Comparison study on Dynamical downscaling using regional model

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Contents

Global model vs. Regional Model

Global model system :

Covers entire Earth surface

Periodic in zonal direction (circulations)

Forecast model system

Regional model system:

Covers Limited area

Boundary condition is needed for integration period

Not a forecast model (as a stand alone model)

Usage of Regional model system:

1. Produce more detailed information from global analysis data set

   (Higher resolution, lower computing costs)

   ➔ "Downscaling"

2. Quasi-Idealized experiments

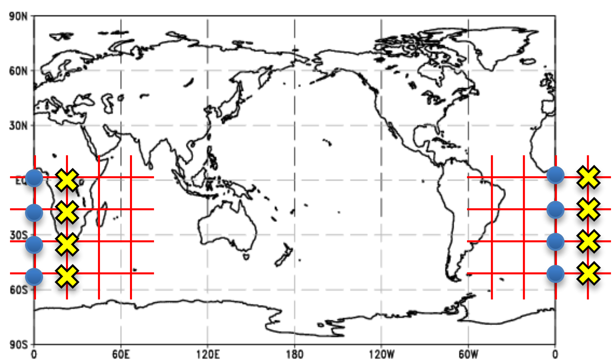
Why a regional model requires boundary conditions?

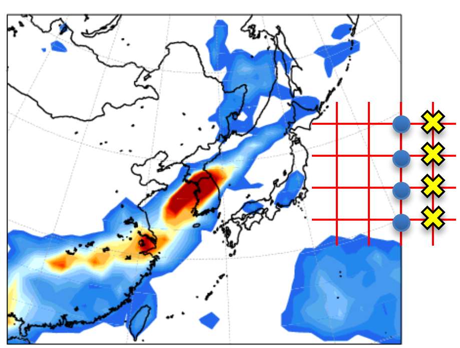
1-D advection equation

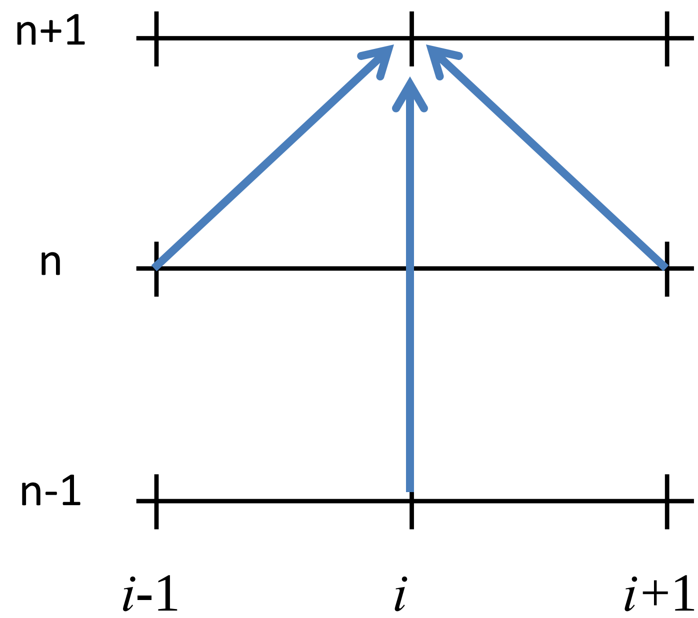
$$\frac{\partial u}{\partial t} + c\frac{\partial u}{\partial x} = 0$$

Discretization : centered for time and space

$$\frac{u_i^{n+1} - u_i^{n-1}}{2\Delta t} + c\frac{u_{i+1}^{n} - u_{i-1}^{n}}{2\Delta x} = 0$$







n : time step

I : space

Impact of lateral boundary conditions on downscaling

Downscaled results with different boundary conditions

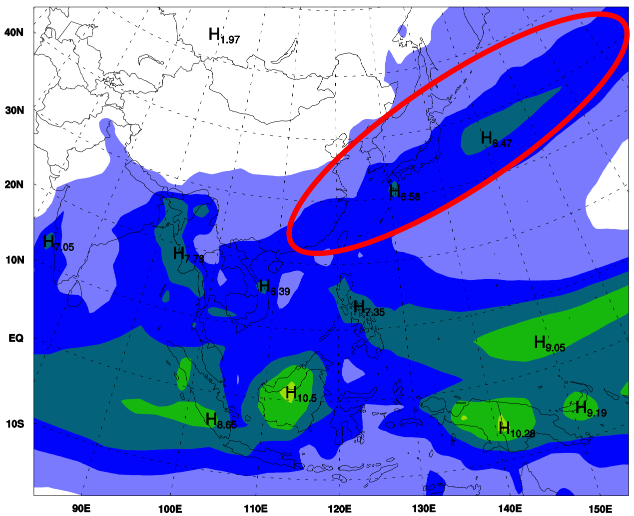
Regional Model : GRIMs RMP

B.Cs. : NCEP-DOE Reanalysis 2

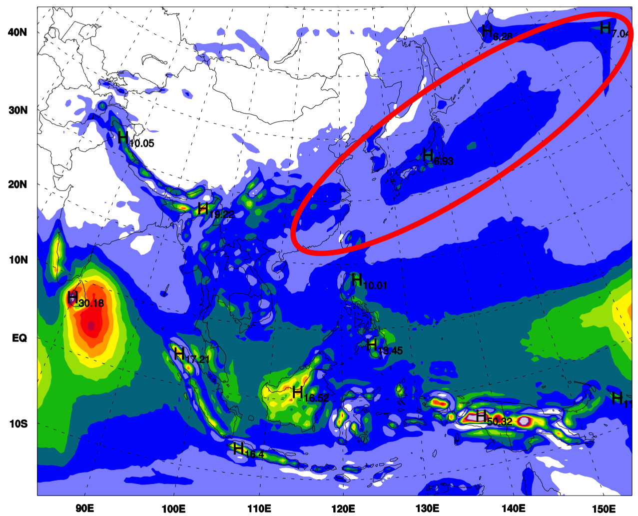
ERA-INTERIM

Annual Mean Precipitation (mm/day) for present 20 years

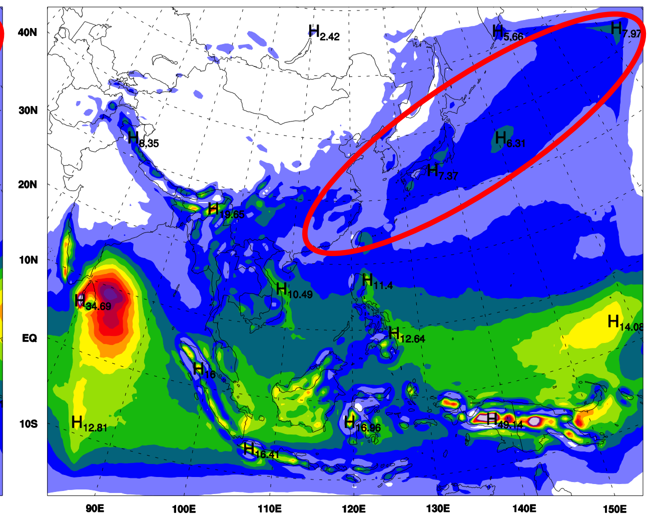
OBS (GPCP)



RMP_RA2



RMP_INT



Garbage in, Garbage out.

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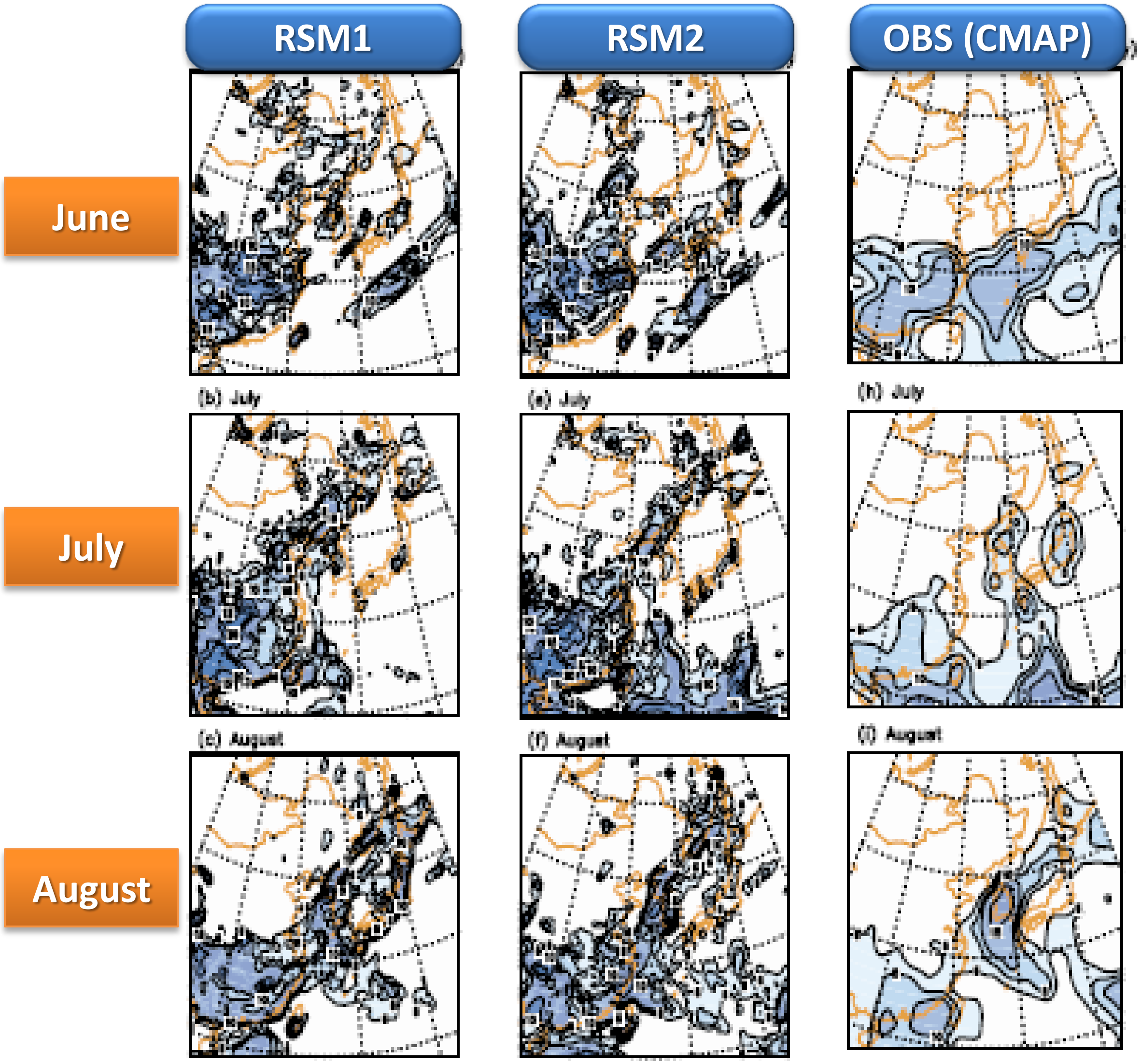
Physics consistency



Regional Model : NCEP RSM

RSM1 : NCEP-NCAR RA1

RSM2 : NCEP-DOE RA2

MRF non-local PBL scheme is used for RSM

NCEP-NCAR uses Louis local PBL scheme.

NCEP-DOE uses MRF non-local PBL scheme.

Using consistent physics of regional model with the physics used to generate B.C. can reduce spin-up and improve downscaling results.

Table 2. Correlation coefficient of simulated precipitation over the model domain (over South Korea)

Code	Coefficient
RSM1	0.45(0.37)
RSM2	0.58(0.41)

High-resolution configuration

What are we expecting from high-resolution downscaling?

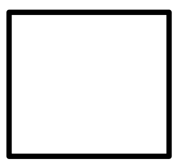
Precipitation algorithms (CPS and MPS)

In real atmosphere, dynamical motion → RH > 1 → clouds form → produces rain

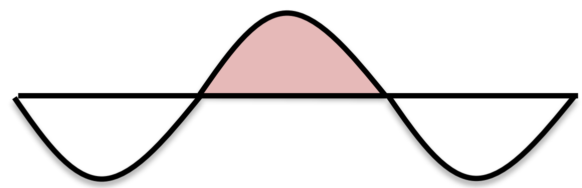
In modeled atomsphere, RH < 1

But generate clouds by releasing CAPE → requires parameterized precip. process

Deep convection : 1~10km



$\overline{RH} < 1$



$\Delta x \rightarrow 0$, more grid-resolvable precipitation

Thus, we need the cumulus parameterization scheme to account for releasing conditional instability due to subgrid scale motion

- Grid-resolvable, explicit, large-scale, cloud, microphysics: Supersaturation → clouds
- Subgrid scale, implicit, cumulus parameterization, parameterized convection, deep convection: Convectively unstable → clouds

Precipitation components

Total precipitation = **Convective precipitation** + **Large-scale precipitation (Non-convective)**

Convective precipitation: Sub-grid scale, implicit precipitation from convective parameterization (deep convection)

Large-scale precipitation (Non-convective): Grid resolved scale, explicit precipitation process. supersaturation (RH>1) forms cloud → produce rain (Cloud microphysics)

Convective Rain Ratio (CRR)

: CRR = Convective Rain / Total Rain

Large CRR : higher possibility of heavy rainfall

Clim Dyn
DOI 10.1007/s00382-013-1841-6

Assessment of future climate change over East Asia due to the RCP scenarios downscaled by GRIMs-RMP

Ji-Woo Lee · Song-You Hong · Eun-Chul Chang · Myoung-Seok Suh · Hyun-Suk Kang

Horizontal Resolution

RMP : 50 km

HG2 : 1.875° × 1.25°

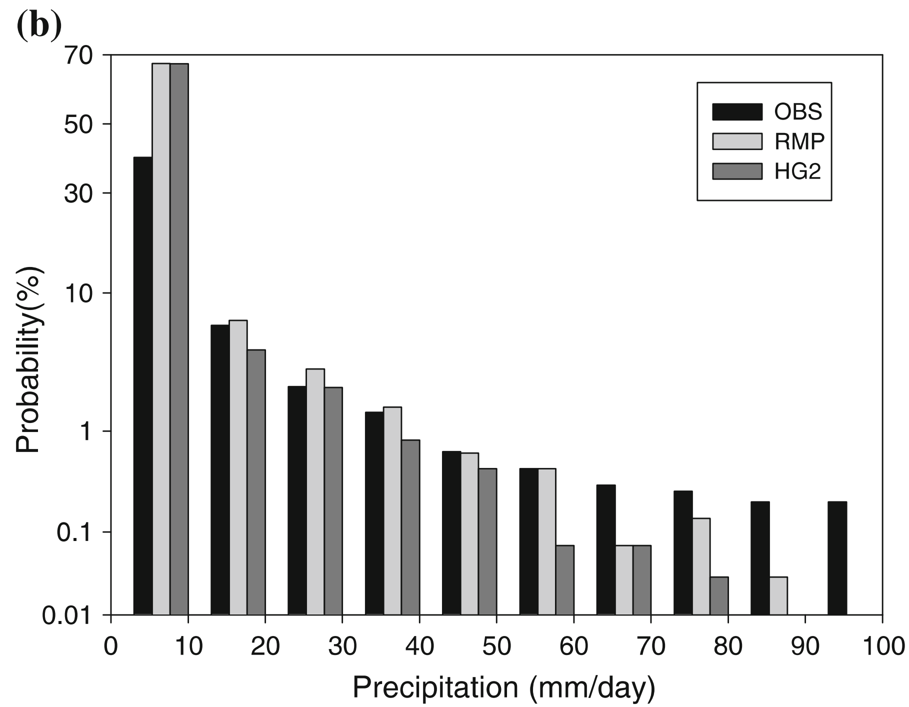


Fig. 5 **a** Number of heavy rainfall occurrences (over 40 mm d^{-1}) in JJA, and **b** probability distribution of domain-averaged precipitation in the period of 1998–2005, obtained from the TMPA observation (OBS), RMP and HG2 for the South Korean region. Note that R and S in (**a**) refer to mean and standard deviation, respectively

Theor Appl Climatol
DOI 10.1007/s00704-013-1034-6

ORIGINAL PAPER

Potential for added value to downscaled climate extremes over Korea by increased resolution of a regional climate model

Ji-Woo Lee · Song-You Hong

Precipitation

Temperature 2-m

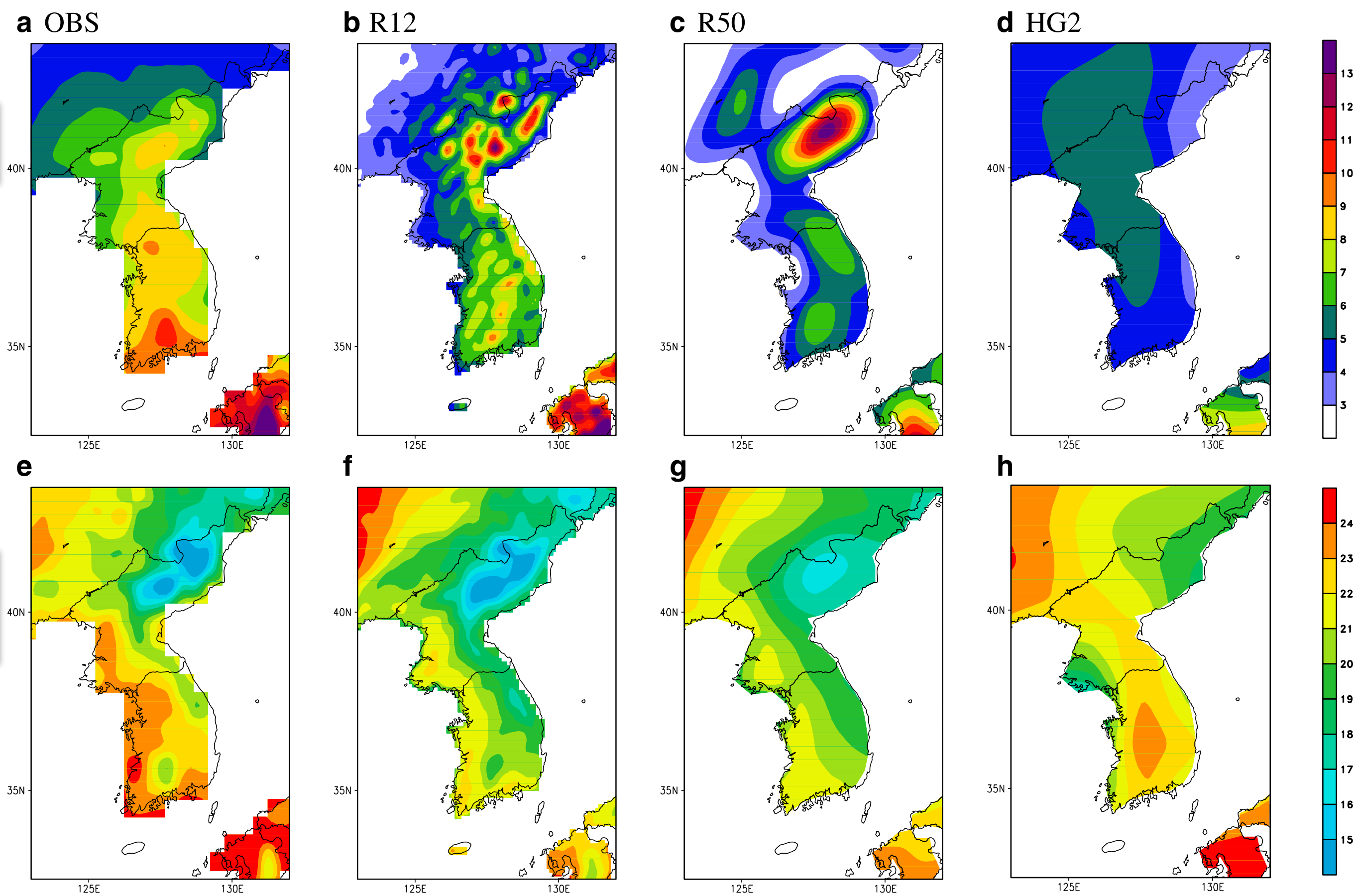


Fig. 4 Seasonally averaged precipitation (millimeters per day) between 1980 and 2005 obtained from **a** the CRU observation (*OBS*) data and the **b** R12, **c** R50, and **d** HG2 results for the JJA; **e**–**h** same as (**a**–**d**), but for near-surface (2 m) temperature (degrees Celsius)

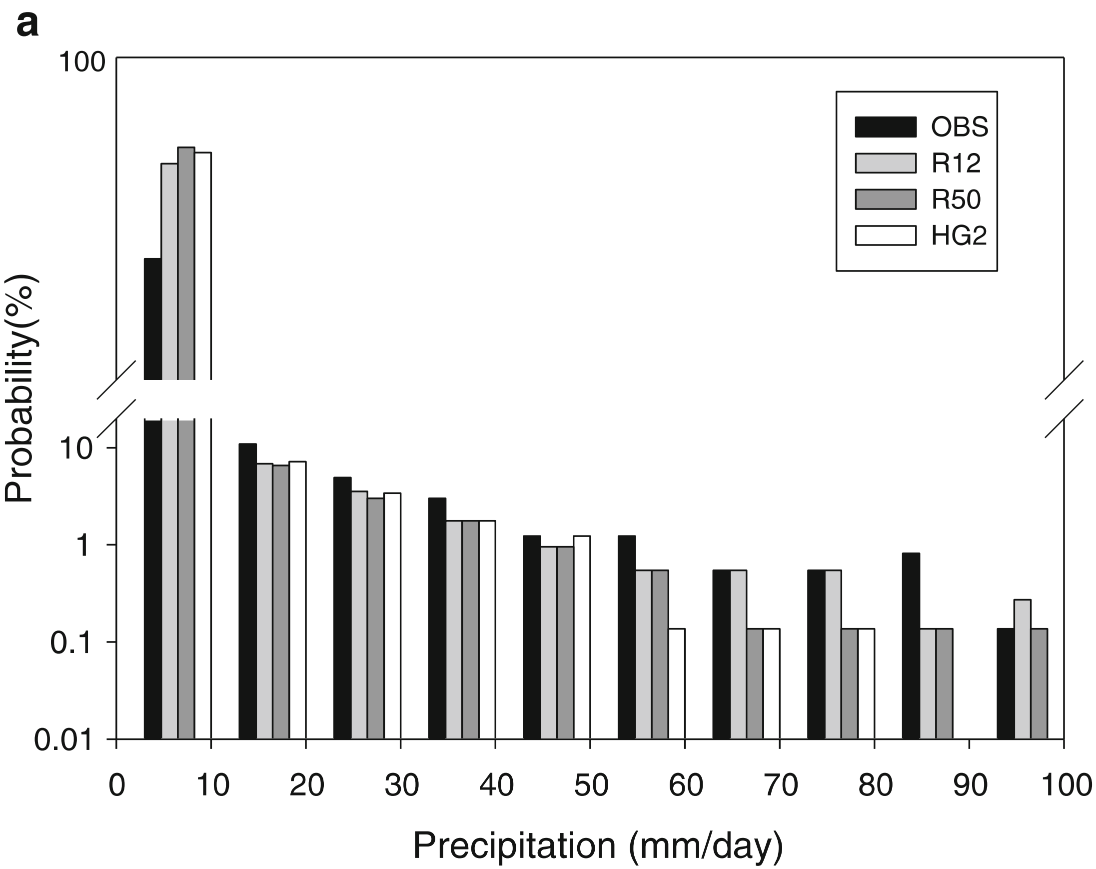


Fig. 6 The probability distribution of the domain-averaged **a** daily precipitation and **b** maximum 2-m temperature for the JJA in the period between 1998 and 2005 obtained from the observation data (*OBS*), and the R12, R50, and HG2 simulations for the southern Korean region (34–38° N, 126–130° E). The TMPA (Seoul station data) is used for the observation data of the precipitation (temperature) with a bin size of 10 mm day^{-1} (5 °C). It should be noted that the vertical axis label in (**a**) is log scale

