2.7 INTERCOMPARISON OF WATER AND ENERGY BUDGETS FOR FIVE MISSISSIPPI SUB-BASINS BETWEEN ECMWF REANALYSIS (ERA40) AND NASA-DAO fvGCM FOR 1990-1997.

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1. INTRODUCTION

The ECMWF 40-year reanalysis (ERA40) is proceeding in three streams (Simmons and Gibson, 2000), and the most recent period, 1989-2000, will be complete this year. The analysis system uses a recent version of the model physics, including the land-surface scheme described in Van den Hurk et al. (2000), and a 3-D variational assimilation system. The horizontal resolution of the spectral model is triangular truncation at T_L-159, and there are 60 levels in the vertical, including a well resolved stratosphere. Documentation of the Integrated Forecast System (IFS), cycle 23r4, is available at http://www.ecmwf.int/research/ifsdocs/index.html . A summary and discussion of the observations available at different times during the 40-year reanalysis is available at http://www.ecmwf.int/research/era/Observations/. Surface energy and water budgets, averaged over river basins, are computed and archived during the analysis cycle. We use these and the river basin estimates from Maurer et al. (2001) to assess the systematic biases in the surface energy and water budget of both the ECMWF reanalysis, and the NASA-DAO atmospheric finite-volume GCM (fvGCM) for five Mississippi sub-basins. The fvGCM was run with 1x1.25^o horizontal resolution for the 15 years, 1986-2000, using observed varying sea surface temperatures. The DAO fvGCM results from a collaboration between NASA and NCAR. It uses DAO's finite-volume dynamical core (Lin, 1997; Lin and Rood, 1996). The atmospheric physics and land-surface model are taken from NCAR CCM3 in which the land-surface scheme is from Bonan (1998), the deep convective parameterization is from Zhang and McFarland (1995) and the shallow convection scheme is from Hack (1994).

For selected Mississippi sub-basins, we

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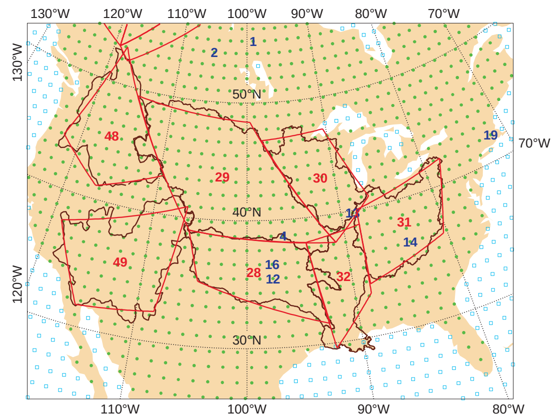

Figure 1. River basin budgets in ERA-40 for the continental USA.

compare the mean monthly annual cycle from short-term forecasts (both 0-12hr and 12-24hr to show the model spinup) of the ECMWF reanalysis (ERA-40) for the eight years, 1990-1997, with the corresponding mean from the same years extracted from a 15-year atmospheric GCM run (initialized on 1/1/1986 in free-running mode with specified 'observed' varying sea surface temperatures). Thus it can be regarded as a comparison of the fvGCM model's climate with the reanalysis. Earlier budgets of the Mississippi derived from the first ECMWF analysis, ERA-15, and the NCEP model and reanalysis are described in Betts et al. (1998,1999), Roads et al. (1997, 1999) and Roads and Betts (2000).

2. RIVER BASIN INTERCOMPARISONS

For ERA-40, averages over selected basins are output for hourly time intervals (accumulated from the full time resolution data) for selected river basins. We analyze here the sub-basins of the Mississippi denoted 28-32 in Figure 1, representing respectively the Red-Arkansas, the Missouri, Upper Mississippi, Ohio-Tennessee, and the lower Mississippi. The ERA-40 averages are over all gridpoints, indicated as green dots, inside each red quadrilateral, which are approximations to the actual river basin boundaries shown in brown. We averaged the hourly data up to one month. For the fvGCM, we similarly averaged over grid-points (from the 1x1.25 grid) within the red quadrilaterals, and averaged the archived daily means (derived from 30-min timesteps) up to one month. The figures we will show are an eight-year mean annual cycle:1990-1997.

