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Development of next-generation KIM at KIAPS and recent update

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Outline

- Introduction to KIAPS project
- Recent upgrade of global NWP (KMA operation)
- Ongoing research at KIAPS
- Summary

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KIAPS project and KIM model

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

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Korean Integrated Model (KIM) ➔ medium-range (10-day), 12km

- **Dynamical core (Choi et al., 2018)**

Fully compressible Euler **NONHYDROSTATIC** shallow-atmosphere
x-y: **SPECTRAL ELEMENT METHOD**, **CUBED SPHERE GRID**
z: finite difference method, Lorenz staggered grid (hybrid-sigma)
t: 3rd order Lunge-Kutta

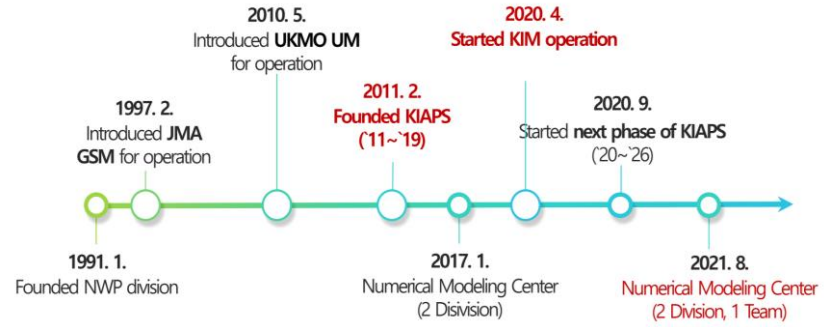
- **Physics (Hong et al., 2018 and many others ..)**

Revised RRTMG (RRTMK), Revised Noah-LSM,
Scale-aware non-local PBL, Scale-aware mass flux convection KSAS
Subgrid orographic GWD, Nonorographic GWD,
WSM5, Prognostic/diagnostic CLD

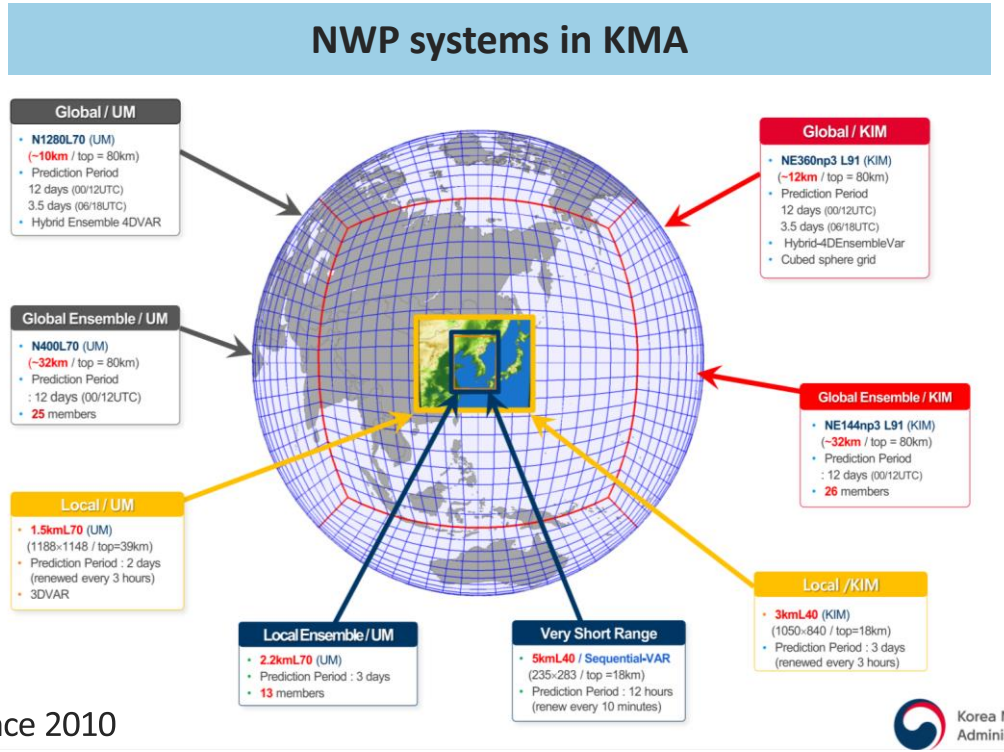
- **Data assimilation (Kwon et al., 2018, others..)**: Hybrid 4D EnVar with LETKF

KIM seamless prediction system from short-range(km-resolution) to sub-seasonal range(4 weeks)

Operational Weather Prediction Systems at KMA



KMA's history of NWP



Global numerical predictions since 1997 (JMA GSM)

