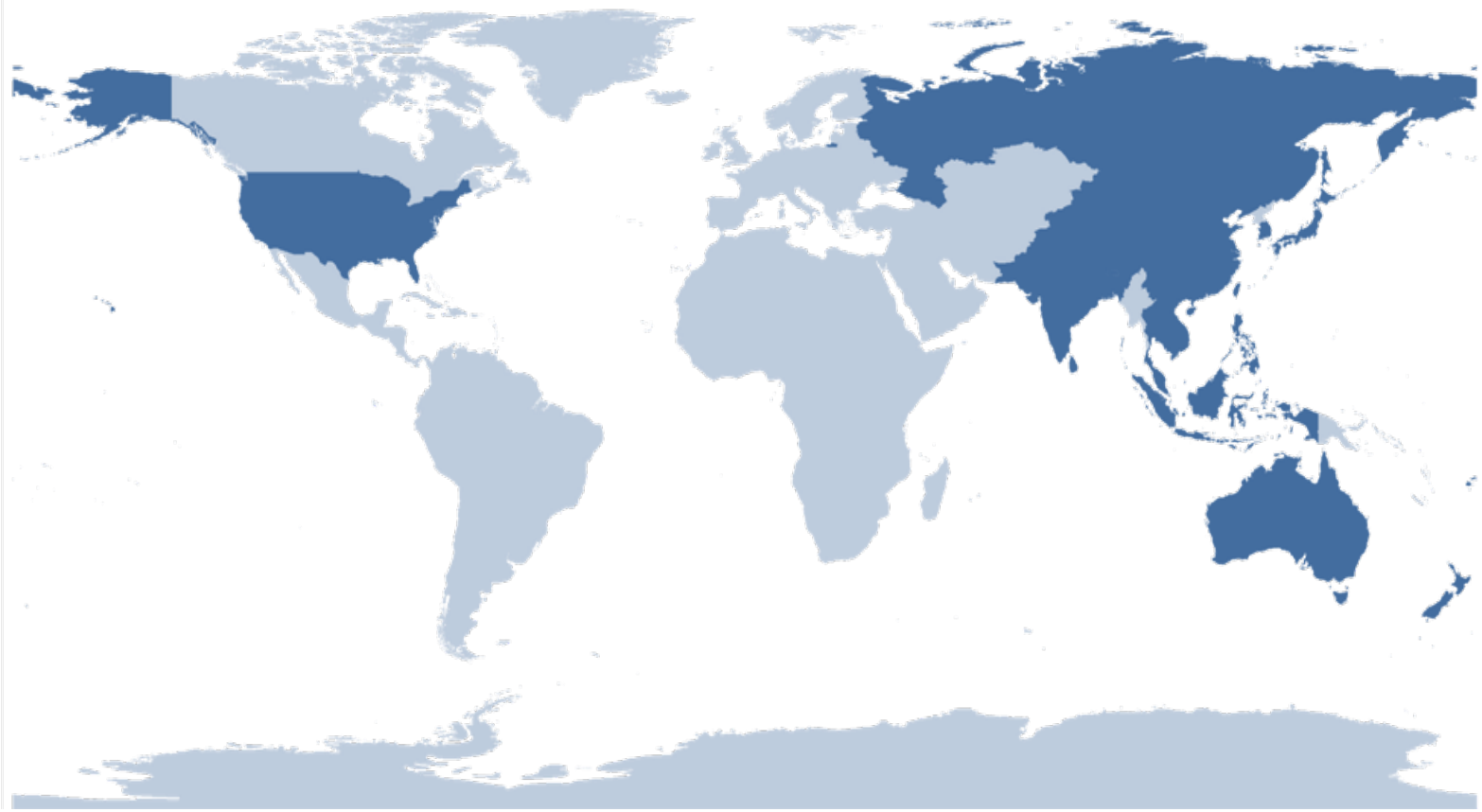
FINAL REPORT for APN PROJECT

Project Reference Number: ARCP2011-01CMY-Wang

"Building Asian Climate Change Scenarios by Multi-Regional Climate Models Ensemble"



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“Building Asian Climate Change Scenarios by Multi-Regional Climate Models Ensemble”

Project Reference Number: ARCP2011-01CMY-Wang
Final Report submitted to APN

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OVERVIEW OF PROJECT WORK AND OUTCOMES

Minimum 2pages (maximum 4 pages)

Non-technical summary

Facing the fact that high resolution projection of regional climate change is required for impact, vulnerability and adaptation studies, this project coupled multi-RCMs with one GCM in order to produce high-confidence regional climate change projection. The implication of project meets the urgent needs of providing accurate regional climate change information to impact and assessment community.

The project is the extension and continuation of Regional climate Modeling Intercomparison Project RMIP for Asia (RMIP), which has been operated under the support of Asia-Pacific Network for Global Change Research (APN). Based on the successful completion of RMIP, the project "Building Asian Climate Change Scenarios by Multi-Regional Climate Models Ensemble" was set to be carried out to build high resolution climate change scenarios for Asia for 2040-2070 using regional climate models' outputs, and to develop the envelope analysis of ensemble for Asian regional climate projection with the full evaluation and assessment of uncertainty.

With the completion of project, the highly confident climate change is produced and will be provided to research communities for impact and adaptation studies, with an envelope analysis of ensembles and uncertainty range. To fulfill the research targets in for this project, one preparing meeting and three project workshops have been held during 2010-2012.

Objectives

The main objectives of the project are listed as following:

1. To provide the high confident scenarios of regional climate change in Asia based on an ensemble of the results from nine RCMs.
2. To provide a scientific base for impact, assessment communities and policy makers so that better understanding of monsoon Asia climate change will be achieved, by adequately detect and assess the sources and magnitudes of uncertainty in Asian climate change projection.
3. To set up a regional climate modelling network and establish connection with other regional climate research networks around the world on the base of data and technique sharing.

Amount received and number years supported

The Grant awarded to this project was:

US$ 39,760 for Year 1

US$ 40,000 for Year 2

US$ 40,050 for Year 3

Activity undertaken

Research Activities:

Two sets of simulations for both contemporary and future climate have been carried out by participating groups. With multi-RCM results following analyses and activities are undertaken:

- Projecting high resolution regional climate change for 2040-2070 for Asia by using the ensemble of nine regional climate models' outputs;
- Based on the nine RCM simulations, detecting and assessing the sources and magnitude of uncertainties in Asian climate change projection;
- Calculating the change and variance of controlling climate factor of Asian climate, including the Asian monsoon system, and its impacts on Asian climate;
- Exploring and developing new methods and techniques for regional climate model outputs ensembles.

Non-Research Activities:

- On 26-28, May 2008, the preparing meeting was held in Beijing, China. On the meeting the latest process in Asian regional climate studies was presented and RMIP activities summarized. The agreement has been reached to propose new APN project about Asian climate projection to APN.
- On January 28- 29, 2010, the first project workshop was held in Tsukuba, Japan, with the Meteorological Research Institute/Japanese Meteorological Agency as local host.
- On February 26- 27, 2011, the second project workshop was held at Melbourne, Australia, with CSIRO as local host.
- On February 27- 28, 2012, the third and last project workshop was held at Jeju, Korea, with Yonsei University acting as local coordinator.

Results

- From the launching of the APN project in 2009, three project workshops have been held with the financial support provided by the project.
- The simulation results have been submitted by individual research group and the analyses are produced. Asian regional climate change projection is generated based on the multi-model simulations. Data server is set up and all data are available through sftp.
- A regional climate modelling network is established during execution of the project based on data and technique sharing.

Relevance to the APN Goals, Science Agenda and to Policy Processes

The new challenge facing the policy makers and scientific communities is to devise the adaptation and mitigation strategies to reduce the risk induced by climate change on regional scale. However, absent the reliable information of magnitude and range of climate changes, policy making process will possibly turn out to be debating competition, where people either call for immediate actions or wait for more evidence and information.

