Dealing with atmospheric water in a nested RCM

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A nested Regional Climate Model, by definition, requires information from an external source. The needed initial and boundary conditions are generally provided by a GCM (General Circulation Model) for climate projections or by objectives analyses for current climate simulations. An implicit assumption in using a RCM stipulates that the atmosphere simulated by the regional model will follow the general state of the driven atmosphere. In other words, it is expected that a RCM will generate the high-resolution details without altering the large-scale atmospheric circulation. This implies that the large-scale means of the atmosphere should be similar in the RCM and in the pilot.

A complete RCM evaluation includes an estimation of the hydrological cycle, which is sensitive to the atmospheric water content. Differences in the pilot and in the RCM atmosphere will be reflected in the hydrological cycle and could modify the nested model humidity flux divergence.

To quantify the RCM and pilot humidity, an atmospheric water budget can be used. The budget equation takes the form of:

$$P - E = \qquad (1)$$

$$-\frac{\partial r}{\partial t} - \nabla \cdot r\vec{V} - \frac{\partial c_w}{\partial t} - \nabla \cdot c_w\vec{V} - \frac{\partial c_i}{\partial t} - \nabla \cdot c_i\vec{V} + \varepsilon$$

where P is the total precipitation (large-scale plus convective), E the evaporation, r the water vapor mixing ration, c_w the cloud water, c_i the cloud ice and V the horizontal wind. The residual term ε is introduced to take into account errors from approximations in numerical formulation or interpolation.

Different deep convective parameterizations could be used to illustrate RCMs behavior regarding the atmospheric water content. Each convective parameterization follows particular triggering conditions and closure assumption, therefore modifying the humidity distribution and influences the hydrological cycle. The resulting atmosphere can differs from one type of parameterization to another.

To illustrate the topic, an experiment is conducted with the Canadian RCM (Caya and Laprise, 1999) and includes the atmospheric water budget computation. The CRCM is run for 4 months, from May to August 1988. The water budget is computed for JJA only, May being used for spin-up. The domain is centered over Texas and is composed of 141 x 121 grid points of 45 km of resolution, including a 9 grid points sponge zone, and is covering USA, Mexico and the surrounding sea. In the vertical, 18 levels up to 30 km in the atmosphere are used. The timestep is 15 minutes. ECMWF analyses of 2.5° resolution and 14 vertical levels provide the driving data every 12 hours. Two convective options are tested: the CGCMii moist adjustment scheme (McFarlane et al. 1992) and the Bechtold-Kain-Fritsch (BKF) (Bechtold et al. 2001) deep and shallow convective schemes. Table 1 provides the atmospheric water budget for every run as well as for the ECMWF driving data.

The dominant variables for every simulation are P, E and the water vapor divergence. (Over a period that is long enough the local rate of change of water vapor is less than the 3 dominant terms while the terms for cloud water and ice are always a few order less.) For the ECMWF analyses, there is positive divergence. In the CRCM with the GCMii moist adjustment scheme, the atmospheric water budget behavior is similar to the analyses and there is divergence of the water vapor flux. There is less precipitation than evaporation. The humidity lost over the domain has a source that is a draining from the soil water. However with the BKF' scheme have convergence of water vapor over the domain and more precipitation than evaporation.

Table 1. JJA Water Budget (kg m^{-2} day^{-1}). ∅ means that either the field is not available either the variable is not pronostic.

Experiment	P	E	$\partial r/\partial t$	$\nabla \cdot r\vec{V}$	$\partial cw/\partial t$	$\nabla \cdot cw\vec{V}$	$\partial ci/\partial t$	$\nabla \cdot ci\vec{V}$	ε
Moist adj.	2.59	2.79	0.08	0.26	∅	∅	∅	∅	0.14
BKF	3.60	3.27	0.07	-0.54	≅ 0	≅ 0	≅ 0	≅ 0	-0.13
ECMWF	∅	∅	0.14	0.40	∅	∅	∅	∅	∅

Such differences in the atmospheric water budget are reflected in the time-series liquid soil water content presented on Fig. 1. The simulation using the moist adjustment has a total water decrease while the simulation with BKF shows a slight increase over the 4 months.

The simulations are too short to allow the model to reach equilibrium and to get final conclusions. This raises questions. The equilibrium value of the model atmospheric water value may differ between CRCM simulation and the pilot. What are the implications? Is a RCM that has a mean atmospheric humidity profile that differs from the pilot able to simulate a reliable climate change projection? If the mean humidity profile of the atmosphere is different in a climate change context, will the RCM be able to capture the differences? These questions should be examined.

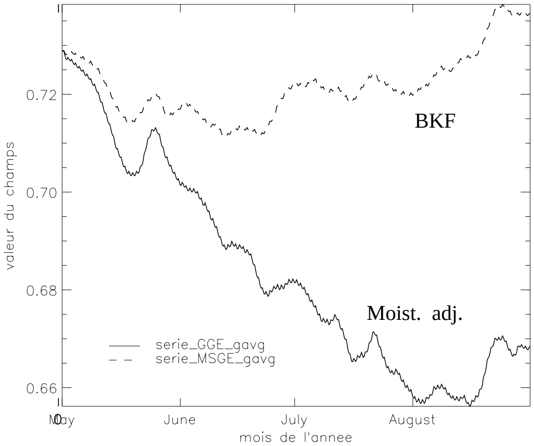

Figure 1. Time series grid-averaged liquid water soil content (%).

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