Table 1 The frequency of heavy rainfall (averaged rainfall over 40 mm day^{-1}) and sweltering days (T_{max}>30 °C) per year obtained from the observation data (OBS; TMPA for precipitation and Seoul station record for temperature), and the R12, R50, and HG2 simulations

	Heavy rainfall	Sweltering days
OBS	4.38	30.38
R12	2.92	28.24
R50	1.91	9.82
HG2	1.52	18.76

The frequencies are tabulated over the southern Korean region (34–38° N, 126–130° E) in the JJA from 1998 to 2005 for precipitation and from 1980 to 2005 for temperature

The simulation of Lee waves by the hydrostatic and non-hydrostatic dynamical frames

Eun-Chul Chang

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Experimental Design

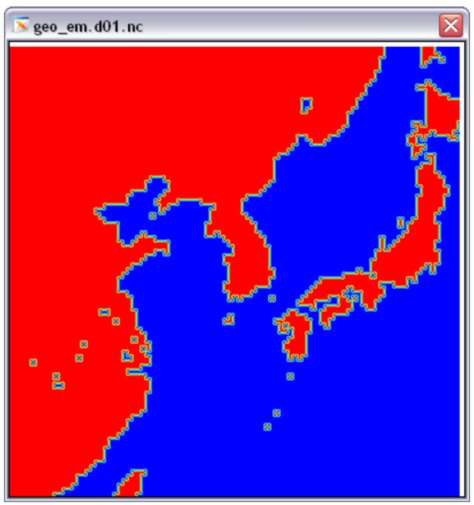
2005. 04. 04. 12 UTC ~ 06. 00 UTC
Downslope windstorm of Gangneung

WRF model v3.1.1
NCEP FNL (1^{o} x 1^{o}) data is used for I.C & B.C

Exp1 : Hydrostatic option for all domain

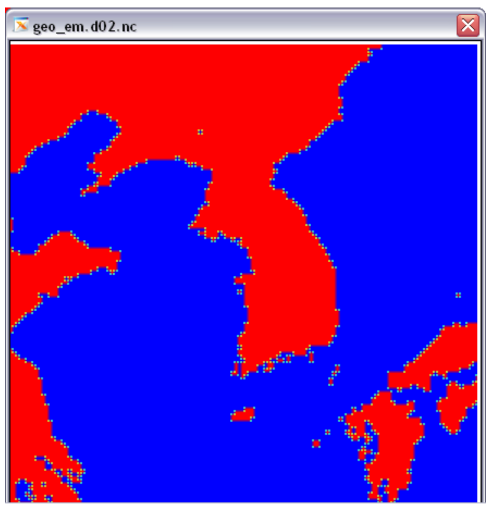
Exp2: Non-hydrostatic option for all domain

Domain 1



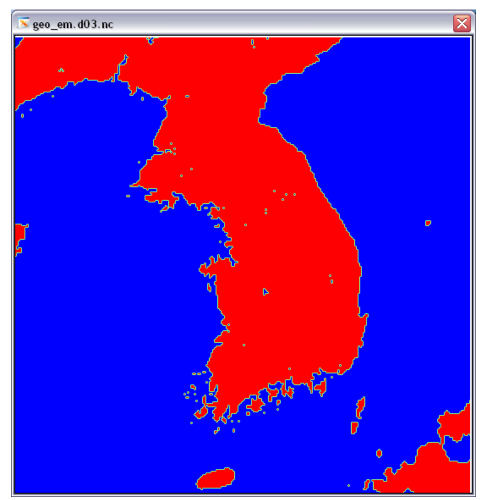
27 km (100x100)

Domain 2



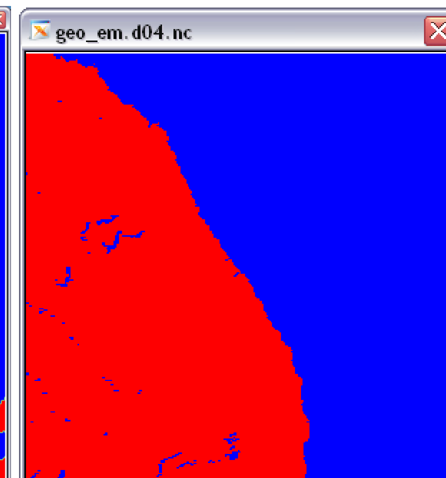
9 km (145x145)

Domain 3



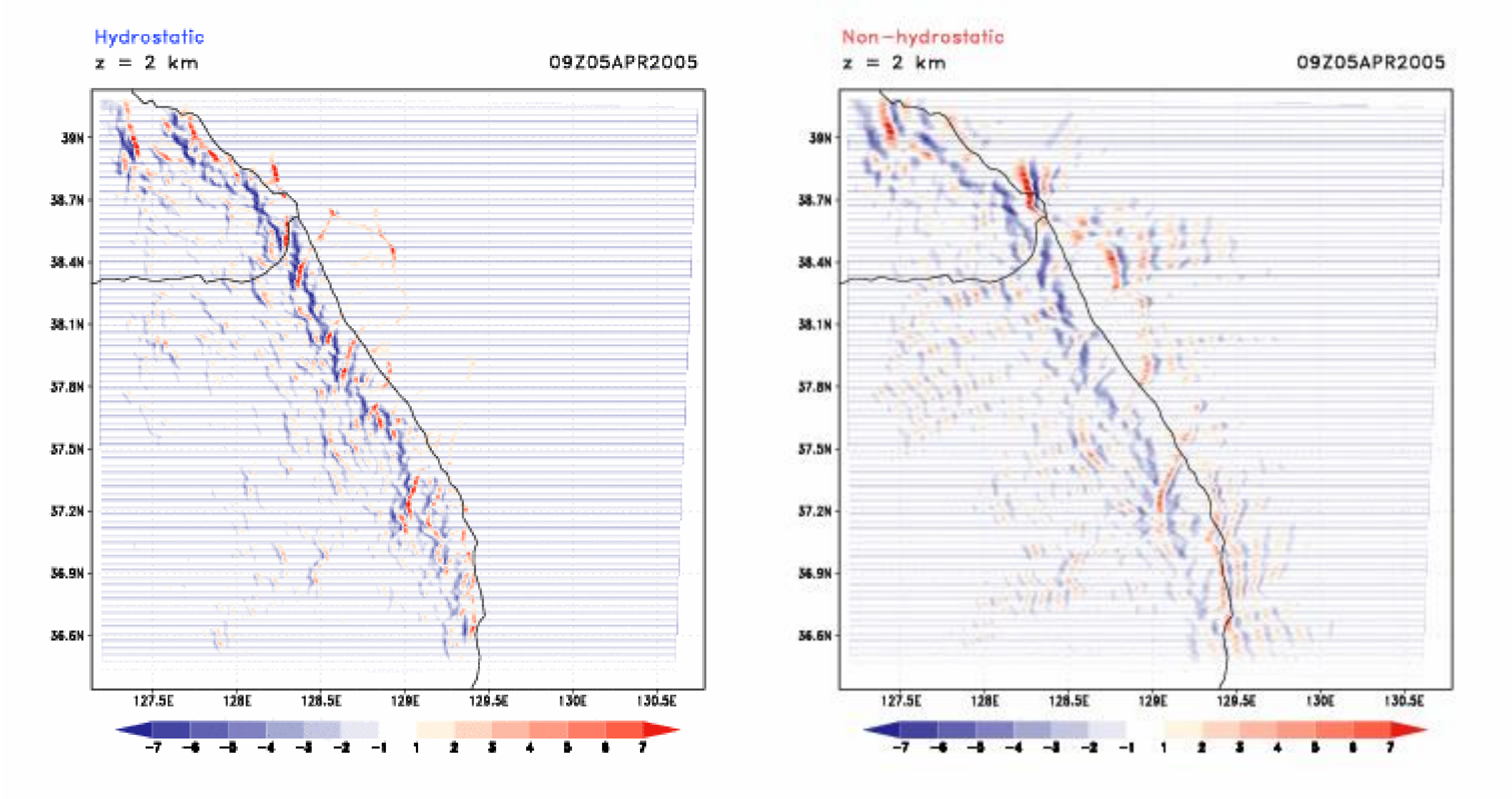
3 km (271x271)

Domain 4

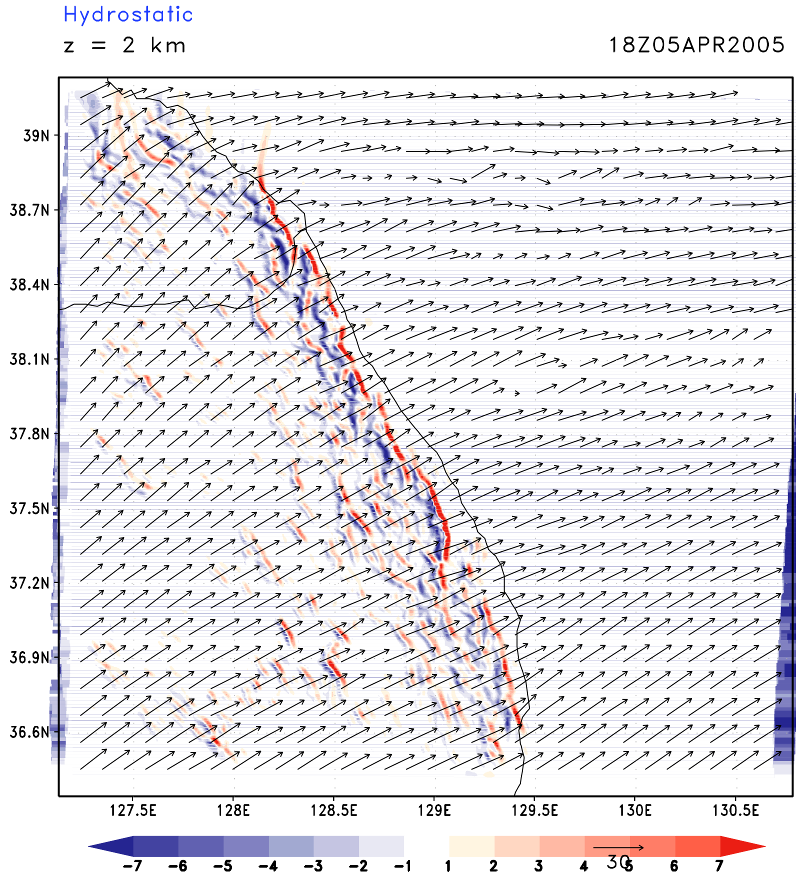


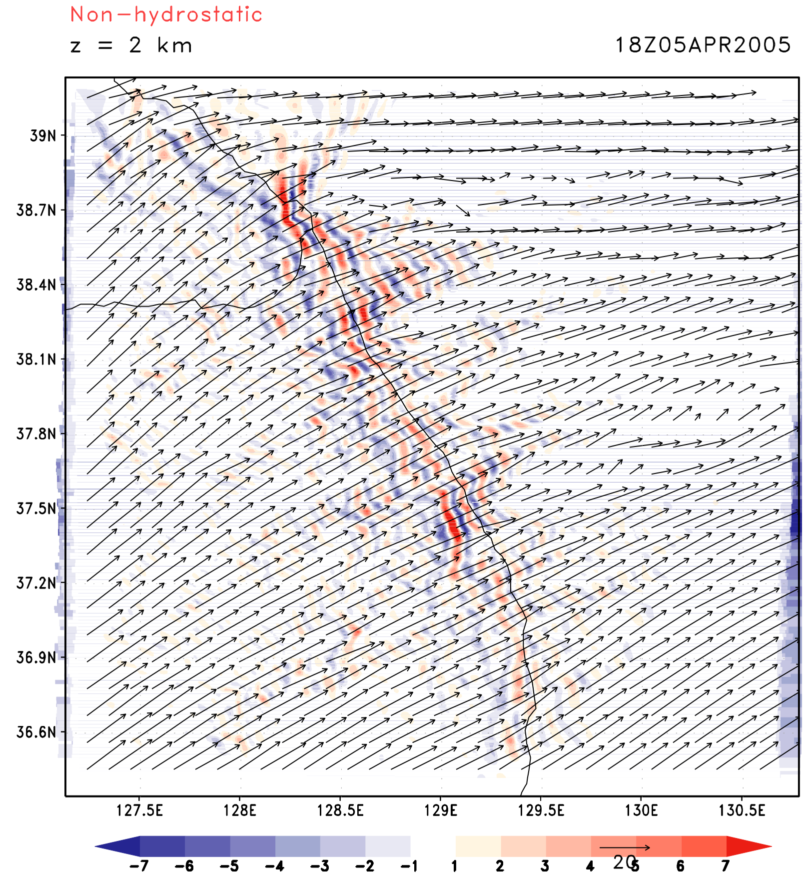
1 km (301x301)

Vertical velocity (m/s) at z = 2 km

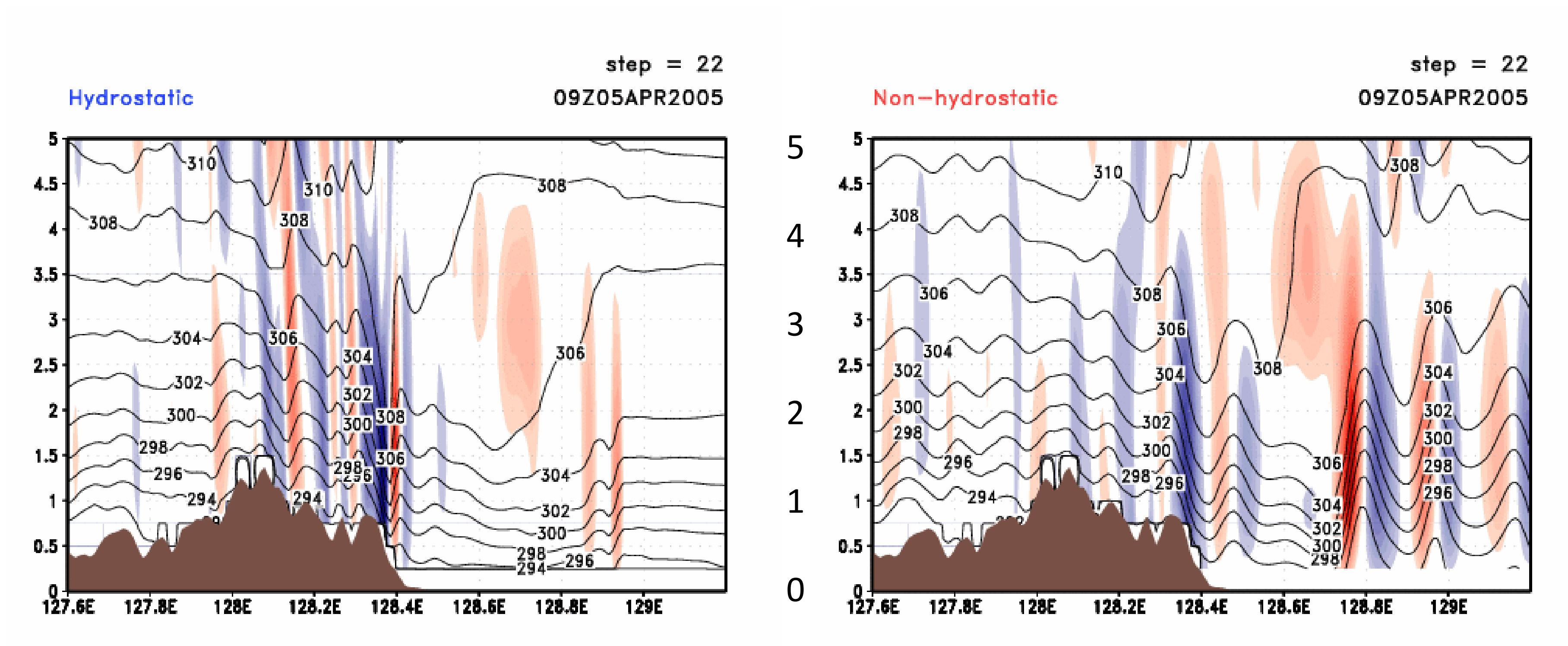


Vertical velocity (m/s) and horizontal wind at z = 2 km





Cross section : vertical velocity & potential temperature



Model dynamics & physics

Model dynamics

Solve the governing equations in a grid system

V. Bjerknes (1904) pointed out for the first time that there is a complete set of 7 equations with 7 unknowns that governs the evolution of the atmosphere:

Newton's second law or conservation of momentum

(3 equations for the 3 velocity components);

$$\frac{d_a \mathbf{v}_a}{dt} = \mathbf{F}/m \quad \Rightarrow \quad \frac{d\mathbf{v}}{dt} = -\alpha \nabla p - \nabla \phi + \mathbf{F} - 2\Omega \times \mathbf{v} \qquad (1\text{-}3)$$

The continuity equation or conservation of mass;

$$\frac{1}{M}\frac{dM}{dt} = 0 \qquad \frac{\partial \rho}{\partial t} = -\nabla.(\rho \mathbf{v}) \qquad (4)$$

Model dynamics

The equation of state for ideal gases

$$p\alpha = RT \qquad (5)$$

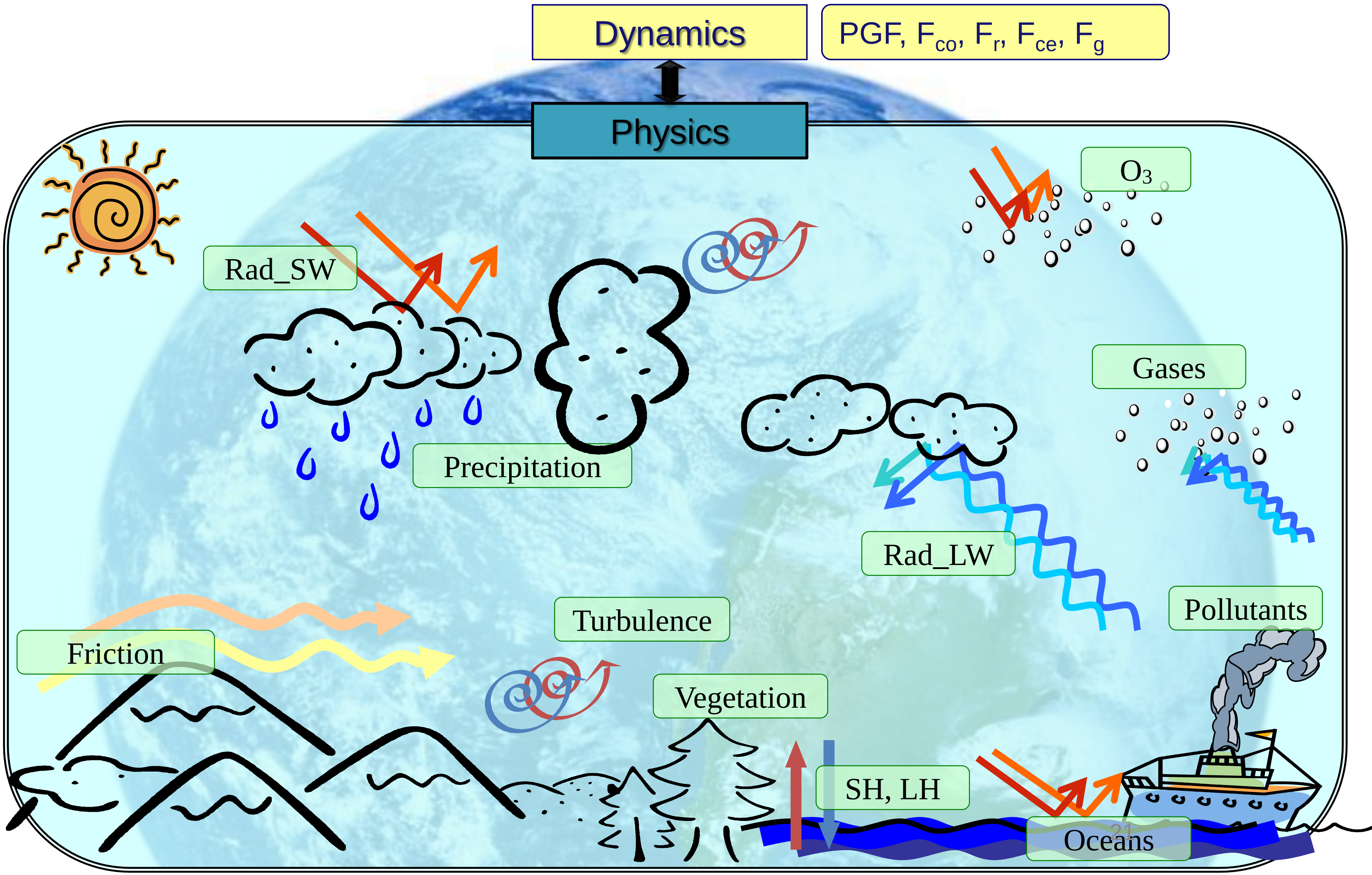
The first law of thermodynamics or conservation of energy

$$Q = C_v \frac{dT}{dt} + p\frac{d\alpha}{dt} \qquad \frac{ds}{dt} = C_p \frac{1}{\theta}\frac{d\theta}{dt} = \frac{Q}{T} \qquad (6)$$

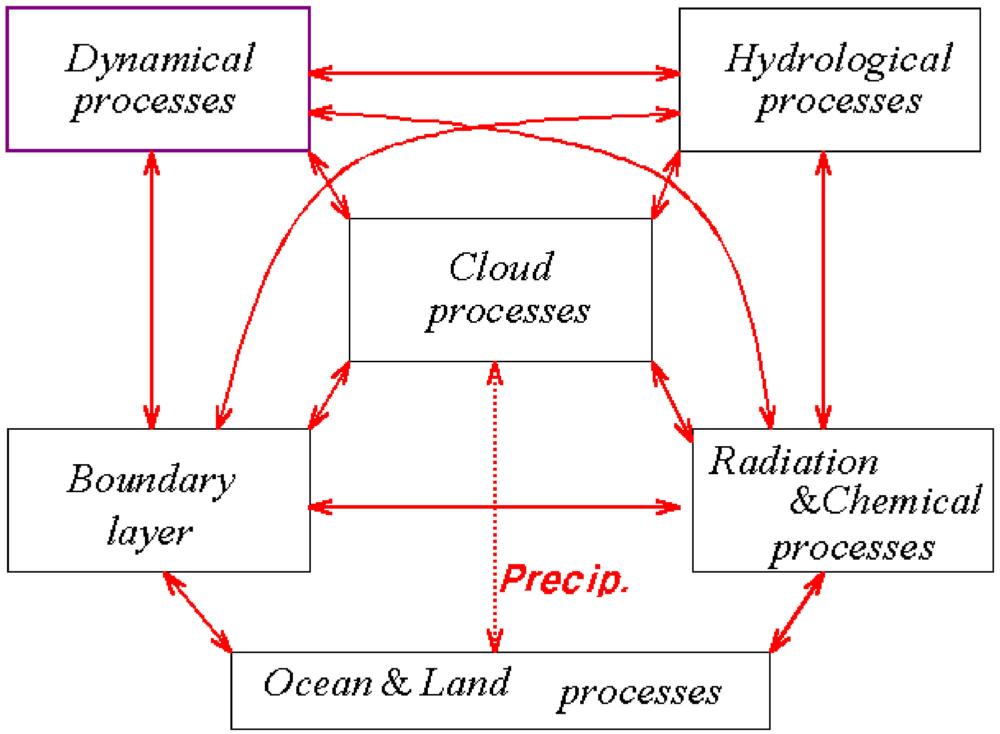
Conservation equation for water mass

$$\frac{dq}{dt} = E - C \qquad \frac{\partial r q}{\partial t} = -\nabla.(r\mathbf{v}q) + r(E - C) \qquad (7)$$

7 equations, 7 unknown (u, v, w, T, p, ρ and q)


Dynamics
PGF, F_{co}, F_r, F_{ce}, F_g
Physics
O_3
Rad_SW
Precipitation
Gases
Rad_LW
Pollutants
Turbulence
Friction
Vegetation
SH, LH
Oceans

Schematic configuration of physics



* Physical process in the atmosphere
: Specification of heating, moistening and frictional terms in terms of dependent variables of prediction model
→ Each process is a specialized branch of atmospheric sciences.

