Uncertainty in Analyzed Water and Energy Budgets at Continental Scales

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Dr. John Roads spent considerable effort to satisfy the broad goals of the Global Water and Energy Budget Experiment (GEWEX), specifically closing the water and energy budgets. Regional Hydroclimatology Projects (RHPs, formerly Continental Scale Experiments, CSEs) have served the overall GEWEX goal of better understanding the global water and energy cycle by providing regional focus on observations, models, analyses and the unique regional physical processes. Roads et al. (2002, henceforth RKS02) used the NCEP Reanalysis 2 and GEWEX observation data sets over RHP domains to evaluate all the RHPs inter relationships among the water and energy budget terms, identifying the impact of the data assimilation on the budgets and characterizing the climatology of key regional atmospheric circulations. While NCEP R2 has been a key tool for weather and climate research for more than a decade, we know that individual analyses retain model uncertainty in the resulting analyses, especially in the physical fields (those not directly related to the assimilated states). While the RKS02 work was developed, one effort in the Coordinated Enhanced Observing Period (CEOP, Phase I) was designed to provide a number of analysis data sets in order to quantify the model uncertainty in operational analyses and reanalyses (Bosilovich et al. 2009).

During CEOP Phase I, data from 8 global analysis systems (research and operational NWP) was collected for the period of Oct 2002 – Dec 2004. The multi-model analysis for CEOP (MAC) homogenized the disparate nature of each of the data sets, provided uniform spatial and temporal structure, and produced mean and variance of the data at 6 hourly, daily and monthly time scales (Bosilovich et al. 2009). Since the original release of the MAC data, both the ECMWF Re-analysis (ERA) Interim and Modern Era Retrospective-analysis for Research and Applications (MERRA) have been included in the data set, to bring the number of analysis systems to 10. While Bosilovich et al. (2009) evaluated the variance of precipitation and outgoing longwave radiation among the analyses, here we consider the regional analysis performed by RKS02 on NCEP R2. The MAC analyses and mean have been area averaged to the regions shown in RKS02, and the evaluation areas have also been updated to include recent additions to GEWEX RHPs of HyMEX, La Plata and Murray Darling.

RKS02 compare the complete energy and water budget annual means to temperature in order to characterize the climate regimes of each of the GEWEX RHPs. They also suggest that the functional relationship shown in the comparison may provide insight to how regional water and energy budgets may change in warmer climates. Figure 1a reproduces the RKS02 comparison of total column water with surface temperature, except that the time period is only for 27 months and for each RHP there are multiple analysis data sets as well as the mean of the analyses. Total column water compares to temperature much the same as shown in RKS02s NCEP R2 study, owing to the adherence of the modeling systems to the Claussius-Clapyeron relationship. Still noteworthy in this figure is that despite each system doing different data analysis and modeling as well as for a limited period of time, there are

small variations about the ensemble relative to each climate regime for each RHP. The distribution of points for the ensemble of the analyses is remarkably close to that shown in RKS02 (their Figure 2a).

Likewise, the ensemble precipitation (Figure 1b) distribution as a function of RHP is also quite comparable to that of RKS02 (their Figure 2c). However, the range of variability among the different analyses precipitation is much more noticeable, and some RHPs also indicate a temperature variation associated with the precipitation (Figure 1b). Variations tend to be greater in the warmer RHPs, but relative to the ensemble mean there is some variability in precipitation even in the cold regions. Apparent outliers are also easily identified in the precipitation comparison. As opposed to many other budget variables, gauge or merged satellite measurements could also be added here to better define the uncertainty of the analysis data (RKS02 added a GPCP curve based on all temperature regimes not just the RHP areas). The main point is that significant variations in precipitation exist among analysis-derived precipitation. While application purposes, such as land model forcing, can always revert to an observation data set, the analyses provide a complete set of water and energy budget terms, and the uncertainty of the precipitation will be reflected in both energy and water budgets.

RKS02 also considered the mean annual cycle of the RHP water and energy budget terms (their figures 9-11). The consideration of multiple analyses adds an extra dimension to such an evaluation. Specifically, the uncertainty of each system also adds more information, and by using several systems we can provide the variance of the data. Figure 2 provides the mean annual cycle of ensemble mean precipitation and evaporation for the Mississippi and Amazon River basins, including 1 standard deviation of the ensemble and the range of values in individual member mean annual cycles. While there is reduction in the variations during the respective cold or dry seasons, the analyses produce a wide range of variations in precipitation during the wet seasons. While the result is not surprising in and of itself, the data allows the quantification of this variation, and also raises the question on what the RKS02 RHP study would have concluded with consideration that the NCEP R2 water and energy budgets include some uncertainty in key physical terms. It is important to note that the MAC data used here is for a limited period in time and also does not include all the variables used in the RKS02 evaluation.

