CLIMATE SCIENCE
TRAINING FOR SECTORS

3

SESSION 3 - The climate system

Department Vanuatu Meteorology and Geo-Hazards

SPREP
Secretariat of the Pacific Regional Environment Programme

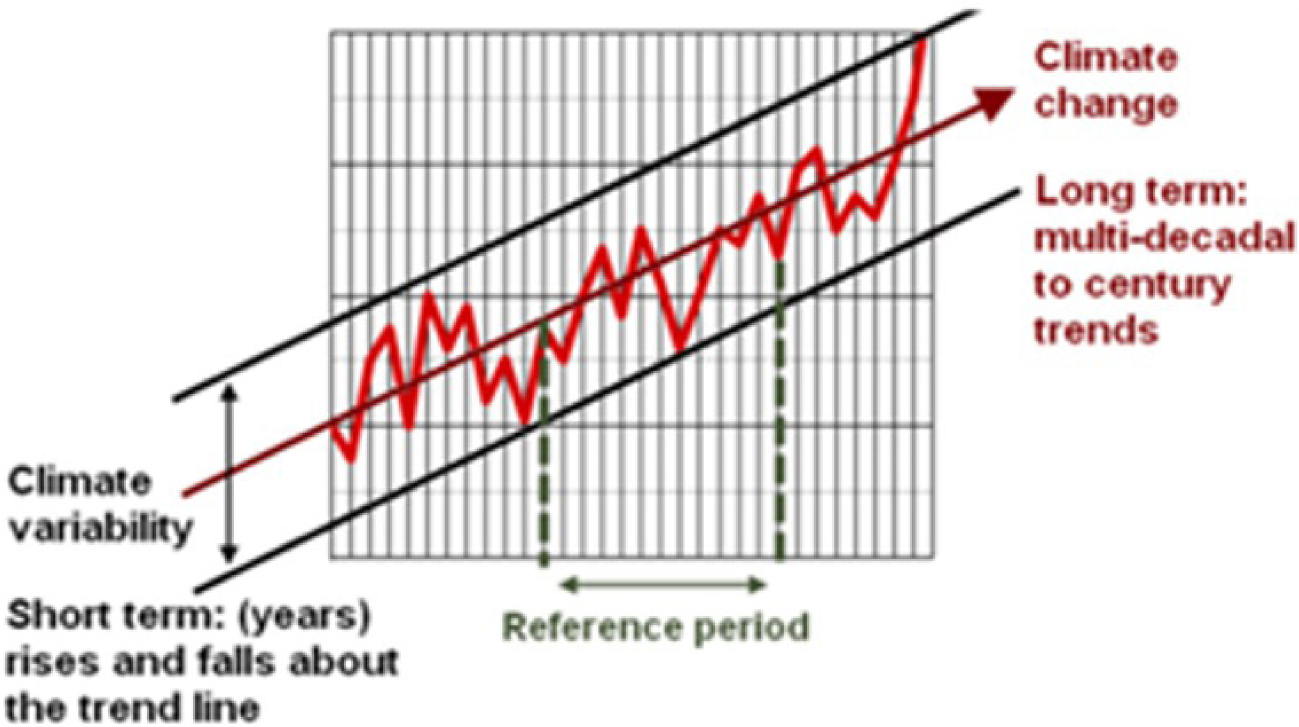
GREEN CLIMATE FUND

KLAEMET SAVE
REDI · ADAPT · PROTEKT

Adapting to the impacts of climate variability and change in the South Pacific

Introduction

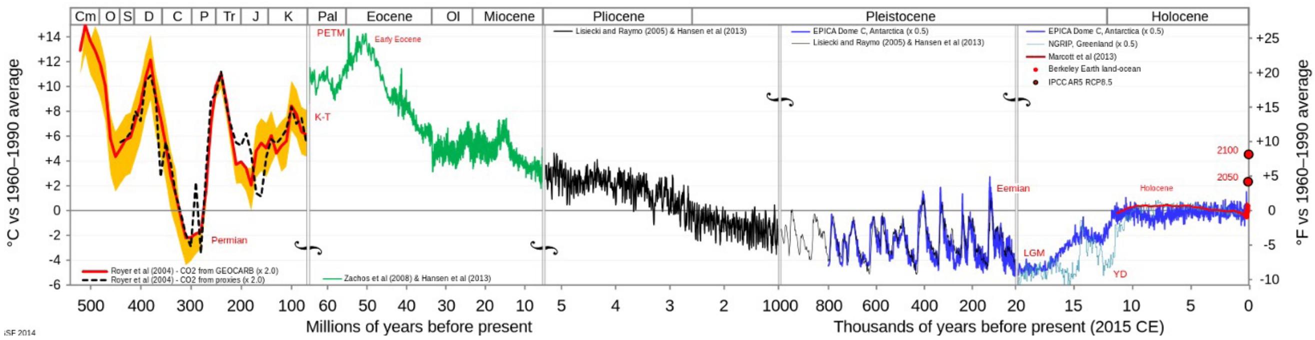
Climate variability and change



Climate variability: Shorter-term fluctuations on seasonal, interannual or decadal timescales. These fluctuations can cause temperature to change around the long-term average. Sources of climate variability include large-scale ocean-atmosphere phenomena such as El Niño-Southern Oscillation (ENSO), the South Pacific Convergence Zone (SPCZ), Intertropical Convergence Zone (ITCZ) and the West Pacific Monsoon (WPM).

Climate change: Longer-term changes in the earths climate – driven by factors including changes in the Earth's orbit and position in relation to the sun, volcanic eruptions, changes in atmospheric chemistry and anthropogenic climate influences (e.g. increased greenhouse gas emissions).

Understanding the past…

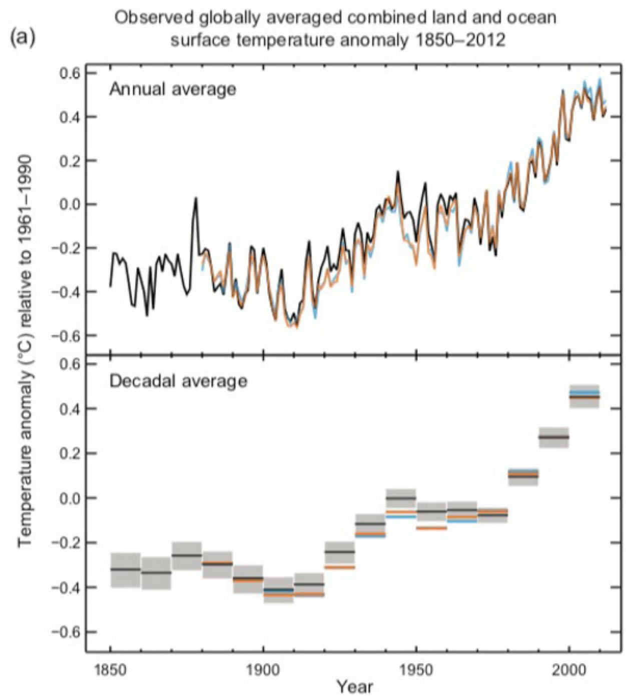


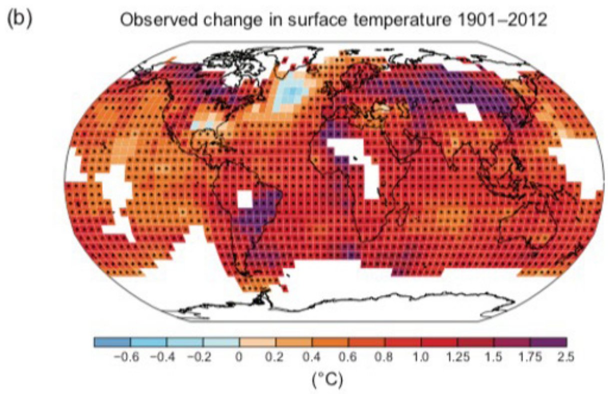
(Source: http://gergs.net/2015/06/updating-the-geological-temperature-plot/all_palaeotemps/)

Palaeoclimate and geological archives show that climate has always fluctuated, particularly over long time scales (i.e. decadal to centennial).

Climate change signals within these proxies are complex, with many indicating cyclical fluctuations within the climate system.

Temperature change





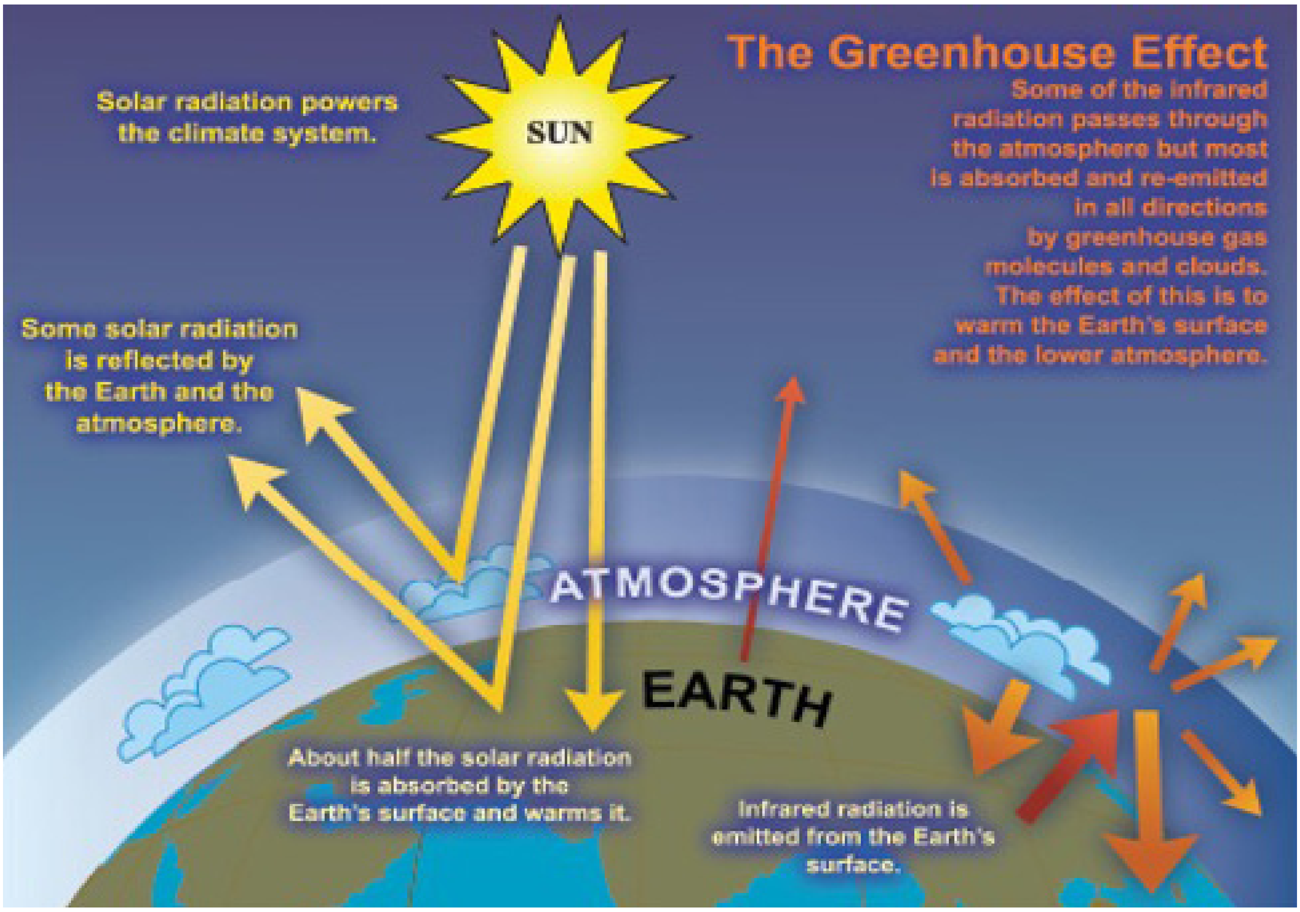
Since 1880, global land and ocean surface temperatures have increased by 0.85°C (IPCC 2013).

Temperature change is just one component of climate change. Others include melting glaciers and polar ice, declining snow cover and rising sea levels.

Greenhouse Effect

The natural greenhouse effect (presence of carbon dioxide and other greenhouse gases (GHGs), is an important and essential element of the Earth's climate system as it maintains temperatures suitable for life on earth.

Increased amounts of GHGs in the atmosphere have trapped more energy within the atmosphere, resulting in an increase in global land and ocean surface temperature (0.85°C over the period 1880 to 2012).

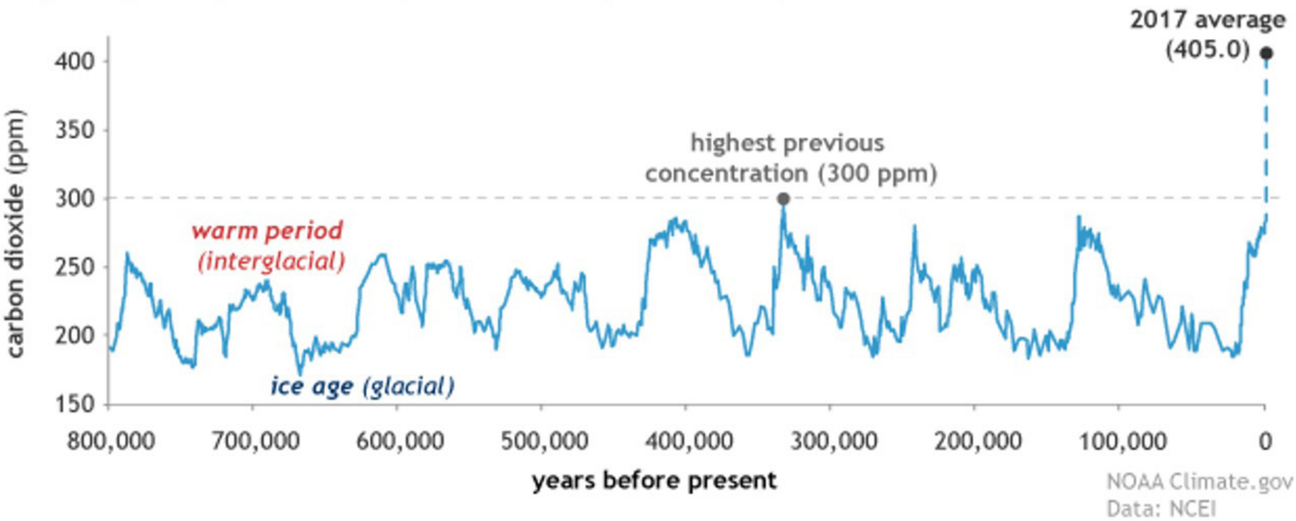


Source: https://www.ipcc.ch/publications_and_data/ar4/wg1/en/faq-1-3.html

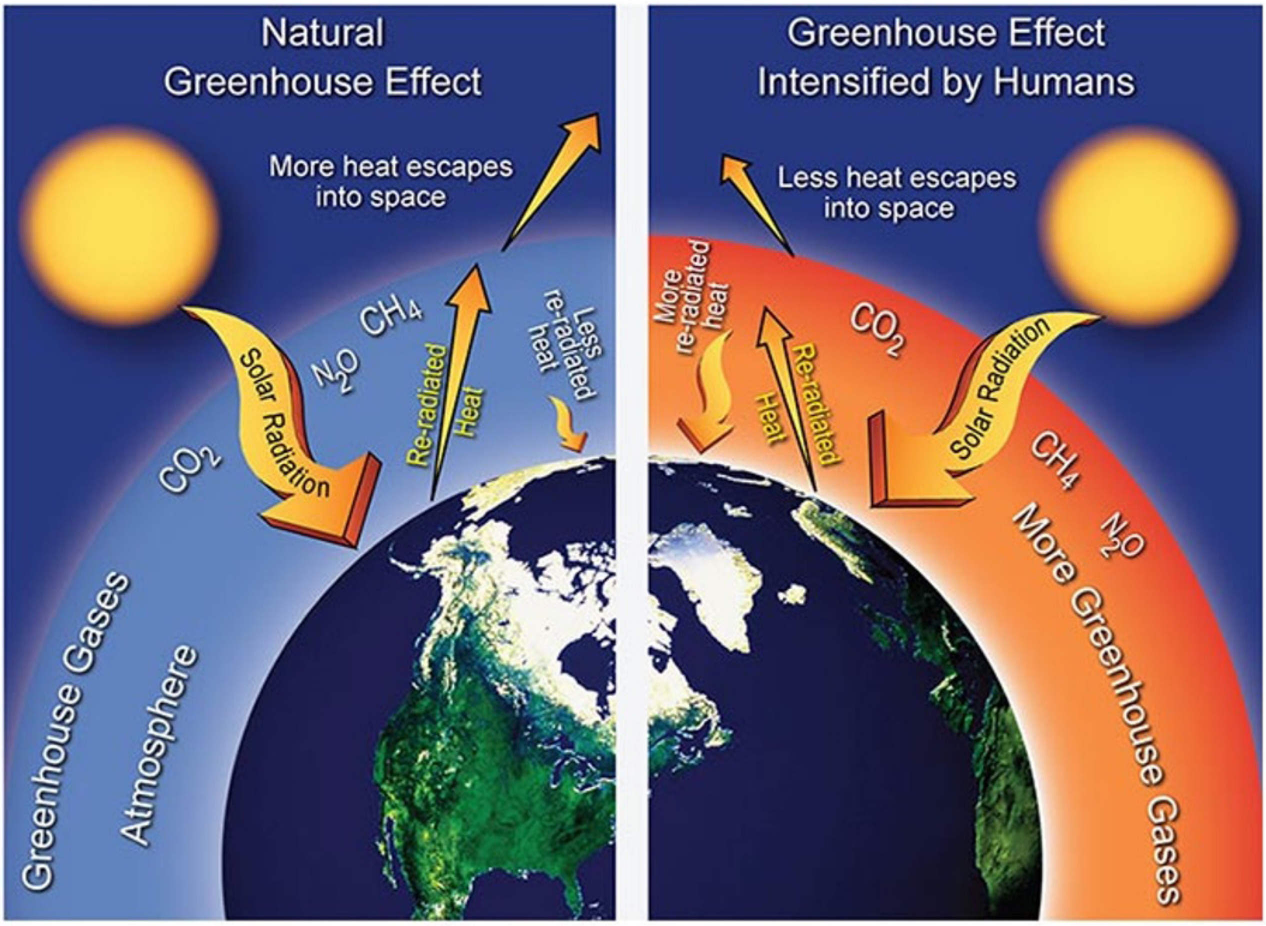
Anthropogenic climate change

The quantities of CO_2 (and other gases) have increased significantly in recent years and are a product of man-made activity (e.g. industrialisation). This causes an enhancement of the greenhouse effect and what is now referred to as anthropogenic climate change.

