Korea Institute of Atmospheric Prediction Systems - KIAPS: Its Birth, Plans and Progress

Young-Joon Kim

With contributions from

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Korea Institute of Atmospheric Prediction Systems
Seoul, Korea

www.kiaps.org
Background: NWP efforts at KMA

Korea Meteorological Administration

- National Meteorological Satellite Center
- National Meteorological Supercomputer Center
- Meteorological Ship
- Satellite Observational System (COMS): $7.5 Million per year
- Unified Radar Network
- Supercomputer: $20 Million per year
- KMA Operational NWP Model
- UM: $0.2 million per year

Cutting-edge observational data
Supercomputing capability
Advanced NWP model from UK
History of KIAPS

- **Jan 2009:** Established strategy to improve the accuracy of weather forecast at KMA
- **Mar 2010:** Assessed feasibility as a destination project
- **Mar-Aug 2010:** Performed detailed study of plan for development of the Korean NWP model
- **Aug 2010:** Passed the pre-feasibility assessment by the Ministry of Strategy and Finance to allocate 94.6 million US dollars for 9 years (2011-2019)
- **Dec 2010:** Assigned 3 million dollars budget for 2011
- **Jan 2011:** Launched the ‘Next Generation Model Development Center’ Preparatory Center
- **Feb 2011:** Established the ‘Next Generation Model Development Center’ Foundation
- **Apr 2011:** Held the inauguration ceremony
- **Nov 2011:** Signed a Memorandum of Understanding (MOU) with the COAPS/FSU and COLA
- **Dec 2011:** Held 1st International Symposium on Recent Advances in the NWP Model Development
- **Dec 2011:** Assigned 10 million dollars budget for 2012 from National Congress
- **Dec 2011:** Elected the director, Dr. Young-Joon Kim (NRL, USA)
- **Jan 2012:** Changed the official name to ”Korea Institute of Atmospheric Prediction Systems”
- **16 Mar 2012:** Inaugurated the new director
Funding of about $100 million from 2011 to 2019

To Develop Global NWP System Optimized to the Topographic & Meteorological Features of Korean Peninsula

To Reduce the Economic Loss Caused by Natural Disasters and Enhance Productivity of Industrial Sector

To Build Science & Technology Capacity That Stimulates the NWP Research Fields

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
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 Source Technology

- To set up an R&D center and hire work force
- To design the basic structure of the KIAPS-GM
- To build an evaluation system of the development software

2011-2013

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

2014-2016
Organizational Chart (2012)

As of May 2012; 35 scientists & 12 staff members (= total 47 to grow to 58, or 70~80 including contractors & visitors by the end of 2013)
<table>
<thead>
<tr>
<th>Field (ocyte)</th>
<th>Persons (ocyte)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Systems Development</strong> (ocyte)</td>
<td><strong>8 (5)</strong></td>
</tr>
<tr>
<td>Systems Development (ocyte)</td>
<td><strong>5 (2)</strong></td>
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<tr>
<td>Web Development (ocyte)</td>
<td><strong>1 (1)</strong></td>
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<td><strong>Model Validation</strong> (ocyte)</td>
<td><strong>6</strong></td>
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<tr>
<td>Model Validation (ocyte)</td>
<td><strong>2</strong></td>
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<tr>
<td>Ocean/Sea Ice/Wave (ocyte)</td>
<td><strong>1 (1)</strong></td>
</tr>
<tr>
<td>Middle Atmosphere (ocyte)</td>
<td><strong>1</strong></td>
</tr>
<tr>
<td>Aerosol (ocyte)</td>
<td><strong>1</strong></td>
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<tr>
<td>Land Surface (ocyte)</td>
<td><strong>1</strong></td>
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<tr>
<td><strong>Data Assimilation</strong> (ocyte)</td>
<td><strong>11</strong></td>
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<tr>
<td>Data Assimilation (ocyte)</td>
<td><strong>4 (2)</strong></td>
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<td>Pre-processing (ocyte)</td>
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<td>4D Var/Ensemble Methods (ocyte)</td>
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<tr>
<td><strong>Physical Parameterization</strong> (ocyte)</td>
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<td>Radiation (ocyte)</td>
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<td>Microphysics (ocyte)</td>
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<td>Large-Scale Cloud (ocyte)</td>
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<tr>
<td>Convection (ocyte)</td>
<td><strong>1</strong></td>
</tr>
<tr>
<td>Gravity Waves (ocyte)</td>
<td><strong>1</strong></td>
</tr>
<tr>
<td>Boundary Layer (ocyte)</td>
<td><strong>1</strong></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>35</strong></td>
</tr>
</tbody>
</table>

P: Permanent, C: Contractor

(ocyte): outside atmospheric sciences
## KIAPS Science Advisory Committee
(Consisting of World-Renowned Scientists & Administrators)

