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CEOP's Future Role in Water Resource Risk Management

Ann Henderson-Sellers, Director of the World Climate Research Programme (WCRP).


Ann Henderson-Sellers

We are so vulnerable to fluctuations in water supply that the availability of water is predicted to be a major trigger of future global conflicts. Current pressure on potable and agricultural supplies worldwide will be exacerbated, particularly in developing nations, by climate fluctuations, whatever their cause, because response times of meteorological, hydrological, engineering, social and political systems differ. A key commitment from the Johannesburg 2002 World Summit on Sustainable Development was to 'develop integrated water resources management and water efficiency plans by 2005'.

CEOP, established in 2001 by WCRP's Global Energy and Water Cycle Experiment (GEWEX), was motivated by international efforts focused on measuring, understanding and modeling of the water and energy cycles within the climate system. CEOP has gained the interest of other international organizations, including being selected as a transitional element of the first stage of GEOSS and as the first element of the Integrated Global Water Cycle Observations (IGWCO) theme within the framework of the Integrated Global Observing Strategy Partnership (IGOS-P). These are remarkable achievements, which deserve praise. With this heritage, it is straightforward for CEOP to take fully into account the new WCRP strategic framework in planning the assembly of coordinated data sets and developing the scientific goals of its Phase 2.

CEOP has been implemented with the support of a large number of field scientists, numerical weather prediction centres and space agencies. Here, I take this opportunity to raise another area of coordinated enhanced observation relevant to CEOP and of importance for future water resource risk management. Stable water isotopes have an innovative contribution to make to the goal of reducing uncertainty in water availability predictions, which is just becoming attainable. Two rare but naturally occurring isotopes of water, $^{1}H_2{}^{18}O$ and $^{1}H^{2}H^{16}O$, have practical applications in diagnosis of climate and Earth Systems and hence in water resource risk mitigation. The potential of these stable isotopes as tracers and validation tools in hydrological systems derives from the systematic and different (from each other and from the most abundant nuclide: $^{1}H^{1}H^{16}O$) paths and residence times.

It seems to me that CEOP Phase 2 could be very readily extended to allow and encourage testing of novel hypotheses such as: Observation and analysis of the diurnal fluxes of $^{1}H_2{}^{18}O$ and $^{1}H^{2}H^{16}O$ between the soil, plants and atmosphere can accurately determine the partitioning of precipitation into transpiration, evaporation and total runoff (surface plus soil drainage). If validated, by CEOP, this type of hypothesis can contribute (i) to improving the accuracy with which land-surface schemes partition net available surface energy into latent and sensible heat fluxes and thus (ii) to decreasing the uncertainty in hydro-climate modelling and water resource vulnerability predictions. Two examples from large river basins already involved in CEOP illustrate the potential benefits of including stable water isotopes into CEOP Phase 2.

All land surfaces recycle precipitation, the most effective system being the Amazon Basin, which recycles about half its rainfall with a water recycling time of about 5.5 days. Field measurements of water isotopes in the Amazon in the 1970s demonstrated the importance of the soil and vegetation by differentiating moisture sources and mapping the fate of water intercepted by the vegetation. In a complete simulation of the Amazon's forest hydrology, the land surface must correctly partition the moisture fluxes between water evaporation (fractionating), transpiration (non-fractionating), re-evaporated canopy-intercepted rainfall (non-fractionating if complete) and runoff. Statistically significant temporal changes (1965-1990) in water isotopic signatures detected in the Amazon are more consistent with the effects of greenhouse warming, possibly combined with land-use change, than with the effects of deforestation alone. However, very recent isotopic data "fingerprint" the impact of deforestation: vegetation removal prompting less recycling and less re-insertion of heavy isotopes into the basin system.

The Murray Darling basin poses a complementary but equally significant challenge for water risk management. Specifically, global and regional models exhibit large sensitivity to land-cover characterization and to land-use changes. A GEWEX inter-model comparison reveals a lack of quantitative skill in the Murray Darling

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demanding the imposition of additional constraints on the surface water and energy budget. New river and groundwater isotope measurements from Australia substantiate the identification of the 2003-2004 El Niño drought as evaporatively most extreme.

Since its establishment, CEOP has developed comprehensive composited data sets that have stimulated a number of research projects, which are continuing to advance our understanding of processes important for future water management. I very much applaud CEOP's progress to date and encourage the development of CEOP Phase 2 as broadly as possible, for example to include stable water isotopes, so that its endeavours maximize the benefits delivered to end-users.

Initial Comparisons of Model Analyses during the North American Monsoon Experiment (NAME)

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CEOP collections of data assimilation products from operational and research numerical weather prediction centers are a link between the implementation of global observations and model development. As many as 11 international centers are contributing data and guidance on analysis data. Presently, four centers have contributed data for the full EOP3 and EOP4 periods (namely NCEP, UKMO, JMA and ECPC/RII). These contributions are being evaluated and compared to observations with an overall objective to better characterize the uncertainty of analysis data. In addition, the CEOP collection of both model and observed data can provide a central baseline for long term development at individual centers.