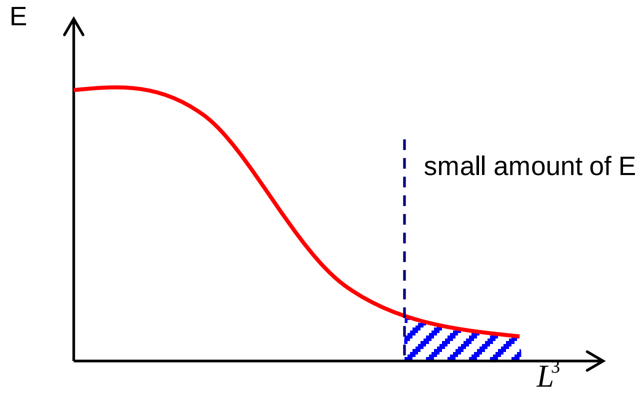
* Parameterization
The formulation of physical process in terms of the model variables as parameters. (constants or functional relations)

Subgrid scale process

* Subgrid scale process

Any numerical model of the atmosphere must use a finite resolution in representing continuum certain physical & dynamical phenomena that are smaller than computational grid.

- Subgrid process (Energy perspective)



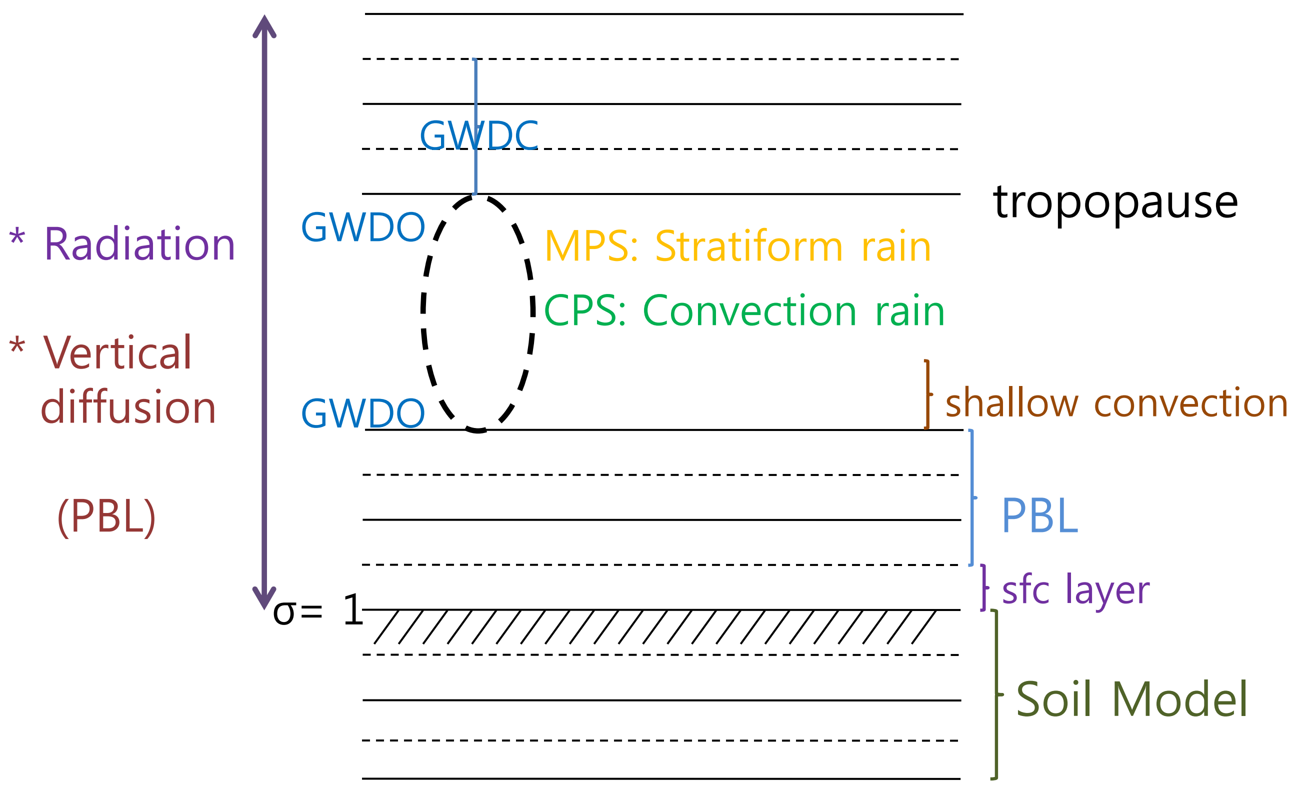
- $\Delta x \rightarrow 0$, the energy dissipation takes place by molecular viscosity (smallest grid size >> idealized situation)

- Objective of subgrid scale parameterization

"To design the physical formulation of energy sink, withdrawing the equivalent amount of energy comparable to cascading energy down at the grid scale in an ideal situation."

In modeled atmosphere : 7 or more

$$\frac{d\ln\theta}{dt}=\frac{H}{c_pT}\;,\qquad \frac{dq}{dt}=S,\qquad \frac{d\vec{u}}{dt}=\nabla_z\vec{\tau}$$



Regional Models

Introduction

The Weather Research and Forecasting (WRF) model is a numerical weather prediction (NWP) and atmospheric simulation system designed for both research and operational applications. WRF is supported as a common tool for the university/research and operational communities to promote closer ties between them and to address the needs of both. The development of WRF has been a multi-agency effort to build a next-generation mesoscale forecast model and data assimilation system to advance the understanding and prediction of mesoscale weather and accelerate the transfer of research advances into operations. The WRF effort has been a collaborative one among the National Center for Atmospheric Research's (NCAR) Mesoscale and Microscale Meteorology (MMM) Division, the National Oceanic and Atmospheric Administration's (NOAA) National Centers for Environmental Prediction (NCEP) and Earth System Research Laboratory (ESRL), the Department of Defense's Air Force Weather Agency (AFWA) and Naval Research Laboratory (NRL), the Center for Analysis and Prediction of Storms (CAPS) at the University of Oklahoma, and the Federal Aviation Administration (FAA), with the participation of university scientists.

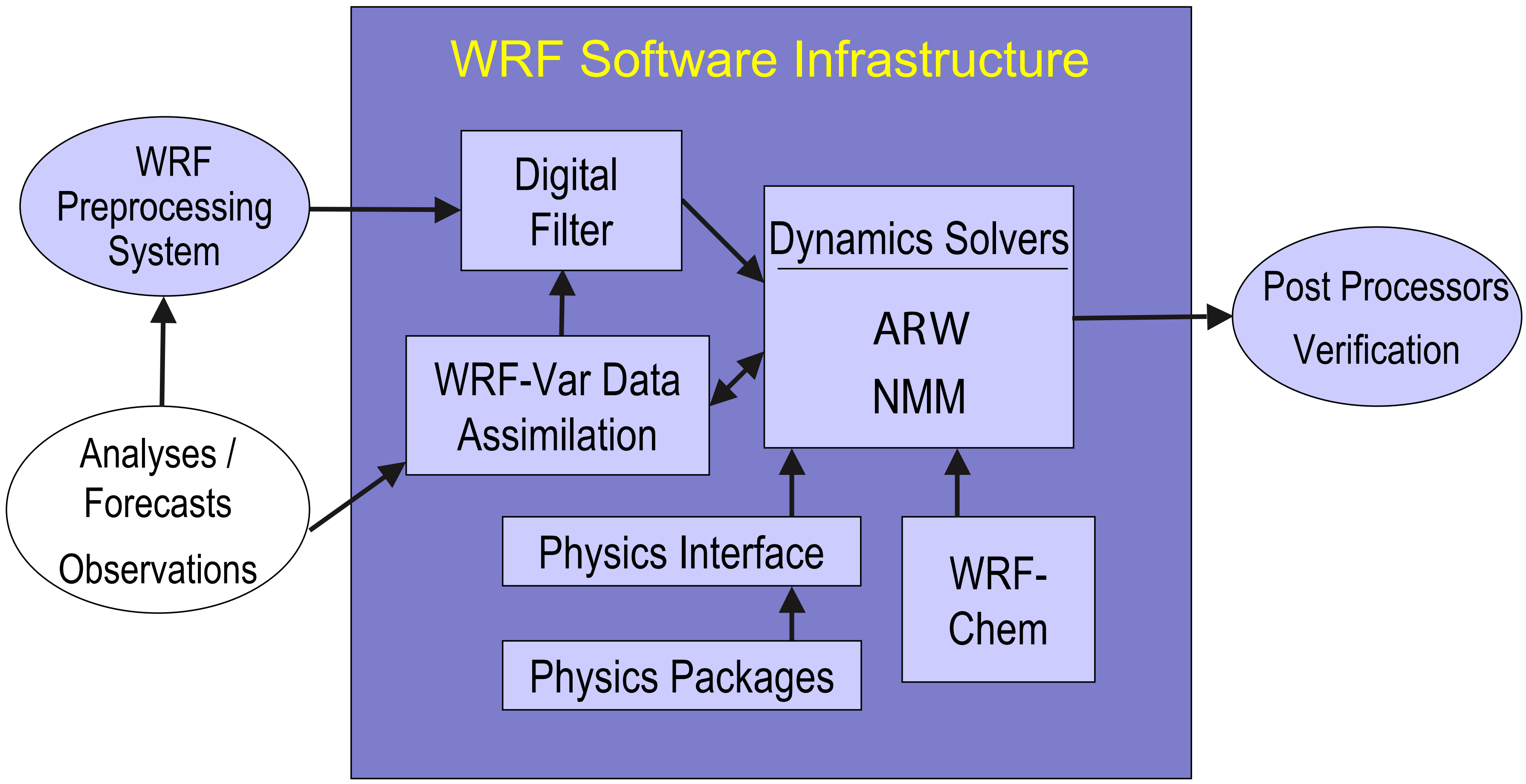


Figure 1.1: WRF system components.

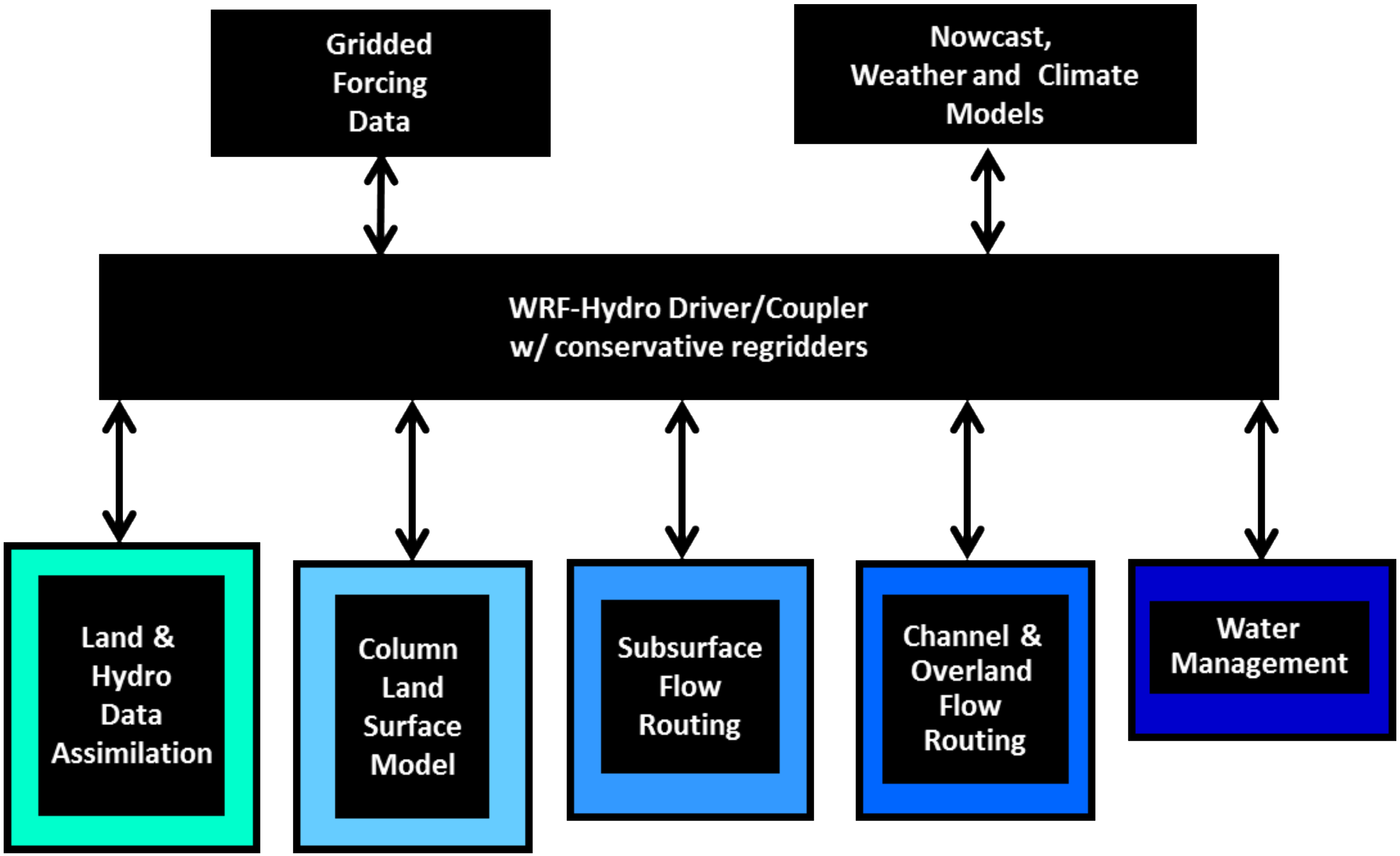
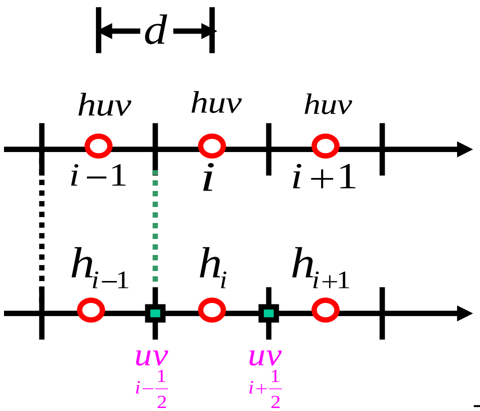


Figure 1.1. Generalized conceptual schematic of the WRF-Hydro architecture showing various categories of model components.

Grid systems- Staggered grids

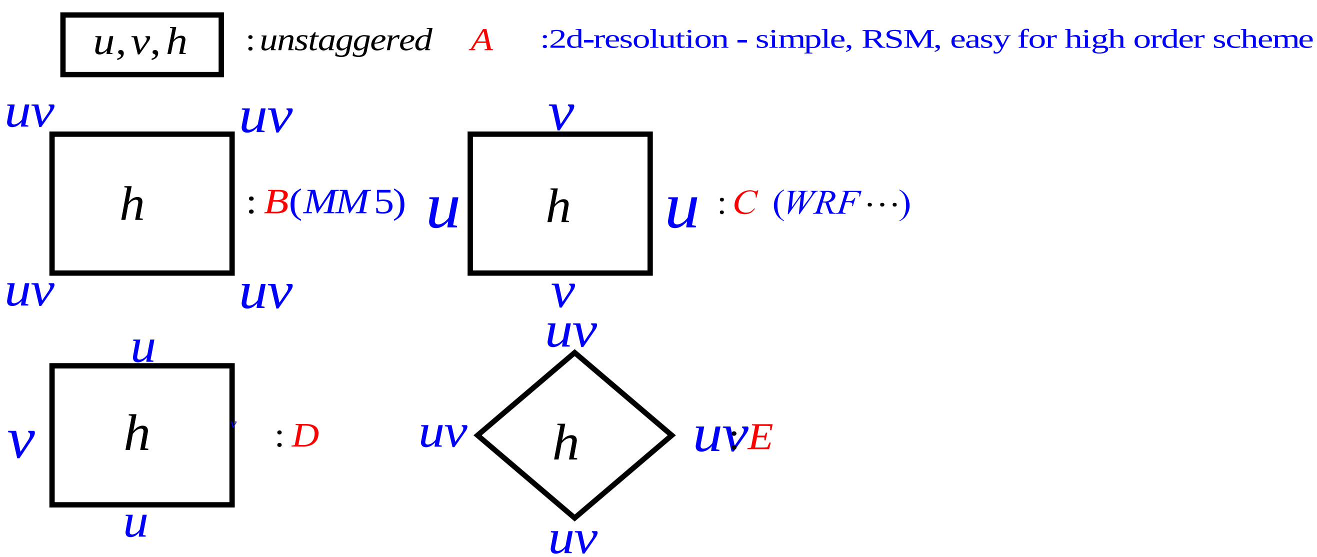
Staggered grids - Horizontal



$$u\frac{\partial h}{\partial x} = \frac{h_{i+1}-h_{i-1}}{2\Delta x}u_i$$

$$u\frac{\partial h}{\partial x}\bigg|_{i-\frac{1}{2}} = u_{i-1/2}\frac{h_i - h_{i-1}}{\Delta x}$$ Doubled resolution

$\Rightarrow$



Regional Climate Model system (RegCM)

Regional Model: REGCM4

A Regional Climate Model system

The Regional Climate Model system RegCM , originally developed at the National Center for Atmospheric Research (NCAR), is maintained in the Earth System Physics (ESP) section of the ICTP. The first version of the model, RegCM1, was developed in 1989 and since then it has undergone major updates in 1993 (RegCM2), 1999 (RegCM2.5), 2006 (RegCM3) and most recently 2010 (RegCM4). The latest version of the model, RegCM4, is now fully supported by the ESP, while previous versions are no longer available. This version includes major upgrades in the structure of the code and its pre- and post- processors, along with the inclusion of some new physics parameterizations. The model is flexible, portable and easy to use. It can be applied to any region of the World, with grid spacing of up to about 10 km (hydrostatic limit), and for a wide range of studies, from process studies to paleoclimate and future climate simulation.

Model improvements currently under way include the development of a new microphysical cloud scheme (to be released by the end of 2014), coupling with a regional ocean model, inclusion of full gas-phase chemistry, upgrades of some physics schemes (convection, PBL, cloud microphysics) and development of a non-hydrostatic dynamical core.

ESP also supports the Regional Climate Research Network, or RegCNET. The objective of RegCNET is to expand and strengthen the network of model users and to develop collaborative research projects across the network to improve the understanding of climate change at the regional scale. The RegCNET also provides a forum for current and future model users to discuss relevant issues, exchange research experiences and formulate needs and priorities for further model development and dissemination.

