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**1934-22**

**Fourth ICTP Workshop on the Theory and Use of Regional Climate Models: Applying RCMs to Developing Nations in Support of Climate Change Assessment and Extended-Range Prediction**

***3 - 14 March 2008***

**Improvement of Dynamical Downscaling for Asia and other regions.**

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# Improvements of Dynamical Downscaling for Asia and other regions

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University of California
San Diego

# Acknowledgements

Das, S. (India), Gao, X. (China), Goswami, P. (India), Hong, S-.Y. (Korea), Kang, H. (Korea), Lu, M.-M. (Taiwan), Mohanty, U. C. (India), Murazaki, K. (Japan), Sasaki, T. (Japan), Sun, L. (U.S.), and Takayabu, I. (Japan).

*This work is not exhaustive in any way. It is a small effort to summarize information I was able to collect in relatively short time.*

# Outline of the talk

- Review of the dynamical (and some statistical) downscaling activity over Asia.
  - International collaborations
    - APCC
    - RMIP
  - Korea
  - China
  - India
  - Taiwan
  - Japan

- What are necessary to improve the dynamical downscaling? Focusing on the numerics of the regional model.

# Asian collaborative projects (1)

- APEC (Asia-Pacific Economic Cooperation) Climate Center (**APCC**).
  - Located in Busan, Korea
  - APEC countries (China, Indonesia, Japan, Philippines, Singapore, Taiwan, Canada, Chile, Korea, Russia, Papua New Guinea, Brunei, Australia, Malaysia, Mexico, Thailand, New Zealand, Peru, Vietnam, United States…)
  - Aiming at providing useful seasonal forecasts for APEC countries

6 administration division staff
13 scientific division staff
India, China, Japan, Korea

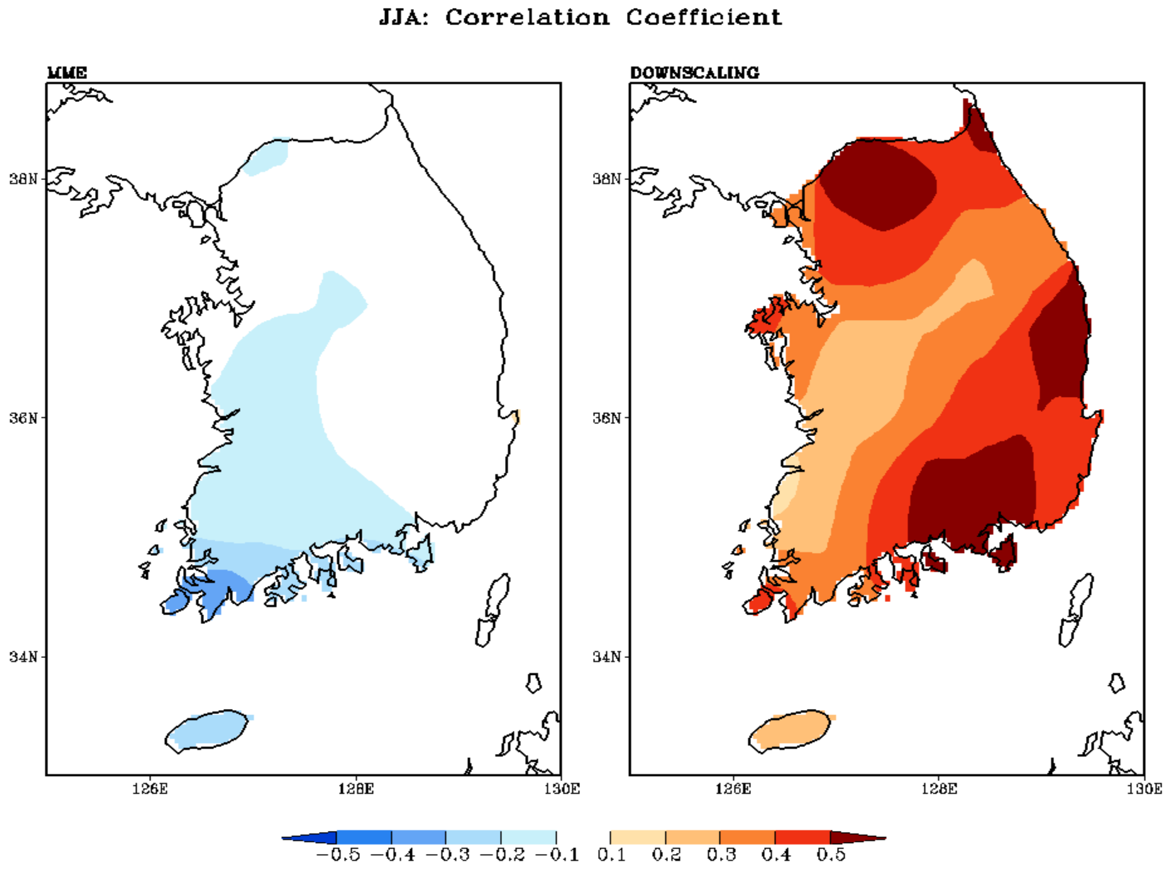
# APCC forecasts

- Based on:
  - MSC(Canada), CWB(Taipei), SNU(Korea), MRI/KMA(Korea), IAP(China), MGO(Russia), IRI(USA) and NCEP(USA) model forecasts.
- Multi-model ensemble method (all statistical)

1. CPPM – Coupled Pattern Projection Method (downscaling);
2. MME – simple composite of bias corrected model ensemble means;
3. Superensemble - multiple regression based blend of model ensemble means (MR);
4. Synthetic multi-model ensemble (SE) – multiple regression on leading PCs.
5. Probabilistic – position of the forecast PDF in respect to the historical PDF.

- Four times a year

# Korea

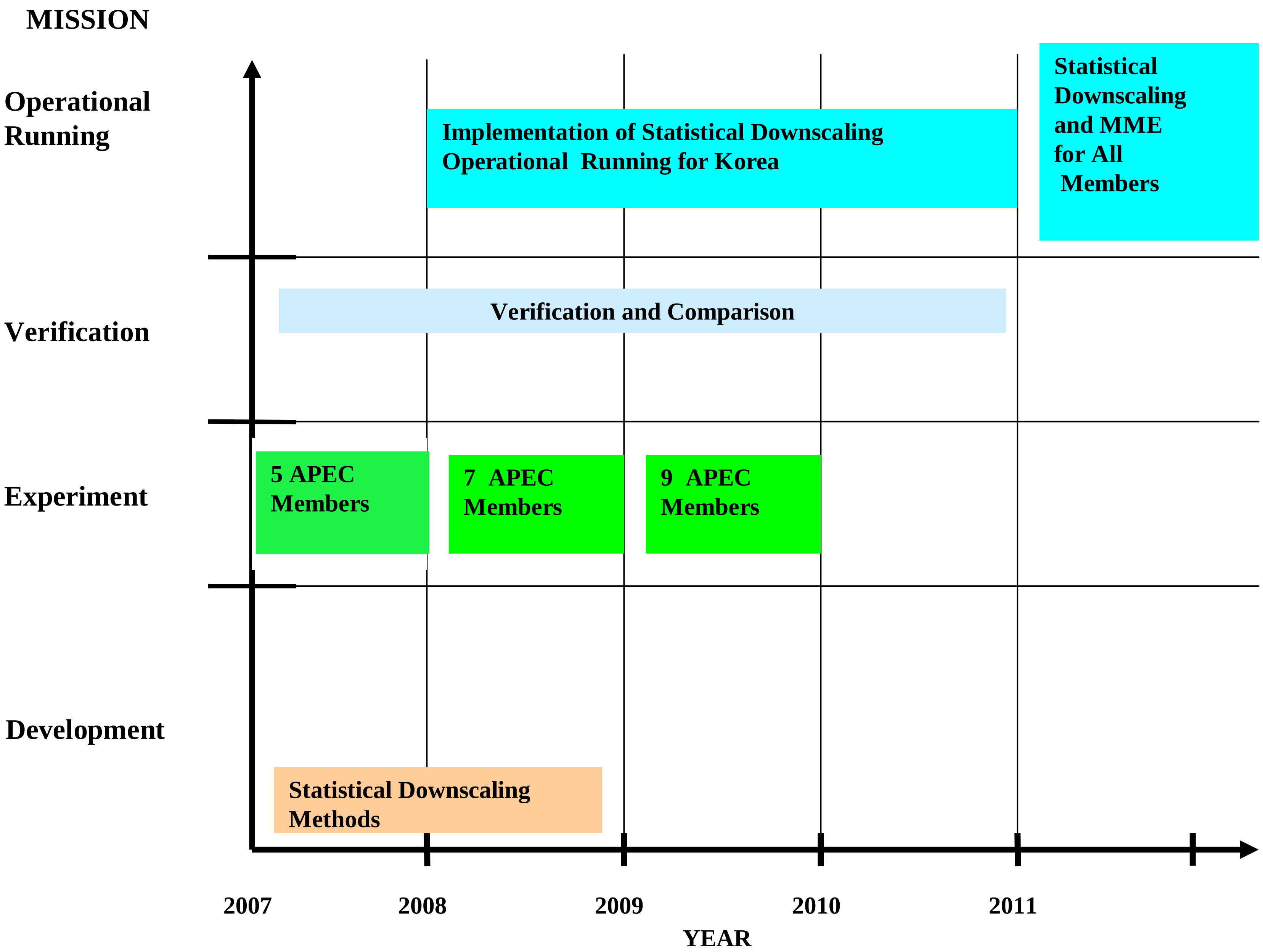



**Spatial Distribution of Correlation Coefficient between station observation and forecast. (1983-2003)**

**MME**: Simple Composite of Multi-Model Output Precipitations

**DOWNSCALING: Simple Composite of Multi-Model Downscaled Precipitation**

# 5 Year Plan for Downscaling at APCC



# Asian collaborative projects (2)

- Regional Model Intercomparison project for Asia (**RMIP**).

  - Managed by Congbin Fu
    China, U.S., Korea, Australia, Japan.

# RMIP
# - Objectives -

1) to assess the current status of East Asian regional climate simulation,
2) to provide a scientific basis for further RCM improvement, and
3) to provide scenarios of East Asian regional climate change in the twenty-first century based on an ensemble of RCMs that are nested within a GCM.