A key consideration in analyses is the precipitation field. When moisture is assimilated, there is a significant impact on the simulated physical processes. Analysis products tend to provide precipitation from the forward integration of the model (e.g. 6 hours forecast from the analysis). As such, the model influence on precipitation data is substantial. In principle, comparisons of these data can provide information on the modeled processes. In an initial investigation, we evaluated the four primary contributions to the CEOP model archives during the North American Monsoon Experiment (NAME, Higgins et al., 2006) period (June – September 2004). We will follow some comparisons included in the North American Monsoon Model Assessment Project (NAMAP2, e.g. Gutzler et al. 2005) in order to facilitate comparisons with the regional and global simulations. In addition to the contributions to CEOP, we also include the North American Regional Reanalysis (NARR, Mesinger et al. 2006), which assimilates rain rate (gauge over land, CMAP for oceans). We use the merged Tropical Rainfall Measurement Mission (TRMM) rainfall product for a baseline (Huffman et al. 2006, *http://precip.gsfc.nasa.gov/*).

Figure 1 shows the difference between July and June 2004 monthly mean precipitation in the North American monsoon region for TRMM and each of the analysis systems. Generally speaking, the analyses show the increase of precipitation in the monsoon region including Arizona, and the decrease of precipitation in the south central United States. The global analyses favor increasing tropical convection in the southwest corner of this figure, similar to TRMM, but the NARR increases precipitation farther north. The NARR captures the maximum precipitation in Northern Mexico. This comparison is generally reasonable at large scales, though some differences with TRMM are apparent. The TRMM precipitation shows a wide swath where there is little change in the precipitation, so that New Mexico is not increasing from June to July. All of the analyses show increases in New Mexico.

Figure 2 shows the time series for the accumulation of precipitation throughout the 2004 season for Arizona-New Mexico (AZNM, lon 115-108W, lat 32-35N) and the core monsoon region (CORE, lon 112-106W, lat 24-30N). The occurrences of major rainfall events in the TRMM data are generally represented well by the reanalyses. The major differences are the magnitude of the events. A noticeable feature is that the JMA rainfall is nearly double the other data (scaled on the right axis). It appears to be a regional bias in the generation of convective precipitation. The ECPC RII system starts raining late in the season, but eventually catches up with strong late season events. Also, there is a tremendous range of variations in the analysis systems.

We will evaluate the processes contributing to precipitation in the systems (e.g. Betts 2006). However it should be noted that not all the analyses provided the same diagnostic variables. Additionally, the models have different spatial resolutions. The NCEP and ECPC systems are approximately 2 degrees while UKMO, JMA and NARR are more fine scale. Subsequent work in this region should consider carefully the spatial resolution of the analysis systems (Berbery and Fox-Rabinovitz, 2003).

Lastly, it is worthwhile to mention that the comparisons produced here were done remotely using a Grads Data Server (GDS) as the source for the data. In an effort to show the utility of this approach the scripts and instructions to use them are made available for download at ftp://gmaoftp.gsfc.nasa.gov/pub/data/mikeb/CEOP/NAME_example.zip. While some experience with Grads will help running these scripts, the data is also accessible with Ferret, MatLab and IDL. Only a portion of the model data is currently available online.

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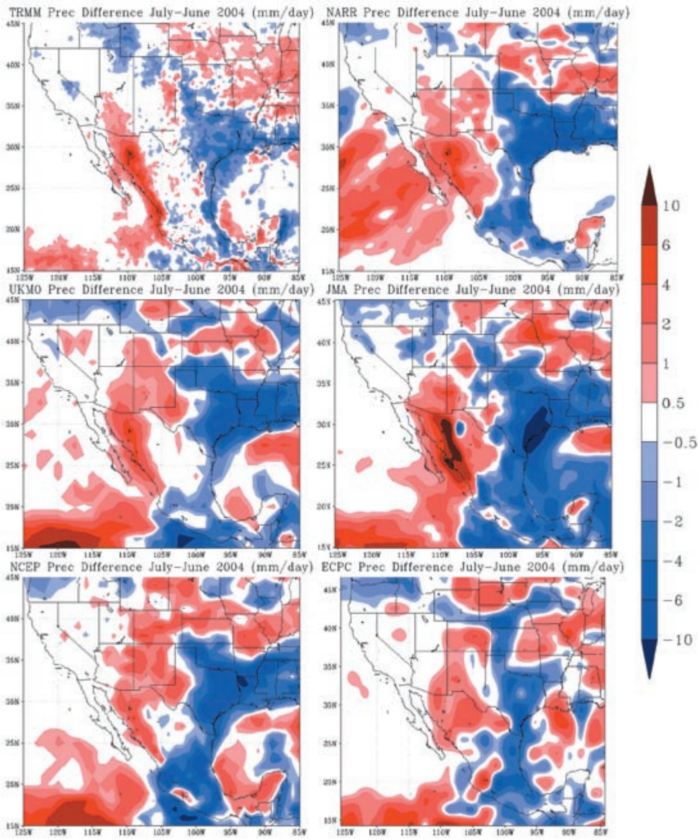

Figure 1: Differences of monthly mean precipitation (July-June, 2004) showing the extent of the North American monsoon onset in the TRMM observations, NARR, and four of the contributed analyses to the CEOP archives. Units are mm day $^{-1}$.

