Development of Global NWP Model: KIAPS-GM

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www.kiaps.org
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
• Introduction to KIAPS
• Development of KIAPS Global Model (KIAPS-GM)
• Physical Parameterizations for KIAPS-GM
• Atmospheric Compositions and Ocean Forecasting
• Model Verification and Validation
• Summary and Future Plans
Modules of KIAPS Global NWP System

- **OBS data**: Satellite, Radiosonde, Radar, GPS, Aircraft, Sounding etc.
- **Data Assimilation**
- **Dynamical Core**
- **Physics**
- **High-performance Computing Environment**
- **Forecast System**
  - Framework to connect core modules
  - Coupler for external models
  - Post-processing System and IO modules
  - Whole forecast system
- **Application Modules**
  - Observation Processing
  - Data Assimilation
  - Framework
  - Global NWP Model
  - Dynamical Core
  - Framework
  - Physics
  - IO Module
  - Post processing
  - Visualization
  - Forecast Results
  - Verification
  - Weather Forecaster
- **External Models**
  - Land SFC
  - Ocean
  - Sea Ice
  - Ocean Wave
  - Chemistry
  - Aerosol
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

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

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

2011-2013
Stage 1
- Establishment of the Foundation & Development of Core Modules

2014-2016
Stage 2
- Developing Test Model

2017-2019
Stage 3
- Developing Operational Model
### Roadmap of KIAPS-GM Development

<table>
<thead>
<tr>
<th>Year</th>
<th>System Development</th>
<th>Validation</th>
<th>Physics</th>
<th>Dynamical Core</th>
<th>Observation Processing Data Assimilation</th>
</tr>
</thead>
<tbody>
<tr>
<td>2013</td>
<td>KIAPS-GM System (v0.9)</td>
<td>Validation</td>
<td>Vegetation Chemistry</td>
<td>Hydrostatic Core</td>
<td>4D Var./Ens. DA</td>
</tr>
<tr>
<td>2014</td>
<td>Optimization (Serial, Parallel, I/O) and User Interface</td>
<td>Sensitivity to Resolution, Case Studies, Refinements, Upgrades</td>
<td>Ocean Sea ice Wave</td>
<td>Improve-ment</td>
<td>Initial Version of Ens-3D Var. DA and Optimization</td>
</tr>
<tr>
<td>2015</td>
<td>Operational System</td>
<td>Sensitivity to Time-scale</td>
<td>Optimiza-tion</td>
<td>Nonhydrostatic Core</td>
<td>4D Var./Ens. DA and Optimization</td>
</tr>
<tr>
<td>2016</td>
<td></td>
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<tr>
<td>2017</td>
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<tr>
<td>2018</td>
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<tr>
<td>2019</td>
<td></td>
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</tr>
</tbody>
</table>

#### KIAPS-GM System (v0.9)
- Initial Version of Model Physics and Validation System
- Sensitivity Tests, Improvements
- Validation
- Design
- Radiation, PBL, Cloud, Convection, Land-surface, GWD
- Vegetation Chemistry
- Ocean Sea ice Wave
- Optimiza-tion
- Sensitivity to Resolution, Case Studies, Refinements, Upgrades
- Sensitivity to Time-scale

#### Data Assimilation System
- 4D Var./Ens. DA
- Initial Version of Observation Processing System
- Operational Observation Processing System and Optimization

#### Operation
- Operational Model (~10 Km)
- Operational Observation Processing System and Optimization

#### Predictability
- Sensitivity to Time-scale
- Operational System
- Operational Observation Processing System and Optimization

#### Core modules
- Test Model (~25 Km)
- Operational Model (~10 Km)

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

#### Physics
- Radiation, PBL, Cloud, Convection, Land-surface, GWD
- Vegetation Chemistry
- Ocean Sea ice Wave
- Optimiza-tion
- Sensitivity to Resolution, Case Studies, Refinements, Upgrades
- Sensitivity to Time-scale

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

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

#### 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
- Operational System
Development 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°X1°)
    - 70 vertical levels (upto 0.003 hPa, 80 Km)
    - Hybrid sigma vertical coordinate
    - Lorenz grid, finite different vertical discretization

- **Physical Parameterizations**

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

- **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)
• **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

<table>
<thead>
<tr>
<th>Process</th>
<th>Scheme</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radiation</td>
<td><strong>RRTMG</strong> <em>(Iacono et al., 2008)</em> with Ferrier’s cloud optical properties scheme</td>
</tr>
<tr>
<td>Cumulus convection</td>
<td><strong>Mass flux scheme</strong> based on Simplified Arakawa-Schubert <em>(Pan and Wu 1994)</em> deep convection and Han and Pan <em>(2011)</em> shallow convection</td>
</tr>
<tr>
<td>Macrocloud</td>
<td><strong>Diagnostic liquid/ice cloud fraction</strong> <em>(Wilson and Gregory, 2003)</em></td>
</tr>
<tr>
<td>Microphysics</td>
<td><strong>WRF Single Moment 6-class scheme</strong> <em>(WSM6, Hong &amp; Lim, 2006)</em></td>
</tr>
<tr>
<td>OGWD</td>
<td><strong>Linear mountain gravity wave drag scheme</strong> <em>(McFarlane, 1987)</em></td>
</tr>
<tr>
<td>NOGWD</td>
<td><strong>Lindzen-type spectral scheme</strong> <em>(Linzen, 1981; Molod et al. 2012)</em></td>
</tr>
<tr>
<td>Land surface</td>
<td><strong>Noah model</strong> <em>(Ek et al., 2003)</em></td>
</tr>
<tr>
<td>Surface layer</td>
<td>Scheme based on <strong>Monin-Obuhkov similarity theory</strong> <em>(Long, 1986)</em></td>
</tr>
<tr>
<td>PBL</td>
<td><strong>Non-local 1st order K closure scheme</strong> <em>(Troen and Mahrt, 1986; Hong and Pan, 1996; Han and pan, 2011)</em></td>
</tr>
</tbody>
</table>
• 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 (1°X1°)
    : 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**