Operating various applications with UKMO UM models since 2010

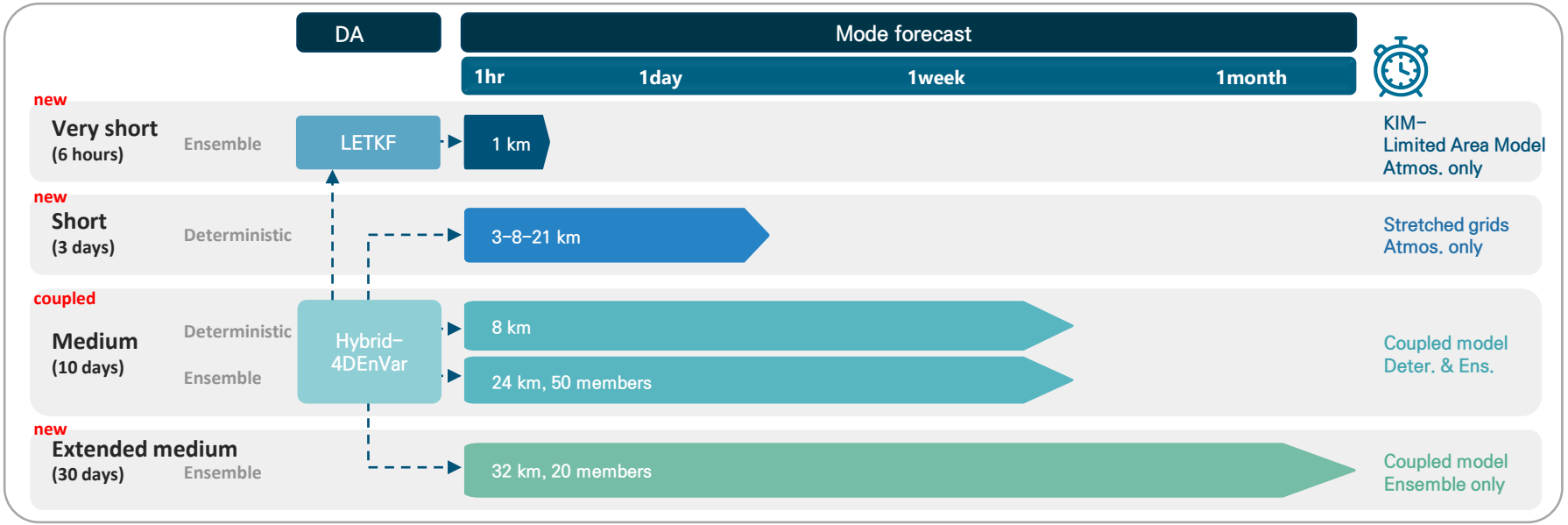
NWP systems at KMA (Courtesy to Jongchul Ha)

To begin global NWP support with KIM in 2020 (deterministic/ensemble)

Local KIM ~ KIM physics and WRF dynamics

Seamless prediction by the next-generation KIM

Various applications for the integrated KIM system for very short to extended-range under development in KIAPS II



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R2O 2024: KIM4.0

Upgrade in KIM3.9 → 4.0

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Enhancement in horizontal resolution

Model resolution from 12 to 8 km with optimization in topography, hyperviscosity

Data assimilation resolution from 32 to 24 km with improved land initialization

→ Overall improvement in global RMSE & Korean weather

Revised scale-aware parameter in CPS

Targeting gray-zone (less than 10 km) simulation,

Modified scale-aware parameter in convective updraft

→ reducing exceesive subgrid precipitation and enhancing heavy rain simulation in Asian / Korean domain

Update in physics

Seaice temperature initialization

Update and correction in ozone & aerosol climatology

Modification in cloud overlapping

RRTMG5.0

Data assimilation, system development

Land initialization: CDF, consistency with physics etc.

New grid partitioning, KIM-IO upgrade

Speed optimization for components of scientific workflows, code refactoring

→ The KIM4.0 e-suite was finalized and implementation into operatoin is planned in mid-2025 after parallel running test

History of resolution increase in KIM (25km L50 ➔ 8 km L91)

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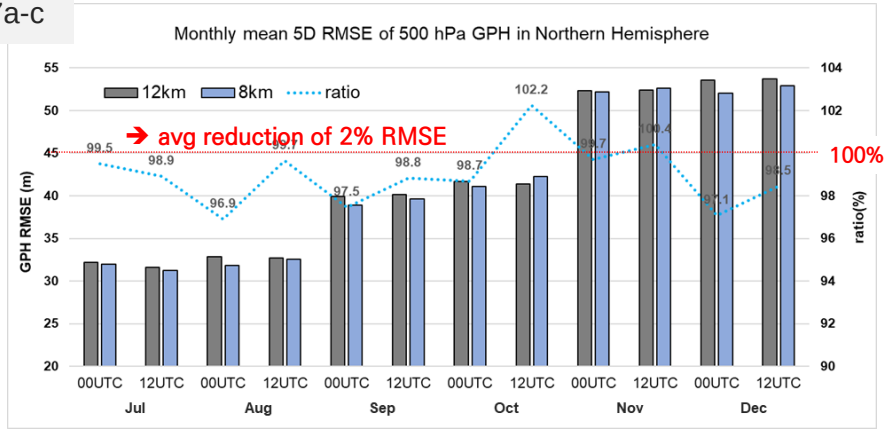
➢ Resolution update in KIM (2015~current)