Global/Regional Integrated Model system (GRIMs)

Global Model Program (GMP)

Regional Model Program (RMP)

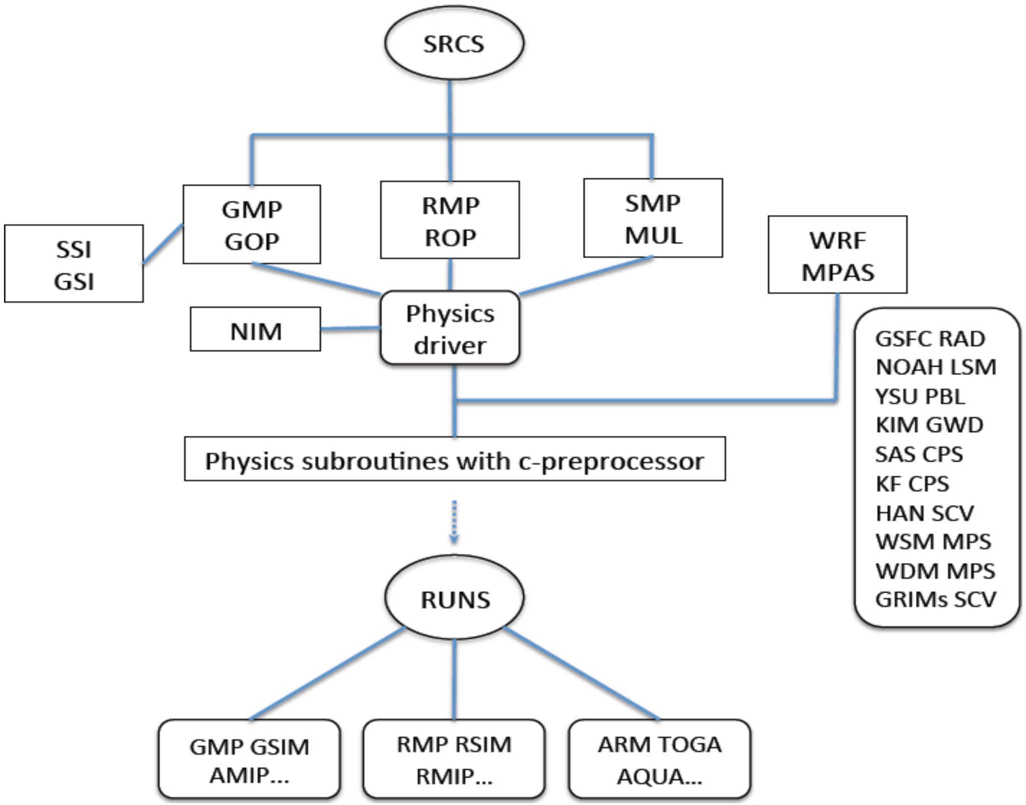
Global Ocean Program (GOP)

Regional Ocean Program (ROP)

Spectral dynamic core : T62 — T426

1. Spherical harmonics (SPH) system
2. Double Fourier series (DFS) system

Structure of GRIMs



Coupled Regional Ocean Model

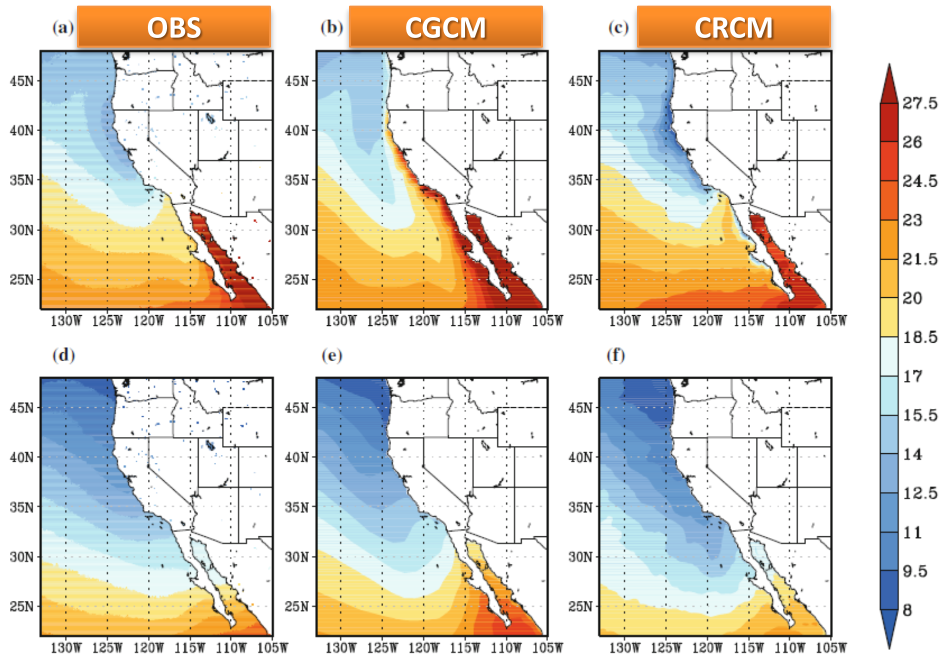


Fig. 2 Summer SST climatology (°C) from a AVHRR, b CCSM3, and c CPL; and the winter SST climatology from d AVHRR, e CCSM3, and f CPL

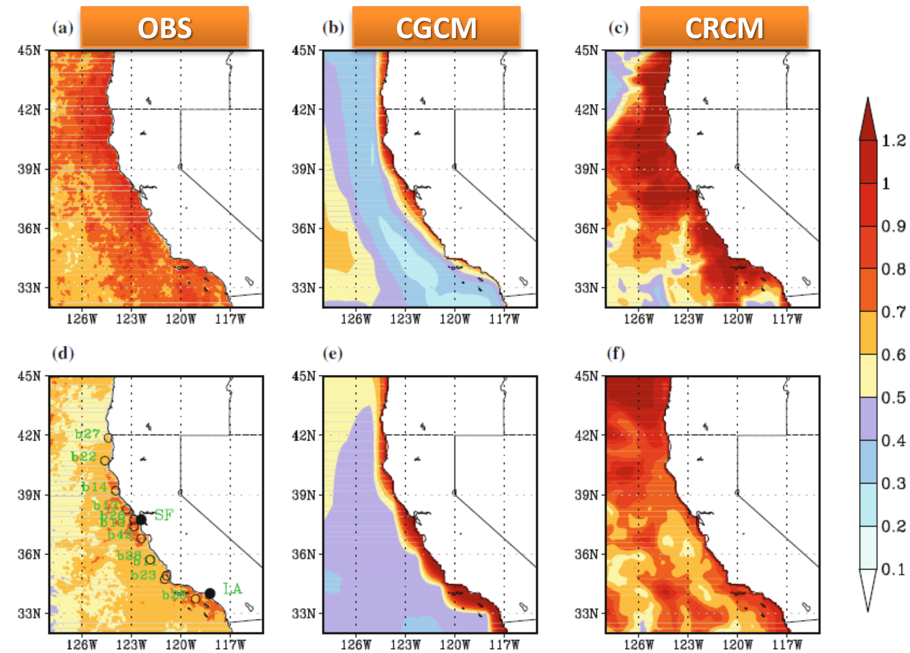


Fig. 3 Monthly SST variance (°C) in summer from a AVHRR, b CCSM3, and c CPL; and monthly SST variance (°C) in winter from d AVHRR, e CCSM3, and f CPL. The buoy stations (*white circle*) and COOP stations (*solid circle*) are shown in (d)

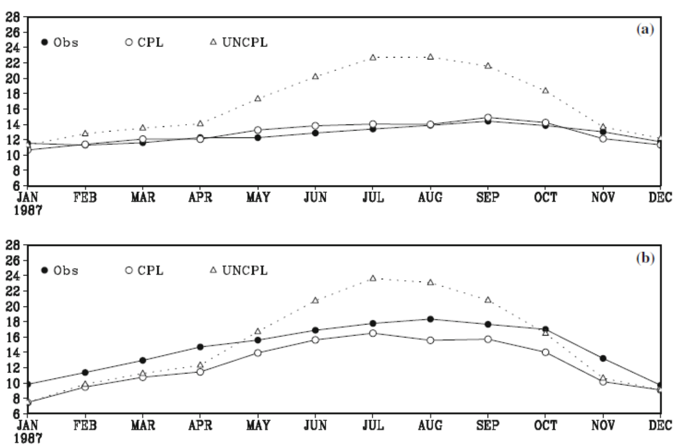


Fig. 4 Monthly T2m climatology (°C) from observation, CPL and UNCPL over a buoy station of Half Moon Bay (37.36°N, 122.88°W), b COOP station of San Francisco (37.775°N, 122.418°W), c buoy

Regional Model Intercomparizon Project
(RMIP)

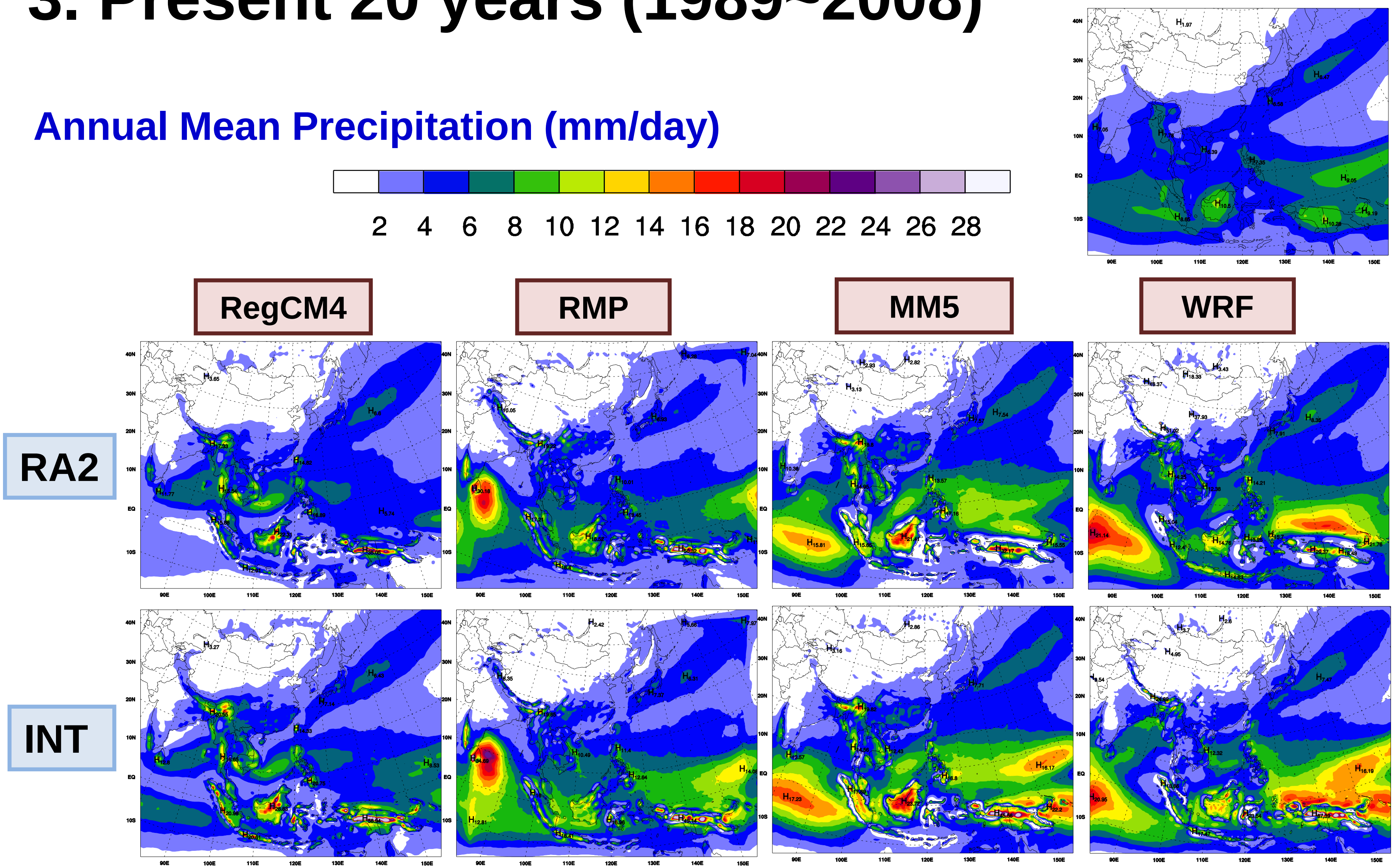
Regional Climate Models

Model Configuration	RegCM4	RMP	MM5	WRF
Vertical levels	σ-18	σ-22	σ-24	σ-27
Dynamic framework	Hydrostatic	Hydrostatic	Non-hydrostatic	Non-hydrostatic
PBL scheme	Holtslag	YSU	YSU	YSU
Cumulus convection	Emanuel	SAS	Kain-Fritch2	Kain-Fritch2
Explicit moisture	Scheme of Hsie et al. (1984)	WSM1	Reisner2	WSM3
Land surface	CLM3.5	NOAH	CLM3	Unified Noah
Longwave radiation	CCM3	GFDL	CCM2	RRTM
Shortwave radiation	CCM3	GSFC	CCM2	Dudhia
Spectral nudging	Yes	Yes	Yes	Yes

3. Present 20 years (1989~2008)

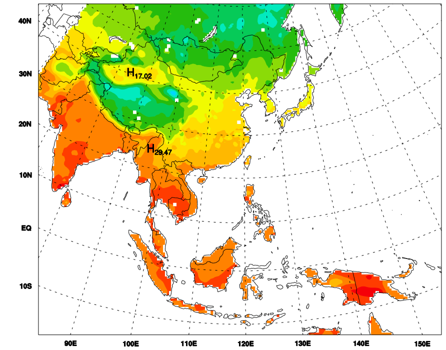
OBS(GPCP)

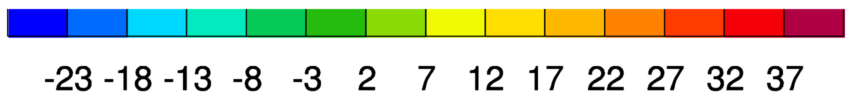
Annual Mean Precipitation (mm/day)

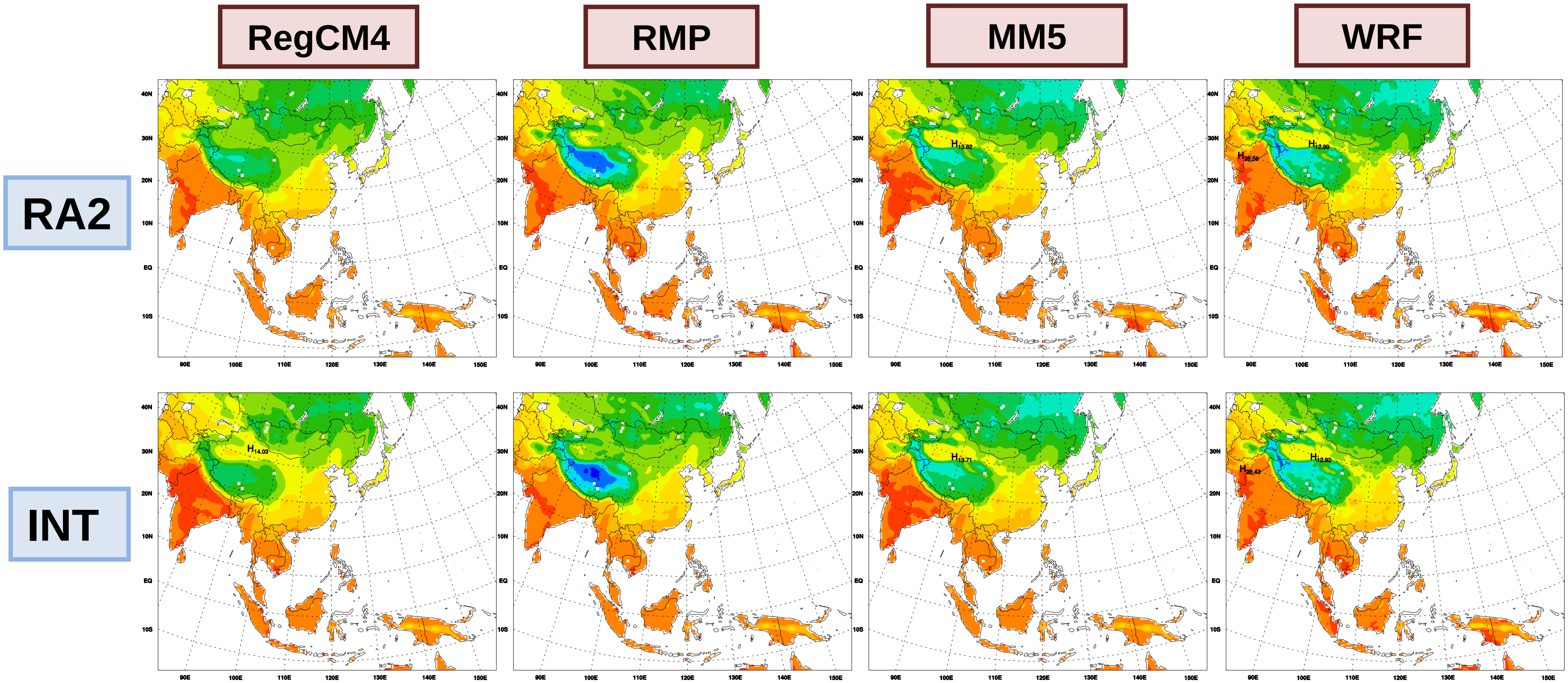


Annual Mean surface air temperature (^oC)

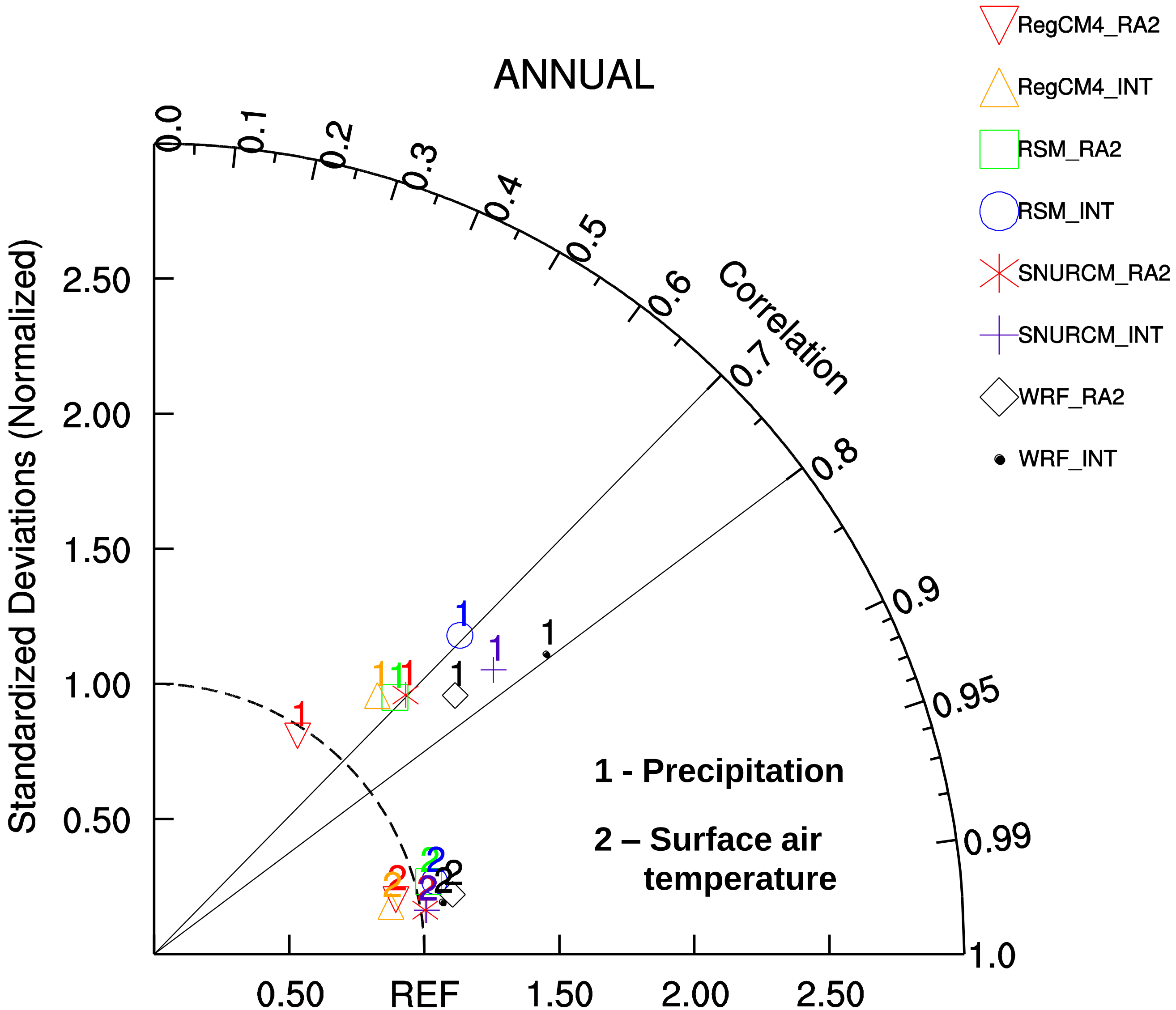
OBS(CPC)







Taylor Diagram of precipitation and SAT (1989-2008)



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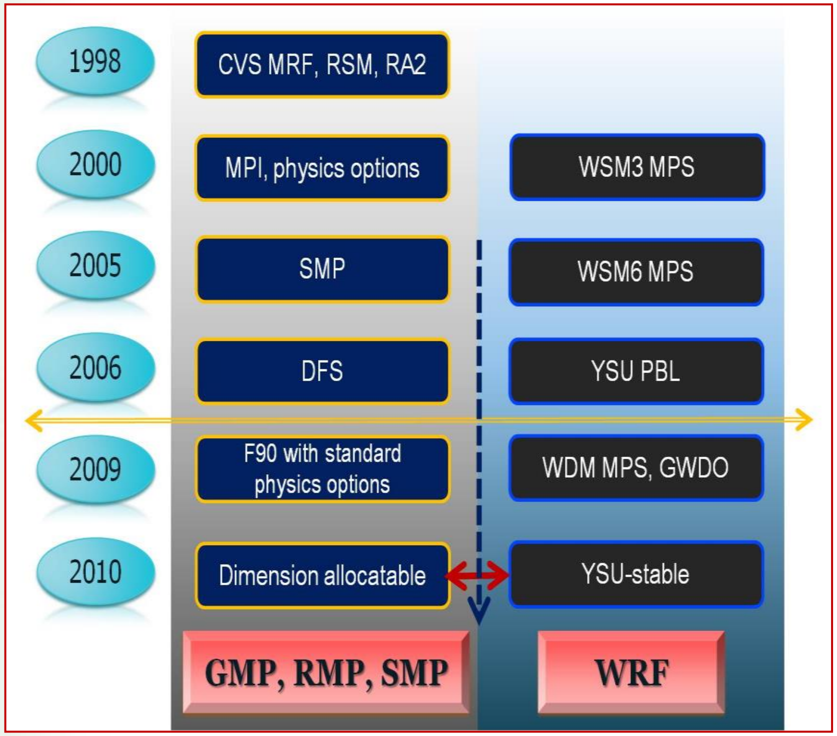
GRIMs

GLOBAL/REGIONAL INTEGRATED MODEL SYSTEM

History



- The GRIMs is based on the dynamic features and physics parameterization of the NCEP Seasonal Forecast Model. (Kanamitsu et al. 2002, BAMS).

- Since 2000, the Numerical Modeling Laboratory in Yonsei University has developed the advanced dynamic core and physical processes.

GRIMs

GLOBAL/REGIONAL INTEGRATED MODEL SYSTEM

Characteristics

- The GRIMs is a state-of-the-art spectral atmospheric model designed for numerical weather prediction, seasonal simulations, and climate researches.

- The GRIMs not only keeps the advantages of the predictability of the operational model but also includes the advanced dynamics and physics schemes developed by *Korean scientists*.

- The GRIMs has a great flexibility with multi-platforms from a personal computer to super-computers, with either a thread mode or a message parallel interface(MPI) mode.

- Within Fortran 90 programs with C-pre-processor source codes, a global model program (GMP), a regional model program (RMP), and single-column model program (SMP) can be selected. Horizontal and vertical resolutions, dynamic cores, and physics algorithms are optional as well. (e.g., evaluation of the predictabilities from T62(~200 km) to T510(~30 km) : Hong et al, 2010)

GRIMs – Dynamical Core

Dynamical Core

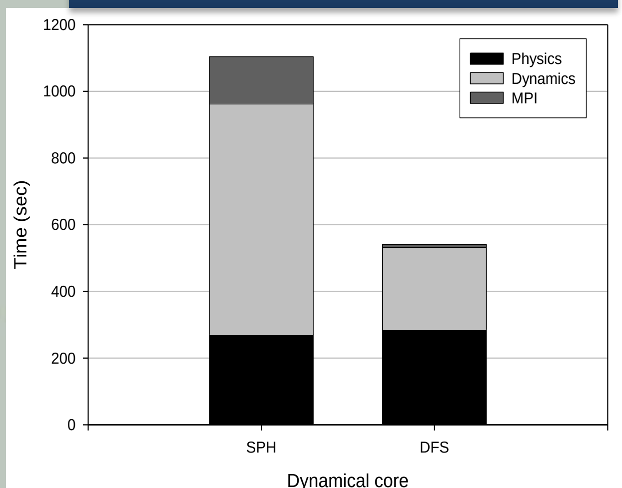
Spherical Harmonic (SPH)

- Widely used in operational center
- Computational efficiency is of concern at high resolution
- References :
  - Juang (2005)
  - Kanamitsu et al. (2002)

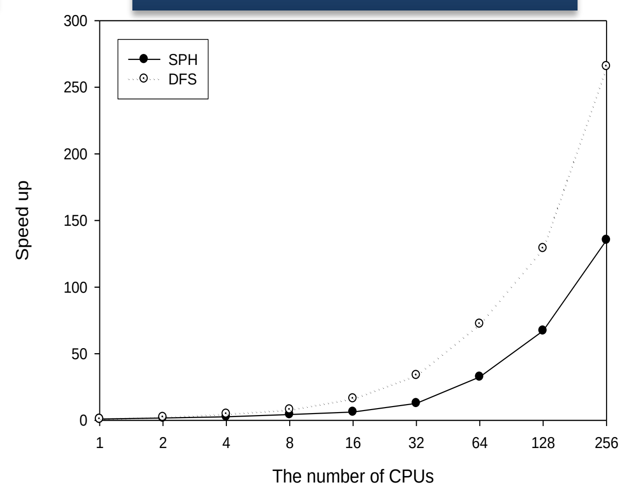
Double Fourier Series (DFS)

- Unique core developed by Cheong (Cheong, 2006)
- Implemented by Park and Hong (Park et al. 2008, 2010)
- Alleviates the MPI problem, but still preserves the advantages of spectral core numerics

32 CPU
(4 nodes with 8 cpus)



Scaling efficiency

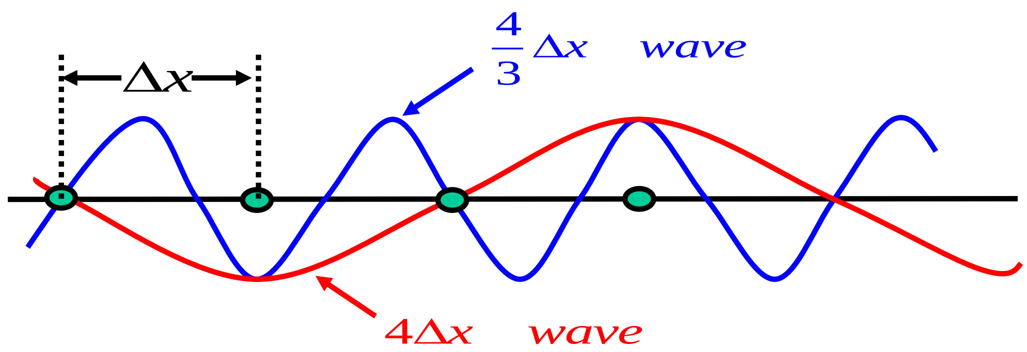


- Efficiency of DFS is two times higher than that of SPH.
- The efficiency can be higher at higher resolutions with more nodes.

