The Construction and Applicaiton of the MaCOM Model: A Chinese-Approach to an Independent, Globalized, Digitized Modernization of Ocean Forecasting

Miaoyin Zhang[1], Yu Zhang[1*]

[1] Key Laboratory of Research on Marine Hazards Forecasting, National Marine Environmental Forecasting Center, Ministry of Natural Resources, Beijing 100081, China

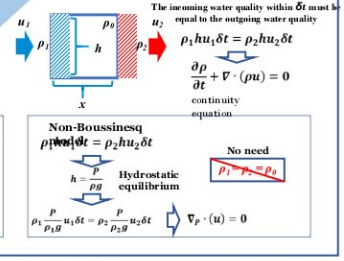
Abstract

The Mass Conservation Ocean Model (MaCOM 1.0) is constructed by National Marine Environmental Forecasting Center (NMEFC), affiliated to Ministry of Natural Resources of China, in the demands of an accurate, autonomous, and high-efficient numerical model for marine environmental forecasting from regional to global scale. The MaCOM model was released to the public in 2021, which fills the gap in the operational oceanography numerical forecasting in China, and shows great application values in areas such as climate change assessment, marine scientific research, and marine environmental security.

The MaCOM model is innovative in conservation of mass, horizontal grid dimension reduction, parallel graph topology communication and GPU acceleration, which is in general featured as multigrid support, and high-efficiency and energy-saving heterogeneous computing. In MaCOM, the assumption of volume conservation in current mainstream global ocean circulation models is replaced by the true mass conservation of sea water. The seawater temperature and salinity dynamics are adjusted to conform to the physical reality, and the speed is faster (less than 1 day) after the adjustment, which can meet the demand of short and medium term ocean forecast. The precision of core elements forecasts, such as sea surface temperature and sea surface height, has been significantly improved. The operational efficiency of the model is an important technical index to evaluate a marine operational forecasting model. At present, the mainstream global ocean circulation models all adopt MPI parallel computing technology to improve the operation efficiency. The MaCOM mode also uses MPI parallel scheme to realize efficient operation, which is mainly embodied in three aspects: mode parallel meshing, communication design, and optimization, and asynchronous parallel I/O design.

The Mass Conservation Ocean Model (MaCOM) model is a newly established and operated global circulation model, which adopts a complete physical framework. The key feature of which is **mass conservation**, **enthalpy conservation**, **salt conservation**, and based on **pressure coordinates**.

Vertical pressure coordinate



Accurate simulation of Enthalpy | **Accurate simulation of Salinity**

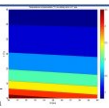
1 **Mass Conservation**

Demands:
Mass Conservation
Salinity g/kg
Conservative temperature Θ

Current mainstream settings:
Volume Conservation
(Boussinesq approximation)
Salinity kg/m^3
Potential temperature θ

Accurate simulation of Salinity

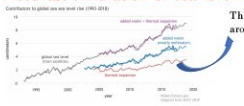
$Salinigy \pm 1\ PSU \Rightarrow Temperature \pm 2\sim4\ ℃$



Two sources of errors in salinity simulation

	1. Error due to unit conversion	2. Error caused by precipitation-evaporation conversion
Volume Conservation	salinity unit: kg/m^3 different from observation	$\eta_{emp} = \delta t (P-E)/\rho_0$ higher uncertainty for ρ_0
Mass Conservation	salinity unit: g/kg same with observation	$\eta_{emp} = \delta t (P-E)$ low uncertainty for g

Accurate simulation of sea-level rise

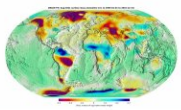


The warming-induced thermal expansion contributes around 40% in the global sea-level rise

Mass conservation model can directly reproduce the thermal expansion effects

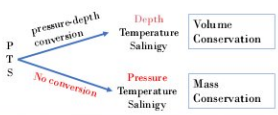
Volume conservation model need secondary diagnose of static sea level change through precipitation-evaporation and density variation

Assimilation of bottom pressure



Only numerical models based on pressure coordinates can achieve direct assimilation of bottom pressure data obtained from gravity satellite

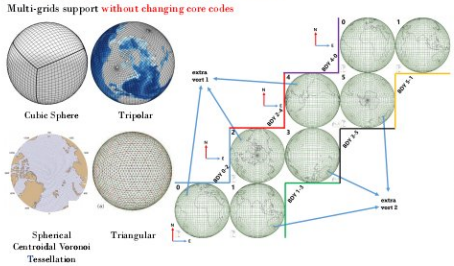
Accurate simulation of air pressure



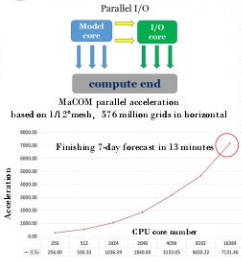
Mass conservation model can directly use air-pressure as upper boundary condition, thus more precise