KIAPS Version	Release	Horizontal resolution		Vertical levels / model top		Remark
KIM2.0	July 2015	NE120NP4	**~25km**	**L50**	**~50 km**	Non-hydrostatic dynamic core with KIM physics package (Hong et al, 2018)
KIM3.0	April 2017	NE360NP3	**~12km**	**-**		
KIM3.1	Feburary 2018	**-**		**L91**	**~80 km**	**CPS sensitivity to dz is fixed** (Lee et al, 2019)
KIM3.7	February 2022	NE576NP3	**~8km**	**-**		**Scale-aware parameterization modified** in KIM4.0 (2024)

➢ Global RMSE improvement by resolution increase from 12 km to 8 km

KIM3.7a-c



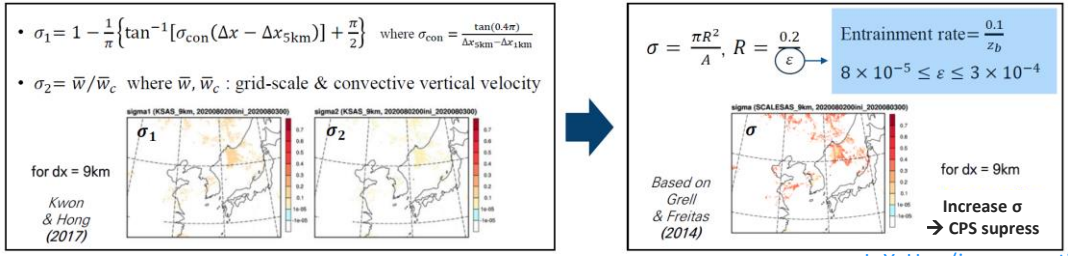
Forecast improvement includes:
- reduced RMSE scores in mid-to high- latitudes
- longer predictabilities for high-impact weathers (e.g. 1~2 days for heat wave simulations)
- typhoon simulations

Highlights in KIM4.0 performance: heavy rainfall

Modified Scale-aware parameter (convective updraft fraction, σ) considering entrainment rate

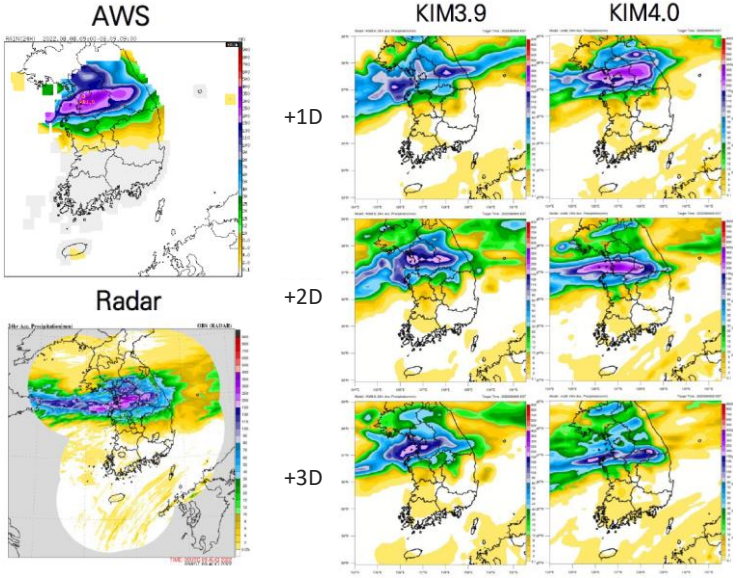
Reduction in the excessive CPS precipitation and stabilization

→ decrease excessive light rain by CPS and increase in grid precipitation

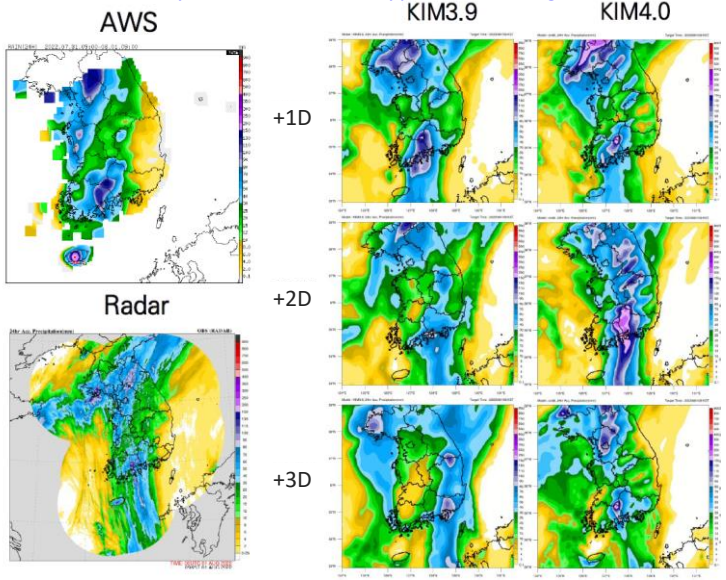


J.-Y. Han (in preparation)

