New Coupled Modeling System based on the Korean Integrated Model (KIM)

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1. Introduction

The Korean Integrated Model (KIM) was developed for global numerical weather prediction and has been operating in real-time since April 2020. To expand its capabilities, ranging from deterministic medium-range weather forecasts to probabilistic sub-seasonal to seasonal predictions, it is essential to improve the representation of physical processes and the interactions between the atmosphere and surface. To this end, the Korea Institute of Atmospheric Prediction Systems aims to develop a new coupled modeling system. This involves advancing the land surface processes, coupling ocean, sea ice, wave, river-routing models, and enhancing ensemble forecast and coupled data assimilation. Figure 1 provides a concise overview of the framework of the newly developed KIM coupled modeling system.

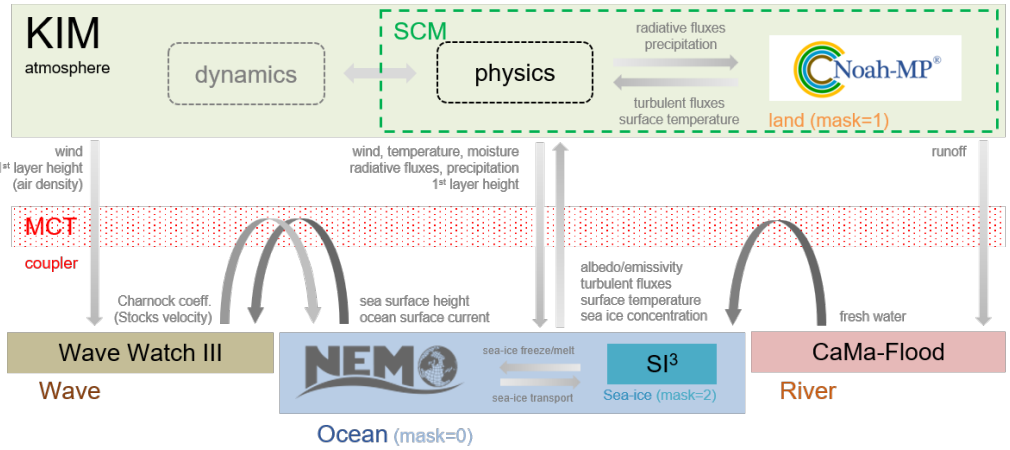

Figure 1: The framework of KIM coupled modeling system

2. Model description

The new coupled model integrates advancements of component models and enhances the effectiveness of their coupling. Its design allows the land surface model (LSM) to exchange state directly with the atmospheric model, while other components interact via a coupler, which is maintained at the latest version (Table 1).

Table 1: Configuration of coupled models

Description	Land	Ocean	Sea-ice	Wave	River-routing
Model	Noah-MP	NEMO	SI^3	WW3	CaMa-Flood
Version	5.0	4.0		7.13	4.0
Coupler		MCT-based			
Exchange frequency	every time step	1-h			
Grid system	cubed-sphere	Tripolar (eORCA)		Lat-Lon	Catchment-based
Resolution	100~6 km	0.25° (L70, 3-layer sea ice)		0.5°	0.25°

The Noah LSM has been replaced with the Noah with multi-parameterization options (Noah-MP) LSM to enhance the biophysical and hydrological complexity of the land surface. The Noah-MP version 5 has been optimized for physical consistency with atmospheric components, such as radiation and boundary layer schemes, and further improved to enhance the performance of the coupled model. The Land Information System (LIS) is utilized for land surface data assimilation, focusing on soil moisture and snow.

The Nucleus for European Modelling of the Ocean (NEMO), including the Sea Ice Modelling Integrated Initiative (SI^3), is an integrated modelling framework for marine-related dynamics and physics. To enhance atmosphere-ocean coupling, physical consistency among the components has been ensured, and physical parameterizations for the surface layer have been improved. Additionally, the NEMO framework has been updated with a new parallel IO process, and NEMO-VAR will be employed for the ocean data assimilation.

The new coupled modeling system also incorporates the WAVEWATCH III (WW3) and the Catchment-based Macro-scale Floodplain (CaMa-Flood) models to account for the effects of ocean waves and to convey runoff from the land surface to the ocean, respectively. These components interact with both atmosphere and ocean models (Fig. 1) and are expected to more realistically enhance atmosphere-land-ocean interactions.

3. Evaluation

Individual components of the coupled model are evaluated in offline mode using external atmospheric forcing, such as ERA5 for Noah/Noah-MP and JRA55-do for NEMO. The initial states of the ocean and sea ice are forced by ORAS5 and G/PIOMAS data, without data assimilation currently under development. These offline results are used to identify major sources of systematic bias and to determine the priority for resolution. Single column model is also utilized to evaluate the performance of the LSM using point-scale observations.

The current version of the coupled KIM (CPL) demonstrates comparable performance on medium-range weather forecasting compared to the atmosphere-only model (ATM). However, it tends to simulate surface temperatures that are warmer over the ocean and colder over sea ice. In seasonal simulation, the coupled model replicates atmospheric circulation and precipitation features more closely to the observations, particularly over tropics, due to its more realistic representation of atmosphere-surface interactions (Fig. 2). Furthermore, the fully coupled model has been found to remain stable for long-term integrations exceeding 20-years.

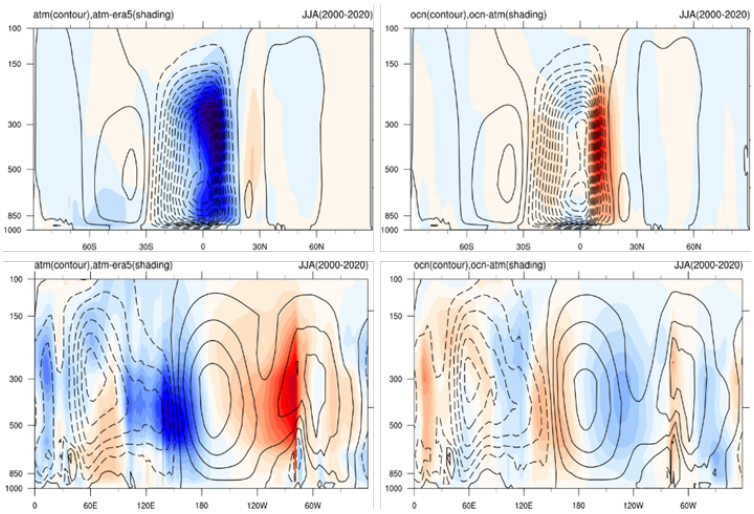

Figure 2: Evaluation of coupling effects on (top) Hadley and (bottom) Walker circulations: (left) bias of ATM and (right) CPL minus ATM