KIAPS
KOREA INSTITUTE OF ATMOSPHERIC PREDICTION SYSTEMS

Progress in Developing the Next-Generation KIM at KIAPS

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- **Ongoing Research & Highlights in 2025**

- Dynamics & Physics
- Coupled System Development
- Data Assimilation
- Machine Learning Research, R2O …

KIAPS Project I [2011~2019] & II [2020~2026]

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Phase I 2011~2019

Phase II 2020~2026

Stage 2: 2014~2016	Stage 3: 2017~2019	Stage 1: 2020~2022	Stage 2: 2023~2026

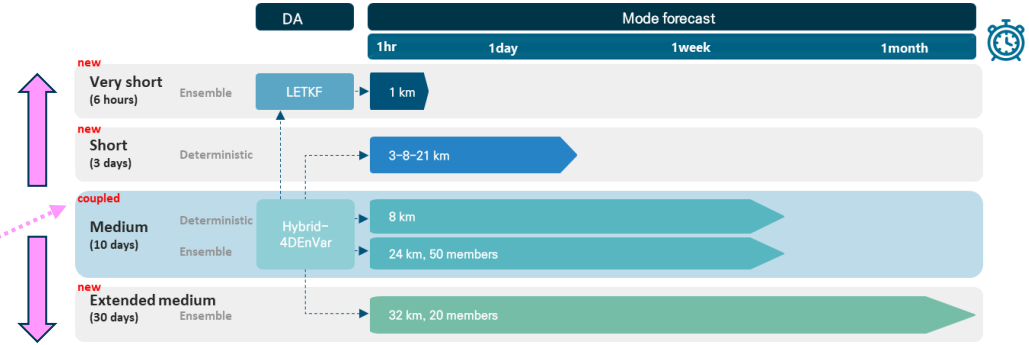
2015 2016 2017 2018 2019 2020 2021 2022 2023 2024 2025 2026

Korean Integrated Model, KIM

- Dynamical core (Choi et al., 2018)
  Fully compressible Euler Nonhydrostatic shallow-atmosphere
  ***x-y*: Spectral Element Method, Cubed Sphere Grid**
- Advanced Physics (Hong et al., 2018 and many others ..)
  Scale-aware subgrid physics, revision for advanced physics
- Data assimilation (Kwon et al., 2018)
  Hybrid 4D EnVar with LETKF

Next-generation seamless prediction system

From very short to extended-range predictions
horizontal resolution 1 km ~ 32 km featuring scale-adaptive physics
Coupled system designed for seamless prediction across scales



Korean Integrated Model

KIAPS

The **Korea Institute of Atmospheric Prediction Systems** (**KIAPS**)
delivered the global NWP system to the Korea Meteorological Administration (KMA)

KIM : Korean Integrated Model

- Cubed-sphere grid global model
- Horizontal resolution : NE360NP3 (~12 km, 20.4.~25.4.), NE576NP3 (~8 km, 25.5.~)
- Vertical resolution : 91 levels with 1 Pa top

Dynamical Core

Non-hydrostatic dynamical core

- Spectral element method
- Cubed-sphere grid (Equi-angular gnomonic projection)
- Split-explicit RK3, 2nd-order for nonlinear equation
- 6th-order horizontal diffusion and divergence damping

Physics Package

Advanced physics package

- RRTMK RAD (Baek, 2017)
- Noah LSM (Koo et al., 2017)
- Scale-aware PBL (Shin and Hong, 2015)
- GWD (Choi and Hong, 2015; Choi et al., 2018)
- Scale-aware CPS/SCV (Han et al., 2019)
- WSM5 MPS (Bae and Park, 2019)
- Prognostic CLD (Park et al., 2016)

Data Assimilation

KPOP and Hybrid-4DEnVar

- Directly assimilation of observation on the native cubed sphere
- Hybrid-4DEnVar with LETKF to generate analysis increment
- Incremental analysis update (IAU) method to update KIM analysis

Highlights of 2024 (reported at WGNE39)

KIAPS

Operational upgrade KIM4.0 (8 km global model)

Model: from 12 to 8 km, DA: from 32 to 24 km

+ scale-aware CPS update

➡ ***KIM4.0 operation began in May 2025 at KMA***

Global stretched grid and LAM approaches for short-range prediction

Domain and grid configuration, dynamics and boundary condition, test runs and stability checks, early validation, utilities

Physics update

New diagnostic cloudiness scheme (Kang et al 2025), Refinement in scale-aware physics: CPS (Han 2025), improvement in subgrid orography (Koo and Hong 2025), gravity-wave drag (Kim, 2025)

Couple modeling and ensemble systems

Coupling ATM-OCN-SIC-LAND models (Noah-MP, NEMO/SI^3, WW3, CaMa-Flood) and initial development in weakly coupled ocean- land- data assimilation

Sub-seasonal EPS system

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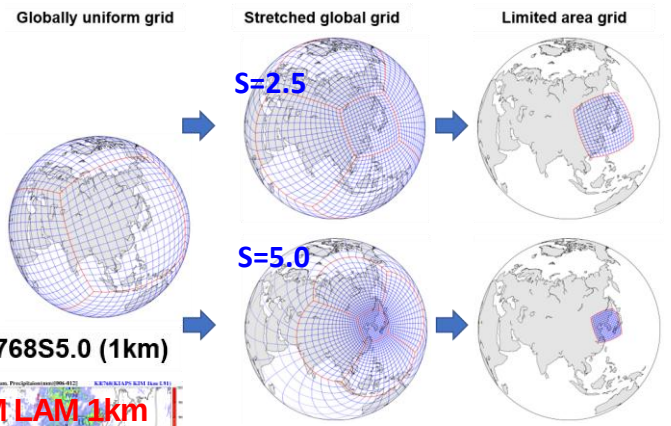
Progress in 2025

