From: Andy Pitman
Sent: Tuesday, 31 October 2023 9:42 AM
To: Portfolio Committee 7
Subject: Re: Inquiry into the Climate Change (Net Zero Future) Bill 2023 - witness invitation
Attachments: Compound Events_Briefing note_DIGITAL.pdf; Detection & Attribution Briefing note_FA DIGITAL.pdf

hi

I was asked to forward two briefing notes I mentioned in my evidence. These are attached.

A third, on Event Attribution is forthcoming.

Thanks

Andy Pitman

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High Impact Compound Events in Australia

- Compound events are combinations of weather and climate hazards that have the potential to cause more severe socio-economic impacts than hazards occurring in isolation.
- Australia has experienced a variety of compound events that have led to loss of life and negatively impacted the Australian economy over the past decades.
- Future climate change will lead to an increase in prolonged hot and dry compound events over all of Australia which is likely to exacerbate fire risk and have negative impacts on agricultural productivity and human health.
- Current climate models project an increase in wet and windy compound events in the northern parts of Australia dominated by tropical cyclones and thunderstorms, and a decrease in events in the south where fronts and frontal systems are the dominant drivers of extreme wind and rain.
- The ARC Centre of Excellence for Climate Extremes is leading research that will ultimately help businesses and governments better assess the risks posed by compound events.

This is the third in a series of briefing notes on compound events. The broad area of compound events science was addressed[1,2], in March 2022, followed by a global-scale assessment of how compound events might respond to climate change in April 2022[3,4].

This report focuses on Australia, at a higher level of spatial detail than is possible globally, and utilises data sets that are specific to Australia. By focusing on Australia, areas of confidence and uncertainty can be more clearly identified. Future work to resolve weaknesses in model agreement is highlighted at the end of this briefing note.

Compound events in Australia

Many major catastrophic events in Australia have characteristics typical of compound events. While climate scientists have tended to focus on single drivers of events (what was the role of La Niña, is rainfall intensifying, how is the risk of heatwaves increasing?), almost all catastrophic events are the consequence of multiple drivers acting together. There is growing awareness that assessment of single meteorological drivers in isolation will not fully capture the potential changes in extreme weather and climate events as the climate shifts. To do so will require an assessment of the risk of multiple hazard events occurring concurrently or consecutively.

Compound events are highly diverse in terms of their characteristics. They may arise from multiple hazards or drivers, they may be a succession of hazards, or be hazards in multiple connected locations, or they may be simply a more severe event as the result of preconditioning[5].

Compound events involve multiple elements of weather and climate jointly causing an impact on a socioeconomic or ecological system.

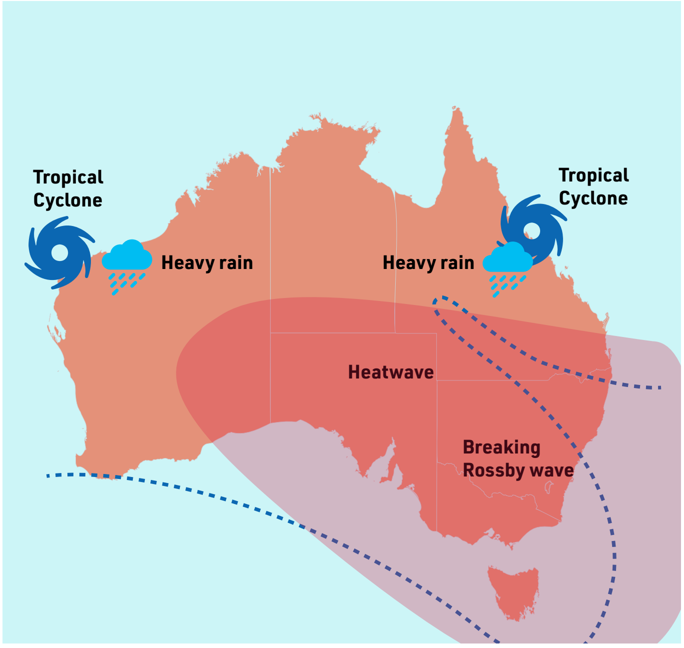
One of the first compound events identified in Australia exhibited both temporal and spatial compounding: the simultaneous occurrence of the 2009 heatwave in Victoria, which culminated in the Black Saturday bushfires, and two tropical cyclones making landfall in Western Australia and Queensland, bringing strong winds and heavy rainfall leading to infrastructure damage and localised flooding. All three events arose because atmospheric processes were connected by large-scale atmospheric dynamics related to atmospheric waves[6,7], (Figure 1).

