U.S. CONTRIBUTIONS TO THE CEOP

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The diverse U.S. involvement in an international effort to develop an integrated global data system for the simulation and prediction of water and energy budgets, monsoons, and river flows reveals many opportunities for readers during its new data analysis phase.

The Coordinated Enhanced Observing Period (CEOP) was proposed by the Global Energy and Water Cycle Experiment (GEWEX) to develop an integrated global dataset for use in addressing issues related to water and energy budget simulations and predictions, monsoon processes, and the prediction of river flows. A two-and-a-half-year period of enhanced observations was initially proposed in 1997 during a GEWEX Hydrometeorology Panel (GHP) meeting, and since that time has been endorsed by the GEWEX Scientific Steering Group (SSG), the Joint Scientific Committee (JSC) of the World Climate Research Programme (WCRP), and the Integrated Global Observing Strategy Partnership (IGOS-P). In particular, CEOP is a central component of the Integrated Global Water Cycle Observations (IGWCO) theme of IGOS-P. IGWCO harnesses the energies and interests of a community of water cycle scientists who plan strategies for expanded use of Earth observations in the water resources sector. The science questions that motivate GEWEX and other WCRP projects in the areas of water and energy budget simulations and predictions and monsoon studies have guided the development of CEOP so that it contributes to the numerical modeling and observational analysis needs of these projects and climate research. CEOP takes advantage of the infrastructure, data systems, and heritage of the mature GEWEX Continental Scale Experiments (CSEs) located in a number of critical regions around the world (Sorooshian et al. 2005; Lawford et al. 2004), and makes maximum use of the datasets being provided by new satellites, including *Terra* and *Aqua*. While many countries have contributed to this global initiative, the leadership for this effort has come primarily from Japan and the United States.

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As outlined by Koike (2004), the guiding goal of CEOP is "to understand and model the influence of continental hydroclimate processes on the predictability of global atmospheric circulation and changes in water resources, with a particular focus on the heat source and sink regions that drive and modify the climate system and anomalies." CEOP has two major phases. During phase I the emphasis was on the development of datasets and tools for addressing scientific problems. The three areas that have been developed during phase I are the reference site data management, satellite data integration, and model output data products and handling. Scientific research has progressed under the guidance of two working groups: one that focuses on water and energy simulation and prediction and the other on intermonsoonal model studies. In both of these areas CEOP has maintained very close ties with its roots in GEWEX. In addition, through its activities in Earth system observations and data management, it has developed links with the Committee on Earth Observation Satellites (CEOS), IGOS-P and its IGWCO theme, and the Group on Earth Observations (GEO).

The following article outlines the contributions of U.S. partners to different components of the CEOP program, including its scientific objectives and observational strategies, and the benefits of this effort for U.S. science. This article is intended to provide the U.S. meteorological and hydrological communities with more information about the program in general, and about U.S. contributions in particular. It also is intended to provide the reader with some background on how he/she can become more actively involved with the program.

BACKGROUND. CEOP is focused on the measurement, understanding, and modeling of water and energy cycles within the climate system. It is motivated by the synchronism of the new generation of Earth observing satellites and the existence of mature GEWEX CSEs. The primary goal of its first phase was to develop a consistent, comprehensive, integrated dataset for 2001–04 to support research objectives in climate prediction and monsoon system studies. GEWEX nurtured the development of CEOP because it could potentially contribute to many of its global initiatives including the Global Soil Wetness Project (GSWP), the International Satellite Land Climatology Project (ISLSCP), the Project for Intercomparison of Land Surface Parameterizations (PILPS), the GEWEX Cloud System Study (GCSS), and the Global Land–Atmosphere System Study (GLASS). CEOP data will also contribute to studies of the global atmospheric circulation and water availability. Detailed implementation planning for CEOP began in 2000 with a workshop at the National Aeronautics and Space Agency (NASA) Goddard Space Flight Center (GSFC) (Bosilovich and Lawford 2002).

CEOP was officially launched at a kickoff meeting in Tokyo, Japan, in March 2001. It has gained commitments from a broad range of international organizations including both IGOS-P and CEOS, which have recognized CEOP as the first element of the IGWCO.

While the initial planning inputs for U.S. involvement came through the GEWEX Americas Prediction Project (GAPP), which is sponsored by the National Oceanic and Atmospheric Administration (NOAA) and NASA, it soon expanded to include other U.S. groups whose interests were broader than those of GAPP. The reference station data were provided by three U.S. agencies including the Department of Energy's (DOE's) Atmospheric Radiation Measurement–Cloud and Radiation Testbed (ARM–CART) site; three sites funded through the NOAA portion of GAPP and managed by NOAA's Air Resources Laboratory; and a site in Arizona that is part of the National Science Foundation (NSF) Science and Technology Center (STC) for the Sustainability of semi-Arid Hydrology and Riparian Areas (SAHRA) at the University of Arizona (Sorooshian et al. 2002). The data management capabilities developed at the University Corporation for Atmospheric Research [UCAR; and most recently at the National Center for Atmospheric Research (NCAR)] in large measure to deal with GAPP data, are now being used to control the quality of, archive, and distribute the datasets from all 35 CEOP reference stations around the world.

