Evaluation of a gray-zone PBL scheme at sub-kilometer resolutions

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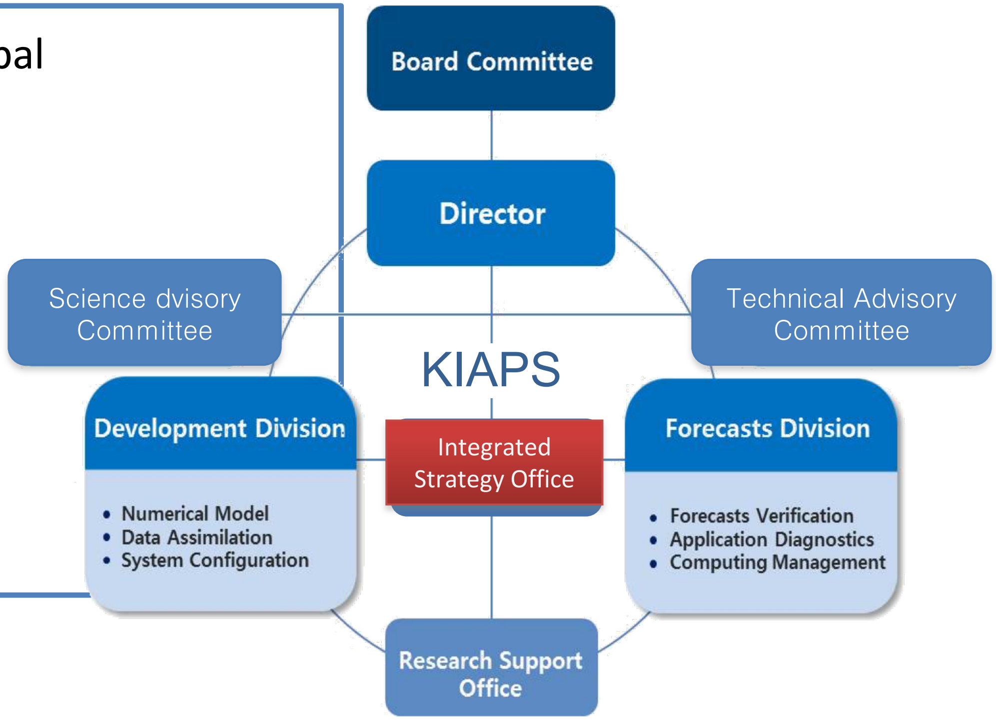
(Korea Institute of Atmospheric Prediction Systems: KIAPS)

Presentation

- ✓ Overviews of KIAPS activities
- ✓ A turbulent transport at gray-zone resolutions
  (Shin-Hong PBL, Shin and Hong, 2013, 2015)
- ✓ PBL and precipitation at grey-zone resolutions

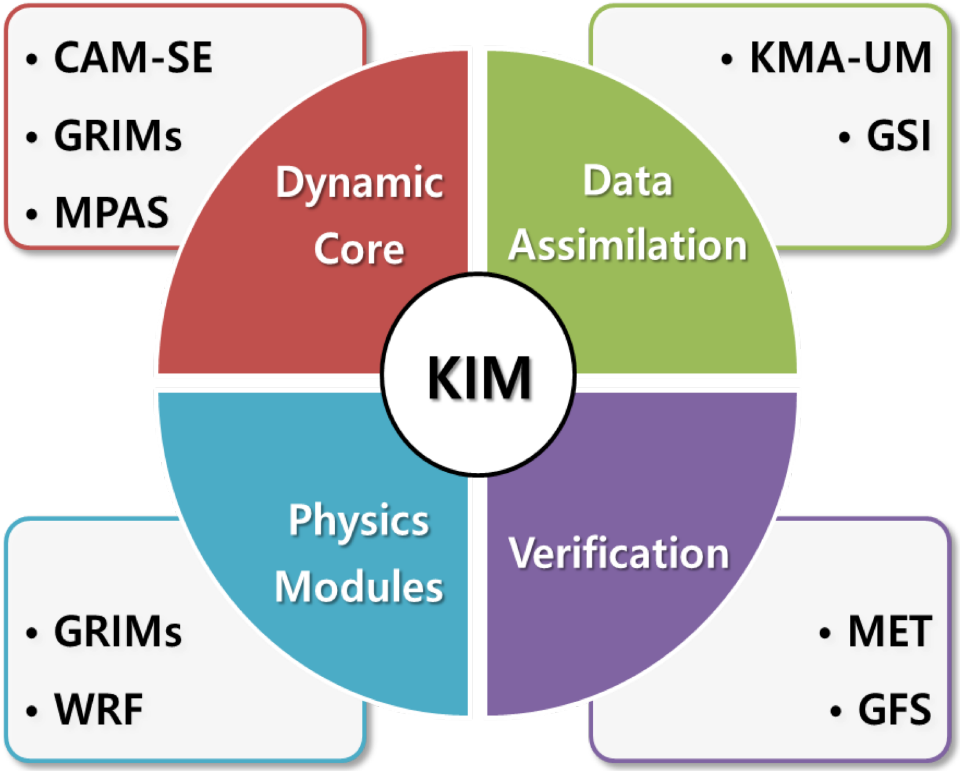
Organization of KIAPS (as of April 2018)

- ❒ Purpose : Developing a next generation global operational model for KMA
- ❒ Project period : 2011~2019(total 9 years)
- ❒ Total Budget: $95 million
  2018 budget -$10 million
- ❒ Public institution sponsored by government
  - organization: 2divisions, 6teams, 2office
  - Man power: 58/58 + 11 + 1



Total	Director	Research Staff				Administrative staff			
		Principal Researcher	Senior Researcher	Researcher	Assistant	Principal Staff	Senior staff	Staff	Assistant
58+12	1	13 +1	26	12	5	1	2	3	6

Strategy (Sep. 2014) ：Reference models



Develop major components of the model autonomously, but with the strategy of benchmarking performance of KIM with the reference models

KIM was coded from scratch with major scientific elements extracted from previous developments or publications

Korean (formerly KMA, KIAPS) Integrated Model (KIM) system

Dynamic core (non-hydrostatic over a cubed sphere)

- Cubed sphere, horizontal: Spectral element, vertical: Finite difference
- Flux-type compressible governing equations
- Time-split time integration: Slow mode → third-order Runge-Kutta

  Horizontal sound wave and gravity wave → Forward-Backward

  vertical sound wave and buoyancy → implicit

2D Shallow Water Test → 2D (x-z) Slice Dry Dynamical Core Tests → 3D Dry Dynamical Core Tests → 3D Aqua-Planet Experiments (APE) → 3D Atmospheric Model test

2D Shallow Water Test

1. Advection of cosine bell
2. Steady state
3. Translating low
4. Zonal flow over an isolated mountain
5. Rossby-Haurwitz wave

2D (x-z) Slice Dry Dynamical Core Tests

1. Linear hydrostatic mountain wave
2. Simulations The Schar-type mtn.
3. Density current
4. Inertial-gravity wave
5. Rising thermal bubble

(Choi et al., 2014, GMD)

3D Dry Dynamical Core Tests

1. Steady-sate
2. Baroclinic wave
3. 3D Rossby-Haurwaitz wave
4. Mountain-induced Rossby wave
5. Pure gravity wave
6. DCMIP pure advection test
7. *DCMIP Mountain-wave over a Schar-type*
8. Held-Suarez

3D Aqua-Planet Experiments (APE)

1. Control APE
2. 3KW1 APE

3D Atmospheric Model test

1. *the 5-case for a severe weather*

(Choi and Hong, 2016, APJAS)

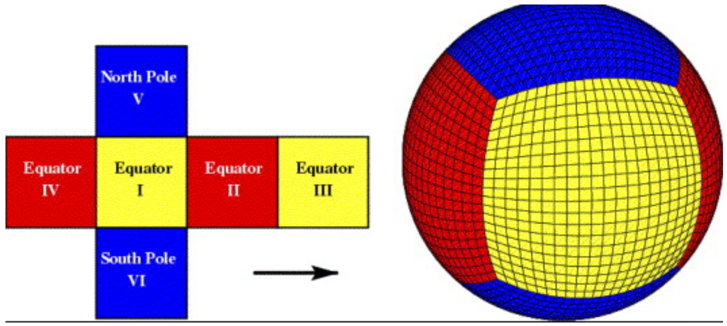
Semi-real time forecasts : July 2015

Resolution : about 25 km for both UM and KIM

UM : KMA operational model

COLD : KIM with UM initial conditions

WARM : KIM with 3Dvar assimilation

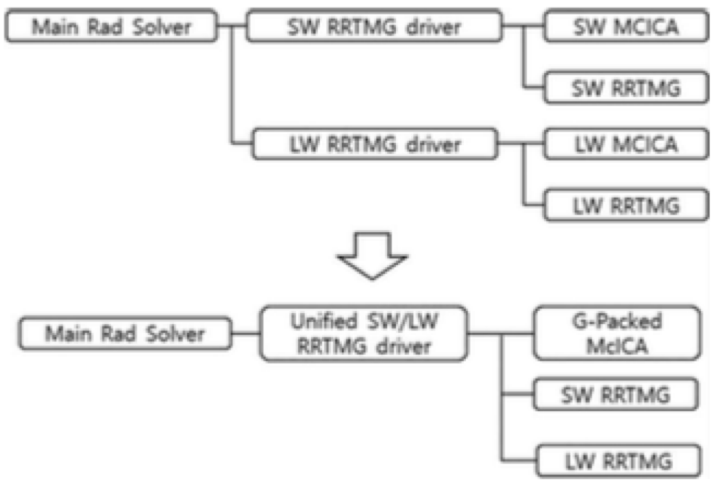


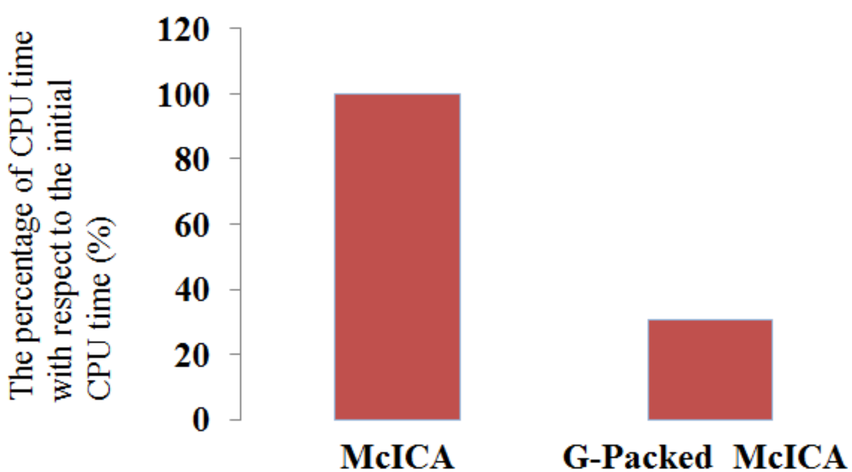
* KIM : non-hydrostatic core with v2.x physics
* KIM : updated every 3 months in stage 2
(2.0: 1507, 2.1: 1510, 2.2: 1601...)
and will be updated every 6 months in stage 3 (2017-)

