cSINGV: A convective-scale coupled atmosphere-ocean-wave model for Singapore

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INTRODUCTION

- We present the development and evaluation of cSINGV which is a high-resolution (1.5 km) convective-scale coupled atmosphere–ocean–wave model developed for the Western Maritime Continent (WMC), with a focus on Singapore.
- Results show that cSINGV enhances the representation of diurnal rainfall cycles, especially in capturing their timing and spatial distribution. The coupled model also aligns more closely with satellite-based rainfall estimates over ocean regions compared to the uncoupled setup.
- For surface wind speed and air temperature, differences between the coupled and uncoupled models are relatively minor. However, the coupled model shows a good agreement with satellite and reanalysis data in simulating sea surface temperature and significant wave heights.
- We continue to evaluate the value of fully coupled atmosphere–ocean–wave systems for enhancing regional weather prediction, particularly in simulating extreme weather such as Sumatra squall lines.

DATA AND METHODOLOGY

- cSINGV uses SINGV[1], NEMO[2] and WAVEWATCH3[3] (WW3) as its atmosphere, ocean and wave components (Fig. 1).
- SINGV and NEMO having a horizontal resolution of 1.5 x 1.5 km whereas WW3 uses a horizontal resolution of 1.5-3 km.
- 80 vertical levels (Terrain following) for SINGV and 51 vertical levels (Sigma coordinate) for NEMO
- Initial and Lateral boundary conditions for ATM and Ocean were taken from ERA5[4] and GLORYS12V1[5]. WW3 LBCs from in-house Global wave model.
- Coupler: OASIS3-MCT[6]; Coupling frequency : 1 hour
- OSTIA[7], ERA5 and GPM[8] data were used for model validation.

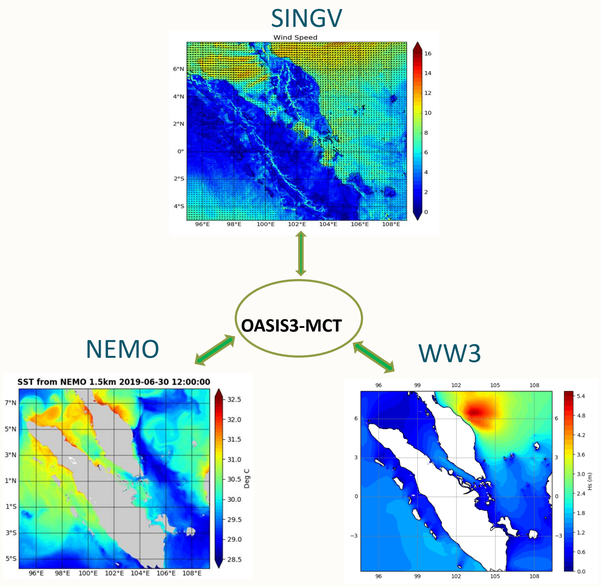


Fig. 1. Schematic representation of cSINGV model.

WW3 (SMC) model

Wavewatch3 v7.12 model is used for coupling with SINGV and NEMO

The SMC technique creates a multi-resolution grid (with improved computational efficiency, Fig.2), which can refine the coastal areas better than a regular WW3 grid, of particular interest in the complex coastal regions surrounding Singapore.

A uniform increment of 1.5 km is used for all the locations where averaged depths are less than 40 m and about 3 km for the rest of the domain.

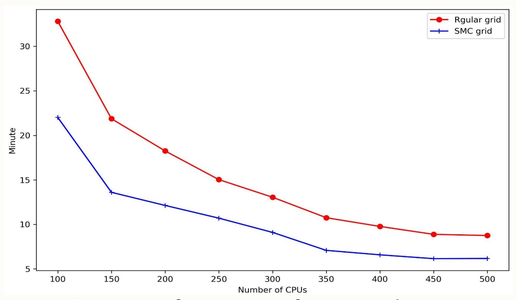


Fig. 2. Performance of SMC grid against regular WW3 grid.

cSINGV: Model Eavaluation

- A six-month-long simulation (January 2019 to June 2019) using a fully coupled atmosphere–ocean–wave model is conducted for model evaluation.
- Daily accumulated precipitation averaged over the region 5°S–8°N from the cSINGV/SINGV models is compared with GPM precipitation. The comparison shows good agreement over the six-month period (Fig. 3).
- The diurnal cycle of precipitation over the ocean is improved in the cSINGV model compared to the SINGV model (Fig. 4)
- The Fractions Skill Score (FSS) of precipitation against GPM-IMERG data indicates that the coupled model performs better than the uncoupled model for both light and heavy rainfall events (Fig. 5) .
- Evaluation of 10 m wind speed and 2 m air temperature shows that the coupled model performs comparably to the uncoupled model (Fig. 6).
- The impact of coupling on winds at different vertical levels is illustrated in Fig. 7
- The cSINGV model demonstrates improved prediction of significant wave height compared to the standalone WW3 model during the tropical storm Pabuk event (Fig. 8).