The production of three-dimensional global fields and Model Output Location Time Series (MOLTS) for CEOP builds upon the experience of GAPP and the GEWEX Continental-scale International Project (GCIP), where the National Centers for Environmental Prediction (NCEP), the NOAA Forecast Systems Laboratory, and the Canadian Meteorological Center produced three-dimensional fields and MOLTS for a specialized data archive at UCAR. A similar process has been adopted for CEOP but products produced by NCEP and the Global Modeling and Assimilation Office (GMAO) at GSFC are now being sent to the Max Plank Institute (MPI), which is the central CEOP output archive for storage and analysis.

One important contribution to these global datasets is the GSFC-led Global Land Data Assimilation System (GLDAS) outputs that have been developed using similar principles that were successful in the National Land Data Assimilation System (NLDAS).

Initial plans for CEOP identified four observation periods beginning in July 2001 and extending through December 2004 [International GEWEX Project Office (IGPO) 2001]. A 3-month preliminary data period established a prototype dataset and established the basis for the annual cycles of data collection, analysis, and integration that followed. Table 1 shows the four observation periods in the first phase of CEOP.

While CEOP has a heavy focus on observations, it is also developing a science program. As described in Koike (2004), these science activities have an emphasis on simulating and predicting water and energy budgets and carrying out studies to better understand the monsoon processes. Working groups were also established for data management, model output data products, and satellite data. During the first phase of CEOP, these working groups reported to the CEOP science advisory committee and a CEOP management committee. CEOP also reported to the GEWEX SSG.

OVERALL SCIENCE PRIORITIES. *Water and Energy Simulation and Prediction (WESP).* The CEOP WESP working group is using CEOP observations to diagnose, simulate, and predict water and energy fluxes and reservoirs over land on diurnal to annual temporal scales and assess the benefits of these data for hydrologic predictions for water resource managers. WESP studies are designed to determine what components of the global water and energy cycles can be measured, simulated, and predicted at regional and global scales. It addresses the following questions: 1) What are the gaps in our measurements? 2) What are the deficiencies in our models? 3) What is our skill in predicting water and energy budgets on climatological time scales?

Specific areas under WESP with U.S. involvement include Water and Energy Budget Studies (WEBS), Land Data Assimilation Systems (LDAS), and transferability studies (see Roads et al. 2003a,b for further details). WESP also helps to define the CEOP data needs. A key goal is to identify model processes and state variables that can be compared to in situ and satellite measurements, as well as to each other, and then to develop community intercomparison projects that can help to define and quantify measured and modeled processes.

In a recent WESP study carried out by NCEP, datasets from the first CEOP Enhanced Observing Period (EOP-1) were compared with outputs from two land surface models for three reference sites, including one in the United States. Koike (2004) described an intercomparison study at NCEP that showed that simulated daytime sensible heat fluxes were consistently closer to observations than the simulated latent heat fluxes, which tended to be higher than observations. It was concluded that net radiation and ground heat flux differences were likely sources of the higher values of simulated latent heat fluxes (Koike 2004). CEOP datasets have also been used in evaluating the ability of the Regional Spectral Model to simulate precipitation (Meinke et al. 2007), the ability of models to estimate skin temperature (Bosilovich et al. 2007), and the assessments of diurnal water and energy budgets (Ruane and Roads 2007). More complete documentation of various WESP activities is provided in the WESP Major Activities Plan (Roads et al. 2005b, available online at www.gewex.org/reports/wesp03_2.pdf).

Monsoons. The overall objective of the CEOP monsoon initiative is to use CEOP data to better understand the water and energy cycles in regional and global monsoon systems, their driving physical mechanisms, and possible teleconnections, with the ultimate aim toward improved predictions. CEOP is providing satellite and model output data for reliable quantitative descriptions of the multiscale energy and water cycle processes of the monsoon systems, their interactions with conditions at the Earth's surface, and possible physical interconnections among the

TABLE 1. CEOP schedule.

SCHEDULE	2001	2002	2003	2004	2005	2006	2007
CEOP preliminary data period	1 Jul	30 Sep					
CEOP buildup phase		1 Oct	30 Sep				
First CEOP annual cycle			1 Oct	30 Sep			
Second CEOP annual cycle				1 Oct	31 Dec		
Buildup for phase II						1 Jan	31 Dec

monsoon systems of the world. The CEOP monsoon initiative focuses on four of the major monsoon regions around the globe: 1) the Asian–Australia monsoon; 2) the North American monsoon; 3) the South American monsoon; and 4) the West African monsoon. CEOP is now planning a second phase which will utilize the data sets from phase I to address many of the science questions and issues outlined above. This second phase will continue until 2010. At the time of this publication a draft of the CEOP Phase 2 Implementation/Science Plan is available at: http://monsoon.t.u-tokyo.ac.jp/ceop/document/phaseII_plan/.

