Using Climate Model Output to Understand and Adapt to Climate Change

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The Challenge of Adaptation to Climate Change

Adaptation to climate change at the regional and local levels has long been considered particularly challenging largely because of uncertainty about change in regional climate. This makes it difficult for planners to identify what type of future to plan for (e.g., a wetter or drier climate).

The challenge is whether and how information on potential changes in future regional climate could be harnessed to give planners insight on the likelihood of change in key variables. Information on whether key climatic variables such as temperature, precipitation, precipitation intensity, and sea level are expected to increase or decrease can help planners anticipate the kind of future to plan for. Even if timing and magnitude are uncertain, if for example, a drier climate appears more likely than a wetter climate, planners may be able to hedge their bets to reduce the vulnerability of sensitive systems to a drier climate.

Using Climate Model Output

The old approach

For many years, the impacts and adaptation community has used regional estimates of climate change from climate models to guide their analysis. The old approach relied upon a limited number of scenarios, typically taken from a few general circulation models (GCMs) to help identify possible changes. The problem was that this approach did not indicate if the scenarios reflected a reasonable range of future climates or whether some were more probable than others.

A new approach

We use the output of many climate models to better capture agreement and disagreement among them. The difference in regional forecasts across models is a minimum range of uncertainty. Where models are in agreement about the direction of change in key variables, we can conclude that such a change seems probable. Where models may disagree about the direction of change, we can use the range as a minimum definition of uncertainty. We can also see if a relatively high proportion of models agree about the direction of change in specific variables. Such information can be used to examine how a system could be affected by climate change (the scenarios approach) or to assess the relative likelihood that a threshold (e.g., extreme flooding or drought) could be exceeded (the threshold approach).

Addressing Key Uncertainties

The approach needs to allow users to address key uncertainties about regional climate change. There are three fundamental sources of uncertainty:

1. Greenhouse and other gas emissions
   The IPCC SRES scenarios project a very wide range of emissions of key greenhouse gases (GHG) such as CO_2 and other gases like SO_2.
2. Climate sensitivity
   How much global mean temperature (GMT) will warm for a CO_2 doubling has traditionally been thought to be between 1.5 and 4.5°C, although a number of recent studies conclude that there is a low probability of substantially higher increases in GMT.
3. Pattern of regional change
   This third source of uncertainty concerns relative regional changes in temperature and precipitation. Both global temperatures and precipitation will rise, but some areas will warm more than others and some areas will receive increased precipitation while others will face decreases.

Using MAGICC/SCENGEN

The tool MAGICC/SCENGEN (M/S)[1] can be used to address these three uncertainties. The tool is easy to apply as it can be run on a laptop in a few minutes (Figure 1).

Figure 1. MAGICC and SCENGEN.

MAGICC is a one-dimensional model that estimates GHG concentrations and change in GMT and sea level. MAGICC allows users to select:

- GHG emissions scenarios, thus addressing uncertainty #1 (Figure 2)
- Climate model uncertainties (including climate sensitivity, aerosol feedbacks, carbon cycle, thermohaline circulation, and ice melt), thus addressing uncertainty #2 (Figure 3).

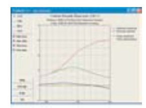
Figure 2. CO_2 emissions from the A1FI and B1 emission scenarios.

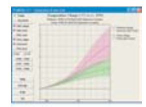
Figure 3. MAGICC projections of increase in GMT for the A1FI and B1 emission scenarios for 2 x CO_2 sensitivities of 1.5 to 4.5°C.

SCENGEN uses the regional pattern of relative changes in temperature and precipitation across 17 GCMs,[2] expressed as regional change relative to increase in GMT by model. GMT comes from MAGICC. This pattern of relative change is preferable to averaging regional GCM output because it controls for differences in climate sensitivity across models.

SCENGEN can be used to examine the extent to which the GCMs agree or disagree about regional projections of temperature and precipitation. It calculates a signal-to-noise ratio for all models. The latter divides the average model projection for a region by the intermodel standard deviation. This indicates the extent to which the climate models agree or disagree about the direction of change in temperature and precipitation.

