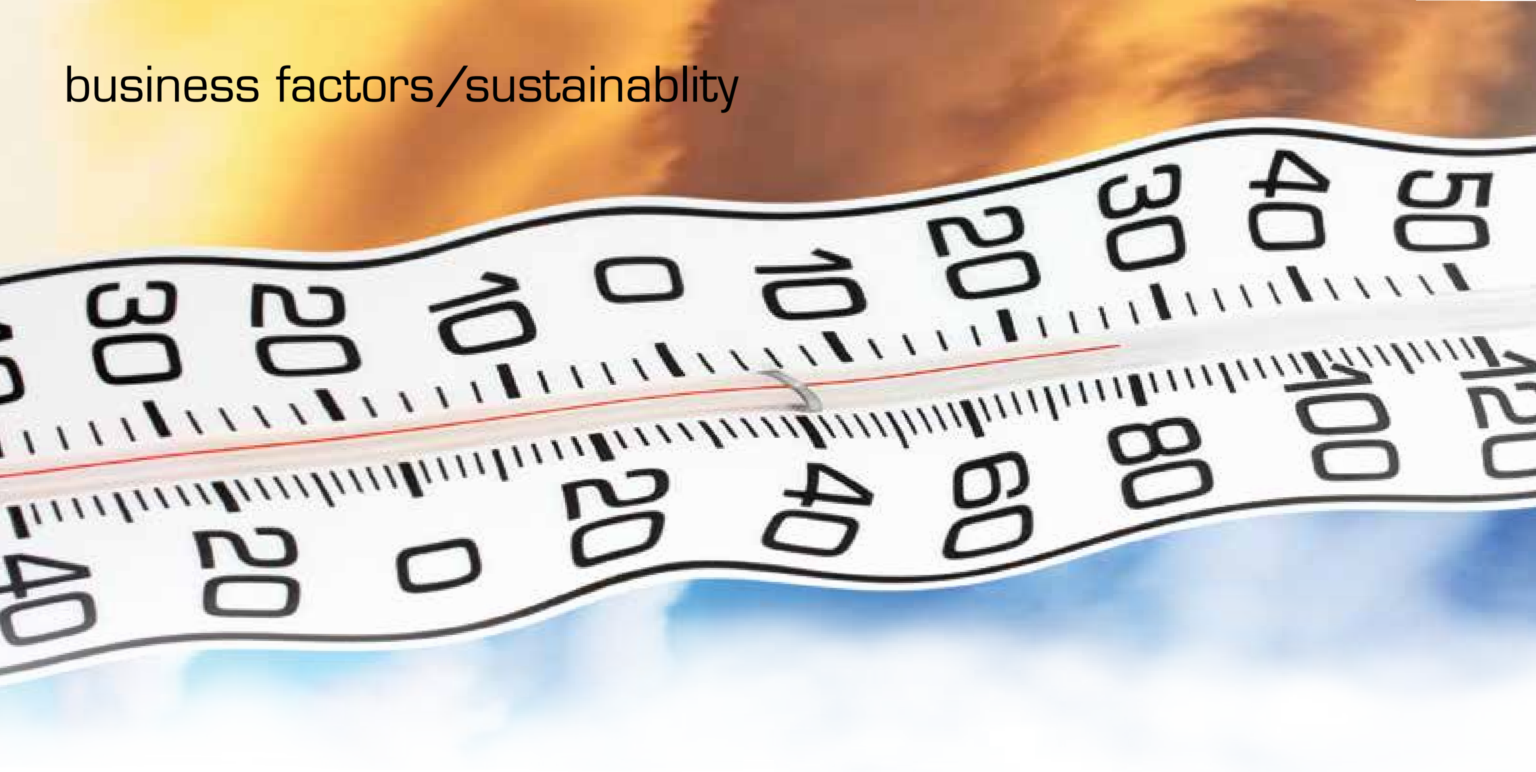

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New IPCC climate models released: Understanding the planning implications for water resiliency

ASSESSMENT REPORTS (ARs) FROM THE UNITED NATIONS INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE HAVE BEEN A COMPREHENSIVE SOURCE OF INFORMATION FOR VARIOUS ENTITIES SINCE 1990, GUIDING POLICIES, STRATEGIES, PLANNING, AND ATTITUDES RELATING TO CLIMATE CHANGE; THE AUTHORS COMPARE AR4 OF 2007 AND AR5, WHICH IS BEING RELEASED IN FOUR PARTS.