*** Real-time forecasts in a non-hydrostatic spectral element with full physics, along with its own data assimilation on a cubed sphere grid

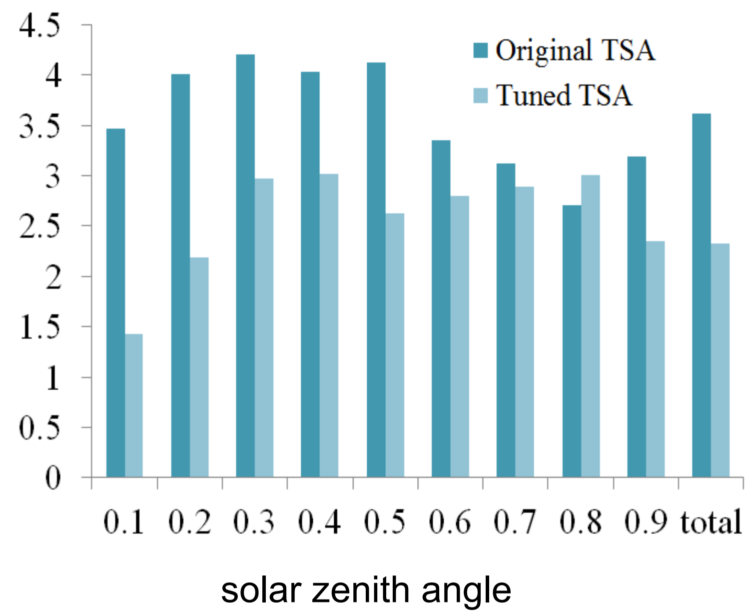
RAD (RRTMK, Baek 2017, JAMES) V3.0

- Unification of SW and LW solver
- G-Packed McICA : 3 times faster than McICA cy
- Revised two-stream approximation : reduces RMS error to 60 %





Mean r.m.s error of each cosine of solar zenith angle μ_0 bin



GWD

V3.0

Stationary convective GWD
(Jeon et al. 2010/Chun and Baik 1998)

+

Rayleigh friction (or uppermost diffusion)

→

Spectral convective GWD
(Song and Chun 2005; Choi and Chun 2010)

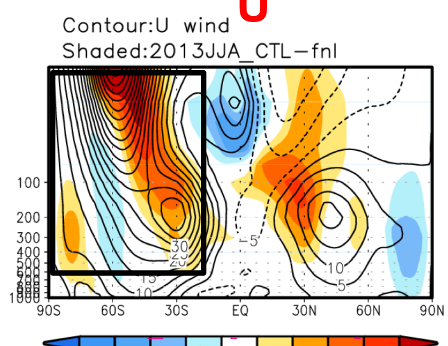
+

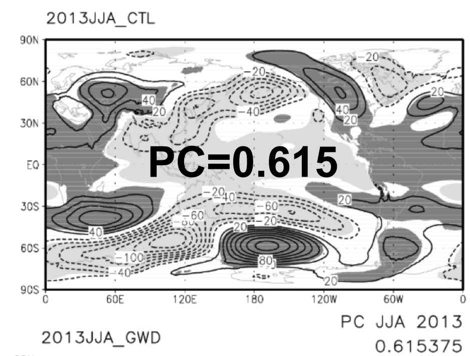
Spectral frontal GWD
(Charron and Manzini 2002; Richter et al. 2010)

U

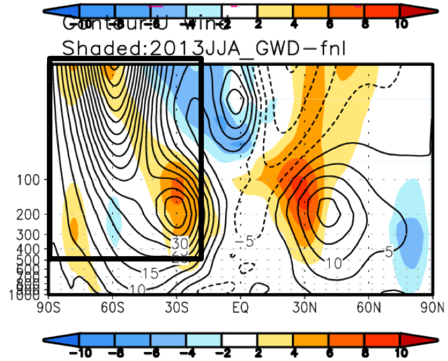
500 hPa eddy

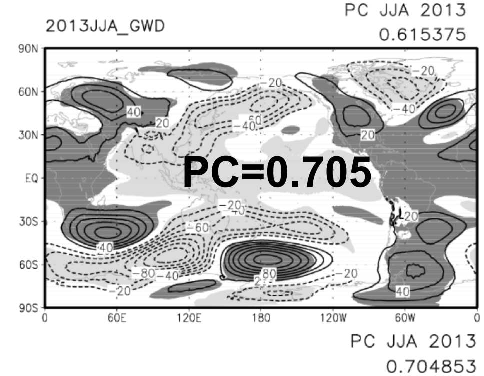
OLD





NEW



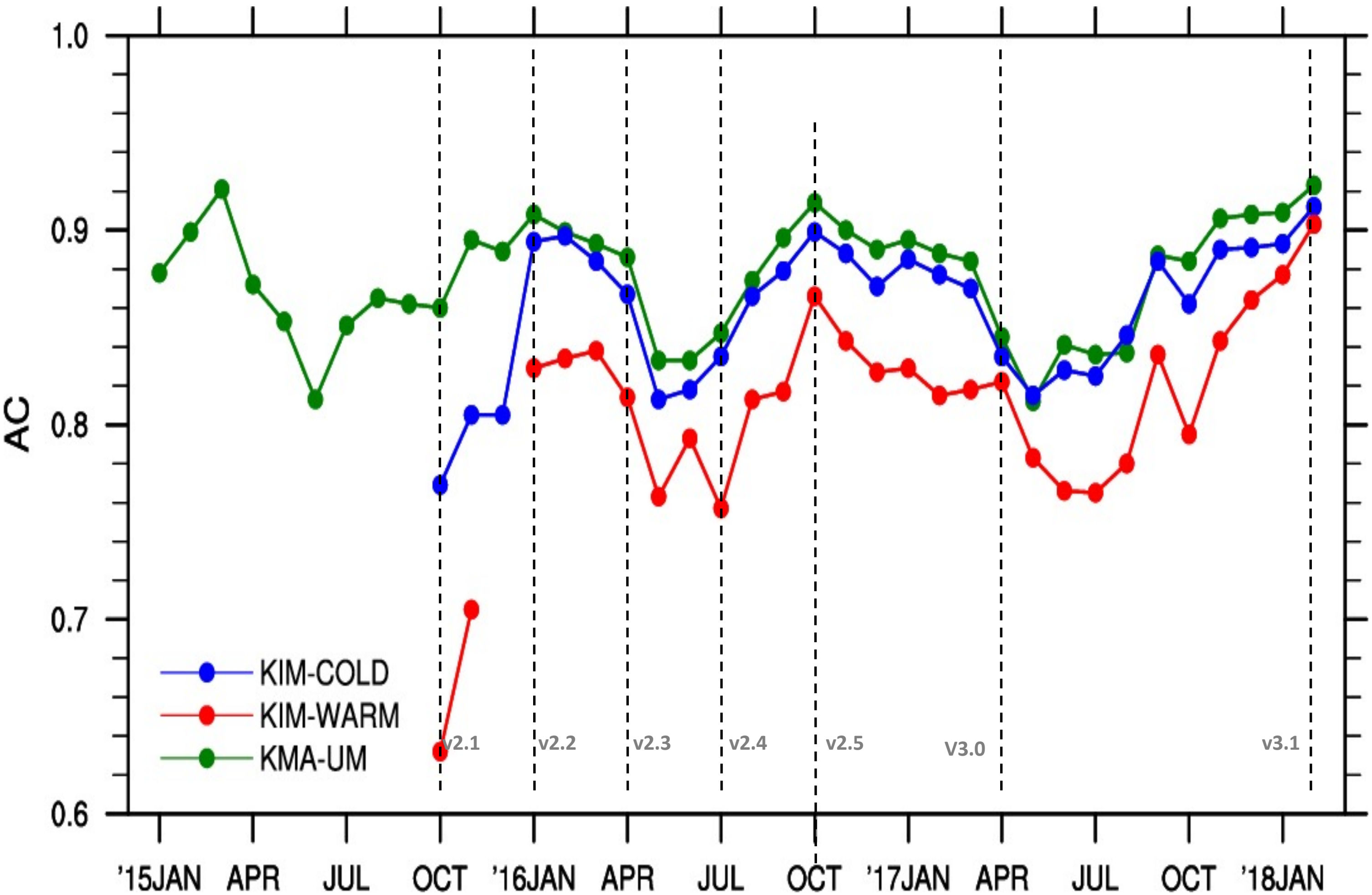


KIM physics packages (KIM 3.1)

Physics schemes		KIM 3.1	Remarks
Cumulus parameterization (CPS)		Han et al. (2016) Kwon and Hong (2017)	Routed in GFS CPS of GRIMs, but with the improved cloud microphysics and the inclusion of scale-aware function, names KSAS (gray-zone SAS)
Shallow convection (SCV)		Hong and Jang (2018)	Routed in Tiedtke SCV (Tiedtke 1989) of GRIMs, but with improved diffusivity, and triggering function
Cloud microphysics (MPS)		Hong et al. (2004) Bae et al. (2018)	Routed in WSM5 (Hong et al. 2004) of WRF, but with the inclusion of cloud properties in radiation package (Bae et al. 2016)
Radiation (RAD)		Baek (2017)	Routed in RRTMG (Iacono et al. 2008) of WRF, but with a newly developed unified RAD package
Cloudiness (CLD)		Park et al. (2016)	A newly developed prognostic cloudiness package based on the Tiedtke prognostic cloudiness (Tiedtke 1993)
Vertical diffusion (PBL)		Shin and Hong (2015) Lee et al. (2018)	Routed in YSU PBL (Hong et al. 2006, Hong 2010) of WRF, but with the inclusion of scale-aware function and stratocumulus mixing
Aerosol chemistry (AER)		Choi et al. (2018)	A newly generated 3D aerosol data, based on IFS MACC 2D aerosol climatology
Orographic gravity wave drag (GWDo)		Choi and Hong (2015)	Routed in GWDo (Kim and Arakawa 1995, Hong et al. 2008) of GRIMs, but with the inclusion of orography blocking and anisotropy of mountains
No-mountain gravity wave drag (noGWDo)		Choi et al. (2018)	A newly developed source-based spectral non-orographic GWD, based on Choi and Chun (2011) and Richter et al. (2010).
Land surface layer (LSM)		Koo et al. (2017, 2018)	Routed in Noah 3.0 of GRIMs (Ek et al., 2002, Chen and Dudhia, 2000), but a revised snow physics and the inclusion of form drag
Ocean surface layer (OSM)		Kim and Hong (2010), Lee and Hong (2018)	Routed in GRIMs, but with the inclusion of salinity effect in latent heat flux computation

