General circulation model recommendations for Alberta

Diana Stralberg

Department of Biological Sciences

University of Alberta

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Alberta Biodiversity Monitoring Institute
CW-405 Biological Sciences
University of Alberta
Edmonton, Alberta, Canada T6G 2E9
Phone: (780) 492-6322
E-mail: abmiinfo@ualberta.ca

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As of the IPCC's 4th Assessment report, 24 general circulation models (GCM) developed by 17 climate modeling groups from 12 countries have been used to develop projections of future climate scenarios as part of the World Climate Research Project (WCRP) Coupled Model Intercomparison Project Phase 3 (CMIP3) (Meehl et al. 2007) (http://www-pcmdi.llnl.gov/ipcc/about_ipcc.php). Although these models share fundamental characteristics and are not generally independent from one another (Jun et al. 2008, Masson and Knutti 2011, Pennell and Reichler 2011), the projections they produce can be quite variable and there is no consensus on how best to combine them (Knutti et al. 2009). Oftentimes, a few GCMs are somewhat arbitrarily (or rarely, systematically) selected for comparison purposes. Recently it has become popular to evaluate "multimodel" or "ensemble" predictions based on averaging across multiple GCMs. The most straightforward way to do this is simply to average across all available models, giving each one equal weight. However, this may result in inappropriate smoothing of model variability (Knutti et al. 2009). Furthermore, many have pointed out that all GCMs are clearly not created equal, and that it may be useful to weight models by their predictive accuracy, as measured by their ability to predict historic climate conditions (Gleckler et al. 2008, Knutti 2010, Terando et al. 2012). Alternatively, such an evaluation may be used to select a handful of "best" models for a given purpose. Unfortunately this is not as straightforward as it may seem, as all GCMs have their strengths and weaknesses. Different variables are better predicted by different models over different time scales and different regions, depending on how the GCMs were parameterized and which modules were best developed (Gleckler et al. 2008). Furthermore, it has been shown that historical prediction accuracy does not correlate well with future projections (Räisänen 2007, Jun et al. 2008, Knutti et al. 2009).

Although there is little agreement about which GCMs are best and how they should be combined, a few principles have emerged that can help guide their appropriate use. First, there are some models that consistently perform poorly and should probably not be used (Räisänen 2007, Scherrer 2011). Second, although multi-model ensembles have consistently outperformed individual GCMs in predicting historical climates, "a few good models are better than the multimodel average" (Knutti et al. 2009). Third, models with higher spatial resolution (generally the newer models) tend to perform better in historical climate evaluations (Chen et al. 2011), although improvements have not been as great as might have been expected (Knutti et al. 2009). Finally, it is difficult to characterize models, in terms of historical performance or future predictions, without focusing on a particular region of interest (Gleckler et al. 2008). In light of these issues, I have developed a process for conservatively selecting suites of models to evaluate with respect to Alberta climate change:

1. Of the 24 GCMs included in CMIP3, I excluded eight based on their failure to replicate key climatic processes according to one or more evaluations (Wang et al. 2007, Scherrer 2011) (marked with an 'X' in Table 1). Four of these were identified by both studies as "obviously bad" (Scherrer 2011) (last four entries in Table 1). *Ensemble projections should therefore be limited to the 16 remaining GCMs (only 15 available for SRESA2).*
2. These 16 GCMs were ranked according to the combined rankings from four evaluations of historical climate predictions, two for the northern hemisphere (20°-90°) (Gleckler et al. 2008, Walsh et al. 2008), one for the arctic region (Wang et al. 2007), and one for China (Chen et al. 2011); as well as their spatial resolution (Table 1). Two high-resolution models were only evaluated by the Chinese study, but ranked highly therein (first two entries in Table 1). Notably, although some common patterns emerged, the rankings from the four studies were quite different. *Thus, differential weighting of these 16 GCMs does not currently seem warranted. Additional Alberta-specific historical validation exercises would be necessary to justify explicit GCM weightings.*
3. A separate consideration from historical accuracy is the nature of future projections, which may be more readily evaluated for Alberta. My goal was to identify groups of models that provide similar projections for Alberta, as well as a representative model from each of those groups. I performed an affinity propagation cluster analysis (Frey and Dueck 2007) using end-of-the century (2071-2100) climate projections based on a high emissions scenario (SRESA2). I used CMIP3 projections downscaled to a 500-m grid cell resolution using the ClimateWNA tool (Wang et al. 2011), which is based on PRISM climate normals (Daly 2006). For a suite of 10 temperature and precipitation variables, these projections were averaged across the province and used as the basis of a cluster analysis to identify groups of models with similar future projections. GCMs were also plotted against the first two axes of a principal components analysis (PCA) to describe their climatic characteristics. Four groups of GCMs were identified by the cluster analysis, one of which (cluster 2) contained a single, low-ranking member (Table 1). The identified clusters were not highly distinct (Figure 1) and varied slightly depending on climate variables used, region analyzed, and level of climate

downscaling, based on exploratory analyses. *Thus the clusters should not be over-interpreted, but may be useful as a guideline for selecting GCMs to represent broadly-defined future climate-change scenarios. The clusters may be described by the following future climate-change scenarios: (1) smaller temperature increase; (2) wetter; (3) drier; (4) wetter and less seasonal (i.e. less difference between summer and winter temperatures).*

