GEWEX
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NEWS

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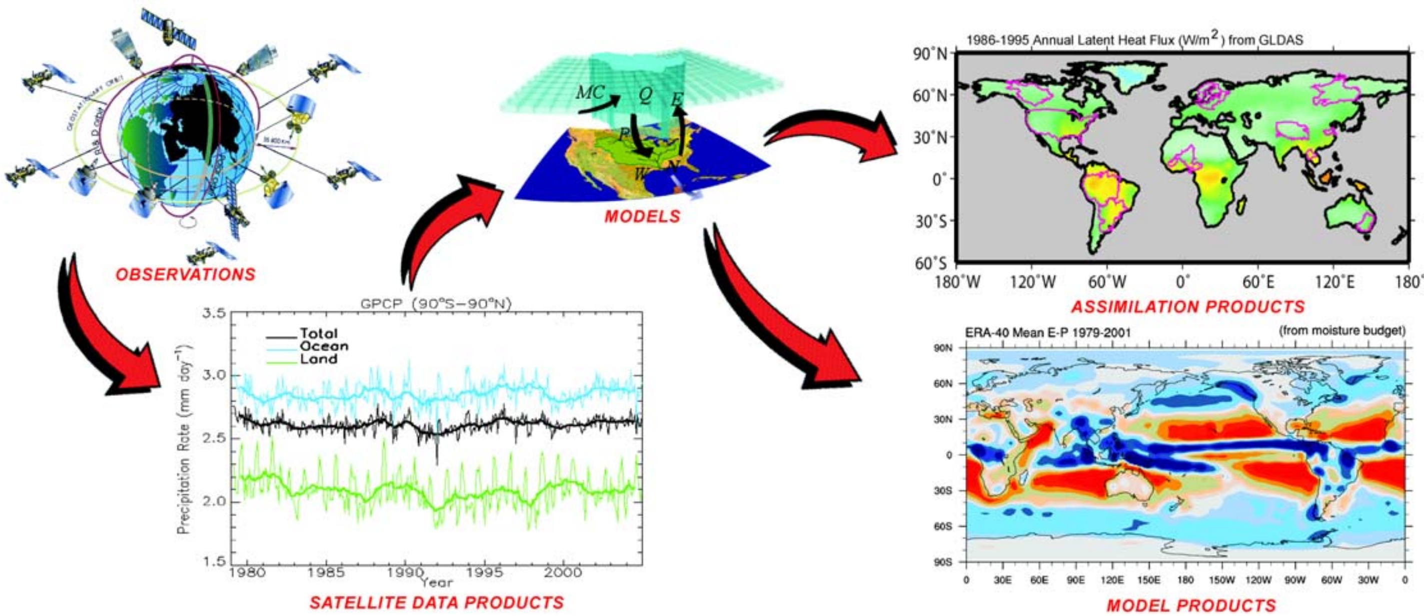
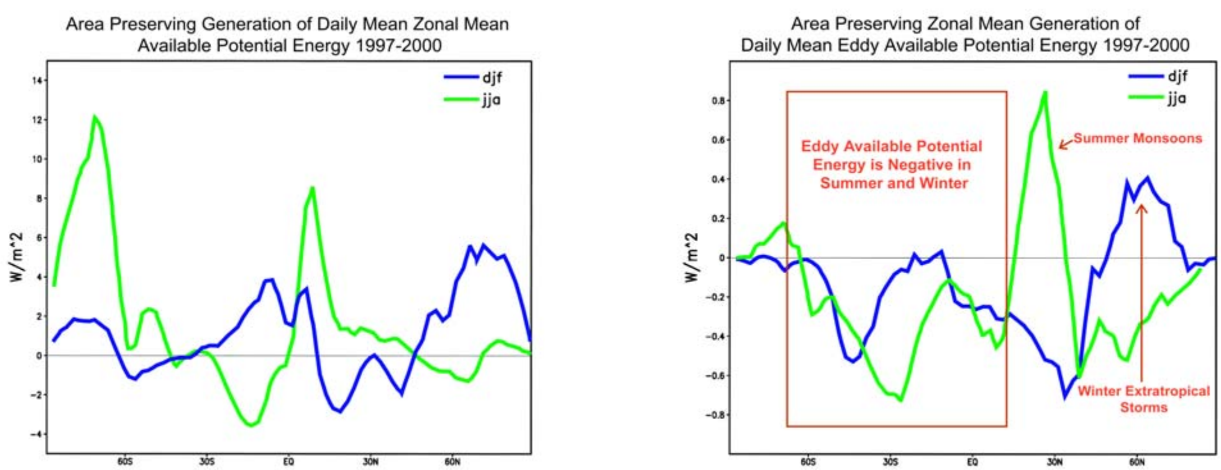
GEWEX ADDRESSES WATER AND ENERGY BUDGETS USING SATELLITE DATA PRODUCTS AND MODELS



For initial GEWEX Hydrometeorology Panel water and energy budget study results for the period of 1986–1995, see the article by J. Roads on page 6. For results from the evaluation of the water cycle by ERA-40 using observation constrained land models, see article by K. Trenberth et al. on page 8.

NEW SATELLITE ESTIMATES OF AVAILABLE POTENTIAL ENERGY SUPPORT THE VIEW THAT ATMOSPHERIC EDDIES ARE A NET SINK OF ENERGY



Left panel shows zonal, seasonal average generation of available potential energy, and right panel shows eddy available potential energy. Both were determined from observation-based calculations of atmospheric heating/cooling by radiation, precipitation and surface fluxes. See article by W. Rossow et al. on page 3.

COMMENTARY

LEADERSHIP CHANGES IN WCRP AND JSC: NEAR-TERM CHALLENGES FOR GEWEX

Soroosh Sorooshian, Chair
GEWEX Scientific Steering Group

The annual Joint Scientific Committee (JSC) meeting was held in Pune, India in March. It was a busy meeting including a joint International Geosphere-Biosphere Programme–JSC (World Climate Research Programme) meeting where areas of mutual interest and potential collaboration were discussed. It also was the first meeting with Ann Henderson-Sellers in place as the WCRP Director. Peter Lemke, the outgoing Chair was replaced by John Church. On behalf of GEWEX, I thank Peter for his leadership, keen interest and participation in many of the GEWEX activities including the Coordinated Enhanced Observing Period (CEOP).

It is natural to expect changes with new leadership and this meeting was no exception. One immediate change is that the Coordinated Observation and Prediction of the Earth System has been absorbed as part of the WCRP Strategic Plan. However, many of the specific initiatives such as the WCRP Observation and Assimilation Panel and WCRP Modelling Panel will continue to perform their functions of coordination across the WCRP projects. The Pune meeting placed more focus on activities such as extremes, monsoons, and Anthropogenic Climate Change (ACC). All WCRP projects are asked to contribute to ACC studies. Specific to GEWEX and CEOP, a number of decisions and recommendations were provided at the meeting. Some of highlights, which will require serious discussion and attention are summarized below.

The JSC expressed appreciation for the GEWEX roadmap which responds to WCRP's strategic framework; a special subgroup was established to review the objectives, implementation, milestones, and timeline of our roadmap. We will work closely with Drs. T. Yasunari, G. Wu, D. J. Griggs, and J. Shukla as they undertake this review but will also proceed to refine and implement the actions in the roadmap.

The JSC encouraged GEWEX to increase its contribution to predictability and prediction studies and to accelerate progress on studies related to the role of land-surface processes in predictability on intraseasonal, seasonal and longer time scales. My commentary in the November 2005 issue of *GEWEX News* emphasized the vital importance of the GEWEX prediction focus, which is on the end-to-end aspects of prediction that may provide a more direct link to societal benefits. Understanding the water and energy application end of the WCRP prediction efforts does require much more emphasis by the JSC. This objective would be greatly aided by having a land surface or hydrologic expert as a JSC member, who could advise on the full range of GEWEX modelling activities (i.e., Hydrological Ensemble Prediction Experiment, HEPEX) and assist in assessing the possibilities and limitations of hydrological predictability studies.

The CLIVAR Monsoon Panel and the GEWEX Hydrometeorology Panel were encouraged to work more closely together, and the JSC recommended that all four WCRP projects establish focal points (with a JSC member) to define how to bring the monsoon studies into a more coordinated program. The JSC approved the CEOP Phase II plan, subject to a technical review by experts from each WCRP project, in order to propose ways to prevent potential overlaps with existing WCRP activities.

In order to address these recommendations, as well as our continued effort to streamline GEWEX panel activities, planning for a simultaneous meeting of all the GEWEX projects, including CEOP is underway. The Pan-GEWEX meeting is planned for 9–13 October 2006 in Frascati, Italy. We look forward to working with Drs. Ann Henderson-Sellers and John Church as they lead WCRP into the future.

Contents

RECENT NEWS OF RELEVANCE TO GEWEX

SOIL MOISTURE WORKSHOP IN THE NETHERLANDS

A workshop on *in situ* soil moisture measurements was held on 28–29 March at the European Space Research and Technology Centre in Noordwijk, The Netherlands. Representatives from a number of countries participated in the workshop and agreed to work towards establishing standards for soil moisture data. Soil moisture measurements are important for the validation of soil moisture missions as well as being a critical climate variable for prediction and advisory services for agriculture. Peter van Oevelen, the European GEWEX Coordinator, organized the Workshop and will continue to coordinate these plans through his European Space Agency and International Global Water Cycle Observations (IGWCO) Theme connections.

CLOUDSAT/CALIPSO LAUNCHED

On April 28th, the National Aeronautics and Space Administration (NASA) launched the final two satellites of the "A-Train," a string of international satellites in closely matched orbits to aid in climate studies. CloudSat, a NASA platform will use its radar to provide detailed distributions of rain and snow forming inside clouds, which will provide key data for determining the atmosphere's energy and water budget. The Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations (CALIPSO), a joint French-US satellite, will use a lidar to provide measurements of dust and other aerosols in clear air and in thin clouds. The two satellites will follow one another, flying only 15 seconds apart, effectively providing simultaneous observations of the same section of the atmosphere.

The lead satellite in the "A-Train," Aqua, which launched in 2002, is a water- and energy-observing platform. Last in line is Aura, an atmospheric chemistry-measuring satellite launched last year. The fourth satellite in the string is Parasol, a French platform launched in 2004 which carries instruments to measure aerosols and clouds. The data from this comprehensive satellite measurement system is expected to improve the accuracy of long-range climate models.

