WEATHER AND CLIMATE ANALYSIS OF WATER VAPOR TRANSPORT AND SURFACE INTERACTIONS COUPLING TO PRECIPITATION PROCESSES

Final Report

1 June 2009 – 31 May 2014

Paul A. Dirmeyer (co-PI*)
Center for Ocean-Land-Atmosphere Studies
Institute of Global Environment and Society
11125 Snowshoe Lane
Rockville, Maryland 20852 USA

NASA Grant: **NNX09AI84G**

Year four of our research plan has focused on synthesis of previous results, including submission of the central research paper presenting the climatology of evaporative sources of precipitation estimated from MERRA, and its variations for cases of extremes (droughts and floods. The core collaborative work with Bosilovich et al. (GSFC) with the GEOS5 GCM still has yet to be completed, and a no-cost extension for the project will be requested. Results from this research has been presented at multiple venues as published, as indicated at the end of the report.

Comparing evaporative sources of terrestrial precipitation and their extremes in MERRA using relative entropy

Dirmeyer et al. (2014) present a global synthesis of results using the Quasi-Isentropic Back Trajectory (QIBT) method of estimating the evaporative source regions for precipitation, using MERRA as the source of meteorological input data. We also performed estimates using the MERRA-Land product of Reichle et al. (2012), which corrects for MERRA precipitation biases and canopy interception biases in the land surface model. Figure 1 shows the global difference in uncorrected minus corrected evaporative sources. The impact of positive precipita-

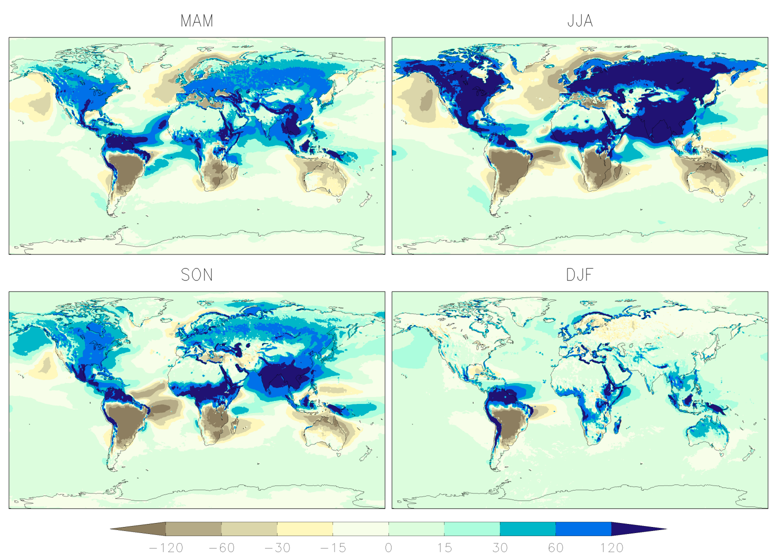


Figure 0. Difference in total seasonal evaporative source (kg m^{-2}) for precipitation over ice-free land MERRA-Land minus MERRA.

* PI: Michael G. Bosilovich, Global Modeling and Assimilation Office, Earth Sciences Division, NASA/GSFC Code 610.1, Greenbelt, MD 20771-0001, 301-614-6147, (fax 301-614-6297)

tion biases over much of the Northern Hemisphere, and the excessive canopy evaporation, is evident in the excessive blue coloration, peaking during JJA. Negative biases are evident across much of the Southern Hemisphere.