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/m^2, respectively). Relative to the base period 1986–2005, RCP8.5 (the highest emissions scenario, equivalent to AR4 A1FI), the IPCC published a projected warming of 3.7°C (2.6–4.8°C range) by 2100. Unfortunately, the global community is on track to exceed this emissions target and temperature of 2.0°C, which is considered a potential tipping point. Only RCP2.6 will result in a 1.0°C (0.3–1.7°C range) warming by 2100 (IPCC, 2013b).

General circulation models (GCMs) that describe the relationships between and dynamics of oceans and the atmosphere that together create our global climate are important fundamental tools used to assess changes in climate. Various research institutes develop their own models and report results for agreed inputs (such as RCP8.5) on a publicly accessible website (CMIP5). Various methods are then used to downscale these datasets to enhance resolution to more regional and local scales for application in climate-risk assessments. SimCLIM 2013[1] is integrated modeling software that ingests many of these downscaled datasets using the median (the 50th percentile, not the average) to generate ensemble results. Use of the median eliminates more extreme model results, providing a more balanced perspective of climate change for the locales in question across the range of GCM projections.

[1] SimCLIM 2013; CLIMsystems, Hamilton, N.Z.

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).

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

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.

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 & Sedláĉek, 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 1 Overview of RCPs

Description		CO_2 Equivalent	SRES Equivalent	Publication—IA Model
RCP8.5	Rising radiative forcing pathway leading to 8.5 W/m^2 in 2100	1,370	A1FI	Raiahi et al, 2007—MESSAGE
RCP6.0	Stabilization without overshoot pathway to 6 W/m^2 in 2100	850	B2	Fujino et al, 2006; Hijioka et al, 2008—AIM
RCP4.5	Stabilization without overshoot pathway to 4.5 W/m^2 in 2100	650	B1	Clarke et al, 2006; Smith and Wigley 2006; Wise et al, 2009—GCAM
RCP2.6	Peak in radiative forcing at ~ 3 W/m^2 before 2100 and decline	490	None	van Vuuren et al, 2007; van Vuuren et al, 2006—IMAGE

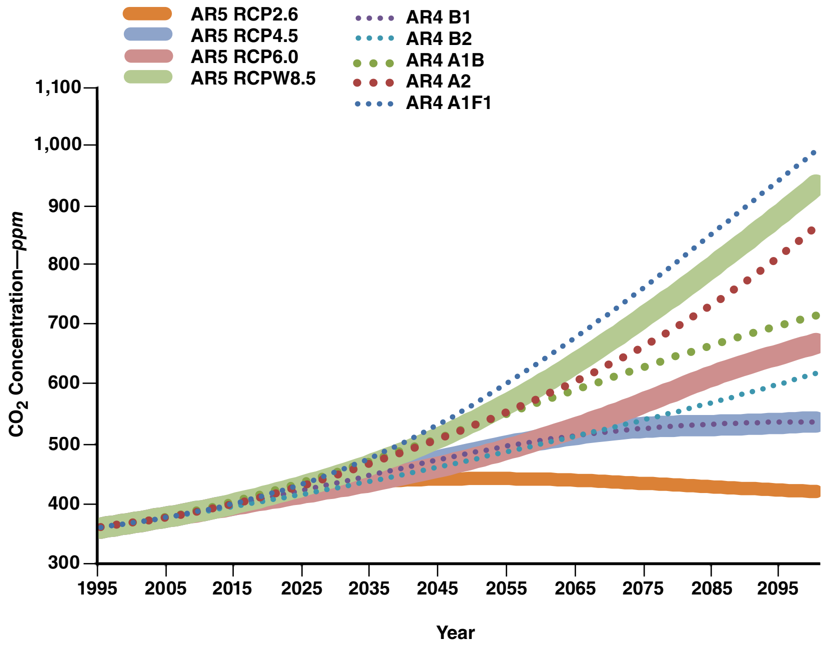
Sources: van Vuuren et al, 2011b; Moss et al, 2010; Rogeli et al, 2012

