The Fifth Assessment Report (AR5) of the United Nations (UN) Intergovernmental Panel on Climate Change (IPCC) is being released in four parts between September 2013 and November 2014, superseding the 2007 Fourth Assessment Report (AR4) as the most comprehensive review of climate science and policy. The First Assessment Report (FAR) emerged after the IPCC was established in 1988 by the World Meteorological Organization and the United Nations Environment Programme. These entities were given the task of preparing a report on all aspects of climate change and its impacts in order to inform development of practical response strategies. After its 1990 release, the FAR exposed the need for international cooperation and spurred creation of the UN Framework Convention on Climate Change (UNFCCC), the key international treaty to guide greenhouse gas (GHG) reduction (referred to as climate change mitigation) and provide a framework for managing consequences of nonreduction (referred to as climate-change adaptation). Since 1995 regular assessments have been released along with a number of special scientific reports. The previous report (AR4) was released in 2007.

These assessment reports and related updated scientific publications assist national governments in their communications with the UNFCCC and help them review their GHG emissions and plans for mitigation, potential impacts, and adaptation.
Using Integrated Modeling Software and GCMs to Determine Climate Change Effects

Climate change is “any systematic change in the long-term statistics of climate elements (such as temperature, pressure, or winds) sustained over several decades or longer” (AMS, 2012). Because this change is predominantly driven by greenhouse gas emissions such as carbon dioxide and methane largely associated with burning fossil fuels, assumptions about how much carbon (emissions) is being added to the carbon cycle is necessary to assess potential effects on Earth’s environment. The Intergovernmental Panel on Climate Change (IPCC, 2013) developed four representative concentration pathways (RCPs). The four RCPs—RCP2.6, RCP4.5, RCP6.0, and RCP8.5—are named after a possible range of radiative forcing values in the year 2100 relative to preindustrial values (+2.6, +4.5, +6.0, and +8.5 W/m², respectively).

Recently released and forthcoming AR5 reports contain more extensive information on climate change’s socioeconomic impacts and thus its role in sustainable development. The report’s features include a new set of scenarios applied across three working groups:
- Working Group I: The Physical Science Basis (released and available on the IPCC website)
- Working Group II: Impacts, Adaptation and Vulnerability (released Mar. 31, 2014, and available on the IPCC website)
- Working Group III: Mitigation of Climate Change (approved and Summary for Policy Makers available as of April 14 on the IPCC website)

Additional activities include a task force on GHG inventories, a synthesis report that will integrate science from the three working-group reports, and special reports issued through AR5 and previous assessment cycles. Specifically written for policymakers, government officials, government advisors, and experts, the jargon-free and accessible synthesis report will not be released until its adoption, expected in late October in Copenhagen, Denmark. In the United States, the IPCC reports have supported a series of national climate assessments (NCAs) issued by the US Global Change Research Program. The Draft Third NCA Report, supported in part by data from IPCC AR5, was released for comment in early 2013 and is being finalized.

Differences in AR4 and AR5 Model Results

General circulation models (GCMs), also known as global climate models, are mathematical models of either the atmosphere or ocean and have been a substantial part of the assessment process since 1990. The number of climate-science modeling groups producing GCMs has increased markedly during successive IPCC assessments, from five groups generating eight models for the FAR in 1990 to 27 groups producing 61 models for AR5.

These models represent the natural (physical, chemical, and biological) processes of the atmosphere, ocean, cryosphere, and land surface and are the most sophisticated available for simulating effects of increased GHG concentrations on the global climate system. Over time there has also been an expansion in modeled variables, including both the marine and atmospheric environment. For AR5, many models generate daily climate elements (e.g., maximum, minimum, and mean temperatures and precipitation).

For example, only 12 AR4 GCMs produced daily precipitation outputs; with AR5, more daily datasets support improved modeling of extreme rainfall events. Previously, a location’s monthly rainfall could show a drying signal in contrast to increased intensity and frequency of daily rainfall events. Few groups had managed to develop effective methods for extracting meaningful information on extreme events using fewer daily GCM datasets. More than 20 GCMs (of the current 61) have all the necessary data for post-processing and integration with extreme-rainfall-event models for...
risk assessments and the 40 models that can generate spatial scenarios.

