METEOROLOGICAL SERVICE SINGAPORE
Centre for Climate Research Singapore

Progress in CCRS's Regional Coupled model for Weather and Climate

Rajesh Kumar
Dept. of Weather Research, CCRS, Meteorological Service Singapore.

In collaboration with
Juan M Castillo, Claudio Sanchez, Jian-Guo Li and Segolene Berthou
Met Office, Exeter, EX1 3PB, UK
Byoung Woong An, Pratiman Patel and Kalli Furtado
Dept. of Weather Research, CCRS, Meteorological Service Singapore.

Coupled Atm-Ocean-Wave model (cSINGV)

Coupled model details

Atmosphere: SINGV (UM 12.2)/RA2T
Ocean: NEMO (4.0.4)
Waves: Wavewatch3 (v7.12)

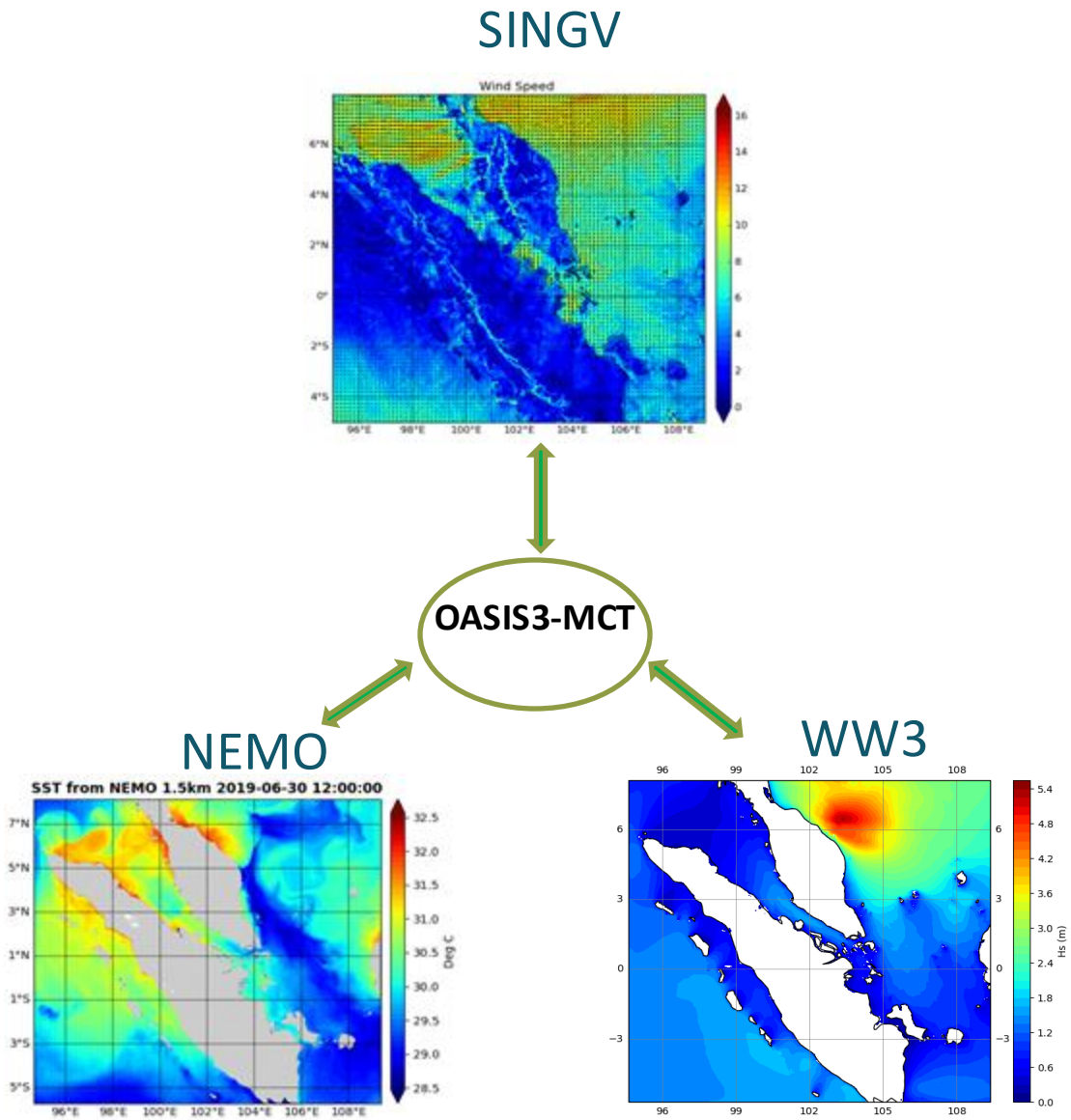
Horizontal Resolution : uniform 1.5 x 1.5 km
80 vertical levels (Terrain following) for SINGV
51 vertical levels (Sigma coordinate) for NEMO
1.5-3 km SMC grid for WW3

Initial and Lateral boundary conditions

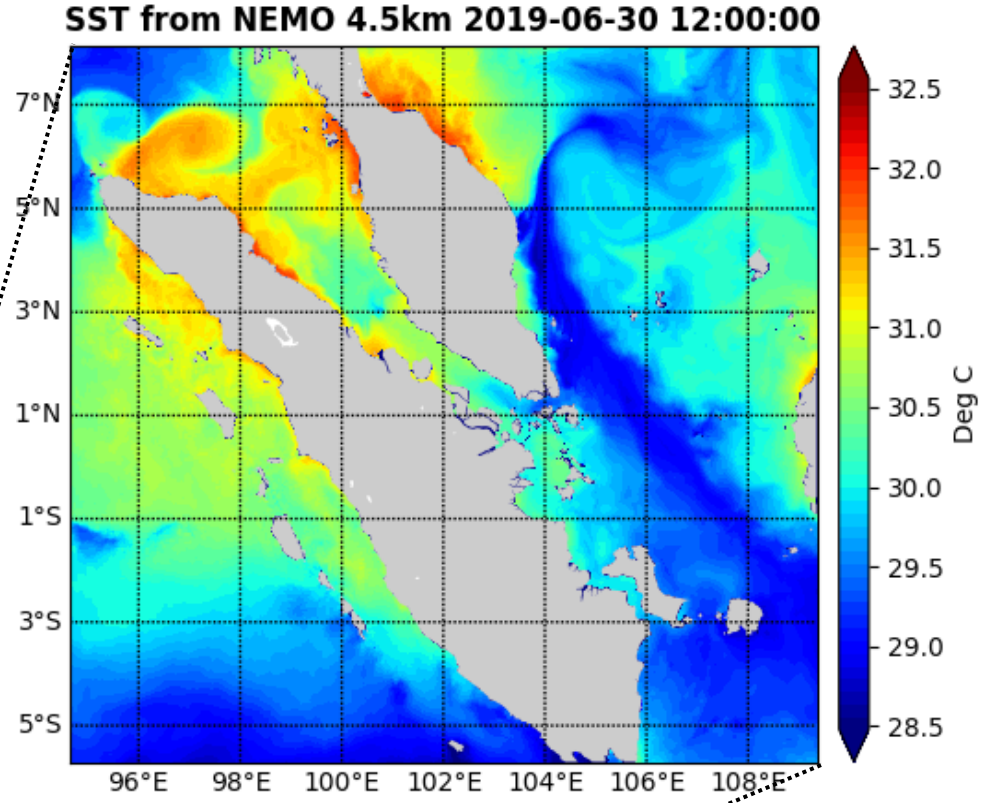
SINGV – ECMWF reanalysis (ERA5)
NEMO – Mercator Ocean reanalysis
WW3 – In-house Global wave model
Tidal forcing: Incorporated (FES2014)

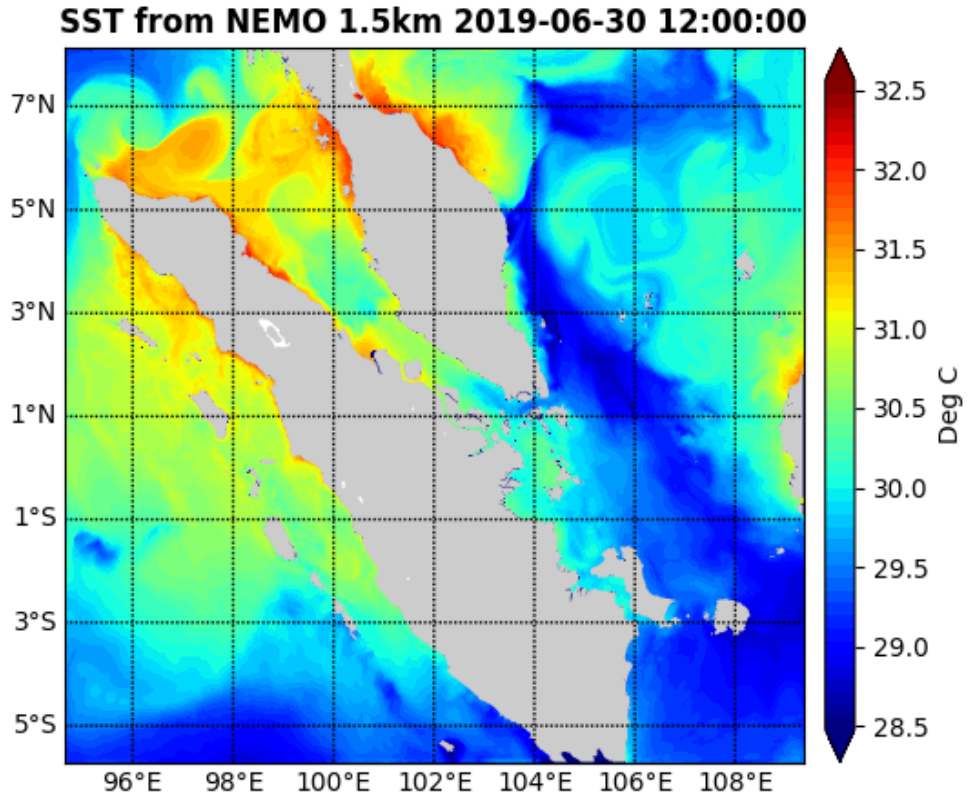
Coupler: OASIS3-MCT

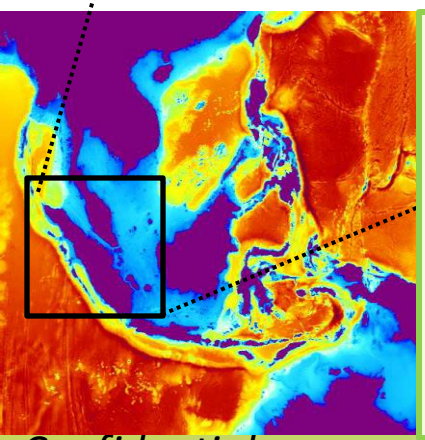
Coupling frequency : 1 hour



Development of a 1.5 km NEMO model for cSINGV



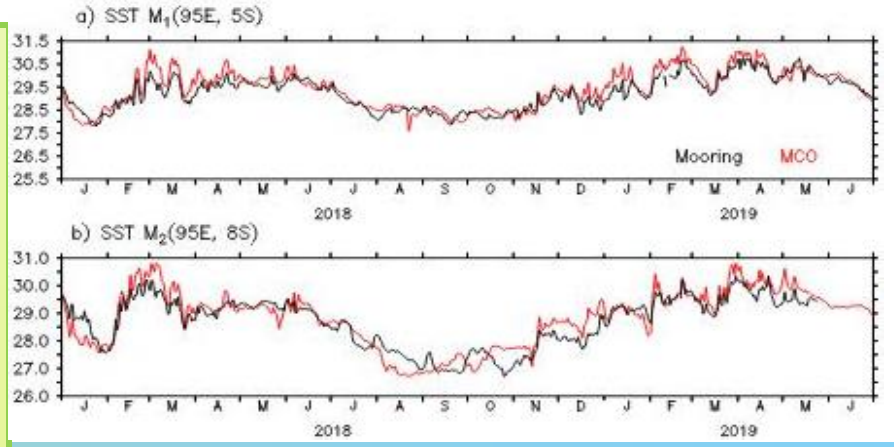




A 6-month long NEMO only simulation (01-01-2019 – 30-06-2019) shows that new 1.5 km NEMO configuration is stable.

