The IPCC Fifth Assessment Report in Context: Implications for End Users in the Transition From AR4

A CLIMsystems Technical Report

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About CLIMsystems

CLIMsystems, established in 2003, has an impressive international footprint delivering innovative climate modelling tools backed by high quality data processing capabilities. The science underpinning the models is supported by a prestigious scientific advisory panel of preeminent climate change scholars. The extensive network of Associates located around the world and affiliated with a range of stakeholder groups further strengthens the commitment and capacity for CLIMsystems to deliver high quality products and services to the climate change community.

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Glossary

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

National Communications: A series of reports have been required to be submitted to the UNFCCC (United Nations Framework Convention on Climate Change) on the current status of signatory countries to the Kyoto Protocol on progress in achieving the goals set out by the COP (Conference of Parties) to the Convention. These reports include major sections on national greenhouse gas inventories and adaptation risk and planning across key sectors. To date there has been an uneven meeting of the obligations to report across the two streams: Annex 1 or more developed countries (41) and Non-Annex 1 countries, the developing and least developed. In the case of the latter there is no deadline for submission of reports. Some non-Annex 1 countries have yet to complete their First National Communication while some Annex 1 countries are preparing their Sixth communication which is due on 1 January 2014.

RCP (Representative Concentration Pathway): Each RCP defines a specific emissions trajectory and subsequent radiative forcing. A 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 produce 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 6-12 hours over the period being analyzed. This unchanging framework provides a dynamically consistent estimate of the climate state at each time step.

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

Uncertainty: Uncertainty refers to a state of having limited knowledge. Uncertainty can result from lack of information or from disagreement over what is known or even knowable. Uncertainty may arise from many sources, such as quantifiable errors in data, or uncertain projections of human behaviour. Uncertainty can be represented by quantitative measures or by qualitative statements. Uncertainty in climate change projections is a major problem for those planning to adapt to a changing climate. Uncertainty in projections of future climate change arises from three principal causes: natural climate variability; modelling uncertainty, referring to an incomplete understanding of Earth system processes and their imperfect representation in climate models; and uncertainty in future emissions.

The IPCC and Assessment Reports

The Fifth Assessment report (hereafter AR5) of the United Nations Intergovernmental Panel on Climate Change (hereafter IPCC) is being released in four parts between September 2013 and November 2014. It supersedes the Fourth Assessment Report (hereafter AR4) released in 2007 as the most comprehensive review of climate science and policy. The original or First Assessment Report (hereafter FAR) was born out of the establishment of the Intergovernmental Panel on Climate Change in 1988 by the World Meteorological Organisation and the United National Environment Programme. These entities were to prepare a report on all aspects of climate change and its impacts with the purpose of informing the crafting of practical strategies in response. FAR was released in 1990 and exposed the need for international cooperation to tackle the issues it raised. Moreover, that report spurred the creation of the United Nations Framework Convention on Climate Change (hereafter UNFCCC) which is the key international treaty to guide humanity in its reduction of greenhouse gases and provides a framework for managing the consequences of not doing so. Since 1995 there have been regular assessments released as well as a number of important methodology and special scientific reports. The publications are used to assist governments in executing their national communications to the UNFCCC and review their greenhouse gas emissions plans for mitigation and impact and adaptation plans at the scale of the independent State.

AR5 will have more extensive information on the socio-economic impacts of climate change and thus climate change's role in sustainable development. The 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" and Working Group III "Mitigation of Climate Change". Additional activities include a Task Force on Greenhouse Gas Inventories. There shall be a Synthesis Report that will integrate the science from the three working group reports and special reports issued through the Fifth and previous assessment cycles. The Synthesis Report is specifically written for policy makers and government officials, advisors to government and, experts. The report is to be free of jargon and accessible to its broad audience as it is widely read, used and quoted in official reports and action statements. The Synthesis report will not be released until the meeting of the Conference of Parties in a yet to be determined location in December 2014.