4. Multiple factors may be considered in the selection of representative GCMs. A strictly quantitative selection of the top-ranked GCM in each cluster is not necessarily advisable given the variability in the rankings, and the fact that the first two models are less well-established. In addition, the Russian model is generally low-ranking, and its separation in the cluster analysis may rather suggest that it should be excluded. Furthermore, it would be desirable to include North American models, which are generally well-established and high-performing, and the Canadian model in particular. Finally, it may be desirable to evaluate the set of models that are most distinct from one another, and therefore represent the broadest set of future climate-change scenarios. This was done by directly examining the climatic distances used to identify clusters (Figure 2). *This identifies the following models as most distinct: INM-CM3.0, Russia (wetter), CGCM3.1(T47), Canada (wetter and less seasonal), GFDL-CM2.1, USA (drier), UKMO-HadGEM1, UK (drier and much warmer). The least distinct, most central, and therefore most representative model overall is ECHAM5/MPI-OM, Germany. These five GCMs would constitute a complementary suite of models for climate-change evaluation purposes in Alberta.*

Table 1. GCM ranking and cluster membership. GCMs from CMIP3 project (http://www-pcmdi.llnl.gov/ipcc/about_ipcc.php).

GCM, Country	combo rank	Alberta cluster*
INGV-ECHAM4, Italy/Germany	1	3
CSIRO-Mk3.5, Australia	5	4
ECHAM5/MPI-OM, Germany	6	1
CCSM3, USA	6	4
GFDL-CM2.1, USA	6	3
GFDL-CM2.0, USA	7	3
UKMO-HadCM3, UK	8	3
UKMO-HadGEM1, UK	8	3
CSIRO-Mk3.0, Australia	9	1
CGCM3.1(T63), Canada	9	X
ECHO-G, Germany/Korea	11	3
CGCM3.1(T47), Canada	12	4
CNRM-CM3, France	13	3
PCM, USA	13	4
INM-CM3.0, Russia	17	2
BCCR-BCM2.0, Norway	19	1
MIROC3.2(medres), Japan	X	X
MRI-CGCM2.3.2, Japan	X	X
MIROC3.2(hires), Japan	X	X
IPSL-CM4, France	X	X
FGOALS-g1.0, China	X	X
GISS-ER, USA	X	X
GISS-EH, USA	X	X
GISS-AOM, USA	X	X

* 1= smaller temperature increase; 2 = wetter; 3 = drier; 4 = wetter and less seasonal (i.e. less difference between summer and winter temperatures).

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Figure 1. Biplot of climate variables and GCMs on the first two axes of a PCA analysis. MAT = mean annual temperature; MWMT = mean warm month temperature; MCMT = mean cold month temperature; EMT = extreme minimum temperature; TD = summer/winter temperature difference; MAP = mean annual precipitation; MSP = mean summer precipitation; PAS = percent of precipitation as snow; Eref = reference evapotranspiration; CMD = climatic moisture deficit (Wang et al. 2011).