To improve the modeling and prediction skills of monsoon processes, an international CEOP Monsoon Systems Working Group has defined a CEOP Intermonsoon Model Study (CIMS). CIMS has focused initially on issues relevant to model physics improvement via simulations and cross validation of model outputs with detailed observations. From a modeling viewpoint, elucidating the fundamental processes associated with diurnal cycles, annual cycles, and monsoon intraseasonal oscillations would facilitate identification of model errors and biases and provide important clues for improving model physics, particularly with respect to water and energy cycles and atmosphere–land–ocean surface interactions. Model validation data will be derived from CEOP global datasets and MOLTS as well as from in situ observations from reference sites. The synergistic use of global satellite data, in conjunction with high-resolution space and time observations from field sites is critical. Numerical experiments will be designed to target the simulation of fundamental physical processes that are likely to uncover limitations in model physics. In addition to its scientific goals, CIMS will demonstrate the synergy and utility of CEOP integrated satellite data, in situ observations, and assimilated data in providing a pathway for model physics evaluation and improvement.

Initially, the most direct U.S. involvement in monsoon measurements has come through the North American Monsoon Experiment (NAME), a joint GAPP/Pan-American Climate Study (PACS) initiative. NAME is aimed at determining the sources and limits of predictability of warm season precipitation over North America. A multiscale, tiered approach is being carried out with analysis, diagnosis, and predictive model development components (Higgins et al. 2006). The NAME data collection phase occurred at the same time as CEOP dataset development in 2003–04 and the NAME research phase will be concurrent with a major part of the second phase of CEOP.

A key issue for CEOP's relationship with NAME is the strong international collaboration between the United States and Mexico that facilitates international cooperation on data collection and exchange. Additional anticipated benefits of a strong NAME–CEOP collaboration include utilization of new in situ and satellite measurements of atmospheric, surface, and hydrological parameters over the Americas; international experience assessing the capabilities and limitations of assimilated data products; production of consistent datasets that can serve as test beds for the validation of numerical model products and remote sensing data; advances in coupled models over land and ocean areas; and advances in the development of the climate observing system.

Preliminary results reported by Lau et al. (2004) highlighted the importance of the diurnal variability in monsoon processes. Examination of the North American Monsoon System (NAMS) Gulf of California's low-level jet (LLJ) revealed a pattern with moisture flux changes from the north, paralleling the Sierra Madre mountain range toward the east as temperatures increase in the afternoon. This pattern is linked with the onset of monsoon rain in the U.S. southwest.

BENEFITS OF CEOP TO OTHER U.S. SCIENCE PROGRAMS.

GAPP and U.S. GEWEX Activities. Through its involvement in CEOP, GAPP has gained further exposure internationally for its datasets, which are now used worldwide. This advance has been facilitated by the efforts of UCAR until 2005 and now NCAR to integrate GAPP observations into a standard format with other observations, thereby integrating them into global data products that are much more useful to global climate modelers than they would otherwise have been. The need to adhere to timely data submission standards has also been helpful in introducing more discipline into data delivery. In addition, GAPP investigators can now take the results they have acquired for the United States and test them on a global scale using comparable data from reference sites on each continent.

The large potential involvement of other groups to contribute to CEOP has provided new venues for discussing issues of concern to GEWEX and GAPP. In particular, CEOP has provided an opportunity for groups such as the CEOS Working Group on Information Systems and Services (WGISS) to make more contributions to the needs of GEWEX and GAPP. For example, U.S. members of WGISS have been very helpful in developing data mining and visualization tools and in having Open Data Access

Protocol (OpenDAP) adopted as the major server for CEOP.

Climate and weather prediction. The Climate Change Science Program (CCSP) has benefited from CEOP's science priorities, CIMS and WESP, which are improving the simulation of fundamental physical processes for climate predictions and global change projections. For example, insolation data from CEOP reference data sites are currently used to force a surface energy and water balance model and to provide better boundary conditions for climate models. Land surface temperature data are used to evaluate the surface model accuracy as a first step to improve these models. Reference site data along with infrared temperatures are being used to monitor drought and vegetation conditions. These data are also used to provide more realistic boundary conditions for numerical weather prediction models. These contributions are expected to increase as CEOP moves from the data collection and dataset development phase (phase I) to the data analysis and research phase (phase II).

GAPP/CEOP Sites	Latitude/Longitude	Vegetation Type
Lamont, Oklahoma (SGP)	36° 36' 36"N/97° 29' 24"W	Rangeland/Cropland
Bondville, Illinois	40° 00' 36"N/88° 17' 24"W	Corn/Soybeans
Fort Peck, Montana	48° 18' 36"N/105° 06' 00"W	Northern Grassland
Oak Ridge, Tennessee	35° 57' 36"N/84° 17' 24"W	Deciduous Forest
Mt. Bigelow, Arizona	32° 25' 12"N/110° 43' 48"W	
DOE/US CEOP Sites		
Barrow, Alaska	71° 19' 12"N/156° 37' 12"W	Tundra

FIG. 1. Location of CEOP reference sites in the United States.

U.S. REFERENCE SITES. CEOP plans identified 35 well-instrumented reference sites covering small- to intermediate-scale areas, including five in the contiguous United States, which could provide representative measurements in different regions and climate zones of the Earth. The objectives of the U.S. CEOP reference sites (Fig. 1) are to 1) provide data on surface energy and carbon fluxes for various ecosystem types, 2) provide the necessary meteorological forcing data in order to test and evaluate the land surface models that are currently integrated into both regional- and global-scale models, and 3) provide insight into factors that control the surface energy balance over seasonal and annual cycles and their feedback into the local water balance. Each of these sites has a basic set of instrumentation and some make supplementary measurements. Table 2 provides a list of the variables that are currently measured at the reference sites.