<table>
<thead>
<tr>
<th>Name</th>
<th>Affiliation</th>
<th>Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simon W. Chang*</td>
<td>NRL</td>
<td>Superintendent, Marine Meteorology Division</td>
</tr>
<tr>
<td>Francis X. Giraldo*</td>
<td>NPS</td>
<td>Professor, Applied Mathematics</td>
</tr>
<tr>
<td>Chris Gordon*</td>
<td>UK Met Office</td>
<td>Head, Science Partnerships</td>
</tr>
<tr>
<td>Michel Jean*</td>
<td>Meteorological Service of Canada</td>
<td>Director General, Weather and Environmental Operations</td>
</tr>
<tr>
<td>Eugenia Kalnay*</td>
<td>University of Maryland</td>
<td>Distinguished University Professor (Former Director, NCEP/EMC)</td>
</tr>
<tr>
<td>Joseph Klemp*</td>
<td>NCAR</td>
<td>Senior Scientist, MMM/NCAR</td>
</tr>
<tr>
<td>Bill M. Lapenta*</td>
<td>NOAA</td>
<td>Acting Director, EMC/NCEP/NOAA</td>
</tr>
<tr>
<td>Martin Miller*</td>
<td>ECMWF</td>
<td>Former Division Head, Model Development</td>
</tr>
<tr>
<td>Kamal Puri</td>
<td>BMRC</td>
<td>Head, Model Development Center</td>
</tr>
<tr>
<td>David Randall*</td>
<td>Colorado State University</td>
<td>Director, CMMAP/Professor</td>
</tr>
</tbody>
</table>

*Participants of the 2nd International KIAPS Symposium, 12-14 November 2012*
# International Networking for Collaboration

**KIAPS NWP Technology Advisory Committee**

*(All Korean scientists for now, later to expand to international scientists)*

<table>
<thead>
<tr>
<th>Name</th>
<th>Area of Expertise</th>
<th>Affiliation</th>
<th>Based In</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jong-Jin Baik</td>
<td>Cloud Physics</td>
<td>Seoul National University</td>
<td>KOREA</td>
</tr>
<tr>
<td>Hyeong-Bin Cheong*</td>
<td>Dynamical Core</td>
<td>Pukyong National University</td>
<td>KOREA</td>
</tr>
<tr>
<td>So-Young Ha**</td>
<td>Data Assimilation</td>
<td>NCAR/MMM</td>
<td>USA</td>
</tr>
<tr>
<td>Jongil Han*</td>
<td>Clouds</td>
<td>NCEP/EMC</td>
<td>USA</td>
</tr>
<tr>
<td>Song-You Hong**</td>
<td>Physics</td>
<td>Yonsei University</td>
<td>KOREA</td>
</tr>
<tr>
<td>Hyun-Mee Kim</td>
<td>Data Assimilation / Predictability</td>
<td>Yonsei University</td>
<td>KOREA</td>
</tr>
<tr>
<td>Jinwon Kim*</td>
<td>Land Surface / Biosphere</td>
<td>UCLA</td>
<td>USA</td>
</tr>
<tr>
<td>Young-Tae Kim</td>
<td>Numerical Methods</td>
<td>Gangneung Wonju National University</td>
<td>KOREA</td>
</tr>
<tr>
<td>Hyun-Cheol Lee*</td>
<td>Dynamical Core</td>
<td>GFDL/NOAA</td>
<td>USA</td>
</tr>
<tr>
<td>Myoung-In Lee*</td>
<td>Cumulus</td>
<td>UNIST</td>
<td>KOREA</td>
</tr>
<tr>
<td>Sukyung Lee*</td>
<td>Stratosphere</td>
<td>PennState University</td>
<td>USA</td>
</tr>
<tr>
<td>Yign Noh*</td>
<td>LES / Ocean Modeling</td>
<td>Yonsei University</td>
<td>KOREA</td>
</tr>
<tr>
<td>Jai-Ho Oh*</td>
<td>Global Modeling</td>
<td>Pukyong National University</td>
<td>KOREA</td>
</tr>
<tr>
<td>Hoon Park*</td>
<td>Operational NWP</td>
<td>KMA</td>
<td>KOREA</td>
</tr>
<tr>
<td>Seon-Ki Park</td>
<td>Data Assimilation / Predictability</td>
<td>Ewha Womans University</td>
<td>KOREA</td>
</tr>
<tr>
<td>Sungsu Park*</td>
<td>Boundary Layer / Clouds</td>
<td>NCAR</td>
<td>USA</td>
</tr>
</tbody>
</table>

*Participants of the 1st International KIAPS Technology Workshop, 23-24 July 2012; **To hold a separate summer school
Systems Development
Computing Environment at KIAPS

• **Linux cluster for R&D (DELL)**
  - Onsite system
  - Performance: 2.3 TFLOPS (Infiniband)
  - 256 AMD Cores [1536 cores in 2012]
  - 50 TB storage (home+scratch+data) [350 TB, 2012]