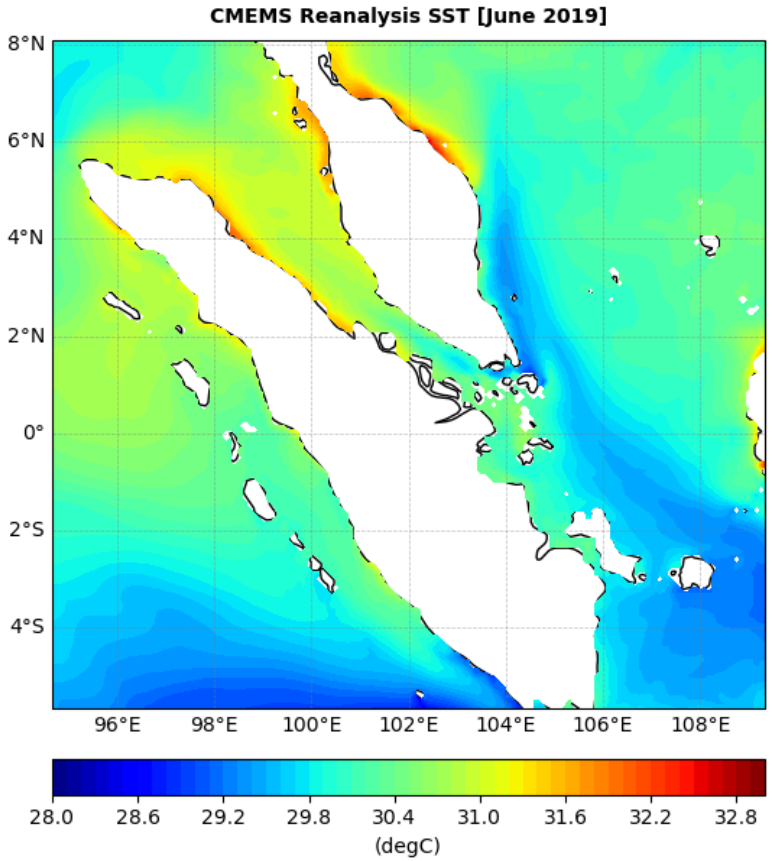
4.5 km NEMO has been validated[1].

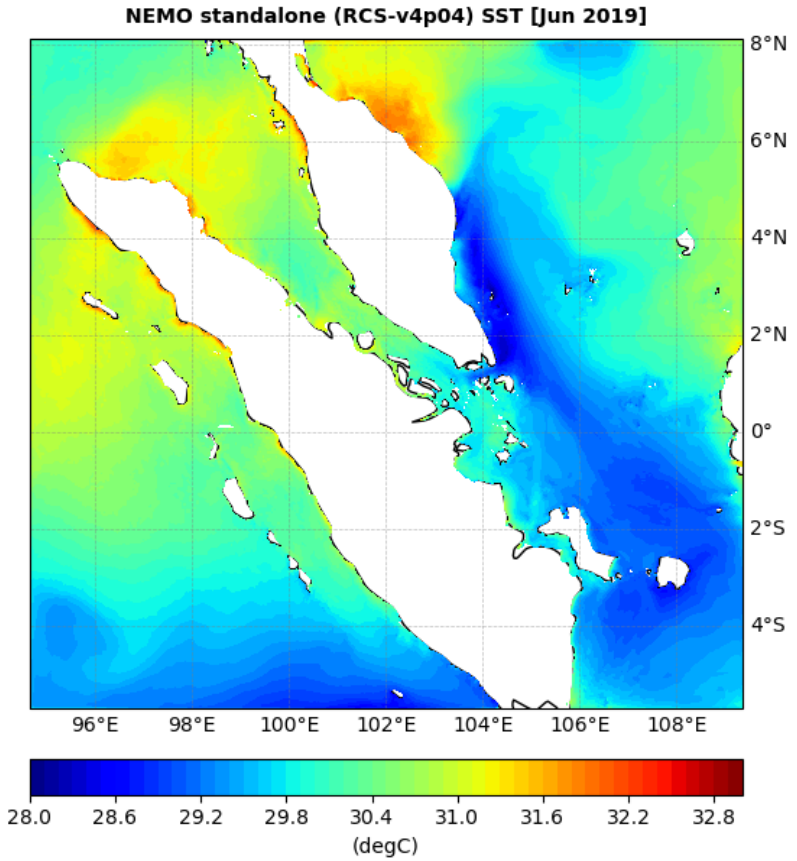
1.5 km NEMO: no spin-up, initial condition is taken from Mercator 1/12° ocean product[2]

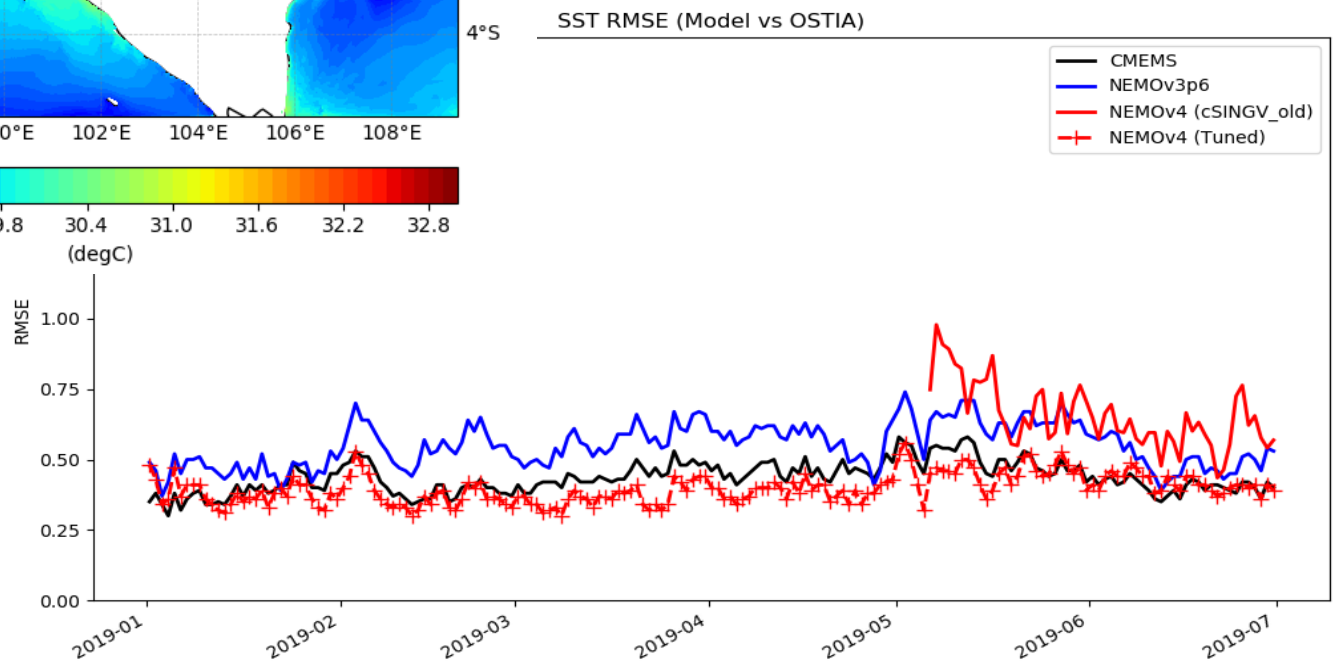


[1] Thompson et al., 2021(Geosci. Model Dev., 14, 1081–1100, 2021) [2]https://marine.copernicus.eu/

1.5 km NEMO model validation against OSTIA





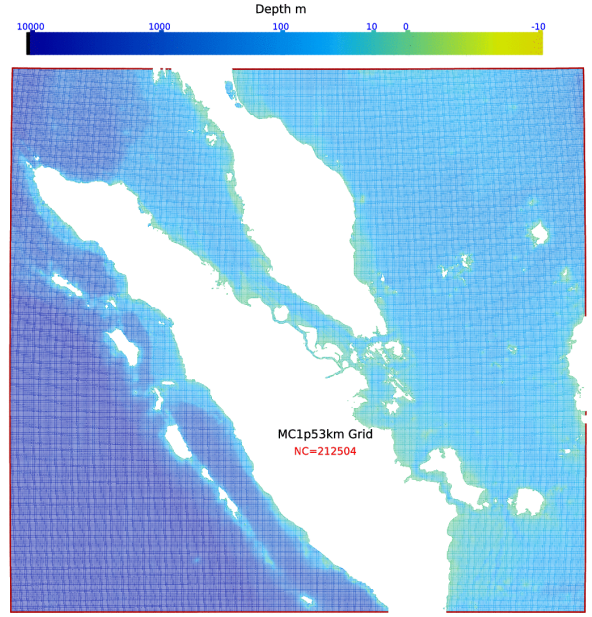


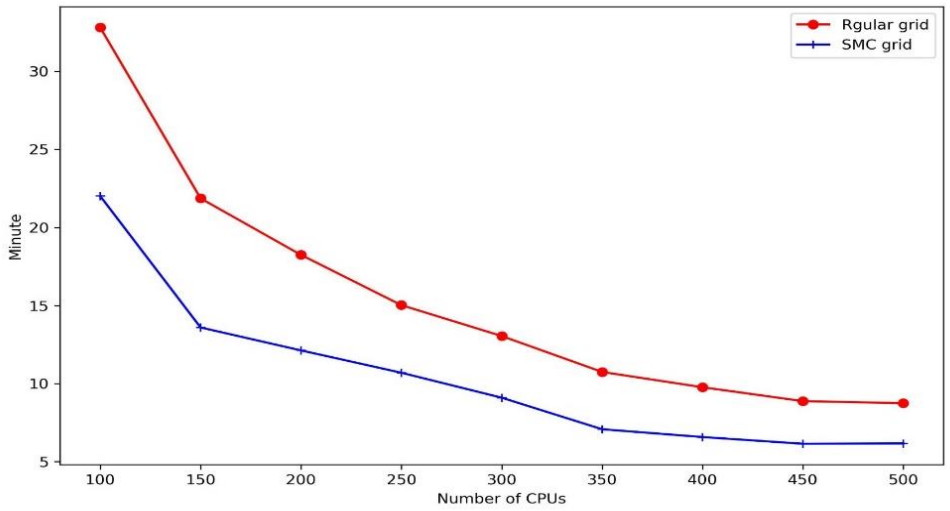
Development of a 1.5-3km WW3 model for cSINGV

