Workshop on Land Surface Modeling in Support of NWP and Sub-Seasonal Climate Prediction
George Mason University, Fairfax, VA, USA, 5-6 December, 2013

KIAPS
KOREA INSTITUTE OF
ATMOSPHERIC PREDICTION SYSTEMS

Development of Global NWP Model: KIAPS-GM

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www.kiaps.org

Vision and Goals of KIAPS

About $10 million funding per year
58 human resources + advisory group

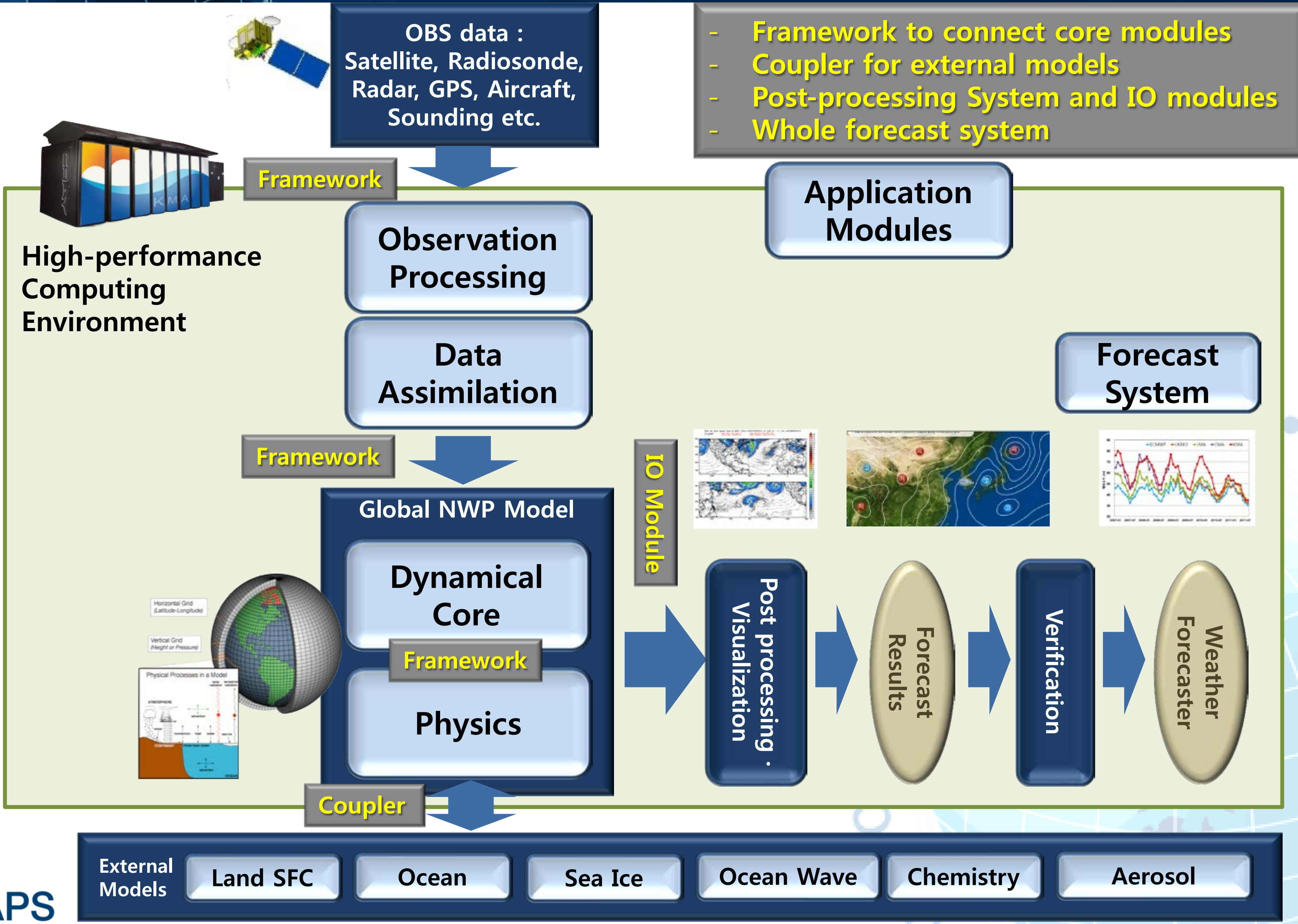
To Develop Global NWP System Optimized Performance on Korean Peninsula & East Asia	To Build Science & Technology Capacity That Stimulates the NWP Research Fields	To Reduce the Economic Loss Caused by Natural Disasters and Enhance Productivity of Industrial Sector

To Achieve World-Class Status of NWP Technology by Year 2020

To Join the Meteorologically Advanced Nations
Through the development of KIAPS Global NWP System

Contents

Modules of KIAPS Global NWP System



KIAPS

9-Year 3-Stage Project Plan

Stage 1

Establishment of the Foundation & Development of Core Modules

- To set up an R&D center and hire work force
- To design the basic structure of the KIAPS-GM
- To build an initial version of KIAPS-GM and validation system

2011-2013

Stage 2

Developing Test Model

- To develop the modules for dynamical core, physical parameterization, and data assimilation
- To develop the KIAPS-GM Ver. 0.9
- To evaluate the KIAPS-GM Ver. 0.9 against the KMA operational model

2014-2016

Stage 3

Developing Operational Model

- To develop and finalize the KIAPS-GM Ver. 1.0 for operational use
- To develop the KIAPS-GM post processing system

2017-2019

Roadmap of KIAPS-GM Development

2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019

System Development
- Design and Development of Framework and Coupler
- I/O, Parallelization, and Post-processing
- KIAPS-GM System (v0.9)
- Optimization (Serial, Parallel, I/O) and User Interface
- Opera -tional System

→ **Operation**

Validation
- Initial Version of Model Physics and Validation System
- Sensitivity Tests, Improvements
- Validation

Physics
- Design
- Radiation, PBL, Cloud, Convection, Land-surface, GWD
- Vegetation Chemistry
- Ocean Sea ice Wave
- Optimiza -tion

Validation / Physics (continued)
- Sensitivity to Resolution, Case Studies, Refinements, Upgrades
- Sensitivity to Time -scale

→ **Predictability**

Dynamical Core
- Design
- Shallow-water Model
- Hydrostatic Core
- Improve -ment
- Low Resolu -tion
- Nonhydrostatic Core
- Improve -ment
- Complex topogra -phy
- High Resolu -tion
- Optimiza -tion

→ **KIAPS-GM**

Observation Processing Data Assimilation
- Design
- Initial Version of Var./Ens. DAs
- 4D Var./Ens. DA
- Initial Version of Ens-3D Var. DA
- 4D Var./Ens. DA and Optimization
- Processing System for Principal Observations
- Initial Version of Observation Processing System
- Operational Observation Processing System and Optimization

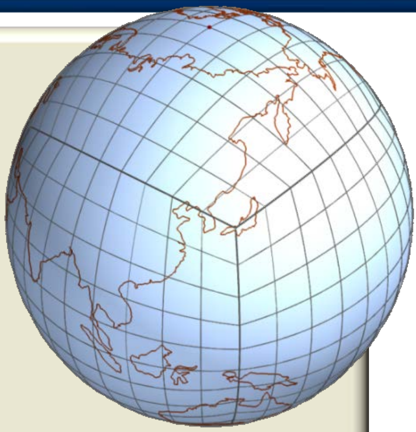
→ **Data Assimilation System**

Core modules | Test Model (~25 Km) | Operational Model (~10 Km)

KIAPS

Development of KIAPS-GM

Configuration of KIAPS-GM



KIAPS-GM v0.09

- KIAPS-GM Framework
- Global 3-D hydrostatic dynamical core based on HOMME
  - Spectral element horizontal discretization
  - Cubed sphere horizontal grid of ne30np4 (1^oX1^o)
  - 70 vertical levels (upto 0.003 hPa, 80 Km)
  - Hybrid sigma vertical coordinate
  - Lorenz grid, finite different vertical discretization
- Physical Parameterizations

Cumulus	Mass flux scheme based on Simplified Arakawa-Schubert (Pan and Wu 1994) deep convection and Han and Pan (2011) shallow convection	OGWD	Linear mountain gravity wave scheme (McFarlane,1987)
		NOGWD	Lindzen-type spectral scheme (Linzen, 1981; Molod et al. 2012)
Macro-cloud	Diagnostic liquid cloud fraction and ice cloud fraction (Wilson and Gregory, 2003; Wilson and Ballard, 1999)	PBL	Non-local 1st order K closure scheme (Troen and Mahrt, 1986; Hong and Pan, 1996; Han and pan, 2011)
Micro-Physics	WRF Single Moment 6-class scheme (Hong & Lim, 2006)	Surface Layer	Scheme based on Monin-Obuhkov similarity theory (Long, 1985;1986)
Radiation	RRTMG (Iacono et al., 2008) with Ferrier's cloud optical properties scheme	Land Surface	Non-local 1st order K closure scheme (Troen and Mahrt, 1986; Hong and Pan, 1996; Han and pan, 2011)

- MCT coupler: external modules will be coupled using MCT coupler and will interact with surface layer scheme as an optional component.