ANALYZING THE VARIATIONS OF THE GLOBAL ENERGY AND WATER CYCLE

William B. Rossow[1], John J. Bates[2], Joy Romanski[3], Yuanchong Zhang[3], Ken Knapp[2], and Ely Duenas[1]

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The core of the Earth's climate system is an energy cycle that converts absorbed solar radiation into heat and associated terrestrial radiation into the circulations of the atmosphere and ocean. A key exchange of energy within this system, which also couples the circulations of the atmosphere and ocean, is between the surface and the atmosphere, primarily through evaporation cooling of the surface and precipitation heating of the atmosphere, thereby intimately linking the energy and water cycle. Because of the Earth's spherical shape, its rapid rotation, and its elliptical orbit about the sun, the solar heating is neither uniform nor constant. Because of the turbulent nature of the atmospheric and oceanic motions that transport heat and water, the response of the system is not steady. Hence, the "climate," which is usually portrayed as a static state of a single system, is actually an amalgam of variations of energy and water exchanges among several climate system components that respond on a broad range of space-time scales and are coupled by the exchanges of energy and water. Although some statistics of these variations may be static, the energy-water cycle is fundamentally dynamic.

Basic questions about the climate are: (1) how variable is the climate with a "statistically steady" forcing (natural variability)? and (2) how sensitive is the climate to systematic changes in the forcing (climate change)? The latter is determined by numerous feedback processes that operate to alter the exchanges of energy and water inside and outside the system, but in a truly dynamic climate system, the former is also influenced by these same processes. To learn the answers to these questions, therefore, we must observe the varying relationships among the components of the climate system and diagnose the variations of their exchanges of energy and water to determine how they regulate and modulate the climate response to forcing. For this purpose, the observations must have a combination of high space-time resolution and global, long-term coverage that can only be provided, in practice, by systematic satellite observations. The former is required to accurately resolve the energy and water exchange variations at the weather-process-level and the latter is required to provide enough examples of the different possible configurations of the climate system to understand the range of multi-variate, non-linear relationships that are produced by the interactions of the processes.

To describe the complete energy-water cycle requires measurements of the thermodynamic state of all of the climate components and the hydrodynamic state of the atmosphere and ocean, as well as all the properties of them that affect the energy and water exchanges. The state is described by the 4-dimensional distribution of temperature, humidity and winds in the atmosphere, of the temperature, salinity and currents in the ocean and the temperature and "water content" of the land and ice. To calculate the exchanges of energy requires determination of the tendencies of the state variables and their atmospheric and oceanic transports which are functions of spatial derivatives of these variables. Additional properties that are needed to calculate radiative exchanges are the gas composition of the atmosphere (including the main greenhouse gases), aerosols, clouds, and surface spectral albedo/emissivity. The main additional quantities to determine the water cycle are precipitation (rain and snow), water storage on the land as snow/ice and in the deep aquifer, as well as water runoff from the land to the ocean.

The state of the atmosphere has been observed and analyzed for many of the past decades by the operational weather and national climatolgical services, but these data were not compiled specifically for climate studies until the concept of reanalysis was developed. The World Climate Research Programme (WCRP) was established, in part, to coordinate activities to develop a number of data sets that were missing for describing the energy-water cycle (Global Atmospheric Research Program, GARP, 1975). The first three activities organized were projects to compile observations of the properties of clouds (the International Satellite Cloud Climatology Project, ISCCP), the thermodynamic state of the world ocean (the World Ocean Circulation Experiment, WOCE) and precipitation (the Global Precipitation Climatology Project, GPCP). The cloud data set, when combined with the atmospheric state data sets, has now been used by the Surface Radiation Budget (SRB) Project to reconstruct the complete radiation budget at the surface and top of atmosphere, supported by a series of satellite Earth Radiation Budget (ERB) satellite missions [Nimbus-7, ERB Experiment (ERBE), Scanner for Radiation Budget (ScaRab), Clouds and the Earth Radiant Energy System (CERES), Geostationary ERB (GERB)] and establishment of the Baseline Surface Radiation Network (BSRN). NASA also began measuring the properties of the stratosphere, particularly to monitor volcanic aerosol, ozone and water vapor variations. Now these various compilations are being brought together with efforts to estimate the remaining surface fluxes of heat and water under the auspices of the GEWEX Radiation Panel (GRP) to foster analyses of the global energy-water cycle. The table on the next page summarizes some of the data products available and their characteristics.

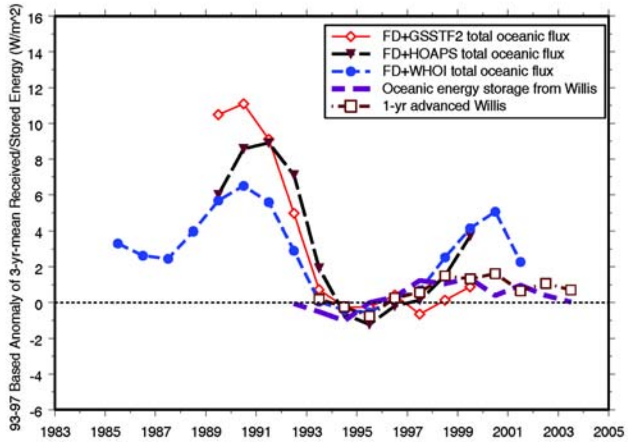
To illustrate the type of analyses that can be performed with such a compilation of data sets, we show the first direct observation-based determination of the generation of zonal mean and eddy available potential energy (G_Z and G_E, respectively) as defined for one form of the atmospheric energy cycle suggested by Lorenz (1967). These quantities are determined from the atmospheric heating/cooling by radiation (ISCCP-FD, Zhang *et al*., 2004), precipitation (GPCP, Adler *et al.*, 2003) and surface sensible heat fluxes for oceans and land (GSSTF2, Chou *et al.*, 2003; GLDAS, Rodell *et al.*, 2004). The period covered is 1997–2000 because that is the only common period for which daily results are available from all sources. A land surface model was used for the surface sensible heat fluxes over land because no data set is available for this quantity as yet. The figures at the bottom of page 1 summarize the results and show very interesting features. First, as suggested by Lorenz, but contradicted by the results of Peixoto and Oort (1992), G_E is generally negative, (i.e., the atmospheric eddies are a net sink of energy). Second, the largest values of G_Z appear in the tropics and polar regions: the "baroclinic wave" zone exhibits almost no net energy generation in the zonal mean. Third, the largest absolute values of G_E are associated with the tropical monsoons in the summer hemisphere and midlatitude storms in the winter hemisphere. With these results we can now study the individual contributions to these energy generation terms.

As another illustration, the decadal variations of the surface energy fluxes over the ocean (GSSTF2, Chou *et al.*, 2003; ISCCP-FD, Zhang *et al.*, 2004) are compared in the figure (page 5) with an independent estimate of variations of the heat content of the upper ocean (Willis *et al.*, 2004). Given the uncertainties associated with these data products, the results still show a (lagged) correlation of more than 0.5. Again, with these results in hand we can diagnose the separate contributions to the heat budget of the ocean influenced by different atmospheric processes.

To stimulate more extensive analyses of the variations of the global energy-water cycle and the processes that influence them, the GRP proposes organizing a complete set, at least one data set for each of the

Energy and Water Cycle Element/ Data Set Names	Period Covered	Sampling Spatial (km)	Time (hrs)
Atmospheric State			
*TOVS (no winds)	1979-Present	280	24
*NCEP/NCAR	1948-Present	280	6
ERA-40	1963-2003	280	6
Clouds			
*ISCCP	1983-2005	280	3
SOBS	1971-1996	280-560	3-24
Ozone			
TOMS	1978-2003	110	24
*SBUV	1978-2005	280	24
SAGE II	1979-2005	560	Monthly
Trace Gases			
CO_2, CH_4, etc.	1958-Present	Global	Monthly
Aerosols			
*GACP (ocean only)	1981-2004	280	Monthly
*NOAA aerosol (ocean only)	1995-2005	110	24
SAGE II (strat.)	1984-2005	560	Monthly
Radiation			
NIMBUS-7 (TOA)	1978-1985	280	12
ERBE (TOA)	1984-2002	280	24
CERES (TOA)	2000-Present	110	3
*SRB (TOA-SRF)	1983-2004	110	3
*FD (TOA-SRF)	1983-2005	280	3
Precipitation			
*GPCP	2002-Present	280	3
*GPCP	1997-Present	280	24
*GPCP	1979-Present	280	Pentad
Surface Fluxes			
GSSTF2 (oceans)	1989-2000	110	24
HOAPS (oceans)	1987-2000	110	24
Oceanic State			
*Reynolds (SST)	1982-2005	110	Weekly
*World Ocean Atlas (Levitus)	1948-1998	110-560	Monthly
*WOCE	1990-1997	----	----
Ocean Surface Winds			
Wentz	1987-2005	110	24
Ocean Currents			
T/P-Jason	1992-2005	50-110	5-Day
GRACE	2002-2005	----	----
Key Supporting Data Sets			
Baseline Surface Radiation Network	1994-2005	35 sites	5 Min
Global Precipitation Climatology Centre	1951-2004	50	Monthly
Global Runoff Data Centre	1970-2005	4500 Sites	Daily

Some available global, long-term data sets that can be used to quantify variations of the global energy-water cycle. References and relevant web site addresses for these data sets can be found on the GEWEX Radiation Panel web site at http://grp.giss.nasa.gov/gewexdsets.html. Asterisks indicate data sets to be provided on the National Climatic Data Center (NCDC) active server.



Comparison of the decadal-scale anomaly in net surface fluxes and variations of annual upper-ocean heat content.

components of the energy-water cycle, in two forms. The first is a summary of the data sets in the form of monthly mean global maps, all in the same grid covering the same time period, posted on and downloadable from the GRP web site (*http://grp.giss.nasa.gov/gewexdsets.html*). The second is to begin providing access to the original versions of these data sets (with a variety of map grids, sampling intervals and periods covered), starting with the four GRP products for radiation, precipitation, clouds and aerosols, on an active server to be hosted by NCDC. The online summary is now available and the data sets are being assembled for the server and should be available by the summer of 2006.

References

Adler, R. F., and Coauthors, 2003. The Version-2 Global Precipitation Climatology Project (GPCP) Monthly Precipitation Analysis (1979–present). *J. Hydrometeor.*, 4, 1147–1167.

Chou, S.-H., E. Nelkin, J. Ardizzone, R. M. Atlas, and C.-L. Shie, 2003. Surface turbulent heat and momentum fluxes over global oceans based on the Goddard satellite retrievals, Version 2 (GSSTF2). *J. Clim.*, 16, 3256–3273.

GARP, 1975. *The Physical Basis of Climate and Climate Modelling*, Global Atmospheric Research Program Pub. Series, No. 16, pp. 265.

Lorenz, E., 1967. *The Nature and Theory of the General Circulation of the Atmosphere*, World Meteorological Organization, WMO-No. 218.TP.115, pp. 161.

Peixoto, J., and A. H. Oort, 1992. *Physics of Climate*, American Institute of Physics, New York, pp. 520.

Rodell, M., P. R. Houser, U. Jambor, et al., 2004. The Global Land Data Assimilation System. *Bull. Amer. Meteor. Soc*., 85, 381-394.