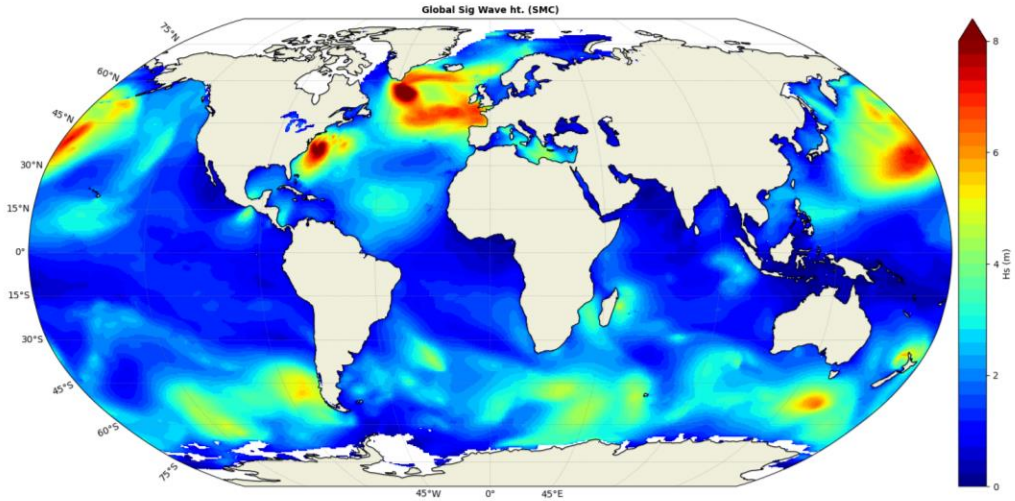
Wavewatch3 v7.12 model is used for coupling with SINGV and NEMO

The SMC technique creates a multi-resolution grid 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 for all the locations where averaged depths are less than 40 m and about 3 km for the rest.







SMC61250 global wave model grid: 50, 25,12 and 6 km resolutions is used to generate the LBCs for cSINGV-WW3.

Development of a 1.5-3km WW3 model for cSINGV

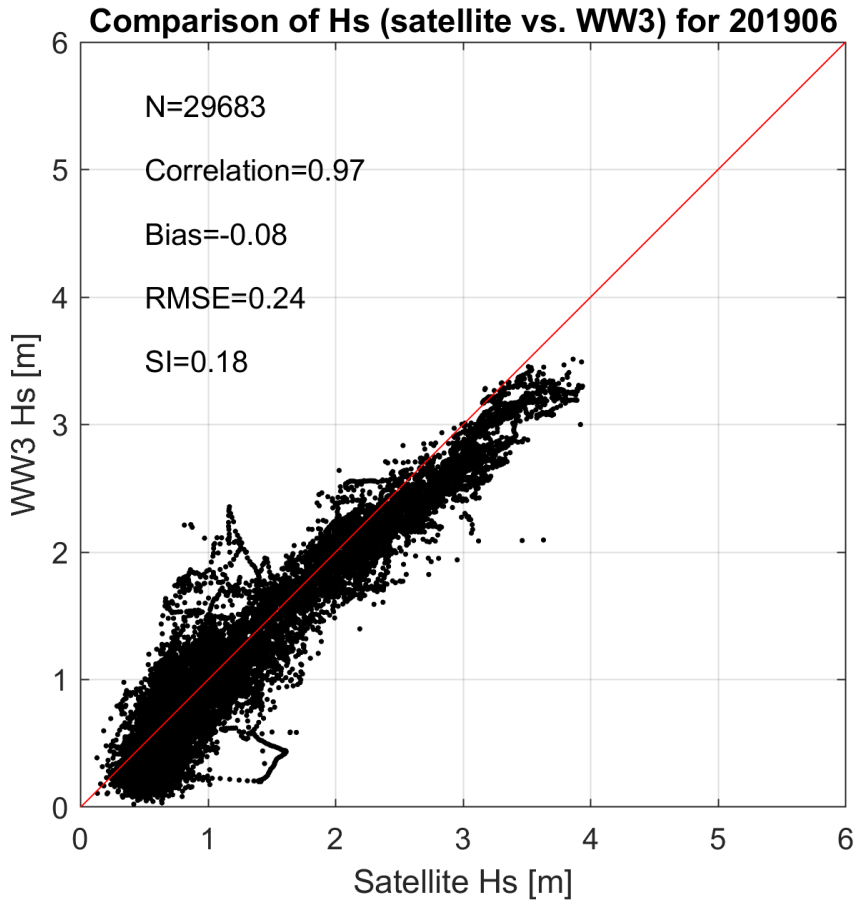
Tuning the wave model

Currently using ST4 physics package.

Tuning the growth parameter (Betamax)

Expt. No.	BETAMAX	Correlation	Bias	RMSE	SI
1	1.0	0.97	-0.18	0.27	0.20
2	1.25	0.97	-0.14	0.25	0.18
3	1.39 (MO)	0.97	-0.12	0.25	0.18
4	1.43 (ECMWF)	0.97	-0.12	0.25	0.18
5	1.5	0.97	-0.11	0.25	0.18
6	1.75	0.97	-0.08	0.24	0.18
7	2.0	0.96	-0.06	0.25	0.18

A total of 29683 observational data were used for the model validation.



Scatter plot by Kaushik Sasmal, TCOMS

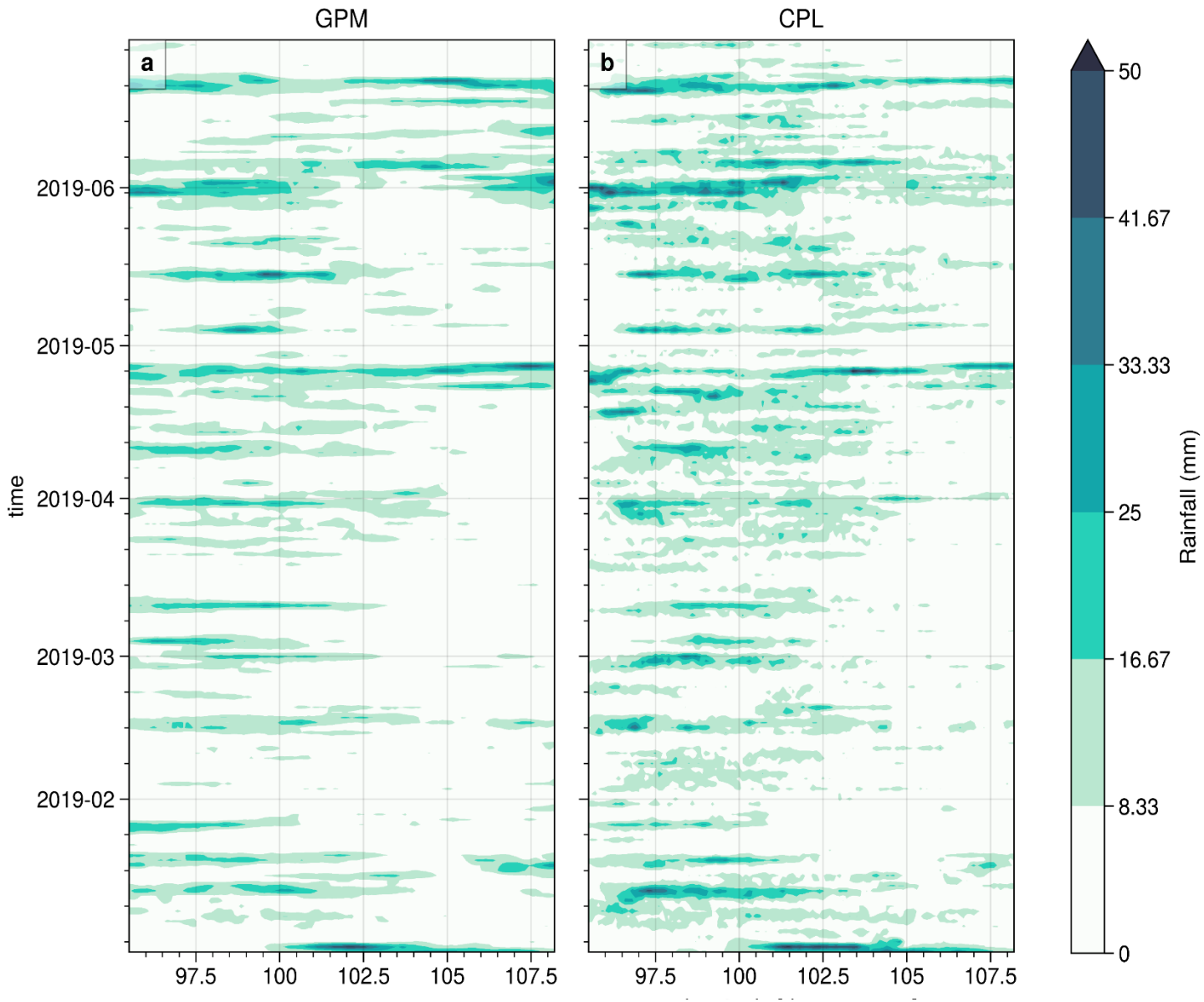
cSINGV model evaluation

Validation of SINGV in the cSINGV model (precipitation)

Completed Six-month long simulation of fully coupled atmosphere-ocean-wave model.

