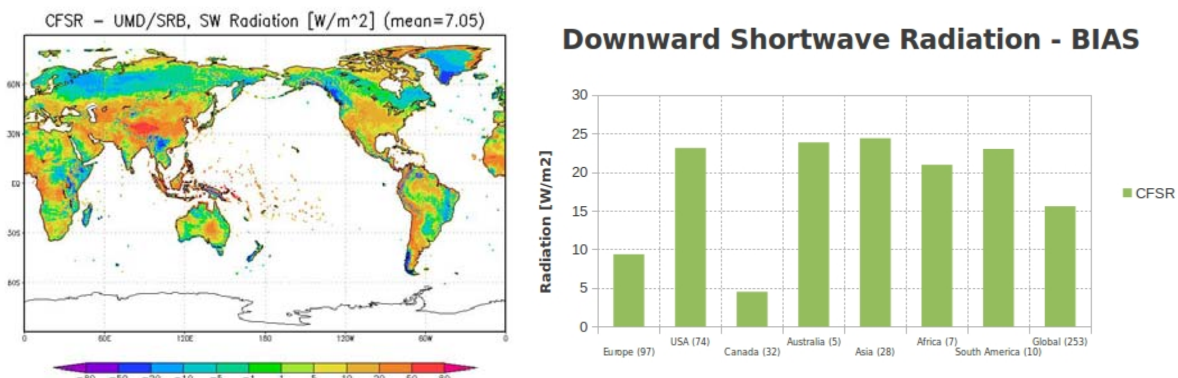
Project Title: Regional and global evaluation of CFS-R and 20th Century Reanalysis for the terrestrial water cycle
PI: Eric F. Wood, Princeton University
Final Report
Grant #: NA11OAR4310082 (GC11-555)

1. Results and Accomplishments

We have focused on three main areas of evaluation: a) annual mean global and continental precipitation and surface radiation budgets; b) terrestrial water budgets at monthly to inter-annual time scales and basin scale; c) large-scale meteorological and soil moisture droughts; and d) precipitation and temperature extremes at the daily scale.

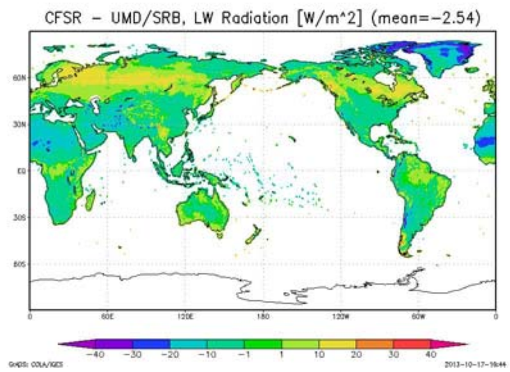
a) Global and Continental Analysis of monthly precipitation and surface radiation. In terms of water and energy balances, precipitation and incoming radiation are the most important drivers land surface hydrology. Their evaluation can be based on the direct comparison with global datasets derived from in situ/satellite observations and on the analysis of the output of hydrological models in terms of generated runoff.

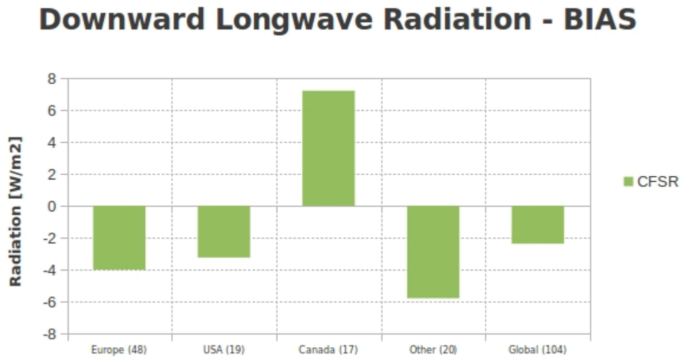
Incoming shortwave radiation from CFSR were compared with the satellite based estimates from U. Maryland (UMD) and the NASA Surface Radiation Budget (SRB) for 1984-2009. The CFSR shows a global positive bias of about 7 W/m^2 (Figure 1) with significant local variations. For high latitudes, the bias is generally slightly negative, while it is strongly positive sub-tropical to mid-latitude regions, with the highest peak over Tibet and southern China, where the bias is greater than 50 W/m^2.



