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# Intercomparison of Land Surface Process Modelling in Asian Drylands

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**ABSTRACT:** For better prediction of the future climate at Asian drylands by using climate models, a community of Asian scientists, including young scientists, was formed to intercompare numerous land surface process models. These models are sub-modules of climate models to reproduce water, energy and vegetation processes at land surface, and are used independently, i.e. "offline," from climate models in the present study. The Asian Dryland Model Intercomparison Project (ADMIP) is an international project driven by this community. The data needed to drive the models at the target sites were collected and archived: one of the finest data sets for Asian drylands was constructed. Then, these data were used to drive a number of state-of-the-art numerical models of land surface processes. The outputs generated were also archived, and they were subject to mutual comparison. This way of comparison is called model intercomparison, which sheds light on differences in the reproducibility of land surface processes caused by different coding between the models. This gave an insight into the current status of modelling skills of land surface processes at Asian drylands.

**KEYWORDS:** *land surface model, terrestrial ecosystem model, drought prediction, land degradation, Asian drylands*

## Introduction

### *Why Drylands?*

Drylands account for 40% of the earth's land surface, and also a similar fraction of Asian land surface (FAO, 2008; Figure 1). Characterized by dry climate, low vegetation cover and low nutrients, its ecosystem and the society that depends thereon, have inherently large vulnerability to the external perturbations, such as climate change and land-use change. IPCC AR4 predicts drier climate in the extratropical arid regions during the latter half of this century, and overgrazing and/or land-use change are triggering desertification and land degradation in Asian drylands, especially in the transitional zones (Fu, 2009). Because it concerns the poorest population groups, essentially living off threatened natural resources, desertification and land degradation are challenges for achieving the Millennium Development Goals (UNCCD).

### *What is Land surface Process Modelling?*

In order to facilitate sustainable land management in Asian drylands, increasing our predictive capability of land surface processes is indispensable. This can be achieved through improvement of land surface process modelling, that refers, in this proposal, to land surface models (LSMs, Figure 2) and terrestrial ecosystem model (TEMs), each of which are briefly described below.

Land surface models (LSMs) were initially developed as a sub-module of general circulation models (GCMs) to incorporate energy and water exchange at the land surface into global atmospheric simulation (Manabe, 1969). Since the mid-1980s, LSMs have been developed separately from those of their parent GCMs. Now, most sophisticated LSMs in the world compute processes such as heat and water budget for different land cover/use, transpiration and carbon assimilation of plants, river discharge, groundwater, urban environment, and even usage and control of river water by human beings (Pitman, 2003; Oki & Kanae, 2006).

Terrestrial ecosystem models (TEMs) has also been developed in conjunction with GCM simulations, particularly to incorporate response of ecosystems to elevated $CO_2$ concentrations in future projections. TEMs specialize in carbon dynamics, such as plant growth, ecological succession and soil organic processes at longer time-scales larger than, for example, months, while LSMs, that major in water and energy at shorter time-scales such as hours and days, take vegetation as a static component. Though these models are initially developed for a sub-module of GCMs as stated, they can be used independently of GCMs (offline), and can serve as a modelling tool for land surface environments at the regional and point scales.

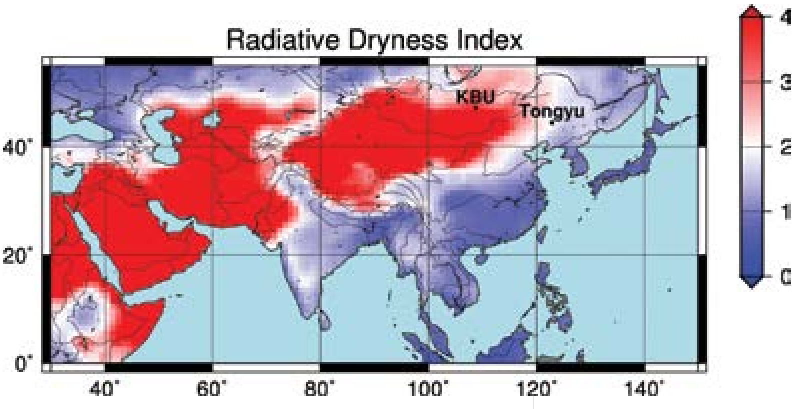



**Figure 1.** Dryland in Asia, indicated by the radiative dryness index (RDI), which is proportional to the ratio of the net radiation to the precipitation. RDI=1-2 is steppe, and RDI>3 is desert. The target stations of the project are marked.