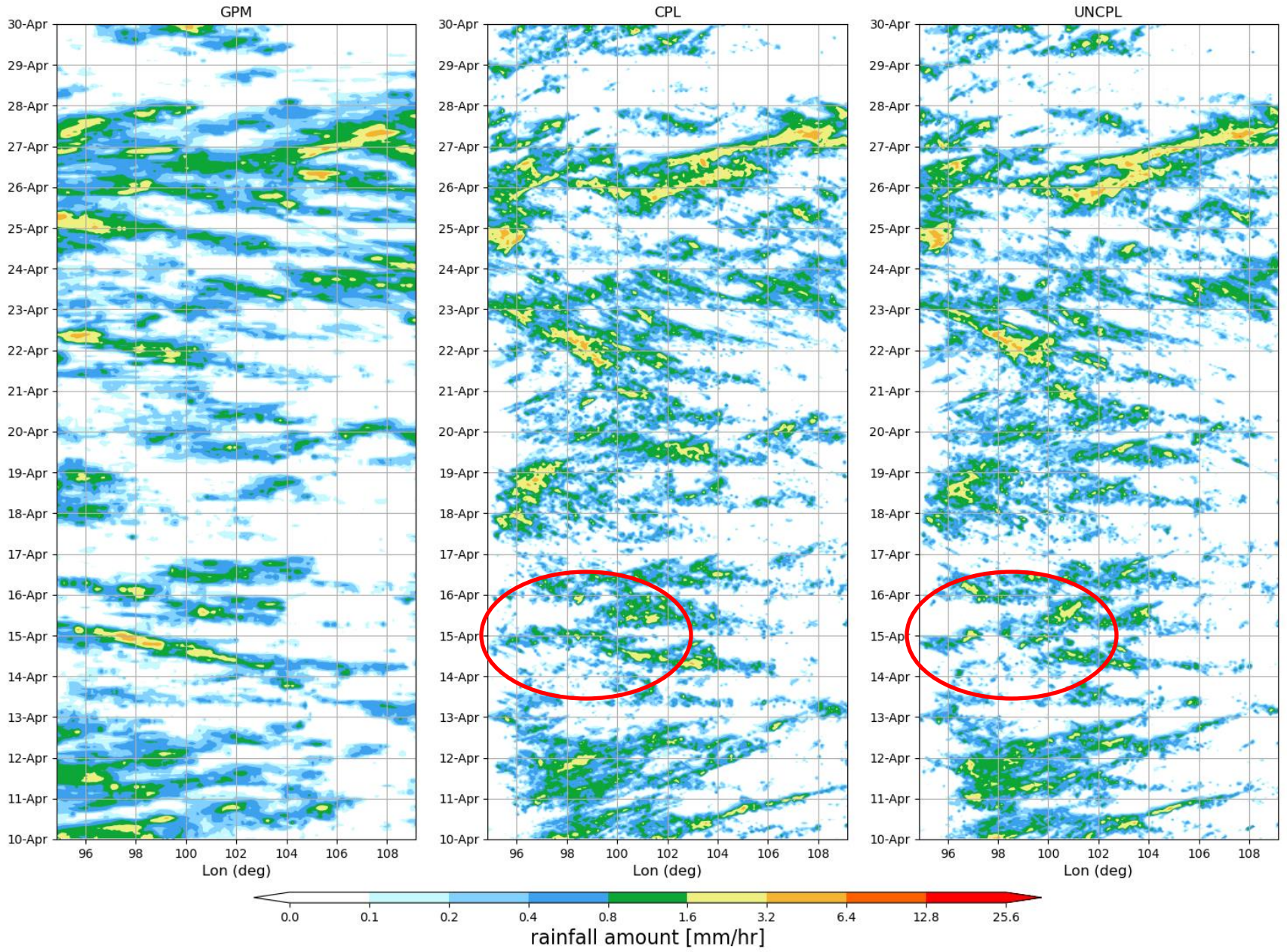
- ✓ SINGV LBCs from ERA5 (3 hourly)
- ✓ NEMO LBCs from daily MERCATOR data.
- ✓ WW3 LBCs from in-house Global wave model (hourly).

Daily accumulation of precipitation is compared with GPM



Validation of SINGV in the cSINGV model (precipitation)

- A six-month-long simulation of a stand-alone atmospheric model was completed to compare its performance with that of a coupled atmosphere-ocean-wave model.
- The hourly accumulation of precipitation was compared with GPM data for the period from April 10th to April 30th.
- The coupled model demonstrated improved precipitation accuracy.

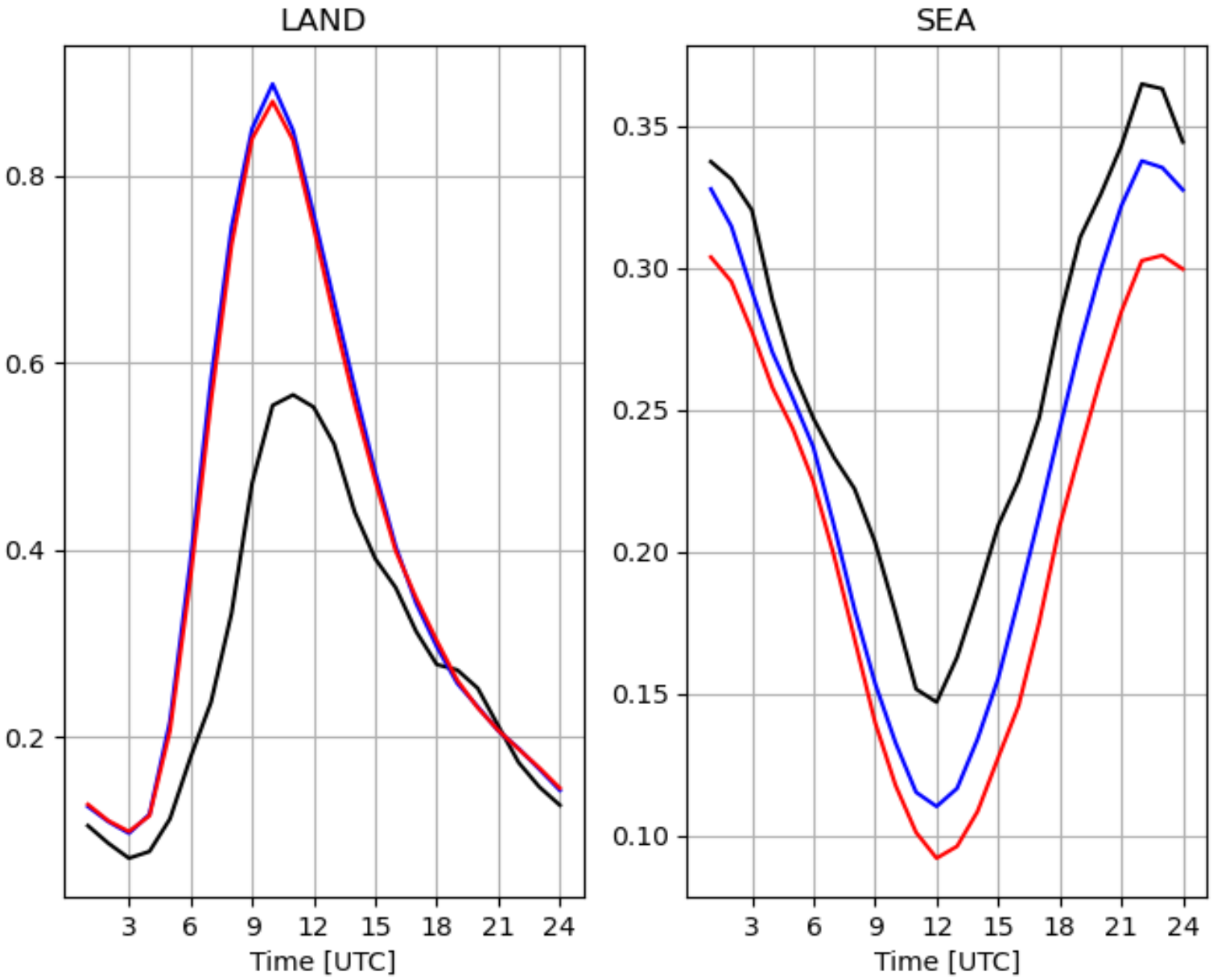


Validation of SINGV in the cSINGV model (precipitation)

The diurnal cycle of precipitation was computed for six months (Jan-Jun, 2019).

Hourly precipitation accumulation was compared with GPM data (black line).

The coupled model (blue line) shows an improvement in precipitation over the sea.



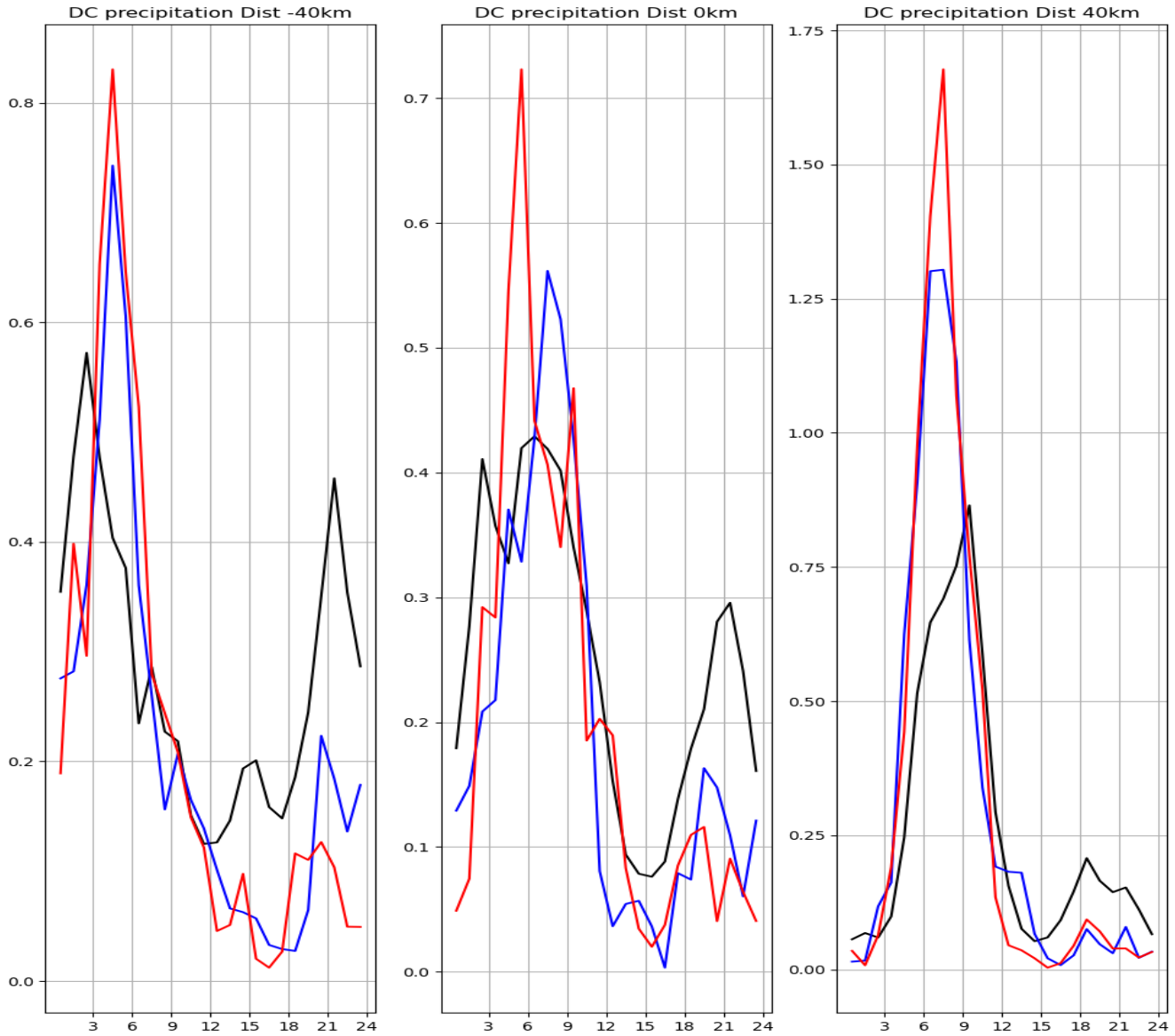
DC plot by Claudio Sanchez, RMED, UKMO

Validation of SINGV in the cSINGV model (precipitation): X-Section over Singapore

The diurnal cycle of precipitation over Singapore region was computed for six months (Jan-Jun, 2019).