Figures 1 and 2

Similar errors are obtained when comparing against in-situ data from 220 FLUXNET stations globally (Figure 2). The results for large regions show positive biases of about 15 W/m2, with the lowest values in Europe and Canada. The same comparison was done for the incoming longwave radiation. The CFSR shows a global negative bias of about -2.54 W/m^2. Locally, the CFSR shows an opposite behavior over high latitude regions, where the bias is mostly positive, and the northern equatorial regions, where the bias tends to be negative (Figure 3).

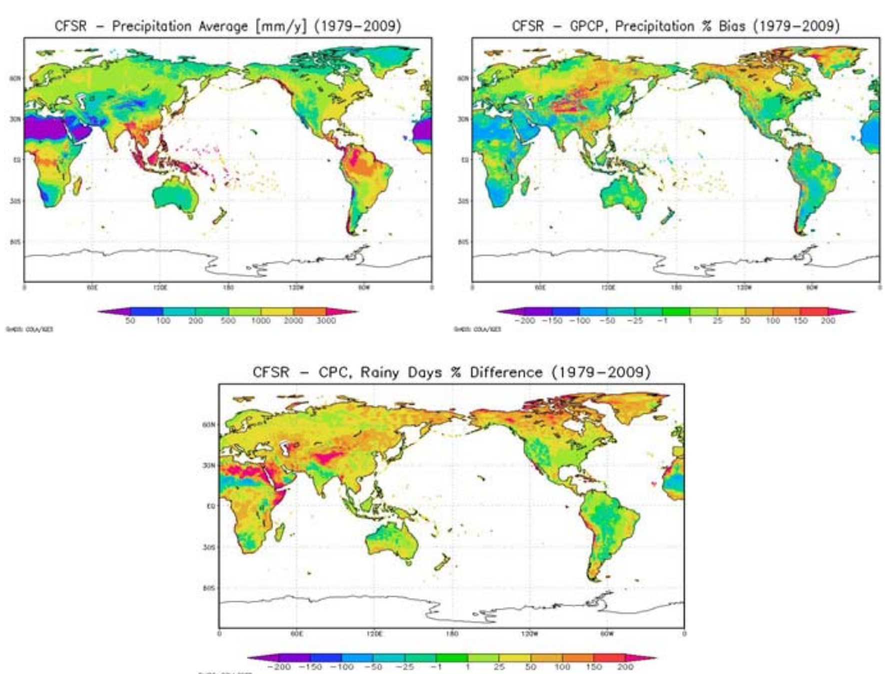




Figures 3 and 4

Similar results are obtained against 104 FLUXNET stations with longwave data. Again the global bias is again around -2 W/m^2 and locally it is negative over all regions apart for Canada, where radiation tends to be higher in CFSR (Figure 4).

Figure 5a shows comparisons of CFSR against the GPCP global precipitation product. The CFRS reproduces the spatial distribution of precipitation and the global annual mean. However, CFSR underestimates precipitation in arid and semi-arid regions, as shown by Figure 5b, where the percent bias of CFSR is around -80%. Tropical regions are almost unbiased and there is a positive bias for high latitude areas, while central-southern Asia has the highest values of percent bias, around 170%.



Figures 5a,b,c

The number of rainy days was also evaluated against the CPC daily product (Figure 5c). The comparison confirms the results of the comparison of the precipitation between CFSR and GPCP.

CFSR tends to overestimate the number of rainy days, especially for high latitudes, where the percent difference with CPC is around 50%, and even greater differences are observed over China and northern Africa. Even though the average number of rainy days in CFSR is globally high, in arid and semi-arid regions it is usually underestimated, especially near the Sahara, where the percent difference with CPC is around -75%. This explains the underestimation of precipitation over arid regions compared to GPCP.

b) Analysis of monthly water budgets at basin scale

The basin scale CFSR water budget analysis is carried out over 32 selected major river basins around the world (Figure 6), and these basins cover all the main climate regimes of interest. The basin mean monthly values for all the terrestrial water budget terms (precipitation, evapotranspiration, runoff, and terrestrial water storage) are calculated from CFSR for the 32-year period from 1979 to 2010. The same monthly basin mean values are also calculated from a number of other global reanalysis datasets, including 20CR, MERRA, and ERA-Interim, and as well as from observational datasets including the Global Precipitation Climatology Center (GPCC) gauge based dataset for precipitation, the Max Planck Institute (MPI) flux tower based dataset for evapotranspiration, and the Global Runoff Data Center (GRDC) gauge based dataset for runoff.