### *What is Model Intercomparison?*

The current most sophisticated LSMs and TEMs utilize the latest scientific knowledge on the hydrosphere, atmosphere and biosphere, and use state-of-the-art computer simulation techniques. Nevertheless, uncertainties in the model results are, in general, large, and the origins of these uncertainties are still a matter for research targets. In particular, it is already known that the ability of these models to reproduce land processes at Asian dryland surface processes are still limited (Figure 2), partly because they are not sufficiently tested at short grass vegetation in Asian drylands, where plant activities are strongly regulated by water availability. In other words, Asian drylands are one of the largest gap regions in land surface modelling work. Note that most LSMs and TEMs are initially developed for tropical and boreal forests as a major target. In addition, until recently, the observed data that is needed to drive and validate these models were not easily available for Asian drylands.

The model intercomparison (Henderson-Sellers et al., 1993, 1995; Figure 3) is a way toward

**HIGHLIGHTS**

- A community was formed for the intercomparison of land surface process models for Asian drylands with 18 participating models and their operating scientists.
- The procedure of model intercomparison was documented.
- One of the finest data sets for Asian drylands was constructed for modelling work.

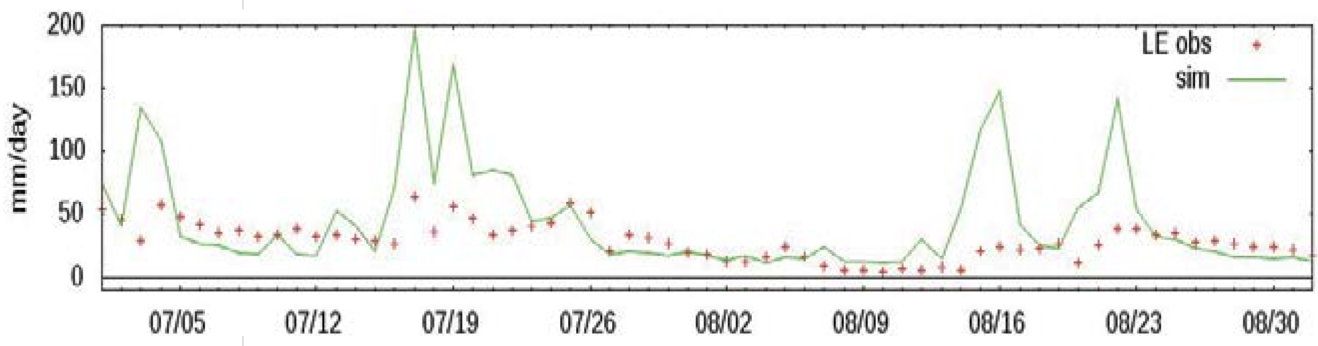



**Figure 2.** An example of LSMs simulation results of evaporation at Mongolian grassland (line) compared with the observations (cross)

improvement of LSMs and TEMs, where multiple models are run with a common driving meteorological data set, and the results are compared to identify relative model performance as well as ensemble characteristics common to all of the models tested. This facilitates intensive tests of LSMs at the targeted site as well as provide best-estimate of model uncertainties from the inter-model variations.

### *Target Phenomena and Scientific Questions*

*Target Phenomena*

Target phenomena that will be tested through the intercomparison of LSMs and TEMs are energy, water and carbon exchange at the land surface under a water-limited environment, and/or under the control of vegetation growth, at the temporal scales of three-hourly, daily and monthly.

*Scientific Questions*

Scientific questions that will be answered through the intercomparison of TEMs and LSMs are:

- What is the ability of models to reproduce energy, water, and carbon exchange at dryland surface (reproducibility)?
- Do current ecosystem models, developed mainly for forests, reproduce energy, water and carbon exchange in arid regions?
- Does the current complexity of models effectively simulate land surface processes (complexity issues, also related to benchmarking)?
- Does the multi-model ensemble of LSMs outperform single model output (ensemble)?

