Rationale for the ClimateBC/NA 8-model ensemble mean

Colin Mahony, Research Climatologist, British Columbia Ministry of Forests

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Consistent with Mahony et al. (2022) and Hausfather et al. (2022), ClimateBC/NA users wishing to use an ensemble mean projection should use the 8-model ensemble mean provided in the new version of ClimateBC/NA, rather than the 13-model ensemble mean. However, all 13 models provided in ClimateBC/NA are valid for analysis relative to warming levels.

Hausfather et al. (2022), published this week, note that the latest generation of global climate models (CMIP6) includes several models that run "too hot." Specifically, these models have a global temperature response to greenhouse gas forcing (equilibrium climate sensitivity, ECS) that is well above the 2-5°C range assessed by the IPCC as "very likely" based on multiple lines of observational evidence. Consistent with IPCC practices, Hausfather et al. (2022) advise that these models should be down-weighted or excluded in the calculation of ensemble mean projections relative to time (i.e., with years on the x-axis). However, they note that these models are useful in ensemble analysis relative to global warming levels (i.e., with temperature change on the x-axis). Their perspective is authoritative and consistent with current best practices in climate modeling.

ClimateBC and ClimateNA provide future projections for 13 global climate models selected by Mahony et al. (2022). This 13-model ensemble matches the distribution of ECS in the CMIP6 generation of global climate models. All 13 models provided in ClimateBC/NA are valid for analysis relative to warming levels. However, using a similar rationale to Hausfather et al. (2022), Mahony et al. (2022) recommended an 8-model general-purpose ensemble that excludes climate models with ECS above or below the IPCC 2-5°C range (See Box 1 below). ClimateBC/NA users wishing to use an ensemble mean projection should use the 8-model ensemble mean provided in ClimateBC/NA v7.3, rather than the 13-model ensemble mean. Further, ensemble analyses of climate change relative to time should use the 8-model ensemble, or at least exclude CanESM5 and UKESM1-0, the two models with very high ECS.

The differences between the 13-model and 8-model ensembles are illustrated in Figure 1. For mean summer daily maximum temperature (tasmax/Tmax_sm) averaged over North America, the 13-model ensemble mean is 0.5°C (13%) warmer than the 8-model ensemble mean. The proportional differences are greater in higher emissions scenarios (Figure 1a). The difference between the ensembles is roughly equal to the difference between adjacent scenarios in mid-century (2040-2070), but is less than differences among scenarios later in the century. This emphasizes that uncertainty in future emissions overshadows the differences between the 13-model and 8-model ensemble means.

The range of year-to-year variability is much greater in the 13-model ensemble (Figure 1b). This is largely due to the extreme warming produced at high latitudes by the UKESM1-0 model. While interannual variability of individual model runs does not affect most users of ClimateBC/NA (since they are averaged out in the climate normals), Figure 1b illustrates the importance of careful ensemble selection in analysis of climate time series.