CO_2—carbon dioxide, IA–integrated assessment, RCP—representative concentration pathway, SRES—Special Report on Emissions Scenarios

B1, B2, and A1Fl 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/m^2, respectively).

FIGURE 1 GHG scenarios from IPCC AR4 and AR5 CO_2 concentration



AR4—Fourth Assessment Report, AR5—Fifth Assessment Report, CO_2—carbon dioxide, GHG—greenhouse gas, IPCC—Intergovernmental Panel on Climate Change, RCPs—representative concentration pathways, SRES—Special Report on Emission Scenarios

B1, B2, A1B, A2, 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/m^2, respectively).

Currently the global atmosphere is close to 400 ppm. CO_2 equivalents and concentrations of CO_2 and non-CO_2 gases are increasing at a rate that is of concern (Prinn, 2013).

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.[1] 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).

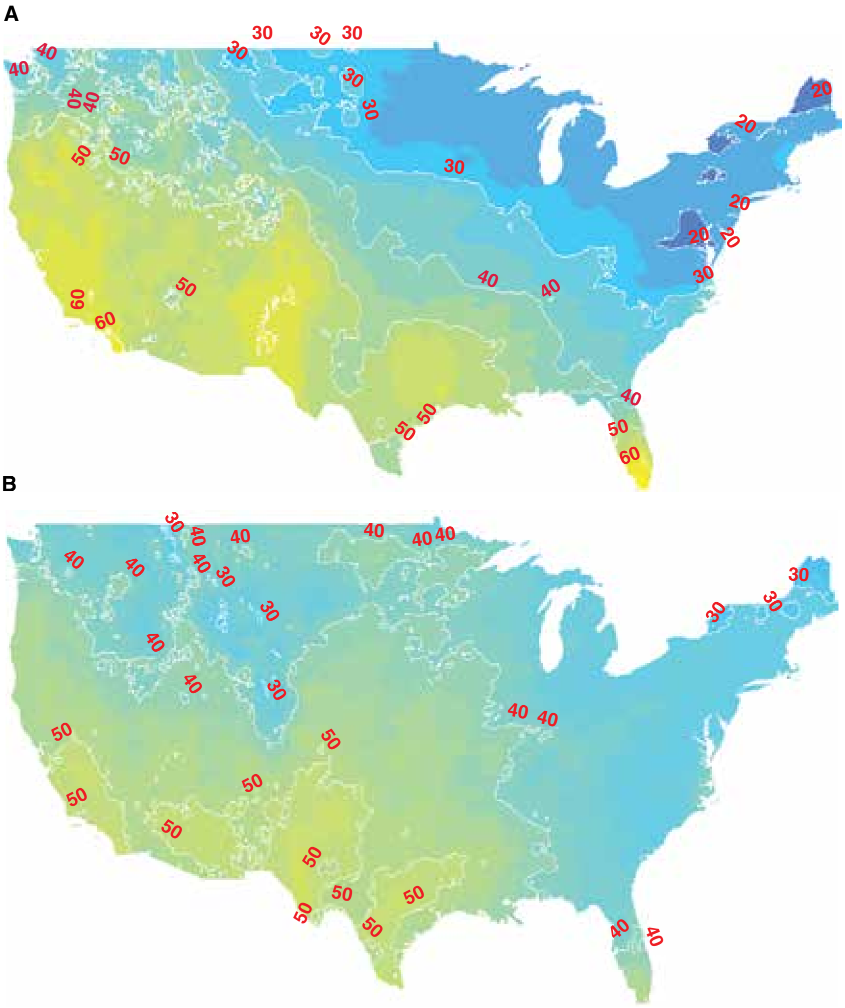
SEA LEVEL RISE

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.

