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Subgrid Orographic Gravity Wave Drag Parameterization for Korea Institute of Atmospheric Prediction Systems (KIAPS) Integrated Model (KIM)

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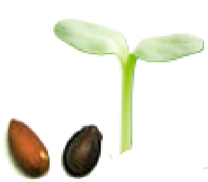
Overview of KIAPS

- **KIAPS was founded at Feb. 15th 2011**
- **Purpose : Developing a next generation global operational model for KMA**
- **Project period : 2011~2019 (total 9 years)**

step1

Foundation and basic research

- Establish the foundation of KIAPS research and development environment
- Efforts on laying out future model development – model dynamics, physics and data assimilation



2011-2013

step2

Release beta version

- Complete developing major model components based on KIAPS own research
- Release the KIAPS beta version model
- conduct semi realtime experiments with KIAPS beta version and evaluate skills to the KMA operational model

2014-2016

step3

Finalize the operational system

- Finalize the KIAPS operational version 1.0 and run on semi-operational basis
- Stabilize the model system by further diagnostics and verifications
- Release the KIAPS system to international users

2017-2019

2011-2015 Major accomplishment

KIM : KIAPS Integrated Model

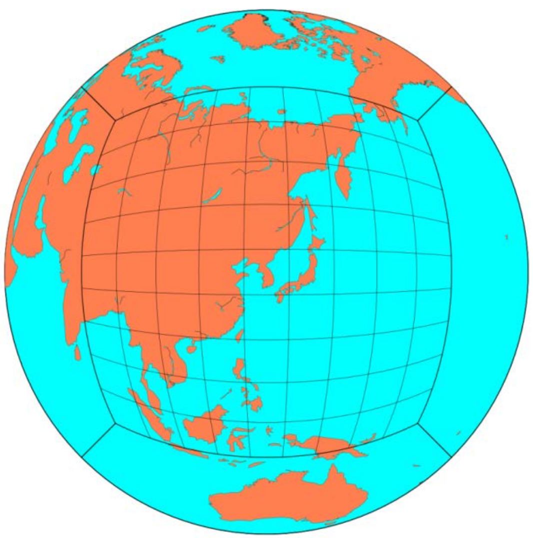
Sonde, Aircraft, SFC
AMSUA, GPSRO, IASI

3DVAR
LETKF

Data	QC	DA	Dynamical core Physics components	Verification Analysis

3D Hydro & Non-hydro over cubed sphere grid

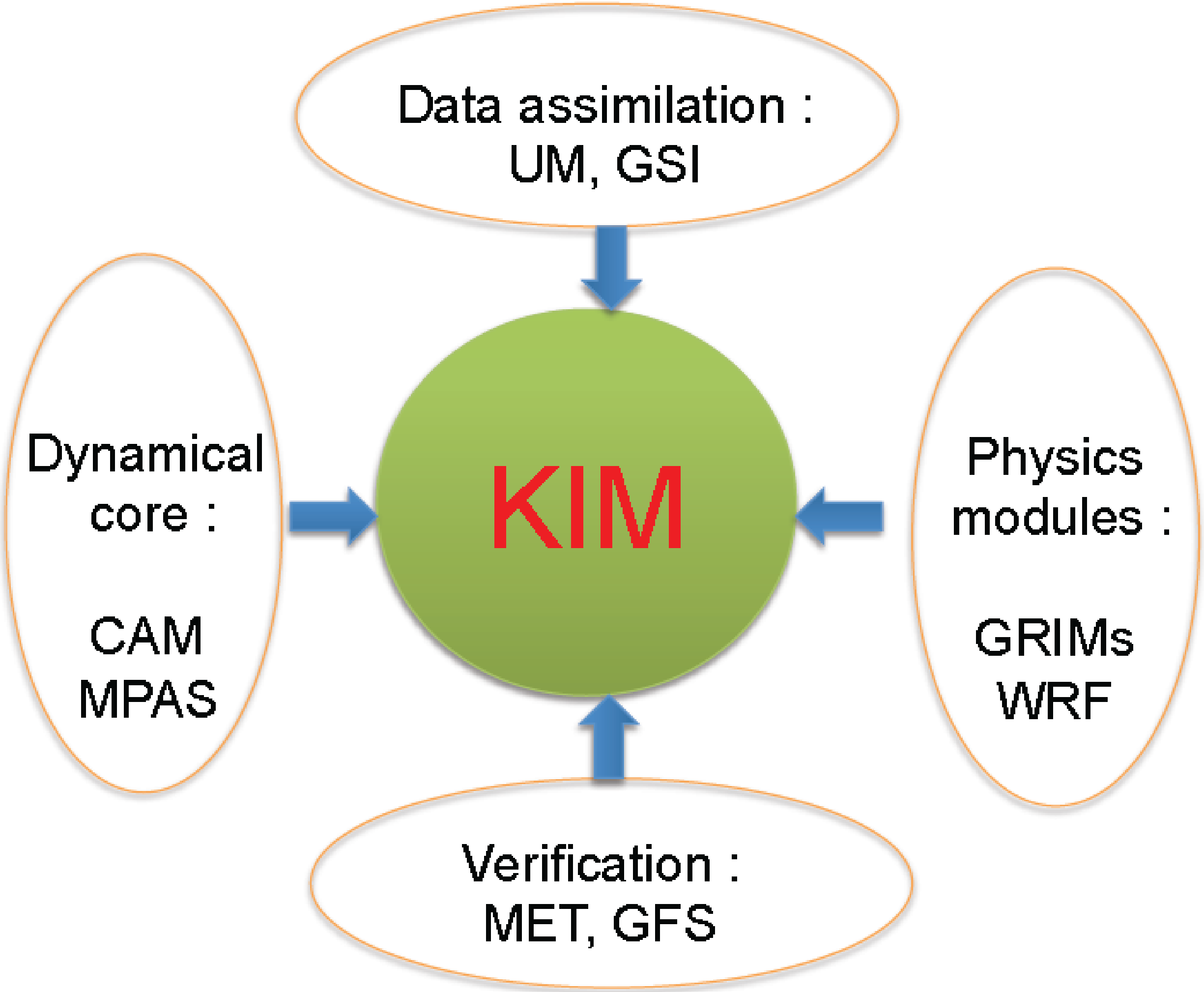
Evaluation and feedback to model



Setup the standard physics package
Develop the advanced physics modules

Reference models

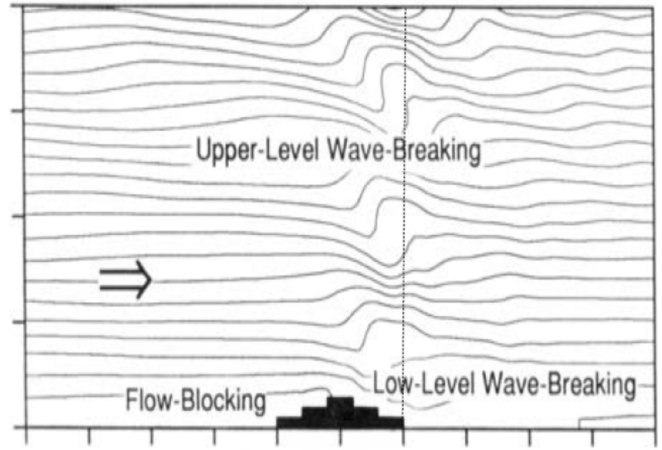
KIM : KIAPS Integrated Model



❖ GRIMs: Global/Regional Integrated Model system (Hong et al. 2013)

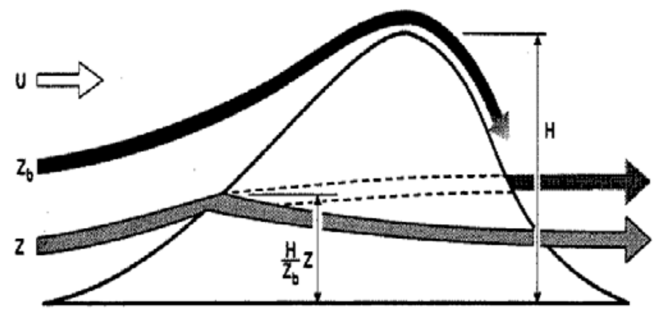
Introduction

- The parameterization of the **effects of subgrid-scale orography** in global numerical weather prediction and climate models is crucial for successful weather and climate predictions (e.g., Palmer et al., 1986; Miller et al., 1989)
- **Subgrid orographic parameterizations (SOPs)** describe the transport of momentum induced by subgrid-scale orography to large-scale flow



Kim and Doyle (2005)

- **Subgrid orographic drag**
  - ✓ **Drag due to upper-level GW breaking (GWD)**
    - The GWs generated by flow over mountains propagate vertically and produce drag at upper levels when breaking
  - ✓ **Drag due to low-level wave breaking**
    - The low-level breaking and trapped lee waves downstream can enhance drag in the lower troposphere
  - ✓ **Drag due to flow blocking (FBD)**
    - The FBD is forced by flow blocked on the mountain flanks or flowing around the mountain under upstream stable conditions, providing drag near the surface, where the blocking occurs.



