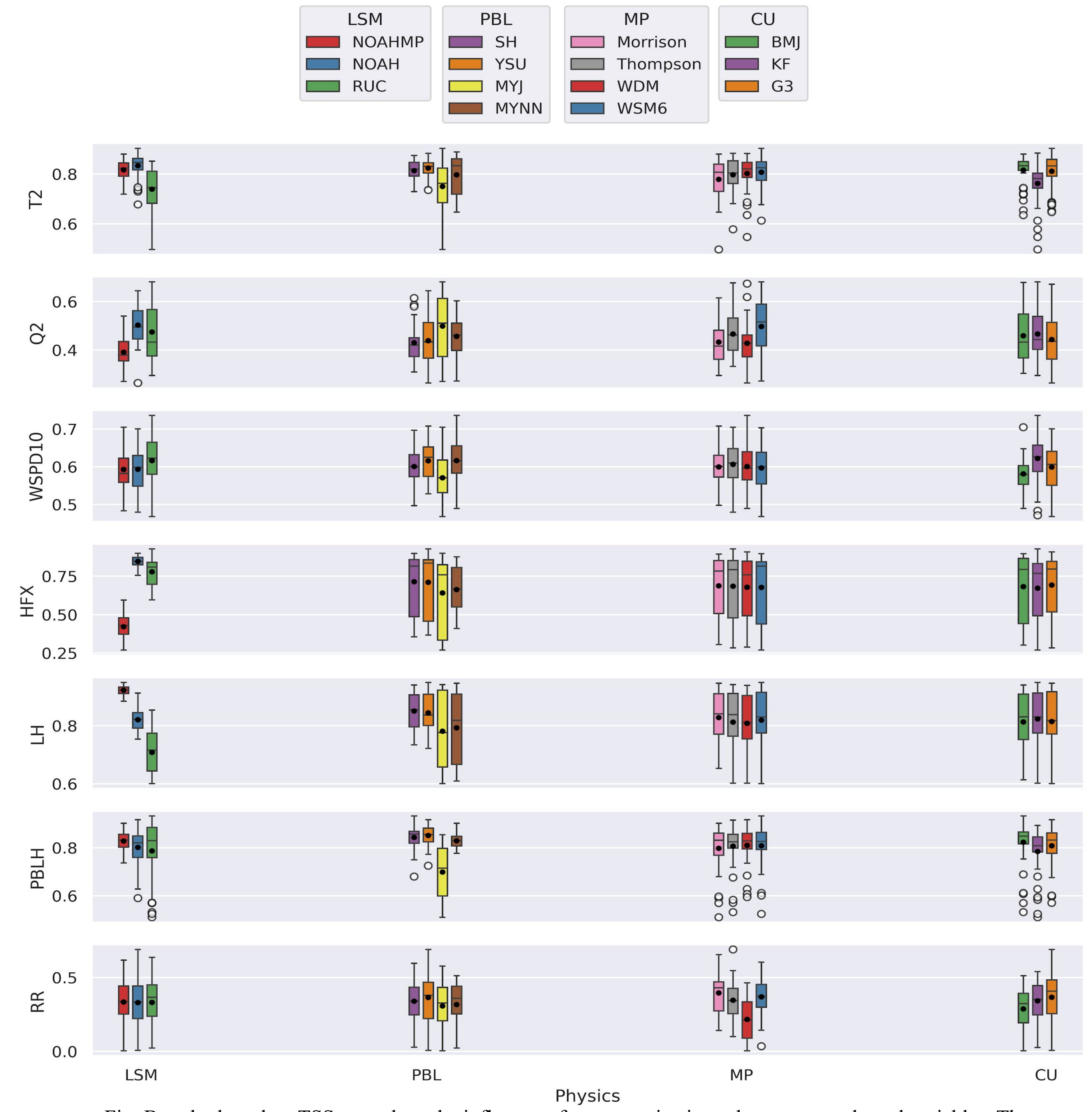


Fig: Boxplot based on TSS to analyze the influence of parameterization schemes on evaluated variables. The black dot represents the mean of the respective group.

- While variables are significantly influenced by physical processes, the relative importance of their parameterizations varies depending on the specific variable. For instance, the Noah LSM is most effective in simulating HFX, while the NoahMP performs better for LH.