Aliasing Problem

"Numerical experiments show that nonlinear computational instability arises only when there are changes in sign in the velocity" (same sign : linear)

ex) $L = \frac{4}{3}\Delta x < 2\Delta x \qquad L' = 4\Delta x > 2\Delta x$



: $\frac{4}{3}\Delta x$ waves from nonlinear term is represented as $4\Delta x$ waves

→ Energy is accumulated at $4\Delta x$ (aliasing)

→ Computationally unstable even if the model is linearly stable.

(nonlinear instability)

How to digitize a field

Values on grid points

- □ **Geographical location is given**
- □ **Discrete representation**

Easy to understand.

No computation necessary.

Computer display utilize this method.

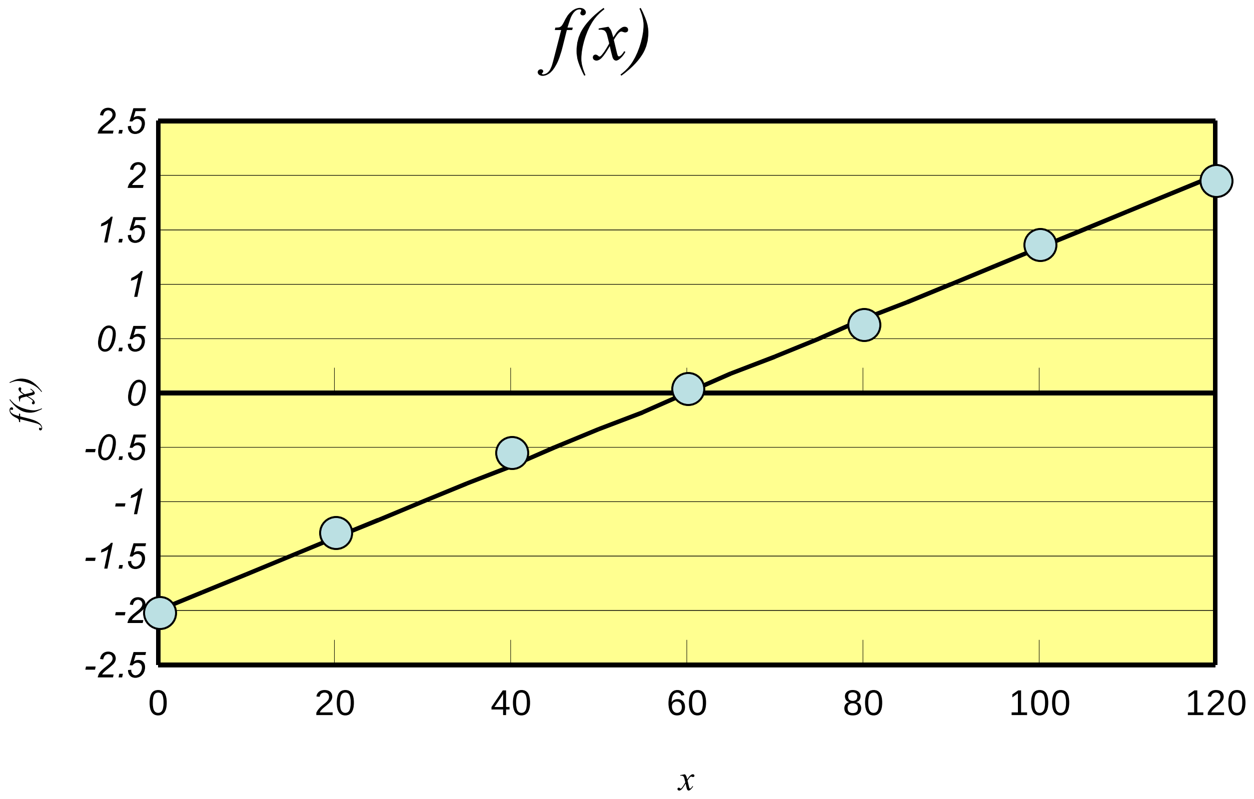
Will be referred to as *physical space*

==========================

Notation in this presentation:

Physical space in **RED**

Trivial 1-D example



Physical space:

***f*(*x*) is expressed by 7 numbers**

(-2.0, -1.33, -0.67, 0., +0.67, +1.33, +2.0)

Any other method to digitize fields?

$f(x)=ax+b$

$a=0.67$

$b=0.$

***f*(*x*) is expressed by 2 numbers (0.67, 0.)**

Note Continuous representation

==========================

Notation in this presentation:

Functional space in **BLUE**

Can we do similar procedure for more general field distributions?

Fourier Series

- **Combination (or summation) of sine and cosine waves with different wave length.**

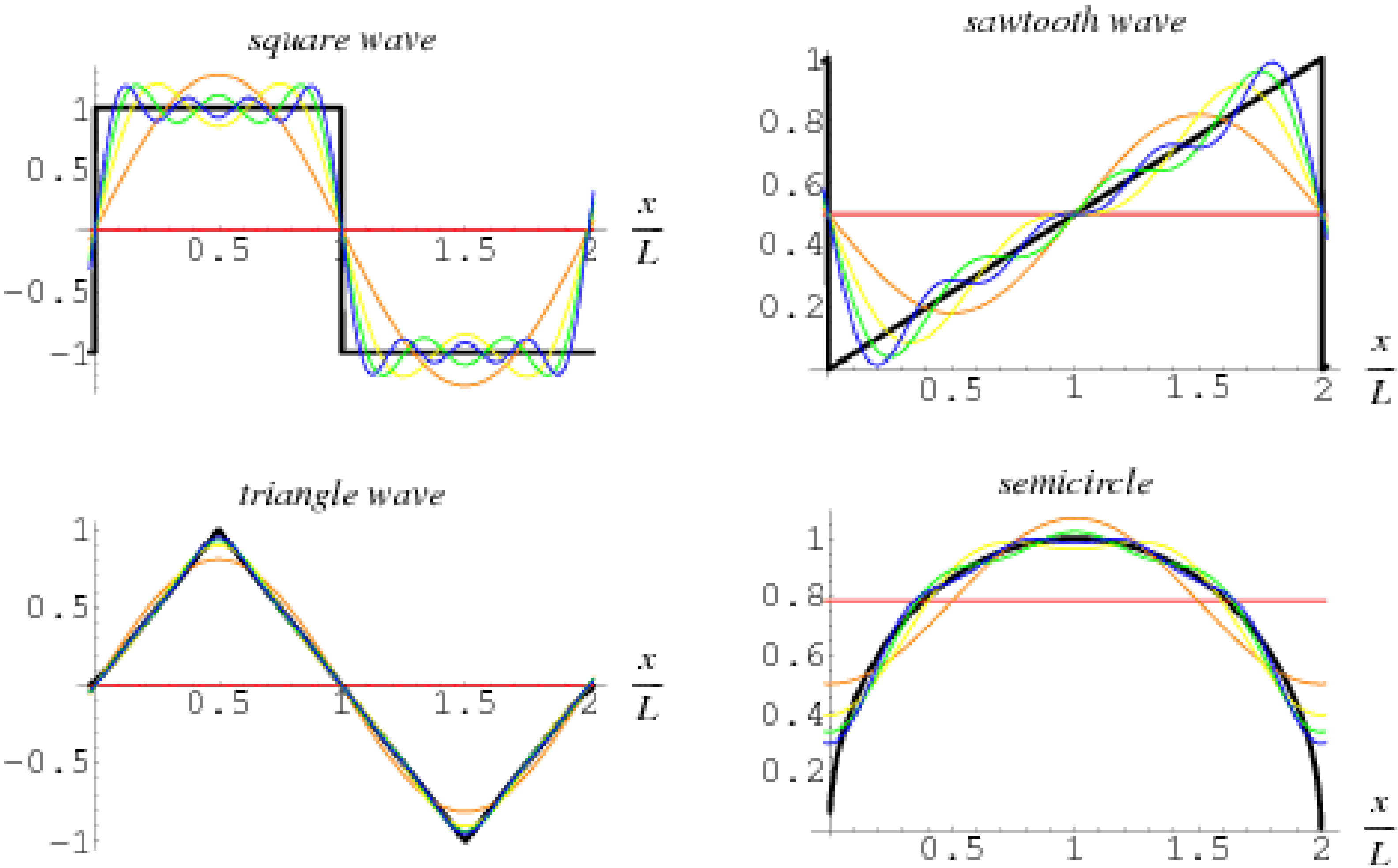
Joseph Fourier

Fourier's discovery

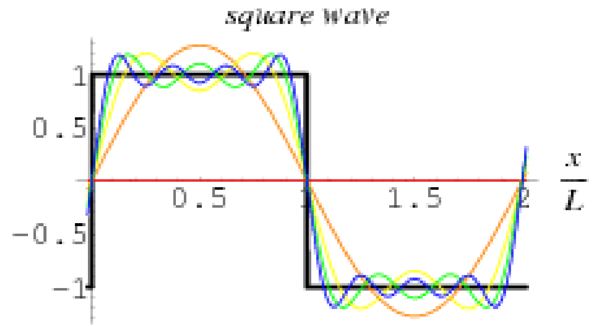
He claims that any function of a variable, whether continuous or discontinuous, can be expanded in a series of sines of multiples of the variable.

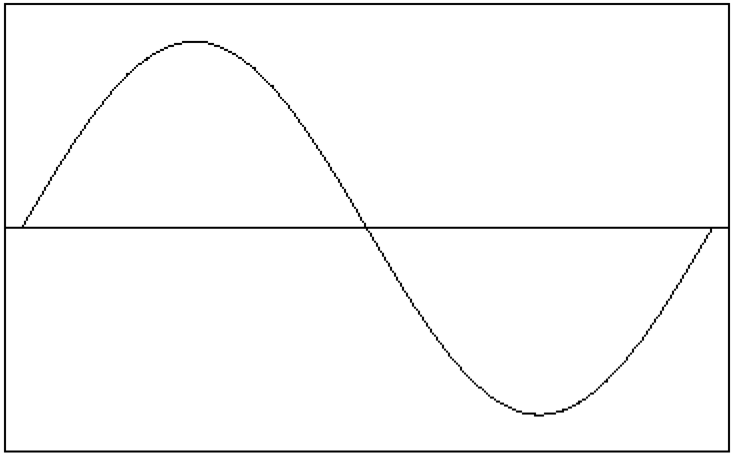
Though this result is not correct, Fourier's observation that some discontinuous functions are the sum of infinite series was a breakthrough. The question of determining when a function is the sum of its Fourier series has been fundamental for centuries. Joseph Louis Lagrange had given particular cases of this (false) theorem, and had implied that the method was general, but he had not pursued the subject. Johann Dirichlet was the first to give a satisfactory demonstration of it with some restrictive conditions. A more subtle, but equally fundamental, contribution is the concept of dimensional homogeneity in equations; i.e. an equation can only be formally correct if the dimensions match on either side of the equality.

Any distribution can be expressed (approximately) by the Fourier Series

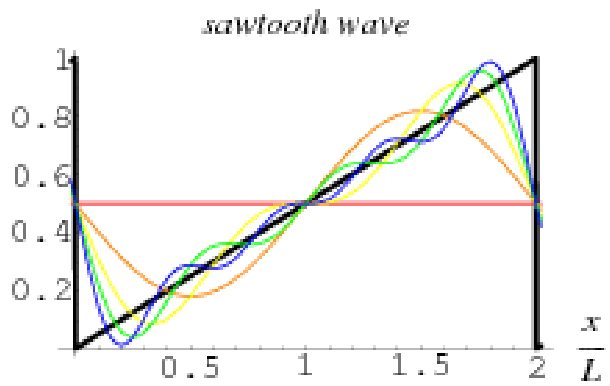


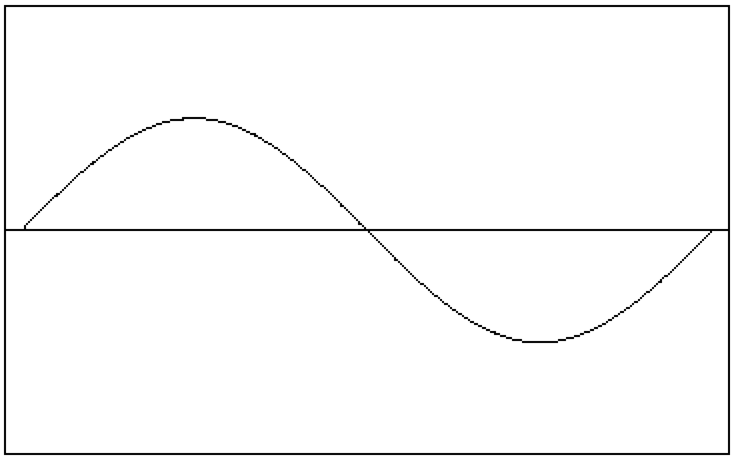
Fits better with more wave components



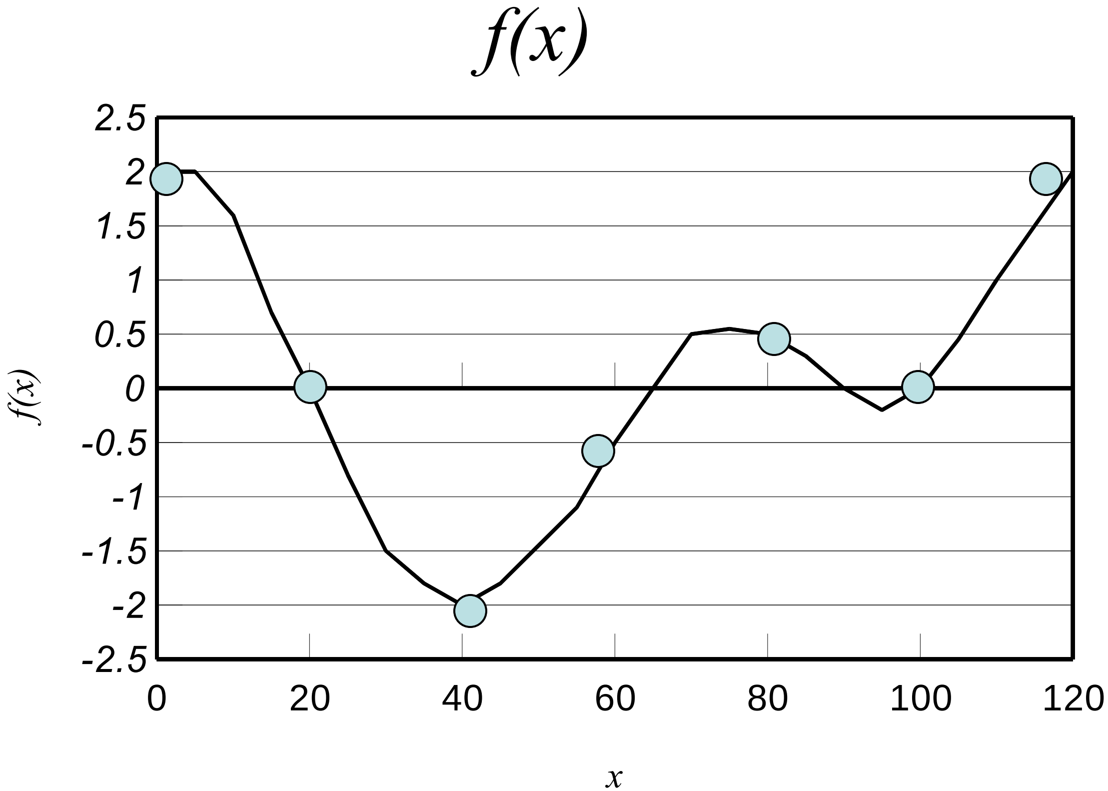


Fits better with more wave components





More general example



Physical space:

***f*(*x*) is expressed by 7 numbers**

(2.0, 0.0, -2.0, -0.5, 0.5, 0.0, 2.0)

Wave space:

If we use the following series of functions:

$f_0(x)$=constant
$f_1(x)$=sin(2B/L•x), $f_2(x)$=cos(2B/L•x),
$f_3(x)$=sin(2B/L•2x), $f_4(x)$=cos(2B/L•2x),
$f_5(x)$=sin(2B/L•3x), $f_5(x)$=cos(2Bx/L•3x)

then,

$$f(x) = 0.000 - 0.772 \bullet f_1(x) + 1.083 \bullet f_2(x) + 0.722 \bullet f_3(x) + 0.750 \bullet f_4(x) + 0.000 \bullet f_5(x) + 0.167 \bullet f_6(x)$$

Now, **$f(x)$ is expressed by 7 different numbers!!**

(0.000, -0.772, 1.083, 0.722, 0.750, 0.00, 0.167)

Wave space

Values of coefficients of a series of functions

Will be referred to as *wave space*

No geographical location
Known set of mathematical functions
Continuous representation
Space derivatives can be computed analytically.

Not possible to visualize

grid point space

Values on grid points.

Will be referred to as *grid point space*

- **Geographical location specified**
- **Physical values themselves**
- **Discrete representation**
- **Space derivatives computation requires finite difference approximation.**

Easy to visualize

Advantage of the spectral method

1. No space truncation error
2. No phase speed error
3. Satisfies conservation properties
4. No pole problem
5. No aliasing

Disadvantages of the spectral method

1. Restricted by boundary condition.

2. Difficulties in handling discontinuity and

   positive definite quantities

   ==>Gibbs phenomena

   Semi-Lagrangian

3. For very high resolution (>T1000), efficiency may become

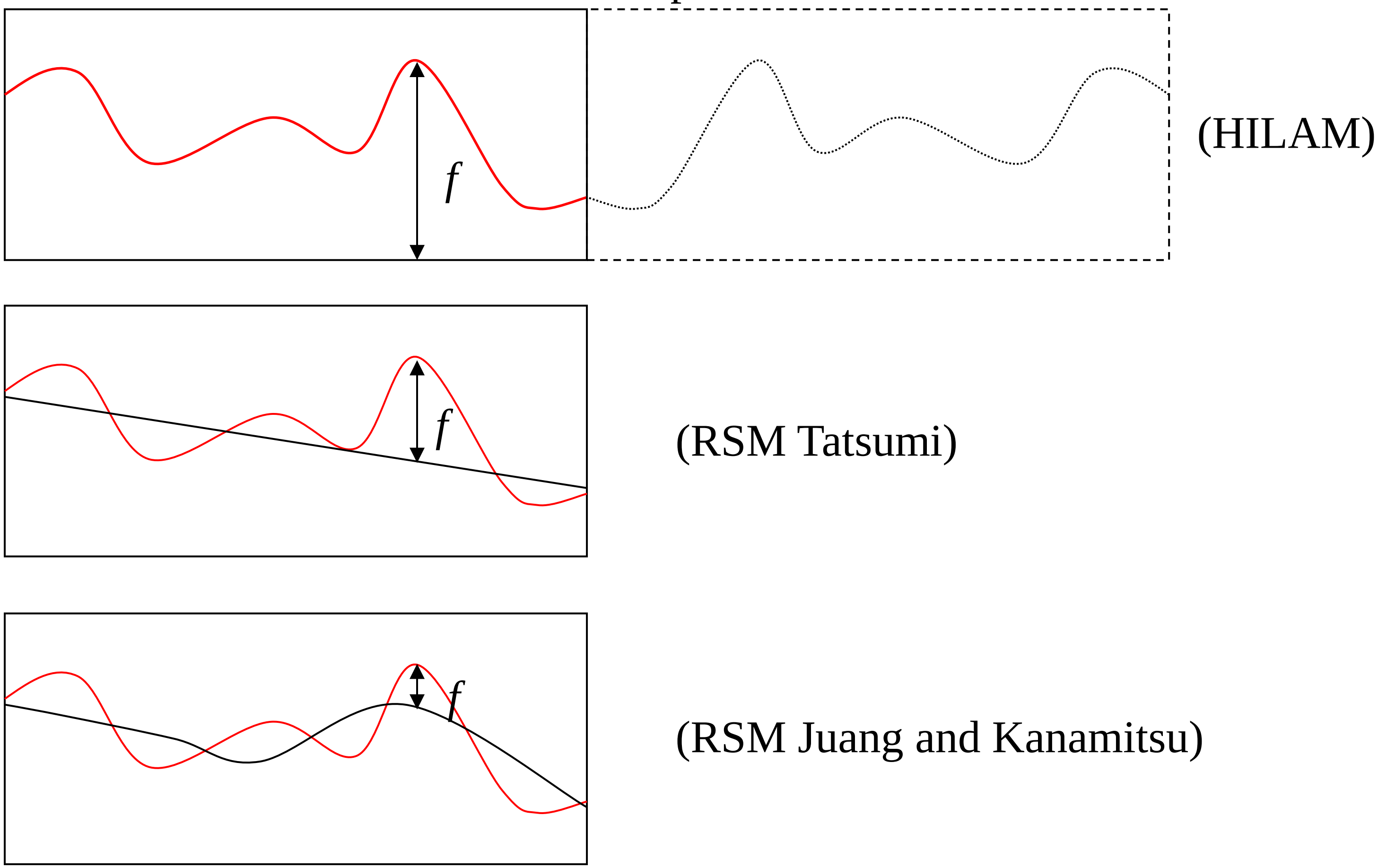
   a problem.

   Double Fourier Series

The Regional Spectral Model

- Juang, H.-M. and M. Kanamitsu, 1994: The NMC nested regional spectral model. *Mon. Wea. Rev.*, **122**, 3-26.