Lott and Miller (1997)

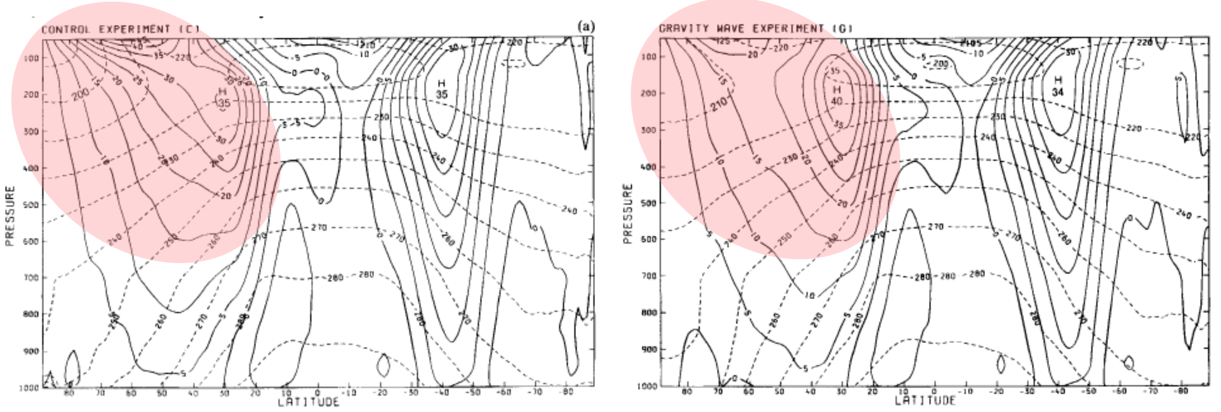
Introduction

At an early stage,

SOPs concentrated mainly on parameterizing the effects of the upper-level GWD and were based on the two-dimensional (2D) linear GW theory for an idealized mountain (e.g., Boer et al., 1984; McFarlane, 1987)

Without GWD **With GWD**

January



Palmer et al. (1986)

Since then,

SOPs have been improved to include more sophisticated orographic effects, such as the aforementioned low-level wave breaking (e.g., Kim and Arakawa, 1995; Hong et al., 2008) and flow blocking (e.g., Lott and Miller, 1997; Scinocca and McFarlane, 2000; Webster et al., 2003; Kim and Doyle, 2005), as well as orographic specifications, such as orographic anisotropy (e.g., Gregory et al., 1998; Scinocca and McFarlane, 2000; Kim and Doyle, 2005)

Purposes

- **The sugrid orographic parameterization (SOP)** from Hong et al. (2008) based on Kim and Arakawa (1995) implemented in the Global/Regional Integrated Model system (**GRIMs**), which is the reference model in developing/revising physics components for KIAPS Integrated Model (**KIM**), **is updated**

Gravity wave drag (GWD), drag due to low-level wave breaking

in the 2-D framework

+

Orographic anisotropy

Flow-blocking drag

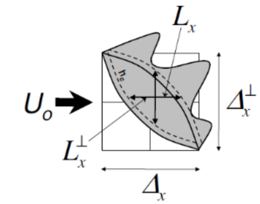
in the 3-D framework

- The impacts of the updated SOP on **short-range forecast** are investigated for a heavy snowfall event over East Asia
- The parameterization is statistically evaluated based on the skill of **medium-range forecasts**.
- The impacts on **seasonal simulations** are examined during a boreal winter

Subgrid Orographic Parameterization (SOP): Orographic GWD (OGWD) parameterization

- **Orographic GW stress at reference level** (Hong et al., 2008/Kim and Arakawa, 1995)

$$\boxed{\tau_{\mathrm{GWD}} = \rho_0 E \frac{m}{\lambda_{\mathrm{eff}}} G \frac{|U_0|^3}{N_0}} \quad \mathrm{E} \equiv (OA+2)^{C_E Fr_0/Fr_c} \quad m \equiv (1+L_x)^{OA+1} \quad G \equiv \frac{Fr_0^2}{Fr_0^2 + C_G OC^{-1}}$$



- To include **effects of orographic anisotropy** the **orographic direction** (OD), which is equivalent to the horizontal aspect ratio of the orography, is introduced according to Kim and Doyle (2005)

$$OD \equiv \frac{L_x^{\perp}}{L_x}$$

- The (inverse) **Froude number** is redefined through multiplication with OD
- h: orographic height ($\equiv \sigma_h$), σ_h : **standard deviation of orography**

$$Fr_0 \equiv h \frac{N_0}{U_0} OD$$

- E: enhancement factor for representing the **nonlinear enhancement of drag due to the low-level wave breaking**, which is calculated by the **orographic asymmetry** (OA) representing the shape and location of subgrid-scale orography relative to the grid and the Fr_0 normalized by its critical value ($Fr_c = 1$)
- m: number of subgrid-scale orography ($\equiv (1+L_x)^{OA+1}$)
- G: asymptotic function that provides a smooth transition between the non-blocking and blocking cases and includes the effect of **orographic convexity** (OC) corresponding to the vertical orographic aspect ratio
- λ_{eff}: effective grid length, which is used practically as a tuning coefficient
- C_E and C_G are set to 0.8 and 0.5, respectively, based on the mesoscale simulation results

Subgrid orographic data sets are based on the 30 sec USGS orography

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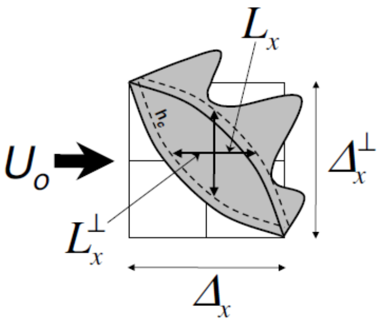
Subgrid Orographic Parameterization (SOP): Flow-blocking drag (FBD) parameterization

- **Flow-blocking stress**

(Kim and Doyle, 2005)

$$\tau_{\mathrm{FBD}} = \frac{1}{2}\rho_0 \frac{m}{\Delta_x^2} C_d \Delta_x^{\perp} L_x^{\perp} h_B |U_0|^2$$



- Follows bulk aerodynamic drag form based in part on scale analysis
- Δ_x^2 : grid box area
- $\Delta_x^{\perp}$: length of large-scale grid in the cross-wind direction
- $L_x^{\perp}$: width of dominant subgrid-scale orography along the cross-wind direction
- **C_d : bulk drag coefficient**
- **h_B : height of blocked layer**

Parameter	Kim and Doyle (2005)	Update
Height of blocked layer (h_B)	$h_B = U_0/N_0\,(Fr_0 - Fr_c)$	According to dividing streamline theory (Snyder et al. 1985) $\int_{h_B}^{H} N^2(z)(H-z)\,dz = \frac{U^2(h_B)}{2}$
Bulk drag coefficient (C_d)	1	According to Lott and Miller (1997) **max(2-1/*OD*,0)** *OD*: horizontal aspect ratio of subgrid orography

* The blocked layer occurs when the potential energy exceeds the kinetic energy

* $C_d \sim 1$ for isotropic orography, $C_d \sim 2$ for flow orthogonal to an elongated orography, $C_d \sim 0$ for flow along the elongated orography.