2 Multiple meshgrid support

Multi-grids support without changing core codes



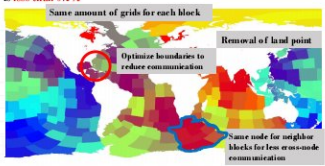
3 Graph topology parallel framework



★Total removal of land point saves up to 28% storag and computing

★Flexible boundary division reduces parallel communication (the average communication points accounts for less than 3%

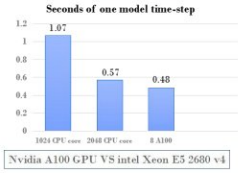
★Calculation load balancing is realized by keeping same amount of points in the calculation process, the maximum load imbalance rate is less than 0.1%



4 GPU parallel acceleration capacity

Global ten-kilometer (1/12 °) ocean circulation numerical forecast needs only one 8-card GPU server instead of 40-60 CPU computational nodes

Calculation of energy consumption reduced by 90%
Equipment acquisition cost is reduced by 2/3

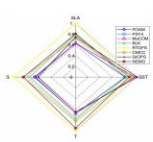


Nvidia A100 GPU VS intel Xeon E5 2680 v4

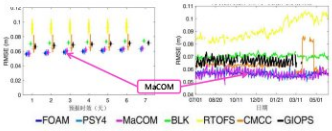
Evaluations of the MaCOM

Comparison of RMSE for 24hrs forecasts

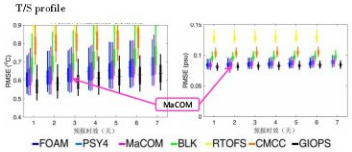
Model (country)	T(℃)	S(psu)	SST(℃)	SLA(m)
FOAM (UK)	0.61	0.08	0.49	0.06
PSY4 (FRA)	0.63	0.08	0.58	0.06
MaCOM (CHN)	0.63	0.08	0.59	0.06
BLK (AUS)	0.70	0.10	0.50	0.07
RTOFS (US)	0.94	0.13	0.56	0.09
CMCC (ITL)	0.80	0.10	0.56	0.06
GIOPS (CAN)	0.57	0.08	0.64	0.07
NEMO (previous version of China's global forecasting system)	0.79	0.12	0.53	0.07



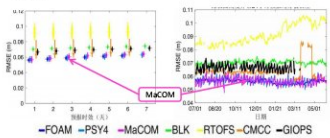
SLA



T/S profile

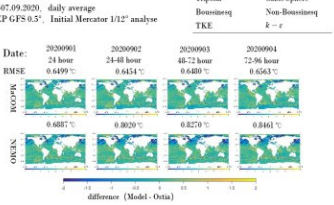


SSTA



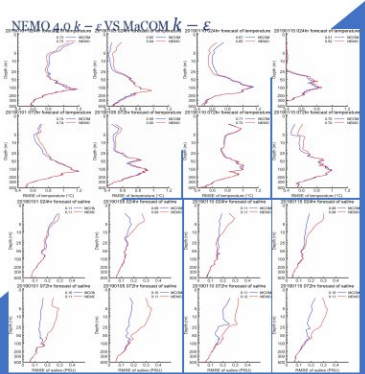
NEMO 3.6 VS MaCOM
01.09.2020-07.09.2020, daily average
Forcs: NCEP GFS 0.5°, Initial Mercator 1/12° analyse

NEMO	MaCOM
Tripolar	Cubic Sphere
Bousinesq	Non-Boussinesq
TKE	$k-\varepsilon$



›In terms of the T/S profile forecasting, MaCOM is above average
›In terms of the SLA, MaCOM is in the lead position, and shows significant improvement compared with our previous global operational oceanography forecasting system.

NEMO 4.0 $k-\varepsilon$ VS MaCOM $k-\varepsilon$



The MaCOM model establishes a series of key technologies and methods that can be controlled independently, and effectively fills the gap in the construction and implement of autonomous ocean circulation numerical systems in China. The prediction skills of MaCOM model in aspects of vertical structure of thermohaline, sea surface temperature, sea surface height anomaly, and current field are comparable to that of international mainstream ocean circulation models.