FIGURE 2 Comparison of AR4 (A) and AR5 (B) model agreements for change in precipitation for the continental United States



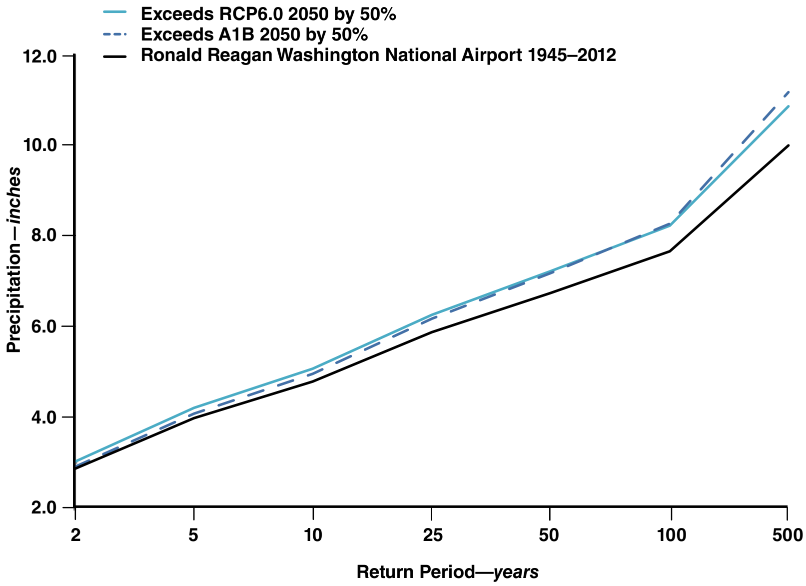
AR4—Fourth Assessment Report, AR5—Fifth Assessment Report

The red values correspond to the percentage of the models that agree that the precipitation will decrease from climate change.

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-

FIGURE 3 Historical and projected 24-hour precipitation and return periods comparing AR4 and AR5 data for 2050 with medium GHG emissions (ensemble median) at Ronald Reagan Washington National Airport, Washington, D.C.



A1B—one of six descriptors in a scenario list used in risk assessment, AR4—Fourth Assessment Report, AR5—Fifth Assessment Report, GHG—greenhouse gas, 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/m^2).

water management, and floodplain management. Modeling software[2] 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

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.

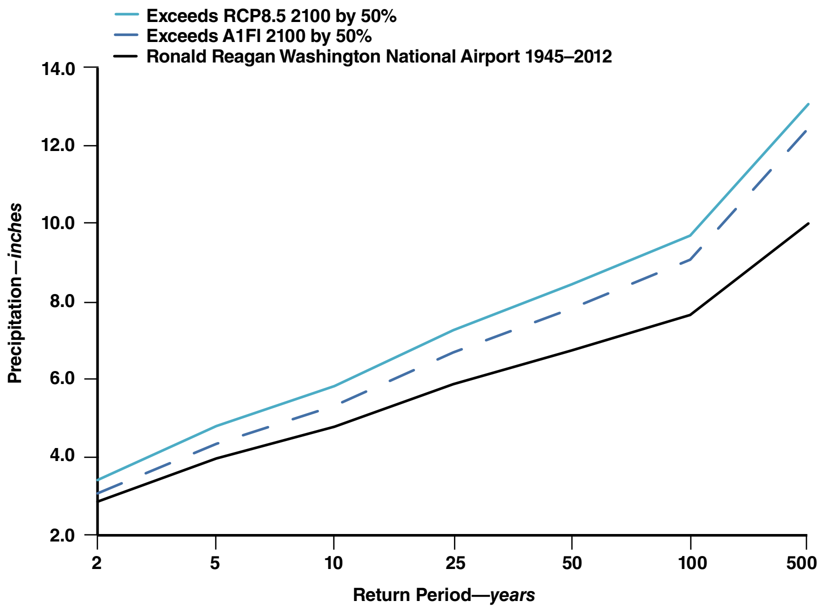
	Historical Rainfall *inches*	Medium-Emission Scenario Rainfall Projections (2050, Median of Ensemble GCMs)—*inches*		Change From Historical—%	
Return Year	1945–2012	RCP6.0 2050	A1B 2050	RCP6.0 2050	A1B 2050
2	2.86	3.02	2.91	6	2
5	3.98	4.21	4.08	6	3
10	4.78	5.08	4.95	6	4
25	5.88	6.26	6.18	7	5
50	6.74	7.22	7.18	7	6
100	7.66	8.23	8.27	7	8
500	10.00	10.85	11.16	9	12