CO_2 during ice ages and warm periods for the past 800,000 years

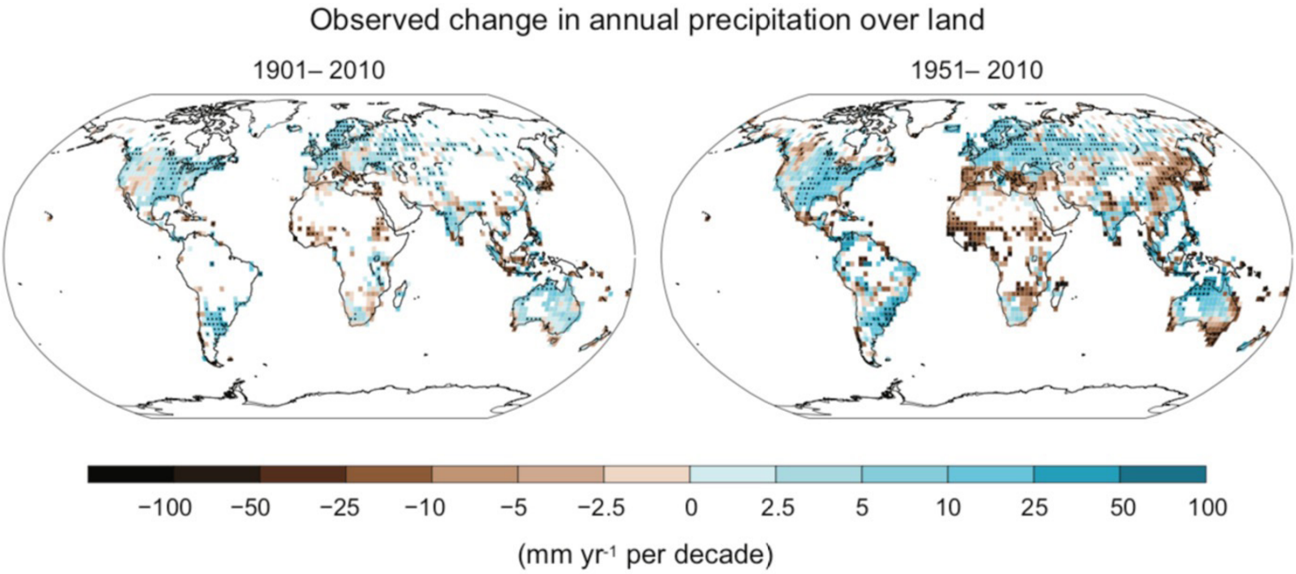


Anthropogenic climate change



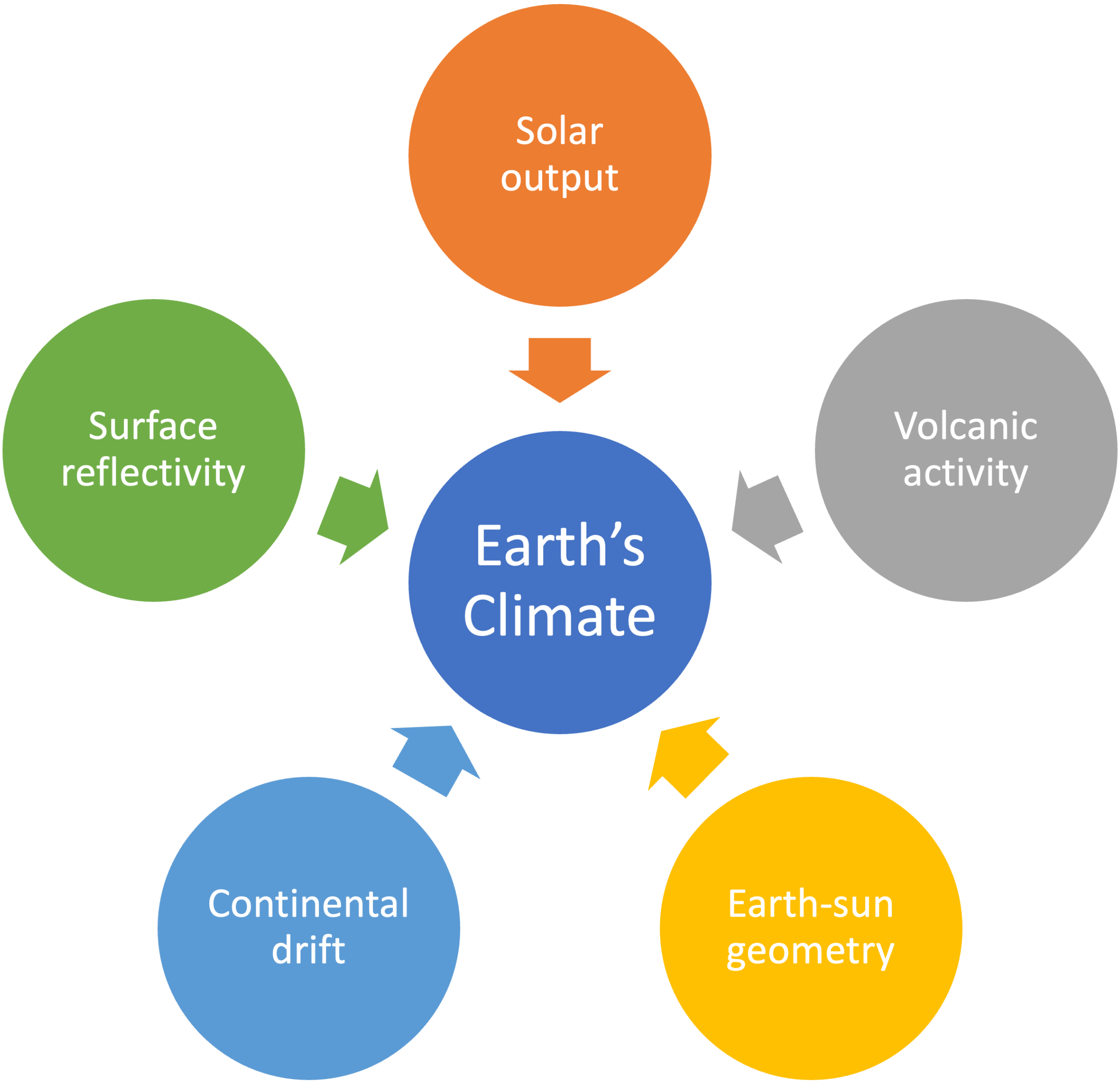
Source: https://nca2014.globalchange.gov/report/appendices/climate-science-supplement/graphics/human-influence-greenhouse-effect

Precipitation change



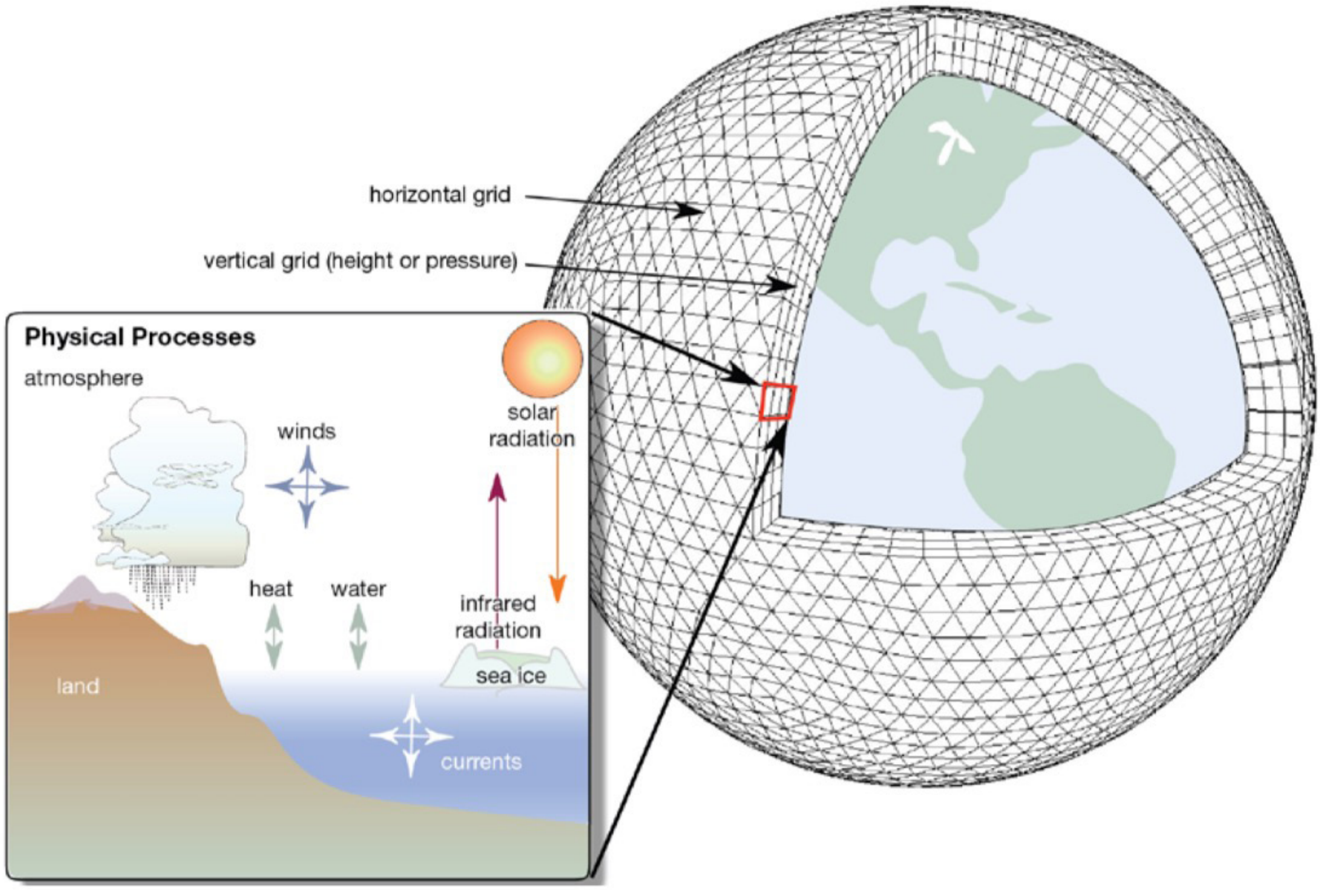
Source: IPCC, 2013

Other natural causes driving climate change



Global Climate Models – interpreting climate change information

Global Climate Models or General Circulation Models (GCMs)



Source: Australian Bureau of Meteorology and CSIRO (2011)

GCMs are used to simulate complex interactions between the atmosphere, oceans, land surface and cryosphere and include variable such as temperature, precipitation and wind. GCMs are calculated over a three-dimensional array of grids covering the globe.

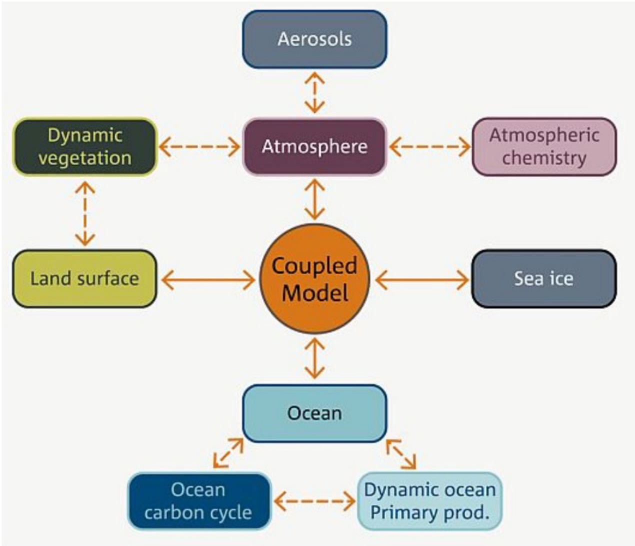
.

Components of a GCM

Weather conditions simulated by GCMs change according to a complex set of mathematical rules that model the laws of physics (e.g. conservation of mass, energy and momentum). GCMs are able to simulate hourly to daily weather.

GCMs typically represent large-scale synoptic features of the atmosphere, including the movement of high and low pressure systems and large ocean currents.

Many uncertainties lie in using GCMs including: mesoscale weather (smaller than synoptic scale) and simulation of feedback mechanisms such as clouds and radiation, ocean circulation and ice and snow albedo.

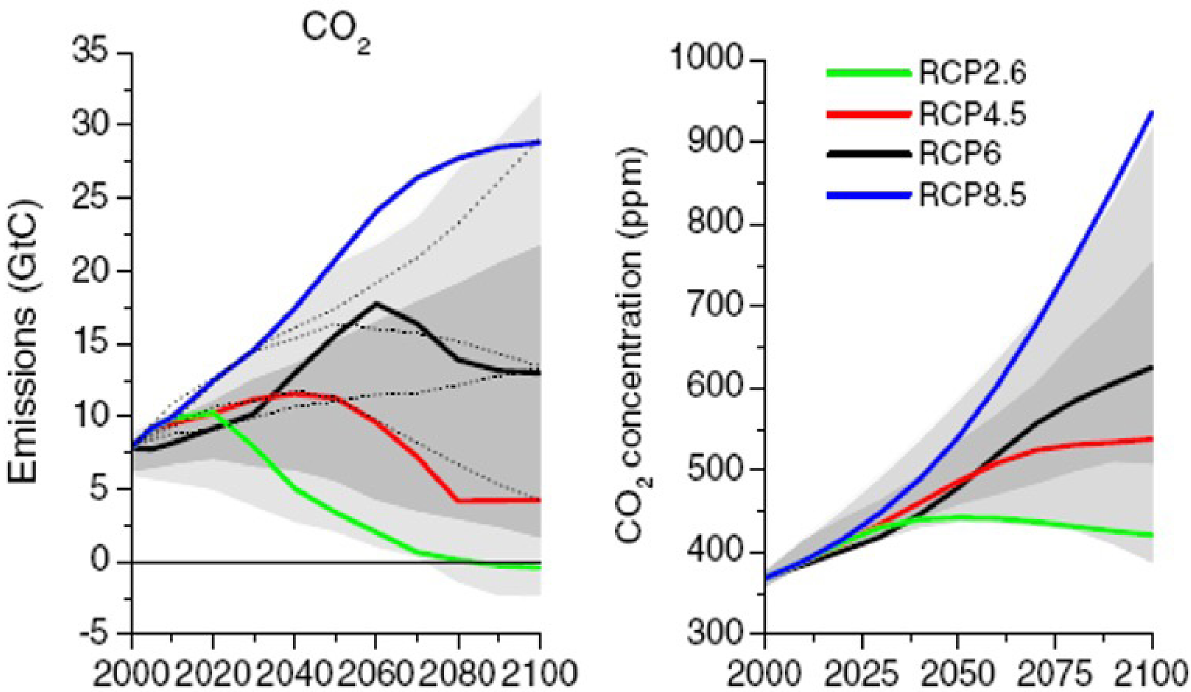


Source: https://www.climatechangeinaustralia.gov.au/en/climate-campus/modelling-and-projections/climate-models/

Climate change scenarios and projections

Climate projections are made by running GCMs with prior assumptions about the pattern of greenhouse gas emissions. These are referred to as Representative Concentration Pathways (RCPs).

Four RCPs were selected and defined by their total radiative forcing (a cumulative measure of anthropogenic GHG emissions) pathway and level by 2100 and represent a broad range of potential climate scenarios.



RCP8.5: assumes global annual GHG emissions continue to rise throughout the 21st century

RCP6.0: assumes global annual GHG emissions peak around 2080, with emissions declining thereafter

RCP4.5: assumes global annual GHG emissions peak around 2040, with emissions declining thereafter

RCP2.6: assumes global annual GHG emissions peak between 2010-2020 with emissions declining thereafter.

RCP and future climate

Depending on the RCP scenario, GCMs can be run to predict changes in future climate.

Projected changes in global mean surface air temperature and global mean sea level rise (changes expressed in relation to the 1986-2005 reference period)

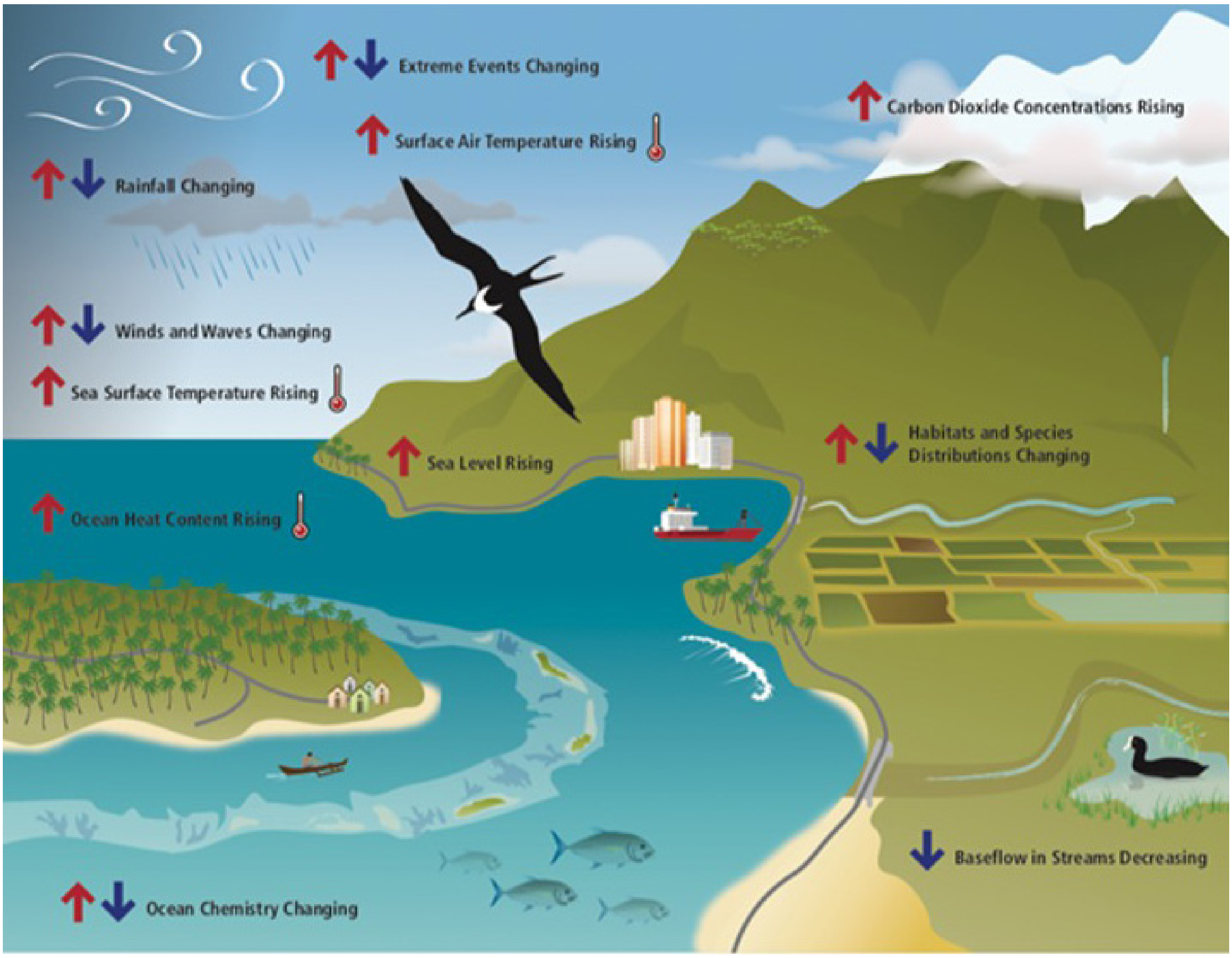
Source: IPCC 2013

		2064 - 2065		2081 - 2100	
	Scenario	**Mean**	**Likely range**	**Mean**	**Likely range**
Global Mean Surface Temperature Change (°C)	RCP2.6	1.0	0.4 to 1.6	1.0	0.3 to 1.7
	RCP4.5	1.4	0.9 to 2.0	1.8	1.1 to 2.6
	RCP6.0	1.3	0.8 to 1.8	2.2	1.4 to 3.1
	RCP8.5	2.0	1.4 to 2.6	3.7	2.6 to 4.8
Global Mean Sea Level Rise (m)	RCP2.6	2.4	0.17 to 0.32	0.40	0.26 to 0.55
	RCP4.5	0.26	0.19 to 0.33	0.47	0.32 to 0.63
	RCP6.0	0.25	0.18 to 0.32	0.48	0.33 to 0.63
	RCP8.5	0.30	0.22 to 0.38	0.63	0.45 to 0.82

While global changes in temperature and sea level are expected to rise, regional differences may vary significantly.