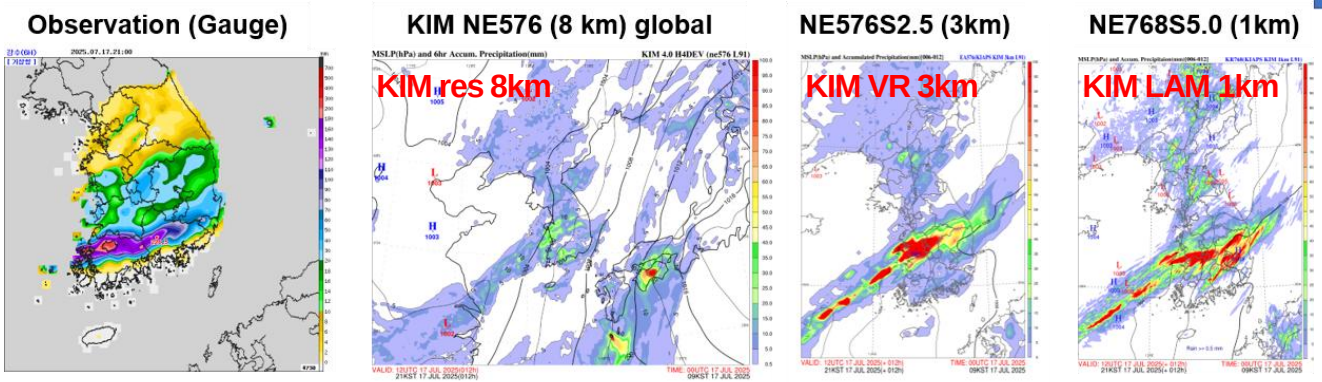
Development of Short-Range Prediction Systems: VR and LAM

➢ KIM variable-resolution grid system and the limited-area model (LAM) configuration

(1) Variable-resolution grid : a stretched global grid with an S factor
- implemented using Schmidt Transformation ***(Choi and Nam, 2025)***

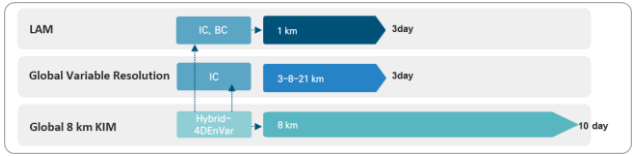
(2) Limited Area Model
- configured on a single panel of the cubed sphere
- incorporates lateral boundary conditions ***(Kim et al., under review)***





← KIAPS' internal operation testing
forecast @2025071700 +12h

I.C and Lateral BC: from 8km global KIM



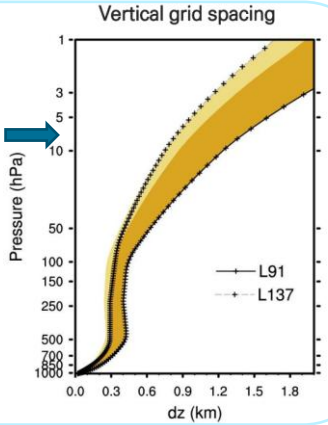
Very-high-resolution (1-3 km) systems capture intense precipitation signals for heavy rainfall events, closely matching observations

Enhanced Vertical Resolution (91 → 137L)

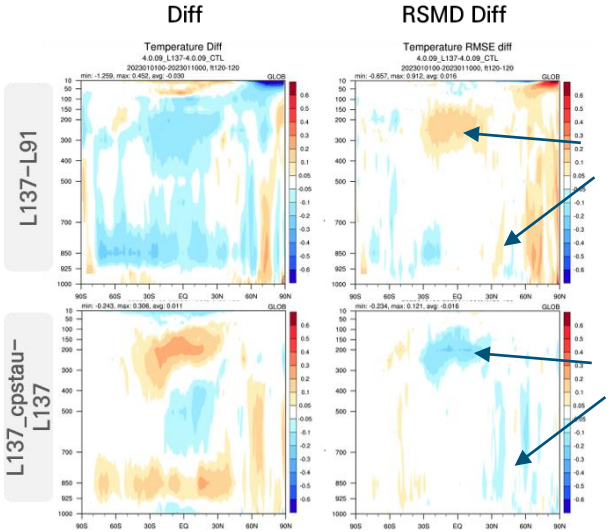
Ongoing research to further improve vertical resolution

- **Reduce sensitivity of sub-grid hydrometeor process to dz**
  - High sensitivity of convection schemes to vertical resolution in the troposphere
  → modulating in sub-grid hydrometeor processes to mitigate sensitivity
- **Advantages of higher vertical resolution in simulations**
  - Improved representation of boundary layer mixing and moisture exchange
  - Enhanced stratospheric modeling, including QBO simulation

New vertical profile development
Utilizing ECMWF L137 profile
Top/bottom ~ identical
Overall 30% reduction in dz (below 100 hPa) ~ 40% (above 100 hPa)



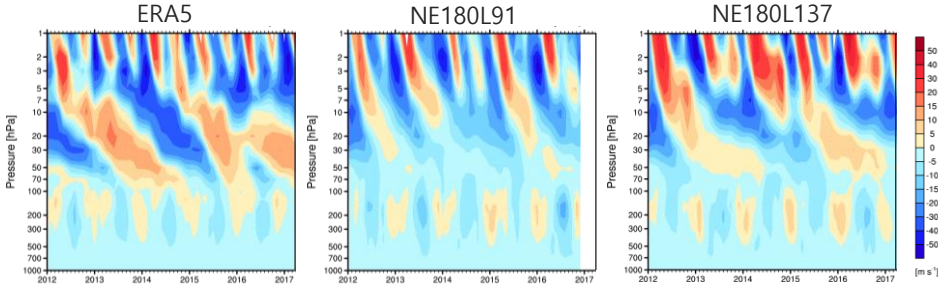
Impact of cps-tau on dz sensitivity (radiative cooling)



RMSE increase due to physics sensitivity to dz (L91→L137)

Impact of sub-grid hydrometeor revision (cpstau)