Willis, J. K, D. Roemmich, and B. Cornuelle, 2004. Interannual variability of upper ocean heat content, temperature and thermosteric expansion on global scales. *J. Geophys. Res.*, 109, (1–13).

Zhang, Y.-C., W. B. Rossow, A. A. Lacis, M. I. Mishchenko, and V. Oinas, 2004. Calculation of radiative fluxes from the surface to TOA based on ISCCP and other global data sets: Refinements of the radiative transfer model and the input data. *J. Geophys. Res*., 109.

GHP WATER AND ENERGY BUDGET STUDY

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The goal of the GEWEX Hydrometeorology Panel (GHP) Working Group on Water and Energy Budget Studies (WEBS) is to develop the best available water and energy budgets for the global land regions associated with the GEWEX Continental-Scale Experiments (CSEs). In short, WEBS uses observationally based products developed by GEWEX and other global communities, as well as products from the current global atmospheric and land reanalyses to establish not only the current uncertainty in estimating water and energy processes and variables from current observations and models, but also to better understand how well these processes and variables can be simulated and ultimately predicted. These observation/model comparisons may eventually become a key contribution toward the development of better climate predictions of water and energy processes in climate models.

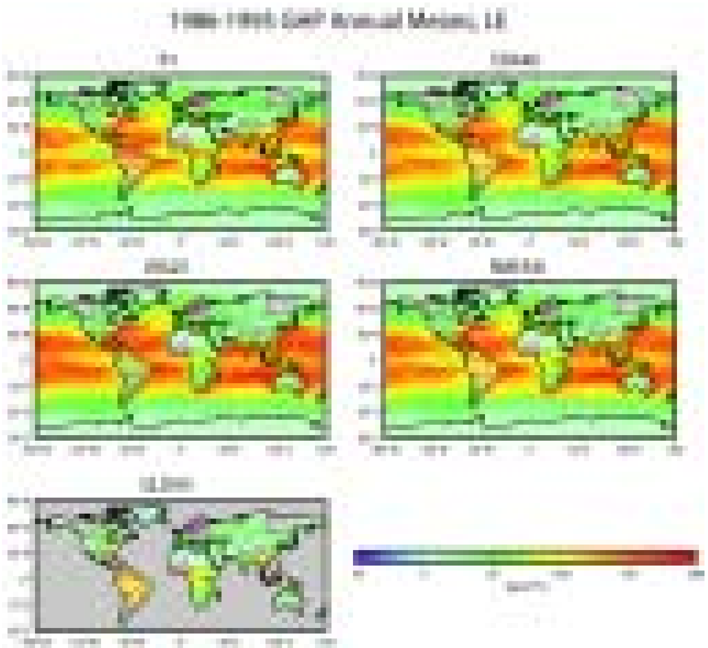
The time period 1986–1995 was chosen for the initial WEBS study, although it was earlier than most of the CSE start dates (c.a. 1995), to take advantage of the global data sets available from the GEWEX International Satellite Land-Surface Climatology Project (ISLSCP) Initiative I and II data sets. Collections of regional data (e.g., Roads et al., 2003) developed as a part of the CSE studies were deemed inadequate for these more globally focused studies.

WEBS is using observationally based GEWEX Radiation Panel (GRP) global data sets including the NASA Water Vapor Product (NVAP), the International Satellite Cloud Climatology Project (ISCCP) radiation and water vapor products, the Surface Radiation Budget (SRB) Project radiation products and Global Precipitation Climatology Project (GPCP) precipitation products. WEBS is also examining two Global Runoff Data Centre (GRDC) runoff-based global data products developed by the University of New Hampshire, as well as the National Oceanic and Atmospheric Administration Climate Prediction Center Merged Precipitation (CMAP) precipitation and the Climate Research Unit (CRU) surface air temperature global data sets. Using more than one set of observationally based global data sets allows some characterization of the potential level of uncertainty in these data sets.

WEBS will also utilize global reanalyses from the National Centers for Environmental Prediction (NCEP, R1, and R2), the European Centre for Medium Range Weather Forecasts (ECMWF, ERA-40), the Japanese Reanalysis Agency (JRA) as well as data from the NASA Global Land Data Assimilation System (GLDAS) and the Global Soil Wetness Project (GSWP) under the GEWEX Modelling and Prediction Panel (GMPP). In particular, GLDAS is providing three unique LDAS simulations from the MOSAIC, Noah, and CLM land surface models, with the same observationally based forcing data. Although some hydrometeorological processes and variables can be obtained only from these atmospheric and land-based model analyses, there are at least some observations, mentioned above, that can be used for evaluation.

In order to make progress, the initial WEBS activity has been limited to analysis of the bulk-integrated water and energy processes in the atmosphere and land. State variables include precipitable water, soil moisture, snow equivalent water, atmospheric energy, and surface air and skin temperature. Water and energy budget processes include precipitation, moisture convergence, evaporation, runoff, heat convergence, latent heat of condensation, atmospheric radiative cooling, surface radiative heating, sensible and latent heat transfers from the surface to the atmosphere, ground heat flux, and the associated radiation fluxes.

As examples of the WEBS comparisons, see the two figures on page 7 and the figure on the bottom left side of page 20. These demonstrate our current uncertainty in estimating the global latent heat flux (evaporation) over large continental-scale regions. There are currently no well-established global land latent heat flux data sets, although ocean data sets are slowly becoming available. Land evaporation is complicated by soil and vegetation heterogeneity and currently only model estimates are the "best available." Since atmospheric reanalyses must use soil and vegetation properties influenced by model precipitation and radiation, it could be assumed that currently available off-line GLDAS products using a single observationally based forcing could provide the most reliable estimates. However, an intrinsic advantage of atmospheric reanalyses is that they are a coupled land-atmosphere solution, whereas current GLDAS models use uncoupled atmospheric forcings (e.g., surface

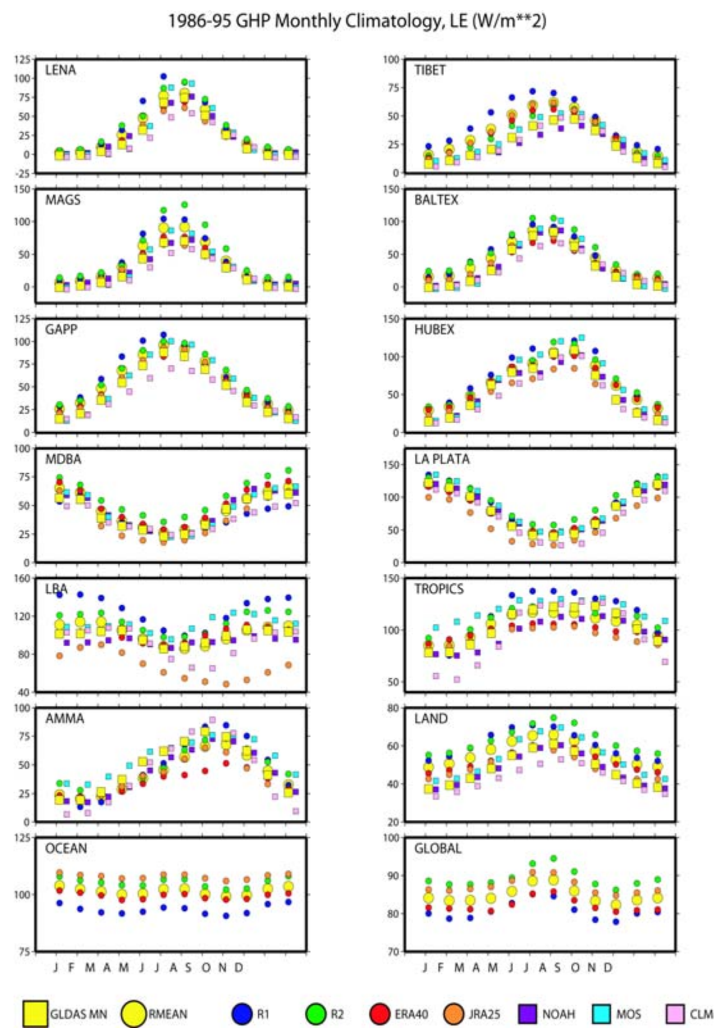


1986–1995 annual latent heat flux (W/m^2) climatology from R1, ERA40, JRA, GLDAS and the reanalyses ensemble means. CSE areas outlined for further analyses include the Mackenzie GEWEX Study (MAGS), the GEWEX Americas Prediction Project (GAPP), the Large-scale Biosphere Atmosphere Experiment in Amazonia (LBA), the La Plata Basin (LPB) Project, the Baltic Sea Experiment (BALTEX), the GEWEX Asian Monsoon Experiment (GAME) areas – including the Lena River Basin, Tibet, the HUBEX area and GAME-Tropics, the Murray-Darling Basin (MDB) Project, and the African Monsoon Multidisciplinary Analysis Project (AMMA) Project Nigerian River Basin.

winds, temperatures, humidities) which likely produce some unknown error. Future coupled atmospheric reanalyses, which assimilate precipitation and radiation are expected to provide better estimates as are promising experimental remote sensing techniques.

The figure at the right shows that the level of uncertainty among the individual GLDAS land surface models for most regions seems to be only slightly less than the level of uncertainty for the evaporation among the different reanalyses, despite their use of a common forcing. Apparently differences among the land surface models are also a major contribution to the uncertainty. It might be further assumed that the average global latent heat flux from the atmospheric reanalyses "balances" the reanalyses' precipitation, which is usually greater than the observed precipitation. This suggests that the lower mean values associated with GLDAS may be more realistic, although atmospheric analysis increments also contribute to these natural balances. Suffice it to say that some uncertainty remains in the latent heat flux (and evaporation) at global and regional scales from our "best available" analysis systems.

GEWEX has the larger goal of developing similar "best available global budgets" over both the ocean and land and in collaboration with the companion World Climate Research Programme (WCRP) Climate Variability and Predictability (CLIVAR) Project on much longer time scales. GHP and GRP (see article by W. Rossow et al. on page 3) WEBS assessment efforts include atmospheric and land data assimilation systems that will eventually be merged. A long-term goal is to have a much more comprehensive description of not only the global average bulk water and energy processes, but also a better description of their associated vertical and temporal distributions and how these variations



1986–1995 monthly latent heat flux (W/m^2) means from R1, R2, ERA40, JRA, Noah, CLM, Mosaic and the atmospheric and land reanalyses ensemble means for GHP CSE regions as well as for the global land (–60 to +60), Ocean (–90 to 90), and the entire globe.

might change on diurnal to centennial time scales. This will ultimately require collaborative efforts with other WCRP projects, including the Climate and Cryosphere (CLiC) Project and Stratospheric Processes and their Role in Climate (SPARC) Project.