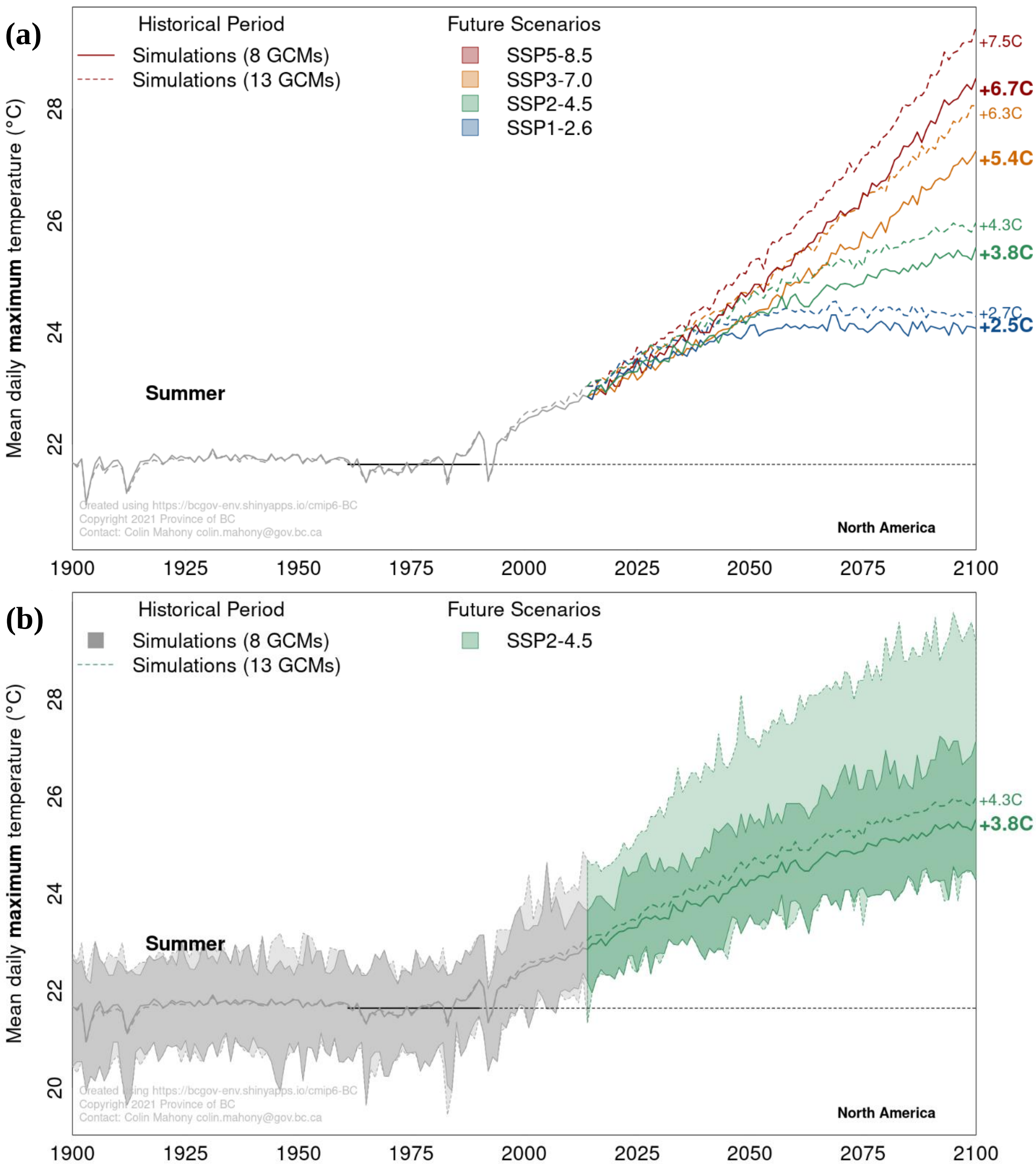

Figure 1: Comparison of the ClimateNA 13-model ensemble (dashed lines) and 8-model ensemble (solid lines). The variable is mean summer daily maximum temperature (tasmax/Tmax_sm) averaged over North America. The 8-model ensemble excludes models with equilibrium climate sensitivity (ECS) outside the IPCC-assessed 2-5°C range. (a) Ensemble mean projections for the four main CMIP6 marker scenarios. (b) Ensemble mean and full range (min/max for all simulations of all models) for the SSP2-4.5 scenario. Similar plots for other variables and subregions are available from the [cmip6-NA] and [cmip6-BC] apps.

Box 1—Reconciling the equilibrium climate sensitivity of the CMIP6 ensemble with observational constraints (excerpted from Mahony et al. 2022)

The 13-model ensemble, like the full CMIP6 ensemble, has a mean (3.7°C) and upper limit (5.6°C) of equilibrium climate sensitivity that substantially exceeds the IPCC AR6 assessed best estimate ECS of 3°C and very likely upper limit of 5°C (Arias et al. 2021). In other words, the 13-model ensemble contains models that simulate stronger global warming than is supported by multiple lines of observational evidence. Five (38%) of the 13 models are above the IPCC AR6 assessed likely upper limit on ECS of 4°C, and two (15%) of the models are above the very likely upper limit of 5°C. If the ensemble were to strictly conform to the IPCC assessed range, there would be only two models exceeding 4°C ECS and no models exceeding 5°C, following the IPCC's probabilistic definitions of likely (one-sided $p>83\%$) and very likely (one-sided $p>95\%$).

The need to reconcile the CMIP ensemble ECS range with observational constraints is a new dilemma for climate change impacts and adaptation researchers. It is long been agreed that model democracy (one model, one vote) is not a strictly valid method of assessing climate change uncertainty (Knutti 2010, Leduc et al. 2016). However, prior to CMIP6 this objection was somewhat academic since the distribution of ECS in CMIP ensembles approximately matched the (wider) range of ECS supported by other lines of evidence (Schmidt 2021). For practical purposes it was reasonable for analysts to use the multimodel ensemble spread in previous CMIP generations as a proxy for scientific uncertainty on climate change. This approach is no longer valid given the incongruence between the CMIP6 ensemble range of ECS and the IPCC assessed range (Schmidt 2021). Careful model selection is now required to avoid biasing regional climate change analyses.

There are several viable approaches to constrain CMIP6 ensembles in downscaled regional analyses. Weighting the models based on observational constraints is possible for regional analyses (Ribes et al. 2021). However, in practice many analyses will require simply selecting a subset of the CMIP6 ensemble that is closer to the IPCC assessed range, as we have done with the 8-model subset. The disadvantage of this approach is that it discards valuable information from the excluded models. The CanESM5 and UKESM1 models are advanced models from respected modeling centers, with demonstrated skill in modeling many Earth system processes (Eyring et al. 2021). Expressing variables of interest relative to the amount of regional or global warming is a widely practiced technique that facilitates inclusion of high-ECS models by removing the timing of the warming as a factor in the ensemble spread (Arias et al. 2021). It is conceivable that both techniques could be used in a single study; to use the 8-model ensemble for time-relevant analyses and a larger ensemble for analyses where the warming level is more relevant. These considerations highlight that the full CMIP6 ensemble is a somewhat arbitrary collection of non-independent models, and careful ensemble selection is necessary to achieve a meaningful representation of modeling uncertainty.

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