KIM Real time forecasts skill

500hPa geopotential height anomaly correlation at t=+120h fcst



2018. Feb
UM : 0.923
WARM: 0.903
COLD: 0.912

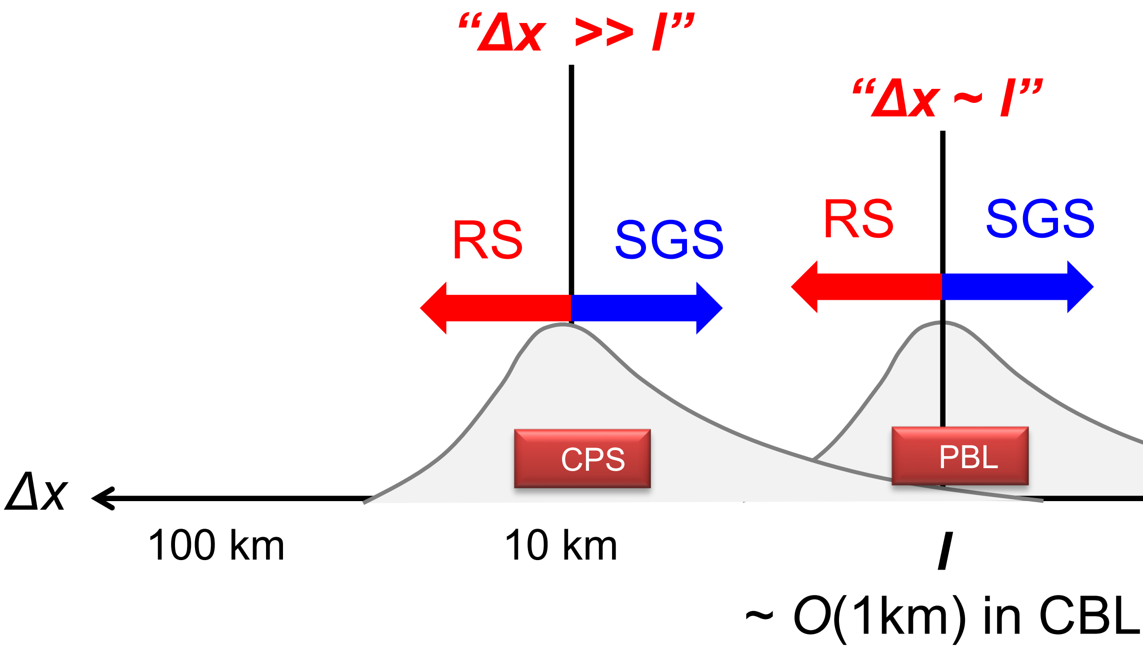
Already good enough for operational use, but a lot of room for improvement

Plan for KIM 3.2 (2018 summer)

KPOP	• Add SSMIS • Add MT-Saphir • Increase computational efficiency
Hybrid-4DEnV	• VarBC applied for microwave radiance observations • Assimilation of sea level pressure • Improve multi-resolution outer-loop
Dynamics	• applying UP-based state-vector solver • implementing 2nd-order of basis function
RAD	• new lookup table of optical properties for ice/snow
LAND	• consistent fractional snow coverage for calculating snow albedo and surface flux
PBL	• Mixing hydrometeors in conserving the total water
GWD	• bug fix in subgrid orographic drag (Toy/ESRL) • improvement of resolution dependency of GWD scheme
CPS	• bug fix for calculating subgrid-scale hydrometeor via deep convection scheme
SCV	• generating subgrid-scale hydrometeor via shallow convection scheme and linking with prognostic cloud fraction and radiation schemes
MPS	• adopting partial cloudiness • eliminating condensation process from water vapor to rainwater
PROGC	• applying freezedry effect
Phys coupling	• applying variation-resolution

A turbulent transport at gray-zone resolutions

At high resolutions : PBL gray-zone



In the gray zone:

the process is ***partly resolved***.

Operational NWP/GCM → **within 5 years**

Hong and Dudhia (2012)

(Hydrostatic → Non-hydrostatic)

Mesoscale simulations in research communities

CRM **Bryan et al. (2003)**

Gray-zone PBL: Concepts & Methods

- **Shin, H. H., and S.-Y. Hong, 2013**: Analysis on Resolved and Parameterized Vertical Transports in Convective Boundary Layers at Gray-Zone Resolutions. ***J. Atmos. Sci.***, doi:10.1175/JAS-D-12-0290.1.

- **Shin, H. H., and S.-Y. Hong, 2015**: Representation of the Subgrid-Scal e Turbulent Transport in Convective Boundary Layers at Gray-Zone Resolutions**. Mon. Wea. Rev.**

Methods

(1) Construction of the 'true' data for 50–4000 m Δ

D (=8000 m ~ Δ_{1DPBL})
Domain size

50–4000 m Δ *Reference data*
(includes gray zone)

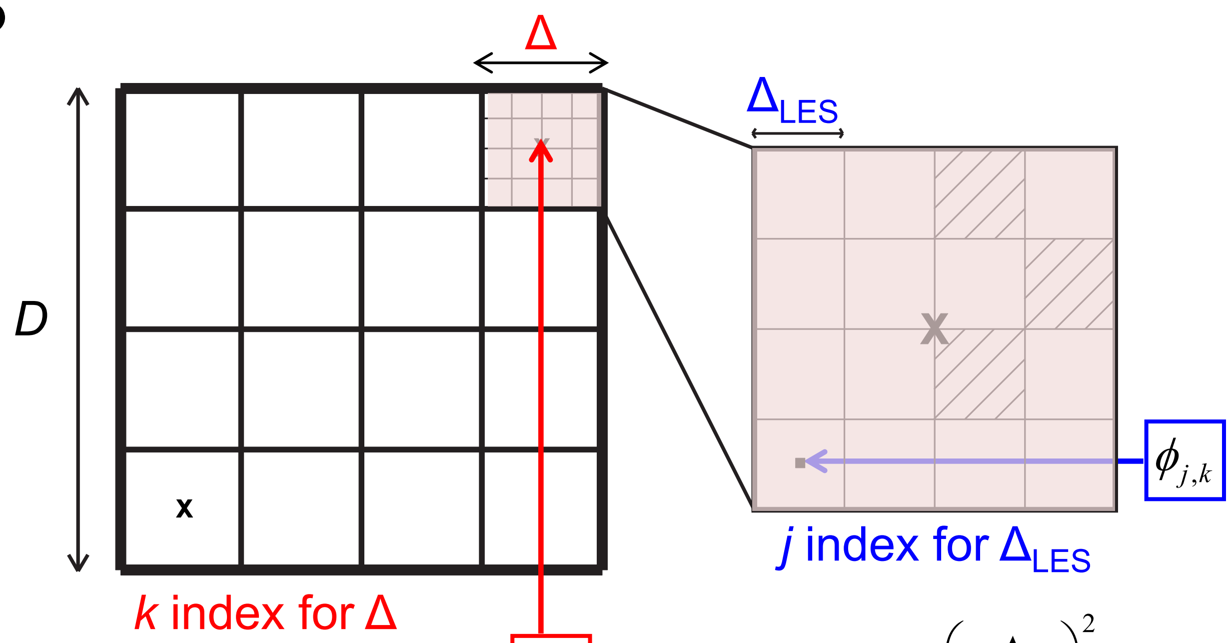
Δ_{LES} (=25 m)
Benchmark LES

For a variable φ

$$<\phi>=(JK)^{-1}\sum_{j,k}\phi_{j,k}$$

$$=K^{-1}\sum_{k}\overline{\phi}^{\Delta_k}$$

$$K=\left(\frac{D}{\Delta}\right)^2$$

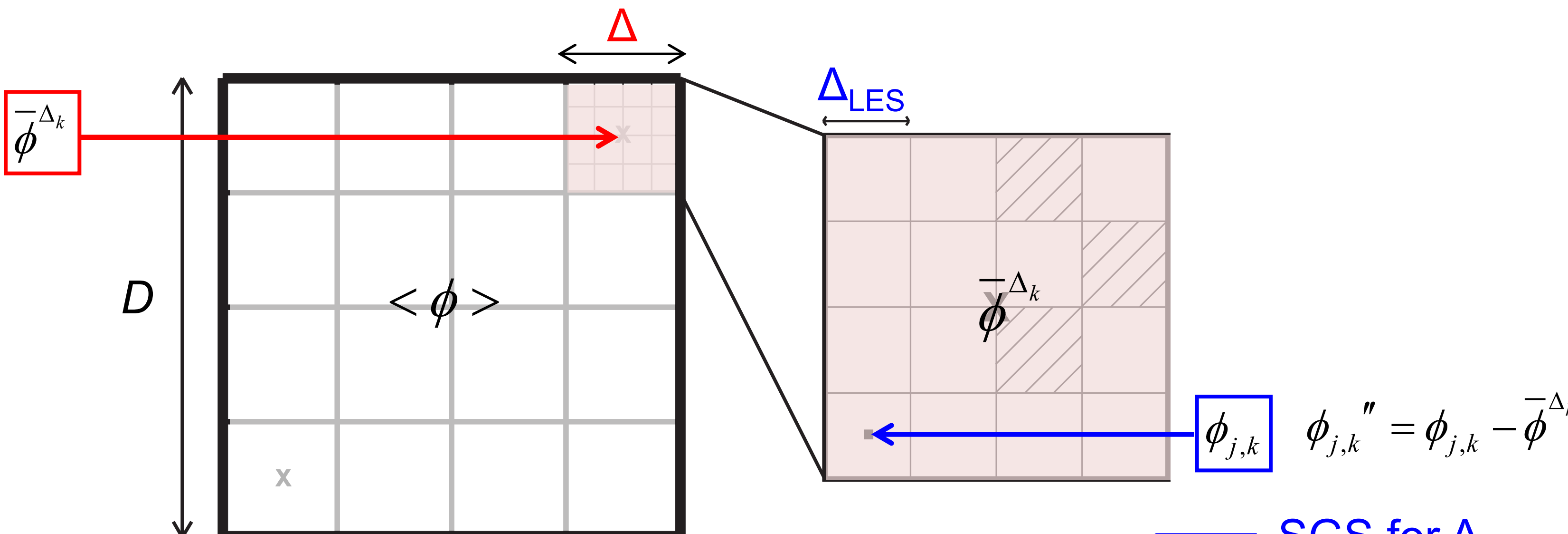


$$\boxed{\overline{\phi}^{\Delta_k}}=(J)^{-1}\sum_{j}\phi_{j,k} \quad J=\left(\frac{\Delta}{\Delta_{LES}}\right)^2$$