To summarize, this GHP WEBS effort is particulary focused on the first GEWEX Phase II objective: "Produce consistent research quality data sets complete with error descriptions of the Earth's energy budget and water cycle and their variability and trends on interannual to decadal time scales, and for use in climate system analysis and model development and validation." In addition, WEBS is answering important GEWEX Phase II questions, such as "Are the Earth's Energy Budget and Water Cycle Changing?" Additional focus on this latter objective will eventually be carried out by examining the interannual variations in the available data sets, in collaboration with the GHP Worldwide Study of Extremes and Transferability Working Groups and, as mentioned above, other GEWEX and WCRP communities.

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Reference

Roads, J., R. Lawford, E. Bainto, E. Berbery, S. Chen, B. Fekete, K. Gallo, A. Grundstein, W. Higgins, M. Kanamitsu, W. Krajewski1, V. Lakshmi, D. Leathers, D. Lettenmaier, L. Luo, E. Maurer, T. Meyers, D. Miller, K. Mitchell, T. Mote, R. Pinker, T. Reichler, D. Robinson, A. Robock, J. Smith, G. Srinivasan, K. Verdin, K. Vinnikov, T. VonderHaar, C. Vorosmarty, S. Williams, and E. Yarosh, 2003. GCIP Water and Energy Budget Synthesis. *J. Geophys. Res.* 108, 1–39.

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EVALUATION OF THE ATMOSPHERIC WATER CYCLE IN ERA-40 USING OBSERVATIONALLY CONSTRAINED LAND MODEL RESULTS

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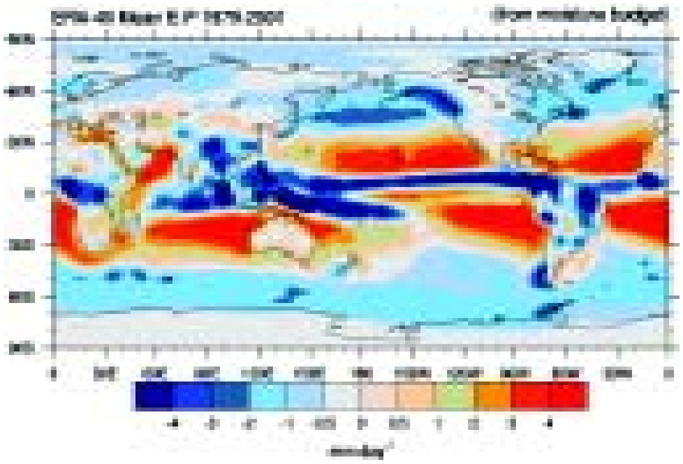
Quantifying the various storage and flux components of the global water and energy cycle and determining their variability and changes, and their causes, are a central goal of GEWEX and other global projects. Our quantitative knowledge about these components is still fairly limited because of a lack of reliable data for global clouds, precipitation, evaporation, terrestrial runoff, and other fields (Trenberth et al., 2006). Improved long-term observations and global analyses of these fields are critical for studying the global climate and its future changes. However, most fields have been studied in isolation rather than in the framework of the entire cycle. A synthesis of observed atmospheric data through global analyses of multi-variate data can potentially help. In particular, European Centre for Medium-Range Weather Forecasts (ECMWF) ERA-40 reanalysis data have been used to examine atmospheric moisture transports and their convergence, storage changes, and thus to compute evaporation (E) minus precipitation (P) from the total vertically integrated atmospheric moisture budget.

The figure on page 9 shows the long-term annual mean distribution of E-P derived using 6-hourly fields of atmospheric winds and humidity from the ERA-40 reanalyses (Uppala et al., 2005). The strong evaporation in the subtropics over the oceans is readily apparent (E>P) and so too are the tropical Inter-Tropical Convergence Zones and monsoon rains, where P>E. This figure nicely shows the main characteristics of the E-P field, but the values should not be considered quantitatively correct. For instance, over land it is generally expected that P>E, because runoff is positive, although exceptions can arise if water is transported into a region from rivers or aqueducts, or if major lakes exist. In this figure, positive E-P that is clearly "not physical" exists in parts of South America, Africa, Asia, southwestern North America, and especially over Australia.

As an alternative over land, the results for the period 1979–2000 from observed precipitation and estimates of evapotranspiration from a stand-alone integration of the Community Land Model Version 3 (CLM3) (Bonan et al., 2002; Qian et al., 2006)



Long-term (1979–2001) annual mean E-P computed from monthly means of the vertically integrated atmospheric moisture budget using 6-hourly ERA-40 reanalysis data.

forced with the specified observed precipitation and other atmospheric forcings are used. The CLM3 is a substantial improvement over previous versions of land surface models and represents the surface with five primary subgrid land cover types, 16 plant functional types, and 10 layers for soil temperature and water, with explicit treatment of liquid soil water and ice. Representation of the seasonal cycle by the CLM3 shows significant improvements over previous generation models in regards to seasonality in surface air temperature, snow cover and runoff (Bonan et al., 2002; Dickinson et al., 2006). In the simulation used here to estimate E over land, the CLM3 was forced with observed monthly precipitation and other fields blended with high frequency weather information from the National Centers for Environmental Prediction (NCEP)-NCAR reanalysis (Qian et al., 2006). Values are reported on a T42 grid (~2.8^{o}), on a monthly basis from 1948 to 2004.

For precipitation (P) we make use of Version 2 of the Global Precipitation Climatology Project (GPCP) data (Adler et al., 2003) that blends satellite and gauge data to provide global coverage, and the PREC/L data set from Chen et al. (2002), which includes both the Global Historical Climatology Network and synoptic data from the NOAA/Climate Prediction Center's Climate Anomaly Monitoring System. These were combined to ensure complete coverage to drive the model, with the PREC/L data predominant in the blend over land. A more complete discussion is given in Trenberth et al. (2006).

In the top panels of the figure on the bottom (right side) of page 20, the zonal mean over land of the E and P fields are given. Their difference E-P is given in the bottom left panel. These results can be contrasted with those from ERA-40, given in the bottom right panel. In the bottom left panel, P>E throughout most of the year, as would be expected over land for the annual mean. The only way this could not be true is if there is large storage of moisture on land in one month which subsequently evaporates in another. Indeed, water storage on land as snow that subsequently melts in spring and replenishes the soil moisture can result in E>P for those months in the extratropics. Results from the Gravity Recovery and Climate Experiment (GRACE) satellite mission based on variations in gravity also suggest substantial annual cycles in water storage on land in lower latitudes, especially in monsoon areas (Wahr et al., 2004), and there is some evidence for this in the results shown just south of the equator in May-June, where E exceeds P in the dry season by close to 0.05 Eg, with contributions from the Amazon, Australia and southern Africa.

In the ERA-40 E-P (see figure on page 20), however, both the moisture divergence and E-P are strongly positive in the subtropics of the summer hemisphere (the storage term is important and systematic but an order of magnitude smaller). In fact this is true in ERA-40 data over Australia for 9 months of the year as well as for the annual mean, which is clearly not physically possible. Hence the low level mass divergence associated with subsidence in the downward branch of the monsoon circulations is accompanied by a low level divergent moisture flux that is not correct in ERA-40. Spurious sources of moisture exist either from surface evaporation that fails to dry out the ground or from increments in the analysis that continually restore the moisture fields to observed levels. Hence, the ERA-40 moisture budget is not balanced. Note that this is not a problem with the assimilating model but rather with the specified boundary conditions (such as soil moisture) and the assimilation itself, and how the fields are updated with new observations. The problem is not confined to Australia, but for other continents the divergence in some areas and months is compensated for by convergence elsewhere. Therefore, much greater credence is given to the land model result for the zonal mean E-P over land.

This study shows the deficiences in ERA-40 with regard to the hydrologic cycle and indicates that substantial improvements are required in these global reanalyses. Efforts are being made to achieve this. Major problems are evident throughout the tropics and subtropics, with evaporation too strong over land in the subtropics, exceeding the actual moisture supply, and precipitation too strong in the monsoon trough and convergence zones. Much more reliable estimates are available over land from ground-based networks of precipitation and we have used estimates of evapotranspiration from a sophisticated land model driven by realistic forcings. Hence, plausible estimates of evapotranspiration can be made physically consistent with the supply of moisture and runoff, as well as the available energy supply, although undercatch biases in raingauge data (Yang et al., 2005; Adam et al., 2006) make it difficult to precisely balance the water budget over high latitudes and high terrain.

Acknowledgments: *Lesley Smith, Taotao Qian, and John Fasullo helped with the computations.*

References

Adam, J. C., E. A. Clark, D. P. Lettenmaier, and E. F. Wood, 2006. Correction of global precipitation products for orographic effects. *J. Clim.*, 19, 15–38.

Adler, R. F., et al., 2003. The Version 2 Global Precipitation Climatology Project (GPCP) monthly precipitation analysis (1979–present). *J. Hydrometeor*., 4, 1147–1167.

Bonan, G. B., et al., 2002. The land surface climatology of the community land model coupled to the NCAR community climate model. *J. Clim.*, 15**,** 3123–3149.

Chen, M., P. Xie, J. E. Janowiak, and P. A. Arkin, 2002. Global land precipitation: a 50-yr monthly analysis based on gauge observations. *J. Hydrometeor.*, 3, 249–266.

Dickinson, R. E., et al., 2006. The Community Land Model and its climate statistics as a component of the Community Climate System Model. *J. Clim.*, in press.

Qian, T., A. Dai, K. E. Trenberth, and K. W. Oleson, 2006. Simulation of global land surface conditions from 1948 to 2002: Part I: Forcing data and evaluations. *J. Hydrometeor*., in press.

Trenberth, K. E., L. Smith, T. Qian, A. Dai, and J. Fasullo, 2006. Estimates of the global water budget and its annual cycle using observational and model data. *J. Hydrometeor.*, submitted.

Uppala, S. M., et al., 2005. The ERA-40 reanalysis. *Quart. J. Roy. Meteor. Soc.*, 131, 2961–3012.

Wahr, J., S. Swenson, V. Zlotnicki, and I. Velicogna, 2004. Time-variable gravity from GRACE: First results, *Geophys. Res. Lett.*, 31, L11501, doi:10.1029/2004GL019779.

Yang, D. Q., D. Kane, Z. P. Zhang, D. Legates, and B. Goodison, 2005. Bias corrections of long-term (1973–2004) daily precipitation data over the northern regions. *Geophys. Res. Lett.*, 32, L19501.