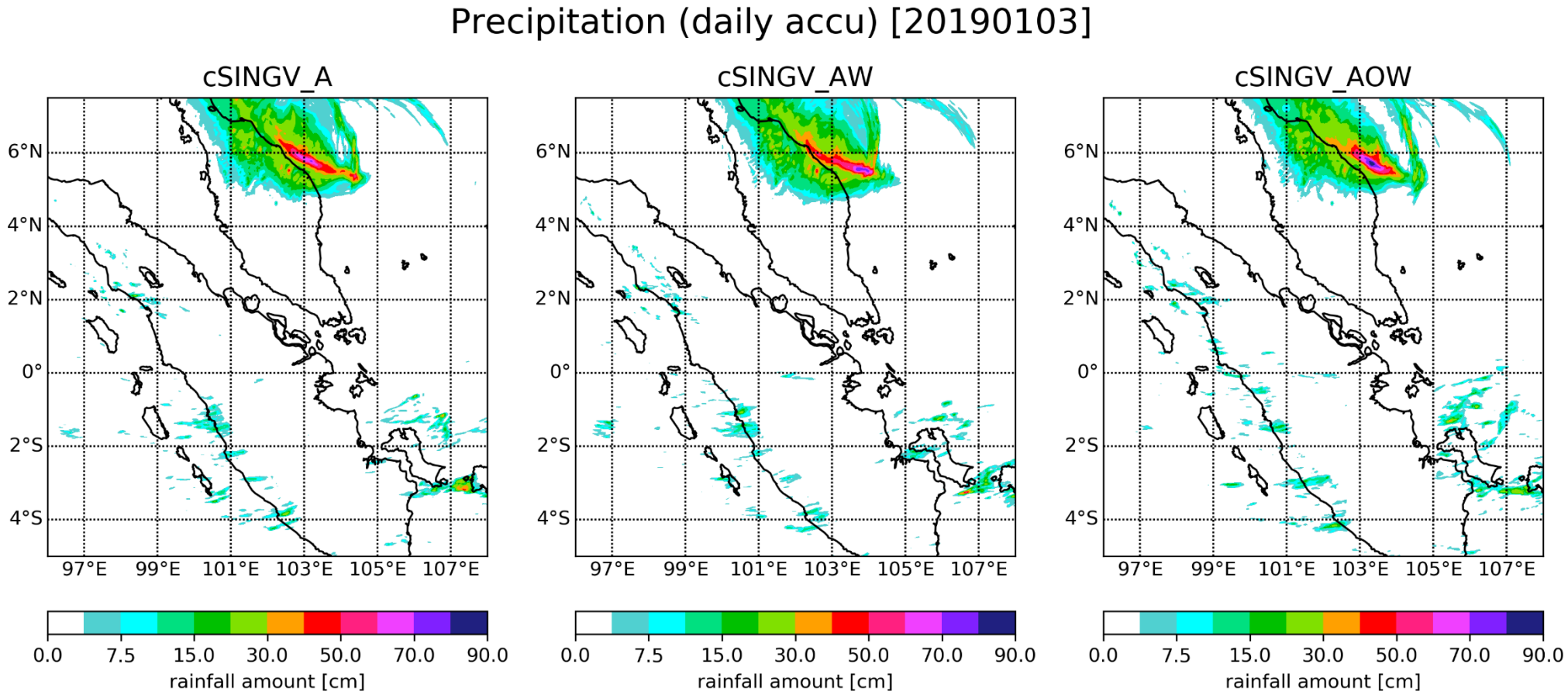
Hourly precipitation accumulation was compared with GPM data (black line).

The coupled model (blue line) shows an improvement in precipitation near the coastal area



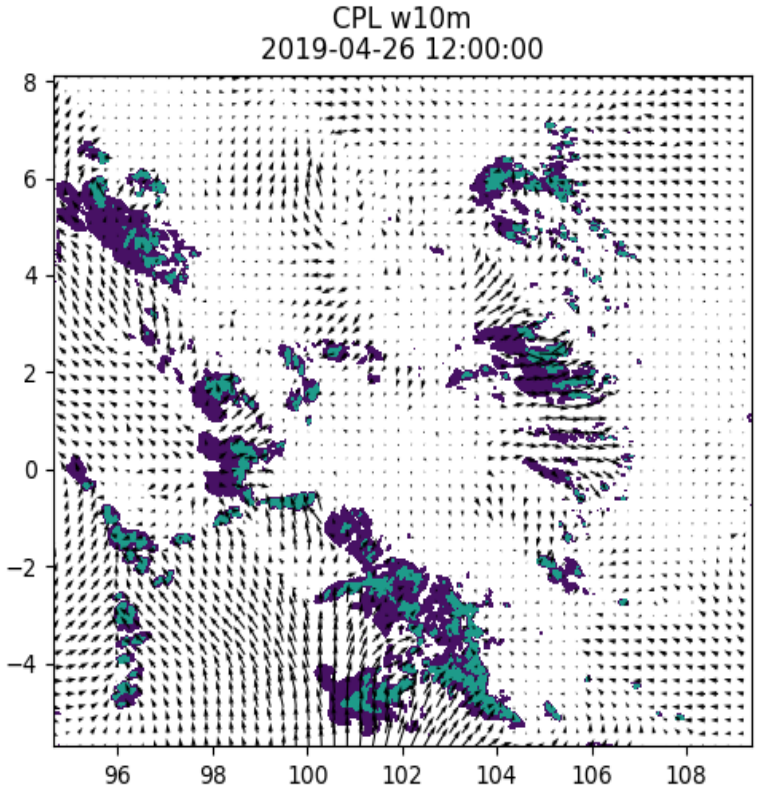
DC plot by Claudio Sanchez, RMED, UKMO

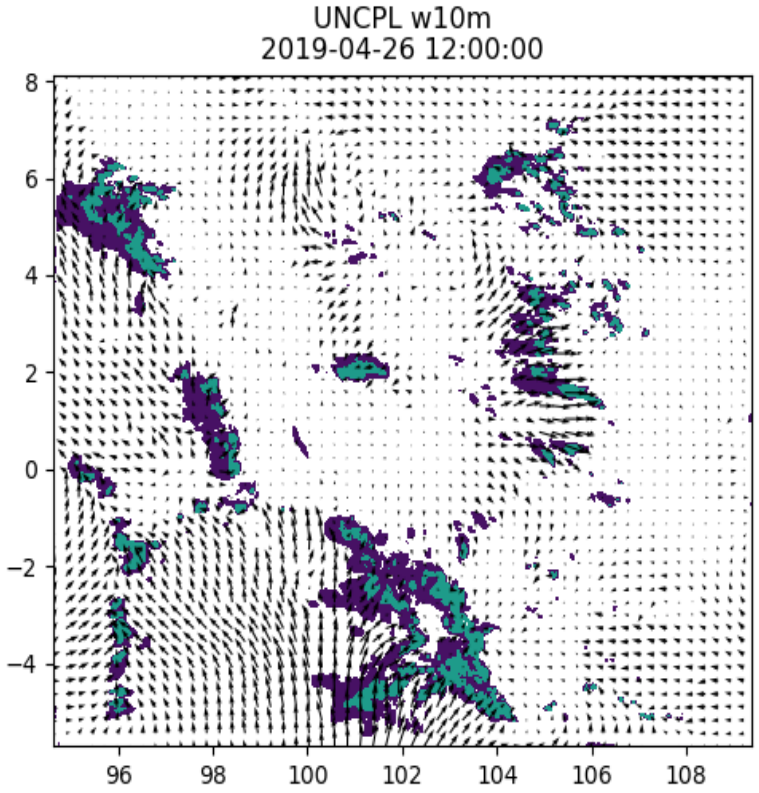
Coupled Atm-Ocean-Wave model: Precipitation changes

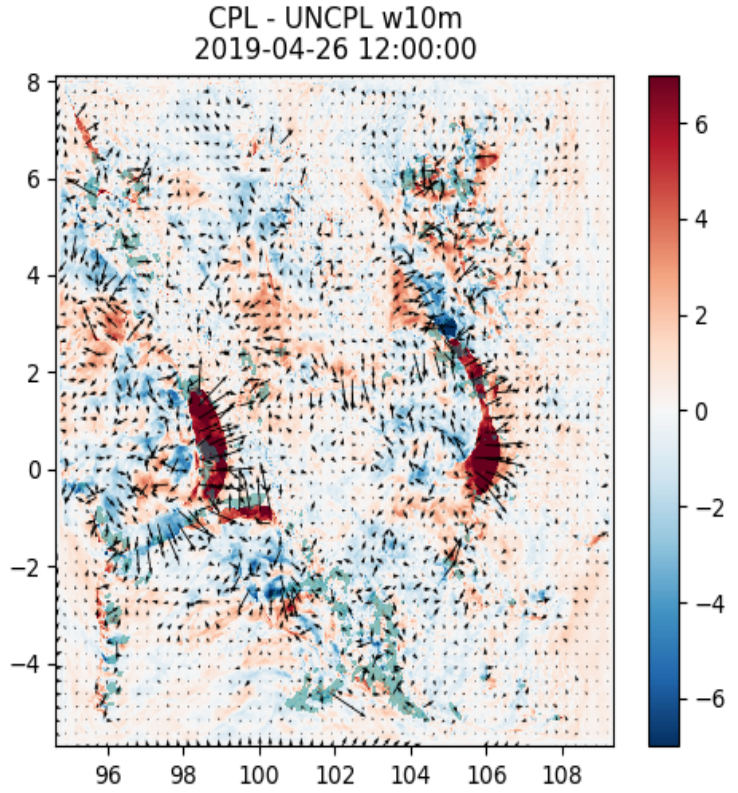


Coupled Atm-Ocean-Wave model: Squall event

- The analysis of wind speeds during a squall event indicates that the 10-meter wind in the coupled model exhibits higher velocities compared to the uncoupled model.
- Similar impacts of coupling on squall lines are observed in several other cases as well.







