Climate Systems

National Environmental Science Program

Climate Science for Natural Hazards Researchers

Natural Hazards Research Forum
1st May 2023

John M Clarke
CSIRO Climate Science Centre

Climate Systems

National Environmental Science Program

Outline

1. What is “climate”?
2. How (and why) has it changed?
3. Climate Projections: the science of describing plausible future climates
4. Why are there different results for the future?
5. What is the role of natural variability?
6. How do I use climate projections?

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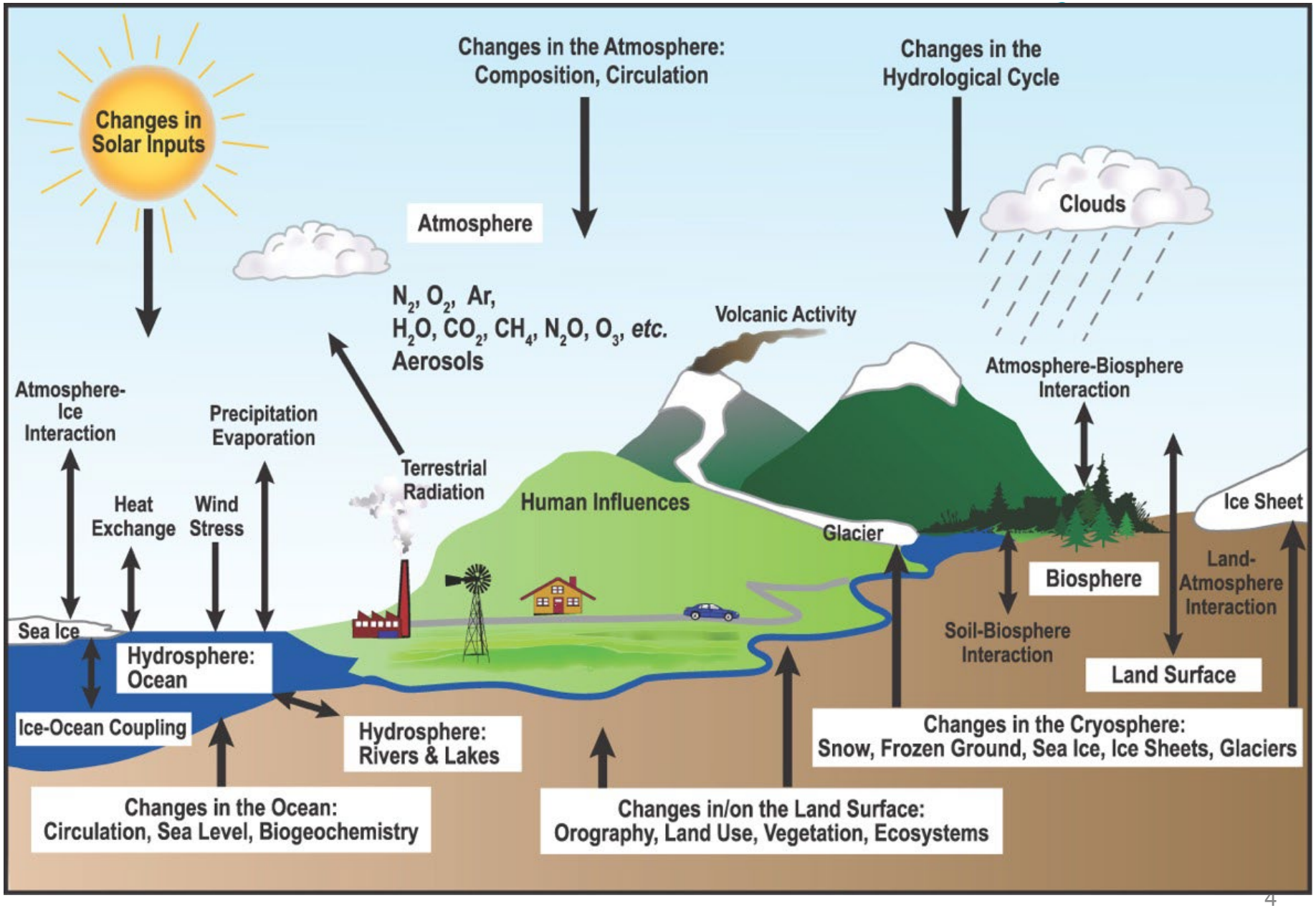
The climate system



Source: IPCC Fourth Assessment Report (Working Group 1)

The greenhouse effect

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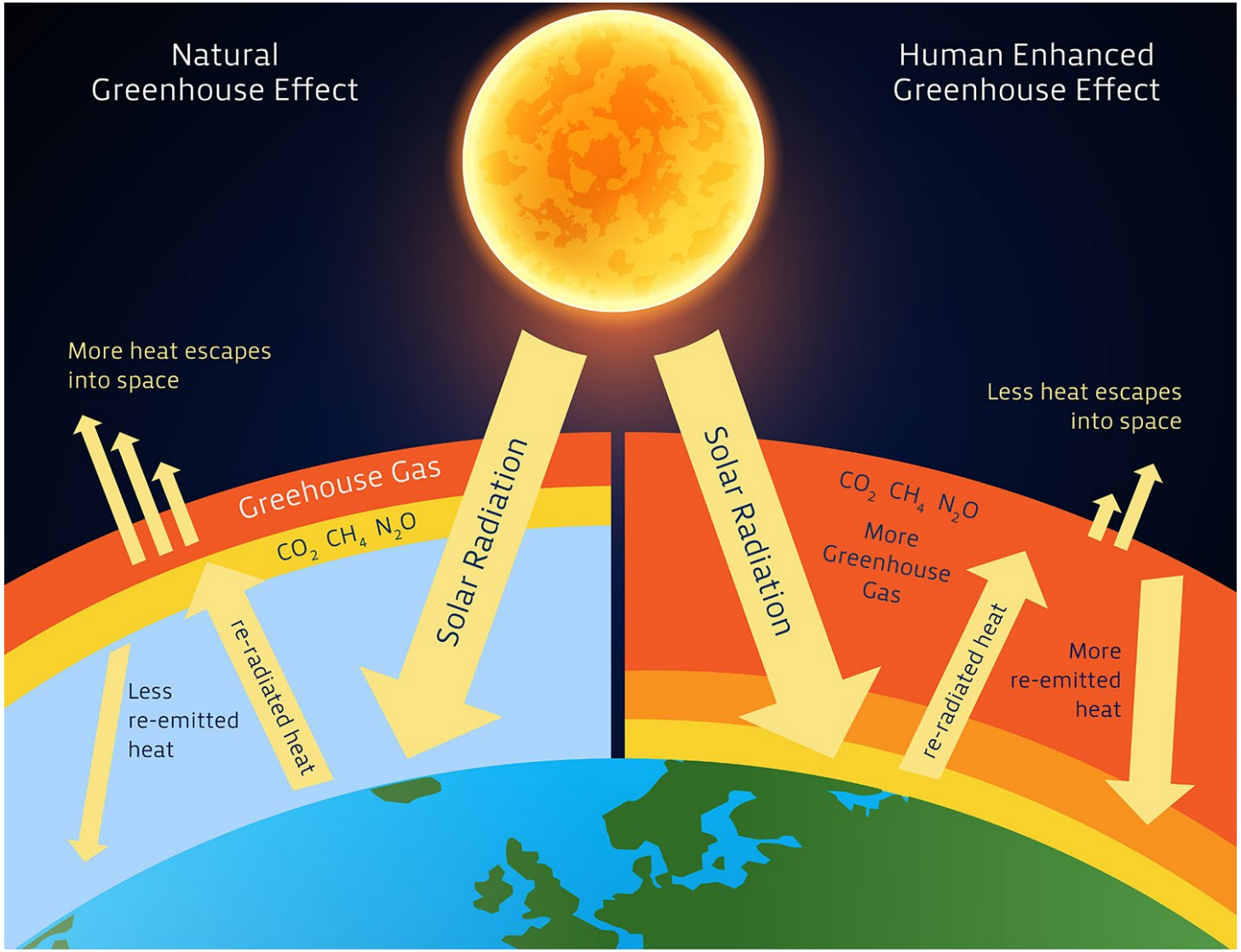
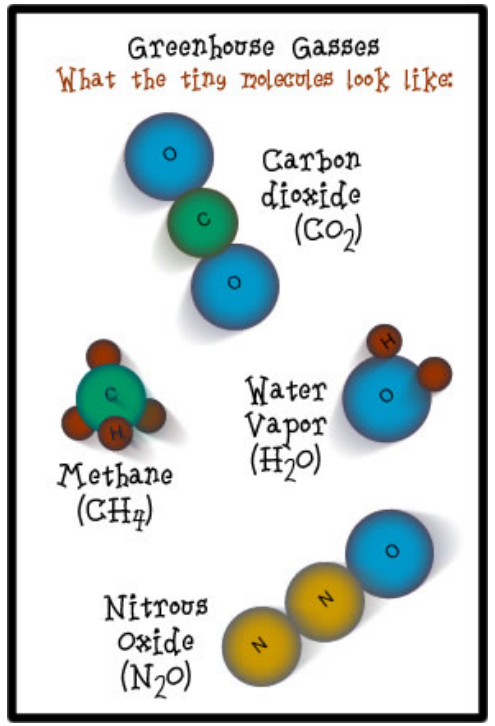
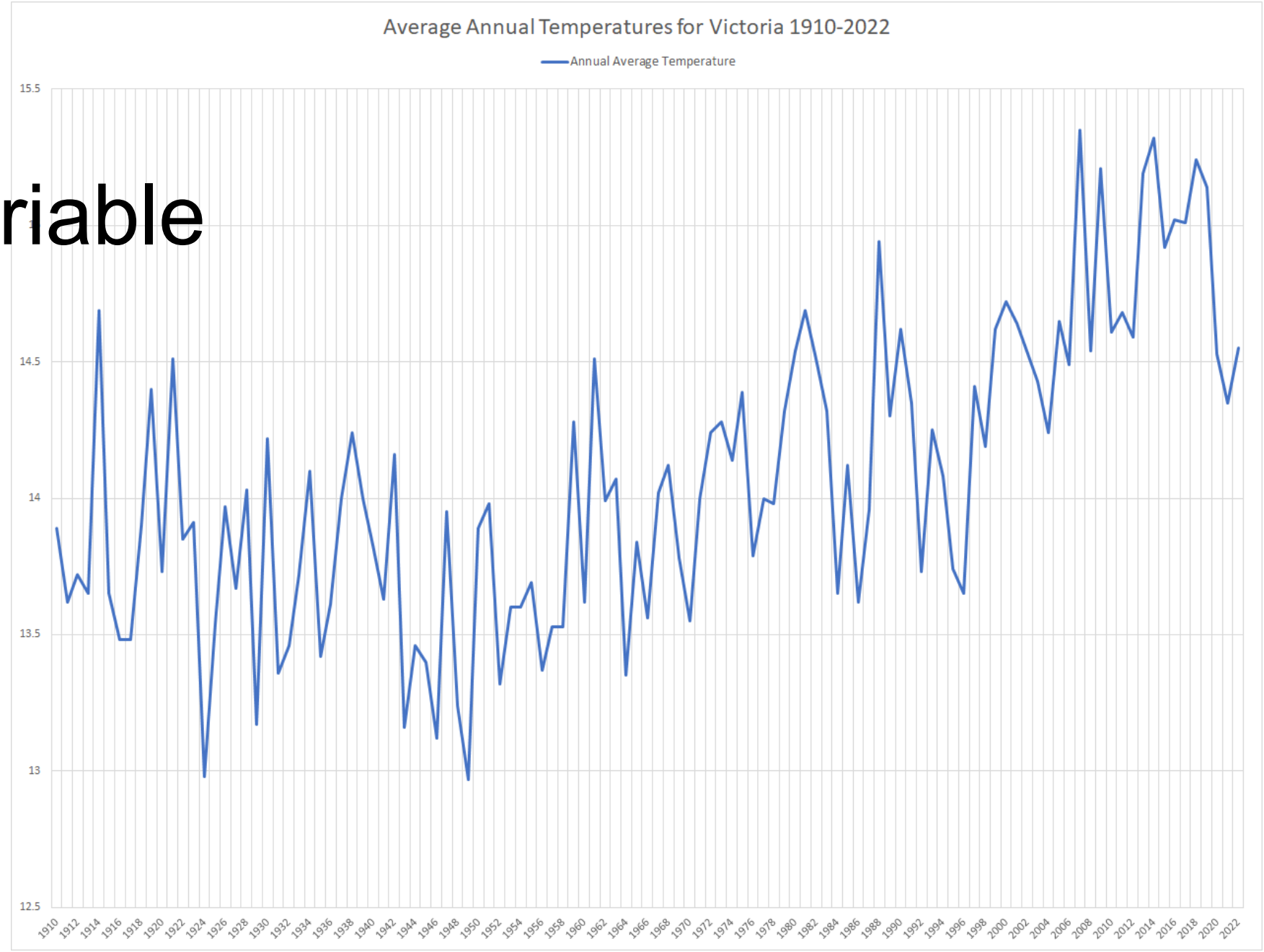




Climate is variable

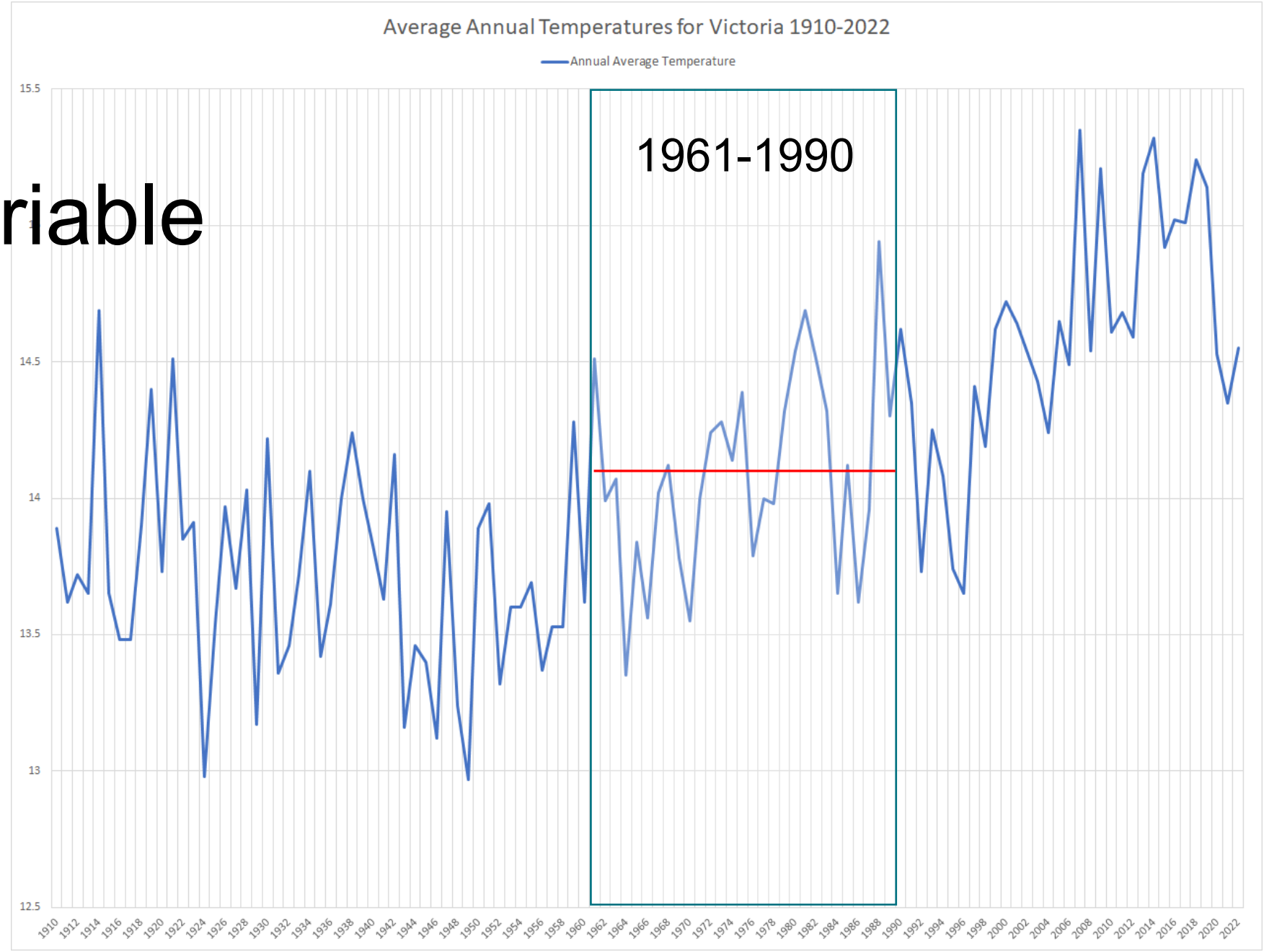
- Variability is natural (day, season, annual, decadal, etc.)