Physical Parameterizations for KIAPS Global Model (KIAPS-PPACK)

Selection of Physics Schemes

- Strategy
  - use of existing schemes as original modules to elevate efficiency
  - select schemes → make as offline modules → rewrite/refine (codes, ancillary/input data) → combine as a physics package

- Based on the comprehensive analysis of global NWP models and climate models, we can find common features of technology trends of physical parameterization schemes of world's leading operational models.

- Other issues such as coupling facilities (easy to modularize, intuitive to understand/modify), computational efficiency, open source (license free), are also considered.

- Finally, the initial version of physics package for KIAPS-GM (KIAPS-PPACK) has been designed/developed.

Selection of Physics Schemes

Process	Scheme
Radiation	**RRTMG** (Iacono et al., 2008) with Ferrier's cloud optical properties scheme
Cumulus convection	**Mass flux scheme** based on Simplified Arakawa-Schubert (Pan and Wu 1994) deep convection and Han and Pan (2011) shallow convection
Macrocloud	**Diagnostic liquid/ice cloud fraction** (Wilson and Gregory, 2003)
Microphysics	**WRF Single Moment 6-class scheme** (WSM6, Hong & Lim, 2006)
OGWD	**Linear mountain gravity wave drag scheme** (McFarlane,1987)
NOGWD	**Lindzen-type spectral scheme** (Linzen, 1981; Molod et al. 2012)
Land surface	**Noah model** (Ek et al., 2003)
Surface layer	Scheme based on **Monin-Obuhkov similarity theory** (Long, 1986)
PBL	**Non-local 1st order K closure scheme** (Troen and Mahrt, 1986; Hong and Pan, 1996; Han and pan, 2011)

Rewriting and Refining Physics Schemes

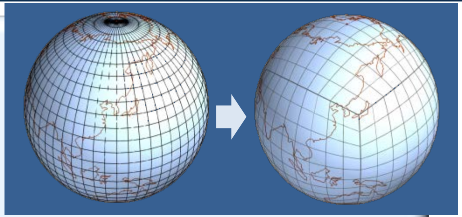
- **Following the KIAPS fortran coding standard**
  - Fortran 90
  - Use of KIAPS kinds module
  - Modularization

- **Standardization of codes**
  - Standard variable names
  - Common constants, functions and modules
  - Identical dimensions
  - Sort out necessary/unnecessary variables
  - Use of tendency as output variables

- **Vertical/Horizontal resolution**
  - **cubed-sphere grid of ne30np4 resolution (1ºX1º)**
    : 2-dimension (nx, ny) to 1-dimension (n column)
  - **70 vertical levels, hybrid sigma coordinate**
  - **Lorenz grid**
  - **bottom to top vertical index**

→ **Modifying as offline modules of each physics process including radiation, land surface, surface layer, pbl, cumulus convection, macrocloud, microphysics, ogwd, nogwd**

Redefinition of Ancillary Data



- **Ancillary and input data**
  - – land-sea-ice mask, surface albedo
  - – vegetation type, soil type, secondary & general parameters of LSM
  - – topography, slope type

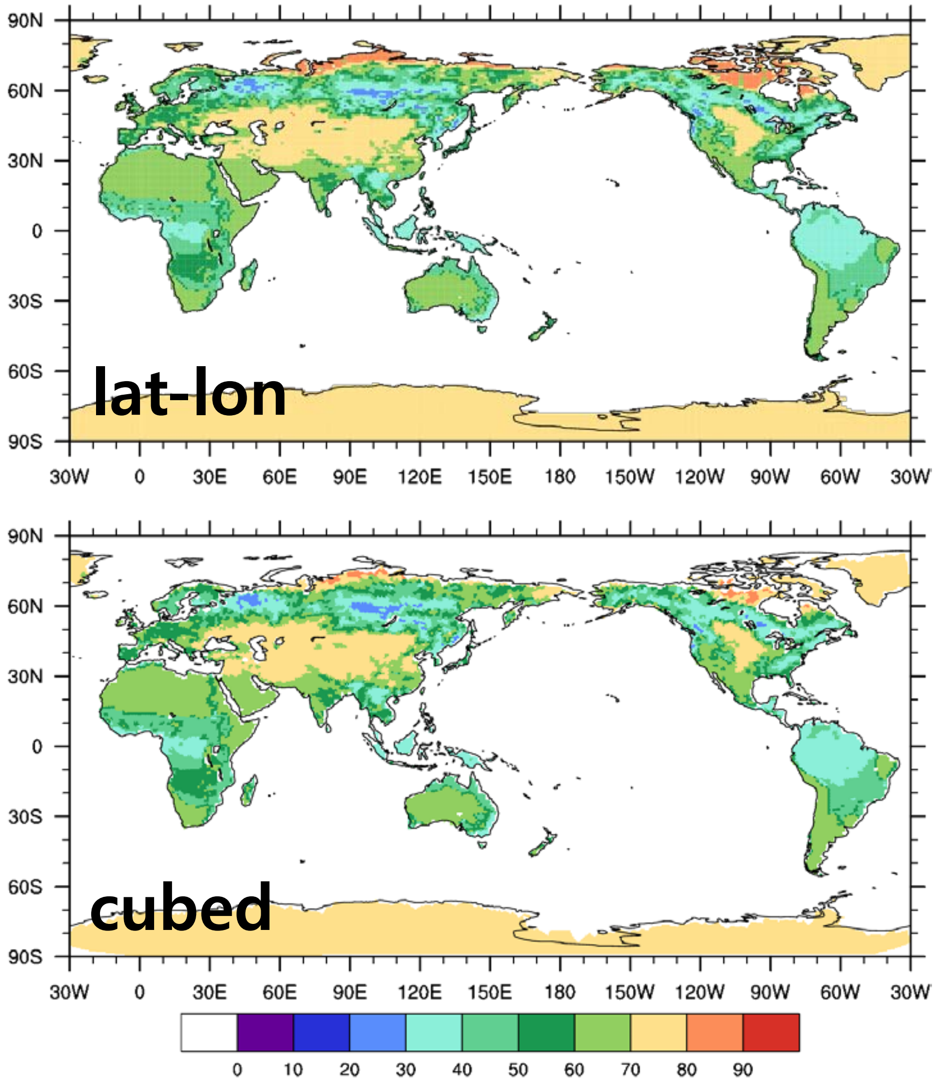
→ Because the KIAPSGM is developed based on the cubed sphere, the ancillary data on lat-lon grid should be re-defined on the cubed sphere using the **SCRIP conservative remapping method** for most of parameters and **maximum weighting method** for the index type parameters (i.e., vegetation and soil type, land-sea mask, land fraction).

- Detailed information on 2D parameters of Noah LSM

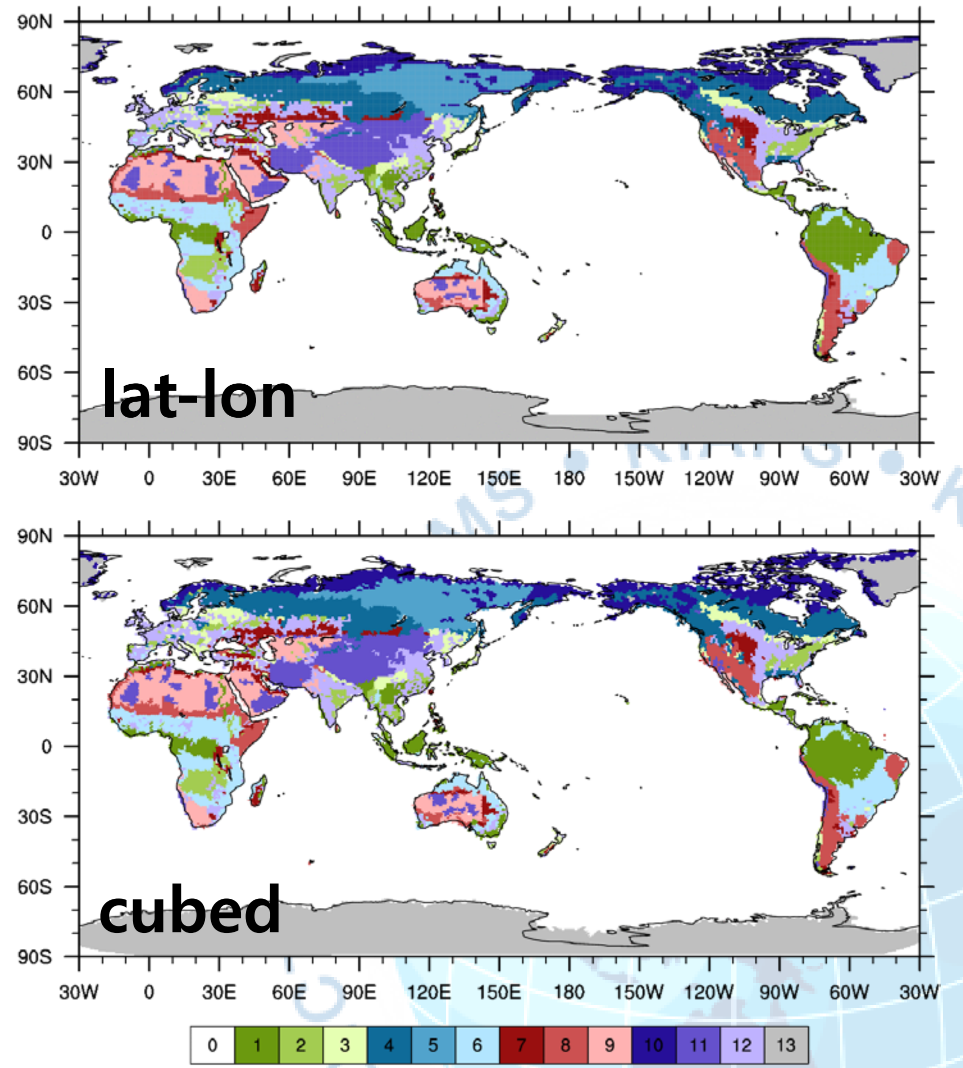
Variable	Unit	Resolution	Source	Reference
Vegetation type	index	1°x1°	SiB 13-type (GFS) Kuchler 32-vtype (1983), Matthew land-use (1984,1985)	Dorman and Sellers (1989)
Soil type	index	1°x1°	SiB 9-type (GFS) FAO soil map (1974), Matthew veg (1983,1984)	Staub and Rosenzweig (1987)
Slope type	index	1°x1°	islope (GFS)	Zobler (1986)
Deep soil temp	K	1°x1°	GRIMs ancillary data	Hong et al. (2013)
Green veg. fraction	%	0.144°x0.144° monthly	NOAA/AVHRR NDVI 5-yr clim. data (1985-1987, 1989-1991) (GFS)	Gutman and Ignatov (1977)
Min. green veg. fraction	%	0.144°x0.144° monthly	NOAA/AVHRR NDVI 5-yr clim. data (1985-1987, 1989-1991) (GFS)	Gutman and Ignatov (1977)
Max. snow albedo	%	1°x1°	Defense Meteorological Satellite program winter of 1978-1979 (GFS)	Robinson and Kukla (1985)
Albedo	%	0.144°x0.144° monthly	NOAA/AVHRR Green Vegetation Index (1985-1989)	Csiszar and Gutman (1999)