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/m^2).

return periods for the AR4 and AR5 projections in 2100 using high-emissions scenario RCP8.5, A1FI, and historical data from Reagan National Airport (1945–2012). Table 3 summarizes the percent change in the projected 24-hour precipitation (relative to historical) for the year 2100 projections with high GHG emissions scenarios. The comparisons in Figure 4 and Table 3 show that AR5 projections are considerably higher than those for AR4 for the high GHG emissions scenarios for 2100.

FIGURE 4 Historical and projected 24-hour precipitation and return periods comparing AR4 and AR5 data for 2100 with high GHG emissions (ensemble median) at Ronald Reagan Washington National Airport, Washington, D.C.



A1FI—one of six descriptors in a scenario list used in risk assessment, AR4—Fourth Assessment Report, AR5—Fifth Assessment Report, GHG—greenhouse gas, RCP—representative concentration pathway

RCP8.5 is named after a possible range of radiative forcing values in the year 2100 relative to preindustrial values (+8.5 W/m^2).

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 3 Comparison of 24-hour total rainfall projections in 2100 for high-emission scenarios for AR4 and AR5 with historical estimates at Ronald Reagan Washington National Airport, Washington, D.C.

	Historical Rainfall *inches*	High-Emission Scenario Rainfall Projections (2100, Median of Ensemble GCMs)—*inches*		Change From Historical—%	
Return Year	1945–2012	RCP8.5 2100	A1FI 2100	RCP8.5 2100	A1FI 2100
2	2.86	3.43	3.07	20	7
5	3.98	4.81	4.35	21	9
10	4.78	5.83	5.32	22	11
25	5.88	7.26	6.69	24	14
50	6.74	8.43	7.83	25	16
100	7.66	9.70	9.07	27	18
500	10.00	13.06	12.45	31	24

A1FI—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

RCP8.5 is named after a possible range of radiative forcing values in the year 2050 relative to preindustrial values (+8.5 W/m^2).

Glossary

GCM (general circulation model or global climate model): This model represents the physical processes in the atmosphere, ocean, cryosphere, and land surface and is the most advanced tool available for simulating the response of the global climate system to increasing greenhouse gas (GHG) concentrations.

National communications: A series of reports has been required for submission to the United Nations Framework Convention on Climate Change on the current status of signatory countries to the Kyoto Protocol. The reports document progress achieved on meeting the goals set out by the Conference of Parties to the Convention and include major sections on national GHG inventories and adaptation risk and planning across key sectors. To date there has been an uneven meeting of obligations to report across the two streams: Annex 1 (more developed) countries (41) and non-Annex 1 countries (developing and least developed). For the latter there is no deadline for report submission. Some non-Annex 1 countries have yet to complete their first national communication while some Annex 1 countries are preparing their sixth national communication, which was due Jan. 1, 2014.