How AR4 and AR5 are different

Climate modelling through General Circulation Models (hereafter GCM's but also known as Global Climate Models) has been a substantial part of the assessment process since its inception in 1990. The number of modelling groups involved in producing general circulation models has increased markedly over the successive assessments. The models represent the natural (physical, chemical and biological) processes of the atmosphere, ocean, cryosphere and land surface. These models are the most sophisticated currently available for simulating how the global climate system is likely to respond to increases in greenhouse gases. The teams doing this work have expanded from only five groups in 1990 generating eight models for the FAR to 27 groups producing 61 models for AR5. Along with the growth in the number of modelling groups has come an expansion in the number of variables modelled now extending to the marine environment as well as the atmosphere. For example, with AR5 many models now have daily temperature data, with minimum, mean and maximum values, so change pattern for these variables can be extracted for the first time. Even the AR4 models of 2007 lacked this sort of information. Also with AR4 only 12 GCMs produced daily outputs for precipitation. With AR5 more daily outputs have been archived.

This is critical for the modelling of extreme rainfall events. With only monthly data previously available the nuanced situation whereby a place's monthly rainfall could show a drying signal but individual extreme rainfall events increased in intensity could not be easily assessed using available model data. Only a handful of groups, including CLIMsystems, managed to develop methods for working with the limited daily GCM data. Currently more than 20 models of the current suite of 61 have all the data necessary for post-processing and incorporation in extreme rainfall event tools that can be applied in risk assessments. With further processing a total of 40 of the 61 models are available for spatial scenario generation. This is a considerable enrichment in data and adds additional information for any set of tools that are applied to real world problems. This greater set of model outputs also improves the statistical significance of results. This further supports the IPCC prerogative that advises that an ensemble or mean of a group of models be applied when using general circulation model data in risk assessments (Stocker *et al.*, 2010).

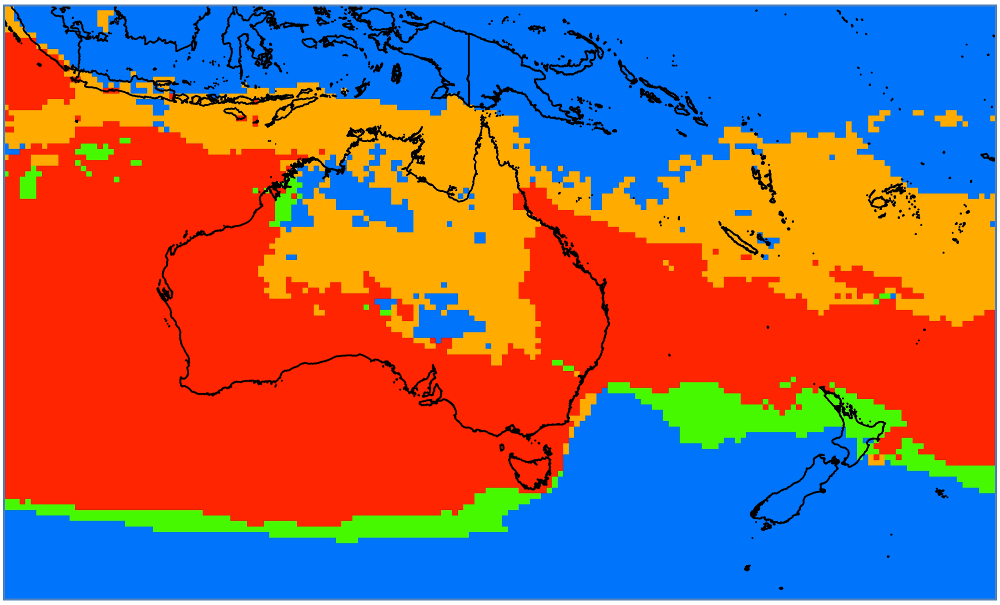
The other key piece of information required when generating climate outputs are the global scenario parameter curves. Prior to AR5 this vital piece of work was created through the storylines of emissions scenarios (Special Report On Emission Scenarios (SRES)) and prior to that FAR was driven by analogue and equilibrium scenarios for impact assessment that included business as usual as well as policy scenarios. The SRES scenarios published in 2000 were applied in the TAR and AR4 and replaced the IS92 scenarios used in the SAR of 1995. There were 40 SRES scenarios developed that represented different assumptions on pollution, change in land-use and other driving forces of climate change. This list of 40 was refined to six families for application in risk assessments with the descriptors A1FI, A1B, A1T, A2, B1 and B2. In 2005 the process of moving away from SRES began with the development of representative concentration pathways (RCPs) introduced at an IPCC Expert Meeting on Emissions Scenarios followed by IPCC workshops later in 2005 and 2007. The RCPs for the first time include scenarios that explore approaches to climate change mitigation in addition to the traditional 'no climate policy' scenarios. Each RCP represents a different emission pathway including RCP8.5 leading to a greater than 1370 PPM (Parts Per Million) CO_2 equivalent by 2100 with a continued rise post-2100, RCP6.0 which stabilizes by 2100 at 850 PPM CO_2 equivalent by 2100 without overshoot, RCP4.5 which also stabilizes by 2100 but at 650 PPM CO_2 equivalent without overshoot and RCP2.6 which peaks at 490 PPM CO_2 equivalent before 2100 and then declines. It is important to remember that the global atmosphere is currently at close to 400 PPM CO_2 equivalents and the concentrations of CO_2 and non- CO_2 gases are increasing at a rate that is concerning (Prinn 2013).