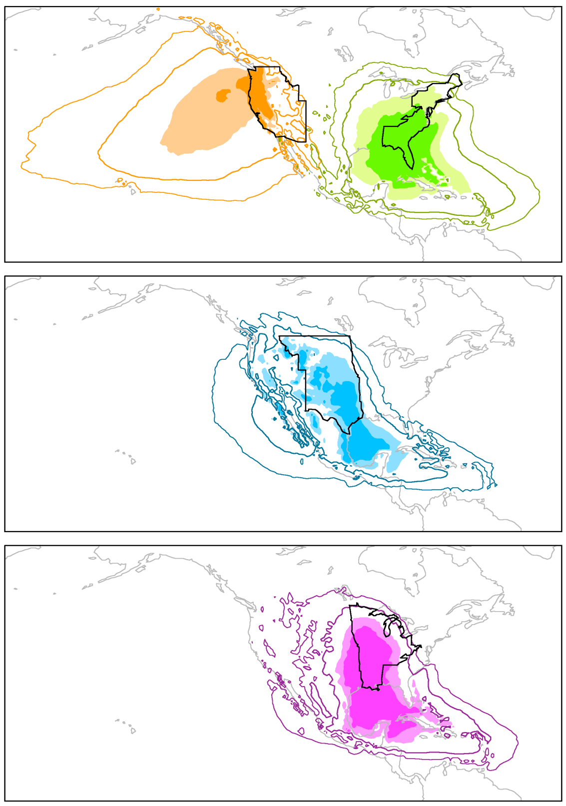
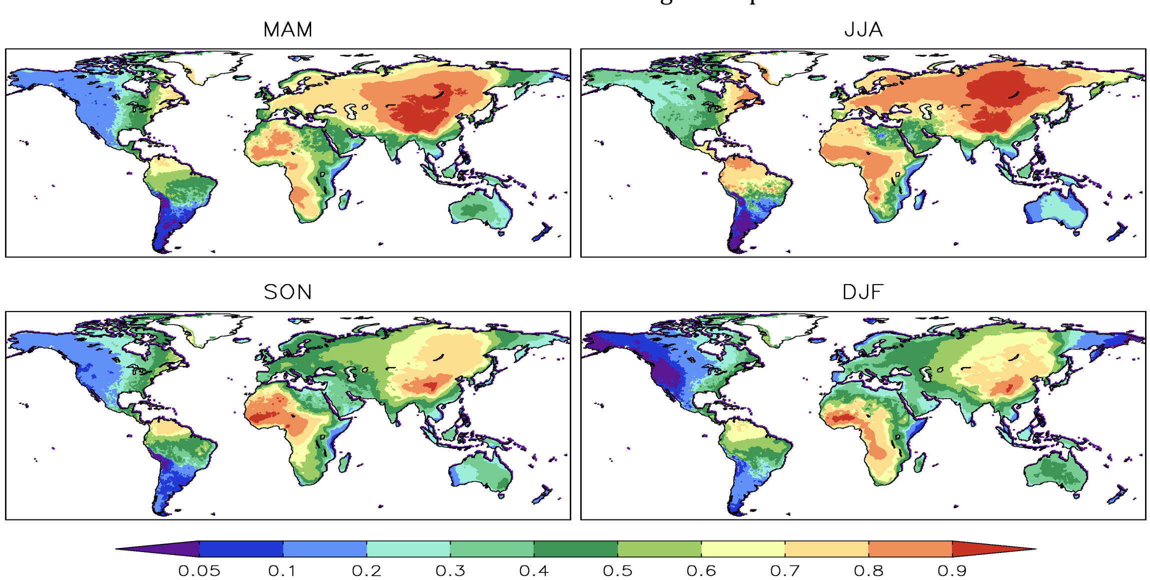


Figure 2. Annual mean evaporative source for precipitation over the outlined states, expressed as the fraction originating from each MERRA grid box (normalized so the global sum for each equals 1). The contours represent 50 and 100 PPM, shading is greater than 200 and 300 PPM.

Figure 2 shows the annual total evaporative source for precipitation over four regions of the conterminous United States. This gives a clear picture of the regional variations in the source of evaporated moisture that ultimately supply rain and snow over different parts of the country. Figure 3 shows estimates of the fraction of precipitation at each terrestrial point that originated as evaporation from land, as opposed to ocean.

Relative entropy (also known by other names, e.g., Kullback–Leibler divergence) is an objective quantification of the similarity between two PDFs. It is frequently applied to one-dimensional probability distributions, but the mathematics are valid at higher dimensionalities as well. We apply this method to the two-dimensional patterns of evaporative source distributions to determine whether their normalized PDFs are significantly different from their climatological patterns during situations of drought or flood. If the

Figure 3. Fraction of total precipitation originating as evaporation from land.



PDF for extreme precipitation is statistically similar to climatology (relative entropy is low), we may conclude that the general circulation and remote conditions are not the driving factor behind precipitation extremes. Previous reports have shown the results of those calculations.