Data source: Bureau of Meteorology

Climate is variable

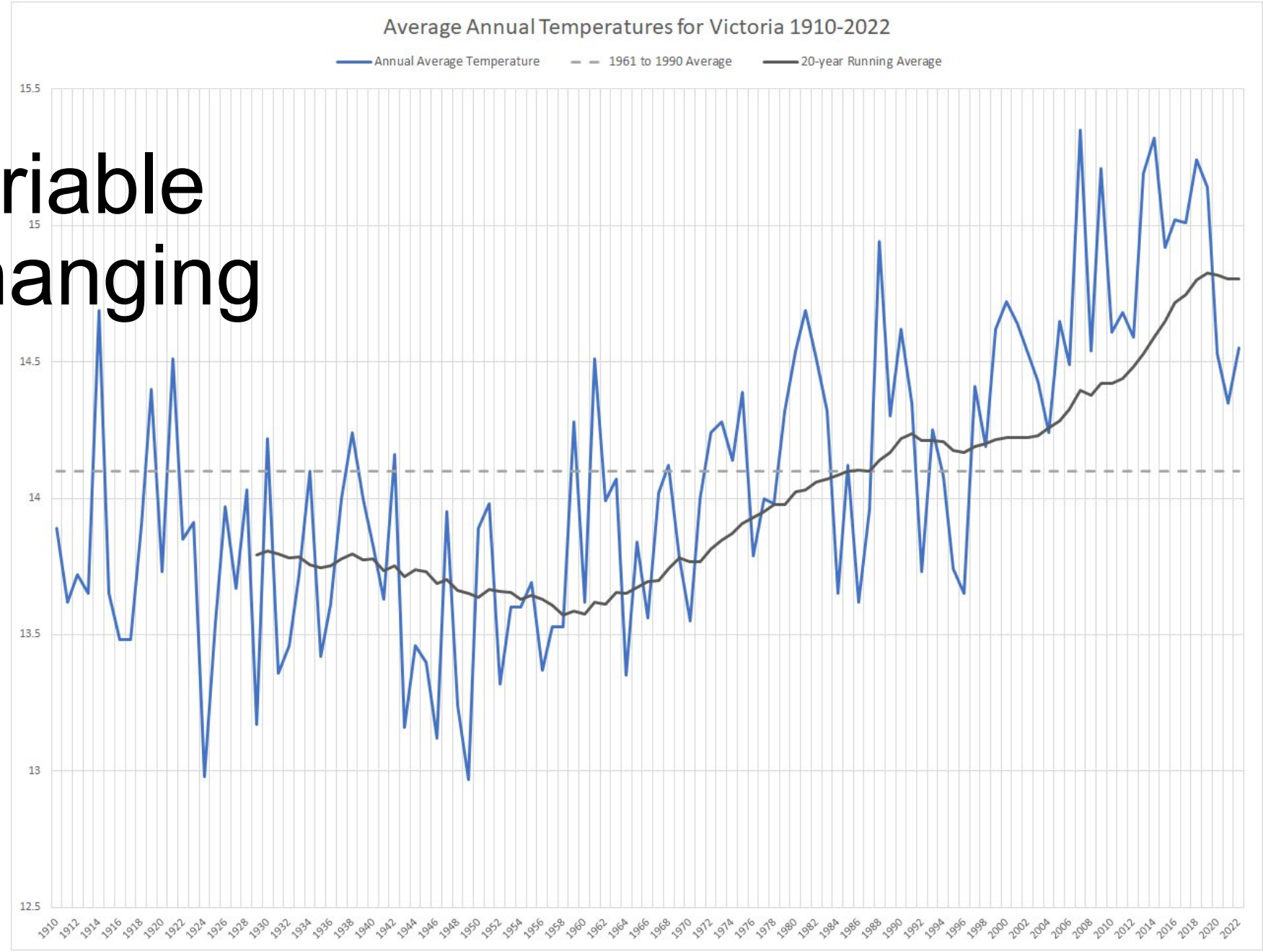
- Variability is natural (day, season, annual, decadal, etc.)
- Long-term record allows us to calculate averages
- 1961-1990 WMO standard period (“Climate Normal”) used as a reference



Data source: Bureau of Meteorology

Climate is variable …but also changing

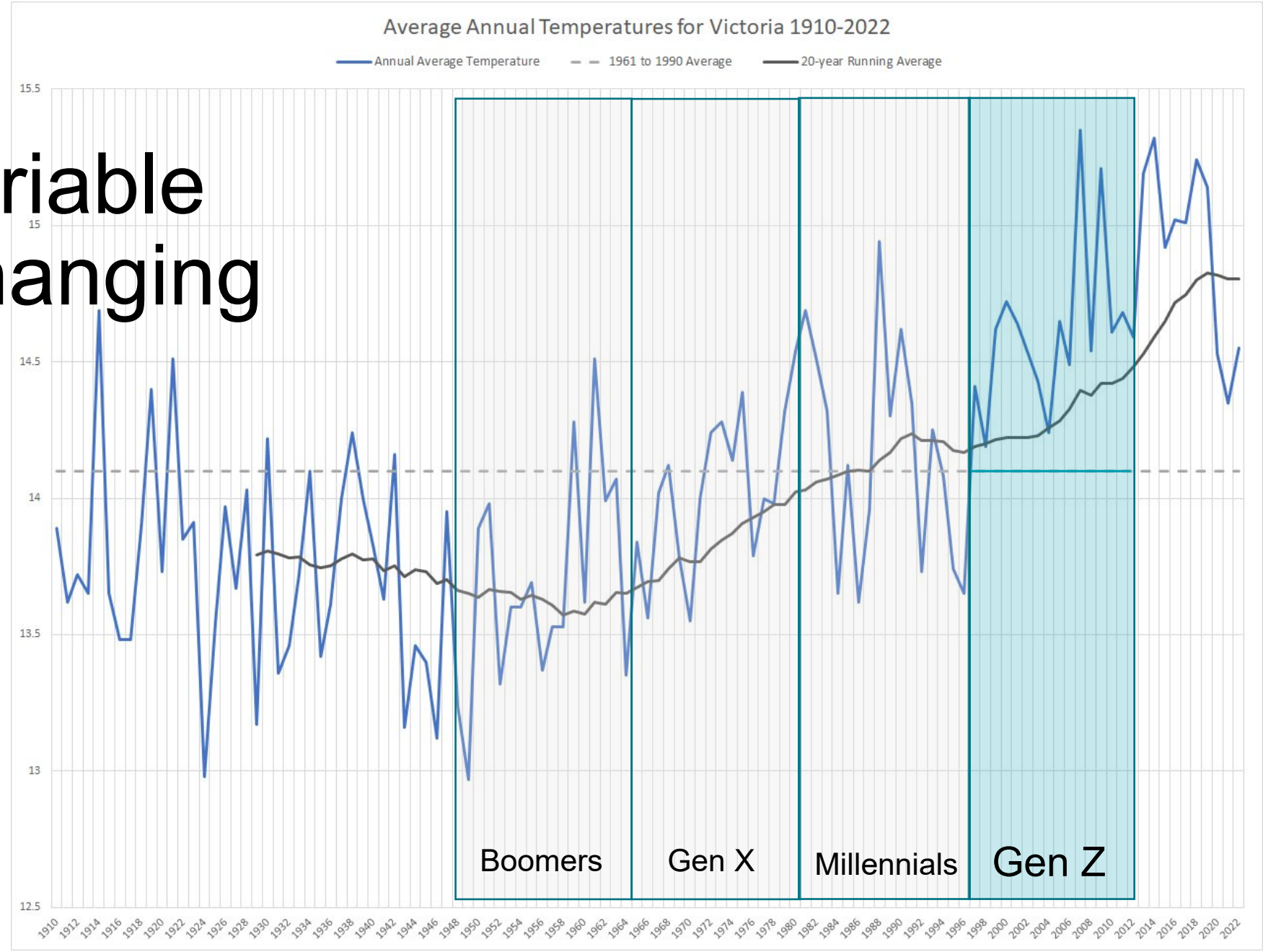
- Background change trend caused by us
- NB. Trend is very clear for temperature; less so for rainfall



Data source: Bureau of Meteorology and CSIRO

Climate is variable …but also changing

- Background change trend **caused by us**
- NB. Trend is very clear for temperature; less so for rainfall
- Gen Z has never lived a below-average year



Data source: Bureau of Meteorology and CSIRO

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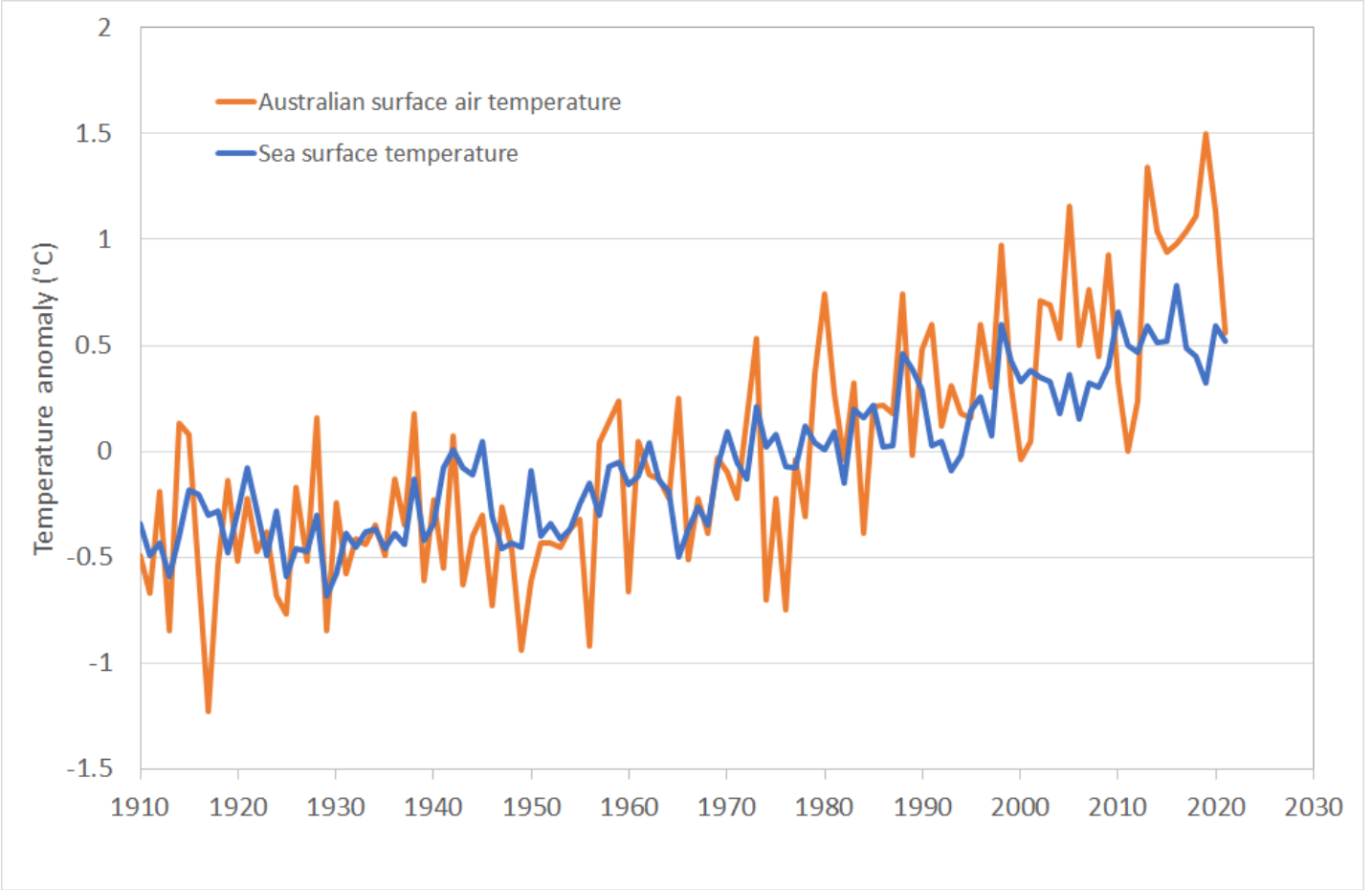
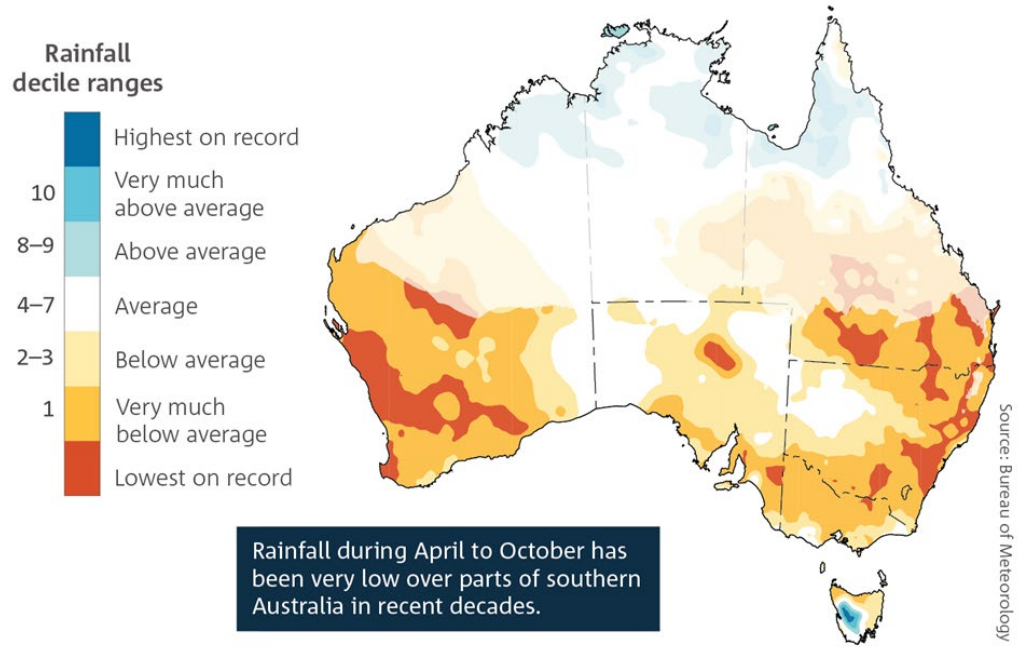
Temperature

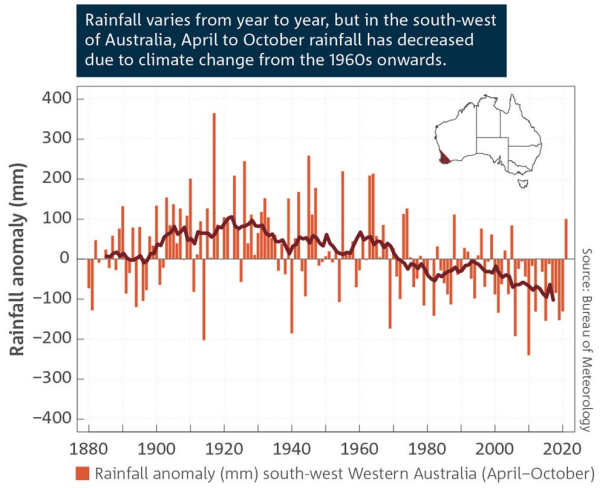
- Australia's climate has warmed by an average of 1.47 ± 0.24 °C since national records began in 1910.
- Our sea surface temperatures have increased by an average of 1.05 °C since 1900.

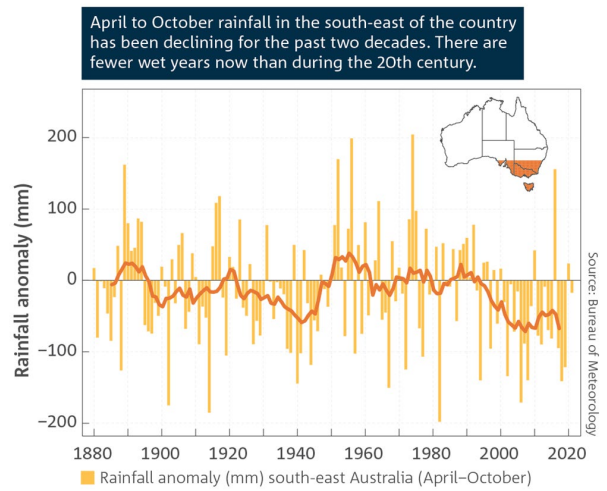


Rainfall - southern

- There has been a decline of around 15% in April to October rainfall in the south-west of Australia since 1970.
- Across the same region, May to July rainfall has seen the largest decrease, of around 19% since 1970.
- In the south-east of Australia, there has been a decrease of around 10% in April to October rainfall since the late 1990s.

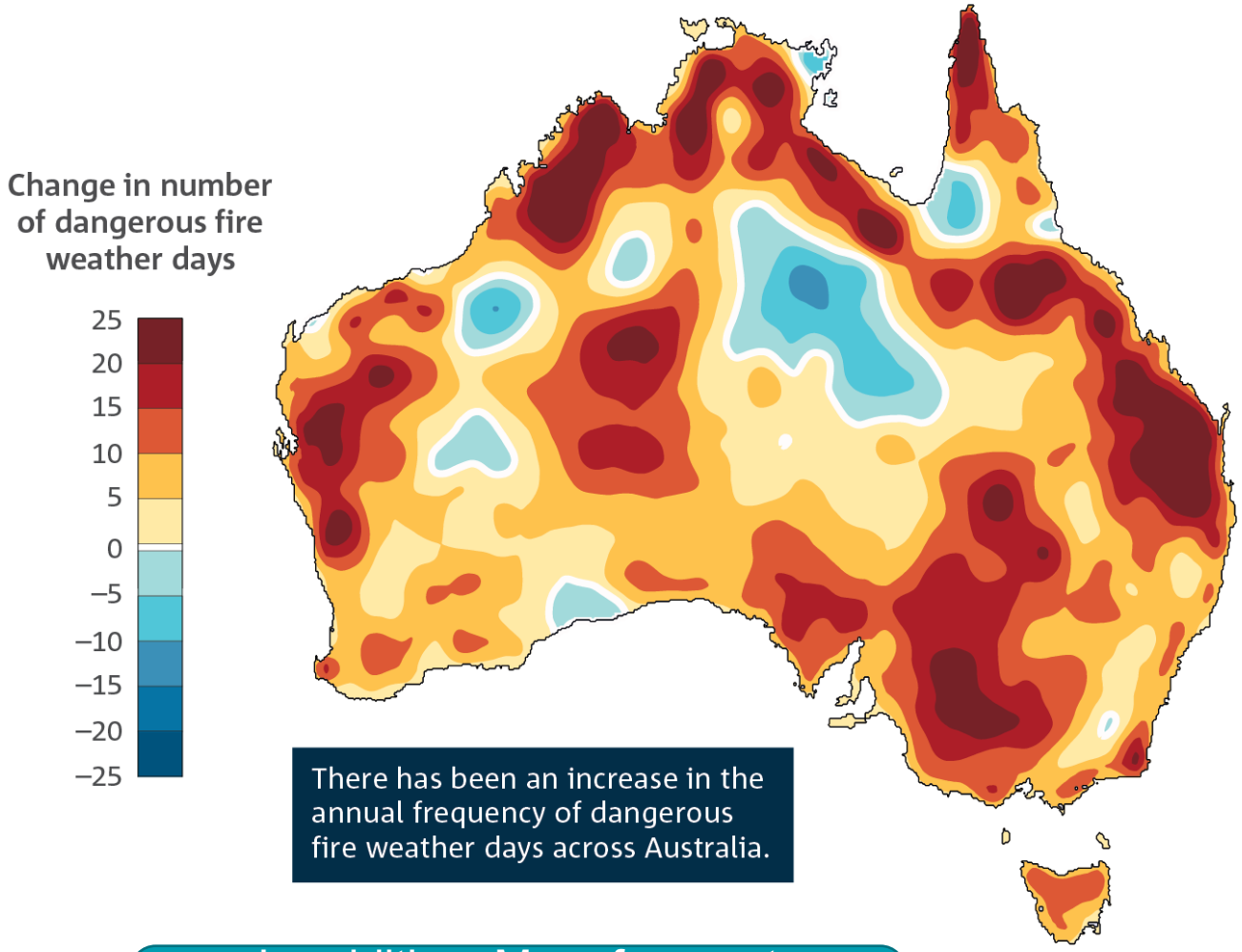






Fire weather

- There has been an increase in extreme fire weather, and a longer fire season, across large parts of the country since the 1950s.
- This has led to larger and more frequent fires, especially in southern Australia



In addition: More frequent ‘megafires’ (>1M ha) and less time between fires

Human cause of change – 150+ years of science

382 *On the Heat in the Sun's Rays.*

ART. XXXI.—*Circumstances affecting the Heat of the Sun's Rays;* by EUNICE FOOTE.