• **Interim system of KMA supercomputer suite (Cray XE6)**
  - Offsite system
  - Performance: 16.9 TFLOPS (Gemini)
  - 2016 cores
  - 255 TB storage (home+scratch+data)
  - [210 TB backup and 330 TB archiving system, 2012]

• **R&D maintenance system**
  - Trac-Wiki system
  - SVN repository
KIAPS Coding Standards

• **Software Standards**
  – Programming languages for development
    • Fortran 95, CPP, Python, Bash, GNUmake
  – Coding standards
    • UK Unified Model, NASA GEOS5, NCAR CESM

• **Modeling Frameworks**
  – Earth System Modeling Framework (ESMF)
  – Program for Integrated earth System Modeling (PRISM)
  – Component-based development based on ESMF
  – Model execution environment based on PRISM

• **Couplers**
  – Cpl component in ESMF
  – OASIS4 in PRISM
  – MCT in NCAR CPL7
  – Development based on ESMF and OASIS
KIAPS System Framework & Coupling

Graphical / Text-based User Interface

Preprocess, Configure, Build

KIAPS Global Model

Data Assim

Atm Obs

In/Output

Obs Preprocessing

In/Output

Atm Data Assim

Framework

Forecast Model

Dynamical Core

Framework

Physical Parameterization

Framework

Infrastructure

Other Models

Land-Surface

Ocean

Sea Ice

Ocean Wave

Chemistry

Aerosol

Coupler

Model I/O module

Forecast System Output

Post Processing Output
Web/Python-Based Post-Processing System (In Progress)

- Separation of development and operation post-processing
- Django Web Framework
- WebGL-based 3D visualization for development
- Python-based post-processing backend
- Various Python modules: Matplotlib, PyNGL, Basemap, etc
Dynamical Core
Dynamical Core: Horizontal Grid Choice

- **Lat-Lon Grid**
  (À§°æµµ °ÝÀÚ)

- **Triangular/Icosahedral Grid**
  (»ï°¢/Á¤ 20¸éü °ÝÀÚ)

- **Cubed-Sphere/Hexahedral Grid**
  (Á¤ 6¸éü °ÝÀÚ)

- **Yin-Yang Grid**
  (À½¾ç °ÝÀÚ)

- **Hexagonal Grid**
  (À°°¢ °ÝÀÚ)

- **SCVT Grid**
  (º¸·Î³ëÀÌ °ÝÀÚ)
Goals for Stage 1 (2011-2013)

- 2011: Review the next generation global dynamical core development trend & Setup development strategy
- 2012: Study grid structures & discretization methods
- 2013: Develop global SWE model w/ parallelization

Model Development Strategy (3 options/choices)

- Finite Volume core on icosahedral / SCVT grid
- Spectral Element / Discontinuous Galerkin core on Cubed Sphere grid
- Semi-Lagrangian core on Yin-Yang grid

Rationale for SE-CG/DG

- Excellent scalability under MPP environment
- High order accuracy in numerics
- Grid structure flexibility with AMR support
## KIAPS Dyn. Core Option Comparison

<table>
<thead>
<tr>
<th></th>
<th>FV</th>
<th>SE-CG/DG</th>
<th>FD</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Grid System</strong></td>
<td>Icosahedral / SCVT</td>
<td>Cubed-Sphere</td>
<td>Yin-Yang</td>
</tr>
<tr>
<td><strong>Benchmark Model</strong></td>
<td>NCAR MPAS, DWD/MPI-M ICON</td>
<td>NPS/NRL NUMA, NCAR HOMME</td>
<td>UKMO UM, CMC GEM</td>
</tr>
<tr>
<td><strong>Scalability</strong></td>
<td>Good</td>
<td>Best</td>
<td>Medium</td>
</tr>
<tr>
<td><strong>High order convergence</strong></td>
<td>Medium</td>
<td>Best</td>
<td>Medium</td>
</tr>
<tr>
<td><strong>Local/Global Conservation</strong></td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td><strong>AMR</strong></td>
<td>Static (Gradual)</td>
<td>Dynamic</td>
<td>Nesting</td>
</tr>
<tr>
<td><strong>Operational Model Considerations</strong></td>
<td>Variable resolution approach needs rigorous validation</td>
<td>Never been applied to operational environment</td>
<td>Long-term feasibility?</td>
</tr>
<tr>
<td><strong>Single-Processor Efficiency</strong></td>
<td>Medium</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td><strong>Overall Efficiency</strong></td>
<td>?</td>
<td>Good</td>
<td>?</td>
</tr>
</tbody>
</table>
Research Progress in 2012

- Element-based Galerkin Methods Assessment (Modal / Nodal, CG / DG)
  - Unified CG / DG Framework
  - Legendre-Gauss-Lobatto (LGL) Quadrature point preferred to Legendre-Gauss
  - Quadrilateral grid preferred to triangular grid
  - Nodal form preferred to Modal form