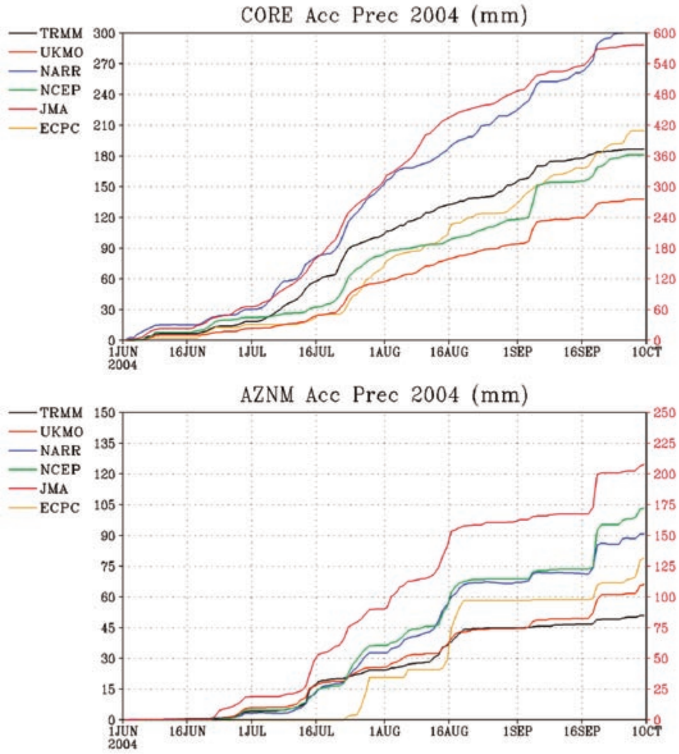

Figure 2: Time series of accumulated precipitation for the five analyses and TRMM observations. JMA precipitation is scaled by the right axis. Units are mm.

Inter-comparisons of Prediction Skill of Operational GCMs and a Land Data Assimilation System

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1. Introduction

Diagnosing model errors by comparing model output with observations is the basis for improving representations of key physical processes. CEOP archives model output and in-situ data with a global coverage and provides a unique platform to detect model deficiencies in global and regional scales. Model skill is being evaluated at individual NWP centers using CEOP data (See reference papers submitted to a CEOP special issue), but it is necessary to have model-cross comparisons (Bosilovich, 2005). In this article, we briefly report the results of an inter-comparison study within the framework of a full annual cycle, multi-site, multi-parameter, and multi-model output. Details can be found in Yang et al. (2006).

2. Data

Observations at 27 reference sites and model output location time series (MOLTS) from JMA and BMRC (hourly), NCEP, UKMO, ECPC, and GLDAS (3-hourly) for Oct. 2002 ~ Sep. 2003 (EOP3) were compared. We present the results for the first 6-hr forecast of BMRC, ECPC/SFM6, and JMA, the first 24-hr forecast of UKMO and NCEP.

3. First results of GCM inter-comparisons

Figure 1 shows all-sites mean bias error (MBE) and root mean square error (RMSE) in monthly-mean values. The symbol μ denotes the measured monthly-mean values.

Radiation budget. Downward shortwave radiation (SWD) was over-predicted by all of the models. Downward longwave radiation (LWD) was under-predicted by NCEP, JMA and ECPC but reasonably predicted by UKMO (MBE ~ 0). The latter was based on the Edwards and Slingo (1996) scheme. Compensation of errors in SWD and LWD results in smaller biases in SWD+LWD. Errors in net radiation are similar to that in SWD+LWD. The SWD over-estimation and LWD under-estimation by GCMs have been found in many early studies (e.g. Cess et al. 1995; Garratt and Prata 1996). This might be due to radiation schemes' errors and/or due to under-prediction of cloudiness (Milton and Earnshaw, 2006).

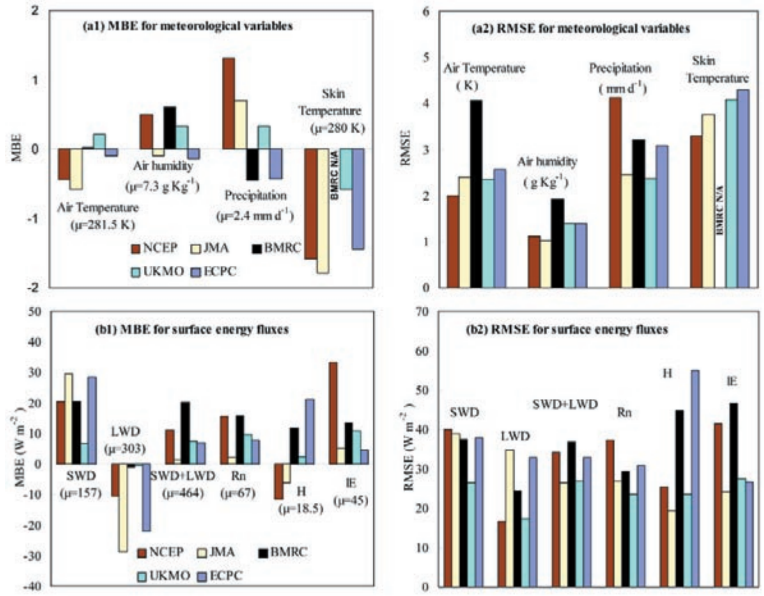

Figure 1: All-site mean bias error (a1, b1) and root mean square error (a2, b2) in monthly-mean values. SWD-Downward Shortwave Radiation, LWD-Downward Longwave Radiation, Rn-Net Radiation, H-Sensible heat flux, IE-Latent heat flux.

