

2025 DTC Visitor Program Final Report

Test and Evaluation of the MPAS Model in the Reproduction of Mesoscale Convective Systems over Midlatitude and Tropical Regions

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1. Background and motivation

Severe storms accounted for 50.8% of weather and climate disasters over the past four decades, which have resulted in trillions of dollars in economic losses and thousands of fatalities across the U.S. (NOAA/NCEI, 2024). Notably, Mesoscale Convective Systems (MCS) contribute substantially to severe storms (Cui et al., 2026) and their frequency and intensity have increased over this period (Feng et al., 2016, Prein et al., 2021). Forecasting skill for both precipitation and severe weather at operational centers is minimal during the summer (Sukovich et al., 2014; Herman et al., 2018), when MCS are largely responsible for these events. Inaccurate representation of MCS is considered to be the primary cause of this poor performance (Schumacher & Rasmusssen, 2020; Yin et al., 2013; Furgione, 2013; Stevenson & Schumacher, 2014; Sakaguchi et al., 2018; Tai et al., 2021; Feng et al., 2023a; Paccini & Stevens, 2023). Even state-of-the-art Numerical Weather Prediction (NWP) models under convection-permitting resolutions underestimate the occurrence of robust MCS while producing too strong convective intensity, which contributes to an overestimation of convective precipitation while underestimating stratiform precipitation (Feng et al., 2023a). Recent tests of the Rapid Refresh Forecast System (RRFS) based on the Finite Volume Cubed Sphere (FV3) dynamical core of the Unified Forecast System (UFS) show that forecasts produce too intense convective storms during the warm season, resulting in a high bias for precipitation (Carley et al., 2024). This poor performance is related to the grid staggering used in the FV3 (D-grid), which has half the effective resolution of the C-grid staggering used in models such as Weather Research and Forecasting (WRF), Cloud-Model 1

(CM1), and Model for Prediction Across Scales (MPAS). Carley et al. (2023) identified that the effort required to adapt FV3 to the convective scale is unfeasible, and concluded by recommending MPAS as the new dynamical core for RRFSv2. The National Oceanic and Atmospheric Administration's (NOAA) National Severe Storms Laboratory (NSSL) conducted several tests with MPAS using configurations similar to RRFS, which have shown impressive results with superior performance for convection-allowing forecasts (Clark et al., 2023; Carley et al., 2024; Clark et al., 2026). All of this triggered NOAA to announce in early 2026 that MPAS has been chosen to be the dynamical core of the next-generation National Weather Service (NWS) operational model (Aligo et al., 2026). Currently, MPAS features include established variable-resolution global and limited-area modeling frameworks, basic pre- and post-processing capabilities, physical suites, and data assimilation with the Joint Effort for Data assimilation Integration MPAS (JEDI-MPAS; Liu et al., 2022; Guerrette et al., 2023; Jung et al., 2024). However, there are remaining questions about MPAS configurations and performance to accurately reproduce MCS over midlatitude and tropical regions given its novelty and relatively scarce assessment, especially when compared to extensively tested NWP models such as WRF. In this sense, the present project aims to provide insight into the current capabilities of MPAS in reproducing MCS through testing and evaluation for convective applications ($\Delta x \leq 3$ km). This project is part of a broader effort of the Developmental Testbed Center (DTC) towards advancing community adoption of MPAS through testing and evaluation (DTC, 2026).

1.1. Objectives

This DTC visitor project aims to investigate the MPAS' performance to reproduce MCS under different environments by fulfilling the following specific objectives:

1. Development of a simulation framework for MCS reproduction within the MPAS model;
2. Testing and diagnostics to detect issues related to model components (initialization lead time, modeling framework, physical parameterizations);
3. Assess the model skill to reproduce the movement and propagation of MCS;
4. Evaluate the 24-h precipitation forecast associated with the MCS passage;
5. Determine the ability of MPAS to capture the initiation and evolution of MCS in very short-range forecasts;
6. Propose potential solutions to identified shortcomings in the model evaluation.

2. Material and methods

2.1. Case studies

We selected four MCS cases to address the proposed objectives, which are summarized in **Table 1**. Several MCS cases that overpassed the U.S. Department of Energy (DOE) Atmospheric Radiation Measurement (ARM) facilities (Mather & Voyles, 2013) deployed at the T3 site near Manacapuru, Amazonas (hereafter MAO) during the GoAmazon2014/5 campaign (Martin et al., 2016) are reported in Wang et al. (2019; 2020). Two squall lines (i.e., an MCS type) were selected and are representative of wet and dry season tropical cases. The midlatitude MCS cases were selected not only focusing on the MCS itself but also due to the occurrence of associated severe weather events. The first case took place in the Southeastern U.S. and corresponds to a quasi-linear convective system (QLCS; Kosiba et al., 2024; Silcott et al., 2025), which generated an astounding 114 tornadoes (EF0-EF2, corresponding to 38% of the tornadoes recorded in March 2022) in a period of 24 hours (12-12 UTC on March 30-31, 2022) and \$1.3 billion in economic losses (SPC, 2022; NCEI NOAA, 2024; 2026). The second midlatitude MCS case took place in Southern Brazil between November 7 and 8, 2025, when a QLCS and embedded supercell generated EF0-EF4 tornadoes, which almost destroyed a small town in the state of Paraná, Brazil (~\$22M in economic losses; SIMEPAR, 2026). These MCS cases are useful to test the model performance to reproduce both tropical and midlatitude MCS as well as to investigate MPAS' ability in predicting the associated severe weather.

Table 1 - Selected MCS cases over tropical and midlatitude regions.

Region	Location	Date and time*	Season	MCS morphology
Tropical	Central Amazon	20150412 12:00 UTC	Wet	Squall line
Tropical	Central Amazon	20140917 17:00 UTC	Dry	Squall line
Midlatitude	Southeastern U.S.	20220331 00:00 UTC	Transition Spring-Summer	QLCS
Midlatitude/ extratropical	Southern Brazil	20251107 22:00 UTC	Spring	QLCS

*Date and time correspond to the mature stage of the observed MCS.

2.2. Data

Given the selected MCS cases span over different periods and regions, the data used as boundary conditions and to evaluate the model performance varies according to each case, as indicated below. The European Centre for Medium-Range Weather Forecasts (ECMWF) Reanalysis data (ERA5; Hersbach et al., 2020) with 0.25° of horizontal resolution (<https://doi.org/10.5065/BH6N-5N20>) and National Centers for Environmental Prediction (NCEP) Global Forecast System (GFS) 0.25° forecasts (<https://doi.org/10.5065/D65D8PWK>) were employed as boundary conditions for Amazon cases. The ECMWF Integrated Forecast System (IFS) High-Resolution (HRES) Operational Forecasts, version 49r1, with ~ 9 km of horizontal resolution (<https://doi.org/10.5065/D68050ZV>) were employed as boundary conditions for Southeastern U.S. and Southern Brazil cases.

ARM radiosonde atmospheric vertical profiles (Keeler et al., 2001; Keeler, Burk & Kyrrouac, 2014) launched daily at 6-hr intervals provide observed temperature and humidity, which were used to characterize the pre-MCS environment within ~ 6 hr before MCS overpass for Amazon cases. The University of Wyoming's standard-resolution radiosonde dataset provides radiosonde soundings of atmospheric profiles (<http://weather.uwyo.edu/upperair/sounding.shtml>) for the Southeastern U.S. and Southern Brazil cases.

ARM ground-based meteorological (MET) instruments (Kyrrouac & Shi, 1993; Kyrrouac, Shi & Tuftedal, 2014) provided 1-min interval observations of surface pressure, 2-m temperature and relative humidity, and 10-m wind speed for the Amazon cases. These variables are used to characterize the cold pool intensity. Equivalent potential temperature, θ_e , is calculated based on Bolton (1980) to allow identification of MCS cold pool overpass that is related to a maximum drop in θ_e (Schiro & Neelin, 2018; Ramos-Valle et al., 2023). Surface observations from Synoptic stations and METeorological Aerodrome Reports (METAR) were used to infer accuracy of the simulated near-surface conditions for the Southern Brazil and Southeastern U.S. cases, which provided 2-m temperature and relative humidity, 10-m wind speed, and surface pressure.

The gridded global merged multi-satellite geostationary top-of-atmosphere infrared (IR) brightness temperature (Tb) product with a grid spacing of 4 km from NOAA Climate Prediction Center/NCEP (Janowiak et al., 2017) was used to perform the MCS tracking (<https://doi.org/10.5067/P4HZB9N27EKU>) for all MCS cases.

The latest Global Precipitation Measurement (GPM) Integrated Multi-satellite Retrievals for GPM (IMERG) gridded precipitation product (Huffman et al., 2020) with 10 km grid spacing was used to perform MCS tracking and precipitation evaluation of the Southern Brazil and Amazon cases (<https://doi.org/10.5067/GPM/IMERG/3B-HH/07>). The multisensor gridded precipitation dataset from NOAA's Stage IV analysis (Lin and Mitchell, 2005; <https://doi.org/10.5065/D69Z93M3>), available over CONUS with a grid spacing of 4 km, was used to perform the MCS tracking and precipitation evaluation for the Southeastern U.S. case.

Severe weather reports from the NOAA NWS Storm Prediction Center (SPC) are used to verify the Significant Tornado Parameter (STP) for the Southeastern U.S. case (SPC, 2022). Preliminary data from PREVOTS - PRETS (*Plataforma de Registros de Tempo Severo*) provides severe weather registered during the Southern Brazil case (<https://www.prevots.org/>). The multiradar/multisensor project (MRMS; Smith et al., 2016) composite reflectivity product is constructed from a regional mosaic of reflectivity from the WSR-88D radars around the U.S. and Canada, which provides composite radar reflectivity (<https://registry.opendata.aws/noaa-mrms-pds>).

2.3. MPAS model and experimental design

The MPAS model is a global fully compressible, non-hydrostatic model (Skamarock et al., 2012), whose spatial discretization is performed using Spherical Centroidal Voronoi Tessellations (SCVT) through a finite volume method with C-grid staggering (Thuburn et al., 2009; Ringler et al., 2010) and a height-based terrain-following vertical coordinate (Klemp, 2011). Temporal discretization is performed via time-split integration technique (Klemp et al., 2007) with a third-order Runge Kutta scheme and explicit time splitting (Wicker and Skamarock, 2002). Numerical experiments were performed using the MPAS model version 8.3.1 (<https://github.com/MPAS-Dev/MPAS-Model/releases/tag/v8.3.1>). **Figure 1** shows the employed variable-resolution global

60-3 km meshes, which were configured to ensure 3 km grid spacing over the studied areas using the `grid_rotate` tool (https://github.com/MPAS-Dev/MPAS-Tools/tree/master/mesh_tools/grid_rotate). The 60-3 km mesh is provided in the MPAS repository (<https://www2.mmm.ucar.edu/projects/mpas/site/downloads/meshes.html>).

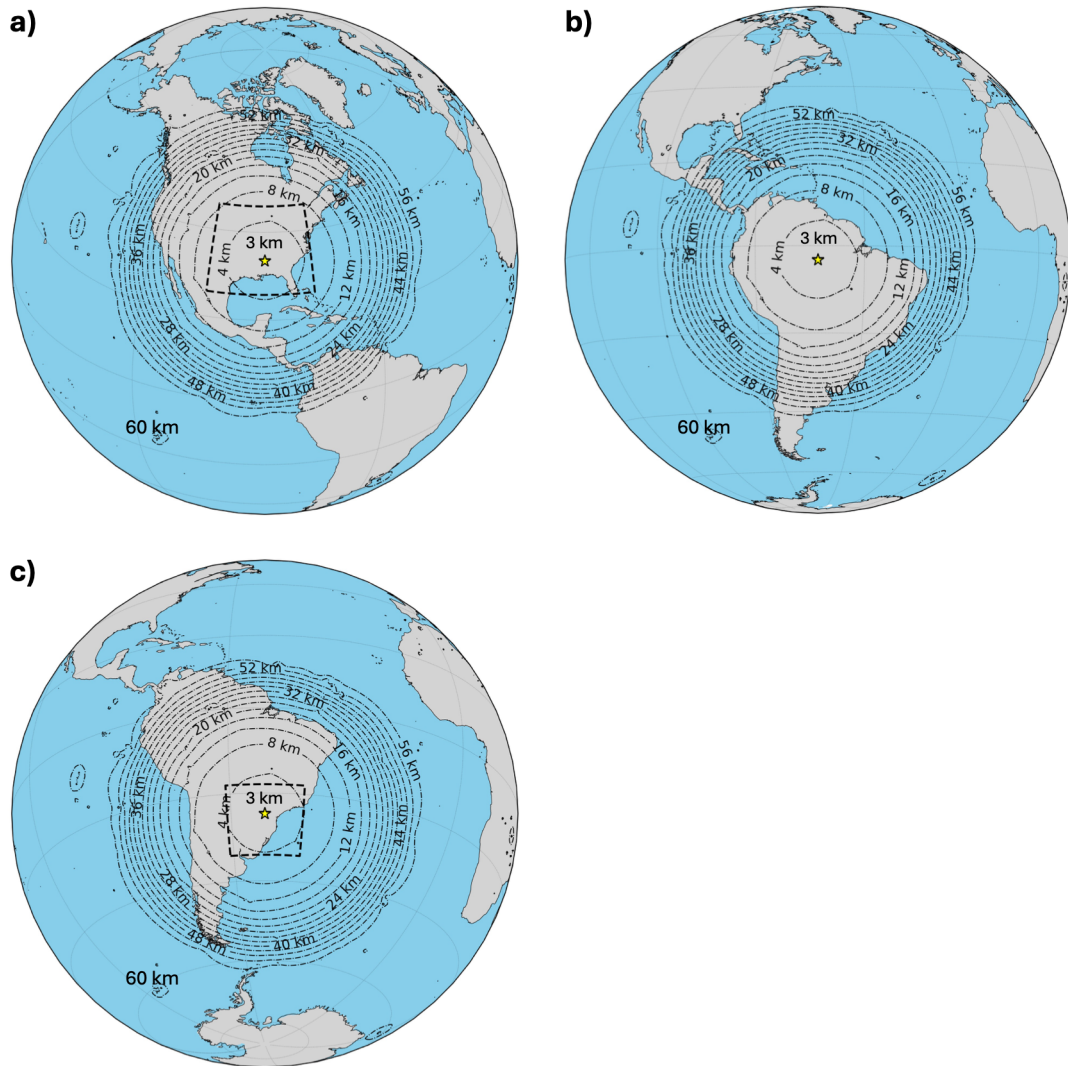


Figure 1 - Variable-resolution global 60-3 km meshes with 3 km refinement zone centered over **a)** Southeastern U.S., **b)** Central Amazon, and **c)** Southern Brazil. The dashed black line indicates the mesh resolution between 3 km (refinement zone) and 60 km with smooth transition. The dashed black boxes in **a)** and **c)** represent the regional 3 km domains employed for Southeastern U.S. and Southern Brazil cases. The yellow star indicates the center of the refinement zone.

Additionally, we performed regional 3 km (black dashed boxes in **Figs. 1 a,c)** simulations for midlatitude MCS cases to compare the impact of different modeling frameworks (global vs.

regional). The vertical grid is configured with 65 vertical levels, and the model top is set at 30 km for both global and regional simulations. All runs assume a fixed time step of 15 s. Land initialization uses the Moderate Resolution Imaging Spectroradiometer (MODIS) dataset (Broxton et al., 2014). MPAS has two built-in physical suites, which are Mesoscale Reference (MR) and Convection-Permitting (CP), summarized in **Table 2**.

Table 2. Physics suites tested within the MPAS model in the present study.