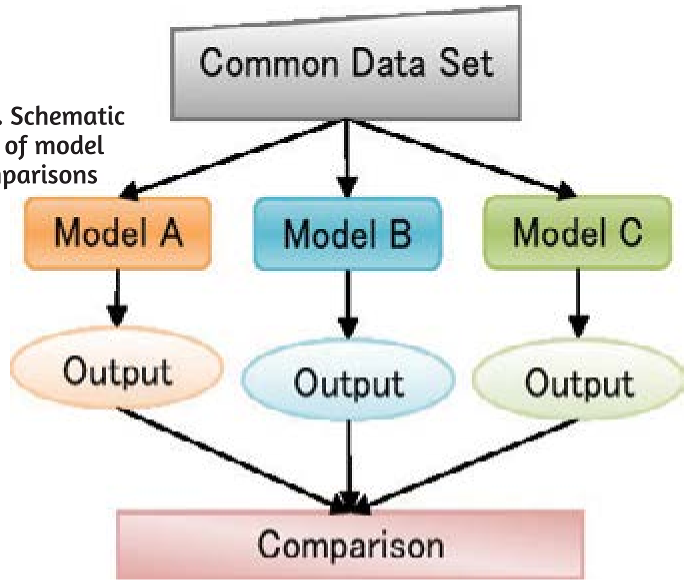



**Figure 3.** Schematic diagram of model intercomparisons

### *The Purpose of this Project*

In the project, several LSMs and TEMs were intercompared using common data obtained from Asian drylands. LSMs and TEMs were chosen from selected research and operational institutes. Two selected sites provided meteorological data to drive the models. These sites started their observations within this century, and have continued the observations to acquire high-quality and continuous data that are needed to drive LSMs and TEMs in the intercomparison.

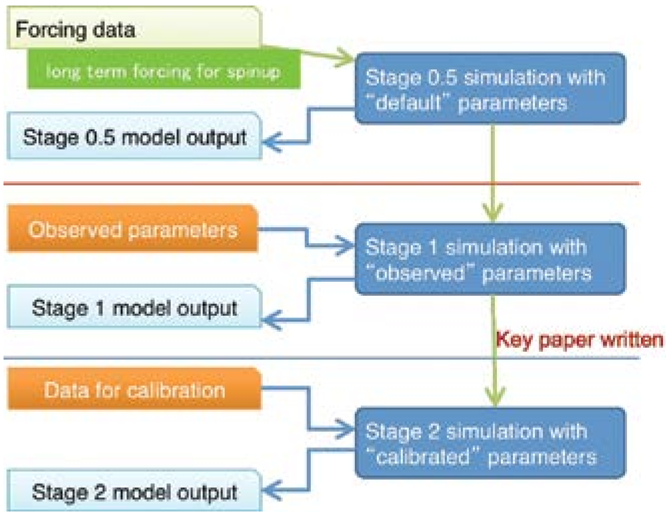



**Figure 4.** Schematic diagram for the blind policy in ADMIP

Through the intercomparison work, the project aimsed to increase modelling capacity of drylands in Asia and build a "land surface modelling community" in the region for future cooperation.

## Intercomparison Design

### *Target Sites*

Two target sites were chosen for the intercomparison. The observed data at these sites were archived and used in the intercomparison.

*a) Tongyu (China)*

- Contact: Dr. Ailikun (MAIRS-IPO, ailikun@gmail.com)
- Target period: 2003–2009
- Note: GEWEX-CEOP registered
- Website: http://www.eol.ucar.edu/projects/ceop/dm/insitu/sites/ceop_ap/Tongyu/Cropland

*b) Kherlen Bayan Ulaan (KBU, Mongolia)*

- Contact: Dr. Jun Asanuma (Tsukuba University, asanuma@suiri.tsukuba.ac.jp)
- Target periond: 2003–2007
- Note: GEWEX-CEOP and IGBP-AsiaFlux registered
- Websites:
  - » http://www.eol.ucar.edu/projects/ceop/dm/insitu/sites/ceop_ap/Northern_Mongolia/Kherlen
  - » http://asiaflux.yonsei.ac.kr/network/021KBU_1.html

### *Intercomparison Stages (Blind Policy)*

In general, a model will perform better when it is provided with more information about the target location. However, different models will perform differently depending on the extent of information provided about the target site.