Definition of prediction variable



RSM Basics

Definition of perturbation

$$A_t = A_r + A_g$$

A_t: Full field (to be predicted)

A_r: Perturbation (rsm variable, to be predicted)

A_g: Global model field (known at all times)

Semi-Lagrangian advection scheme for radioactive tracers in a regional spectral model

Eun-Chul Chang[1] and Kei Yoshimura[2]

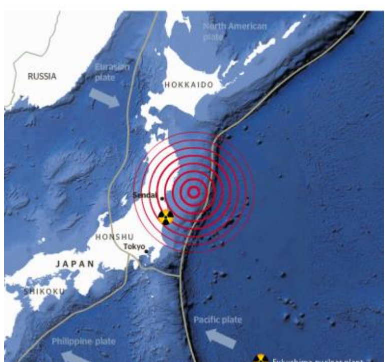
[1]Department of Atmospheric Science, Kongju National University

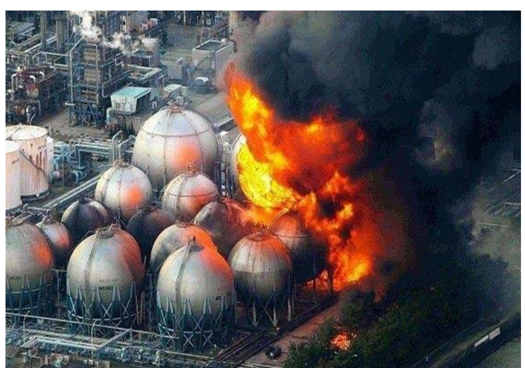
[2]Atmosphere and Ocean Research Institute, University of Tokyo

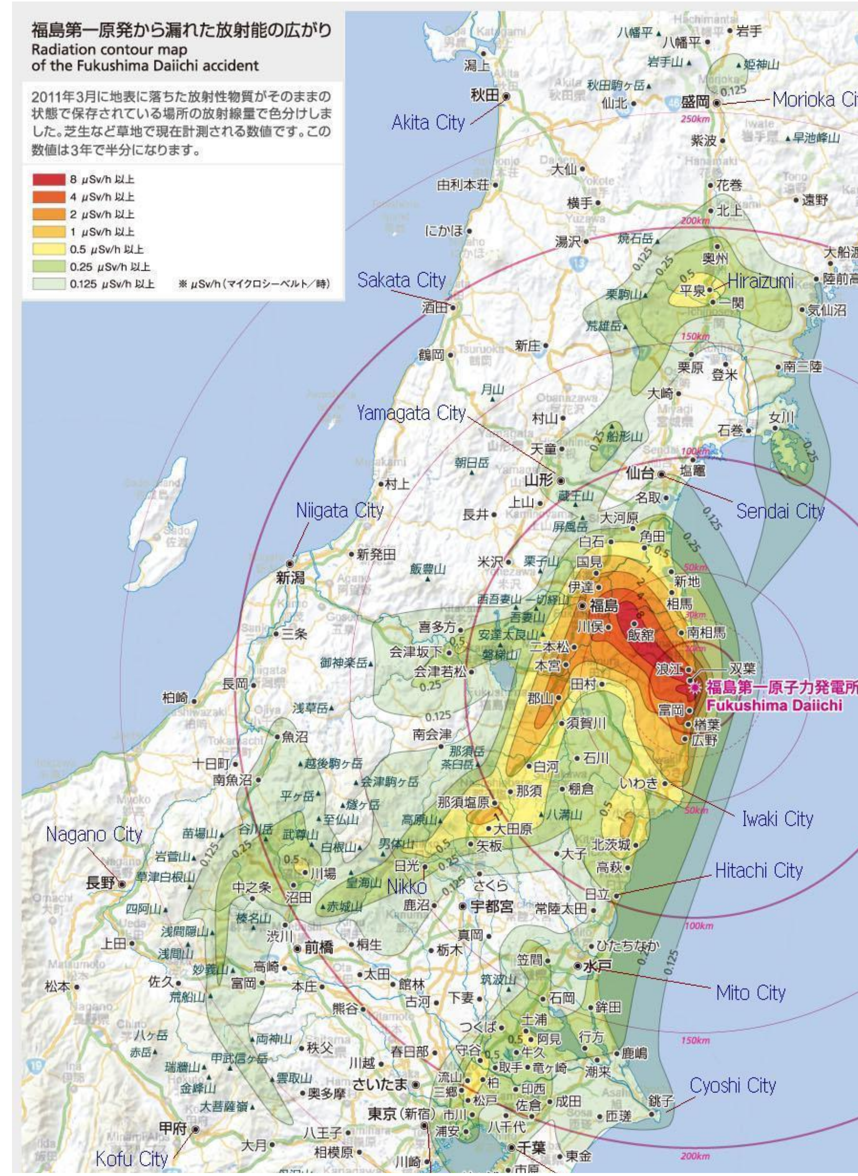
Background

Fukushima Daiichi Nuclear power plant disaster

March 11, 2011	“Great East Japan Earthquake” occurred (magnitude 9.03)
	Tsunami (14~15m) hit 6 reactors in the Fukushima Daiich Nuclear power plant
March 12, 2011	Unit 1 reactor : Hydrogen explosion
March 14, 2011	Unit 3 reactor : Hydrogen explosion
March 15, 2011	Unit 4 reactor : Hydrogen explosion near fuel pool
	Unit 2 reactor : Hydrogen explosion



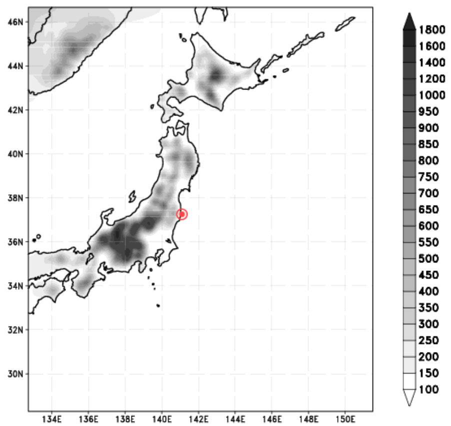




Background

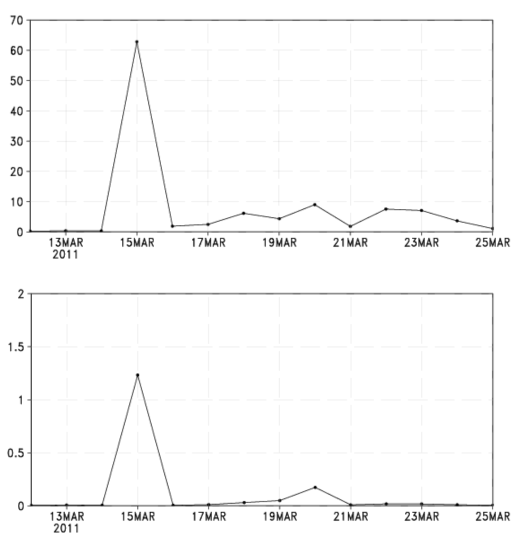
Simulation of Fukushima case by using the Regional Spectral Model

Experimental domain

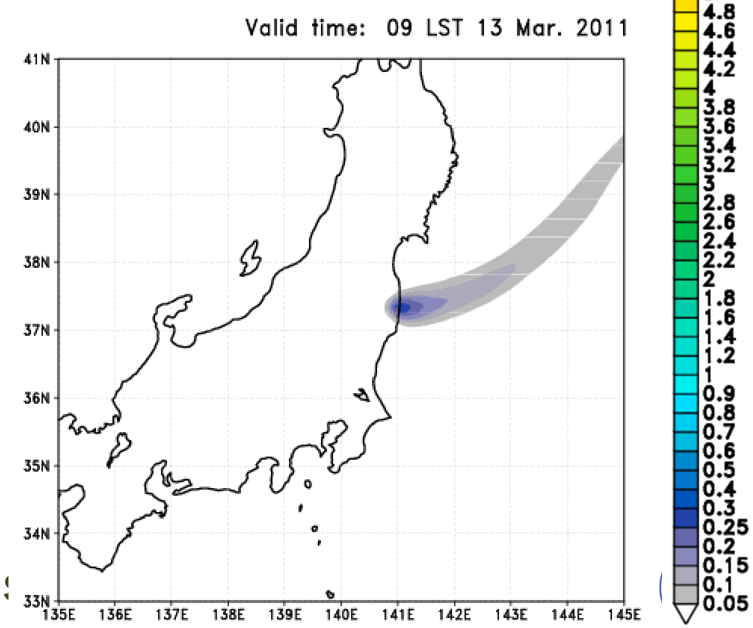


Model	**IsoRSM (Yoshimura et al., 2010)** (Isotopes-incorporated Regional Spectral Model)
Domain	Horizontal : 10 km (161 x 200) Vertical : 28 layers
I.C. & B.C	NCEP-DOE Reanalysis II
Integration period	2011. 03. 12. 00 UTC – 2011. 03. 25. 00 UTC (13 days)

Daily averaged Emission rate [Bq m^{-2} s^{-1}] (Chino et al., 2011)

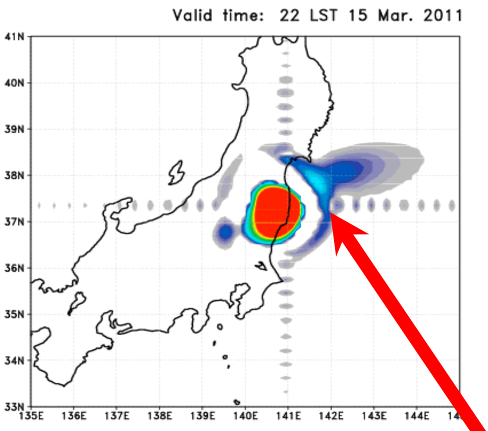


Column accumulated ^{131}I

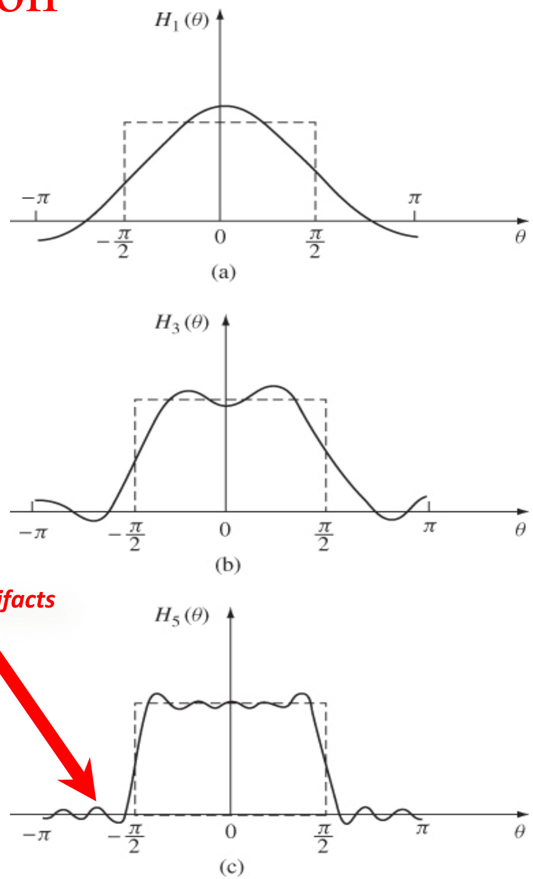


Background

"Gibbs phenomenon"



Ringing artifacts



Fourier transform

- **Gibbs phenomenon** is one disadvantage of **spectral model system**.
- In this study, **tracer advection** part is replaced by the **semi-Lagrangian advection scheme** to avoid Gibbs phenomenon.

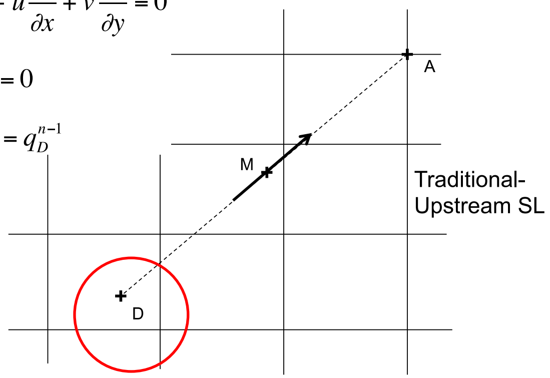
NDSL scheme

Non-iteration dimensional-split semi-Lagrangian (NDSL; Juang 2007, 2008)

$$\frac{\partial q}{\partial t} + u\frac{\partial q}{\partial x} + v\frac{\partial q}{\partial y} = 0$$

$$\frac{Dq}{Dt} = 0$$

$$q_A^{n+1} = q_D^{n-1}$$



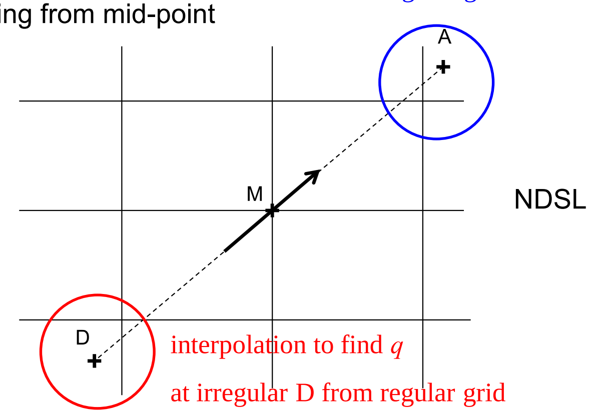
iteration to find q at D

q_A^{n+1} values are defined at regular grid

remapping to find q

at regular grid from irregular A

Starting from mid-point



interpolation to find q

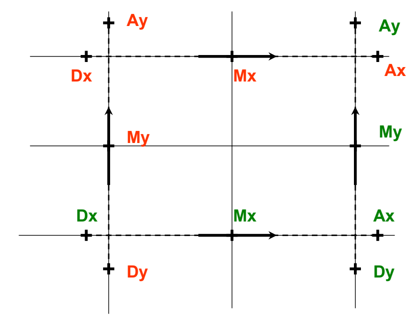
at irregular D from regular grid

No guessing and no iteration

but one 2-D interpolation and one 2-D remapping

$\vec{V}_M^n$ values are defined at regular grid

dimensional-split



Final result is mean of

x - y advection and

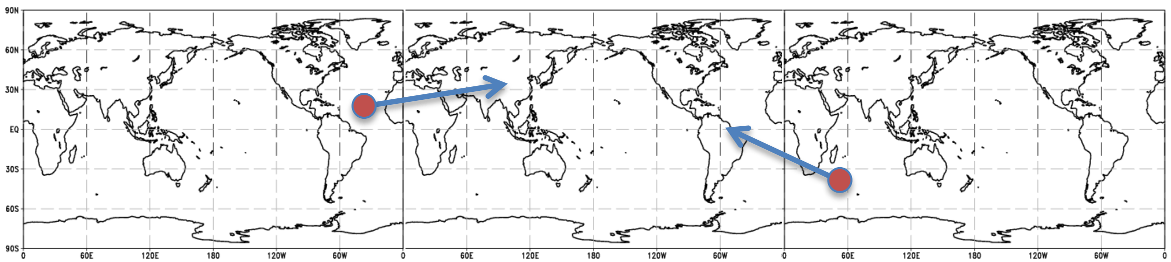
y - x advection

NDSL scheme was only applied to Global model version (NCEP GFS and GRIMs GMP).

There was no regional version of NDSL scheme.

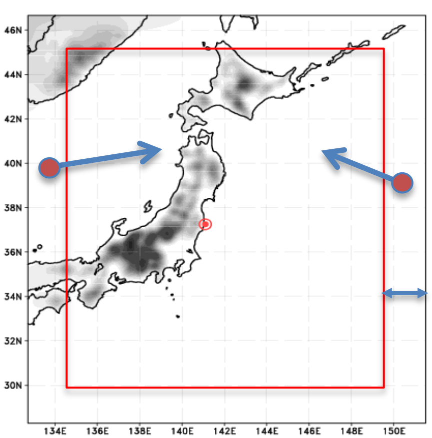
Non-cyclic boundary in a regional model

In a global model : cyclic boundary



cyclic domain | Actual domain | cyclic domain

In a regional model



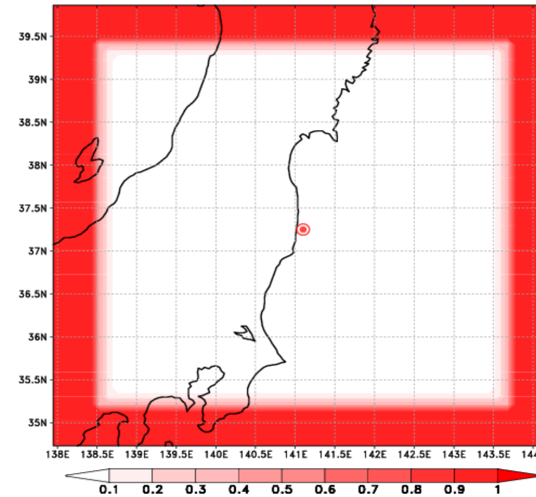
10 km resolution, Δt = 40 sec

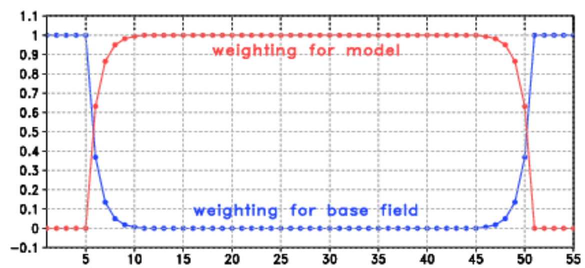
Fastest wave (Sound wave): 300 m/s

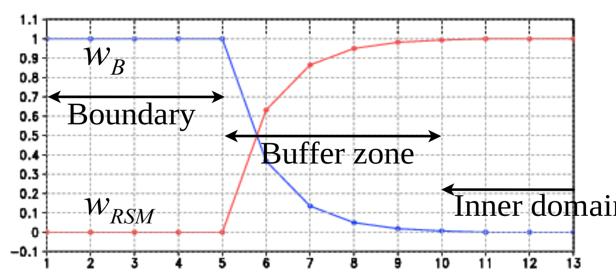
Longest distance in one Δt : 300 m/s × 40 sec = 12 km (less than 2Δx, 2Δy)

Boundary for Semi-Lagrangian = 5 grids (50 km from domain edge)

Weighting function for boundary







$$F = w_B F_B + w_{RSM} F_{RSM}$$

Result : idealized test (2-dimensional)

x-y directional advection

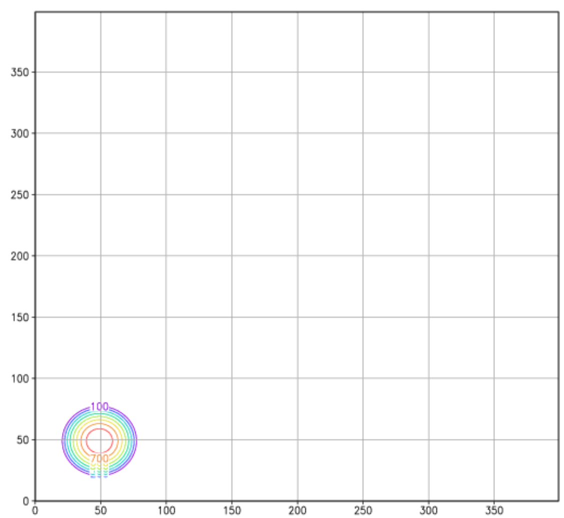
$\Delta x = 10$ km

$\Delta y = 10$ km

$\Delta t = 100$ sec

uniform u-wind : 10 m s^{-1}

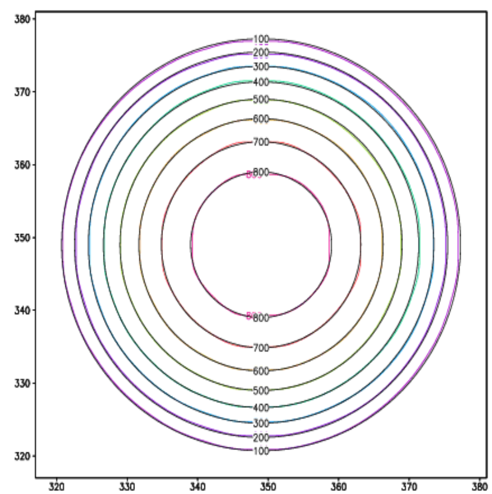
uniform v-wind : 10 m s^{-1}



at 3000 step (~ 83 hour)

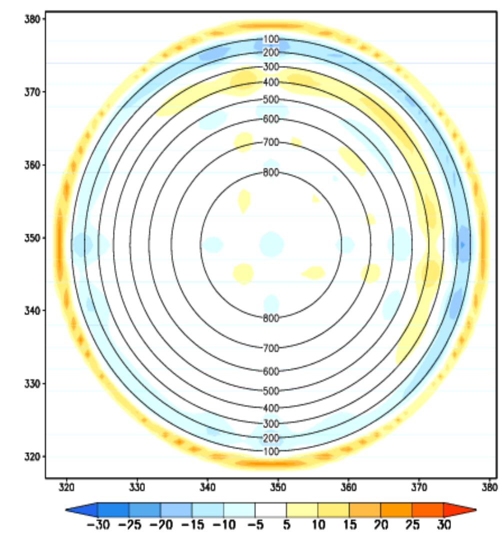
NDSL : rainbow

analytic solution : black



analytic solution : contour

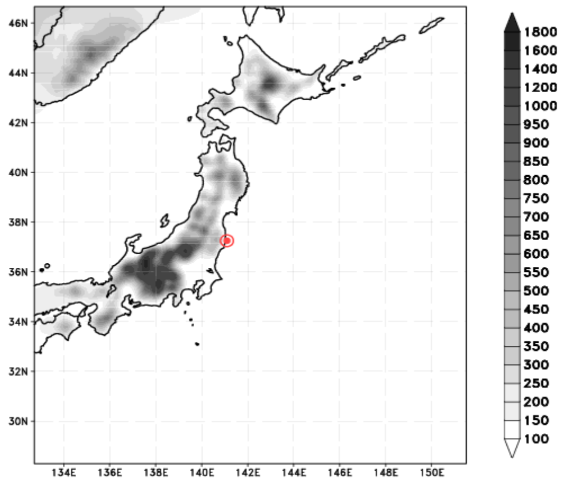
NDSL - Analytic : shaded



$$\frac{(total\ mass) - (initial\ mass)}{(initial\ mass)} \approx 10^{-15}$$

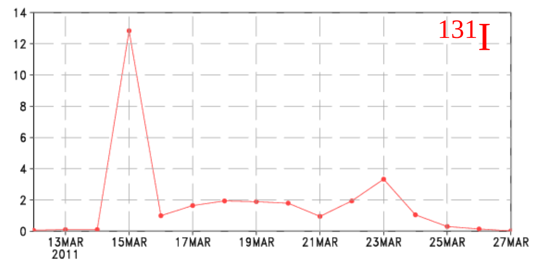
Real case : Fukushima nuclear power plant accident case

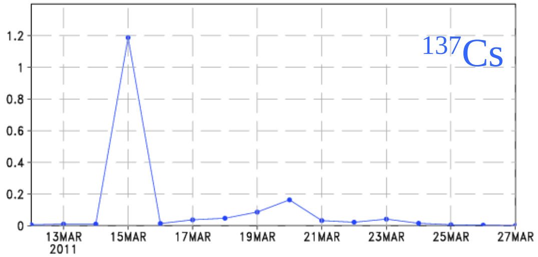
Domain and orography



Model	IsoRSM (Yoshimura et al., 2010)
Domain	Horizontal : 10 km (161 x 200) Vertical : 28 layers
I.C. & B.C	NCEP-DOE Reanalysis II
Integration period	2011. 03. 12. 00 UTC – 2011. 03. 28. 00 UTC (16 days)