Parameterization category	Mesoscale reference (MR)	Convection-permitting (CP)	NOAA/GSL*
CV	New Tiedtke Wang (2022)	Grell-Freitas Grell and Freitas (2014)	Grell-Freitas-Li Freitas, Grell, and Li, (2021); Grell and Freitas (2014)
MP	WSM6 Hong and Lim (2006)	Thompson Thompson et al. (2008); Thompson and Eidhammer (2014)	TEMPO Jensen et al. (2023)
PBL	YSU Hong et al. (2006)	MYNN Nakanishi and Niino (2006, 2009)	MYNN-EDMF Olson et al. (2026)
SL	Monin-Obukhov	MYNN Olson et al. (2021)	MYNN Olson et al. (2021)
LSM	Noah Tewari et al. (2004)	Noah Tewari et al. (2004)	Noah ⁺ Tewari et al. (2004)
LR & SR	RRTMG Iacono et al. (2008)	RRTMG Iacono et al. (2008)	RRTMG Iacono et al. (2008)
CFR	Xu-Randall Xu and Randall (1996)	Xu-Randall Xu and Randall (1996)	Xu-Randall Xu and Randall (1996)
GWDO	YSU Hong et al. (2006)	YSU Hong et al. (2006)	Unified Gravity-Wave Physics Toy et al. (2025)

Abbreviations are defined as follows: CV is convection, MP is microphysics, PBL is planetary boundary layer, SL is surface layer, LSM is land surface model, LR is longwave radiation, SR is shortwave radiation, CFR is cloud fraction for radiation, and GWDO is gravity wave drag by orography. *Available in the MPAS model from the UFS repository

(<https://github.com/ufs-community/MPAS-Model>). [†]The RUC LSM is the standard LSM in the NOAA/GSL physics suite, but here it is replaced by the Noah LSM due to the ECMWF boundary conditions.

Recently, the NOAA Global Systems Laboratory (GSL) has been developing a physics suite (see **Table 2**) to be employed in the operational RRFSv2, which was also tested in the present project for the midlatitude MCS cases. Testing these physics suites allows us to evaluate the impact of alternative parameterizations on model performance. Recent studies have demonstrated the advantage of these physics suites under different conditions (e.g., Lui et al., 2020; Liu et al., 2024, Mantovani et al., 2026a,b). Because convection, microphysics, PBL, and surface fluxes interact strongly, observed differences in results from these physics suites should be interpreted as their integrated consequence. NOAA/GSL can be considered an updated version of the CP physics suite, while MR differs more substantially from both.

We performed the simulations summarized in **Table 3** aiming to cover different modeling aspects. The Southeastern U.S. case was employed to test the impact of initialization time, physics suite, and modeling frameworks using the ECMWF-IFS boundary conditions. Some tests were made using ECMWF-ERA5 boundary conditions, but no significant differences were found compared to experiments using ECMWF-IFS (not shown). The impact of the global and regional modeling frameworks was further tested considering the Southern Brazil case. The convection scheme is turned off in all regional experiments. Regarding the tropical MCS cases, we explored the impact of both ECMWF-ERA5 and NCEP-GFS initial conditions (IC) in the Amazon wet case as well as CP and MR physics suites. An additional experiment was made by replacing the Grell-Freitas convection scheme with the New Tiedtke in the CP physics suite. On the other hand, only the impact of the physics suite was tested for the Amazon dry case using ECMWF-ERA5 as IC.

The experimental design evolved iteratively, informed by the results obtained along the project, in order to save computational resources. Our main goal was to assess the MPAS performance at convection-allowing resolution (3 km) through deterministic, short-term forecasts intended to reproduce these observed MCS. Although robust statistics cannot be derived from a few MCS cases, these experiments are useful to gain insights into how accurately MPAS can represent these systems and the associated severe weather. MPAS outputs were regridded from its unstructured mesh to a regular latitude-longitude grid using the `convert_mpas` tool (https://github.com/mgduda/convert_mpas) for consistency in the model-observation comparison.

Table 3. Summary of performed numerical simulations, indicating the MCS case, mesh, initialization lead time, physics suite, and boundary conditions.

MCS case	Mesh	Initial time	Physics	IC/LBC
SE U.S.	60-3 km	12 UTC 20220329	NOAA/GSL	IFS
SE U.S.	60-3 km	00 UTC 20220330	NOAA/GSL	IFS
SE U.S.	60-3 km	12 UTC 20220330	NOAA/GSL	IFS
SE U.S.	Regional 3 km	00 UTC 20220330	NOAA/GSL CV turned off	IFS
SE U.S.	60-3 km	00 UTC 20220330	CP	IFS
SE U.S.	60-3 km	00 UTC 20220330	MR	IFS
SBR	60-3 km	00 UTC 20251107	NOAA/GSL	IFS
SBR	Regional 3 km	00 UTC 20251107	NOAA/GSL CV turned off	IFS
AW	60-3 km	12 UTC 20150411	CP	ERA5
AW	60-3 km	12 UTC 20150411	MR	ERA5
AW	60-3 km	12 UTC 20150411	CPNT*	ERA5
AW	60-3 km	12 UTC 20150411	CP	GFS
AW	60-3 km	12 UTC 20150411	MR	GFS
AD	60-3 km	17 UTC 20140916	CP	ERA5
AD	60-3 km	17 UTC 20140916	MR	ERA5

Abbreviations are defined as follows: SE U.S. is Southeastern U.S., SBR is Southern Brazil, AW is Amazon Wet, AD is Amazon Dry. *CPNT refers to the CP physics suite with the New Tiedtke convection scheme.

2.4. MCS identification and tracking

MCSs were tracked with the Python FLEXible Object TRacKeR (PyFLEXTRKR) MCS tracking algorithm (Feng et al., 2023b) following the MCSMIP protocol (Feng et al. 2025) that defines an MCS as follows:

1) Cloud shield area with Brightness Temperature (T_b) < 241 K must be at least $40,000 \text{ km}^2$ and persist for at least 4 continuous hours, and must contain $T_b < 225$ K at least once during those hours;

- 2) Must contain minimum peak precipitation of 10 mm.h^{-1} inside the cloud shield for 4 hours;
- 3) Must reach a minimum rainfall volume of $20,000 \text{ km}^2 \text{ mm.h}^{-1}$ (i.e., $100 \text{ km} \times 100 \text{ km} \times 2 \text{ mm.h}^{-1}$) at least once during the lifetime.

Since PyFLEXTRKR considers a combined Tb and PF (i.e., Precipitation Feature) based method for MCS definition (Feng et al., 2023b), the MCS tracking is conducted using combined Tb and precipitation (PCP) datasets. To simplify the process and match the temporal resolution of model output, we consider both PCP and Tb on an hourly basis. For the U.S. case, we considered IMERG Tb and Stage IV PCP datasets to conduct the observational MCS tracking at 4 km resolution. For the Amazon and Southern Brazil cases, the MERG Tb data is conservatively regridded from 4 to 10 km to match the IMERG spatial resolution using the open-source Python package xESMF (<https://xesmf.readthedocs.io/>). Then, PyFLEXTRKR framework preprocesses the regridded MPAS outputs by converting the simulated top-of-atmosphere outgoing longwave radiation (OLRTOA) to Tb following Yang and Slingo (2001) and computing hourly rain rates before performing the MCS tracking. Intercomparison of MCS tracking from observational and simulated datasets provides the means for objective evaluation throughout the MCS lifetime.

2.5. Model evaluation

We started our evaluation investigating if MPAS simulations were able to reproduce the MCS life cycle (i.e., convective initiation, MCS genesis, maturation, and decay) by comparing MCS tracking results from both observational and simulated datasets for each case. Then, we compared our results to observed precipitation datasets described in Section 2.2, computing dichotomous metrics summarized in performance diagrams (Roebber, 2009), such as Probability of Detection (POD), Frequency Bias (BIAS), Success Ratio (SR), and Critical Success Index (CSI). We used hourly precipitation thresholds ranging from low measurable precipitation to heavy precipitation ($0\text{-}20 \text{ mm.h}^{-1}$). The Fractions Skill Score (FSS; Roberts and Lean, 2008) was also considered to address the double-penalty problem for precipitation. Near-surface conditions (2-m temperature and relative humidity, 10-m wind speed, and surface pressure) were verified against Synop and METAR observations for the midlatitude cases, and against the ARM MET observations at the MAO site for the Amazon cases, by computing Bias, Mean Absolute Error (MAE), Root Mean Square Error (RMSE), and the Pearson correlation coefficient. For the Amazon cases, this

evaluation focuses on the period comprising 12 hours before and after the MCS overpass the MAO site and includes the ability of the model to reproduce the cold pool signature, identified as a drop in equivalent potential temperature. The pre-MCS environment of the midlatitude cases was further evaluated by comparing simulated vertical profiles and hodographs against the closest available radiosonde observations, from which storm parameters such as the Convective Available Potential Energy (CAPE), 0-1 km Storm Relative Helicity (SRH), 0-6 km Wind Shear, Supercell Composite (SC), and Significant Tornado Parameter (STP; Thompson et al., 2004) were derived. Finally, the spatial distribution of the maximum STP during each event was verified against SPC and PREVOTS severe weather reports through neighborhood-based Relative Operating Characteristic (ROC) curves, summarized by the Area Under the Curve (AUC), and the True Skill Statistic (TSS) computed across STP thresholds.

3. Summary of results

3.1. Southeastern U.S. case

3.1.1. MCS tracking results

Figure 2 shows the MCS features from the observed dataset and MPAS 60-3 km experiments testing model initialization time with ECMWF-IFS IC. The MCS tracking results from the observed dataset indicate that the convective initiation occurred at 22 UTC on 29 March 2022 with MCS mature stage peaking around 00 UTC, and MCS decaying at 20 UTC (46 hours of MCS lifetime) both on 31 March 2022. Maximum cold cloud shield (CCS) area, PF area, and volume of rain occurred during the mature stage, whose Tb and PCP fields are plotted in **Figure 3**. The MPAS experiment initialized at 12 UTC on 29 March 2022 (red) revealed that a longer lead time - allowing the model spin-up before the convective initiation - was not necessarily the best to reproduce the MCS features. Particularly, this experiment showed later convective initiation when compared to the experiment initialized at 00 UTC on 30 March 2022 (blue). The latter was initialized 2 hours after the convective initiation, but was able to better capture the initiation timing. An additional experiment initialized at 18 UTC on 29 March 2022 was carried out but no significant improvement was observed (not shown).

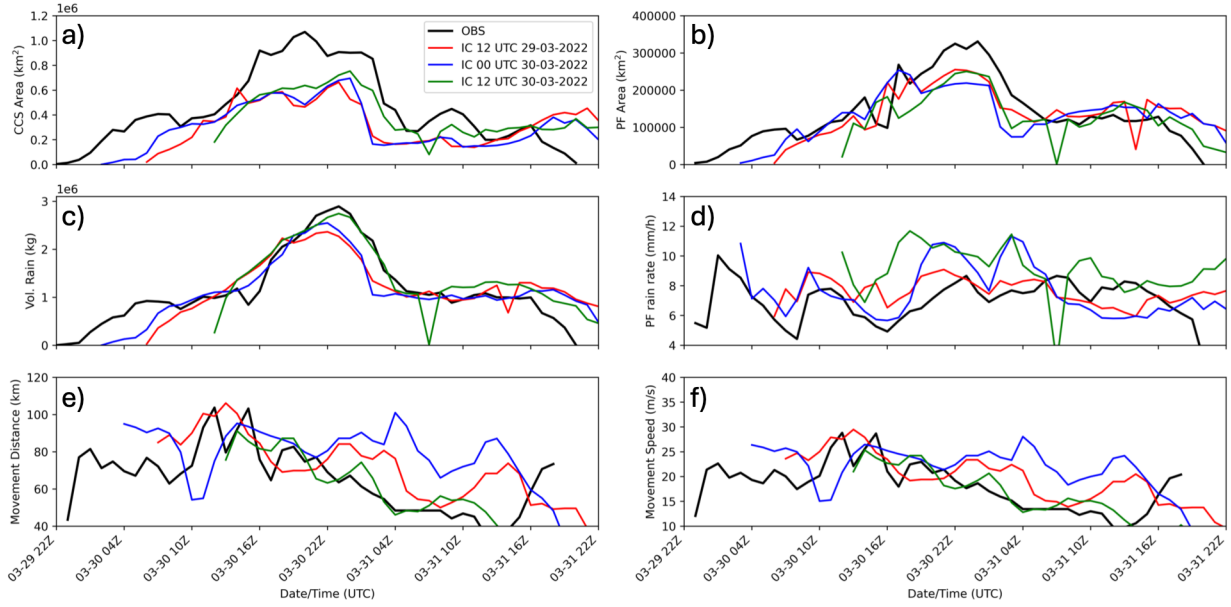


Figure 2 - PyFLEXTRKR MCS features from observational dataset (black) and MPAS simulations (colored) during the period between 22 UTC on 29 March 2022 and 22 UTC on 31 March 2022, which are CCS Area (km^2) **a**), PF Area (km^2) **b**), Vol. rain (kg) **c**), PF rain rate (mm/h) **d**), Movement Distance (km) **e**), and Movement Speed (m/s) **f**).

The experiment initialized during the MCS development at 12 UTC on 30 March 2022 (green) showed better agreement to observed CCS area, and especially volume of rain during the mature stage (**Figs. 2a,c**). Also, this experiment better reproduced the MCS propagation and speed (**Figs. 2e,f**). These experiments are useful to illustrate how sensitive the model is to the initial condition, as expected. Regarding the structure of the storm during its mature stage, the shorter the lead time, the better the agreement with the observed Tb and PCP (**Fig. 3a-h**). Despite the differences, all experiments were able to capture the mature stage of the observed MCS, particularly the period between 12 UTC 30 to 12 UTC 31 March 2022 when the most significant precipitation and severe weather took place. We decided to choose the IC at 00 UTC on 30 March 2022 to conduct further experiments because it covers the entire MCS lifetime and allows us to consider a proper spin-up period. **Figure 4** shows the MCS features comparing the MPAS experiments initialized at 00 UTC on 30 March 2022 (ECMWF-IFS IC) using the variable-resolution 60-3 km global mesh and regional 3 km with NOAA/GSL physics suite against the observations. Differences are observed for volume of rain (**Fig. 4c**) and PF rain rate (**Fig. 4d**), for which the regional 3 km (blue) shows a delayed peak compared to global 60-3 km (red) and less intense rain rates during the mature stage. The global experiment showed more intense movement distance and speed (**Figs. 4e-f**) from

mature to decaying stages, while the regional one was slightly better despite producing more differences during the MCS development. The most prominent shortcoming from the regional experiment is observed during the mature stage, in which the storm structure exhibits a smaller, more intense Tb signature and lacks precipitation in the southern portion (**Figs. 3i-j**). In addition, a delayed timing is observed when compared to the observed storm and the global experiment. These differences impacted the surface verification with the regional experiment showing poor performance (discussed later). This finding led us to conduct further experiments with the global approach rather than the regional one.

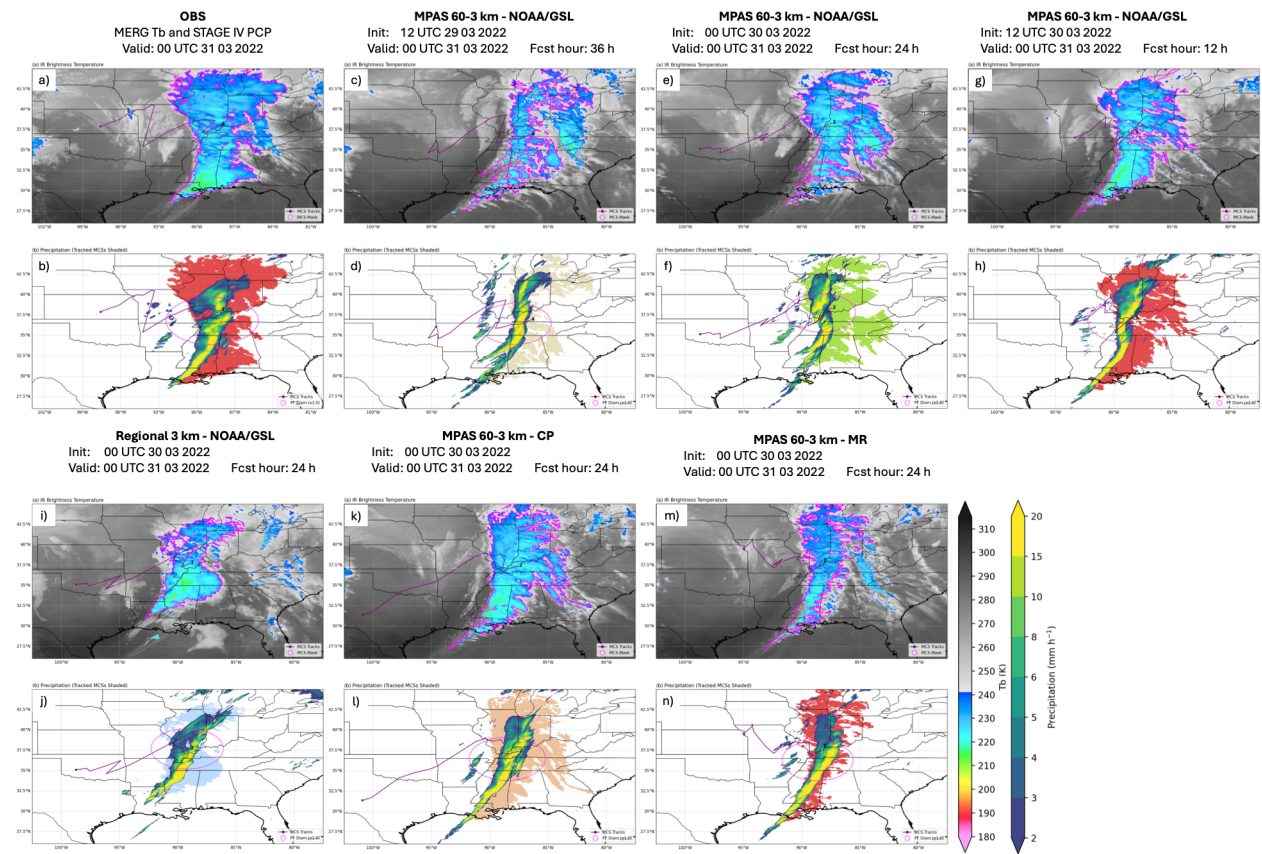


Figure 3 - MCS tracking outputs from observational dataset **a-b**), and MPAS experiments configured with 60-3 km mesh and NOAA/GSL physics suite initialized at 12 UTC on 29 March 2022 **c-d**), 60-3 km and NOAA/GSL initialized at 00 UTC on 30 March 2022 **e-f**), 60-3 km and NOAA/GSL initialized at 12 UTC on 30 March 2022 **g-h**), Regional 3 km and NOAA/GSL initialized at 00 UTC on 30 March 2022 **i-j**), 60-3 km and CP initialized at 00 UTC on 30 March 2022 **k-l**), and 60-3 km and MR initialized at 00 UTC on 30 March 2022 **m-n**). Top figures are the Tb (in K) and bottom figures are the hourly precipitation (in mm.h⁻¹).