CONGBIN FU, SHUYU WANG, ZHE XIONG,WILLIAM J. GUTOWSKI, DONG-KYOU LEE, JOHN L. MCGREGOR, YASUO SATO, HISASHI KATO, JEONG-WOO KIM, AND MYOUNG-SEOK SUH, 2005: BAMS, 257-266. DOI:10.1175/BAMS-86-2-257

# RMIP
# - Project plan -

- **Phase one:** This 18-month simulation (March 1997–August 1998) covers a full annual cycle—East Asian drought and heat waves during the summer of 1997, and flooding in Korea, Japan, and the Yangtze and Songhua River valleys of China, during the summer of 1998. Phase-one tasks entail examining model capabilities to reproduce the annual cycle of monsoon climate and to capture extreme climate events. To date, nine models from five countries have contributed to RMIP's phase one. These include eight limited-area models and one global variable resolution model, the Conformal-Cubic Atmospheric Model (CCAM). Detailed model information is listed in the appendix. **(COMPLETE)**

- **Phase two:** This 10-yr simulation (January 1989–December 1998) assesses the models' ability to reproduce statistical behavior of the Asian monsoon climate. (**INTEGRATION COMPLETE BUT NO REPORT YET**)

- **Phase three:** Simulations with RCMs driven by GCM output under different forcing scenarios, including changes of atmospheric CO2 concentration, sulfate aerosol emissions, and land cover are made. Phase three tasks aim at providing improved climate change scenarios and uncertainty estimates for East Asia through an ensemble of model simulations. (**FUTURE PLAN**)

# RMIP participating models

TABLE 1. Properties of participating RMIP models for phase one.

| Model | RIEMS | DARLAM | CCAM | JSM_BAIM | RegCM | RegCM2a | RegCM2b | ALT. MM5/LSM | SNU RCM |
|---|---|---|---|---|---|---|---|---|---|
| Group leader | C. Fu | J. McGregor | J. McGregor | Y. Sato | J. Kim | M. Suh | H. Kato | W. Gutowski | D. Lee |
| Country | China | Australia | Australia | Japan | South Korea | South Korea | Japan | United States | South Korea |
| Vertical levels | $\sigma$-17 levels | $\sigma$-18 levels | $\sigma$-18 levels | $\sigma$-23 levels | $\sigma$-15 levels | $\sigma$-15 levels | $\sigma$-14 levels | $\sigma$-23 levels | $\sigma$-23 levels |
| Dynamic process | Hydrostatic | Hydrostatic | Hydrostatic | Hydrostatic | Hydrostatic | Hydrostatic | Hydrostatic | Nonhydrostatic | Nonhydrostatic |
| Lateral boundary condition | Linear relaxation | Exponential relaxation | Exponential relaxation | ER+spectral coupling | Exponential relaxation | Exponential relaxation | Exponential relaxation | Linear relaxation | Exponential relaxation |
| Convective scheme | Kuo–Anthes | Arakawa–Gordon | Arakawa–Gordon | Moist convective adjustment | Grell | Kuo–Anthes | Kuo–Anthes | Betts–Miller | Grell |
| Land surface | BATS | Kowalczyk | Kowalczyk | BAIM | BATS | BATS | NCAR/LSM | NCAR/LSM | NCAR/LSM |
| Planetary boundary layer scheme | Holtslag | Louis | Louis | Yamada level 2 Louis scheme | Holtslag | Holtslag | Holtslag | MRF | MRF |
| Longwave radiation scheme | CCM3 | GFDL | GFDL | Sugi | CCM3 | CCM2 | CCM3 | CCM2 | CCM2 |
| Shortwave radiation scheme | CCM3+ Aerosol | Lacis and Hansen | Lacis and Hansen | Lacis and Hansen | CCM3+ Aerosol | CCM2 | CCM3 | CCM2 | CCM2 |

# RMIP Domain

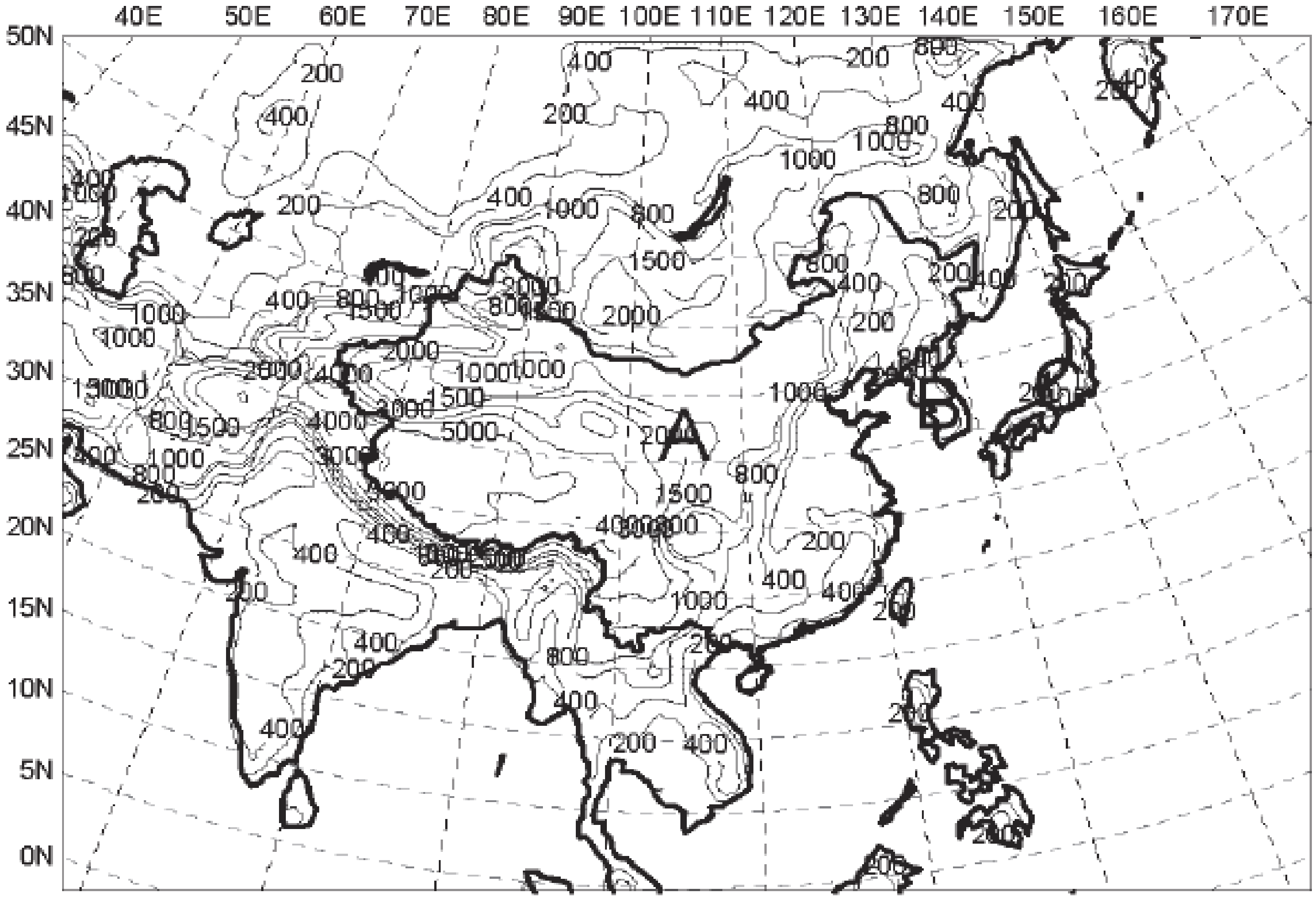



**Fig. 1. MIP simulation domain, showing terrain elevations in (m). Letters mark centers of the analysis regions: mainland China (A), Korean peninsula (B), and Japanese islands (C).**

# RMIP
## - some detail -

- 60km resolution
- NCEP/NCAR reanalysis as a boundary condition for phase 1 and 2.
- CSIRO global warming simulation for phase 3.
- Validation using NCEP/NCAR Reanalysis and CMAP precipitation.

# RMIP Precipitation bias comparison

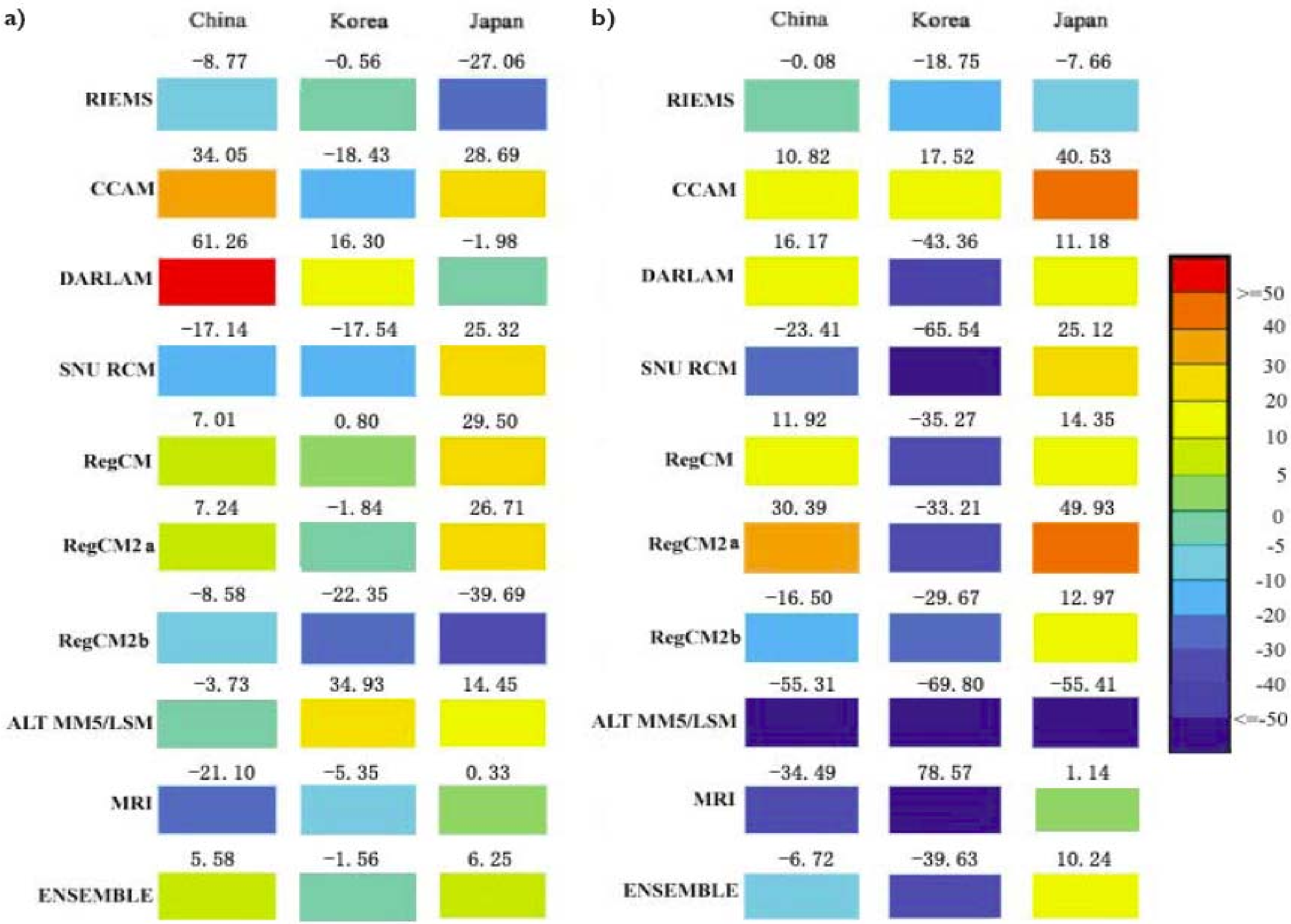



FIG. 3. Seasonal total precipitation bias (%) in (a) winter 1997 and (b) summer 1998.