- Cubed-Sphere Grid Generation and Visualization
  - Currently NCL
  - Paraview to be explored

- Advection Convergence Tests (including irregular grids)
  - High order convergence confirmed
Physical Parameterization
<table>
<thead>
<tr>
<th>Model Center (Country)</th>
<th>Model Name</th>
<th>LW Radiation</th>
<th>SW Radiation</th>
<th>PBL</th>
<th>Deep Convection</th>
<th>Shallow Convection</th>
<th>Cloudiness / Cloud Macro-physics</th>
<th>Orographic GWD/Flow Blocking</th>
<th>Nonorographic / Convective Gravity Wave</th>
<th>Land Surface</th>
<th>Atmospheric Chemistry / Aerosol</th>
<th>Cloud Microphysics / Precipitation</th>
</tr>
</thead>
</table>
Basic Milestones for Physical Parameterization

Stage 1 (2011-2013)
- Develop Core Physics Parameterization Modules
  - Radiation
  - Cloud/Convection
  - PBL
  - Gravity wave
  - Land-surface
  - Physics-Dynamics Coupling

Stage 2 (2014-2016)
- Develop Coupled-Physics Modules
  - Aerosol/Chemistry
  - Ocean/Wave/Sea Ice

Stage 3 (2017-2019)
- Refine, Upgrade and Select
- Validation & Calibration

Development of Physics Package for KIAPS-GM & Coupling to Dynamics

Completion & Improvement of Physics Modules

Validation/Improvement of Full KIAPS-GM Physics Package
Basic Milestones for Model Validation

Stage 1 (2011-2013)

- Develop Validation System
- Applicable for each module/model
  - Single column model (SCM)
  - Large eddy simulation (LES) model

Unified standard
- Use of conventional or new metrics
- Post-processing program with visualization

Stage 2 (2014-2016)

- Organize Sensitivity Tests/Case Studies
  - To improve forecast skill
    - Scale adaptive tuning parameters
    - Capability vs. capacity of scalability
    - Exploitation of the “seamless prediction” approach

Stage 3 (2017-2019)

- Organize Diagnostic Studies
  - Use of KIAPS-GM
  - Research component of KIAPS

KIAPS
Physical Parameterization and Model Validation

Milestones of 2012
- Developed KIAPS-SCM
- Developing KIAPS-LES model
- Developing Radiation, PBL, Cloud, Convection Parameterizations

Recent Progress
- Developed KIAPS-SCM
- Developing KIAPS-LES model

Projected Products of 1st Stage (2013)
- Physics Package of KIAPS-GM
  - Including radiation, PBL, cloud convection, gravity wave and land-surface parameterizations
  - Ready for coupling with other modules (aerosol, chemistry, ocean, wave, sea ice)
- KIAPS Model Validation System
Data Assimilation
Observational Data Assimilation Development

Stage 1 (2011-2013)
Framework for Observational Data Assimilation System

- Performance test of observation preprocessing & QC modules
- Design of detailed development strategy of observation preprocessing/QC modules

Stage 2 (2014-2016)
KIAPS 3-D Observational Data Assimilation System

- Developing KIAPS background error covariance model
  - Rotational/Divergent wind transform equation
  - Linear/Nonlinear balance equation
  - Quasi-geostrophic omega equation
  - Relative humidity equation
  - Statistical tools for the horizontal/vertical transformations

Stage 3 (2017-2019)
KIAPS Observational Data Assimilation System

Observation Processing Testbed Setup

- Synoptics (SYNOP)
  - TEMP&PILOT
  - SHIP/BUU
  - etc.

- Satellite
  - AIRS/IASI
  - SSMI/GPSRO
  - etc.

- Air Quality
  - (e.g.) AOD, CO, O3, NOx

- RADAR
- AWS
- etc.

Development of 2-D Assimilation System

- Developing the KIAPS adjoint code for shallow water model
  (The tangent linear model development complete)

- Developing KIAPS background error covariance model
Observational Data Assimilation Development

Stage 1 (2011-2013)
Framework for Observational Data Assimilation System

Stage 2 (2014-2016)
KIAPS 3-D Observational Data Assimilation System

Stage 3 (2017-2019)
KIAPS Observational Data Assimilation System

Developing Test Model of KIAPS On&Off-line Observation Processing System

- **Satellite**: Bias correction of radiance, use of radiance data over cloud and precipitation regions, thinning/superobbing
- **Synoptic/Asynoptic**: Bias correction of radiosonde, aircraft observation
- Development of **preprocessing/QC** modules for atmospheric chemical compositions (O₃, CO, NOₓ, HCHO)

Developing KIAPS 3-Dimensional Hybrid Assimilation System & Adjoint Models

- Development of 3-Dimensional Hybrid Assimilation System

\[ \nabla_{\text{obs}} \rightarrow \text{Observation Operator} \rightarrow \text{Observational Increment} \rightarrow \text{Adjoint of Observation Operator} \rightarrow \nabla_{\text{mc}} \]

Minimization Loop of 3D-Var

- Development of **adjoint code** for the numerical prediction model

27

KIAPS-EnKF

KIAPS-GM

Background Ensemble

Deterministic Analysis

Shallow-Water Eq.