Climate change models and what they project for future climate in the South Pacific
PART 1: WHAT DO WE KNOW?

Projected impacts of climate change for the South Pacific
Global impacts: El Niño



(Source: Susan Yamamoto, adapted from "Ten Indicators of a Warming World" in NOAA National Climatic Data Center, State of the Climate in 2019 report).

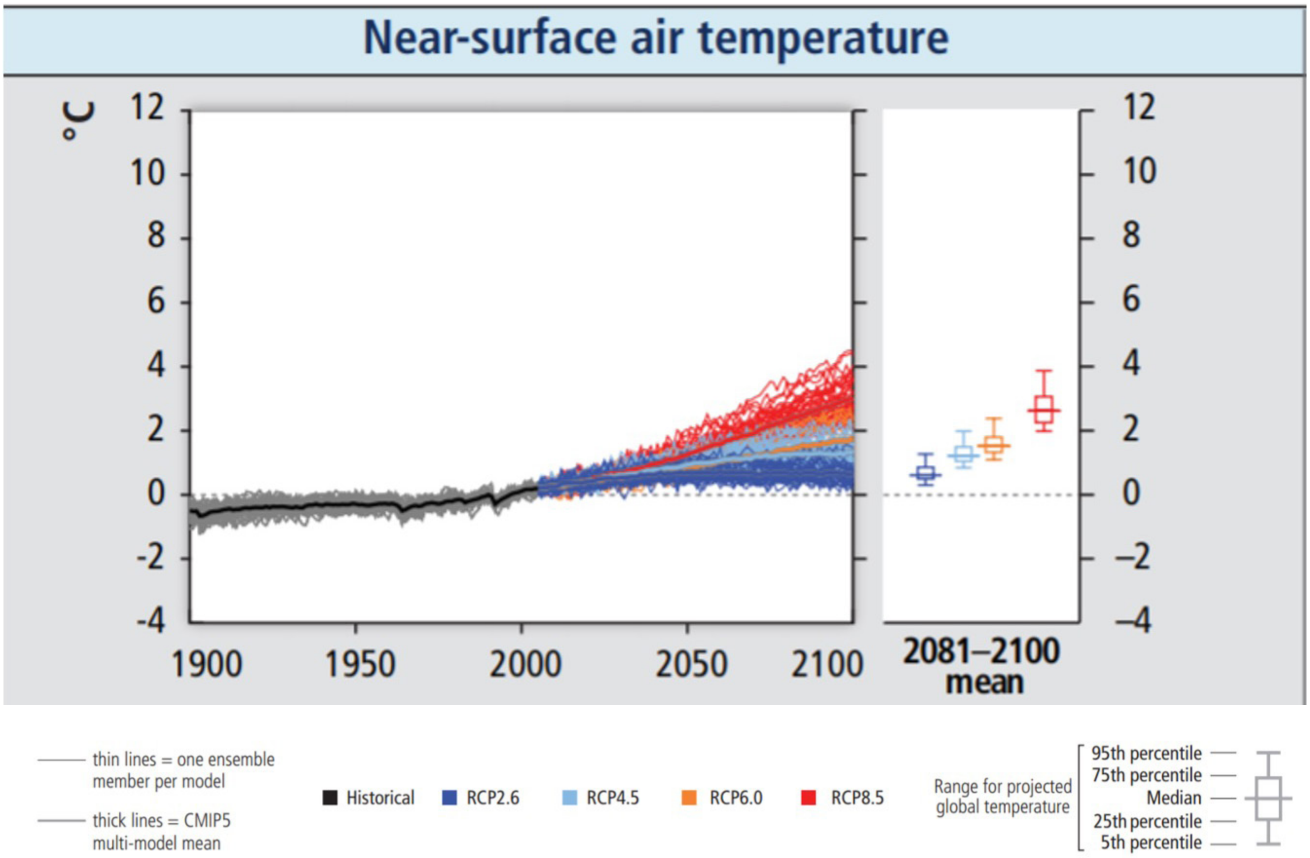
Projected impacts of climate change for the South Pacific

South Pacific nations are particularly vulnerable to changes in atmospheric, physical and biological processes due to their reliance on marine resources, high shoreline to land area ratio and concentration of settlements in coastal regions.

Small island region	RCP4.5 annual projected change for 2081–2100 compared to 1986–2005						
	Temperature (°C)			Precipitation (%)			Sea level (m)
	25%	50%	75%	25%	50%	75%	Range
Caribbean	1.2	1.4	1.9	−10	−5	−1	0.5–0.6
Mediterranean	2.0	2.3	2.7	−10	−6	−3	0.4–0.5
Northern tropical Pacific	1.2	1.4	1.7	0	1	4	0.5–0.6
Southern Pacific	1.1	1.2	1.5	0	2	4	0.5–0.6
North Indian Ocean	1.3	1.5	2.0	5	9	20	0.4–0.5
West Indian Ocean	1.2	1.4	1.8	0	2	5	0.5–0.6

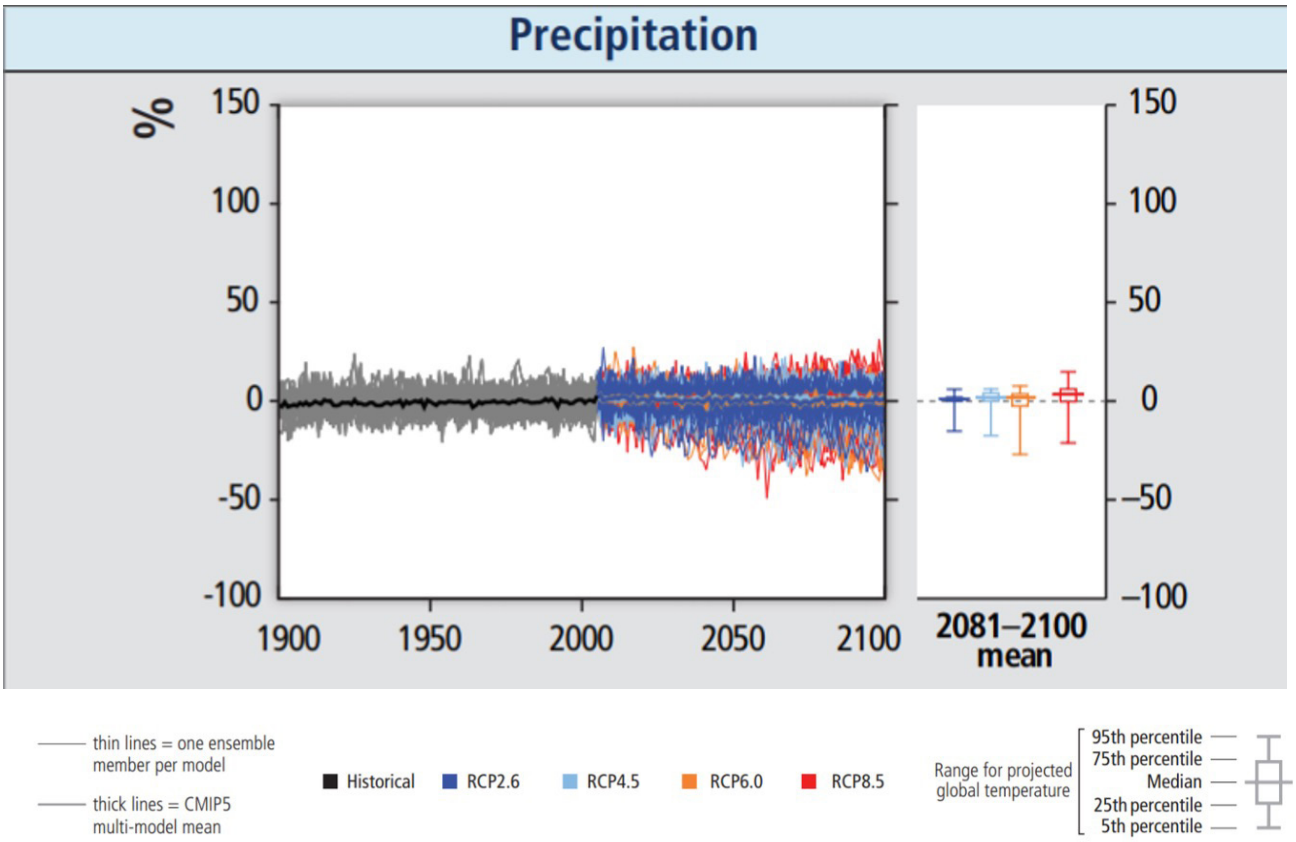
Source: http://www.ipcc.ch/pdf/assessment-report/ar5/wg2/WGIIAR5-Chap29_FINAL.pdf

Projected impacts of climate change for the South Pacific



Source: http://www.ipcc.ch/pdf/assessment-report/ar5/wg2/WGIIAR5-Chap29_FINAL.pdf

Projected impacts of climate change for the South Pacific



Source: http://www.ipcc.ch/pdf/assessment-report/ar5/wg2/WGIIAR5-Chap29_FINAL.pdf

Projected impacts of climate change for the South Pacific

Island type and size		Island elevation, slope, rainfall	Implications for hazard
Continental	• Large • High biodiversity • Well-developed soils	• High elevations • River flood plains • Orographic rainfall	River flooding more likely to be a problem than in other island types. In Papua New Guinea, high elevations expose areas to frost (extreme during El Niño).
Volcanic high islands	• Relatively small land area • Barrier reefs • Different stages of erosion	• Steep slopes • Less well-developed river systems • Orographic rainfall	Because of size, few areas are not exposed to tropical cyclones. Streams and rivers are subject to flash flooding. Barrier reefs may ameliorate storm surge.
Atolls	• Very small land area • Small islets surround a lagoon • Larger islets on windward side • Shore platform on windward side • No or minimal soil	• Very low elevations • Convectional rainfall • No surface (fresh) water • Ghyben–Herzberg (freshwater) lens	Exposed to storm surge, "king" tides, and high waves. Narrow resource base. Exposed to freshwater shortages and drought. Water problems may lead to health hazards.
Raised limestone islands	• Concave inner basin • Narrow coastal plains • No or minimal soil	• Steep outer slopes • Sharp karst topography • No surface water	Depending on height, may be exposed to storm surge. Exposed to freshwater shortages and drought. Water problems may lead to health hazards.

Source: http://www.ipcc.ch/pdf/assessment-report/ar5/wg2/WGIIAR5-Chap29_FINAL.pdf

Projected impacts of climate change for the South Pacific

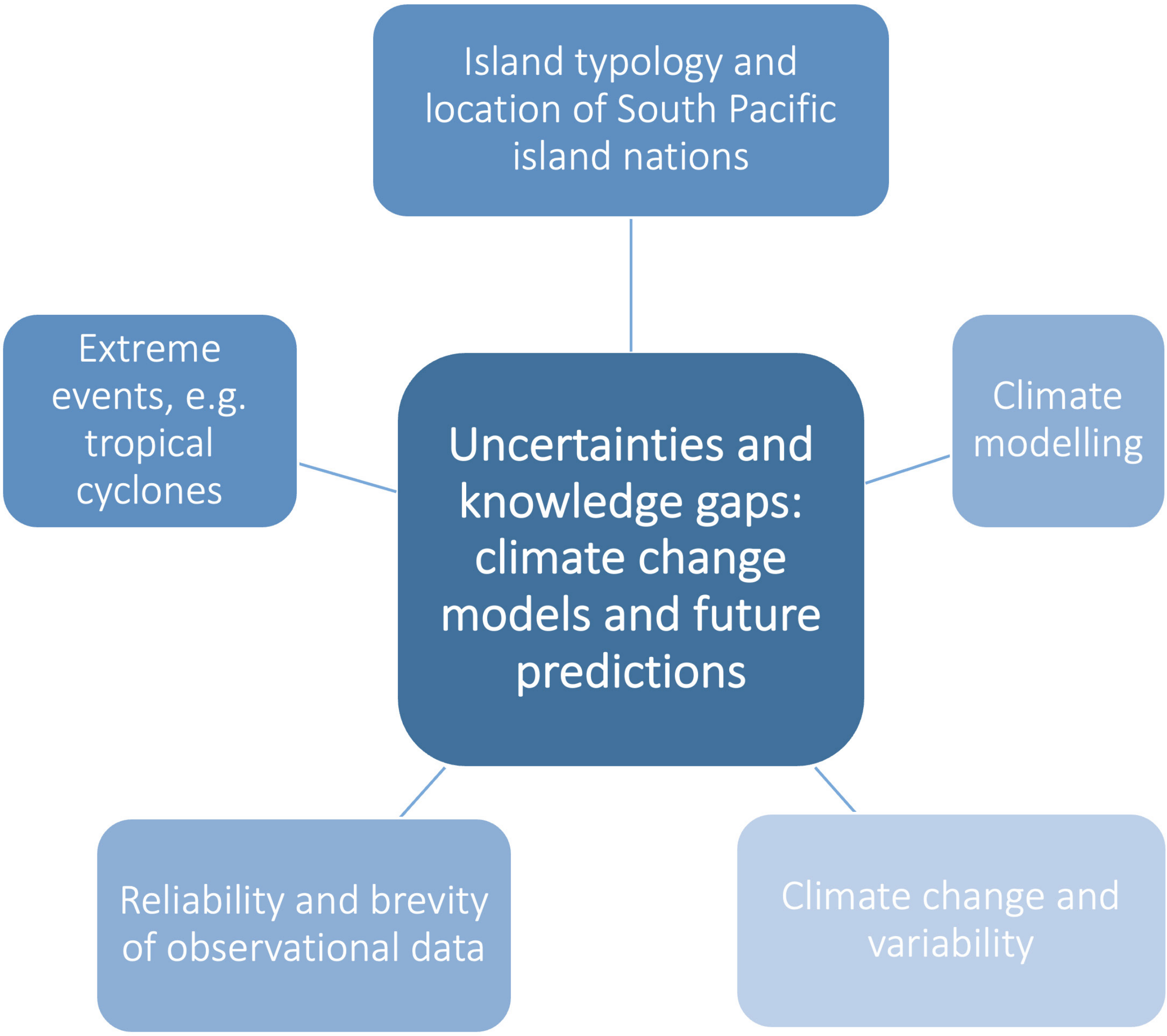
Rank	Absolute exposure (millions affected)	Relative exposure (% of population affected)	Absolute GDP loss (US$ billions)	Loss (% of GDP)
1	Japan (30.9)	Northern Mariana Islands (58.2)	Japan (1,226.7)	Northern Mariana Islands (59.4)
2	Philippines (12.1)	Niue (25.4)	Republic of Korea (35.6)	Vanuatu (27.1)
3	China (11.1)	Japan (24.2)	China (28.5)	Niue (24.9)
4	India (10.7)	Philippines (23.6)	Philippines (24.3)	Fiji (24.1)
5	Bangladesh (7.5)	Fiji (23.1)	Hong Kong (13.3)	Japan (23.9)
6	Republic of Korea (2.4)	Samoa (21.4)	India (8.0)	Philippines (23.9)
7	Myanmar (1.2)	New Caledonia (20.7)	Bangladesh (3.9)	New Caledonia (22.4)
8	Vietnam (0.8)	Vanuatu (18.3)	Northern Mariana Islands (1.5)	Samoa (19.2)
9	Hong Kong (0.4)	Tonga (18.1)	Australia (0.8)	Tonga (17.4)
10	Pakistan (0.3)	Cook Islands (10.5)	New Caledonia (0.7)	Bangladesh (5.9)

Note: Small islands are highlighted in yellow.

Source: http://www.ipcc.ch/pdf/assessment-report/ar5/wg2/WGIIAR5-Chap29_FINAL.pdf

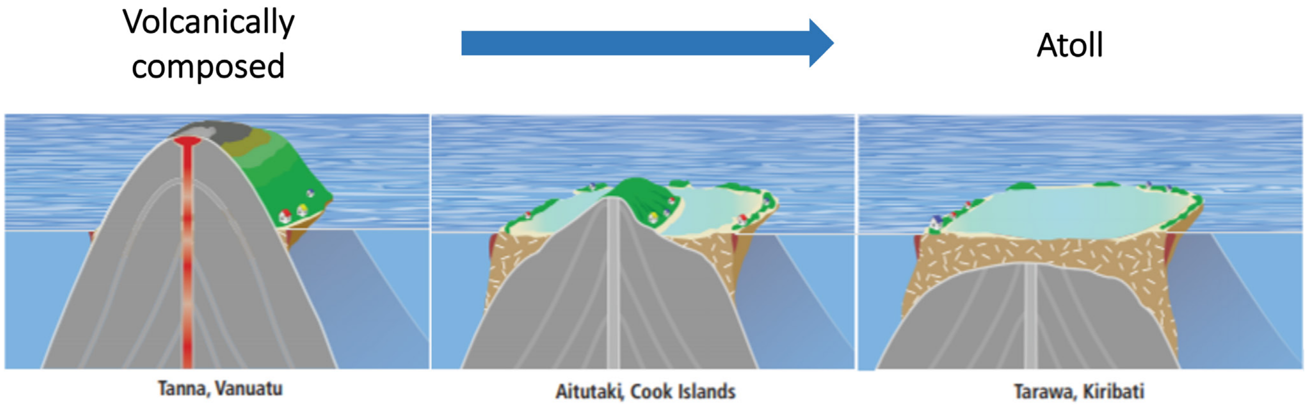
Climate change models and what they project for future climate in the South Pacific.
PART 2: UNCERTAINTIES AND KNOWLEDGE GAPS?