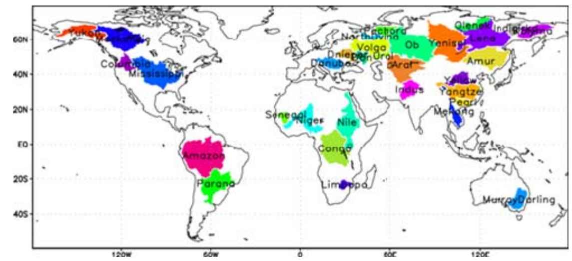


Figure 6 32 major global basins

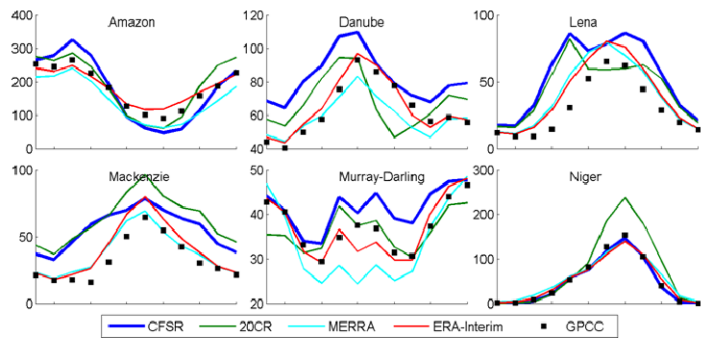


Figure 7 Seasonal cycle of precipitation over 6 basins.

The seasonal cycle of basin mean precipitation from CFSR is in reasonably good agreement with the GPCC observations and the general skill is comparable to other reanalysis data products (Figure 7). Mild overestimation is seen over a few high latitude basins from CFSR. The ERA-Interim tends to have a better overall performance. CFSR is able to closely reproduce the seasonal cycle of evapotranspiration observed by MPI over most of the global basins except the most difficult areas like the Amazon (Figure 8). All the reanalysis products show a very good agreement on the seasonal cycle of evapotranspiration – the shape of the cycles are all the same and

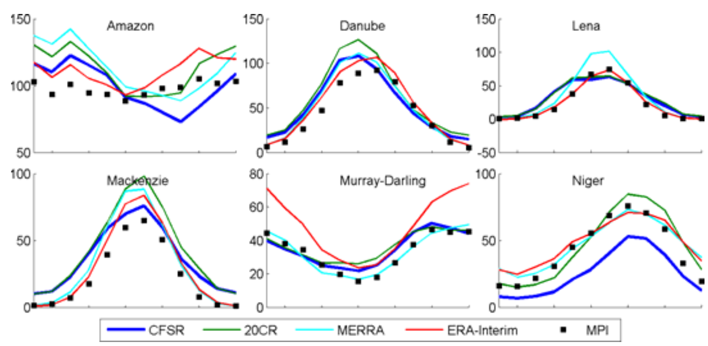


Figure 8 Seasonal cycle of ET over 6 basins.

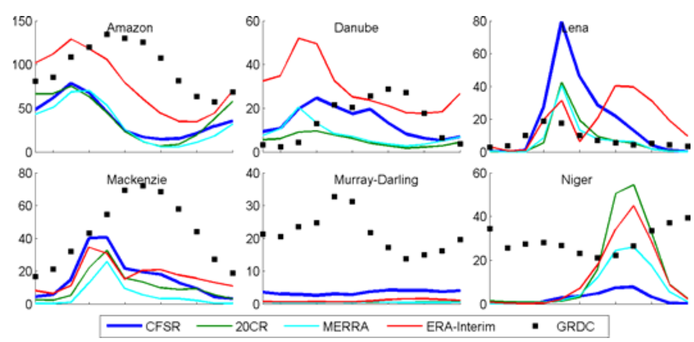


Figure 9 Seasonal cycle of runoff over 6 basins.

the magnitude only differs to a mild extent.

The runoff is the variable of least agreement between CFSR and other reanalysis products and against the GRDC observations as well (Figure 9). CFSR generally has the same shape of seasonal cycle as other reanalysis products, but the magnitude differs significantly from product to product. All the reanalysis products tend to underestimate runoff in most basins compared to GRDC. In order to assess how CFSR and other reanalysis product are able to close the mass balance of water, the water budget imbalance term (due assimilation of surface observations) is also calculated (the influx precipitation subtracted by the outflux evapotranspiration, runoff, and storage change) in Figure 10. The results show that CFSR has a significant amount of imbalance and such an imbalance has a strong seasonal cycle in most places (i.e. loss or gain of water in certain seasons all of the time). Other reanalysis products show similar behavior except MERRA, which does not assimilate land surface observations.