Redefinition of Ancillary Data

Maximum snow albedo (%)

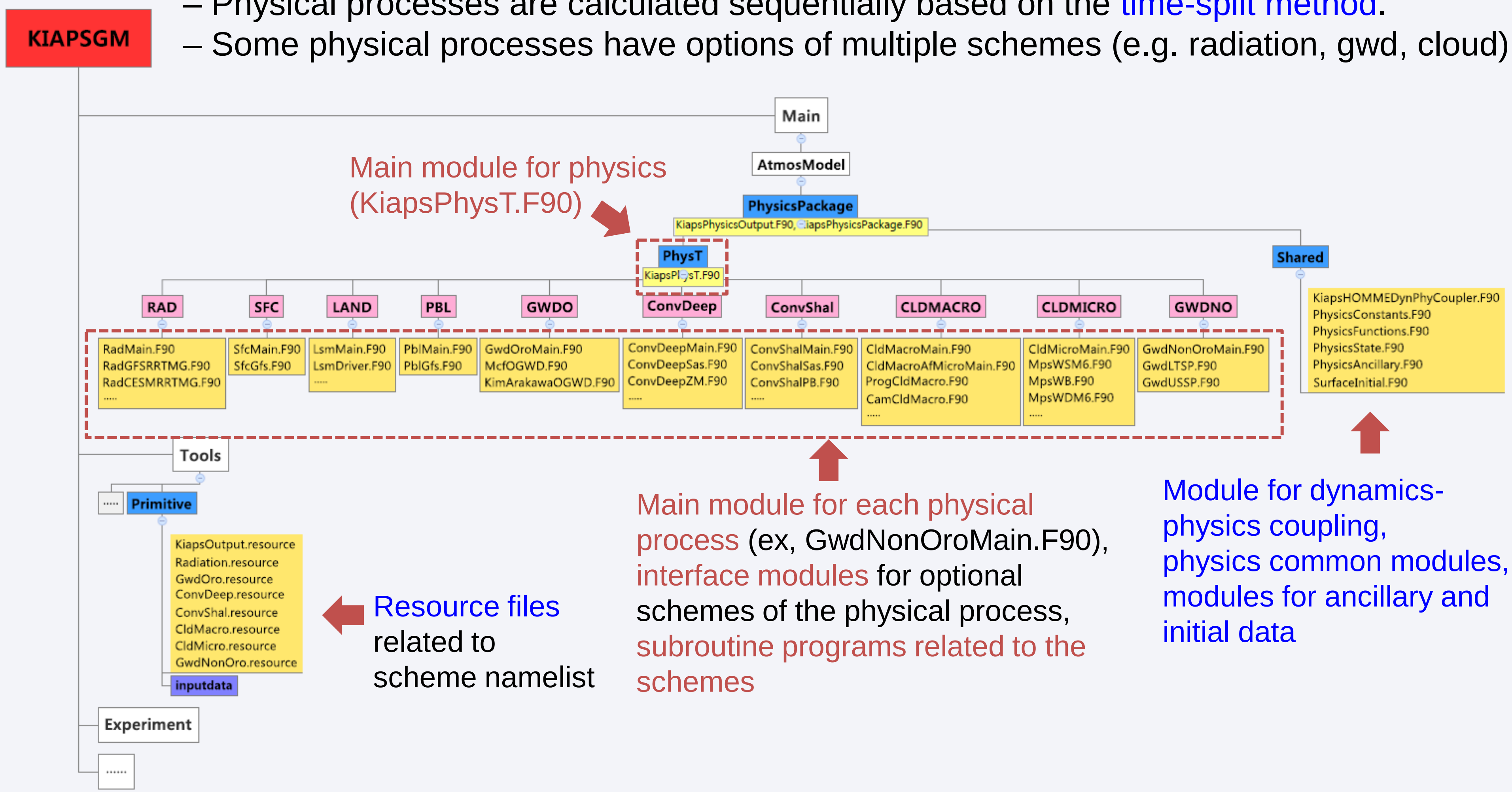


Vegetation type (Index)