Uncertainties and knowledge gaps



Uncertainties and knowledge gaps: island typology and size

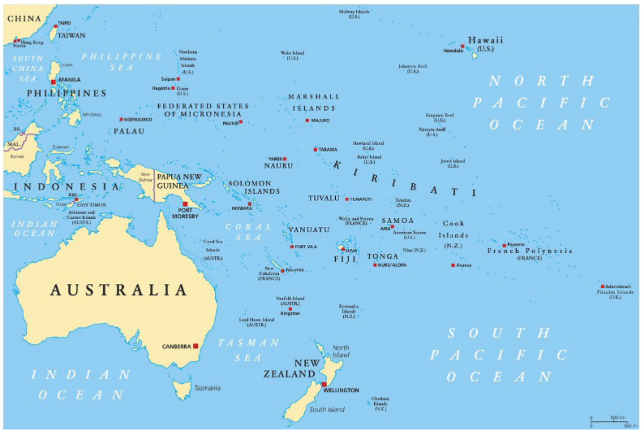
Geographically, the SWPs massive spatial extent, unfavourable shoreline to landmass ratio and combination of low-lying coral atolls, reef and volcanically composed islands amplify the complexity of modelling future climate on these regions.



Adapted from source: http://www.ipcc.ch/pdf/assessment-report/ar5/wg2/WGIIAR5-Chap29_FINAL.pdf

Small island topography is often too detailed for global or even regional climate models to resolve. For example, the typical GCM grid cell size is 50-100 km^2, and the total land area of Nauru and Tuvalu is 21 km^2 and 26 km^2, respectively. Even for South Pacific nations with larger total land area, this is usually composed of many small islands and granularity in model outputs prevents any localised projections to be made.

Uncertainties and knowledge gaps: observational data



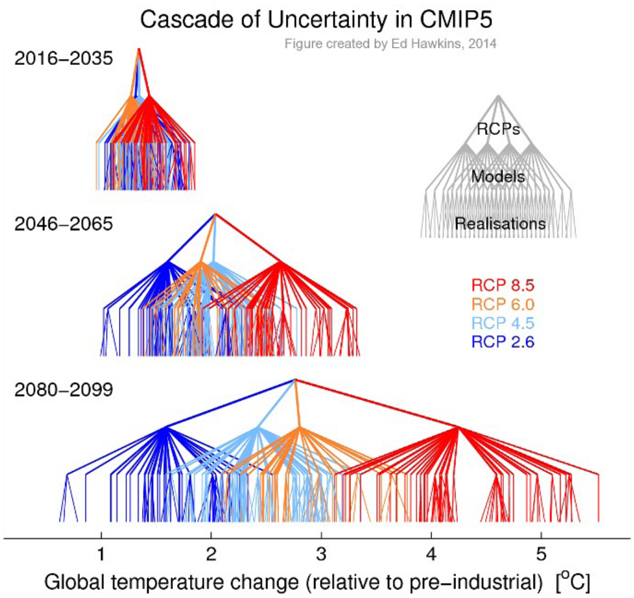
Source: Getty Images

Lack of access and/or availability and/or Inconsistent collection of observed hydrometeorological and coastal data are a well-recognised constraint.

Local meteorological station data may be absent or of poor quality (e.g. missing data, short record length etc.), particularly in island peripheries.

To deal with this, adaptation strategies are required that increase and improve monitoring of hydroclimatic conditions (and associated data collection) and utilise unconventional types of data (e.g. remote sensing data, traditional knowledge) and that enable decision making under uncertainty

Uncertainties and knowledge gaps: climate modelling



Lack of reliable observational data and an inability to successfully model the exceptionally complex climate system increases model uncertainty.

While it is well known that some GCMs perform better than others for certain climate variables, seasons and regions, information as to which GCMs perform poorly (or well) for the South Pacific region remains a fundamental knowledge gap.

No comprehensive assessment or comparison of the various downscaling approaches exist for the South Pacific.

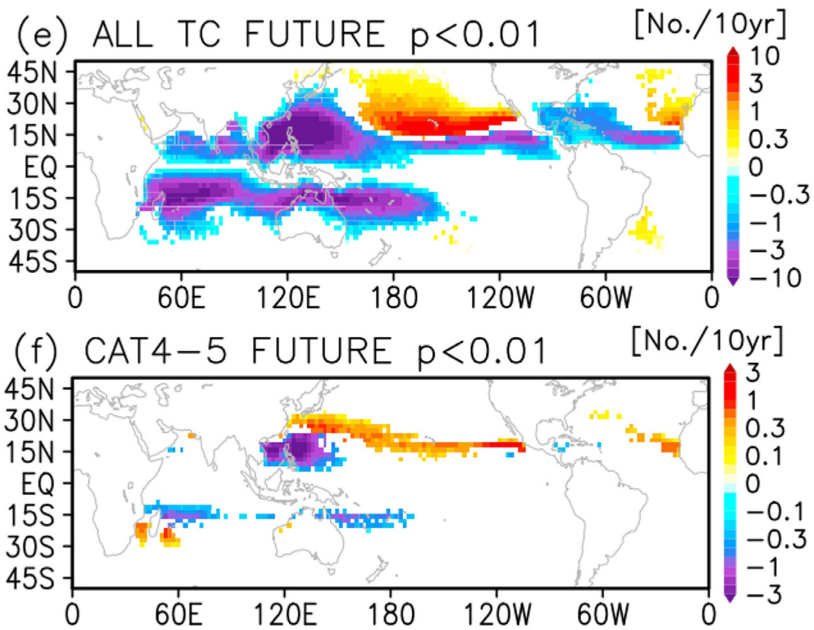
Lack of consistent use of climate change scenarios does not allow for comparison of impact assessment across the South Pacific region.

Uncertainties and knowledge gaps: climate change and variability

The distinction between observed impacts of climate variability and the observed or projected impact of climate change is often unclear. Key drivers of climate variability and change in the South Pacific include variations in air and ocean temperatures, ocean chemistry, rainfall, wind strength and direction, sea levels and wave climate and extremes such as tropical cyclones, drought and storm swell events. All have different impacts depending on their magnitude, frequency and temporal and spatial extent of the event.

There is low agreement on how large scale climate drivers, such as ENSO, will be affected by climate change. This is particularly important for the South Pacific as it will limit the capacity to predict changes to the position of the South Pacific Convergence Zone (SPCZ), and the impact that this will have on seasonal/interannual rainfall, droughts, wave climate and cyclogenesis. It is crucial to conduct a rigorous assessment of the drivers and impacts of existing (i.e. natural) climate variability and to put projected anthropogenic climate change impacts in context with respect to the risks associated with existing climatic variability.

Uncertainties and knowledge gaps: extreme events



A recent review on the topic of tropical cyclone formation and climate change, published since the production of the IPCC AR5, highlights that there is still little agreement between different climate models on how regional cyclogenesis will be affected by climate change (Walsh et al. 2016).

Climate change adaptation options

Climate change adaptation

The Pacific has been identified as one of the World's most at risk regions for climate change, so adapting to climate change requires the building of resilience.

Effective climate change adaptation must be informed by a sound understanding of the climate risks and vulnerabilities.

Climate Risk is a function of the likelihood and severity of climate impacts.

Vulnerability is a function of Climate Risk and Adaptive Capacity.

The aim of climate change adaptation is to build resilience against the impacts of climate variability and change by increasing Adaptive Capacity so as to reduce Vulnerability.

Assessing climate risks

Assessing climate related vulnerabilities

Table 2: Matrix to determine level of risk associated with each climate-related hazard.

		Severity of impacts			
		None/Trivial	Medium	Serious	Disaster
Likelihood of impacts	Almost None (<25% chance)	Low	Low	Medium	Medium
	Unlikely (25-50% chance)	Low	Low	Medium	High
	Likely (50-75% chance)	Low	Medium	High	Very High
	Very Likely (75-90% chance)	Low	Medium	High	Very High
	Almost Certain (90-100% chance)	Medium	High	Very High	Very High

Table 3: Possible climate-related risk categories and recommended actions (from the World Bank guidelines on Climate and Disaster Risk Screening (http://climatescreeningtools.worldbank.org/)).

Risk category	Recommended actions
Insufficient understanding	Gather more information to improve your understanding of climate and geophysical hazards and their relationship to the project.
Low Risk	If confident that climate and geophysical hazards pose Low Risk to the project, continue with project development. However, you are encouraged to monitor the level of climate and geophysical risks to the project as it is developed and implemented.
Medium Risk	For areas of Moderate Risk, you are encouraged to conduct additional studies, consultation, and dialogue to better understand the risk and the costs and benefits of adaptation options that could be used to mitigate it. Also consider gathering additional information to increase the level of confidence in the risk rating.
High Risk	For areas of High Risk, you are strongly encouraged to explore and implement adaptation measures to manage or reduce those risks.
Very High Risk	For areas of Very High Risk, it is essential that appropriate adaptation measures are implemented to manage or reduce climate-related risks.

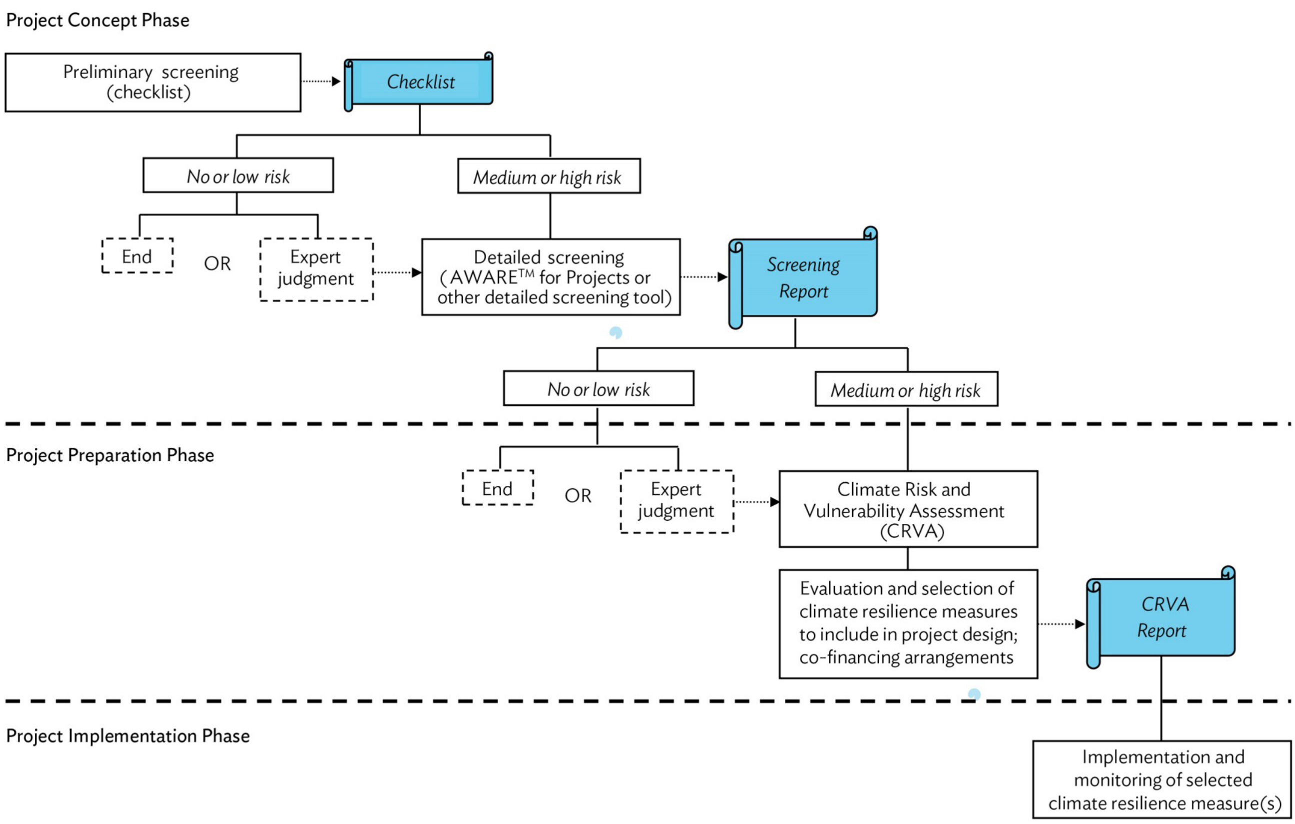
Assessing climate related vulnerabilities

Table 4: Matrix to determine climate-related vulnerability.

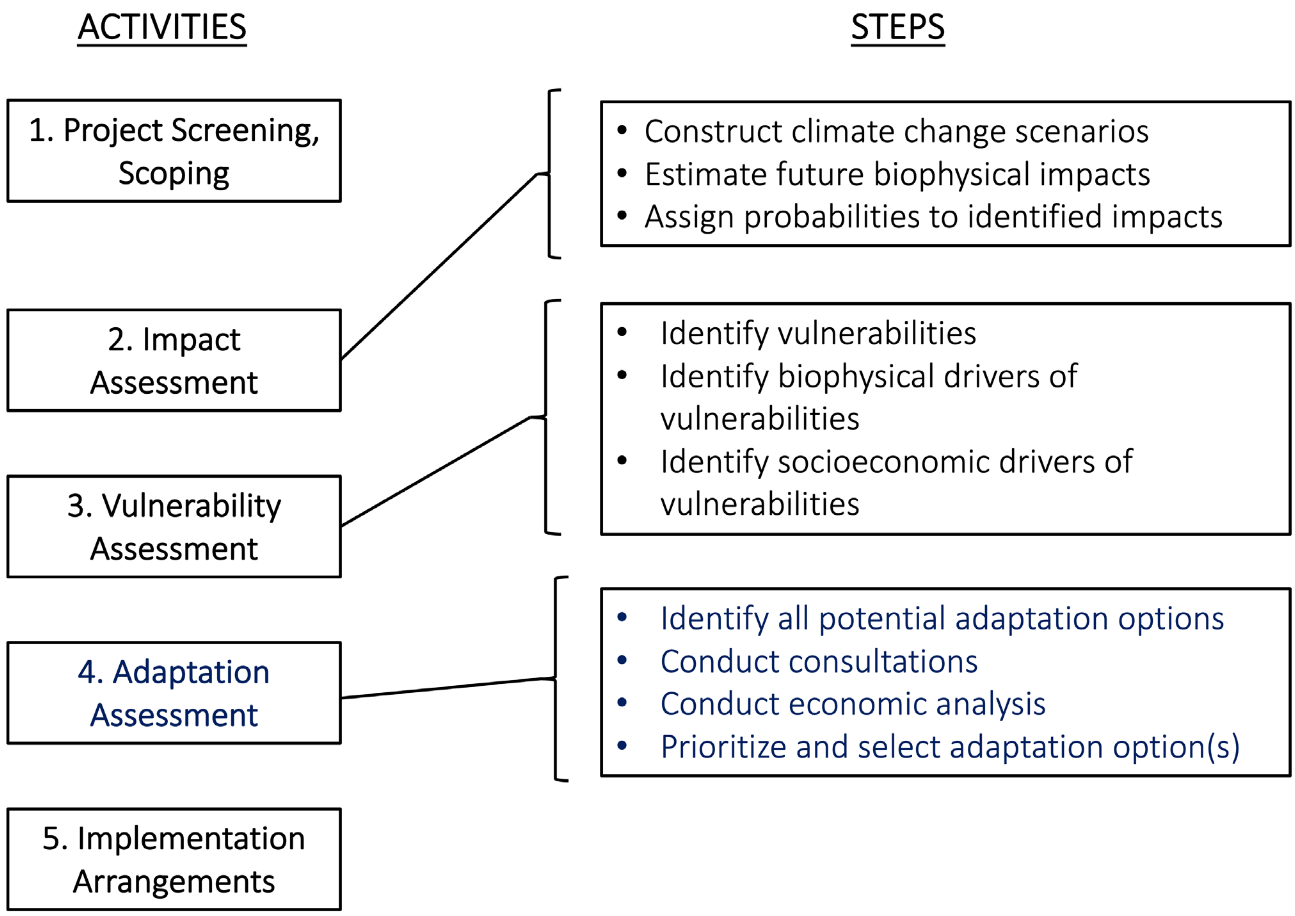
		Adaptive Capacity			
		Minimal*	Moderate#	Significant^	Outstanding+
Climate-related risk category	Insufficient understanding	n/a	n/a	n/a	n/a
	Low Risk	Low	Low	Low	Low
	Medium Risk	Medium	Medium	Low	Low
	High Risk	High	High	Medium	Medium
	Very High Risk	Extreme	Extreme	High	High

* Minimal adaptive capacity means no formalized capacity and that climate hazard awareness and analytical abilities are very limited.
# Moderate adaptive capacity means climate hazard assessment is not a normal part of project planning, development or implementation (or a normal part of budget planning).
^ Significant adaptive capacity means climate hazard awareness and the skills and resources needed to analyze hazard risks are significant considerations in budgets as well as project planning, development and implementation.
+ Outstanding adaptive capacity means climate hazard awareness and analytical abilities related to hazards have been fully mainstreamed in project planning, development and implementation.

