HOW CLIMATE CHANGE WILL IMPACT ON THE WATER INDUSTRY

Key findings of the UN Intergovernmental Panel on Climate Change Fifth Assessment Report

PB Urich, P Kouwenhoven, Y Li, K Freas, J Poon

INTRODUCTION

The Fifth Assessment Report (AR5) of the United Nations (UN) Intergovernmental Panel on Climate Change (IPCC) will be released in four parts between September 2013 and November 2014 and supersedes 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 Organisation and the United Nations Environment Programme (UNEP). These entities were tasked with preparing a report on all aspects of climate change and its impacts to inform the crafting of practical response strategies.

After its 1990 release, FAR exposed the need for international cooperation and spurred the creation of the UN Framework Convention on Climate Change (UNFCCC), the key international treaty to guide greenhouse gas (GHG) reduction and provide a framework for managing consequences of non-reduction. Since 1995, regular assessments have been released, as well as a number of important methodology and special scientific reports. All of these publications assist national governments in their communications with the UNFCCC and help them review their GHG emissions and plans for mitigation, impact and adaptation at the independent State level.

AR5 contains more extensive information on climate change's socio-economic impacts and, hence, its role in sustainable development. Features include a new set of scenarios that are applied across the three working groups:

- Working Group I – "The Physical Science Basis";
- Working Group II – "Impacts, Adaptation and Vulnerability";
- Working Group III –"Mitigation of Climate Change".

Additional activities include a Task Force on Greenhouse Gas 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 policy makers and government officials, advisors to government and experts, the Synthesis Report will be jargon-free and accessible to a broad audience as it is read, used and quoted in official reports and action statements. The report will not be released until the Conference of Parties meeting (location undetermined) in December 2014.

USING SIMCLIM AND GCMS TO DETERMINE FUTURE CLIMATE CHANGE

Climate change is about future development of the Earth's climate. Because this change is driven by carbon dioxide (CO_2) emissions from burning fossil fuels, we have to make assumptions about how much CO_2 is being added to the carbon cycle.

IPCC developed different scenarios, with the RCP8.5 representing the most extreme emission scenario. Unfortunately, that pathway is the one the global community is currently following. More conservative emission scenarios will still reach expected 1.92°C warming, albeit later.

GCMs are used to determine future climate change. Various research institutes develop their own models and report results for agreed inputs (like the RCP8.5) on a publicly accessible website (CMIP5). CLIMsystems' integrated modelling software, SimCLIM, uses model results and takes the median (the 50-percentile, not the average) from these results in generating ensemble outputs. Using the median eliminates more extreme model results.