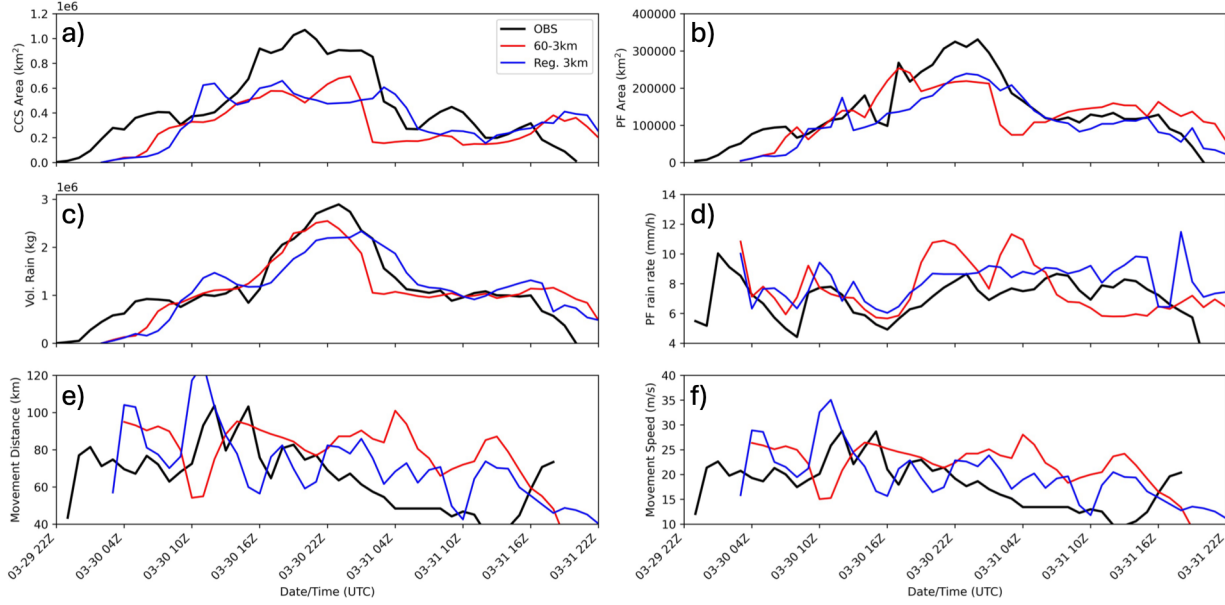


Figure 4 - Same as Fig. 2, but for MPAS experiments testing the global and regional modeling frameworks.

Figure 5 shows the MCS features from the observed dataset and MPAS 60-3 km experiments initialized at 00 UTC on 30 March 2022 (ECMWF-IFS IC) testing the physics suites (**Table 2**). These experiments revealed the MPAS sensitivity to physics suites and the impact on MCS reproduction. In general, all experiments were able to reproduce the MCS mature stage with MR being slightly better than CP and NOAA/GSL to capture the convective initiation timing and MCS genesis. Both CP (best) and NOAA/GSL showed better agreement to observed CCS area during the mature stage, while MR presented lower values. CP and MR (best) outperformed the NOAA/GSL physics suite to reproduce the observed volume of rain. All experiments showed more intense rain rates than observed, which can be attributed to several factors such as the misrepresentation of precipitation intensity due to too wide, undiluted, and strong updrafts leading to excessive riming (Fan et al., 2017; Wang et al., 2020, 2022), lower MCS precipitation efficiency compared to observed estimates (Kukulies et al., 2026), spurious vertical transport of condensates limiting stratiform precipitation (Varble et al., 2014a,b; Wang et al., 2019; 2020), and inaccurate deep convective upscale growth (Zhang et al., 2021). NOAA/GSL showed weaker Tb and more segmented precipitation swath (**Figs. 3e-f**) than CP (**Figs. 3k-l**) and MR (**Figs. 3m-n**). On the other hand, NOAA/GSL showed better reflectivity fields compared to MRMS data (not shown).

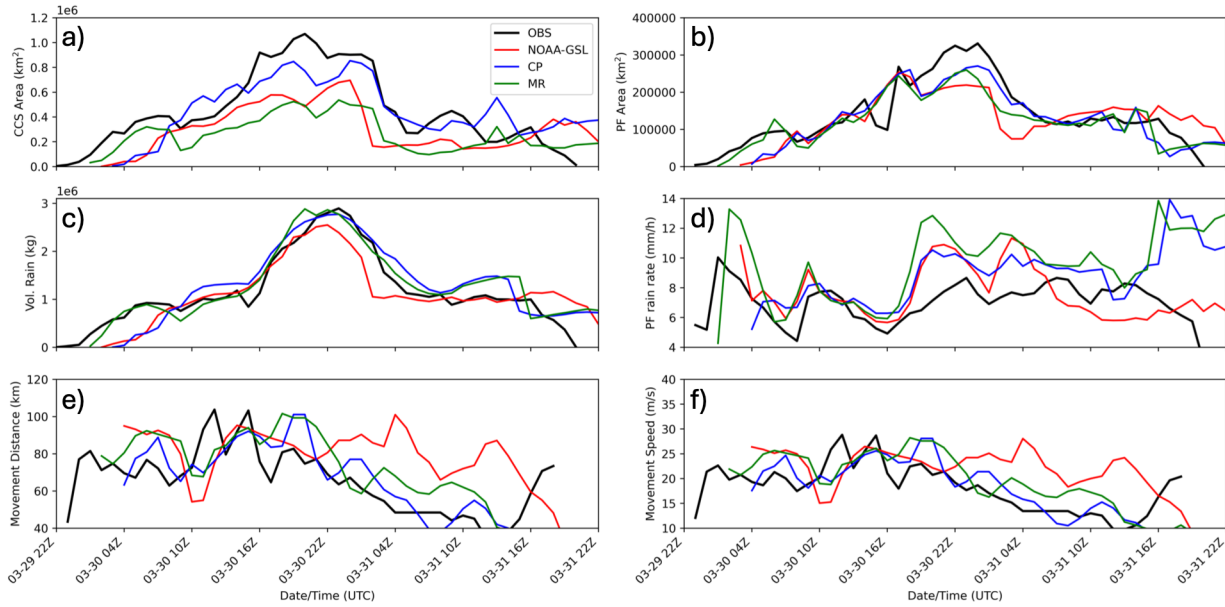


Figure 5 - Same as Fig. 2, but for MPAS 60-3 km experiments testing physics suites.

3.1.2. Surface verification

Figure 6 shows the accumulated precipitation and verification metrics between 12 UTC 30 and 12 UTC 31 March 2022 for the global and regional experiments. A strong precipitation swath is observed between northwest Arkansas and southwest Michigan with intense spots mostly over Kentucky, Tennessee, Alabama, Mississippi, and northwestern Florida (**Fig. 6a**). The global experiment showed more accurate precipitation over the domain despite differences to Stage IV observations (**Fig. 6b**), while the regional one clearly overestimated precipitation over some regions such as Arkansas and Tennessee (**Fig. 6c**). **Figure 7b** shows how the regional run produced more intense, displaced precipitation compared to the observations, and consequently inaccurate timing, which the global experiment better reproduced (**Fig. 7a**). FSS indicated that the global had better skill and performance across most thresholds (**Figs. 6d,e**), while both showed similar skill for precipitation thresholds above 40 mm.h^{-1} . The regional run presented warmer and wetter biases compared to the global one, and a positive bias for surface pressure (**Fig. 8a**). The global run presented better correlations for most surface variables (**Fig. 8c**). **Figure 9** shows the accumulated precipitation and precipitation verification for the experiments evaluating the physics suites. Both CP and MR (**Figs. 9c, d**) improved precipitation in the southernmost region compared to

NOAA/GSL (Figs. 9b) showing more intense values. This translates into skillful precipitation prediction and better performance from both CP and MR, where NOAA/GSL was penalized due to producing less precipitation (Figs. 9e,f). MR showed better skill for light-to-moderate precipitation, while CP was slightly better for more intense thresholds. MR showed slightly better performance (lower bias and RMSE, better correlation) for some surface variables such as meridional wind component (U), humidity (Q), and surface pressure (SP) when compared to CP and NOAA/GSL (Figs. 8d-f).

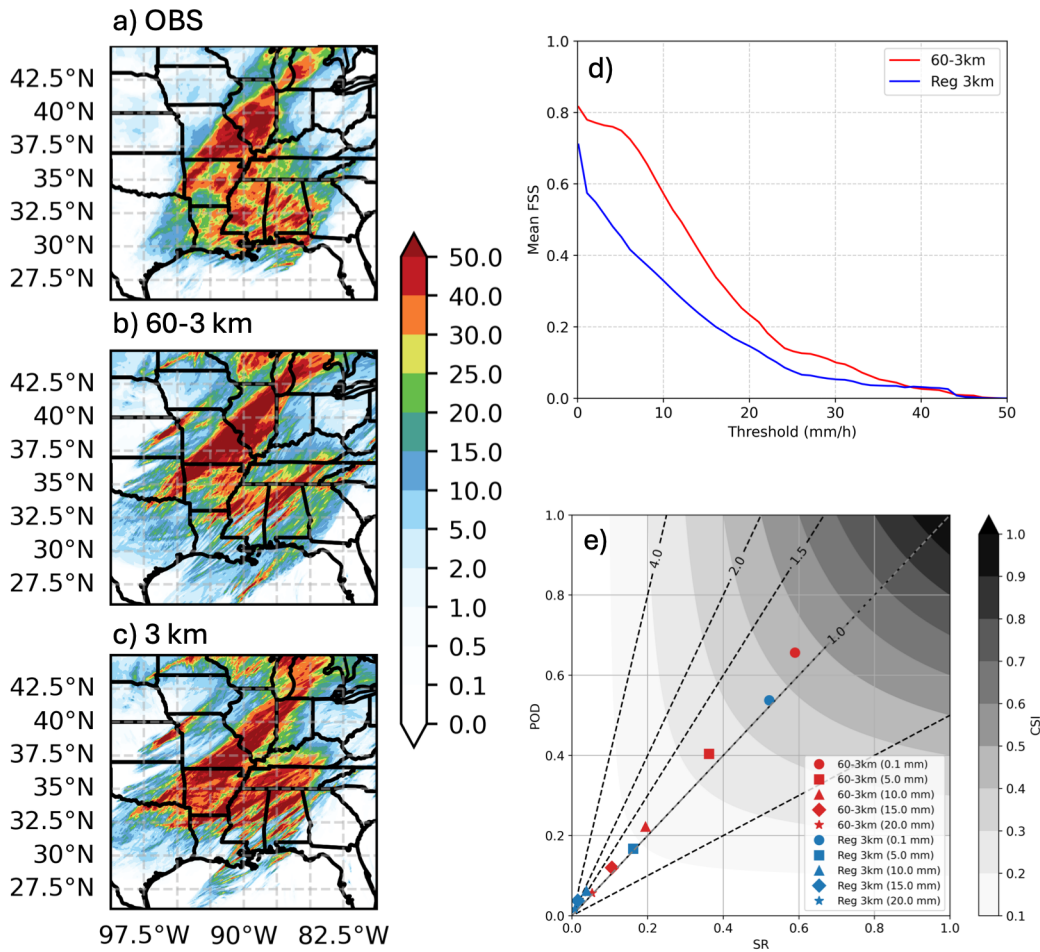


Figure 6 - Accumulated precipitation (in mm) between 12 UTC-12 UTC 30 and 31 March 2022 from OBS a), and MPAS 60-3 km experiments initialized at 00 UTC on 30 March 2022 using global 60-3 km mesh b), and regional 3 km c). Mean FSS is plotted for several precipitation thresholds d) together with Performance Diagram e).

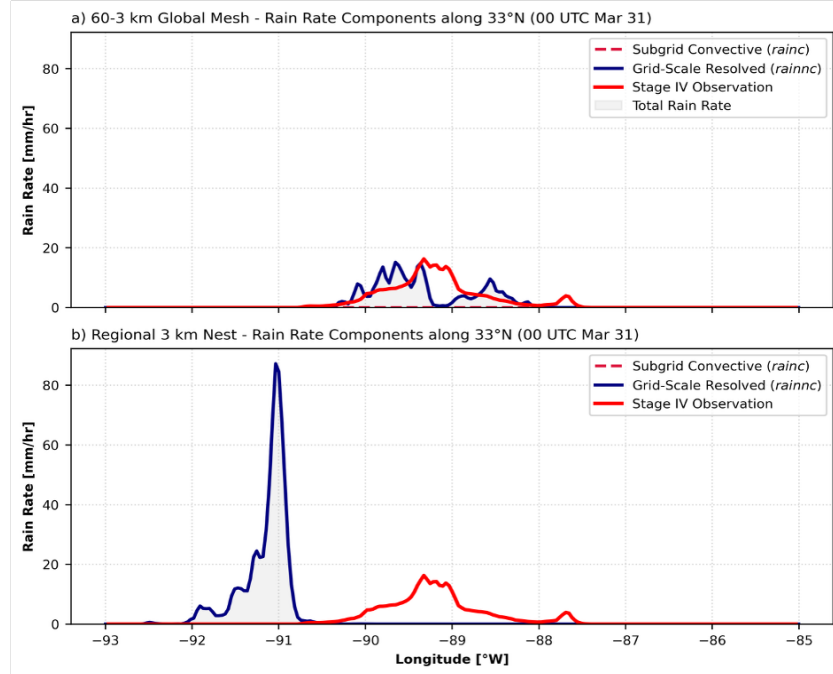


Figure 7 - Rain rate components along 33°N latitude at 00 UTC on 31 March 2022 from global 60-3 km **a)**, and regional 3 km experiments **b)** compared against Stage IV observations.