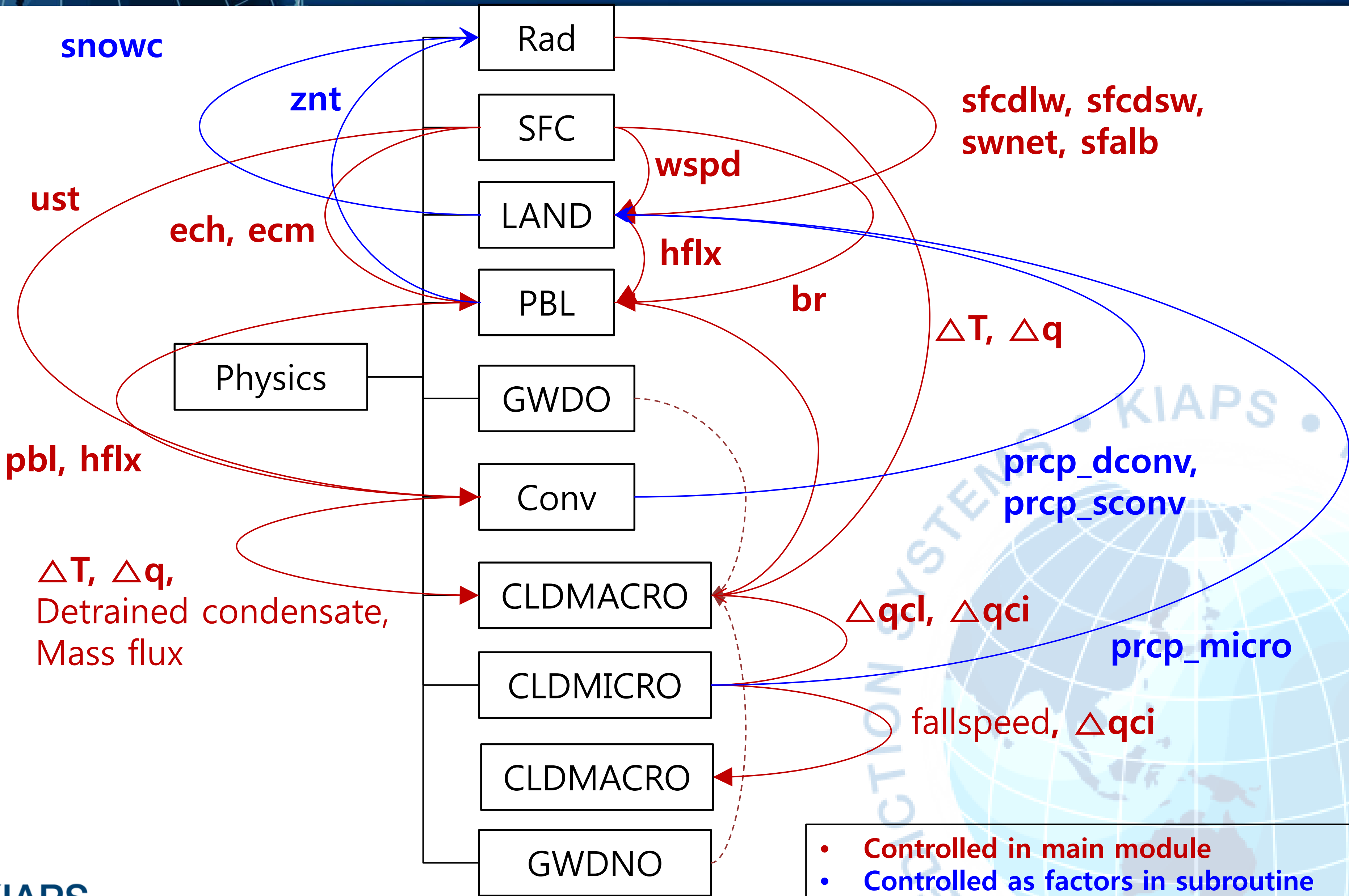


Structure of KIAPS-PPACK

- KIAPS-PPACK (KAIPS Physics Package):
  - Physical processes including radiation, surface layer, land surface, boundary layer, orographic gravity wave drag, cumulus convection, macrocloud, microphysics, nonorographic gravity wave drag
  - Physical processes are calculated sequentially based on the time-split method.
  - Some physical processes have options of multiple schemes (e.g. radiation, gwd, cloud)



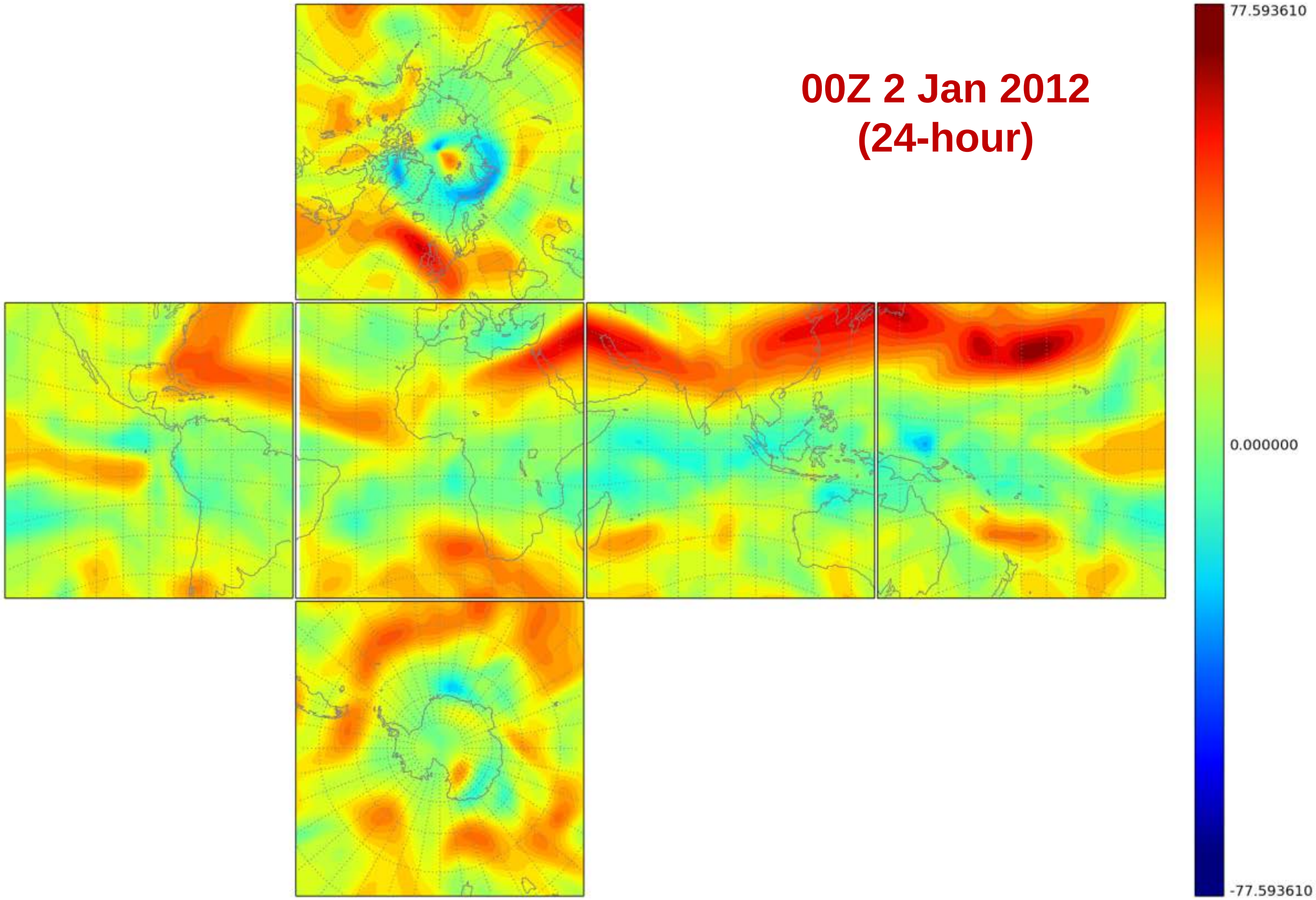
Interaction among Physics



Preliminary Results of KIAPS-GM

- Model version : KIAPS-GM v0.09 (ne30np4 (1°X1°) 70L(upto 0.003 hPa)
- ATM IC : 00Z 01~04Jan2012 ERA-Interim (**4 members**)
- Surface Initial : 00Z 01Jan2012 ERA40
- BC : 1983-2012 Climatological HadISST and Sea-ice (monthly)

☐ **200 hPa zonal wind**



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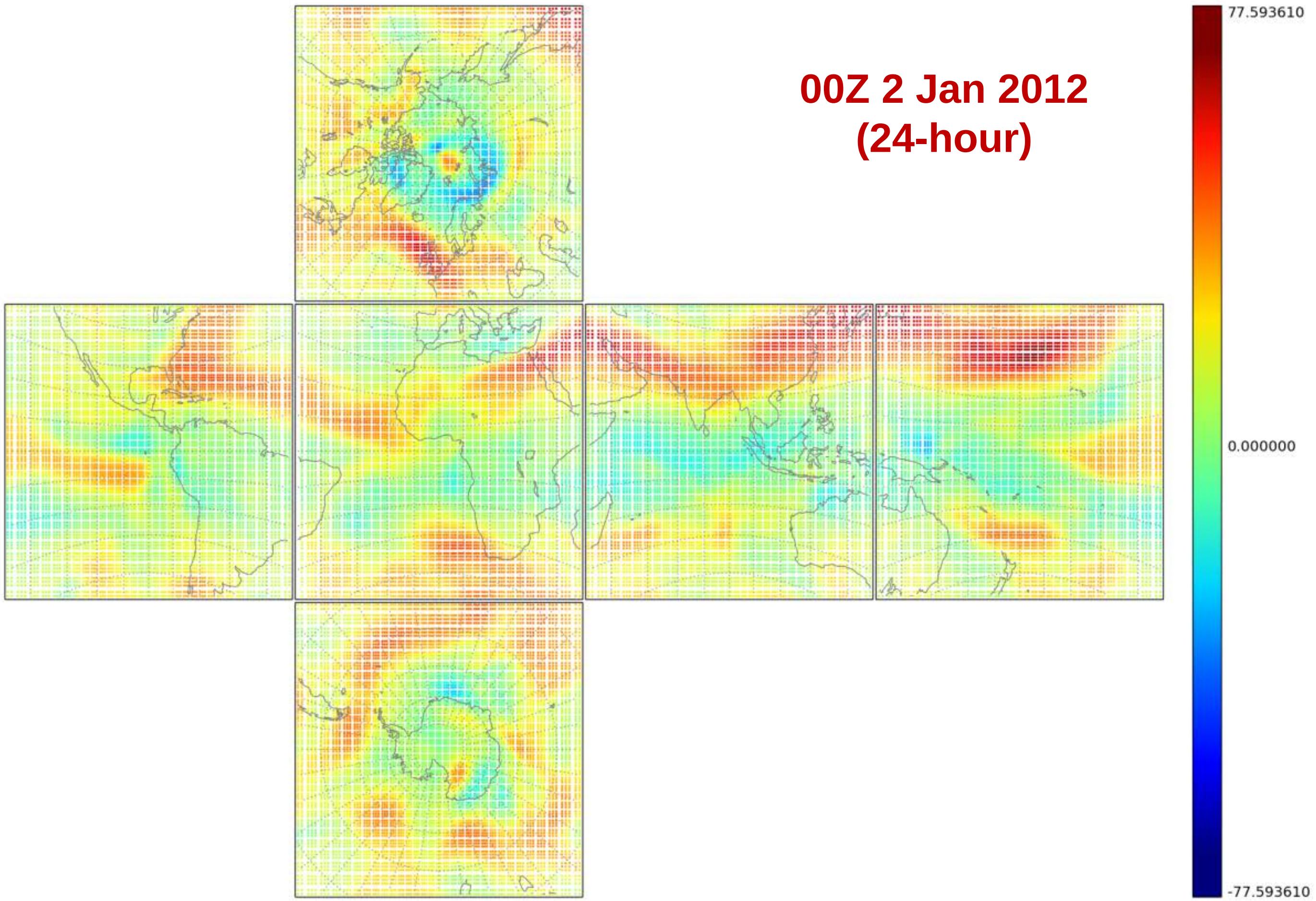