QBO simulations: L91 vs L137



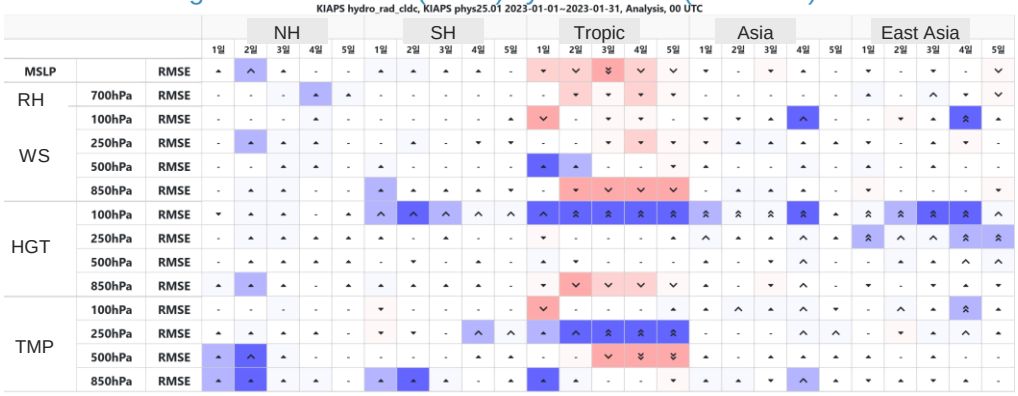
QBO diagnosis by +/- transition of u-wind (~5.5 S – 5.5 N average)
25 km resolution (NE180) with ERA5 initial

Revision of the Physics Package

Physics candidates for the next version (→Phys26.01)

Physics	Revision candidates	Main focus
Radiation (1)	Effective radius of ice Tau (lifetime) of sub-grid cloud	Correcting systematic cooling biases in atmospheric temperature Reducing underestimation of long-wave flux at the surface
Cloudiness	Included snow in cloud fraction	RAD-MPS-CLD revision
Convection	Moisture flux considering scheme(MFC)	Precipitation (Korea/Global domain)
Radiation (2)	Modified aerosol optical characteristics	Aerosol impact, applicability
Boundary Layer	EDMF, background diffusion	Dry bias in low troposphere, near-surface cold bias
OGWD	New ancillary data (orography 4 km → 500 m)	Global wind/tmp bias, high resolution support

Verification of RAD-MPS-CLD revision,
using a low-resolution (25km) cycle testbed (Jan 2023)



Development of a Coupled Modeling System

KIAPS

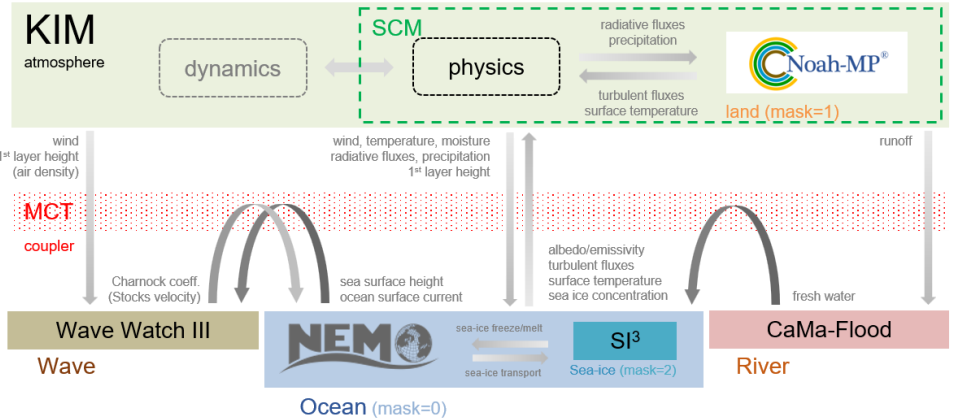
➢ A new coupled model built upon KIM

State-of-the-art surface models:

- Inland component: Noah-MP (V5.0), CaMa-Flood (V4.0)
- Marine component: NEMO/SI^3 (V4.0), WW3 (V7.13)

Enhanced interaction between components

- Physical consistency in parameterizations, constants, processes
- High computational/parallel efficiency
- Advancements in component model processes



:: Specification of surface components ::

		LSM			OCN	SIC	WAV	RIV
Model		Noah-MP			NEMO	SI^3	WaveWatch III	CaMa-Flood
Version	current	4.0.1	4.2 → 4.4	5.0	4.0		7.13	4.0.0 (4.1)
	origin	LIS	WRF	GitHub	–		–	–
	latest	5.1 (MAY 2025)			5.0 (DEC 2024)		7.13 (?)	4.2 (MAR 2024)
Coupler		–			MCT-based			
Initial data		ERA5			ORAS5 (GODAPS)	ERA5/GIOMAS PIOMAS(N.H.)	–	–
Exchange freq.		every time step (same with KIM)			1h (fixed; same with radiation)			
Grid system		cubed-sphere (same with KIM)			tripolar		(regular) lat-lon	unit-catchment
Resolution		100~6 km (NE045~768; same with KIM)			25 km (eORCA025)		50 km	25 km

Upgrade of the Coupled Model

Major updates in 2025

Process	Updates
Land (Noah-MP)	• Monin-obukhov length consistency (w/ PBL) • Barren type emissivity, snow thermal conductivity • Adjustment of sub-grid tile fraction, roughness length, thermal conductivity • Stomatal-photosynthesis parameterization
Ocean (NEMO)	• eORCA025 grid • Lateral diffusion on momentum, • TKE scheme, Prandtl number • Stokes drift ancillary data, Surface turbulent mixing energy • Langmuir circulation parameterization • Adding climatological runoff • Surface temperature parameterization consistency with KIM
Seaice (SI^3)	• Adjustment of skin temperature parameterization • Conductive flux boundary condition • Ice albedo consistency with KIM • Enhanced downward longwave radiation • Lüpkes et al. (2012)-based exchange coefficients
Wave (WW3)	• Wave-induced turbulent mixing energy • Stokes drift velocity • H_s-based ocean roughness
Operation	• Processor decomposition, precision, stability, compile option • Output process • Land initialization