Methods

(2) Construction of the ‘true’ data for 50-4000 Δ

Turbulent vertical transport over the whole domain, for Δ



SGS for Δ_{LES}

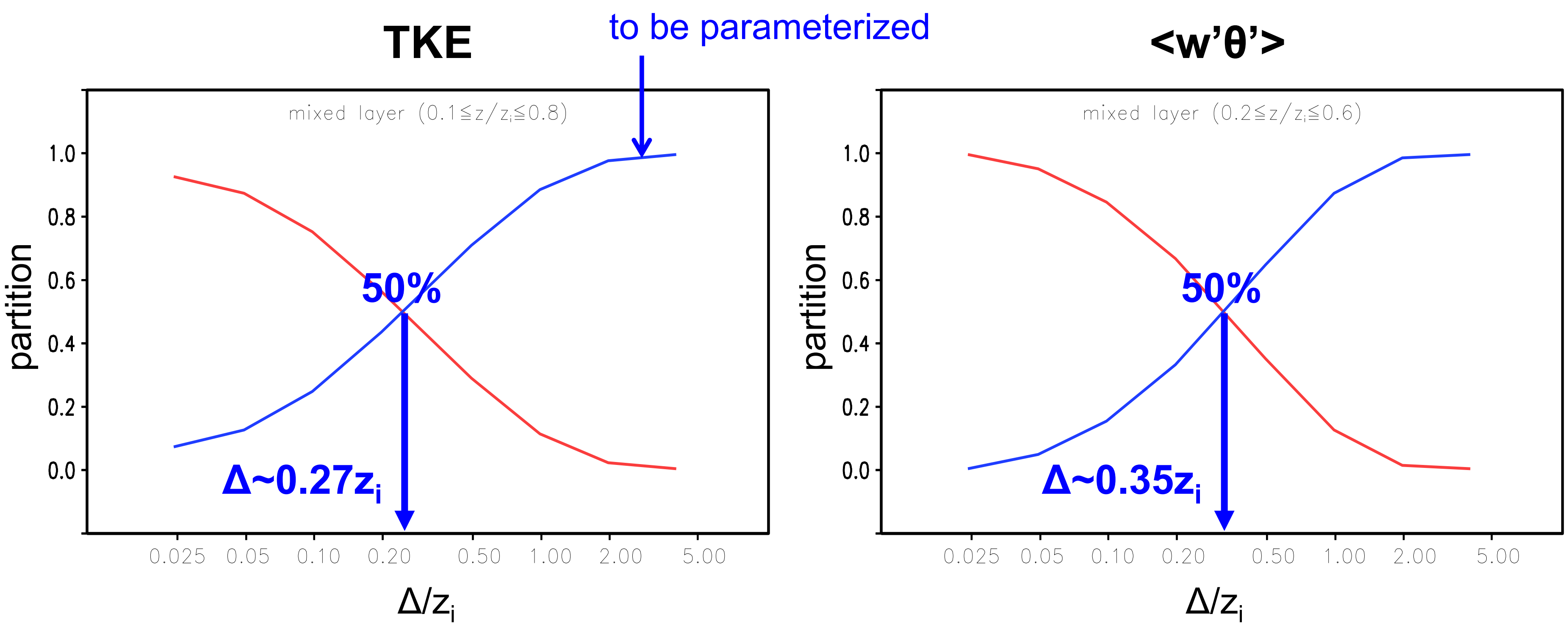
$$
\begin{aligned}
\langle w'\phi' \rangle &= K^{-1}\sum_k \left(\overline{w}^{\Delta_k} - \langle w \rangle\right)\left(\overline{\phi}^{\Delta_k} - \langle \phi \rangle\right) + K^{-1}\sum_k \left[J^{-1}\sum_j \left(w''_{j,k}\phi''_{j,k} + f^{w\phi}_{j,k} \right) \right] \\
&= K^{-1}\sum_k \left(\overline{w}^{\Delta_k} - \langle w \rangle\right)\left(\overline{\phi}^{\Delta_k} - \langle \phi \rangle\right) + K^{-1}\sum_k \left(\overline{w''\phi''}^{\Delta_k} + \overline{f^{w\phi}}^{\Delta_k} \right) \\
&= \langle w'\phi' \rangle^{R(\Delta)} \qquad\qquad + \langle w'\phi' \rangle^{S(\Delta)}
\end{aligned}
$$

Resolved for Δ **SGS for Δ**

Dorrestijn et al. (2013)
Honnert et al. (2011)
Cheng et al. (2010)

Resolution dependency

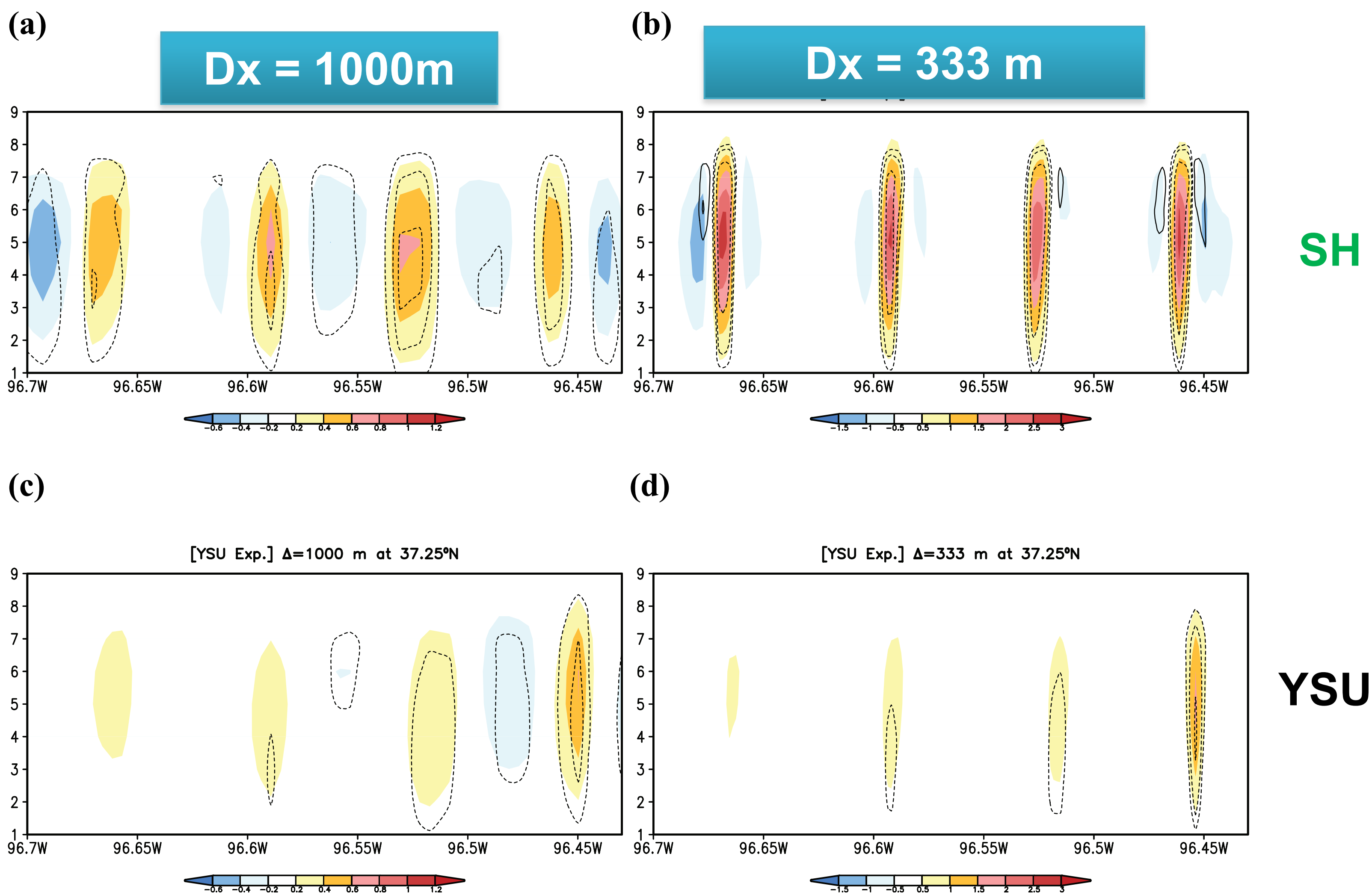
In mixed layer



SGS <w’θ’> is 50%–90%: Δ is 360 m – 1230 m

3D real case experiments : IHOP2002

- *w* (shaded) and *v'w'* (contour) : y-time cross-section



PBL and precipitation at gray-zon ne resolutions

(YSU PBL vs. Shin-Hong PBL)

PBL and precipitation at gray-zon ne resolutions

(YSU PBL vs. Shin-Hong PBL)

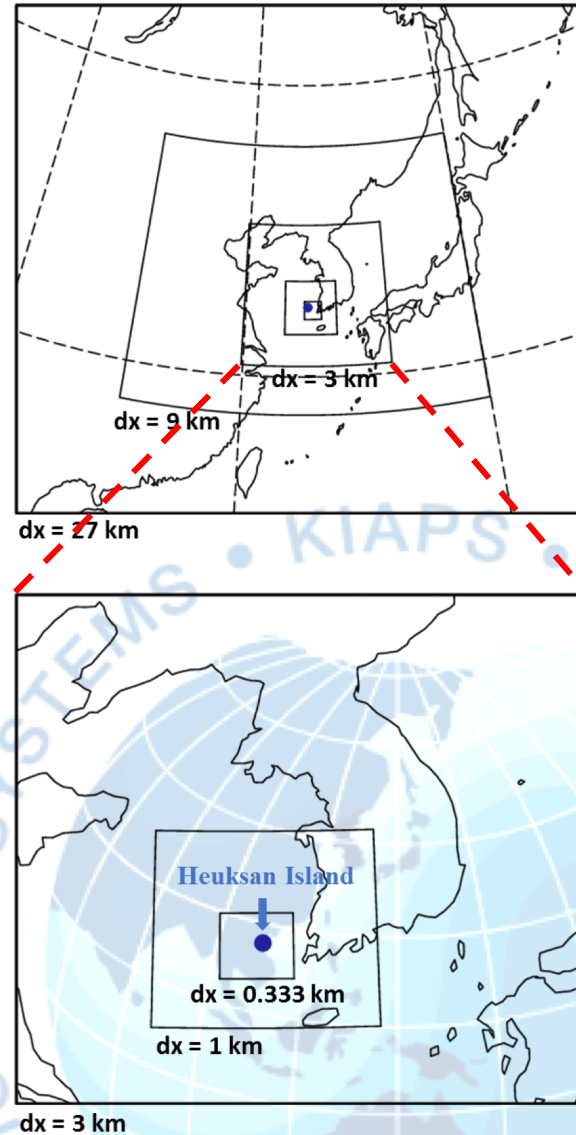
Reluctant to put my name in the scheme…

Hailey Hyeyum Shin (now in GFDL)
Song-You Hong (now in KIAPS)

Let me call SH PBL ….!