ASSESSMENTS OF WATER AND ENERGY BUDGETS IN THE AMAZON BASIN

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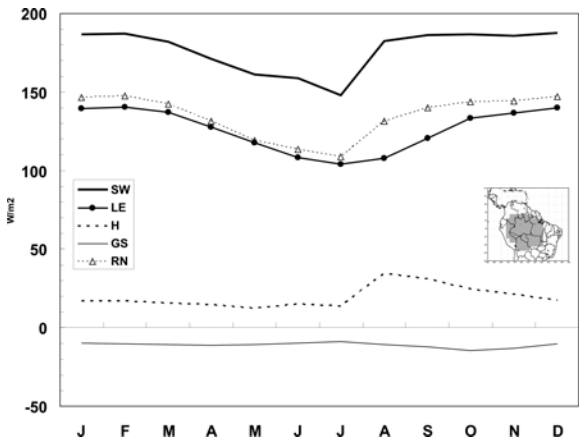
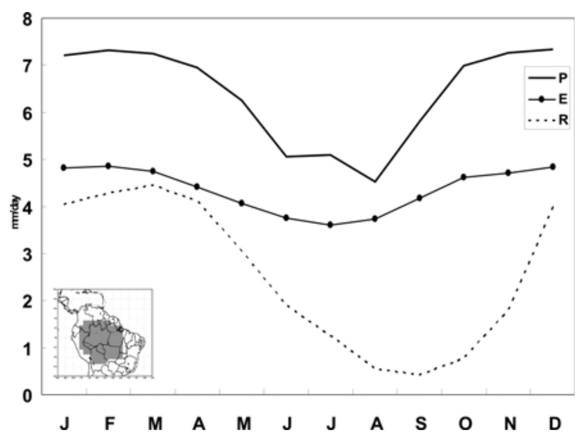
The emphasis of many of the Amazon Basin climate studies has been on the movement of water in the terrestrial system, considering precipitation and evapotranspiration as the forcing and streamflow and storage as the response. In this context, water that evaporates from the land surface is lost to the system if advected out of the prescribed region, but recycled in the system if it falls again as precipitation. A description of the hydrological cycle requires a knowledge of the energy budget because the ratio of the sensible and latent heat fluxes is very important for maintaining the water and energy cycles. In summary, the way in which the climate of the Amazon Basin functions will depend on the participating components.

The surface and upper-air observational network in the Amazon region is very sparse and by itself cannot provide the comprehensive data needed to determine the components of the energy and water balance estimates with a high degree of certainty. The implementation of the Large-scale Biosphere Atmosphere Experiment in Amazonia (LBA), as one of the GEWEX Continental Scale Experiments (CSEs) has allowed for the implementation of reference sites across Amazonia that have provided data for quantification of the components of the energy balance and water balances. In most cases, to augment the scarce observations, we have had to rely on imperfect models or products from data assimilation or gridded reanalyses and rainfall data sets, such as the global reanalyses produced by the National Center for Environmental Prediction (NCEP). Such reanalyses can highlight characteristics of the circulation and water balance and have provided useful estimates of some of the components of the water budget where observations were not available. However, it has not been established that this description will be superior to that obtained from objective analysis and radiosonde observations, especially over continental regions.

The figures (a and b) on the next page show the annual cycle of the components of the water (P=Precipitation, ET=Evapotranspiration and R=Runoff) and energy (SW=Short Wave radiation, RN=Net Radiation, H=Sensible heat, LE=Latent Heat, and GS= Heat storage term) budgets in Amazonia derived from the NCEP reanalyses. Both the water and energy budget terms show that during summer atmospheric



a) Energy Balance



b) Water Balance

Seasonal cycle of the components of the (a) energy and (b) water balance estimated for the Amazon Basin during 1979–2000. The components of the balance were derived from the NCEP/NCAR reanalyses and the runoff in (b) from observations and Obidos.

water vapor, P, ET, LE, and H all increase. The H peak in winter is corroborated by surface observations at some sites in Amazonia.

The table in the next column provides a comparison of the Rondônia pasture site and the Manaus forest. By comparing the values in the table with (b) of the figure above we can see that the RN and H are closer to the observed values, while LE seems to be higher in the NCEP reanalyses. This is also observed in the water budget, and by comparison of observed ET at Rondônia and Manaus with the NCEP reanalysis. The seasonal cycle (a) shows similarities with those values derived by Roads et al. (2002) also exhibiting the same problem with the reanalyses in overestimating LE and thus, evapotranspiration.

The figure at the top of page 20 shows a summary of the estimates of the balance from four different studies for the entire Amazon Basin. These studies use either the global reanalyses, or a combi-

	Rondônia	**Manaus**
Wet Season	RN= 128.6 Wm^{-2} H= 45.5 Wm^{-2} LE= 83.0 Wm^{-2}	RN= 112.1 Wm^{-2} H= 40.0 Wm^{-2} LE= 80.3 Wm^{-2}
Dry Season	RN= 113.0 Wm^{-2} H= 49.1 Wm^{-2} LE= 63.9 Wm^{-2}	RN= 129.5 Wm^{-2} H= 58.6 Wm^{-2} LE= 69.1 Wm^{-2}

nation of the reanalyses and observations (gridded or station data). In the long term, the basin average precipitation P should be balanced by ET+R, and C=R. The studies from Zeng (1999) using the NASA-Goddard Earth Observing System (GEOS) reanalyses and Costa and Foley (1999) using the NCEP reanalyses show differences between C and R, which are much smaller than the NCEP reanalysis, suggesting a source of water inside the basin which could have been artificially added during the reanalyses computations. In studies by Roads et al. (2002) and Marengo (2006), C is different from R by almost 50% indicating a large imbalance. This imbalance may be due to large uncertainties in the evaporation, moisture convergence, and precipitation from station data. Grid-box products also show some discrepancies due to sampling problems and interpolation techniques. The same problems exist for R estimates because they vary by almost 10% depending on whether the measurement at the gauging site or an estimate at the mouth of the River. For the Amazon region, the errors can be almost as large as the runoff itself. In addition, errors in the moisture convergence are almost as large as the error in the evaporation. There are some differences in P, depending on the source of data (reanalyses, observations) and the period of time covered. The imbalance is larger over the southern Amazon region than over the northern region and also exhibits interannual variability.

Further work should show the details of the water and energy balance components and how they can be affected by local and remote forcing. LBA reference site data have been an essential data source for the validation of model and reanalyses estimations.

References

Costa, M. H., and J. A. Foley, 1999. Trends in the hydrologic cycle of the Amazon Basin. *J. Geophys. Res.*, Vol. 104, No. D12, p. 14,189.

Marengo, J. A., 2006. On the Hydrological Cycle of the Amazon Basin: A historical review and current State-of-the-art. In Press, Revista Brasileira de Meteorologia.

Roads, J., M. Kanamitsu, and R. Stewart. 2002. CSE Water and Energy Budgets in the NCEP-DOE Reanalyses. *J. Hydromet.*, 3, 227–248.

Zeng, N., 1999. Seasonal cycle and interannual variability in the Amazon hydrologic cycle. *J. Geophys. Res.*, 104, 9097–9106.

ASSESSING WATER AND ENERGY BUDGETS FOR THE MACKENZIE BASIN – MAGS WEBS

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The regional climate system functions by the exchange of water and energy between the region and its environment and through the internal cycling and conversion of these quantities within the region. Advances in our knowledge and understanding of the climate of a region are thus ultimately measured by our capability to quantify, and predict the water and energy cycle for the basin. In fact, one of the major objectives for the GEWEX Continental-Scale Experiments (CSEs) is to develop state-of-the-art water and energy budget assessments for their corresponding study basins by using currently available data sets in the Water and Energy Budget Studies (WEBS, Roads et al., 2003).

The Mackenzie GEWEX Study (MAGS) CSE was developed to understand and model water and energy cycling at high-latitudes (Stewart et al., 1988). The Mackenzie River Basin (MRB) in northwestern Canada stretches from 52°N to 70°N and covers about 1.8 million km^2. The Basin is characterized by vastly diverse physiographic features and climatic conditions. The North Pacific atmospheric circulation features and their interactions with the mountainous coastal region of western Canada exert particularly strong influences on the transport of water and energy into and through the Basin.

Although a number of previous studies (e.g., Strong et al., 2002) have focused on quantifying specific components of the MRB water and energy cycle, the MAGS WEBS (Szeto et al., 2006) represents the first attempt at developing a comprehensive climatology of water and energy budgets for the Basin. In this preliminary effort, we focus on basin-scale vertically integrated atmospheric and surface water and energy budgets for the period 1997–2002 (MAGS itself spanned from 1994–2005). For this vast, remote and data-sparse region, we have to rely heavily on the use of assimilated and remotely sensed data to evaluate its water and energy budgets. In particular, data from global National Centers for Environmental Prediction (NCEP-R2), European Centre for Medium-Range Weather Forecasts (ERA-40) and regional (Canadian Meteorological Centre, CMC) analyses, the Canadian Regional Climate Model (CRCM) climate simulations along with various *in situ* and remotely sensed measurements were used to obtain independent estimates of the budgets. The methodologies outlined in Roads et al. (2003) were adopted in the evaluation of the budgets. Apart from the development of state-of-the-art budget estimates for the MRB, the relative merits of current models, data assimilation systems, and other global climate data sets in representing components of the water and energy cycle of this northern region were also assessed.

Examples of results from the study are given in the table on page 13 which summarizes the basin-average annual budgets evaluated by using the different data sets. A CD-ROM containing comprehensive compilations of the budget results can be obtained from the author (*Kit.Szeto@ec.gc.ca*) and more detailed discussions of the results can be found in Szeto et al. (2006).

Not surprisingly, the largest spreads in the budget estimates are found in purely modeled surface fluxes such as evapotranspiration (ET) and sensible heat flux (SH). Although the CRCM simulation was performed in "climate mode," the model simulated a very reasonable climate for the MRB when compared with observations and analysis data. Noteworthy points for its basin budgets include the low bias in its ET throughout the year and its delayed snowmelt (and subsequently weak SH and over-estimated peak runoff) during spring. All of these budget biases can be partially attributed to the strong cold bias that affected its lower model troposphere within the MRB, especially during the cold season. Despite the large differences between the model resolutions and model physics that are employed in the CMC and ERA data assimilation systems, quite similar budgets were derived from these two data sets, and in general they compared the best to available observations. The NCEP R2 reanalyses have been used in numerous hydrometeorological studies related to the MRB; water and energy budgets assessed for the Basin from the data set exhibit the strongest relative biases, and compared the least favorably to available observations in general. In particular, its warm-season water cycle for the Basin is significantly stronger than those in other data sets. In addition, the NCEP model produces consistently higher E than others throughout the year. The R2's SH into (from) the surface during the cold (warm) season are also substantially stronger (weaker) than those from other data sets. These results suggest that the NCEP-R2 reanalysis should be used with caution for certain hydrometeorological studies in the Basin.

For the global satellite and blended data sets, the results show that (i) the annual basin average precipitable water estimate from the National Aeronautics and Space Administration (NASA) Water Vapor Project (NVaP) data set compares extremely well with those estimated from analysis data sets; (ii) both the Climate Prediction Center (CPC) Merged Analysis of Precipitation (CMAP) and the Global Precipitation Climatology Project (GPCP) precipitation are lower than others, with the low biases particularly worse during the summer; and (iii) the International Satellite Cloud Climatology Project (ISCCP) FD radiative fluxes (the "global observations" for radiative fluxes in the table below) compare well with estimates from others, particularly the ERA-40.