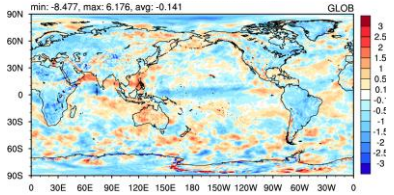
Ongoing research

- Multi-scale evaluations
- Land-atmosphere interactions, coupling processes
- River routing, lake physics
- ATM-OCN-SIC physics
- Wave model resolution improvements, sea spray effects

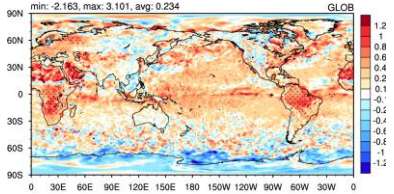
Evaluation of CPL2024 vs CPL2025

10-m wind speed

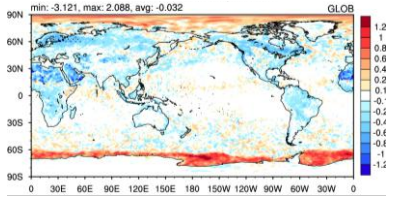
ATM



CPL2024-ATM

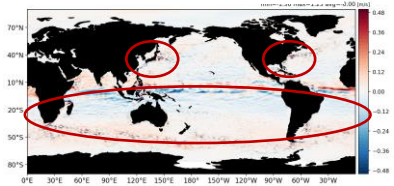


CPL2025-CPL2024

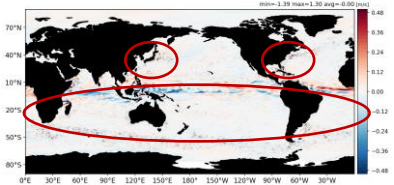


Zonal current

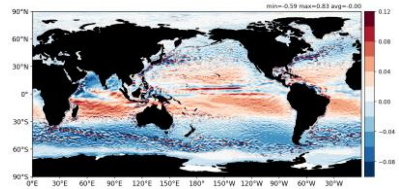
CPL2024



CPL2025



CPL2025-CPL2024

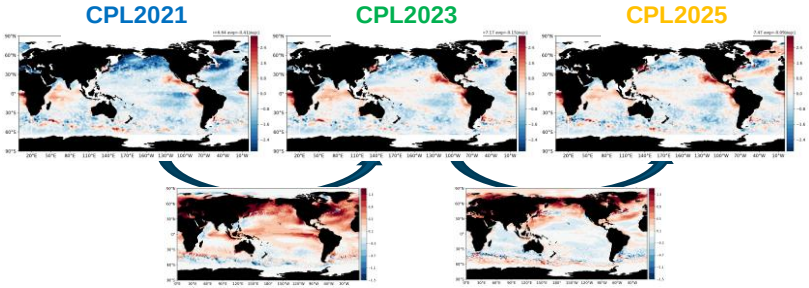


Evaluations of the KIM coupled model

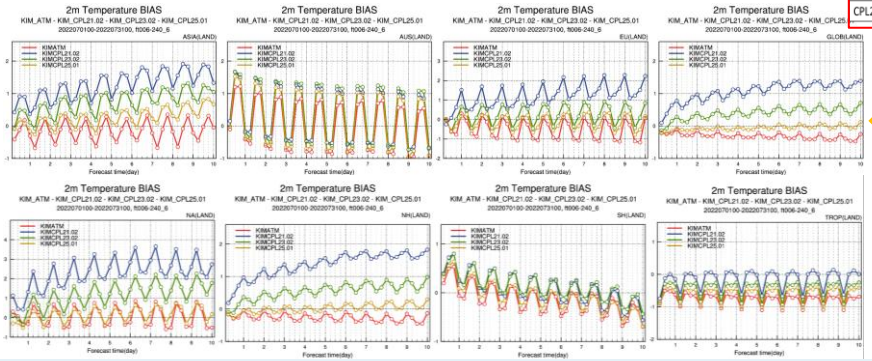
Improvement in verification and testing

- **Expand evaluations with Various testbeds**
  - Long-term simulations (e.g. CMIP), sub-seasonal prediction, extreme events simulation
  - Single column model, off-line experiments
  - Adopting new verification tools: PCMDI, ocean verification

Mean SST bias in JJA 2022

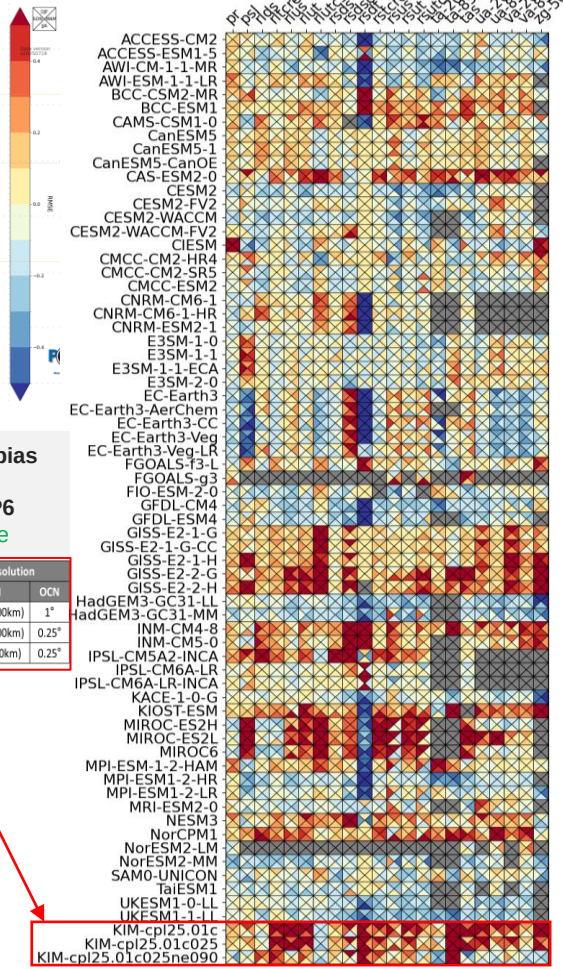


T_{2m} bias in 10-D predictions Jul 2022



Evaluation of mean bias in CMIP simulations compared with CMIP6
Using PCMDI package