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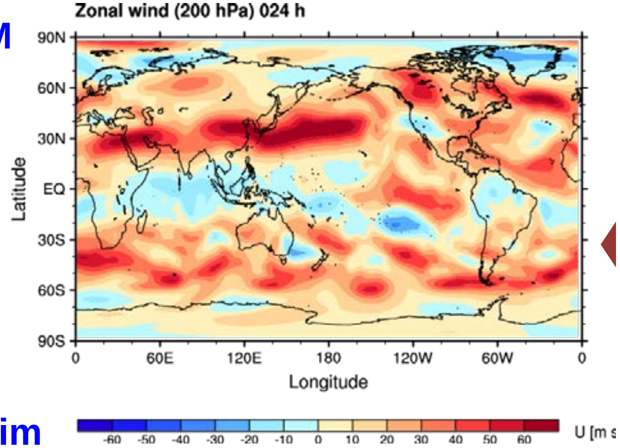
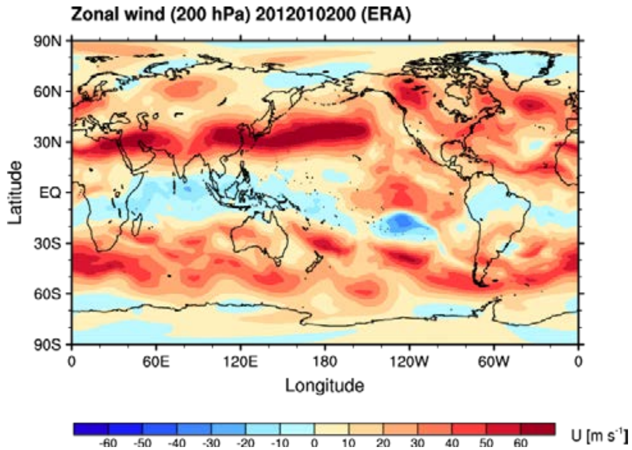
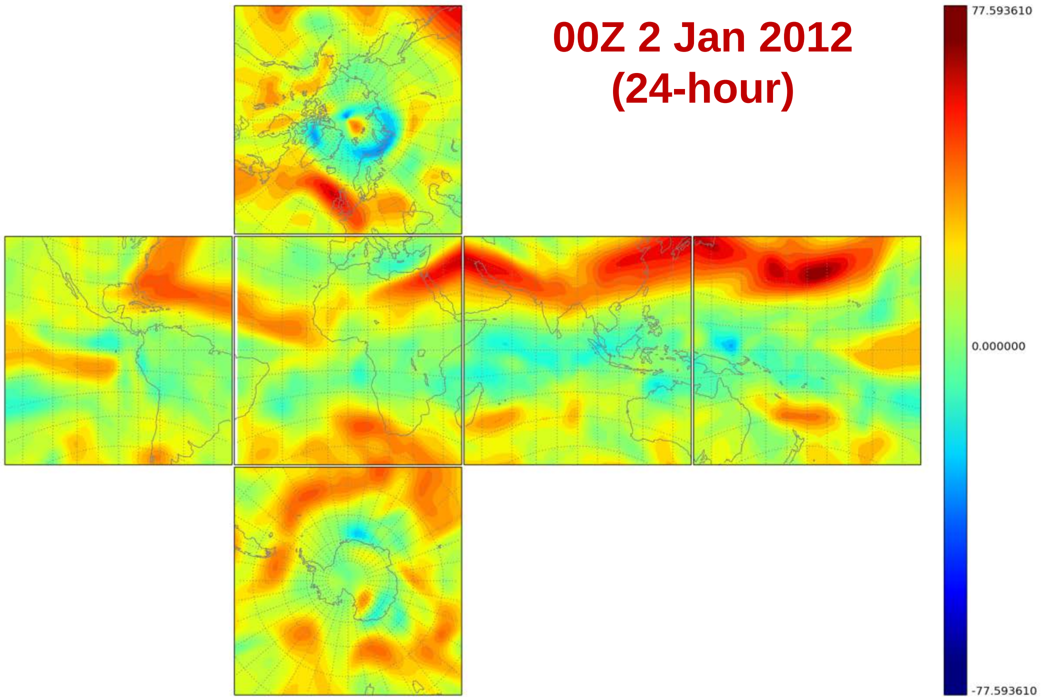
KIAPS-GM



ERA-Interim



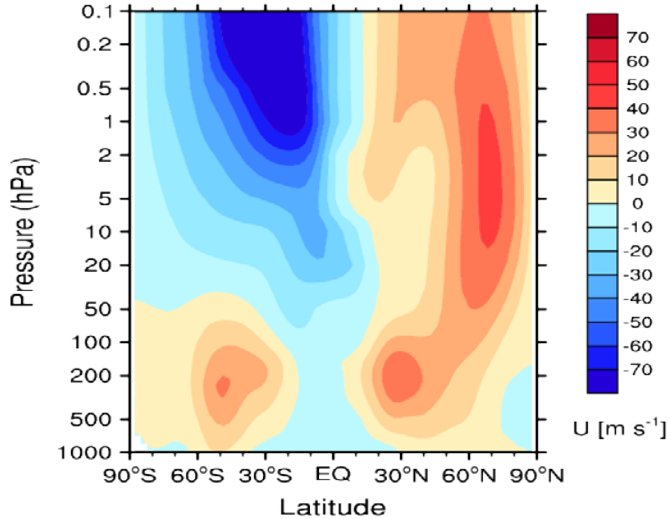


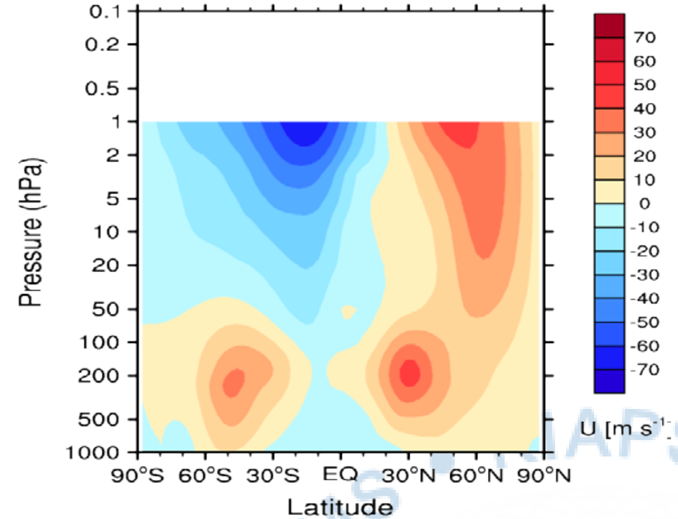
Preliminary Results of KIAPS-GM

January

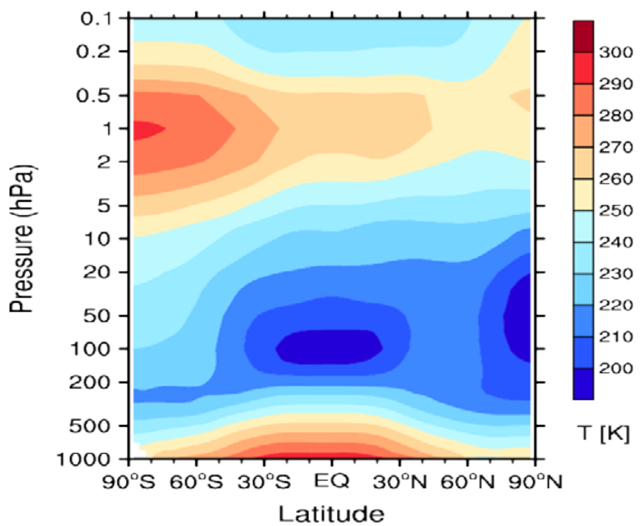
	KIAPS-GM (ensemble man)	ERA-Interim (1982-2011)