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Experimental designs

Experiments	CTL	SOP
	Original parameterization (original orographic GWD)	Updated parameterization (**orographic anisotropy + flow-blocking drag**)

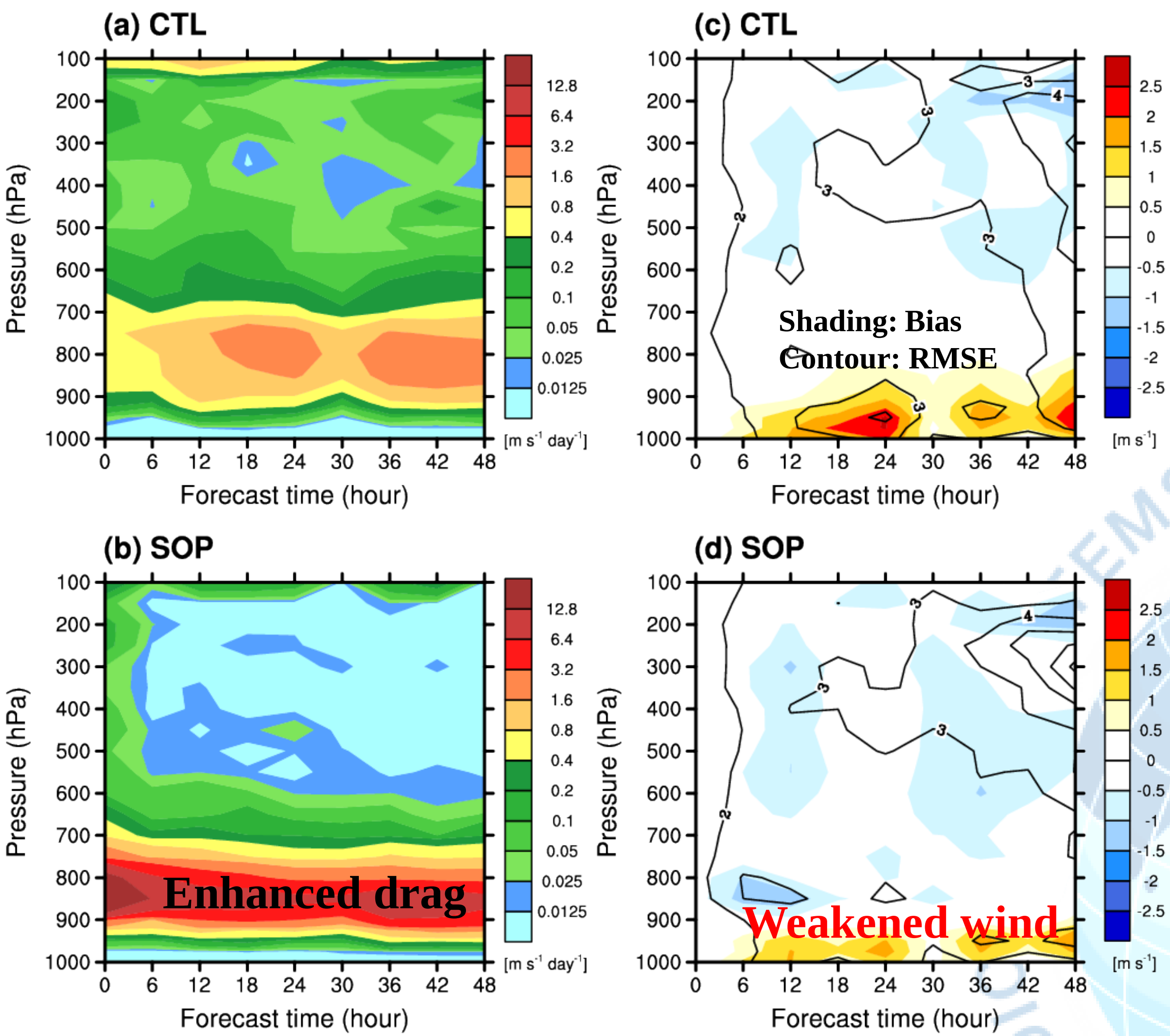
	Short-range forecast	Medium-range forecasts	Seasonal simulation
Period	00 UTC 3-5 Jan. 2010	February 2014	DJF 2013/2014
Case description	Heavy snowfall event over South Korea	Anomalously long-lasting heavy snowfall event	Similar to climatology under the normal SST
Model	GRIMs v3.2.3		
Resolution	T510(~25km) L64(~0.3hPa)	T254(~50km) L64(~0.3hPa)	T126(~100km) L64(~0.3hPa)
Initial time	00 UTC 3 January 2010	Every 00 UTC for February 2014	00 UTC 1-5 November 2013
# of run(ensemble)	1	28	5
Integration	2 days	10 days	4 month (spin-up: 1month)
Initial data	GFS analysis		
Boundary data	GFS analysis		SST: OISST, sea ice: climatology

Impacts on short-range forecasts: Heavy snowfall event (00 UTC 3-5 January 2010)

Subgrid orographic drag | **Wind speed bias and RMSE** | East Asia

CTL

SOP



Shading:
Bias against FNL
Contour:
RMSE against FNL

← **Reduced wind bias and RMSE**

* Drag: $\sqrt{(dU/dt)^2 + (dV/dt)^2}$ (has an opposite sign to the wind)

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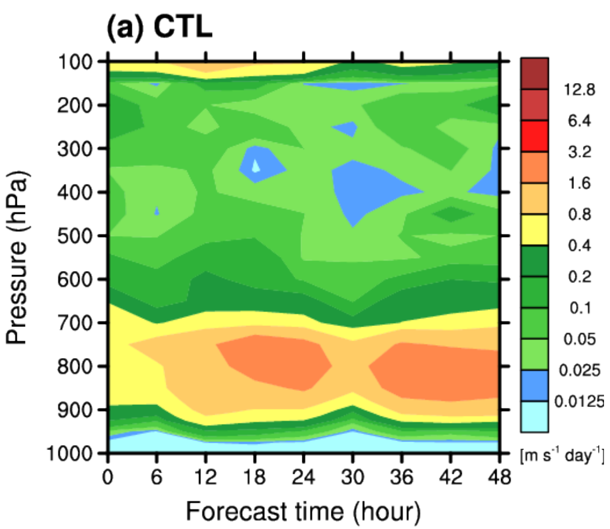
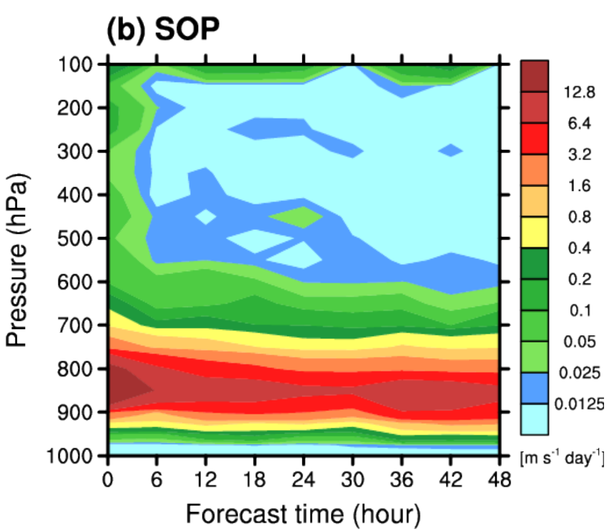
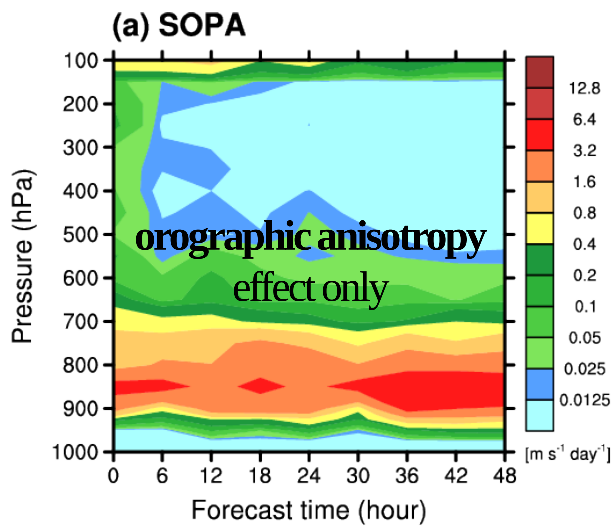
Impacts on short-range forecasts: Heavy snowfall event (00 UTC 3-5 January 2010)