<table>
<thead>
<tr>
<th>Variable</th>
<th>Unit</th>
<th>Resolution</th>
<th>Source</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slope type</td>
<td>index</td>
<td>1°x1°</td>
<td>islope (GFS)</td>
<td>Zobler (1986)</td>
</tr>
<tr>
<td>Deep soil temp</td>
<td>K</td>
<td>1°x1°</td>
<td>GRIMs ancillary data</td>
<td>Hong et al. (2013)</td>
</tr>
<tr>
<td>Green veg. fraction</td>
<td>%</td>
<td>0.144°x0.144° monthly</td>
<td>NOAA/AVHRR NDVI 5-yr clim. data (1985-1987, 1989-1991) (GFS)</td>
<td>Gutman and Ignatov (1977)</td>
</tr>
<tr>
<td>Min. green veg. fraction</td>
<td>%</td>
<td>0.144°x0.144° monthly</td>
<td>NOAA/AVHRR NDVI 5-yr clim. data (1985-1987, 1989-1991) (GFS)</td>
<td>Gutman and Ignatov (1977)</td>
</tr>
<tr>
<td>Max. snow albedo</td>
<td>%</td>
<td>1°x1°</td>
<td>Defense Meteorological Satellite program winter of 1978-1979 (GFS)</td>
<td>Robinson and Kukla (1985)</td>
</tr>
<tr>
<td>Albedo</td>
<td>%</td>
<td>0.144°x0.144° monthly</td>
<td>NOAA/AVHRR Green Vegetation Index (1985-1989)</td>
<td>Csiszar and Gutman (1999)</td>
</tr>
</tbody>
</table>
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

- Detrained condensate, Mass flux
- Controlled in main module
- Controlled as factors in subroutine
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

00Z 2 Jan 2012
(24-hour)
200 hPa zonal wind

Model version: KIAPS-GM v0.09 (ne30np4 (1°X1°) 70L(upto 0.003 hPa)
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- **Surface Initial**: 00Z01Jan2012 ERA40
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**200 hPa zonal wind**

KIAIPS-GM

ERA-Interim

00Z 2 Jan 2012 (24-hour)
Preliminary Results of KIAPS-GM

January

□ Zonal mean zonal wind

□ Zonal mean temperature
January Precipitation

KIAPS-GM (ensemble mean)

GPCP (1981-2000)

Precipitation (JAN)

[Map of January Precipitation with color scale showing values from 0.2 to 17 mm day⁻¹]
Preliminary Results of KIAPS-GM

January OLR

□ OLR at TOA

KIAPS-GM

CERES

Zonal mean

Outgoing Longwave Flux at TOA 005 d

[Image showing OLR maps and zonal mean graphs]

Outgoing Longwave Flux at TOA (CERES) 20120105

KIAPS-GM

CERES

[Graph showing zonal mean]
After identifying errors and defects of KIAPS-GM, we are in the process of debugging our physics codes.
• 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

**Chemistry model**
- **Purpose:** mainly to predict stratospheric ozone
- **Design/selection**
<table>
<thead>
<tr>
<th>Stratosphere Photoc</th>
<th>General description</th>
<th>2D CTM (stratosphere) + 3D CTM</th>
<th>Ozone climatology/DA</th>
</tr>
</thead>
</table>
| Cariolle&Teyssedre (2007) | Linear + chem_het | MOZART3 + MOZART4 + REAM | • SPARC  
• ERA-40 reanalysis  
• Li&Shine (1995) |
| LINOS v2 (Hsu & Prather, 2009) | | | |

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

**Ocean wave model**
- **Purpose:** to predict ocean waves to improve the description of the atmospheric boundary layer (via surface roughness length over ocean)
- **Strategy:** coupling wavewatch III with atmospheric model using MCT (different horizontal resolutions)

**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

<table>
<thead>
<tr>
<th></th>
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</thead>
<tbody>
<tr>
<td><strong>Physics Package</strong></td>
<td><strong>Developing Test Model (KIAPS-GM v0.9)</strong></td>
<td><strong>Developing Operational Model (KIAPS-GM v1.0)</strong></td>
</tr>
<tr>
<td><strong>Design</strong></td>
<td><strong>Radiation, PBL, Cloud, Convection, Land-surface, GWD</strong></td>
<td><strong>Vegetation Chemistry</strong></td>
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<td><strong>Vegetation Chemistry</strong></td>
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<td><strong>Optimization</strong></td>
</tr>
<tr>
<td><strong>Validation System</strong></td>
<td><strong>Sensitivity Tests, Improvements</strong></td>
<td><strong>Validation</strong></td>
</tr>
<tr>
<td><strong>Validation</strong></td>
<td><strong>Case Studies, Sensitivity to Resolution</strong></td>
<td><strong>Refinements, Upgrades</strong></td>
</tr>
<tr>
<td><strong>Physics Package (100 Km)</strong></td>
<td><strong>Sensitivity to Time-scale</strong></td>
<td><strong>Sensitivity to Time-scale</strong></td>
</tr>
</tbody>
</table>

### Physics Package (100 Km)
- Wave
- Aerosol Chemistry
- Ocean Sea ice

### Physics Package (25 Km)

### Physics Package (10 Km)

### Implement in the framework
(Development of Initial Version)
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

**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.

**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)
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**
- 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

Database

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

- README file
- Created per each resolution and year
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.
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!