Similarly, there is a large variety of known connections between atmospheric processes that are likely responsible for up to half of summertime rainfall in the northwest of the continent[8], heatwaves over south eastern Australia[9], and the formation of east coast lows, which can bring extreme rainfall to the eastern seaboard of Australia[22]. When analysing climate hazards, an insurance company might think cyclones occurring in one part of Australia are independent of heatwaves and fire occurring in another part of Australia, but in fact these can be connected through the atmosphere and are not independent.

Some compound events are of the type where multiple drivers combine to lead to a major event. An example was the Black Summer bush fires of 2019/20 in southeast Australia. These were linked with widespread landscape dryness, likely associated with the extended period since the occurrence of a La Niña event and a negative phase of the Indian Ocean Dipole[10]. Together with strong winds, clear skies causing additional drying, and high fuel loads[11] they allowed the occurrence of fires with impacts of the unprecedented extent seen during that summer.

Similarly, the extreme rainfall in New South Wales in 2021/22 combined strong on-shore moisture flow, a blocking high-pressure system over the Tasman Sea, Rossby wave breaking, and a range of important synoptic-scale features. Added to these weather-scale features was a double-dip La Niña which meant that catchments were saturated before the latest and very extreme rainfall occurred[12]. This was a compound event where a series of synoptic-scale mesoscale rainfall features happened to occur sequentially in the same geographic location, and antecedent conditions were important (Figure 1).

These sorts of events are experienced in many regions of Australia. The Australian Royal Commission into National Natural Disaster Arrangements (2020)[13] noted that some communities will have to cope with the effects of multiple natural hazard events immediately, with the prospect of being affected by further hazard events before recovery efforts have been completed. In addition, they noted that to properly manage natural disasters of national scale and consequence, it was necessary to assess the risk of multiple hazard events occurring concurrently or consecutively. Looking ahead, the Australian Prudential Regulation Authority (APRA[14]) has instructed businesses to assess "the impact of multiple extreme weather events arising concurrently" when assessing future climate risk (APRA, 2021). In effect, the Royal Commission and APRA have asked for a clear focus on compound events.



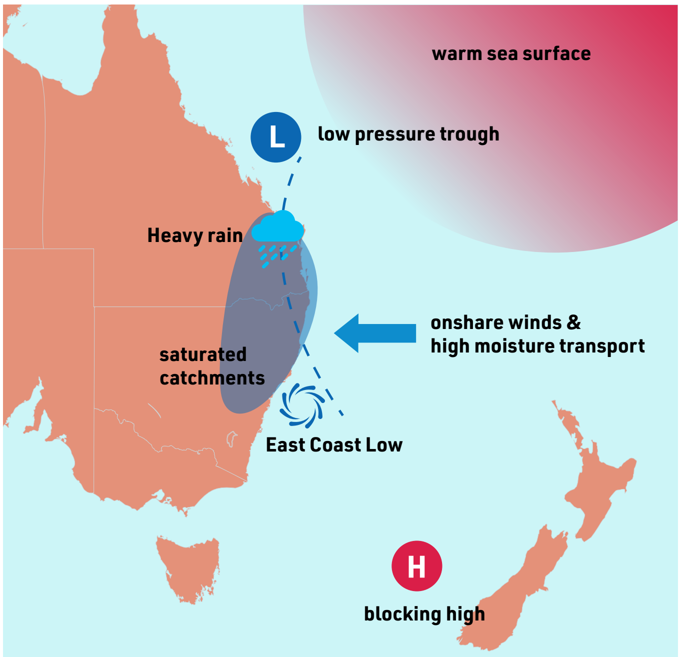


Fig. 1. Schematic of the conditions preceding the February 2009 Black Saturday Bushfires (left), and the conditions that lead to the devastating floods in Queensland and Northern New South Wales in February/March 2022 (right).

Compound events are a key focus area at the ARC Centre of Excellence for Climate Extremes. In recent research, we examined the current and future projected frequency of two important compound events in Australia; the joint occurrence of hot and dry, and wet and windy conditions. We also discuss how our science can inform businesses around the risk of these events in the future.

What do observations tell us about Australian compound events?

The examples above illustrate that compound events can arise from numerous phenomena in a multitude of possible combinations, and from interactions on a wide variety of temporal and spatial scales. From this large set of possible combinations and scales of interaction,

we focused on two compound events that have had significant impacts on the Australian socioeconomic system over the past: the joint occurrence of wet and windy, and prolonged hot and dry, conditions over roughly three decades (1980–2014).