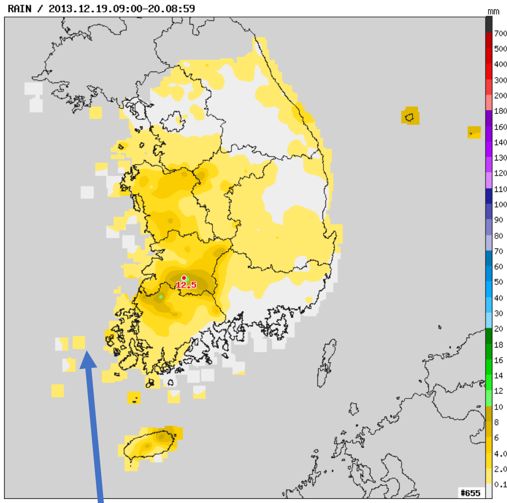
Experimental Design

Model	WRF v3.7.1	
Horizontal resolution	27-9-**3-1-0.333 km** (1-way nesting)	
Vertical resolution	L51 (top: ~50 hPa)	
Time integration	**48-h (00 UTC 18-20 December 2013)**	
Initial & boundary conditions	FNL analysis (1° x 1°, 26 levels with top ~ 10 hPa) NCEP SST analysis (0.5° x 0.5°)	
Diffusion	2nd order vertical diffusion with constant coefficient, 2D Smagorinsky horizontal diffusion	
Physics	Convection	KSAS (scale aware, Kwon and Hong)
	Microphysics	WSM5
	Radiation	RRTMG SW & LW
	PBL	**YSU** (Hong et al. 2006) **SH** (Shin and Hong 2015)
	Land surface	Noah



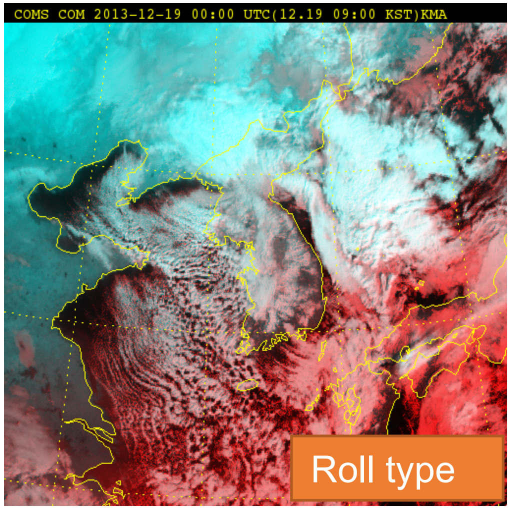
Case overview

2013.12.19-20 00 UTC

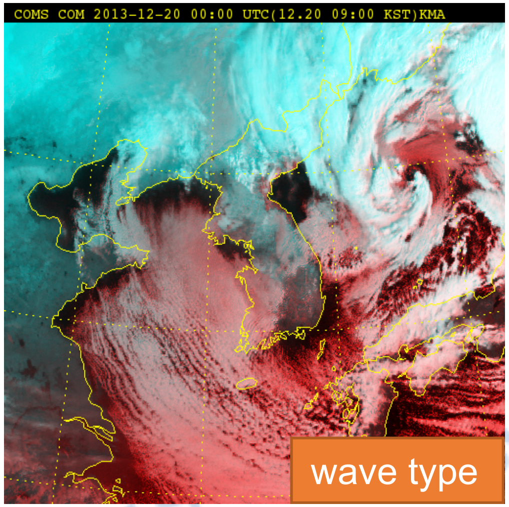


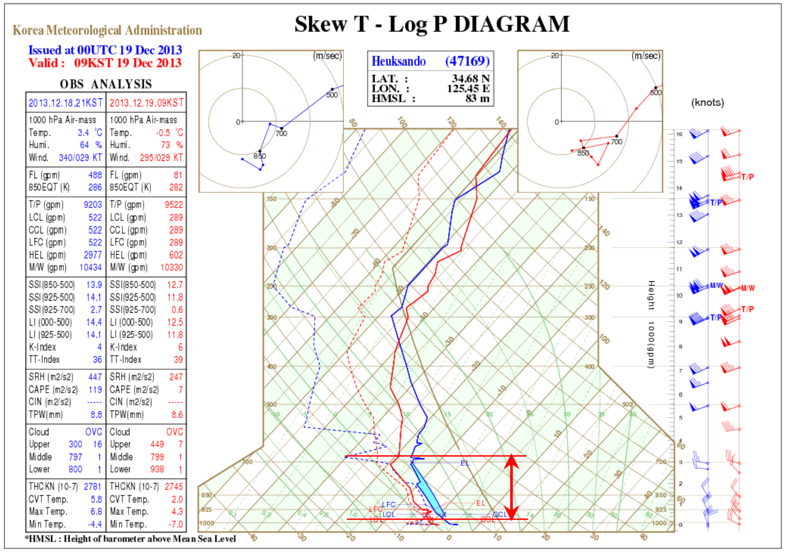
Heuksan Island

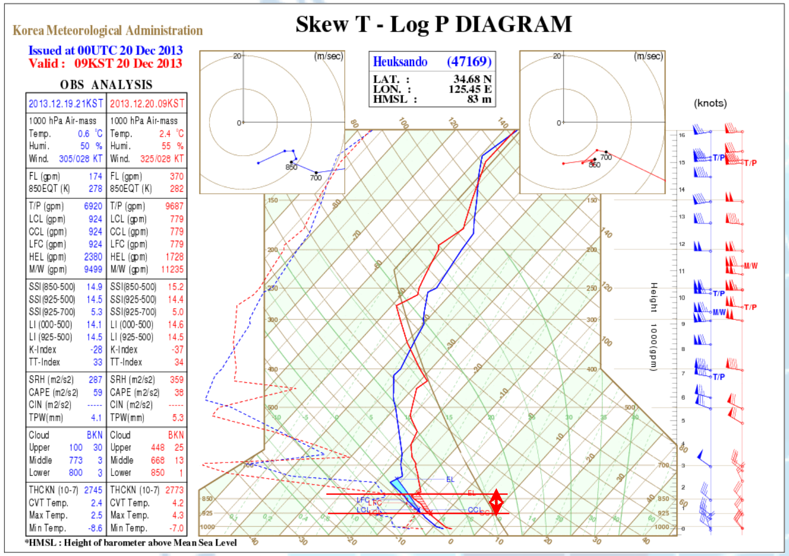
2013.12.19 00 UTC



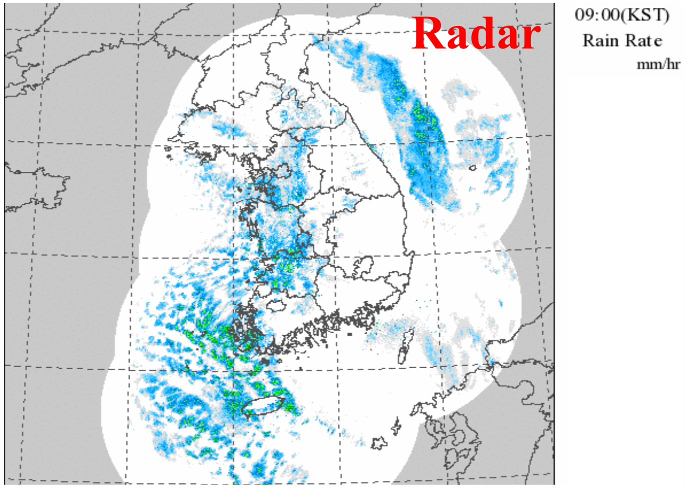
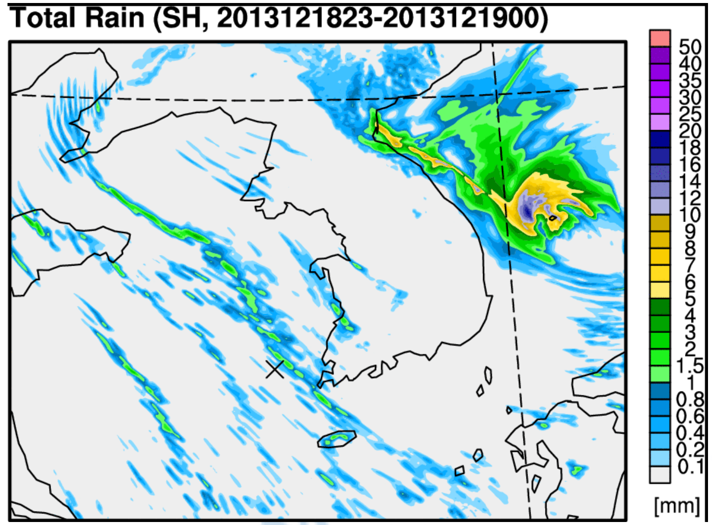
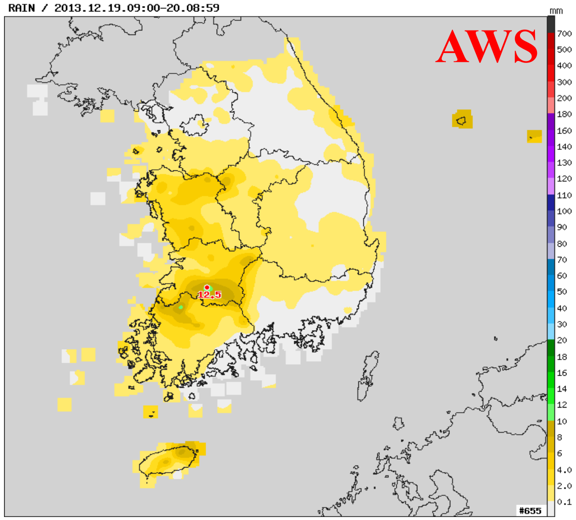
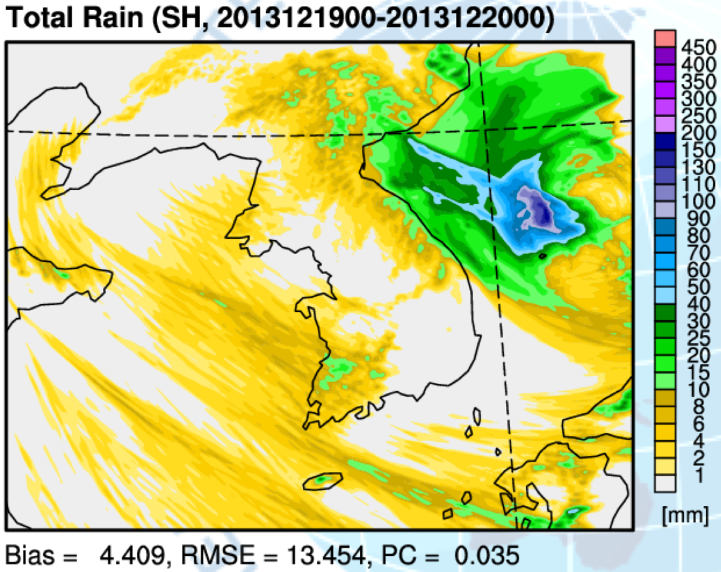
2013.12.20 00 UTC