A heavy rain case with stationary front (9 Aug 2022)



A heavy rain case with a typhoon (1 Aug 2022)



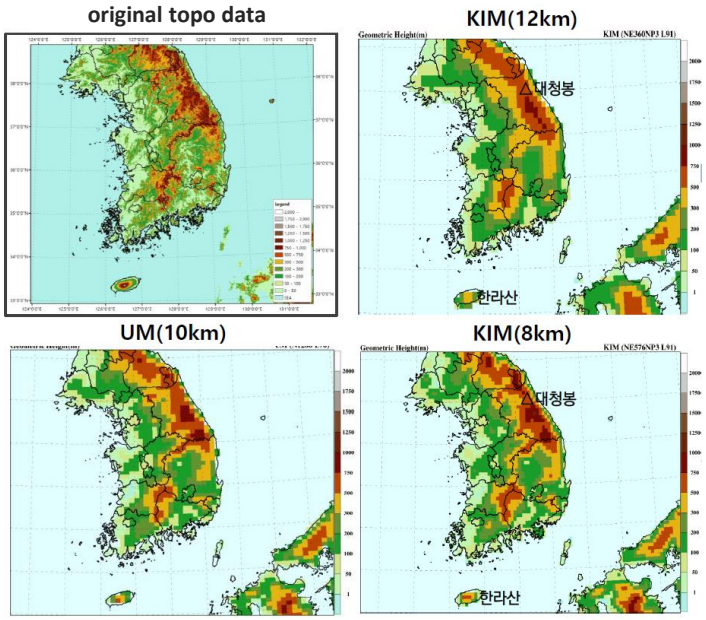
Highlights in KIM4.0 performance: accuracy in topography

High resolution topography in 8km KIM

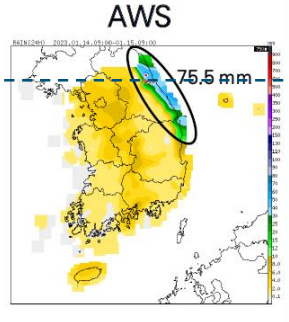
Increase in the model resolution (12 → 8km)

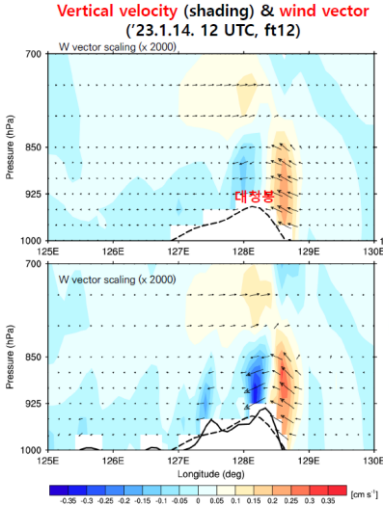
+

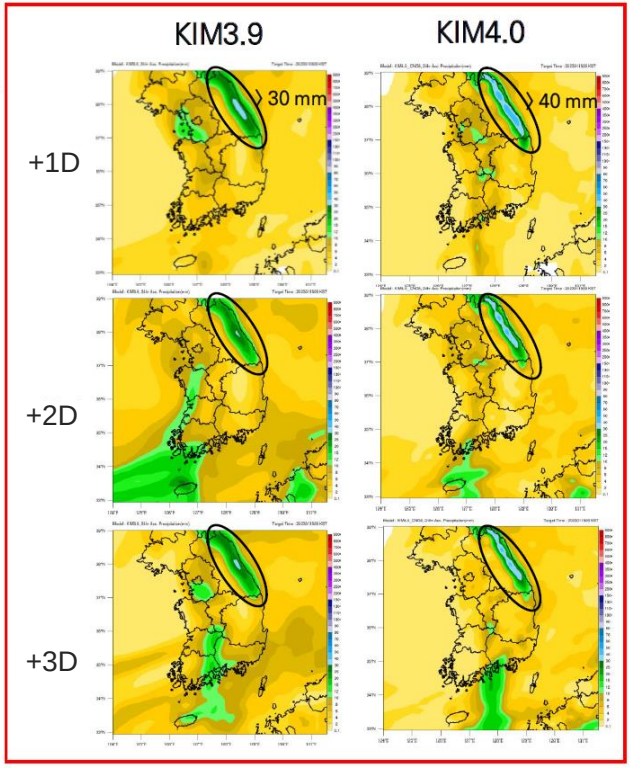
Detailed topo. (low filtered) patched over the Korean area



snowfall event
('23.1.14~15, 09KST)







Highlights in KIM4.0 performance: global scores

Scorecards : KIM4.0 vs KIM3.9

KIM4.0 shows overall improvements in global performance except in the Southern extratropical regions. Related to this physics updates in subgrid orography and cloudiness are planned