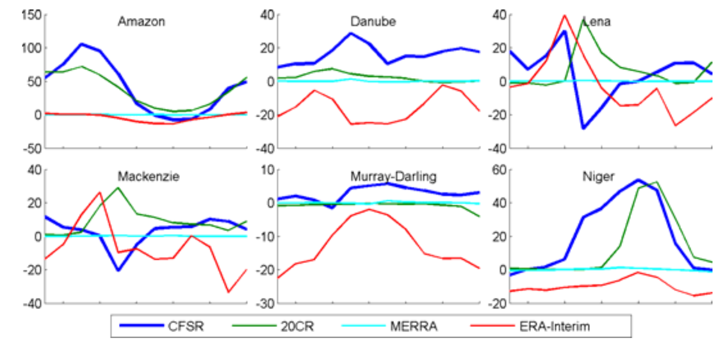


Figure 10 Seasonal cycle of water budget imbalance.

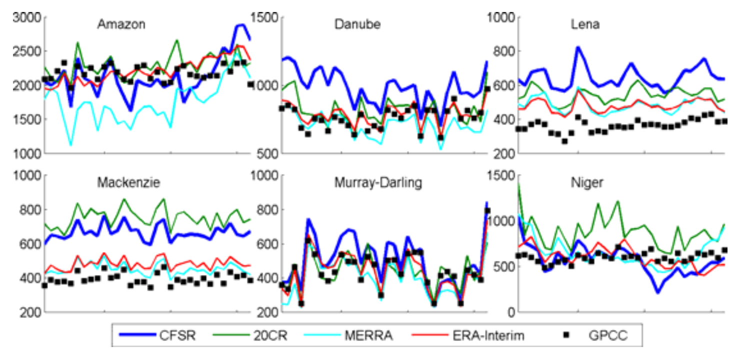


Figure 11 Annual time series of precipitation.

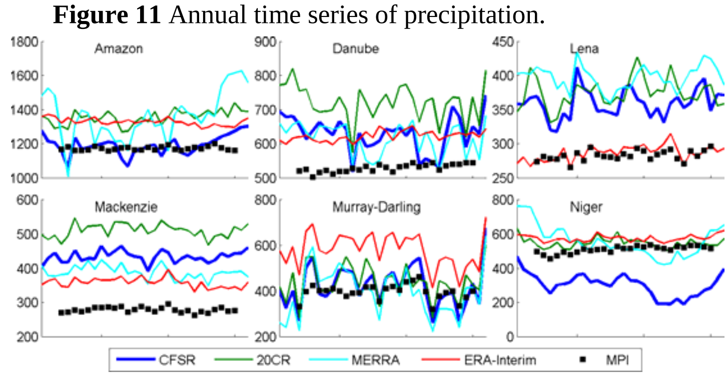


Figure 12 Annual time series of evapotranspiration.

Over the 32 year period, CFSR is able to reproduce the inter-annual variability of the precipitation (Figure 11). The long-term trend of precipitation in CFSR and all other datasets including the GPCC is not significant compared to the inter-annual variations. The inter-annual variability in evapotranspiration (Figure 12) is also mild compared to the absolute amount of evapotranspiration itself and no significant conclusions can be drawn on the trend from CFSR.

c) Meteorological and soil moisture droughts

The depiction of drought was evaluated against other modern reanalyses and our best estimates from off-line land surface modeling. Drought was defined in terms of meteorological drought, based on the Standardized Precipitation Index (SPI), hydrological drought based on the Standardized Runoff Index (SRI) and agricultural/soil moisture drought based on Soil Moisture Percentile Index (SMI). Figure 13 shows the global land averaged (excluding Greenland and Antarctica) SMI and area in drought for the CFS-R, 20CR, MERRA, and ERA-Interim, compared to an off-line simulation using the VIC land surface model (LSM). There is some consistency among the datasets but divergence in recent years between the CFS-R, MERRA and 20CR compared to the ERA-