(Read before the American Association, August 23d, 1856.)

MY investigations have had for their object to determine the different circumstances that affect the thermal action of the rays of light that proceed from the sun.

Several results have been obtained.

First. The action increases with the density of the air, and is diminished as it becomes more rarified.

The experiments were made with an air-pump and two cylindrical receivers of the same size, about four inches in diameter and thirty in length. In each were placed two thermometers, and the air was exhausted from one and condensed in the other. After both had acquired the same temperature they were placed in the sun, side by side, and while the action of the sun's rays rose to 110° in the condensed tube, it attained only 88° in the other. I had no means at hand of measuring the degree of condensation or rarefaction.

The observations taken once in two or three minutes, were as follows:

Exhausted Tube		Condensed Tube.	
In shade.	In sun.	In shade.	In sun.

Marcou's Geological Map of the United States. 383

The high temperature of moist air has frequently been observed. Who has not experienced the burning heat of the sun that precedes a summer's shower? The isothermal lines will, I think, be found to be much affected by the different degrees of moisture in different places.

Thirdly. The highest effect of the sun's rays I have found to be in carbonic acid gas.

One of the receivers was filled with it, the other with common air, and the result was as follows:

In Common Air.		In Carbonic Acid Gas.	
In shade.	In sun.	In shade.	In sun.
80	90	80	90
81	94	84	100
80	99	84	110
81	100	85	120

The receiver containing the gas became itself much heated—very sensibly more so than the other—and on being removed, it was many times as long in cooling.

An atmosphere of that gas would give to our earth a high temperature; and if as some suppose, at one period of its history the air had mixed with it a larger proportion than at present, an increased temperature from its own action as well as from increased weight must have necessarily resulted.

On comparing the sun's heat in different gases, I found it to

1856: Eunice Foote (1819-1888)

- Pioneering work on 'greenhouse effect'
- Tested effect of sun's rays on several gases
- Demonstrated CO_2 heated more than air
- "…an atmosphere of [carbon dioxide] would give our earth a high temperature"
- Hypothesised as explanation for higher global temperatures in the distant past

An atmosphere of that gas would give to our earth a high temperature; and if as some suppose, at one period of its history the air had mixed with it a larger proportion than at present, an increased temperature from its own action as well as from increased weight must have necessarily resulted.

On comparing the sun's heat in different gases, I found it to be in hydrogen gas, 104°; in common air, 106°; in oxygen gas, 108°; and in carbonic acid gas, 125°.

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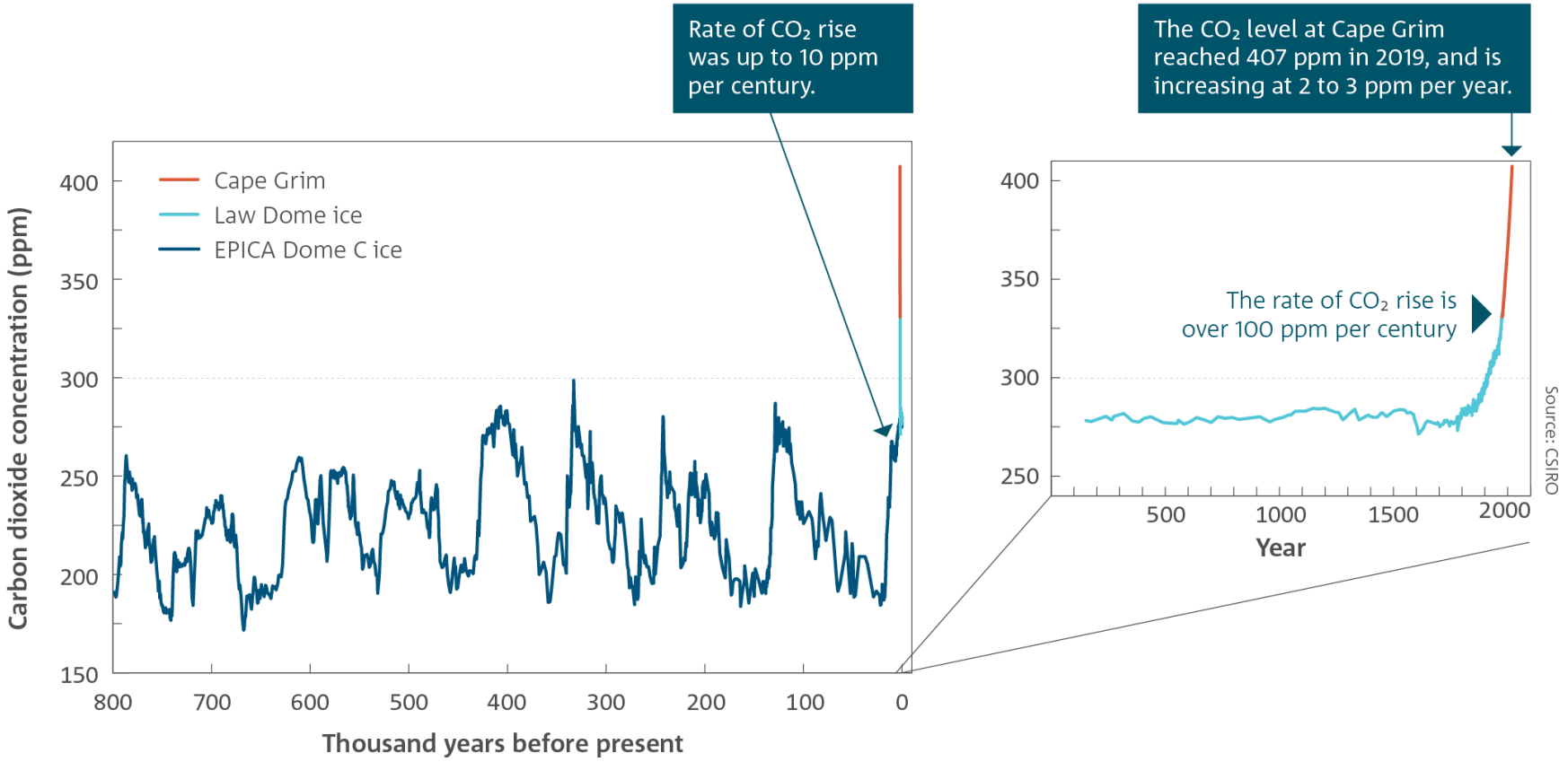
Atmospheric carbon dioxide

Concentrations of carbon dioxide, methane and nitrous oxide have increased to levels unprecedented in the last 2,000,000 years



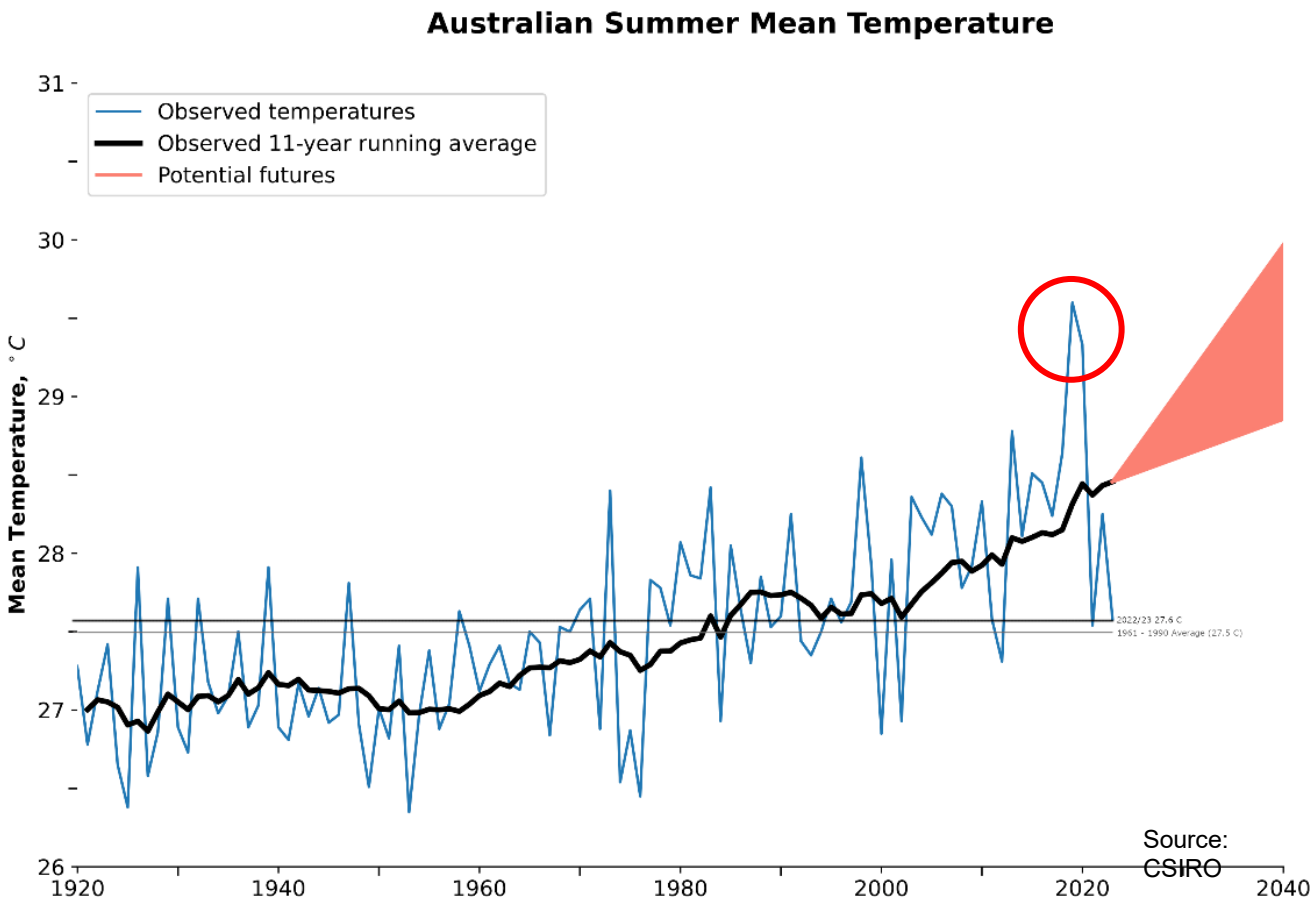
2021
414 ppm CO_2
516 ppm $CO_{2\text{-e}}$

Extreme events more frequent/intense

- Black Summer of 2019-20
- Extreme fire conditions made >30% more likely by climate change
- Smoke impacted 80% of Australians
- 400+ deaths from smoke
- 100s due to heat
- $2.2bn insurance claims

Source: Twitter @Nic_Asher

Source: ABC News Matthew Doran



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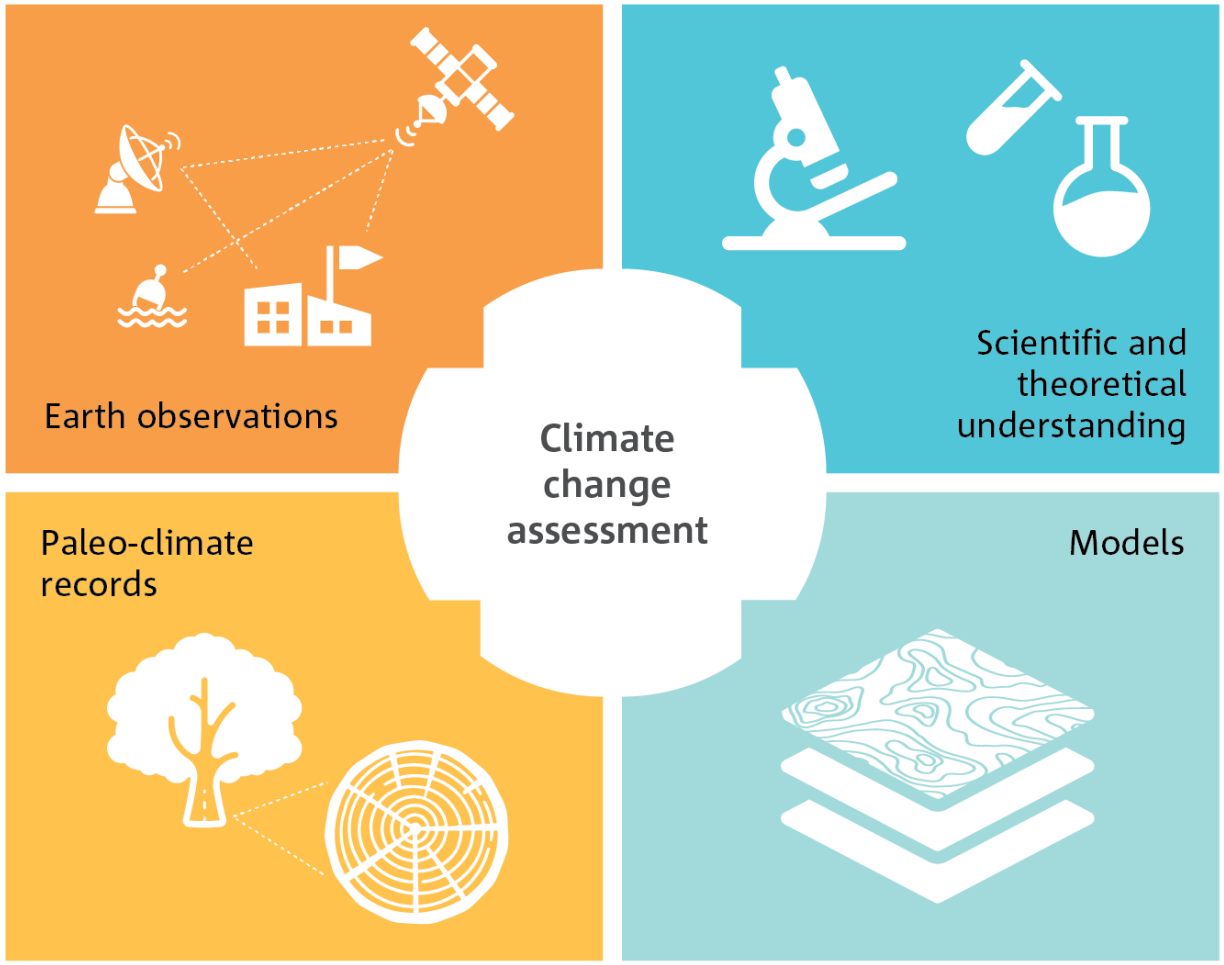
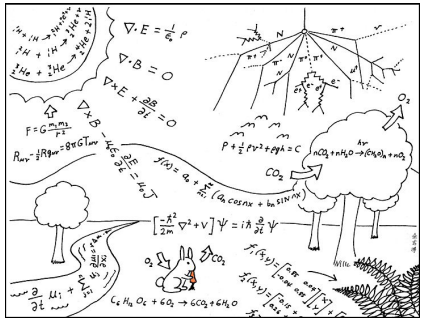
Developing climate change projections

- Consilience: Multiple lines of evidence used to assess climate change
- Knowledge is always improving in all these fields (hence the need for updated assessments)