1) The Southern Great Plains (SGP) ARM–CART reference site is the centerpiece of the Department of Energy's ARM program (see online at www.arm.gov/sites/sgp.stm for further details). The SGP site consists of about three-dozen in situ and remote-sensing instrument clusters arrayed over an area roughly 350 km^2 (225 mi^2) on a site in north-central Oklahoma and south-central Kansas. A well-instrumented central facility is located on 160 acres of cattle pasture and wheat fields. It is surrounded by smaller, unmanned facilities located so that the measurements reflect conditions over the typical distribution of land uses within the site. Details on the list of instruments and measurements are available online at www.arm.gov/docs/sites/sgp/sgp.html. DOE ARM sites in Alaska and at Darwin, Australia, are also part of the CEOP network.
2) The Bondville, Illinois, AmeriFlux reference site is located on farmland in the Midwestern United States, near Champaign, Illinois. Details on the goals and organization of the AmeriFlux program are available online at http://public.ornl.gov/ameriflux/. The climate of the site is seasonal, with cold winters and warm summers. The main flux tower is located in an agricultural ecosystem, which has been planted on alternating years, with soybeans or corn. The vegetative growth during the summer months is very dynamic after planting, which usually occurs in late April or early May.

TABLE 2. Variables recorded at CEOP sites.	
METADATA	**SURFACE MEASUREMENTS**
Latitude	Air temperature
Longitude	Relative humidity
Elevation	Wind
Site map	Surface pressure
Site photos	Rain
Site type	Snowfall
Site contacts	Skin temperature
Record length	Upward shortwave radiation
	Downward shortwave radiation
UPPER-AIR MEASUREMENTS	Upward longwave radiation
Temperature	Downward longwave radiation
Wind	Upward photosynthetically active
Specific humidity	Radiation
	Downward photosynthetically active
SUBSURFACE MEASUREMENTS	Radiation
Soil temperature	Net radiation
Soil moisture	Sensible heat flux
	Latent heat flux
ADVANCED SYSTEM MEASUREMENTS (Not available at all sites):	Ground heat flux
	Momentum flux
Precipitation radar	Carbon dioxide flux (not all sites)
	Evaporation (not all sites)
LIDAR	Streamflow (not all sites)
Vertical profiler	Vegetation cover
RASS	Reservoir level (not all sites)
Flux tower	

3) The Fort Peck AmeriFlux site is located on the Fort Peck Tribes Reservation in northeastern Montana. The main flux tower is located at a grassland site near the Poplar River. Depending on the available soil moisture, the grasses begin to green up in early April but usually dry out by mid-July.
4) The Walker Branch Watershed is a part of the DOE National Environmental Research Park near Oak Ridge, Tennessee. The tower is located on a spur ridge within a 9.57-hectare watershed. The forest canopy on the watershed is generally characterized as an eastern broadleaf, which usually buds in early April and is active until mid- to late October.
5) The SAHRA Mt. Bigelow site is located on Mt. Bigelow at 2583 m above sea level in the Santa Catalina Mountains of the Coronado National Forest northeast of Tucson, Arizona. The flux tower is located within a subalpine mixed forest of predominantly Douglas fir and ponderosa pine. The site represents a semiarid climate in a sky island landscape [a type of continental terrain consisting of a sequence of valleys and mountains isolated by the surrounding desert floor (Brown-Mitic et al. 2006, manuscript submitted to *J. Arid. Environ.*)].

Reference site data management and quality control. All reference site data for CEOP phase I (2001–04) have been archived at the NCAR-based (formerly UCAR based) central CEOP Data Archive (CDA) in harmonized data formats for easy access and use. CEOP data policy is in accordance with Resolution 40 of the 12th Congress of the World Meteorological Organization (WMO) in 1995. CEOP reference site data are provided to data users only for scientific studies designed to meet CEOP objectives. The CDA offers CEOP reference site data files to potential CEOP data users through electronic means, (e.g., the Internet) or other designated media (e.g., CD-ROMs). Whenever CEOP reference site data distributed by CDA are used for publication of scientific results, the data's origin must be acknowledged and referenced.

While all U.S. data are made available in an unrestricted manner with minimal delay and free of charge, this is not the case with datasets from some other countries. Maintaining continuous, high-quality measurements during the planned CEOP periods, performing quality and error checking procedures, and submitting data and related documentation to the CDA requires substantial effort by the data providers, and consequently some data providers do restrict their accessibility until they have completed adequate quality checks. The CEOP data policy is designed to accommodate these reasonable concerns on the part of data providers.

Table 3. CEOP satellite datasets for EOP-1.

Satellite (s)	Sensor	Radio frequency	Level	Observation
DMSP F13, F14, F15	SSM/I	High, low	1B	Brightness temperature
NOAA-12, -14, -16	AVHRR	VIS		Albedo (%)
NOAA-12, -14, -16	AVHRR	IR		Temperature (°C)
GMS	S-VISSR	VIS		Albedo (%)
GMS	SVISSR	IR		Temperature (°C)
TRMM	TMI	High, low	1B11	Brightness temperature
TRMM	PR		L2A25	Rain rate
Terra	MODIS			

Reference site data are categorized as standard (category 1) or enhanced or experimental (category 2) data. Standard data (no problems in data interpretation or usage) is freely open to the science community after the basic turnaround period of six months. Enhanced or experimental data (data that are complex and where the instruments need continuous monitoring) will be freely open to the science community after a prolonged turnaround period of 12 months at the most. Each CEOP reference site is responsible for separating its data into these categories.

