3.8

THE WATER CYCLE AND PRECIPITATION RECYCLING DURING THE 1993 UNITED STATES FLOOD

Michael Bosilovich, Larry Takacs, Siegfried Schubert and Gregory K. Walker
NASA Data Assimilation Office

1 INTRODUCTION

During June and July of 1993, devastating and persistent rainfall caused substantial damage in the Midwest United States primarily focused on the Mississippi River Basin. Above normal springtime rains primed the region for flooding. The resulting wet soil was thought to be a major source of water for the heavy summer precipitation. On the other hand, northward moisture transport was extremely intense during the summer. There has been considerable discussion on whether the source of water for the intense precipitation is local (precipitation recycling) or remote (transported from the oceans).

Figure 1 shows the observed precipitation anomalies for June and July 1993, when the heaviest precipitation occurred. During June, large amounts of precipitation fell across the north central and north western United States. In July, a concentrated center of extremely heavy precipitation occurred in the central United States. Some observing stations reported more than 11 inches of precipitation for during July. The character of the precipitation that occurs in June is quite different from that in July. Figure 2 shows the time series of daily precipitation averaged over the central United States. In June, synoptic scale cyclones crossed the US triggering the precipitation events (note the 4-5 day periodicity). While in July, significant precipitation occurred almost every day.

There have been numerous studies testing the impact of the surface wetness on the extreme precipitation. The consensus of modeling studies is that wet soil contributed to the extreme precipitation (e.g. Beljaars et al. 1996, Viterbo and Betts, 1999 and Bosilovich and Sun, 1999). The wet surface conditions provide and environment of moist instability, but not necessarily a source of water (Dirmeyer and Brubaker, 1999; Bosilovich and Schubert, 2001).

In this study, we have implemented passive tracers to diagnose the geographic source of water for precipitation, called Water Vapor Tracers (WVT), into the NASA Data Assimilation Office (DAO) Data Assimilation System (DAS) (Bosilovich and Schubert, 2002). The WVT diagnostics can produce detailed budgets of the geographical sources of water that precipitates in any region, and they consider physical and dynamical tendencies at the model time step. The 1993 summer has been reanalyzed with the new WVT diagnostics to better understand the local and remote source of water for precipitation during the 1993 flood. Because the DAS also uses observations of water in the atmospheric hydrologic budget, we will also evaluate the impact of the observations on the local and remote sources of water and on the precipitation in the DAS.

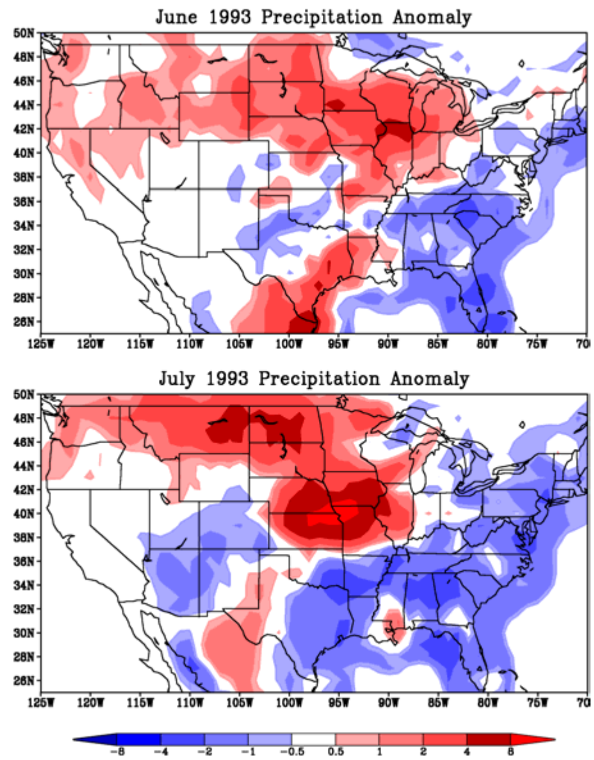


Figure 1 Observed precipitation anomaly (mm day^{-1}) from the NOAA CPC gridded gage data (Higgins et al. 1996).