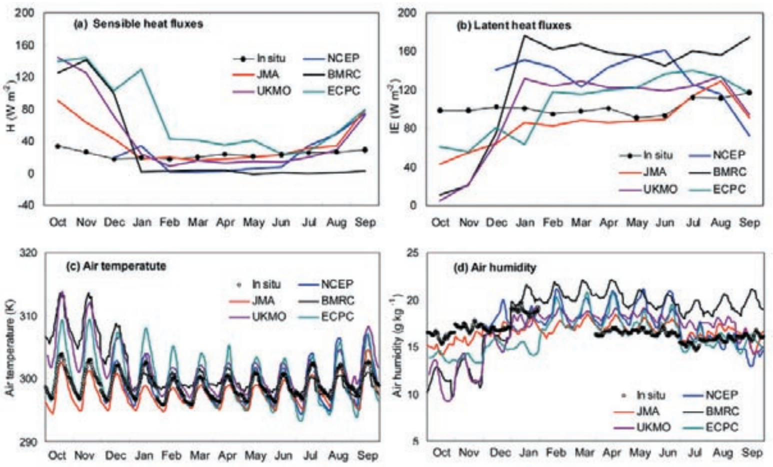

Figure 2: Observed and modeled monthly mean values (a and b) and monthly mean diurnal variation (c and d) at the LBA-Santarem site for CEOP/EOP3. NCEP data are not available during Oct-Nov 2002.

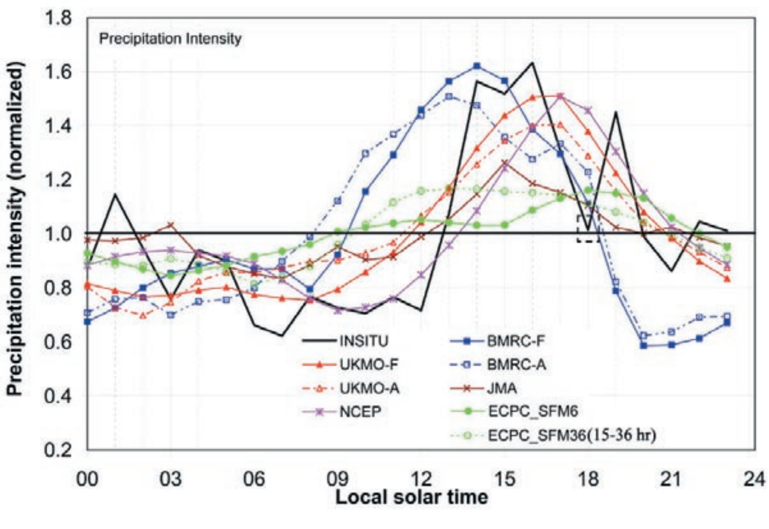

Figure 3: Composite diurnal cycle of precipitation intensity of observations and model output (F-forecast, A-analysis) at 16 sites in rainy seasons (three months with maximum precipitation amount). Only inland data except CAMP/Tongyu site were used for ECPC.

Surface energy budget. The RMSE values of surface heat fluxes (> 20 Wm^{-2}) are comparable to the observed heat fluxes themselves, indicating that surface energy budget was not well modeled. Based on flux data at seven sites, JMA and UKMO produced better results, ECPC and BMRC generally over-predicted H (sensible heat flux) in the summer, and NCEP generally over-predicted IE (latent heat flux). The accuracy of near-surface variables can be directly related to the modeling accuracy of surface energy budget. Figure 2 is an example, showing that over-prediction of H and under-prediction of IE results in warm and dry biases at the LBA/Santarem site during Oct-Dec. In NCEP, a strong coupling between E (evaporation) and P (precipitation) was found, and thus the model's over-prediction of precipitation (see Fig.1 (a1)) may be related to its over-prediction of E. NCEP has updated its LSM since May 2005 and improved their prediction of precipitation (Mitchell et al. 2005), which supports our results.

Diurnal cycle of precipitation. The diurnal cycle of rainfall from CEOP in-situ data is comparable to reports of early studies (not shown). Figure 3 shows the observed and modeled diurnal cycle of precipitation intensity that was normalized by mean precipitation amount at each site and then averaged over 16 sites. All the models generally produced an afternoon peak, but its intensity is different among models. No model was able to reproduce the minimum in the early evening (around 18 LST). Using a method (Goldenburg et al. 1990) to separate convective and stratiform precipitation, we found that the observed minimum was caused by a rapid decrease of convective rainfall in the early evening and start of stratiform precipitation afterwards (not shown). JMA, NCEP, and UKMO yielded the diurnal cycle better than other models. There is no remarkable difference in precipitation diurnal cycle between forecast ('F') and analysis ('A') for both UKMO and BMRC, implying that the diurnal cycle is mainly determined by the nature of each model rather than the initial conditions. The diurnal cycle in ECPC/SFM is sensitive to spinup period (see the comparisons between 6-hr and 36-hr forecasts).