The contribution of irrigation water to precipitation

Irrigation is an important human activity over the earth surface that has strong local and regional impacts and has received increasing attention in climate research. There is no explicit irrigation in MERRA. We used data of irrigation-caused ET increase from a hydrological model that has sophisticated considerations on irrigation and other human activities, and add that to MERRA ET. QIBT is used to estimate the contribution of the ET increase to precipitation. Results show substantial contributions to precipitation over heavily irrigated Asian regions (Fig 4). The contribution of irrigation to precipitation is much less than irrigation caused ET increase over most areas, and for the same ET increase, precipitation increases are greatest over wet areas, where it is most easily trigged. ET increases over dry areas is mostly transported by prevailing winds to places where precipitation can be triggered. Results have been presented in a manuscript (Wei et al. 2012b).

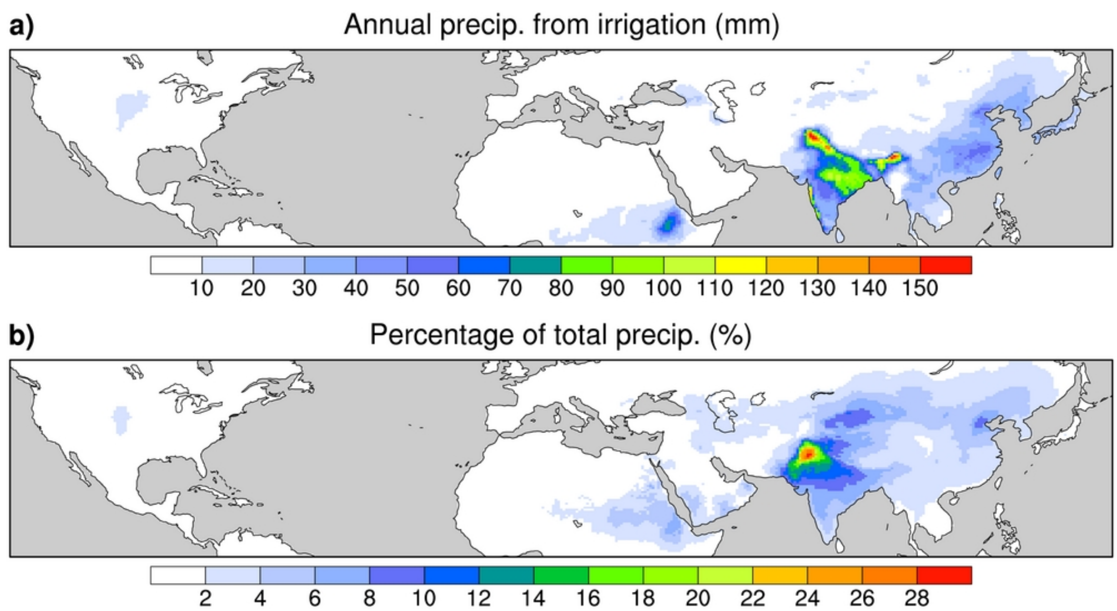


Figure 4. *Results of the 10-year QIBT analysis that shows (a) the mean annual total precipitation from the ET of irrigation and (b) the percentage of the total precipitation that is from the ET of irrigation.*

Water vapor sources for Yangtze River Valley (YRV) precipitation and its implications

YRV is selected as a region for detailed study using the back-trajectory method because of the frequent floods over there. Another reason is there is no spurious decadal variation in MERRA precipitation over this region, which is scarce in reanalysis datasets because of the changes in observation systems. This study not only investigated the moisture sources for YRV rainfall, but also discussed the implications of the results for land-atmosphere interactions and rainfall prediction. Results have been published in Wei et al. (2012a) and presented by Wei (2011).

Figure 5 shows that although the local and surrounding land region is the main moisture sources for YRV rainfall (Figure 2b), the correlations between the moisture contributions and rainfall (Figure 2a) and especially the correlations between the moisture contributions and the total ET are low over this region. Thus, ET over this land region is not very useful for rainfall prediction (Fig 5d). In addition, it is also found that soil moisture does not control the variation of ET over this region because the soil is very wet and the ET variation is mainly controlled by available energy (Dirmeyer 2011). Therefore, the two components that links soil moisture to precipitation (SM-ET and ET-P) are both weak over this region, so soil moisture over this region cannot provide much information for precipitation prediction over YRV.

