Evaluation and validation of the hydrological cycle simulated by the Canadian Regional Climate Model (CRCM) using an integrative approach

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Evaluation and validation of the hydrological cycle simulated by the Canadian Regional Climate Model (CRCM) (Caya and Laprise, 1999) are important aspects of model development. Usually, at the regional scale, only precipitation and river streamflow observations are available. We, therefore, need to develop a methodology for validation of water cycle components that makes use of available observations.

In this contribution, an integrative analysis approach is presented. This approach links both the terrestrial and atmospheric branches and involves a long-term time means of the hydrological cycle components, spatially averaged over a given river basin.

The water budget equations for the atmospheric and terrestrial branches can be expressed as:

$$\frac{\partial W}{\partial t} = C - (P - E) \qquad (1)$$

$$\frac{\partial (M + S)}{\partial t} = (P - E) - R \qquad (2)$$

where W (kg m^{-2}) is the column storage of the atmospheric water, C is the vertically integrated horizontal moisture flux convergence, E (kg m^{-2} s^{-1}) is evapotranspiration, and P (kg m^{-2} s^{-1}) is precipitation. The quantity $M+S$ (kg m^{-2}) represents the storage of soil moisture (M) and the accumulated snowpack (S), and R (kg m^{-2} s^{-1}) is the total runoff.

The following approach can be used to perform the analysis of the annual means of the water cycle components. Taking time and spatial averages of the atmospheric and terrestrial water budget equations (1) and (2) over a multiyear period and over a given river basin leads to the following equations:

$$\left[\overline{C}\right] = \left[\overline{P}\right] - \left[\overline{E}\right] \qquad (3)$$

$$\left[\overline{R}\right] = \left[\overline{P}\right] - \left[\overline{E}\right] \qquad (4)$$

where $\overline{X}$ presents the time average of component X, and $\left[X\right]$ is the spatial average. Annual mean tendencies of atmospheric and terrestrial water storage can safely be neglected because they tend toward zero when averaged over long period of time.

In order to validate the various components of equations (3) and (4) simulated by the model, the corresponding observed values have to be known. An estimation of annual mean precipitation for a given basin ($\left[\overline{P}\right]_{OBS}$) can be obtained from the existing gridded precipitation analysis data sets. These datasets are not free from errors (for various reasons), but presently they constitute the best estimate of the real precipitation at the regional scale. The river streamflows observed at gauging stations are available for many river basins, so fairly good accuracy can be obtained for the value of annual mean runoff for a given basin $\left[\overline{R}\right]_{OBS}$. Evapotranspiration observations are seldom available at the regional scale and evapotranspiration must be estimated as a residual using the water budget analysis. We used the time- and space- averaged terrestrial water budget equation (4) to obtain the quasi-observed evapotranspiration:

$$\left[\overline{E}\right]_{QOBS} = \left[\overline{P}\right]_{OBS} - \left[\overline{R}\right]_{OBS} \qquad (5).$$

The model-simulated atmospheric water vapor convergence over the basin can be compared with the convergence computed from reanalysis data ($\left[\overline{C}\right]_{REAN}$). It must be emphasized that the characteristics of reanalysis data, such as spatial and temporal sampling, vertical resolution, and treatment of the lower boundary layer in the computation, limit the accuracy of estimated water vapor convergence.

The validation of the annual cycle of water budget components is more complex and involves larger uncertainties. While terrestrial and atmospheric water storage components can be neglected for multi-year means, they cannot for monthly means; these terms can be particularly large during spring and fall. For the annual cycle analysis, the averaged water budget equations become:

$$\left[\frac{\partial \overline{W}_i}{\partial t}\right] = \left[\overline{C}_i\right] + \left[\overline{E}_i\right] - \left[\overline{P}_i\right] \qquad (6)$$

$$\left[\frac{\partial (\overline{M}+\overline{S})_i}{\partial t}\right] = \left[\overline{P}_i\right] - \left[\overline{E}_i\right] - \left[\overline{R}_i\right] \qquad (7)$$

where $\overline{X}_i = \frac{1}{J}\sum_{j=1}^{J} X_{i,j}$ is the climatological monthly mean, based on J years, with $X_{i,j}$ the monthly mean for month "i" and year "j". Quasi-observed evapotranspiration is now obtained as a residual of the atmospheric water balance as:

$$\left[\overline{E}_i\right]_{QOBS} = \left[\frac{\partial \overline{W}_i}{\partial t}\right]_{REAN} - \left[\overline{C}_i\right]_{REAN} + \left[\overline{P}_i\right]_{OBS} \qquad (8).$$