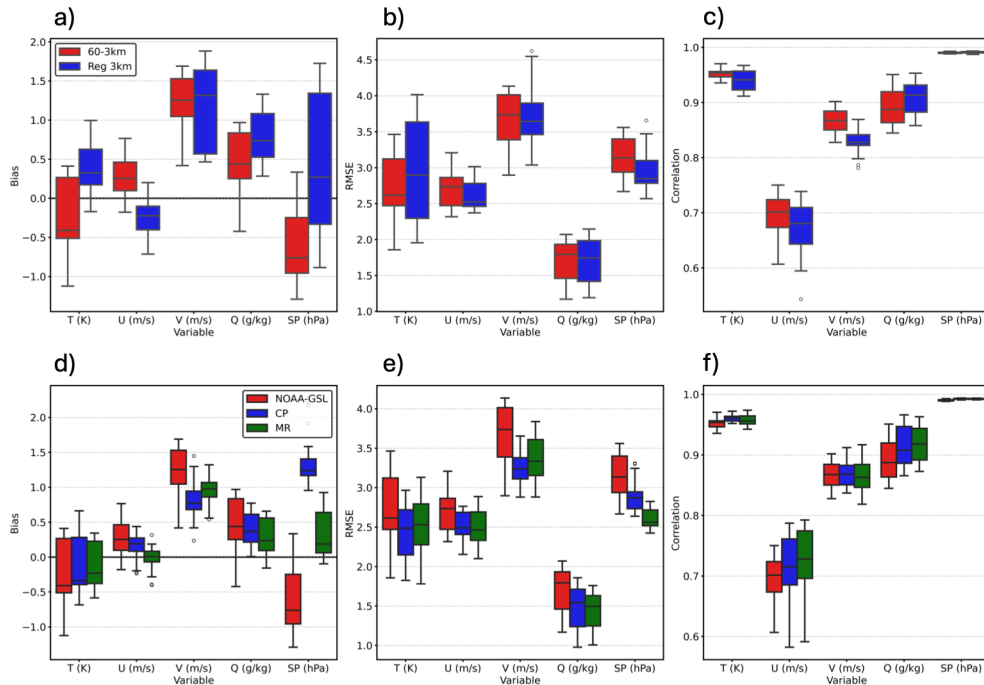


Figure 8 - Surface verification for 2-m temperature and humidity, 10-m wind speed, and surface pressure from modeling frameworks (top-row) and physics suite (bottom-row) experiments using Synop and METAR observations as reference for the period between 12 UTC-12 UTC 30 and 31 March 2022. Variables are plotted in x-axis and statistics in y-axis as Bias **a,d)**, RMSE **b,e)**, and Pearson Correlation Coefficient **c,f)**.

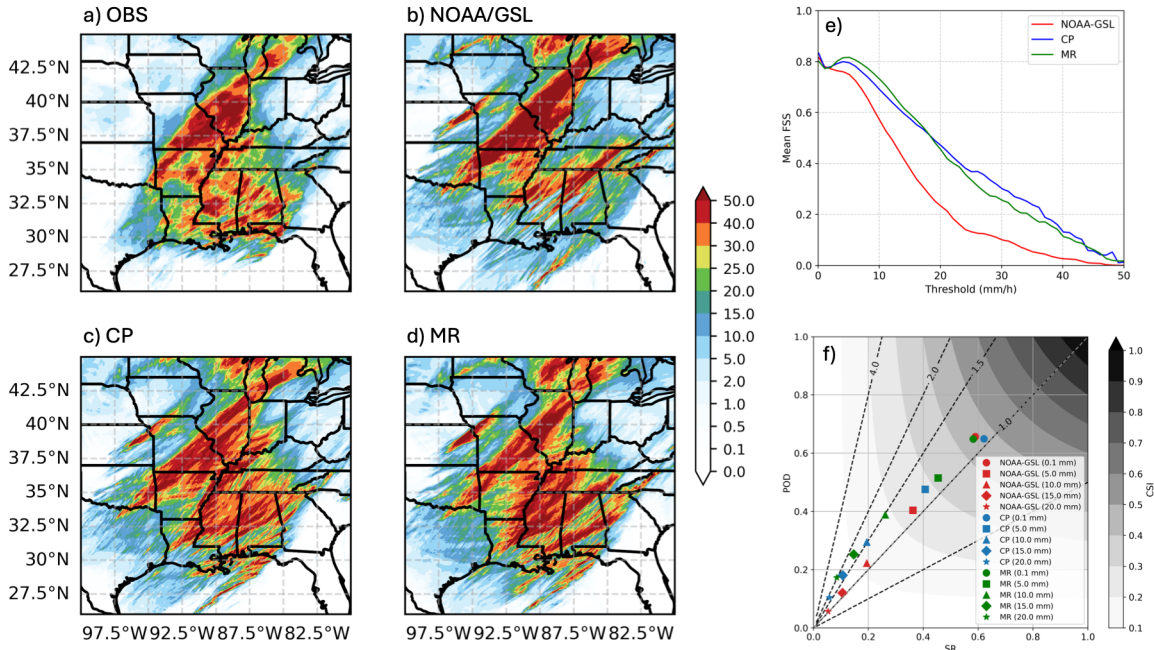


Figure 9 - Similar to Fig. 6, but for the physics suite experiments.

3.1.3. Severe weather

Figure 10 shows the MRMS reflectivity data overlayed by SPC reports during the MCS passage and illustrates the severe weather generated by this storm. The pre-MCS environment at 18 UTC on 30 March 2022 was investigated using a radiosonde sounding launched in Jackson, Mississippi (**Fig. 11a**) before the passage of the MCS. In general, both global and regional experiments were able to reproduce the vertical structure. The larger differences are observed near the inversion layer (~ 700 hPa), which the global run reproduced slightly better than the regional one. Hodograph indicates a reasonable agreement from both global and regional (**Fig. 11b**). The regional run showed too low CAPE, SRH, and Shear parameters compared to observation at Jackson location. For example, parameters computed from observed sounding indicate STP equal to 1.0, which is closely matched by global run (STP = 0.8) while regional one shows only 0.3 (**Fig. 11c**). Similar behavior is found for the Supercell Composite (SC), for which the global run (SC = 4.1) showed better agreement with the observed value (SC = 4.3) compared to the regional one (SC = 1.2). A tornado was reported about 3 hours later (21 UTC) near the southwest side of Jackson (SPC, 2022).

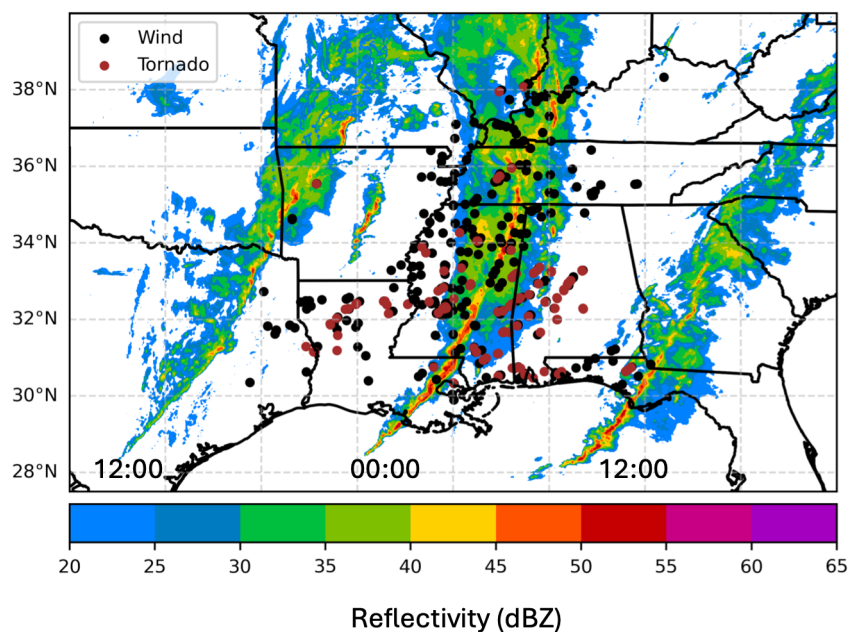


Figure 10 - MRMS reflectivity (in dBZ) between 12 UTC on 30 March 2022 and 12 UTC on 31 March 2022 (from left to right) overlaid by SPC reports for wind (black dots) and tornadoes (red dots). A total of 434 reports occurred during the period (114 tornadoes, 318 wind, 2 hail; SPC, 2022).

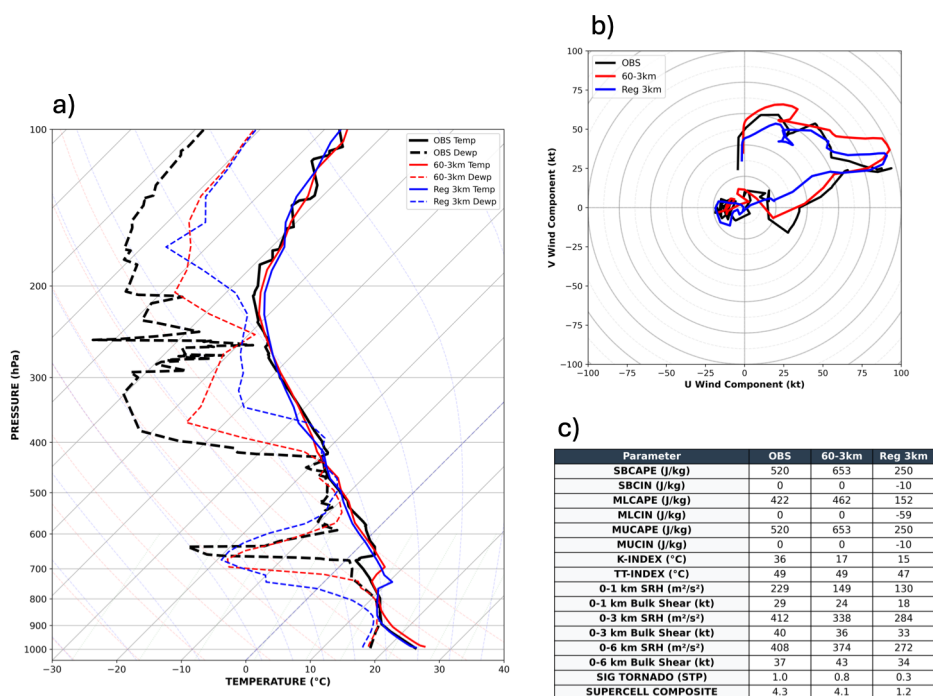


Figure 11 - Skew-T diagram at 18 UTC on 30 March 2022 in Jackson, Mississippi (Station 72235) a), hodograph b), and table presenting storm parameters c) for the global and regional experiments.

Figure 12 shows the pre-MCS environment conditions from the physics suites experiments. Both CP and MR runs showed improved depiction of the height of inversion layer when compared to the NOAA/GSL physics suite. On the other hand, NOAA/GSL seems to do a better job capturing the strength of the inversion layer and a slightly better job reproducing the dewpoint sounding profile (**Fig. 12a**). CP and MR showed very similar hodographs and good agreement with the observed one, while NOAA/GSL showed more differences (**Fig. 12b**). Regarding the storm parameters (**Fig. 12c**), MR showed higher CAPE values in general while CP showed more intense SRH and Shear values compared to observed sounding. MR (STP = 1.3) overestimated the observed STP (= 1.0) compared to CP and NOAA/GSL (STP = 0.8), and also overestimated the SC (= 5.9).

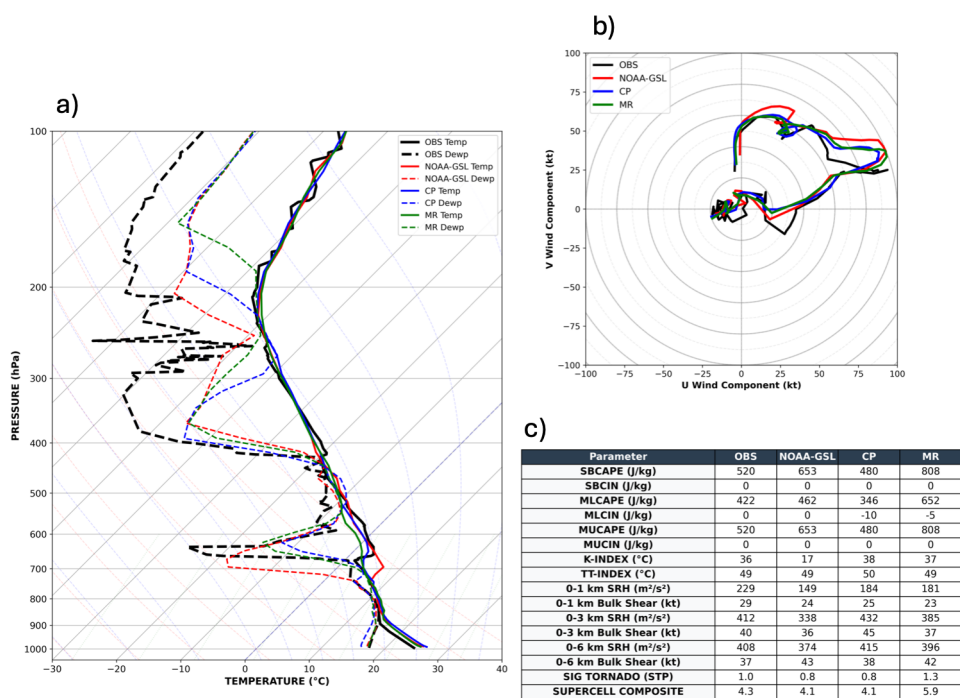


Figure 12 - Same as Fig. 11, but for the physics suite experiments.

Figure 13 shows the maximum STP from modeling framework and physics suite experiments overlayed by SPC reports during the period. All experiments showed STP > 1.0 over the region of the tornado outbreak according to the SPC reports. The main differences are in terms of intensity, with the regional showing higher STP values over the Southeastern U.S., while MR showed less intense ones. In regions where there were more occurrences of tornadoes such as Louisiana, Alabama and Northwest Florida, all experiments showed STP > 5.0, indicating their usefulness in

predicting the tornado outbreak. **Figure 14** shows neighborhood ROC curves and TSS, the former indicating that the regional experiment (AUC = 0.896) had slightly better, but still very similar, performance compared to the global one (AUC = 0.877; **Fig. 14a**). TSS suggests that the global experiment is more suitable for STP values up to 3 and regional is better for STP > 3.0, but they had almost the same maximum TSS (= 0.637-0.638; **Fig. 14b**). CP (AUC = 0.876) showed very similar performance to NOAA/GSL (AUC = 0.875), while MR (AUC = 0.873) shows slightly lower performance. On the other hand, despite TSS also indicating similar skill, the MR (TSS = 0.649) was slightly more skillful than CP (TSS = 0.644) and NOAA/GSL (TSS = 0.637). **Figure 15** shows the differences between global and regional runs for storm parameters such as CAPE, SRH 0-1 km, and Shear 0-6 km. This comparison indicates that regional showed more intense STP values due to increased CAPE and SRH 0-1 km, despite reduced Shear 0-6 km compared to global.

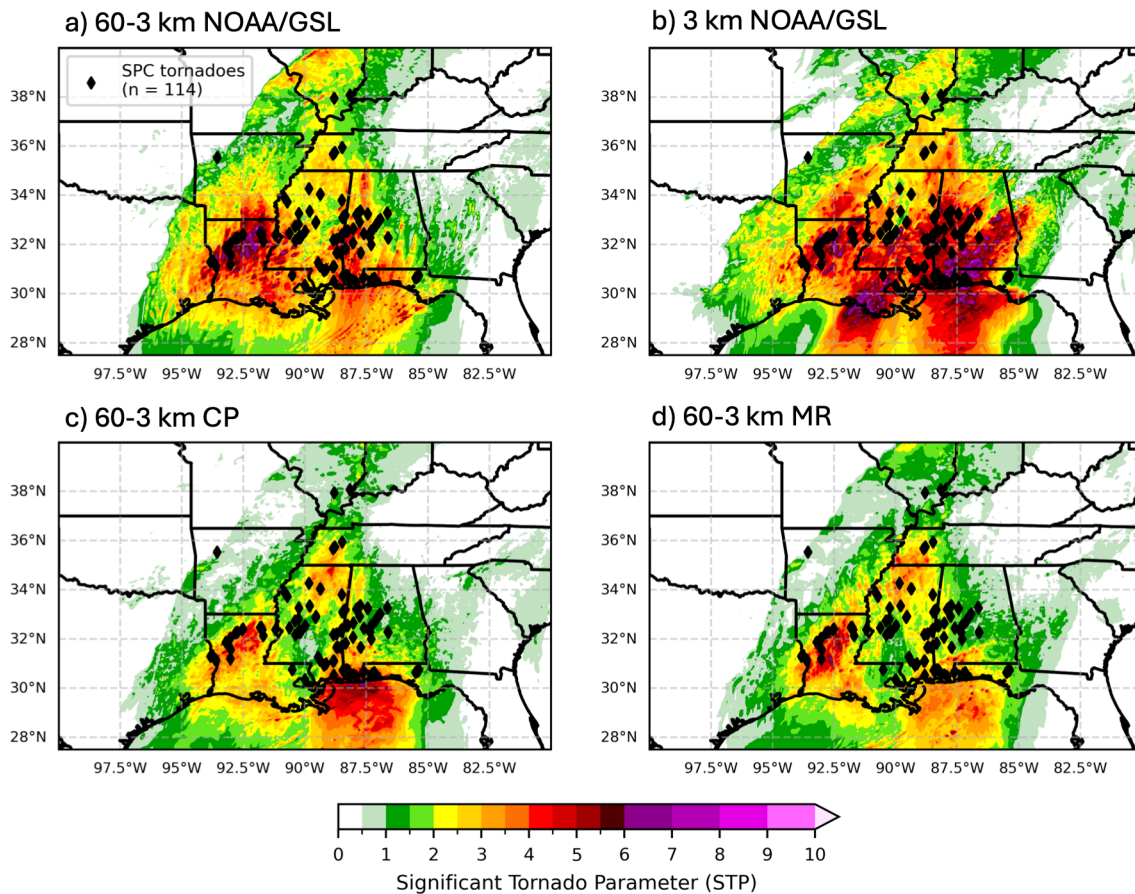


Figure 13 - Significant Tornado Parameter (STP) from 60-3 km NOAA/GSL **a)**, Regional 3 km NOAA/GSL **b)**, 60-3 km CP **c)**, and 60-3 km MR **d)** experiments overlaid by SPC tornadoes report. STP fields from model output are the maximum value during the period (12-12 UTC 30-31 March 2022).