Primitive Eq.

Non-Hydrostatic Eq.

\[ \rightarrow \text{Stage 3} \]
KIAPS Data Assimilation System

Option 1: KIAPS Ensemble of 4D-Var System

Outer loop (High-resolution)

KIAPS-GM

Ensemble of Background

Ensemble of Analysis

Inner loop (Low-resolution)

Observational Increment

Observational Operator

Observational/Model Operator

Updates

Descent Algorithm

Option 2: KIAPS Ensemble of 4D-Var System

Stage 1 (2011-2013)
Framework for Observational Data Assimilation System

Stage 2 (2014-2016)
KIAPS 3-D Observational Data Assimilation System

Stage 3 (2017-2019)
KIAPS Observational Data Assimilation System

KIAPS Real-time OPS

KIAPS Off-line Obs. Preprocessing/QC System

KIAPS On-line Obs. QC System

- Variational BC module
- Variational QC module

KIAPS Data Assimilation System

KIAPS-GM

Ensemble of Background

Ensemble of Analysis

Observational Increment

Observational Operator

Observational/Model Operator

Updates

Descent Algorithm

Observational Data Assimilation Development
KIAPS Real-time OPS

Option 2: KIAPS 4D-Var/EnKF Hybrid System

Outer loop (High-resolution)

KIAPS-EnKF

KIAPS-GM

Ensemble of Background

Deterministic Analysis

Inner loop (Low-resolution)

Observational Increment

Observational Data Assimilation Development

Stage 1 (2011-2013)
Framework for Observational Data Assimilation System

Stage 2 (2014-2016)
KIAPS 3-D Observational Data Assimilation System

Stage 3 (2017-2019)
KIAPS Observational Data Assimilation System

KIAPS Data Assimilation System
KIAPS Data Assimilation System

Option 3: KIAPS 4D-Ensemble-Var

Inner loop (Low-resolution)
- Observational Increment
- Observation Operator
- Adjoint of Observation Operator
- Ensemble of Background Trajectories
- Ensemble of Analysis Trajectories
- Updates
- Descent Algorithm

Outer loop (High-resolution)
- Observation Operator
- Adjoint of Observation Operator
- Ensemble of Background Trajectories
- Ensemble of Analysis Trajectories
- Updates
- Descent Algorithm

KIAPS Real-time OPS

KIAPS Off-line Obs. Preprocessing/QC System

KIAPS On-line Obs. QC System
- Variational BC module
- Variational QC module

Stage 1 (2011-2013)
Framework for Observational Data Assimilation System

Stage 2 (2014-2016)
KIAPS 3-D Observational Data Assimilation System

Stage 3 (2017-2019)
KIAPS Observational Data Assimilation System

KIAPS Data Assimilation System

Observational Data Assimilation Development
Summary
Basic Design of KIAPS-GM with Options

Systems Development
- Software standard
- Model framework
- Coupler: Combination of existing framework (ESMF/PRISM) & coupler (MCT or OASIS) and new development

Dynamical Core
- Icosahedral or SCVT
- Grid isotropy, Variable resolution
- Multi-scale physical parameterization
- Cubed Sphere
- Scalability, High order convergence
- Expensive, Shortage of experts in Korea
- Yin-Yang Grid
- No pole problem, orthogonal equidistant coordinate
- Overlapping region treatment

Physical Parameterization
- Radiation
  - Seed-up
  - Cloud fraction
  - Non-LTE for mesosphere
  - PBL
    - K-profile, TKE
    - Regime vs. Process
- Land-surface
  - Verification of Monin-Obukhov similarity theory
  - Sea surface roughness
- Gravity wave
  - Topography, efficiency
  - Turbulent mixing, irrevocable hearing
- Large-scale condensation
  - Cloud fraction, liquid/ice water as prognostic variables
  - Physical consistency
- Cloud microphysics
  - Explicit consideration of various ice components
  - Second moment
- Convection
  - Mass flux with bulk model
- Vertical Resolution
  - CP vs. Lorenz grid
  - Smooth vertical grid interval

Data Assimilation
- Long Assim. Window
- Ensemble of 4D-Var
  - High skill
    - TL and Adjoint models, Parallelization of minimization
- 4D-Var/EnKF Hybrid
  - High skill
    - Develop two systems: TL and Adjoint models & Ensemble system
- 4D-Ensemble-Var
  - Scalability, TL and Adjoint models not required
  - Under construction as an operational mode

Observation Pre-processing
- Variational Quality Control
- Variational Bias Correction
- Synoptic/Asynoptic Observation Data
  - Radiosonde bias correction
  - Radar/ground GPS data
  - Improvement/development based on sensitivity test
- Satellite Data
  - Bias correction of radiation data
  - Use of radiance data over cloud and precipitation regions
  - Improvement of thinning/superobbing techniques
- Use of New Obs.
  - Cloud/precipitation
  - Trace gases/aerosols
  - Land surface