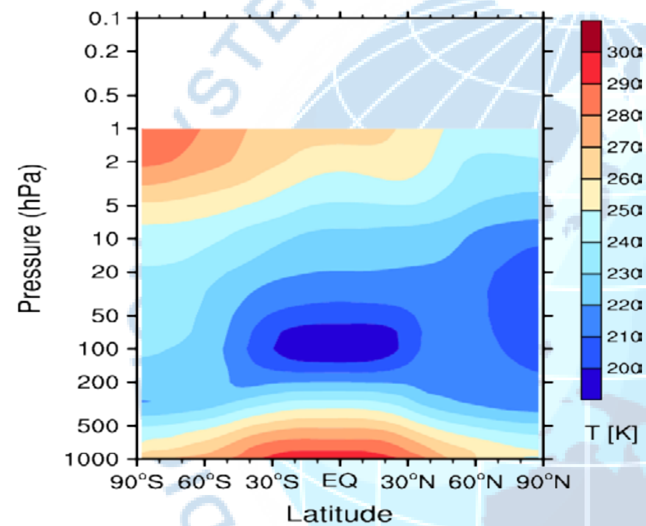
☐ Zonal mean zonal wind





☐ Zonal mean temperature

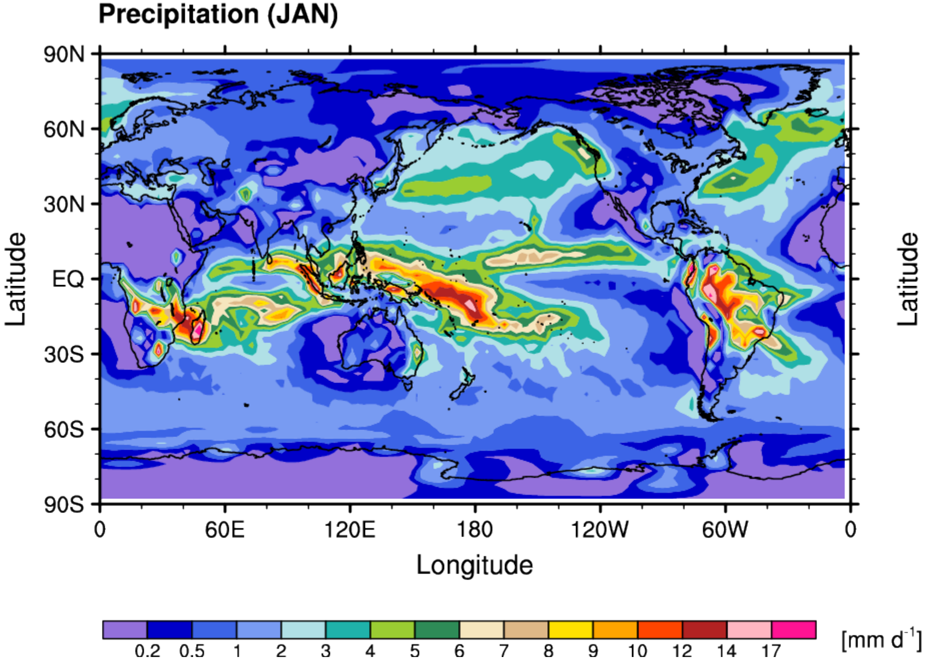




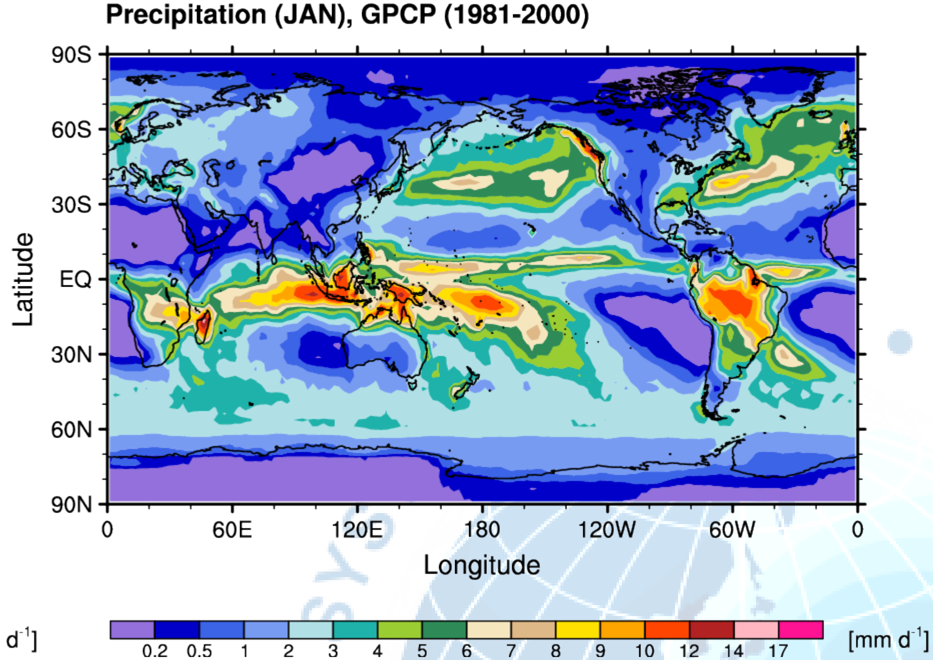
Preliminary Results of KIAPS-GM

January Precipitation

KIAPS-GM (ensemble mean)



GPCP (1981-2000)

