Multiple models used in weather forecasting and climate impact assessments

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Multiple models are commonly used in weather forecasting and climate impact assessments, two large sub-disciplines within atmospheric science. The atmosphere and the other components of the climate system contain many important phenomena that are not explicitly resolved in existing numerical models, a prominent example being the convective processes that drive warm-weather precipitation, such as thunderstorms. As a result of differences in the representation of these sub-grid scale processes and a host of other factors, including numerical methods, resolution, and observational data sets for initialization, numerical models used for simulating weather and climate can differ dramatically.

Multiple models have been used for climate impact assessments for more than two decades, with the first prominent climate model intercomparison conducted by the Intergovernmental Panel on Climate Change (Houghton et al., 1990). The Department of Energy's Program for Climate Model Diagnosis and Intercomparison has organized and archived climate model output for use in impact assessments since 1989. The current climate model intercomparison project is CMIP5 and includes 20 climate modeling groups from around the world. Regional versions of such intercomparison projects, which feature models with finer spatial resolution, have recently been started, such as the North American Climate Change Assessment Program (Mearns et al., 2009). Climate models have steadily improved over the years as a result of improved representation of physical processes, higher resolution, and better computer resources (Reichler and Kim, 2008).

A consistent finding of global climate model intercomparison projects is that the multi-model mean is often superior to any individual climate model (Reichler and Kim, 2008). Studies at the regional scale, such as the state of Pennsylvania (Shortle et al., 2009; Shortle et al., 2013), support this finding.

Multiple models also facilitate hypothesis testing. For example, multiple climate model simulations support the hypothesis that most of increase in global-mean temperature over the past 100 years is a result of greenhouse gas increases (Hegerl et al., 2007). At the regional scale, multiple models were used to ask the question if the mean climate of Pennsylvania was better simulated with global vs. regional climate models (Shortle et al., 2013). The higher resolution of the regional models did not translate into better simulations of the spatial average of Pennsylvania's climate. This question would have been impossible to answer without multiple models.

The degree of model consensus is also a useful indicator of how strongly a conclusion can be made about some aspect of future climate change (Meehl et al., 2007). An example at the regional scale is shown (Fig. 1) presents projections of temperature and precipitation change in the Chesapeake Bay Watershed by the end of the 21st century for a given greenhouse gas emissions scenario (Najjar et al., 2010). There is unanimous agreement that the watershed will continue to warm, somewhat less consensus that winter and spring precipitation will increase, but very little agreement regarding summer and fall precipitation change. Another example is for projections of global sea-level change: climate model error roughly doubles the uncertainty beyond that due to the emissions scenario (Rahmstorf, 2007).

To assess the usefulness of multiple models in weather forecasting, meteorologists at the Pennsylvania State University were interviewed. Their responses unanimously confirmed the power of multiple modeling and reinforce many of the advantages noted above for climate models. Here are some selected quotes:

"I would be lost without multiple atmospheric model output—I use it every day that I forecast."
–Paul Knight, Broadcast Meteorologist

"Use of ensembles has become the norm for tropical cyclone forecasting. Ensembles provide the envelope of possibility for the storms, which gives much more information than any single realization."
–Jenni Evans, Tropical Meteorologist

"For severe storms, we use multiple models in large part because they differ in resolution and how far out they go in time." –Yvette Richardson, Severe Storms Meteorologist

"Without multi-model ensembles it is hard to know how much to trust any one model. Consensus—a weighted average of forecasts—almost always beats any one model."
–George Young, Meteorologist

"Nate Silver's election prediction is essentially the same technique we use in meteorology. By simply taking a poll of polls—an ensemble—his margin of error was much less than the margin of error of any individual poll."
–Paul Markowski, Severe Storms Meteorologist

In summary, it is difficult to envision the fields of climate science and weather forecasting without multiple models, in short because the model-mean is often superior to any individual model and because the model spread provides a useful estimate of the uncertainty in the simulation or forecast.

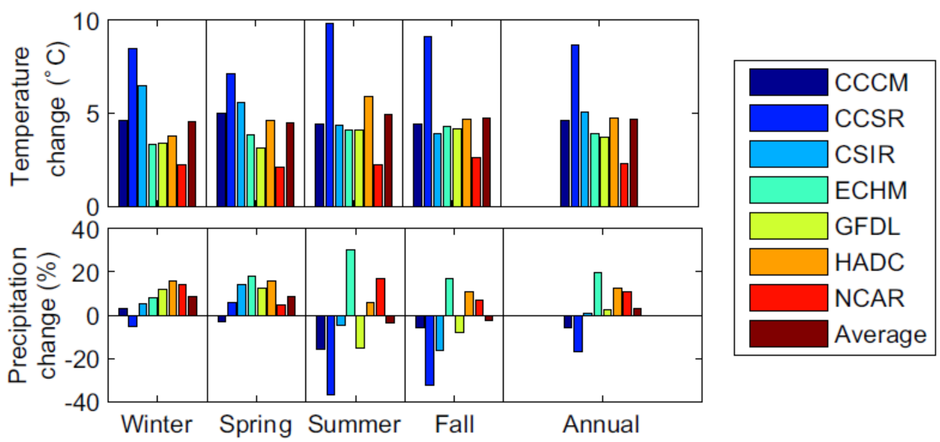

Fig. 1. Simulated temperature and precipitation change by the end of the 21st century in the Chesapeake Bay Watershed under the A2 emissions scenario. The different colors show different climate models. From Najjar et al. (2010).

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