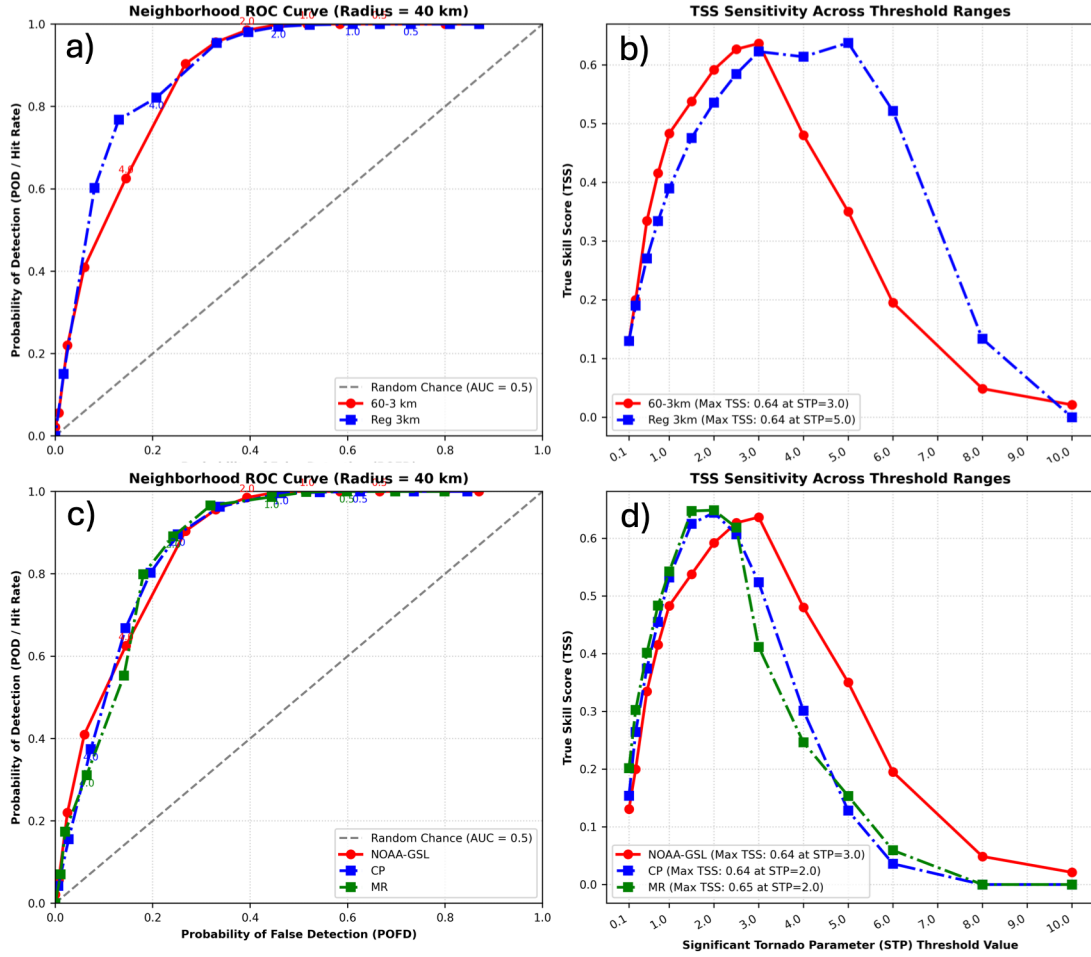


Figure 14 - Neighborhood ROC curve and TSS sensitivity across STP thresholds for modeling frameworks experiments **a, b)**, and physics suites experiments **c, d)**.

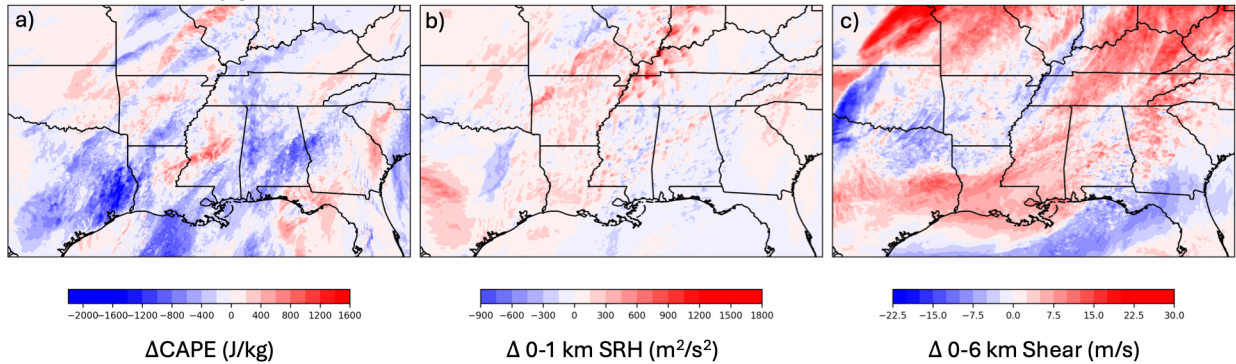


Figure 15 - Difference between global - regional experiments for CAPE (in J/kg) **a)**, 0-1 km SRH (in m^2/s^2) **b)**, and 0-6 km Shear (in m/s) **c)**.

3.2. Southern Brazil case

3.2.1. MCS tracking results

Figure 16 shows the MCS features from the observed dataset and MPAS experiments initialized at 00 UTC on 7 November 2025 testing modeling frameworks. Both experiments showed a delayed initiation of PF area and volume of rain (**Fig. 16c,d**), which the regional experiment overestimated after the mature stage, showing higher CCS area (**Fig. 16a**). This can be observed through the Tb and PCP fields during the mature stage as shown in **Figure 17**. The regional experiment overestimated the observed Tb, while the global one shows better agreement. The same is observed in the PCP field, where the regional experiment shows a longer precipitation swath with spurious precipitation in the northwestern part of the domain that is not observed (**Fig. 17d**). Despite the reasonable agreement in terms of timing for the Tb field, the comparison among precipitation fields suggests that both experiments are delayed in timing, showing the precipitation more to the south than observed (storm propagates northward). MCS movement and speed features suggest the global run is slightly better, while the regional run showed higher distance and speed during MCS decaying.

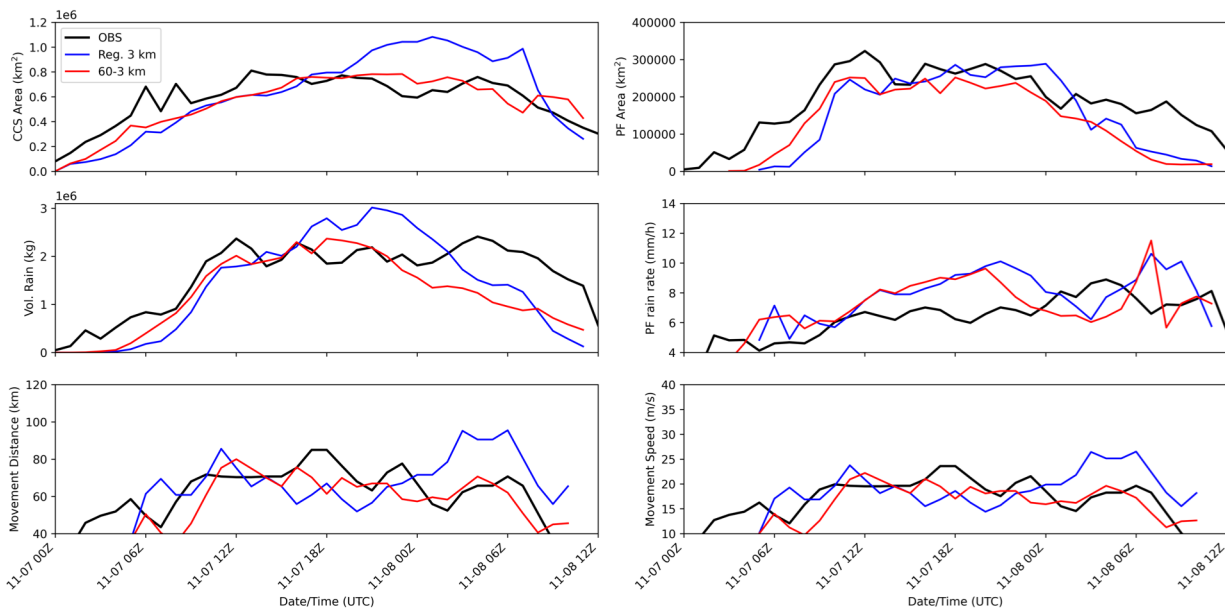


Figure 16 - Same as Fig. 4, but for the Southern Brazil case.

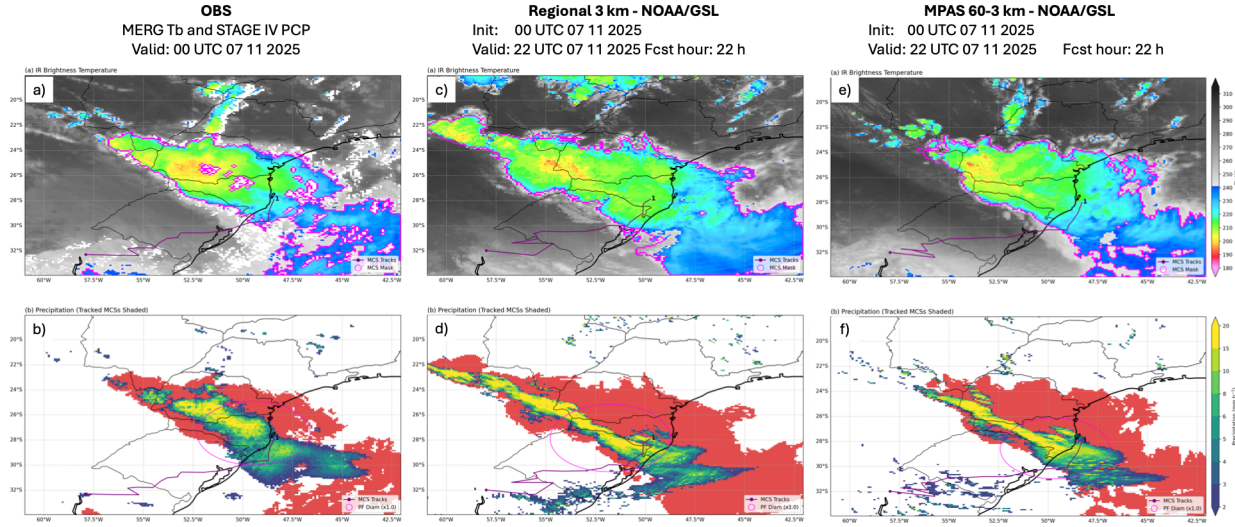


Figure 17 - MCS tracking outputs from observational dataset **a-b**), and MPAS experiments using NOAA/GSL physics suite initialized at 00 UTC on 7 November 2025 and configured with the regional 3 km domain **c-d**), and 60-3 km mesh **e-f**). Top figures are the Tb (in K) and bottom figures are the hourly precipitation (in mm/h).

3.2.2. Surface verification

Figure 18 summarizes the surface verification for precipitation using IMERG as reference and **Figure 19** shows the box plots of Bias, RMSE, and Pearson correlation for surface variables. Both experiments were able to reasonably reproduce the observed strong precipitation over the southern part of the domain, but clearly underestimated around latitudes 24-26°S and 18-22°S. They also showed similar timing with the global experiment producing more precipitation in the beginning of the period, while regional overestimates the observed domain averaged precipitation (**Fig. 18e**). This translates into very similar skills as indicated by the FSS (**Fig. 18f**), with global being slightly better for low-to-moderate and heavy precipitation. Global presented slightly warmer and wetter biases compared to the regional simulation, while the latter showed a larger bias for surface pressure, indicating storm propagation issues. Regional presented in general higher RMSE and lower correlation than global. Both underestimated the wind speed components showing negative biases.

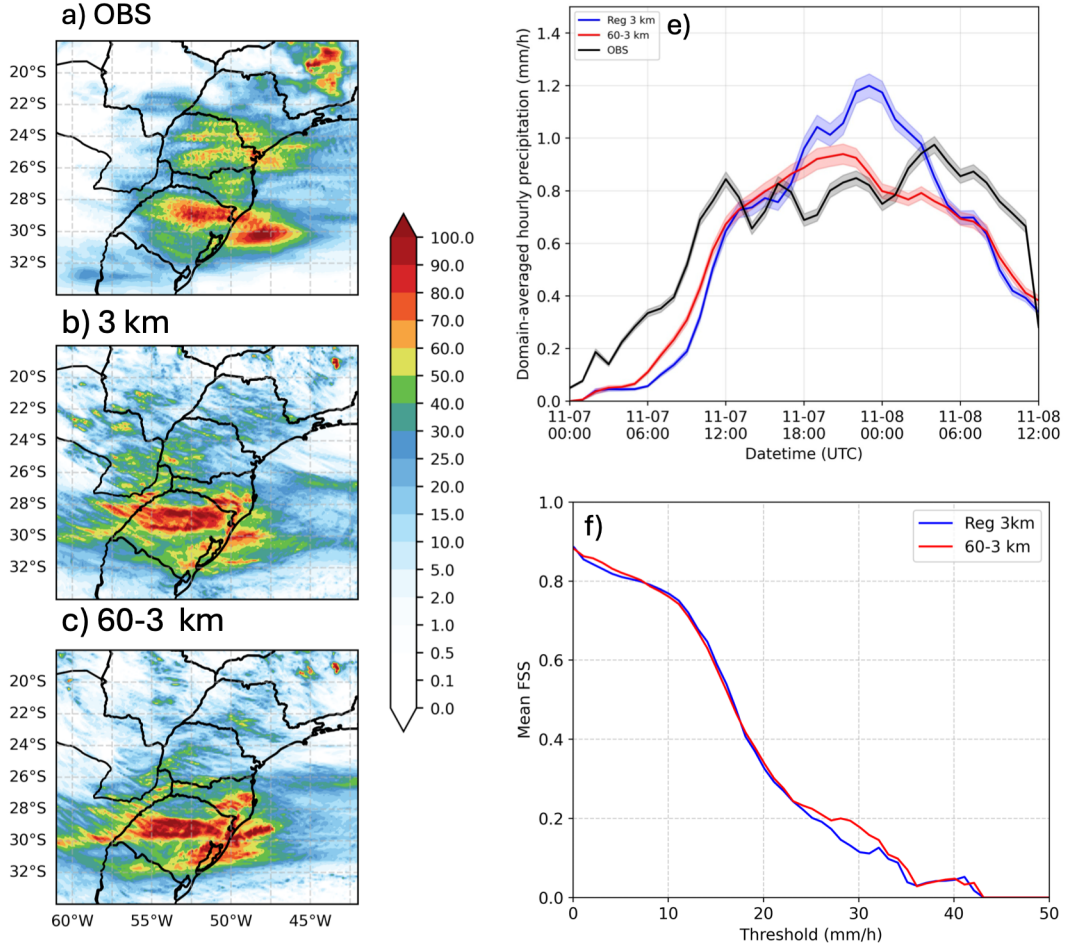


Figure 18 - Accumulated precipitation (in mm) between 12 UTC-12 UTC 7 and 8 November 2025 from OBS (IMERG) **a)**, and MPAS experiments initialized at 00 UTC on 7 November 2025 with global **b)** and regional **c)** configurations. Domain averaged hourly precipitation from observation and model experiments **e)**, and mean FSS for several thresholds **f)**.