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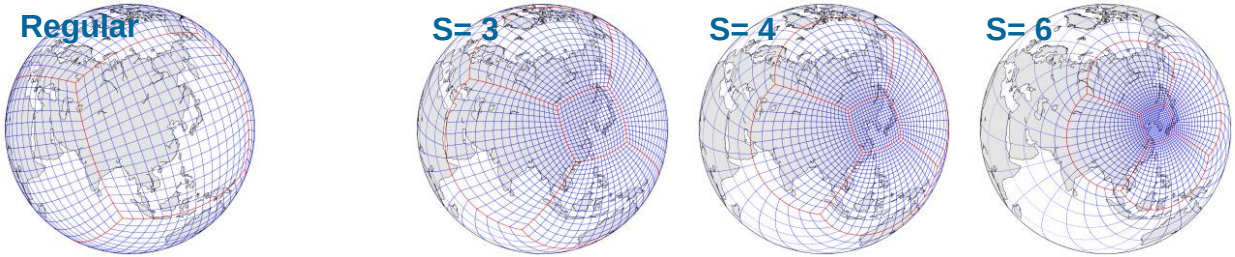
Ongoing Research for the next-generation KIM

KIAPS research for the next-generation KIM

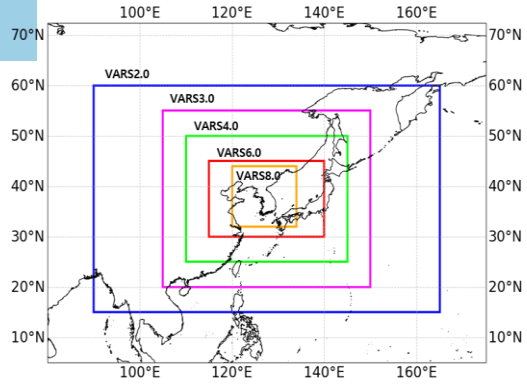
Component	Research topics
Data assimilation	Hybrid-4DEnVar for Global model LETKF for Limited Area Model Weakly coupled data assimilation
Dynamics	High resolution dynamics (global uniform grid) Globally variable-resolution model Limited Area Model(LAM) based on KIM variable resolution grid Vertical resolution enhancement, SMoothed vertical Hybrid coordinate (SMH) low-filtered topography, adoptive time step
Physics	Scale-adoptive physics for gray-zone (convection, subgrid-scale orography, gravity wave drag) Microphysics: considering aerosol indirect effect Advanced physics: represent cloud edge effect on radiation, microphysics included graupel and hail Many other physics update to reduce systematic bias of KIM, mass-flux PBL
Coupled modeling	Coupling KIM with NEMO (ocean), SI3 (seaice), Noah-MP (land), WW3 (wave), CaMa-Flood(river) & advancements in components
Ensemble prediction	Adopting model physics perturbation(SPP), currently using SPPT, SPDT, SSST Consistenty in forecast/hindcast Initialization
Framework	Modeling framework and Scientific workflows system development High performance computing: parallelization, memory, input/output(KIM-IO)

Global variable-resolution grid

A global stretched grid of KIM using schumidt transformation

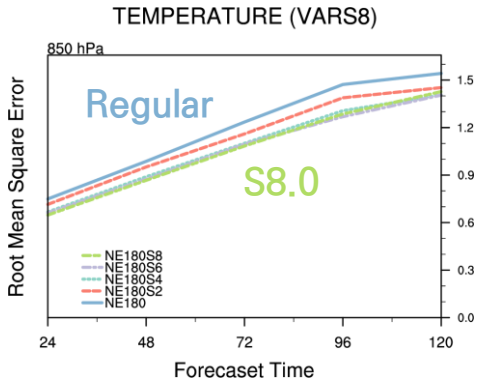


Visusalization of global regular grid and streched grid with various stretched-factor(S)

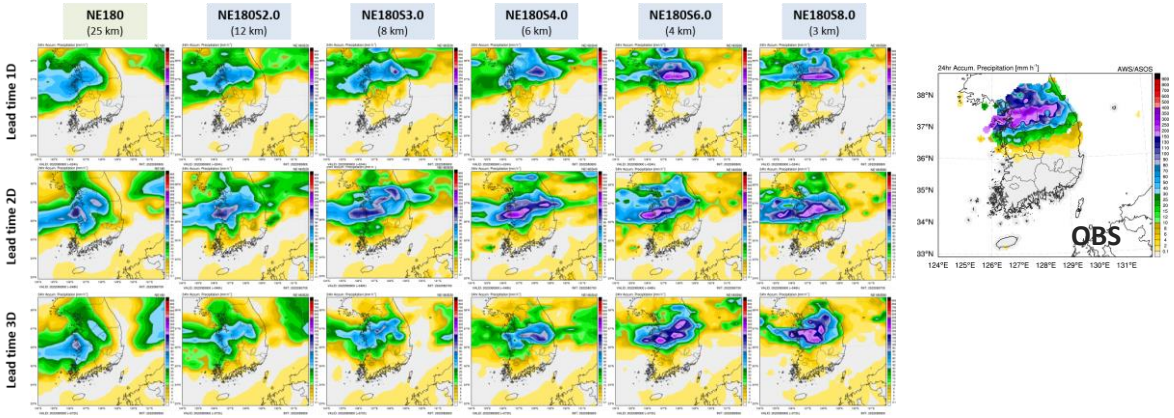


Face 1 (high-resolution domain) with S factor

Development of DyCore ➔ Idealized test ➔ Real case study with full physics ➔ Scale-aware physics