Table 1. Overview of representative concentration pathways (RCPs) (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	Stabilization without overshoot pathway to 6 W/m2 at 2100	**850**	**B2**	**Fujino *et al.*; Hijioka *et al.* 2008 – AIM**
RCP4.5	Stabilization 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**

Change in Distribution of Precipitation

Many parts of the world are fairly dry (<800 mm per year), with much more rain over the oceans and the equator. Overall the AR5 precipitation projections are fairly similar to that of AR4 on a global scale. However, when the ensemble medians of models is created and compared between AR4 and AR5 some important areas of the world show evidence of a shift in the signal in the GCM results. For example, in Australia the 21 GCM ensemble median AR4 data show a signal towards an increase in the annual precipitation for roughly the northern third of the continent. With the processing of a 40 model ensemble of AR5 results the signal has reversed with the ensemble showing a drying for much of the northern part of the continent. Importantly, the nuances of the arrival of the northern region's precipitation are critical to any analysis. The models are also based on data trending through the entire 21st century which - while it represents a huge increase in the volume of data to manage - does not necessarily lead to an overall improvement in model performance (Knutti and Sedláček 2012).



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

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

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 is getting wetter, but the AR5 signal is for it to get drier

BLUE: both AR4 and AR5 agree that the area is getting wetter

Extreme Temperatures and Precipitation

The IPCC concluded in AR4 (Solomon *et al.,* 2007) that climate change has begun to affect the frequency, intensity, and duration of extreme events such as extreme temperatures, extreme precipitation and floods and droughts. Some of the changes in weather extremes observed in the late 20th century are projected to continue into the future. A subsequent assessment by the IPCC in its special report on managing the risks of extreme events to advance climate change adaptation (SREX) confirms these assessments (Seneviratne et al., 2012).

The ability of global climate models to reproduce extremes on different time scales is of great importance. In 1950 the researcher Jennings discovered the relationship between a global maximum of precipitation and duration and, since that time his findings have been reinforced by numerous studies. The question now is how do the new models perform and how can their results be folded into decision making?

In general, the high temperature extremes in the late 20th century are plausibly modelled. Their 20 year return values on a global scale are within the range of uncertainty in historical reanalysis data of about 1^{0} C. Discrepancies at a local scale can be greater with values of up to ca. 5^{0} C. The differences between the models are greater over the land than the oceans. The uncertainties in low extremes are greater than that of the warm extremes, however; they are still well within the estimates obtained from different reanalysis data.

Extremes in precipitation have always been more difficult to model. This has not changed with the latest results. Large uncertainties remain especially over the tropical and subtropical regions. The performance of the AR5 models is very similar to that of the AR4 models. Both perform better in the extratropics where they compare favourably with observational records. Globally and by the end of the 21st century the various RCPs express different possible shifts in precipitation intensity. For example, RCP 2.6 global multi-model results indicate a 6% increase of high extreme daily precipitation while the RCP 4.5 experiment shows a 10% increase and RCP 8.5 20% by the end of the century. These changes in extremes are 2 to 3 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 drying regions in the subtropics. Perhaps most indicative is the shortening of 20 year return periods to 14, 11 and 6 years for RCPS 2.6, 4.5 and 8.5 respectively by the end of the 21st century compared with the historical 1986 to 2005 period.

In summary AR5 extremes for temperatures and precipitation are generally in agreement with the outcomes of 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 availability of GCM daily data permits the application of ensembles with more members than in AR4. This means that statistical analysis of the uncertainty across models has improved while acknowledging that uncertainty in certain regions and locations remains particular high for precipitation but less so for temperature.