# RMIP
# - tentative conclusions -

- Diversity in the model bias (temperature and precipitation).
- Ensemble average tends to reduce the biases.
- Precipitation simulation better in winter than in summer.
- Most models reproduced extreme events to some degree.

# Korea

# GCM vs. RCM for research tool
Prof. Song-You Hong
Yonsei University, Seoul, Korea

**General Circulation Model (GCM)**

- Predictability in the long term integration
  → lack of confidence in the results from the sensitivity experiments
- Low resolution
  → cannot resolve mesoscale features

**Regional Climate Model (RCM)**

- Observed large-scale forcing → can provide realistic physical mechanism in response to a different external forcing
- High resolution → can resolve detailed evolution which cannot be reproduced in GCM

**Research tools**

- Hong and Pan (2000, J. Geophys. Res) : Soil moisture impact in North America
- Hong and Kim (2007, J. Climate) : Soil moisture impact in East Asia
- Hong and Kalnay (2000, Nature ) : Role of SST and soil-moisture feedback
- Park and Hong (2004, JG-letter) : External forcing on Indian monsoon.
- Song et al. (2006, in review) : Effects of the Tibetan Plateau on Asian monsoon
- Seol and Hong (2008, in review) : Effects of the Tibetan snow on Asian monsoon
- Yhang and Hong (2008, J. Climate) : Tool for physics evaluation and development

# China

# Seasonal forecast in BCC/CMA by BCC_RegCM1.0

# (China)

## Case study of JJA 2006 and JJA 2007 forecast, made in the previous March

**YM Liu et al**

BCC: Beijing Climate Center

# Model

- ✓ **Model ： BCC_RegCM1.0**

  **(based on RegCM2, Giorgi et al, 1993)**

- ✓ **Physics**

  **Land surface--- BATS**

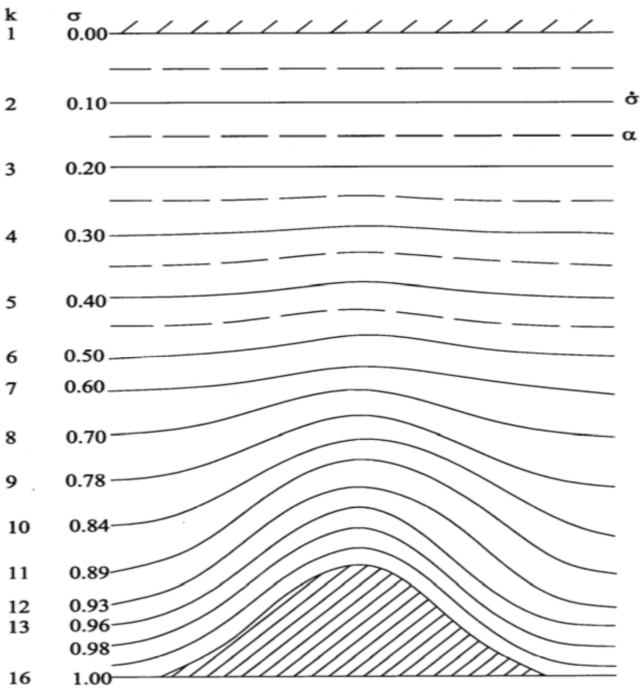
  **Convection --- MFS**

  **Radiation --- CCM3 Package**

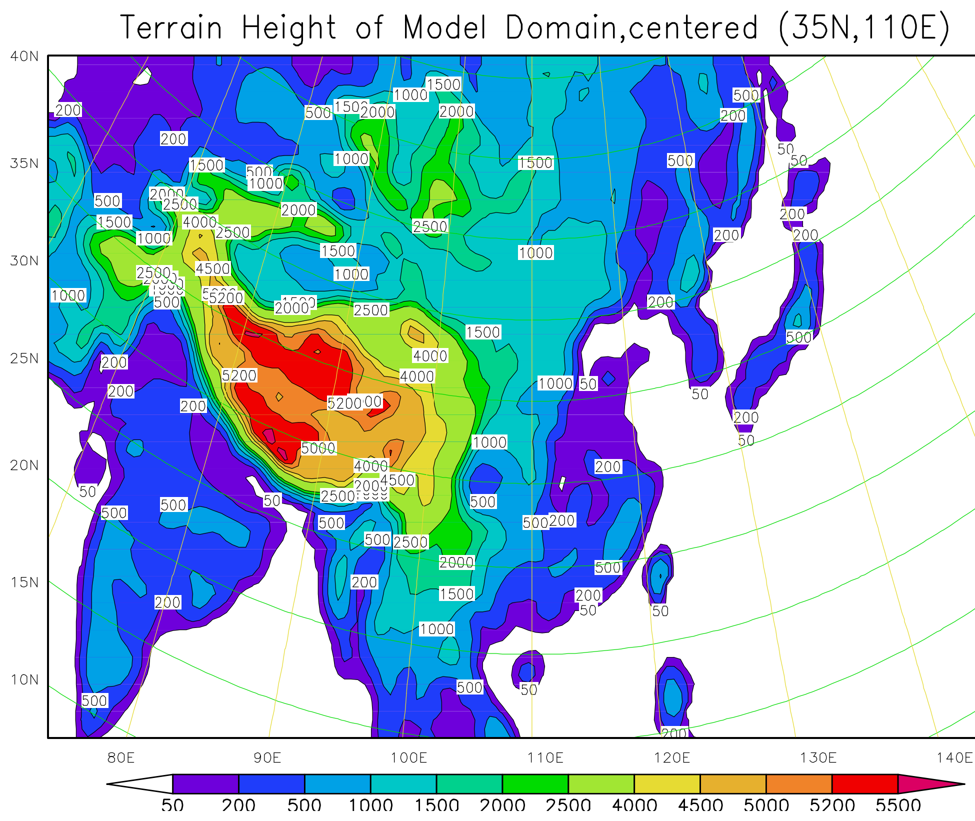
  **PBL --- Holtslag**

- ✓ **Driving field:**
  - ➢ **AOGCM Forecast in BCC: BCC_CGCM1.0**
  - ➢ **12 hour update for lateral conditions**

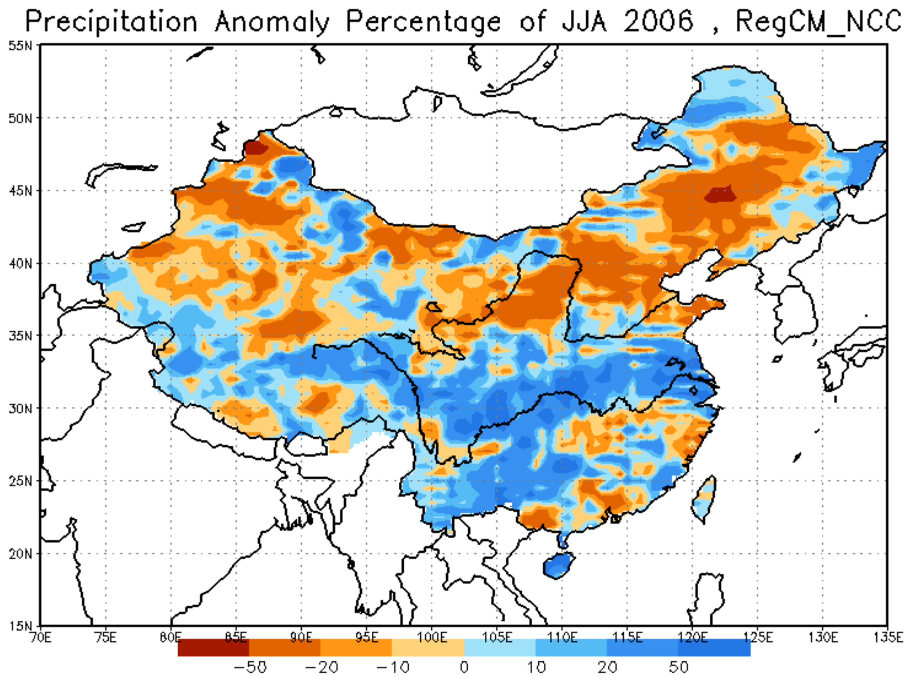
# Vertical layers, model domain, topography, resolution: 60 km

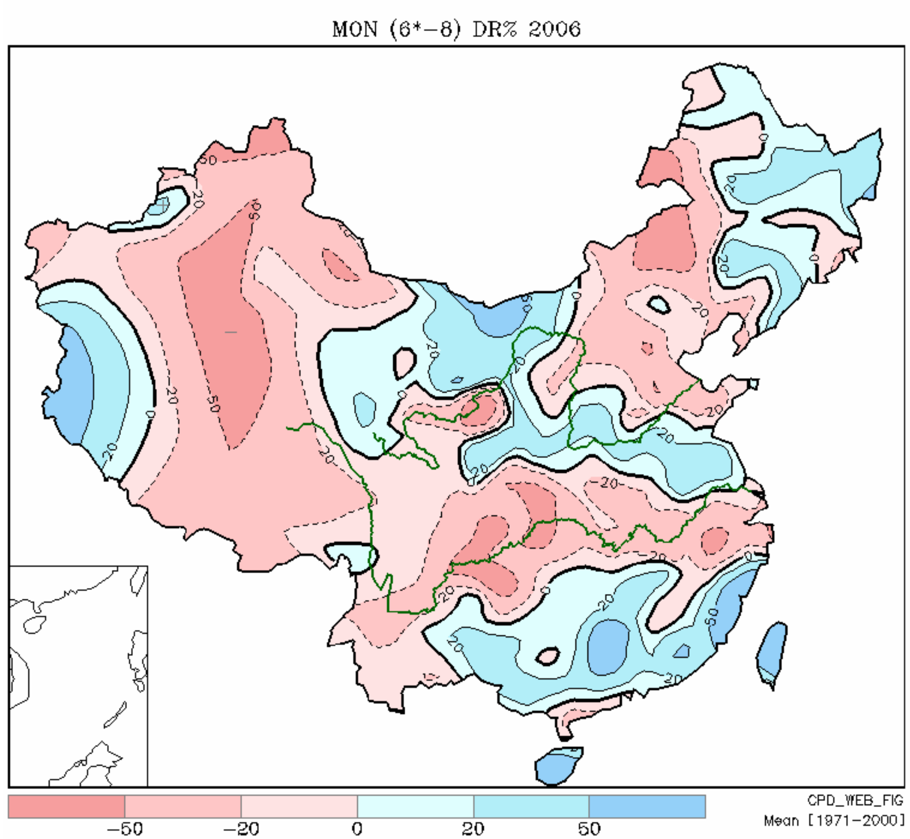



模式垂直网格结构。变量$\dot{\sigma}$定义在整模式层上，
以α表示的其他变量定义在半模式层上。



# Validation of forecast of JJA 2006, precipitation




**forecast** **observation**

# India

# Simulation of the Indian Summer Monsoon using ISRO Vegetation Fraction and Downscaling by a Regional Climate Model

Someshwar Das[1], Surya K. Dutta[1], S.C. Kar[1], U.C.Mohanty[2] and P.C. Joshi[3]

