GEWEX Water and Energy Budget Comparisons

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1. Introduction

Closing atmosphere and surface water and energy budgets was one of the goals of the previous Global Energy and Water-cycle Experiment (GEWEX) Hydrometeorology Panel (GHP; see Lawford et al. 2004), which was comprised of representatives from the regions formerly known as the GEWEX Continental-Scale Experiments and now known as the GEWEX Regional Hydroclimate Projects (RHPs). Towards this goal, a number of RHP Water and Energy Budget Studies (WEBS) were launched (e.g. Roads et al. 2003; Szeto et al. 2008) to bring together needed regional data sets and model simulations. Since those initial GHP pilot projects, there have been a number of important new global observational estimates, atmospheric reanalyses, and land data assimilation data sets that have become widely available and have provided some impetus for doing another WEBS for not only individual RHPs but also for more global regions.

The regional studies of GHP are complemented by GEWEX Radiation Panel (GRP) efforts to obtain a complete global description of the water and energy cycle. Observation-based GRP global data sets now include the: National Aeronautics and Space Administration (NASA) water VAPor Product (NVAP; Randel et al. 1996); International Satellite Cloud Climatology Project (ISCCP) cloud products (Rossow and Schiffer 1999), which also include water vapor and radiative fluxes (Zhang et al. 1995, 2004), and the Global Aerosol Climatology Project (GACP; Mishchenko et al. 2007) uncertainty; independent radiative fluxes from the Surface Radiation Budget (SRB; Stackhouse et al. 2000) project; and Global Precipitation Climatology Project (GPCP, Adler et al. 2003) precipitation. Also now available are two runoff based global data products developed by the Univ. of New Hampshire in cooperation with the Global Runoff Data Center (GRDC; Fekete et al. 1999, 2002), as well as the Climate Prediction Center's (CPC's) Merged Analysis of Precipitation (CMAP, Xie et al. 1997) precipitation and temperature data sets and Climate Research Unit (CRU; see Brohan et al. 2006) and CPC surface air temperature global data sets. Having more than one independent set of global observation-based data sets potentially allows some assessment of the associated uncertainty.

Information about our current ability to simulate and predict these processes is obtained by comparison of these observational based data sets to more model based output/data sets such as atmospheric reanalyses, which now include: two global reanalyses from the National Centers for Environmental Prediction / National Center for Atmospheric Research (NCEP/NCAR R1, Kalnay et al. 1996) and NCEP / Dept. of Energy (NCEP/DOE R2, Kanamitsu et al. 2002), the European Centre for Medium Range Weather Forecasts (ERA40; Uppala et al. 2005), Japanese 25 year Reanalysis (JRA25; Onogi et al. 2007) as well as output from the NASA Global Land Data

Assimilation System (GLDAS; Rodell et al. 2004) - a project that contributed to the GEWEX Modeling and Prediction Panel (GMPP) Global Soil Wetness Project (GSWP; Dirmeyer et al. 2006). Since GSWP, GLDAS has now developed 3 new upgraded and unique LDAS simulations from the NASA Mosaic, NCEP Noah, and NCAR Common Land Model (CLM) land surface models (LSMs). All GLDAS simulations used the same observation-constrained meteorological forcing datasets.

The focus of this study employs global data sets to go beyond the earlier RHP-based studies to examine more global-scale features. We have limited the present WEBS to the bulk-integrated (atmosphere and surface) water and energy budget processes, including: precipitation, vertically integrated atmospheric moisture convergence, total evaporation (including transpiration), total runoff, vertically integrated atmospheric energy convergence, latent heat of condensation, atmospheric radiative cooling, surface radiative heating, sensible and latent heat transfer from the surface to the atmosphere, and the associated radiation fluxes. Some combination error and tendency terms are also defined, which include the ground (and ocean - vertical and horizontal) energy fluxes. Water and energy state variables include: precipitable water, terrestrial soil moisture, snow equivalent water, atmospheric sensible heat, surface air and skin temperature.

It needs to be stressed here that the chosen observational estimates, atmospheric reanalyses, and GLDAS simulations are in some cases, only representative rather than fully inclusive samples of available research water and energy data sets that can be used to assess not only regional but also global water and energy budget means and uncertainties. In that regard, GSWP developed a more comprehensive set of community LDAS simulations of the surface budgets and there are a number of more comprehensive assessments for radiation, precipitation, clouds, and aerosols currently underway. What is perhaps unique here is our attempt to combine a relatively diverse collection of observational estimates, atmospheric reanalyses, and LDAS simulations for a global to regional assessment of our current ability to characterize, close and simulate surface and atmosphere water and energy budgets and to characterize the current uncertainty. We hope this effort provides some context for these individual assessments as well as for future assessments within individual RHP regions. We also note that there have been many previous attempts to provide syntheses of water and energy budgets, but these syntheses have not really focused on the uncertainty, which is more of a focus here.