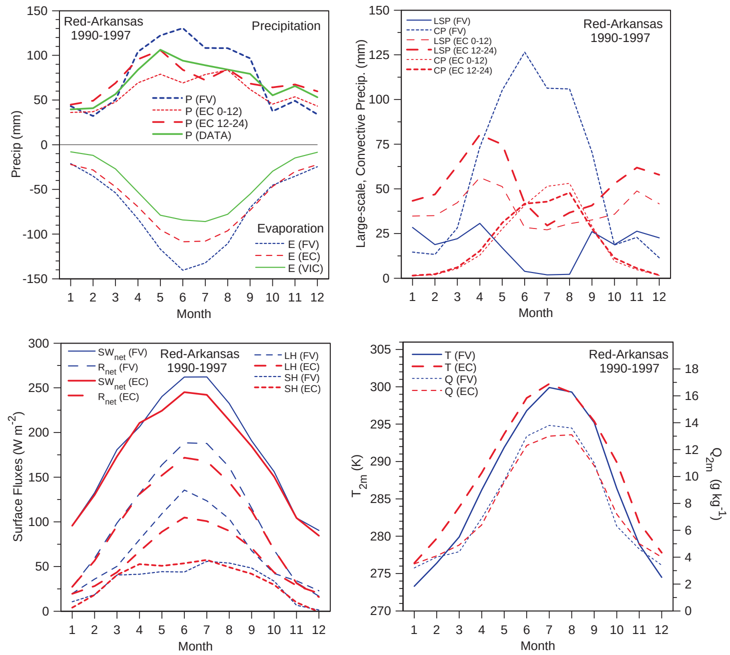

Figure 2. a) precipitation and evaporation for ERA40, fvGCM climate and observations, b) Large-scale and convective scale precipitation, c) terms in energy budget, d) temperature and specific humidity.

2.1 ***Red-Arkansas basin means***.

Figure 2a compares monthly mean precipitation and evaporation. The color code is fvGCM model in blue, ERA40 in red, and in Figure 2a the data from the VIC model in Maurer et al. (2001) (averaged over the Red-Arkansas basin) is in green. For ERA-40, two curves are shown: dotted is the precipitation from the 0-12 forecasts, and long dashes from the 12-24 h forecasts. These show that ERA-40 has considerable spinup of precipitation in the first 24 hours. We see that compared with the data, the 12-24 hr ERA40 precipitation is a little high in winter and low in summer. In contrast, the fvGCM climate precipitation is low in winter and rather high in summer by 25%. Not surprisingly, evaporation is correspondingly higher in the fvGCM in summer than in ERA40, and both are higher than the Maurer et al. estimate, which comes from using the VIC streamflow model and the observed precipitation. The VIC model estimate of evaporation could be biased low, because precipitation is not corrected for undercatch (which could be 5-10%), while the runoff that is simulated is corrected upward a few percent to account for diversions (Lettenmaier, 2002, personal communication). Evaporation may be high in the fvGCM because canopy interception evaporation may be overestimated, because sub-grid rainfall variability is ignored. Both ERA40 and fvGCM however have too little runoff, compared to streamflow observations (not shown).

Figure 2b compares large-scale (LSP) and convective-scale (CP) precipitation, as produced by the models. There are large differences. The spinup of ERA40 is in the large-scale precipitation (LSP), and it has a peak of large-scale precipitation in Spring. Convective precipitation (CP), which has a small spin-down, only exceeds LSP in summer. In contrast, the fvGCM model has much less LSP throughout the year, and almost none in summer, when its CP is very large. Since the models have opposite biases in winter and summer with respect to the precipitation observations, this suggests that in winter the LSP may be a little high in ERA40 (after spinup) and low in the fvGCM; while in summer, the CP is low in ERA40 and rather high in the fvGCM. The two models have different convective parameterizations: the ERA-40 scheme is a mass-flux scheme (Tiedtke, 1989) with a convective available potential energy (CAPE) closure for deep convection (Gregory et al., 2000), while this version of the fvGCM uses the Zhang and McFarland (1995) scheme, which adjusts towards a threshold CAPE. ERA-40 uses the large-scale cloud scheme of Tiedtke (1993), while the fvGCM has only a diagnostic grid-scale condensation, when mean relative humidity reaches 100%, and no explicit representation of stratiform clouds or their microphysics,

Figure 2c compares the surface energy balance of the two models. Four pairs of curves are shown in descending order: SWnet , Rnet, latent heat flux (LH) and sensible heat flux (SH). In summer the fvGCM has more net SW and consequently a larger Rnet at the surface (the differences in net LW are small). Comparisons of the ERA-40 radiation model with observations (Morcrette, 2002a,b) show that while the LW fluxes have little bias, the incoming SW may have a high bias of order 10 W m^{-2}. This suggests that the fvGCM may have a high bias in SWnet as large as 30 Wm^{-2}. The partition of Rnet at the surface is quite different between the models. The fvGCM has more evaporation (as seen in Figure 2a) in the warm season. The seasonal cycles of the surface SH flux differ, with the fvGCM being lower in spring and greater in late summer and in the Fall.