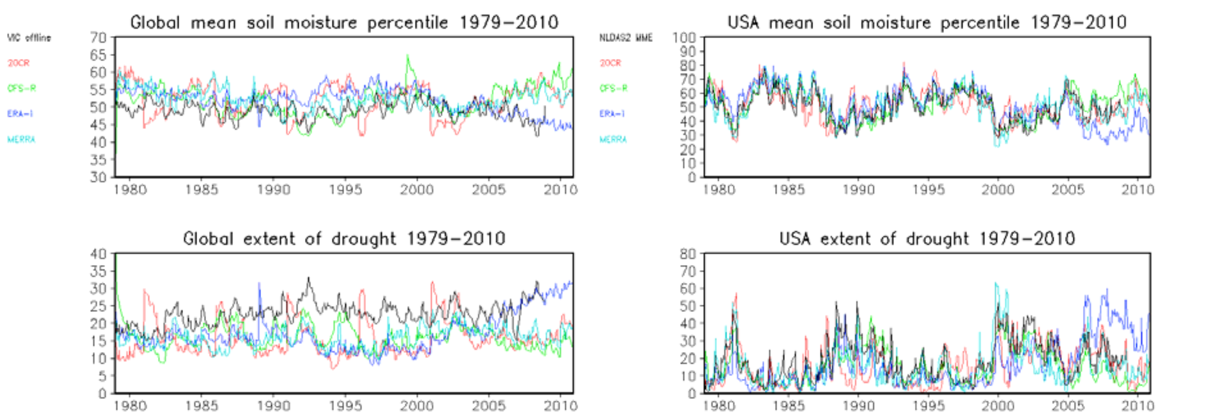


Figure 13. (left) Global land averaged soil moisture percentile and area in drought for 1979-2010 for the four renalyses and the VIC dataset. (right) Same, but for the conterminous US. The NLDAS2 multimodel ensemble mean is used as the baseline dataset.

Interim and VIC datasets. Figure 8 also shows the same data averaged over the US, indicating that the regional agreement amongst the datasets is much better, although again showing divergence in recent years. Figure 14 shows examples of drought events for the US for the four reanalyses and NLDAS-2 offline land surface model simulations. All reanalysis datasets identify the drought events, but with varying consistency in the spatial extent and severity of the drought.

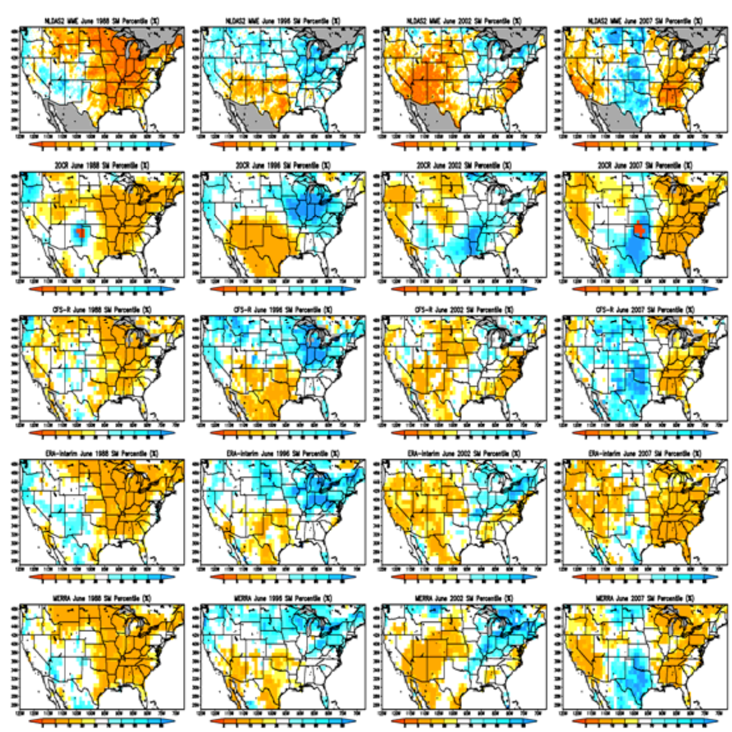


Figure 14. Example drought events over the US as represented by the (from top to bottom) NLDAS2 MME, 20CR, CFS-R, ERA-interim, MERRA. The events are (from left to right) central US 1988, southern US 1980, western US 2002, and southeast/California 2007.

d) Precipitation and temperature daily extremes

Daily temperature extremes were calculated based on index definitions from the ETCCDI (Expert Team on Climate Change Detection and Indices). Trends in these data for 1979-2010 were calculated from the four reanalysis datasets, and show that CFS-R is overall consistent with the other datasets and expected warming. All datasets show general increases in the number of warm days/nights, warm spells, and summer days, and decreases in the number of cold days/nights, cold spells and frost days. However, the spatial consistency in the trends is regionally dependent with large differences between some datasets, in particular the MERRA in South America for some indices (Figure 15).