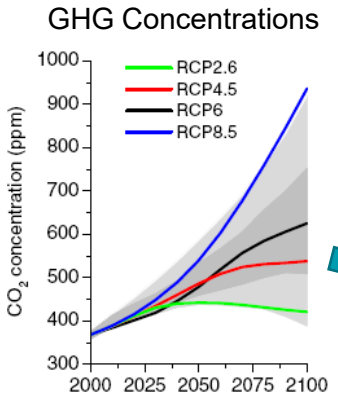


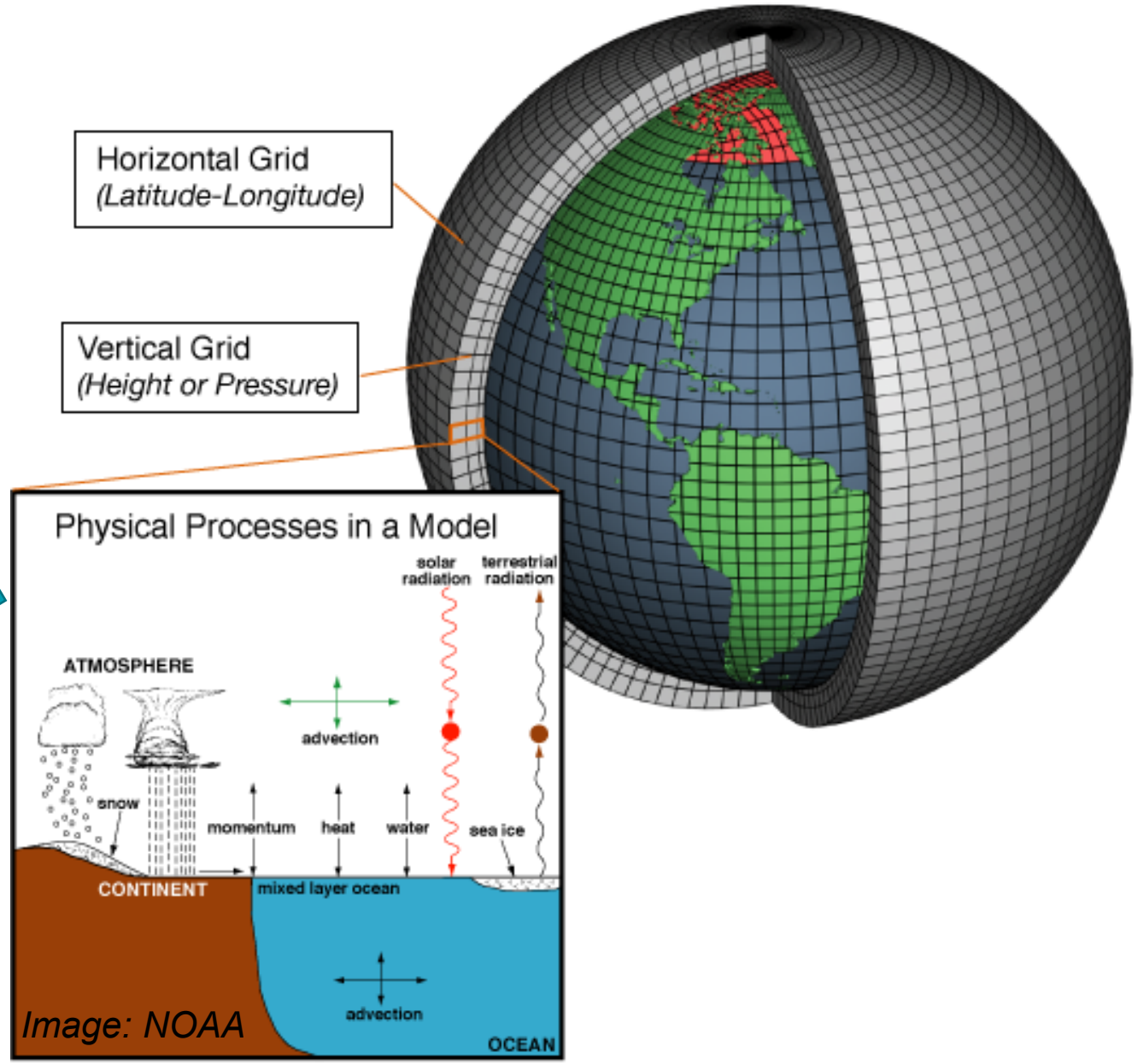
Source: CSIRO

Global climate models

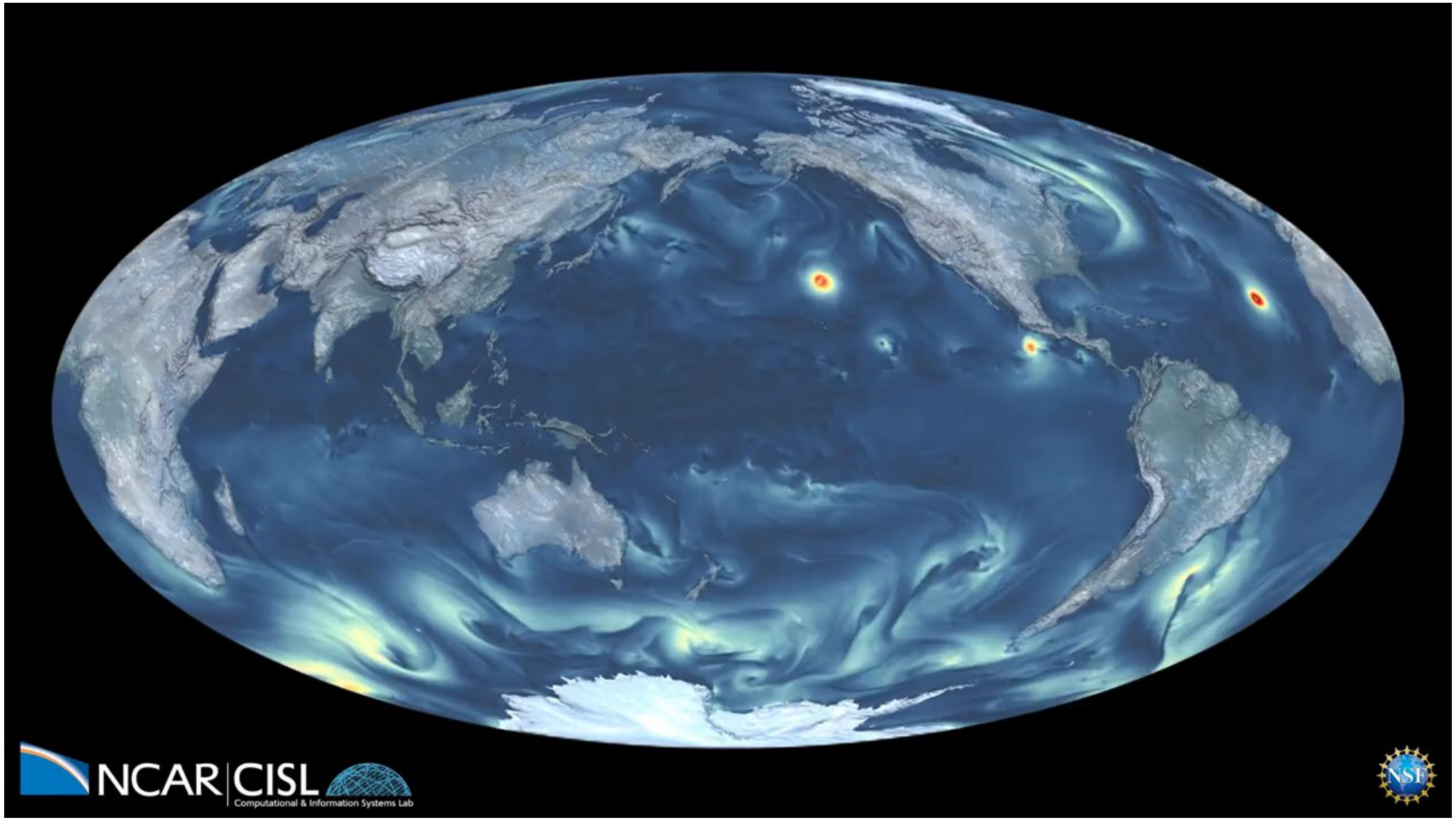


Equations
+
Supercomputers



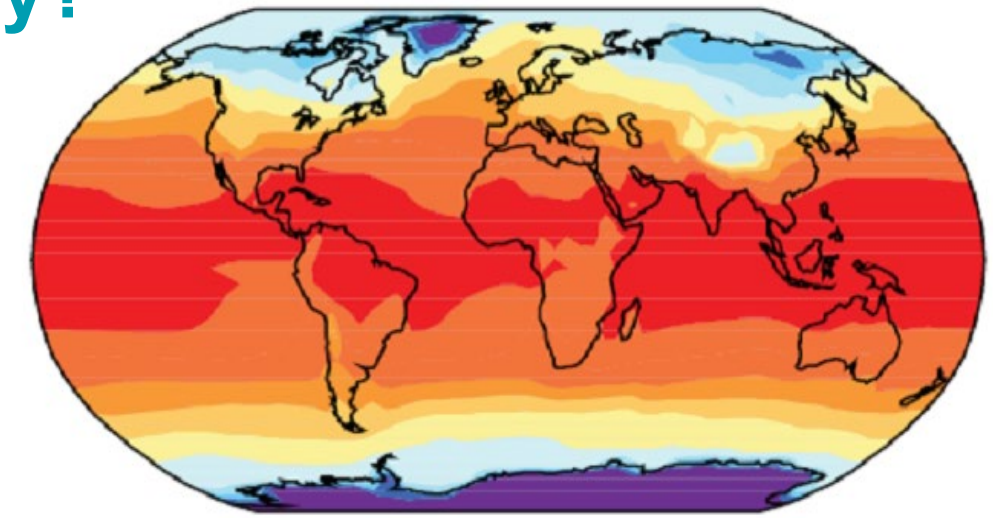


Earth’s atmosphere simulated by a model

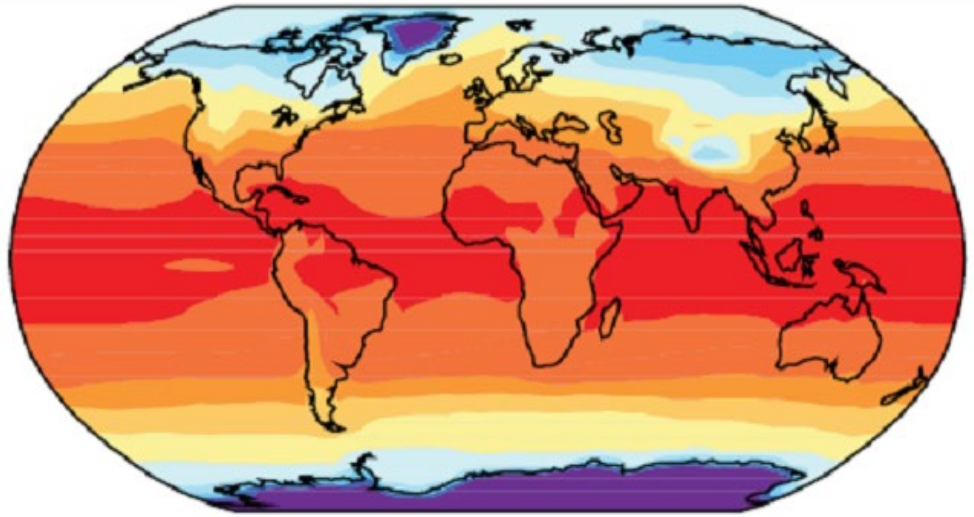


But how good are they? (Model evaluation)

Observations



Average temperature 1980–99



Climate model average

(IPCC 4th Assessment Report, 2007)

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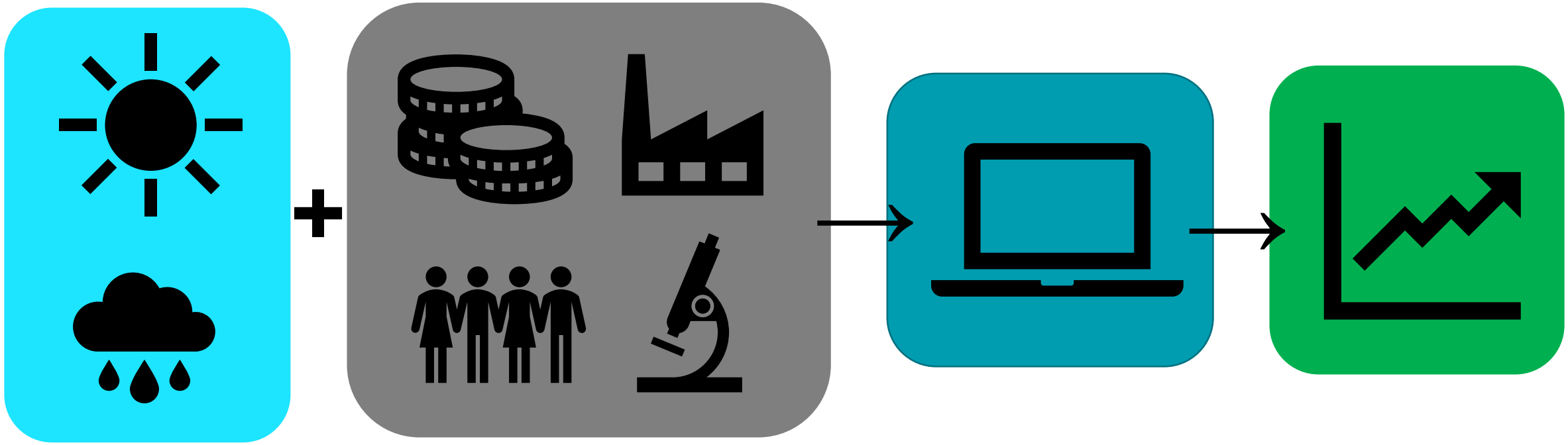
Developing climate change projections



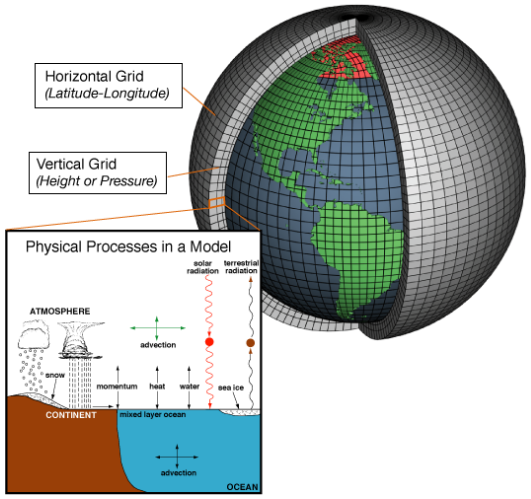
Observations and understanding of the climate system

Future scenarios

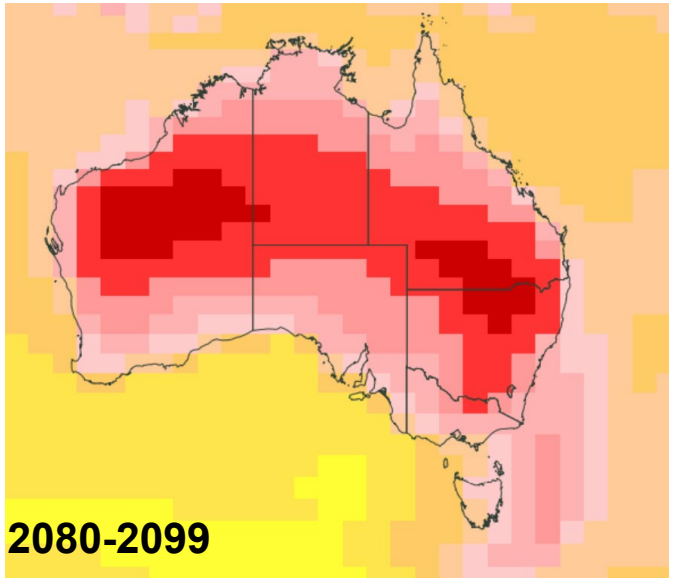
Global climate models

Climate change projections

Climate models: output



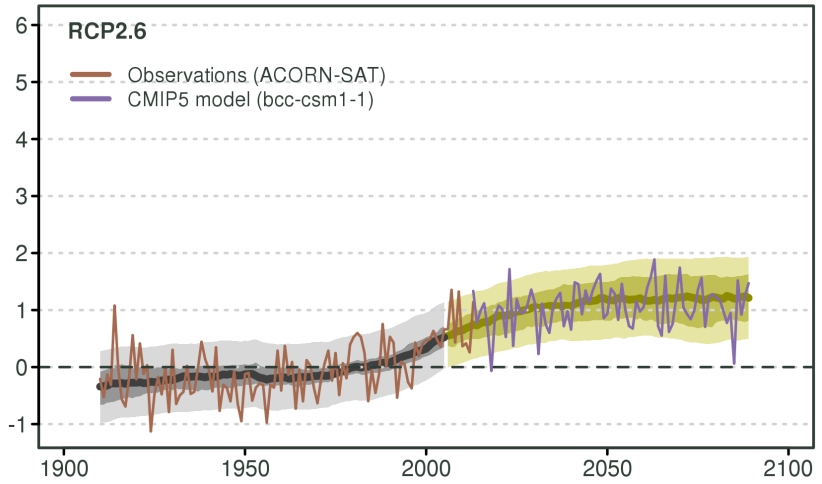
Gridded output



Peel off just the surface layer and we have a grid for every time step…

But to understand climate we average grids over decades.

Timeseries output



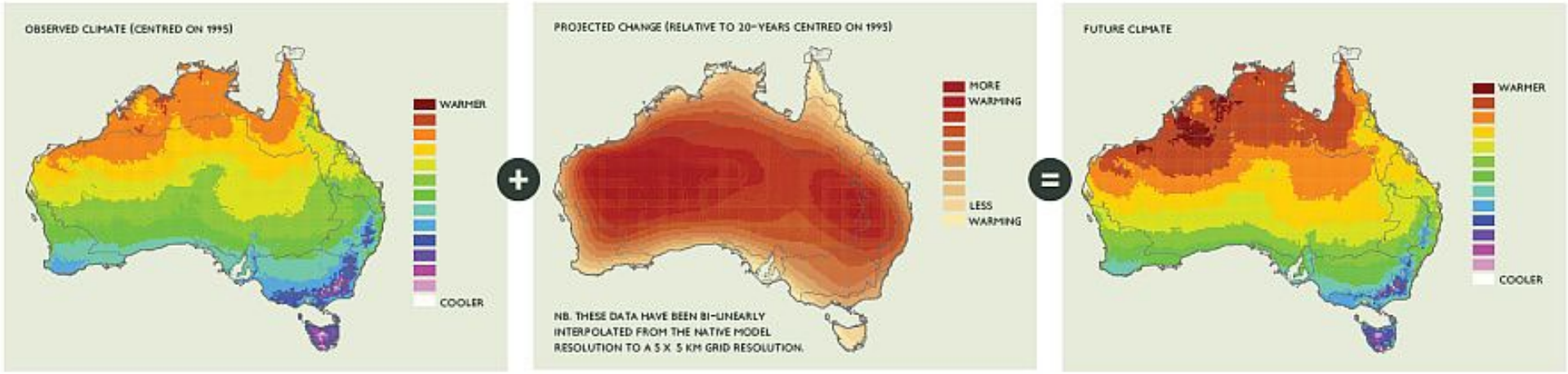
A model run produces just one plausible ‘timeseries’ for a particular climate scenario – we like to assess many models to build a more complete picture .