Despite the work of RKS02 and many others, the primary objectives set out at the start of GEWEX have not reached a sufficient closure. GEWEX is in the process of revising the imperative efforts needed to make progress in our understanding and application of the Earth's water and energy cycles, and certainly analysis and reanalysis data will play a considerable role in that, simply because we cannot directly observe all the important components. It is also apparent that, at this time, no one single analysis or reanalysis system can be relied upon to provide the benchmark water and energy budget globally, regionally, and at all times. One aspect of GEWEX's mission is making improvements to the modeling systems that we must rely on, and to do that, global and regional model data is needed, along with sufficient observations to constrain the model results. The RHPs, then, will continue to play a

significant role in the GEWEX science plan. Additionally, collecting and homogenizing the analysis data was not a straightforward task, and was only completed with support of a funded science project.

To continue to improve models and data analysis systems, the availability of model data to a wide range of researchers is required. There are possibilities and opportunities for ongoing sources of model data to support GEWEX. Atmospheric reanalyses have become a key science utility, and there are many more options and available systems now than at the time RKS02 performed their study. However, the number of centers providing reanalysis is relatively low, with new data only coming in 5 year cycles, at best. On the other hand, THORPEX Interactive Grand Global Ensemble (TIGGE) is providing the analysis and forecast from a larger number of operational NWP centers for a few years and continuing on in time (Bougeault et al. 2010). The main disadvantage of the TIGGE data set is that not all the water and energy budget terms considered by RKS02 are included in their data streams, and even more important, not all the data providers include all the requested variables making comparisons more difficult. Regional modeling experiments have also provided useful insight into the variation of water and energy budgets, and the transferability of models among the different RHPs (Takle et al 2007). Regardless of the source(s) of the model and analysis data, the reduction of uncertainty of the analyses and their based on GEWEX research will provide one fundamental metric to determine GEWEX's success.

Dataset:

The 27-month MAC data set, including all 10 members and the ensemble mean and standard deviation, at 6-hourly, daily, and monthly averages is available in GRIB and NetCDF formats with documentation at: http://gmao.gsfc.nasa.gov/research/modeling/validation/ceop.php Also on this page are a document and spreadsheet detailing how the MAC data set was developed from the generous data contributions of participating NWP and research centers.

References:

Bosilovich, M.G., D. Mocko, J.O. Roads, and A. Ruane, 2009: A Multimodel Analysis for the Coordinated Enhanced Observing Period (CEOP). J. Hydrometeor., 10, 912–934.

Bougeault, Philippe, and Coauthors, 2010: The THORPEX Interactive Grand Global Ensemble. *Bull. Amer. Meteor. Soc.*, **91**, 1059–1072. doi: 10.1175/2010BAMS2853.1

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

Takle, E.S., J. Roads, B. Rockel, W.J. Gutowski Jr., R.W. Arrit, I. Meinke, C.G. Jones, and A. Zadra, 2007: Transferability intercomparison: An opportunity for new insight on the global water cycle and energy budget, Bull. Amer. Soc., 88, 375-384

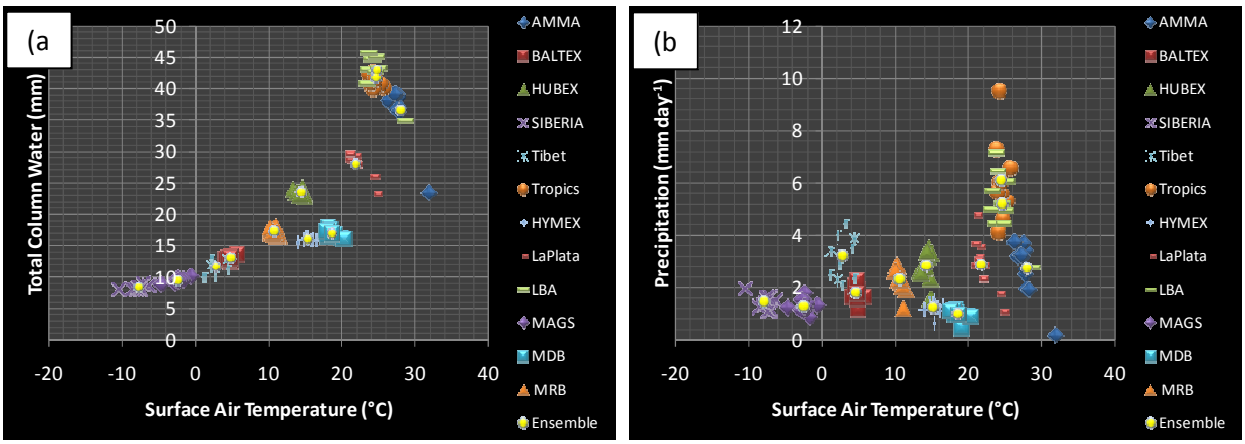

Figure 1 As in RKS02 Figure 2, annual average (except for Oct 2002-Dec 2004) surface temperature compared to (a) total column water and (b) precipitation for each of the Regional Hydroclimatology Projects currently participating in GEWEX. However, instead of only one reanalysis, each analysis system contributing to the Multi-model Analysis for CEOP (MAC) is given a marker, so that the range of analyses is evident in the evaluation. The ensemble of analyses is also included (yellow circle).