Figure 2d shows the mean annual cycle of 2-m mean temperature and mixing ratio for the two models. Except in summer, ERA40 is warmer than the fvGCM, and in winter the fvGCM is colder by 3K. In mid-summer, the large excess in Rnet, shown in Figure 2c, is driving a larger LH flux, rather than heating the surface. The larger evaporation is possible because of the extra rainfall. The cause of the cold bias in the fvGCM in winter is less obvious, as there is only a slightly larger evaporation in the fvGCM, and the other surface fluxes are similar. The dotted curves (with scale on the right-hand axis) compare mixing ratio. The differences are small, with the fvGCM being a little moister in early summer (despite being a little cooler, implying a lower LCL), and a little drier in fall and winter, when the model is colder.

2.2 *Missouri basin means*

Figure 3 shows the corresponding plots for the Missouri basin. There are many similarities to Figure 2, so we will only comment on the differences. Precipitation is a little low in ERA-40 in summer, and correspondingly summer evaporation is close to the VIC estimate. ERA-40 shows no spinup or spin-down in convective precipitation. In the cool season E remains higher in ERA-40 (which has no seasonal cycle in the vegetation) than both the fvGCM and the VIC estimate. Both the temperature and the SH flux are lower in the fvGCM than in ERA-40 throughout the year,

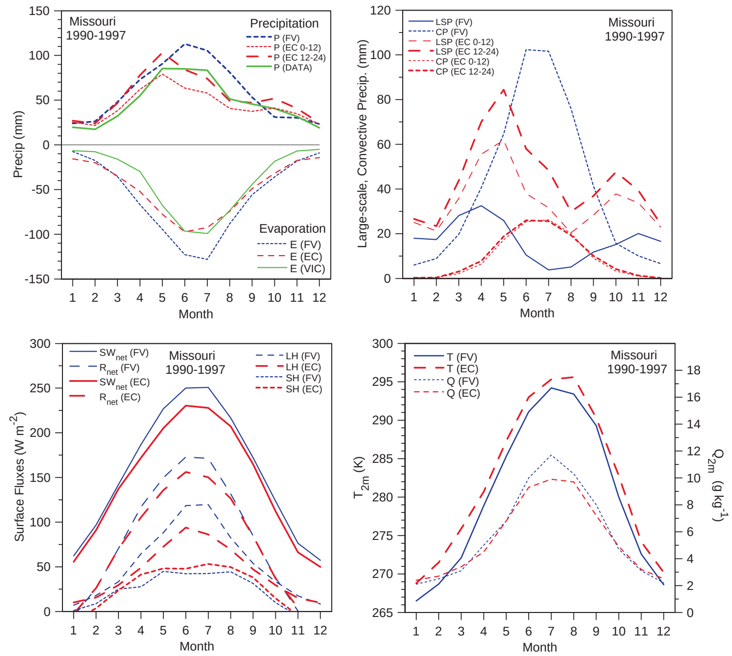

Figure 3. As Figure 2 for Missouri river basin.

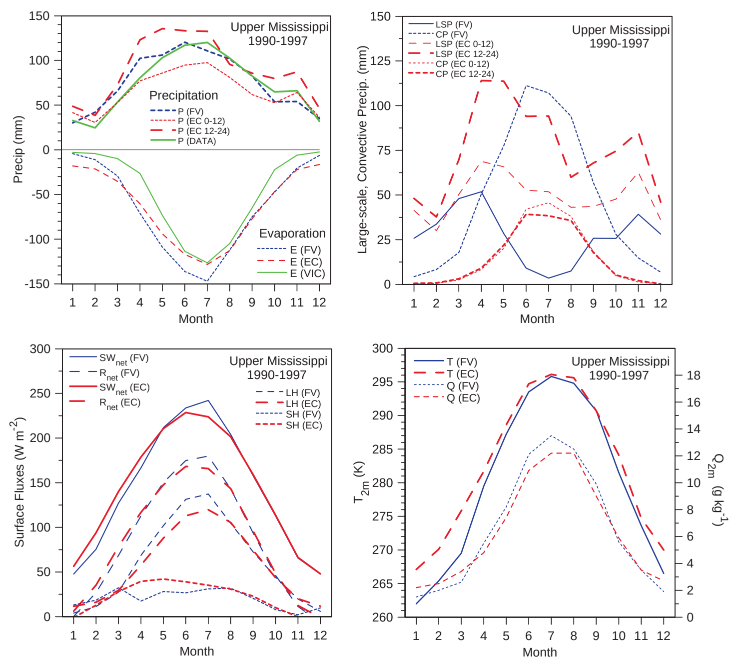

Figure 4. As Figure 2 for Upper Mississippi river basin.