Locally-relevant, application-ready datasets

Many ways to do this, many choices:

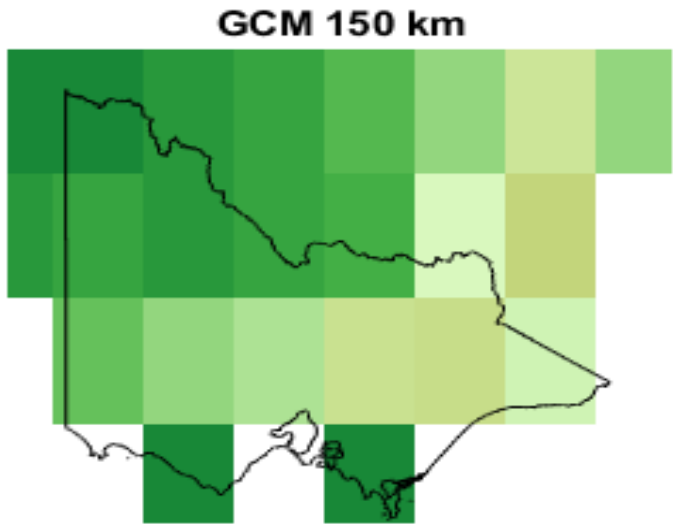
- Further statistical or dynamical modelling
- Post-processing – by scaling observations (simple or complex) or bias correction

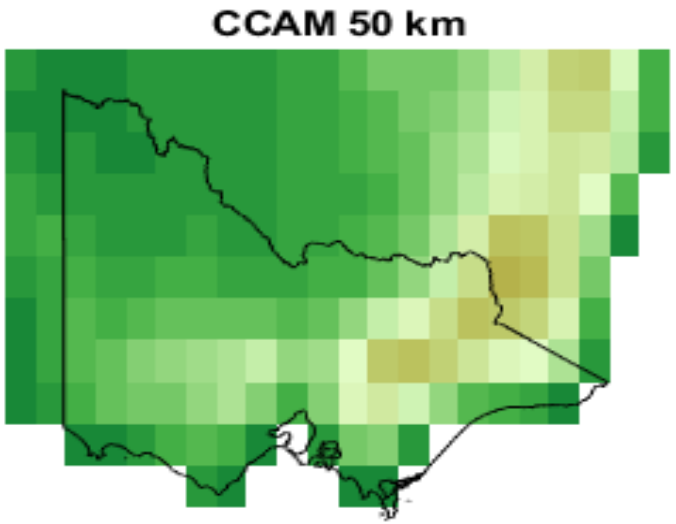
Simplest method is ‘delta scaling’ (more complex from there):

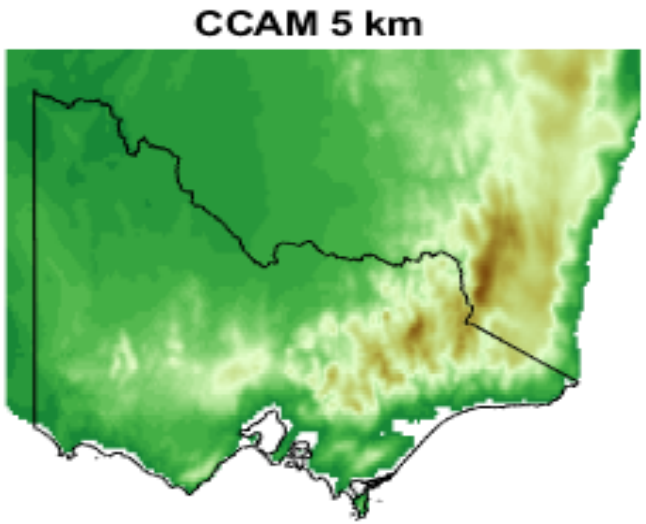


Best to use a method appropriate to the application

Regional climate modelling (downscaling)







"Realised Added Value"

Topography of Victoria represented with different grid resolutions.

This looks more realistic, and it **potentially** gives new information on regional-scale climate change

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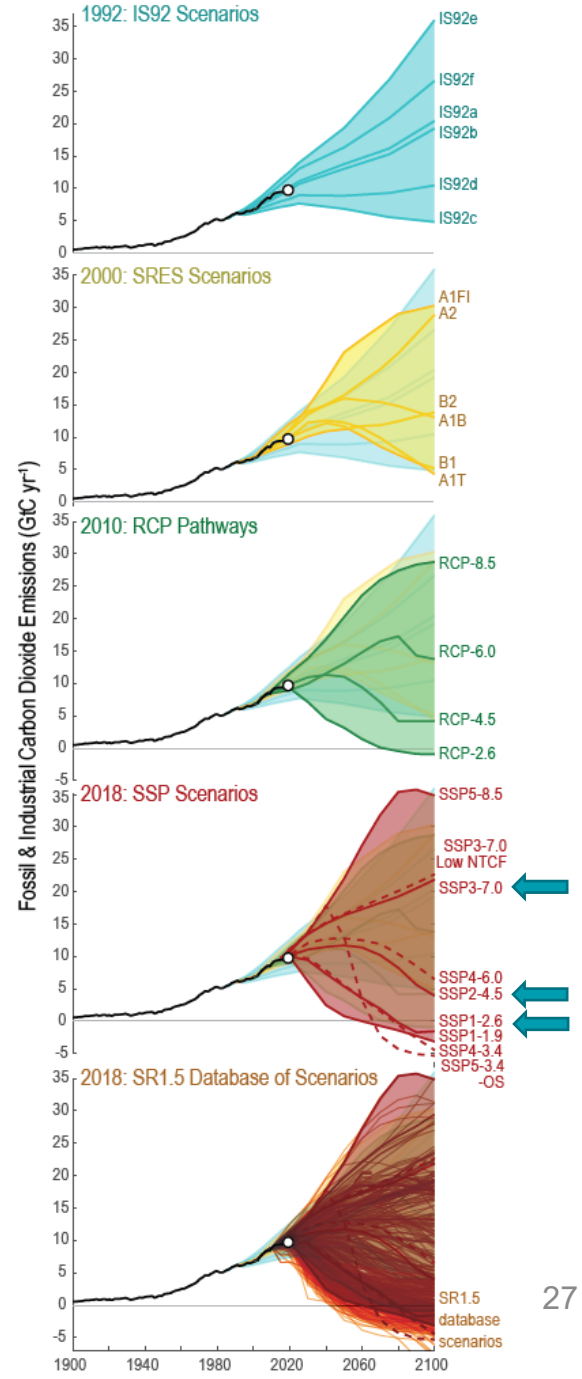
Emissions Scenarios – what, why?

- Climate projections are essentially a “what if” exercise: if we follow X pathway, we get Y
- Since climate change is driven by atmospheric greenhouse gas concentrations…
- …and we can’t know the future…
- …we need a set of scenarios of how greenhouse gases might plausibly change in future
- These are refined over time as we understand past changes in emissions and climate better

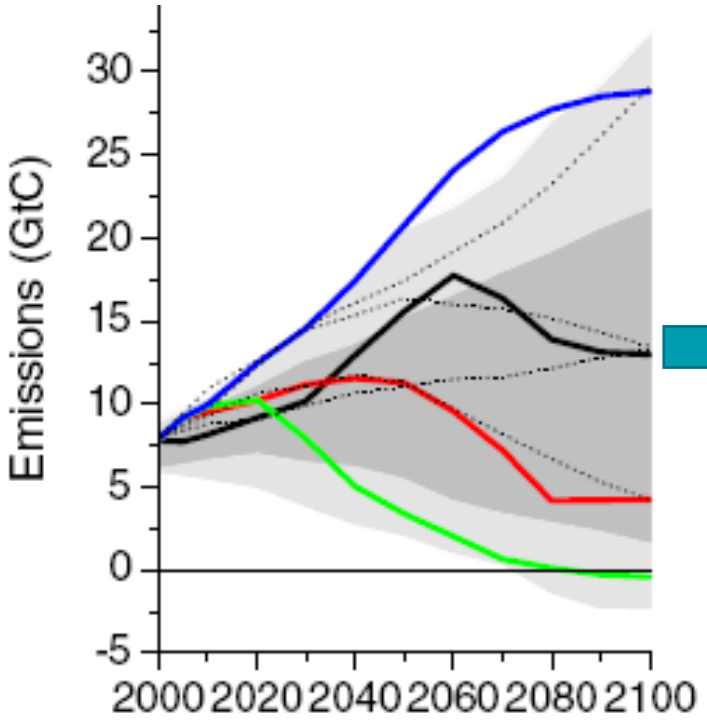
CCiA ‘Application-Ready’ data (used in CSA):
- RCP4.5
- RCP8.5

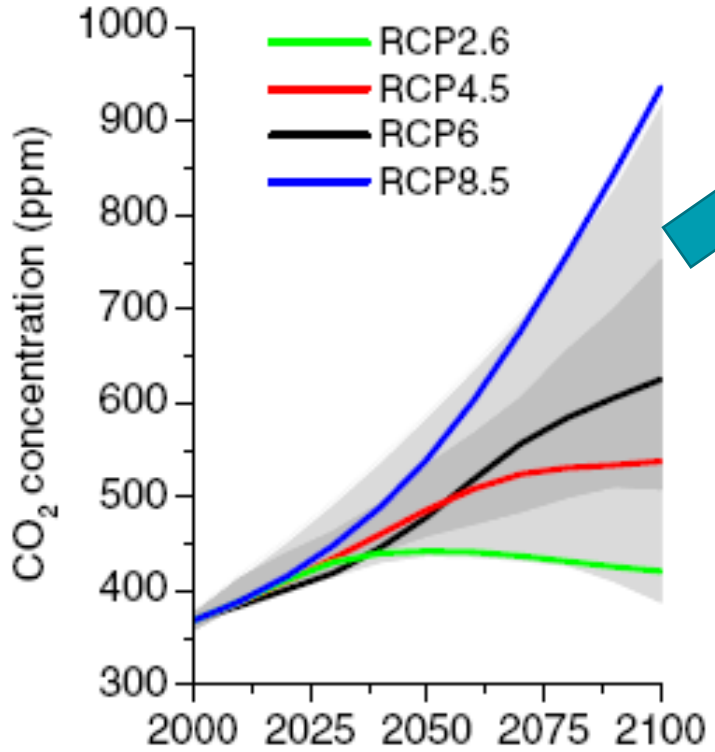
(RCP2.6, RCP6.0 avail for other data types)

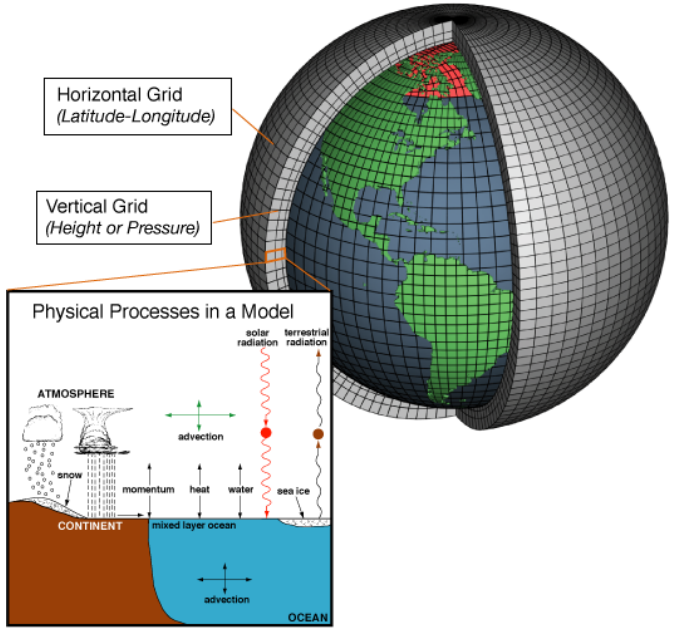
RCP8.5/SSP5-8.5 now widely regarded as unrealistically high



Emissions vs concentrations



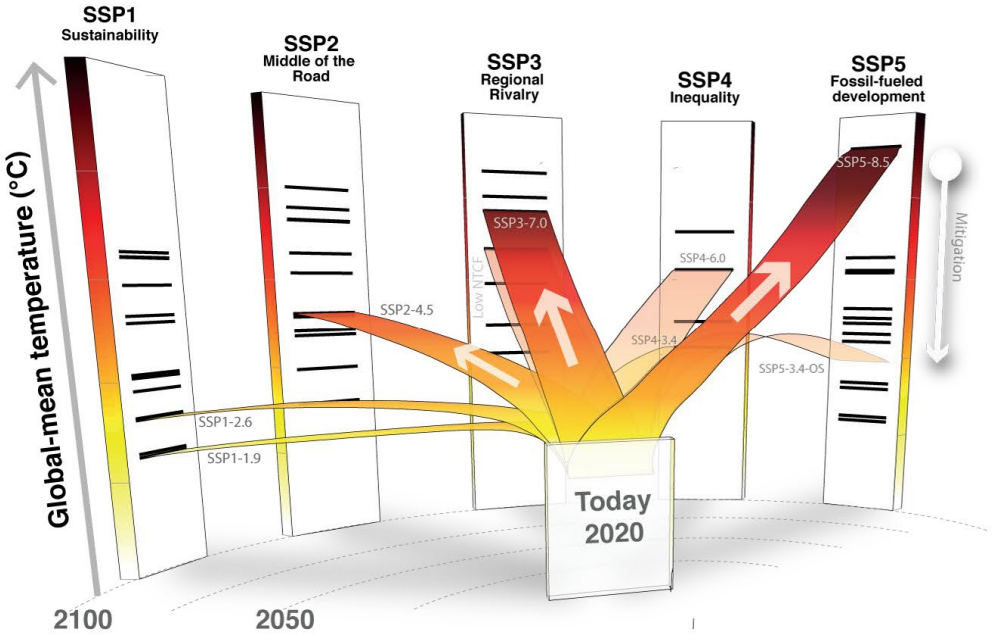


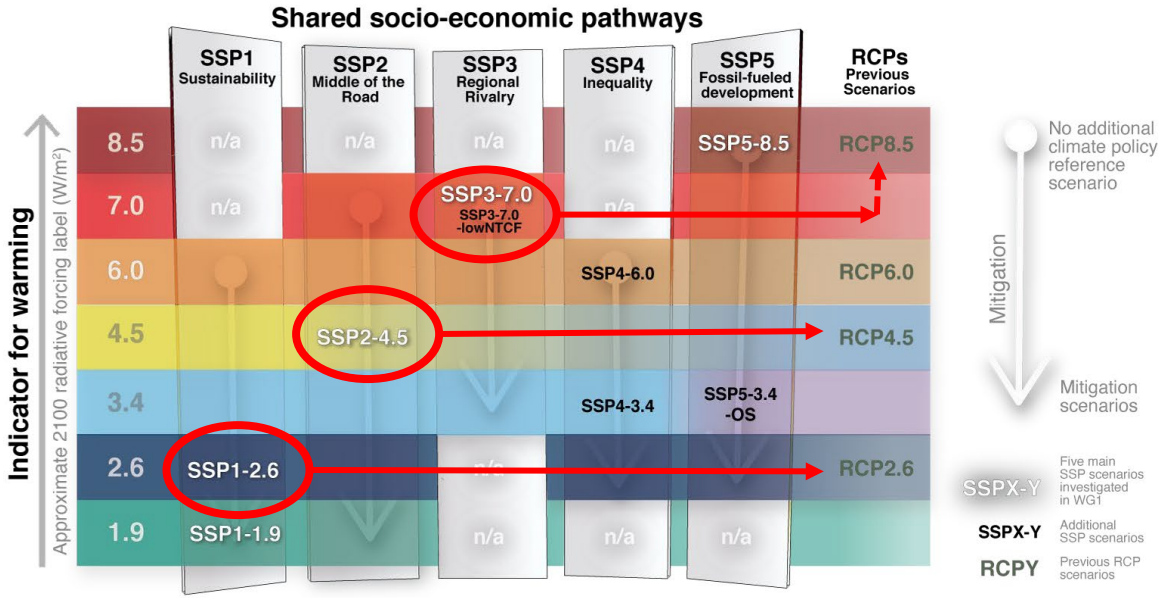


Climate modelling
Projections

Policy
Paris Agreement
Inventories

RCPs and SSPs: what's equivalent to what?





The SSP scenarios used in AR6, their indicative temperature evolution and radiative forcing categorization, and the five socio-economic storylines upon which they are built

IPCC AR6 WG1, Cross-Chapter Box 1.4

ACS = "Australian Climate Service"
NPCP = "National Partnership for Climate Projections" (led by DCCEEW)

ACS/NPCP Nationally coordinated downscaling prefers:

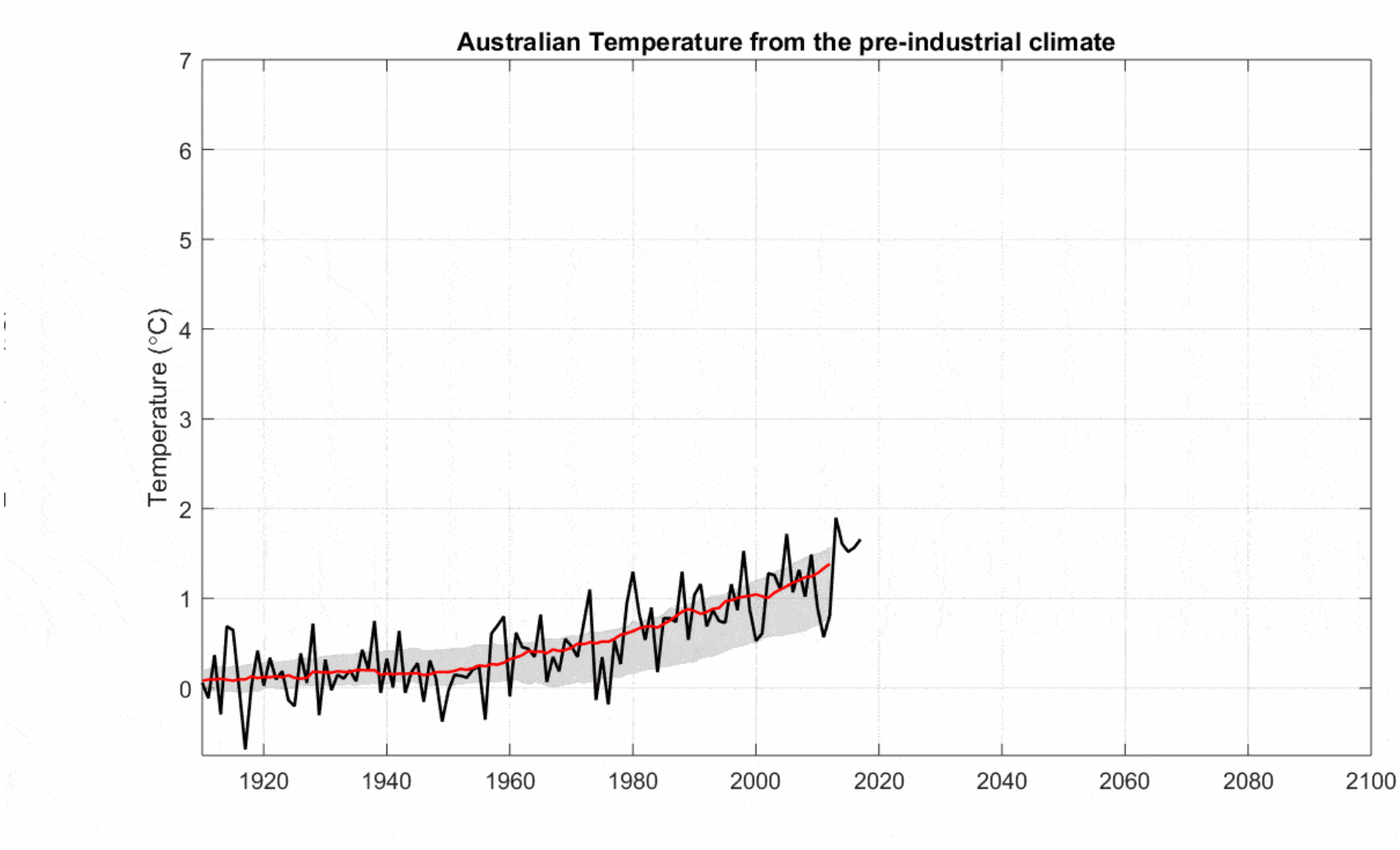
- SSP1-2.6
- SSP2-4.5
- SSP3-7.0

Projected changes in global surface temperatures (multiple lines of evidence)