This project deals with the issues such as the change and variability of monsoon climate in future, and sources and range of uncertainty in climate change projections. It contributes not only to

the climatic research communities by providing more insight information, but also to the social-economic scientists and decision makers by improving their scientific understanding of projected climate change scenarios in Monsoon Asia, and therefore justifying policy decision making process.

Self evaluation

APN project "Building Asian Climate change Scenario by Multi-Regional climate Models Ensemble" is one of the long-term regional collaboration to promote Asian climate study. During three project years, the project grouped the regional modelling teams' efforts over Asia-Pacific region, and finished the long-term integrations for both control and future climate. Model validation over research domain, effects of key factors and processes that affect monsoon system and climate extremes, etc., are analyzed, and regional climate change projection are built with adequate assessment of uncertainty.

Potential for further work

The future activity of the project "Building Asian Climate Change Scenarios by Multi-Regional Climate Models Ensemble" includes promotion of project application by establishing connection to other APN projects, such as the approved project led by Dr. Yinpeng Li of University of Waikato which aims to develop a co-evolutionary urban climate change decision support tool (UrbanCLIM), to support climate change impact and risk assessment for the major sectors: health, transport, water. The project will also expand the regional climate modelling network by actively involving with WCRP's CORDEX activities.

Publications (please write the complete citation)

A working group paper on: "Building Asian Climate Change Scenarios by Multi-Regional Climate Models Ensemble"

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Dr. Yuqing Wang, Department of Meteorology, School of Ocean and Earth Science and Technology, University of Hawaii, USA

Dr. William Gutowski, Department of Geological and Atmospheric Sciences, Iowa State University USA

References

Fu, C., S. Wang, Z. Xiong, W.J. Gutowski, D.K. Lee, J.L. McGregor, Y. Sato, H. Kato, J.W. Kim, and M.S. Suh, 2005: Regional Climate Model Intercomparison Project for Asia. ***Bull. Amer. Meteor. Soc.***, **86**, 257–266.

Acknowledgments

Thanks to all the project team members for their great efforts and good collaboration. Thanks to Monsoon Asia Integrated Regional Study (MAIRS) IPO for its strong support. Special thanks to Dr. Kazuo Kurihara from Meteorological Research Institute, Japan Meteorological Agency, Dr. John McGregor from Marine and Atmospheric Research, the commonwealth Scientific and Industrial Research Organisation and Dr. Songyou Hong from Yonsei University, for their great contributions to coordinate the project workshops.

TECHNICAL REPORT

Minimum 15-20 pages (excluding appendix)

Preface

High resolution information about climate change, variability and extremes is required to develop regional climate change scenarios, which are used in impact, vulnerability and adaptation studies. Facing the fact that in most projection studies coarse-resolution GCMs are applied, this project will couple nine RCMs from 5 countries with at least one GCM, therefore high-confidence regional climate change projection with qualified uncertainty range will be provided. Two sets of simulations for both contemporary and future climate will be carried out. The ensemble technique will then be developed and used to estimate the uncertainty and provide more reliable Asian climate change projection.

Table of Contents

1. Introduction
   1.1 Background
   1.2 Scientific objectives
   1.3 Participating teams
   1.4 Timelines
2. Methodology
   2.1 State of art methodology of regional climate change study
   2.2 Experimental design
   2.3 Analysis plan
3. Results & Discussion

3.1 Data collection

3.1.1 Metrological observation data

3.1.2 Simulation results

3.2 Asian climate change

3.2.1 Model validation

3.2.2 Regional climate change

4. Conclusions

5. Future Directions

References

Fu, C., S. Wang, Z. Xiong, W.J. Gutowski, D.K. Lee, J.L. McGregor, Y. Sato, H. Kato, J.W. Kim, and M.S. Suh, 2005: Regional Climate Model Intercomparison Project for Asia. ***Bull. Amer. Meteor. Soc.***, **86**, 257–266.

1.0 Introduction

1.1 Background

Asian climate is characteristic with the marked variabilities at the seasonal, interannual and interdecadal time scales. The summer monsoon rainfall contributes most of the annual total precipitation and monsoonal precipitation regimes determine the regional water availability for agricultural practices and urban use, and therefore are important for water management policies. Changes in monsoon circulations on the interannual scale can affect the occurrence frequency of droughts and floods, hence have significant impacts on agriculture, water resources and natural ecosystem development in Asia. On the decadal to century time scale, the anthropogenic forcing factors play a dominant role in addition to the natural variability, particularly because of the rapidly developing economy and growing population in Asia.

In order to assess the vulnerability and adaptation to climate change impact over Asian monsoon region, building high quality regional climate change scenarios has become challenges to climatic research communities. Through GCMs are still the principle tools for climate prediction, they are unreliable when applying to generate the high spatial resolution climate projections, due to their incapability to solve the critical regional topographic features, such as land use, in-land waterbody, soil processes, etc. The generation of regional climate scenarios therefore usually depends on the following methods to downscale GCM generated large-scale climate changes: 1) regional climate model, which are based on fundamental physics and forced at the boundaries by GCMs. It focuses on the area of interest, providing the characterisation of regional structures; 2) empirical/statistical downscaling, which employs the dynamically motivated linear and non-linear regression techniques to produce comparable outputs to RCMs, assuming local scale climate is largely a response to large scale forcing.

At the moment, the Regional Climate Model coupled with Global Climate Model is widely used to explore the possible future climate changes at regional scale because of its detailed and

realistic description of physical processes and its ability to take regional anthropogenic forcings into consideration. Moreover, the Asian climate is characterized of monsoon variability on different time scales. The responses and interactions of monsoon system to global climate change require more detailed investigation so that accurate regional climate projection can be provided to impact and assessment communities. Regional climate models have shown promising abilities to reproduce the Asian monsoon climatology in regional detail, and assess the interactions between monsoon system and mesoscale forcings such as topography, land-use distribution, etc.

The regional climate simulation and scenario building process are accompanied by large uncertainty. When producing the regional climate change, in addition to the uncertainties associated with the future emission scenarios and GCM simulations, a relatively high level of uncertainty arises from Regional Climate Model inner physics when applying regional climate modelling to downscale future climate change. To assess the statistical significance and the reliability of future climate change generated by RCMs, and to address the quantification of the uncertainty, the multi-regional climate model projects, such as PRUDENCE, ENSEMBLES, have been carried out and coordinated with the impact assessments in recent years. Their results quantify the confidence and uncertainties in predictions of future climate. Also useful information can be provided to policy makers for adapting to and mitigating the regional climate change.

Under such circumstance, APN funded project "Regional climate Modeling Intercomparison Project RMIP for Asia (RMIP)" are designed and implicated to understand and improve the capacities of regional climate models, and to explore the possibilities of using multi-RCMs to provide high confident information on regional climate. RMIP discussed the current RCMs' abilities to simulating Asian Monsoon climatology and variability, provides detailed evaluation of models' dynamical and physical processes interactions with Asia monsoon climate, and offers insights into the application of ensemble technique in reducing uncertainty in Asian climate simulation as well as improving accuracy in the regional climate simulation.

Based on the fully assessment of the regional climate model's advantages and disadvantages in simulating the Asian monsoonal climate, and having better confidence in projecting regional climate change, a new APN project "Building Asian Climate Change Scenarios by Multi-Regional Climate Models Ensemble" was proposed and approved. The project aims to build high resolution climate change scenarios for Asia for 2040-2070 using regional climate models' outputs, and to develop the envelope analysis of ensemble for Asian regional climate projection with the full evaluation and assessment of uncertainty. The highly confident climate change information can therefore be provided to research communities for impact and adaptation studies, with an envelope analysis of ensembles and uncertainty range. The project also intends to explore the new ensemble methods for reducing uncertainties.