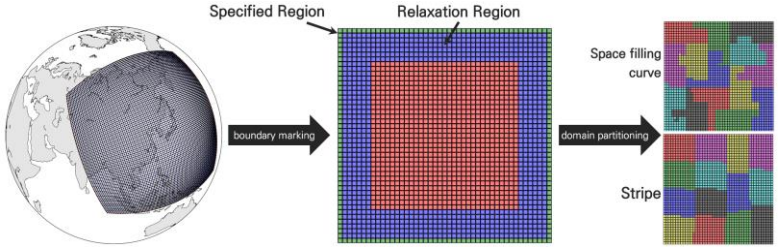
RMSE of T850 in the Korean domain (Jul 2022)



Heavy rain case simulation (24h prcp, 8 Aug 2022) with various S factor with the base grid NE180 (25 km)

One-way nesting Limited Area Model(LAM)

Key features & progress



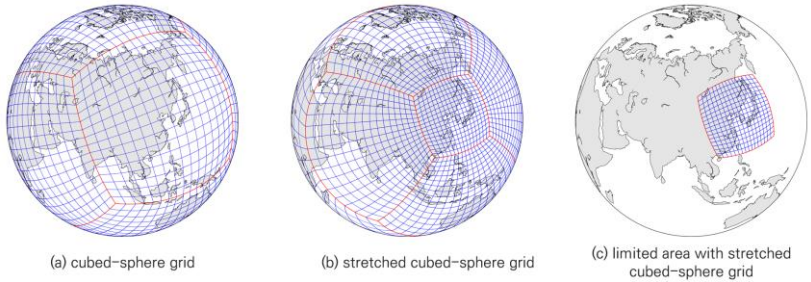
Boundary making and domain partioning in the KIM LAM

Creating limited area grids only on the first face in a cubed-sphere grid

The LAM domain adjusted by stretching the cubed-sphere

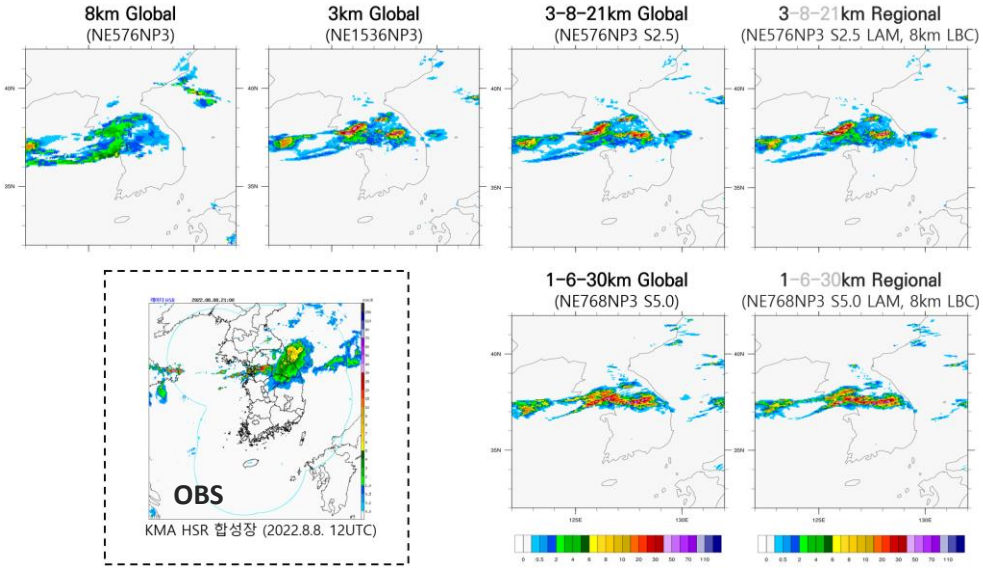
Progresses so far

- Generation of LAM grids, assignment of lateral boundary grids
- Domain partitioning, Differential operators
- Parallelization, and so on



(a) cubed−sphere grid (b) stretched cubed−sphere grid (c) limited area with stretched cubed−sphere grid

Visusalization of global regular, stretched- (variable resolution), and limited area model (LAM) on the cubed-sphere grid



Case simulation with various grid structures and resolutions for a heavy rain case on 8 Aug 2022. 1-h acumulated precipitation (+12h) in comparison with radar observation