3. Preliminary results

Fig. 1a shows how the annual mean 2-meter temperature, T2m, was used to order the RHP regions from the cold Lena and MacKenzie (MAGS) river basins to the hot African region of AMMA. There is not too much disagreement between the observations, reanalyses, and GLDAS simulations, although a few regions do stand out. For example, the atmospheric reanalyses' Tibetan plateau 2-meter temperatures tend to be relatively lower than the observational estimates and GLDAS. **Fig. 1b** shows how the atmospheric precipitable water is exponentially related to T2m, although there are obviously exceptionally dry regions like the MDB and AMMA region and an exceptionally moist HUBEX region. The reanalyses and observations are in fairly good agreement, with perhaps the major exception again being the AMMA region, where the available atmospheric observations are relatively scarce and the atmospheric structure is seasonally complex in that the region since it is touched in different ways by the Atlantic Intertropical Convergence zone, especially during the Boreal summer.

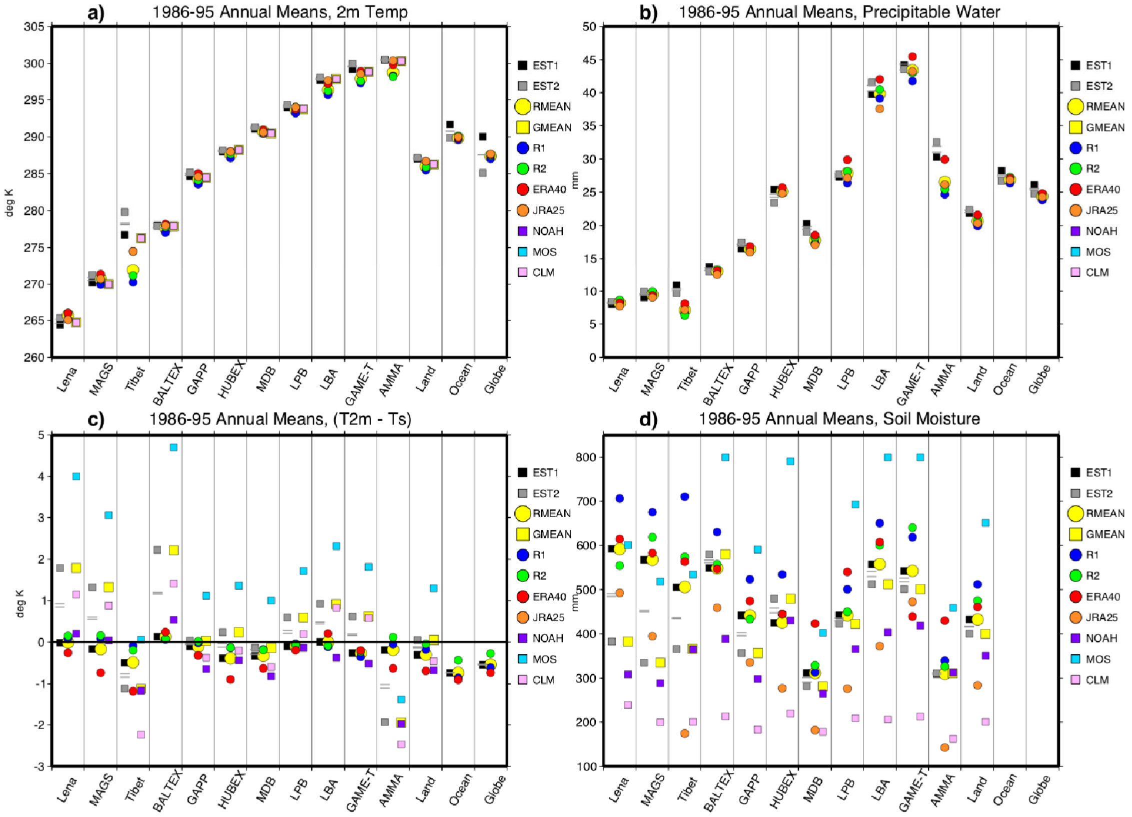

Fig. 1a Annual mean 2 m temperature for each of the identified regions. The two observational estimates are shown by the black and gray squares. These observational estimates straddle their mean plus or minus one standard deviation of 10-year means, shown by the hatched lines. Individual reanalyses are shown by the small circles and their mean is shown by the large yellow circle. Individual GLDAS simulations are shown by the small squares and their mean is shown by the large yellow square. **Fig. 1b** Annual mean precipitable water. **Fig. 1c** Annual mean T2m-Ts. **Fig. 1d** Annual mean soil moisture.