REMOTE SENSING. NOAA and NASA, in cooperation with other international space agencies, are providing satellite data products from the Geostationary Operational Environmental Satellite (GOES), the Polar Orbiting Environmental Satellite (POES), the Advanced Earth Observing Satellite (ADEOS), the Tropical Rainfall Measuring Mission (TRMM), and the *Aqua* and *Terra* satellites. For the purposes of this discussion, satellite data and products are categorized as being systematic or research. The University of Tokyo is providing the primary CEOP satellite data archive. Table 3 provides a list of satellite sensors for which data are being assembled for EOP-1.

Research Satellites. The types of new data products from research satellites are becoming more numerous and well known. Data from NASA's Earth Observing Systems, including the *Terra* and *Aqua* satellites, are important data resources. Data from the TRMM and *Terra* satellites were available during the first CEOP data collection phase (EOP-1), and therefore are being considered first. The experimental TRMM data demonstrated the capability to use the advantages of active microwave techniques to improve passive microwave data products (Kummerow et al. 2000). Data from new satellites will be added to the archive as they become available. Satellite data will be added as new satellites are launched and data delivery is shown to be reliable. For example, EOP-1 will use satellite data from *Terra* and European Space Agency Environmental Satellite (ENVISAT), and *Aqua* data are being added for EOP-2 and EOP-3 or whenever they become available.

Many Moderate Resolution Imaging Spectroradiometer (MODIS) data products are becoming more accessible through CEOP. The level-1 data, measured at resolutions of 250 m–1 km, are being processed to level-3 physical quantities on regular grids. Snow cover and land surface temperatures are available on fine resolution (0.05°) global grids at daily, weekly, and monthly time scales (Hall et al. 2005; Salmonson and Appel 2004; Wan et al. 2004a,b). Land surface properties (vegetation indices, leaf area index, and albedo) are now being implemented in global parameterizations (Tian et al. 2004a,b). The development of algorithms and new data continues with the eventual production of a surface evaporation product (Nishida et al. 2003). The *Aqua* Clouds and the Earth's Radiant Energy System (CERES) instrument is being used to develop radiation products. Many of these and other data products are available through data centers operated by NASA and NOAA. CEOP also avails itself of many new products being developed for the 2001 to 2004 period to address science issues related to the water and energy budget. For example, the first retrievals from the Gravity Recovery and Climate

Table 4. Research satellites and their sensors.

Satellite	Sensor
Aqua	AIRS, MODIS, CERES, AMSR
ENVISAT	ASAR
Terra	MODIS, CERES, MISR, ASTER
TRMM	PR, CERES, TMI
GRACE	KBR, ACC

Experiment (GRACE) satellite are now being used to derive mass variations (Tarpley et al. 2004) and show great promise for hydrological research (Rodell et al. 2004a). Data formats, such as the climate model grid used in MODIS products, will certainly contribute to the accessibility and usability of water cycle data from experimental satellites. Table 4 shows some of the recent satellites and sensors that will benefit CEOP.

Routine satellites. CEOP relies heavily upon satellite data products from the polar-orbiting (NOAA series) and geostationary (GOES series) satellites' data streams. For polar-orbiting satellites, the primary emphasis is on the data produced by the Advanced Microwave Sounding Unit (AMSU), the Advanced Very High Resolution Radiometer (AVHRR), and the Special Sensor Microwave Imager (SSM/I) sensors. Image and atmospheric sounding products derived from the geostationary satellites are also defined and coordinated for inclusion in the CEOP satellite data integration scheme. The geostationary satellite instrument complex includes an imager and an infrared sounder that provides images and pixel-scale resolution products for the Western Hemisphere. The polar-orbiting satellite instrument complex consists of imagers, an infrared sounder, and a microwave sounder that provide a basis for observational products on a global scale at 1° × 1° or 2.5° × 2.5° resolution. NOAA is currently providing CEOP with basic radiance data for the CEOP reference and MOLTS sites from AVHRR, the High Resolution Infrared Radiation Sounder (HIRS), and AMSU instruments on the NOAA polar orbiter spacecraft. These datasets consist of orbital segments that contain one or more CEOP sites from both the morning and afternoon spacecraft. In order to facilitate the combined analysis of satellite and reference site data, an array of data from each satellite product is extracted for a square 250 m^2 on each side and centered on each reference site.

Routine products that are relevant to CEOP include precipitation products from both geostationary and polar-orbiting satellites as well as snow cover, surface radiation, land surface temperature, vegetation index, global cloud cover, and radiation budget parameters. Daily and pentad (5 day) precipitation products produced as those part of the GEWEX Global Precipitation Climatology Project (GPCP) will be provided to the CEOP archive in the same format. Similarly, blended precipitation analyses derived from the microwave-based precipitation measurements along with the geostationary infrared estimates for the GEWEX GPCP along with daily snow cover maps produced from combined polar-orbiting microwave estimates, AVHRR, and geostationary imagery are being prepared for the CEOP data archives.