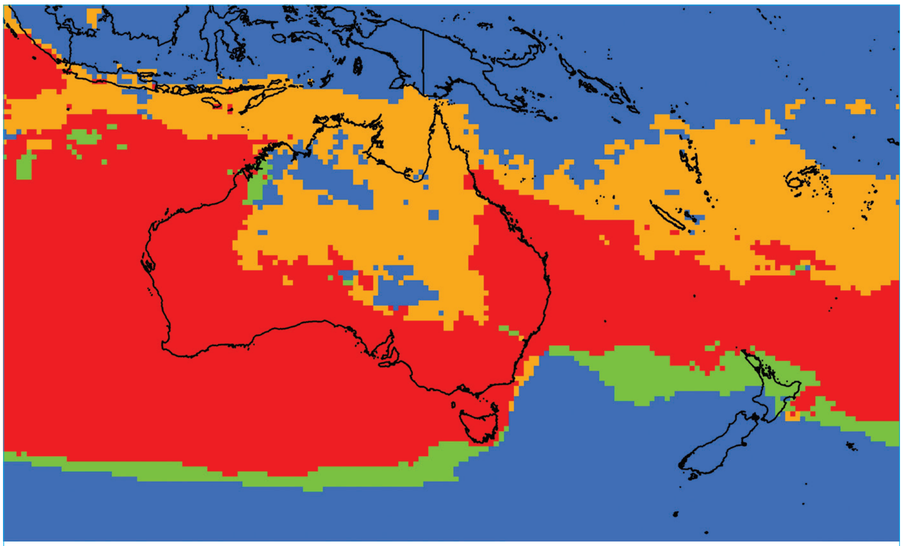
HOW AR4 AND AR5 ARE DIFFERENT

Climate modelling through General Circulation Models (GCMs), also known as Global Climate Models, has been a substantial part of the Assessment process since 1990. The number of modelling groups producing GCMs has increased markedly over successive Assessments, starting with five groups generating eight models for the FAR (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 increased GHG concentrations on the global climate system.

Over time there has also been an expansion in modelled variables, including both the marine and atmospheric environment. For AR5, many models have daily varying temperatures (with minimum, mean and maximum values) so that change patterns can be extracted for the first time; AR4 models did not contain this information. Only 12 AR4 GCMs produced daily precipitation outputs; with AR5 more daily outputs results in better modelling of extreme rainfall events.

Previously, a location's monthly rainfall could show a drying signal, even though individual extreme rainfall events increased in intensity, and few groups had managed to develop methods for working with such limited daily GCM data.



	AR4<0 (drier)	AR4>0 (wetter)
AR5<0 (drier)	RED	ORANGE
AR5>0 (wetter)	GREEN	BLUE

RED	Both AR4 and AR5 agree it is getting drier
GREEN	AR4 signal is getting drier, but AR5 signal indicates it is getting wetter
ORANGE	AR4 signal is getting wetter, but AR5 signal is for it to get drier
BLUE	Both AR4 and AR5 agree it is getting wetter

Figure 1. Comparison of change in precipitation between AR4 (21-model ensemble) and AR5 (40-model ensemble).

More than 20 models (of the current 61) have all the necessary data for post-processing and incorporation into extreme rainfall event models for risk assessments, and 40 models can generate spatial scenarios. This considerable data enrichment adds additional information for any set of tools applied to real world problems and improves the statistical significance of results. The IPCC is still advising that an ensemble or mean of a group of models be applied when using GCM model data (Stocker *et al.*, 2010).

Global scenario parameters are also necessary to generate climate outputs. Prior to AR5 this information was communicated through the storylines of emissions scenarios (Special Report on Emission Scenarios [SRES]). Prior to that FAR was driven by analogue and equilibrium scenarios for impact assessment that included business as usual (as well as policy) scenarios. Forty SRES scenarios represented different assumptions on pollution, 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 process moved away from SRES with the development of representative concentration pathways (RCPs) introduced at an IPCC Expert Meeting on Emissions Scenarios, followed by IPCC workshops (2005, 2007). For the first time the RCPs include scenarios that explore approaches to climate change mitigation in addition to traditional 'no climate policy' scenarios. Each RCP represents a different emission pathway:

- RCP8.5 leads to a greater than 1370 PPM (parts per million) CO_2 equivalent by 2100 with a continued rise post-2100;
- RCP6.0 stabilises by 2100 at 850 PPM CO_2 equivalent to 2100 without overshoot;
- RCP4.5 stabilises by 2100, but at 650 PPM CO_2 equivalent without overshoot;
- RCP2.6 peaks at 490 PPM CO_2 equivalent before 2100 and then declines.

The global atmosphere is currently 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). Table 1 provides an RCPs overview.

OVERALL AR5 FINDINGS

CHANGE IN PRECIPITATION DISTRIBUTION

AR5 model precipitation projections are similar to AR4 on a global scale; however, when ensemble medians of models are created and compared (AR4 versus AR5) some important geographic areas show signal differences in GCM results. For example, in Australia the 21 GCM ensemble median AR4 data show a signal towards an increase in annual precipitation for the northern third of the continent. Processing a 40 model AR5 ensemble reverses the signal and shows drying for much of the northern part of the continent, as shown in Figure 1. The models are based on data trending through the entire 21st century, which represents a huge increase in data volume, but does not necessarily lead to model performance improvement (Knutti and Sedláček, 2012).