	Near term, 2021–2040		Mid-term, 2041–2060		Long term, 2081–2100	
Scenario	Best estimate (°C)	*Very likely* range (°C)	Best estimate (°C)	*Very likely* range (°C)	Best estimate (°C)	*Very likely* range (°C)
SSP1-1.9	1.5	1.2 to 1.7	1.6	1.2 to 2.0	1.4	1.0 to 1.8
SSP1-2.6	1.5	1.2 to 1.8	1.7	1.3 to 2.2	1.8	1.3 to 2.4
SSP2-4.5	1.5	1.2 to 1.8	2.0	1.6 to 2.5	2.7	2.1 to 3.5
SSP3-7.0	1.5	1.2 to 1.8	2.1	1.7 to 2.6	3.6	2.8 to 4.6
SSP5-8.5	1.6	1.3 to 1.9	2.4	1.9 to 3.0	4.4	3.3 to 5.7

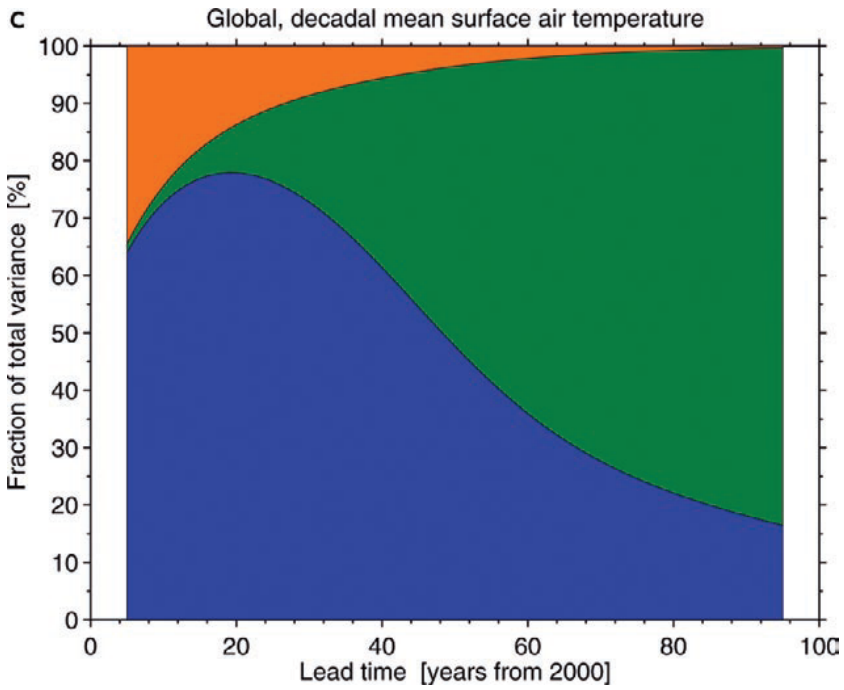
Summary for Policy Makers Table SPM.1, p.SPM-17
Changes relative to 1850-1900

Projections

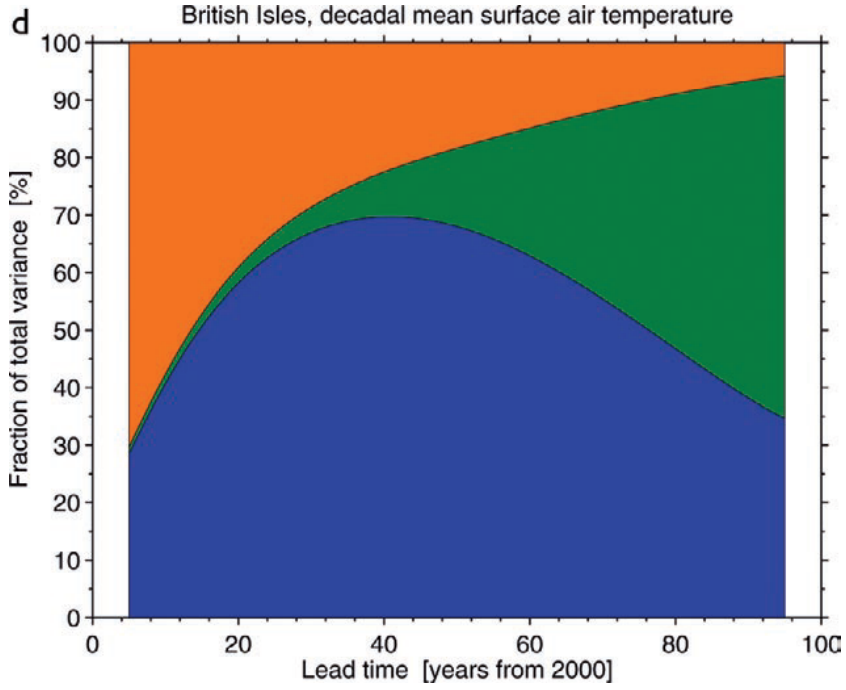


Showing the uncertainties as a graph

Global



Local



Fraction of total variance

Hawkins and Sutton (2009)

Internal variability

Scenario

Models

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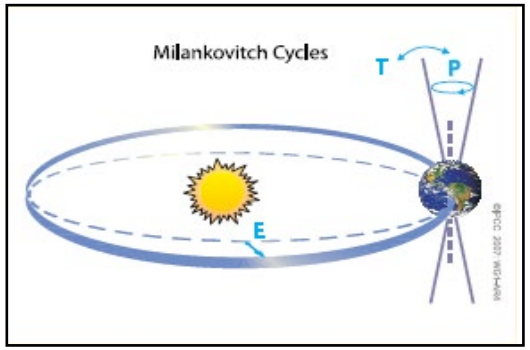
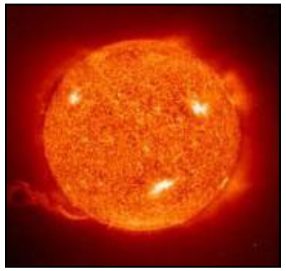
Climate change or climate variability?



Changes in Earth's orbit

1000s yrs

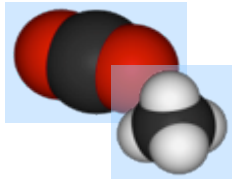


Solar changes

Decades

Changes in greenhouse gases

Natural + Human



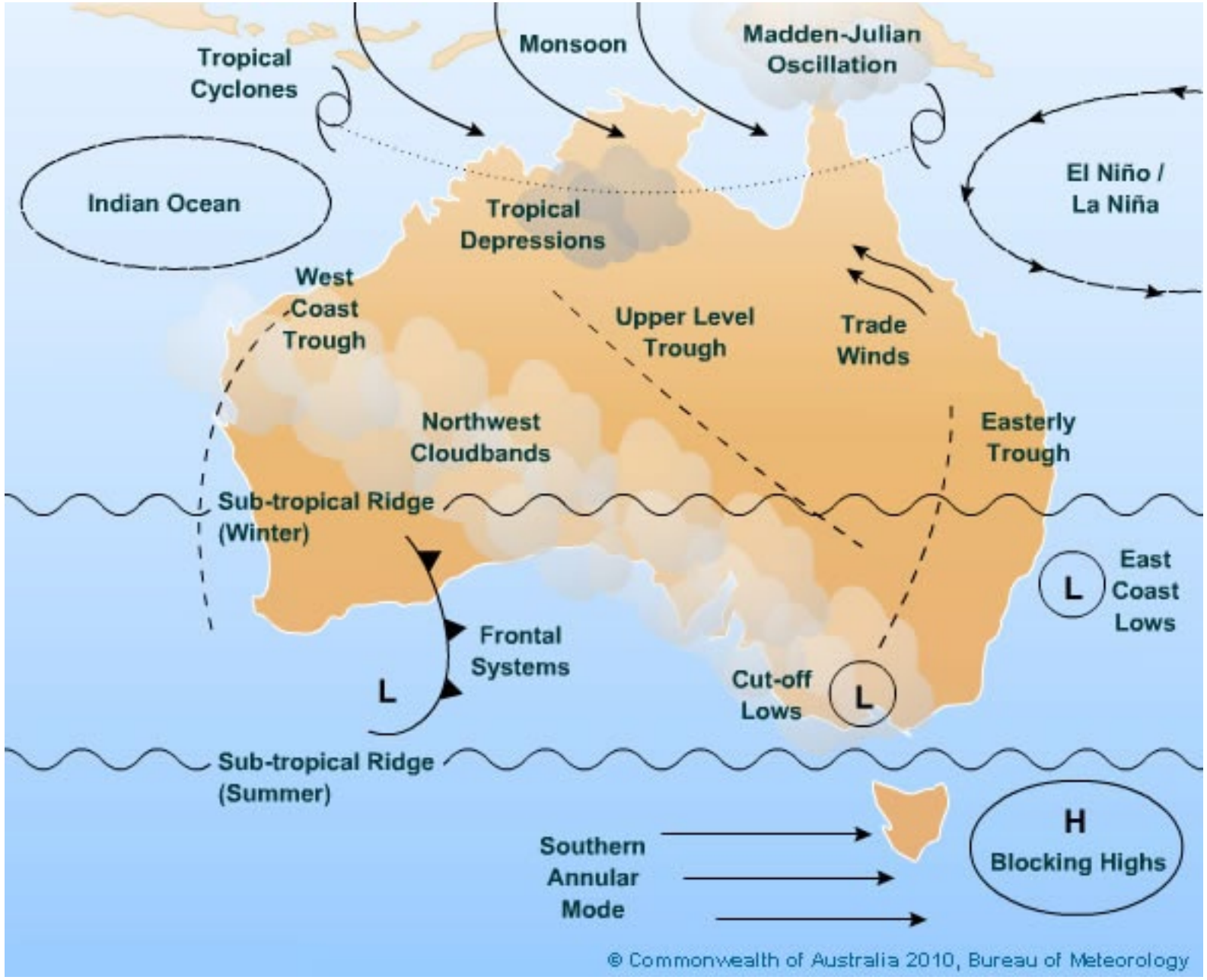
Volcanic eruptions

Unpredictable, impacts yrs

Australia's climate influences

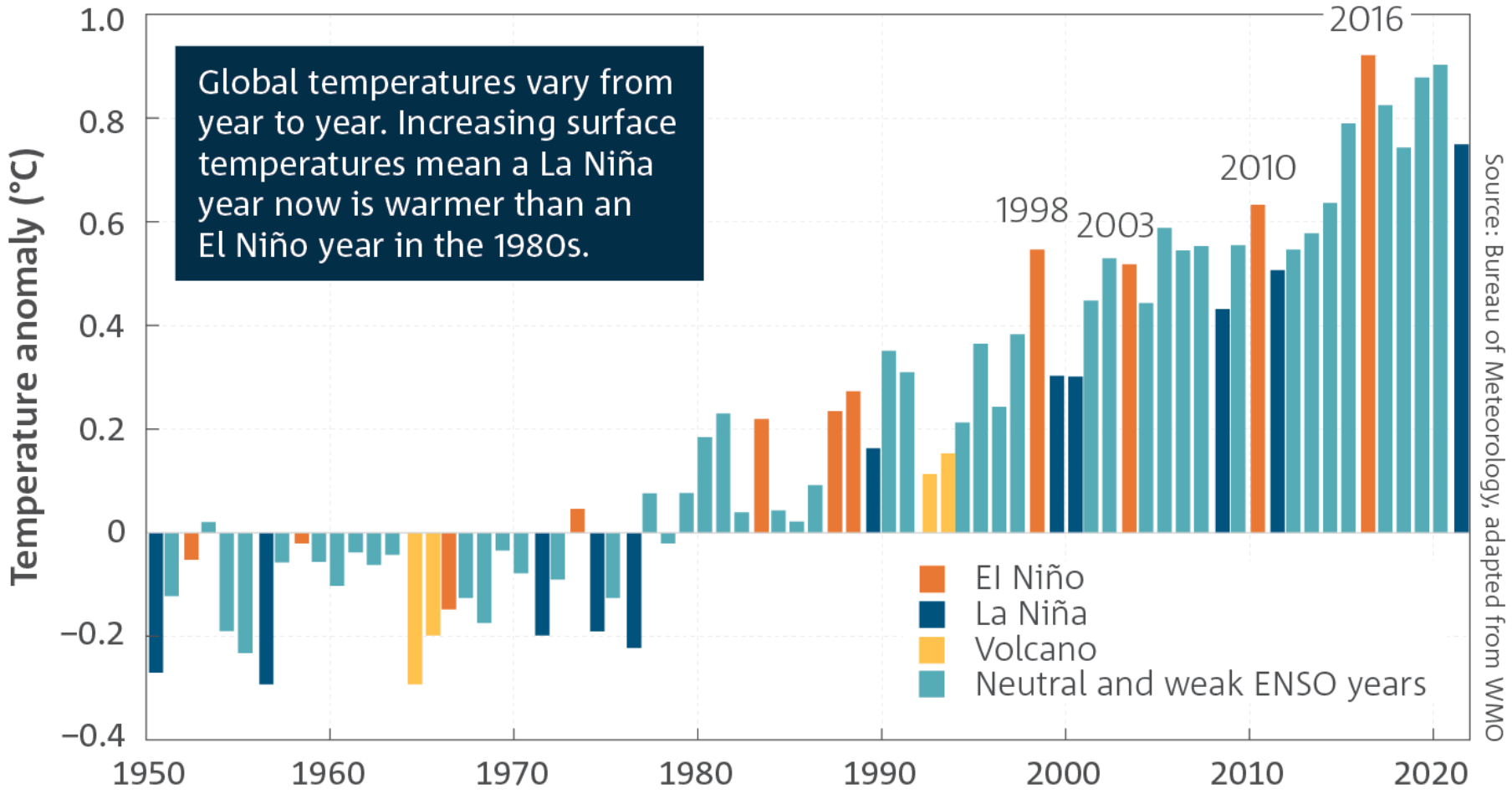
Climate influences or **‘drivers’** modulate the occurrence of particular weather patterns.

These change with season as well!



Global average temperatures

- Natural variability against a background trend
- La Nina 2021 hotter than all El Nino years prior to 2016



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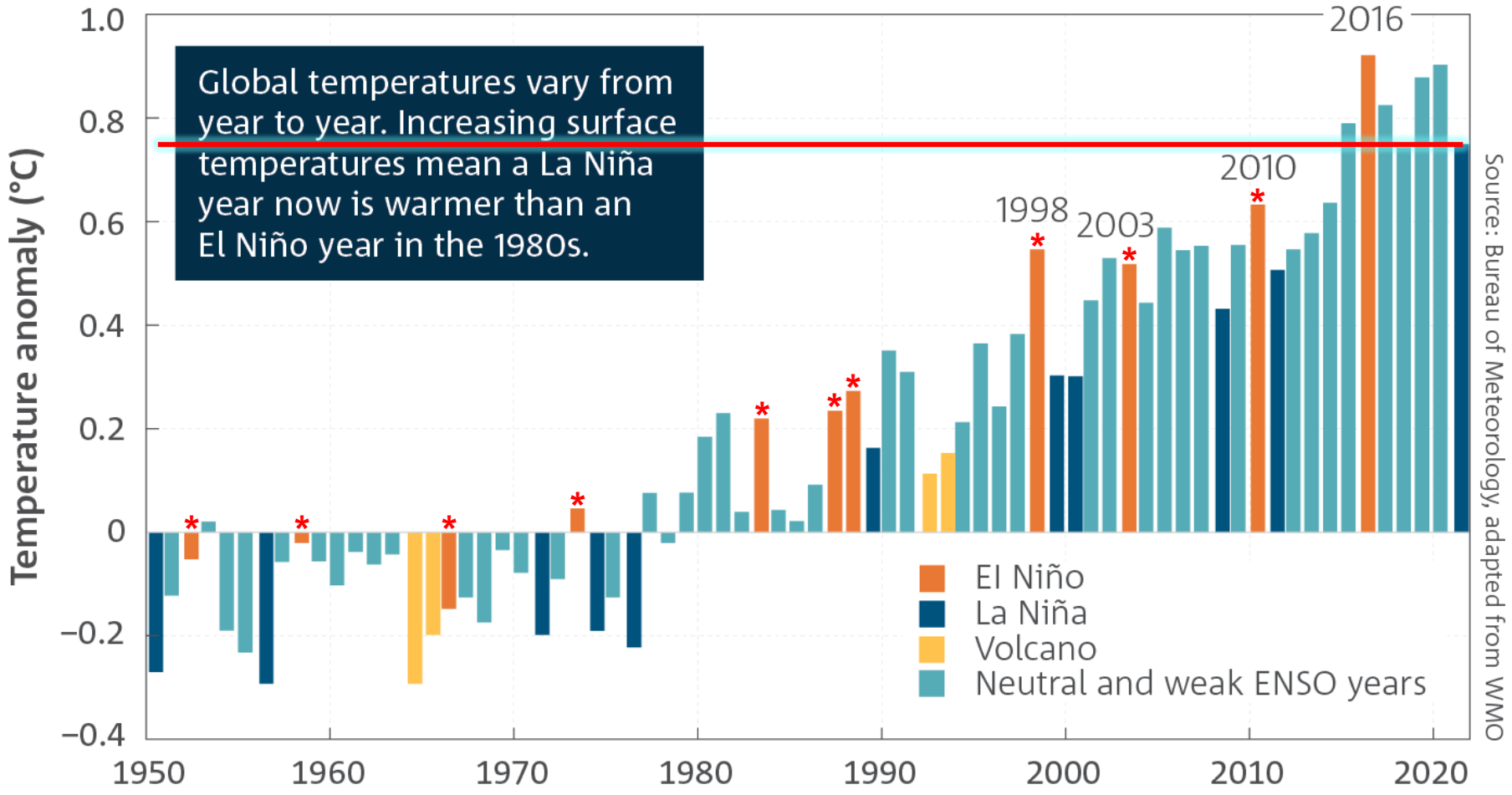