4. GLDAS Evaluation

GLDAS embeds three land models: Mosaic, Noah LSM, and CLM. In general, Noah LSM and CLM simulated Tsfc better than GCMs and Mosaic. Mosaic yielded obvious cold biases for nighttime (not shown). However, the three LSMs produced quite different heat fluxes, as shown in Figure 4 for GAPP/Bondville and BALTEX/ Cabauw. Both model ~ observation and model ~ model differences are large for the summer season.

5. Recommendation for Phase 2 activities

This study is our first step to evaluate the prediction skill of CEOP-participating models and it provides some clues for further identification of model deficiencies. The second step should focus on inter-comparisons and improvements of physical schemes, for which NWP centers and data analysis groups have to collaborate. It is crucial to develop an inter-comparison platform, for setting priority of target processes, providing offline source code of each scheme and auxiliary input data, collecting benchmark data set, and implementing comparisons.

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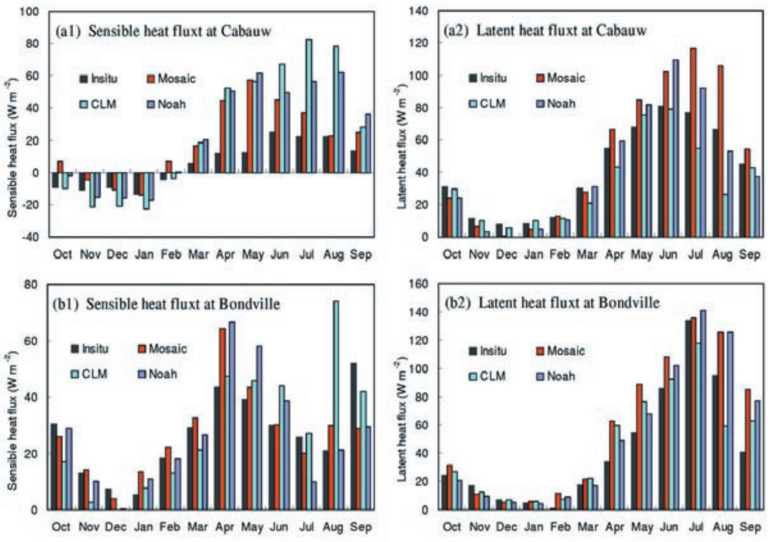

Figure 4: Comparison of surface heat fluxes between observation and three GLDAS products (Mosaic, CLM, Noah) at Cabauw (a1, a2) and Bondville (b1, b2).

GLDAS Output Supports CEOP Studies

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The Global Land Data Assimilation System (GLDAS; Rodell et al., 2004) has entered a new phase, led by scientists in the Hydrological Sciences Branch at NASA's Goddard Space Flight Center. NASA's Energy and Water Cycle Study (NEWS) program now supports the project, and NASA's Land Information System (LIS; Kumar et al., 2006) has improved the software infrastructure. In this phase we seek to integrate the best water and energy cycle observations as data for parameterizing, forcing, constraining, and evaluating sophisticated land surface models (LSMs). Advanced techniques, including relatively mature data assimilation schemes, are being incorporated and tested. These will augment the ability of GLDAS to synthesize data from multiple ground and space based observation systems in a physically coherent manner.

LSM	Resolution	Grids	MOLTS	Options
Noah	0.25	✓	✓	
Noah	0.25	✓	✓	MODIS snow cover assimilation
Noah	1.0		✓	
CLM2	1.0		✓	
Mosaic	1.0		✓	

Table 1. GLDAS output datasets currently available through the CEOP archive, including global grids and model location time series (MOLTS).

During the period of the project (2005-10), we will develop many output datasets and make them available to the CEOP community. These will include results from multiple LSMs, which have been run at different resolutions (typically 1.0° and 0.25°) using different parameters, forcings, and assimilation options. Table 1 lists the GLDAS output datasets that have been delivered to the CEOP archive to date for EOP1-4. Each simulation was parameterized and forced using a standard set of inputs, including meteorological analyses from NOAA's Global Data Assimilation System (GDAS) and observation-based precipitation and solar radiation fields. The output