This data enrichment adds information for tools applied to real-world problems and improves the statistical significance of results. The IPCC advises that an ensemble or combination of models be applied when using GCM data (Stocker et al, 2010). The ensemble approach reduces model-specific bias, thereby providing the best available representation of projected climate change (Knutti et al, 2010).

Global scenario parameters are needed to generate GCM results. Before AR5, the Special Report on Emission Scenarios (SRES) contained storylines (IPCC, 2000) that described this information. The FAR was driven by analog and equilibrium scenarios for impact assessment that included business-as-usual (as well as policy) scenarios. Forty SRES scenarios represented different assumptions on emissions based on economic growth, land use change, and other driving forces of climate change. This scenario list was refined to six families for application in risk assessments with the descriptors A1FI, A1B, A1T, A2, B1, and B2.

In 2005, the SRES scenarios were replaced with representative concentration pathways (RCPs; van Vuuren, 2011a). RCPs replaced the SRES storylines with a more scientifically based approach to GCM scenario input. RCPs now include scenarios that explore approaches to climate change mitigation in addition to traditional “no climate policy” scenarios. Table 1 provides an overview of RCPs; Figure 1 compares emission scenarios from AR4 and AR5.

Recently released and forthcoming AR5 reports contain more extensive information on climate change’s socioeconomic impacts and thus its role in sustainable development.

OVERALL AR5 FINDINGS

Change in precipitation distribution. Globally, AR5 model precipitation projections are similar to AR4’s; however, when ensemble medians of models are compared, some important geographic areas show significant differences in GCM results. The models are based on data trending through the twenty-first century, representing a huge increase in data, although increased data do not necessarily lead to improved model performance (Knutti & Sedláček, 2013).

Figure 2 compares the model agreement for change in precipitation for the continental United States between AR4 (part A) and AR5 (part B) using 16 models for AR4 and 39 for AR5. The figure highlights geographies that in general are becoming drier or wetter. Red values demonstrate the percentage of the models agreeing that the precipitation will decrease from climate change. Therefore, a 50% contour-line value indicates that just as many models project a precipitation increase as project a precipitation decrease.

Although AR4 results have now been superseded by AR5 results, it is worthwhile to highlight the differences for the United States because many current climate change policies and plans have been based on AR4 results.

The AR4 image in Figure 2 has some 60% contour lines but no 70% line, which means that 60–70% of the model projections agree there is a likelihood of drier conditions. The 40% boundary stretches from the US Pacific Northwest to the Southeast.

<table>
<thead>
<tr>
<th>RCP</th>
<th>Description</th>
<th>CO₂ Equivalent</th>
<th>SRES Equivalent</th>
<th>Publication—IA Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>RCP8.5</td>
<td>Rising radiative forcing pathway leading to 8.5 W/m² in 2100</td>
<td>1,370</td>
<td>A1FI</td>
<td>Raaihi et al, 2007—MESSAGE</td>
</tr>
<tr>
<td>RCP6.0</td>
<td>Stabilization without overshoot pathway to 6 W/m² in 2100</td>
<td>850</td>
<td>B2</td>
<td>Fujino et al, 2006; Hijjoka et al, 2008—AIM</td>
</tr>
<tr>
<td>RCP4.5</td>
<td>Stabilization without overshoot pathway to 4.5 W/m² in 2100</td>
<td>650</td>
<td>B1</td>
<td>Clarke et al, 2006; Smith and Wigley 2006; Wise et al, 2009—GCAM</td>
</tr>
<tr>
<td>RCP2.6</td>
<td>Peak in radiative forcing at ~ 3 W/m² before 2100 and decline</td>
<td>490</td>
<td>None</td>
<td>van Vuuren et al, 2007; van Vuuren et al, 2006—IMAGE</td>
</tr>
</tbody>
</table>

Sources: van Vuuren et al, 2011b; Moss et al, 2010; Rogelli et al, 2012

CO₂—carbon dioxide, IA—integrated assessment, RCP—representative concentration pathway, SRES—Special Report on Emissions Scenarios

B1, B2, and A1FI are descriptors of families in a scenario list used in risk assessments.