Corresponding Author Address: Your Michael G. Bosilovich, Data Assimilation Office, NASA GSFC Code 910.3, Greenbelt, MD 20771 email: mikeb@dao.gsfc.nasa.gov

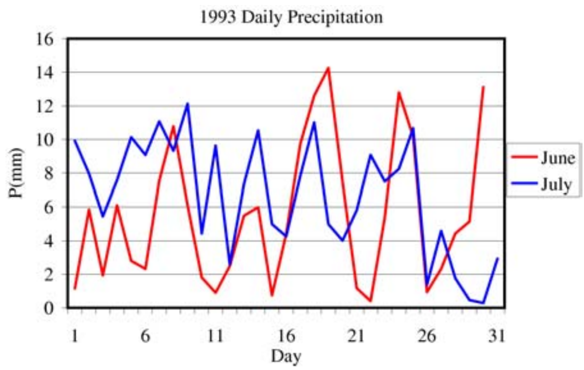


Figure 2 Daily precipitation time series for June and July 1993 from Higgins et al. (1996) gridded gage data. The data were area averaged over 37° – 46° Lattitude and –100° - -87° longitude.

2 METHODOLOGY

2.1 FV Data Assimilation System

The atmospheric numerical model used in this study is called the Finite Volume General Circulation Model (FVGCM). The atmospheric dynamics are based on the flux form semi-Lagrangian advection (Lin and Rood 1996, 1997). Collins et al. (2002) provide a comprehensive description of the dynamical core. The atmospheric physics are from the National Center for Atmospheric Research (NCAR) Community Climate Model version 3 (CCM3) including the convection, radiation, boundary layer and land surface parameterizations (Kiehl et al. 1998 and Bonan 1998). The resulting climate and atmospheric circulation are discussed by Chang et al. (2001). The FVDAS analysis is performed by the Physical-space Statistical Analysis System (PSAS, Cohn et al. 1998), which also corrects long-term biases (Dee and da Silva, 1998; Dee and Todling, 2001), to compute the tendencies or increments that account for the forecast error in the model's prognostic equation.

2.2 WVT Formulation

The implementation of water vapor tracers utilizes existing generic passive tracers regarding advective transport (semi-lagrangian as in Lin and Rood, 1996) and boundary layer turbulent transport processes, but computes the physics tendencies of tracer water due to precipitation processes proportional to the prognostic water vapor variable. The prognostic equation for water vapor is,

$$\frac{\partial q}{\partial t} = -\nabla_3 \cdot (qV) + \left.\frac{\partial q}{\partial t}\right|_{turb} + \left.\frac{\partial q}{\partial t}\right|_{cond} + \left.\frac{\partial q}{\partial t}\right|_{revp} + \left.\frac{\partial q}{\partial t}\right|_{D} + \left.\frac{\partial q}{\partial t}\right|_{A} \tag{1}$$

At any one point in the atmosphere, the physical tendencies that act on the water vapor are turbulence (*turb*, includes surface evaporation), condensation (*cond*), rain evaporation (*revp*), redistribution by the convection (*D*) and a source/sink from the observational analysis (A). The prognostic equation for any one tracer is,

$$\frac{\partial q_T}{\partial t} = -\nabla_3 \cdot (q_T V) + \left.\frac{\partial q_T}{\partial t}\right|_{turb} + E_{surf} + f_C \left.\frac{\partial q}{\partial t}\right|_{cond} + f_R \left.\frac{\partial q}{\partial t}\right|_{revp} + f_D \left.\frac{\partial q}{\partial t}\right|_{D} + f_A \left.\frac{\partial q}{\partial t}\right|_{A} \tag{2}$$

Turbulent tendency of the water vapor tracers occurs whenever tracer water is present, but surface evaporation may only be occurring in the tracer's predefined source region. We assume that tracer water is well mixed with the total water vapor. The physical tendencies of tracer water by precipitation processes are computed proportional to the tendencies of total water vapor. Proportionality relationships for condensation (f_C), rain evaporation (f_R) and convection (f_D) are given by,

$$f_C(L) = \frac{q_T(L)}{q(L)}$$

$$f_R(L) = \frac{\int_1^{L-1}\left(\left.\frac{\partial q_T}{\partial t}\right|_{cond} + \left.\frac{\partial q_T}{\partial t}\right|_{revp}\right)d\sigma}{\int_1^{L-1}\left(\left.\frac{\partial q}{\partial t}\right|_{cond} + \left.\frac{\partial q}{\partial t}\right|_{revp}\right)d\sigma} \tag{3}$$

$$f_D(L) = \begin{cases} \dfrac{q_T(L)}{q(L)} & \left.\dfrac{\partial q}{\partial t}\right|_{D} < 0 \\[2ex] \dfrac{\int_{LM}^{L+1} \left.\frac{\partial q_T}{\partial t}\right|_{D} d\sigma}{\int_{LM}^{L+1} \left.\frac{\partial q}{\partial t}\right|_{D} d\sigma} & \left.\dfrac{\partial q}{\partial t}\right|_{D} > 0 \end{cases}$$

L is a given model level, LM is the lowest model level, integrations are done on the sigma vertical coordinate.