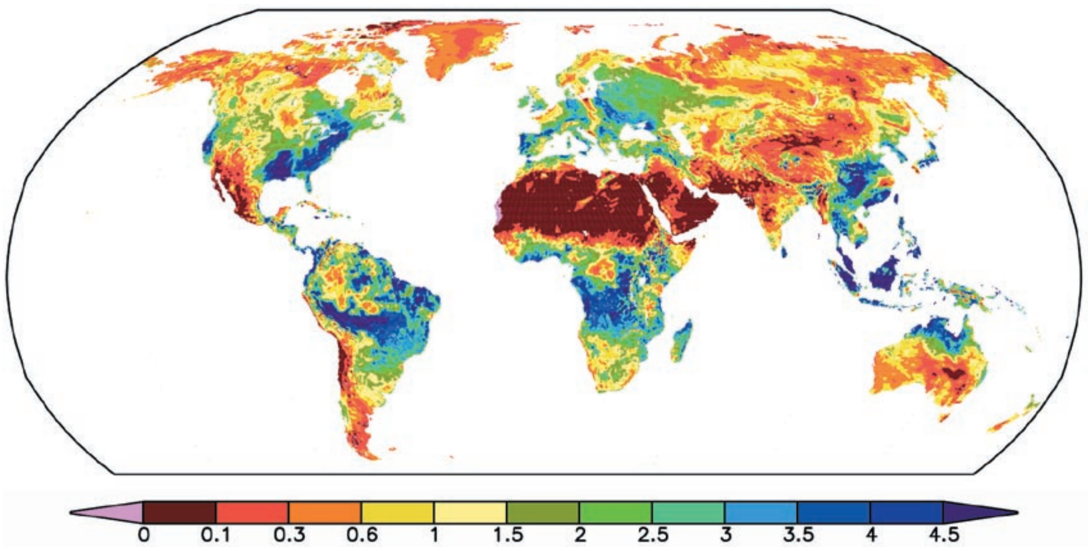

Figure 1. Rate of evapotranspiration [mm/day] on 1 May 2006 from the 0.25° GLDAS/Noah snow assimilation simulation.

variables provided include soil moisture in multiple layers, snow water equivalent (SWE), surface and air temperatures, near surface specific humidity, and all the land surface water and energy fluxes (see the example in Figure 1). GLDAS output has already supported many CEOP related investigations, including several to be described in the upcoming special issue of the Journal of the Meteorological Society of Japan.

The newest GLDAS output dataset is from a 0.25° simulation of the Noah LSM, which featured assimilation of snow cover data derived from the Moderate Resolution Imaging Spectroradiometer (MODIS) aboard NASA's Terra satellite. Daily MODIS snow cover maps were upscaled to 0.25°, quality controlled, and then imposed on the modeled SWE using the procedure developed by Rodell and Houser (2004). Preliminary evaluation indicates that assimilation of MODIS snow cover into GLDAS/Noah improves modeled SWE. Based on snow depth observations from the US National Weather Service Cooperative Observer Program (Co-op), from which SWE was estimated using a constant ratio of 10:1, GLDAS/Noah tended to underestimate SWE in the control simulation. The assimilation scheme often was able to increase modeled SWE towards measured SWE (Figure 2). The scheme only has a direct effect where snow cover is partial or ephemeral, i.e., at midlatitudes and particularly at the start and end of the winter. However, it indirectly affects subsequent snowfall accumulation and, via snow's control of albedo, the surface energy balance.

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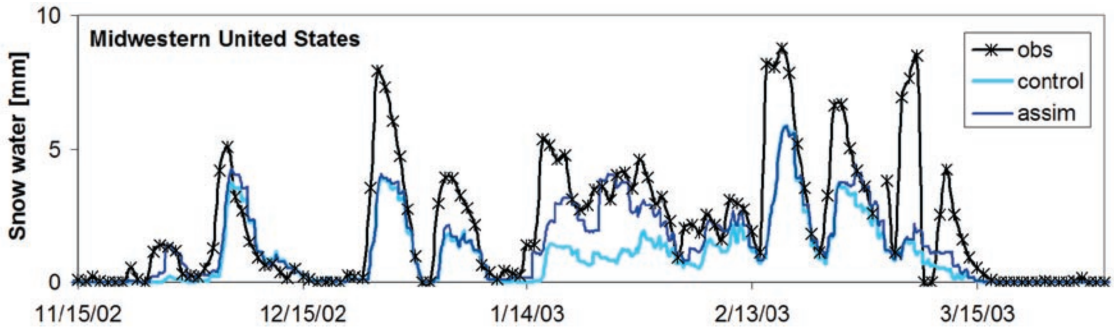

Figure 2. Time series of snow water equivalent [mm], averaged over the Midwestern United States, from Co-op ground based observations (black) and GLDAS/Noah control (light blue) and assimilation run (dark blue) outputs.

Comparing the Diurnal Behaviour of Model Output with In-Situ Data in the MDB

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The Australian Bureau of Meteorology is one of the operational NWP centres that has contributed EOP3 MOLTS data to CEOP. The data were generated by running forecasts based on the archived six hourly operational analysis files to obtain the intermediate hourly output which was not saved at the time and by saving the values of the requested fields at the model grid columns closest to each of the 41 designated CEOP reference sites. The model version which was operational during EOP3 (Seaman et al 1995) was a spectral T239L29 model which corresponds to a horizontal grid spacing of about 80km with 29 vertical levels.

The Murray-Darling Basin (MDB) dataset comprises data from 10 stations which spans an area equivalent to about 32 model grid points and therefore provides an opportunity to investigate the local spatial variability of the fields near the model MOLTS point. Figure 1 shows the MDB region giving the locations of the stations from the CEOP in-situ surface data set along with the adjacent model grid points. Note that the MOLTS data is only written out for the heavily emphasised grid point centred just south of Kyeamba.