RCP2.6, RCP4.5, RCP6.0, and RCP8.5 are named after a possible range of radiative forcing values in the year 2100 relative to preindustrial values (+2.6, +4.5, +6.0, and +8.5 W/m², respectively).
where 60–70% of the model projections agree that conditions are likely to get wetter.

Applying AR5 models changes this message. The highest value in the AR5 image is the 50% contour (in the southern states). Because there is no 60% contour, this means that now between only 50 and 60% of the models project a drying in these areas (which also means that 40–50% of the models project an increase in precipitation). Moving north and west, the agreement for drier conditions declines to values of 30–40%, indicating that 60–70% of the model projections agree that conditions could get wetter. The diagonal zones depicted with AR4 are no longer visible. In the US Midwest the message is less clear because the area between 40 and 50% drier has become much wider.

What are the differences between AR4 and AR5, and what do these differences mean?
- For most of the United States, a minority of the models (< 50%) now (with AR5) indicate drier conditions, implying that a majority (> 50%) indicate wetter conditions. This applies to the average weather conditions. Extreme events are likely to become more extreme and more frequent everywhere in the United States.
- Under AR5, the highest agreement for getting wetter is lower than under AR4; this represents more uncertainty that will need to be taken into consideration when planning.
- Although the southeastern United States seems to have decreased potential to become drier, results for the Midwest represent a more uncertain future.

Comparing global AR4 and AR5 patterns, the range of values for climate projections from AR5 is smaller than that from AR4; agreement among AR5 model output is better than among AR4 models, even though there are more AR5 models (40) than AR4 models (21).

EXTREME TEMPERATURES AND PRECIPITATION

In AR4, the IPCC concluded (Solomon et al, 2007) that climate change has begun to affect the frequency, intensity, and duration of extreme events (i.e., extreme temperatures, extreme precipitation, and consequent floods and droughts), some of which are projected to continue. A subsequent IPCC assessment (a special report on managing risks of extreme events to advance climate change adaptation) confirms these assessments (Seneviratne et al, 2012).

The ability of GCMs to reproduce extremes with different time scales is of great importance. In 1950 the researcher Arthur H. Jennings discovered the relationship between the global maximum of precipitation and duration; since that time, his findings have been reinforced by numerous studies. Now the question is how the new models perform and how their results can be folded into decision-making.

Large uncertainties in modeling precipitation remain, especially over tropical and subtropical regions. Return periods for extreme precipitation are expected to shorten for much of the world except in some of the subtropics’ drying regions. A strong indicative trend is the shortening of 20-year return periods to 14, 11, and six years for RCPs 2.6, 4.5, and 8.5, respectively, by the end of the century, compared with the historical 1986–2005 period.

In summary, AR5 and AR4 extremes for temperatures and precipitation are in general agreement (Kharin et al, 2013). Annual precipitation may show a decrease for many
locations; however, the intensity of extreme events is likely to increase. The expansion in the number of AR5 GCM daily datasets permits the application of ensembles with more GCM results than are provided in AR4. Although statistical analysis of uncertainty across models has improved and can be quantified, uncertainty in certain regions and locations remains particularly high for precipitation (less so for temperature).

MARINE CHANGES: SURFACE TEMPERATURE, COOLING, AND DESALINATION

AR5 offers opportunities to model the marine environment and its wide range of biophysical ocean variables, improving AR4 ocean model shortcomings (Griffies et al, 2010; Mora et al, 2013). More than 40 variables are available from limited GCM runs, and processing of some biogeochemical models is now available for application through a modeling tool. The currently available variables include sea surface temperature, net primary productivity of carbon by phytoplankton, dissolved nitrate concentration, dissolved oxygen concentration, pH, dissolved phosphate concentration, total alkalinity, dissolved iron concentration, and dissolved silicate concentration, all at the surface.

Much of the interest in these model data relates to sea surface temperature changes as they relate to cooling requirements for power plants cooled by seawater. Increasingly, power plant shutdowns are occurring as sea surface temperatures increase and the seawater cooling potential decreases (van Vliet et al, 2012). Similarly, changes in sea surface temperatures combined with other biophysical characteristics make it possible to model potential changes in algal bloom frequency (which can affect desalination operations).