[1]National Centre for Medium Range Weather Forecasting, NOIDA
[2]Centre for Atmospheric Science, IIT, Delhi
[3]Space Application Centre, ISRO, Ahmedabad

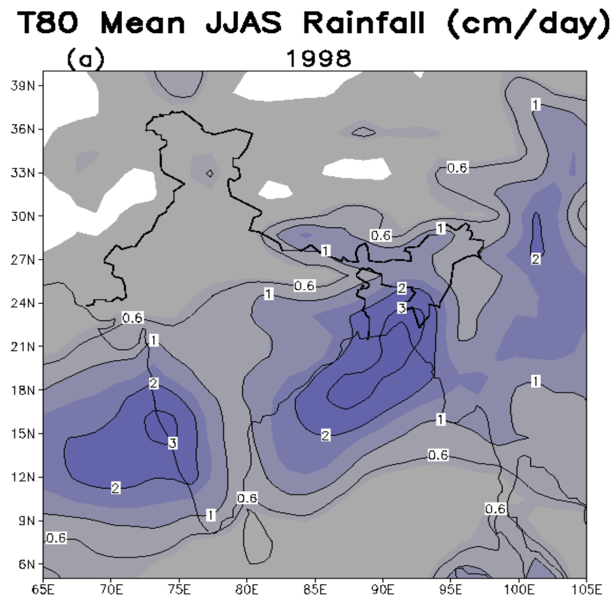
**Simulation of the Indian Summer Monsoon using ISRO Vegetation Fraction and Downscaling by a Regional Climate Model**

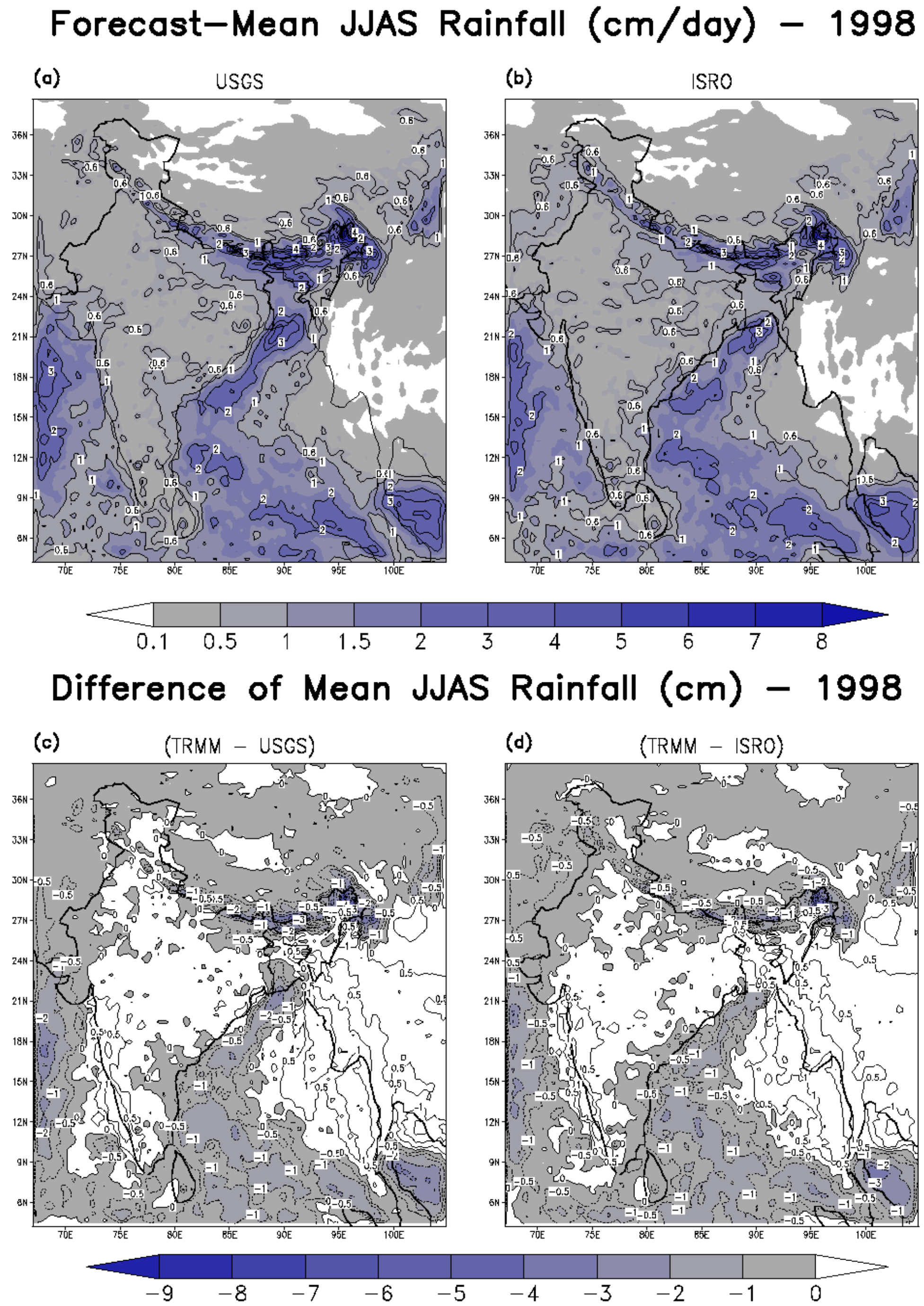
# Experiments

- MM5 downscaling of T80 global model.
- Resolution of outer domain 90km and inner domain 30km
- Years: 1998 (Normal Monsoon)
- 2002 (Deficient Monsoon)
- Initial Condition: 00Z, 16 May
- Integration up to 30 September
- Hindcast runs with USGS and ISRO Vegetations
- Forecast runs with USGS and ISRO Vegetations

Total 8 Experiments

Das et al. (2007)




Das et al. (2007)

# Executive Summary

- Finer spatial variations in rainfall are produced better by MM5 than T80.
- Simulations with ISRO vegetation are better in many aspects in most of the cases.
- In some cases, MM5 simulations produced anomalous circulation over the Saudi-Arabian region

Das et al. (2007)

# RCM Work in IIT, Delhi
# (U C Mohanty Group)

Development and Sensitivity Exp.