One of the primary foci of the next phase of CEOP is the study of diurnal cycles. Figure 2 shows the mean diurnal variation of screen level temperature and specific humidity and 10m wind speed obtained by sorting the series into daily time bins representing the diurnal cycle. This assumes that the non-diurnal behaviour is random

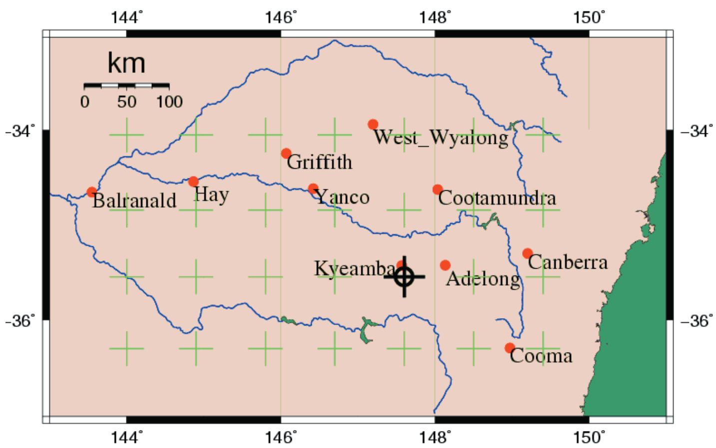

Figure 1: The Murray Darling Basin with the locations of the in-situ data stations and the adjacent model grid point centres marked. The model's MOLTS point is the heavy cross just south of Kyeamba.

and that the diurnal behaviour itself is invariant over the total time of the series; an assumption that is certainly not correct for annual series of variables where seasons play an important role. The binning technique is also sensitive to the presence of model spin-up and temporal artefacts due to the use of constant radiation fields over the 3 hour radiation time step. The latter introduces a lag in the radiation which is responsible for the lag in phase of the temperature. The model largely misses the diurnal structure of the screen level specific humidity but (apart from the obvious discontinuities) gives a fair representation of the variation in wind speed.

Currently a new model is undergoing development and testing at BMRC. It will incorporate a more comprehensive land surface scheme with four soil levels, prognostic cloud and a more efficient radiative transfer scheme. A new assimilation scheme is also undergoing testing and the combination is expected to go operational at the Bureau later this year. It is planned to repeat EOP3 with the new system and to continue the cycle up to the present. The MOLTS output has been modified to include all physical process tendencies as well as some extra variables to aid in budget calculations. The 4 grid points surrounding each model MOLTS point will also be archived as well as gridded data (albeit at a coarser temporal resolution). The combination of hourly MOLTS and gridded data together with the upgraded physics and extra variables should provide a useful testbed for the comparison of model and in-situ data.

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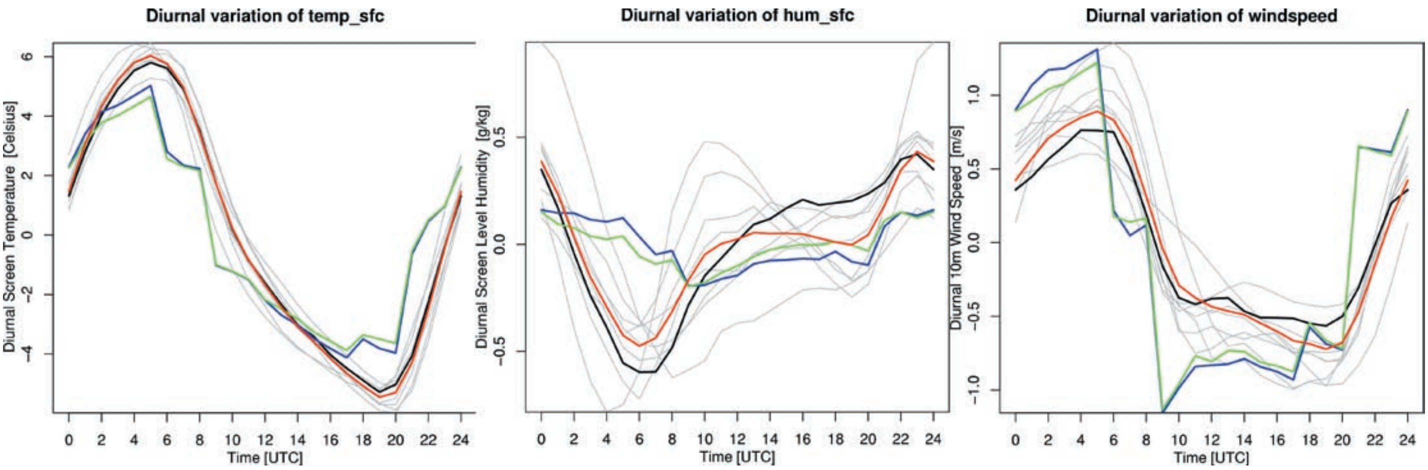
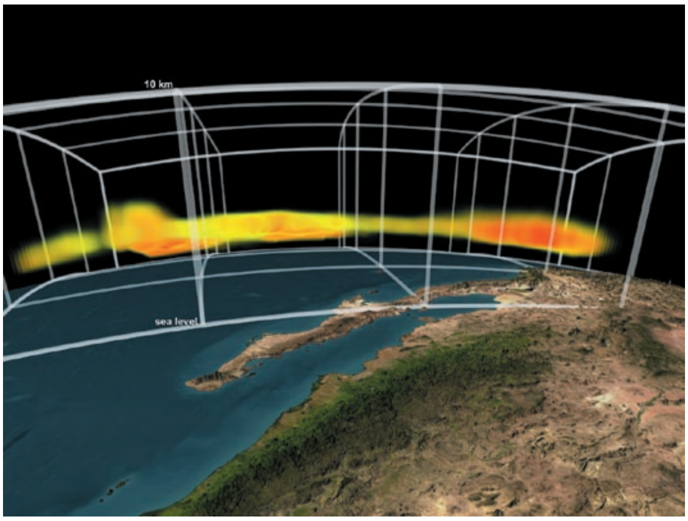


Figure 2: The diurnal variation (relative to each mean) of screen level temperature (left) and specific humidity (centre) and 10m wind speed (right). The different MDB sites are plotted in grey with Kyeamba in black. The mean MDB results are in red and the model is green (the analysis cycle) and blue (the 12-36 hour forecast cycle).