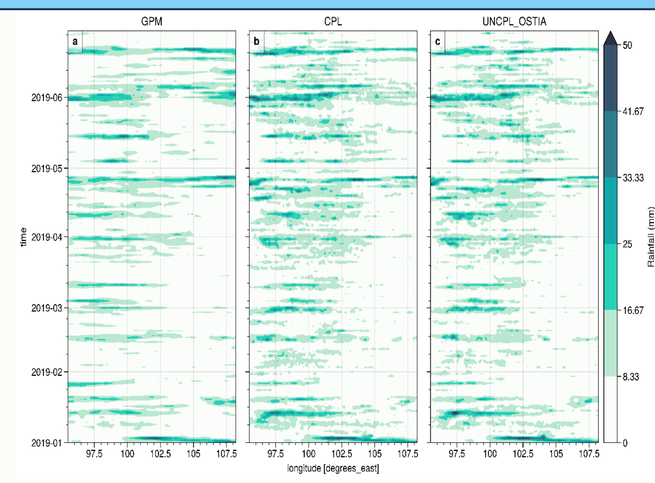
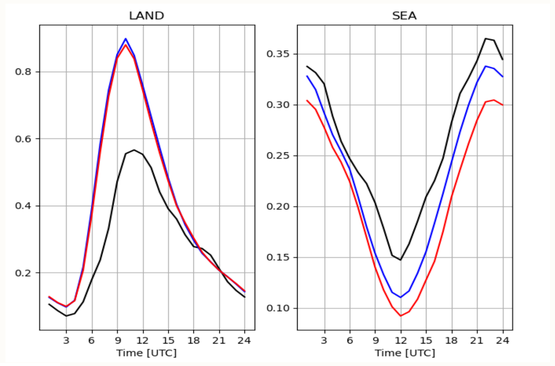


Fig.3: Comparison of precipitation from the coupled model (cSINGV), uncoupled model (SINGV), and GPM for the period January–June 2019.



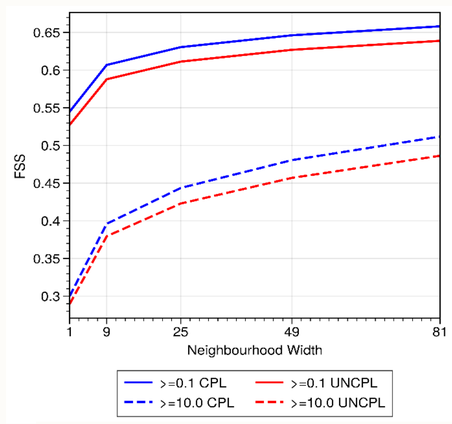


Fig.5: Fractions Skill Score (FSS) of precipitation against GPM-IMERG data for cSINGV (blue) and SINGV (red) for June 2019 .

Fig 6.: RMSE of 10 m wind speed (top) and 2 m air temperature (bottom) for cSINGV and SINGV compared against MetDB data.