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 floods and droughts), some of which

Table 1. RCPs Overview (van Vuuren *et al.*, 2011; Moss *et al.*, 2010; Rojeli *et al.*, 2012).

	Description	CO_2 Equivalent	SRES Equivalent	Publication – IA Model
RCP8.5	Rising radiative forcing pathway leading to 8.5 W/m² in 2100.	1370	A1FI	Raiahi *et al.*, 2007 – MESSAGE
RCP6.0	Stabilisation without overshoot pathway to 6 W/m² at 2100	850	B2	Fujino *et al.*; Hijioka *et al.*, 2008 – AIM
RCP4.5	Stabilisation without overshoot pathway to 4.5 W/m² 2100	650	B1	Clark *et al.*, 2006; Smith and Wigley, 2006; Wise *et al.*, 2009 – GCAM
RCP2.6	Peak in radiative forcing at ~ 3 W/m² before 2100 and decline	490	None	van Vuuren *et al.*, 2007; van Vuuren *et al.*, 2006 – IMAGE

are projected to continue. A subsequent IPCC assessment (a special report on managing risks of extreme events) to advance climate change adaptation [SREX]) 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 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 do the new models perform and how can their results be folded into decision making?".

In general, high temperature extremes in the late 20th century are plausibly modelled, with 20-year return values (on a global scale) that are within the range of uncertainty in historical reanalysis data of about 1°C. Local scale discrepancies are greater, with values of up to 5°C, with more extreme differences over the land than the oceans. The uncertainties in low extremes are greater than that of the warm extremes; however, they still fall well within estimates obtained from different reanalysis data.

Precipitation extremes have always been challenging to model. Large uncertainties remain, especially over tropical and subtropical regions, with AR5 models performing similarly to AR4 models. Both perform better in the extra-tropics where they compare favourably with observational records. By the end of the century, the various RCPs express different possible shifts in precipitation intensity. RCP 2.6 global multi-model results indicate a 6% increase in high extreme daily precipitation, while the RCP 4.5 experiment shows a 10% increase and RCP 8.5 20%.

These changes in extremes are two to three times greater than the corresponding multi-model change in global annual precipitation. 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 to 2005 period.

In summary, AR5 extremes for temperatures and precipitation are generally in agreement with the AR4 models (Kharin *et al.*, 2013). While annual precipitation may show a decrease for many locations, the intensity of extreme events is likely to increase. The expansion in the GCM daily data availability permits the application of ensembles with more members than that in AR4. This means that, while statistical analysis of uncertainty across models has improved, it acknowledges that uncertainty in certain regions and locations remains particularly high for precipitation (although less so for temperature).

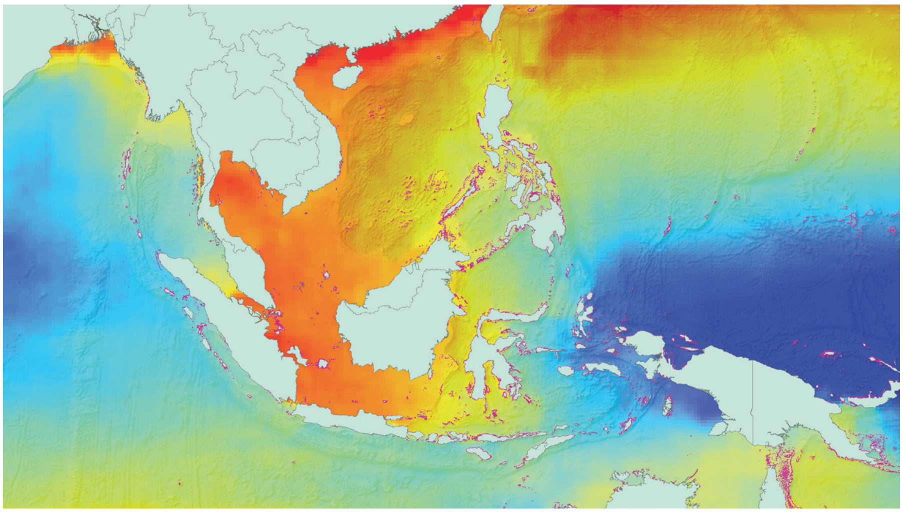


Figure 2. Signal of change in ocean surface pH in the Western Asia-Pacific (the Coral Triangle). The redder colour represents a stronger change.