Bulletin of the American Meteorological Society (BAMS), Volume 87, No. 7, July 2006 publishes the article by Chahine et al.: "AIRS: Observing the Global Atmosphere in 3-D" presenting results from AIRS (Atmospheric Infrared Sounder) during its first years of operation.



In September 2002 the Atmospheric Infrared Sounder (AIRS) instrument on NASA's Aqua spacecraft began providing a detailed, global, three-dimensional record of atmospheric conditions. The image shows an AIRS snapshot of water vapor as a storm approaches the California coast on January 1, 2003. A broad minimum over the deserts of Baja California separates moist areas in the temperate north and tropical south. Blue denotes low water vapor content; green medium and red areas signify high water vapor content. The vertical grid ranges from 250 millibar pressure at the top to 1000 millibar pressure at the bottom. This is one scene of an animation available at *http://svs.gsfc.nasa.gov/search/Instrument/AIRS.html*, and was created by the Scientific Visualization Studio at NASA/Goddard Space Flight Center.

The AIRS data are also contributed to the CEOP integrated database.

The Sixth CEOP International Implementation/Science Planning Meeting will be held in Washington, D.C., USA, from Monday 12 – Wednesday 14 March 2007.
The Third IGWCO Workshop will follow up the CEOP event from 14 – 16 March with a joint CEOP/IGWCO session on Wednesday 14 March 2007.

The Fifth International Implementation/Science Planning meeting for the Coordinated Enhanced Observing Period (CEOP), 26-28 February, 2006, Paris, France

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The fifth international implementation/science planning meeting for CEOP was held at the UNESCO facilities in Paris, France, 26-28 February. The agenda and all of the presentation material presented at the meeting can be found through the CEOP Home Page at: *http://www.ceop.net*. The second Integrated Global Observing Strategy Partners (IGOS-P) Integrated Global Water Cycle Observations Theme (IGWCO) Workshop and Business meeting was held at the same venue just following the CEOP meeting to allow maximum participation in both events by the science community and relevant agency representatives. The meeting included more than 100 scientists and representatives of relevant agencies and organizations from 16 Countries.

The meeting was hosted by the World Climate Research Programme (WCRP) Coordinated Observation and Prediction of the Earth System (COPES) strategy, support unit located in Paris, France. Connections to the 10-year Implementation Plan for the Global Earth Observation System of Systems (GEOSS) were also highlighted at the meeting. CEOP will contribute to both COPES and GEOSS.

The participants addressed several important issues including (a) endorsement of a concept for finalizing the CEOP Phase 2 Implementation/Science Plan; (b) ideas for maximizing the science and technology benefits from both CEOP and IGWCO; and (c) specific thoughts related to the framework for oversight of the science, implementation plans and results during the initial phase of IGWCO and CEOP Phase 2.

In this context, the main themes of the CEOP Meeting were assessments and plans. Two types of assessments were addressed, (i) An assessment that dealt with the degree to which the commitments made by agencies and organizations to CEOP, such as for the provision of coordinated in-situ, satellite and model data; had been fulfilled, and (ii) An assessment that focused on the degree to which CEOP has been able to apply the resources it has been provided to meet its observational and science goals up to the present. To achieve these goals at the meeting over forty technical papers and a corresponding number of posters were presented.

In keeping with the intent of the Joint Scientific Committee (JSC) to WCRP recommendations, each step identified in the CEOP planning process will have to include specific implementation strategies that will ensure close and effective connections to other national and international activities concerned with research of the Earth's water and energy cycle including, especially the core projects of WCRP.

Of particular importance was the joint session of the CEOP Science and Advisory and Oversight Committees. The outcome of this session, which was Co-Chaired by Drs Akimasa Sumi (JAXA) Jack Kaye (NASA), was an articulation of the highest priority issues CEOP must address as it moves forward. The main recommendations/actions included:

(i) CEOP must take extra effort to underwrite its current level of success in development of its in-situ, model, and satellite datasets.

(ii) In the context of its data collection process CEOP must continue its relationship with data archive Centers at the Max-Planck Institute (Hamburg, Germany); National Center for Atmospheric Research (Colorado, USA) and University of Tokyo (Tokyo, Japan).

(iii) Expansion of the scientific scope of CEOP seems reasonable and constitutes a natural development. Such expansion may require additional data types as reflected in the CEOP Phase 2 Implementation/Science Plan, but should be viewed as a process that can not be reconciled with work being undertaken by other international initiatives.

The NCAR CEOP Data Management and Reference Site Data Archive web pages have been moved to another location. The new URL is: *http://www.eol.ucar.edu/projects/ceop/dm/*

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