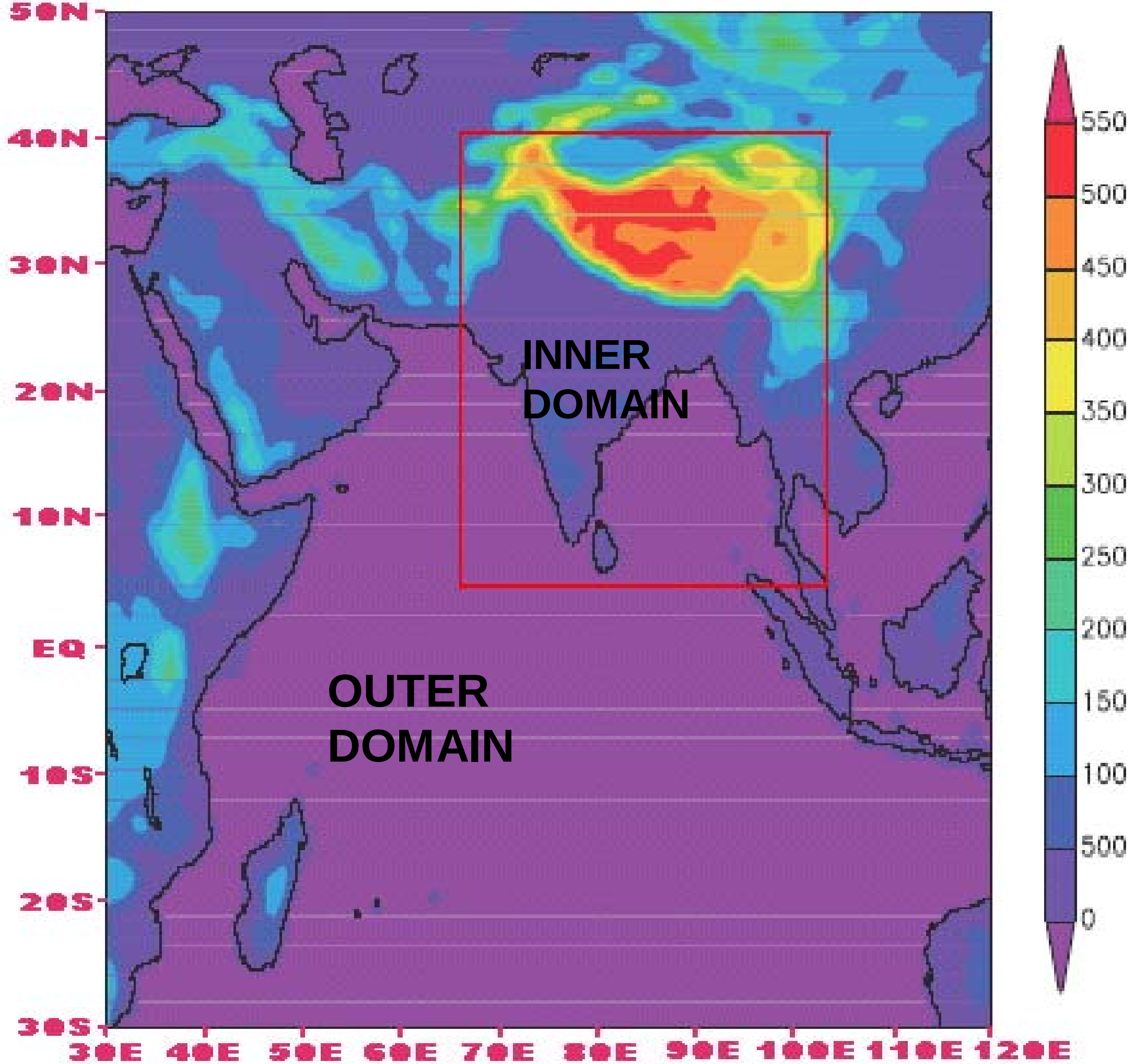
Evaluation and validation

Impact of observed data

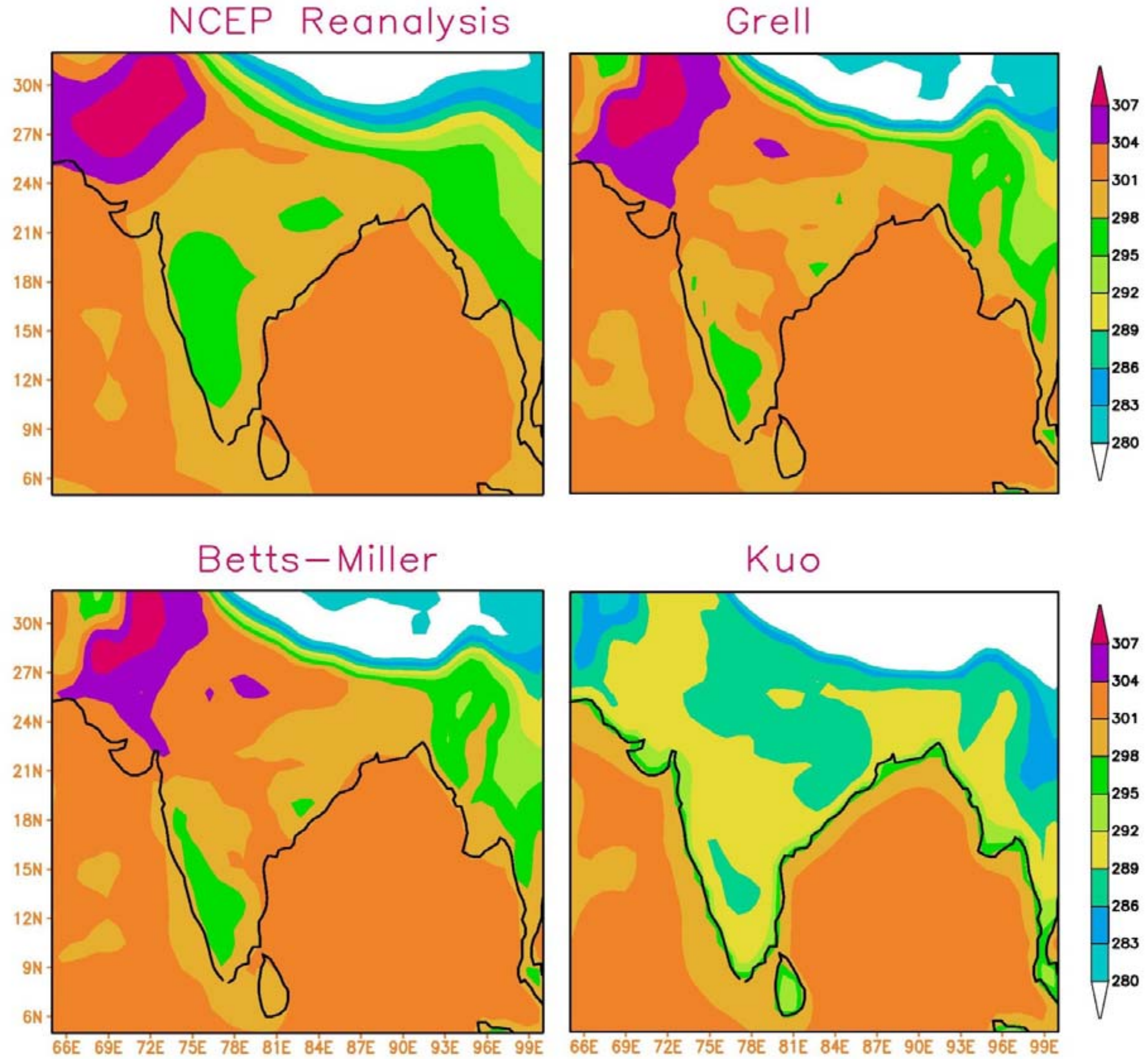
# Experiments Conducted with RCM MM5

| Experiments | Data used for IC and BC | Descriptions |
|---|---|---|
| Sensitivity Experiments with different cumulus schemes | NCEP/NCAR reanalysis data and USGS geophysical data | Simulation carried out separately for various year with three different cumulus schemes namely Grell, Betts-Miller and Kuo |
| Sensitivity Experiments with different land schemes | NCEP/NCAR reanalysis data and USGS geophysical data | Three different land surface schemes such as Noah, Multi-Layer and Pleim-Xiu has been examined in RCM simulation |
| Control simulation | NCEP/NCAR reanalysis data and USGS geophysical data | Simulation carried out separately for various year with the best combinations of cumulus and land surface schemes from sensitivity experiments |
| Impact of satellite derive vegetation fraction/type | Satellite derive vegetation fraction and other geophysical parameters from USGS; NCEP/NCAR reanalysis data | Simulation carried out separately for various year with the best combinations of cumulus and land surface schemes from sensitivity experiments |
| Influence of satellite derive soil-moisture | Satellite derive soil-moisture and other geophysical parameters from USGS; NCEP/NCAR reanalysis data | Simulation carried out separately for various year with the best combinations of cumulus and land surface schemes from sensitivity experiments |
| Impact of combined satellite derive vegetation fraction/type and soil moisture | Satellite derive vegetation fraction & soil-moisture and other geophysical parameters from USGS; NCEP/NCAR reanalysis data | Simulation carried out separately for various year with the best combinations of cumulus and land surface schemes from sensitivity experiments |

# Model Domain



# Sensitivity of simulation to convective parameterization




T2m July 1998

# Mohanty Results

- **The monthly circulation for the month of July is captured by the model with reasonable accuracy.**
- **The simulation of monthly climate, particularly, surface air temperature are found to be more close to the verification analysis with the use of Grell cumulus parameterization scheme.**
- **The diabatic heating pattern as shown in the model simulation using Grell scheme is in close resemble with the precipitation bands (figure not shown)**
- **The land surface parameterization is found to have significant impact in regional scale simulation of monsoon rainfall over India.**
- **The precipitation & surface air temperature over the India as a whole and also in homogeneous regions are better simulated with Noah LSM scheme than Multi-layer & Pleim-Xiu LSM schemes**

  - **The significant changes in vegetation fraction datasets of USGS and SAT are observed many places (such as Rajasthan, Andhra Pradesh, Orissa, Western Ghats and some parts of north east India) over India**
  - **Model simulation shows significant difference in precipitation between control simulation and the simulation using SAT vegetation fraction data over the regions mentioned above where vegetation fraction differs in the two datasets**
  - **The distribution of rainfall features over peninsular and north east India with SAT soil moisture is close resemblance with IMD observation**
  - **The simulation with both soil moisture and vegetation fraction & type is improved in wind and precipitation compare with the control simulation**