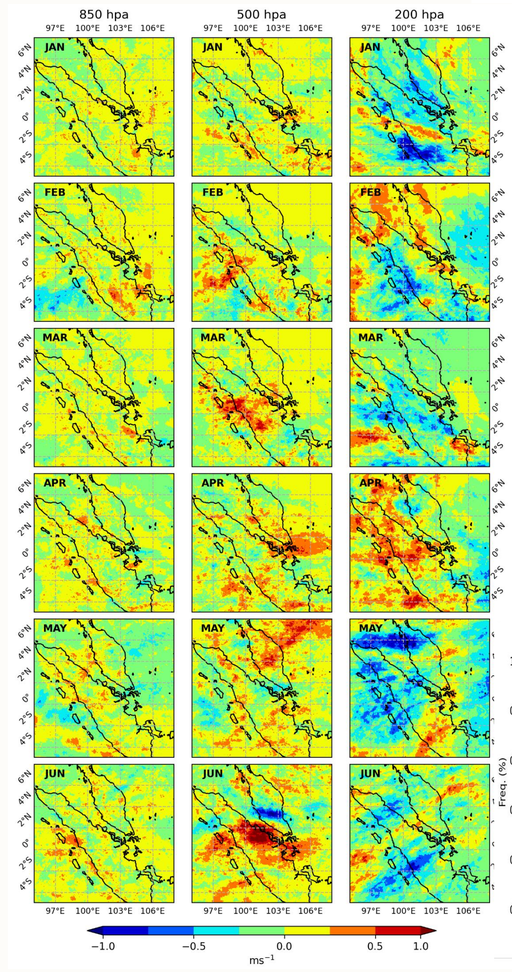


Fig 7: Mean difference between cSINGV and SINGV (cSINGV – SINGV) winds at different vertical levels for the entire six-month period.

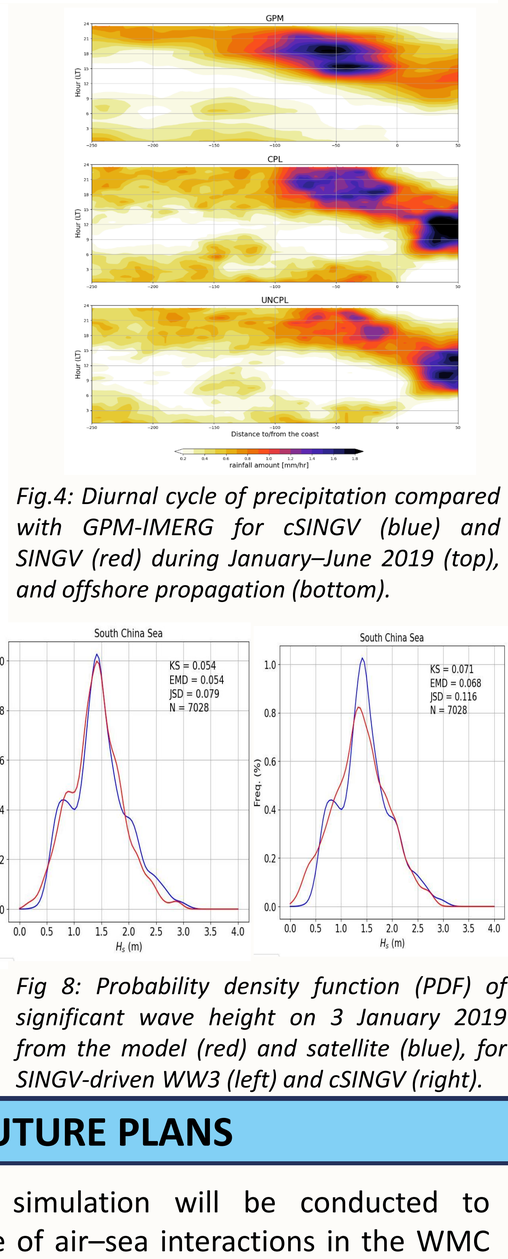


Fig.4: Diurnal cycle of precipitation compared with GPM-IMERG for cSINGV (blue) and SINGV (red) during January–June 2019 (top), and offshore propagation (bottom).

Fig 8: Probability density function (PDF) of significant wave height on 3 January 2019 from the model (red) and satellite (blue), for SINGV-driven WW3 (left) and cSINGV (right).

CONCLUSIONS

- The fully coupled SINGV-NEMO-WW3 configuration (cSINGV) was developed and implemented in the Regional Coupled Suite (RCS[9]), with performance evaluated over a six-month simulation.
- The cSINGV model was assessed against MetDB observations for wind and air temperature, and GPM-IMERG data for precipitation.
- Precipitation from cSINGV shows strong agreement with GPM-IMERG, indicating good model skill in replicating observed rainfall patterns.
- The model also demonstrates an improved simulation of the diurnal cycle of precipitation.
- The impact of coupling is evident in the modification of wind speed across different pressure levels.
- Coupling WW3 with NEMO and SINGV results in enhanced representation of significant wave height

FUTURE PLANS

- One-year cSINGV simulation will be conducted to investigate the role of air–sea interactions in the WMC region.
- The model will be further evaluated using rain gauge data and upper-air observations to assess its performance. This study will aim to quantify the added value of fully coupled atmosphere–ocean–wave systems in enhancing regional weather prediction, with a particular focus on extreme weather events such as Sumatra squalls.
- In the longer term, the goal is to develop a regional coupled climate model to support future climate projection studies.

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FURTHER INFORMATION
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