In order to evaluate model differences in terms of how they rely on data provided, three stages with varying extents of information were defined as an experimental design of the intercomparison.

In stage 0.5, no information was given to the models, except the time series of meteorological variables and the location of the sites, for example longitude and latitude. This is called the "blind" stage. The performance of the model at this "blind" stage was tested. At stage 1, the models will be given information about the target site, such as soil and vegetation properties. This information is provided when the models are run within climate models. Stage 2 will provide the models with data for calibration.

*Stage 0: Analyses of Existing Data Set*

Basic investigation of the results from previous intercomparison or analyses. For example, GSWP 1 and 2, GLDAS and CEOP-MOLTS, were used to evaluate overall performance.

*2) Stage 0.5: With "Default" Parameter Set*

"Totally-blind" stage. No observed information was made available at this stage. Data provided was climatological values of LAI derived from MODIS for LSMs.

*3) Stage 1: With "Observed" Parameter Set*

This stage of the project is about to get underway and is the "half-blind" stage. Data to be provided will include LAI from MODIS, albedo, vegetation type and properties including root profiles, soil type and properties for LSM. For TEMs, soil type and properties were provided.

*4) Stage 2: With "Calibrated" Parameter Set*

"Calibration" stage. In addition to the data that is expected under Stage 1, other data provision will include energy, water and carbon fluxes for LSMs; and energy, water and carbon fluxes, above- and below-ground biomass; and LAI for TEMs.

### *Registered Models*

LSMs and TEMs registered for the project are listed in Table 1.