1.2 Scientific objectives:

The main scientific objectives of the project are as following:

- To provide the high confident scenarios of regional climate change in Asia based on an

ensemble of the results from nine RCMs.

- To provide a scientific base for impact, assessment communities and policy makers so that better understanding of monsoon Asia climate change will be achieved, by adequately detect and assess the sources and magnitudes of uncertainty in Asian climate change projection.
- To set up a regional climate modelling network and establish connection with other regional climate research networks around the world on the base of data and technique sharing.

1.3 Participating groups

The project combines the efforts of eleven research groups from Australia, China, Japan, S. Korea, and United States. Scientists from India, Mongolia, and Russia are involved with the project through data sharing and project results application.

The participating teams and collaborators are:

- Institute for Climate and Global Change Research, Nanjing University, People Republic of China, Dr. Shuyu Wang
- School of Earth and Environmental Sciences, Seoul National University, Republic of Korea, Professor Dong-Kyou Lee
- Department of Geological and Atmospheric Sciences, Iowa State University, Iowa State University, USA, Dr. William Gutowski
- Department of Atmospheric Sciences, Yonsei University, Republic of Korea, Dr. Songou Hong
- Meteorological. Research Institute, Japan Meteorological Agency, Japan, Dr. Kazuo Kurihara
- Storm, Flood and Landslide Research Department National Research Institute for Earth Science and Disaster Prevention, Japan, Dr. Koji Dairaku
- Atmospheric Sciences Department, Nanjing University, People Republic of China, Dr. Jianping Tang
- Marine and Atmospheric Research, the commonwealth Scientific and Industrial Research Organisation, Australia, Dr. John L. McGregor
- National Climate Center, China Meteorological Administration, China, Dr. Xuejie Gao
- Institute of Atmospheric Physics, Chinese Academy of Sciences, Dr. Deming Zhao
- Department of Meteorology, School of Ocean and Earth Science and Technology, University of Hawaii, USA, Dr. Yuqing Wang
- Monsoon Asia Integrated Regional Study, Chinese Academy Sciences, Dr. Ailikun, aili@mairs-essp.org

1.4 Timelines

The project was executed according to the proposed timeframe:

- Year 2009, Experiment design by the participating RCM groups; preparation of initial and boundary fields for both control and future climate simulations; starting the integration for control and future climate; drafting annual reports;
    - Year 2010, Continuation of integration for control and future climate; analyzing the

results and building Asian climate change scenarios; developing and testing new ensemble methods; drafting annual reports and related papers;

- Year 2011, Assessing sources and ranges of uncertainty in climate change projection for Asia; analyzing the change and variability of Asian monsoon system and its impacts; drafting project reports and related papers;

2.0 Methodology

2.1 State of art methodology of regional climate change study

Accurate simulation of regional climate change has been listed as one of the high priority areas in climatic change study. RCMs have been developed and widely used to simulate the regional climate in Asia over past 20 years. Studies have demonstrated that the RCMs can reproduce the monsoon climatology over Asia that is not fully captured by the GCM. However, great inconsistency and uncertainties have been detected in simulating the Asia regional climate.

Regional multi-model projects have been carried out all over the world in last 10 years. In earlier stage, these projects focused on the comparison and validation of Regional climate model's ability to simulate regional climate on the limited time periods. APN rewarded project Regional climate Model Intercomparision Project for Asia (RMIP) has been conducted to assess participating RCMs' capability to reproduce seasonal cycle, mean climate and extreme events in Asian area. The later projects have more coordination with regional climate projection, observation campaigns, GCM simulation groups and impacts assessments community, etc. Considering the scenario building process is accompanied by large uncertainties associated with the future emission scenarios and GCM simulations, the multi-regional climate model projects, such as PRUDENCE, ENSEMBLES, have been carried out and coordinated with the impact assessments in recent years to assess the statistical significance and the reliability of future climate change generated by RCMs, and to address the quantification of the uncertainty, y. Their results quantify the confidence and uncertainties in predictions of future climate. Also useful information can be provided to policy makers for adapting to and mitigating the regional climate change.

2.2 Experimental Design

Dynamic downscaling is applied in this project to generate Asian regional climate change projections. The common framework of project has been designed by participating scientists (Fig. 2-1). Totally eleven RCMs and one stretching-grid GCM are integrated to downscale at least one GCM, ECHAM from Max Planck Institute, Germen. IPCC AR4 SRES scenario A1B is used as baseline emission scenario.

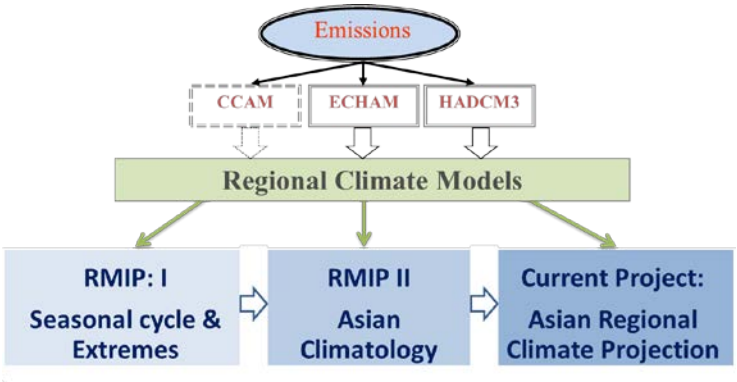

Fig. 2-1, Multi-model ensemble system for Asian climate change projection

The simulation consists of two respective time slices: one is for contemporary climate from 1978 to 2000; the other is for future climate from 2038 to 2070.

WCRP CORDEX East Asia domain was adopted by all participating climate models, with the study focus on East Asia Monsoon region, and extended attention on climate change over Southeast Asia and South Asia areas. 10 sub-regions have been identified on the base of their individual climatic characteristics (Fig.2-2). All participating models use the uniform horizontal resolution of 30-km and buffer zone with 15-gridpoints.

Fig.2-2 simulation Domain and classification of sub-regions

2.3 Analysis plan

With model results, validation of participating models over research domain has been completed by individual modeling group firstly by comparing the model results with observation. The effects of physical processes and other key factors that affect Asian monsoon climate were investigated.

The analysis scheme of the project is shown in Fig. 2-3. With the multi-model results that submitted by research team, climate projection is built by analyzing mean climate change and

changes in climatic extremes, such as heat wave, heavy Precipitation, and uncertainty estimates are obtained by means of applying statistical methods such as the weighted mean, multivariate linear regression, singular value decomposition, and Bayesian statistical methods.

The projected climate change is obtained by comparing the results of control and future simulation. The sources and magnitudes of uncertainty in Asian climate change simulation are evaluated and the issue of uncertainty arising from the climate change projection addressed using ensemble analysis.

To fulfill the objectives of this project, the following analysis activities are applied:

1) Analyzing the results of nine RCMs nested with GCM for current climate simulation to validate the RCMs' capacities of producing the monsoon climate, extreme events and to examine the statistical behavior of participating RCMs;

2) Detecting the error and uncertainty arising from driving GCM by comparing RCMs results to observation;

3) Exploring and developing methods and techniques for regional climate model outputs ensemble;

4) Analyzing the RCM results for future climate change; constructing climate change scenario for monsoon Asia;

5) Calculating the change and variance of controlling climate factor of Asian climate, i.e., Asian monsoon system, and its responses to global climate change;

6) Detecting and assessing the sources and ranges of uncertainty in Asian climate change projection;

7) studies on changes in aridity, tropical cyclone will be conducted by individual or groups that are interested in the subject;

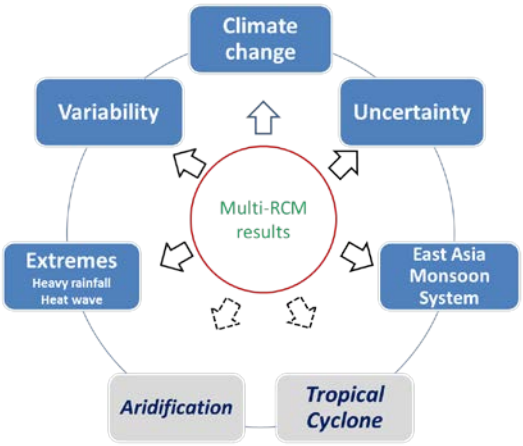

Fig.2-3 Analysis scheme

3.0 Results & Discussion

3.1 data collection

The database consists of both observation and simulation is constructed.