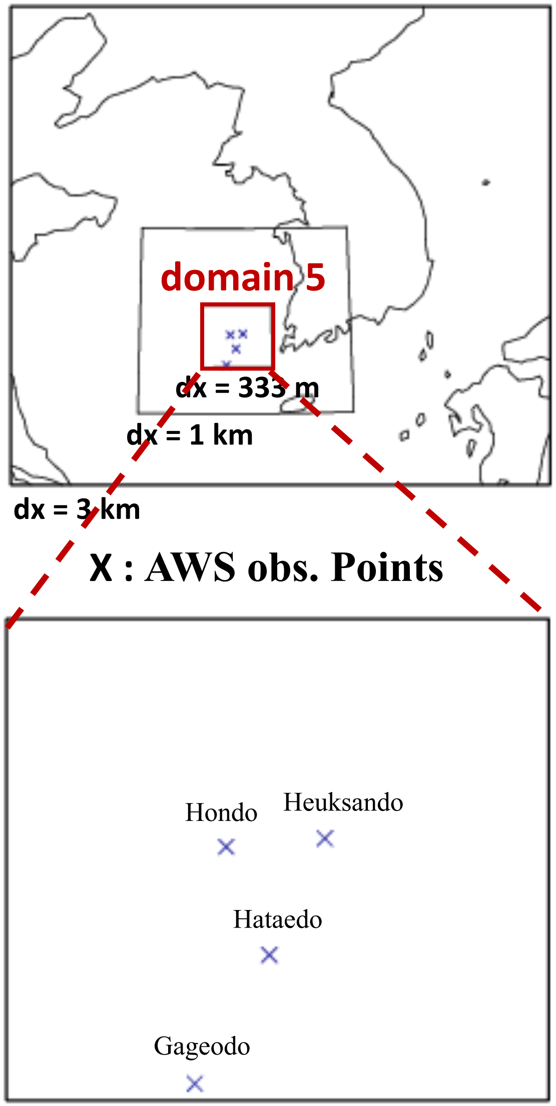


Precipitation

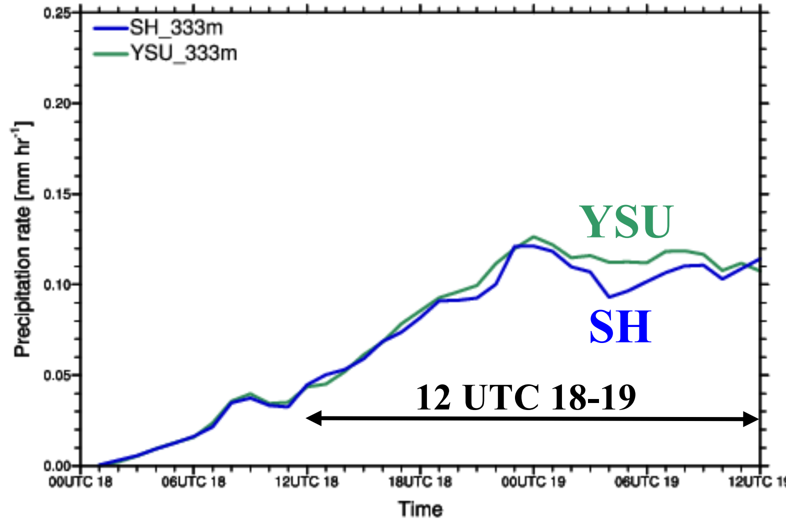
	Observation	Simulation : SH_3km
Precipitation rate (2013.12.19-20)		
24h-accumulated precipitation (2013.12.19-20)		

KIAPS

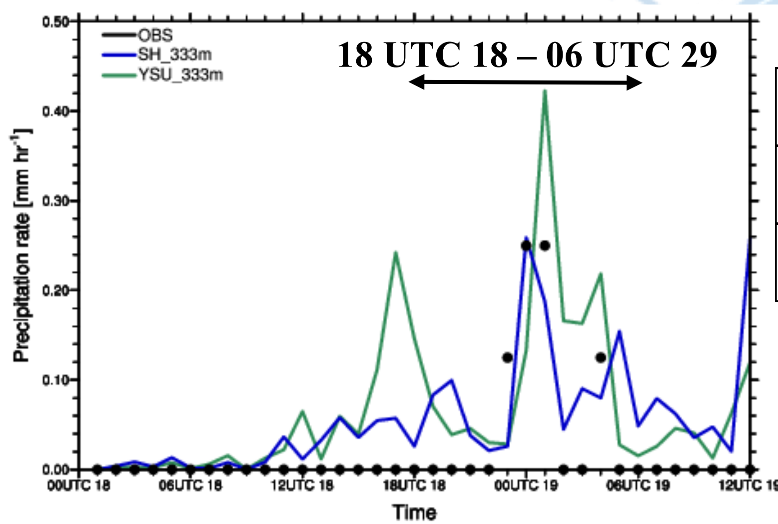
Time series of precipitation (dx = 333 m)



Average over domain 5



Average over observation points

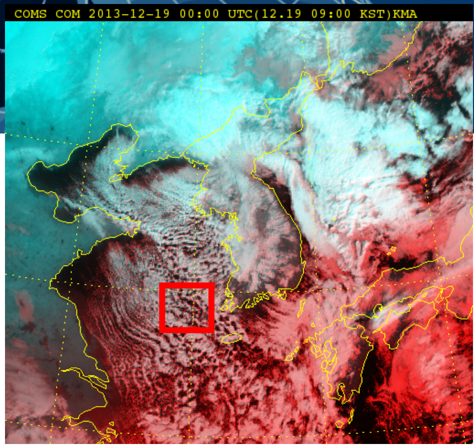


12-hr accumulation
(18 UTC 18 – 06 UTC 29)

OBS	0.75 mm
SH_333m	1.11 mm
YSU_333m	1.49 mm

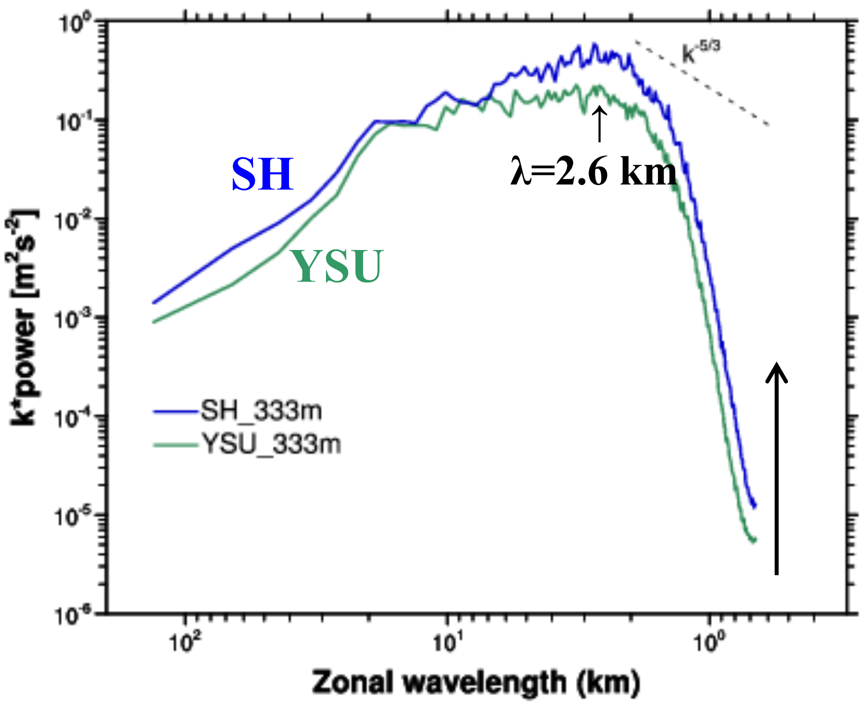
KIAPS

W at 950 hPa (dx = 333 m)