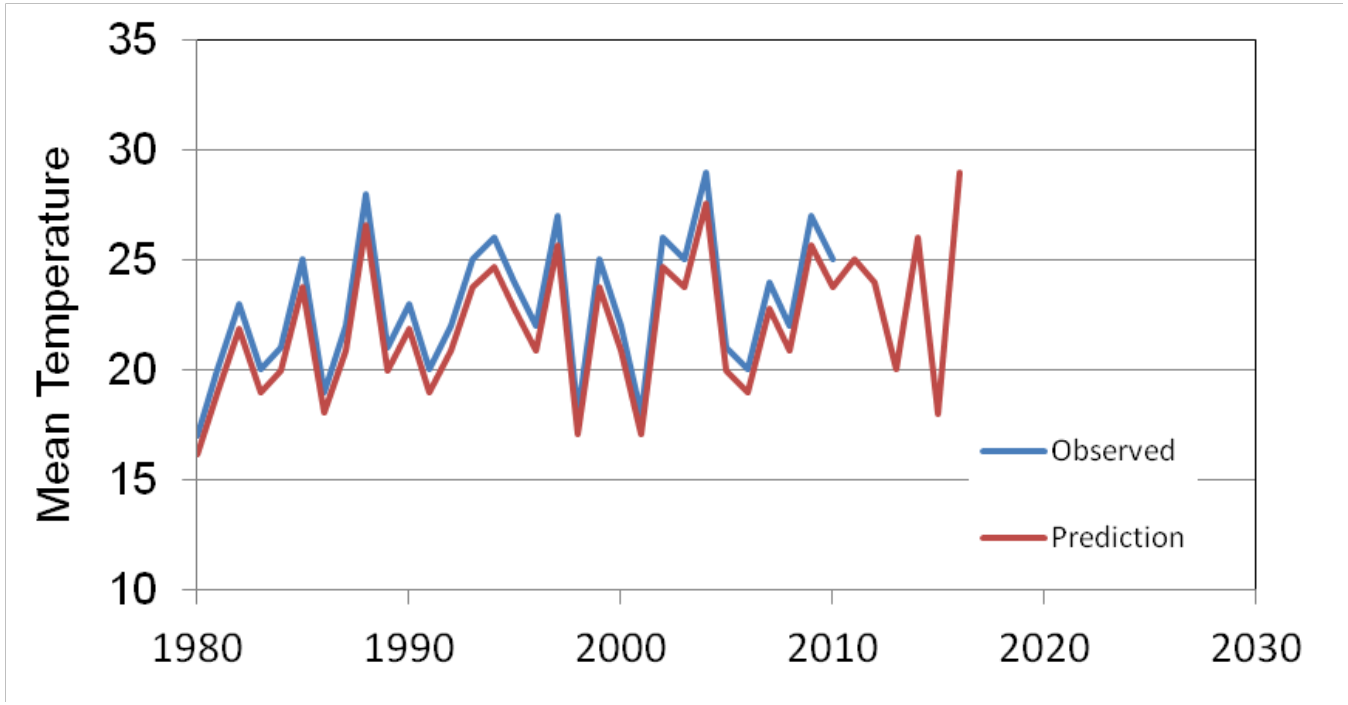
Climate Systems
National Environmental Science Program

Outline

1. What is “climate”?
2. How (and why) has it changed?
3. Climate Projections: the science of describing plausible future climates
4. Why are there different results for the future?
5. What is the role of natural variability?
6. How do I use climate projections?

Projections not predictions

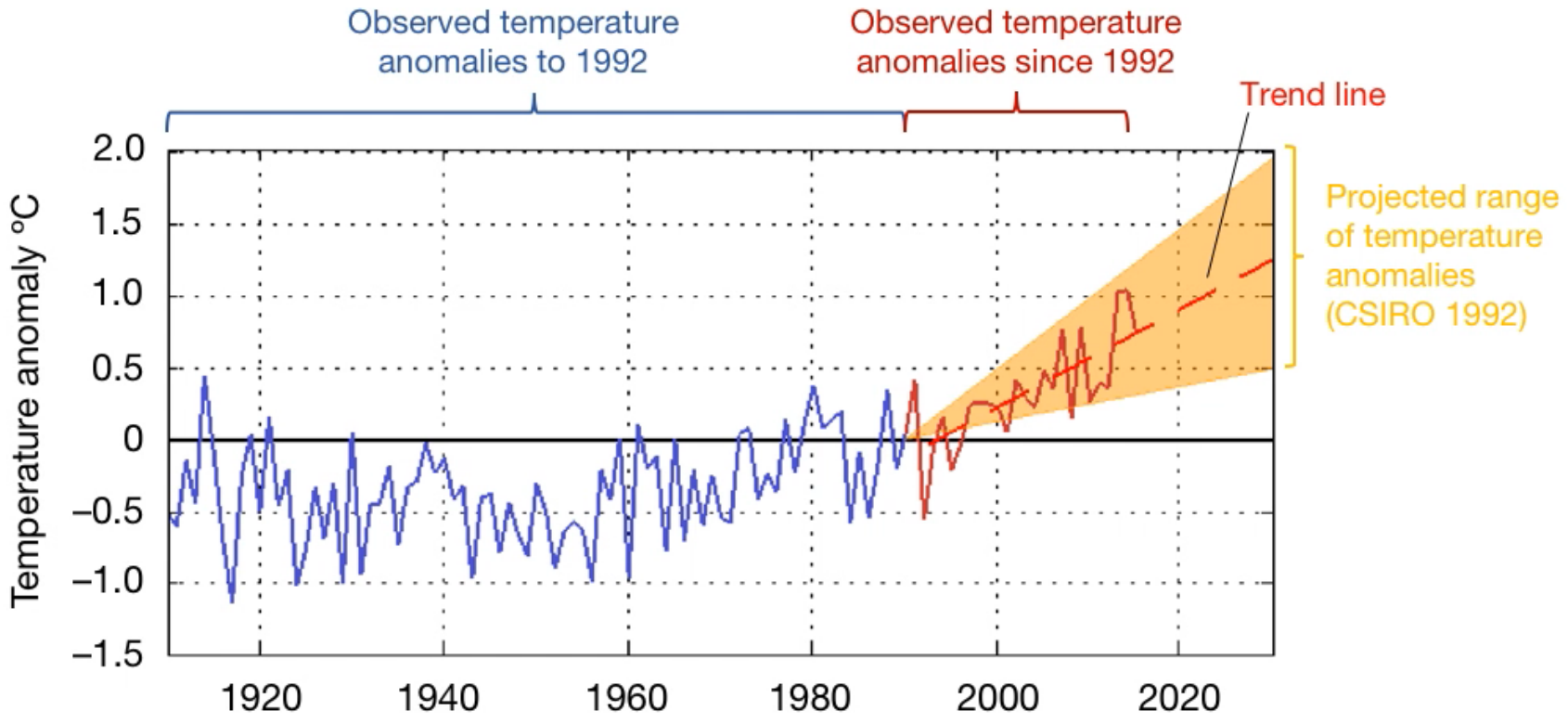
- A ***prediction*** estimates a sequence of events – NOT what climate projections do!



Fri. 20 Sep	Sat. 21 Sep	Sun. 22 Sep	Mon. 23 Sep	Tue. 24 Sep
22	15	12	12	13
15	10	3	4	3

Projections not predictions

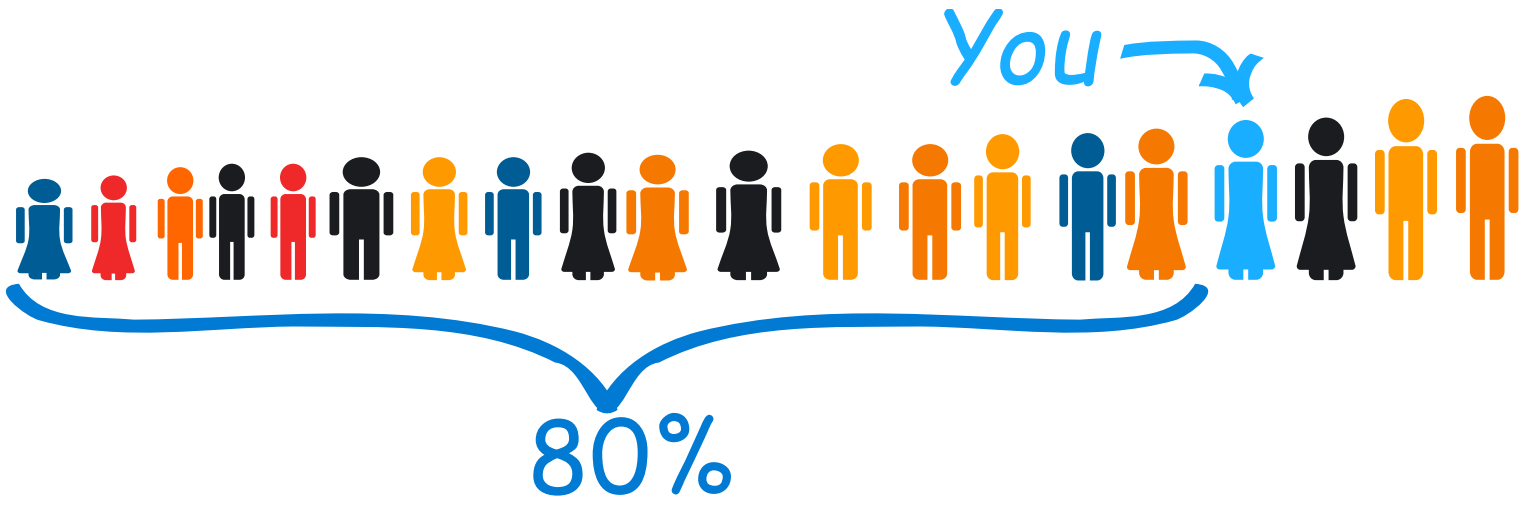
- A ***projection*** simulates the response of the climate system to a scenario of climate change



doi:10.1007/s10584-016-1840-9

Barplots show 10th to 90th "percentile" range

- Percentiles describe how values are 'distributed' within the dataset ('population')
- In example below, not everyone is the same height
- Rank people from shortest to tallest
- If 80% of people are shorter than 'you', you sit at the 80th percentile
- Flipping that around, 20% of people are taller than 'you'



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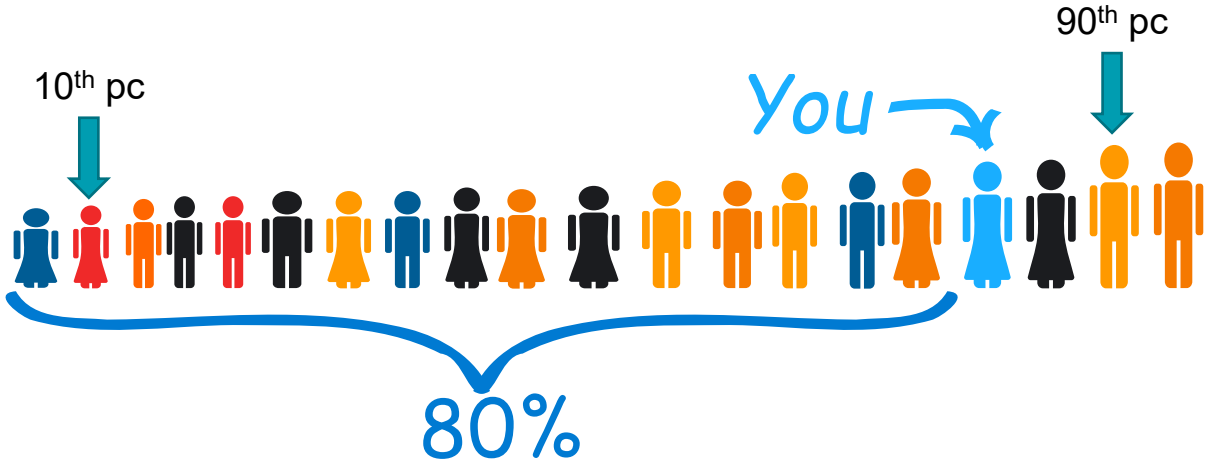
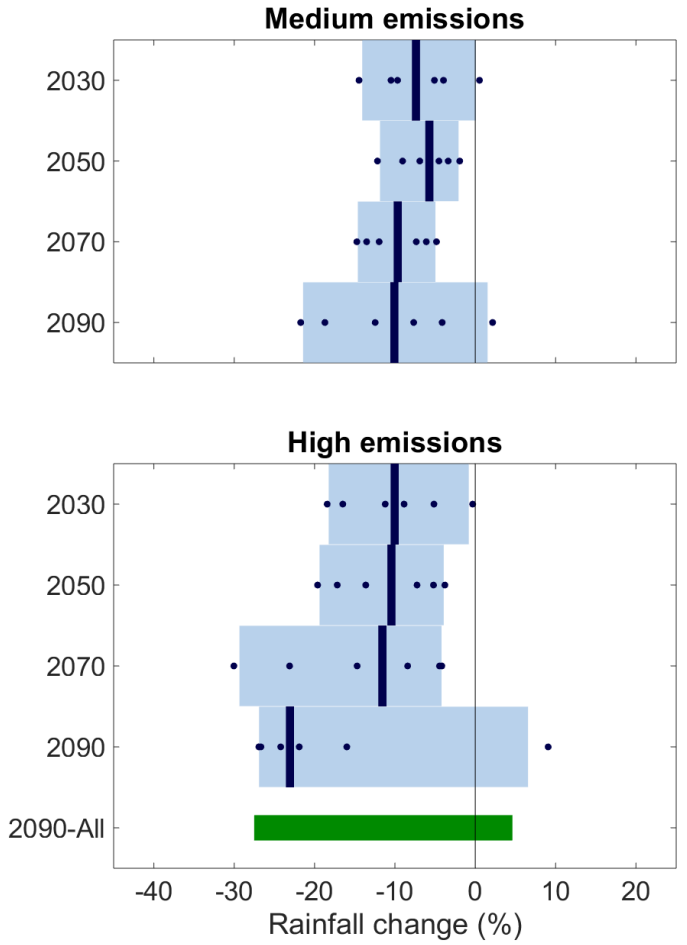
- Flipping that around, 20% of people are taller than 'you'
- Similarly, 10th and 90th percentiles can be calculated



Why?

- It's common practice in science to reduce the prominence of the most rare values
- In projections, this helps to downplay (without discarding the more extreme values for which climate scientists have less confidence
- Note that because there are only six 'data points' (model results) in this example, the 10th and 90th percentiles sit partway between two points (mathematically calculated)



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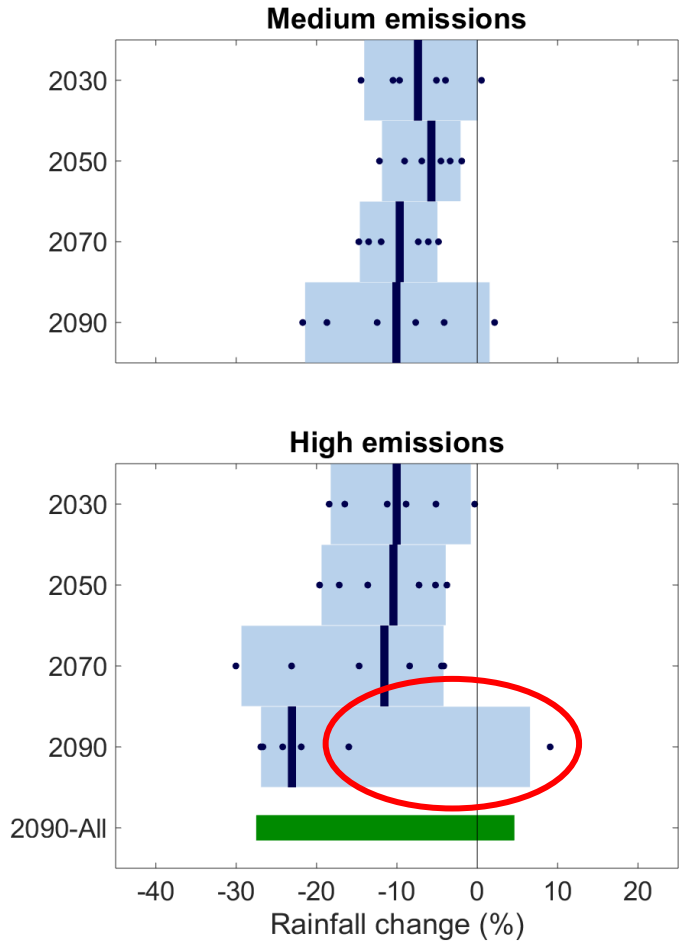
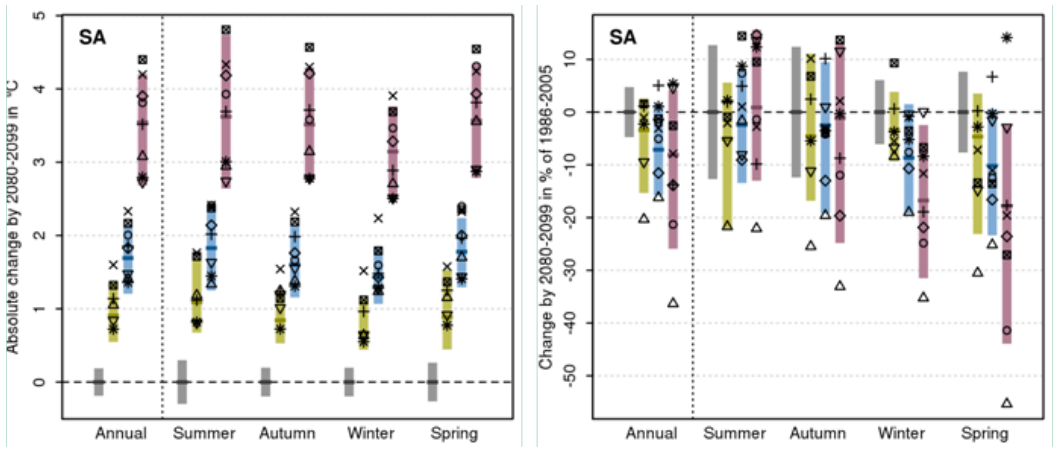
- Note that because there are only six 'data points' (model results) in this example, the 10th and 90th percentiles sit partway between two points (mathematically calculated)
- See how a single 'outlier' value can 'skew' the 90th percentile when there is a small number of values (in this case, 6)
- This is often the case with downscaled data because there are fewer simulations (values) to draw on