RCP (representative concentration pathway): Each RCP defines a specific emissions trajectory and subsequent radiative forcing. Radiative forcing is a measure of the influence a factor has in altering the balance of incoming and outgoing energy in the earth–atmosphere system, measured in watts per square metre. For example, RCP 2.6 represents 3.0 W/m^2 before the year 2100, declining to 2.6 W/m^2 after 2100.

Reanalysis: This is a systematic approach to producing datasets for climate monitoring and research. Reanalyses are created through an unchanging (frozen) data assimilation scheme and model(s) that ingest all available observations every 6–12 hours during the period being analyzed. This unchanging framework provides a dynamically consistent estimate of the climate state at each time step.

Signal (versus noise): Signal is the attribution of climate change as a result of human activities in contrast to the natural variability in the climate systems.

Uncertainty: Uncertainty plays a key role in policy formation because decisions often turn on the question of whether scientific understanding is sufficient to justify particular types of responses.

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, policymakers, and a wide range of stakeholders. The links among climate modelers, those charged with downscaling 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.

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FOOTNOTES

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

[2] SimCLIM 2013; CLIMsystems, Hamilton, N.Z.

REFERENCES

AMS (American Meteorological Society), 2012. *Glossary of Meteorology.* American Meteorological Society, Boston, Mass. http://glossary.ametsoc.org/wiki/Climate_change (accessed January 2014).

Clarke, L.E.; Edmonds, J.A.; Jacoby, H.D.; Pitcher, H.; Reilly, J.M.; & Richels, R., 2007. Scenarios of Greenhouse Gas Emissions and Atmospheric Concentrations. Sub-report 2.1A of Synthesis and Assessment Product 2.1. Climate Change Science Program and the Subcommittee on Global Change Research, Washington.

Fujino, J.; Nair, R.; Kainuma, M.; Masui, T.; & Matsuoka, Y., 2006. Multigas Mitigation Analysis on Stabilization Scenarios Using Aim Global Model. *The Energy Journal,* Special Issue 3:343.

Griffies, S.; Adcroft, A.J.; Aiki, H.; Balaji, V.; Bentson, M.; Bryan, F.; Danabasoglu, G.; Denvil, S.; Drange, H.; England, M.; Gregory, J.; Hallberg, R.W.; Legg, S.; Martin, T.; McDougall, T.; Pirani, A.; Schmidt, G.; Stevens, D.; Taylor, K.E.; & Tsujino, H., 2010. Sampling Physical Ocean Fields in WCRP CMIP5 Simulations. CLIVAR Working Group for Ocean Model Development (WGOMD). Committee on CMIP5 Ocean Model Output. www.clivar.org/sites/default/files/imported/organization/wgomd/references/WGOMD_CMIP5_ocean_fields.pdf (accessed January 2014).

Hijioka, Y.; Matsuoka, Y.; Nishimoto, H.; Masui, M.; & Kainuma, M., 2008. Global GHG Emissions Scenarios Under GHG Concentration Stabilization Targets. *Journal of Global Environmental Engineering,* 13:97.

IPCC (Intergovernmental Panel on Climate Change), 2013a. Summary for Policymakers in *Climate Change 2013: The Physical Science Basis.* Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (T.F. Stocker, D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex, & P.M. Midgley, editors). Cambridge University Press, Cambridge, U.K., & New York.

IPCC, 2013b. Scenario Process for AR5. http://sedac.ciesin.columbia.edu/ddc/ar5_scenario_process/RCPs.html (accessed January 2014).

IPCC, 2000. *Special Report on Emissions Scenarios.* Cambridge University Press, Cambridge, U.K. www.grida.no/publications/other/ipcc%5Fsr/?src=/climate/ipcc/emission/ (accessed January 2014).

Jennings, A.H., 1950. World's Greatest Observed Point Rainfalls. *Monthly Weather Review,* 78:4.