Marine changes - surface temperature and acidification issues; cooling and desalination

The AR5 models offer opportunities for modelling the marine environment. For the first time the world's modelling groups have made a concerted effort to model a wide range of biophysical ocean variables improving on shortcomings in the AR4 ocean models (Griffies *et al*., 2010; Mora *et al*., 2010). More than 40 variables are available from limited GCM runs. Processing of some biogeochemical models has occurred at CLIMsystems and they have been made available for application through Esri ArcGIS tools. Currently available variables include: sea surface temperature, net primary productivity of carbon by phytoplankton; dissolved nitrate concentration at the surface; dissolved oxygen concentration at the surface; pH at the surface; dissolved phosphate concentration at the surface; total alkalinity at the surface; dissolved iron concentration at the surface; and dissolved silicate concentration at the surface.

Much of the interest in these marine model data relates to sea surface temperature changes as they relate to requirements for power plants cooled by seawater. Increasingly there are examples of power plant shutdowns required as sea surface temperatures increase and the cooling potential of the seawater decreases. Similarly, changes in sea surface temperatures combined with other biophysical characteristics to make it possible to model potential changes in frequency of algal blooms which can impact on desalination operations and extreme events like coral bleaching.

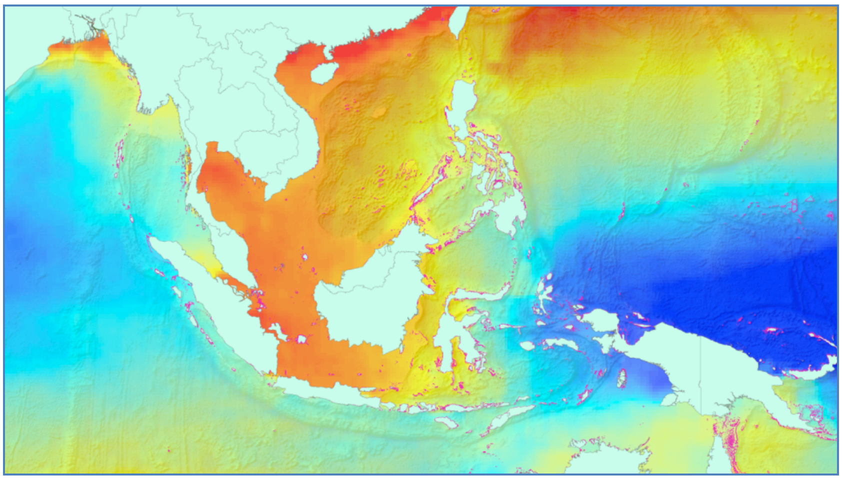


Figure 2: Signal of change in ocean surface pH in the Western Asia-Pacific (the Coral Triangle). The redder colour represents a stronger change.

One of the greatest concerns related to climate change and the oceans is degradation of the carbonate/reef environment. About a third of the CO_2 released in the atmosphere dissolves in the oceans, where it lowers the pH slightly. This effect is known as ocean acidification. Ocean acidification is of great concern: small changes in pH impact the $CaCO_3$-CO_2 equilibrium, slowing coral growth and weakening the coral that does grow under such conditions. The image in figure 2 shows the changes in pH from 12 models from AR5. Because pH is a log-scale unit, the ratio of pH for 1995 and 2035 is presented. The redder colour shows a stronger change. This is mostly occurring in shallower areas, as there is a contribution from temperature increase as well.

Sea Level Rise

Global mean sea level 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 the consistency of process-based models with observations and physical understanding. The IPCC notes that there is currently insufficient evidence to evaluate the probability of specific levels above the *likely* range. Global mean sea level is unlikely to exceed the above levels by the end of the 21st century unless there is a substantial change in the condition of the Antarctic and Greenland ice sheets. Research is focused on better understanding of the potential for rapid and catastrophic sea level rise over a much shorter timeframe (Krinner and Durand, 2012).

While mean sea level rise is of importance it is equally important to recognize at least two other factors: first, sea level rise does not occur evenly across the globe with some areas rising faster than others as a result of changes in ocean currents, sea water temperatures (the thermal expansion component varies), air pressure and geo-tectonic movements: for example 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. Secondly, and, in addition to sea level rise, are extreme sea level events. These often -- but not exclusively -- arise with the confluence of events such as exceptional seasonal high tides, wind and hence wave set ups associated with either 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. It can now be modelled by CLIMsystems in conjunction with mean sea level rise for a location in order to gain a better understanding of return periods for certain extreme events and the actual potential sea level during such an event.