2.3 *Upper Mississippi basin means*

For the Upper Mississippi, the spinup of ERA-40 LSP is larger than for the Missouri basin, while the fvGCM has little precipitation bias in summer. The fvGCM has a lower Rnet in winter than ERA-40 and the January cold bias has increased to -5K. It is possible however that ERA-40 has a small warm bias (~1K) over snow covered regions, as this has been seen in operational forecasts (P. Viterbo, personal communication, 2002). Changes to the albedo in the presence of snow, may have slightly overcorrected the large cold bias at high latitudes that was seen in previous versions of the model (Viterbo and Betts, 1999).

2.4 *Ohio-Tennessee basin means*

For this basin, the 12-24 hr precipitation in ERA-40 is higher than the fvGCM, as well as the observations, throughout almost the whole annual cycle; quite a different pattern from the Red-Arkansas basin. The annual cycle of evaporation and LH flux is noticeably flatter in ERA-40 than the fvGCM. Despite having a higher SH flux and a much lower evaporation, the fvGCM is colder in January by 7K than ERA-40,

2.5 *Lower Mississippi basin means*

This basin's characteristics are an overestimate of precipitation in ERA-40 in the summer, and rather low precipitation in the fvGCM climate in the cool seasons. Figure 6b shows the low cool season LSP in the fvGCM, and that the difference in CP between the 2 models is smallest for this basin. In October, when precipitation is lowest in the fvGCM, we see SH>LH flux for the fvGCM, in sharp contrast to ERA-40.

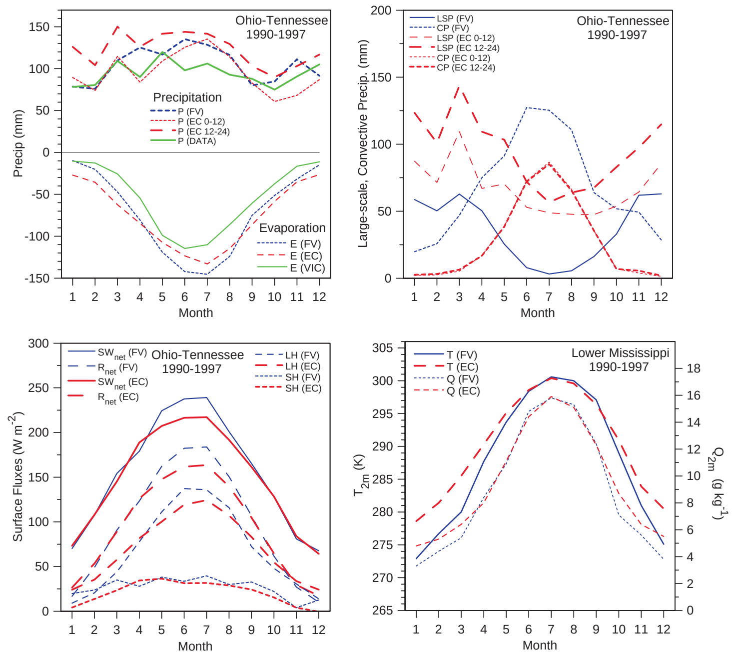

Figure 5. As Figure 2 for Ohio-Tennessee river basin.