3.1.1 Metrological observation data

3.1.1.1 Station Data

- Precipitation
  - Monthly
    - ✓ 195 stations for (China, 1961-2003)
    - ✓ 700 stations for (China, 1961-2007)
  - Daily
    - ✓ 195 stations for (China, 1961-2003)
- Temperature
  - Monthly
    - ✓ 195 stations for (China, 1961-2003)
    - ✓ 700 stations for (China, 1961-2007)
  - Daily
    - ✓ 195 stations for (China, 1961-2003)

3.1.1.2 Gridded Data

- Precipitation
  - Monthly
    - ✓ CRU (Global, 0.5x0.25, 1950-2006)
    - ✓ CMAP (Global, 2.5x2.5, 1979-2004)
    - ✓ GPCP (Global, 2.5x2.5, 1979-2004)
    - ✓ TRMM (Global, 0.5x0.25, 1998-2007)
  - Daily
    - ✓ ARHRO (Asia, 0.25x0.25, 1960-2003)
    - ✓ CN-05 (China, 1x1, 1961-2005)
- Temperatures
  - Monthly
    - ✓ CRU *T, Tmax, Tmin* (Global, 0.5x0.25, 1950-2006)
  - Daily
    - ✓ CN-05 *T, Tmax, Tmin* (China, 1x1, 1961-2003)

3.1.2 Simulation results

Out of 11 participating RCM and 1 stretching-grid GCM, 9 RCMs and the GCM have finished the integration. By 2012 simulation results produced by 9 RCMs and 2 GCMs have been submitted to project (Table 3-1).

Table 3-1, Simulation Results Availability

Model	Group Leader	Institution
CCAM	John McGregor	CSIRO/Australia
CCAM-60km	Jack Katzfey	CSIRO/Australia
NIED-RAMS	Koji Dairaku	NIED/Japan
ReGCM3	Xuejie Gao	CMA/China
GRIMs	Song-You Hong	YSU/Korea
iRCM	Yuqing Wang	HSU/USA
WRF	Tang Jianping	NJU/China
WRF_SN	Tang Jianping	NJU/China
WRF_RRTM	Tang Jianping	NJU/China

SNU	Dong-kyou Lee	SNU/Korea
ReGCM4	Tang Jianping	NJU/China

The required model outputs are listed in Table 3-2 based on the data availability. Daily and three-hourly surface and upper-level variables, such as temperature, precipitation, wind, sea level pressure for both current and future climate are collected, and monthly average are calculated. High confident scenarios of regional climate change in Asia can be built accordingly, and the variations in climate extremes that might result from climate change can be estimated. With the outputs of surface energy and water budget, key model processes that dominate regional climate change can be identified. Finally the sources and magnitude of uncertainties in Asian climate change projection will be detected and assessed.

Table 3-2, Model Outputs submitted by participating models

Surface variables (daily)	Surface variables (3-hourly)
1. Average temperature	1. 2m temperature
2. Maximum temperature	2. Relative humidity
3. Minimum temperature	3. Convective precipitation
4. Total precipitation	4. Large scale precipitation
5. Sea level pressure	5. Evaporation
6. Snow cover	6. 10m wind (U,V)
7. Surface wind	7. Surface upwelling shortwave radiation
8. Surface runoff	8. Surface downward shortwave radiation
9. Sensible heat	9. Surface upwelling longwave radiation
10. Latent heat	10. Surface upwelling longwave radiation
11. Total Soil moisture	11. Latent heat
12. Net radiation flux	12. Sensible heat
	13. Column soil moisture
	14. Total runoff
Upper level (daily, 200, 500 and 850hPa	**Upper-level variables (3-hourly)**
1. Zonal/Meridional winds	1. TOA upwelling shortwave radiation
2. Geopotential height	2. TOA upwelling longwave radiation
3. Temperature	3. Cloud fraction
4. Relative or Specific humidity	4. Precipitable water

3.2 Asian climate change

3.2.1 Model validation

Before generating regional climate change projection, each research team evaluate its model's abilities of simulating current climate are assessed over the simulation domain. The participating climate models can reproduce the current climate (1980-2000) reasonably.

3.2.1.1 Surface air temperature

Models give reasonable spatial distributions of surface air temperature, with seasonal biases within the range of -2C~2C over most of simulation domain (Fig. 3-1).

Both RCMs and ECHAM5 have colder ocean, and cold biases over Tibet, Southeast Asia and India is simulated. Comparably RCMs have higher skill scores than driving GCM in simulating surface air temperature, especially over higher latitude except for model RAMs (Fig.3-2). It can be concluded

that RCMs could reduce temperature biases over sub-regions such as arid/semi-arid area, Northern China, Center China, Tibet and Southeast Asia. Warm biases over northern boundary produced by RCMs required detailed analysis.

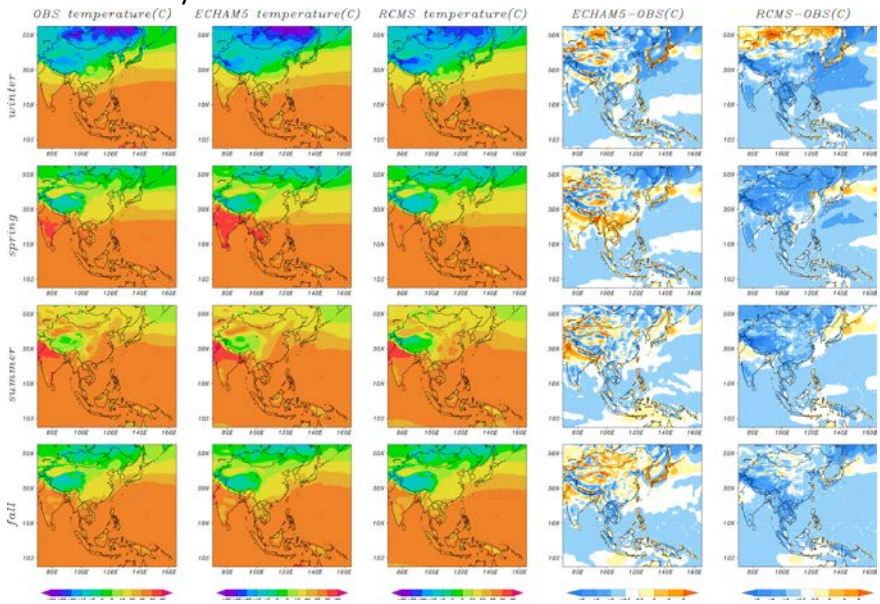

Fig. 3-1 Seasonal temperature biases by both ECHAM5 and RCMs (C)