We used a combination of observations and reanalysis data. For rainfall and temperature, we used daily data from the Australian Bureau of Meteorology via the Australian Water Availability Project (AWAP; Jones et al., 2009).

These data are based on in-situ rain gauge and thermometer measurements and are provided as a gridded dataset at 0.05° × 0.05° spatial resolution (approximately 5 km × 5 km).

We obtained 3-hourly wind speed from the European Centre for Medium-Range Weather Forecasts (ECMWF) Reanalysis v5 (ERA5) global reanalysis dataset (Hersbach et al., 2020). Because the ERA5 reanalysis uses satellite data for records from 1979, we limited our analysis to the period from 1980 onwards.

Our analysis focused on relatively mild extremes. This is necessary to provide a sufficiently large sample size to allow statistically significant analyses. Thresholds for wind and rainfall were set at their respective 99th percentiles, which represents an event that occurs roughly 3 times a year. Hot events were defined as three consecutive days with daily temperatures above the 95th percentile of the climatological mean of those days, while dry events were those months with 3-month rainfall of −1.3 standard deviations below the climatological mean. Figure 2 shows the resulting observed return period (the average time between events) for the co-occurrence of hot and dry, and for wet and windy conditions.

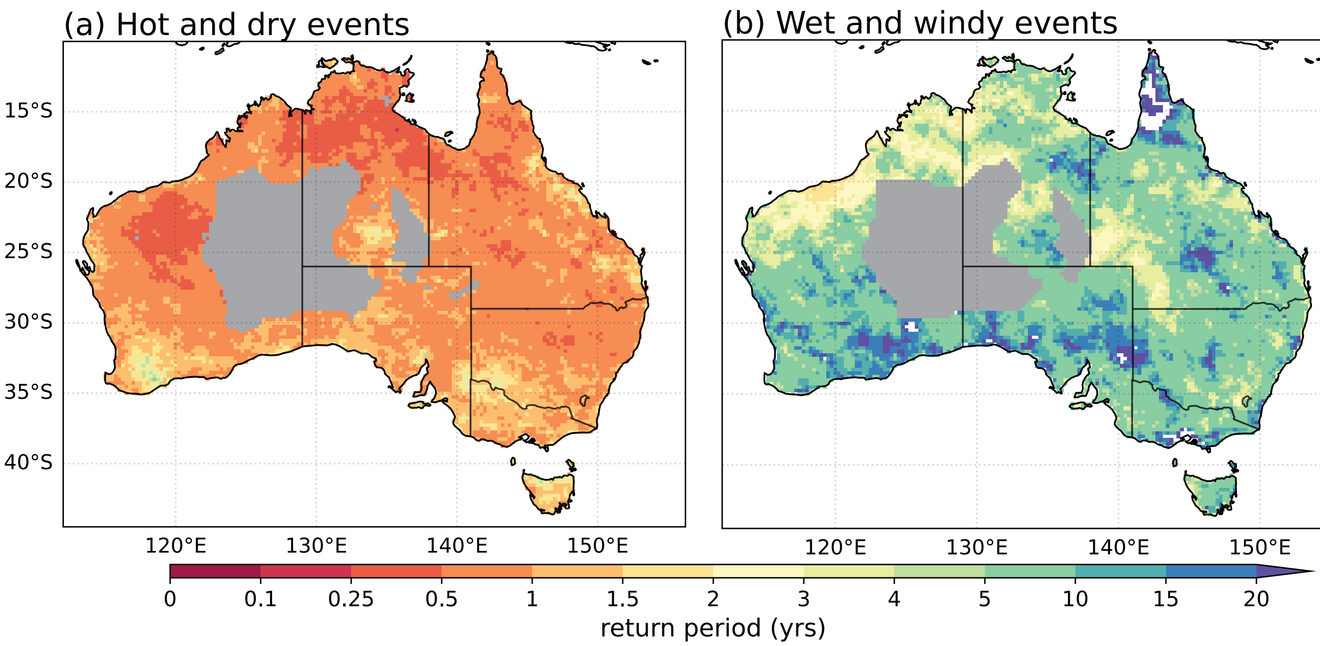


Fig. 2. Observed climatology for (a) hot and dry events and (b) wet and windy compound events derived from the Australian Water Availability Project (AWAP) temperature and precipitation, and ERA5 wind speed, for the time period 1980–2014. Grey areas mask regions where AWAP precipitation data has more than 10% of missing data. Note that the climatology is limited to return periods of less than 35 years due to limiting the datasets to the satellite era, and the statistical method used to determine event likelihood.