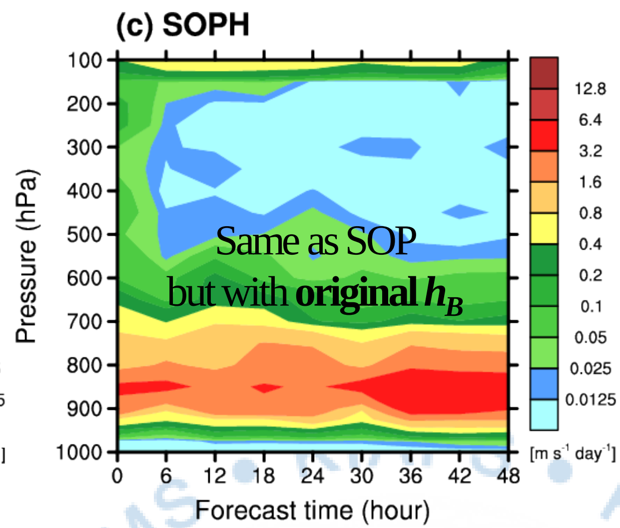
Orographic drag

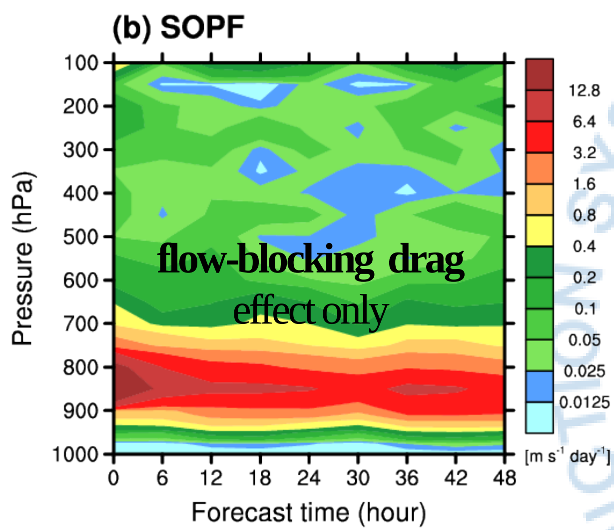
East Asia

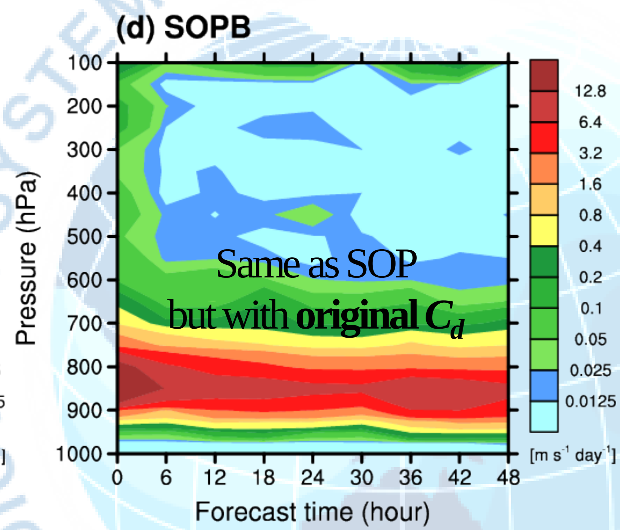












* h_B: height of blocked layer, C_d: bulk drag coefficient

Impacts on short-range forecasts: Heavy snowfall event (00 UTC 3-5 January 2010)