ADB climate risk management framework

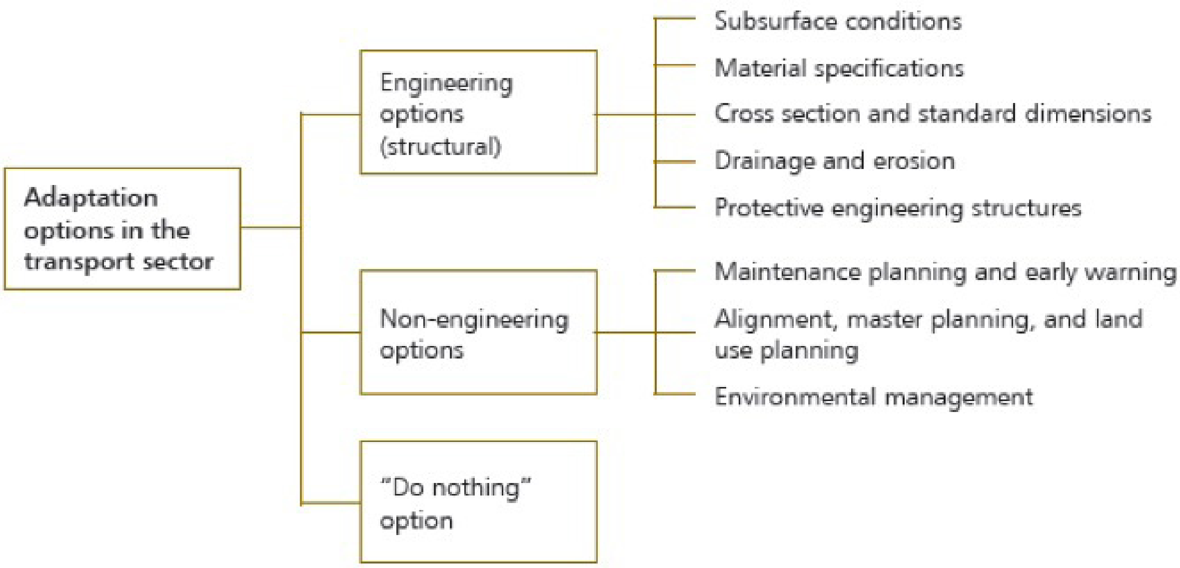


Climate risk and vulnerability assessment



Adaptation

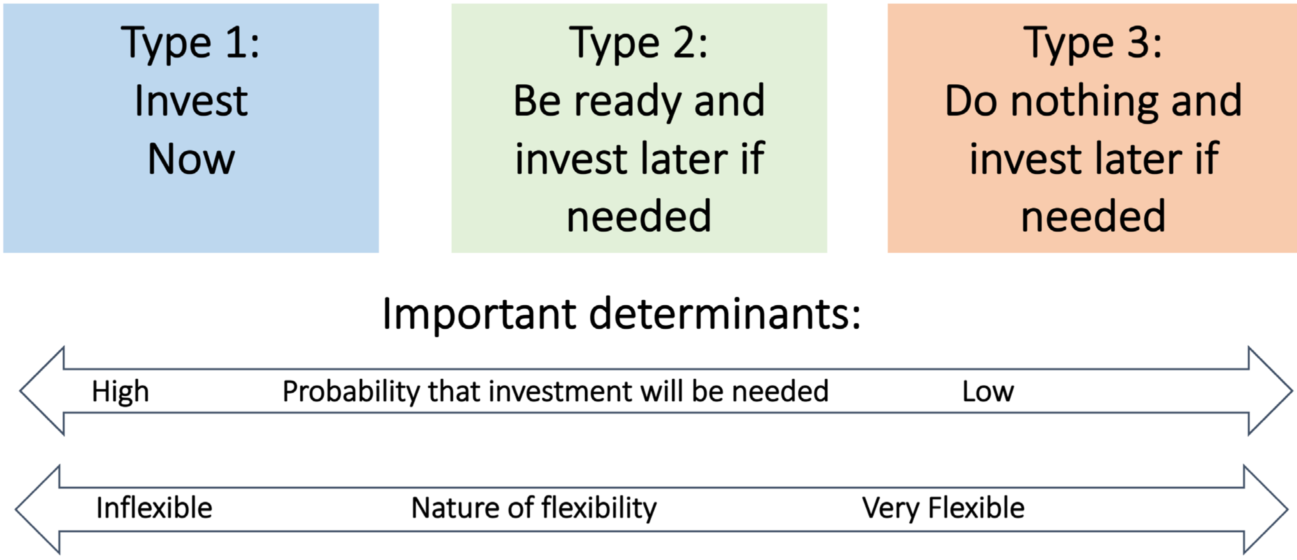
Figure 1 Nature of Adaptation Options in the Transport Sector



Source: ADB.

Adaptation

Not all adaptation interventions must be made up front:

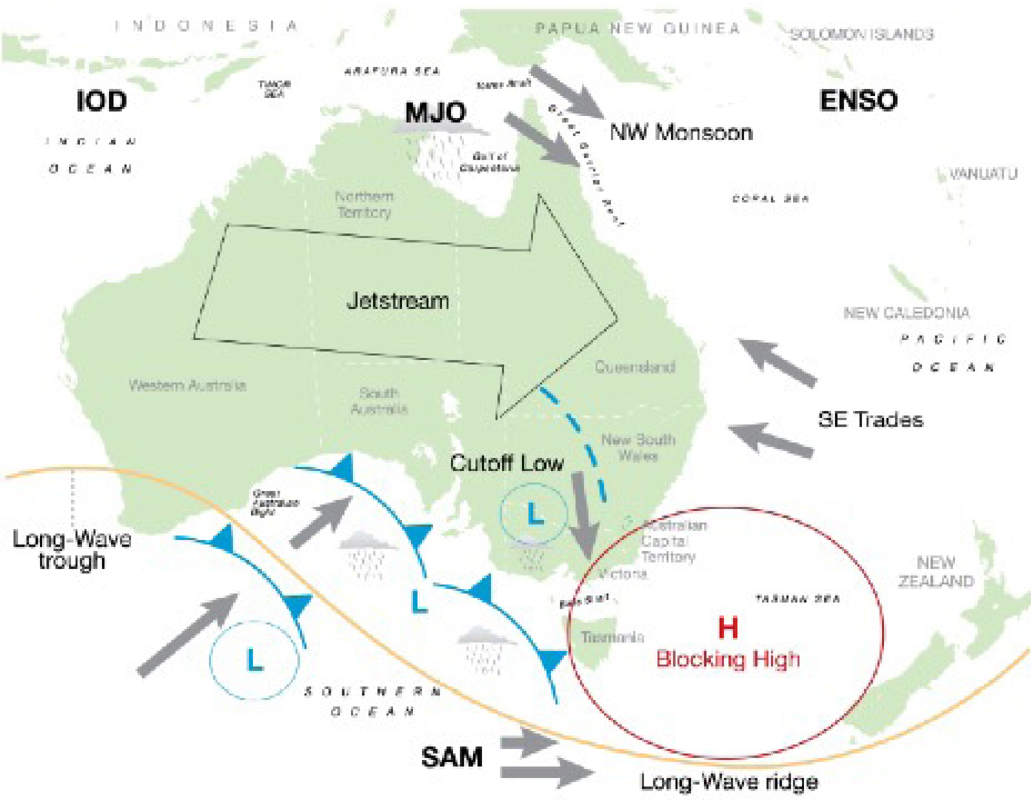


It is not always necessary to act now; although it is important to assess now!

Climate change adaptation – Bridging the gap between end user needs and climate science capability

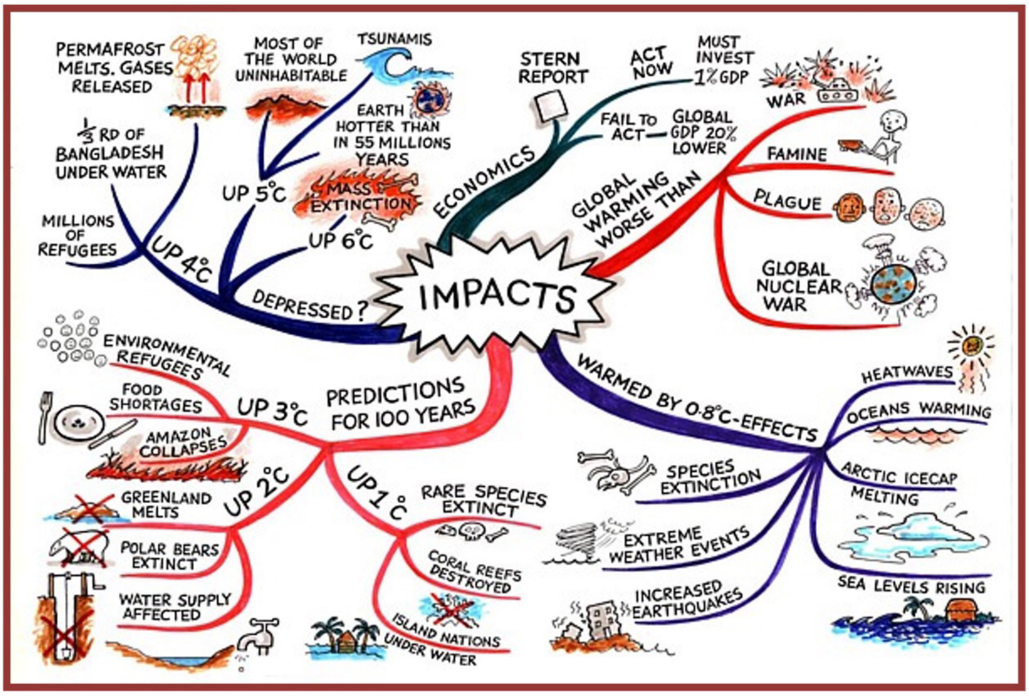
Uncertainty in current understanding

We know a lot more now than we did 20 years ago but still many unknowns or things we don't fully understand.



Source: Risbey et al. (2009)

Uncertainty of future impacts

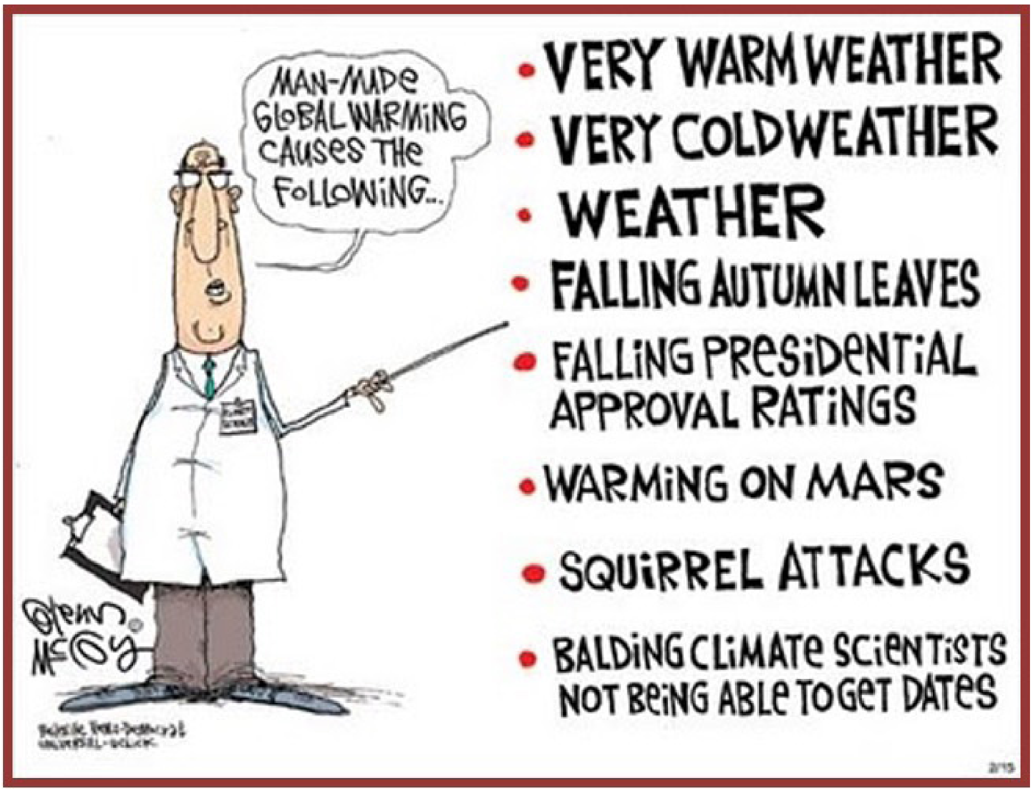


Source: http://www.mindmapart.com/climate-impacts-mind-map-jane-genovese/

Despite uncertainty decisions still have to be made… So how should we respond?

Uncertainties inherent

- Impacts
- Terminology
- Forecasts & projections



Source: http://www.itulip.com/forums/showthread.php/17259-Man-Made-Global-Warming-Climate-Change-Global-Climate-Disruption-Causes...?p=177991

'The gap'

- There is a gap between what climate science can currently provide and what end users of that information require in order to make robust adaptation decisions
  - » between different science disciplines
  - » between science providers and science users
  - » across sectors (e.g. agriculture-v-mining)
- What can climate science currently provide and what is feasible for the future?
- How do you go about making this science info useful for hydrology and water resources management?

Reasons for the gap

Uncertainty – in climate science and about future in general

- Seems also to be more about uncertainty about what to do about uncertainty (discussed later)

Challenges of interdisciplinary research

- peer reviewed literature, while scientifically sound, becoming increasingly irrelevant to end-users
  - » minimal time/incentive for end-users to be involved in peer-review publication process (e.g. as editors, reviewers, contributors etc.)
  - » journal papers (and competitive grant funding) focused on "new science" rather than practicalities, implementation, participatory research, extension, capacity building etc.
- (Mis)understanding, (mis)use of key terminology
  - » weather versus climate
  - » precision versus accuracy (e.g. downscaled info not necessarily better)
  - » prediction, forecast, and projection
  - » uncertainty, likelihood, risk and vulnerability
  - » best estimate scenario, median scenario, plausible scenario
- Lack of consensus on core terminology
- E.g. resilience…17 definitions and counting (Miller et al. 2010)!!
- Hard to get there if we can't define the target!

Communication (or lack of)

- Also, sometimes the science and caveats are lost in the process

Non-climatic influences

- gap not just between science and decision makers
- for anything to happen, seems decision has to be socially, politically, economically & environmentally acceptable (e.g. MDB plan, Tillegra Dam etc)

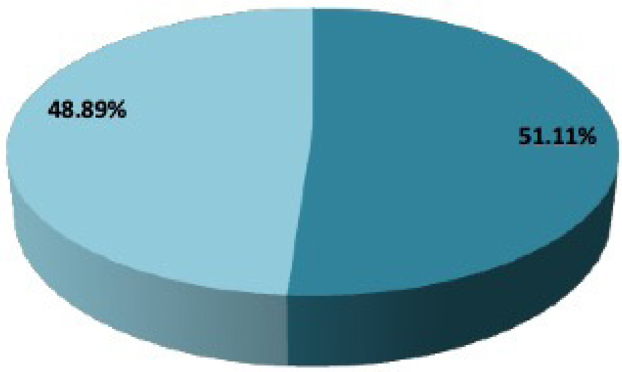
Expectations from the climate science also differ between producers and users of that information

- Results from a 2012 NCCARF Synthesis and Integrative Research Project (Verdon-Kidd, Kiem, Austin)
  - » Bridging the gap between end user needs and climate science capability
  - » http://www.nccarf.edu.au/publications/decision-making-under-uncertainty

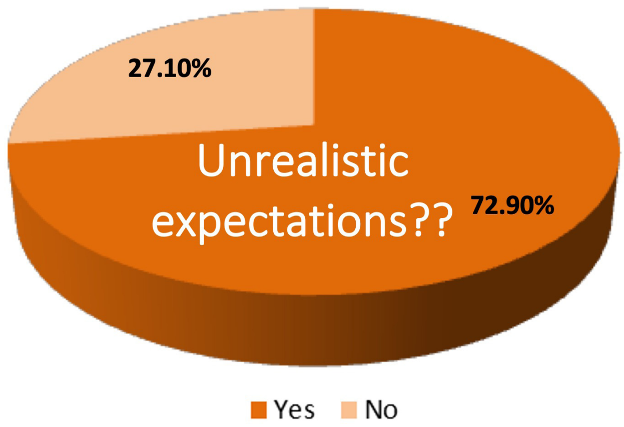
Provider and end-user views on advances in climate information

Providers believe advances in next 5-10 years will be:

- Resolution
- Downscaling
- Understanding
- But **NOT** reduced uncertainty

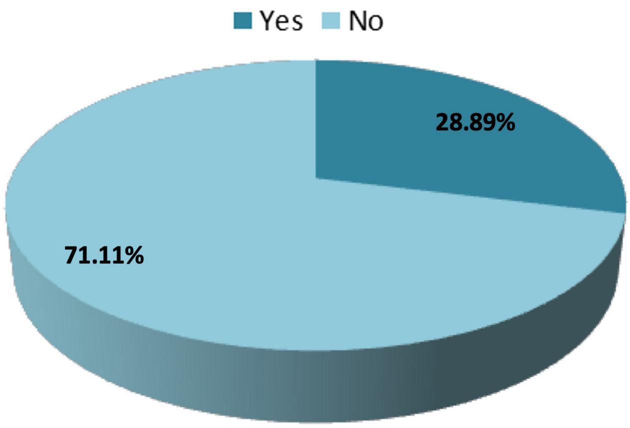


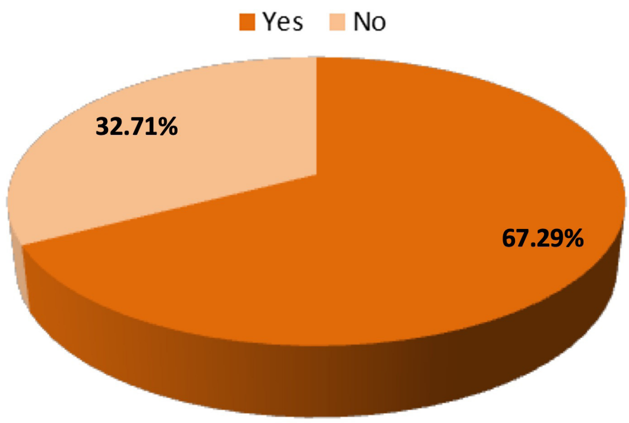
Provider *"Will advances in climate modelling in the next five to ten years reduce uncertainty?"*



End-user *"Do you expect uncertainties in climate projections to reduce in the next five to ten years?"*

Does reduced uncertainty equal better decisions and adaptation?





Provider and **end-user** opinions on whether it is necessary to reduce current uncertainty to enable effective decisions and adaptation to climate change.