How will this picture change in the future?

Global climate models can be used to explore this question, and Figure 3 shows the results for a medium emissions scenario (SSP2-4.5). The medium emissions scenario is a plausible trade-off between the low emissions scenario that is more likely to be an infeasible future and the high emissions scenario with changes that are unlikely to be adaptable to. SSP2-4.5 results in global mean warming of 2.1–3.5°C above pre-industrial levels by 2100.

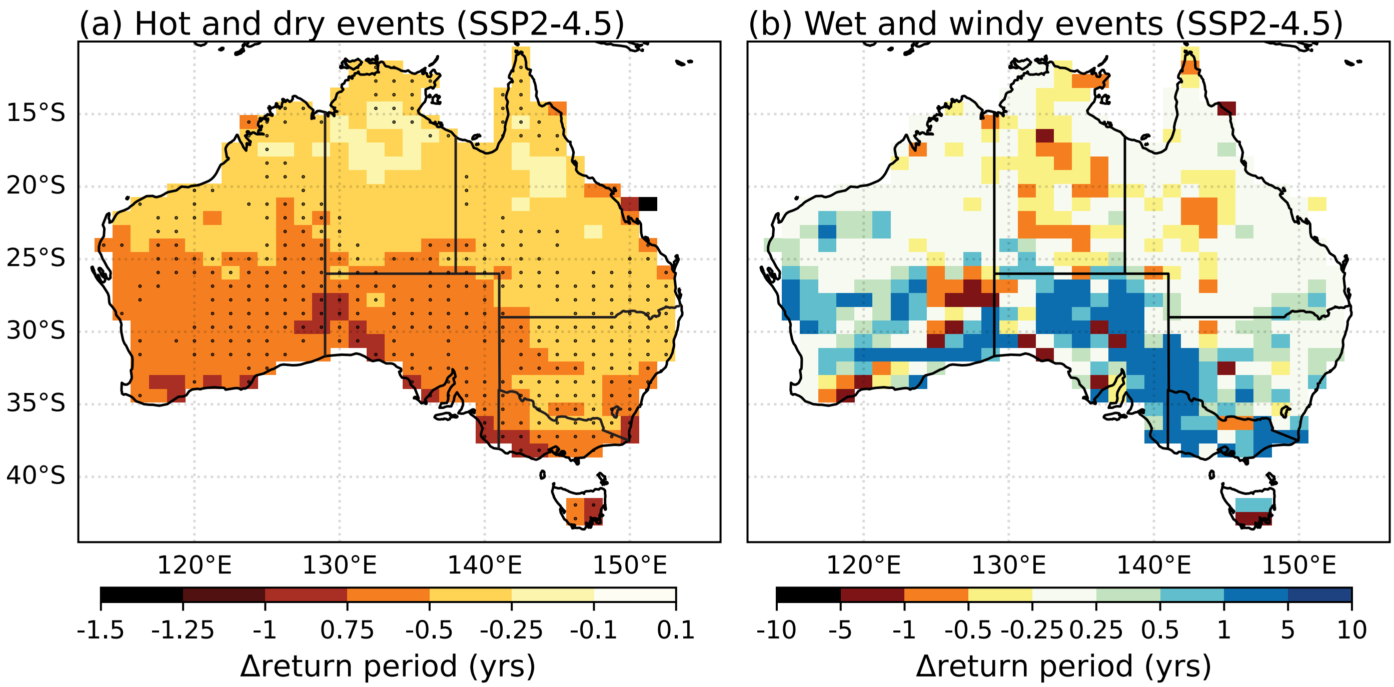


Fig. 3. Multi-model median change in return period for hot and dry, and wet and windy events in 2066–2100 compared to 1980–2014 following a moderate (SSP2-4.5) emissions scenario. The black dots indicate regions where the models produce a reasonably robust result.

Figure 3 illustrates two major features of this future scenario. First, hot and dry events increase everywhere in Australia, indicated by the negative changes in return period. A negative change in return period means an event of a given size that occurs at present, will occur more frequently in the future. The changes in the return period are mostly around 0.5 to 0.75 years, representing a substantial increase in risk. Second, for wet and windy events the changes are generally quite small over the continent as a whole. However, there is an increase in the return period over Victoria, South Australia, and to a lesser degree over Western Australia and New South Wales. At present, these regions experience roughly one wet and windy event every 5 to 20 years (Figure 2b). This is projected to increase by roughly 1 to 5 years on average. There are places where the return periods are projected to decrease but these are scattered across the continent, and may well be unreliable and associated with noise in the climate projections.