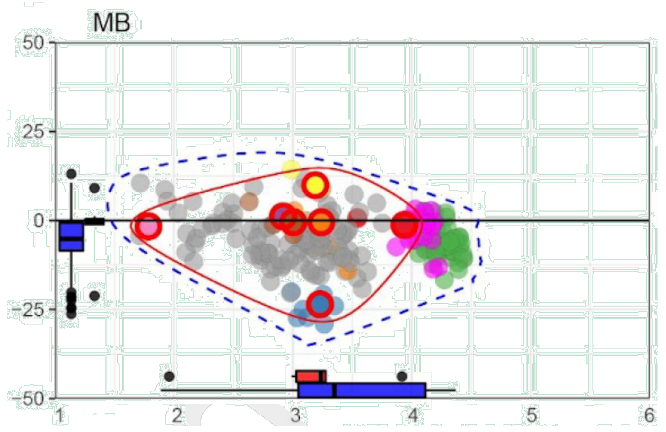


Selecting a representative model sub-set

- CCiA Eight-model subset (CMIP5)
- Australian Climate Service (ACS) working towards a standard subset for
  - Downscaling (strict limitations on choices) – in review
  - General projections (fewer restrictions on choices) – coming



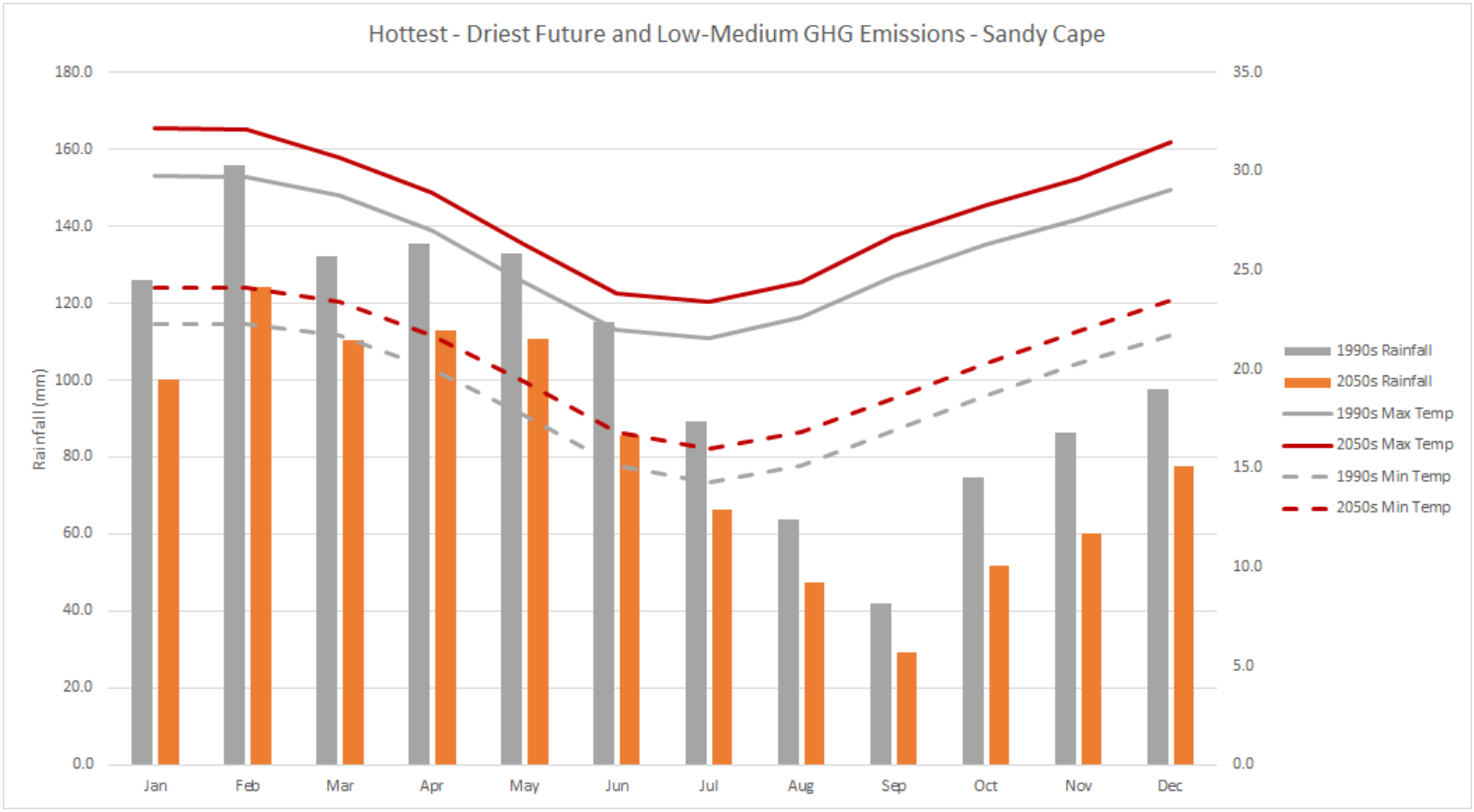
CCiA

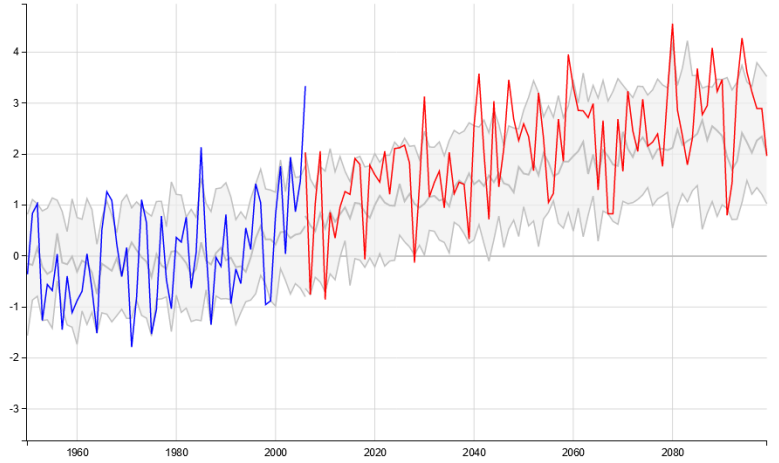


ACS

Hottest, Driest Future

Low-medium emissions





https://www.climatechangeinaustralia.gov.au/en/projections-tools/threshold-calculator/
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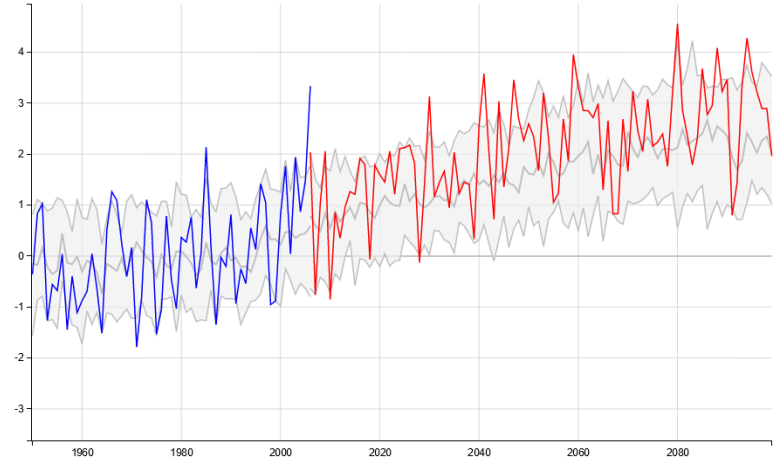

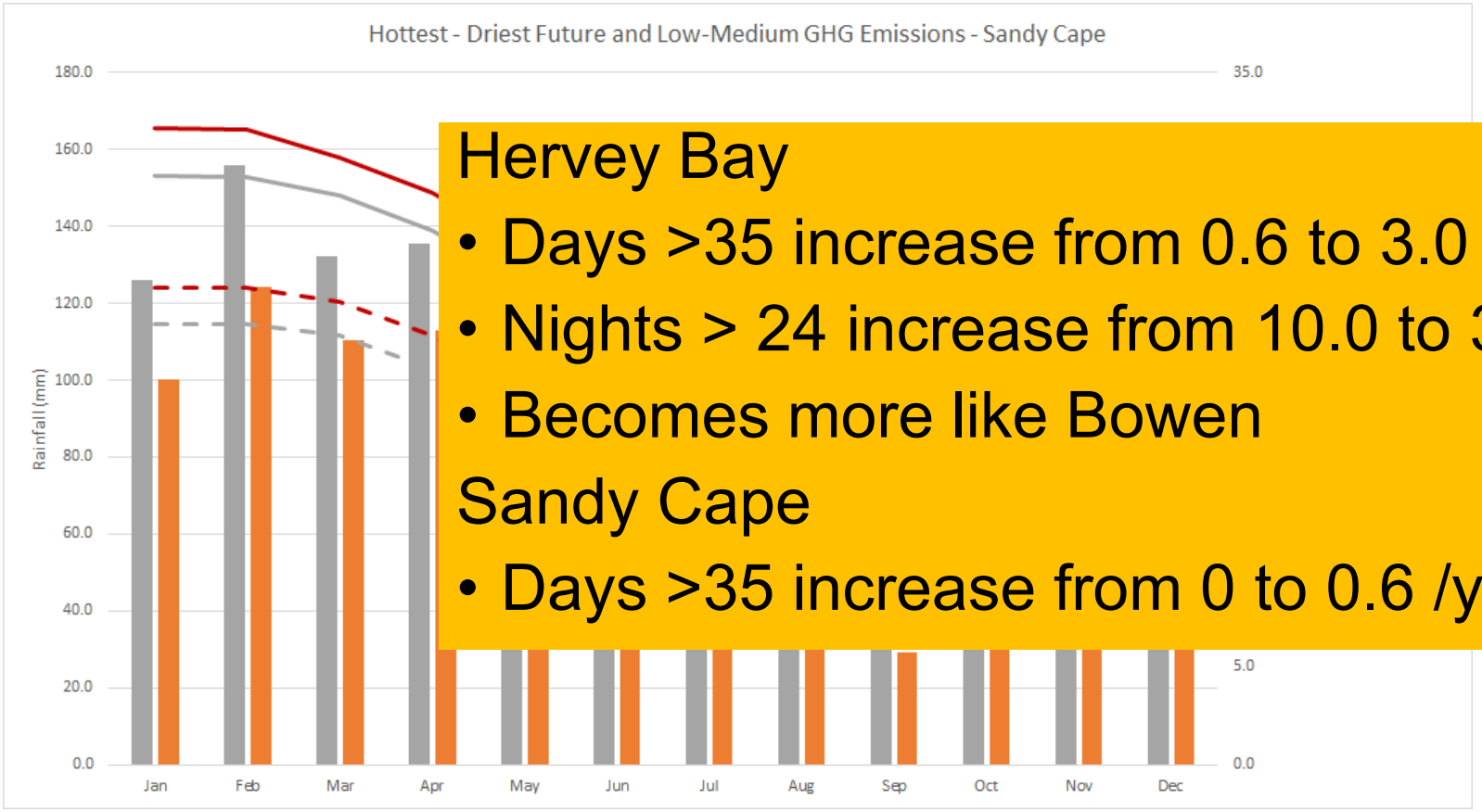

Hervey Bay

- Days >35 increase from 0.6 to 3.0 /yr
- Nights > 24 increase from 10.0 to 36.4 /yr
- Becomes more like Bowen

Sandy Cape

- Days >35 increase from 0 to 0.6 /yr

https://www.climatechangeinaustralia.gov.au/en/projections-tools/threshold-calculator/
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In the lab! | Self-service | Co-design

Robust projections for use

Multiple climate model datasets

Evaluate each model for the region (know their strengths & weaknesses)

Unacceptable skill

Acceptable skill

Describe the total range of futures

ID the important climate metrics for the issue/question

Can projections adequately provide those metrics?

No

Re-assess

Yes

ID which 'futures' have meaning for the issue/question

Check the data for each 'key' future

Do data meet the need?

Yes

Get the data

No

Re-examine

Do you need more help?

No

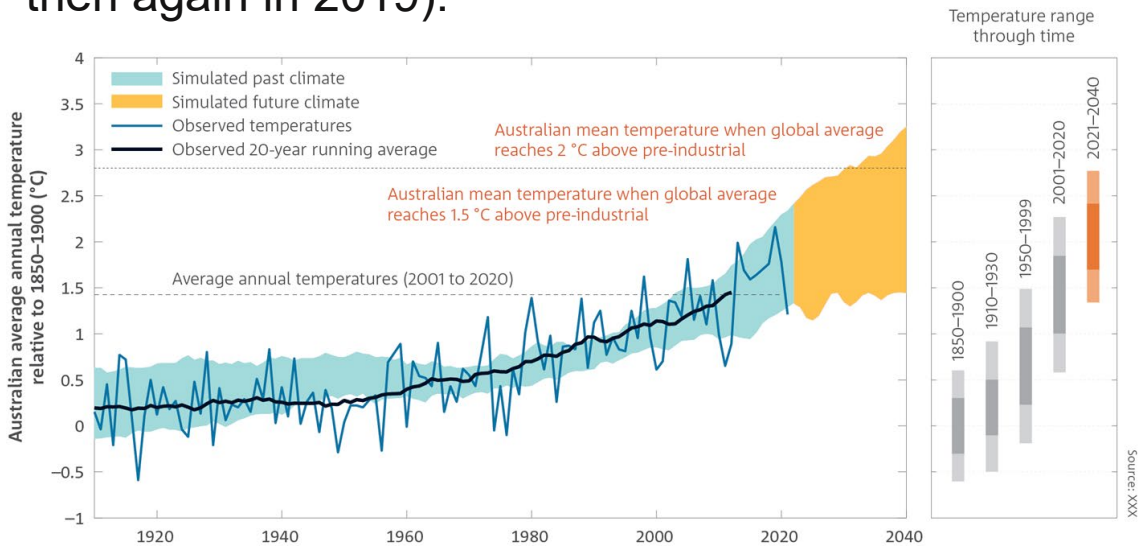
Cool!

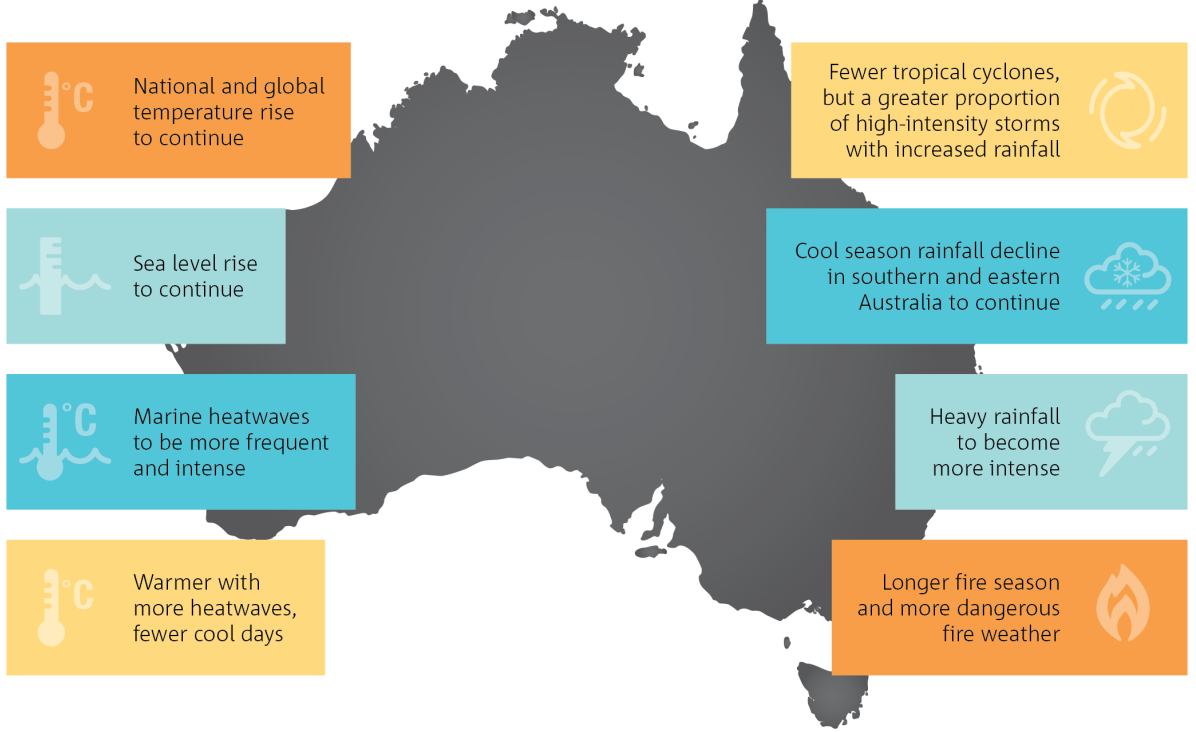
Yes

Co-design solutions

Future climate

Ongoing climate variability means each year will not necessarily be hotter than the last, but the underlying probabilities are changing. This leads to less chance of cool years and a greater chance of repeatedly breaking Australia's record annual average temperature (e.g. record set in 2005 was subsequently broken in 2013 and then again in 2019).





The amount of climate change expected in the next decade is similar under all plausible global emissions scenarios. However, by the mid-21st century, higher ongoing emissions of greenhouse gases will lead to greater warming and associated impacts, while lower emissions will lead to less warming and fewer impacts.

Climate Systems

National Environmental Science Program

Any questions?

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John.Clarke@csiro.au

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Australian Government Bureau of Meteorology

CSIRO

Australian National University

University of Tasmania

UNSW Sydney

Monash University

The University of Melbourne

Victoria State Government Environment, Land, Water and Planning

Government of South Australia Department for Environment and Water