MARINE CHANGES: SURFACE TEMPERATURE AND ACIDIFICATION ISSUES; COOLING AND DESALINATION

AR5 offers opportunities to model the marine environment and its wide range of biophysical ocean variables, improving on 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 Esri ArcGIS tools. 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 impact on power plants cooled by warming seawater. Increasingly there are examples of power plant shutdowns as sea surface temperatures increase and the seawater cooling potential decreases. 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), as well as extreme events like coral bleaching.

One of the greatest concerns related to climatic change and oceans is degradation of the carbonate/reef environment. About a quarter of the CO_2 released in the atmosphere dissolves in the oceans where it lowers pH, causing ocean acidification (Mora *et al.*, 2013). A small pH change affects the $CaCO_3$-CO_2 equilibrium, slowing coral growth and weakening the coral that can grow under these conditions. Figure 2 shows the pH changes of 12 models from AR5. Because pH is a log-scale unit, the ratio of pH for 1995 and 2035 is presented, with the redder colour showing a stronger change. This mostly occurs in shallower areas, as temperature increase contributes as well.

SEA LEVEL RISE

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

- 28–60 cm (RCP2.6)
- 35–70 cm (RCP4.5)
- 37–72 cm (RCP6.0)
- 53–97 cm (RCP8.5)

Confidence in the projected ranges comes from process-based model consistency, in addition to observations and physical understanding. The IPCC notes that there is currently insufficient evidence to evaluate the probability of specific levels above the likely range. It

Table 2. Return periods of maximum temperature events for baseline period and 2040 projections.				
	Baseline Climate °C (1984-2012)		2040 (RCP8.5-high) 35-GCM Ensemble	
Event	1-day	7-day average	1-day	7-day average
1:10yr	42.3	35.9	44.3	37.8
1:20yr	43.5	37.0	45.4	38.8
1:50yr	45.0	38.1	47.0	39.9
1:100yr	46.2	38.9	48.2	40.5

Table 3. Return periods for extreme temperature events in 2040 based on an RCP 8.5 with high climate sensitivity for a 35 GCM ensemble.				
	2040 (RCP8.5-high) 35-GCM ensemble			
Event	1-day	Δfrequency	7-day	Δfrequency
1:10yr	1:3.2	3.1x	1:3.7	2.7x
1:20yr	1:6.3	3.2x	1:6.3	3.2x
1:50yr	1:15.9	3.1x	1:12.5	4.0x
1:100	1:32.7	3.1x	1:21.3	4.7x

is unlikely that global MSL will exceed these levels by the end of the century unless there are substantial changes in the Antarctic and Greenland ice sheets. Current research is focused on better understanding the potential for rapid and catastrophic sea level rise over a much shorter timeframe (Krinner and Durand, 2012).

While MSL rise is important, it is also critical to recognise at least two other factors:

- Sea level rise does not occur evenly across the globe; some areas rise faster than others because of changes in ocean currents, seawater temperatures (the thermal expansion component varies), air pressure and geo-tectonic movements (e.g. land rising can partially or totally offset sea level rise in some localities, or subsidence owing to tectonic or other activities such as groundwater extraction can exacerbate local sea level rise).
- Extreme sea level events (in addition to sea level rise) often (but not exclusively) arise with the confluence of events such as exceptional seasonal high tides, wind and waves associated with tropical depressions or extra tropical low pressure systems and coastal bathymetry. Extreme sea level (surge) events can have a profound impact on people and property. This can now be modelled for a location, in conjunction with MSL rise, in order to improve understanding of return periods for extreme events and the actual potential sea level during such an event.