Kharin, V.V.; Zwiers, F.W.; Zhang, X.; & Wehner, M., 2013. Changes in Temperature and Precipitation Extremes in the CMIP5 Ensemble. *Climatic Change*, 119:2:345. http://link.springer.com/article/10.1007%2Fs10584-013-0705-8#page-1 (accessed January 2014).

Knutti, R.; Abramowitz, G.; Collins, M.; Eyring, V.; Gleckler, P.J.; Hewitson, B.; & Mearns, L., 2010. Good Practice Guidance Paper on Assessing and Combining Multi Model Climate Projections. IPCC Expert Meeting on Assessing and Combining Multi Model Climate Projections. National Center for Atmospheric Research, Boulder, Colo.

Knutti, R. & Sedláček, J., 2013. Robustness and Uncertainties in the New CMIP5 Climate Model Projections. *Nature Climate Change,* 3:369. http://dx.doi.org/10.1038/nclimate1716.

Krinner, G. & Durand, G., 2012. Glaciology: Future of the Greenland Ice Sheet. *Nature Climate Change,* 2:396. http://dx.doi.org/ 10.1038/nclimate1557.

Mora, C.; Wei, C.-L.; Rollo, A.; Amaro, T.; Baco, A.R.; Billett, D.; Bopp, L.; Chen, Q.; Collier, M.; Danovaro, R.; Gooday, A.; Grupe, B.; Halloran, P.R.; Ingels, J.; Jones, D.O.B.; Levin, L.; Nakano, H.; Norling, K.; Ramierez-Llodra, E.; Rex, M.; Ruhl, H.; Smith, C.R.; Sweetman, A.K.; Thurber, A.R.; Tjiputra, J.F.; Usseglio, P.; Watling, L.; Wu, T.; & Yasuhara, M., 2013. Biotic and Human Vulnerability to Projected Changes in Ocean Biogeochemistry over the 21st Century. *PLoS Biology,* 11:10. http://dx.doi.org/10.1371/journal.pbio.1001682.

Moss, M.; Edmonds, J.A; Hibbard, K.A.; Manning, M.R.; Rose, S.K.; van Vuuren, D.P.; Carter, T.R.; Emori, S.; Kainuma, M.; om Kram, T.; Meehl, G.A.; Mitchell, J.F.B.; Nakicenovic, N.; Riahi, K.; Smith, S.J.; Stouffer, R.J.; Thomson, A.M.; Weyant, J.P.; & Wilbanks, T.J., 2010. The Next Generation of Scenarios for Climate Change Research and Assessment. *Nature,* 463:747. http://dx.doi.org/10.1038/nature08823.

Prinn, R., 2013. 400 ppm CO2? Add Other GHGs, and It's Equivalent to 478 ppm. *Oceans at MIT.* http://oceans.mit.edu/featured-stories/5-questions-mits-ron-prinn-400-ppm-threshold (accessed January 2014).

Riahi, K.; Grübler, A.; & Nakicenovic, N., 2007. Scenarios of Long-term Socio-economic and Environmental Development Under Climate Stabilization. *Technological Forecasting and Social Change,* 74:7:887. http://dx.doi.org/10.1016/j.techfore.2006.05.026.

Rogelj, J.; Meinshausen, M.; & Knutti, R., 2012. Global Warming Under Old and New Scenarios Using IPCC Climate Sensitivity Range Estimates. *Nature Climate Change,* 2:248. http://dx.doi.org/10.1038/nclimate1385.

Seneviratne, S.I.; Nicholls, N.; Easterling, D.; Goodess, C.M.; Kanae, S.; Kossin, J.; Luo, Y.; Marengo, J.; McInnes, K.; Rahimi, M.; Reichstein, M.; Sorteberg, A.; Vera, C.; & Zhang, X., 2012. Changes in Climate Extremes and Their Impacts on the Natural Physical Environment. In *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation* (C.B. Field, V. Barros, T.F. Stocker, D. Qin, D.J. Dokken, K.L. Ebi, M.D. Mastrandrea, K.J. Mach, G.-K. Plattner, S.K. Allen, M. Tignor, & P.M. Midgley, editors). A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change (IPCC). Cambridge University Press, Cambridge, UK, and New York.