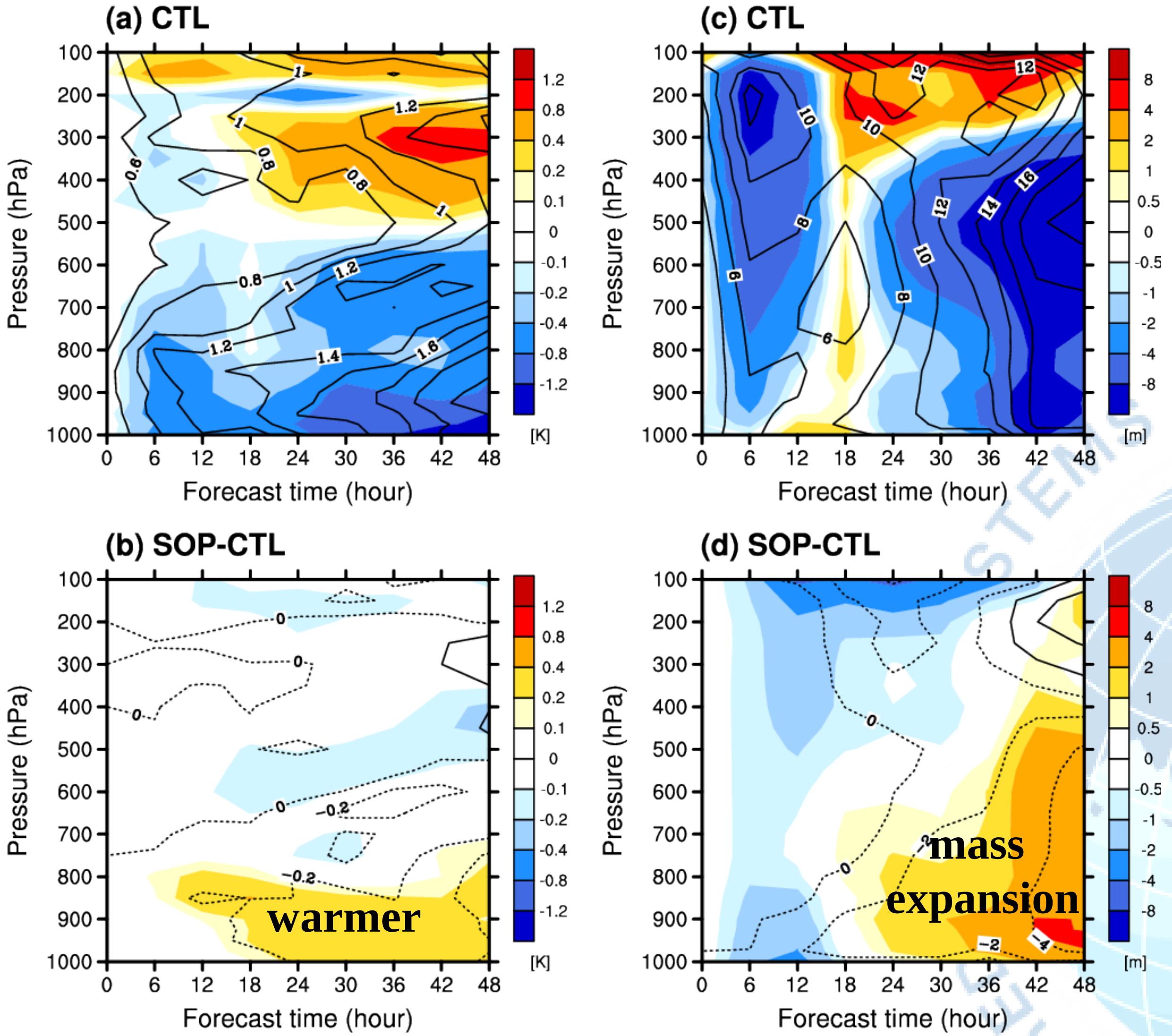
Temperature bias and RMSE

Geopotential height bias and RMSE

East Asia

CTL

SOP-CTL



Shading:
Bias against FNL
Contour:
RMSE against FNL

Shading:
T and GPH differences
Contour:
RMSE differences

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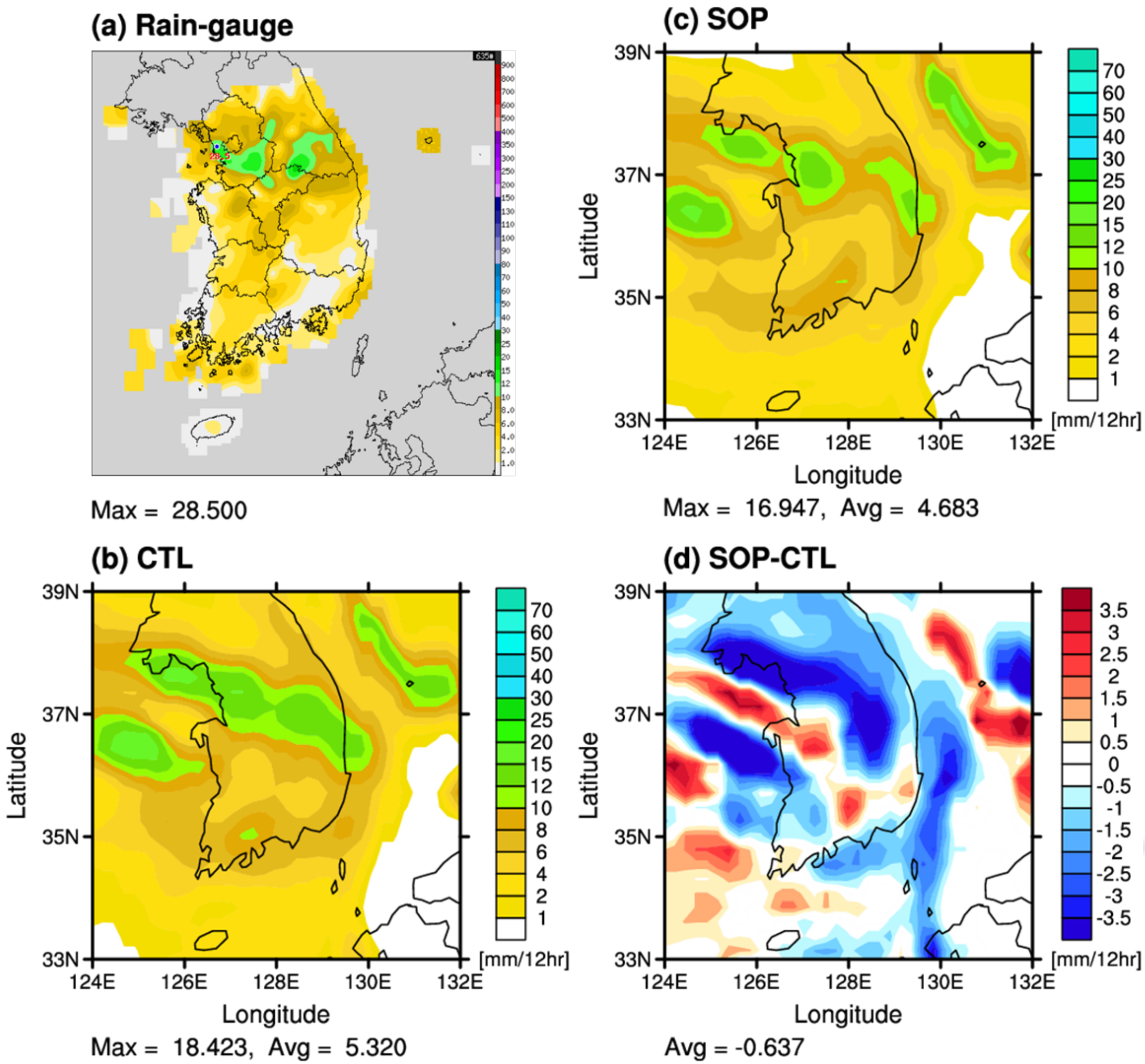
Impacts on short-range forecasts: Heavy snowfall event (00 UTC 3-5 January 2010)

12h-accumulated precipitation rate (18 UTC03-06UTC04 January 2010)



Additional flow-blocking drag

↓

Weakens wind near surface

↓

Decreases turbulent exchange coefficient

↓

Reduces surface heat flux

↓

Reduces snowfall

↓

Improved snowfall overestimation

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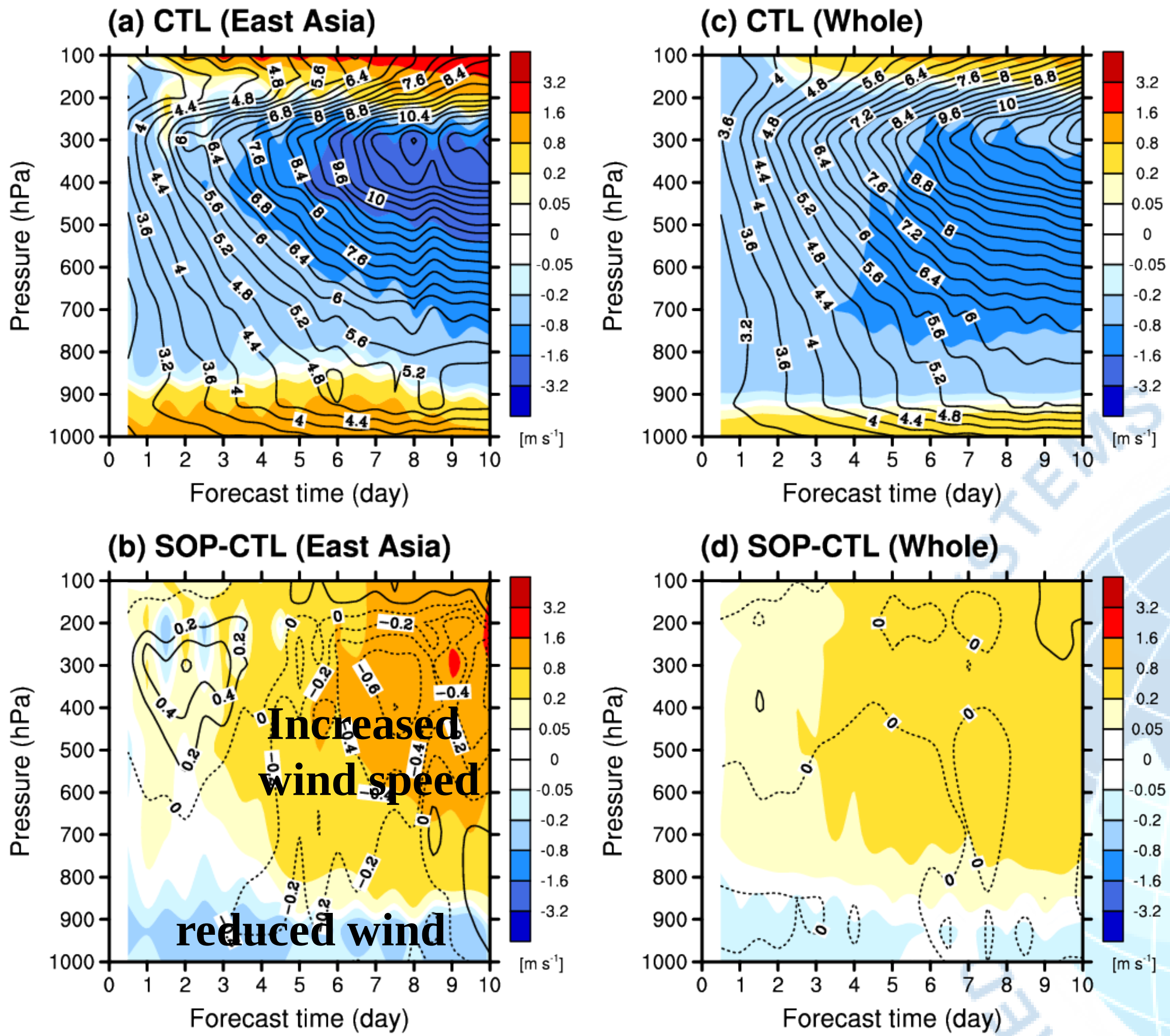
Impacts on medium-range forecasts (average of 10-day forecasts for February 2014)