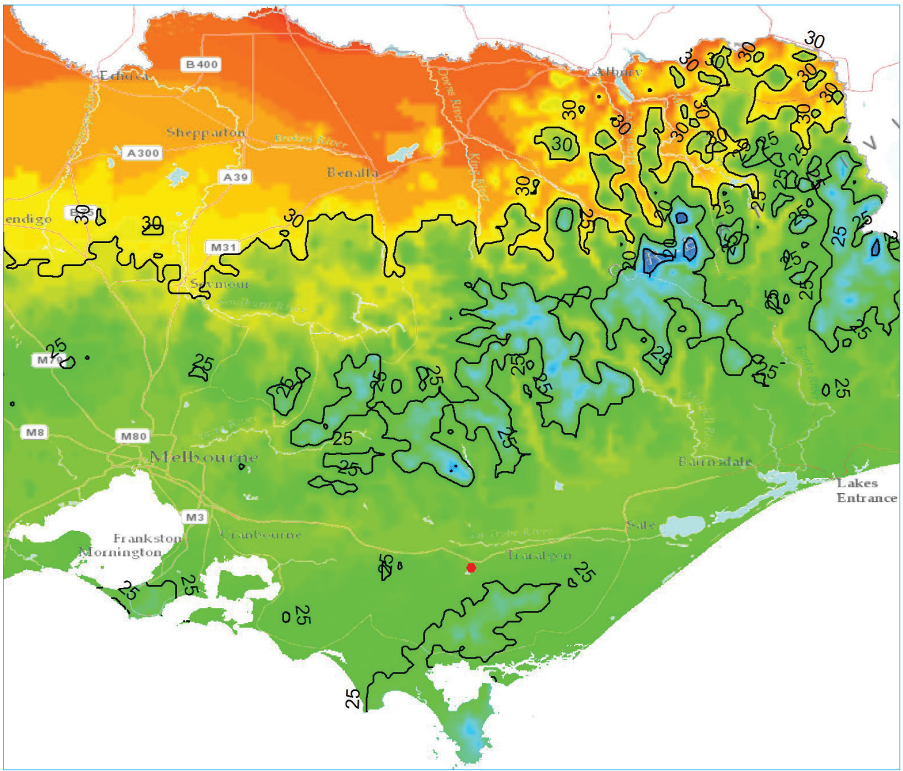


Figure 3. The spatial distribution of the daily maximum temperature (TMax) averaged over January and February 1995 for the baseline climate of Victoria.

CASE STUDY: CLIMATE CHANGE IMPACTS ON THE HAZELWOOD COAL-FIRED POWER STATION

The GDF SUEZ Hazelwood is a brown-coal fired power station located 150km east of Melbourne in the Latrobe Valley, Victoria. Recently, CLIMsystems analysed future climate impacts on the station, including the change in ambient temperatures.

The power station produces around 10 terawatt (TW) hours of energy, supplying up to 25% of Victoria's energy requirements and 5.4% of Australia's energy demand. The power station is a heat-intensive operation and relies on water extracted from a dedicated cooling pond.

The SimCLIM software tool analysed climate variability and change over a downscaled geographical area and set timeframe and identified that future temperature increases will:

- Reduce power-generating capacity as it becomes harder for the power station to expend heat and cool its operations;
- Increase power demands through increased residential and commercial air-conditioning requirements.

METHODS

The SimCLIM tool used results produced by institutes around the world for AR5 to examine changes in ambient temperature. Specifically, it used the results of an ensemble of 35 GCMs and applied the RPC8.5 scenario with high climate sensitivity (by 2040, the global mean temperature will have risen 1.92°C compared to 1990 levels).