KIAPS
# Roadmap of KIAPS-GM Development

<table>
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</tr>
</thead>
<tbody>
<tr>
<td><strong>System Development</strong></td>
<td><strong>Model/Module Verification</strong></td>
<td><strong>Physical Parameterization</strong></td>
<td><strong>Dynamical Core</strong></td>
<td><strong>Observation Processing/Data Assimilation</strong></td>
<td><strong>Establishing the Foundation &amp; Developing Source Technology</strong></td>
<td><strong>Developing Test Model</strong></td>
<td><strong>Developing Operational Model</strong></td>
<td><strong>Operation</strong></td>
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<tr>
<td>Design of Framework and Coupler</td>
<td>Development of Computation modules, I/O, DA, Coupling Techniques and Post-processing</td>
<td>Development of Verification System</td>
<td>Development of Verification System</td>
<td>Sensitivity Test</td>
<td>Development of Verification System</td>
<td>Sensitivity Test</td>
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<td>Radiation, PBL, Cloud, Convection, Land-surface, Gravity wave</td>
<td>Verification/Design of Model Physics</td>
<td>Aerosol, Chemical, Ocean, Wave, Sea Ice</td>
<td>Improvement/Completion of Physical Parameterization modules</td>
<td>Selections, Refinements &amp; Upgrades</td>
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<td>Grid structure, SWE Model Development</td>
<td>Hydrostatic, Nonhydrostatic Core Development</td>
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<td>Framework for DA</td>
<td>3D-Var/LETKF/Hybrid</td>
<td>Adjoint model development</td>
<td>Adjoint model development</td>
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<tr>
<td>Design of Obs. DB</td>
<td>Implementation of Obs. DB</td>
<td>Testbed setup/analysis of modules/performance test</td>
<td>Testbed setup/analysis of modules/performance test</td>
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<td>Testbed setup/analysis of modules/performance test</td>
<td>Improvement/Development of Obs. Preprocessing/QC modules</td>
<td>4D-Var Hybrid system building/Optimization</td>
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## Workforce at KIAPS

(As of June, 2012)

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<thead>
<tr>
<th>Total</th>
<th>Scientists</th>
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<th>Total</th>
<th>Admin</th>
<th>Temp</th>
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<td>Assistant</td>
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<td>10</td>
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<td>58</td>
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</table>
# KMA’s Supercomputing Resources

## Cray XE6 MPP System

- **Processor:** AMD 2.1GHz (12 core)

<table>
<thead>
<tr>
<th>Initial Phase</th>
<th>Technology</th>
<th>Peak Perform. TFlop/s</th>
<th>Storage</th>
<th>Backup</th>
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<tbody>
<tr>
<td>Interim* (for KIAPS)</td>
<td>Cray XE6</td>
<td>16.9</td>
<td>255 TB</td>
<td>210TB+330TB</td>
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<tr>
<td>Initial System</td>
<td>Cray XT5</td>
<td>36.6</td>
<td>883 TB (Tier0)</td>
<td>1580 TB (Tier1)</td>
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<tr>
<td>Main System</td>
<td>Cray XE6</td>
<td>379</td>
<td>4.5 PB</td>
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</tbody>
</table>

### System 1
- Interim System*
  - Haenam*

### System 2
- Initial System
  - Haebit

### System 3-1: Operational
- Main Computer System
  - Haeon

### System 3-2: Research/Backup
- Main Computer System
  - Haedam
KIAPS Cluster System for Model Development

- AMD-based processors (64 cores/node)
  - 256 cores (Currently)
  - Projected number of cores: 3072 (as of the end of 2013)

- Lustre storage system for high-performance IO
  - 50TB (Currently)
  - Projected size: 670 TB (by the end of 2013)

- Backup and Archiving system
  - None (Currently)
  - Projected size: 600 TB (by the end of 2013)
Initial Development of Shallow Water Model Framework (In Progress)

- Hierarchical Component-based Framework (FORTRAN 90)
- Framework APIs to generate, terminate and reference variables
- Component composed of Set, Ini, Run, and Fin module procedures
- Build system based on GNU make
- A toy model constructed using this framework
Local Reproduction of KMA Update/Forecast Procedures

- Understanding of KMA operational cycle
  - **Early analysis**: Regular cycle using observations for 2h 25m
    - 15hr forecast (4/day)
    - 10.5day 00/12 UTC forecast, 3day 06/18 UTC forecast
  - **Late analysis**: Additional cycle using more observations for 6h 25m
    - 15hr forecast (4/day) to provide better background for early analysis

- Independent implementation of the KMA operation system
  - Observational preprocessing, variation analysis, forecast model
- Basic forecast system is set up for KIAPS researchers to conduct operational cycles for better understanding forecast procedure
Dynamical Core Requirements for KIAPS

- Global, Nonhydrostatic
- High scalability with no singularity on the grid structure
- High-order accuracy
- Computational efficiency
  - must be able to make the KMA cut-off time
- Non-oscillatory advection
  - positive definite, monotonicity option
- Local & global conservation
- Adaptive Mesh Refinement capability or Nesting capability
Local high-order CG and DG methods are very accurate.