Verification of wind speed against radiosonde

	East Asia	Whole globe

CTL

SOP-CTL

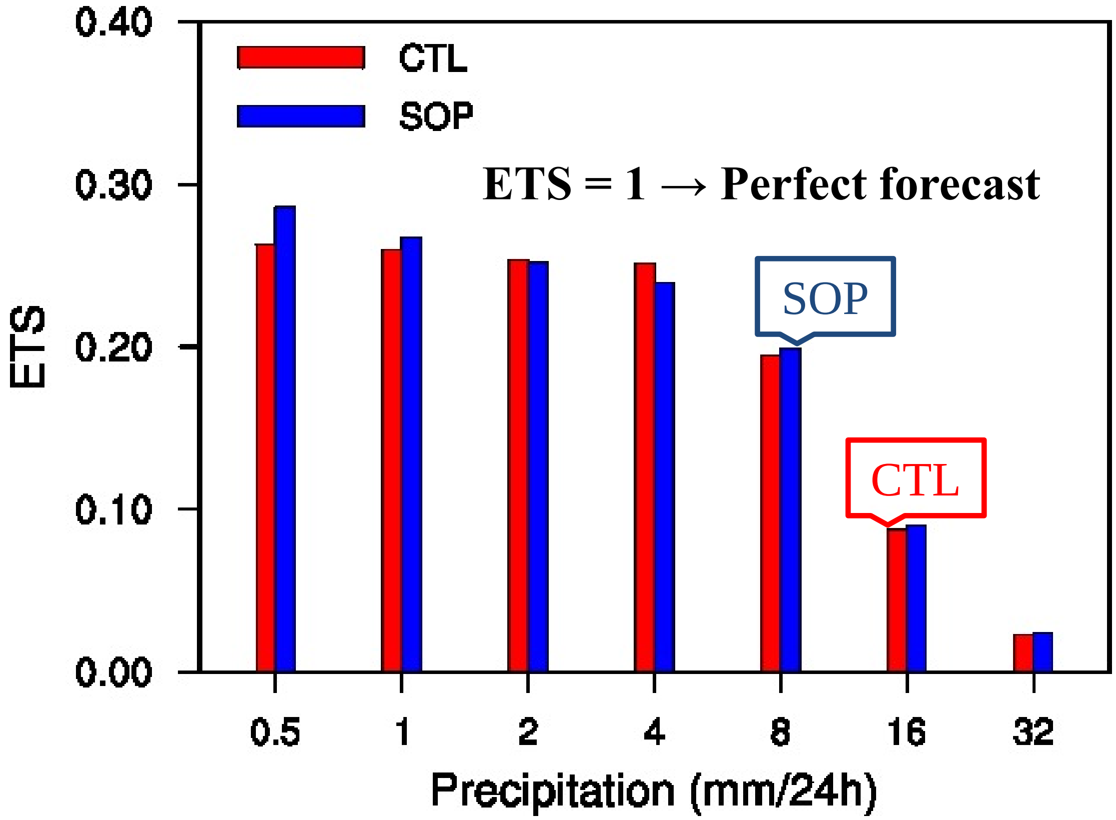


Shading: Bias
Contour: RMSE

Shading: Wind speed differences
Contour: RMSE differences

Impacts on medium-range forecasts (February 2014)

Verification of precipitation against rain gauge over South Korea



Statistical skill of the **equivalent threat scores (ETS)** for 1- to 5-day forecasts

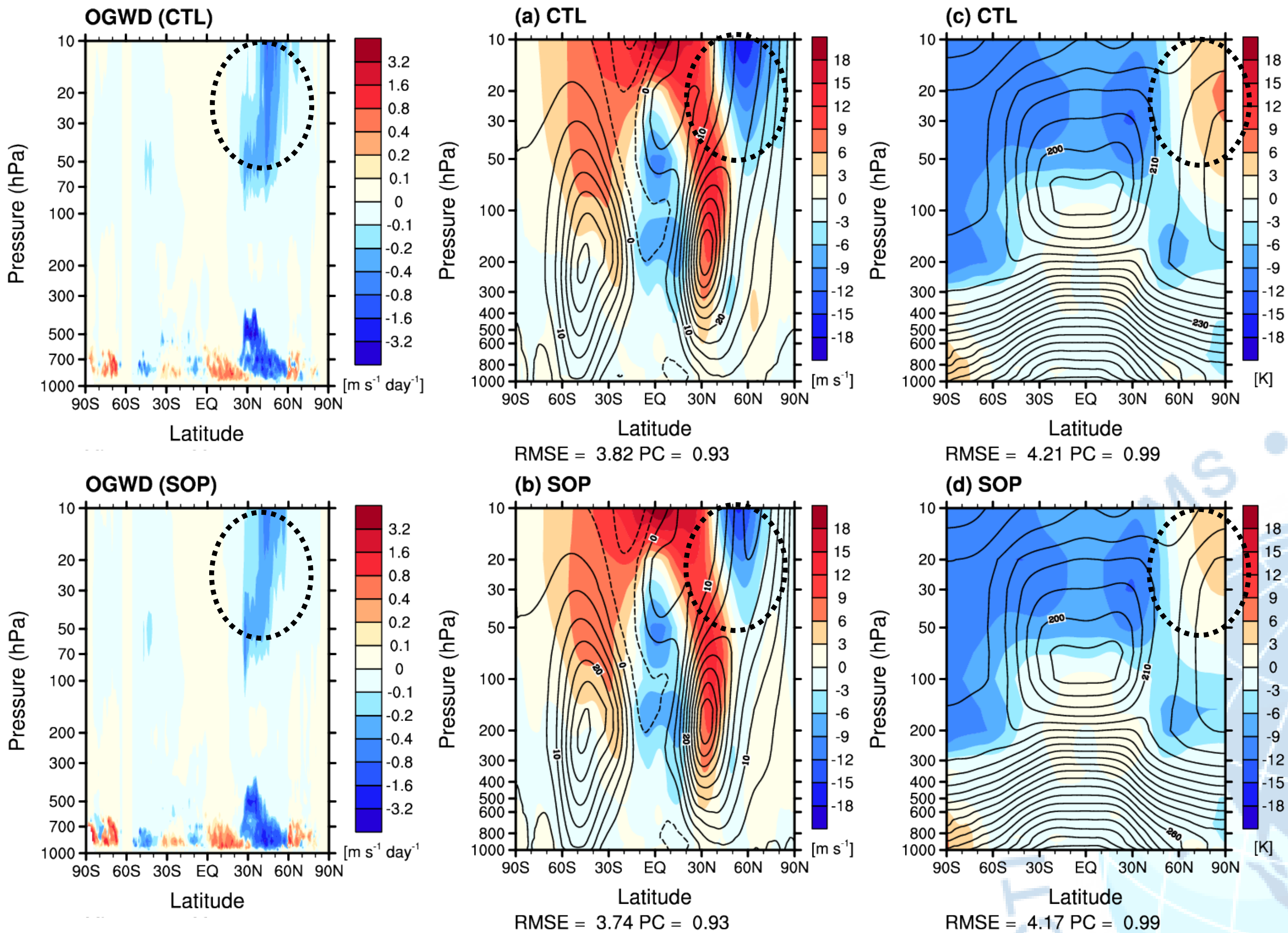
- The equivalent threat scores (ETS) for 28-number forecasts during February 2014 when an anomalously long-lasting heavy snowfall event over South Korea occurred is calculated
- It is found that the skill for the precipitation is mostly improved in the SOP experiment

Impacts on seasonal simulation: DJF 2013/2014

Zonal-mean zonal drag	Zonal-mean U	Zonal-mean T

CTL

SOP



	RMSE	
	U	T
CTL	3.82	4.21
SOP	3.74	4.17

Shading in U and T: Bias against FNL

In SOP: reduced GWD in the winter stratosphere (due to orographic anisotropic effects) → reduced easterly bias (stronger polar night jet) → reduced warm pole bias

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KIAPS Integrated Model (KIM) Semi-real-time