SEA LEVEL RISE

AR5 global mean sea level (MSL) rise for 2100 (relative to 1995) for the RCPs is projected in the following 5–95% ranges:

- 28–61 cm (RCP2.6)
- 36–71 cm (RCP4.5)
- 38–73 cm (RCP6.0)
- 53–98 cm (RCP8.5)

Confidence in the projected ranges comes from model consistency in addition to observations and physical understanding. Current evidence is insufficient to evaluate the probability of specific levels above the likely range (IPCC, 2013a). It is unlikely that global MSL will exceed the previously listed ranges of levels by the end of the century unless there are substantial changes in the rate of melting of the Antarctic and Greenland ice sheets.

CASE STUDY: CLIMATE CHANGE IMPACTS ON EXTREME PRECIPITATION IN WASHINGTON, D.C., AND NORTHERN VIRGINIA

Two Northern Virginia jurisdictions, just outside Washington, D.C., were interested in understanding projected changes in extreme rainfall and how they might affect design criteria for urban drainage, storm-
water management, and floodplain management. Modeling software was used to analyze climate variability and change over a downscaled geographical area encompassing rain gauges in the Washington, D.C., and Northern Virginia regions and time frames from 2050 to 2100. One jurisdiction used 2011 AR4 data and the other used 2013 AR5 data. In both cases downscaled projections were based on long-term historical rainfall datasets for Ronald Reagan Washington National Airport.

The modeling software uses results produced by institutes around the world for AR4 and AR5 to examine changes in 24-hour total rainfall for return periods from two through 100 years. Specifically in this case the software used the results of an ensemble of 12 GCMs for the AR4 data and 22 GCMs for the AR5 data.

### PROJECTIONS TO 2050 WITH MEDIUM GHG EMISSIONS SCENARIOS

Figure 3 compares 24-hour total precipitation and corresponding return periods for the AR4 and AR5 projections in 2050 using a medium GHG emissions scenario RCP6.0, A1B and historical results from Reagan National Airport (1945–2012) for different return periods. Table 2 summarizes the percent change in the projected 24-hour precipitation (relative to historical) for the 2050 projections with medium emissions scenarios. The comparisons show that AR4 and AR5 projections are fairly consistent for the medium emissions scenarios at 2050, though AR5 projections are higher than AR4 at lower return intervals and lower at higher return intervals.

### PROJECTIONS TO 2100 WITH HIGH GHG EMISSIONS SCENARIOS

Figure 4 compares 24-hour total precipitation and corresponding

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**TABLE 2** Comparison of 24-hour total rainfall projections in 2050 for medium-emission scenarios for AR4 and AR5 with historical estimates at Ronald Reagan Washington National Airport, Washington, D.C.

<table>
<thead>
<tr>
<th>Return Year</th>
<th>Historical Rainfall inches</th>
<th>Medium-Emission Scenario Rainfall Projections (2050, Median of Ensemble GCMs)—inches</th>
<th>Change From Historical—%</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1945–2012</td>
<td>RCP6.0 2050</td>
<td>RCP6.0 2050</td>
</tr>
<tr>
<td>2</td>
<td>2.86</td>
<td>3.02</td>
<td>6</td>
</tr>
<tr>
<td>5</td>
<td>3.98</td>
<td>4.21</td>
<td>6</td>
</tr>
<tr>
<td>10</td>
<td>4.78</td>
<td>5.08</td>
<td>6</td>
</tr>
<tr>
<td>25</td>
<td>5.88</td>
<td>6.26</td>
<td>7</td>
</tr>
<tr>
<td>50</td>
<td>6.74</td>
<td>7.22</td>
<td>7</td>
</tr>
<tr>
<td>100</td>
<td>7.66</td>
<td>8.23</td>
<td>7</td>
</tr>
<tr>
<td>500</td>
<td>10.00</td>
<td>10.85</td>
<td>9</td>
</tr>
</tbody>
</table>

A1B—one of six descriptors in a scenario list used in risk assessment, AR—assessment report, GCM—general circulation model or global climate model, RCP—representative concentration pathway

RCP6.0 is named after a possible range of radiative forcing values in the year 2050 relative to preindustrial values (+6.0 W/m²).
CONCLUSIONS