Physics package

Key features in KIM physics package

Scale-aware physics processes

- Convection, gravity wave drag, subgrid-scale orography processes for variable-grid system

Considering complexity of topography and cloud

- Application of subgrid-scale topographic effect and revision in cloud overlapping

Consistency between physics processes

Physics schemes in KIM

Physics process	Scheme
Radiation (RAD)	RRTMK
Land surface (LAND)	Revised Noah LSM
Subgrid-scale orography (SSO)	
Planetary boundary layer (PBL)	Scale-aware YSU
Gravity wave drag (GWD)	Source-based spectral non-orographic GWD
Convection (CPS/SCV)	KSAS
Microphysics (MPS)	Revised WRF single-moment five-class microphysics scheme
Cloudiness (CLD)	Prognostic CLD

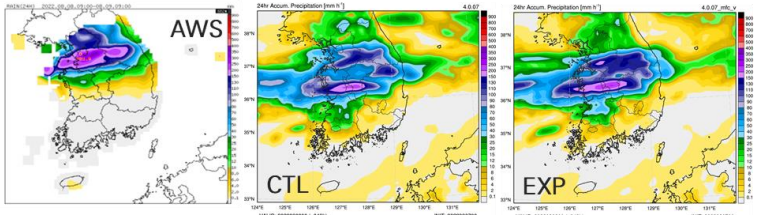
Major progress in 2024

Updated physics package PHYS24.01

- Development of diagnostic cloudiness scheme for consistency between hydrometeors and cloudiness (Park et al, in preparation)
- Improved global simulatoin with new surface processes especially with subgrid orography (Koo et al, under review in WF)
- Refinement in scale-awareness of physics

Revisions in scale-aware parameterization

- CPS considering different heavy rainfall mechanism over Korea
- Refinement of subgrid-scale orography statistics and turbulent orographic form drag
- Modification in reference-level frontal GWD momentum flux



Improvement in precipitation simulation over South Korea by applying a new method using column-integrated moisture flux convergence

Coupled model development

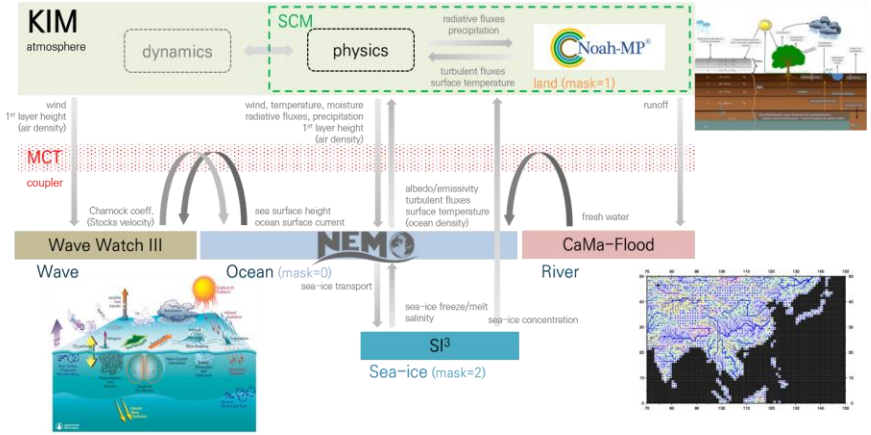
Key features in KIM coupled system

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)

Advanced interaction between components

- Physical consistency in parameterization, constant, etc.
- High computational/parallel efficiency



[KIM coupled system]

Major progress in 2024

Performance improvement

- Mitigated temperature bias over vegetation and snow
- Ocean vertical mixing w/ wave breaking and turbulence model

Optimization of computational efficiency

- New parallel I/O process in NEMO/SI^3
- Parallelization in CaMa-Flood and post-processing

Details in coupled model component and configuration

		Land			Ocean	Sea ice	Wave	River
Model		Noah-MP			NEMO	SI^3	WaveWatch III	CaMa-Flood
Version	current	4.0.1 (2021)	4.4 (2022)	5.0 (2023)	4.0 (4.2.2 in 2025)		7.13	4.0.0 (4.2 in 2025)
	origin	LIS	WRF	GitHub	-		-	-
	latest	5.0			4.2.2		7.14	4.2
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; fixed)		50 km (fixed)	25 km (fixed)