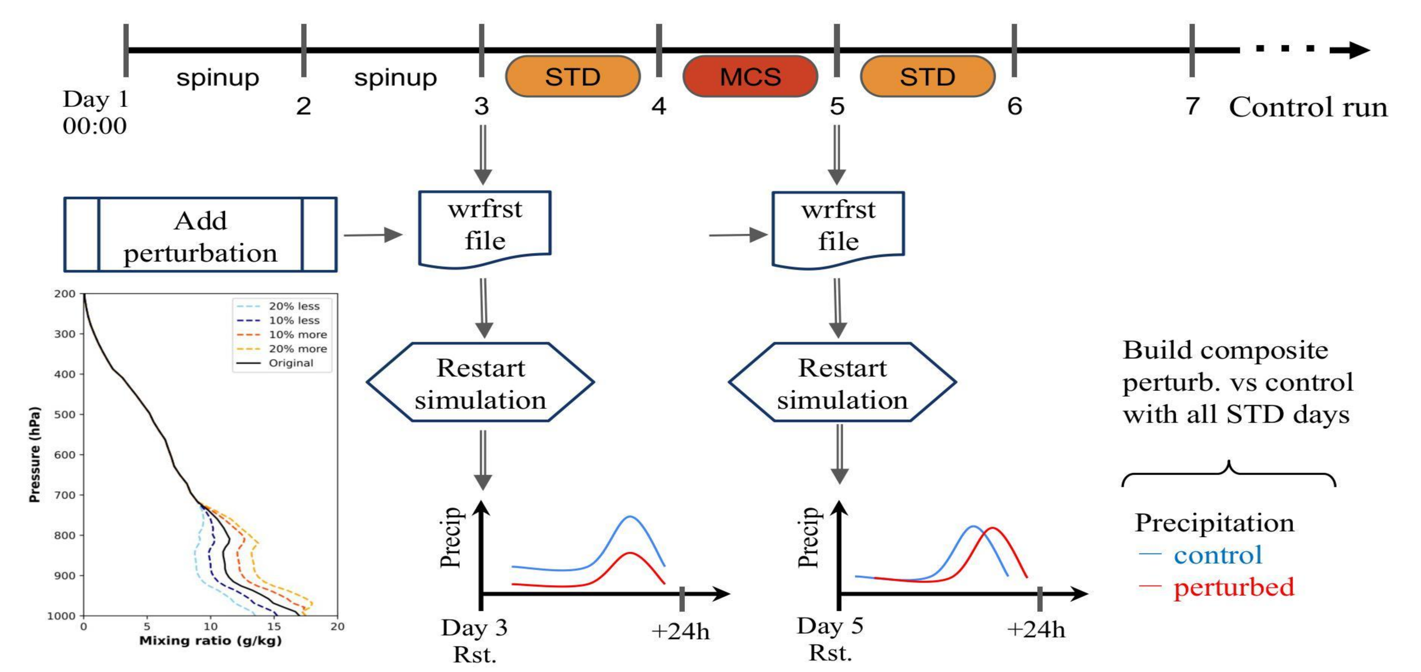
Kruskal-Wallis Test: A statistical method used to determine whether significant differences exist in the impact of various schemes on a variable within a physical process.

Variable	LSM	PBL	MP	CU
T2	**Group A** - Noah, NoahMP **Group B** - RUC	**Group A** - MYNN, SH, YSU **Group B** - MYJ	**Group A** - Morrison, Thompson, WDM, WSM6	**Group A** - BMJ, G3 **Group B** - KF
Q2	**Group A** - Noah, RUC **Group B** - NoahMP	**Group A** - MYJ, MYNN, SH, YSU	**Group A** - WSM6 **Group B** - Morrison, Thompson, WDM	**Group A** - BMJ, G3, KF
WSPD10	**Group A** - Noah, NoahMP, RUC	**Group A** - MYNN, SH, YSU Group B - MYJ	**Group A** - Morrison, Thompson, WDM, WSM6	**Group A** - BMJ, G3 Group B- KF
HFX	**Group A** - Noah **Group B** - RUC **Group C** - NoahMP	**Group A** - MYJ, MYNN, SH, YSU	**Group A** - Morrison, Thompson, WDM, WSM6	**Group A** - BMJ, G3, KF
LH	**Group A** - NoahMP **Group B** - Noah **Group C** - RUC	**Group A** - MYJ, MYNN, SH, YSU	**Group A** - Morrison, Thompson, WDM, WSM6	**Group A** - BMJ, G3, KF
PBLH	**Group A** - Noah, NoahMP, RUC	**Group A** - MYNN, SH, YSU **Group B** - MYJ	**Group A** - Morrison, Thompson, WDM, WSM6	**Group A** - BMJ, G3, KF
RR	**Group A** - Noah, NoahMP, RUC	**Group A** - MYNN, SH, YSU, MYJ	**Group A** - Morrison, Thompson, WSM6 **Group B** - WDM	**Group A** - G3, KF **Group B** - BMJ

Table: Scheme categories based on Kruskal Wallis test of the Taylor Skill Score, where Group A represents the best scheme category.

Future Work

Conduct the sensitivity experiments to assess how moisture and wind shear influence the shallow-to-deep convective transition in the Amazon Basin.



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