# Taiwan

# CWB Seasonal Climate Forecast System

*developed at*

# Meteorological Research and Development Center Central Weather Bureau

Mong-Ming Lu

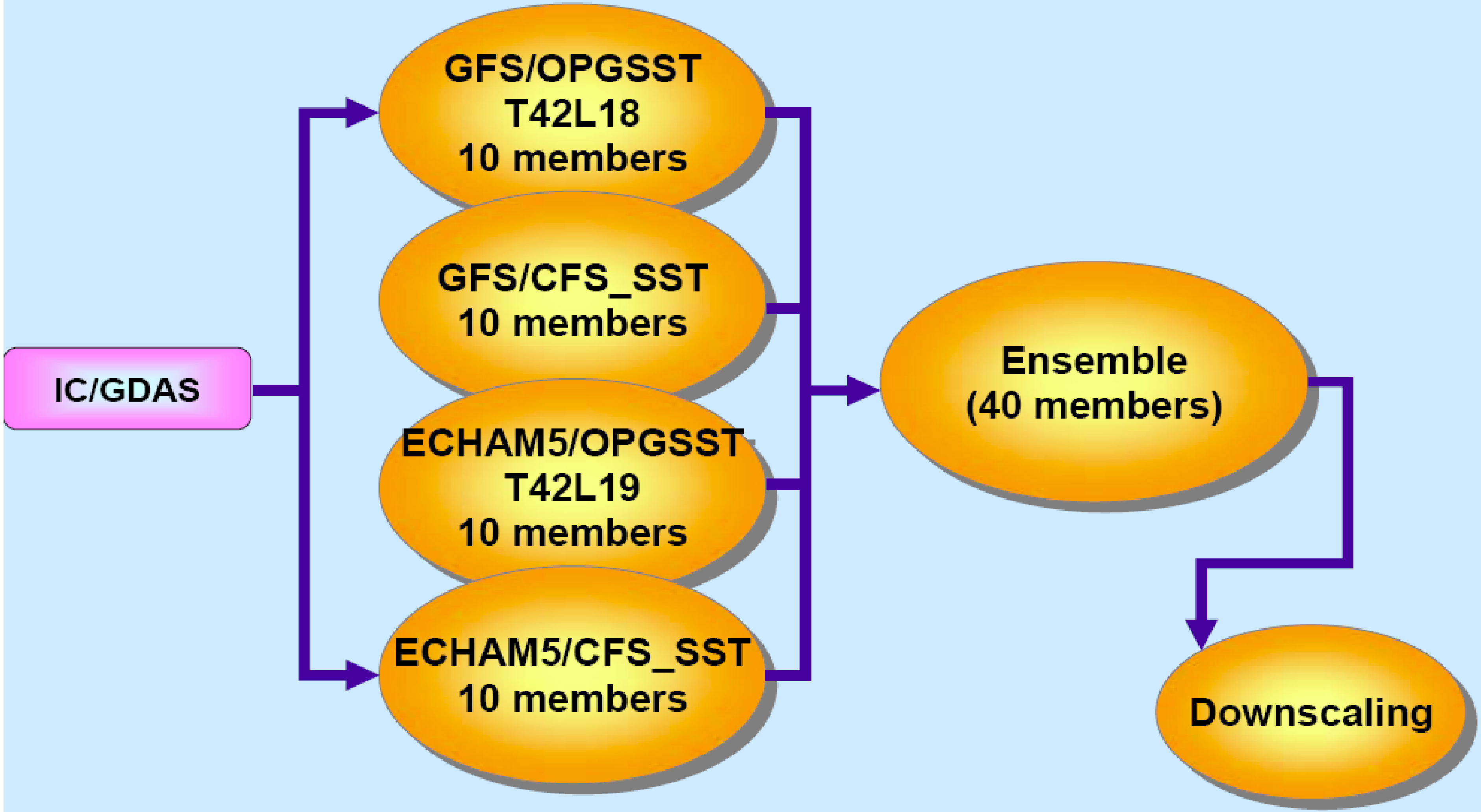
Central Weather Bureau

Taipei, Taiwan

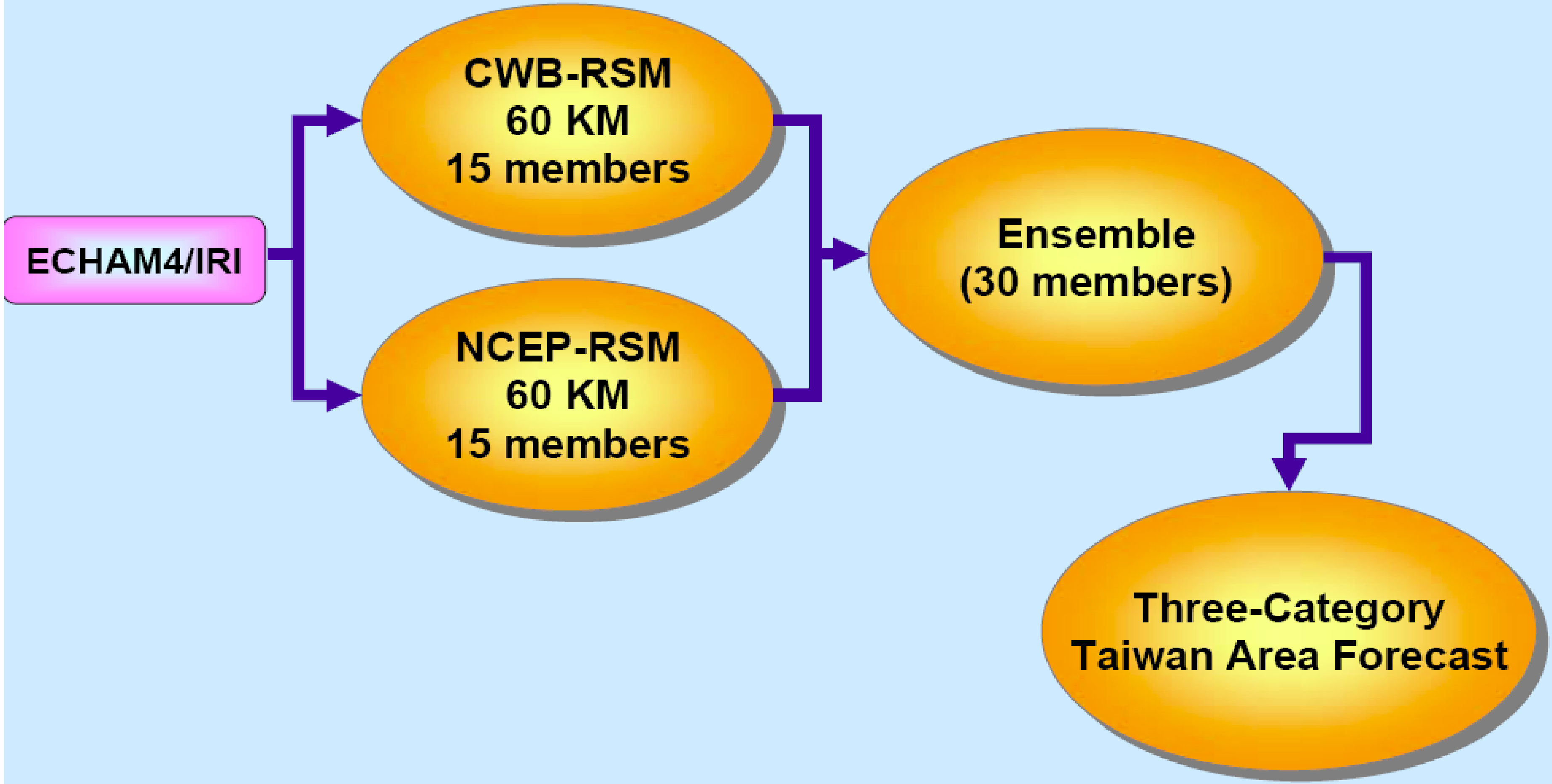
# Components

- Optimized Global Sea Surface Temperature
- (OPGSST) Forecast System
- Pre-processing System for Atmosphere Models
- Two-tier Dynamical Forecast System
- Statistical Downscaling System
- Dynamical Downscaling System

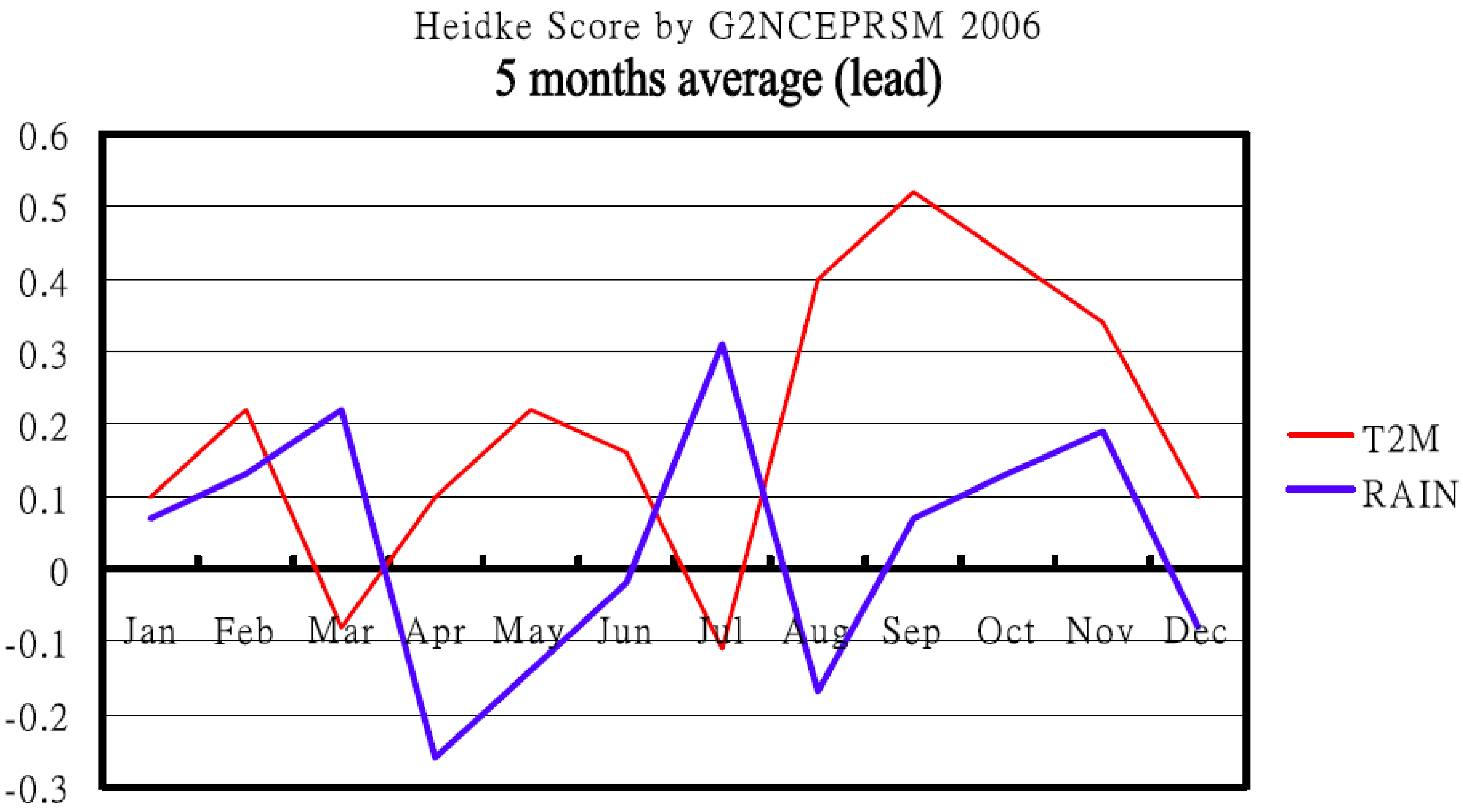
# Two-tier Dynamical Forecast



# Dynamical Downscaling



# Dynamical Downscaling



# Summary

- The first generation CWB seasonal forecast system has been developed and will be operational in 2008.
- There are five major components in the seasonal forecast system: 1) Optimized Global Sea Surface Temperature (OPGSST) Forecast System, 2) Pre-processing System, 3) Two-tier Dynamical Forecast System, 4) Statistical Downscaling System, and 5) Dynamical Downscaling System.
- 25-year hindcast forecasts have been completed.
- A preliminarily analysis shows a reasonable skill in a 3-month lead.
- A regional one-tier forecast system is under investigated. Local precipitation and SST relationship in NWP has been improved.
- CWB will contribute to APCC probabilistic (MME) forecasts by delivering our model forecast products.

# Japan

# Downscaling of JRA-25 using MRI-RCM20

K. Murazaki, K. Kurihara, T. Sasaki, I. Takayabu and T. Uchiyama
Meteorological Research Institute
(Environmental Application Division)

# MRI-RCM20

## (Meteorological Research Institute-Regional Climate Model)

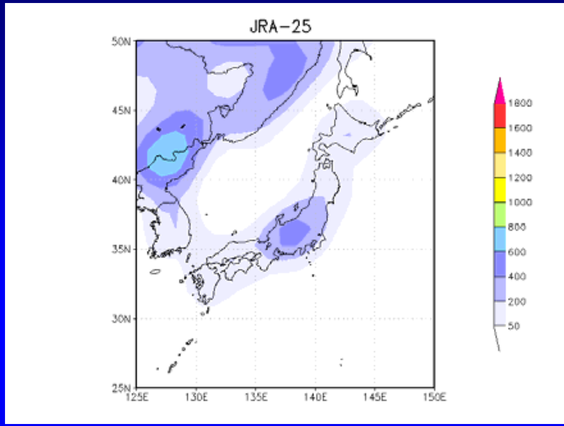
- Model resolution: about 20km with 36 hybrid vertical levels. The grid number is 181x181.
- Based on a regional spectral model originally developed by the JMA as a short-range forecast model.
- Mellor and Yamada (1982) level-2 scheme for vertical diffusion, the Arakawa and Shubert (1974) cumulus convection and convective adjustment schemes, the shortwave radiation scheme by Lacis and Hansen (1974), the long-wave radiation scheme by Sugi et al. (1990), and the land surface process by Takayabu et al. (2004).

