Assessing the Impact of Scale-Aware Convective Parameterization Schemes on Tropical Cyclone Simulations in the South China Sea Using WRF, MPAS, and CPAS

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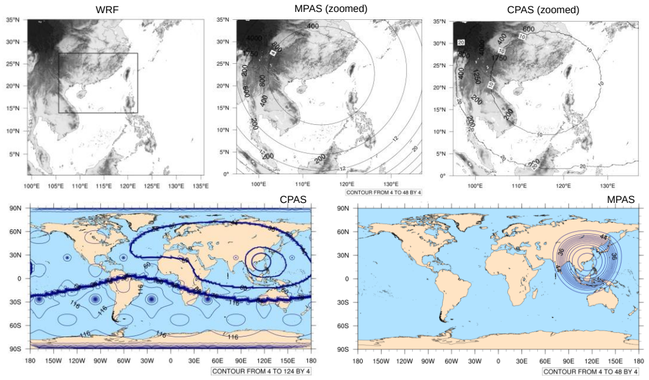
Introduction

Tropical cyclones (TCs) remain challenging to simulate at grey-zone scales (1-10 km). This study evaluates the performance of WRF, MPAS, and CPAS in TC simulations over the South China Sea, focusing on the role of scale-aware convective parameterization schemes (CPS). CPAS, featuring innovations like Customizable Unstructured Mesh Generation (CUMG) and Hierarchical Time-Stepping (HTS), improves precipitation representation and vertical moisture transport while addressing MPAS's outer rainband deficiencies. Challenges such as resolution transitions and double TC interactions highlight the need for further CPS refinement to enhance TC forecast accuracy.

Model Configuration & Experimental Design

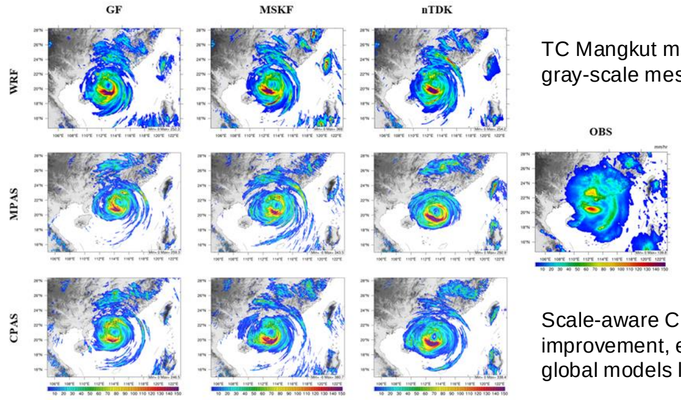
- 3 Advanced NWP Models: (1) WRF with 9-3 km 1-way nesting domains, (2) MPAS with 60-3 km mesh, (3) CPAS with 96-48-24-12-3 km mesh
- Physics Configuration: New Tiedtke (NTDK), Multi-Scale Kain-Fritsch (MSKF), Grell-Freitas (GF) Scale-aware CPS, WSM6 microphysics, YSU PBL, Noah LSM, RRTMG
- ERA 5 as initial conditions (and boundary conditions for WRF)
- 96-hour integration period, 12-hour spin-up time
- No nudging or TC bogus



Model Comparison

Model	Mesh Design	Grid Type	Model Type	Application
WRF	Nested domains	Rectangular grid	Regional model	High-resolution **regional forecasts** with fixed nested domains
MPAS	Variable-resolution mesh	Voronoi mesh	Global/Regional model	Seamless global-to-regional simulations
CPAS	Customized variable resolution mesh	Voronoi mesh	Global/regional model	High computation efficiency and arbitrary resolution refinement, including extreme resolution refinement for small region

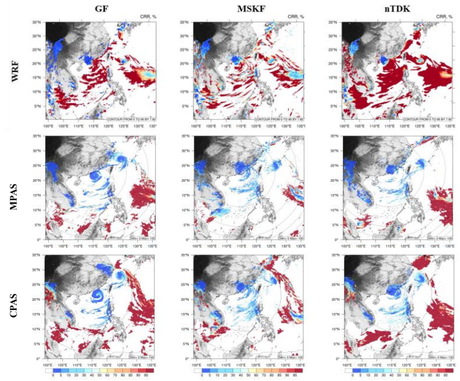
Large-scale Precipitation Pattern Analysis: CPAS vs WRF and MPAS



TC Mangkut moved into 3 km gray-scale mesh

Scale-aware CPS is a significant improvement, especially for global models like CPAS.