Also shows impressive scalability on massively parallel computers.

Les Carr pre-conditioner (Carr, Borges, Giraldo SISC 2012) allows to use IMEX while improving computational efficiency of CG with MPP.

Vertical-horizontal scale is >> 1.

1D-IMEX wins for all accuracy levels.

Simulations for T=100s, grid of 6**^3 elements with 4th degree elements for a total of 200,000 gridpoints and 1 million DOFs.
To provide the scientific basis of decision-making to construct the KIAPS global forecast system
- Number of ensembles
- Necessary/unnecessary physical module including aerosol, chemistry, ocean, wave, sea ice, land surface, vegetation, etc.
- Balance between scalability (cost) vs. forecast skill
- Stochastic approach
- Optimal resolution
- Coupling strategy

To define national challenges for the scientific decision-making
- Local severe weather/extreme events (e.g., Typhoon, storm surge, drought, cold surge, heat wave)
- Risk management

To monitor the forecast skill and to research the predictability
- Comparison with other operational centers (WMO verification standard)
- Define new metric of forecast skill in Korea
Physical Parameterization and Model Validation

Global NWP System

- Observation
- Data Assimilation

Forecast Model

- Atmosphere
  - Dynamics
  - Physics
  - Chemistry
  - Ocean/Wave
  - Ocean/Ice
  - Land surface

Parameterization Development

- New Parameterization
- Test by extended integrations
- Test in global model
- Test in single column model

To find parameters using empirical relations

References:
- Theory
- Field Data
- CRMs
- Mesoscale models
- LES

Complexity
Cost
Generality
### Detailed Milestones of Physics/Validation

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<thead>
<tr>
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</thead>
<tbody>
<tr>
<td>Design of Module/Validation Systems</td>
<td>Radiation, PBL, Cloud, Convection, Land-surface, Gravity wave</td>
<td>Aerosol, Chemical, Ocean, Wave, Sea Ice</td>
<td>Selections, Refinements &amp; Upgrades</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Validation/Design of Model Physics</td>
<td>Improvement/Completion of Physical Parameterization modules</td>
<td>Validation/Improvement of Model Physics</td>
<td></td>
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<tr>
<td>Development of Validation System</td>
<td>Sensitivity Test</td>
<td>Diagnostics/Case Study using Test Model</td>
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</tbody>
</table>

#### KIAPS-GM

- **Physical Parameterization**
- **Model Validation**
- **Predictability**

#### Forecast Model

- **Observation**
- **Data Assim.**

#### Forecast Model Components

- **Dynamics**
- **Ocean/Wave**
- **Ocean/Ice**
- **Physics**
- **Land surf.**
- **Chemistry**
- **Post-processing**
- **Forecast**
- **Validation**
3-D Observational Data Assimilation

Forecast variables
- Temp.
- Wind
- Humidity

Background [X_b]
- Background error covariance [B]
- Observation operator [H(X_b)]

Forecast operator [M(X_a)]
- Background for the next analysis

Observation
- SFC
- Upper
- Satellite
- OBS Database
- Observation [y]
- Observation error covariance [R]
- Thinning/Quality Control (QC)

Adjoint model of the observation operator
- Cost function minimization

Analysis [X_a]

Cost function minimization:
\[ J(X) = (X - X_b)^T B^{-1} (X - X_b) + (y - H(X_b))^T R^{-1} (y - H(X_b)) \]

\[ \hat{X}_a = X_b + (B^{-1} + H^T R^{-1} H)^{-1} H^T R^{-1} (y - H(X_b)) \]

Weight (Error Assumptions)
- Innovation (= obs - model)

Innovation
Observational Data Assimilation Development

Stage 1 (2011-2013)
Framework for Observational Data Assimilation System

[Obs.] Observation Processing
- Testing & Analyzing performance of obs. preprocessing/QC modules
- Designing detailed development strategy for each obs.

[Assim.] KIAPS 2-D Assimilation System
- Developing the KIAPS adjoint codes for shallow water model
- Developing KIAPS background error covariance model

Stage 2 (2014-2016)
KIAPS 3-D Observational Data Assimilation System

[Obs.] KIAPS On&Off-line Obs. System
Developing
- Satellite obs.
- Synoptic/Asynoptic obs.
- Chemical compositions
- Development of preprocessing/QC modules for each obs.