In addition to GPCP precipitation data, precipitation estimates from the Precipitation Estimation from Remotely Sensed Information using Artificial Neural Networks (PERSIANN) algorithm (Sorooshian et al. 2000) is also made available for CEOP data analysis. PERSIANN provides 0.25° × 0.25° precipitation estimates from 50°S to 50°N coverage. These data have been customized to select the neighborhood area (2.5° × 2.5° size) centered at the reference sites. Six-hour accumulated rainfall time series at each reference site are routinely generated and plotted.

Surface radiation and land surface temperature products are produced operationally from geostationary satellite imagery at 50-km resolution over the continental United States on an hourly basis. Experimental radiation products for the Western Hemisphere are also being produced from GOES data. Estimates of radiation budget parameters, including planetary albedo and outgoing longwave radiation (OLR) based on measurements from the polar-orbiting imagers, are routinely produced in addition to OLR data produced from HIRS infrared channels. Other types of information produced for the satellite product database include 1) the vegetation index and quantities derived from it, 2) global cloud cover information, and 3) cloud optical depth and cloud liquid water and ice path estimates. The National Environmental Satellite Data and Information Services (NESDIS) routinely makes these products available to CEOP.

Data Integration. Through the efforts of international programs with a mandate to promote the integration and interoperability of Earth observations including IGOS-P and its IGWCO theme and more recently the Global Earth Observing System of Systems (GEOSS), considerable emphasis is being placed on the development of integrated data products and on integrating capabilities. These innovations are needed to provide users with the most accurate possible representation of water cycle variables for initializing and evaluating models and for supporting management decision support systems. Within the fields of water management, the authors expect that integration could become even more important as management systems begin to consider end-to-end solutions and involve different problems and disciplines (e.g. conjoint management of ground and surface water). Furthermore, data system integration has the potential to contribute to cost efficiency by identifying systems that acquire observations with minimal "added value."

Tools for data integration include data assimilation systems, geographical information systems, observational simulation experiments, and data mining. Opportunities for the combination of different data types to produce more accurate values of individual water cycle variables are listed below. In the longer term, attention must be given to systems that integrate the various variables and to incorporating measured radiances in models.

MODEL OUTPUT PRODUCTS. *Model outputs from data assimilation systems.* The CEOP model output data requirements includes three primary types: 1) one-dimensional, vertical profile and surface, and MOLTS at selected locations; 2) gridded two-dimensional fields, including ground surface state fields, ground surface flux fields, top-of-the-atmosphere (TOA) flux fields, and atmospheric fields; and 3) gridded three-dimensional fields containing all of the atmospheric variables. Both regional and global model output have been provided for the CEOP data collection period from three U.S.-based global modeling centers: NCEP, the Global Modeling and Assimilation Office (GMAO), and the Experimental Climate Prediction Center (ECPC). Each center forwards data to the model output archive center located at MPI at Hamburg, Germany, on a regular basis. Coordinated handling of these data within the international CEOP framework has relied primarily on defining the CEOP data requirements, establishing a template for every suite of products, and determining that at least one major center has agreed to contribute to CEOP. Coordination is based on the agreement by these centers to provide a critical set of variables in an acceptable format. Similar requirements are the basis for agreements on the structure of the international model output archives.

NCEP contributions. NCEP (of NOAA) supports CEOP through the provision of model output data. NCEP participation in other GEWEX projects has accelerated the improvement of NCEP prediction models and similar benefits are beginning to be realized from CEOP research. NCEP has a synergistic relationship with CEOP, that allows it to contribute to and gain benefit from its interactions with CEOP data providers just as it did with GCIP and GAPP.

In cooperation with its partners (NASA, DOE, and U.S. universities and institutes), NCEP provides 2D and 3D output and diagnostics from the NCEP operational Global Forecast System (GFS), its companion 4D Global Data Assimilation System (GDAS), and the NCEP–DOE Global Reanalysis II. NCEP global model outputs span EOP-2 and EOP-3. NCEP has also provided output from the NCEP North American Eta prediction model, its Eta-based North American 4D data assimilation system (EDAS), and its regional reanalysis system (described in Mitchell et al. 2004a,b). The global and regional outputs have been provided in gridded fields at 3-h output intervals and station-specific MOLTS at 3-h intervals from the global systems and 1-h intervals from the regional systems.

Since the beginning of CEOP (1 July 2002), NCEP has produced 3-hourly MOLTS output for the CEOP reference sites from its operational GFS and has archived them at NCAR. Other products that have been provided by NCEP and cooperating agencies include global and North American precipitation analyses and reanalyses, (5 day/2.5° satellite–gauge for global, daily/0.25° gauge-only for the United States–Mexico, hourly/4-km radar–gauge for the United States) global SST analyses (weekly/1° satellite/buoy), global sea ice analyses, and Northern Hemisphere snow cover and sea ice analyses (daily/23 km).