The proportionality rules can be summarized by: sinks of tracer water consider the ratio of tracer water to water vapor at a level (e.g. condensation of water), while the sources of tracer water consider the ratio of vertically integrated stores of tracer water and water vapor (e.g. reevaporation of falling water). Convection (D) acts to redistribute water from lower levels to upper levels. For any regional WVT, the analysis acts as a sink proportional to the total water content, so that, for a sink: $f_A = f_C$ and for a source, $f_A=0$ because a separate WVT is used for all analysis water sources.

The tracer distribution is known at each three-dimensional gridpoint at every time step. Therefore, the WVTs can be processed as any model variable. We will generally look at tracer precipitation and total column water.

$$P_T = -\frac{p_s}{g}\int_1^{LM}\left(\frac{\partial q_T}{\partial t}_{cond} + \frac{\partial q_T}{\partial t}_{revp}\right)d\sigma, \qquad (4)$$

$$Q_T = \frac{p_s}{g}\int_1^{LM} q_T \; d\sigma. \qquad (5)$$

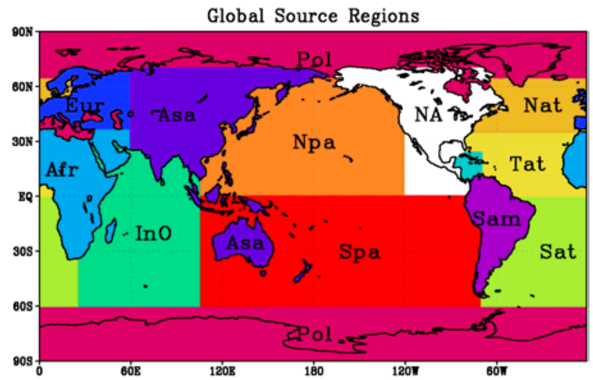
Likewise, the tracer tendencies for the analysis increment can be written as vertical integrals of sources and sinks.

2.3 WVT Configuration

Regional and global WVTs use surface evaporation (from predefined areas) as the source of water. Because, each WVT consumes the computing resources of a prognostic variable in the system, the number of WVTs in the system is finite, and must be chosen to address specific issues. In this study, the WVTs are concentrated on the continental United States, delineating potential key sources of water (Figure 3). For example, the oceanic sources of water off the west coast of Mexico (Baja Oceanic) and the oceanic sources in the Caribbean Sea are specifically tagged (Dirmeyer and Brubaker, 1999). The global tracers represent large continental and oceanic sources of water. The global WVTs primarily help close the water balance, preventing any large source of water from being undetected. Here, we have identified 22 WVTs with an evaporative source. An additional WVT is used to identify the water that enters the system as a source from the analysis increment.

3 SUMMARY

This brief paper provides the background information for this study. In the presentation, we will validate the water cycle with available observations. Using the WVTs, we will break down the geographical sources of water for the 1993 United States Flood in the analysis system, starting in the springtime through the end of the summer. We will also evaluate the impact of the assimilation of water vapor on the water cycle and the dynamical circulation.