The IPCC AR5 has been released in stages with the Working Group I report, The Physical Science Basis, providing the public with a first official glimpse at the science underpinning climate change modeling. In general, there are no dramatic changes from previous models released in earlier assessment reports. However, there is a marked increase in the volume of data and a steady increase in the number of modeling groups providing their scientific perspectives to the modeling initiative. With AR5, the range of new models available for commonly modeled variables of temperature, precipitation, and sea-level rise have been augmented by improved marine biogeochemical variables. The model range represented by AR5 is slightly narrower and the upper bounds for MSL rise are higher than in previous reports, so uncertainty remains an issue that must be managed by climate-data users. Although the number of modeled datasets has expanded and global trends are well modeled, ultimately it is local and regional GCM values that are most critical for water managers. Because of the uncertainty in

<table>
<thead>
<tr>
<th>Return Year</th>
<th>Historical Rainfall (inches) 1945–2012</th>
<th>RCP8.5 2100</th>
<th>A1FI 2100</th>
<th>Change From Historical—%</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>2.86</td>
<td>3.43</td>
<td>3.07</td>
<td>20</td>
</tr>
<tr>
<td>5</td>
<td>3.98</td>
<td>4.81</td>
<td>4.35</td>
<td>21</td>
</tr>
<tr>
<td>10</td>
<td>4.78</td>
<td>5.83</td>
<td>5.32</td>
<td>22</td>
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<tr>
<td>25</td>
<td>5.88</td>
<td>7.26</td>
<td>6.69</td>
<td>24</td>
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<tr>
<td>50</td>
<td>6.74</td>
<td>8.43</td>
<td>7.83</td>
<td>25</td>
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<td>100</td>
<td>7.66</td>
<td>9.70</td>
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<td>13.06</td>
<td>12.45</td>
<td>31</td>
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</table>


RCP8.5 is named after a possible range of radiative forcing values in the year 2100 relative to preindustrial values (+8.5 W/m²).
projections, it is critical that local and regional values are generated for application in risk assessments.

New methods continue to be developed for transforming AR5 data into informative and useful information for planners, policy-makers, and a wide range of stakeholders. The links among climate modelers, those charged with down-scaling and interpreting the data, and end users are being vigorously pursued. However, data are not equal to information; therefore, different user groups require communication within their working context in order to achieve proper interpretation and to avoid jargon.

Material and visualization outputs are needed for all stakeholder and client communications. Raw data must be transformed to express the climate change signal (increase or decrease), and risk levels explained through application of ensembles, web-based tools, hands-on regional and site-specific software, and other media. This is an exciting area because there is an ever-increasing demand for expertise in determining what climate change means for various sectors.

Clearly, uncertainty continues to influence climate change projections. Given current AR5 research and GCM results, water managers need methods to rapidly assess the boundaries of climate change impacts and risk on specific projects using GCM results. Various approaches for assessing, addressing, and managing climate change uncertainty and effects on water planning and infrastructure will be the topic of a future report.

ABOUT THE AUTHORS

Peter Urich is managing director of CLIMsystems in Hamilton, N.Z., and specializes in climate risk and adaptation assessment, problem identification, and client management; peter@climsystems.com. He has bachelor’s and master’s degrees from the University of Wisconsin in Milwaukee and earned his PhD at Australian University in Canberra.

Peter Kouwenhoven is senior scientist with CLIMsystems and specializes in impact modeling, analysis, and adaptation assessment and training; pkouwenh@climsystems.com. Kathy Freas recently retired after 23 years with CH2M HILL in Englewood, Colo., as the leader of the Water Resources and Ecosystem Management Services Team (including climate change services). A Fellow Technologist, she continues to work on some of the firm’s most challenging water and energy management client projects; kathy.freas@ch2m.com. Laurens
van der Tak is a senior fellow technologist in water resources at CH2M HILL in Silver Spring, Md., where he leads the firm’s technical services for climate change and provides client services for complex water management challenges; laurens.vandertak@ch2m.com.

http://dx.doi.org/10.5942/jawwa.2014.106.0088

FOOTNOTES
1SimCLIM for ArcGIS/Marine add-in; CLIMsystems, Hamilton, N.Z., and ArcGIS, Esri, Redlands, Calif.
2SimCLIM 2013; CLIMsystems, Hamilton, N.Z.

REFERENCES


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