Our capability to close the water budget for a region is traditionally assessed by comparing the measured runoff with estimated atmospheric moisture convergence. The annual water budget for the MRB is closed to 6, 8, and 10 percent of the observed runoff using the moisture convergence from ERA-40, CMC, and CRCM, respectively. While these are noted improvements over previous assessments for the region (approximately 25 percent, Strong et al., 2002), magnitudes of the residues in balancing the budgets are often comparable to the budget terms themselves (see table below), suggesting that substantial improvements to both the models and observations are needed before we can use the analysis datasets to accurately close the water and energy budgets for this northern Basin.

The MRB climate system is governed by complex interactions between the atmosphere and surface features and processes that occur on a wide range of spatial-temporal scales. A number of these processes and features are generally not (e.g., organic soil, northern lakes and runoff routing), or are only crudely (e.g., ground frost processes, orographic precipitation and snow sublimation processes) represented in current climate models. These limitations will certainly affect the representation of the region's water and energy cycle in the models. The enhanced understanding of these processes that was developed in MAGS and the incorporation of this knowledge into numerical models will improve our capability to simulate water and energy cycling in northern continental regions, and the results from this study will provide a reference climatology to gauge the progress that will be made in future budget estimates from these improved models and newly available satellite data sets.

References

Roads, J., et al., 2003. GCIP Water and Energy Budget Synthesis (WEBS). *J. Geophys. Res.*, 108 (D16), 8609, doi:10.1029/2002JD002583, 2003.

Stewart, R. E., et al., 1998. The Mackenzie GEWEX study: The water and Energy cycles of a major North American river basin. *Bull. Amer. Meteor. Soc.*, 79, 2665–2683.

Strong, G. S., et al., 2002. Closing the Mackenzie basin water balance, water years 1994–95 through 1996–97. *Atmos. Ocean*, 40, 113–124.

Szeto, K. K., et al., 2006. MAGS Water and Energy Budget Study. *J. Hydromet.*, submitted.

Data/ Parameter	Precipitable Water	Soil Moisture	SWE	T2m	Atmos Enthalpy	Precip	Evap	Moisture Convg	Runoff	DSE Convg	Sensible Heat Flux	Atm W Residue	Atm E Residue
NCEP-R2	9.39	324.3	30.6	270.5	2.31	1.75	-1.75	0.69	-1.02	0.36	-0.27	-0.69	0.32
CMC	8.97	229.2	37.2	270.3	2.32	1.34	-1.07	0.53	-0.27	0.33	0.10	-0.26	0.12
CRCM	9.30	261.3	71.0	267.5	2.32	1.39	-0.74	0.54	-0.66	0.52	0.05	0.12	-0.05
ERA-40	8.80	289.7	49.5	271.3	2.31	1.38	-0.99	0.46	-0.48	0.36	0.10	-0.33	0.23
Reg Obs	10.00		34.2	270.3	2.39	1.28			-0.49				
Glob Obs	9.14					1.00/1.07							
Data/ Parameter	At Latent Heating	Net Surf Radiation	Net Atm Radiation	TOA SWD	TOA SWU	TOA LWU	BOA SWD	BOA LWU	BOA SWU	BOA LWD	% Cloud Cover	Surf W Residue	Surf E Residue
NCEP-R2	0.33	0.37	-0.87	2.15	0.75	1.91	1.28	2.79	0.34	2.21	48.4	1.02	-0.18
CMC	0.25	0.37	-0.91	2.10	0.74	1.90	1.13	2.78	0.24	2.26	55.7	-0.27	0.01
CRCM	0.26	0.27	-0.89	2.10	0.93	1.79	1.04	2.62	0.26	2.11	60.3	-0.06	0.02
ERA-40	0.27	0.39	-0.98	2.14	0.78	1.95	1.05	2.84	0.20	2.38	67.3	0.31	0.04
Reg Obs	0.24										65.0		
Glob Obs	0.19	0.39	-0.99	2.11	0.78	1.88	1.10	2.83	0.21	2.38	67.1		

Summaries of annual basin-average water and energy budgets for the MRB. All water storage terms are in mm, T2m in K, enthalpy in J/km^2, moisture fluxes in mm/day, and energy fluxes in K/day.

WORKSHOP ON GLOBAL MICROWAVE MODELLING AND RETRIEVAL OF SNOWFALL

11–13 October 2005
Madison, Wisconsin

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At the last meeting of the International Precipitation Working Group (IPWG) in October 2004 it was proposed that an expert workshop on the status of global satellite estimates of snowfall be held. This proposal was later endorsed by the GEWEX Radiation Panel (GRP) and the National Aeronautics and Space Administration's Global Precipitation Measurement (GPM) Mission. As a result of this initiative, this IPWG/GPM/GRP Workshop was held at the University of Wisconsin with 42 participants from America, Europe and Asia.

The workshop consisted of one day of overview presentations and one and a half days of extensive working group discussions with a focus on modelling, applications, new technology, and validation. The scientific presentations covered various scientific and programmatic aspects associated with snowfall modelling for radiative transfer, retrieval algorithms and the potential for data assimilation. A final workshop report was produced and can be obtained from the IPWG web site (*http://www.isac.cnr.it/~ipwg/IPWG.html*).

Some of the high priority recommendations from the focus areas include:

- Encourage the generation of community Cloud Resolving Model (CRM)/Numerical Weather Prediction (NWP) model profile databases that represent natural variability. A parallel effort for databases generated from observations or combined model simulations and observations is also encouraged.
- Intensify data assimilation studies including precipitation observations in NWP analysis systems.
- Establish a modelling chain that links cloud models with improved models on cloud microphysical information (e.g., shapes, phase) that can be used for the development of parameterizations for general use in cost-driven applications.
- Develop high-latitude surface emissivity products (10–200 GHz) including error estimates.
- Encourage the development and further refinement of inexpensive ground-based remote sensing instruments for snowfall. In particular, vertically pointing micro radars and microwave transmission links that measure attenuation due to snowfall are of interest.
- Encourage the use of combined active (with sensitivity of 5 dBZ or less) and passive (including high frequency measurements, and oxygen and water vapor absorption bands) satellite data for light rainfall and snowfall detection/retrieval. Missions such as CloudSat, GPM and EarthCare will be extremely helpful.
- Provide high-level coordination of international ground validation programs for snowfall (e.g., through GPM, GEWEX, IPWG), which is urgently needed to advance the current state of snowfall retrievals. Engaging with other disciplines (e.g., atmospheric chemistry, cryosphere) for mutually beneficial collaboration, including the free exchange of unique data sets (e.g., SNOWTEL – SNOwpack TELemetry observations), is strongly encouraged.
- Continue long-term surface-based measurements of snowfall and water equivalent to ensure continuity for climate assessment and monitoring.

The recommendations will be tracked by the IPWG and reported on at their next meeting (October 2006, Melbourne, Australia) as well as at the annual meetings of the GRP. In addition, these recommendations are being utilized by the GPM program in making several planning decisions, including the addition of high frequency channels on the GPM Microwave Imager and the selection of ground sites and required measurements within the ground validation program.

Participants at the IPWG/GPM/GRP Workshop on Global Microwave Modelling and Retrieval of Snowfall.

SECOND IGWCO WORKSHOP AND CEOP SCIENCE MEETING

28 February – 3 March 2006
Paris, France

Richard Lawford
International GEWEX Project Office

The Second Integrated Global Water Cycle Observations (IGWCO) Theme Planning Workshop was held in conjunction with the Fifth Coordinated Enhanced Observing Period (CEOP) Implementation Planning Meeting at UNESCO. The IGWCO Workshop began with a joint session with CEOP and ended with a joint UNESCO/Geological Applications of Remote Sensing (GARS)/IGWCO session on groundwater. About 65 people attended, a significant increase from last year. This article summarizes the IGWCO Meeting. A summary of the CEOP Meeting will be included in the upcoming *CEOP Newsletter*.

The joint CEOP/IGWCO session focused on the coordination of inputs from CEOP and IGWCO to interoperable Earth observing systems. Overviews were given on the Group on Earth Observations (GEO, J. Achache), IGWCO (R. Lawford) and CEOP (T. Koike). In addition a number of international environmental programs and national space agencies reported on their priorities. The following paragraphs highlight the results and actions reported and discussed under each IGWCO activity.

Precipitation: P. Arkin reported that plans are progressing to undertake an evaluation of high resolution precipitation products. A number of scientists have agreed to participate in this intercomparison. Workshops to compare products will be held in conjunction with the 2nd International Symposium on Quantitative Precipitation Forecasting and Hydrology in June 2006 and the International Precipitation Working Group Workshop in October 2006. Issues related to the Global Precipitation Mission (GPM) and TRMM were also discussed.

Soil Moisture: P. van Oevelen reported that plans for the Soil Moisture and Ocean Salinity (SMOS) Mission and its validation are progressing well. A workshop on a global *in situ* Soil Moisture Network (28–29 March 2006) is expected to give feedback on the readiness of the *in situ* community to contribute to the development of a quasi operational soil moisture product. US scientists remain hopeful that the cancellation of the Hydrosphere State Mission (HYDROS) will not diminish their opportunities to be involved in these initiatives.

Water Quality: According to S. Greb, planning is proceeding for a global "experts" conference on water quality monitoring using remote sensing techniques in support of the GEO Work Plan. One goal for this workshop is to develop a 10-year vision for the development of this technology.

Runoff: The World Meteorological Organization (WMO, W. Grabs) proposed an initiative for the production of global runoff products in a planned agreement with the European Space Agency (ESA) and WMO, making use of ESA's experimental and semi-operational altimetry products and in collaboration with the Water Elevation Recovery Mission (WatER) Initiative.

Initial "Fast-Track" GWSP Activities: C. Vorosmarty reported that the Global Water System Project (GWSP) and IGWCO are collaborating on a Digital Water Atlas and Water Indicators. A proposal for an IGWCO/GWSP/GEWEX Hydrology Applications Project (HAP)/International Council of Scientific Unions workshop called "End-to-End Data Evaluation: Geophysical Information-to-Water Resources Applications" was discussed.

Capacity Building: The recent Capacity Building Workshop held in Buenos Aires was described by A. Medico. Follow-up to the workshop will include the development of a program for Latin America that is similar to the Terrestrial Initiative in Global Environment Research (TIGER). C. Ishida (Japan Aerospace Exploration Agency) reported on plans for another capacity building workshop to be held in Bangkok, Thailand in September 2006. Several working groups met to discuss the priorities for discussion at these workshops. A third workshop in this series will be held in Africa in conjunction with TIGER.