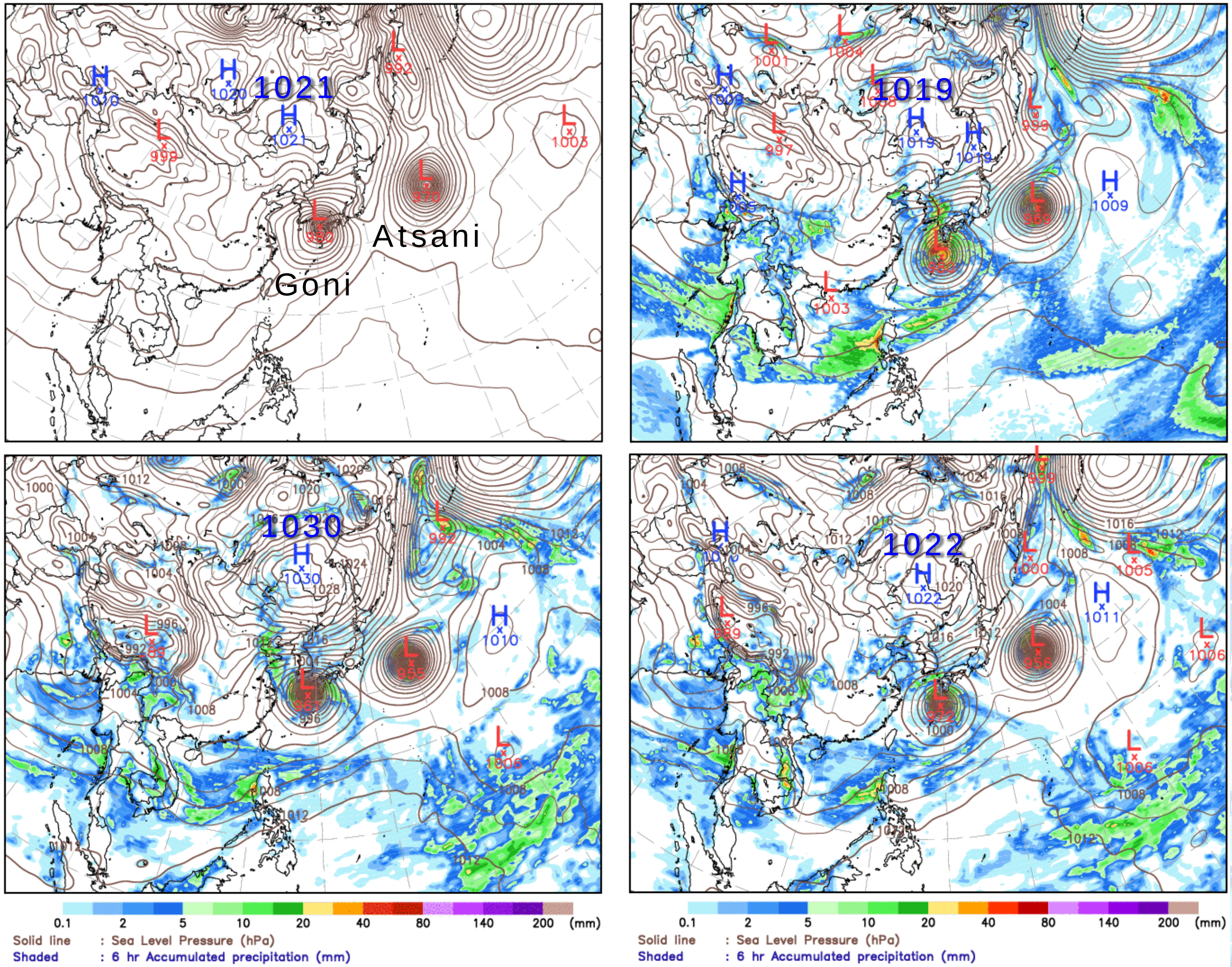
2015082000 + 120 hr: Surface

UM(Anal)

H: 1021
L1: 980
L2: 970

UM(Fcst)

H: 1019
L1: 980
L2: 969



KIM (before SOP update)

H: 1030
L1: 961
L2: 955

KIM (after SOP update)

H: 1022
L1: 972
L2: 956

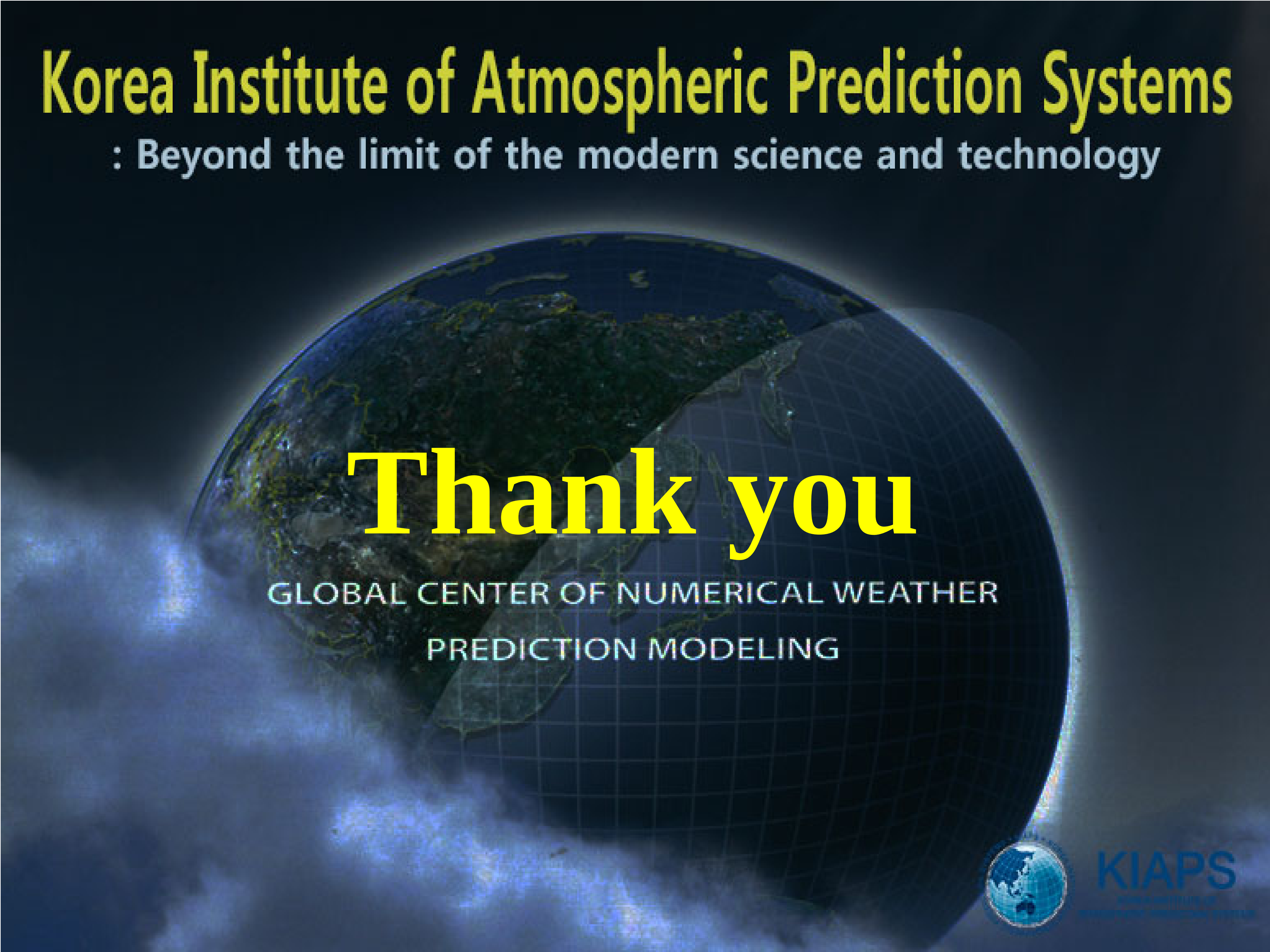
updated subgrid orographic parameterization → improved high pressure system in KIM

Summary

- In this study,
  - ✓ updated the SOP by including the effects of the **orographic anisotropy** and **flow-blocking drag** (FBD)
  - ✓ examined its impact on **short-** and **medium-range** forecasts and **seasonal** simulations during the boreal winter when the effects of SOP are significant

- We found the following characteristics when the SOP is updated
  - ✓ The orographic drag noticeably increases because of the additional flow-blocking drag in the low troposphere.
  - ✓ The enhanced orographic drag directly weakens the wind in the low troposphere and indirectly improves the temperature and mass fields.
  - ✓ The snowfall overestimation over Korea is improved by the reduced heat fluxes from the surface due to the decreased turbulent exchange coefficients, which result from the weakened wind near the surface.
  - ✓ The skill improvements for the medium-range forecasts in terms of the bias and RMSE of the wind speed and temperature are observed globally and for East Asia.
  - ✓ The improvements in the seasonal simulations are found throughout the troposphere and stratosphere during boreal winter.