The extreme temperature events for given return periods are outlined in Table 2 and demonstrate that by 2040 the maximum temperature extremes (for both a 1-day period, as well as for the 7-day average maximum) will be significantly

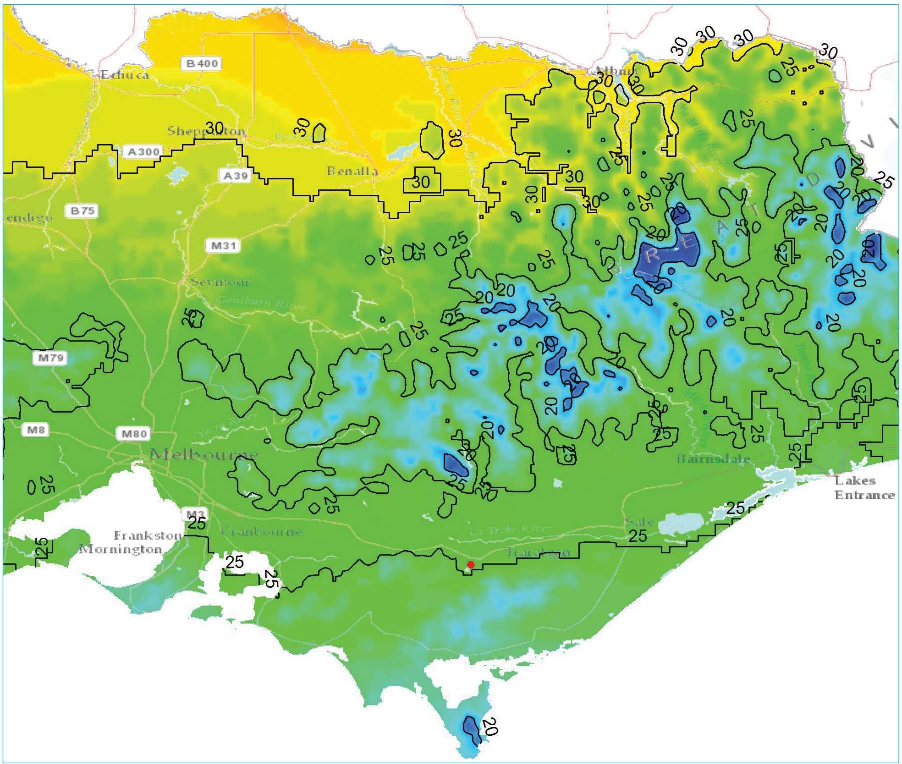


Figure 4. The spatial distribution of maximum temperature by 2040 (RCP8.5-high, 35-GCM ensemble).

higher. Instead of focusing on the temperature increase for a given return period, the analysis can also produce the change in return period for the current extreme events, as shown in Table 3.

The current extreme temperatures will become more than three times more frequent by 2040 (as shown in Table 3). Seven-day heatwaves, with a current return period of 1 in 100 years, will become nearly five times more frequent by 2040 under this emission scenario.

At the power plant location (red dot, Figure 3) the average maximum temperature is around 25°C. Areas closer to the sea or at a higher elevation are cooler, as indicated by the lighter blue colours, and hotter toward the interior along the Murray River. The same colour definition is used in Figure 4, where the 25°C contour line has shifted closer to the power plant. The whole area shows a considerable temperature increase, which will drive increased energy demand from residential and commercial air-conditioning.

CLIMsystems analysed the degree-day sum to assess climate change consequences on the environmental heat-balance, which affects energy demand from air-conditioning and the ability to cool the power plant. Degree-day sum is used for air-conditioning design, as well as the cooling requirements of thermal power generation. The degree-day sum represents the sum of all daily temperatures throughout a year, over a threshold. With a threshold temperature of 25°C, the yearly degree-day sum is distributed per Table 4.

Currently the degree-day sum reaches 128°C.d once every 10 years (on average), but by 2040 this may increase to 191°C.d. As the energy demand for cooling is linear with the degree-day sum, the energy demand to meet this requirement could, therefore, increase by almost 50%. In addition, the energy demand peak that currently occurs every 20 years will be demanded every other year by 2040, while the 100-year peak could occur every three years.