For long-term integration

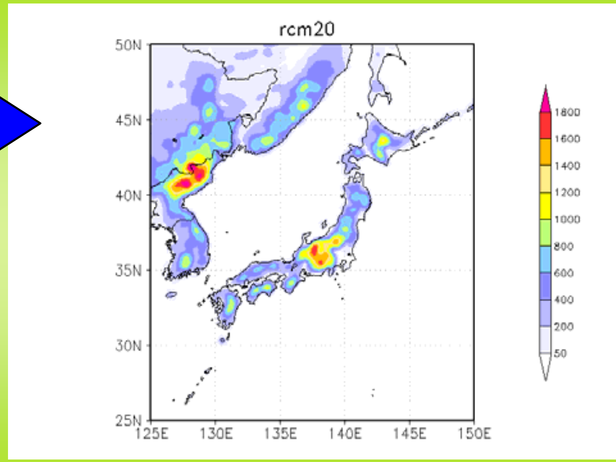
- Spectral boundary coupling method developed at MRI.
- Land surface process by Takayabu et al. (2004)

# How to downscale the JRA-25

26-year reanalysis data

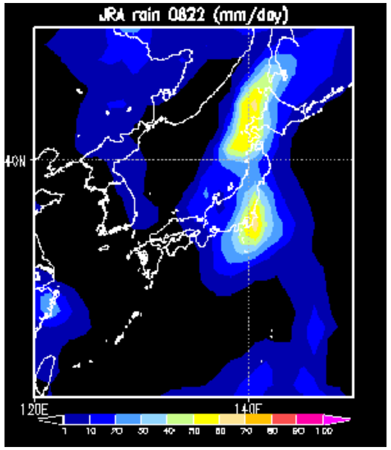



26-year calculation by RCM20

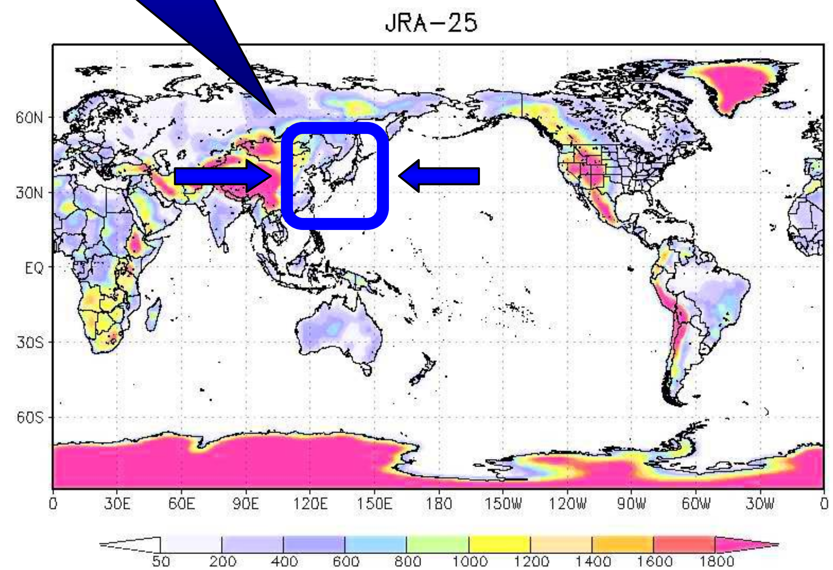


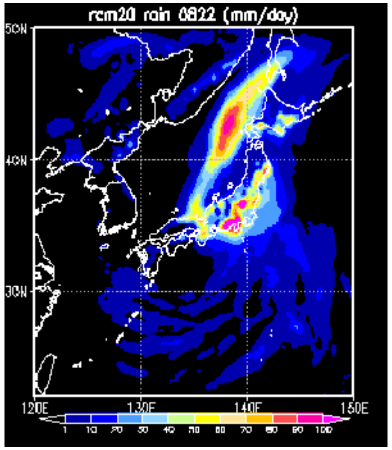

Boundary condition
U,V,T,Q,SST,Ice

SBC(U,V,T)




1.125-resolution data

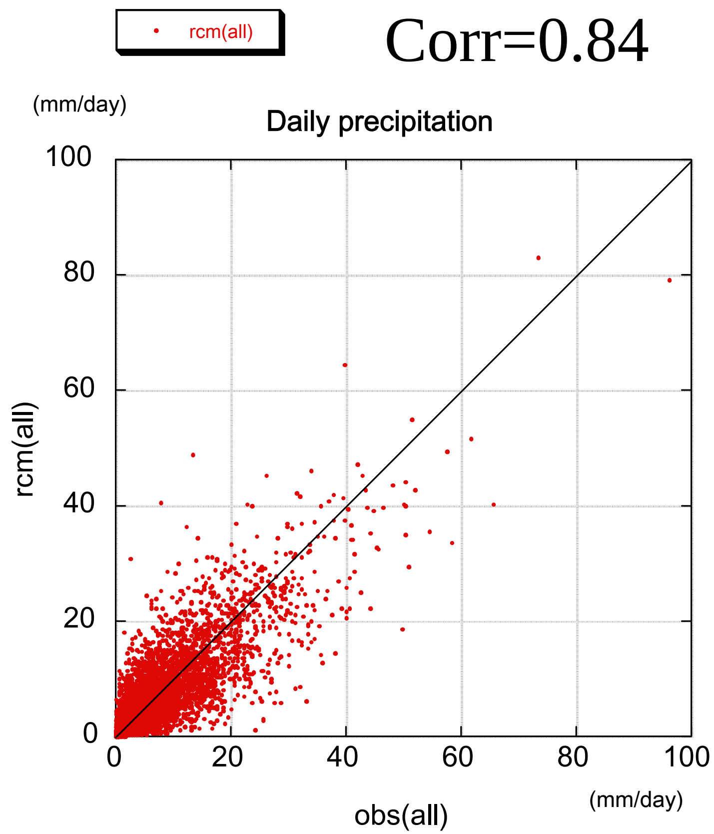


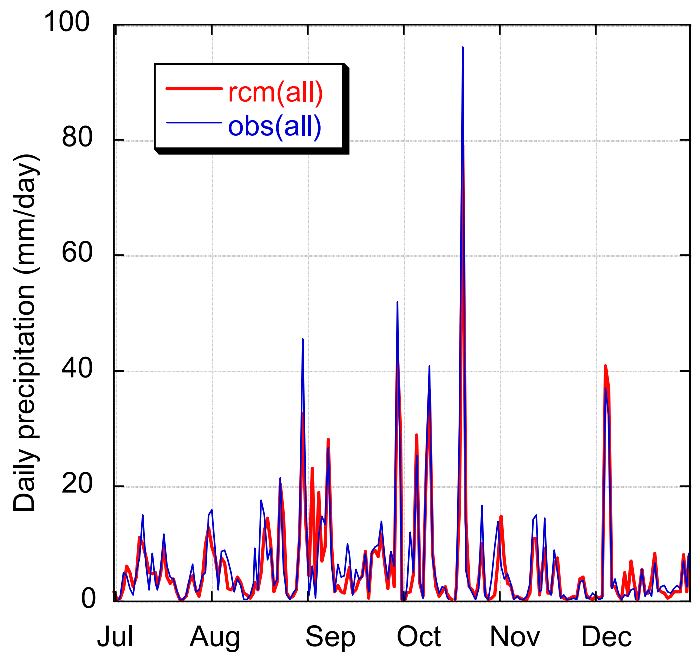




20km-resolution output

# Daily precipitation averaged over Japan

N=9497
Corr=0.84



# Conclusions

- We performed a continuous 26-year simulation over Japan by the MRI-RCM20 nested with JRA-25.
- The MRI-RCM20 improved underestimation of monthly precipitation in JRA-25.
- The results of the MRI-RCM20 are quite similar to JRA-25 in large-scale daily precipitation characteristics but the MRI-RCM20 represents more realistic distribution due to higher resolution.
- The model captured interannual variability of daily precipitation coverage rate in summer and winter. Correlation between the model and observation is surprisingly good (0.82-0.91).
- <u>These results suggest that JRA-25-downscaling dataset with the MRI-RCM20 is quite useful for regional extreme climate studies.</u>

# Reproduction experiment of present-day climate using non-hydrostatic regional climate model

Y. Sasaki, I. Takayabu, K. Kurihara, T. Uchiyama and K. Murazaki
(Meteorological Research Institute,
Japan Meteorological Agency)