Challenges and knowledge gaps to address in order to bridge the gap

Number of votes	Key issue to arise from workshop
12	The need for **'knowledge broker'** to fill the space between developers of climate science information application of that information by end users
8	The requirement for **dialogue** between providers and end users to bridge the gap effectively. This is an extremely complex, time-consuming and resource intensive task which has not been factored into any plans or strategies
7	Greater consideration of **baseline risk** and accounting for **non-stationarity** when developing climate projections
7	Improved **packaging** of climate projections (e.g. climate futures)
6	Improved understanding of **natural variability** drivers and impacts and how that might change in future
6	More focus on **tools and methods** to integrate between projections and decision making.
6	Continue open and frank **dialogue** between scientists and end users in all climate projects
5	Better **communication** of climate science - not just better PowerPoint slides or glossy brochures, but **delivery of practical information** to end users and feedback to climate scientists regarding the end user needs.
5	To better understand how decisions are made
4	Improved **capacity to deal with wide diversity of end-users** (each of which need a different approach and the science community has no capacity to deliver this).
3	More focus ($$) on **attribution of current/recent/historical extremes**
2	Focus on **plausible scenarios** rather than more precise information
2	Black swans...what to do? Ignore and hope for best?
2	Accept the gap is real and unrealistic to expect that to close....what now??
1	More focus ($$) on downscaling
1	More focus($$) on next round of GCM outputs (e.g. CMIP6)
1	Identification of plausible regional adaptation options
0	More focus($$) on GCM/RCM model selection/evaluation
0	More focus($$) on emission scenarios
0	Insights/quantification of relative importance of different sorts of uncertainties (including non-climatic)

The end-users and decisions makers also learnt a lot and in collaboration with the scientists agreed on a wish-list…

More $$$ for modelling or downscaling not on the wish-list

This is at odds with where the research funding is being directed

RED = communication

BLUE = tools

GREEN = natural variability/science

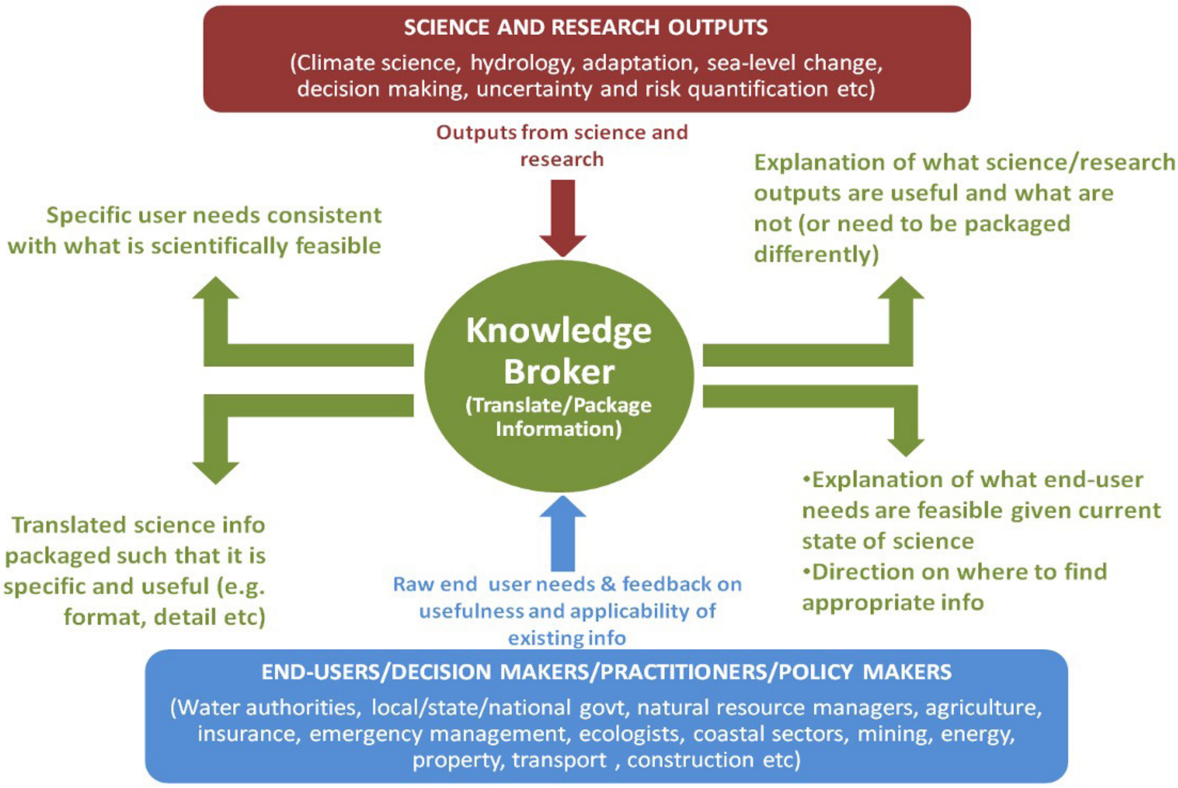
Challenges and knowledge gaps to address in order to bridge the gap

1. Communication/outreach/extension/implementation of science
   - » Dialogue
   - » Practically useful information
   - » Stronger interaction between producers and end-users of climate knowledge
   - » Co-production of knowledge
2. Baseline (current) risk/natural variability/non-stationarity and associated uncertainty…….and how to deal with it
3. Tools and methods to integrate future projections (climate scenarios) with #2 and with decision making that also must consider non-climatic influences

1. Communication, outreach, extension, implementation of science

Need for a 'knowledge broker' (or 'boundary workers/organisation')

- know and communicate who are the end-users and their roles
- understand and communicate what is required by end-users
- know and communicate what is available from climate science (including strengths and limitations and uncertainties)
  - » Tendency to ignore or downplay science limits/uncertainty as opposed to accept, understand and deal with
- synthesise scientific literature and provide regular (annual?) updates
- ensure consistency in terminology
- provide a co-ordinated mechanism for accessing climate datasets
- translate uncertainty into risk (if possible) and facilitate education and discussions between end-users and science providers
- strengthen interactions between climate science producers, impact scientists, adaptation researchers and end-users
  - » Address weaknesses by building teams that contain an appropriate mixture of research and communication/outreach skills
  - » 'Co-production of knowledge' seems to be the buzz word



Communication and packaging of climate information via a 'knowledge broker'

Focus group discussions with key stakeholders on:

- key characteristics of Knowledge Broker
- who and what the Knowledge Broker should be
- what communication methods could or should be used
- how success of Knowledge Broker is defined/measured

Kiem et al (2014) A 'knowledge broker' to bridge the gap between end-user needs and information from climate science: an Australian perspective. Climate Risk Management, May 2014.

Climate change adaptation – Decision making under uncertainty

Challenges #2 and #3

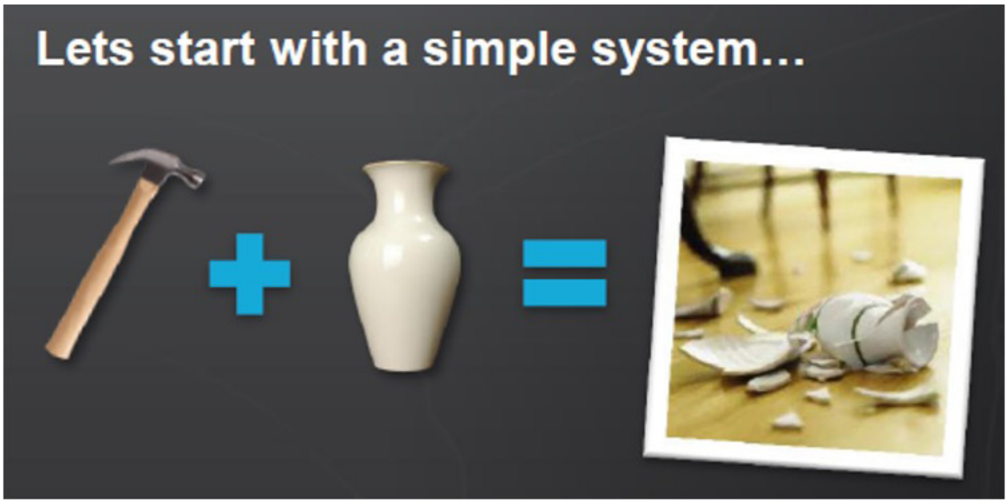
2. Baseline (current) risk/natural variability/non-stationarity and **associated uncertainty**…….and how to deal with it.

3. Tools and methods to integrate future projections (climate scenarios) with #2 and with decision making that also must consider non-climatic influences….**decision making under uncertainty (as opposed to wait and see…)**

Scientific uncertainty

Science is very rarely certain…

So if there is a lot of uncertainty associated with climate science does that mean it is useless?



Question A: what will happen to the vase?

Prediction A: Hit a porcelain vase with a hammer, with sufficient force, and almost certainly it will break

Question B: where will the pieces land?

Prediction B: On the floor… generally off one side of the table… but no way of knowing exactly where for each piece.

High uncertainty associated with B does not disprove A or mean A is wrong

High uncertainty associated with B does not mean we can't do anything to reduce the damage (e.g. don't hit the vase, strengthen the vase, don't put vases near hammers etc…)

High uncertainty about CC does not mean CC won't happen or that we can't do anything to reduce potential risks/vulnerability and increase resilience

Uncertainty does not mean we don't know anything

Uncertainty does not mean there is nothing we can do until we become more certain!!

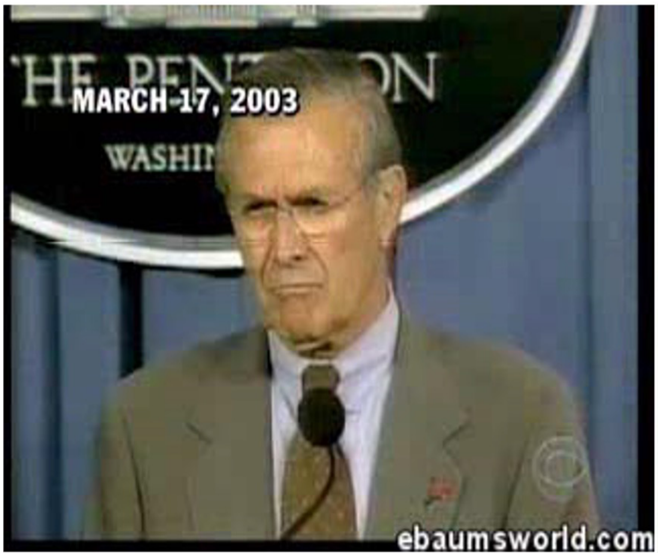
Types of uncertainty

"There are known knowns; there are things we know we know."

"We also know there are known unknowns; that is to say we know there are some things we do not know."

"We also know there are partly-known unknowns; that is to say we think we know there are some things we do not know."

"But there are also unknown unknowns – the ones we don't know we don't know."



Donald Rumsfeld - US Defence Secretary

Prof George Kuczera (Uni. Newcastle)

"Known unknowns": Quantitative uncertainty

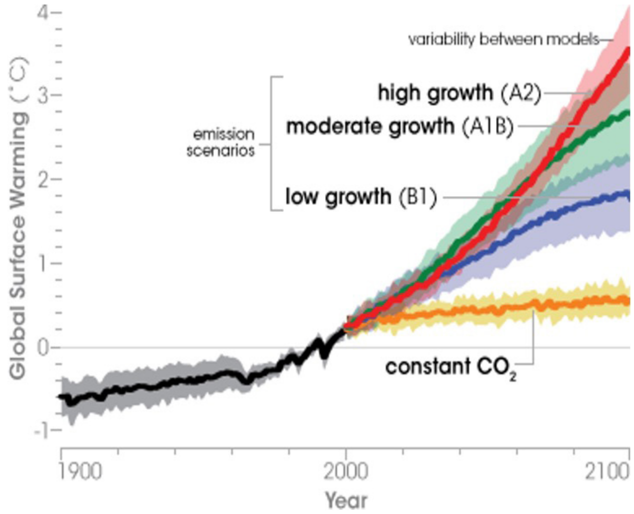
- All outcomes known
- Probabilities can be meaningfully inferred from observations and prior knowledge
- Probability theory can deal with:
- Intrinsic (natural, inherent)
- Epistemic (limited information -> uncertainty about probabilities)

"Partly-known unknowns": Scenario uncertainty

- Scenarios represent assumptions on which the whole analysis is conditioned
- Many, but not all, plausible outcomes known
- Few, if any, observations to validate assumptions
- Greater reliance on judgment

"Unknown unknowns": Total ignorance

Climate change – a partly-known unknown



Future climate change uncertainty

- GCM model uncertainty
- Emission scenario uncertainty
- Spatial resolution
- Downscaling uncertainty
- Bias correction uncertainty

Difficult to meaningfully assign probabilities (Dessai et al, 2009)

Dessai et al (2009), Climate prediction: a limit to adaptation? Chapter 5 in, Living with Climate Change: Are there Limits to Adaptation? W. N. Adger, I. Lorenzoni and K. O'Brien (eds.), Cambridge University Press, Cambridge, U.K., pp. 64-78.

"CLIMATE MODELS CANNOT CAPTURE ALL THE FACTORS THAT AFFECT NATURAL SYSTEMS"

Water levels in the Mekong Basin could rise or fall with climate change — models cannot say which.

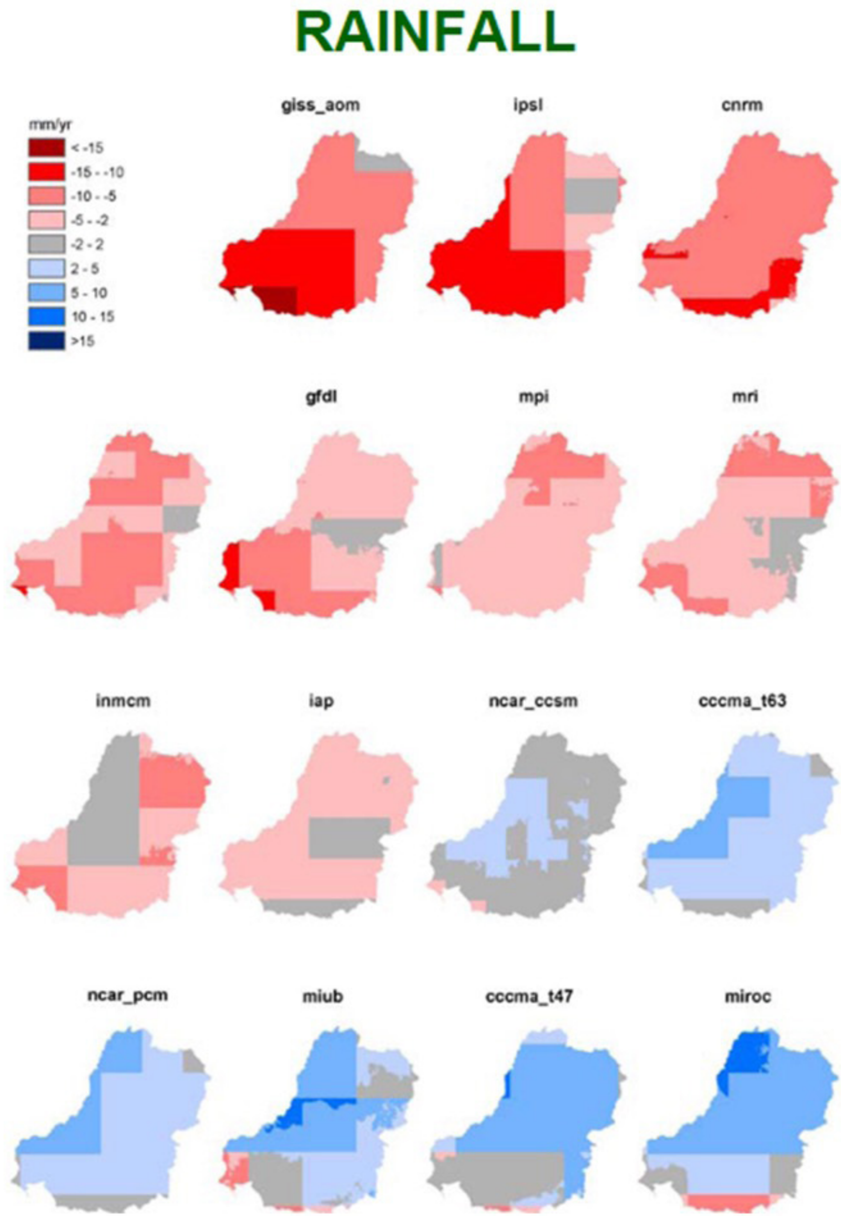
Climate models at their limit?

Estimates of climate-change impacts will get less, rather than more, certain. But this should not excuse inaction, say **Mark Maslin** and **Patrick Austin**.

UK Met Office Had CM3 forecast input into hydrology models for the Mekong:

- Changes in annual discharge : -5.4% to 4.5%
- Changes in monthly discharge -16% to 55%

Similar results for Murray-Darling Basin (MDB) in Aust….



Percentage change in future mean annual rainfall (~2030 relative to ~1990) across the Murray-Darling Basin as projected by 15 different climate models [CSIRO, 2008].

No consensus as to what will happen to MDB rainfall in the future – based on this information should plan be for a wetter or drier future?

So how do you make decisions or do climate change adaptation under uncertainty????

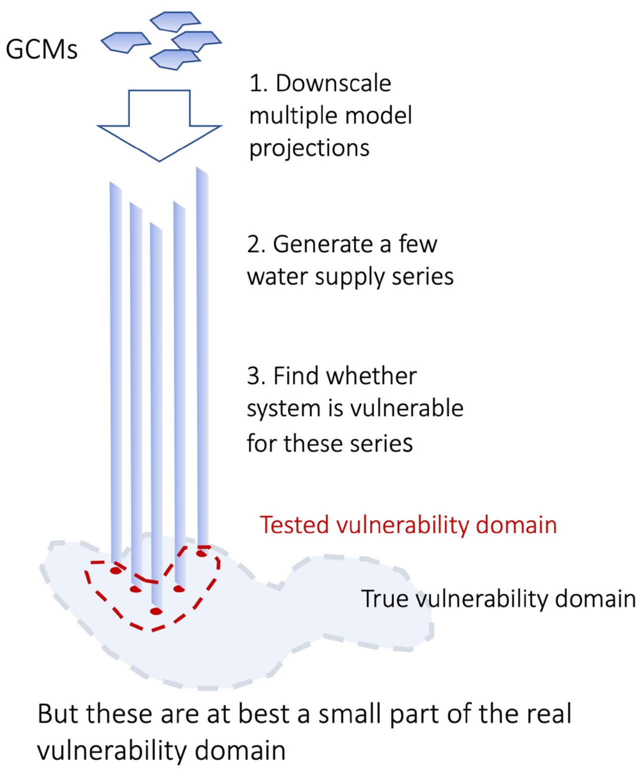
Water resource management example…

Methods for getting from climate science to information that is useful for climate change adaptation

Checklist

- Natural variability
- Pre-instrumental variability/change
- Non-stationarity
- Multiple plausible futures (e.g. GCM scenarios, stochastic, analog)
- Uncertainty quantification
- Can actually deal with uncertainty
- Relevant/useful for hydrology (temporal and spatial resolution, format, variables etc)
- Adaptive

GCM/downscaling based impact assessment then decide (predict-then-plan)