To infer information about localised changes, it is not advisable to extract data at a single pixel from this analysis – one cannot infer a signal from just a few pixels. Instead, conclusions should be drawn based on broader spatial patterns that are more likely to be robust. From Figure 3a the result is clear, with the risk of hot and dry compound events increasing for all of Australia. From Figure 3b there is an increase in the return periods for wet and windy events across much of the southern half of Australia, with either no clear signal or a slight reduction in return periods over the northern parts of the continent.

Why do these compound events appear to change in the future?

Hot and dry compound events

The reductions in the return periods for hot and dry events are largely the result of higher mean temperatures over Australia in the future, a trend that has been observed over the last several decades and which can be directly attributed to increasing concentrations of greenhouse gases in the atmosphere. The larger reductions in return periods over the southern half of Australia are consistent with a global-scale analysis of drought intensity and duration. This reduction in return periods, and more frequent hot and dry events, points to a deterioration of conditions for agriculture in the future[15].

The reliability of these results is closely connected to the ability of climate models to represent the two hazards contributing to this compound event. Therefore, an analysis of the skill of the current generation of global climate models to simulate the major drivers of heat extremes in Australia - such as atmospheric blocking, soil moisture variability and land-atmosphere coupling[16] - would be beneficial, combined with an updated analysis of model skill in simulating drought.

Crucial to simulating drought is the ability to capture long-term persistence of dryness, but also the role of the El Niño Southern Oscillation and the Indian Ocean Dipole. These have been shown to be significant climate drivers for the occurrence of hot and dry events. These large-scale processes are captured with useful skill in many, but not all, global models. The reasonable degree of agreement between models on increasing drought intensity and duration and heightened heatwave risk[17] suggests that it is necessary to plan for the changes shown (at the large scale) in Figure 3.

The results for hot and dry compound events have a range of implications for important socioeconomic sectors in Australia.

More frequent hot and dry events across a continent that is already hot and often dry, offers no obvious benefits but implies considerable costs. Figure 3 shows that the reduction in return periods under a moderate emissions scenario will likely affect major agricultural areas (the wheat belt of Western Australia, and major wine-growing regions in Western Australia, South Australia, Victoria and Tasmania) and most major population centres. Under a high emissions future, these circumstances will worsen to include most of the Murray Darling Basin.

Why do these compound events appear to change in the future?

Wet and windy compound events

The contrasting patterns of future change for wet and windy events (Figure 3b) between the northern and southern regions of Australia suggests changes in the contributions from different weather systems.
For example, Dowdy and Catto (2017)[18] show that between 2005 and 2015, univariate wind and precipitation extremes in northern Australia were commonly caused by cyclones and thunderstorm activity, while frontal systems and fronts with thunderstorms caused extremes in the south-west and south-east of Australia. The current generation of climate models currently use spatial resolutions that preclude the simulation of these smaller-scale weather phenomena which are potentially a major driver of changes in the risk of such compound events. Consequently it is not surprising that the contrasting north-south pattern in the change of wet and windy events is not necessarily robust, given that the degree of correspondence between the models is poor (note the lack of black dots indicating model agreement in Figure 3b).

Regions where cyclones and thunderstorms are the major driver of strong winds and heavy rain, i.e. in the northern parts of Australia, are shown as areas where the return periods for wet and windy events shorten in the future (Figure 3b). The large increases in wet and windy return periods over southern Australia shown in Figure 3b are likely associated with regions where fronts are the key driver. An older generation of climate models tended to capture winter front frequency well, but simulated too high a frequency of frontal precipitation with too low an intensity[19]. Examining the changes in the two components of wet and windy for the CMIP6 models would be very useful, but this research has not been undertaken to date.

The above drivers are very challenging for CMIP6 models to resolve. As such, the current generation of climate models generally show lower skill for combined wet and windy conditions compared with hot and dry events.

To improve skill in simulating the detail of these meteorological events likely requires the development of weather-resolving climate models[20,21], that explicitly resolve, rather than parameterise, key processes such as convection.