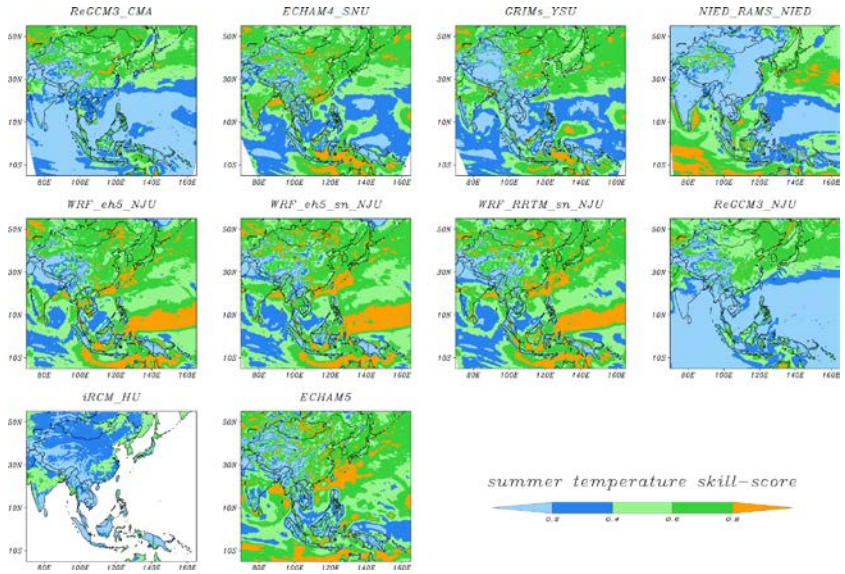

Fig. 3-2 Skill scores of summer temperature at 2m for participating RCMs and driving GCM

The observed seasonal cycle of surface air temperature is well captured by RCMs. But models' ability to simulate the interannual variability is relatively less reliable, with most models underestimate the warming trend during last 20 years (Fig.3-3).

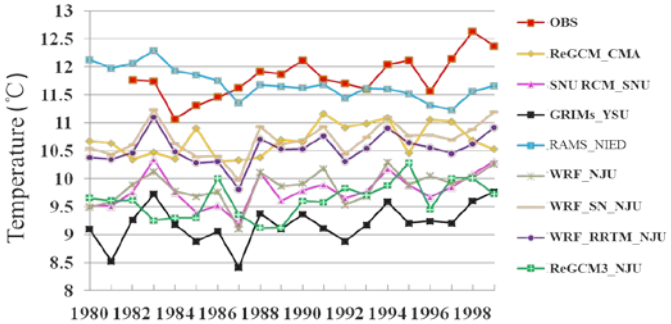

Fig. 3-3 Interannual variability of surface air temperature at 2m averaged over China

3.2.1.2 Precipitation

Both RCMs and GCM overestimate the seasonal rainfall at lower latitude ocean area; comparably RCMs have higher skill score over higher latitude and greatly reduce the precipitation biases over the land (Fig. 3-4). Analysis implies that the biases of RCMs are mostly inherited from driving GCM, more efforts are required to understand the physical processes that dominate the precipitation and improve model's ability to simulate the precipitation over ocean.

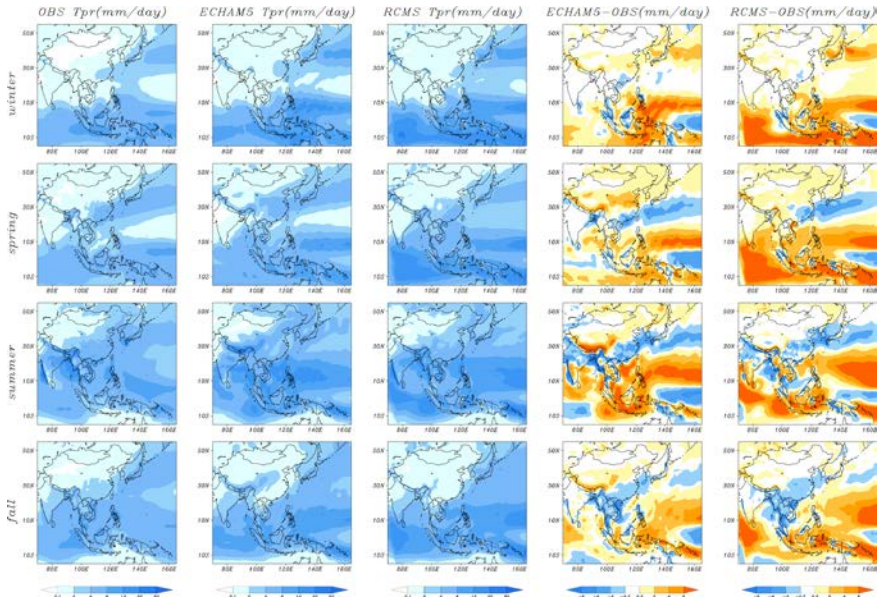

Fig. 3-4 Seasonal precipitation biases by both ECHAM5 and RCMs (mm/day)

Calculating the skill scores of RCMs and driving ECHAM5, it can be found that RCMs improve the precipitation simulation over high latitude region, especially over the arid/semi-arid East Asia (Fig.3-5). Both RCMs and ECHAM5 have limited skill in reproducing the precipitation for Southeast Asia and adjacent ocean.

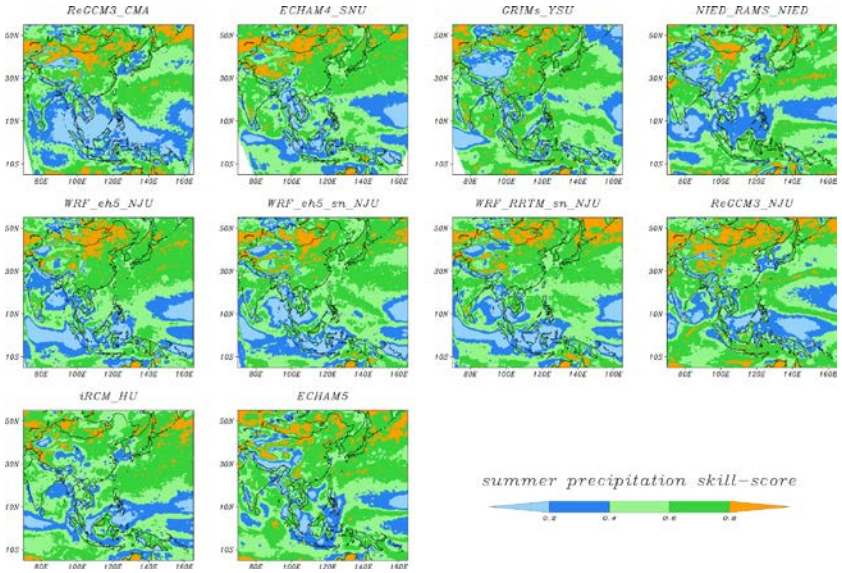

Fig. 3-5 Skill scores of summer total precipitation for participating RCMs and driving GCM

3.2.2 Regional climate changes

3.2.2.1 Surface air temperature

Comparing to the present-day climate (1980-2000), a remarkable warming is produced for future climate in all four seasons. Over the land the temperature increases by 2.54C annually, 2.39 C for summer season and 2.86 for winter season. The warming over the ocean is less phenomenal and shows smaller seasonal variation, with temperature increase around 1.7C (Fig. 3-6).