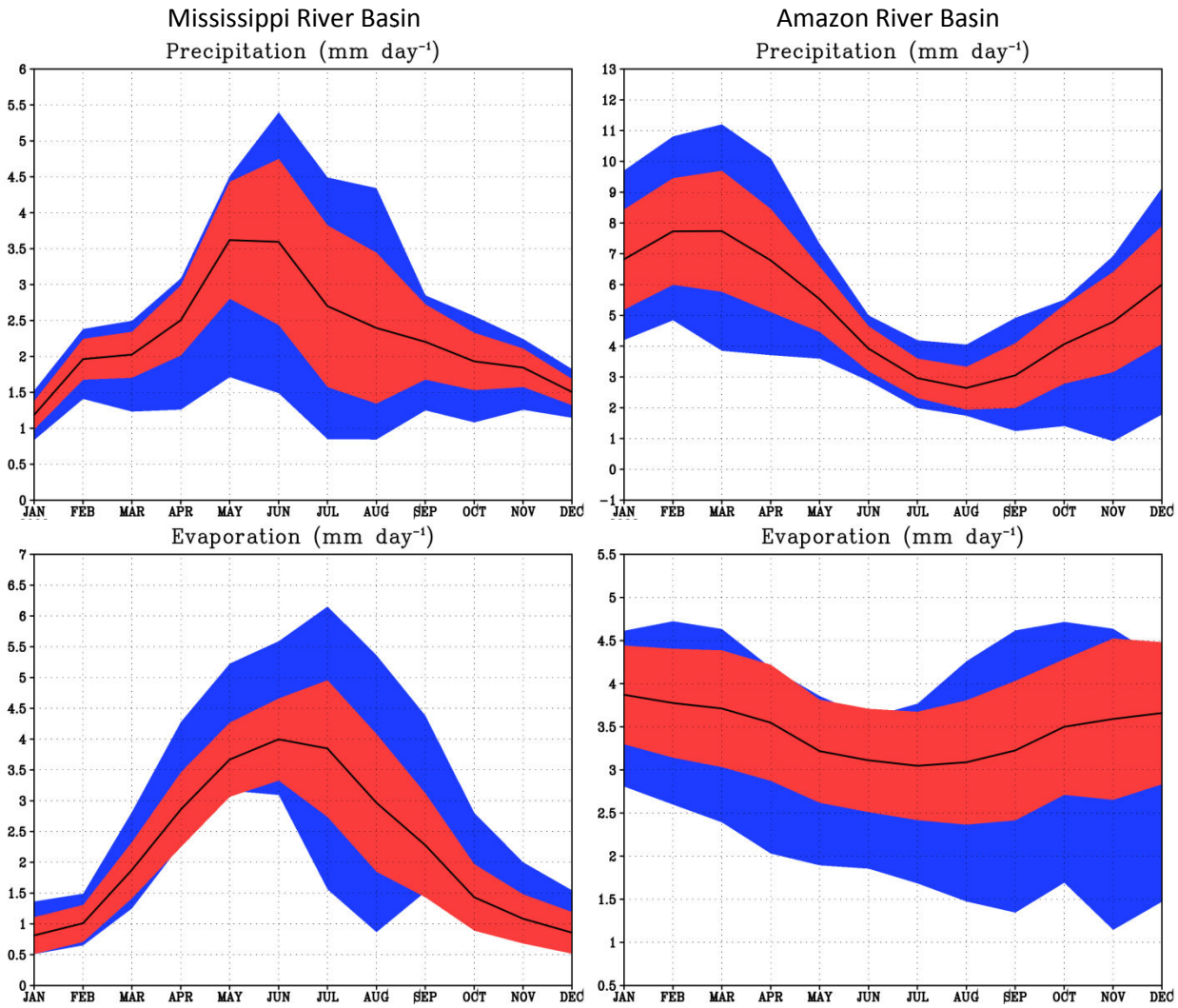

Figure 2 Mean annual cycle (Oct 2002 – Dec 2004) of precipitation (top) and evaporation (bottom) for the Mississippi River Basin (left) and Amazon River Basin (right) area averages. The black line is the ensemble of 10 analyses data, while the red area shows 1 standard deviation of the ensemble mean. The blue area shows the range of analyses mean annual cycles.