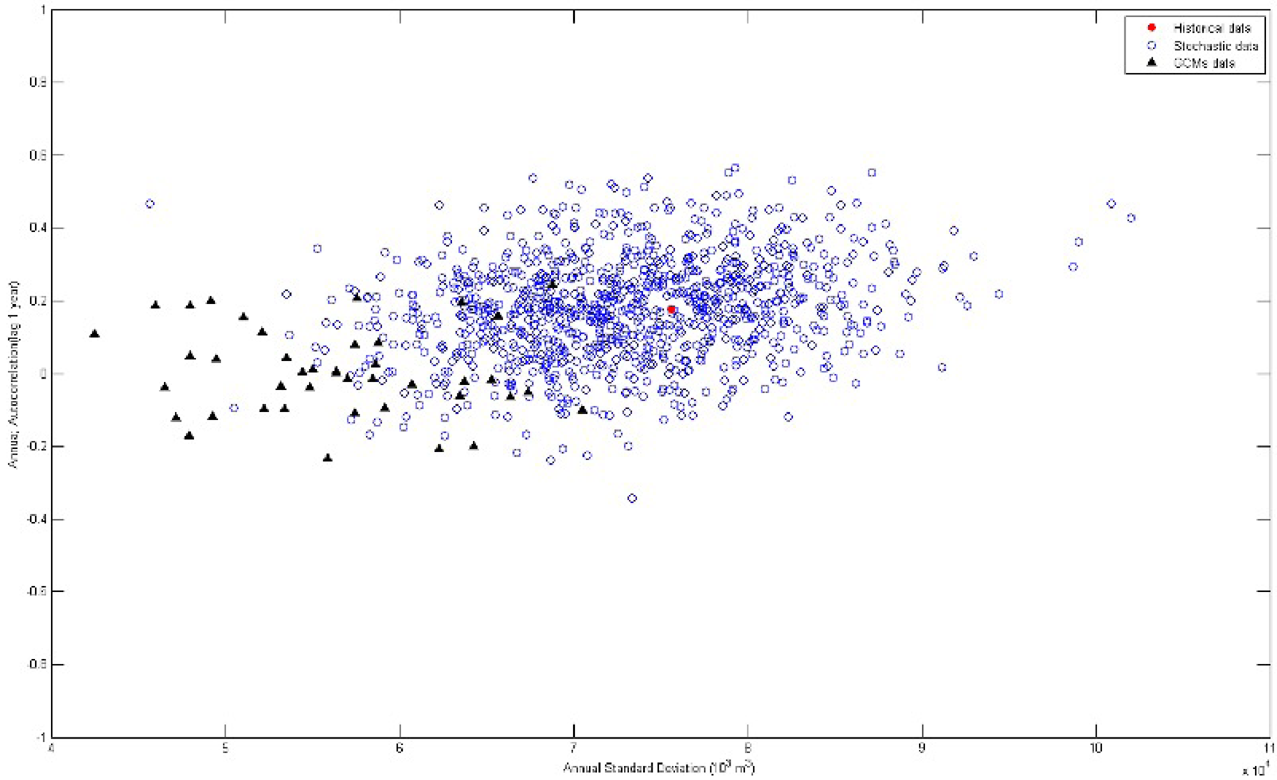
Variety of "downscaling" approaches available – each with pros and cons and all limited by strengths/ weaknesses of overlaying GCM outputs

Uncertainty actually increased via use of GCMs and downscaling

Biases and small sample sizes limit ability to identify risks

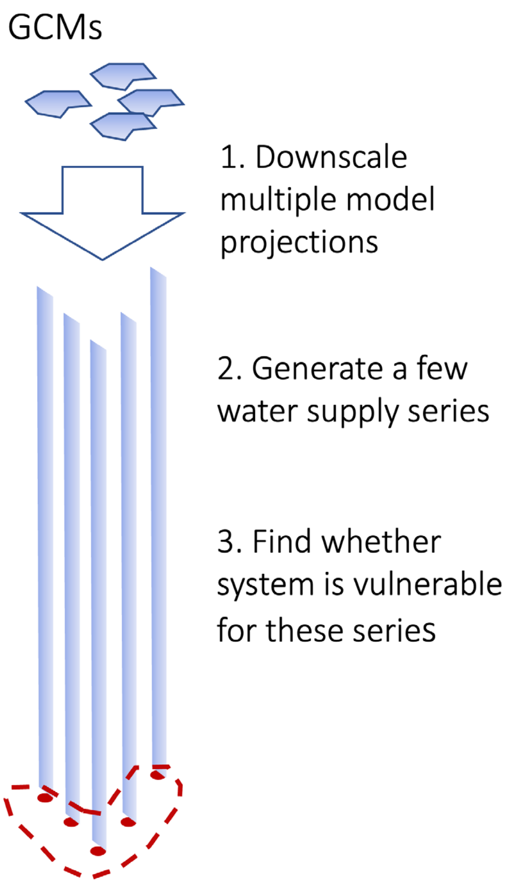
Only looking at a small portion of true vulnerability (i.e. that which can be covered by GCMs)

Realistic representation of natural variability (spatial and temporal) a particular problem – persistence, sequencing, clustering of extremes…

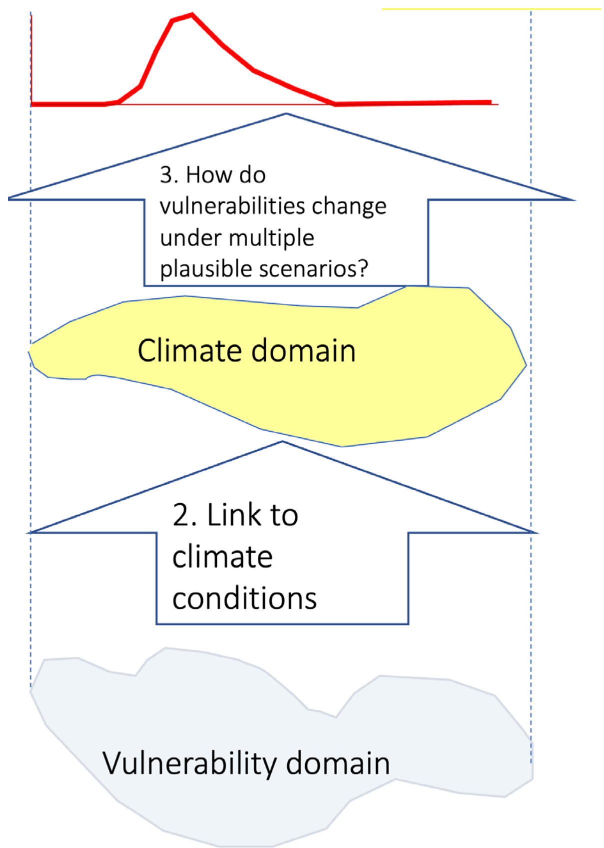


Data Source: Base climate projections downscaled by Maurer et al. (2007) Santa Clara University.

Scenario first (top-down)



Decision first (bottom-up)



1. Where/when is the system vulnerable now

'Decision scaling' or 'scenario neutral'

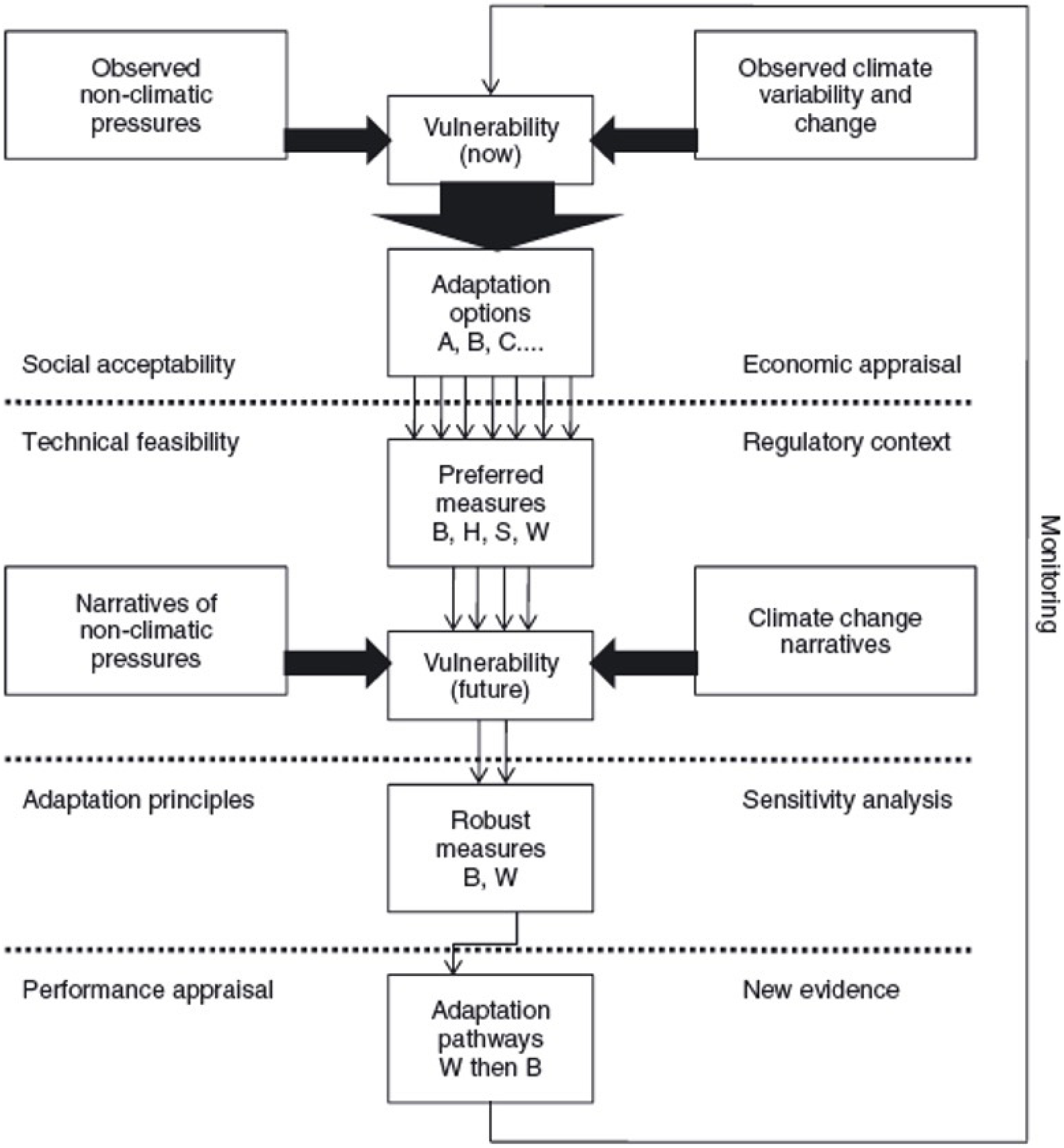


Figure 3. Conceptual framework for a scenario-neutral approach to adaptation planning.

From Wilby & Dessai (2010), Robust adaptation to climate. Change, Weather, 65, 180-185, doi: 10.1002/wea.543

Rather than try to settle arguments between climatologists, hydrologists and statisticians about the "right" way to produce scenarios or characterise uncertainty the approach is to:

- Make plans that work as well as they can for any plausible risk we can imagine
- Use the GCMs and more to inform our imagination
- Switch rules or plans if some work better in some circumstances than others
- Identify where uncertainty most reduces plan performance (or ability to decide) and investigate ways to reduce uncertainty at that specific point (rather than "everywhere all at once")
  - » i.e. focus research effort on the things that REALLY matter
  - » Another example of two-way interaction and benefit of "co-production"…..end-user driven decision scaling actually identifies (for researchers) where the critical knowledge gaps are

Some weaknesses:

- Plausibility is inherently arguable, lacks the apparent scientific credibility of “probability”
  - » Given unknown (or partly known) unknowns, assigning probability difficult anyway
  - » Make plans that work as well as they can for any plausible risk we can imagine
- Vulnerabilities that don’t exist now or cannot be imagined or foreseen now (Black Swans) may occur
  - » Thinking is that if system is robust as possible under every plausible and imagined scenario then the impact of these ‘Black Swan events’ will be covered (or at least minimised)

Working it out:

- This requires simultaneous consideration of the
  - » Damage that would be done if the scenario occurs
  - » The costs (of all types) of preventing the damage
  - » The plausibility of the scenario happening
- Also need to compare ‘action’ with plausible costs of ‘no action’

For example: change parts of the equation….

Huge damages **Low cost solution** **Very plausible** **Use solution**	**Huge damages** **Low cost solution** **Unlikely but can’t rule out** **Still use solution**	**Huge damages** **High cost solution** **Unlikely but can’t rule out** **Don’t implement now but monitor plausibility, cost and explore alternate solutions**

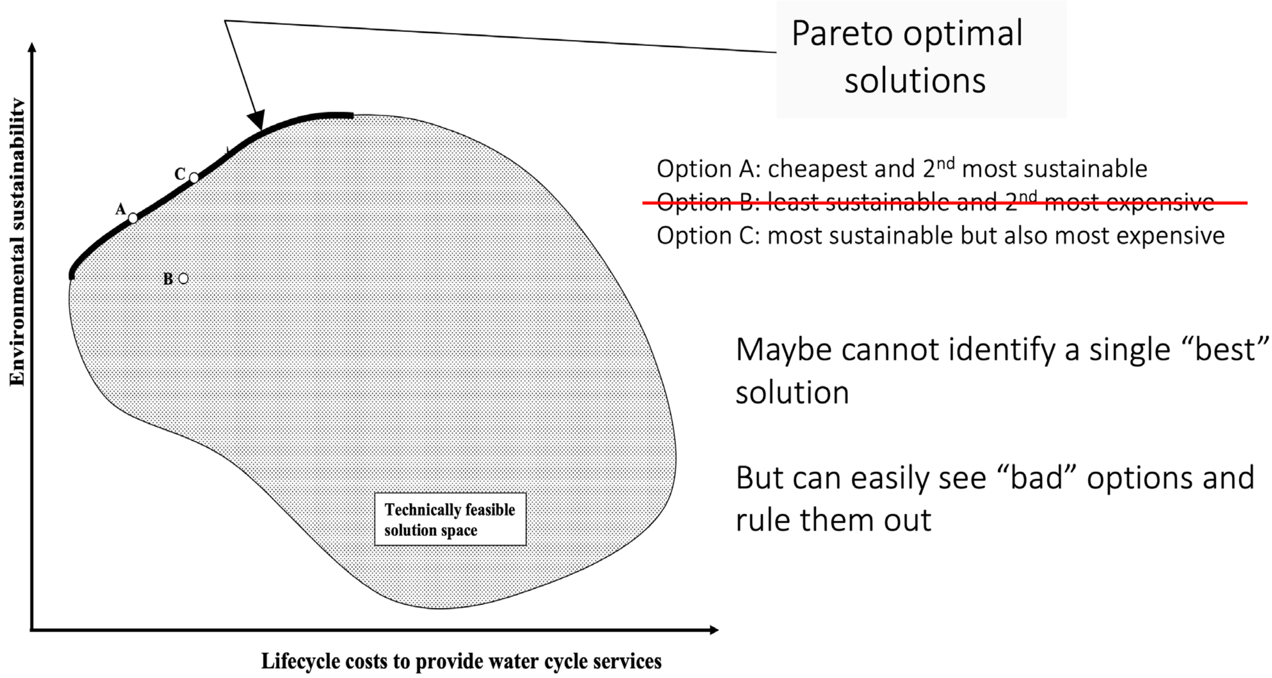
‘Robust optimisation’

- Recent work with Prof George Kuczera, Kiem and Brendan Berghout from Hunter Water
- Given many scenarios and large uncertainties:
  - » Can adopt a conservative strategy
    - optimize system for the worst-case climate change scenario
    - may be unduly “expensive” with other strategies offering similar robustness at far lower “costs”
  - » Alternatively explore trade-off between efficiency and robustness (or sensitivity to different scenarios)

Pareto Optimality

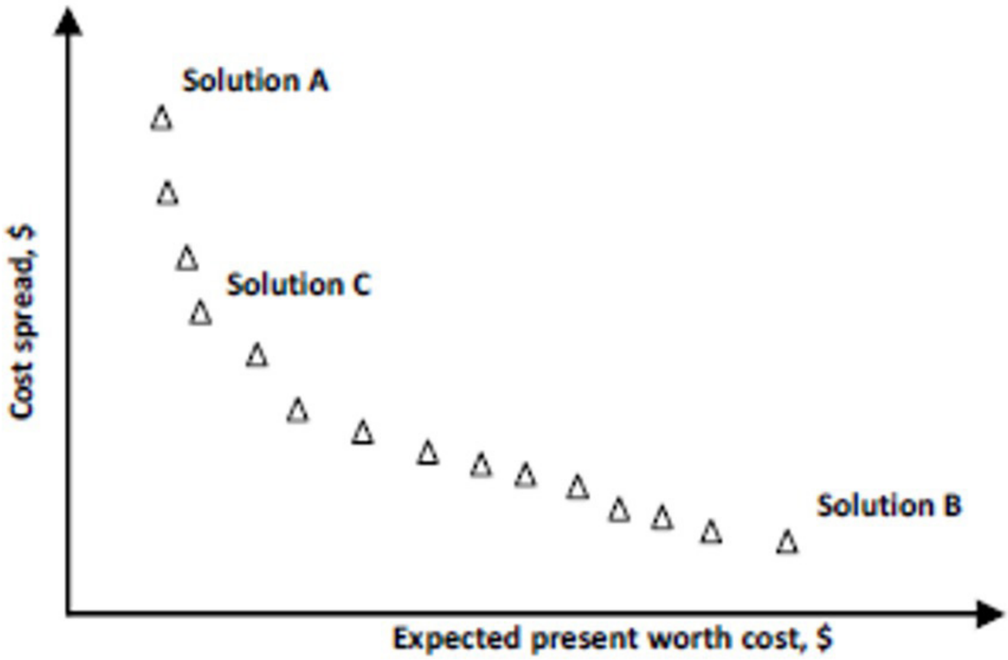
Pareto optimality example with two criteria:

- minimize F1 = lifecycle costs
- maximize F2 = environmental sustainability



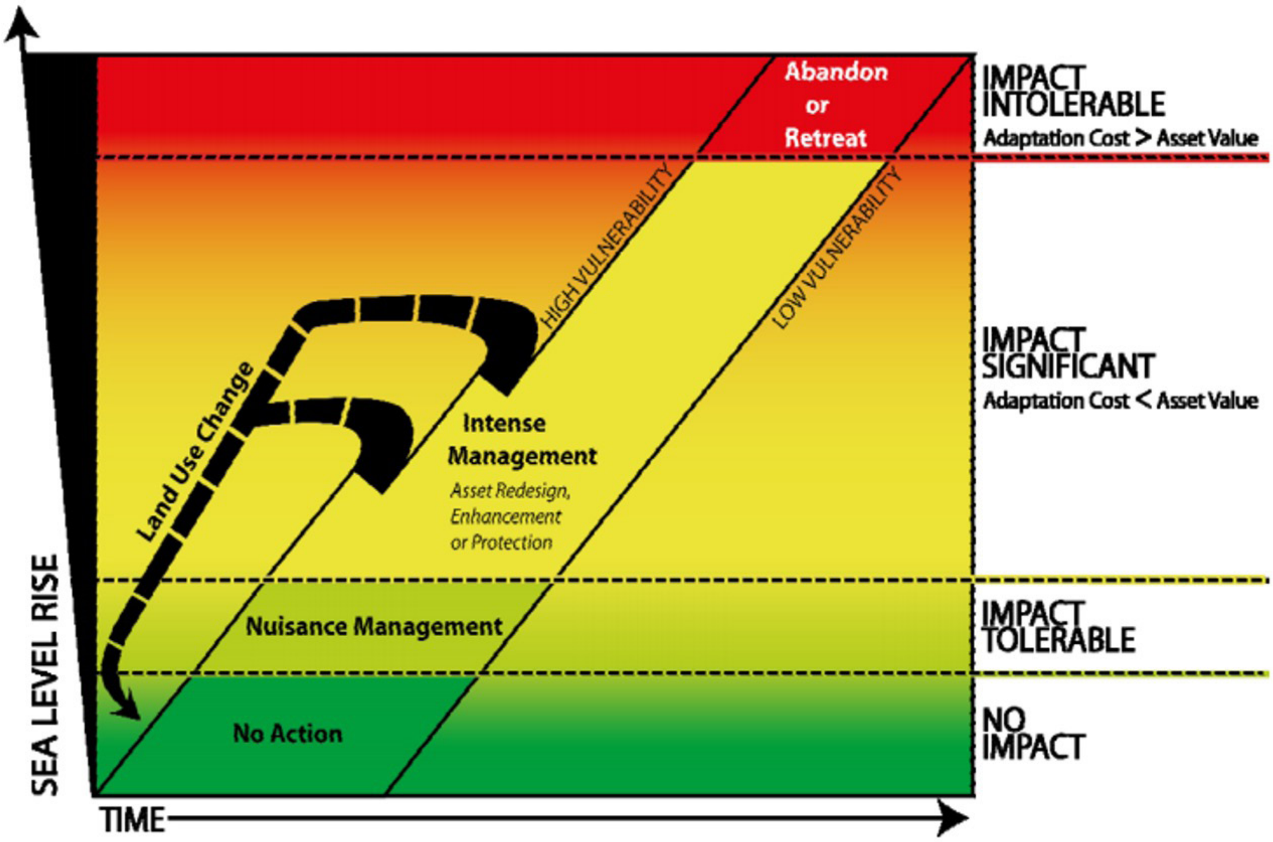
Robust assessment of adaptation options

Solution A is the most efficient (smallest expected present worth cost) but least robust (greatest cost spread), while solution B is the most robust but least efficient (i.e. highest cost). Decision makers will be interested in exploring the trade-offs between robustness and efficiency. For example, solution C may interest decision makers as it is slightly more costly than A but substantially less sensitive to differences between worst and best climate change scenarios.