EXP	Period	Resolution	
		ATM	OCN
CPL25 (cpl25.01c)	1850~2020	ne045 (100km)	1°
CPL25_o25 (cpl25.01c025)	1850~2020	ne045 (100km)	0.25°
CPL25_o25a50 (cpl25.01c025ne090)	1850~2020	ne090 (50km)	0.25°



▶ Improvement in surface simulations (SST, T2M) with CPL upgrades (2021 ➔ 2023 ➔ **2025**)

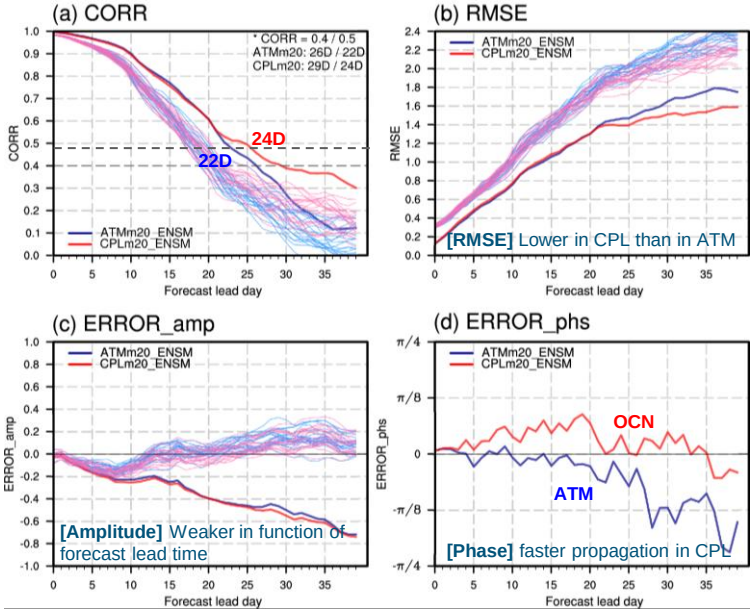
MJO Prediction Skill (40-D): ATM vs CPL

Experiment set up

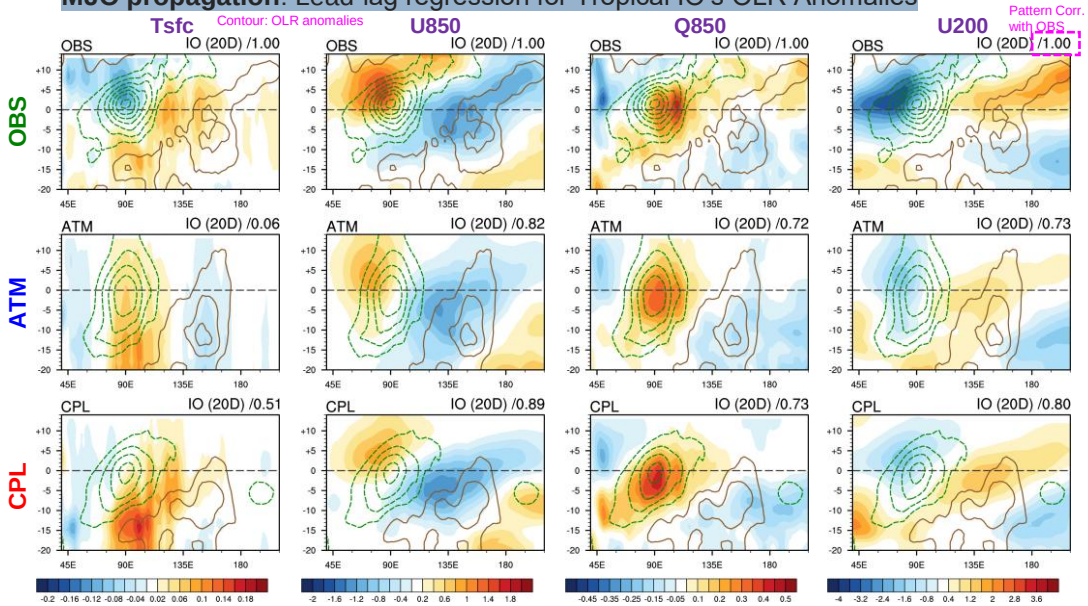
- Number of experiments: 160 set (2001-2020, 1st & 17th Jan, Feb, Nov & Dec initialization)
- Ensemble size: 20
- KIM resolution: 100km

Indian Ocean (IO) : 80-100°E, 10°S-10°N
Regr: rescaled by -1 STD of region's OLR

Verification of MJO



MJO propagation: Lead-lag regression for Tropical IO's OLR Anomalies

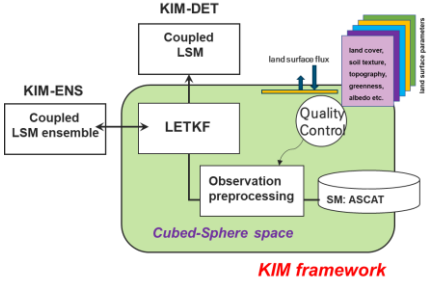


▶ CPL exhibits a propagation pattern more consistent with observations than ATM, particularly in terms of OLR.

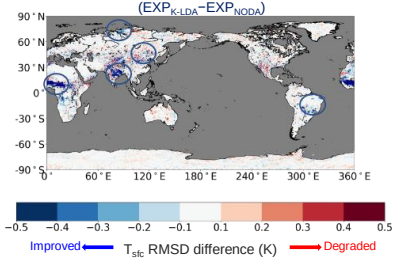
Coupled Data Assimilation

Weakly-Coupled atmosphere-land DA

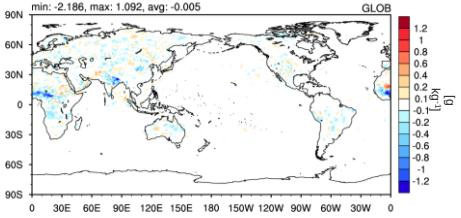
- **New KIM-based land DA framework** using the LETKF
- Land analysis is performed **directly on the cubed-sphere grid**
- Land **background ensemble** is generated from the **KIM ensemble forcings** combined with **additional state perturbations**
- Preliminary **ASCAT soil moisture** assimilation results demonstrate **promising** performance