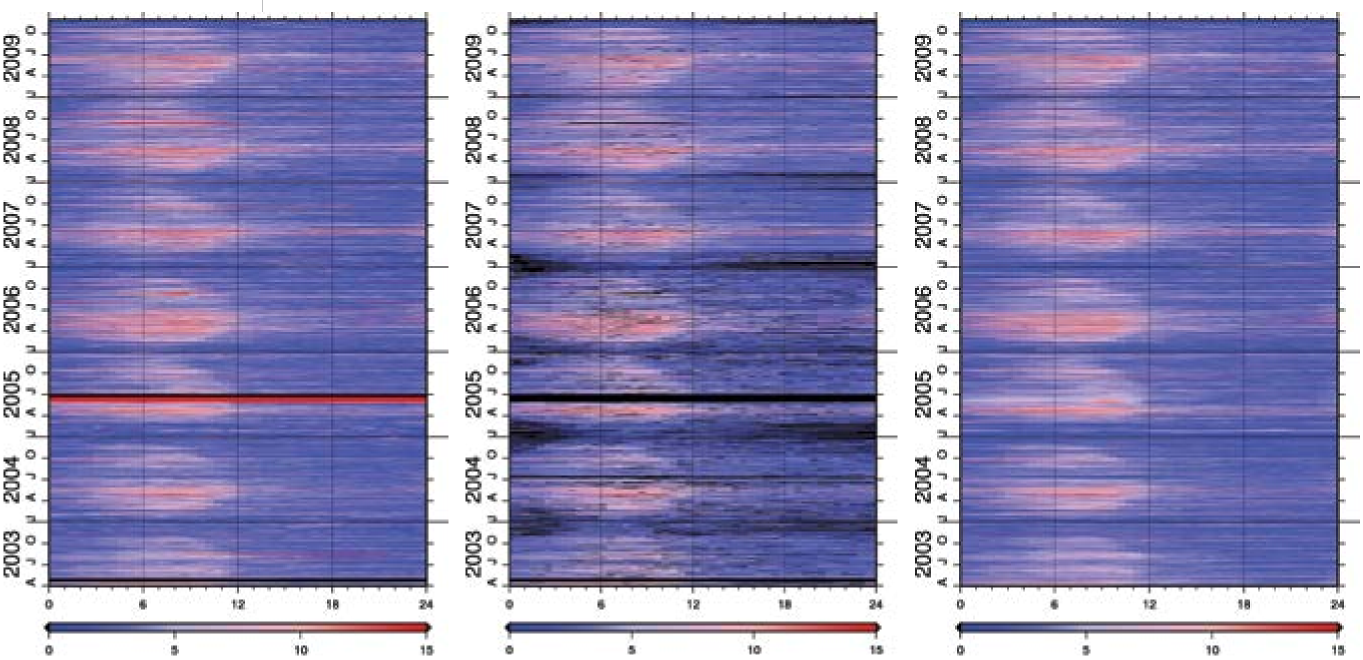
## Results and Discussion

### *Data Preparation*

A forcing data set that can drive LSMs and TEMs were derived from the observational data at Tongyu and KBU. This process includes quality-controlling (QC), which evaluates the quality of each observational value to remove less-qualified data points, and gap-filling (GF), which fill gaps generated during QC using statistical techniques (Lee, Massman, & Law, 2004). Figure 5 is an example of these processes for wind speed, where the number of error values increased after QC and these errors are replaced with statistically-computed values after GF. Through these processes, continuous (i.e., without gaps) and well-qualified data series with high 30-min temporal resolution were generated for KBU and Tongyu.

In addition, forcing data with longer time period was derived from a historical record of meteorological variables. This was needed to run models for a long period to reach a realistic initial state of model variables (spin-up), such as vegetation amount and soil moisture. The "spin-up" data set was derived from a historical forcing record constructed at NCAR (Qian et al., 2006) at KBU, and from

**Figure 5.** An example of data preparation for wind speed (m/s) measured at KBU. The x-axes indicate the time of the day in UTC, while the y-axes are days. Black colour indicates error values. (Asanuma, 2011)




(a) measured values (b) after QC (c) after GF

| Model Acronym | Model name and version | Principal investigator |
|---|---|---|
| BAIM | Biosphere-Atmosphere Interaction Model, ver 2 | Kazuo Mabuchi, Meteorological Research Institute, Japan |
| JULES | Joint UK Land Environment Simulator, ver 2 | Hong Jinkyu, Korea |
| SiBCrop | Simple Biosphere Model-Crop, ver 1 | Erandi Lokupitiya, USA |
| CABLE_UNSW | Community Atmosphere Biosphere Land Exchange, ver 1.0 | Jason P. Evans, Climate Change Research Centre, University of New South Wales, Australia |
| CLM | Community Land Model, ver 3.5 | Jun Asanuma, Tsukuba University, Japan |
| CoLM | Common Land Model, ver 3 | Guo Weidong, Institute of Atmospheric Physics, Chinese Academy of Sciences, China |
| MATSHIRO | Minimal Advanced Treatments of Surface Interaction and Runoff, ver 5.6 | Shin Miyazaki, Hokkaido University, Japan |
| Noah 2.7 | Noah land surface model, revised ver 2.7 | Chen Yingying, Chinese Academy of Sciences, China |
| SiB2 | Simple Biosphere Model, revised ver 2 | Chen Yingying, Chinese Academy of Sciences, China |
| SiBUC | Simple Biosphere including Urban Canopy, ver 1 | Kazuaki Yorozu, Kyoto University, Japan |
| SM/TEA | Soil model | Zhang Xia, Institute of Atmospheric Physics, Chinese Academy of Sciences, China |
| Biome-BGC | Biome-BGC | Kazuhito Ichii, Fukushima University, Japan |
| SEIB-DGVM | Spatially Explicit Individual-Based Dynamic Global Vegetation Model, ver 2.53 | Kaoru Tachiiri, Japan Agency for Marine-Earth Science and Technology, Japan |
| VISIT | Vegetation Integrative SImulator for Trace gases, ver 1 | Akihiko Ito, National Institute for Environmental Studies, Japan |
| SSiB | The Simplified Simple Biosphere model | Qian Li, Institute of Atmospheric Physics, Chinese Academy of Sciences, China |
| HAL | HAL | Masahiro Hosaka, Meteorological Research Institute, Japan |
| DayCent | DayCent | Dennis Ojima, Colorado State University, USA |
| NoahMP | Noah with multiple physics | Guo-Yue Niu, The University of Arizona, USA |

**Table 1.** Registered models

historical meteorological records compiled at the Institute of Tibetan Plateau, Chinese Academy of Sciences. The data was utilized after comparing with ground observations when available, and similar data sets (Figure 6). These include GLDAS (Global Land Data Assimilation System; Rodell et al., 2004) versions 1 and 2, and APHRODITE (Asian Precipitation — Highly Resolved Observational Data Integration Towards Evaluation of Water Resources; Yatagai et al., 2012). It was observed that out of these data sets, Qian et al. (2006) has the best consistency with the observed data, and therefore used in this project.