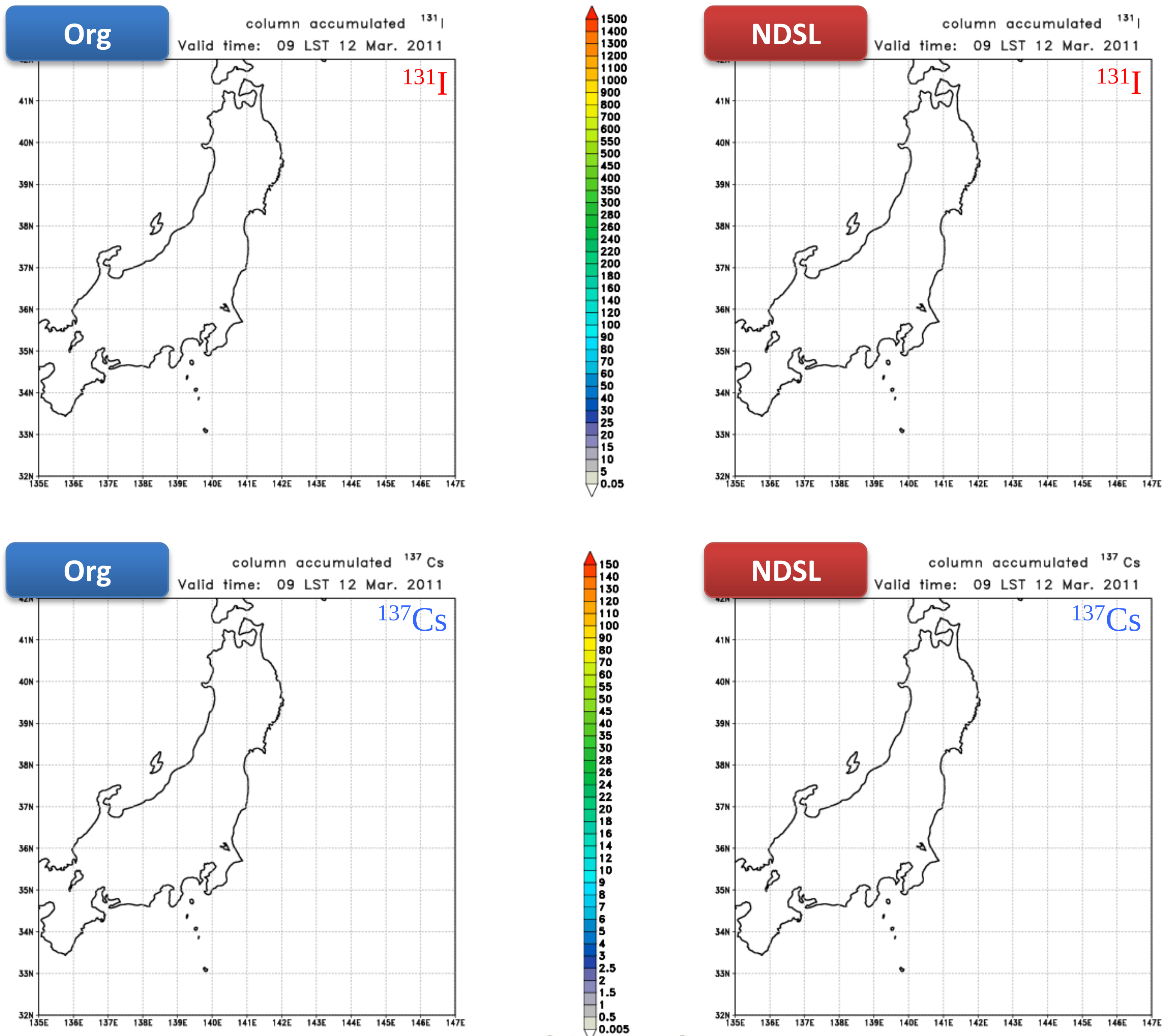
Daily averaged emission rate [MBq m^{-2} d^{-1}]
(Chino et al., 2011)





Experiment	**Description**
Org	Original IsoRSM (Yoshimura et al., 2010)
NDSL	Same as the IsoRSM, but **tracers** are calculated by NDSL (hydrometeor & radioactive particles)

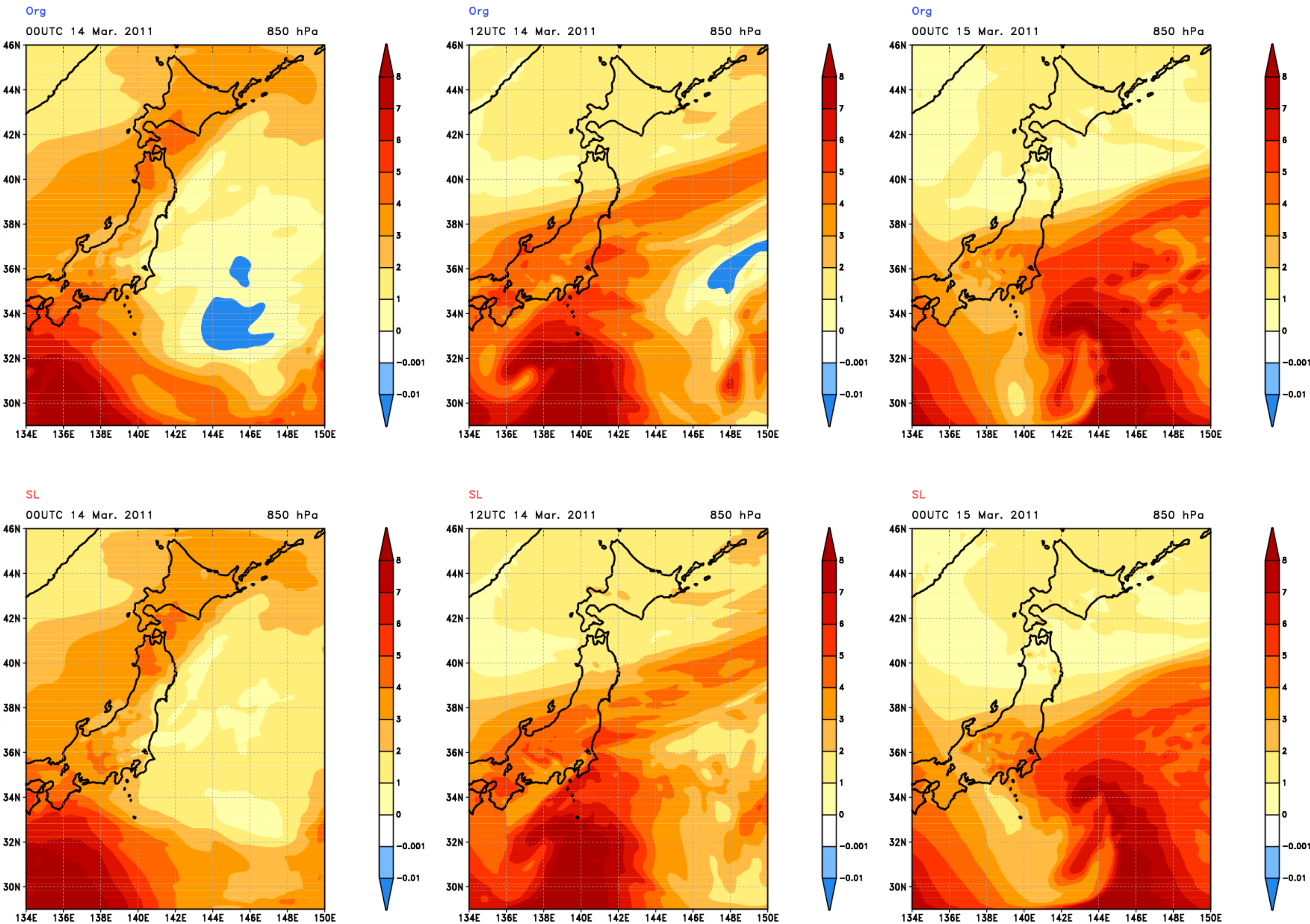
Result : Column accumulated tracers (kBq m^{-2})



Specific humidity (g kg^{-1})

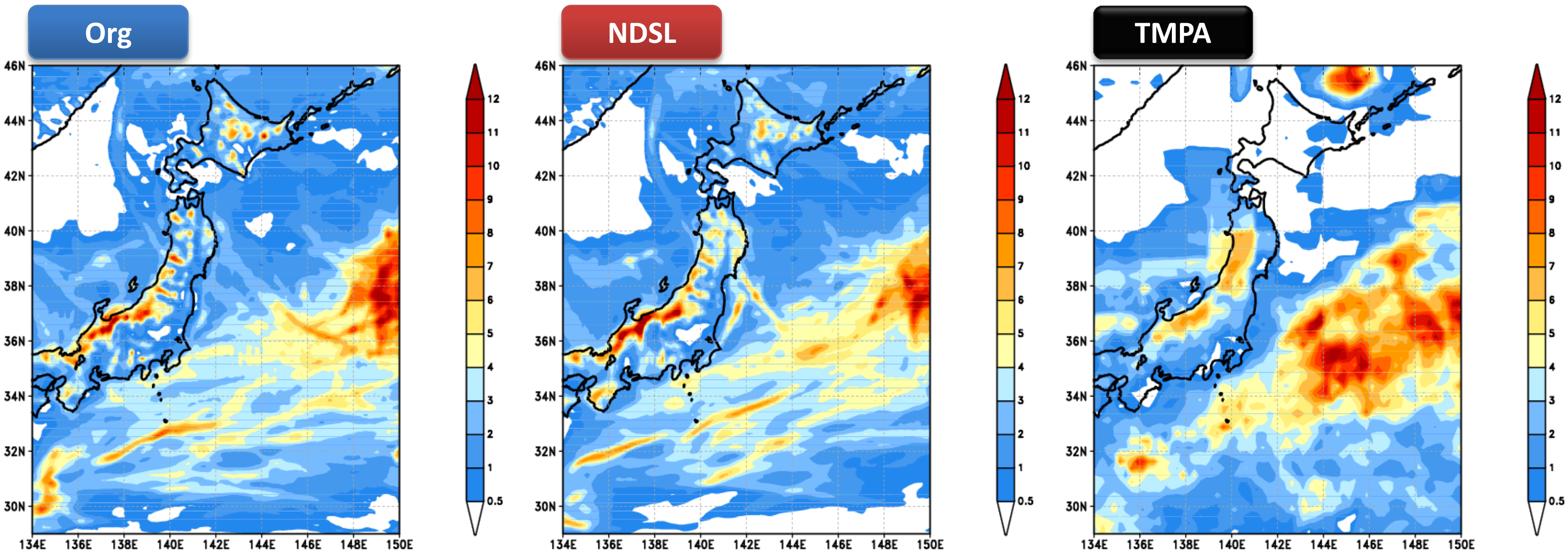
Org

NDSL



Precipitation

Averaged **total precipitation** **for Mar. 12-28, 2011 (mm d^{-1})**



Mass-conservation NDSL advection scheme

Zhang and Juang (2012)

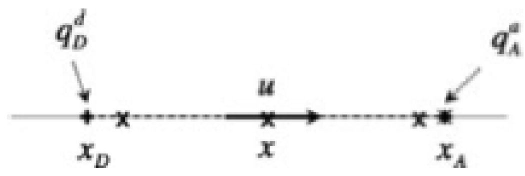


Figure 1. Schematic for the 1D NDSL pure advection.

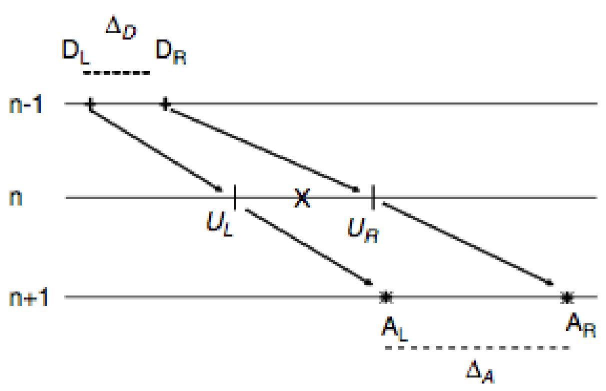


Figure 2. Schematic for the 1D NDSL mass-conservation advection.

1-D continuity equation

$$\frac{\partial \rho}{\partial t} + u\frac{\partial \rho}{\partial x} + \rho\frac{\partial u}{\partial x} = 0, \quad (1)$$

where ρ is a scalar quantity such as density and u is velocity quantity, so the divergence in the last term of (1) can be expressed as

$$\frac{\partial u}{\partial x} = \frac{1}{\Delta_x}\frac{\mathrm{d}\Delta_x}{\mathrm{d}t}, \quad (2)$$

where Δ_x is the cell length (volume). Substitute (2) into (1) and the continuity equation becomes

$$\frac{\mathrm{d}\rho\Delta_x}{\mathrm{d}t} = 0,$$

which is the Lagrangian form of the continuity equation, so local mass conservation can be obtained by

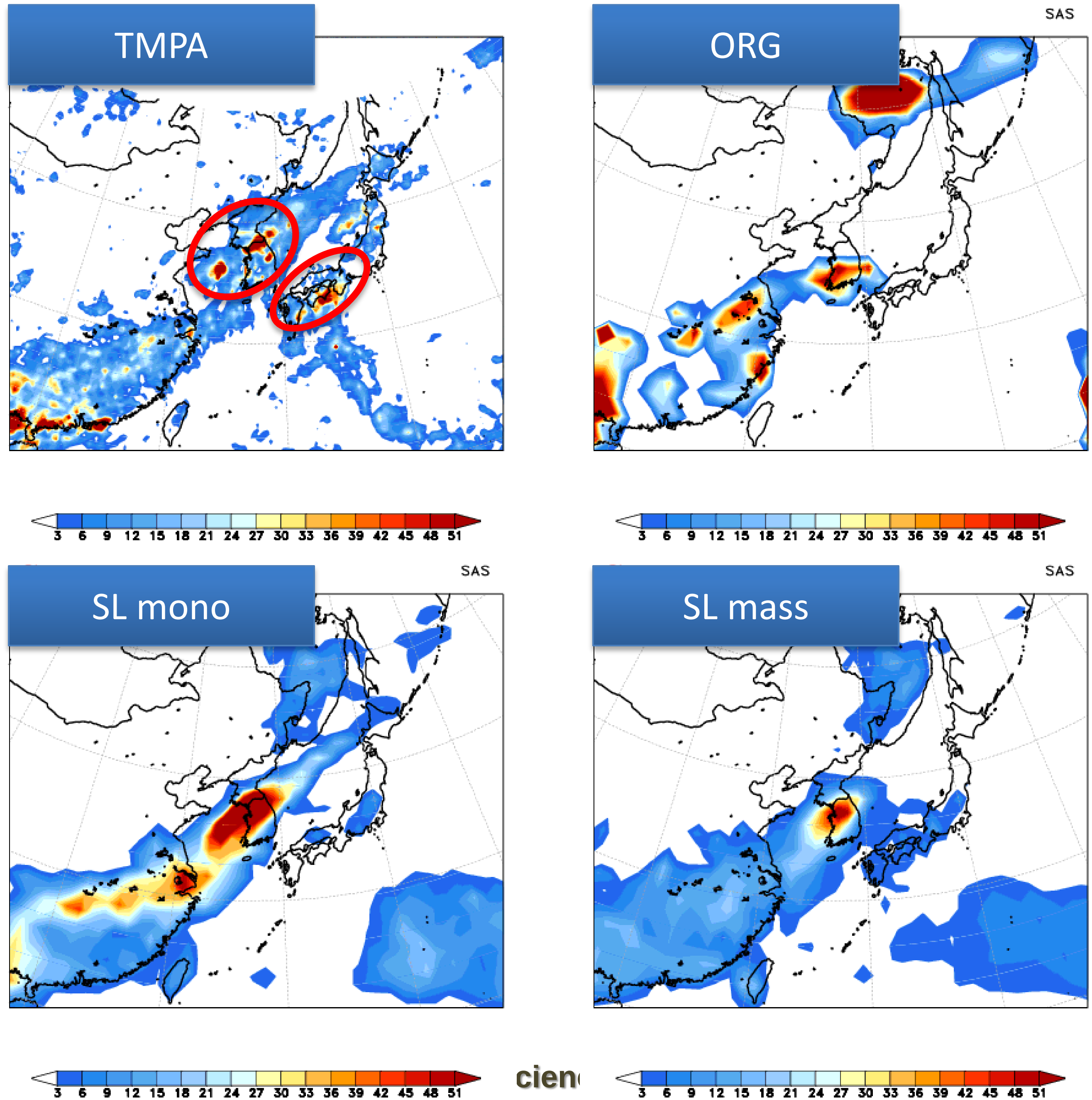
$$(\rho\Delta_x)_{\mathrm{D}}{}^{n-1} = (\rho\Delta_x)_{\mathrm{A}}{}^{n+1}, \quad (3)$$

D: departure location A: arrival location

48 hour averaged precipitation [mm d^{-1}]

2001. 07. 14-16 case
Heavy rainfall case
over mid-Korean peninsular

(50 km resolution)



Summary

1. **Original IsoRSM** has the "Gibbs phenomenon" in advection.

2. Non-iteration dimensional split semi-Lagrangian (**NDSL**) scheme is applied for tracer transport to solve this problem.

3. **NDSL** successfully reproduced radioactive particle transport **without Gibbs phenomenon**.

4. Mass-conserving advection scheme may improve precipitation field.

Errors of Interannual Variability and Multi-Decadal Trend in Dynamical Regional Climate Downscaling

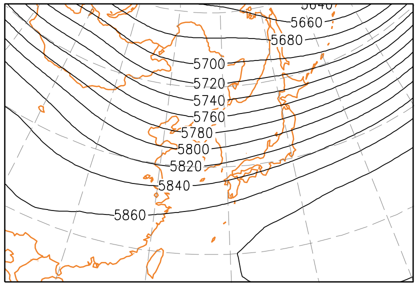
J. Geophys. Res., (2010 JGR)

Kanamitsu, M., K. Yoshimura, Y.-B. Yhang, and S.-Y. Hong

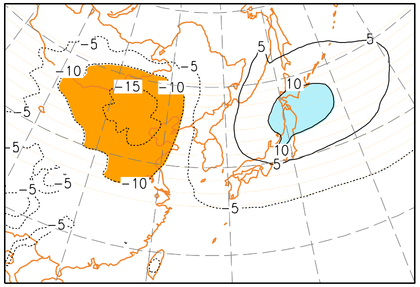
JJA 25-year climatology and error (m)

R2

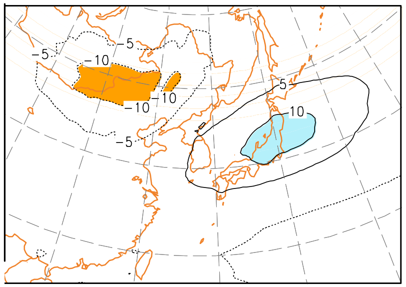
500hPa height



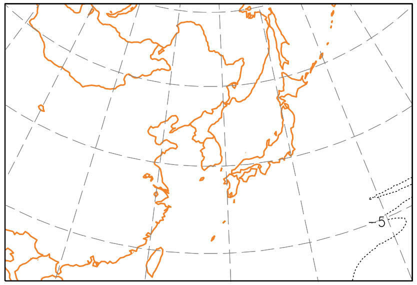
NOSSBC-R2



SSBC-R2



NEWSSBC-R2

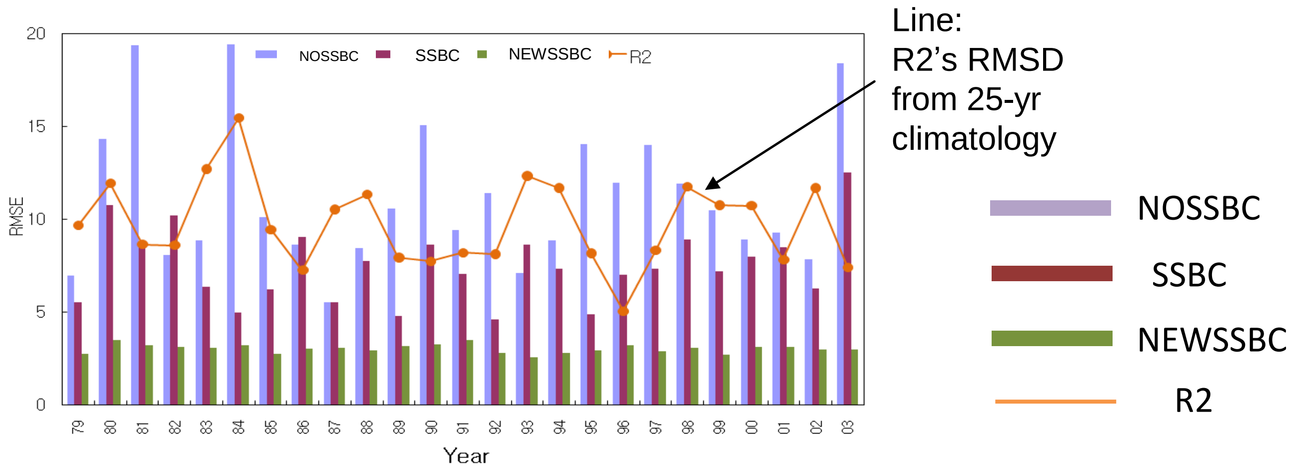


SSBC: Kanamaru and Kanamitsu 2006 – wind tendency nudging,
domain averaged T and Psfc correction

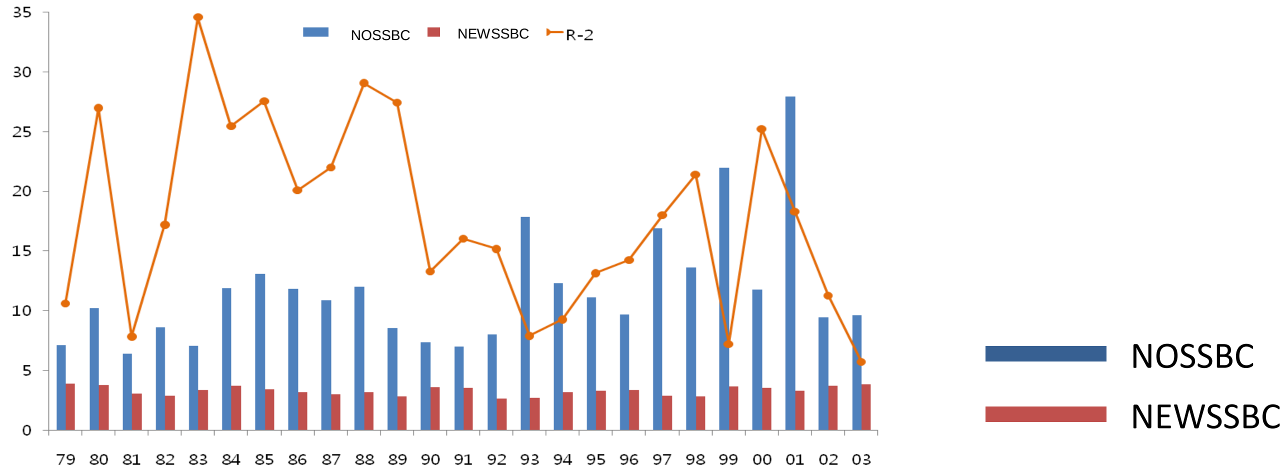
NEWSSBC: Kanamitsu et al. 2010 – Vorticity nudging,
no moisture nudging,