In addition, NCEP and its partners supply output from the NLDAS project to the CEOP database. NLDAS provides land-state fields of soil moisture, temperature, and snowpack as well as surface energy and water fluxes from four distinct land models [Noah (Chen et al. 1996), Mosaic (Koster and Suarez 1992), Variable Infiltration Capacity Model (VIC; Liang et al. 1994), and Sacramento Model (SAC; Burnash et al. 1973)] running in parallel on a common 0.125° continental United States (CONUS) grid and utilizing common surface forcing. The output is provided as hourly gridded fields, from which MOLTS-type output can be easily constructed. Finally, NCEP has made available publicly distributed versions of the NCEP coupled, atmosphere–land, mesoscale Eta model, and the NCEP Noah land model for global transferability studies.

ECPC contributions. The ECPC at the Scripps Institute of Oceanography works closely with NCEP to develop and analyze their global model outputs and analyses and to develop corresponding regional model simulations. In particular, ECPC model output datasets being provided to the international model output archive include 1) NCEP–DOE Global Reanalysis II (RII; Kanamitsu et al. 2002a; L28T62 grid) and 2) a new seasonal forecast model (SFM; Kanamitsu et al.

2002b) used in place of the original model used for Global Reanalysis II. The SFM includes a number of improved parameterizations and is thus expected to provide more realistic analyses, although this is yet to be verified. Beside the standard analysis variables available every 6 h, 6-h forecasts are made at 6-h intervals, and once a day, at 1200 UTC, a 36-h forecast is made. Forecast output is available every 3 h.

ECPC is making a special effort to provide the CEOP/WESP requested variables for the entire CEOP period (1 July–31 December 2004). Gridded output is developed first, and MOLTS (41 CEOP sites) are then extracted from the gridded data. Depending upon outside requests, additional sites could be extracted later from the gridded output stored at ECPC. Also, ECPC is running the regional spectral model (RSM), which is a regional counterpart to the SFM (similar physics) over all of the GEWEX CSEs for the entire CEOP period at 50-km resolution. The RSM is being stored at ECPC and could be made available to interested researchers.

NASA GMAO contributions. The Global Modeling and Assimilation Office (GMAO) at NASA GSFC provides CEOP and the wider scientific community with high-quality, analyzed data products. Data from the GEOS3 operational data assimilation system have been made available for CEOP (for the period 1 July 2001–30 September 2002). In October 2002, an updated system based on the finite-volume GCM and its associated analysis system (GEOS4) began to produce operational data for the NASA instrument teams. CEOP in situ observations were used to validate GEOS4 MOLTS surface energy budget values (Bloom et al. 2005).

In October 2003, GMAO undertook extensive model and data assimilation development activities to address deficiencies in the system. During this development phase, available CEOP in situ observations were used for model validation. GMAO is collaborating with CEOP scientists and hopes to receive feedback on its models, analyses, and diagnostics in the operational system. It is anticipated that the new GEOS5 system will be operational in the near future. At that time a new time series, and possibly the full 4D fields, may be available for CEOP.

Presently, data from the GEOS3 system are available to the CEOP community. The native format is Hierarchical Data Format - Earth Observing System (HDF-EOS), but EOP1 data have been converted to the GRIdded Binary (GRIB) format. Two-dimensional surface fields are available at 3-hourly intervals and three-dimensional, upper-level data are available at 6-hourly intervals (the availability frequencies are identical for the MOLTS). In the new GEOS5, hourly surface data will be produced replacing the MOLTS products. GMAO is preparing for a new retrospective analysis for the satellite era [called the Modern Era Reanalysis for Research and Applications (MERRA)]. MERRA will provide a continuous datastream continuing into CEOP phase II.

NASA/GSFC land data assimilation and integration. NASA's GSFC has developed a suite of Land Data Assimilation Systems (LDAS; see online at http://ldas.gsfc.nasa.gov) in cooperation with researchers at NCEP and several universities. As with the NCEP regional LDAS described above, the goal of NASA regional and global LDASs is to produce optimal output fields of land surface states and fluxes by making use of data from advanced observing systems. The LDASs include GLDAS (Rodell et al. 2004b), NLDAS (Mitchell et al. 2004b), and the new Land Information System (LIS; Peters-Lidard et al. 2004; Kumar et al. 2006). The publicly available LIS software includes all the functionality of the NLDAS and GLDAS systems and is capable of running an ensemble of land surface models (currently Noah, CLM, VIC, Mosaic) on points, regions, or the globe at spatial resolutions from 2° × 2.5° down to 1 km. In addition, the LIS system provides distributed data access via http and GrADS/DODS servers on the LIS Web site http://lis.gsfc.nasa.gov. At spatial resolutions coarser than 1 km, a "tiling" approach may be used to simulate subgrid-scale variability, based on the University of Maryland 1-km global vegetation dataset (Hansen et al. 2000), the 5-min global soils information produced by Reynolds et al. (2000), and the GTOPO30 global digital elevation model (Gesch et al. 1999).