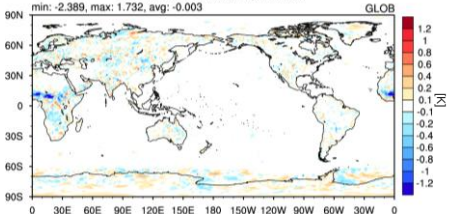
[Surface temperature RMSD difference]
($EXP_{K\text{-}LDA}$−EXP_{NODA})



[2-m specific humidity RMSD difference]
($EXP_{K\text{-}LDA}$−EXP_{NODA})
2022062600-2022070912, ft000-000



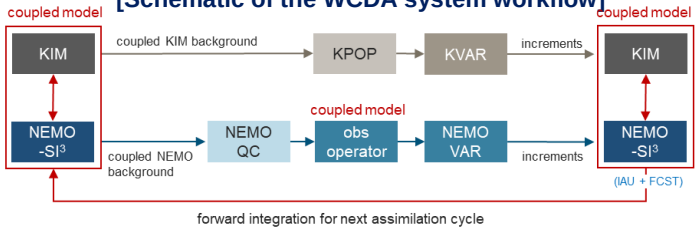
[2-m air temperature RMSD difference]
($EXP_{K\text{-}LDA}$−EXP_{NODA})
2022062600-2022070912, ft000-000



Weakly-Coupled atmosphere-ocean DA

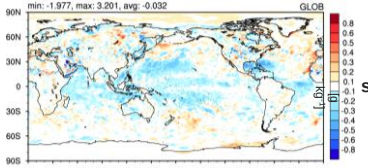
- Models in NEMOVAR (Ocean: **NEMO4**; sea-ice: **SI³**)
- DA scheme: atmosphere (**hybrid-4DEnVar**), ocean/sea-ice (**3DVar-FGAT**)
- **IAU** window: **-03 to 03 hours** (same as KIM)
- **WCDA enhances atmospheric forecasts** compared to the current operational KIM (CTL), which performs atmospheric DA only

[Schematic of the WCDA system workflow]

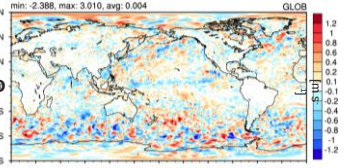


[Near-surface atmospheric forecasts (5-day)]

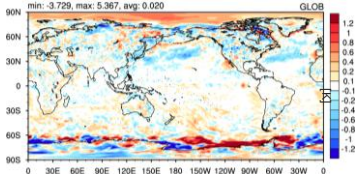
[2-m specific humidity RMSD difference] (WCDA−CTL)



[10-m wind speed RMSD difference] (WCDA−CTL)



[2-m air temperature RMSD difference] (WCDA−CTL)

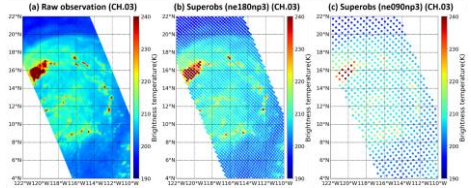


All-Sky Satellite Radiance and Convective-Scale DA

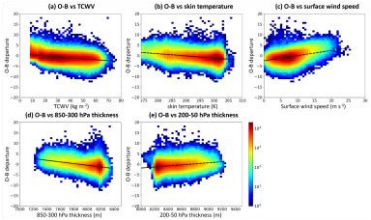
All-sky GMI radiance DA

Development of pre-processing system

[Sensitivity test on superobbing resolution]

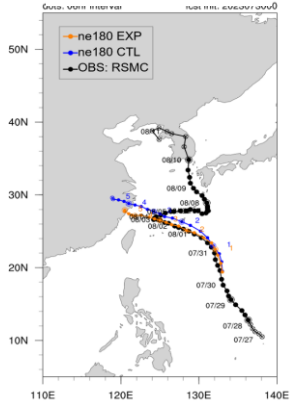


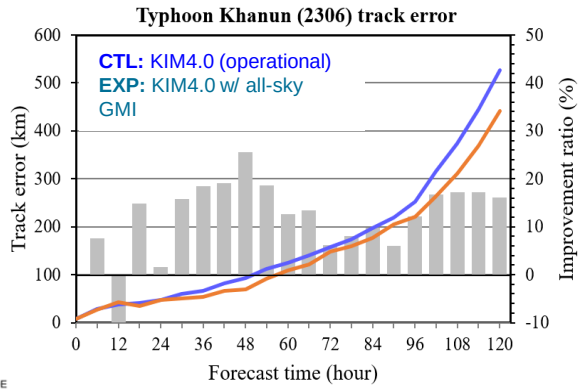
[O-B departure vs. BC predictors]



Improvement in typhoon prediction

[Khanun track]





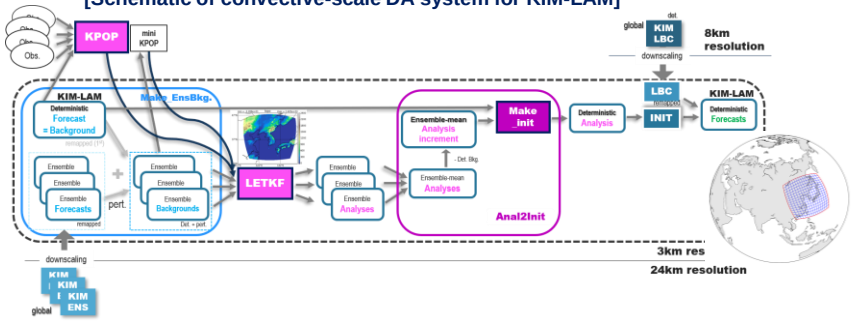
Assimilation of all-sky radiances improves the model initial fields of mass and wind variables, contributing to enhanced typhoon track prediction.