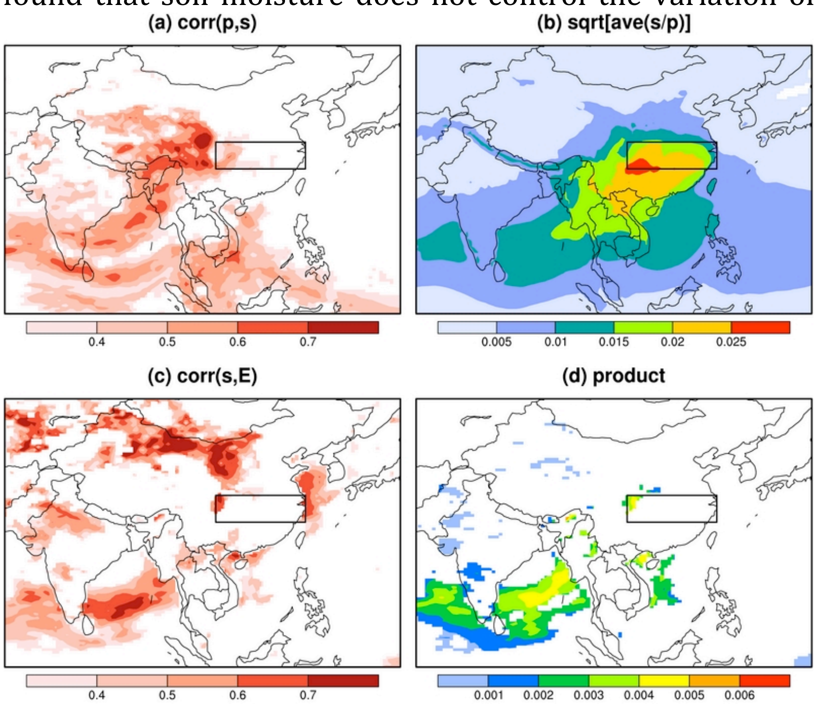


Figure 5. *(a) June-July 1979-2010 interannual correlation between total precipitation over YRV and its evaporative sources; (b) Square root of average percentage of evaporative source that contributes to YRV precipitation; (c) Interannual correlation between total ET and the evaporative contribution to YRV rainfall during June-July; (d) The product of (a)-(c) showing the critical evaporative sources that may contribute to the prediction of YRV precipitation. Only the areas significant at 95% level are shaded.*

Using MERRA and MERRA-Land analyses to quantify land-atmosphere coupling.

Dirmeyer (2011) presented a terrestrial coupling metric that can be calculated from time series of soil moisture and surface fluxes. Many previous studies have concentrated on the temporal correlation between soil moisture and evaporation (as well as sensible heat flux) as an indicator of the degree of control of land surface states on surface fluxes, and thus possibly weather and climate. By multiplying this correlation by the standard deviation of the flux, the degree of impact can be estimated as well. This is mathematically equivalent to the product of the slope of the regression (flux versus soil moisture) and the standard deviation of soil moisture.

We found that global seasonal maps of this index were remarkably similar whether the source of data were from offline simulations of land surface models, coupled land-atmosphere model simulations or reanalyses. However, some notable outliers were found in the patterns from MERRA that were traceable to parameter settings in the land surface scheme in GEOS, and the assimilation of precipitation (auxiliary material in Dirmeyer 2011). Collaboration with Q. Lu and R. Reichle of NASA/GSFC helped to pinpoint these problems in MERRA and MERRA-Land analyses.

Publications:

Dirmeyer, P. A., J. Wei, M. G. Bosilovich, and D. M. Mocko, 2014: Comparing evaporative sources of terrestrial precipitation and their extremes in MERRA using relative entropy. J. Hydrometeor., 15, 102-116, doi: 10.1175/JHM-D-13-053.1.

Dirmeyer, P. A., B. A. Cash, J. L. Kinter III, T. Jung, L. Marx, M. Satoh, C. Stan, H. Tomita, P. Towers, N. Wedi, D. Achuthavarier, J. M. Adams, E. L. Altshuler, B. Huang, E. K. Jin, and J. Manganello, 2012: Simulating the hydrologic diurnal cycle in global climate models: Resolution versus parameterization. *Climate Dyn.*, **39**, 399-418, doi: 10.1007/s00382-011-1127-9.

Dirmeyer, P. A., 2011: The terrestrial segment of soil moisture-climate coupling. *Geophys. Res. Lett.*, **38**, L16702, doi: 10.1029/2011GL048268.