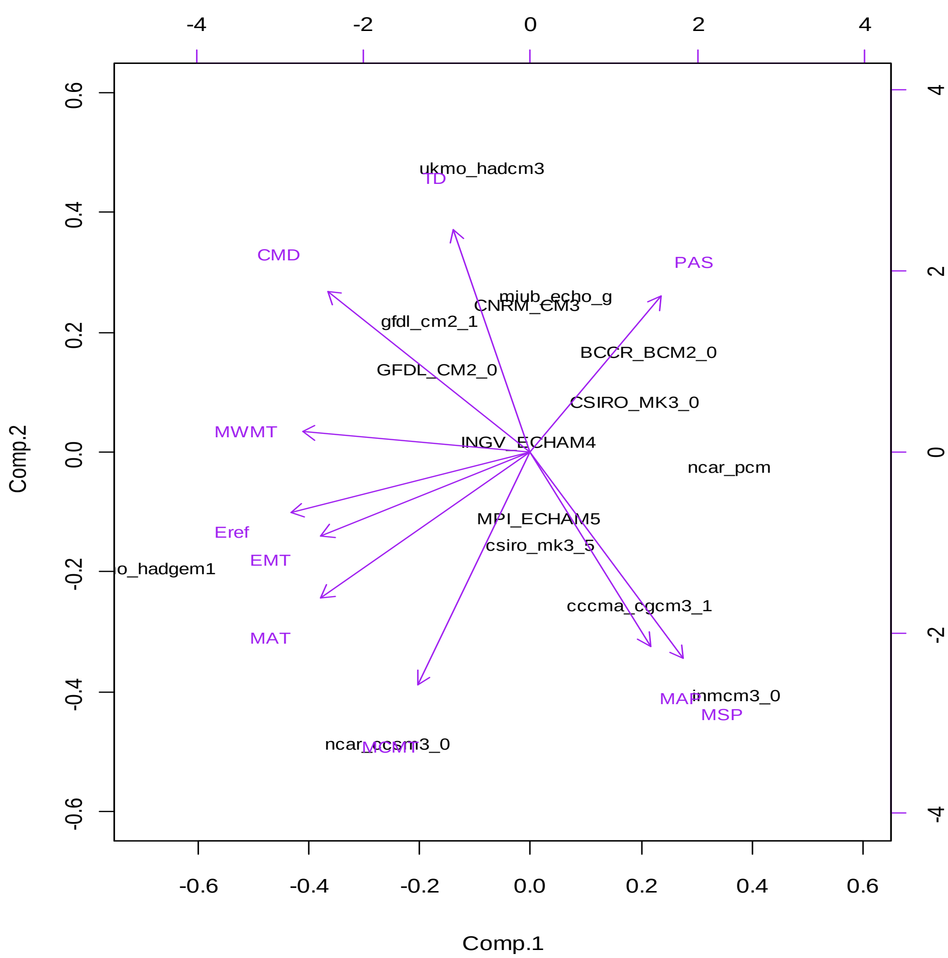
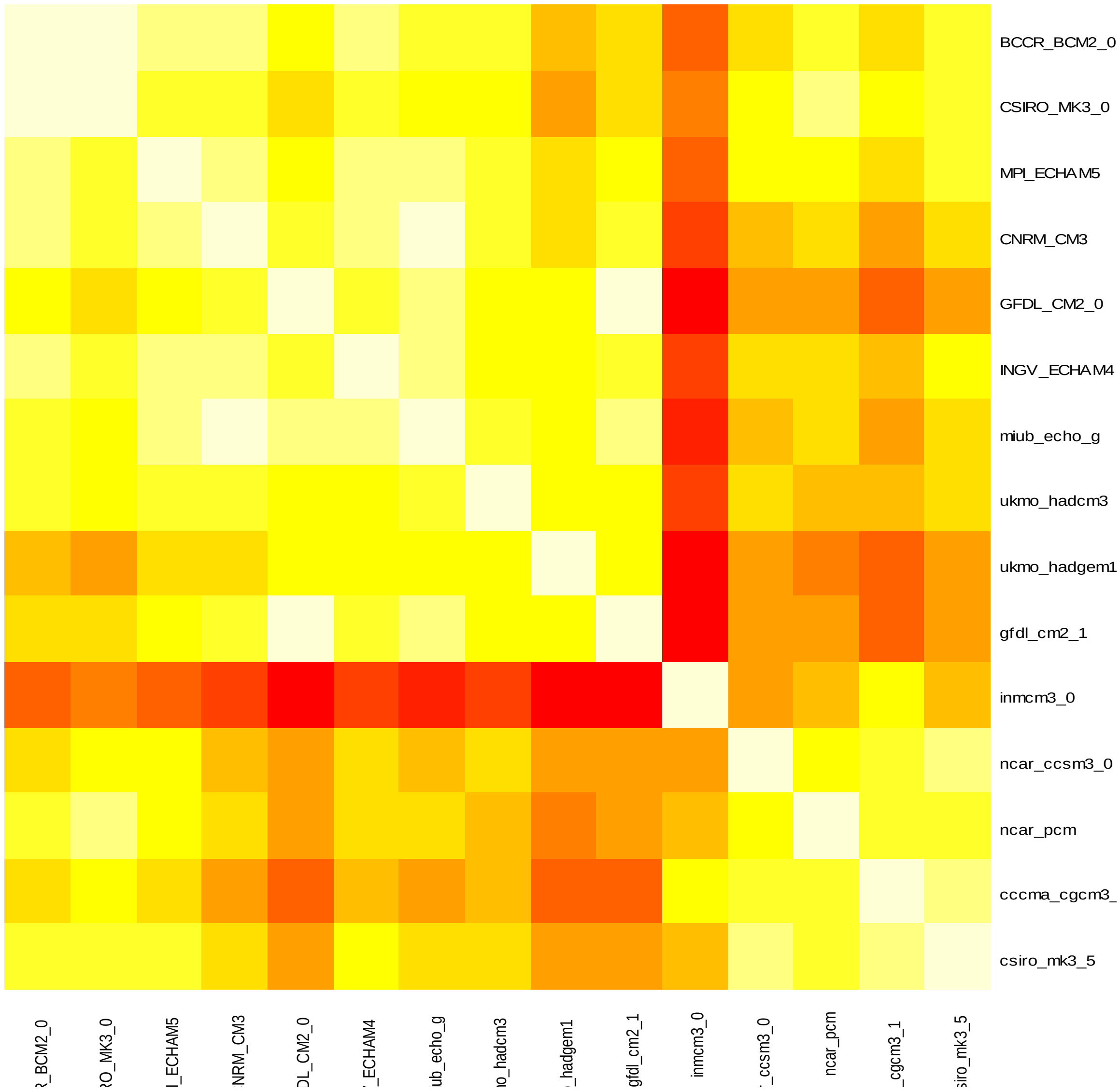


Figure 2. GCM distances for end-of-century (2071-2100) climate projections (SRESA2 emissions scenario). Red = less similar; yellow = more similar.



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