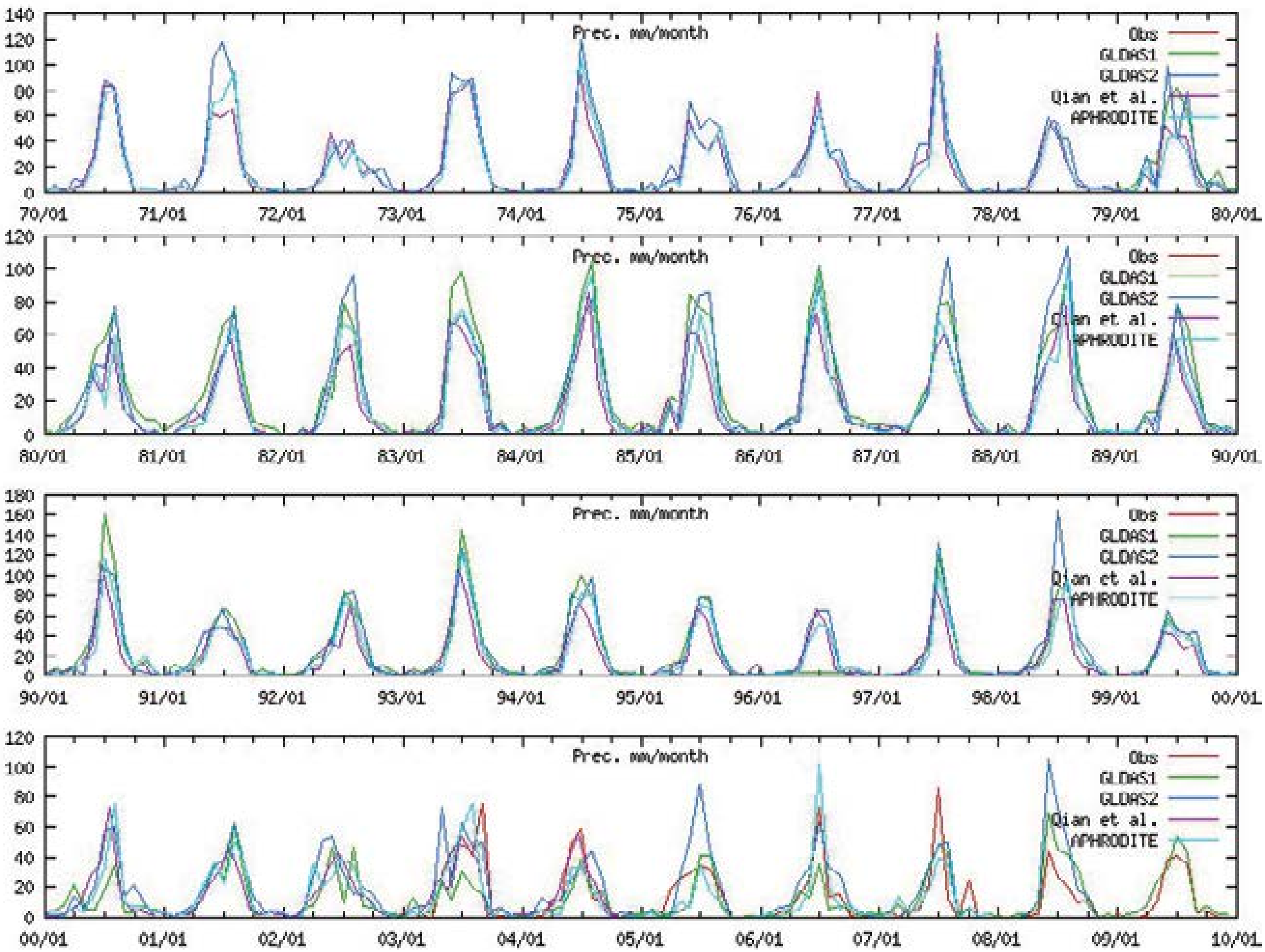



**Figure 6.** Comparison of monthly precipitation between the spin-up data set used in this project (purple line) and that from various sources, for 40 years. The latter includes the ground observation data (i.e. the forcing data, red line) marked as Obs, GLDAS version 1 and 2, and APHRODITE