Wei, J. and P. A. Dirmeyer, D. Wisser, M. G. Bosilovich, and D. M. Mocko, 2013: Where does the irrigation water go? An estimate of the contribution of irrigation to precipitation using MERRA. *J. Hydrometeor.*, **14**, 275-289, doi:10.1175/JHM-D-12-079.1.

Wei, J., P. A. Dirmeyer, M. G. Bosilovich, and R. Wu, 2012: Water vapor sources for Yangtze River Valley rainfall: Climatology, variability, and implications for rainfall forecasting, *J. Geophys. Res.*, **117**, D05126, doi:10.1029/2011JD016902.

Wei, J., and P. A. Dirmeyer, 2012: Dissecting soil moisture-precipitation coupling. *Geophys. Res. Lett.*, **39**, L19711, doi:10.1029/2012GL053038.

Presentations:

Dirmeyer, P. A., 2013: Connections between precipitation extremes and evaporation sources. Mini-symposium on land-atmosphere interactions, Wageningen University, Netherlands, 15 April 2013.

Dirmeyer, P. A., J. Wei, M. Bosilovich, 2013: Comparing evaporative sources using relative entropy – a tool to diagnose the origins of droughts. American Meteorological Society, 27th Conf. on Hydrology, TJ3.4.

Dirmeyer, P. A., 2012: Evaporative moisture sources for African precipitation and diagnosis of extremes. Workshop on the Climate Dynamics of Tropical Africa, Johns Hopkins University, Baltimore MD, 15 November 2012.

Dirmeyer, P. A., J. Wei, M. G. Bosilovich, and D. M. Mocko, 2012: A water cycle perspective on the connection between precipitation extremes and circulation anomalies. 4th WCRP International Conference on Reanalyses, Silver Spring, Maryland, USA.

Dirmeyer, P. A., 2012: Land-Climate Interactions – Past, Present and Future. Seminar presented at the Department of Marine, Earth, & Atmospheric Sciences, North Carolina State University, 31 July 2012.

Dirmeyer, P. A., 2011: A global perspective on local land-atmosphere coupling – present and future. (invited) American Geophysical Union Fall Meeting, San Francisco, CA, H24E-01.

Dirmeyer, P. A., J. Wei and M. G. Bosilovich, 2011: Critical sources of evaporated moisture for terrestrial precipitation. WCRP Open Science Conference, Denver, Colorado, USA, C10-M23B.

Dirmeyer, P. A., 2011: "Land-Atmosphere Interaction and the Global Water Cycle" Seminar presented at the Department of Atmospheric, Oceanic and Earth Science, George Mason University, 5 April 2011.

Dirmeyer, P. A., 2009: "Land-atmosphere interaction and the water cycle" Seminar presented at SEAS Colloquium in Climate Science (SCiCS), Columbia University, 3 December 2009.

Mocko, D. M., M. G. Bosilovich, A. da Silva, P. A. Dirmeyer, and J. Wei, 2012: Water vapor tracers in MERRA replay mode using the NASA/GSFC GEOS-5 GCM. 4th WCRP International Conference on Reanalyses, Silver Spring, Maryland, USA.

Wei, J., P. A. Dirmeyer, D. Wisser, M. Bosilovich, and D. M. Mocko, 2013: Where does the irrigation water go? An estimate of the contribution of irrigation to precipitation using MERRA. American Meteorological Society, 27th Conf. on Hydrology, J2.4.

Wei, J., and P. A. Dirmeyer, 2013: Dissecting soil moisture-precipitation coupling. American Meteorological Society, 27th Conf. on Hydrology, 4B.6.

Wei, J., P. A. Dirmeyer, M. G. Bosilovich, and D. M. Mocko, 2012: Where dies the irrigation water go? An estimate of the contribution of irrigation to precipitation using MERRA. 4th WCRP International Conference on Reanalyses, Silver Spring, Maryland, USA.

Wei, J., 2011: Water vapor sources for the Yangtze River Valley rainfall: Climatology, variability, and implications for rainfall forecasting. Oral presentation at Beijing international conference on climate change, October 20, Beijing, China.

Wei, J., P. A. Dirmeyer, M. G. Bosilovich, and D. M. Mocko, 2011: Where does the irrigation water go? An estimate of the contribution of irrigation to precipitation using MERRA. 4th WCRP International Conference on Reanalyses, Silver Spring, Maryland, USA.