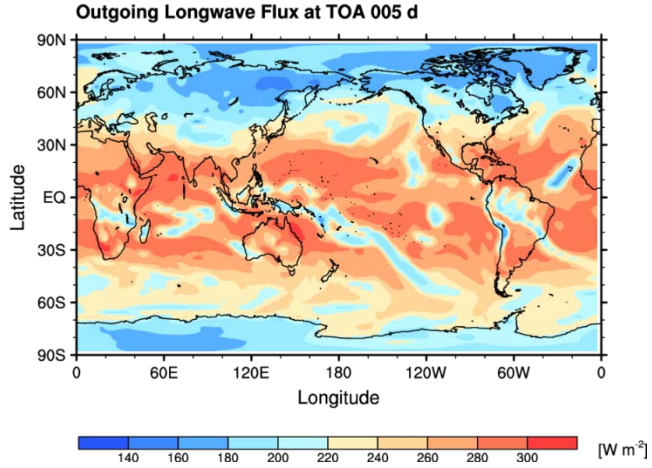


Preliminary Results of KIAPS-GM

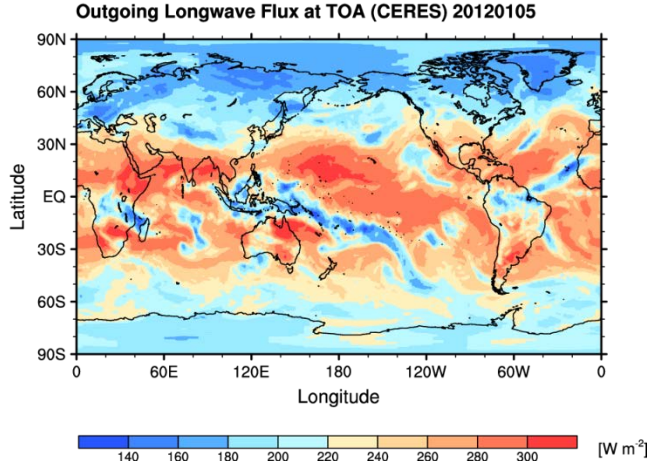
January OLR

☐ **OLR at TOA**

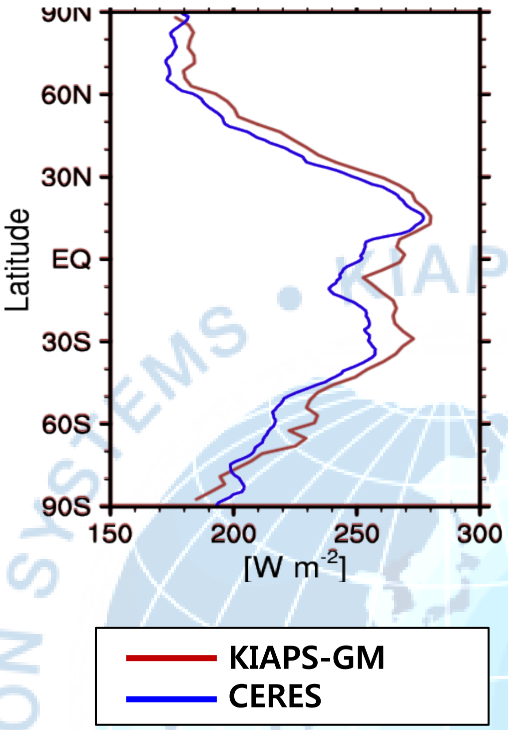
KIAPS-GM



CERES



Zonal mean

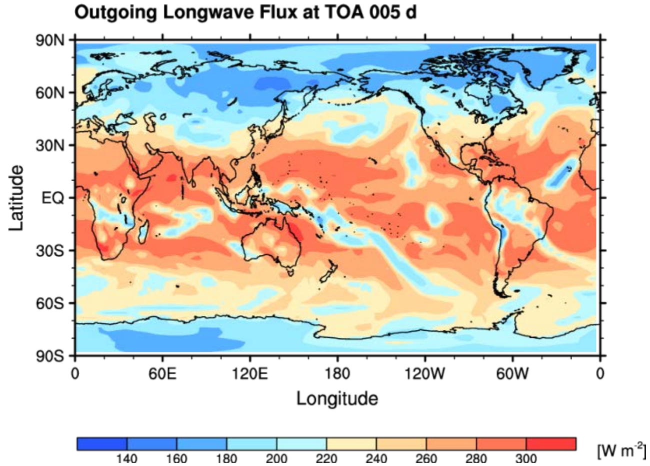


Preliminary Results of KIAPS-GM

January OLR

☐ **OLR at TOA**

KIAPS-GM



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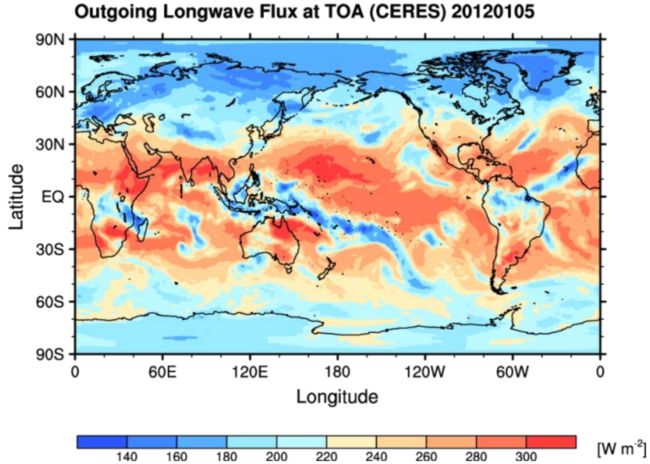
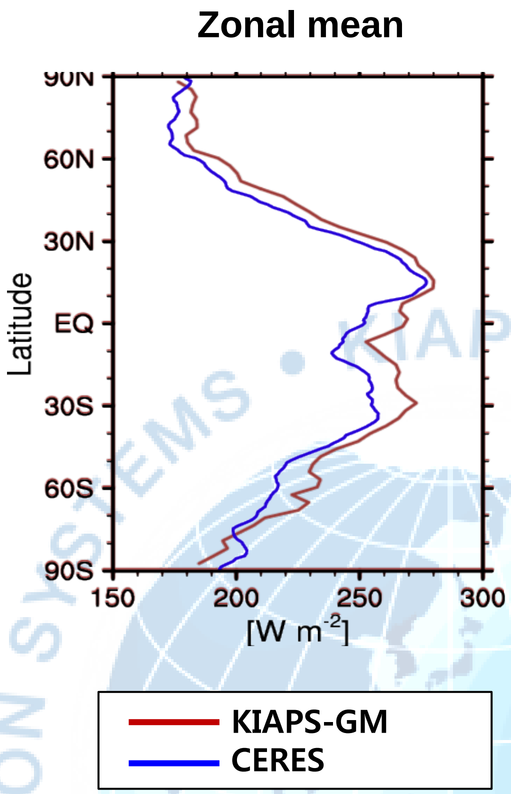




After identifying errors and defects of KIAPS-GM, we are in the process of debugging our physics codes.

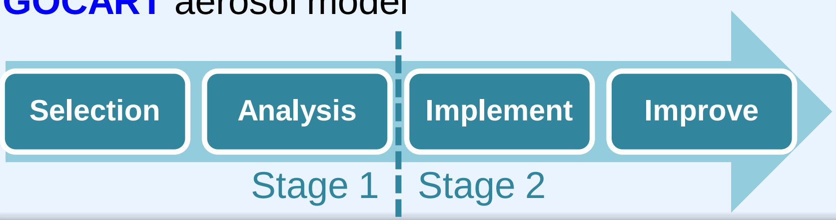
Atmospheric Composition and Ocean Forecasting

- **To enhance the forecast skill and expand the scope of our prediction system**

Aerosol model

- Purpose: to predict tropospheric aerosols to modify atmospheric radiation budget and cloud properties in model physics
- Selection: bulk scheme is more preferable for NWP rather than modal/sectional approaches.

: **GOCART** aerosol model



Ocean wave model

- Purpose: to predict ocean waves to improve the description of the atmospheric boundary layer (via **surface roughness length** over ocean)

$z_{0m} \Leftarrow$ *Not coupled wave model*		$z_{0m} = f(H_s, L_p, T_p) \Leftarrow$ *Wave Model*	
$z_0 = \alpha_C \frac{u_*^2}{g}$ (*Constant*)	Charnock (1995)	Taylor and Yelland (2001)	$\frac{z_0}{H_s} = 1200 \left(\frac{H_s}{L_p}\right)^{4.5}$
$z_0 = 0.032 \frac{u_*^2}{g} + 0.0001$	in YSU PBL scheme	Oost et al. (2002)	$\frac{z_0}{L_p} = \frac{50}{2\pi} \left(\frac{u_*}{c_p}\right)^{4.5}$
$z_0 = 0.018 \frac{u_*^2}{g} + 0.0000159$	in MYJ PBL scheme	Drennan et al. (2005)	$\frac{z_0}{H_s} = 3.35 \left(\frac{u_*}{c_p}\right)^{3.4}$
		...	
		...	

- Strategy: coupling **wavewatch III** with atmospheric model using MCT (different horizontal resolutions)

Chemistry model

- Purpose: mainly to predict **stratospheric ozone**
- Design/selection

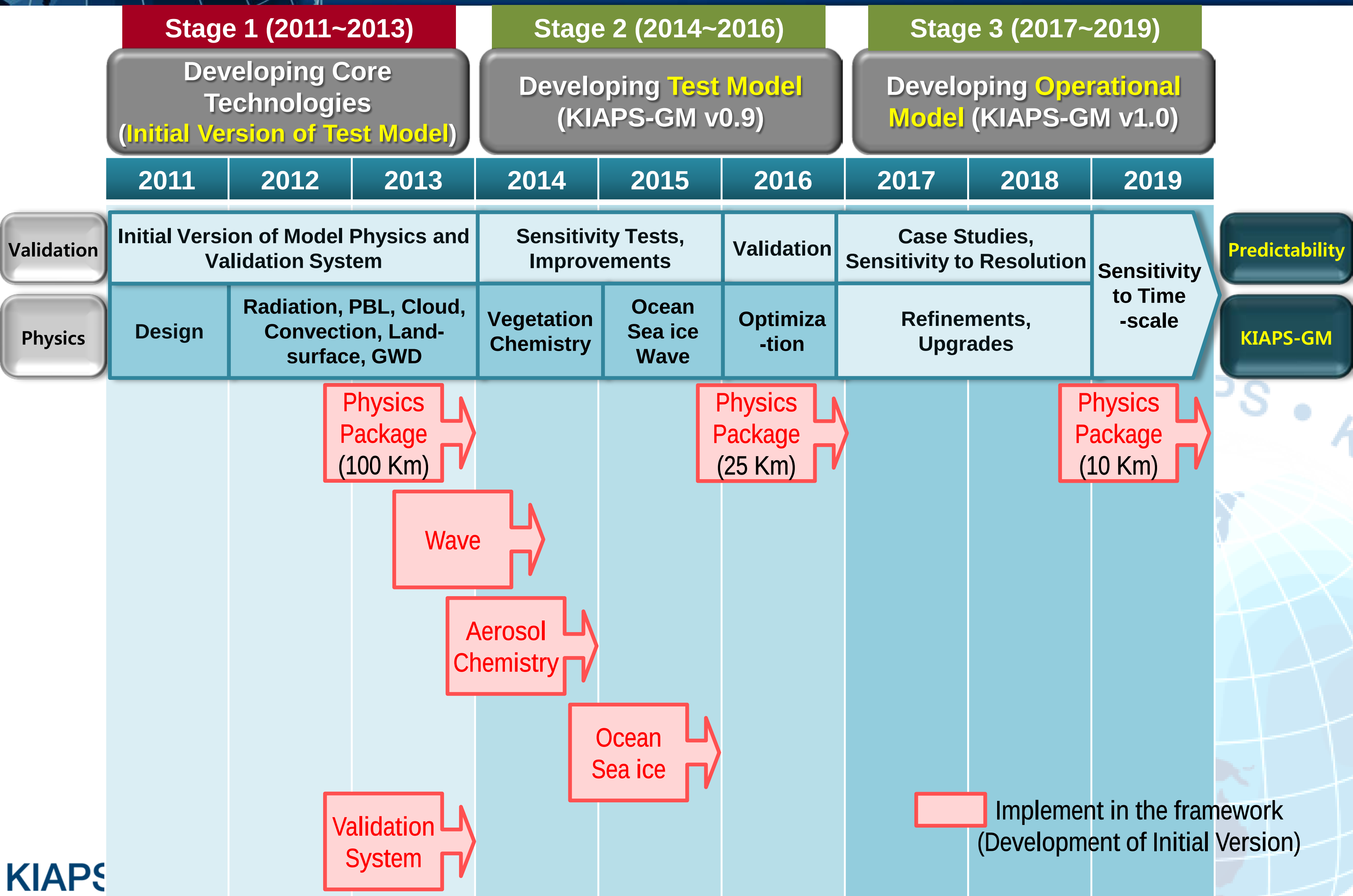
Stratosphere Photochem	General description	2D CTM (stratosphere) + 3D CTM	Ozone climatology/DA
Cariolle&Teyssedre (2007) LINOS v2 (Hsu & Prather, 2009)	Linear + chem_het	MOZART3 + MOZART4 + REAM	• SPARC • ERA-40 reanalysis • Li&Shine (1995)