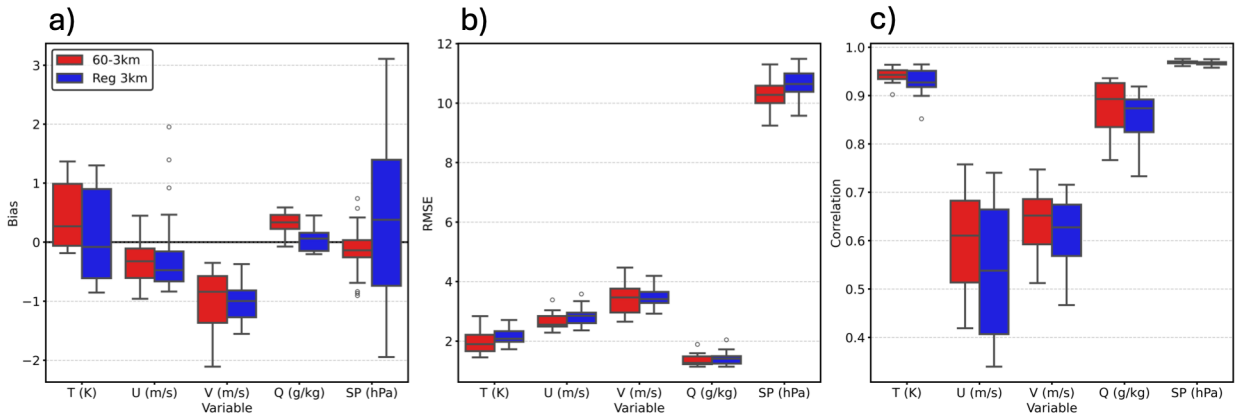


Figure 19 - Similar to Fig. 8, but for the period between 12 UTC-12 UTC 7 and 8 November 2025.

3.2.3. Severe weather

Figure 20 provides the Skew-T diagram and hodograph with the available sounding closest (~200 km west) to the tornado outbreak region. Both MPAS experiments showed good agreement with the observed vertical structure and hodograph at that location where no tornadoes were recorded. Although the storm parameters did not indicate potential for severe weather at that location, the observed profile presented 0-6 km shear of 60 kt, with the global and regional experiments being slightly less intense (50 and 48 kt, respectively). **Figure 21** presents the computed STP overlayed by PREVOTS reports for tornado and both neighborhood ROC curve and TSS. The global run clearly showed more intense STP values across the domain (**Fig. 21a**), particularly where tornadoes were observed, while the regional one showed STP between 0 and 1 in most locations (**Fig. 21b**). This yielded better performance (AUC = 0.642) and skill for the global compared to regional (AUC = 0.513) approach (**Figs. 21c, d**). **Figure 22** shows the difference between global and regional storm parameters, which suggests that the regional experiment produced less SRH and shear, yielding lower STP values despite similar CAPE over the tornado outbreak region.

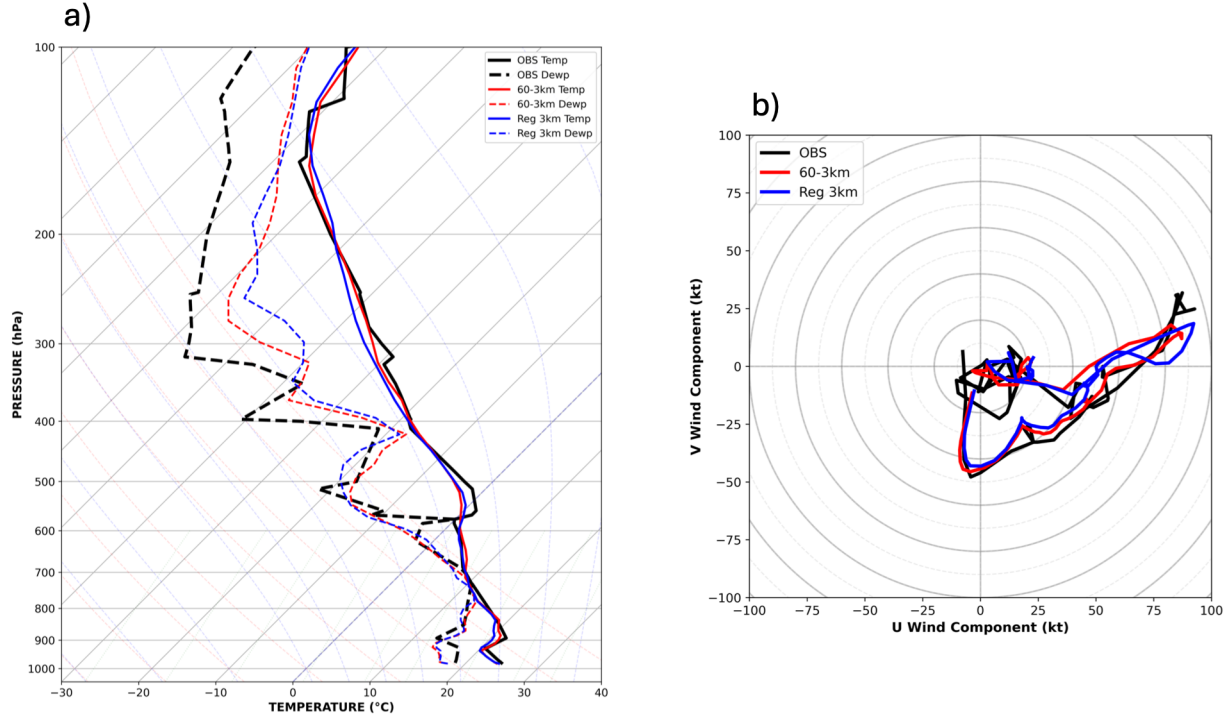


Figure 20 - Skew-T diagram at 12 UTC on 7 November 2025 in Foz do Iguaçu, Paraná, Brazil (Station 83827) **a)**, and hodograph **b)**, for global and regional experiments.

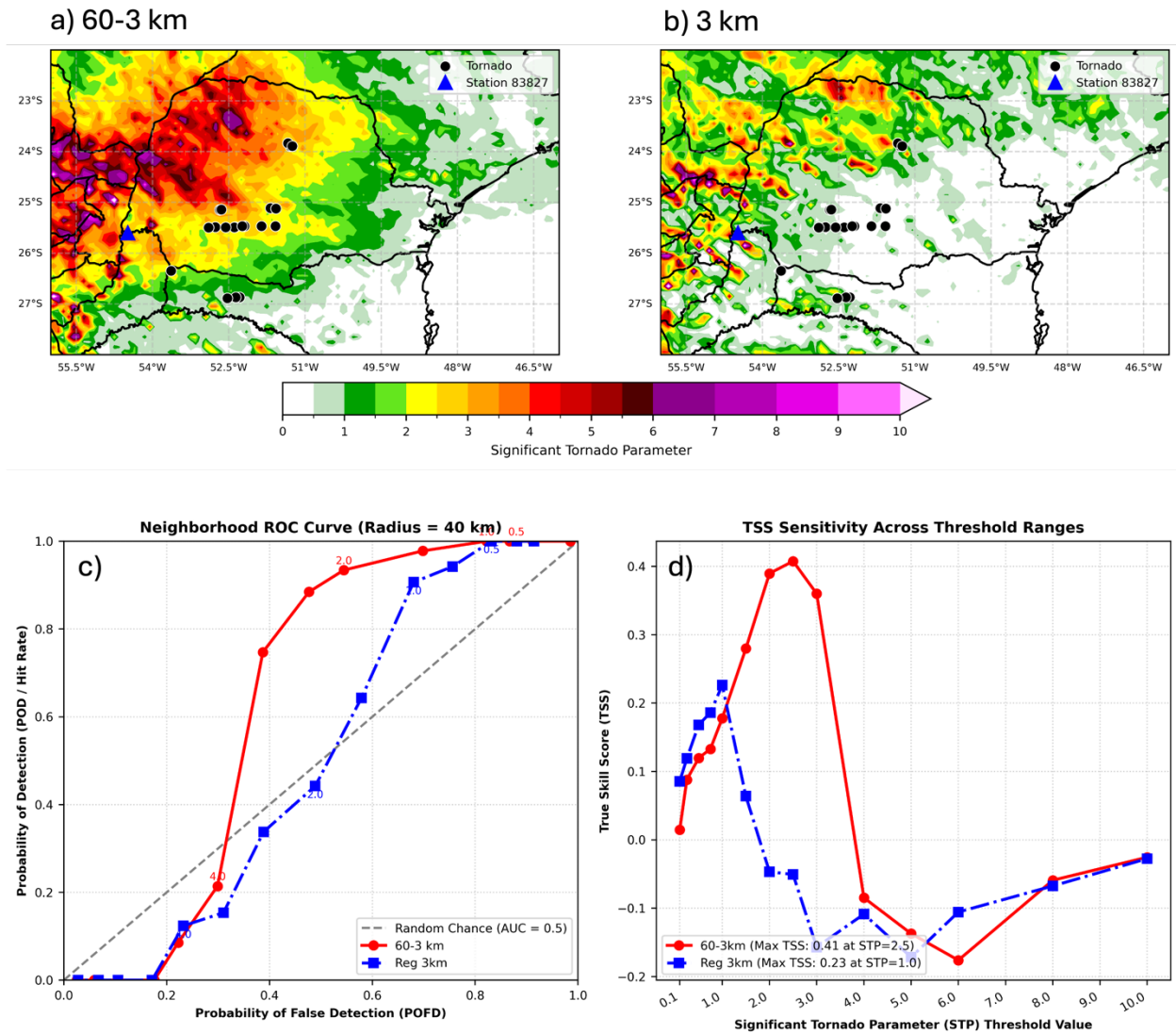


Figure 21 - Similar to Fig. 14, but for modeling framework experiments for the Southern Brazil case.

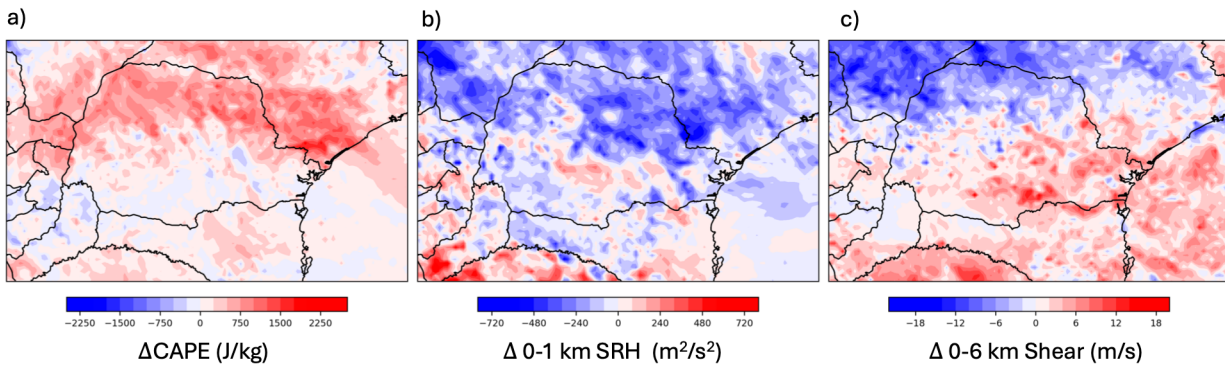


Figure 22 - Similar to Fig. 15, but for the Southern Brazil case.

3.3. Amazon wet case

3.3.1. MCS tracking results

Figure 23 shows the Tb and PCP fields from MCS tracking results for the Amazon MCS case during the wet season. None of the experiments were able to accurately reproduce the observed MCS during the passage over the ARM site (**Fig. 23a,b**) with some experiments such as CP-ERA5 (**Fig. 23e,f**) and CPNT-ERA5 (**Fig. 23k,l**) showing larger differences.

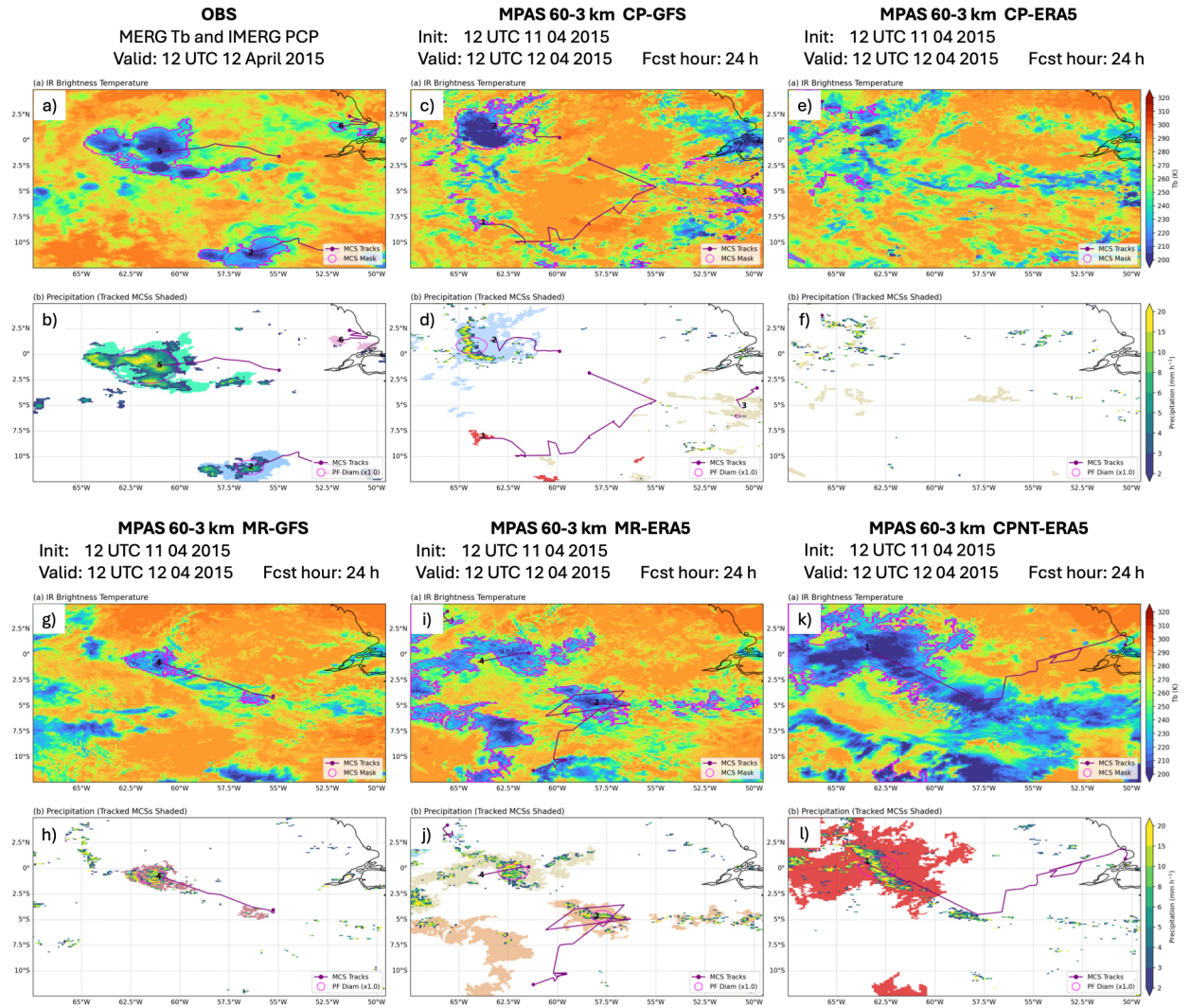


Figure 23 - MCS tracking outputs from observational dataset **a-b**), and MPAS 60-3 km experiments initialized at 12 UTC on 11 April 2015 using CP physics suite and NCEP-GFS IC **c, d**), CP physics suite and ECMWF-ERA5 IC **e, f**), MR physics suite and NCEP-GFS IC **g, h**), MR physics suite and ECMWF-ERA5 IC **i, j**), and CP physics suite with New Tiedtke convection scheme (CPNT) and ECMWF-ERA5 IC **k, l**). Top figures are the Tb (in K) and bottom figures are the hourly precipitation (in mm.h⁻¹).