Choi, H.-J. and S.-Y. Hong, 2015: An updated subgird orographic parameterization for global atmospheric forecast models, *J. Geophys. Res. Atmos.*, **120**, 12,445–12,457, doi:10.1002/2015JD024230.

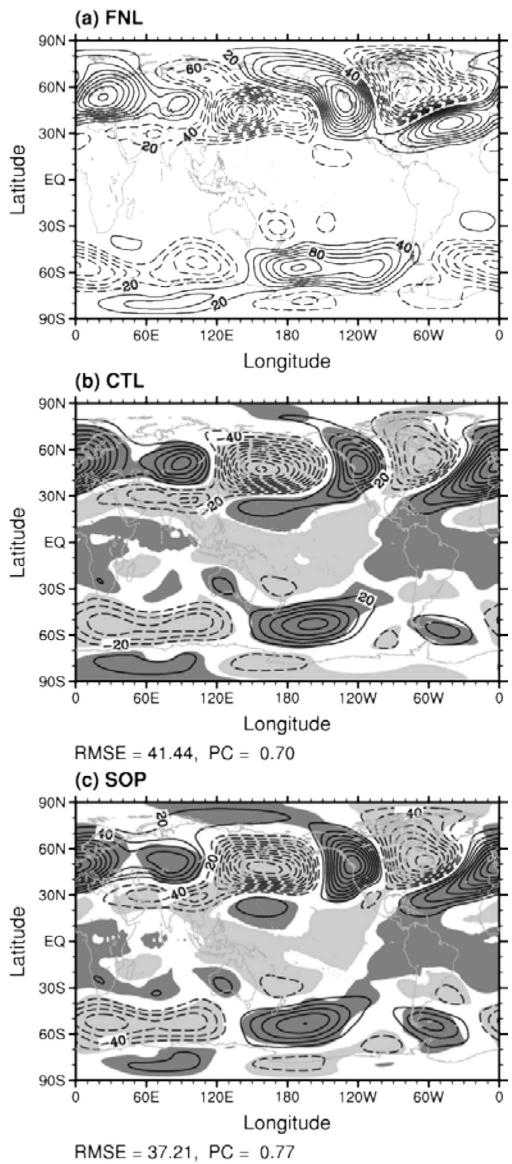

Korea Institute of Atmospheric Prediction Systems
: Beyond the limit of the modern science and technology
GLOBAL CENTER OF NUMERICAL WEATHER
PREDICTION MODELING
KIAPS

Thank you

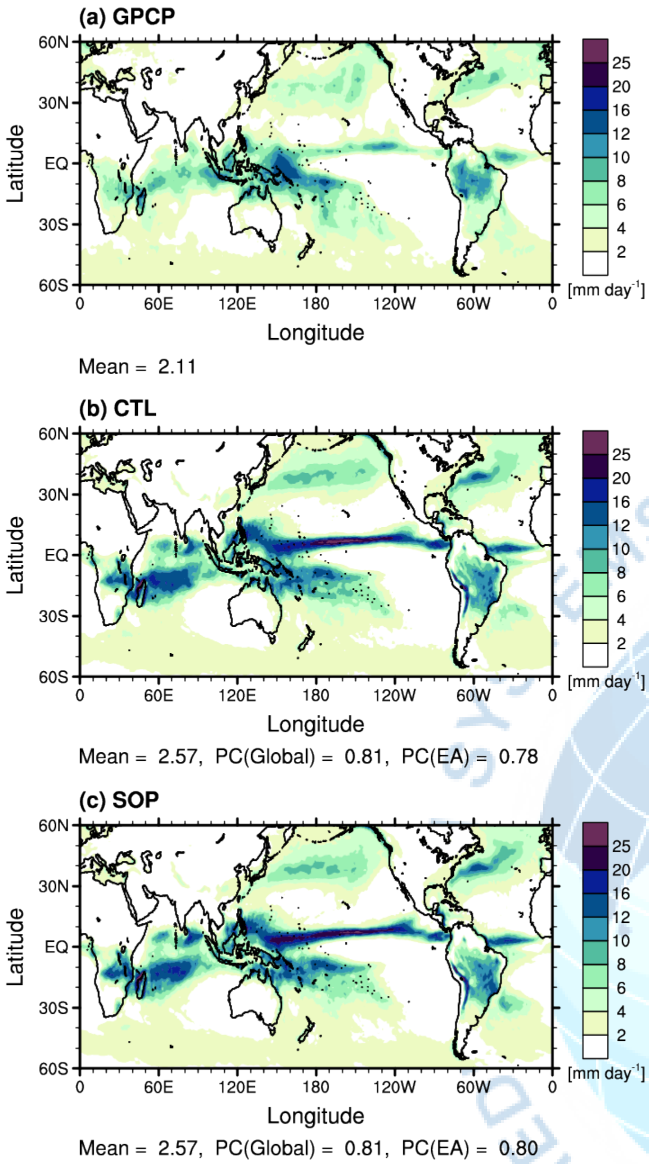
Seasonal simulation: DJF 2013/2014

	PC
CTL	0.70
SOP	0.77

500 hPa GPH eddy



Precipitation



	PC	
	global	EA
CTL	0.81	0.78
SOP	0.81	0.80

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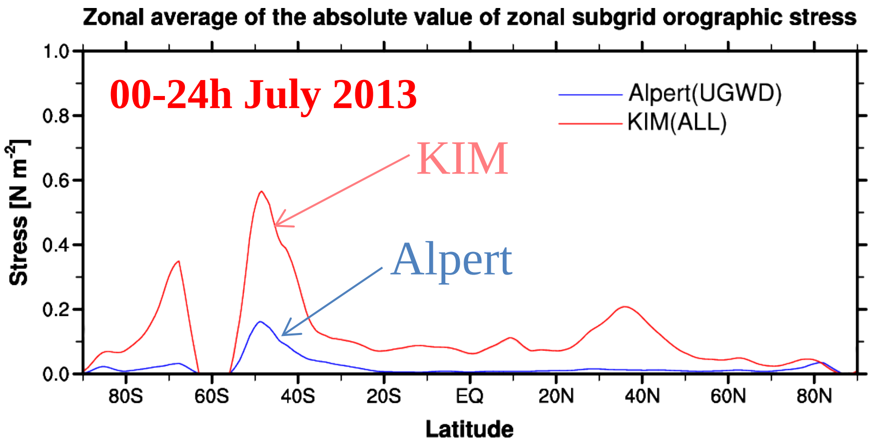
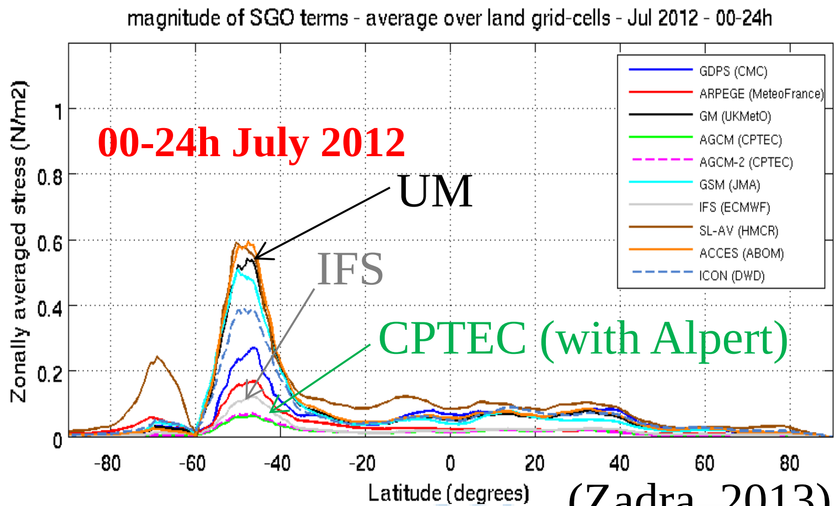
Comparison of subgrid orographic stresses

GRIMs simulations



WGNE inter-comparison



(Zadra, 2013)