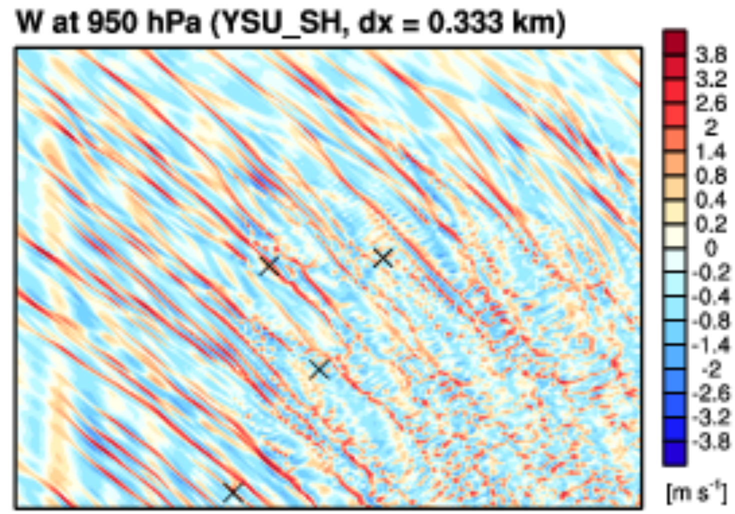


00 UTC 19 Dec 2013

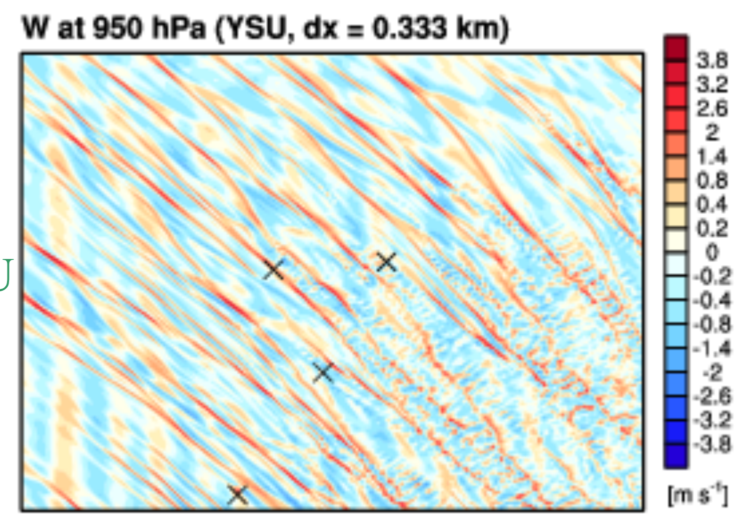
Power spectra of W



SH



YSU



X : AWS obs. points

YSU → SH at dx = 333m: Power ↑

YSU → SH: vertical velocity ↑

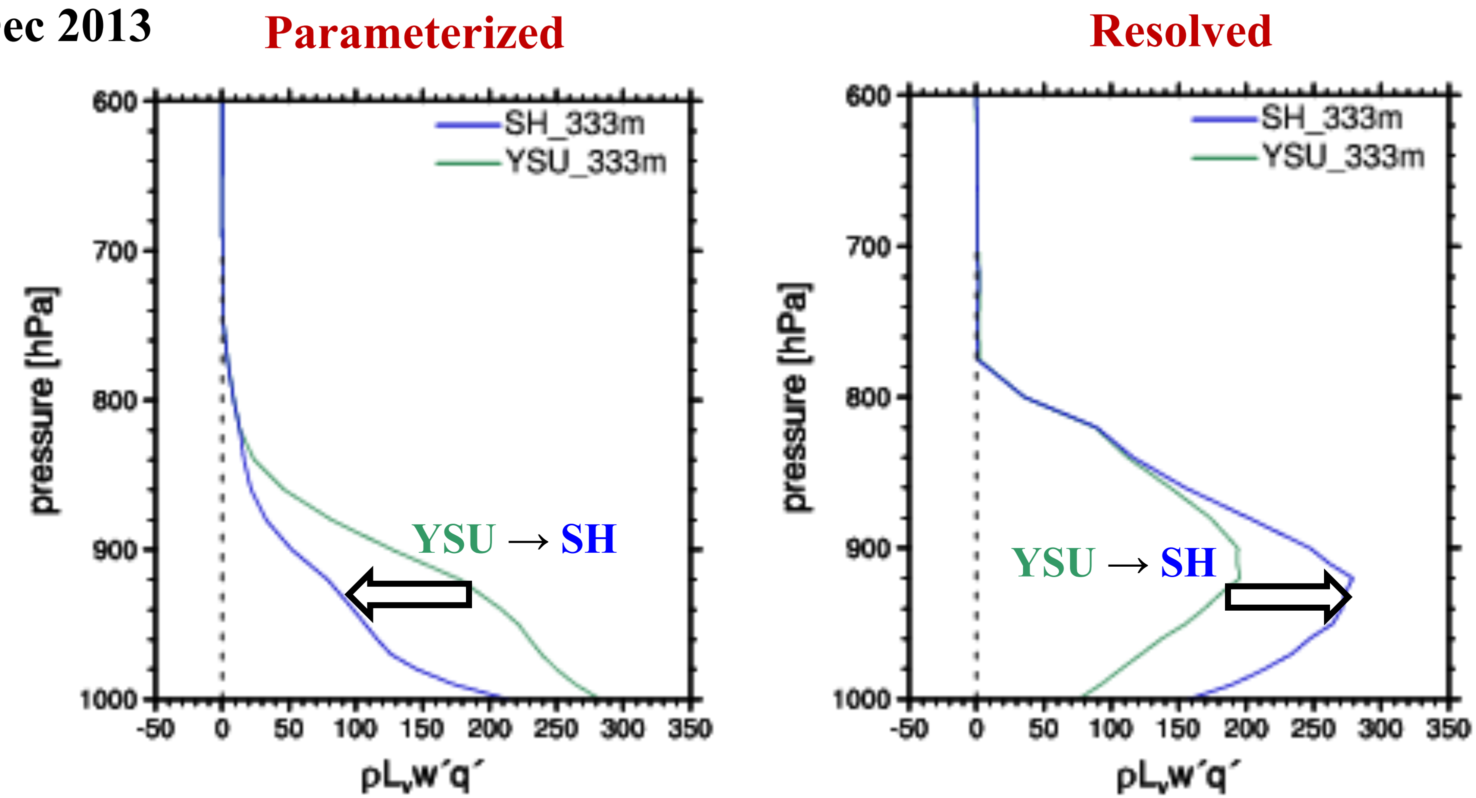
KIAPS

Why surface precipitation decreases

in SH over YSU PBL at 333 m ?

Turbulent moisture flux (dx = 333 m)

00 UTC 19 Dec 2013



	Parameterized flux	Resolved flux
YSU → SH at dx = 333 m	Decrease	Increase

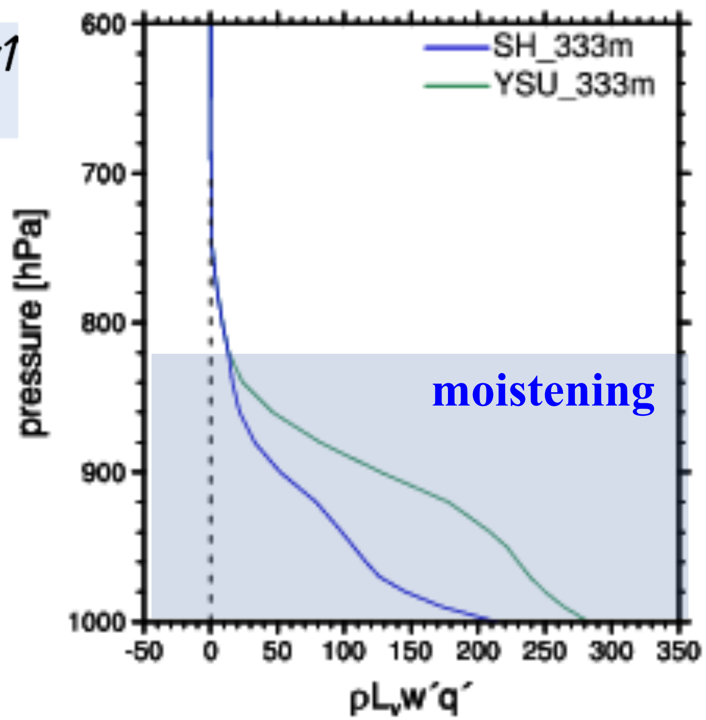
KIAPS

Turbulent moisture flux (dx = 333 m)

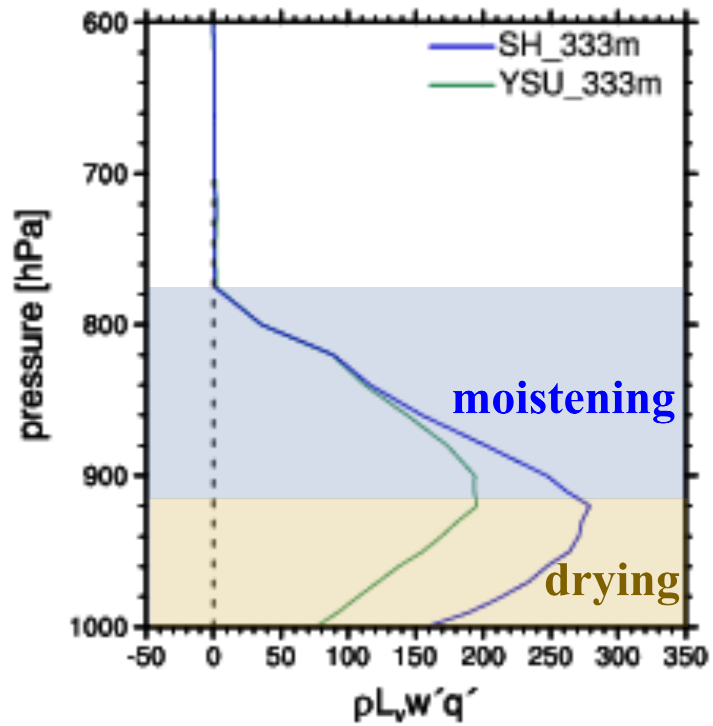
00 UTC 19 Dec 2013

$\partial q/\partial t \sim -\partial w'q'/\partial z$

Parameterized

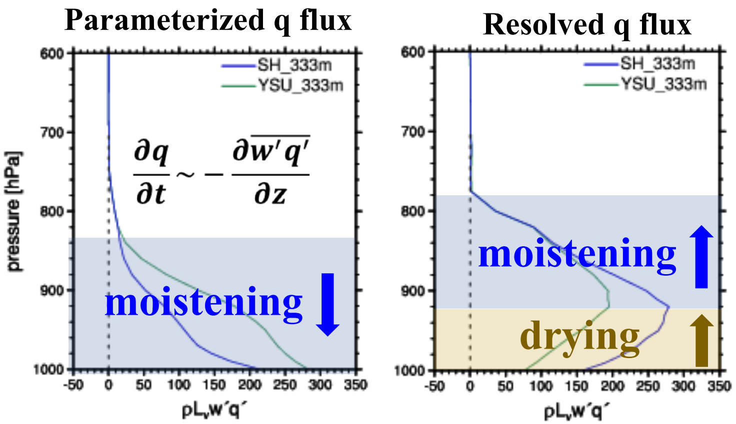


Resolved



	Parameterized flux	Resolved flux
YSU ➔ SH at dx = 333 m	Reduced vertical gradient of moisture flux ➔ Drying	Increased vertical gradient of moisture flux ➔ Drying below ~900 hPa & Moistening above it

Effects on precipitation (dx = 333 m)

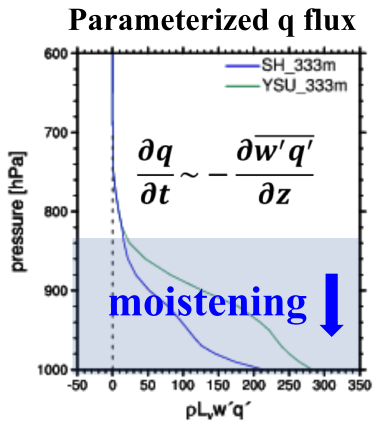


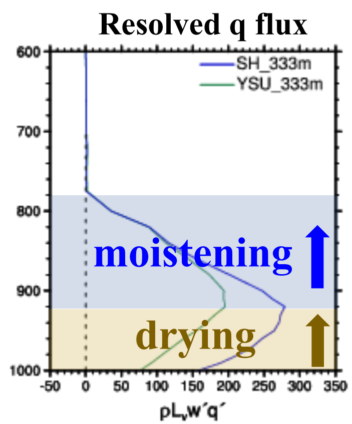
YSU → SH at dx = 333 m

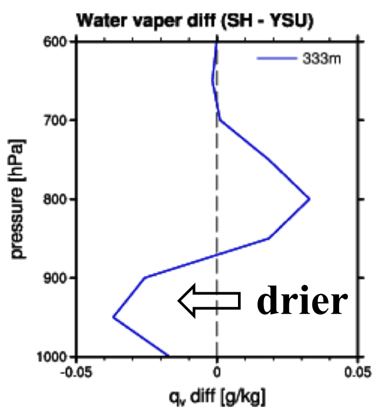
decreased vertical gradient of parameterized moisture flux	increased vertical gradient of resolved moisture flux
↓	↓

stronger vertical mixing of moisture

Effects on precipitation (dx = 333 m)







YSU → SH at dx = 333 m

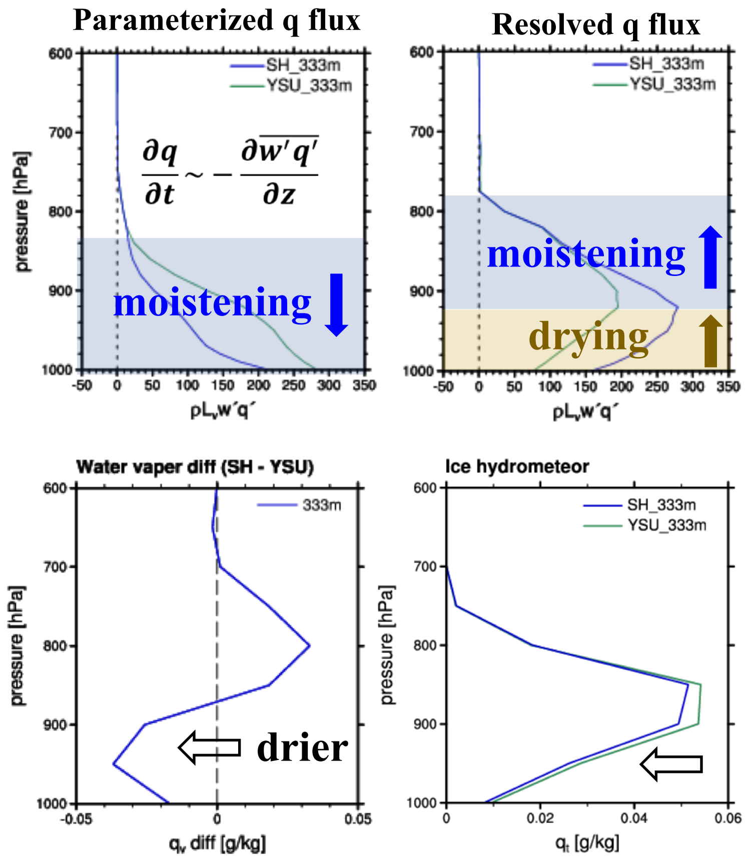
decreased vertical gradient of parameterized moisture flux	increased vertical gradient of resolved moisture flux
↓	↓

stronger vertical mixing of moisture

↓

drier low-levels

Effects on precipitation (dx = 333 m)