Smith, S.J. & Wigley, T.M.L., 2006. Multi-gas Forcing Stabilization With Minicam. *The Energy Journal,* Special Issue 3:373.

Solomon, S.; Qin, D.; Manning, M.; Chen, Z.; Marquis, M.; Averyt, K.B.; Tignor, M.; & Miller, H.L. (editors), 2007. *Climate Change 2007: The Physical Science Basis, Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.* Cambridge University Press, Cambridge, U.K.

Stocker, T.; Qin, D.; Plattner, G.-K.M.; & Midgley, P., 2010. Good Practice Guidance Paper on Assessing and Combining Multi Model Climate Projections. IPCC Expert Meeting on Assessing and Combining Multi Model Climate Projections, Boulder, Colo.

van Vliet, M.T.H.; Yearsley, J.R.; Ludwig, F.; Vogele, S.; Lettenmaier, D.P.; & Kabat, P., 2012. Vulnerability of US and European Electricity Supply to Climate Change. *Nature Climate Change,* 2:676. http://dx.doi.org/10.1038/nclimate1546.

van Vuuren, D.P.; Edmonds, J.A.; Kainuma, M.; Riahi, K.; Weyant, J., 2011a. A Special Issue on the RCPs. *Climatic Change,* 109:1-2:1. http://dx.doi.org/10.1007/s10584-011-0157-y.

van Vuuren, D.P.; Edmonds, J.; Kainuma, M.; Riahi, K.; Thomson, A.; Hibbard, K.; Hurtt, G.C.; Kram, T.; Krey, V.; Lamarque, J.-F.; Masue, T.; Meinshausen, M.; Nakicenovic, N.; Smith, S.; & Rose, S.K., 2011b. The Representative Concentration Pathways: An Overview. *Climatic Change,* 109:1-2:5. http://dx.doi.org/10.1007/s10584-011-0148-z.

van Vuuren, D.P.; den Elzen, M.G.J.; Lucas, P.L.; Eickhout, B.; Strengers, B.J.; van Ruijven, B.; Wonink, S.; & van Houdt, R., 2007. Stabilizing Greenhouse Gas Concentrations at Low Levels: An Assessment of Reduction Strategies and Costs. *Climate Change,* 81:2:11. http://dx.doi.org/10.1007/s10584-006-9172-9.

van Vuuren, D.P.; Eickhout, B.; Lucas, P.L.; & den Elzen, M.G.J., 2006. Long-term Multi-gas Scenarios to Stabilise Radiative Forcing—Exploring Costs and Benefits Within an Integrated Assessment Framework. *Energy Journal,* 27:201.

Wise, M.; Calvin, K.; Thomson, A.; Clarke, L.; Bond-Lamberty, B.; Sands, R.; Smith, S.J.; Janetos, A.; & Edmonds, J., 2009. Implications of Limiting CO_2 Concentrations for Land Use and Energy. *Science*, 324:5931:1183. http://dx.doi.org/ 10.1126/science.1168475.

ADDITIONAL RESOURCES

Climate Change and Water: International Perspectives on Mitigation and Adaptation. Smith, J.; Howe, C.; & Henderson, J. (editors), 2009. AWWA & International Water Association, Denver & London. Catalog No. 20700.

Climate Change Is Real: How Can Utilities Cope with Potential Risks? Smith, J.B., 2008. *Opflow*, 34:2:12.

The Impact of Climate Change on Water Infrastructure. LeChevallier, M.W., 2014. *Journal AWWA*, 106:4:79. http://dx.doi.org/10.5942/jawwa.2014.106.0066.

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