A number of new topics also were introduced that will be advanced in 2006. These include:

- A flood project to fill an apparent gap in the Integrated Global Observing Strategy–Partners (IGOS-P) themes and possibly the GEO plan. A planning workshop will be proposed in collaboration with the International Centre for Water Hazard and Risk Management (ICHARM) Program (Japan), and other organizations.
- IGWCO will consider drought as a possible demonstration project of how to link remote sensing and socioeconomic data.
- The formation of a UNESCO-IGWCO-GARS Working Group on groundwater and the establishment of an initial task list.

THIRD SEAFLUX WORKSHOP

2–3 March 2006
Wakulla Springs, Florida

Carol Anne Clayson
Florida State University

The SeaFlux Project is dedicated to producing climatological data sets of air-sea fluxes of heat, moisture, and momentum, under the auspices of the GEWEX Radiation Panel. Twenty-eight scientists from Europe, Asia, and the United States attended the Workshop which was funded by the National Oceanic and Atmospheric Administration (NOAA) Office of Climate Observation.

Some of the issues discussed at the Workshop concerned the SeaFlux Intercomparison Project and the retrievals of the parameters necessary for the production of air-sea fluxes. Other items included new directions in bulk flux algorithms and issues associated with gridding, blending, and assimilation of data. Further scientific presentations covered recent analyses of the variability of satellite flux data sets, relationships between satellite-derived fluxes and models, and *in situ* data needs for validation and assimilation into the satellite flux fields.

Highlights of the scientific results presented:

- There is some benefit to the use of numerical weather prediction (NWP) or reanalysis products for estimations of near-surface specific humidity, especially in the tropics (creates a very homogeneous field). Other promising satellite-only methods include the use of multi-sensors such as sounders to determine near-surface air temperature and specific humidity. Regional and seasonal biases still exist in the products, and more data is needed at high and low extremes of temperature and humidity.

- The use of satellite-derived surface flux fields leads to improvements in modelling of the equatorial Pacific and other regions as compared to model simulations using the European Centre for Medium Range Weather (ECMWF) fluxes. The Intergovernmental Panel on Climate Change (IPCC) models also show too little variability in tropics, and have bimodal latent heat flux populations (see figure at right).

- Sea-surface temperature (SST) fields from satellite products can vary by over 1°C on average, with seasonal and regional (especially over western boundary currents) biases. The use of skin temperature is important, and diurnal warming is a factor in flux determination.

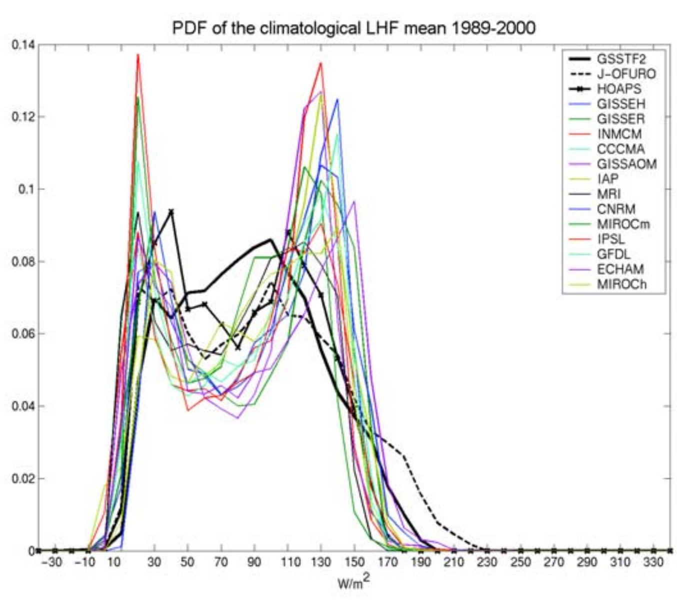
- Several bulk flux parameterizations work well in the lower wind speeds cases, and the use of a displacement height with wave information greatly improves flux estimation at higher wind speeds.

- There are alternative methods to the bulk parameterizations for latent heat flux retrievals on longer time scales that can be used for comparisons of the budgets.

- Use of multiple sensors and multiple times requires careful work with gridding and blending of the products, but can significantly reduce errors.

- More *in situ* data are needed at high wind speeds. More data are available from ships of opportunity. Some high-quality data are available for comparison algorithm development.

- Several different satellite products show evidence of increased evaporation over the last 15 years, which appears to be dependent on wind speed and is consistent with a strengthened Hadley circulation. Precipitation does not display a significant trend.



Probability distribution function of the surface latent heat flux mean from 1989 through 2000 between several satellite-derived data sets and IPCC models. From A. Romanou.

Some of the high priority recommendations from the workshop include:

- Create several test beds of data for developers of satellite-derived surface fluxes. These include: wave data for use in developing parameterizations for wind speeds on the order of 20–0 m/s, SST diurnal warming data sets to investigate effects on fluxes, SST products, monthly evaporation budgets based on hydrologic balance, and longer time series of near-surface air temperature and specific humidity from sounder data.

- Encourage further *in situ* measurements of fluxes, including wave data, especially in regions of high winds and ocean fronts such as western boundary currents. Continue to make such data widely available to the SeaFlux community.

- Continue to explore intercomparisons with data, and encourage continued understanding of differing flux data sets by using ocean models to study oceanic energy transport and SSTs.

- Continue to update the SeaFlux web page with further details of different satellite data sets and their characteristics for general community dissemination.

- Encourage continued research into methods of blending, gridding and error characterization of fields based on multiple satellites, and multiple time and spatial resolutions.

- Identify cause of differences between data sets and models, in long-term and zonally averaged latent heat fluxes.

- Ensure that the community is aware that such data and products as ocean vector winds, microwave imagers and sounders, and SSTs continue with a fairly high spatial and temporal sampling in order to insure our ability to correctly determine variability in the surface fluxes.

The next SeaFlux Workshop is tentatively scheduled to coincide with the 2007 EUMETSAT Meteorological Satellite Conference and the 15th American Meteorological Society Satellite Meteorology and Oceanography Conference in Amsterdam, 24–28 September 2007. The final workshop report will be available on the SeaFlux web site at *http://www.gfdi.fsu.edu/SEAFLUX*.

WORLD WATER FORUM IV

16–21 March 2006
Mexico City, Mexico

Richard Lawford
International GEWEX Project Office

Over 18,000 water specialists attended the Fourth World Water Forum, which featured 5 days of scientific lectures and discussion and several hundred exhibits from international programs, national agencies and private sector developers. Among other topics the scientific sessions dealt with science and technology, risk management and governance. The second World Water Development report, entitled "Water: A Shared Responsibility," was released at the Forum.

GEWEX co-sponsored a booth with the Global Water System Project (GWSP) and the NeWater Project. Jose Marengo who assisted Daniel Petry, Rick Lawford and others at the booth was a valued resource for the many Spanish-speaking visitors.

The Integrated Global Water Cycle Observations (IGWCO) Theme and GEWEX also collaborated with the International Association of Hydrology (IAHS) in a scientific session at the conference. The session featured a number of local actions where remote sensing was being used to support water resource management in the Mekong Basin, Thailand, Africa and Wisconsin. It resulted in a number of recommendations including the following:

1) Governments are urged to support the development of partnerships, research programs, integrated data systems and demonstration projects to advance capabilities for using Earth observation, and to support the training and infrastructure sharing needed to make these technologies widely available.

2) As Earth observation systems lend themselves to delivering information on ungauged or poorly gauged areas, especially those with difficult access and/or that cross administrative boundaries, this information should be used to facilitate the transboundary, basin-scale and regional management of water resources.

3) A set of goals and action plans on information availability for efficient water development

should be established to double the number of data collection, handling and application activities in the least developed countries by 2015.

Through the efforts of Antti Herlevi of the Group on Earth Observations (GEO) Secretariat and the IGWCO Theme, a side event entitled "Space Observations with Wet Feet" also was held. It featured two keynote addresses by Mr. Margolia from the Secretary of State and Dr. Bob Su, as well as a panel with representation from international (Avinash Tyagi) and national programs (Vern Schneider and Diego Fernandez), and funding programs (Kevin Cleaver, World Bank) with Rick Lawford as moderator. Key discussion points from this session were:

- The trend towards decreasing *in situ* networks around the world and reduced availability of data is continuing. GEO is committed to addressing this issue.
- Nations need to view observational networks as an investment rather than an expense.
- Best practices need to be developed for combining satellite and *in situ* data. These practices should be based on a good understanding of processes.
- GEO is moving forward with a number of studies on gaps in *in situ* networks and a workshop on best practices in capacity building.
- GEO should consider developing a special fund to help developing nations to fill the gaps in their observational networks in accordance with some agreed upon standards. GEO should also consider a project that defines observational networks (international, national and project specific) based on function, user need and potential funders.
- Expectations need to be managed regarding the benefits of remote sensing and capacity building because unfulfilled expectations could damage the program's credibility.

This event completed one of the targets for the 2006 GEO Work Plan and drew attention to the new opportunities and goals of GEO.

GWSP SSC MEETING

23–24 March 2006
Oaxaca, Mexico

Richard Lawford
International GEWEX Project Office

The Global Water System Project (GWSP) Science Committee meeting brought together committee members, project leaders, and representatives from the Earth System Science Partnership programs that oversee GWSP to discuss the next steps in the implementation of this Project. The meeting focused on a review of activities and successes to date and strategies needed to move GWSP to its next level of development. GEWEX representatives who attended the meeting included D. Lettenmaier, T. Oki, J. Marengo, G. Sommeria and R. Lawford. GWSP has been focusing on its fast track projects, but is now considering ways of moving towards a more complete set of implementation activities. The fast track projects with the strongest links to GEWEX include:

1) Digital water atlas. This project is underway and panel members have been requested to submit data sets. It is anticipated that GEWEX will also be asked to submit data sets. In the context of these activities a proposal is being developed to launch a workshop on end-to-end data management.

2) Improved world water balance. This project will hold a workshop and a possible intercomparison project. A number of potential workshop contributors from the GEWEX community have been proposed.

3) Development of global water indicators. This activity is going forward in collaboration with other efforts to bring together remote sensing data and socio-economic data sets.

4) Regional initiatives (e.g., Northern Eurasian Earth Science Partnership Initiative (NEESPI).

5) Advanced (educational) Institute on Global Environmental Change and Water.

Other highlights from the meeting include a decision to move forward with a number of basin-wide studies in the context of the global framework provided by GWSP. Depending on how this approach is implemented it could provide context for some GEWEX Continental-Scale Experiment activities.

GEWEX RELEVANT PUBLICATIONS OF INTEREST

The Sensitivity of the Tropical-Mean Radiation Budget

Reference: Clement, Amy C. and B. Soden, 2005. *J. Climate*, Vol. 18, No. 16, pp. 3189–3203.