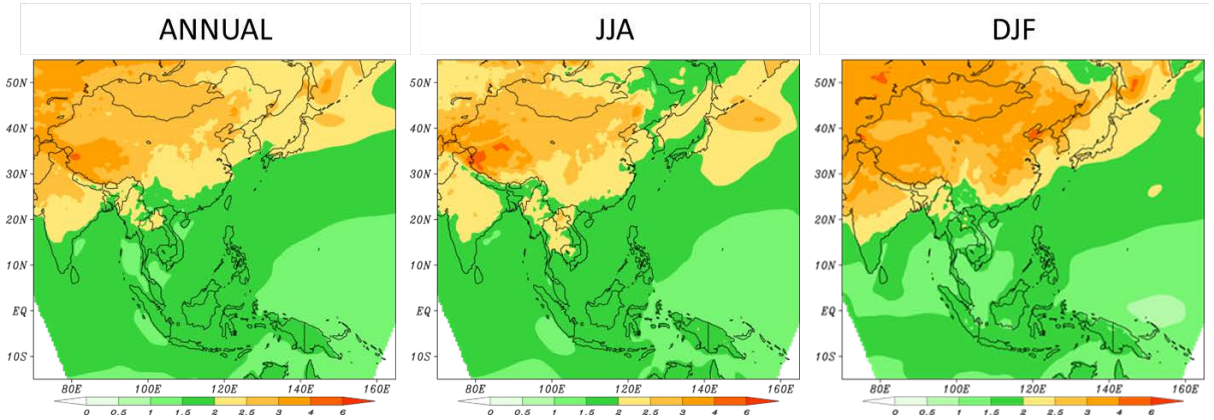

Fig. 3-6 temperature changes by ENSEMBLE RCMs for (C) annual mean, JJA and DJF

Comparing to the driving GCM, RCMs generate less warming. For example, over arid/semi-arid region, the ECHAM5's winter temperature increases by 4.1C, while RCMs have a ensemble warming of 3.38C, with uncertainty range of 2.2-4.03C. For North China the winter warming by ENSEMBLE RCM is 0.7C lower than that of ECHAM5, with uncertainty range of 2.0-4.06C. It's also found that RCMs tend to agree with other each better during summer season, inducing a large intermodal variation during winter seasons (Fig. 3-7).

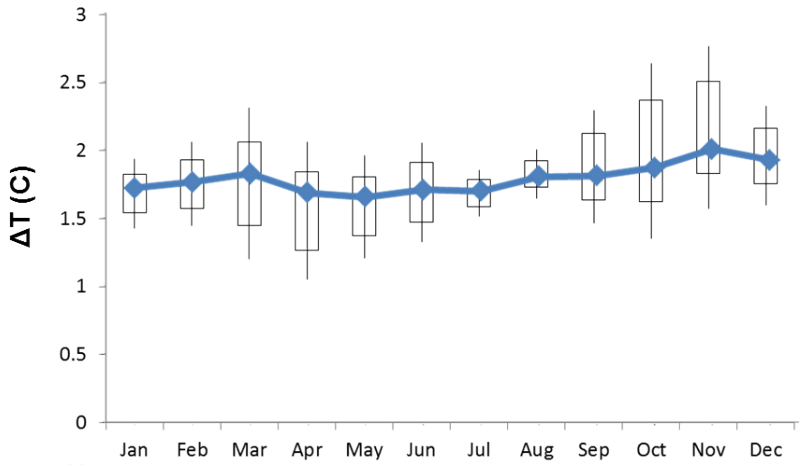

Fig.3-7 Seasonal cycle of temperature change.
Blue line is multi-model ensemble, and the box contains model projected temperature change.

During 2040-2070, the warming trend is likely to continue; and annual mean, summer and winter temperature will increase by 0.46C/10a, 0.44C/10a, and 0.5C/10a respectively (Fig.3-8). GCM and RCMs have similar warming range. Temperature increases more quickly over land (0.63C/10a) than over the ocean 0.46C/10a. The high latitude sub-regions such as Arid/Semi-arid area, North and Center China will experience stronger warming than other regions.

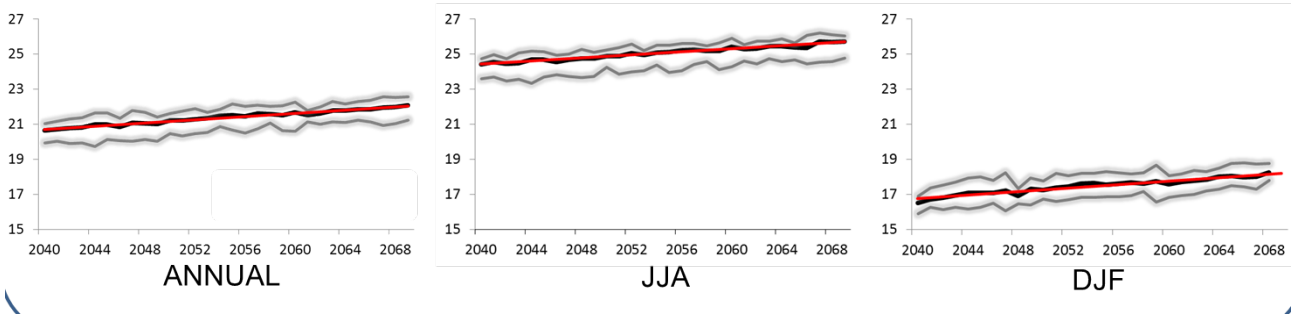

Fig.3-8 Interannual variability of temperature for future climate by multi-RCMs
Black line: RCM ensemble; Red line: linear regression; Grey lines: envelope of T changes by different models

3.2.2.2 Precipitation

During 2040-2070, the precipitation will increase over most East Asia region, with domain averaged increase of 2.46% (.13mm/day) annually. Most significant increase occurs over regions lower than 20N such as Philippine Sea, Indian Ocean, Indonesia and Malaysia, with increasement up to 3mm/day. Over the land, the precipitation increase during summer and spring, with annual increase of 5.23% (Fig. 3-9).

For 10 sub-regions, the signs of precipitation changes generated by ECHAM5 and RCMs are consistent except for Arid/Semi-arid area, North China and Tibet. ECHAM5 generate much larger precipitation changes over Center China, South China and Southeast China. Detailed analyses will be carried out to assess the reliability of simulated precipitation projection.

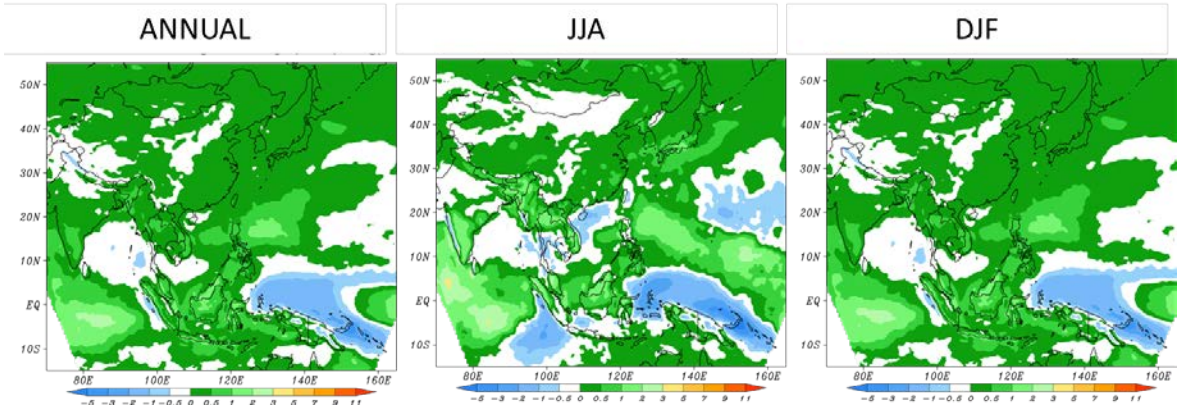

Fig. 3-9 precipitation changes by ENSEMBLE RCMs (mm/day) for annual mean, JJA and DJF

Similar to temperature, the models tend to agree better with each other during the month of February-June. For the rest of year, RCMs produce both positive and negative, and when using regional model rainfall projection, it is advisable to firstly compare it with observations and secondly, to use a suitable collection of grid squares rather than a single square.