Convective-scale DA

Development DA system for KIM limited area version (LAM)

- 3 km resolution with 3-hourly analysis updates
- Ensemble perturbations provide by global KIM ensemble
- KPOP and observation operators updated for LAM background support
- LETKF assimilates high-density observations, including radar data

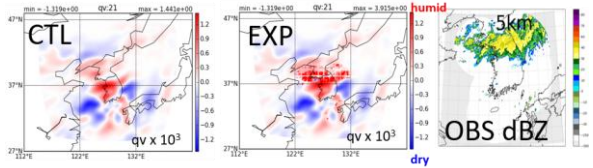
[Schematic of convective-scale DA system for KIM-LAM]



The initial performance of convective-scale DA

- Assimilating radar observations enhances humidity analysis over precipitation areas

[Results for CSDA responses in KIM-LAM]

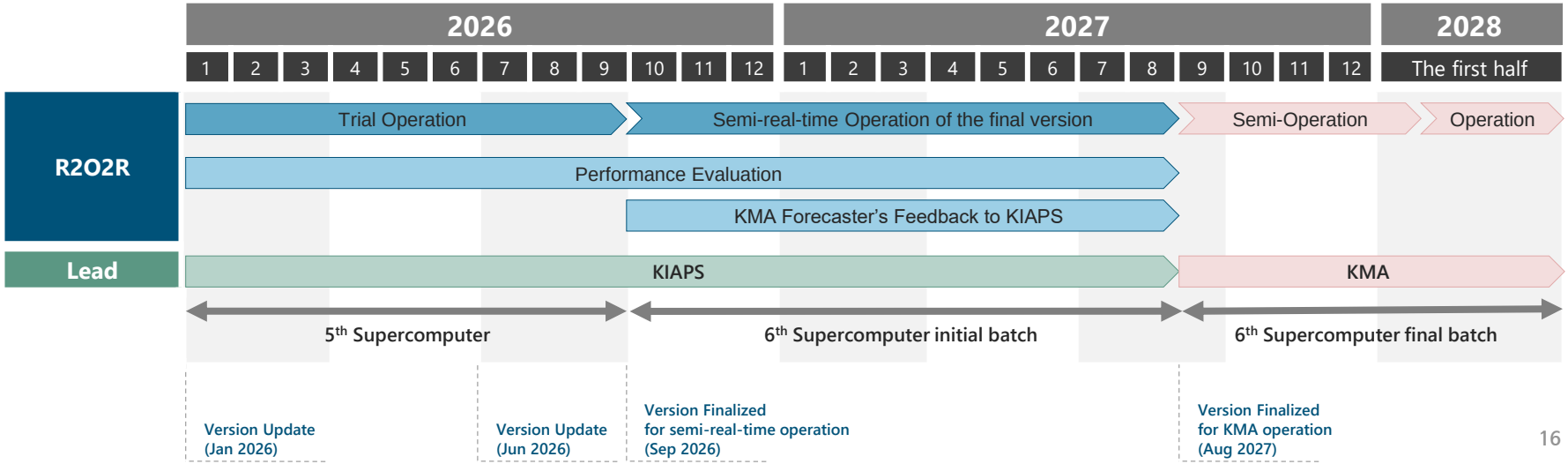


R2O Preparation for the Next-generation KIM

Current status of next-generation KIM trial operation at KIAPS

2025 KIAPS KIAPS Operation	Resolution	Fcst. range	Cycle	Operational period	Resources	Run-time	Storage
Medium range (normal cubed-sphere)	8km L91	10 days	00, 12 UTC	'24.08.22. 00 UTC ~ current	640 nodes	160 min.	4.5 TB
Short-range (stretched grid)	3-8-21km L91	5 days	00, 12 UTC	'25.07.02. 12 UTC ~ current	820 nodes	180 min.	3.0 TB
Very short-range (limited area model)	1km L91	2 days	00, 12 UTC	'25.07.02. 12 UTC ~ current	640 nodes	60 min.	0.4 TB

R2O Strategy and Plan with KIAPS-KMA collaboration

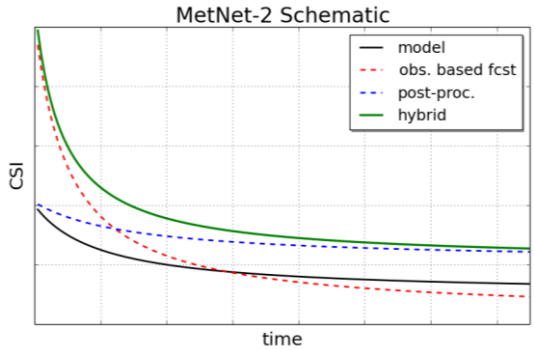


Machine Learning Applications

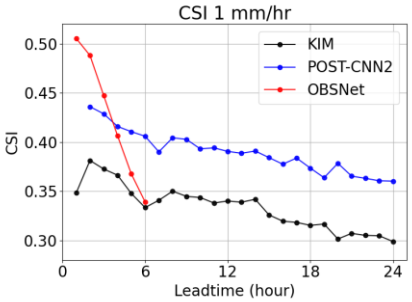
AI for short term precipitation forecast

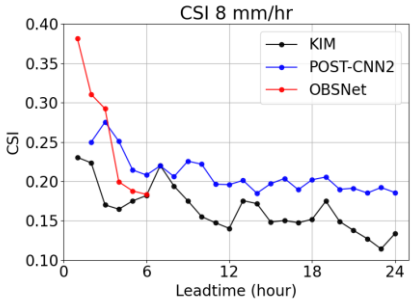
- **Objective**
  - To develop an early warning system for heavy rainfall events with a lead tim of up to 24 hours.