Convective Rain Ratio (CRR) Across Different Resolutions



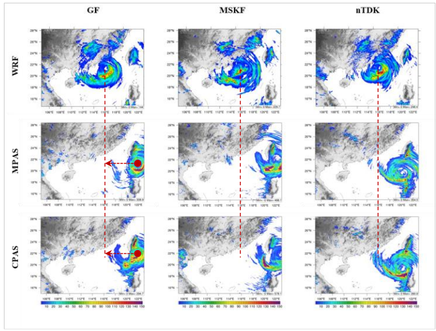
- A Smaller TC Saola (2023) 66-72 hours accumulated precipitation 1800 Sep 1 - 0000 UTC Sep 2, 2023 (the 66 - 72 forecasting hour)
- The CRR exhibits sharp scale-dependent variations across these zones.
- CPAS shows the potential to outperform.
- However, handling resolution transitions remains a challenge.

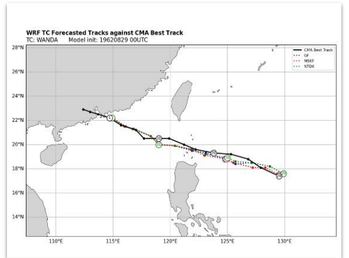
Further information

All CPAS documents and deliverables can be downloaded from:
https://cpas.earth
Contact e-mail: wpsze@clustertech.com

ClusterTech specializes in high-performance computing and AI solutions, and developed CPAS, designed to address the computational demands of atmospheric model users, enhancing simulation accuracy and efficiency.

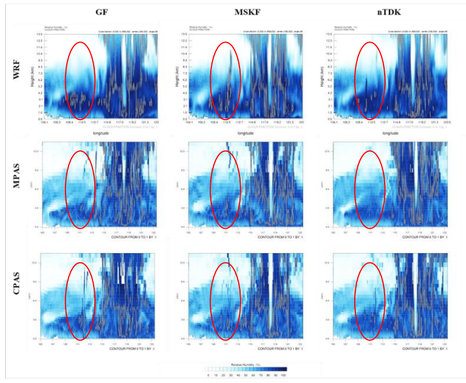
Track Deviation Analysis in Double TC Scenarios





Wanda demonstrated CPAS's strength in precipitation capture but highlighted its limitations in handling multi-storm interactions.

Cloud Fraction and RH Vertical Profile in TC Core



- Both global models show less moisture and cloud cover in outer regions, indicating challenges in simulating moisture convergence and secondary convection.
- CPAS tries to capture more effective small-scale variations in humidity and cloud fraction around outer band than MPAS.

0600 UTC - 1200 UTC Aug 31, 2023 (the 30 - 36 forecasting hour); latitude = 21° N

Summary & further work

- CPAS demonstrates improved balance in TC simulation: Better core-rainband precipitation distribution, enhanced precipitation details in complex coastal regions, and performance comparable to WRF in most cases
- Scale-aware CPS effectiveness varies: MSKF shows optimal performance at 3km (CRR 30-40%), NTDK faces challenges with fine-scale details, and all schemes require improvement in transition zones
- Double TC interactions remain challenging: Track deviations increase in transition zones, and resolution changes affect system interactions
- Moisture transport and convergence need improvement
- **Future Work**: Optimize parameterization for moisture transport, Integrate AI techniques with high-resolution observations, Focus on improved transition zone handling, Develop better approaches for multiple TC scenarios