The terms $\left[\overline{P}_i\right]_{OBS}$, $\left[\overline{R}_i\right]_{OBS}$, $\left[\frac{\partial \overline{W}_i}{\partial t}\right]_{REAN}$ and $\left[\overline{C}_i\right]_{REAN}$ can be obtained from one of the existing datasets based on in situ observations (first two terms) and from reanalysis (last two terms). Finally, monthly values of quasi-observed terrestrial water storage tendencies can be computed as residuals from averaged combined water budget equation:

$$\left[\frac{\partial (\overline{M}+\overline{S})_i}{\partial t}\right]_{QOBS} = \left[\overline{C}_i\right]_{REAN} - \left[\frac{\partial \overline{W}_i}{\partial t}\right]_{REAN} - \left[\overline{R}_i\right]_{OBS} \qquad (9).$$

The hydrological cycle simulated by the CRCM (V. 3.6.3) over the Mississippi River basin for the period 1988-99 is evaluated using the above-presented approach. Gridded precipitation dataset from the Climate Research Unit (CRU TS2.02, Mitchell and Jones, 2005) and "undepleted" (water management effects removed) basin mean runoff (Maurer and Lettenmaier, 2001) are used as observations. The vertically integrated horizontal moisture flux convergence and atmospheric water storage tendencies are obtained from NCEP/NCAR reanalysis data.

Results of the analysis (see Fig. 1 and Figs. 2) suggest that this model version suffers from inadequate representation of land surface processes. The single-layer surface scheme used in the CRCM (V. 3.6.3) cannot accurately represent many of the effects of vegetative control of evapotranspiration as well as runoff generation. The prescribed water holding capacity, made to account crudely for the effects of a vegetative canopy, appears to be excessively high and results in too low runoff as well as too large evapotranspiration. The evapotranspiration overestimation then generates excessive precipitation. The bias in the atmospheric moisture flux convergence could be related to the biases of the CRCM evapotranspiration and precipitation, but the model dynamics should be also investigated for an evaluation of the moisture transport over the basin.

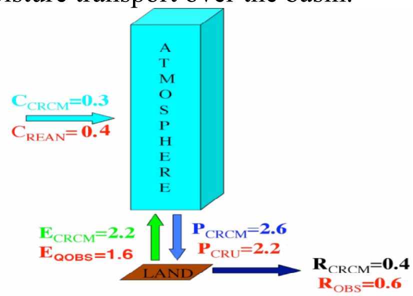
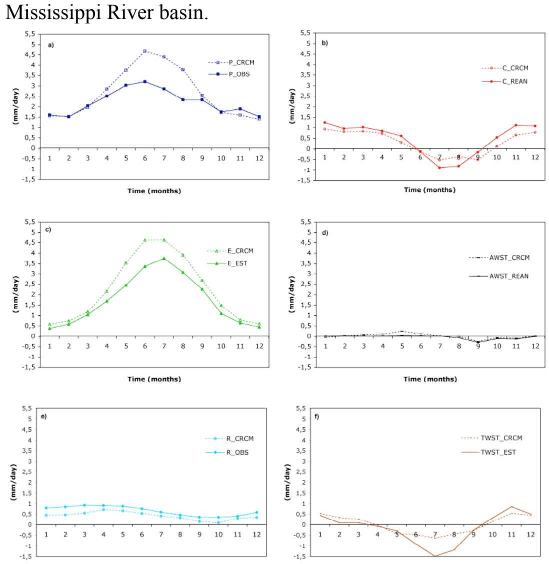


Fig. 1. Annual means (1988-1999) of the atmospheric and terrestrial water budget components, in mm/day, over the Mississippi River basin.



Figs. 2. Annual cycles of the atmospheric and terrestrial water budget components averaged over Mississippi River basin for the period 1988-1999: (a) precipitation, P; (b) vertically integrated horizontal moisture flux convergence, C; (c) evapotranspiration, E. (d) atmospheric water storage tendency, $AWST$; (e) runoff; (f) terrestrial water storage tendency, TWST.

References

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