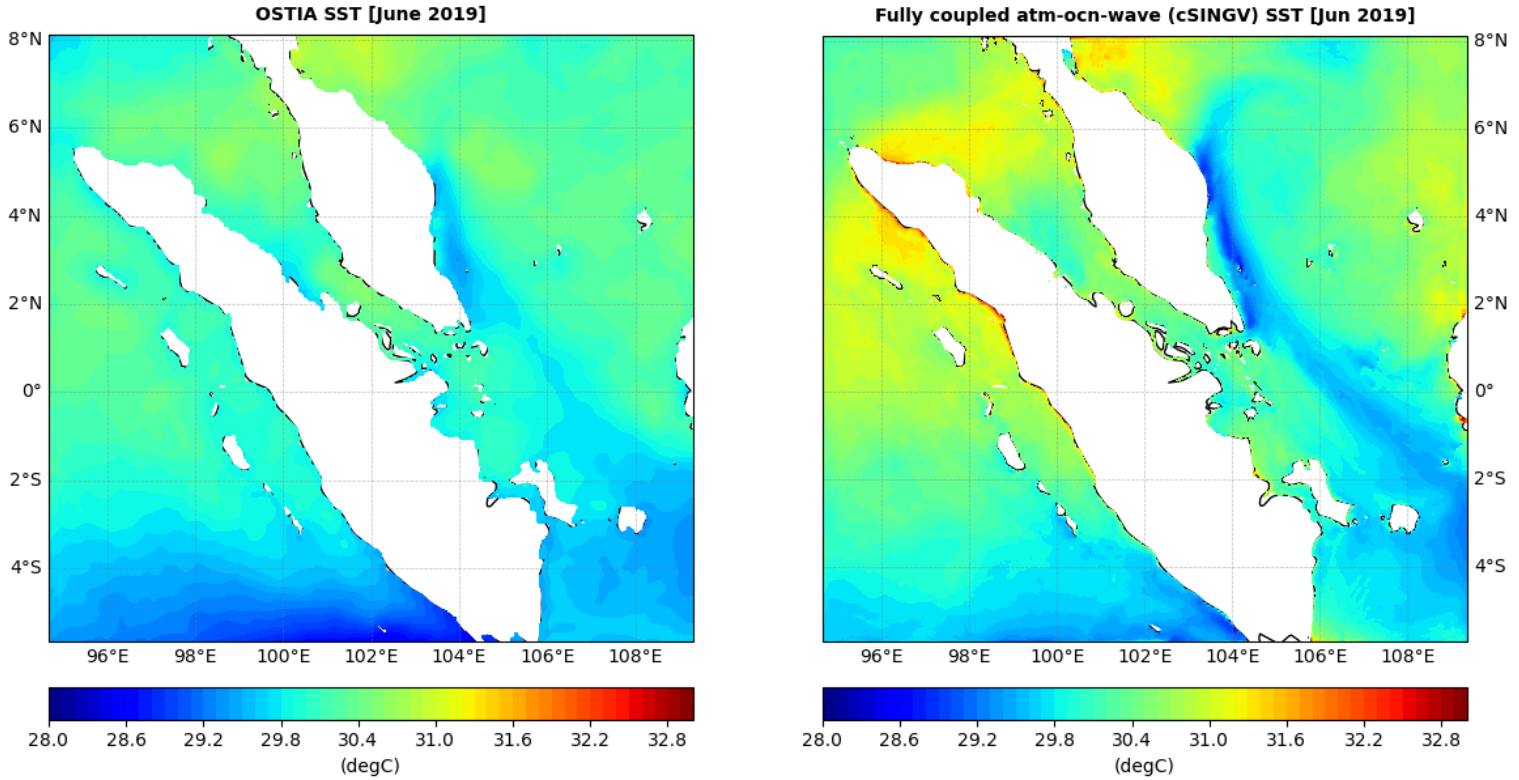
plot by Kalli Furtado

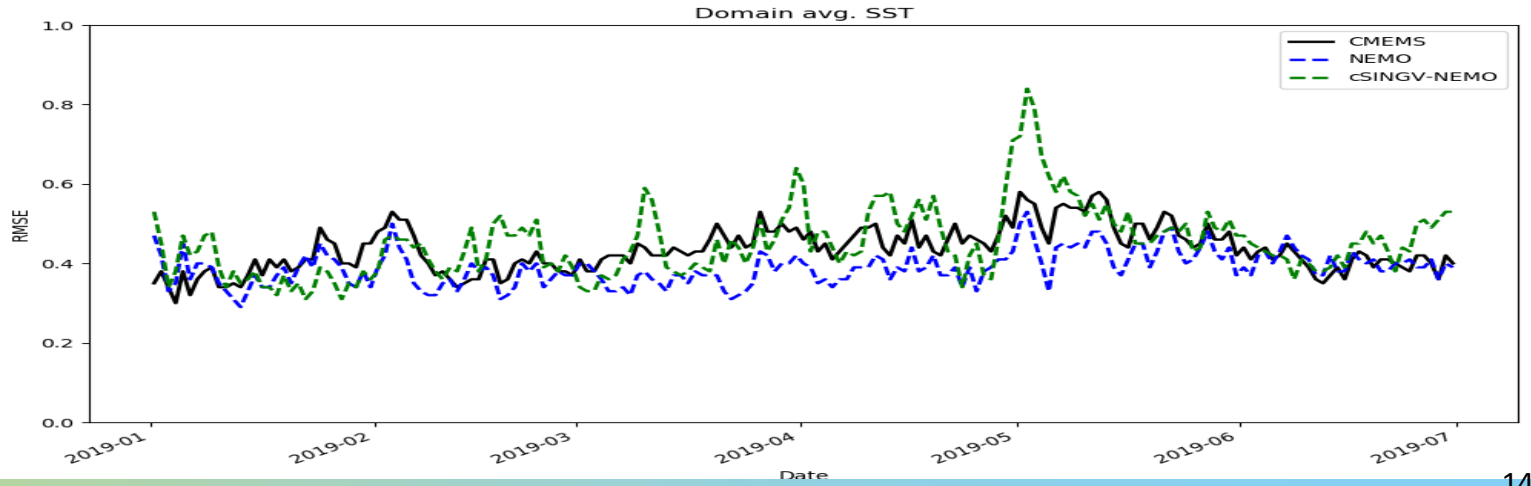
Validation of NEMO in the cSINGV model (sea surface temperature)

The ocean model has been verified using OSTIA, CMEMS, and ORAS5 datasets.

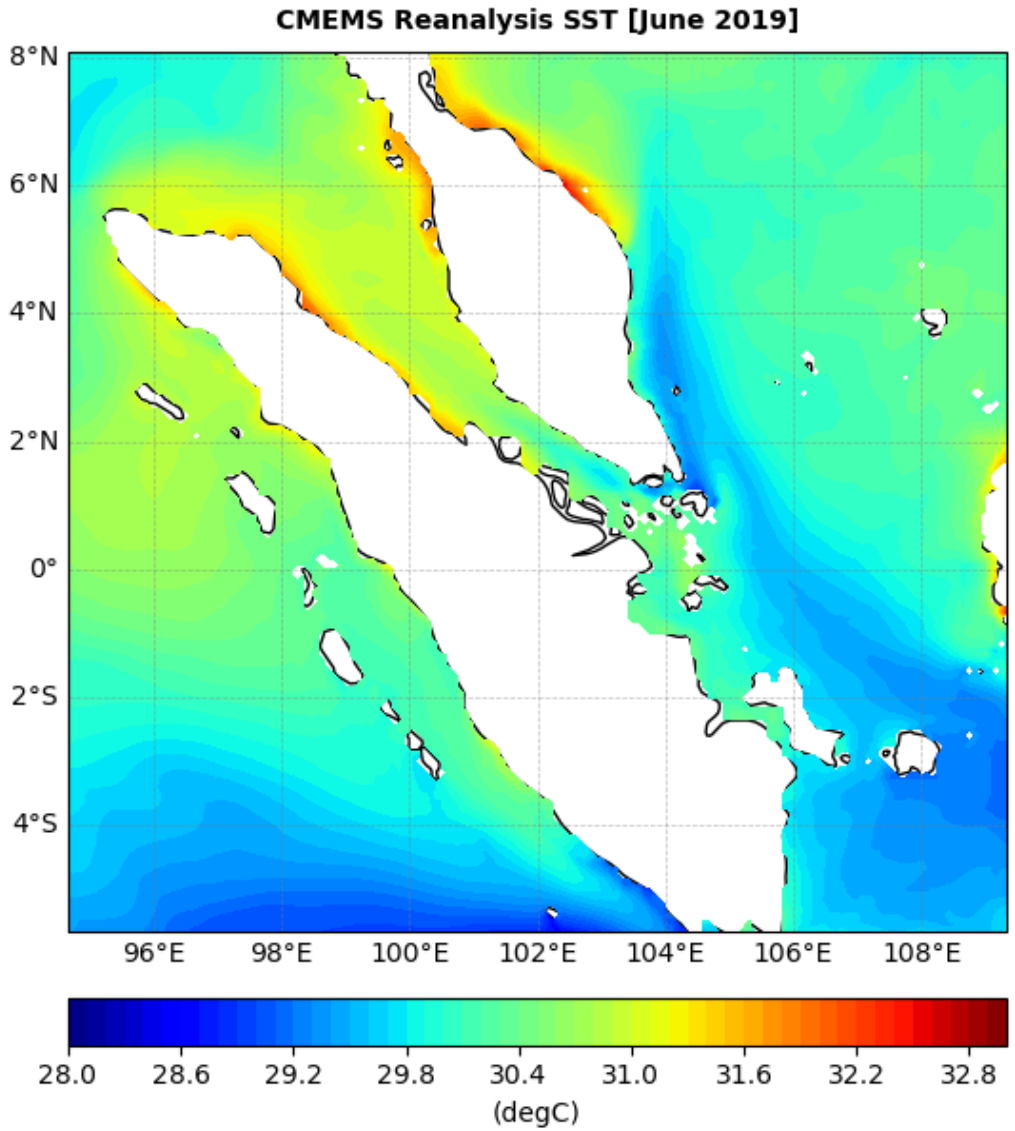
The spatial monthly mean sea surface temperature (SST) for June 2019 exhibits consistent patterns with both OSTIA and reanalysis data.