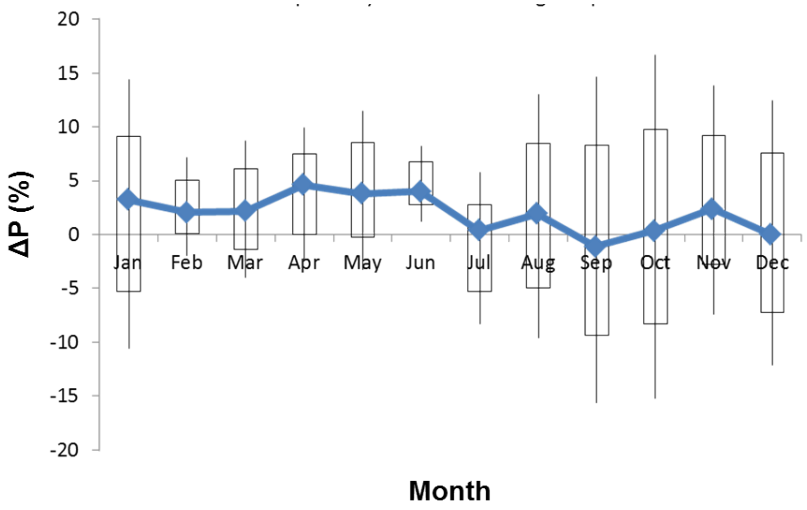

Fig.3-10 Seasonal cycle of precipitation change.
Blue line is multi-model ensemble, and the box contains model projected precipitation change.

In summary:

- RCMs show better performance than driving GCM over certain sub-regions;
- For future climate, temperature will increase by up to 3C and show more warming in DJF and higher latitude;
- Asian precipitation will increase by 2.4%; most increase occurs over land in summer Season;
- Comparing to driving GCM, RCMs tend to have colder and drier future climate;

4.0 Conclusions

- On completion of the project, a high resolution regional climate change for Asia can be provided by using the ensemble of nine regional climate models; based on the muliti-models simulations, the sources and magnitudes of uncertainty in Asian climate change projection

will be detected and assessed. Other studies, such as the variance of key climate controllers of Asian monsoon climate, land surface-atmosphere interaction under global change background will be carried out at the same time.

- From the launching of this APN project in 2009, 3 scientific workshops have been held, and all these meetings were financially supported by this APN project. On the workshops, the project progresses were summarized and discussed, and the latest research results on Asian regional climate studies were presented.
- A project data server has been set up and website is under construction. Data policy concerning data sharing, opening has been established, and it's agreed by all participating members that project results will be available to scientific communities as well as vulnerable and impact study.
- The scientists from developing countries of the Asia region are encouraged to using the participating RCMs results or taking part in the data analysis. Such activities will certainly enhance their capacities in studying regional climate change and strengthen the scientific connections between different regions.
- On the base of collaboration of project, an Asian Climate Change Projection network can be built, and global-level collaborations with regional climate change modelling and projection teams from other continents is formed and effectuated.
- Part of project team join the CORDEX project, which will promote the

5.0 Future Directions

- Project paper is prepared, followed up by a more comprehensive publication plan.
- APN proposal for the next phase is considered. Two components should be included in the future proposals to APN, one on higher resolution simulations (especially for urban areas), the other on extreme events stressing change of precipitation patterns.
- Young scientists will be invited to join the research efforts; social scientists with interdisciplinary training and background are most desirable.
- In terms of project's application, urban and dryland areas could be the focus. Cities and local governments have been staged in all national planning frameworks. The high resolution climate change projections will be used in a new APN project "Development of an integrated climate change impact assessment tool for urban policy makers (UrbanCLIM) ", and technique support concerning data processing will be provided to the new APN project.

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Appendix I

1, Agenda for project workshop I

APN Workshop on Building Asian Climate Change Scenarios by Multi-Regional Climate Models Ensemble

January 28- 29, 2010, Tsukuba, Japan

Day one: Jan 28 (Thursday)

9:10-9:30 **Registration**

9:30-9:40 **Opening and group photo**

※Opening Speech by Dr. Kazuo Kurihara, Dr. Shuyu Wang

※Approval of agenda

※Group photo

9:40-13:00 **Presentations of the Latest Research Results Related to APN Project, Chair by Dr. William Gutowski**

9:40-10:00

- Dong-Kyou LEE: *Uncertainties in regional climate modeling over Asia*

10:00-10:20

- Kazuo KURIHARA:

10:20-10:40

- Song You HONG: *Future climate change scenarios in summer over Korea using a multi-nested downscaling system*

10:40-11:00

- John McGregor: *CCAM simulations for RMIP3*

11:00-11:20 ***Coffee Break***

11:20-11:40

- Koji DAIRAKU: *Assessment of dynamical downscaling in Japan and preliminary experiments for intercomparison in Asia*

11:40-12:00

- Yunqing WANG: *Impact of Indian ocean SSTA on East-Asian summer climate ：observations and Regional Climate Model simulations*

12:00-12:20

- Jia WU: *High resolution climate change simulation of the 21st century over East Asia by RegCM3 - A preliminary analysis*

12:20-12:40

- Jianping TANG: *Regional climate simulations of precipitation and surface air temperature during 1982-2001 over CORDEX East Asia domain*

12:40-13:00

- Deming ZHAO: *RIEMS simulation*

13:00-14:30 ***Lunch***

14:30-18:00 **RCM development and application, Chair by Prof. Dong-Kyou Lee**

14:30-14:50

- William GUTOWSKI: *The coordinated regional downscaling experiment (CORDEX)*

14:50-15:10

- Jens CHRISTENSEN: *On the role of systematic model biases and a way to correct for them*

15:10-15:30

- Phillippe Lucas-Picher: *Investigation of regional climate models internal variability with a ten-member ensemble of ten years over a large domain*

15:30-15:50

- Dong-Hyun CHA: *Impacts of regional factors on East Asian summer monsoon*

15:50-16:10 ***Coffee Break***

16:10-16:30

- Hyun-Suk KANG: *Global and regional climate projections at NIMR/KMA*

16:30-16:50

- Igor SHKOLNIK: *The role of unforced climate variability in RCM simulations for northern Eurasia*

16:50-17:10

- Zhiwei HAN: *Development of RIEMS to study aerosol radiative forcings over East Asia*

17:10-17:30

- Hongxia Gao:

18:30 ***Reception***

Day 2: Jan 29 (Friday)

9:30-10:30 **Discussion on project progress, development, future application, Chair by Prof. Dong-kyou Lee, Shuyu Wang**

- Summery of project progress
- Discussion of future plan, and collaboration with other regional climate projection projects

10:30-10:50 ***Coffee break***

9:00-10:30 **Continuous discussion, Chair by Dong-kyou Lee, Shuyu Wang**

- Summary of project progress
- Discussion of future plan, and collaboration with other regional climate projection projects

12:30-14:30 ***Lunch***

14:30-16:40 **Continuous discussion**

2, Participating list for project workshop I

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by Multi-Regional Climate Models Ensemble
January 28- 29, 2010, Tsukuba, Japan
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3, Agenda for project workshop II

High Resolution Modeling of Climate Change over Asia

APN Workshop of

Building Asian Climate Change Scenarios by Multi-Regional Climate Models Ensemble

February 26- 27, 2011

Jika International Hotel, Melbourne, Australia

Day one: Jan 26 (Saturday)

9:10-9:25 **Registration**

9:25-9:40 **Opening and group photo**

※Opening speech by local host

※Opening speech by project leader

※Approval of agenda

※Group photo

9:40-13:00 **Presentations of the Latest Research Results Related to APN Project, Chair by Dr. William Gutowski**

9:40-10:00

- John McGregor: *CCAM climate simulation driven by bias-corrected SSTs from ECHAM5*

10:00-10:20

- Koji Dairaku: *Assessment of add-value of dynamical downscaling over East Asia*

