Extended Abstract: Simulations of North American Snow Cover by AGCMs and AOGCMs

A. FREI,[1] G. GONG,[2] AND R. BROWN[3]:

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We report on some highlights of recent evaluations of General Circulation Model (GCM) snow simulations in which the authors have participated. Two recent reports focus on evaluations of snow cover extent (SCE) (Frei et al. 2003) and snow water equivalent (SWE) (Frei et al. 2005) simulations for the period 1979-1995 by Atmospheric GCMs (AGCMs) participating in the Second Phase of the Atmospheric Model Intercomparison Project (AMIP-2). We also report on results of a recent preliminary evaluation of SCE simulations by coupled atmosphere-ocean GCMs (AOGCMs) participating in the upcoming Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC-AR4) (Frei and Gong 2005).

Data Satellite observations of Northern Hemisphere SCE are available back to around 1967 (Robinson 1993). Reconstructions of large scale SCE variations back to the early twentieth century over North America have been performed in two studies (Frei et al. 1999; Brown 2000), which utilized station observations of snow depth. The primary data set used for model evaluation of SWE is the gridded SWE data set produced specifically for the AMIP-2 project by Brown et al. (2003).

Models AMIP-2 modeling groups run experiments for the years 1979-1996 with identically specified boundary conditions, including observed sea surface temperatures, so that discrepancies in model results are attributable to internal differences between atmospheric models. All IPCC-AR4 AOGCM simulations are forced with a set of boundary conditions determined by scenarios of anthropogenic emissions of carbon dioxide (CO2) and other gases that influence the global radiation budget. Here we consider twentieth century simulations (20C3M), which use a best estimate of historical emissions between roughly 1850 and 2000; and three twenty-first century climatic change scenarios (COMMIT, SRESA1B, SRESA2), which represent a range of socioeconomic developments and associated emission rates.

Twentieth century results Mean monthly North American SWE (Figure 1a) and SCE (Figure 1b) for observations and AMIP-2 AGCMs demonstrate that models capture the mean seasonal cycle, there is significant between model variability, and models have a tendency to overestimate the ablation rate during spring. The mean spatial pattern of SWE is reasonably well captured by the median value of AMIP-2 models, except for an overly smoothed representation of SWE over the western cordillera related to model orography, underestimation of SWE over eastern NA (figure 2), and the widespread underestimation of SWE during spring.(not shown).

Between-model variability in IPCC-AR4 AOGCMs (Figure 3) is comparable to that found in AMIP-2 AGCMs. Figure 3, which shows ensemble mean time series, also indicates that the models disagree with each other, and with observations, on the timing and magnitude of decadal scale variations. With regards to the magnitude of decadal-scale variability, the disagreements between models and observations are perhaps not as great as they appear. Those models which

[1] Dept. of Geography, Hunter College, New York, NY, USA
[2] Dept. of Earth and Environmental Engineering, Columbia University, New York, NY, USA
[3] Meteorological Service of Canada, Dorval, Quebec, Canada

appear to exhibit smaller decadal scale variability tend to include more ensemble members, and those models which exhibit greater decadal scale variability tend to include only one ensemble member. In fact, the decadal scale variability of ensemble means are consistently smaller than the that of the individual ensemble members, and that of individual members tend to be closer to observed values. This indicates that decadal scale variability in these models is due to internal dynamics, and not due to external forcings.

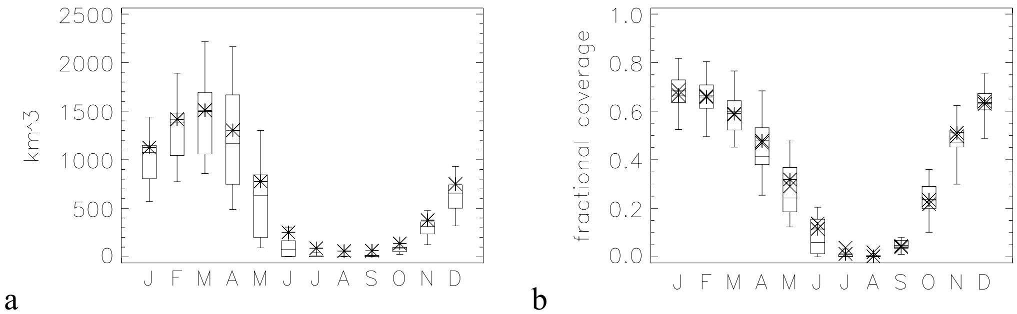

Figure 1. North American SWE (a) and SCE (b). Observations from Brown et al (2003) indicated with asterisks; from Robinson (1993) with crosses. Box and whisker plots indicate model results from 18 AMIP-2 AGCMs, and are interpreted as follows: middle line shows the median value; top and bottom of box show the upper and lower quartiles (i.e. 75th and 25th percentile values); and whiskers show the minimum and maximum model values. Figure adapted from Frei et al (2005).