Interannual variation of 500-hPa height RMSE

Summer



Winter



Large-scale error was corrected, but precipitation was not
Evaluation was limited to a relatively small-domain

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Spectral Nudging Sensitivity Experiments in a Regional Climate Model

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(Manuscript received 6 March 2012; revised 31 May 2012; accepted 1 June 2012)

Model experimental design

Experiment	Description
NO_SSBC	do not use the SSBC
SSBC	apply the original SSBC method of Kanamitsu et al. (2010)
SSBC_UV	Same as the SSBC experiment but for the vorticity and the divergent components
SSBC_ver	apply the vertical weighted damping coefficient to the SSBC experiment
SSBC_UV_ver	Same as the SSBC_ver experiment but for the vorticity and the divergent components

Scale Selective Bias Correction (SSBC)

Kanamitsu et al. (2010, JGR)

$$F_t^{new}(m,n) = \left(\frac{1}{1+\alpha}\right) F_t^{old}(m,n) \quad \text{for} \quad m,n < m_c, n_c$$

Perturbation term

Chang and Hong (more divergent in low levels)

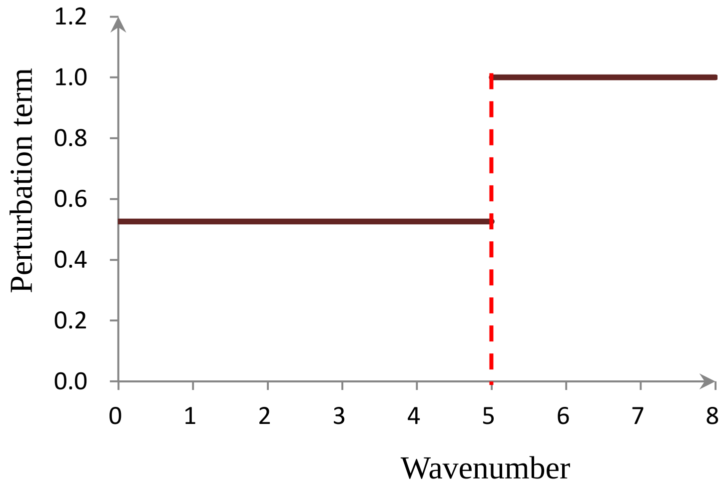
$$F_t^{new}(m,n) = \left(\frac{1}{1+\alpha(1-\sigma)^2}\right) F_t^{old}(m,n) \quad \text{for} \quad m,n < m_c, n_c$$

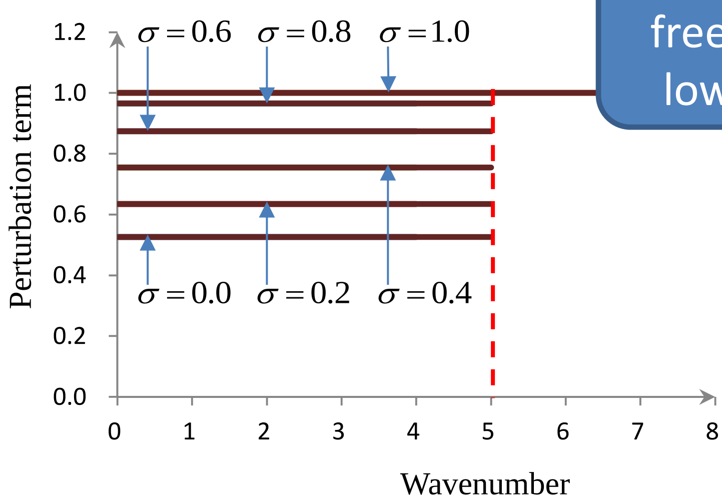
Perturbation term

$(1-\sigma)^2$: Vertical weighting factor

Perturbation term = 1 : perturbation is fully used (regional model perturbation is fully used)

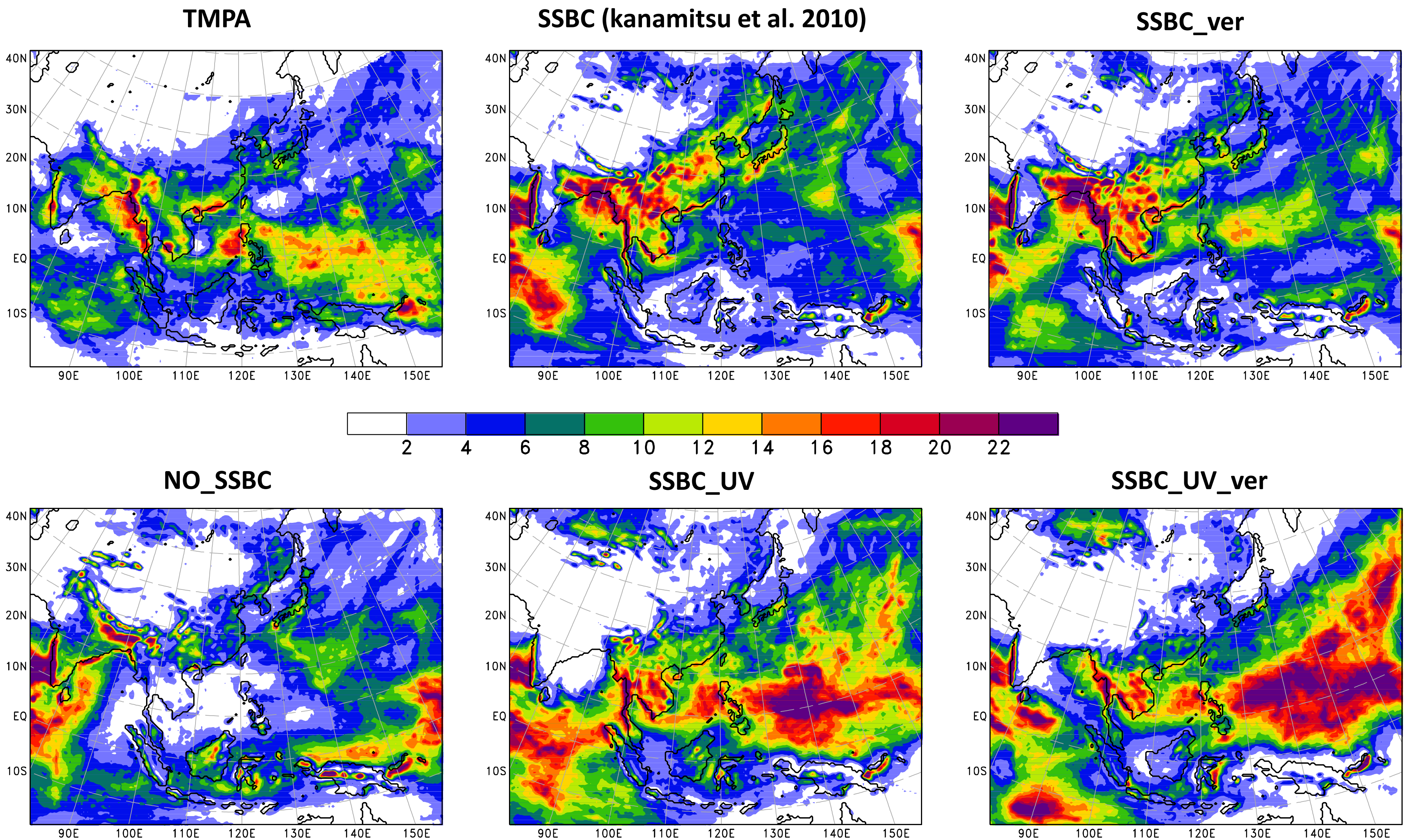
Perturbation term = 0 : perturbation is fully suppressed (global base field is fully used)





More freedom at low levels

Results : precipitation (2001 JJA : *mm* d^{-1})



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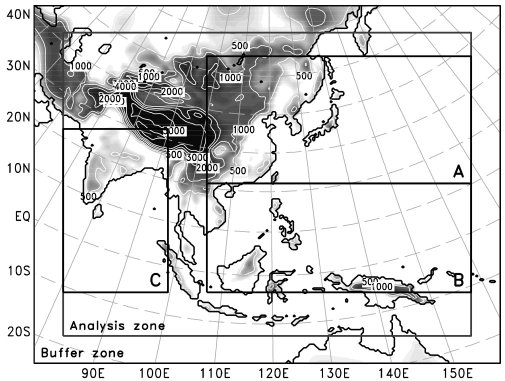


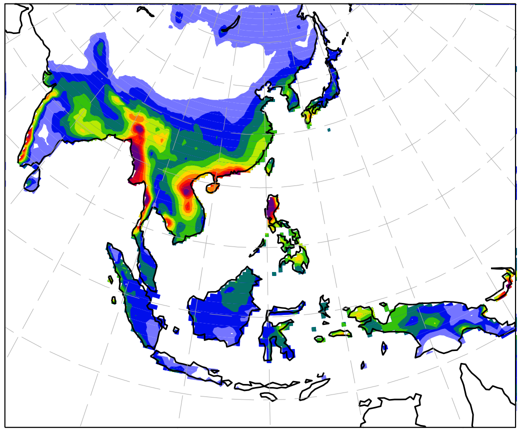
: Best score in PC

: Best score in RMSE

Experiment	Score	Whole	East Asia and Western North Pacific (A)	Western equatorial Pacific (B)	Indian Monsoon region and the Indian Ocean (C)
NO_SSBC	PC	0.37	0.46	0.07	0.09
	RMSE	4.76	2.59	6.01	7.83
SSBC	PC	0.51	0.44	0.30	0.52
	RMSE	4.56	4.09	5.02	7.08
SSBC_UV	PC	0.58	0.51	0.49	0.10
	RMSE	5.39	4.10	6.17	8.07
SSBC_ver	PC	0.57	0.61	0.28	0.55
	RMSE	4.22	2.93	4.92	6.76
SSBC_UV_ver	PC	0.46	0.32	0.35	0.20
	RMSE	6.42	6.40	7.79	6.64

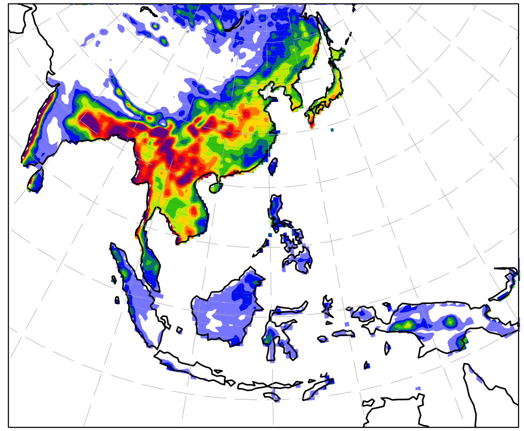
Results : precipitation (*mm d⁻¹*)

CRU



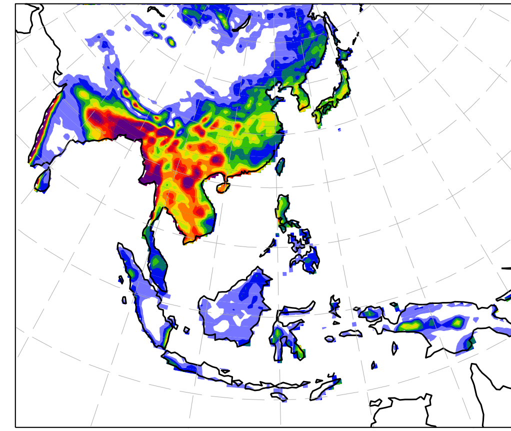
SSBC (kanamitsu et al. 2010)

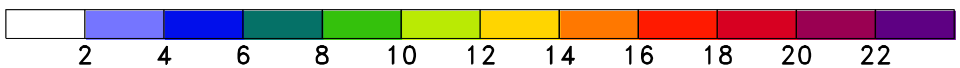
PC: 0.66, Bias: 0.74, RMSE: 4.11



SSBC_ver

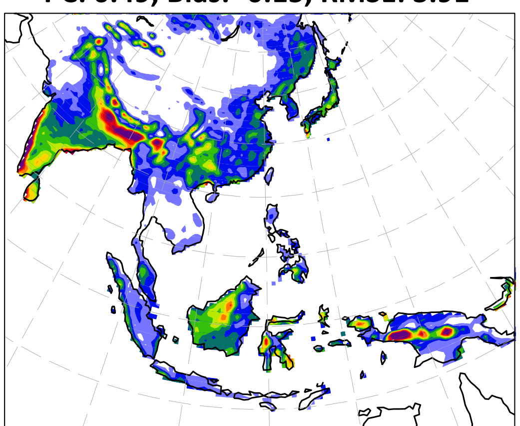
PC: 0.72, Bias: 0.47, RMSE: 3.66





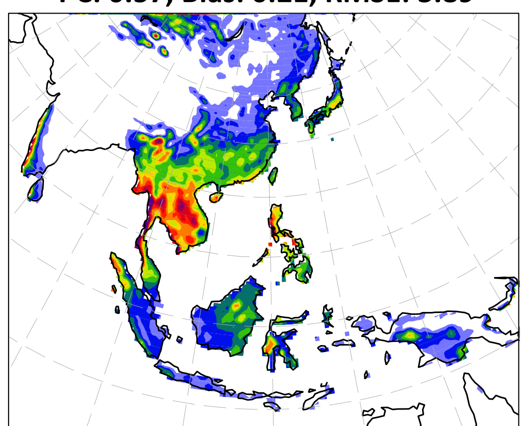
NO_SSBC

PC: 0.49, Bias: -0.15, RMSE: 3.91



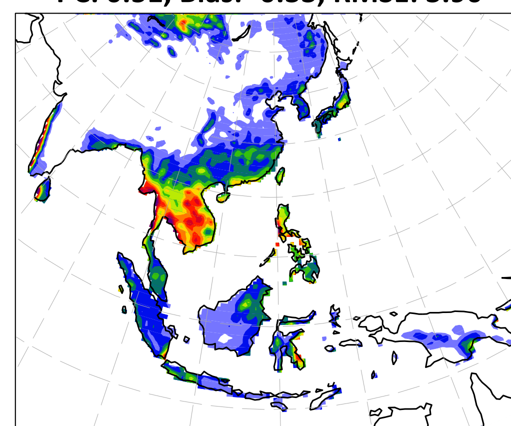
SSBC_UV

PC: 0.57, Bias: 0.21, RMSE: 3.89



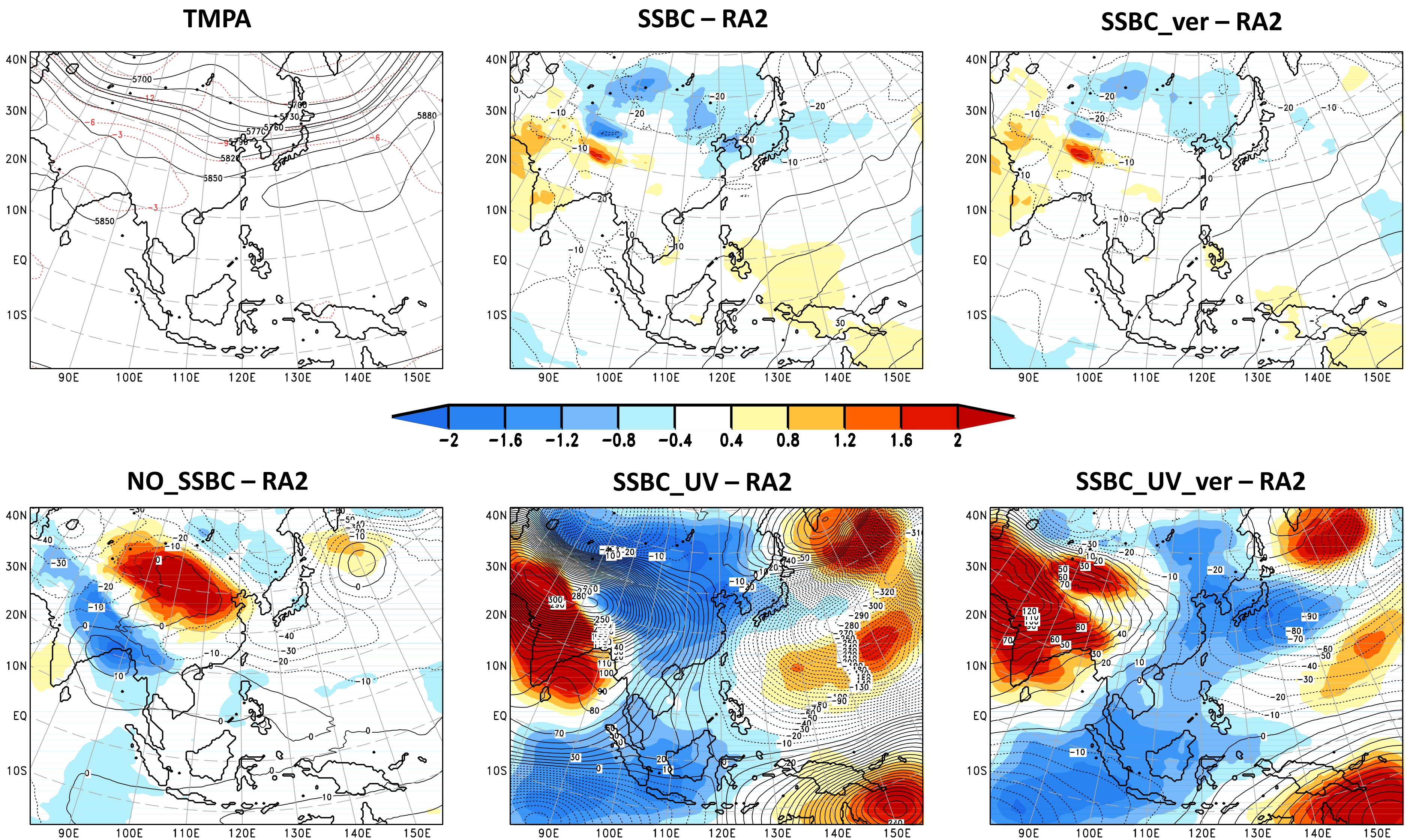
SSBC_UV_ver

PC: 0.51, Bias: -0.33, RMSE: 3.90



500 hPa geopotential height (*gpm*) & temperature

Shaded : Temperature difference
contour : height difference



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Scores for upper-air variables

Experiment	850 hPa wind speed		850 hPa temperature		500 hPa temperature		500 hPa Geopotential height		300 hPa wind speed	
	PC	RMSE	PC	RMSE	PC	RMSE	PC	RMSE	PC	RMSE
NO_SSBC	0.57	2.73	0.94	1.35	0.98	0.64	0.98	22.47	0.99	29.60
SSBC	0.86	1.93	0.97	0.85	0.99	0.39	0.98	16.68	0.99	19.02
SSBC_UV	0.94	1.39	0.94	1.35	0.93	1.44	0.39	130.48	0.69	132.16
SSBC_ver	0.90	1.73	0.97	0.91	0.99	0.35	0.98	17.24	0.99	19.14
SSBC_UV_ver	0.78	2.73	0.93	1.79	0.92	1.47	0.79	51.46	0.90	62.22

: Best score in PC (red box)　**: Best score in RMSE** (blue box)

Revised nudging

↓

Kanamitsu et al. (2010) + vertical weighting

Nudging sensitivity experiments
for 10-year (2001 ~ 2010)
with R-2 reanalysis

Same as in Kanamitsu et al. (2010) setup

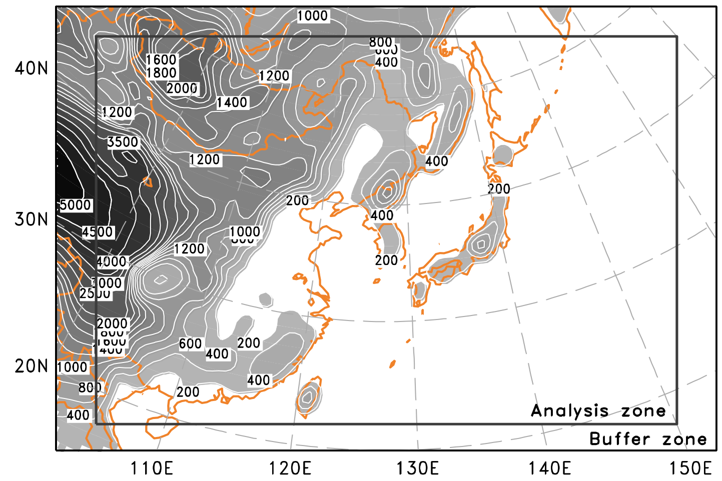
Experimental design

I.C & B.C : NCEP-DOE reanalysis II

Integration period : 2001 JJA – 2010 JJA

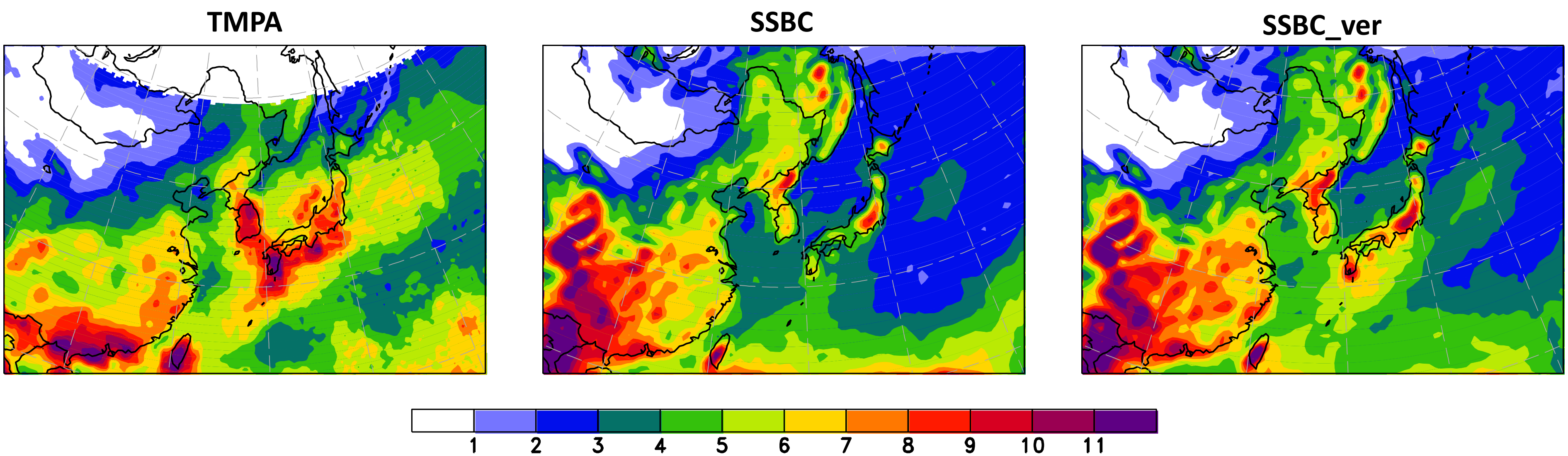
(Discontinuous run: restart every year)

Model domain : East Asia (129 × 86)



Experiment	Description
SSBC	apply the original SSBC method of Kanamitsu et al. (2010)
SSBC_ver	apply the vertical weighted damping coefficient to the SSBC experiment

10-year JJA averaged precipitation (*mm d⁻¹*)



Scores for entire analysis domain

	PC	Bias	RMSE
SSBC	0.62	-0.50	2.20
SSBC_ver	0.73	-0.16	1.86