- continuous version upgrade along with in-house development

Data assimilation

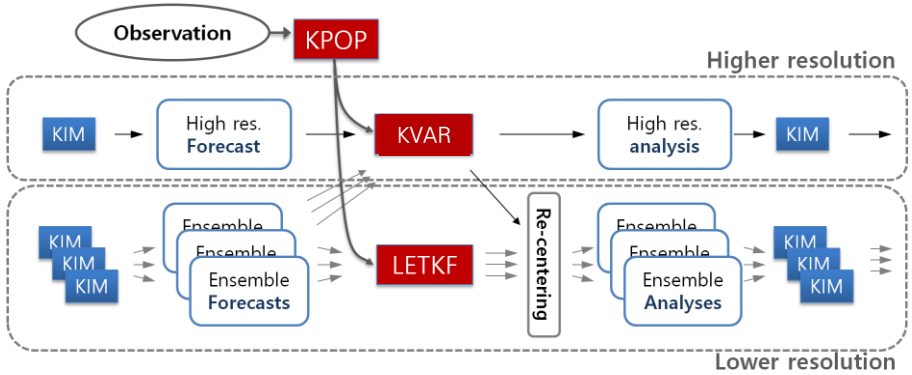
Hybrid-4DEnVar

Flow-dependent background error covariance

- Ensemble forecasts provided by LETKF-based EPS
- ~70 % ensemble background error covariance
- ~30 % static background error covariance

KIM Package for Observation Processing (KPOP)

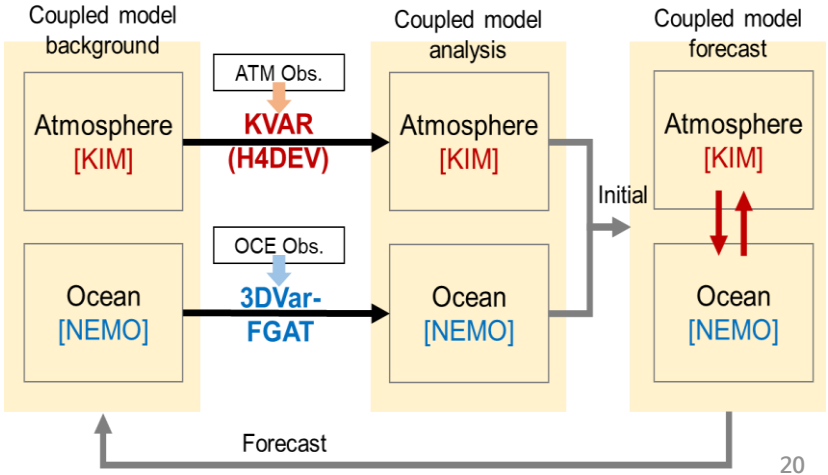
- Observation preprocessing for KVAR and LETKF



Atmosphere-ocean data assimilation

Weakly coupled data assimilation

- Ocean model: NEMO
- Ocean DA method: NEMOVAR
- KVAR and NEMOVAR use Coupled model background
- Atmosphere and Ocean DA with the same frequency (6 h)



Global Ensemble Prediction System

KIM Ensemble Prediction Systems

KIM global ensemble (10d) is already in operation ➔ Next-generation KIM EPS focusing extended-range prediction

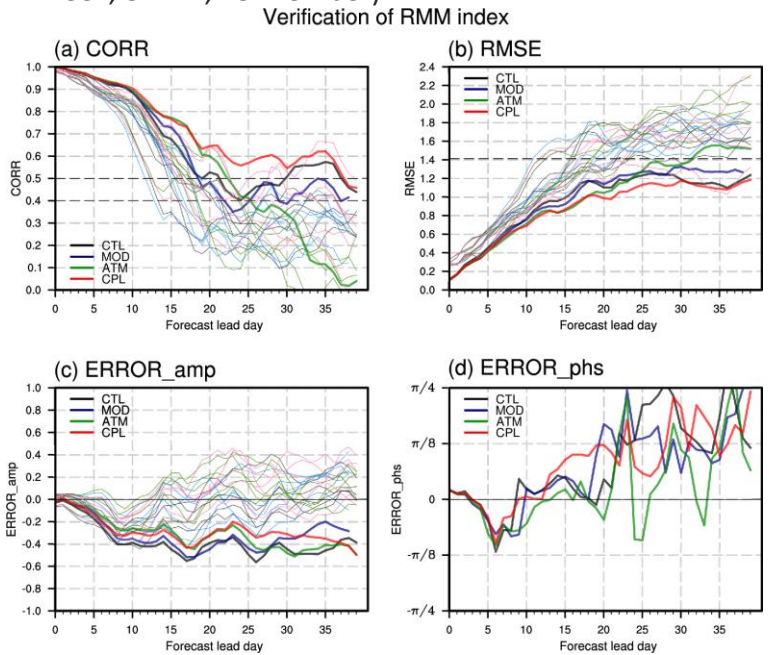
- Targeting medium-range (~2 week, 24 km, 50 member) & extended-range (~4 week, 32 km, 15 member)
- Couple model (atm/ocean/seaice/wave/land)
- Model uncertainty with currently SPPT, SPDT, SSST and developing SPP
- Considering consisteny of land initialization between forecast and hindcast

Progress in 2024

Beta version development of KIM EPS (atm-only)

Hindcast experiments with atm- and cpl- models and evaluation are ongoing

- low resolution (50 km) test
- reanalyses initials
- systematic bias and predictability drivers



MJO skill of uncoupled freerun (ATM) and prescribed SST (MOD), and coupled run (CPL). Initialized on Nov. 1 for 2010-2020.

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Thank you