Fig. 1c shows the difference between the 2-meter temperature, T2m, and the surface skin temperature, Ts, which only comes from the reanalysis models. It should be noted here that the two observational estimates provided here (Rmean and Gmean) are based entirely on models and show the difference between using a reanalysis versus a forced GLDAS simulation. It is perhaps a little surprising that the uncertainty in this surface skin-air temperature difference is relatively large in not only the reanalyses models but also the GLDAS simulations, which all have the same T2m, although this is obviously due to the myriad ways in which Ts can be computed for a large scale region comprised of bare soil, water bodies, vegetation, etc. The AMMA region has perhaps the largest differences. Further examination of the geographic maps for the annual mean, as well as DJF and JJA differences (not shown), suggests that the uncoupled GLDAS surface temperature differences are much larger than coupled reanalyses models. **Fig. 1d** shows the total surface water 2m variations also vary greatly among models. The reanalysis models are perhaps closer than the GLDAS model variations. In general there tends to be somewhat higher values in the colder regions than in the dry subtropical areas, then large amounts in the tropical LBA and GAME-T regions and smaller amounts in the relatively dry AMMA region. Again, there is fairly large disagreement for the land means between the reanalyses and GLDAS simulations, which also have fairly large disagreements among themselves. This was previously discussed by GSWP, who suggested that seasonal variations would have greater agreement than annual means.

Additional variables and budgets are shown in Roads et al. (2008) and are also posted at http://ecpc.ucsd.edu/projects/ghp/WEBS/.

3. Summary

This study made use of observationally based estimates developed by GEWEX and other global communities as well as products from the current global atmospheric and land reanalyses groups to try to characterize the means and uncertainty in simplified bulk-integrated (atmosphere and surface) water and energy budget variables, including: precipitable water, terrestrial soil moisture, snow equivalent water, atmospheric sensible heat, surface air and skin temperature, precipitation, vertically integrated moisture convergence, evaporation, runoff, vertically integrated dry static energy convergence, latent heat of condensation, atmospheric radiative cooling, surface radiative heating, and sensible and latent heat transfers from the surface to the atmosphere. In particular, this WEBS compared NVAP and ISCCP FD water vapor, SRB and ISCCP FD radiation, GPCP and CPC precipitation, GRDC and EOS runoff, CRU and CPC surface temperature, and HOAP3 and GSST2 turbulent fluxes to four recent atmospheric reanalysis data sets NCEP (R1 and R2), ECMWF (ERA40), and JMA (JRA25) and three GLDAS simulations.

It was demonstrated that for the surface terms, the most constrained system, the models from the GLDAS, probably had slightly better analyses over land for many of the surface water and energy terms, in that the closure was smaller when using these estimates for the observed land surface fluxes. It is interesting, however, that the improvements are perhaps smaller than we might have anticipated (Qu and Henderson Sellers, 1998) a priori, that the spread among the reanalyses models was only slightly larger than the corresponding spread among the GLDAS simulations and that the GLDAS 2 m and surface skin temperature differences were quite different from those in the coupled reanalyses. This indicates that current GLDAS simulations might be improved by moving toward more coupled systems while the reanalyses should be moving toward more constrained systems (i.e. by including observed precipitation, as for example was done for the recent North American Regional Reanalysis. See Mesinger et al. 2006 and Nigam and Ruiz-Barradas 2006). It should also be noted that some of the observations as well as constrained atmospheric and land based analyses seemed to have larger errors than we might have anticipated a priori, indicating that more efforts are needed to observe as well as simulate water and energy budgets.

Despite various errors, it did seem that our anticipated theoretical characterization of the global water and energy cycle could still be readily discerned from available observation and model based data/output. On the average, atmospheric precipitation is balanced with surface evaporation; water vapor convergence over land is balanced by outgoing streamflow to the ocean. On the average, net radiation at the top of the atmosphere is balanced by net transport of energy; net surface radiative heating over land is balanced by the net turbulent transport of energy back to the atmosphere;

atmospheric radiative cooling is balanced by the latent heat of condensation associated with precipitation, the sensible heat transport from the surface and the transport of energy from other regions. In addition, it was clear that the terms in the budgets were quite different depending upon the RHP. For example, low latitude RHPs with relatively warm annual mean climates are energy source regions whereas high latitude RHPs with relatively cold climates are energy sink regions. Despite the observational estimates and more model based atmospheric reanalyses and GLDAS data sets showing these characteristic features, they do so with a 10-20% closure error for annual means and even larger closures for individual regions. RMS errors for 10 year means are even larger and presumably even larger errors occur for shorter (monthly) time scales. Much more work is certainly needed to continue to accurately develop all of the appropriate WEBS data sets and to further reduce perceived errors in global and regional atmospheric, ocean, and land water and energy budgets.

Again, further details are provided by Roads et al. (2008)

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