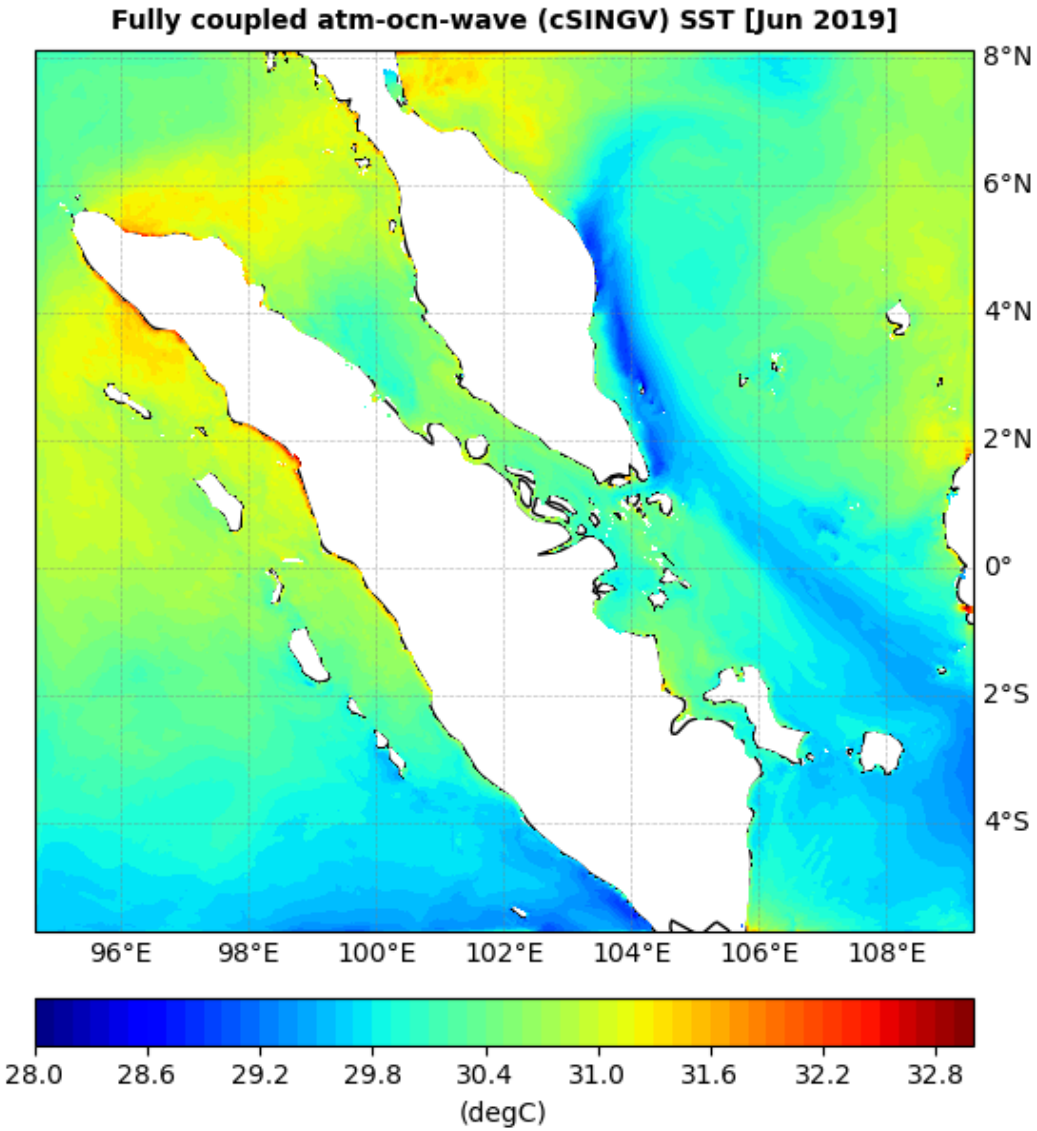
The root mean square error (RMSE) of the domain-averaged daily SST indicates that the NEMO model closely aligns with the global product.



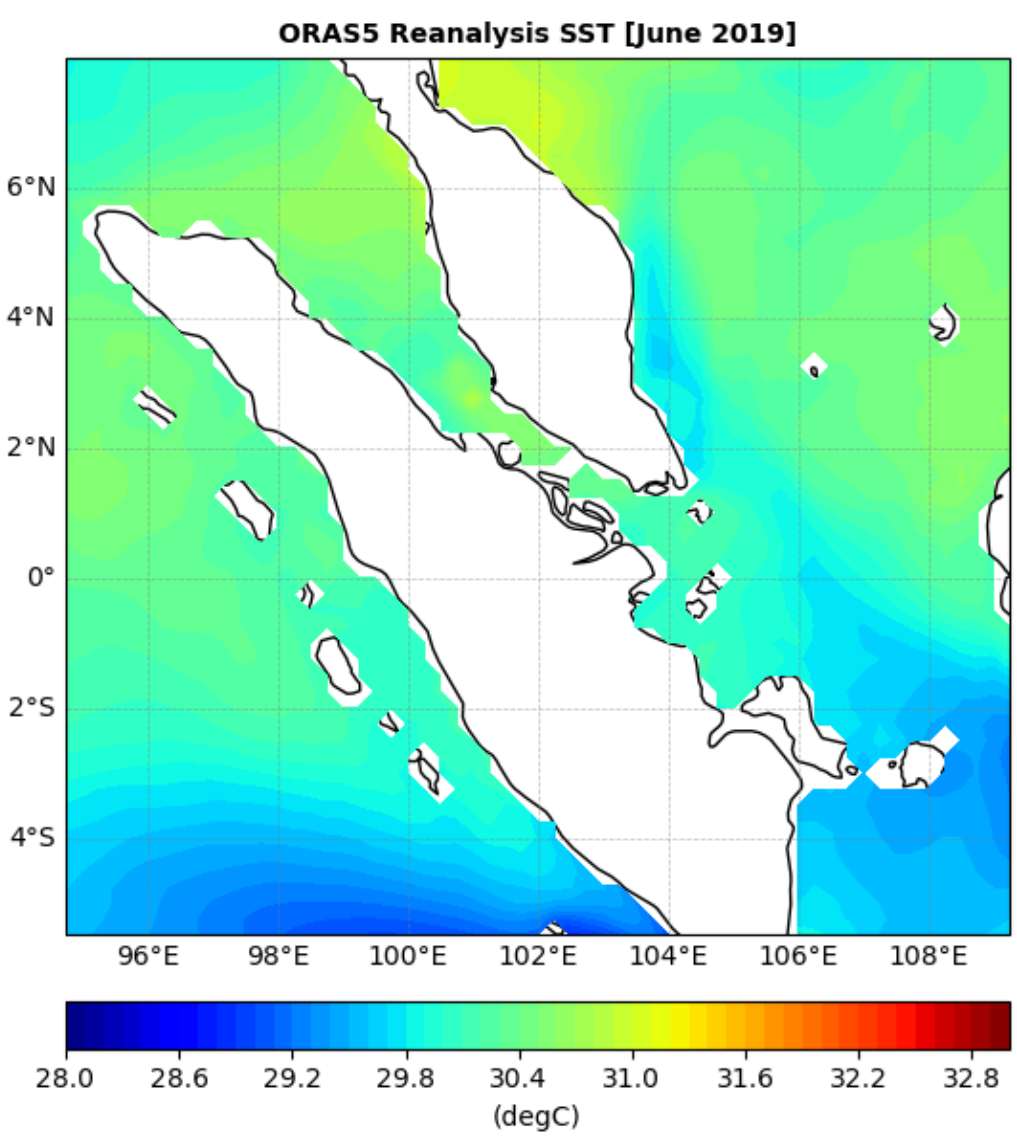


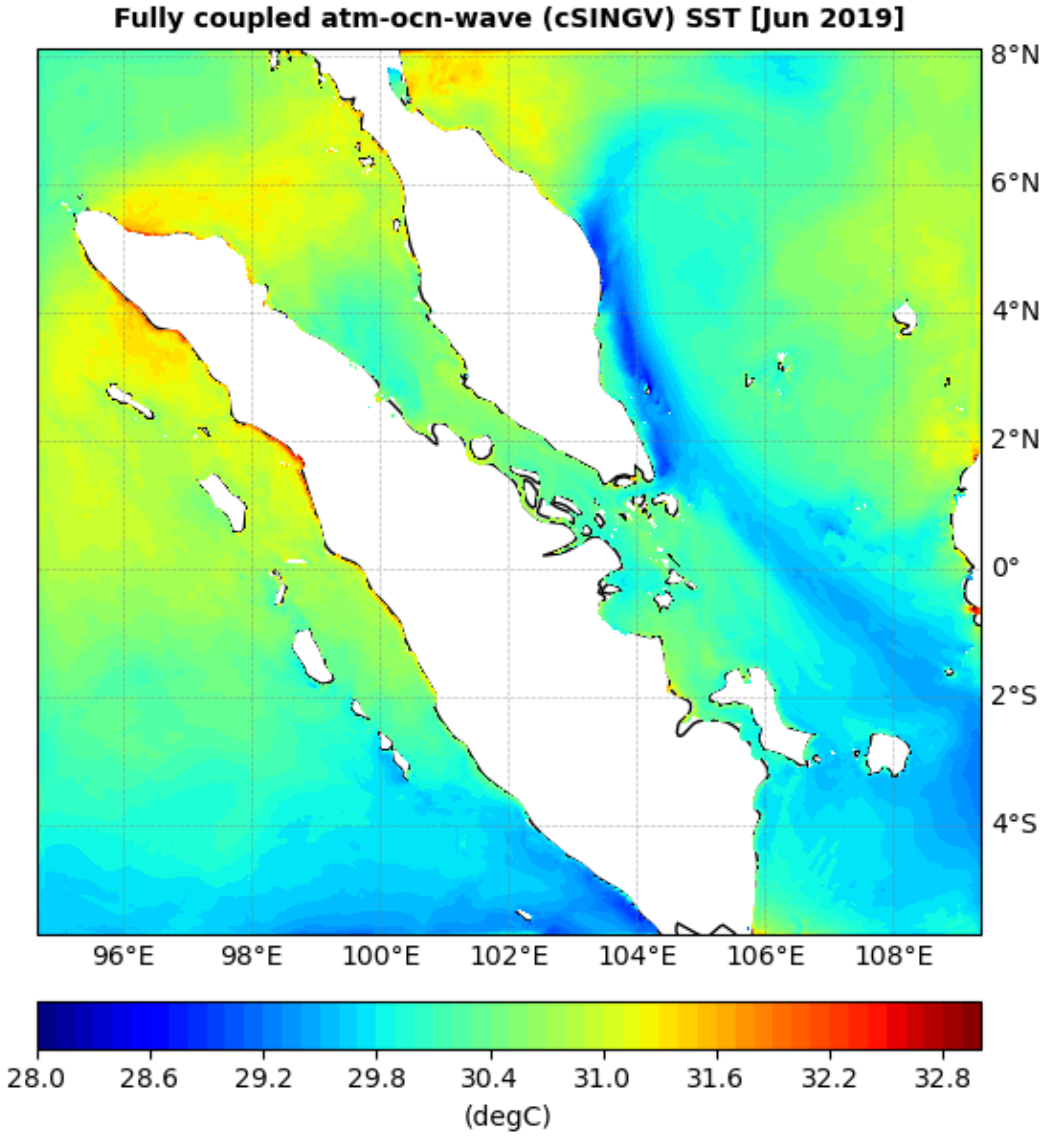
Validation of NEMO in the cSINGV model (sea surface temperature)