[Assim.] KIAPS 3-D Hybrid Assimilation System & Adjoint models
Developing
- Ensemble assimilation system
- Descent algorithm
- Observation operator and its adjoint operator
- Adjoint code for the hydrostatic model

Stage 3 (2017-2019)
KIAPS Observational Data Assimilation System

KIAPS 4-D Hybrid Observational Data Assimilation System Development

- Developing KIAPS 4-D Variational/Ensemble/Hybrid System (involving development of adjoint code for the non-hydrostatic model)
- Developing real-time observation monitoring and processing system
## Comparison of Global DA Systems

<table>
<thead>
<tr>
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<th>ECMWF</th>
<th>UKMO</th>
<th>JMA</th>
<th>NCEP</th>
<th>CMC</th>
<th>NRL</th>
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<tr>
<td><strong>Data assimilation system</strong></td>
<td>Long-window ensemble of 4D-Var</td>
<td>Hybrid of 4D-Var and ETKF</td>
<td>4D-Var</td>
<td>3D-Var</td>
<td>4D-Var and Double EnKF</td>
<td>4D-Var</td>
</tr>
<tr>
<td><strong>Control variable</strong></td>
<td>$\zeta, \eta, T, P_s, q$</td>
<td>$\psi, \chi, p_u, \mu'$</td>
<td>$\zeta, \eta_u, (T, P_s) u, \ln q$</td>
<td>$\psi, \chi, (T, P_s) u, r_h$</td>
<td>$\zeta, \eta_u, (T, P_s) u, \ln q$</td>
<td>$u, v, T, q, p_s$</td>
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<tr>
<td><strong>Inner loop</strong></td>
<td>$T_L159$ ($\sim125$km)</td>
<td>$T_L319$ (35/35)</td>
<td>$T574$</td>
<td>$0.9^\circ \times 0.9^\circ$/$0.45^\circ$</td>
<td>$0.3^\circ$ (40/30)</td>
<td>T119</td>
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<td><strong>Minimization</strong></td>
<td>CG + Lanczos</td>
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<td>L-BFGS</td>
<td>L-BFGS</td>
<td>L-BFGS</td>
<td>Flexible CG</td>
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<tr>
<td><strong>Gravity wave control</strong></td>
<td>N/A (Implicit)</td>
<td>(Internal) DFI</td>
<td>NNMI</td>
<td>Mass conservation constraint</td>
<td>(External) DFI</td>
<td>(External) DFI</td>
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<td><strong>Number of members</strong></td>
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<td>-</td>
<td>96</td>
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<tr>
<td><strong>Model error</strong></td>
<td>SPPT</td>
<td>RP, SKEB</td>
<td>-</td>
<td>-</td>
<td>Homogeneous &amp; Isotropic</td>
<td>(Stochastic / Diurnal-cycle SST)</td>
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<tr>
<td><strong>Covariance inflation</strong></td>
<td>-</td>
<td>Multiplicative</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>Additive</td>
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<tr>
<td><strong>Quality control</strong></td>
<td>· Bayesian QC (SQC)</td>
<td>Bayesian QC (IQC)</td>
<td>· Dynamic QC</td>
<td>· Complex QC</td>
<td>· Complex QC</td>
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<tr>
<td><strong>Radiance bias correction</strong></td>
<td>Variational BC</td>
<td>· Harris &amp; Kelly (2001)</td>
<td>· Variational QC</td>
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<td><strong>Radiosonde bias correction</strong></td>
<td>use of observation monitoring system (T, humidity)</td>
<td>use of reported sonde type (T, $\phi$)</td>
<td>simple statistical correction method (T, $\phi$)</td>
<td>static correction in Complex QC (T, $\phi$) (Collins &amp; Gandin)</td>
<td>-</td>
<td>NCEP CQC</td>
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## Design of DA System for KIAPS?

<table>
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<th>Configuration</th>
<th>Long-window Ensemble of 4D-Var</th>
<th>4D-Var/ETKF Hybrid</th>
<th>4D-Ensemble-Var</th>
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<td>4D-Var</td>
<td>4D-Var</td>
<td>4D-Var</td>
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<td>Inner loop</td>
<td>Tangent linear and Adjoint</td>
<td>Tangent linear and Adjoint</td>
<td>Regression model based on ensemble of trajectories</td>
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<td>Ensemble of 4D-Var</td>
<td>Hybrid of climatological and flow-dependent covariances</td>
<td>Ensemble of 4D-Ensemble-Var</td>
</tr>
</tbody>
</table>

| Efficiency | Scalability | Dependent on numerical model | Less dependent | Independent |
| I/O        | Small ensemble members | Ensemble of states | Ensemble of trajectories |

| Difficulty | Requirements | Tangent linear and Adjoint models | Tangent linear and Adjoint models | Tangent linear and Adjoint models not required |
| Supplements required | Parallelization of minimization | Adaptive coefficients for hybrid | Spatio-temporal localization I/O problem to be solved |

| Operational center | ECMWF | UKMO | Under construction (UKMO, CMC & NRL/Bishop?) |