Case study: Climate change impacts on the Hazelwood coal fired power station

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

The power station produces around 10 terawatt 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 pond for cooling.

The SimCLIM software tool was used to analyses climate variability and change over a downscaled geographical area and set timeframe, CLIMsystems' analysis 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 demand, from increased residential and commercial air conditioning requirements

Methodology

The SimCLIM tool uses results that were produced by institutes around the world for the Fifth Assessment Report (AR5) of the Intergovernmental Panel on Climate Change, to examine changes in ambient temperature. Specifically using the Representative Concentration Pathway 8.5 (RPC8.5) scenario with high climate sensitivity which states that by 2040, the global mean temperature could rise by 1.92°C compared to 1990 levels. The results of an ensemble of 35 Global Climate Models (GCMs) were used.

Climate change is about the future development of the Earth's climate. As the change is driven by CO_2 emissions from burning fossil fuels, assumptions have to be made about how much CO_2 is added to the carbon-cycle. Different scenarios were developed by IPCC, 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 reach the 1.92°C warming as well, albeit later.
To determine the future climate change, GCMs are used. Various research institutes around the world develop their own models and report the results for agreed inputs (like the RCP8.5) on a publically accessible website (CMIP5). SimCLIM uses the results from all models and takes the median (the 50-percentile, thus not the average) from these results. Using the median eliminates the more extreme model results.

The extreme temperature events for given return periods are outlined in the table 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 higher.

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

Instead of focussing 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.

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

This shows that the current extreme temperatures will have become more than three times more frequent by 2040. With seven day heatwaves with a current return period of 1 in 100 years becoming nearly five times more frequent under this emission scenario by 2040.

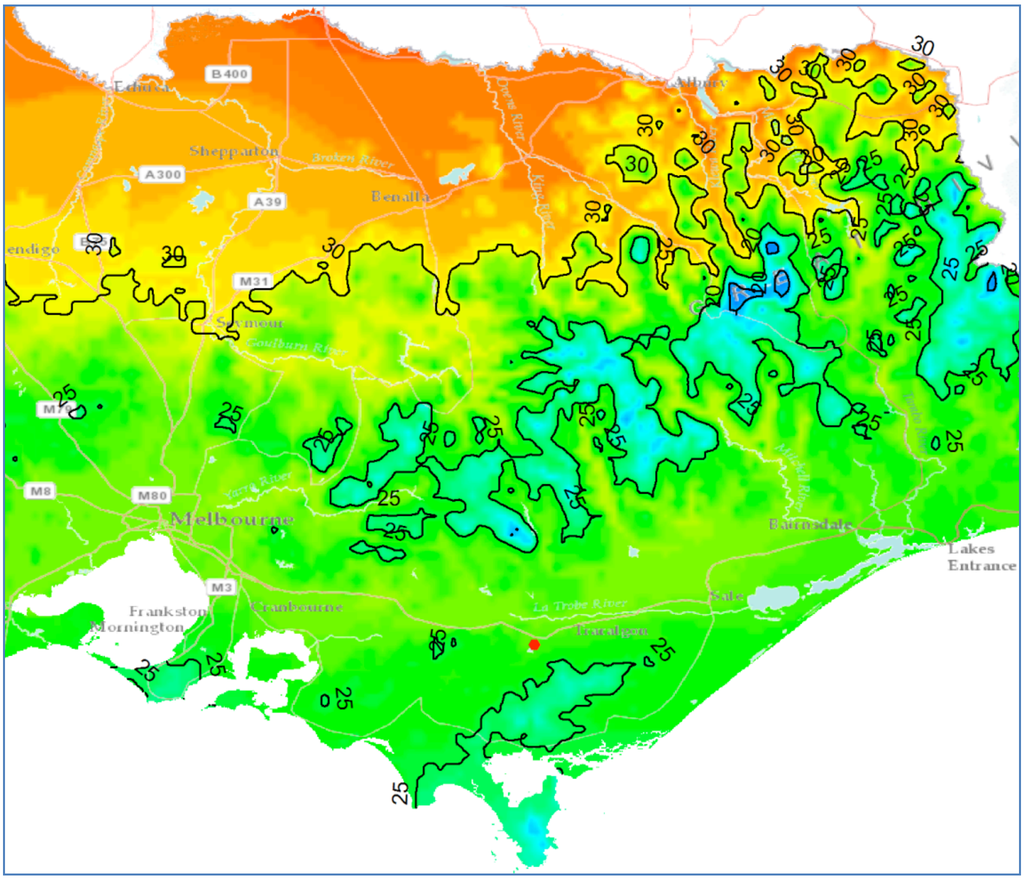


Figure 3: The spatial distribution of the daily maximum temperature (TMax) averaged over January and February for the baseline climate of Victoria.