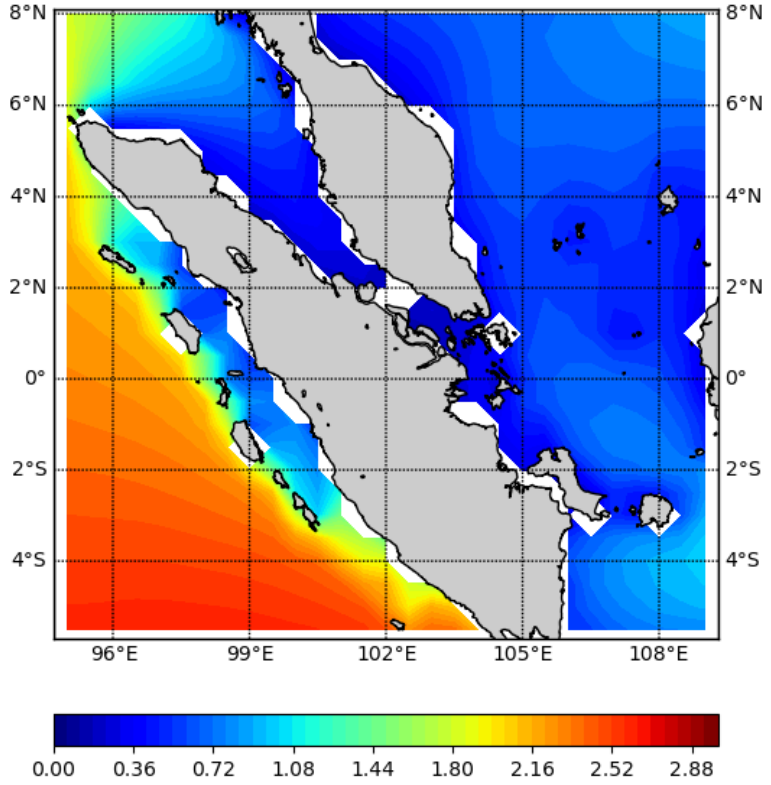
Validation of NEMO in the cSINGV model (sea surface temperature)



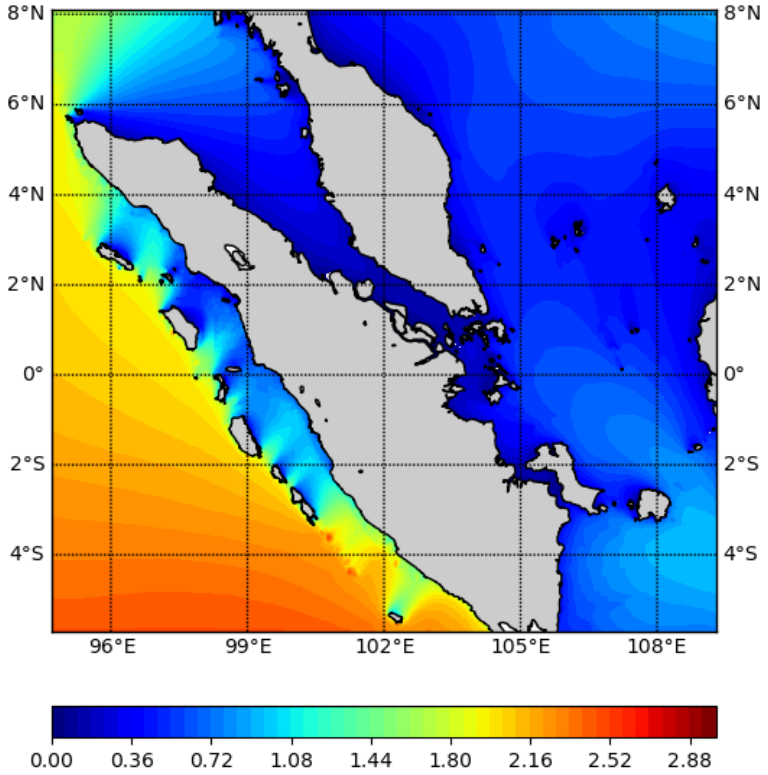


Validation of WW3 in the cSINGV model (significant wave height)

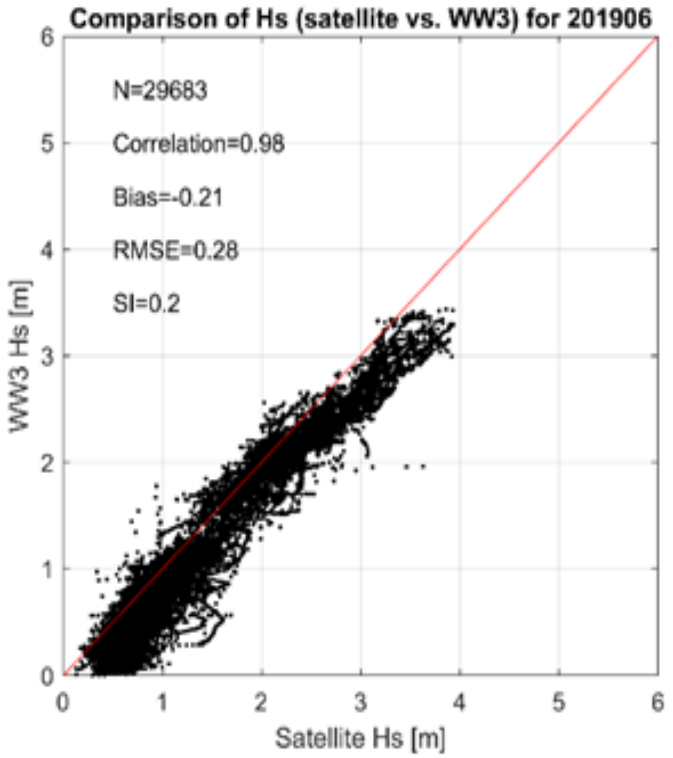
ERA5-Hs



cSINGV-Hs



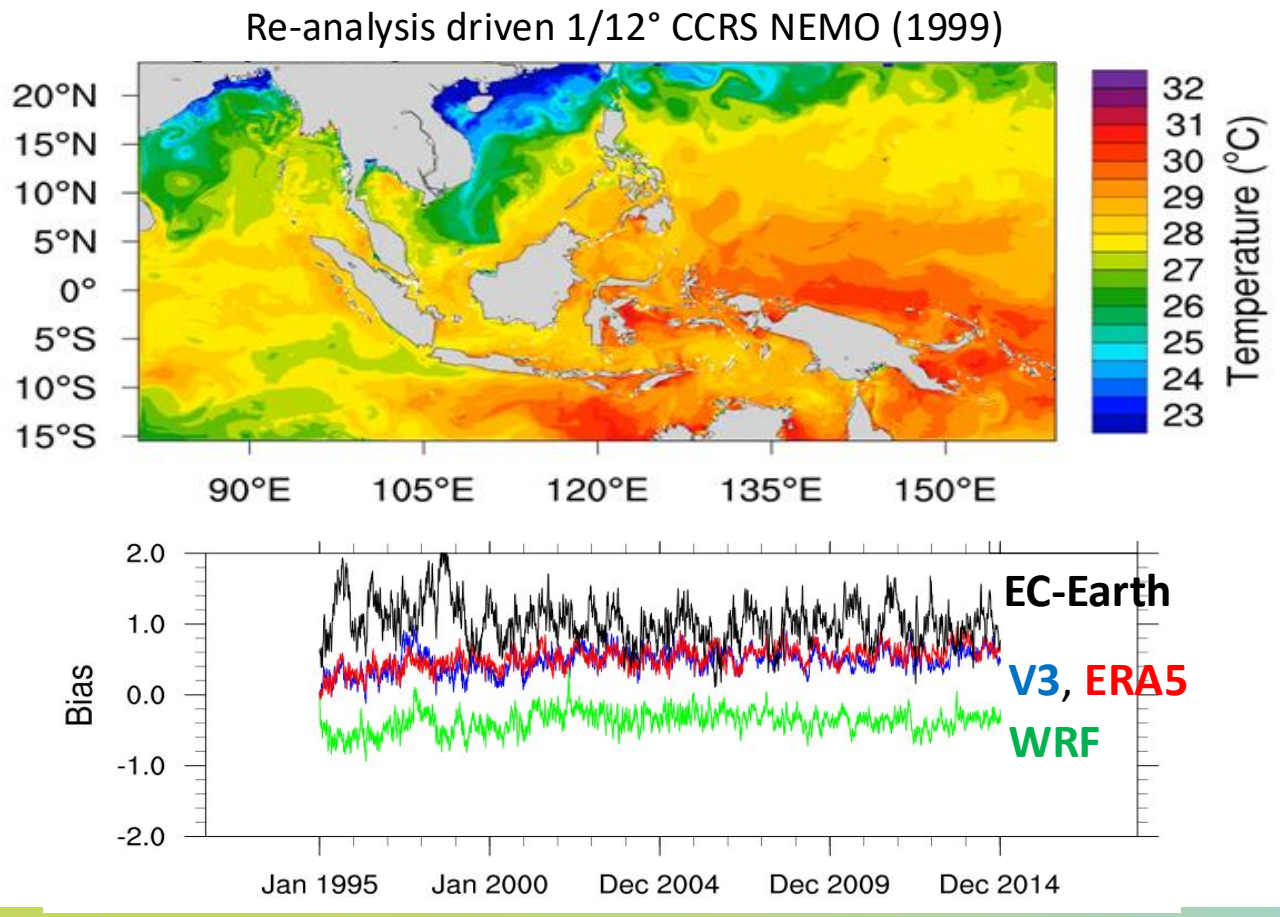
cSINGV Hs compared to JASON-2 altimeter Hs for the month June 2019.



Scatter plot by Kaushik Sasmal, TCOMS

Ocean Model for Climate research (Byoung Woong An)

- Developed & evaluated a NEMO model for climate applications
- LBCs from re-analyses or OGCM projections
- Atmospheric forcing from WRF/SINGV (8km), ERA5 or GCM



Model Specifications

Ocean Model: NEMO 4.0.4

Model Domain: 79 -160°E, 16°S – 24°N

- Horizontal Resolution: 1/12°
- Vertical Resolution: 51 σ-levels
- Initial Conditions: GLORYS2V1
- Lateral Boundary Conditions:

GLORYS2V1/OGCM

- Atmospheric Forcing:

ERA5/SINGV(V3) 8km/EC-EARTH/WRF

- Tidal Forcing: FES 2014

Conclusion

- ✓ Preliminary analysis of the 1.5km coupled SINGV-NEMO-WW3 (cSINGV) model indicates that the atmospheric and marine variables in the cSINGV model demonstrate comparability with observational and re-analysis data.
  - ➢ Precipitation shows reasonable agreement when compared with IMERG data, with an improved representation of the diurnal cycle over the ocean.
  - ➢ The coupling also impacts wind speeds during squall events, demonstrating notable differences in intensity.
- ✓ Developed and evaluated NEMO model for a larger domain and tuned to improve its effectiveness for climate-related applications.
- ✓ Tested the NEMO model using downscaled 8km (V3) data from UKESM and EC-EARTH to ensure robustness and reliability.

Currently in progress:

- ❑ Evaluation of surface wind and air temperature against station data.
- ❑ Conducting a one-year simulation of the cSINGV model and evaluation of its performance.

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Thank you

E-mail: rajesh_kumar@nea.gov.sg