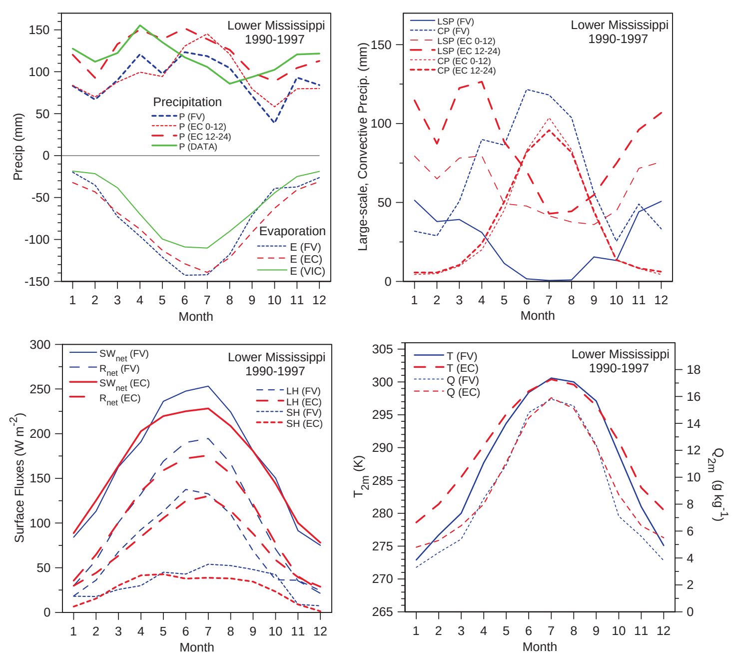

Figure 6. As Figure 2 for Lower Mississippi river basin.

3. DISCUSSION

ERA-40, is an analysis system, incorporating surface, upper air and satellite observations, while for the fvGCM we have one realization of the model "climate" for the same 8-year period, so what general conclusions can be drawn from the differences between the basin budgets? The much higher net shortwave in summer in the fvGCM (for all basins) indicate deficiencies in the radiation and cloud schemes, since the corresponding error in the SW radiation in the ERA-40, while of the same sign, is known to be smaller (Morcrette, 2002b). The large cold surface temperature bias in winter in fvGCM is also a systematic error in this model, and the cause is unclear. Earlier versions of the ECMWF model had a similar error, which was reduced by changes to the stable boundary layer parameterization and the coupling to the ground, as well as the introduction of the thermal impact of soil freezing (Viterbo et al., 1999).

The generally higher evaporation in the fvGCM may in part be caused by too-large evaporation from the canopy reservoir, as well as from generally higher precipitation. The higher evaporation in ERA-40 in winter probably reflects the lack of a seasonal cycle in the vegetation in that model.

The large difference in the partition between LSP and CP in the two models is striking. LSP, which dominates the cool season, is much smaller in the fvGCM, and summer CP is higher than in ERA-40. The partition in a model may depend on resolution, since it is simply a projection of a process which occurs over a very wide range of scales, from the cloud scale, frontal and mesoscale, to the synoptic scale onto the resolved scale and the parameterized deep convection. A quantitative observational basis for this partition depends on the measuring system. The TRMM radar observations (Schumacher and Houze, 2002) show that about 40% of the rain in the tropics falls as stratiform rain. ERA-40 has a similar LSP fraction, but the fvGCM has essentially no LSP in the tropics or over the summer continents. The grid-scale condensation in the fvGCM is determined when mean relative humidity reaches 100%. There is no explicit representation of stratiform clouds or their microphysics, and the Zhang-McFarlane (1995) cumulus parameterization does not detrain liquid water to the large-scale environment. The low precipitation bias in the cool season in the fvGCM, when the LSP is low may suggest also a coupling with the large-scale dynamical field, such as weaker cyclone activity.

The larger spinup of the large-scale dynamics and LSP in ERA-40 makes assessment of its LSP difficult. The hydrological imbalance caused by too little precipitation in the analysis cycle is compensated by the soil water assimilation (Douville et al., 2000), which nudges soil water and temperature using observed surface temperature and humidity biases. For some basins, however, such as the Upper Mississippi and the Ohio-Tennessee, the 12-24 hr precipitation in ERA-40 exceeds that observed by 20-30% in some seasons.

The comparison between different basins are interesting as they show the general nature of certain biases. However the more detailed differences between the basins could have several causes. The climate in the fvGCM may be significantly different from the observed 1990-1997 climate, which is presumably reasonably represented in the reanalysis. Without the observational constraint, the fvGCM climate is more sensitive to local land-surface feed-backs, such as precipitation-evaporation feedback, which is quite strong over this region of the US, at least in the ECMWF model (Beljaars et al, 1996). This could amplify the high precipitation and evaporation in the fvGCM. However remote forcings and interactions, as well as interactions between the cloud, water vapor and radiation fields, could also impact the model climate for the Mississippi basin.

Comparison of river basin budgets with reanalyses is a useful method of assessing the impact of model changes on the surface energy budget and hydrological balances, and we plan to repeat this work with new versions of the fvGCM using different parameterizations. The goal is the accurate representation of the energy and water budgets in both climate and forecast models.

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