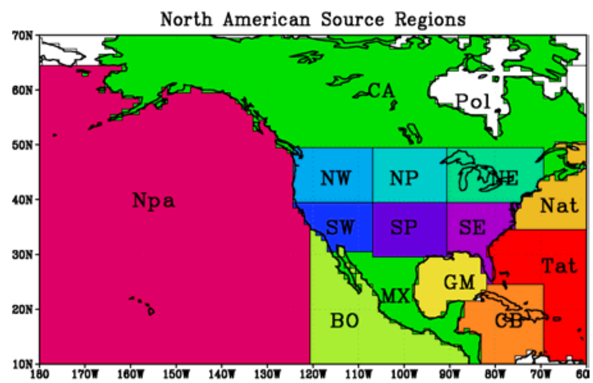


Figure 3 Map showing (a) the global continental and oceanic sources of water, and (b) the North American regional sources of water. The large-scale sources are Nps- north Pacific Ocean, Spa – south Pacific ocean, Sat – south Atlantic Ocean, InO – Indian Ocean, Tat – Tropical Atlantic Ocean, Nat – north Atlantic Ocean, Eur – Europe, Asa – Asia and Australia, Sam – South America, Afr – Africa and Pol – Polar. The regional sources are SE – South East, SP – Southern Plains, SW – South West, NW – North West, NP – Norhtern Plains, NE – North East, CA – Canada, MX – Mexico, BO – Baja Oceanic, CB – Caribbean Sea, and GM – Gulf of Mexico.

4 REFERENCES

Beljaars, A.C.M., P. Viterbo, M. Miller, and A. Betts, 1996: The anomalous rainfall over the United States during July 1993: Sensitivity to land surface parameterization and soil moisture anomalies. *Mon. Wea. Rev*., **124**, 362 - 383.

Bonan, G. B., 1998: The land surface climatology of the NCAR land surface model coupled to the NCAR Community Climate Model, *J. Clim.,* **11**, 1307 – 1326.

Bosilovich, M. G., and S. D. Schubert, 2001: Precipitation recycling in the GEOS-1 data assimilation system over the central United States. *J. Hydromet*., **2**, 26 – 35.

Bosilovich M. G., and S. D. Schubert, 2002: Water vapor tracers as diagnostics of the regional hydrologic cycle. J. Hydromet., *J. Hydromet.,* **3**, 149-165.

Bosilovich, M. G., and W.-Y. Sun, 1999: Numerical simulation of the 1993 Midwestern flood: Land-atmosphere interactions. *J. Clim*., **12**, 1490-1505.

Chang, Y., S. D. Schubert, S.-J. Lin, S. Nebuda and D.-W. Shen, 2001: The climate of the FVCCM-3 Model, NASA/TM-2001-104606, vol. 20, pp. 127.

Cohn, S. E., A. da Silva, J. Guo, M. Sienkiewicz, and D. Lamich, 1998: Assessing the effects of data selection with the DAO physical-space statistical analysis system. *Mon. Wea. Rev.,* **126,** 2913-2926.

Collins, W. D., J. J. Hack, B. A. Boville, P. J. Rasch, D. L. Williamson, J. T. Kiehl, B. Brieglib, C. Bitz, S.-J. Lin, and R. B. Rood, 2002: Description of the NCAR Community Atmosphere Model (CAM2), *NCAR/TN In Preparation*.

Dee, D. P., and A. M. da Silva, 1998: Data assimilation in the presence of forecast bias. *Q. J. R. Meteorol. Soc*., **124** 269-295.

Dee, D. P. and R. Todling, 2000: Data assimilation in the presence of forecast bias: The GEOS moisture analysis, *Mon. Wea. Rev*., **128**, 3268-3282.

Dirmeyer, P. A. and K. L. Brubaker, 1999: Contrasting evaporative moisture sources during the drought of 1988 and the flood of 1993. *J. Geophys. Res*., **104**, 19383-19398.

Higgins, R. W., J. E. Janowiak, and Y. Yao, 1996: A gridded hourly precipitation data base for the United States (1963–1993), Climate Predictions Center Atlas 1, National Centers for Environmental Prediction, 47 pp.

Kiehl, J. T., J. J. Hack, G. B. Bonan, B. A. Boville, D. L. Williamson, and P. J. Rasch, 1998: The National Center for Atmospheric Research Community Climate Model (CCM3), *J. Clim.,* **11**, 1131-1149.

Lin, S.-J., and R. B. Rood, 1996: Multidimensional flux form semi-lagrangian transport schemes, *Mon. Wea. Rev*., **124**, 2046 – 2070.

Lin, S.-J., and R. B. Rood, 1997: An explicit flux-form semi-Lagrangian shallow-water model on the sphere, *Q. J. Roy. Meteor. Soc*., **123**, 2477 – 2498.

Presented at the Symposium on Observing and Understanding the Variability of Water in Weather and Climate, 2003 AMS Annual Meeting, Long Beach CA, February 2003.