Conclusions

The acknowledgement in Australia by the Royal Commission (2020) and the Australian Prudential Regulation Authority (APRA) of the need to consider compound events is welcome. Our results provide the first Australian-specific evaluation of how CMIP6 models project the future risks of two important types of compound events. We note, however, that our results need to be interpreted with care.

The results in Figure 3 show broad-scale future changes which may be robust in the case of hot and dry events but are much more uncertain, with little agreement across the CMIP6 models, for wet and windy events.

A tendency has emerged to utilise climate models for decision-making in ways for which the models were never designed for[22]. To avoid potential misuse of our results, we emphasise that these give broad continental-scale indications of how the risk of two types of compound events might change in the future. It would be inappropriate and inadvisable to extract details from small groups of pixels from our results and use them to inform future risk at the local or urban scale.

The advice from APRA that businesses should consider compound events is appropriate and the acknowledgement by the Royal Commission (2020) to assess the risks of compound events is correct. However, the skill of climate models for simulating the change in the risk of almost all types of compound events is very limited. Earlier, we discussed three compound events and we reflect on these to highlight the limits of future projections at this time.

The 2009 heatwave in Victoria, the Black Saturday bushfires, and the tropical cyclones making landfall in Western Australia and Queensland are physically linked via atmospheric processes, Rossby wave breaking and small-scale synoptic processes. At present, global climate models cannot capture fire weather, tropical cyclones or the synoptic scale processes, and whether the models properly connect these phenomena is unknown. The ARC Centre of Excellence is currently examining whether climate models can make these links.

Further, the Black Summer bushfires of 2019/20 in New South Wales required a very long period of extreme dryness linked to long periods since a La Niña event and a negative phase of the Indian Ocean Dipole, together with strong winds, clear skies causing additional drying, and high fuel loads. Our current climate models struggle with capturing long dry periods, and they do not simulate fuel loads. The ARC Centre of Excellence for Climate Extremes is addressing these aspects of ocean and atmospheric variability to determine why climate models struggle to simulate persistent dry periods. In the meantime, the risks of future conditions like 2019/2020 are unlikely to be reflected in our models, and may be underrepresented in future simulations.

The extreme rainfall in New South Wales in 2021/22 combined strong on-shore moisture flow, a blocking high-pressure system over the Tasman Sea, Rossby wave breaking, and a range of important synoptic-scale features combined with two consecutive La Niña events. Our climate models lack the spatial detail to capture all these elements well.

The ARC Centre of Excellence for Climate Extremes is assessing the drivers of the extreme rainfall event to determine what we can, and cannot, say about the risk of these kinds of events in the future.

Compound events over Australia do represent significant risks and are fundamental to many major disasters. At present, however, we urge considerable caution in using global climate models, which do not resolve weather-scales, as part of the risk assessment process in disaster management, business risk, etc. Rather than using climate model output, we suggest using climate models to inform scenarios, storylines[23,24], and stress testing, or using climate models to modify the statistics represented in current-day catastrophe modelling. These approaches can help break the false assumption that the numerical precision in climate models equates to accuracy at a granular level. In many ways, this echoes the need to take climate models seriously, but not literally[25].

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Detection and Attribution

Detection determines whether a change in the climate is outside the historically expected range.

Attribution investigates the causes of detected changes in the climate.

We can use detection and attribution methods to understand our future risks.

Detection and attribution

Detection and attribution science can be used to establish how anthropogenic climate change is impacting the climate. It is the process in which we identify or 'detect' any changes in weather and climate, and assign or 'attribute' the changes to various causes. Understanding the causes of climate extremes, and how they are impacted by climate change is key to assessing future climate risks. Detection and attribution research has the potential to inform a wide range of areas including climate change adaptation and mitigation policy, and disaster management and response.