- **Development Strategy & Architecture**
  - Observation based precipitation ML model development (OBSNet)
    → U-Net / CNN Model (DeepRaNE, ConvLSTM)
  - NWP post-processing ML model development (POST-CNN2)
    → U-Net / CNN model (ConvNeXT v2)
  - Hybrid model development



- **Verification (preliminary results)**
  - AWS (ground truth), KIM (baseline), OBSNet, POST-CNN2





Other applications of AI

- **AI for observation processing**
  - Bias correction and quality control, and cloud screening

- **Machine-learning based FSOI**
  - Combination with conventional approaches

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Thank you

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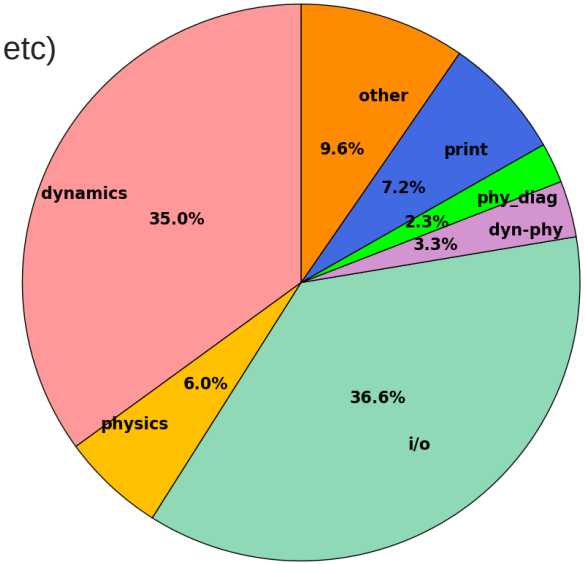
Back up

Launch of KIM4.0 (8 km Global Resolution) at KMA

The Operational 8-km KIM at KMA: Updated Version Active Since May 14, 2025

- **Optimization includes:**
  - Optimization for the KMA's 5th supercomputer (compiler, I/O, environment, etc)
  - "Stripe" partitioning for the cubed-sphere grid
  - High performance parallel I/O method (grouping, rearrangement)
- **MPI rank average elapsed time ratio**
  - 1,500 nodes (Intel Ice-Lake 8368Q 2.6GHz 38Cx2)
  - 15 day time integration, Total elapse time: 160 minute
  - File write elapse time ratio: 36.6% (14.7 TB output file)



MPI rank average elapse time ratio for operational KIM

Ongoing work to improve computational efficiency

- Development of an adaptive time-stepping method
- Exploring the use of large time step

In the upcoming five year plan (2027- 2031), KIAPS aims to further improve the model's performance by utilizing advanced numerical methods, CPU optimization, I/O node development, and GPU porting.

Recent updates to the Operational Ensemble System at KMA (‘25.5)

- A horizontal resolution increase from 32 km to 24 km in Global KIM EPS at KMA with the version upgrade (KIMv4.0)
- Forecast length of global-medium 12d → 15.5d

Ongoing research developing EPS systems at KIAPS (~ 2026)

- Development of a new extended-range prediction system (targeting ~4 weeks, 32-km resolution)
  - Using the KIM model
  - Coupled model system (NEMO/Si3, WW3, Noah-MP) & data assimilation
  → Two global ensemble predictions with KIM (medium-range & extended-range)

- Model uncertainty using Stochastically Perturbed Parameterizations
  - Starting from last year, intensive testing with applicable physics modules has started
  - Searching the optimal perturbation
  - Performance comparison with the current methodology (SPPT, SPDT, SSST)

Stochastically Perturbed Parametrization

Forecast performance improvement through SPP sensitivity experiments

- **Assessing the impact of parameter perturbations on forecast skill**

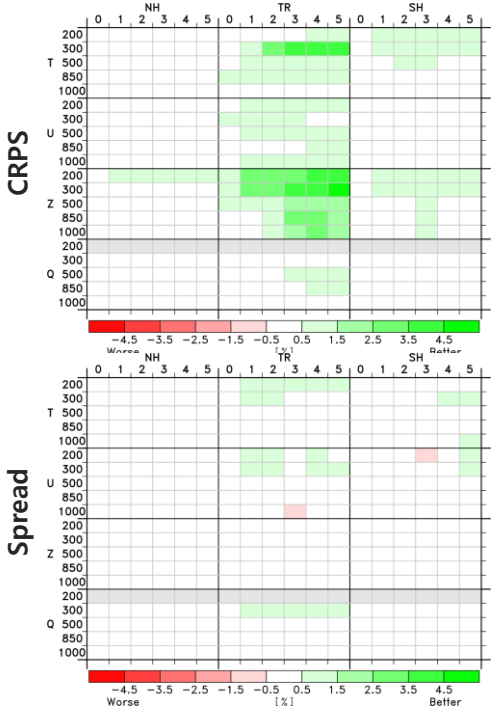
- Forecast experiments initialized on 1, 11, 21, and 31 July 2022
- 15-day forecasts with 25 members at 24 km resolution
- Verification against ERA5 reanalysis to evaluate forecast performance

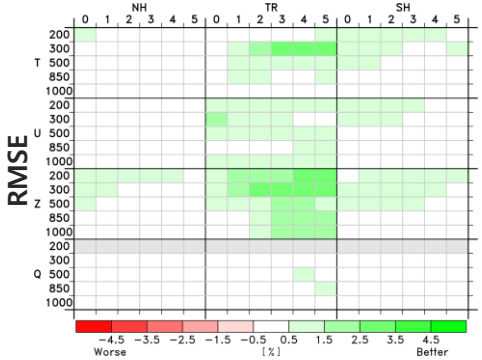
[Perturbed parameter settings]

Physics	Parameter	σ	Distribution
PBL	rl2	0.4	Log-normal
	rlamdz	0.4	Log-normal
	brcr_sbro	0.4	Log-normal
Convection	pgcon	0.4	Normal
	cinacrmx	0.4	Log-normal
Radiation	xres	0.4	Log-normal
Cloud and large-scale precipitation	prevp	0.7	Log-normal

	Experiment setup
Initial date	1, 11, 21, 31, July 2022
Forecast range	15 days
Resolution	NE192NP3 (~24km) L91
Ensemble members	25
Length scale	1,000 km
Time scale	72 h (259,200 s)

Scorecards: SPP combination vs. Control (~ 5days)





- Increased CRPS in the tropics (consistent with reforecast result)
- RMSE improvements aligned with CRPS
- Enhanced spread at upper levels