- To develop offline 2D CTM and linearized scheme with collaboration of other centers
- To produce ozone climatology and assimilation

Ocean/Sea ice/Wave model

- Purpose: to predict ocean states to improve the short-term predictability of extreme events, to provide short and medium range forecasts
- Strategy: globally and regionally two-way coupled atmosphere-wave-sea ice-ocean system using coupler (to support various resolutions)
- Initializing ocean should be considered: downloading real-time ocean initial conditions, or developing coupled initialization system (or ocean data assimilation system)

9-year Roadmap for Physics/Validation



KIAPS

KIAPS-GM Verification & Validation System (KIAPS-GMVV)

- **Purpose**
  - **To provide the scientific basis of decision-making to develop the KIAPS GM (Stage 1~3)**
  - **To define national challenges for the scientific decision-making (Stage 2~3)**
  - **To monitor the forecast skill and to research the predictability (Stage 2~3)**
- **In 2013:**
  - **Initial version of KIAPS-GMVV consists of 4 systems and database.**

System 1

- Web-based model validation system for model developer to analyze short-term forecast data (6/12-hr interval)
- Reference: NCEP/EMC system

System 2

- Text-based model validation system to analyze short-term forecast data (6/12-hr interval)
- Reference: WMO/GDPFS (KMA) standard metrics

Database

- **Global observations** (AIRS, CALIPSO, CERES, MODIS, CAMP, CMORPH, CRU, TRMM)
- **Reanalysis** (ERA-Interim, MERRA)
- **Local observations** (APHRODITE, ASOS)
- **Model forecasts** (UM, GFS)
- **Field campaign dataset** (e.g. ARM TWP-ICE, SGP2000, DYCOMS, YOTC, DYNAMO, BASE, GABLS)

System 3

- To verify model across timescales, but with focus on NWP, it consists of various climate indices with graphics to analyze long simulations

System 4

- To improve physics modules, and to provide validation routines to implement improved physics modules in the KIAPS-GM, it consists of CRMs, LES models, SCM and field campaign data.

KIAPS-GM Verification & Validation System (KIAPS-GMVV)

- **Purpose**
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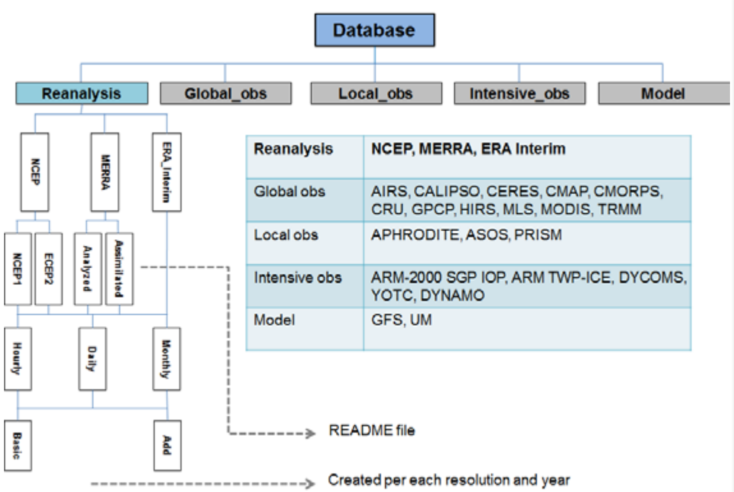
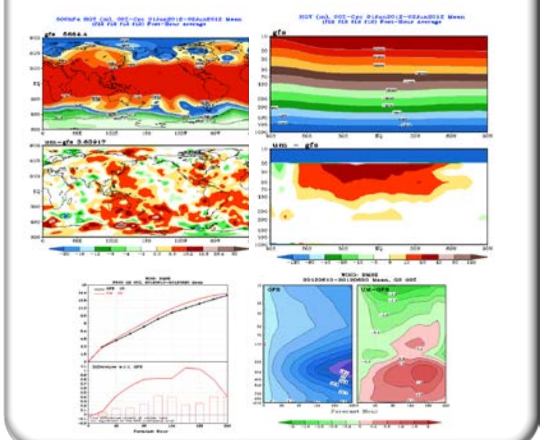
Database



Reanalysis	NCEP, MERRA, ERA Interim
Global obs	AIRS, CALIPSO, CERES, CMAP, CMORPS, CRU, GPCP, HIRS, MLS, MODIS, TRMM
Local obs	APHRODITE, ASOS, PRISM
Intensive obs	ARM-2000 SGP IOP, ARM TWP-ICE, DYCOMS, YOTC, DYNAMO
Model	GFS, UM

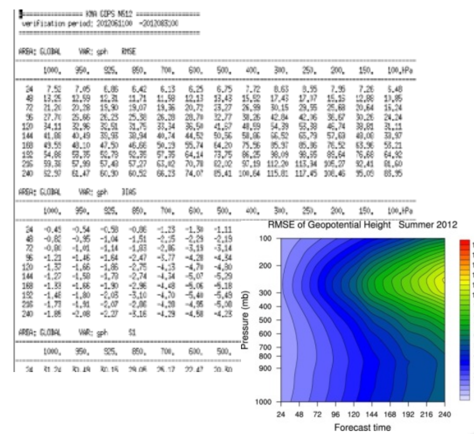
System 1

- Results: UM vs. GFS



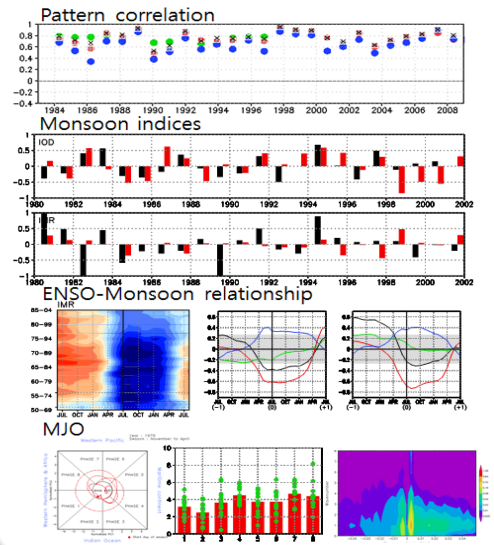
System 2

- Results: UM forecasts



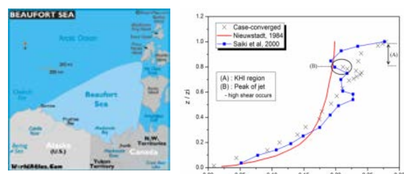
System 3

- Results: observation and models

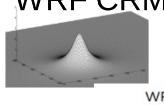


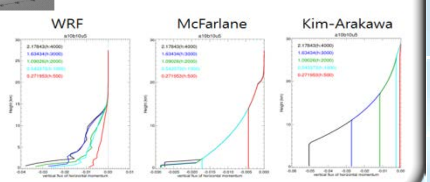
System 4

- Production of reference data using PALM LES model



- Validation of ogwd schemes using WRF CRM





Summary

- **The initial version of KIAPS-GM, new global NWP model, has been developed.**
- **KIAPS-PPACK**, which consists of 9 physical processes including radiation, surface layer, land-surface, boundary layer, cumulus convection, macrocloud, microphysics, orographic gravity wave drag, and nonorographic gravity wave drag parameterization scheme, **has been developed.**
- Verified schemes for operational NWP forecasts were selected.
- All codes were rewritten and refined to be implemented in the KIAPS-GM framework. Standardization of codes and modularization of each physical process were done and eventually KIAPS-PPACK became a flexible system to change/add.
- All ancillary data were converted to the cubed sphere grid.
  - We are in the process of debugging (KIAPS-GM v0.09).
- **The initial version of KIAPS-GMVV**, which consists of four systems and database, **has been developed.** It can produce conventional metrics for operational NWP forecasts.
- All systems are easy to operate (run one script) and it can provide useful information for model developers.
  - KIAPS-GM results will be validated based on KIAPS-GMVV.
  - KIAPS-GMVV will provide the validation routines to implement improved physics modules into the KIAPS-GM.
- KIAPS data assimilation system will be coupled with KIAPS-GM in stage 2.

Future Plans

Projected configuration of KIAPS-GM v1.0 (2019)

- **Global 3-D nonhydrostatic dynamical core**
- **Spectral element horizontal discretization**
- **Cubed sphere horizontal grid less than 10 Km**
- **More than 140 vertical levels**
- **Capability to couple with atmospheric compositions and ocean forecasting system**
- **Coupled with data assimilation system**

Improving KIAPS-PPACK / KIAPS-GM

- Considering **higher resolution** (resolution dependence, scale adaptive), **convection and the grey zone, increase of complexity, stochastic** (e.g. stochastic parameterization, perturbed parameter) or otherwise, **computational efficiency**
- Tackling major shortcomings in classical schemes of NWP model including stable boundary layer, diurnal cycle of boundary layer, roughness length over ocean, the MJO, monsoon variability, etc.
- Forecasting atmospheric compositions and ocean

Improving KIAPS-GMVV

- Define new metrics of forecast skill focusing on Korean weather phenomena

Thank you!