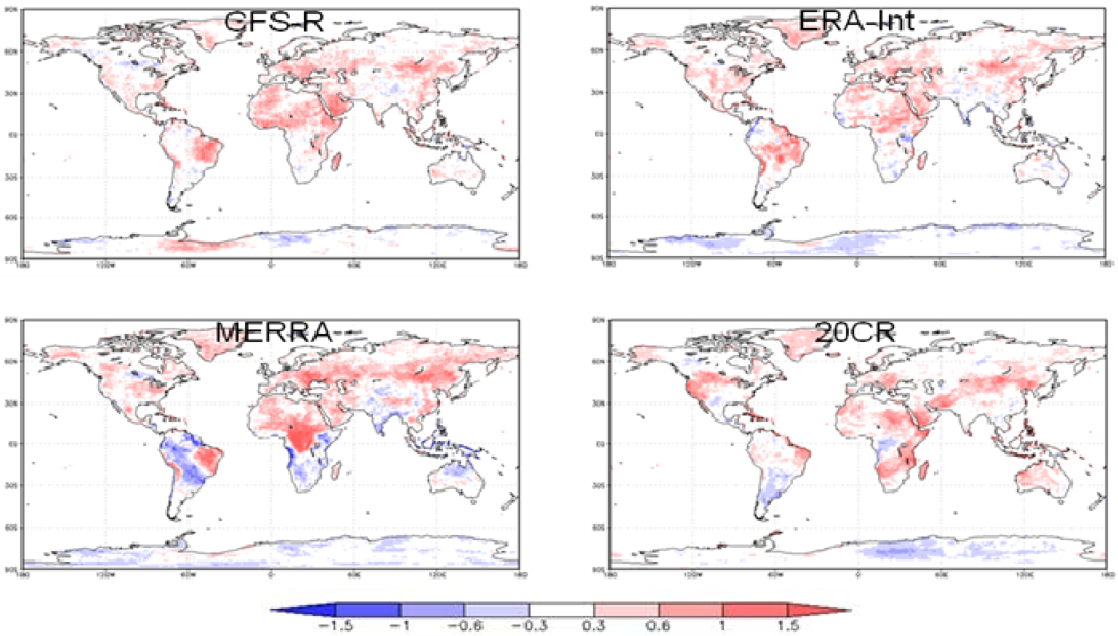


Figure 15. Trends (counts/decade) in warm spell duration (more than 6 consecutive days with Tmax > 90^{th} percentile)

2. Highlights of Accomplishments

- The CFSR does a reasonable job in replicating observed global annual means of precipitation but tends to be too low for precipitation in drier regions and too high in high latitudes, and generally has too many rain days. For surface downward radiation, it tends to be biased high for downward shortwave radiation and high for longwave, but with regional variations.

- A global analysis of the monthly water budgets of the CFS-R was carried out in comparison to other modern global reanalysis products including the 20CR and our best observational estimates. The CFS-R generally does well at representing the seasonal cycle of land water fluxes and their inter-annual variability.

- Drought indices were calculated from the four reanalysis datasets and compared to off-line model estimates of meteorological, hydrological and soil moisture drought for 1979-2010. The datasets generally identify drought periods but with large inconsistencies in the temporal and spatial extent of individual events.

- Daily temperature extreme indices were calculated for the CFS-R and the three other reanalysis dataset, and inter-compared. This revealed broad consistency in the long-term trends globally, but with large inconsistencies in some regions.

3. Publications from the Project:

Pan, M., A. Sahoo, J. Sheffield, E. F. Wood, 2013: Water budgets in modern global reanalyses, in preparation.

Sheffield, J., A. Sahoo, M. Pan, E. F. Wood, 2013: Global and regional drought from recent global reanalyses, in preparation.

Sahoo, A., J. Sheffield, M. Pan, E. F. Wood, 2013: Daily extremes of temperature and precipitation from modern global reanalyses, in preparation.

Goccia, G., and E. F. Wood, 2013: CFSR/VIC-Land: A new high temporal resolution product aimed at improving the CFSR land surface hydrology estimates, in preparation.

4. PI Contact Information.

Prof. Eric F. Wood,
Dept. Civil and Environmental Engineering
Princeton University
Princeton, NJ, 08544, USA
tel: 609-258-4675
email: efwood@princeton.edu

5. Budget for Coming Year

NA

6. Future Work

NA