At the location of the power-plant (the red dot) the average maximum temperature is around 25°C. Areas closer to the sea or with a higher elevation are cooler as indicated by the lighter blue colours and hotter toward the interior along the Murray River.

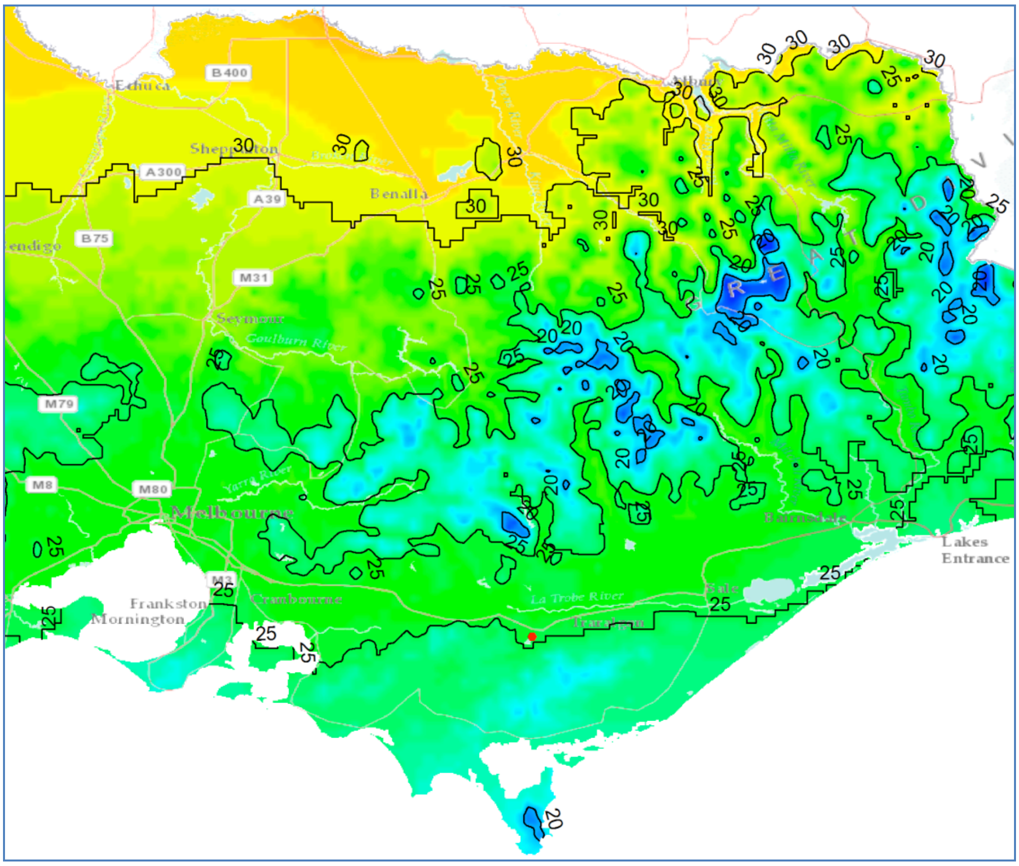


Figure 4: The spatial distribution of maximum temperature by 2040 (RCP8.5-high, 35-GCM).

The same colour definition as in figure 3 is used. The 25°C contour line has shifted closer to the power plant. The whole area shows a considerable increase in temperatures, which will drive the energy demand from residential and commercial air conditioning.

To further analyse the consequences of climate change on the environmental heat-balance -- which will impact both the energy-demand from air conditioning and the ability to properly cool the power plant -- an analysis of the degree day sum was performed. This is a base variable used for air conditioning design as well as the cooling requirement 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 has the distribution as described in table 4.

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

Currently the degree-day sum reaches 128 °C.d once every 10 years (on average). By 2040 this may increase to 191 °C.d. As the energy-demand for cooling is linear with the degree-day sum, that demand for energy to meet this requirement could therefore increase by almost 50%.