### *Intercomparison of the Model Results*

Figures 7 and 8 show the comparison between monthly model outputs of latent heat flux (Qle), and sensible heat flux (Qh), from the participating models. It was found that differences between models are larger with Qh than with Qle. This is in contrast to general knowledge about the physical process in land surface modelling. While sensible heat flux from the surface to the atmosphere, that is the heating of air by the land, is mainly concerned only with the temperature of the land and the atmosphere, latent heat flux from the ground, that is the evaporation from the land into the air also involves moisture of the land. Therefore, modelling of the former is regarded as easier than that of the latter. However, the results shown in Figures 7 and 8 are opposite. This may be attributable to the land's arid characteristics.

## Conclusions

The purpose of this project was to increase the modelling capacity of Asian drylands and develop a "land surface modelling community" in Asia for future cooperation.

Asian scientists, including young scientists, were gathered to build an international project ADMIP, Asian Dryland Model Intercomparison Project, which aimed

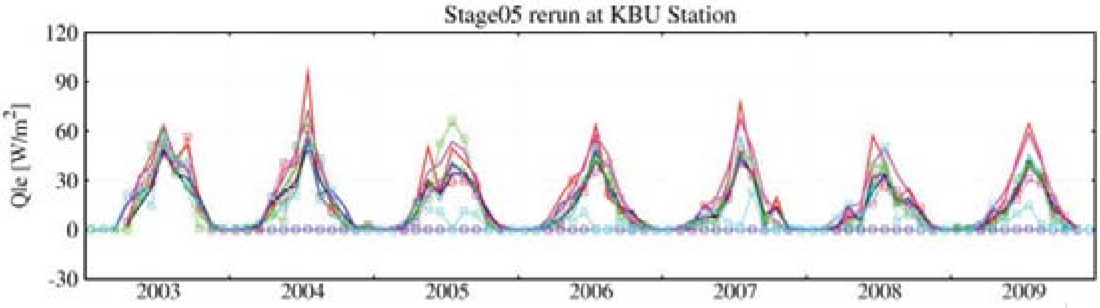



**Figure 7.** Comparison between Qle, latent heat flux, computed by different models (Yorozu et al., 2012)

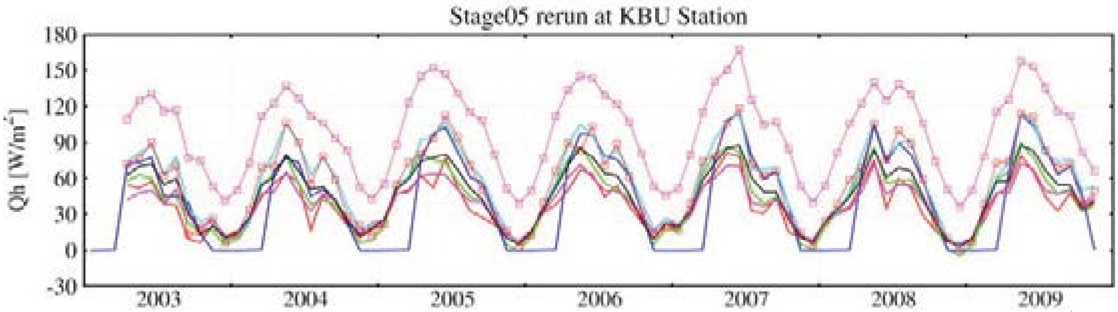



**Figure 8.** Same as Figure 7 but with comparison between Qh (Yorozu et al., 2012)

to intercompare numerous land surface process models. The project protocol of ADMIP, which states the details of model runs and the methods of intercomparison of the model outputs, were composed through discussion among project members.

To date, the project protocol that describes the model intercomparison methodologies were composed and the first model intercomparison was completed.

## Future Directions

At the time of writing, stage 0.5 comparison has been completed and Stage 1 is about to get underway.

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## ARCP2011-03CMY-ASANUMA

### PROJECT TITLE

**Intercomparison of Land Surface Process Modelling in Asian Drylands**

### COUNTRIES INVOLVED

Australia, China, Japan, Mongolia, Pakistan, Republic of Korea, USA

### PROJECT DURATION

2 years

### APN FUNDING

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### PROJECT LEADER

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