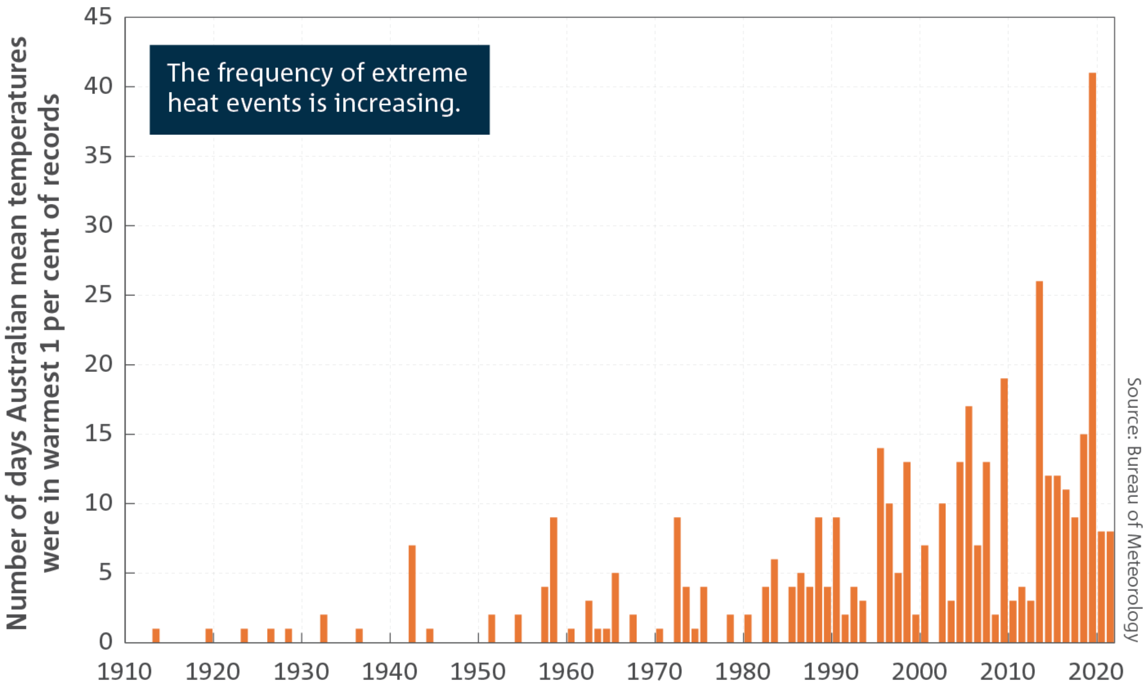
Figure 1: Number of days each year where the Australian area-averaged daily mean temperature for each month is extreme (extremely warm days). Extremely warm days are defined as those where daily mean temperatures are the warmest 1% of days for each month, calculated for the period of 1910–2021. Source: Bureau of Meteorology, http://www.bom.gov.au/state-of-the-climate/australias-changing-climate.shtml

What is detection and attribution?

Detection is the process to determine whether a change in the climate is outside the historically expected range.

It is normal for the climate to vary from year to year due to natural variability (see: Natural variability). However, detection involves identifying a trend that is outside what we expect due to natural variations.

For example, the number of days reaching extreme temperatures has been increasing in Australia since 1950[1] (Figure 1). For 2019, there were 33 days with temperatures over 39°C, exceeding the total number of days over 39°C which occurred across the whole 59 year period from 1960–2018. This is a detected increase which has been unprecedented in the historical period.



Natural variability

There are many different processes that interact to influence the climate we experience. Natural variability refers to changes in the climate that occur due to processes other than human influence. These include processes such as large-scale climate modes like the El Niño-Southern Oscillation (ENSO), volcanic eruptions which can have a cooling effect on the climate, or small changes in the energy received by the Earth's surface from the sun.

Natural variability can lead to large year to year differences in our climate. For example, global temperatures are often higher during El Niño events when heat is released from the ocean to the atmosphere. La Niña years are typically cooler. This cycle means that the increase in global temperatures rise more like a staircase rather than a straight line. Figure 2 demonstrates how year to year differences in temperature are caused by natural variability, but human induced climate change causes the overall long term upward trend.

Natural variability's influence on the climate is important when looking at shorter time scales such as 1 year to 20 years. On longer timescales, the influence of natural variability is minimal compared to human impacts.

Looking across the 1950 - 2022 period in Figure 2[1], the warming trend caused by human impacts becomes evident.