YSU → SH at dx = 333 m

decreased vertical gradient of parameterized moisture flux	increased vertical gradient of resolved moisture flux

↓ ↓

stronger vertical mixing of moisture

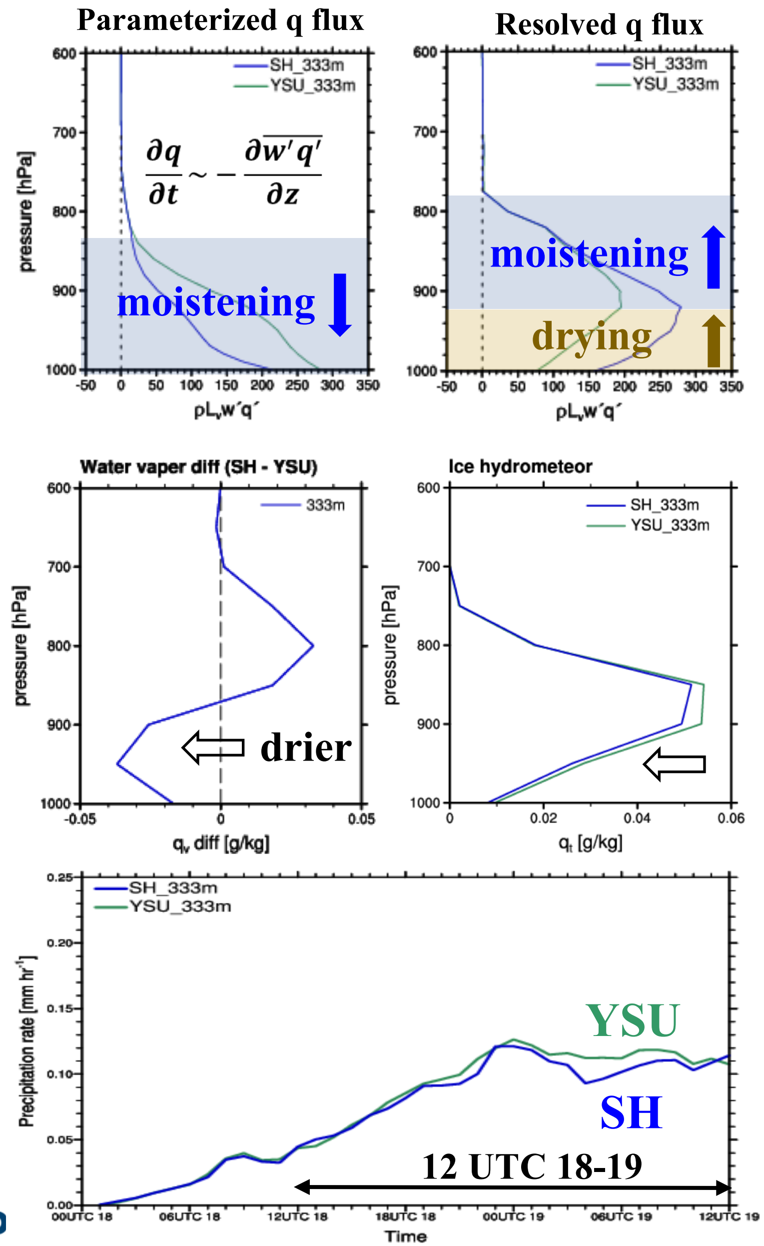
↓

drier low-levels

↓

increased evaporation	decreased ice hydrometeor (mostly snow)

Effects on precipitation (dx = 333 m)



YSU → SH at dx = 333 m

decreased vertical gradient of parameterized moisture flux	increased vertical gradient of resolved moisture flux

↓

stronger vertical mixing of moisture

↓

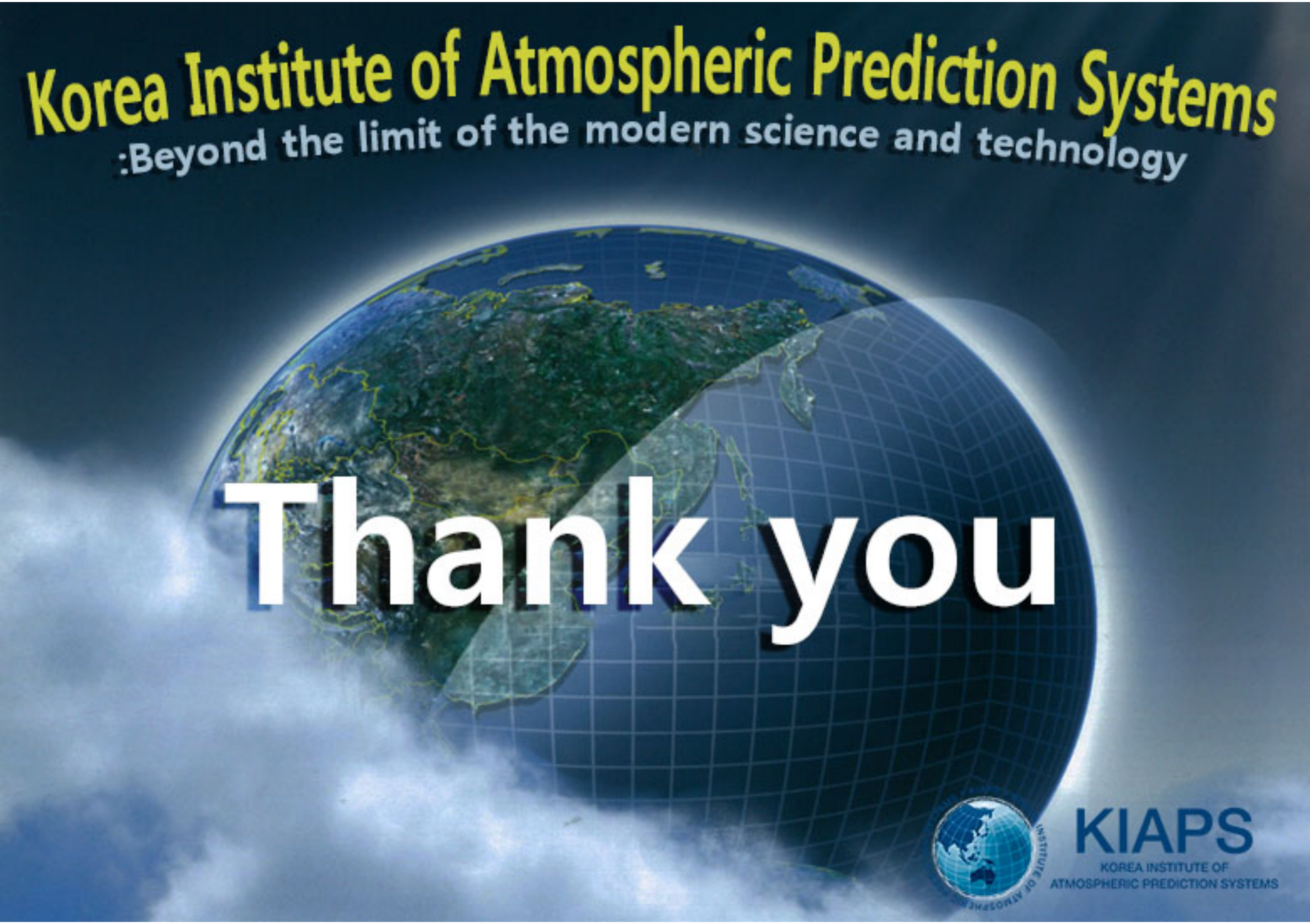
drier low-levels

↓

increased evaporation	decreased ice hydrometeor (mostly snow)
↓	↓
	decreased melting of snow
	↓

decrease in precipitation

KIAP


Korea Institute of Atmospheric Prediction Systems
:Beyond the limit of the modern science and technology
Thank you
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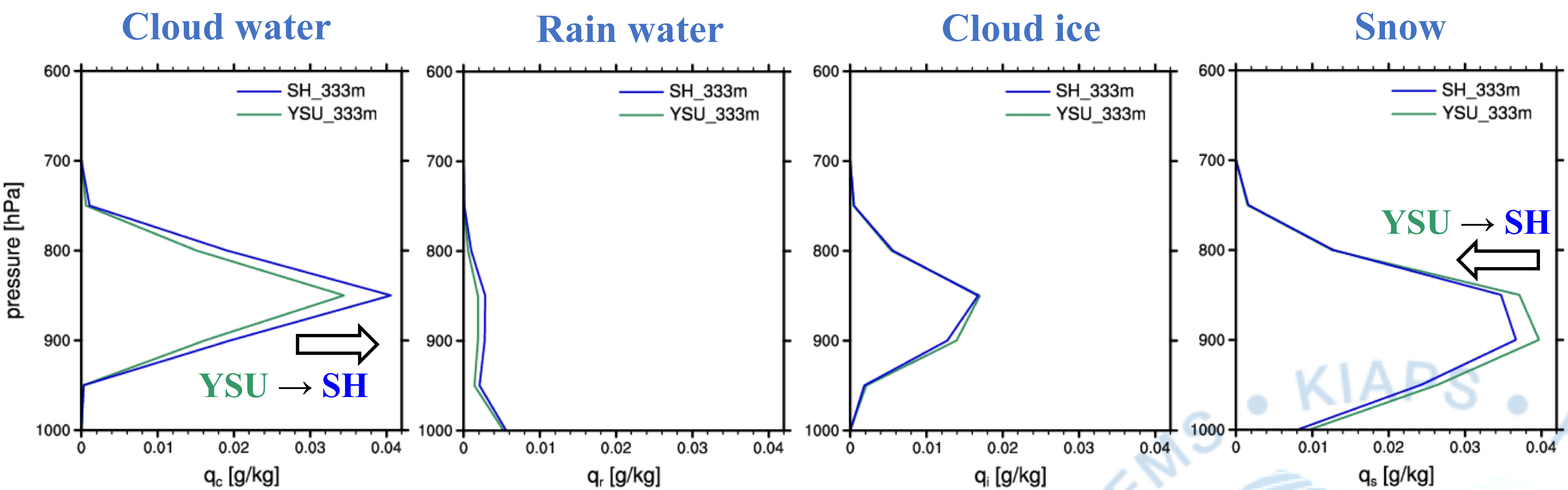
Vertical profile of hydrometers (dx = 333 m)

average over 21UTC 18 to 03UTC 19 Dec 2013



YSU → SH at dx = 333 m

- cloud water increases (snow decreases) more significantly

→ ice particle growth processes are suppressed

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