Summary: A key disagreement exists between global climate model (GCM) simulations and satellite observations of the decadal variability in the tropical-mean radiation budget. Measurements from the Earth Radiation Budget Experiment for 1984–2001 indicate a trend of increasing longwave emission and decreasing shortwave reflection that no GCM can currently reproduce. A series of model sensitivity experiments is performed to investigate the extent to which a strengthening of the Hadley circulation or a change in convective precipitation efficiency can alter the tropical-mean radiation budget. Results suggest that the tropical-mean radiation budget is remarkably insensitive to changes in the tropical circulation. The empirical estimate suggests that it would require at least a doubling in strength of the Hadley circulation in order to generate the observed decadal radiative flux changes. In contrast, small changes in a model's convective precipitation efficiency can generate changes comparable to those observed, provided that the precipitation efficiency lies near the upper end of its possible range. If the precipitation efficiency of tropical convective systems is more moderate, the model experiments suggest that the climate would be rather insensitive to changes in its value.

The Water and Energy Budget of the Arctic Atmosphere

Reference: Semmler, T., D. Jacob, K. H. Schlünzen, and Ralf Podzun, 2005. *J. Climate*, Vol. 18, No. 13, pp. 2515–2530.

Summary: The aim of this study is to calculate the climatological mean water and energy fluxes depending on the season and on the North Atlantic Oscillation (NAO) through the lower, lateral, and upper boundaries of the Arctic atmosphere north of 70°N. The relevant fluxes are derived from results of the regional climate model (REMO 5.1), and forcing data from the European Centre for Medium-Range Weather Forecasts Reanalysis (ERA-15) which is applied to the Arctic region for 1979–2000. The annual and seasonal total water and energy fluxes derived from REMO 5.1 results are very similar to the fluxes calculated from observational and reanalysis data. Even if differences between high and low NAO situations occur in our simulation consistent with previous studies, these differences are mostly smaller than the large uncertainties due to a small sample size of the NAO high and low composites.

GEWEX/WCRP MEETINGS CALENDAR

For a complete listing of meetings, see the GEWEX web site: http://www.gewex.org

22–23 May 2006—ASSESSMENT OF CLIMATE CHANGE FOR THE BALTIC SEA BASIN, Goteborg, Sweden.

23–25 May 2006—17TH SYMPOSIUM ON BOUNDARY LAYERS AND TURBULENCE—SPECIAL GABLS SESSION, San Diego, California, USA.

23–26 May 2006—AGU, GS, MAS, MSA, SEG, AND UGM 2006 JOINT ASSEMBLY, Baltimore, Maryland, USA.

29–31 May 2006—GEO WORKSHOP ON CAPACITY BUILDING, Sao Jose dos Campos, Brazil.

29 May–1 June 2006—40TH CMOS CONGRESS: WEATHER, OCEANS, AND CLIMATE: EXPLORING THE CONNECTIONS, Toronto, Ontario, Canada.

29 May–2 June 2006—9TH MEETING OF THE BSRN, Lindenberg, Germany.

4–8 June 2006—SECOND INTERNATIONAL SYMPOSIUM ON QUANTITATIVE PRECIPITATION FORECASTING AND HYDROLOGY, Boulder, Colorado, USA.

6–9 June 2006—WCRP WORKSHOP ON UNDERSTANDING SEA-LEVEL RISE AND VARIABILITY, Paris, France.

12–15 June 2006—HOLIVAR 2006 OPEN SCIENCE MEETING, London, England.

12–15 June 2006—SPARC-GEWEX/GCSS-IGAC WORKSHOP: MODELLING OF DEEP CONVECTION AND ITS ROLE IN THE TROPICAL TROPOPAUSE LAYER, Victoria, British Columbia, Canada.

24–29 June 2006—EUROPEAN SCIENCE FOUNDATION RESEARCH CONFERENCE ON CLIMATE CHANGE. Nynäshamn, Sweden.

27–29 June 2006—ESTC2006-SIXTH ANNUAL NASA EARTH SCIENCE TECHNOLOGY CONFERENCE, College Park, Maryland, USA.

27–30 June 2006—6TH INTERNATIONAL SYMPOSIUM ON ADVANCED ENVIRONMENTAL MONITORING, Heidelburg, Germany.

6–7 July 2006—2ND GEWEX RADIATION PANEL CLOUDS WORKSHOP, Madison, Wisconsin, USA.

9–12 October 2006—PAN-GEWEX MEETING, Frascati, Italy.

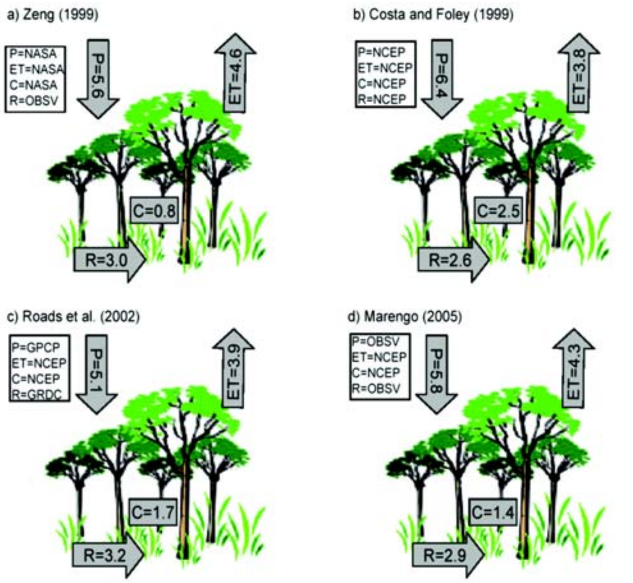
11–15 December 2006—FALL AGU MEETING, San Francisco, California, USA.

14–18 January 2007—87TH ANNUAL AMS MEETING, San Antonio, Texas, USA.

22-26 January 2007—GEWEX SSG-19, Honolulu, Hawaii.

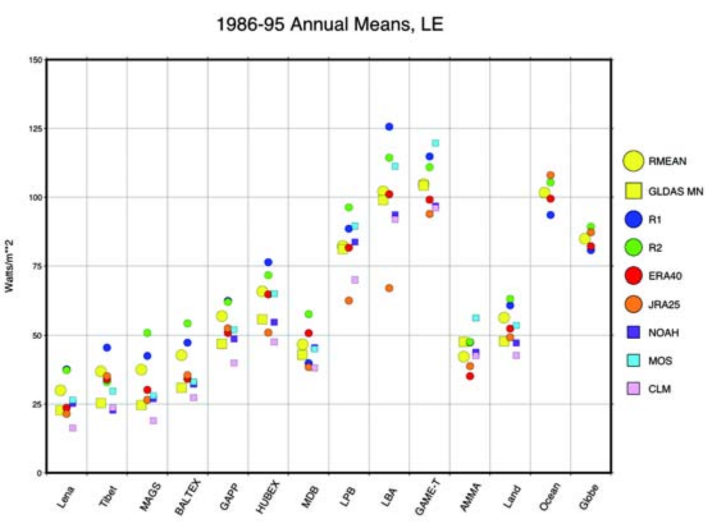
29–30 March 2007—28TH SESSION OF THE WCRP JOINT SCIENTIFIC COMMITTEE, Zanzibar, Tanzania.

DIFFERENCES IN FOUR AMAZON BASIN WATER BALANCE STUDIES



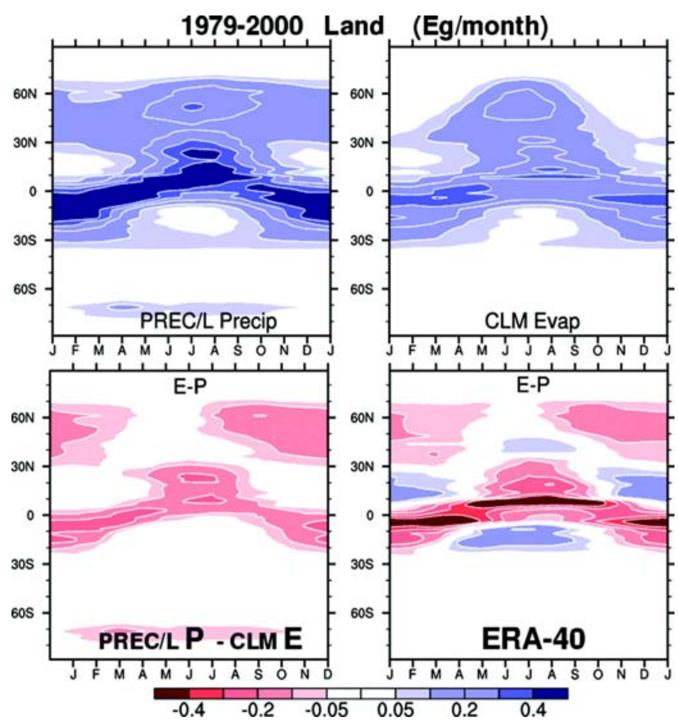
Summary of long-term mean annual water balance components in Amazonia from four studies: (a) Zeng (1999) for the period 1985–93 using estimates of P, ET, and C derived from the NASA-GEOS reanalyses, and R from the Amazon River observations at the Obidos gauging site; (b) Costa and Foley (1999) for the period 1976–96 using estimates of P, ET, R, and C from the NCEP reanalyses; (c) Roads et al. (2002) for 1988–99 using estimates of E and C derived from NCEP reanalyses, P from the GPCP gridded observed data sets and R from the GRDC gridded observed data sets; and (d) Marengo (2005) for 1970–99 using estimates of E and C derived from the NCEP reanalyses, R from the Amazon River observations at the Obidos gauging site, and P derived from station data. Units are in mm day^{-1} (Source: Marengo 2006). *See J. Marengo et al. article on page 10.*

WEBS COMPARISONS SHOW UNCERTAINTY IN ESTIMATING THE GLOBAL LATENT HEAT FLUX OVER LARGE CONTINENTAL-SCALE REGIONS



1986–1995 annual latent heat flux (W/m^2) means from R1, R2, ERA40, JRA, Noah, CLM, Mosaic, and the atmospheric and land reanalyses ensemble means for GHP Continental-Scale Experiment regions, as well as for the global land (–60 to +60), ocean (–90 to 90), and entire globe. The areas are ordered from left to right by their annual mean surface air temperatures in the R1. Note the dry MDB and AMMA areas bracketing the wetter tropical areas. *See article by J. Roads on page 6.*

GLOBAL ANALYSIS STILL REQUIRED FOR IMPROVEMENT IN TOTAL MOISTURE CYCLE REPRESENTATION



Zonal mean over land for the mean annual cycle from 1979–2000 for the PREC/L precipitation (top left), CLM3 land evapotranspiration (top right), their difference as E-P (lower left), and the E-P result from the moisture budget of ERA-40 (bottom right), in Exagrams (10^{18}g)/month. *See article by K. Trenberth et al. on page 8.*