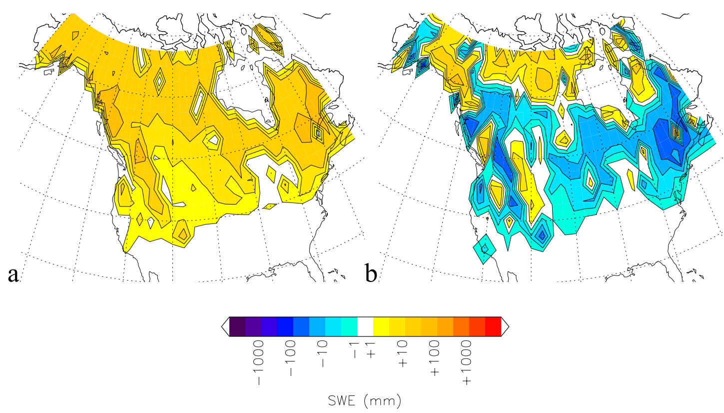

Figure 2. Seasonal (October-June) mean SWE (mm) regridded to 2.5° x 2.5° latitude - longitude resolution. (a) Observed, (b) model anomaly. Regridding was done using linear interpolation, and results are plotted on an Albers equal area projection using a logarithmic scale for contour lines. In (b), blue areas indicate model underestimation of SWE. Figure adapted from Frei et al (2005).

Twenty first century results At the time of this writing, output from five modeling groups are available to evaluate North American SCE variations under the historical emission scenario (20C3M) and all three twenty first century scenarios (COMMIT, SRESA1B, and SRESA2). Under the COMMIT scenario, greenhouse gas emission rates remain constant at year 2000 values. Under the SRES scenarios, emission rates increase either moderately (SRESA1B) or severely (SRESA2). As an example, Figure 4 shows the responses of SCE to each emission scenario for one model. Although trends vary considerably between models, in all cases the decreasing trends for the SRESA1B and SRESA2 scenarios are statistically significant and comparable in magnitude to each other; and, they both decrease at greater rates than under the COMMIT scenario. For all models under the SRESA1B and SRESA2 scenarios, SCE decreases at a greater rate during the twenty first century than during the twentieth century. In contrast, under the COMMIT scenario, while some models do have weak but significant decreasing trends in SCE, in no model does SCE decrease at a greater rate during the twenty first century than during the twentieth century. The differences in responses are not proportional to the differences in forcing under these scenarios, indicating that non-linear dynamics are influencing the snow cover.

Discussion and conclusions Significant between-model variability is found in all comparisons of GCM snow simulations: e.g. the range of simulated snow mass of North America by AMIP-2 AGCMs is ±50% of the estimated value. When using a GCM to evaluate potential changes in regional to continental scale hydrological variations one must exercise caution. However, the median result from all models tends to do a reasonably good job compared to observations. Thus, perhaps a "superensemble" of models, when numerous simulations from different models are combined, may be an effective method. Preliminary evaluations of AOGCMs suggest that: decadal scale variability is associated with internal climatic variations and not with external forcings in these models (whether that is true in the real climate system is unknown); and, decreases in snow extent are expected under realistic scenarios of future emissions, although the precise response of the snow cover to possible future climate variations may be non linear.

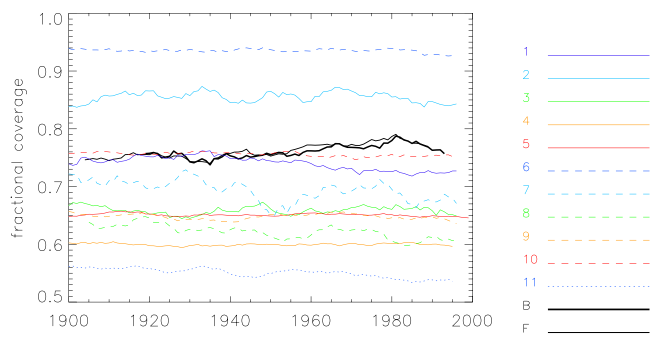

Figure 3. Nine-year running mean of twentieth century January NA-SCE for 11 IPCC-AR4 ensemble-mean model simulations and for reconstructions of observed variations. NA-SCE is defined as the fraction of the land area from 20° N - 90°N and 190° E - 340° E covered with snow. The legend shows the model number, which corresponds to model numbers and ensemble sizes shown in Table 2; "B" and "F" correspond to Brown (2000) and Frei et al. (1999), respectively. Figure adapted from Frei and Gong (2005).

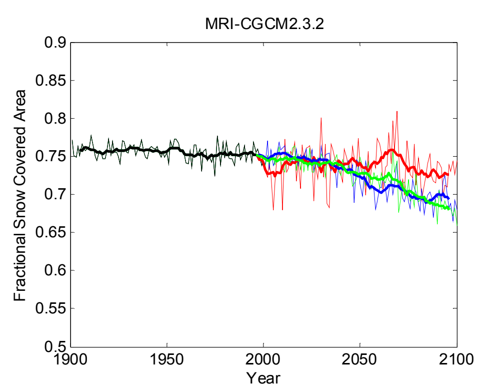

Figure 4. Annual time series (thin line), overlaid with nine-year running means (thick line), of ensemble-mean January NA-SCE for 20th and 21st century scenarios from one AOGCM. 20C3M, COMMIT, SRESA1B and SRESA2 scenarios denoted by black, red, blue and green lines, respectively. Figure adapted from Frei and Gong (2005).

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