LIS integrates satellite and ground-based observations and atmospheric analysis products to provide an assessment of the current state of the land surface. NASA is archiving and providing hourly Land MOLTS at all CEOP reference sites, as described above, including states of soil moisture, soil temperature, and snowpack, as well as surface energy and water fluxes. The LIS land MOLTS have been provided on the LIS Web site for the EOP-1 period from four distinct land models (Noah, CLM, VIC, Mosaic) run in uncoupled, land-only mode on three grids: 0.125° (with and without tiling), 5 km (with and without tiling), and 1 km (without tiling), utilizing common surface forcing. This range of outputs allows the CEOP community to investigate the impact of mesoscale land surface heterogeneity on the accuracy of coarser grid-scale model outputs, and thereby helping to understand the relationship between the point-scale water and energy reference site data with the grid-scale model and satellite products. Further understanding of these relationships is critical to progress toward integrated global water and energy cycle products that optimally combine information from point-scale and satellite observations with models. This activity is an element of WESP activities within CEOP.

Model output archives. NCEP, GMAO, and ECPC outputs are provided to the CEOP global model output archive at MPI in Germany. In addition, MPI receives and archives the global precipitation, SST, sea ice, and Northern Hemisphere snow cover analyses. The MPI archive covers all three of the CEOP phase-I data-collection periods. Regional model and regional 4DDA outputs from NCEP are available through the GEWEX/GAPP-sponsored archives at NCAR, links to which are provided by the MPI CEOP archive. The hourly gridded NLDAS outputs for all three periods are also being provided by NASA and NCEP.

COORDINATION MECHANISMS.

U.S. coordination mechanisms. Between 2000 and 2003 the coordination function for U.S. contributions to CEOP was carried out by the Global Water Cycle Program (GWCP) office located in Washington, D.C. Teleconference calls were used to promote cooperation among components of the U.S. program and to develop strategies for accomplishing common goals. Ad hoc working groups were formed and periodic meetings held to work out the details of activities on specific issues as they arose. The office produced and circulated summaries of the calls and maintained records of plans and agreements.

This coordination function ensured communication among U.S. reference site principal investigators, CEOP data managers, and other data users needed to produce datasets that meet the global requirements of CEOP. CEOP is breaking new ground by providing standard, integrated global datasets. Consequently, many details concerning this standardization were needed to facilitate universal access to and storage of data should be addressed cooperatively. The U.S. coordination function has provided a framework for exploring and resolving issues related to protocols, formats, and timetables. In addition, it provided a mechanism for U.S. CEOP participants to develop consensus positions on the issues and designate points of contact and common messages for the international program. This unity simplified coordination with international CEOP activities on matters such as priorities for data collection and the commitment to specific deliverables.

The U.S. CEOP coordination function also assisted efforts to expand and develop participation of agencies and organizations that could contribute to and derive benefit from CEOP activities and products. It identified opportunities for U.S. CEOP participants to update related science communities on the program, build bridges to other programs, and develop relationships.

International coordination. The CEOP coordination unit consists of an International CEOP Secretariat/Coordination Office, located in Tokyo, Japan, and a Japanese Aerospace Exploration Agency (JAXA)–NASA–NOAA–University of California–supported, International CEOP Coordinator located in the United States. One of this paper's coauthors, S. Benedict, serves as the U.S.-based International CEOP Coordinator. Responsibilities for international coordination relate primarily to CEOP's scientific and technical issues. For example, a key aspect of the international coordination function is to organize the regional observations by the different international CEOP reference sites to support CEOP science priorities. In addition, all of the issues of regional concern addressed by U.S. CEOP and others are addressed globally by the international coordination function. This coordinator plays a role in conveying the requirements for CEOP observations to the reference site operators and other data providers. The benefits of CEOP to CSEs, NWP centers, space agencies, and other stakeholders must be communicated in turn to gain their cooperation. The level of success achieved by this process can be gauged by the large amount of information that has voluntarily been made available concerning the characteristics of the CEOP reference sites. This information can be viewed online at www.joss.ucar.edu/ghp/ceopdm/rsite.html.

SUMMARY AND CONCLUSIONS/INVITATION.

CEOP has completed its first phase and the datasets have either been completed or are nearing completion. Datasets from the buildup phase (see Table 1) have undergone preliminary analyses and the results look promising both in terms of their quality as datasets to be used in modeling and in terms of the information that can be acquired regarding a range of land–atmosphere interactions.

The United States has made major contributions to CEOP through its observational capabilities, modeling expertise, and data services. The U.S. scientific community benefits from access to all of the datasets from other countries, including data from a number of countries that have restrictive data policies. CEOP is progressing well due to NCAR's (formerly UCAR's) processing of the reference site datasets that are being used in process studies and model evaluations. The U.S. CEOP community is encouraging interested scientists to utilize these unique datasets and to assess their value in model and algorithm development and related applications.

Links. The CEOP home page online at http://monsoon.t.u-tokyo.ac.jp/ceop/index.html provides additional background on these topics. The CEOP implementation plan can be viewed at www.gewex.org/ceop/ceop_ip.pdf. The network of CEOP reference sites is still evolving, but the current list can be found online at www.joss.ucar.edu/ghp/ceopdm/ref_site.html. CEOP datasets can also be accessed online at www.joss.ucar.edu/ghp/ceopdm/. Model output data can be accessed online at http://cera-www.dkrz.de. For more information on GLDAS, visit http://ldas.gsfc.nasa.gov. Information and access to the new LIS data service is available online at http://lis.gsfc.nasa.gov. Information about the satellite system and instruments can be found at various web sites including www.osd.noaa.gov.

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