The MR-GFS (Figs. 23 g,h) and CP-GFS (Figs. 23c, d) experiments were slightly better than the others in terms of Tb and PCP fields. An interesting behavior was observed in Tb fields from CP experiments (independent of the IC source), showing spurious convection everywhere around 12 and 00 UTC, which is not observed in the Tb fields from MR experiments (not shown). These differences are probably related to the integrated contribution from convection, microphysics, and PBL schemes from the CP physics suites. We tested the New Tiedtke convection scheme within the CP physics suite (CPNT experiment), but it overestimated the Tb field (Fig. 23k) despite showing precipitation where it is observed. Figure 24 shows the MCS features from these experiments revealing how difficult it is to reproduce this system in a weakly forced environment. MPAS experiments showed differences throughout the MCS lifetime with some of them overestimating most of the MCS features such as CCS area (Fig. 24a) and volume of rain (Fig. 24c). In general, they diverged in terms of MCS lifetime showing longer (e.g., CPNT-ERA5) or shorter (MR-GFS) lifetimes compared to the observed MCS.

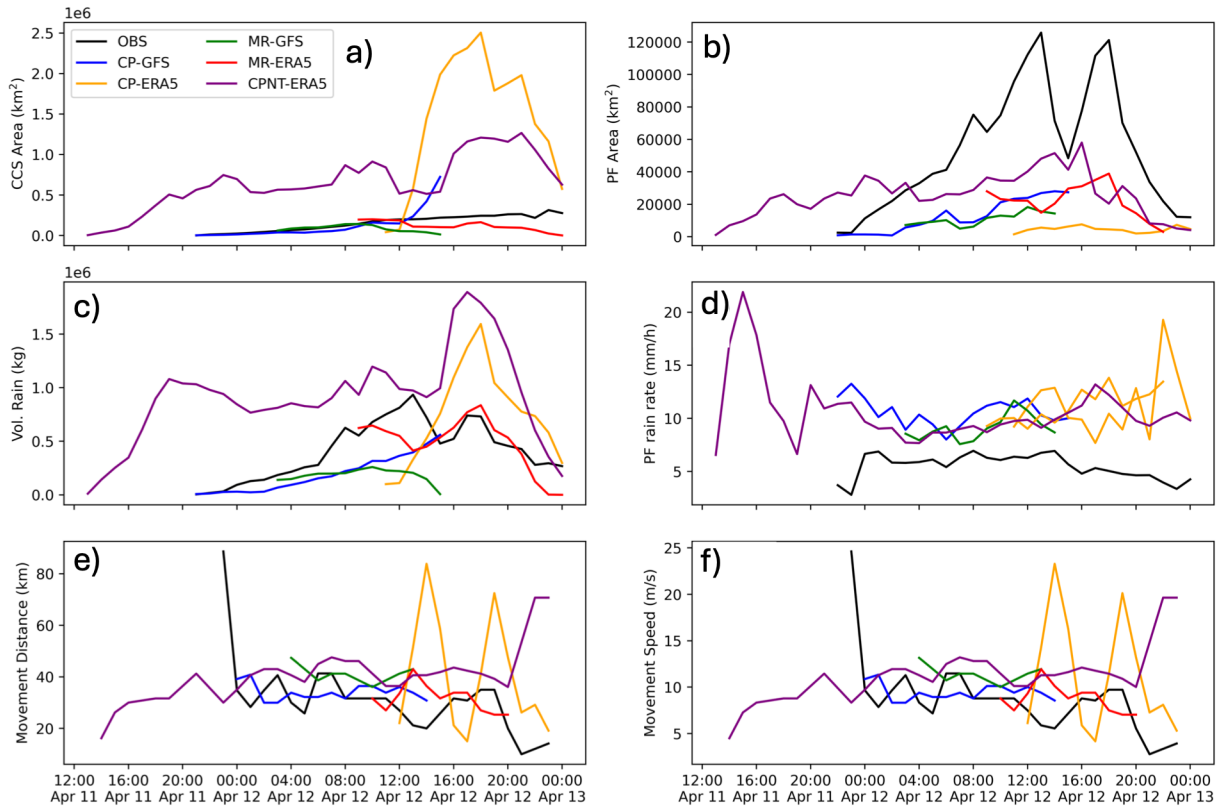


Figure 24 – Similar to Fig. 4, but for the Amazon wet case.

3.3.2. Surface verification

Figure 25 summarizes the precipitation verification for the Amazon wet case. All experiments underestimated the observed precipitation (**Fig. 25a**), as expected and in agreement with the MCS features comparison. Both MR-ERA5 and CPNT-ERA5 experiments appeared to produce more precipitation than the other experiments, but still showed a large underestimation. This translates into poor performance (**Fig. 25b**), particularly for moderate-to-heavy PCP thresholds. MR-ERA5 produced more precipitation and consequently showed higher RMSE (**Fig. 25c**), but it was more skillful experiment compared to the other experiments (**Fig. 25d**).

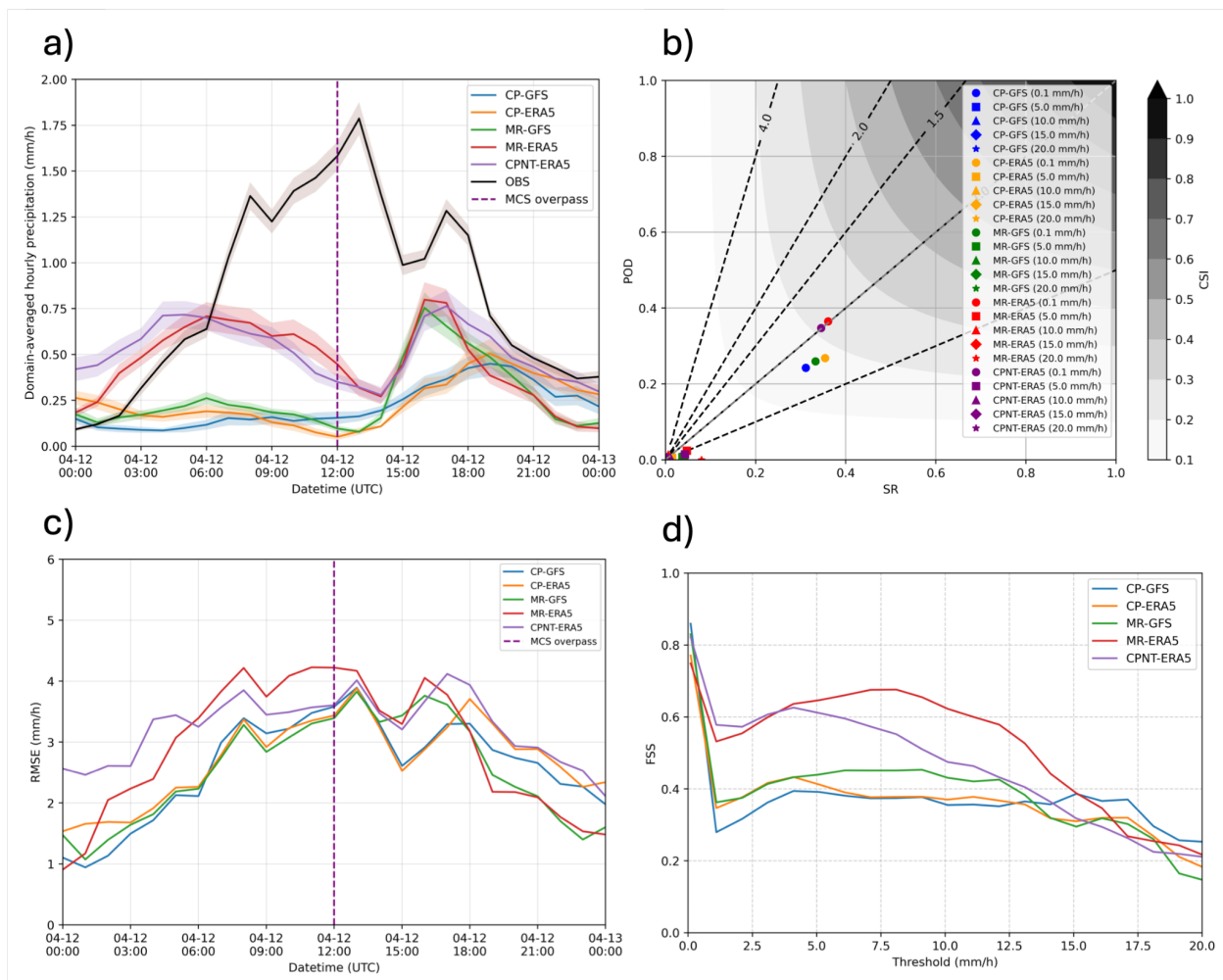


Figure 25 – Precipitation verification summary for MAO wet case. Domain-averaged hourly precipitation (in mm/h) during the period comprising 12 hours prior and after the MCS overpass (indicated by dashed purple line) over the MAO site **a**), Performance diagram summarizing categorical indices **b**), RMSE time series **c**), and averaged FSS for several thresholds **d**).

Figure 26 shows the surface variables and statistical metrics used to verify these experiments against ARM observations at a single observational site (T3). The most significant differences are evident during the MCS passage over the ARM site at 12 UTC on 12 April 2015, where most of the experiments were not able to depict the drop in equivalent potential temperature (**Fig. 26a**) associated with the cold pool. CPNT-ERA5 showed a drop at that time, but with lower temperatures. Also, none of the experiments was able to reproduce the observed increase in wind speed at that time (**Fig. 26e**). Verification metrics (**Figs. 26 f-t**) indicated that the MR experiments showed less error (MAE, RMSE) and better correlation for most variables than CP ones. MR-ERA5 showed better precipitation performance. CPNT-ERA5 was better for equivalent potential temperature as expected.

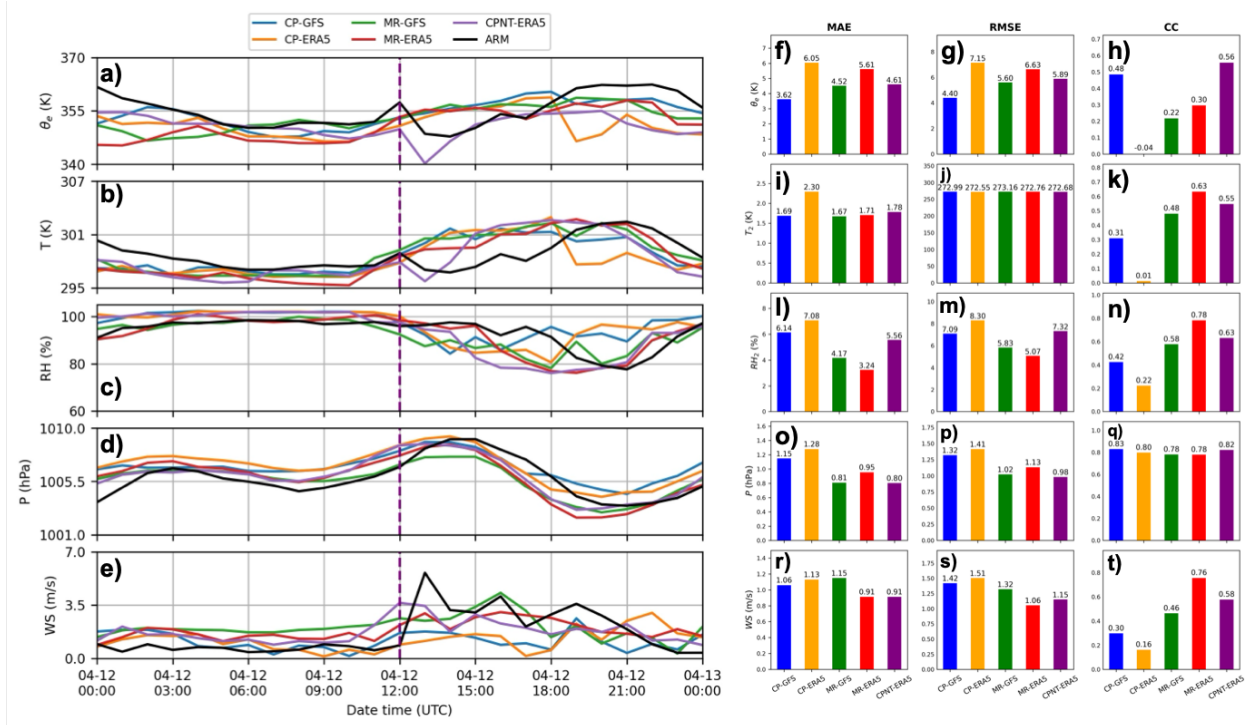


Figure 26 - Cold pool characteristics 12 hours prior and after MCS overpassed at MAO site. Equivalent potential temperature (θ_v , in K) **a**), environmental temperature (T , in K) **b**), relative humidity (RH , in %) **c**), surface pressure (P , hPa) **d**), and wind speed (WS , in m/s) **e**). Statistical indexes were computed for each variable (row biased), which are MAE, RMSE and CC (column biased) as shown in **f-t**). The dashed purple line indicates the time when MCS overpasses over the MAO site at 12 UTC on 12 April 2015.

3.4. Amazon dry case

3.4.1. MCS tracking results

Figure 27 shows the Tb and PCP fields for the MPAS 60-3 km experiments initialized at 17 UTC on 16 September 2014, 24 hours before the MCS passage over ARM site. A squall line is observed over the T3 site with moderate-to-heavy precipitation, clearly an isolated MCS over that region (**Fig. 27a, b**). On the other hand, the CP-ERA5 experiment shows a larger system with cloudiness spreading from the Amazon River delta region, which at this time is identified as two separate systems (#3 and #4, **Fig. 27c, d**). Despite the larger CCS area, this system shows a smaller PF area (**Fig. 28 a, b**) compared to the observations. MR-ERA5 shows better results in terms of positioning and size but still produces more widespread cloudiness than observed (**Fig. 27e**). The precipitation field reveals good agreement with the observations although showing more intense rain rates (**Fig. 27f, Fig. 28d**). MCS features revealed a very different behavior for CCS area and propagation features between CP and MR experiments (**Figure 28**). Compared to the wet case, the results are better in terms of storm structure and MCS features in general. On the other hand, compared to the midlatitude MCS cases, the model clearly struggles to reproduce MCS over the Amazon region even at 3 km grid spacing and without lateral boundary conditions.

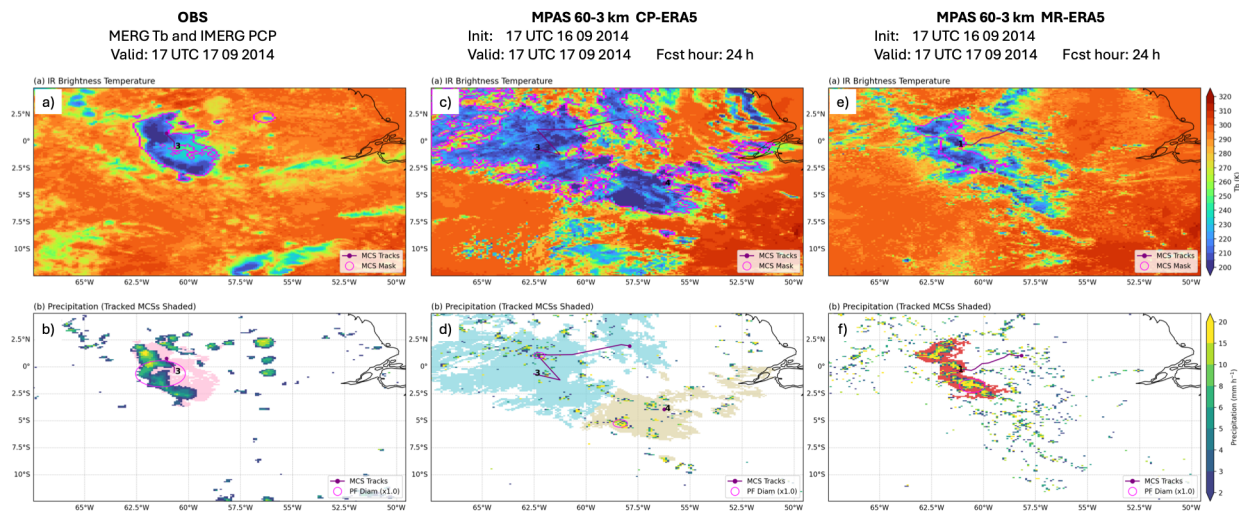


Figure 27 - Similar to Fig. 23, but for the Amazon dry case.

