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

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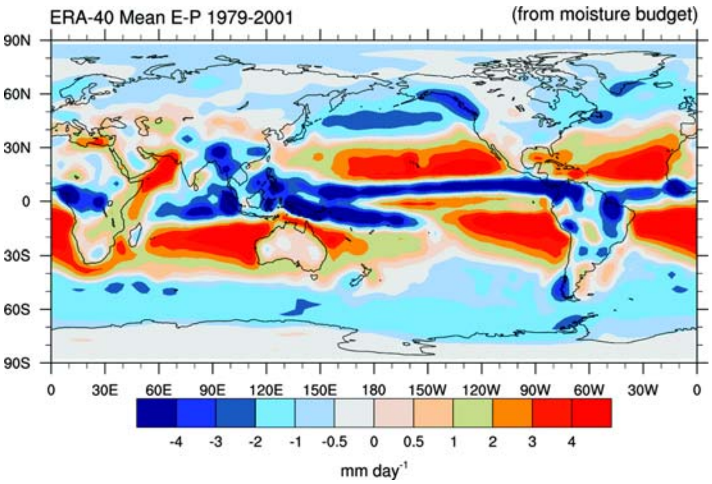
National Center for Atmospheric Research, Colorado, USA

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 is 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



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.

3 (CLM3) (Bonan et al., 2002; Qian et al., 2006) 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°), 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.

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GEWEX/WCRP MEETINGS CALENDAR

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ASSESSMENTS OF WATER AND ENERGY BUDGETS IN THE AMAZON BASIN

José Marengo, Lincoln M. Alves, and Helio Camargo

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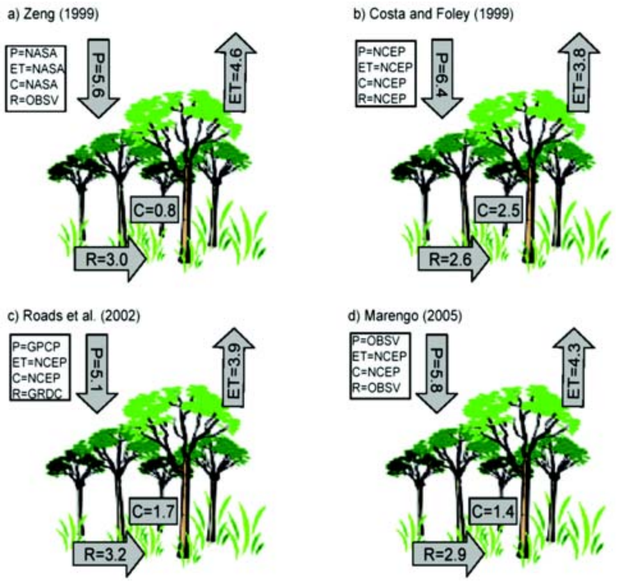
The emphasis of many of the Amazon Basin climate studies has been on the movement of water in the terrestrial system, considering precipitation and evapotranspiration as the forcing and streamflow and storage as the response. In this context, water that evaporates from the land surface is lost to the 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 sparce 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 (LBA) Project, as one of the GEWEX Continental Scale Experiments (CSEs) has allowed for the implementation of reference sites across Amazon 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.

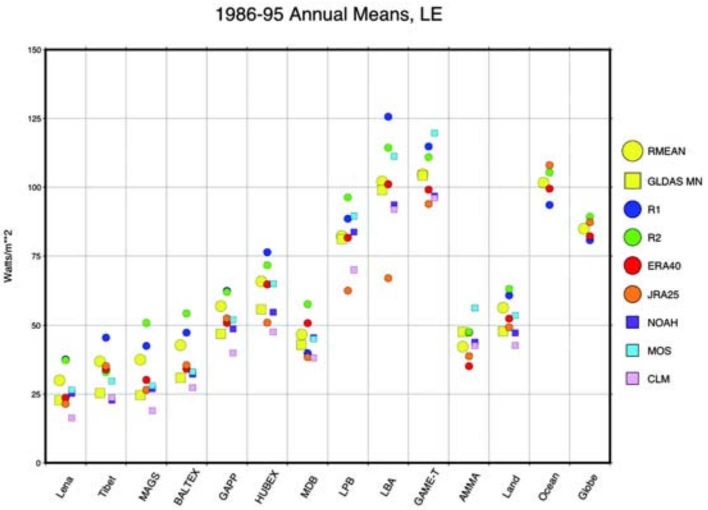
The figures (a and b) on the next page show the annual cycle of the components of the water (P=Precipitation, ET =Evapotranspiration and R=Runoff) and energy (SW=Sort Wave radiation, RN=Net Radiation, H=Sensible heat, LE=Latent Heat, and GS= Heat storage term) budgets in Amazonia derived from

DIFFERENCES IN FOUR AMAZON BASIN WATER BALANCE STUDIES



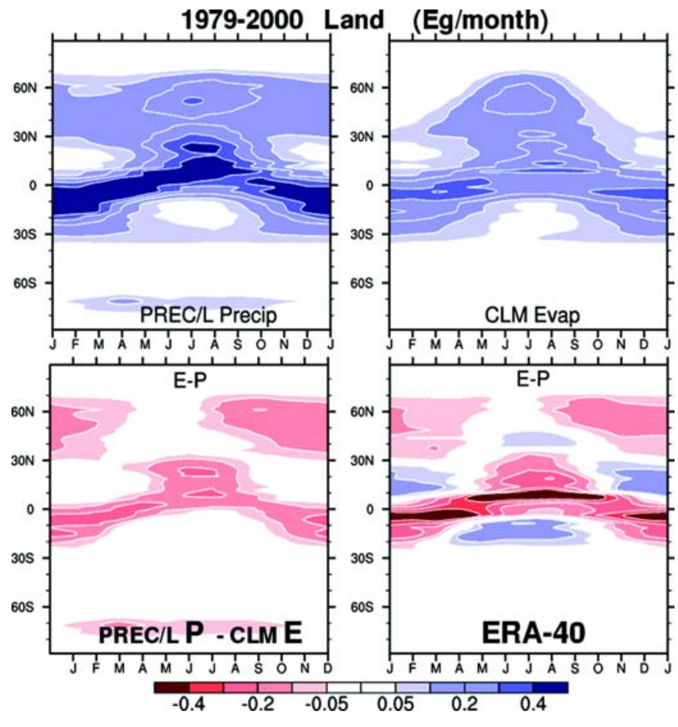
Summary of long-term mean annual water balance components in Amazonia from four studies: (a) Zeng (1999) for the period 1985-93 using estimates of P, ET, and C derived from the NASA-GEOS reanalyses, and R from the Amazon River observations at the Obidos gauging site; (b) Costa and Foley (1999) for the 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 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 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 Trenberth, et al. on page 8.