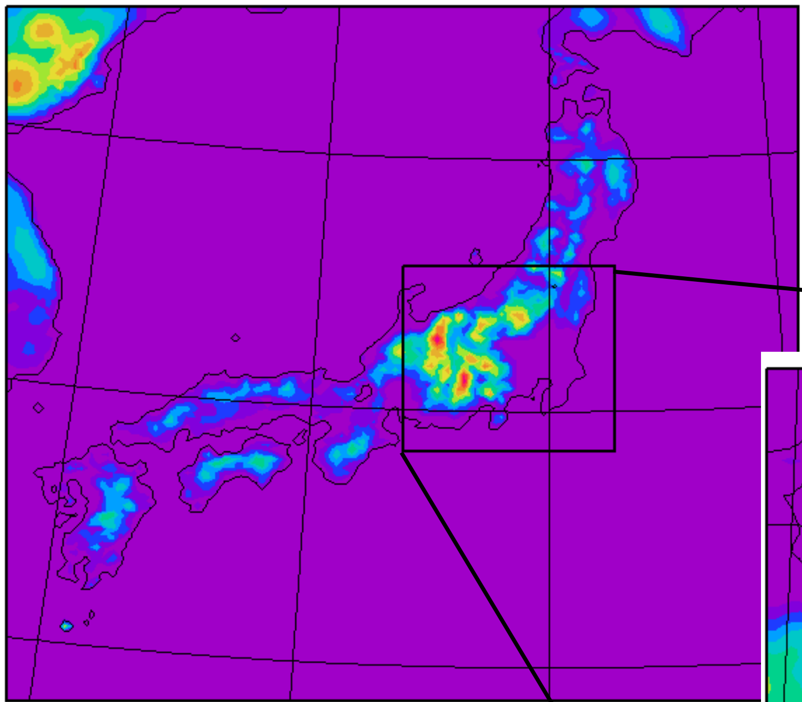
# ＮＨＭ － Non-hydrostatic Regional Model

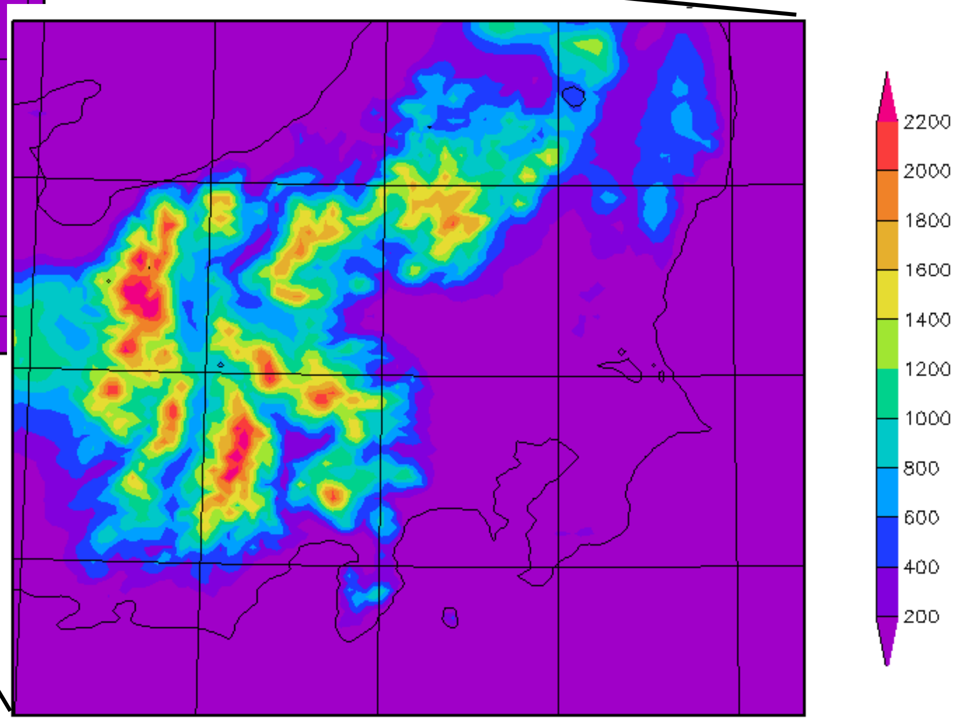
- Elastic, non-hydrostatic HE-VI scheme
- Cloud physics with ice process
- Kain-Fritsch convection scheme
- Land model　　　ＭＪ－SiB
- Turbulent closure. Use turbulent energy
- Initial condition, Boundary condition　　　20kmJMA analysis
- Integration period Aug., 1. 2001～Oct., 1. 2006

# Computational domain

NHM-RCM　4 k m

１００×１００　**grid**

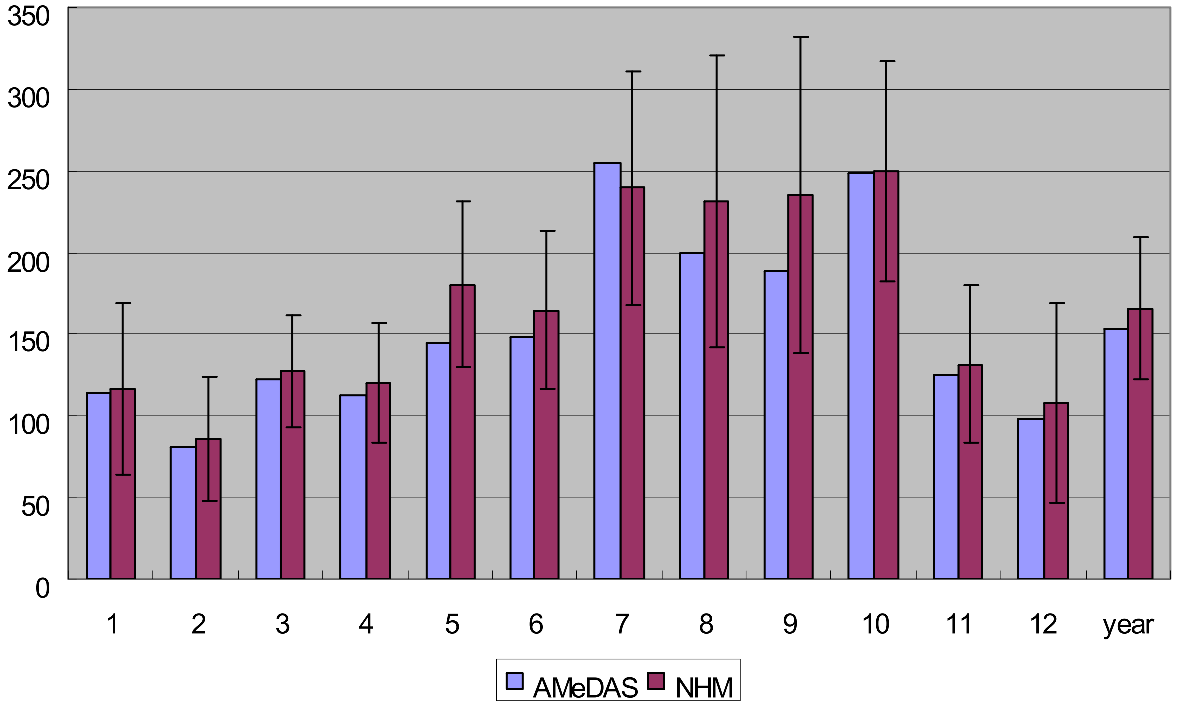




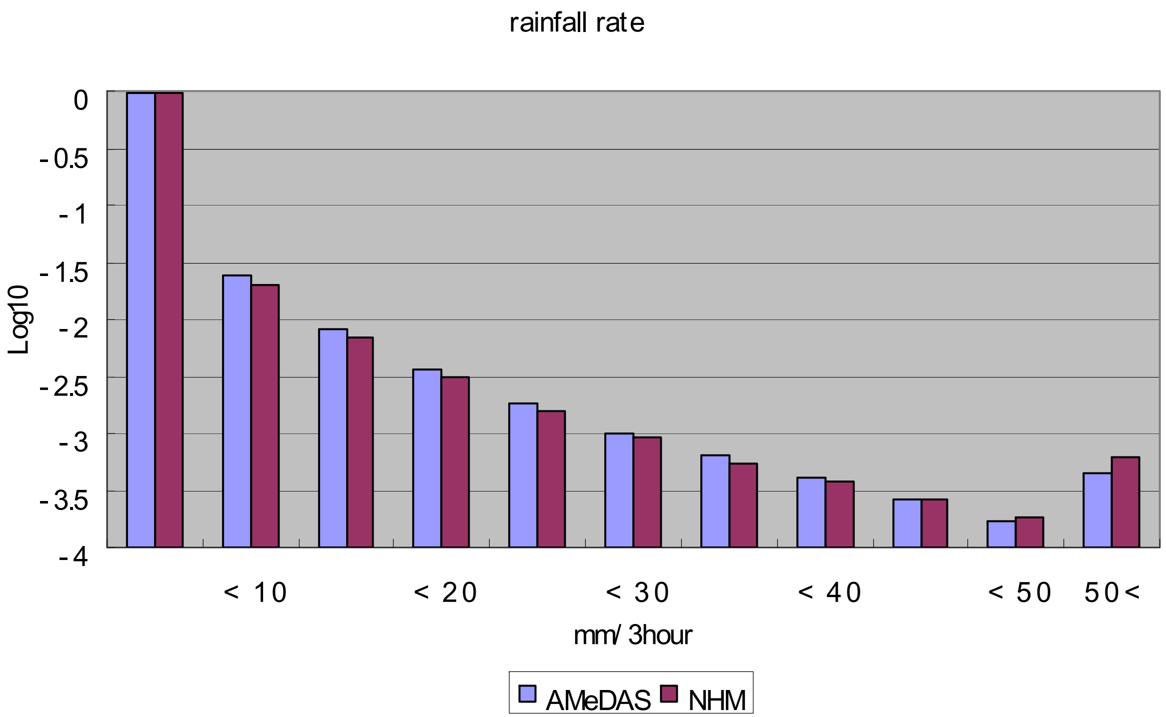

NHM-RCM　１０ k m

１５０×１５０　**grid**

# AMeDAS vs. NHM-RCM
# Monthly accumulated precipitation



# Frequency distribution of 3-hour precipitation intensity



# Summary

- Good monthly averaged precipitation and near surface temperature simulation .
- Frequency distribution of large precipitation agrees well with observation.
- There is a bias in near surface temperature (about positive 0.7C), but standard deviation and its regional variability is small.
- The day-night difference of temperature is smaller than observed (lower max temp and higher min temp).

# Summary of the dynamical downscaling activities in Asian countries

# Summary

- Many regional models performed well.  The  small scale details  obtained agree better with observations.
- Variety of models are used, but model resolution seems to have the greatest impact.
- Model physics and specification of surface parameters are very important for better performance.
- Dynamical downscaling should be used together with statistical downscaling for operational forecasts.
- More international collaborations between Asian countries should be encouraged.

# What is next?

- More experiments with higher resolution downscaling.
  - Examine model performance in a variety of situations, and time scales base on more statistically stable data.
- Improvement of the model physics.
  - Currently making good progress.
- Coupled downscaling.
  - Still at the beginning stage

- Targeted research of the downscaling of seasonal forecast (DeHaan and Kanamitsu talk).
  - Downscaling of all the members? How to deal with the ensemble mean.
- Improvement of the numerics of the regional model. Avoid sensitivity of the simulation to numerical aspects of the model (especially the handling of the lateral boundary condition).

# Problems unique to regional modeling in climate problems

# What makes regional model different from global model?

- Lateral boundary condition.
  - Sensitivity of simulation to the treatment of lateral boundary condition makes it very difficult to understand the regional simulation.
    - Sensitivity seems to be larger than the “natural variability” or “unpredictable noise”.
  - Effect of lateral boundary to the simulation within the domain is not clearly known.
    - Reflection of waves.
    - Damping.
- Current practice
  - Pseudo-radiation conditions
  - Diffusive damping in the boundary zone
  - Tendency modification
  - Flow relaxation

# Lateral boundary condition

- Davies (1983) “Limitations of Some Common Lateral Boundary Schemes used in Regional NWP models”.
  - Fairly exhaustive mathematical study of various lateral boundary conditions.
  - Basically the analysis to prevent reflection of waves at the lateral boundary.
- Most recent work by Marbaix et al. (2003)
- In principle, it is very difficult to formulate boundary condition that satisfies all the requirements.
  - New research is needed

# Regional model is an ill-posed problem

- Elliptic vs. Hyperbolic
- Advection
  - Upstream and downstream
- Wave dispersion and reflection
  - Radiation condition
  - No numerical scheme have been developed to radiate all the possible waves at the lateral boundaries

# Radiation boundary condition

$$\frac{\partial \phi}{\partial t} + c(k) \frac{\partial \phi}{\partial x} = 0, \quad x = x_0, \qquad (2)$$

gives the appropriate boundary condition. Here $\phi$ is a measure of the wave amplitude and $c(k)$ is the phase speed of wavenumber $k$.

***Method of characteristics***

# Possible alternative methods
# -New research is needed -

- Use of vertical normal mode.  More correct specification of lateral boundary conditions may be possible?
- Filtering the reflected wave.  How to detect such reflected waves?
- Two-way nesting (Not so attractive).

# Other leftover problems

- Vertical interpolation of outer forcing field.
  - Preservation of fine vertical structure.
  - Wind-mass balance.  Requirement of initialization.
- Model parameterizations
  - Effect of mountains.
  - Land surface characteristics irregularities.
  - Non-hydrostatic model parameterizations

END