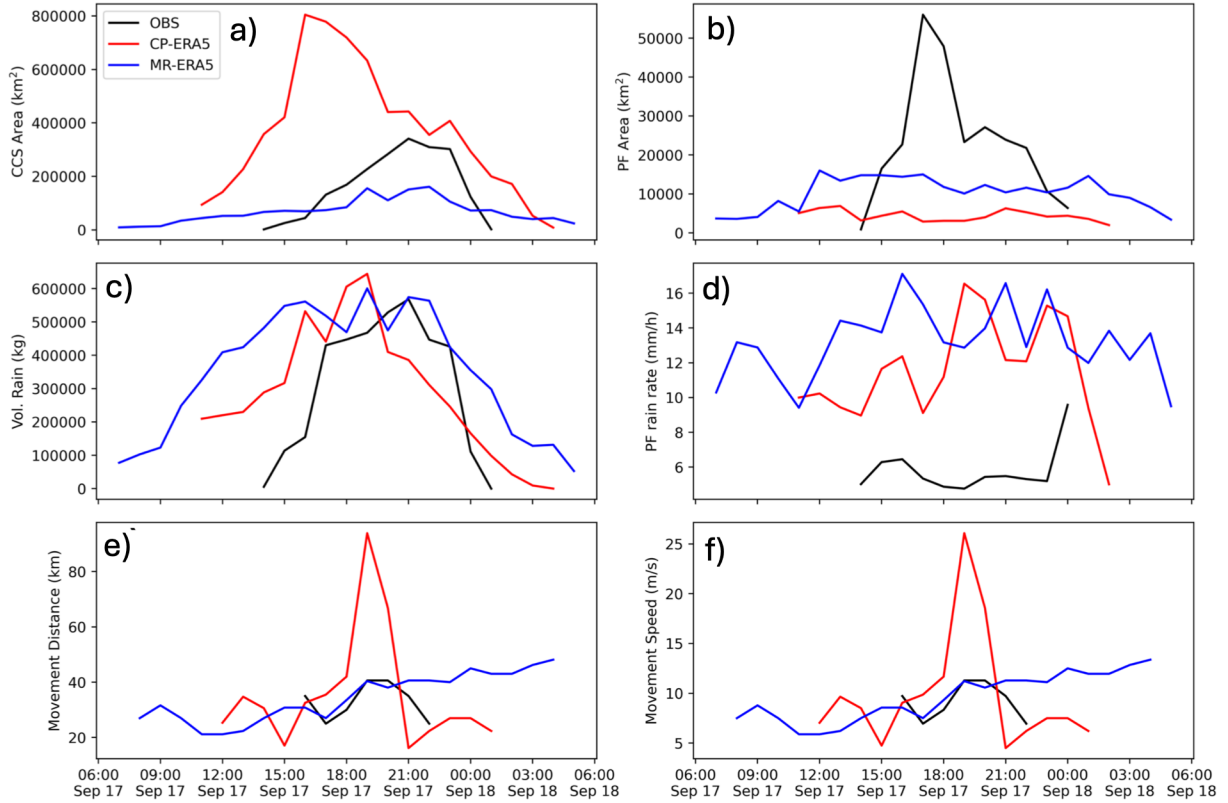


Figure 28 - Similar to Fig. 24, but for the Amazon dry case.

3.4.2. Surface verification

Figure 29 presents the surface variables comparison against observations at T3 site. Neither experiment was able to reproduce the drop in equivalent potential temperature when the MCS overpasses the ARM site. They showed colder temperatures prior to the MCS arrival and warmer ones after the passage, which impacted the relative humidity. Reasonable agreement to the observed surface pressure is observed in general. MR experiment showed lower MAE and RMSE for most of the variables, yielding higher correlation (**Fig. 29f-t**). **Figure 30** illustrates the improvement in this case compared to the wet case, where the model was able to produce more precipitation but still yielded an underestimation as seen before (**Fig. 30a**). MR showed slightly better performance - which is low for both experiments - and is also skillful for low-to-moderate precipitation. CP showed lower RMSE but had the poorest overall performance due to generating spurious convection.

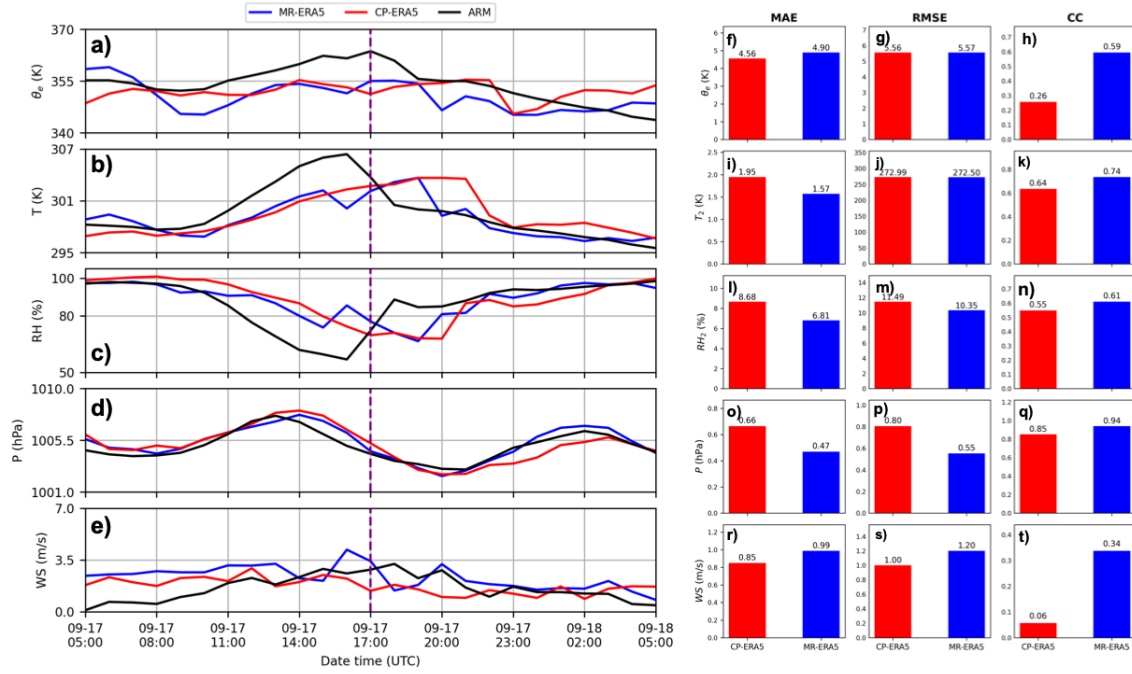


Figure 29- Similar to Fig. 26, but for the Amazon dry case.

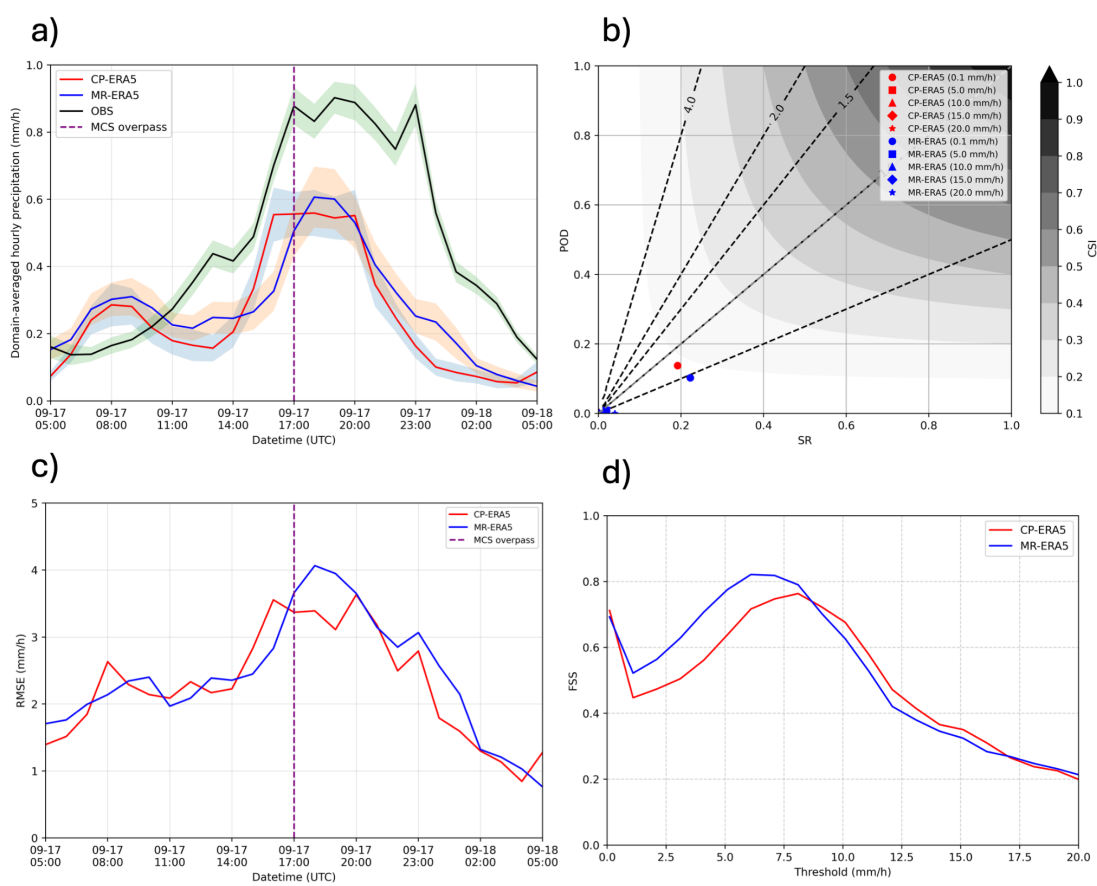


Figure 30 - Similar to Fig. 25, but for the Amazon dry case.

4. Discussion and conclusions

This project tested and evaluated the MPAS model in reproducing MCS over midlatitude and tropical regions at convection-allowing resolution. A complete simulation framework for MCS reproduction was developed, comprising variable-resolution global 60-3 km and regional 3 km meshes centered over each studied region, three physics suites (MR, CP, and the new NOAA/GSL suite under development for RRFSv2), objective MCS identification and tracking with PyFLEXTRKR following the MCSMIP protocol, and a multi-component evaluation encompassing MCS features, precipitation, near-surface variables, and severe weather parameters. This framework, together with the sensitivity experiments summarized in Table 3, allowed testing and diagnosing issues related to the main model components, namely the initialization lead time, the modeling framework, and the physical parameterizations.

For the Southeastern U.S. case, the experiments revealed a strong sensitivity to the initial conditions. A longer lead time - allowing model spin-up prior to the convective initiation - did not necessarily improve the MCS reproduction, whereas shorter lead times better captured the initiation timing and the storm structure during the mature stage. These results indicate that MPAS can capture the initiation and evolution of midlatitude MCS in short-range forecasts, although the forecast quality is strongly modulated by the initial condition. For the tropical cases, initialized about 24 hours before the MCS overpass, the initiation and evolution were poorly captured; therefore, this objective was mainly addressed through the initialization time tests of the Southeastern U.S. case. The comparison between modeling frameworks showed that the variable-resolution global configuration generally outperformed the regional one, which exhibited more intense and displaced precipitation, degraded surface verification, and a poorer depiction of the pre-MCS environment in the Southeastern U.S. case, as well as a strong underestimation of the STP over the tornado outbreak region in the Southern Brazil case. Previous assessments have likewise highlighted strengths and challenges of the MPAS mesh refinement approach for midlatitude storm forecasting (Imberger et al., 2021), and the differences found here may be partly related to the lateral boundary conditions and the missing scale interactions in the regional framework, which deserve further investigation.

Regarding the physical parameterizations, all three suites captured the MCS mature stage and the severe weather environment of the Southeastern U.S. case, but with clear trade-offs: CP and MR better reproduced the volume of rain and the precipitation skill, MR presented superior surface verification, and NOAA/GSL produced a weaker Tb signature and a more segmented precipitation swath. MR clearly improved the reproduction of convective initiation. All experiments produced more intense rain rates than observed, a common behavior of convection-permitting models that has been attributed to too wide, undiluted, and strong updrafts and to the associated microphysical processes (Varble et al., 2014a,b; Fan et al., 2017; Wang et al., 2020; Prein et al., 2020, 2025). In contrast with Mantovani et al. (2026b), who assessed the CP and MR physics suites for severe weather forecasting in Southern Brazil, these suites were not tested here for the Southern Brazil case; instead, the new NOAA/GSL physics suite was tested for the first time in that region, complementing previous evaluation. It is worth mentioning that the NOAA/GSL physics suite tested is not exactly the original one. The original NOAA/GSL was developed to use boundary conditions from the High-Resolution Rapid Refresh (HRRR) model and using the RUC LSM. Additionally, the NOAA/GSL physics suite is still under development.

The tropical cases proved substantially more challenging. None of the experiments accurately reproduced the observed squall line during the wet season: all of them underestimated the observed precipitation, particularly for moderate-to-heavy thresholds, and failed to reproduce the observed cold pool signature at the MAO site. The dry season case showed slightly better agreement in terms of storm structure and MCS features, but the precipitation underestimation and the cold pool misrepresentation persisted. This poor performance in a weakly forced environment agrees with previous studies reporting the difficulty of models in reproducing precipitation and its controlling processes over the Amazon, even at storm-resolving resolutions (Yin et al., 2013; Sakaguchi et al., 2018; Tai et al., 2021; Paccini and Stevens, 2023). Likewise, the underestimation of precipitation associated with the misrepresentation of MCS found here is consistent with previous evaluations of convection-permitting and km-scale models (Feng et al., 2023a; Prein et al., 2025; Kukulies et al., 2026).

Regarding the MCS movement and propagation, MPAS reproduced the observed movement distance and speed reasonably well for the midlatitude cases, especially in the global experiments,

although timing and displacement errors were identified for the Southern Brazil case, in which both experiments showed delayed timing with precipitation displaced to the south of the observed storm. In the tropical cases, the propagation features diverged considerably among the experiments and from the observations. The evaluation of the 24-h precipitation associated with the MCS passage showed skillful forecasts for the midlatitude cases, with high FSS for light-to-moderate precipitation and useful skill even for heavier thresholds, whereas the skill was low for the Amazon cases due to the large precipitation underestimation.

An encouraging result is the potential utility of MPAS for severe weather guidance. All Southeastern U.S. experiments produced STP > 1.0 collocated with the observed tornado reports and STP > 5.0 over the regions with the highest tornado occurrence, with neighborhood ROC AUC around 0.87-0.90, and the global experiment clearly outperformed the regional one in discriminating the tornado outbreak region of the Southern Brazil case. These results are in line with the promising performance of MPAS-based configurations for convection-allowing forecasts reported in recent testbed experiments (Clark et al., 2023; 2026) and support the choice of MPAS as the dynamical core of NOAA's next-generation NWS operational modeling system (Carley et al., 2023; Aligo et al., 2026).

Some limitations and uncertainties must be considered when interpreting these results. The evaluation is based on a small number of MCS cases and on deterministic simulations, and therefore does not provide robust statistics, so the conclusions about model skill should not be generalized. Prein et al. (2022) and Ramos-Valle et al. (2023) simulated several midlatitude and tropical MCS cases - including cases analyzed here - a 4-km WRF setup, but presented results aggregated over all cases; in contrast, the present project provides a detailed, case-by-case evaluation, which is complementary to those studies, but statistically limited. Additional sources of uncertainty include the observational datasets themselves (e.g., satellite-based precipitation estimates for heavy rainfall), the verification against single sounding and surface sites, and the regridding of the model output from its unstructured mesh to regular latitude-longitude grids. Furthermore, the physics suite testing was not homogeneous across cases, which limits direct intercomparisons among them.

Based on the identified shortcomings, potential solutions can be proposed. The strong sensitivity to the initial conditions - particularly the misrepresentation of the convective initiation in the weakly forced Amazon environment - suggests that convective-scale data assimilation with JEDI-MPAS (Liu et al., 2022; Jung et al., 2024), including radar and satellite observations, could substantially improve very short-range MCS forecasts as demonstrated in the 2026 NOAA Hazardous Weather Testbed (HWT) Spring Forecasting Experiment (SFE). The spurious convection produced by the CP physics suite over the Amazon and the general precipitation underestimation point to the need for further testing of scale-aware convection schemes and of ongoing microphysics developments (e.g., TEMPO) in tropical environments, as well as for an improved representation of cold pools and their role in convective organization. The propagation and intensity issues found in the regional framework deserve further investigation, including the sensitivity to domain size and lateral boundary conditions. The domain size was tested using a 3 km CONUS domain, but results were not improved (not shown). Finally, extending this framework to a larger set of MCS cases and to ensemble simulations would provide the robust statistics needed to generalize these findings.

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Any remaining errors or interpretations are my own.

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