The increasing extremes in maximum temperature and degree-day sums (both intensity and frequency) will adversely affect the Hazelwood power station's efficiency. The change in the degree-day sum is one of the most indicative measures of potential impact and can help focus planning not only on reductions in the current GHG emission rate, but also adaptive measures such as energy efficiency and resilience planning for power generation and distribution infrastructure.

The impacts of climate change on the Hazelwood power plant operations will include:

- Increased demand for energy for residential and commercial air conditioning;
- Decreased efficiency of power generation due to increased ambient temperatures; depending on power-plant cooling design the ability to generate power might be seriously affected;
- Decreased efficiency on power delivery through the grid, both from increased temperatures and increased demand;
- Redesign of the power grid in order to meet demand changes.

CONCLUSIONS

The IPCC AR5 is being released in stages. The recent release of the Working Group 1 report "The Physical Science Basis" gives the general public a first official glimpse of the science underpinning climate change modelling. 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 modelling groups providing their scientific perspectives to the modelling initiative. With AR5, the range of new models available for commonly modelled variables of temperature, precipitation and sea level rise has been augmented by improved marine biogeochemical variables. These variables permit new analyses to be conducted on the ecology and potential management options of our ever-changing oceans.

The model range represented by the AR5 is slightly narrower and the upper bounds for MSL rise are higher than in previous reports, so uncertainty remains an issue that

Table 4. Degree days over 25°C for different return period extreme temperature events.

Event	Baseline (°C.d)	2040 (°C.d)	Return Period (2040)	Δfrequency
1:10yr	128	191	1:1.6	6.3x
1:20yr	139	206	1:2.0	10.0x
1:50yr	151	221	1:2.6	19.2x
1:100yr	159	231	1:3.2	31.3x

must be managed by climate data users. 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 modellers, those charged with downscaling and interpreting the data, and end users are being vigorously pursued. However, data are not equivalent to information; therefore, different user groups require communication within their working context in order to achieve proper interpretation and avoid jargon.

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

THE AUTHORS

Peter Urich (email: peter@.climsystems.com) is Managing Director of CLIMsystems in New Zealand.

Dr Peter Kouwenhoven (email: pkouwenh@.climsystems.com) is Senior Scientist with CLIMsystems in New Zealand.

Yinpeng Li (email: yinpengli@climsystems.com) is Senior Climate Scientist with CLIMsystems in New Zealand.

Kathy Freas (email: kathy.freas@ch2m.com) is CH2M HILL's Global Water Resources Director and Global Climate Risk and Resilience Services Leader.

John Poon (email: john.poon@ch2m.com.au) is CH2M HILL's Regional Technology Leader for Resource Systems Management and Technical Leader for two major drinking water reuse projects in India. John's integrated water cycle management projects in Australia use SimCLIM.

GLOSSARY

GCM (General Circulation Model or Global Climate Model) Represent the physical processes in the atmosphere, ocean, cryosphere and land surface, and are the most advanced tools currently available for simulating the response of the global climate system to increasing GHG concentrations.

National Communications A series of reports has been required for submission to the UNFCCC on the current status of signatory countries to the Kyoto Protocol. They document progress achieved on meeting the goals set out by the Conference of Parties to the Convention. These reports 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 or 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 communication, due on 1 January 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 Wm^2 before 2100 declining to 2.6 Wm^2 after 2100.

Reanalysis A systematic approach to producing data sets for climate monitoring and research. Reanalyses are created via an unchanging (frozen) data assimilation scheme and model(s), which ingest all available observations every six to 12 hours over the period being analysed. This unchanging framework provides a dynamically consistent estimate of the climate state at each time step.

Signal (versus noise) The attribution of climate change owing to human activities in contrast to the natural variability in the climate systems.

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 response.

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