Trade-off between expected cost and spread of costs across different climate change scenarios

Threshold or trigger-based approaches



- Triggers are the crucial points at which decisions must be made
- Triggers may be:
  - » physical (e.g. the number of times a tide gauge records a certain height; the average annual rainfall over the last decade)
  - » social (e.g. when the majority of the community are willing to relocate from an area)
  - » economic (e.g. the cost to upgrade a power plant or arterial road outweighs the benefit from the use of that asset)
  - » political (e.g. changes in policy).
- Trigger-based adaptation approaches are useful when operating under uncertainty because they allow for decisions to be postponed to a more appropriate time
  - » allows decisions to be deferred until the trajectory towards the emerging (or projected) threat becomes more obvious (i.e. based on observed trends) or is projected with more certainty by the models
- This provides time to improve risk data and obtain necessary funding, resources and capacity
- It also allows for country or community capacity building and limits burden, costs and inappropriate adaptation measures should projected impacts not eventuate

Methods for getting from climate science to information that is useful for climate change adaptation

Checklist

- Natural variability
- Pre-instrumental variability/change
- Non-stationarity
- Multiple plausible futures (e.g. GCM scenarios, stochastic, analog)
- Uncertainty quantification
- Can actually deal with uncertainty
- Relevant/useful for hydrology (temporal and spatial resolution, format, variables etc)
- Adaptive

GCM based impact assessment then decide	‘Decision scaling’ or ‘scenario neutral’	‘Robust optimisation’ or ‘stress testing’
✗	✓	✓
✗	✓	✓
✓	✓	✓
limited	✓	✓
limited	✓	✓
limited	✓	✓
✗ limited	✓	✓
✗ Not really	✓	✓

ASSESSMENTS

Adapting to the impacts of climate variability and change in the Pacific

Introduction

The following assessment items will test your knowledge and understanding of content and material that was presented in Course 3 – Adapting to the impacts of climate variability and change in the Pacific. As part of Course 3, you are expected to complete the following two assessment:

- **Assessment 3a** – Evaluating current and future climate of the Pacific – a case study (60 marks)
- **Assessment 3b** – Climate modelling and emission scenarios (40 marks)

It is recommended that you complete the assessment tasks **after** working through the entire material presented for Course 3.

This material presents the fundamental science regarding climate adaptation and change in the Pacific. As such, you are encouraged to use this material as a foundation and further research key aspects of interest. Simply restating information provided in course notes in the assessment items is not suggested as is likely to result in a poor mark. Instead, you should undertake some additional research to improve your knowledge and validate your claims and findings.

As part of course 3, you are expected to develop and present a PowerPoint presentation and write a report. You may find the following resources helpful.

Developing and presenting PowerPoint presentations

- https://www.youtube.com/watch?v=9EDiyqP5UCU
- https://hbr.org/2013/06/how-to-give-a-killer-presentation
- https://www.skillsyouneed.com/present/presentation-tips.html
- https://www.entrepreneur.com/article/274646

Report writing

- https://student.unsw.edu.au/report-writing-support
- https://www.griffith.edu.au/library/study/writing-your-assignment/how-to-write-a-report
- http://www.deakin.edu.au/students/studying/study-support/academic-skills/report-writing
- http://www.anu.edu.au/students/learning-development/writing-assessment/report-writing

Marks and grading

The assessment items for Course 3 total 100 marks. Table 1 outlines the grading scheme used for these assessment items.

	Marks (%)
Fail	**0 – 49**
Pass	**50 – 64**
Credit	**65 – 74**
Distinction	**75 – 84**
High Distinction	**85 - 100**

Assessment 3a – Evaluating current and future climate of the Pacific – a case study (60 marks)

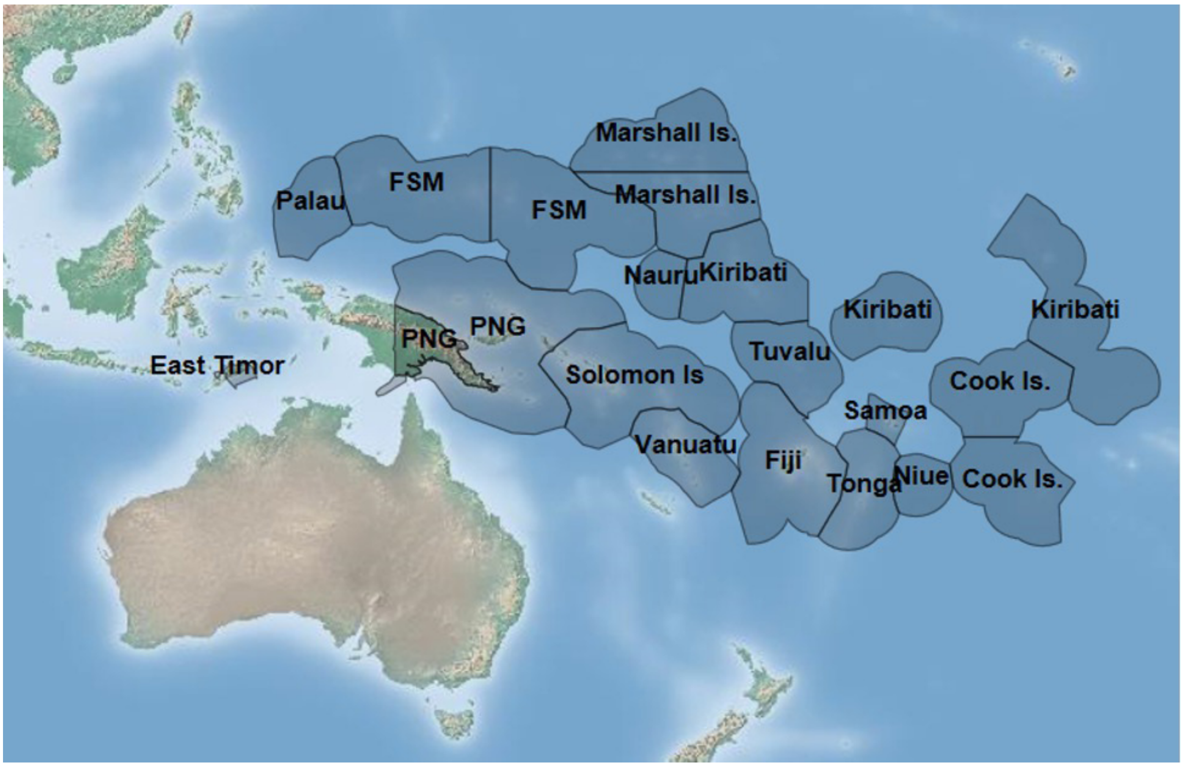
Introduction

Using the Pacific Climate Change resource developed by the Australian Bureau of Meteorology and the CSIRO, spend some time reading about the tools available here: https://www.pacificclimatefutures.net/en/. This resource enables the user to select an island nation in the Pacific and understand the projected future climate for a range of emission scenarios and time periods.

Task and Assessment Information

In order to analyse climate projections for a chosen Pacific nation, you should follow the instructions below:

1. On the Pacific Climate Change website (https://www.pacificclimatefutures.net/en/), select the 'Future climate' tab or navigate here: https://www.pacificclimatefutures.net/en/climate-futures/future-climate/.
2. Select (click) an island nation of your choice (see below)



3. Select an emissions scenario and time period (see below). Once these have been selected, the model will run (this may take some time).

4. Model projections will be summarised (note this may take a few moments to compute).

Using the information available (and the instructions above to navigate the website), you are to discuss and interpret the projected annual rainfall and temperature change (for the 43 models) in 2050 for the following scenarios: **RCP4.5** and **RCP8.5**. You are to write a **report not exceeding four pages** on the projections for your chosen island nation.

Your report should be structured in the following way and address the following:

- **Introduction** – State your chosen island nation and outline its vulnerability to future climate change.
- **Data and Methods** – Outline what methods are used to derive the climate change information you will analyse. You may have to do some research around the Pacific Climate Futures website in order to understand the models and methods used.
- **Results** – interpret the projected annual rainfall and temperature change in 2050 for the RCP4.5 and RCP8.5 scenarios. Is there consensus amongst the models? Are there any general trends?
- **Discussion** – How do you account for both RCP scenarios in future planning? Is one scenario more likely than another? How do you deal with uncertainty in this projection? What is the likely impact for people, places and sectors of your chosen region?
- **Conclusion** – Summarise key findings and knowledge gaps.

A rubric outlining how the presentation will be marked and how marks are allocated are summarised in Table 2.

Table 2. Rubric for Assessment 3a

ASSESSMENT 3A		
	Criteria	**Mark**
Introduction	• Clearly states chosen island nation and outlines its vulnerability to future climate change.	/10
Data and Methods	• Discusses the data and methods used to derive Pacific Climate Futures summary • Outlines the differences between RCP4.5 and RCP8.5 emissions scenarios and what they mean.	/10
Results	• Interprets the projected annual rainfall and temperature change in 2050 for RCP4.5 and RCP8.5 scenarios. • Analysis of model summary and discussion on whether there is consensus amongst models. • Description of any trends.	/20
Discussion	• Discussion on how to account for both RCP scenarios in planning and whether one scenario is more likely than another • Analysis of uncertainty and discussion of how this should be dealt with • Evaluates potential impacts on people, places and sectors	/15
Conclusion	• Presents a concise summary of issues raised in the body of the report	/5
Total	• **The total mark (/60) will be added to your mark from Assessment 3a and 3c to give you a score out of 100.**	**/60**

Assessment 3b – Climate modelling and emission scenarios (40 marks)

The aim of this assessment is to (i) gain a better understanding into the science of climate and climate change and (ii) to use a simple climate model to simulate a few decades of climate system evolution.

This is done using the online resources available at http://www.carbonator.org. By the end of this tutorial you should gain an understanding of the following themes:

- The climate system and its drivers
- Climate variability
- The climate up until present
- Climate models
- Projections of future changes in climate
- Regional climate modelling
- Impacts of climate change

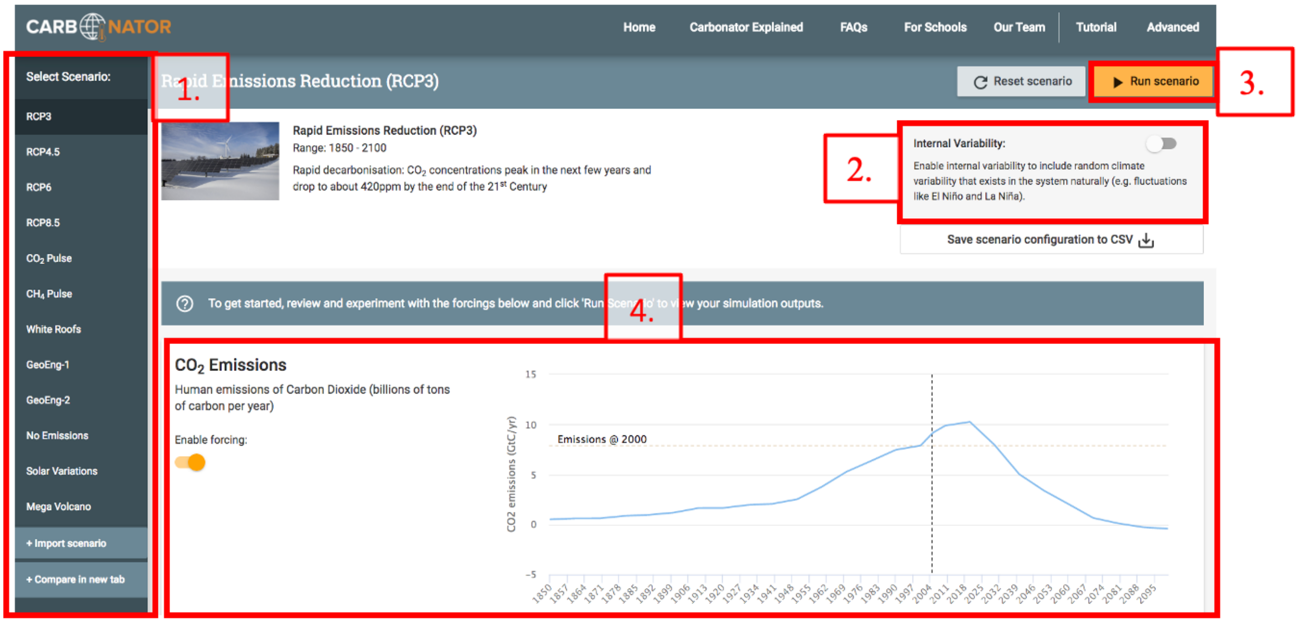
During the course of this assessment you should:

1. Familiarise yourself with the following:

- Read the introductory information about the Carbonator under the 'Carbonator Explained' tab AND the Frequently Asked Questions section under the 'FAQ' tab.
- Read through the information available under the 'For Schools' tab and look through the resources listed under the 'online resources' section.
- - Under the 'Tutorial' tab, complete both the 'How to use Carbonator' and 'Advanced mode' sections of the website.

2. Go back to the Home page and run through all 12 scenarios given. Do this with and without Internal Variability switch on and also play around with all the other options and see what happens when different ones are switched on or off.

- Step 1 – select a scenario
- Step 2 – Run each scenario with and without the 'internal variability' switch enabled.
- Step 3 – Select 'run scenario' when you have made your necessary selections
- Step 4 – Analyse and compare the output(s)



3. Using the Carbonator tool, complete and answer the questions listed in Part A and Part B of this assignment (see below).

Mitigation Strategies
Assessment 3b (Part 1)

(taken from http://144.6.234.149:8080/assets/pdfs/Worksheet_IsThereACheapFix.pdf)

Instructions and questions:

1. Select the 'Business as usual' RCP85 emission scenario.

2. Run the scenario to see how temperature and other climate variables change under this scenario (see tutorial for detailed instructions)

3. Re-edit the scenario, but this time turn off SO2 aerosol emissions [i.e. SO2 emissions is set to zero]

- Comparing the two above scenarios what effect does SO2 have on global temperatures, sea level and pH? (4 Marks)

____
____
____
____
____

- Explain what effect SO2 has on the energy balance (i.e. energy coming into and out of the climate system) (4 Marks)

____
____
____
____
____

4. Reset the scenario and select advanced mode. Scroll to SO2 and select 5 nodes. Move the last two nodes so that instead of SO2 emissions going down after the end of the 20th century, emissions keep rising.

- How does this affect future temperature? (4 Marks)

____
____
____
____
____

5. Repeat the above using more nodes and try to design a scenario that would stabilise temperatures at current levels or gradually bring temperatures back down to pre- industrial levels (i.e. so the temperature difference drops back to close to zero)

- Do you think this is a good solution to the problem of global warming? (4 Marks)

____
____
____
____
____

- Are here any potential side effects? (e.g. take a look at the other climate variables) (4 Marks)

____
____
____
____
____

Resources:

https://en.wikipedia.org/wiki/Climate_engineering
https://www.theguardian.com/global-development/2018/apr/05/scientists-suggest-giant-sunshade-in-sky-could-solve-global-warming

https://www.technologyreview.com/s/540071/dont-count-on-geoengineering-the-oceans/

Influence of Human Activities on Changes to Climate Attribution Assessment 3b (Part 2)

(taken from http://144.6.234.149:8080/assets/pdfs/Worksheet_HowDoWeKnowItsUS.pdf)

Instructions and questions:

- What lines of evidence are there indicating that the climate system is changing? (4 marks)

____
____
____
____
____

- How and why do different climate forcings: Carbon dioxide, Methane, human aerosols, volcanic aerosols, insolation and planetary albedo affect temperatures? (4 marks)

____
____
____
____
____

Select the historical scenario (that uses observations of the above forcings to simulate how the climate system changed between 1850 (the start of the industrial revolution) and 2005 [internal variability should be turned off]. Run the scenario to see how temperature and other climate variables change under this scenario (see tutorial for detailed instructions). Export the output data to a file for later use.

- What climate forcings does Carbonator not account for

2. Re-edit the scenario, but this time turn all forcings except solar and volcanic (the natural forcings). Run the scenario and save the output.

3. Repeat (2), this time turning off all forcings except CO2, CH4 and human aerosols (the human forcings). You may also want to repeat with other combinations of forcings.

4. Load the output data for the various scenarios into your favourite spreadsheet program (e.g. Excel) and plot the temperature for the three scenarios (all forcing, natural forcing only, human forcing only) on a single graph.

- Find estimates of the change in global average air temperature [using reputable sources]. How do these changes compare with the model simulations. (4 marks)

____
____
____
____
____

- What do the model simulations tell us about the contributions of the various forcing to the rise in temperatures? (4 marks)

____
____
____
____
____

- How do results from our simple model compare with state of the art climate models [e.g. see fig 10.7 of the latest IPCC report; chapter 10] (4 marks)

____
____
____
____
____

Resources:

http://www.ipcc.ch/pdf/assessment-report/ar5/wg1/WG1AR5_Chapter10_FINAL.pdf

SPREP 2023