10:20-10:40

- Xuejie Gao: *RegCM3 Simulation of Climate Change over CORDEX-EA domain driven by ECHAM5 —Preliminary Results*

10:40-11:00

- Eun-Cheol Chang/Song You HONG: *CORDEX exercise with a regional spectral model*

11:00-11:20 ***Coffee Break***

11:20-11:40

- Yunqing Wang: *Internal variability of dynamically downscaled western North Pacific Tropical Cyclones with the IPRC Regional Climate Model*

11:40-12:00

- Kazuo Kurihara: *RMIP simulation with MRI-NHRCM for the East Asia*

12:00-12:20

- Jianping Tang/Shuyu Wang: *Verification of Regional Climate Simulation over East Asia Domain Using WRF Model*

12:20-12:40

- Dong-kyou Lee/Suk-Jin Choi: *Current and Future Regional Climate Simulation using ECHAM5 Data over CORDEX Domain*

12:40-13:00

- Deming Zhao/Xiaorui Niu: *RIEMS simulation*

13:00-14:30 ***Lunch***

14:30-18:00 **Continuation of modeling group reports, Chair by Dr. Kurihara**

14:30-14:50

- William Gutowski: *CORDEX Metrics: Description and Opportunity for RMIP Input*

14:50-15:10

- Johnny C.L. Chan: *Potential Use of a Regional Climate Model in Seasonal Tropical Cyclone Activity Predictions in the Western North Pacific*

15:10-15:30

- Hidetaka Sasaki: *Numerical experiments of reproducing the present climate around Japan using NHRCM*

15:30-15:50

- Jack Kazfey: *An ensemble of downscaled climate simulations*

15:50-16:10 ***Coffee Break***

16:10-16:30

- Akihiko Murata: *Future changes in summertime temperature extremes over Japan projected by a high-resolution regional climate model*

16:30-16:50

- Igor Shkolnik: *Climate extremes in 21st century and impact potential over northern Eurasia as inferred from MGO RCM ensemble simulations*

16:50-17:10

- Jiapeng Li: *Verification of Regional Climate Simulation over East Asia Domain Using RegCM3 Model*

17:10-17:30

- Yoo-Bin Yhang:

17:30-17:50

- Boyan Hu: *Regional climate change under IPCC A1B Scenario using WRF model nested in ECHAM5*

*********End of the first day*********

Day 2: Jan 27 (Sunday)

9:20-10:40 **potential application of regional climate projection, chair by Dr. Ailikun**

9:20-9:40

- Linda Stevenson: *APN opportunities and other ongoing activities in the region*

9:40-10:00

- Ho-Ching Lee: *Discourse, Decisions and Policy Responses to Climate Change*

10:00-10:20

- Yinpeng Li: *The perspectives of end-users*

10:20-10:40

- Ailikun: *MAIRS model activities and application*

10:40-11:00 ***Coffee break***

11:00-13:00 **Discussion: on project progress and development, future application, Chair by Prof. Dong-kyou Lee, Dr. William Gutowski, Dr. Shuyu Wang**

- Discussion of future plan, and collaboration with other regional climate projection projects
- Dong-kyou LEE: *Regional Climate Simulations over CORDEX Domain Using Two Reanalysis Data*

12:20-12:40

- Ailikun:

13:00-14:30 ***Lunch***

14:30-15:50 **Discussion: on project progress and development, future application, Chair by Prof. Dong-kyou Lee, Dr. William Gutowski, Dr. Shuyu Wang**

- Discussion of future plan, and collaboration with other regional climate projection projects

15:50-16:10 ***Coffee Break***

16:10- **Discussion: on project progress and development, future application, Chair by Prof. Dong-kyou Lee, Dr. William Gutowski, Dr. Shuyu Wang**

- Discussion of future plan, and collaboration with other regional climate projection projects

*********End of the second day*********

18:30 ***Reception***

4, Participating list for project workshop II

APN Workshop on Building Asian Climate Change Scenarios by Multi-Regional Climate Models Ensemble

Melbourne, Australia

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5, Agenda for project workshop III

The 3rd APN Workshop of

Building Asian Climate Change Scenarios by Multi-Regional Climate Models Ensemble

February 27- 28, 2012

Kal Hotel, Jeju, Korea

Day one: Feb 27 (Monday)

9:10-9:25 **Registration**

9:25-9:40 **Opening and group photo**

※Opening speech by local host and project leader

※Approval of agenda

※Group photo

9:40-10:40 **Presentations of the Latest Research Results Related to APN Project, Chair by Prof. Dong-kyou Lee**

9:40-10:00

- Dong-kyou Lee: *Future regional climate change over the CORDEX East Asia using HadGEM2-AO scenarios*

10:00-10:20

- John McGregor: *An update on CCAM simulations over East Asia*

10:20-10:40

- Kazuo Kurihara: *Results of global warming projection over Japan with MRI-NHRCM and its future plan*

10:40-11:00

- Xuejie Gao: *RegCM3 climate change simulations over CORDEX domain driven by two different global models*

11:00-11:20 ***Coffee Break***

11:20-12:40 **Presentations of the Latest Research Results Related to APN Project, Chair by Dr. Kazuo Kurihara**

11:20-11:40

- Koji Dairaku:

11:40-12:00

- Eun-Cheol Chang/Song You HONG: *Teleconnection patterns between tropical oceans and the East Asian summer precipitation*

12:00-12:20

- Jianping Tang: *Regional climate simulation over CORDEX East Asia domain using WRF with spectral nudging*

12:20-12:40

- Akihiko Murata: *Evaluation of surface air temperature in Japan simulated by non-hydrostatic regional climate model (NHRCM)*

12:40-14:30 ***Lunch***

14:30-18:00 **Continuation of modeling group reports, Chair by Dr. John McGregor**

14:30-14:50

- Igor Shkolnik: *Arctic climate simulation: assessment of modeling performance and resolution issue*

14:50-15:10

- Jiwoo Lee: *Downscaled East Asia Climate from HadGEM2 Simulation by GRIMs*

15:10-15:30

- FenFen Wei: *The impact of different driving input data on regional climate simulation over China in summer*

15:30-15:50 ***Coffee Break***

15:50-16:10

- Seok-Geun Oh: *Development of new ensemble methods based on the performance skills of regional climate models over South Korea*

16:10-16:30

- Suk-Jin Choi: *Future climate change in regional climate simulations over the CORDEX East Asia using HadGEM2-AO RCP scenario*

16:30-16:50

- Huiping Hong: *Climate change projections for the Source Region of Yellow River using RegCM3 model*

Day 2: Jan 27 (Sunday)

9:20-10:40 **potential application of regional climate projection, chair by Dr. Ailikun**

9:20-9:40

- Hina Lotia:

9:40-10:00

- Chuluun Togtokh*: Adaptation of Pastoral Social-Ecological Systems in Mongolia*

10:00-10:20

- Ho-Ching Lee: *Adapting to Climate Change: An Integrated Research Framework in Taiwan*

10:20-10:40

- Yinpeng Li: *From GCM/RCM raw data to user experience: towards an extendable decision support system for urban planning*

10:40-10:40

- Ganjuur Sarantuya:

10:40-11:00 ***Coffee break***

11:00-12:30 **Discussion: on project progress etc, Chair by Prof. Dong-kyou Lee, Dr. Shuyu Wang**

- Shuyu Wang: Program Reports on the Project
- Discussion

12:30-14:30 ***Lunch***

14:30-15:50 **Discussion: on project progress etc, Chair by Prof. Dong-kyou Lee, Dr. Shuyu Wang**

- Discussion

6, Participating list for project workshop III

High Resolution Modeling of Climate Change over Asia
APN Workshop on Building Asian Climate Change Scenarios by Multi-Regional Climate Models Ensemble
Melbourne, Australia
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