Figures 4-7 display scaled model precipitation changes for 2030 using the A1B emissions scenario and a climate sensitivity of 3°C. Figure 7 displays the signal-to-noise ratio for precipitation. While the models on average tend to estimate decreased precipitation for many regions of the United States in 2030 under this scenario, the signal-to-noise ratio is less than 1 for all areas. This indicates that the models do not agree on the direction of precipitation change. Note all the models project increased temperatures for the United States with a signal-to-noise ratio of well above 1.

SCENGEN can also be used to compare models' estimates of current temperature and precipitation patterns and amounts to observed data. This is useful for selecting which models best simulate current climate or for weighting model projections.


Figure 4. Scaled precipitation change by 2030 for the United States using HadCM2.

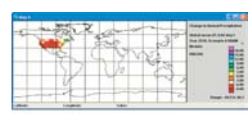
Figure 5. Scaled precipitation change by 2030 for the United States using HadCM3.


Figure 6. Scaled precipitation change for the United States in 2030 over 1990 using average of 16 GCMs.


Figure 7. Signal-to-noise ratio on precipitation change for the United States in 2030 over 1990 using average of 16 GCMs.

Using MAGICC/SCENGEN (cont.)

Aspen

The city of Aspen is sponsoring an assessment of how the ski industry and tourism may be affected by climate change. The Aspen Global Change Institute is coordinating the study. Stratus Consulting, the University of Colorado, and Tom Wigley are subcontractors.

M/S is being used to identify a range of changes in regional temperature and precipitation by 2030 and 2100. The tool was used to determine which GCMs best simulate current global and western North America temperature and precipitation. HadCM2, HadCM3, ECHAM3, ECHAM4, and CSIRO were selected.

The three key sources of uncertainty about regional climate change are being addressed by using M/S:

- Three SRES scenarios will be used to address uncertainty about GHG emissions. A1B will be the "central" scenario. A1FI will be used for high emissions and B1 for low emissions. Since there is little appreciable difference in emissions in 2030, only A1B will be used for that time period. All three will be used for 2100.
- Three climate sensitivities will be used to reflect uncertainty. The central estimate for CO_2 doubling will be 3°C. The low estimate will be 1.5°C and the high 4.5°C. Higher sensitivities are possible.
- All the models project increased temperatures and most project decreased precipitation. The average of the five GCMs will be used for the central scenario. The HadCM2 model will be used as the wettest scenario and ECHAM3 will be used as the driest.

For 2030, we will use combinations of climate sensitivity and regional patterns. For 2100, we will use combinations of GHG emissions, climate sensitivity, and regional patterns.

In addition, the Aspen study will use regional climate model projections for the region supplied by Dr. Ruby Leung of the Pacific Northwest Laboratory and statistical downscaling from the HadCM3 model. The latter will be conducted by Dr. Robert Wilby.

Temperature increases for 2030 over 1990 for two SCENGEN grid boxes that include Aspen are displayed in Figure 8. Precipitation changes are displayed in Figure 9. Grid boxes are from 35 to 45°N and 105 to 110°W.

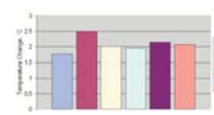
Figure 8. Change in temperature in 2030.

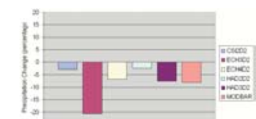
Figure 9. Change in precipitation in 2030.

Other applications

M/S will also be used by Stratus Consulting to create climate change scenarios for USAID funded analyses of climate change adaptation for coastal development and flooding, water supplies, and agriculture in Honduras, South Africa, and Mali and in a NOAA funded assessment of climate change impacts on Boulder, Colorado's long-term water supplies.

Acknowledgments

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References

1. Wigley, T.M.L. 2004. MAGICC/SCENGEN. National Center for Atmospheric Research, Boulder, CO. Available http://www.cgd.ucar.edu/cas/wigley/magicc/.
2. Covey, C., K.M. AchutaRao, U. Cubasch, P.D. Jones, S.J. Lambert, M.E. Mann, T.J. Phillips, and K.E. Taylor. 2003. An overview of results from the Coupled Model Intercomparison Project (CMIP). *Global and Planetary Change* 37:103-133.