Moreover, the peak in energy demand 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 in intensity and frequency) also have an impact on the efficiency of the Hazelwood power station, which as with all thermal power stations will decrease with increasing ambient temperatures. The change in the degree day sum is one of the most indicative measures of the potential impact. It should help to focus planning not only on reductions in the current rate of greenhouse gas emissions but also adaptive measures such as energy efficiency and resilience planning for power generation and distribution infrastructure.

In summary, the impacts of climate change on the operation of the Hazelwood power plant will include:

- increased demand for energy for residential and commercial air conditioning
- decrease in efficiency of the power generation due to increased ambient temperatures depending on the design of the power-plant cooling thus the ability to generate power might be seriously compromised
- decreased efficiency on the delivery of power through the grid, both from increased temperatures and from heightened demand
- redesign of the power grid might be necessary to meet the change in demand

Conclusions

The IPCC AR5 is being released in stages. The recent release of the Working Group 1 report called The Physical Science Basis gives the general public a first official glimpse at the science underpinning climate change modelling. In general, there are no dramatic changes from previous models released as part of the fourth and earlier assessment reports. There is however 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. The range of new models now available not only for the commonly modelled variables of temperature, precipitation and sea level rise have with this report been augmented by better developed 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 depicted in the Fifth Assessment Report is slightly narrower than previous reports and the upper bounds for mean sea level rise are also higher than in previous reports. Uncertainty is still an issue that must be managed by the users of the new information available. Exciting new methodologies for transforming the AR5 data into informative and useful information for planners, policy makers and a wide range of stakeholders continues. The links between the climate modellers and those charged with downscaling and interpreting the data and end users are being vigorously pursued by CLIMsystems and its network of collaborators. Data however is not equal to information. Different user groups need to be communicated with in their working context. Jargon must be avoided. In all communication with stakeholders, limitations, uncertainty and visualized outputs need to be well prepared. Raw data must be transformed to express the climate change signal (increase or decrease) with risk levels explained transparently through the application of ensembles, web-based tools, hands-on site and regionally specific software like SimCLIM, and other media. This is exciting as there are ever growing demands for expertise on what climate change means to various sectors. The stories to be told for those willing to listen are enlightening.

References

Griffies, S., *et al.* (2010) Sampling Physical Ocean Fields in WCRP CMIP5 Simulations. CLIVAR Working Group for Ocean Model Development (WGOMD). Committee on CMIP5 Ocean Model Output. http://www.clivar.org/sites/default/files/imported/organization/wgomd/references/WGOMD_CMIP5_ocean_fields.pdf

Jennings, A. H., (1950) World's greatest observed point rainfalls. Mon. Wea. Rev., 78, 4–5.

Kharin, V. V, Zwiers, F.W. , Zhang, X., Wehner, M. (2013) Changes in temperature and precipitation extremes in the CMIP5 ensemble. Climatic Change. http://link.springer.com/article/10.1007%2Fs10584-013-0705-8#page-1

Knutti, R., Sedláček, J. (2012) Robustness and uncertainties in the new CMIP5 climate model projections. Nature Climate Change DOI: 10.1038/NCLIMATE1716.

Krinner, G., and Durand, G. (2012) Glaciology: Future of the Greenland ice sheet. Nature Climate Change. 2: 396-397.

Mora, C., Wei, C-L., Rollo, A., Amaro, T., Baco, A. R., et al. (2013) Biotic and Human Vulnerability to Projected Changes in Ocean Biogeochemistry over the 21st Century. PLoS Biol 11(10): e1001682. doi:10.1371/journal.pbio.1001682.Moss, M., *et a*l. (2010) The next generation of scenarios for climate change research and assessment**,** Nature, doi:10.1038/nature08823.

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

Rogelj, J., Meinshausen, M., and Knutti, R. (2012) Global warming under old and new scenario**s** using IPCC climate sensitivity range estimates, 2012, Nature Climate Change, DOI: 10.1038/NCLIMATE1385.

Seneviratne S. I., *et al.* (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. A special report of working groups I and II of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, pp 109–230.

Solomon, S., *et al .* (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. ISBN 978-0-521-88009-1.

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. 15pp.

van Vuuren, D.P., *et al.* (2011) The representative concentration pathways: an overview. Climatic Change. 109:5-31.