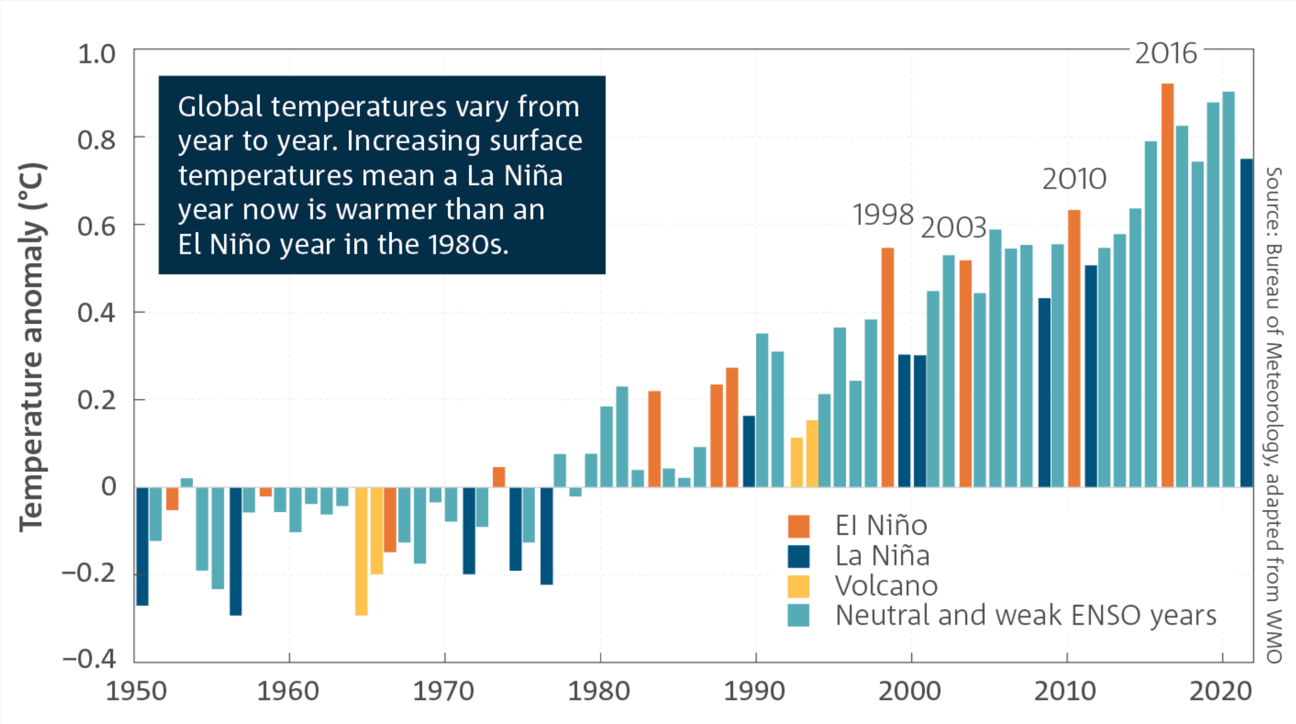


Figure 2: Annual global surface temperature anomalies (deviations from average over 1961-90). Strong El Niño–Southern Oscillation (ENSO) events impact global temperatures. Generally the year after an El Niño event is warmer than average, while the year after a La Niña is generally cooler than average. Large volcanic eruptions cause a global cooling effect. Neutral and weak ENSO years are years where there were no moderate to strong ENSO events. Source: Bureau of Meteorology, http://www.bom.gov.au/state-of-the-climate/

Attribution is the process where the causes of detected changes in the climate are determined.

The causes are known as climate forcings and may be natural (e.g. changes in the solar cycle, volcanic eruptions, La Niña) or human (e.g. emissions of greenhouse gases, deforestation, aerosols).

Two key types of attribution include:

1. attribution of climate variables, and
2. attribution of climate events.

Here we focus on the attribution of climate variables and the process involved in the attribution of a variable.

Attribution of climate variables involves determining the cause of a detected change in a climate variable, such as temperature, precipitation, ocean heat content or sea-level, over a time period. This is often from a pre-industrial period (defined as 1850-1900 in Figure 3) to the present day.

Attribution of climate variables allows us to determine what causes an observed trend in a variable. For example, it is very likely that human influence caused an increase in the global mean sea level (with contributions from sources including melting glaciers, ice sheets and warming oceans) by 0.20m between 1901 and 2018[2].

Figure 3 shows the observed and model simulated changes in global mean sea level due to thermal expansion from different sources relative to 1850 - 1900, a period that shows little change in sea level.

- The orange band shows the historical model simulations of the global mean sea level change due to anthropogenic and natural drivers.
- The green band shows the historical model simulations of the global mean sea level change due to natural forcings only.
- The grey band shows the historical model simulations of the global mean sea level change due to greenhouse gas forcings only.
- The blue band shows the historical model simulations of the global mean sea level change due to aerosols.
- The solid black line shows the best estimate from observations and the other coloured lines show the multi-model mean.
- All shaded areas show the range of results from model simulations.

Figure 3 shows that the observed sea level change is reproduced in model simulations that include both human and natural forcings, but not reproduced if any of these forcings are absent.

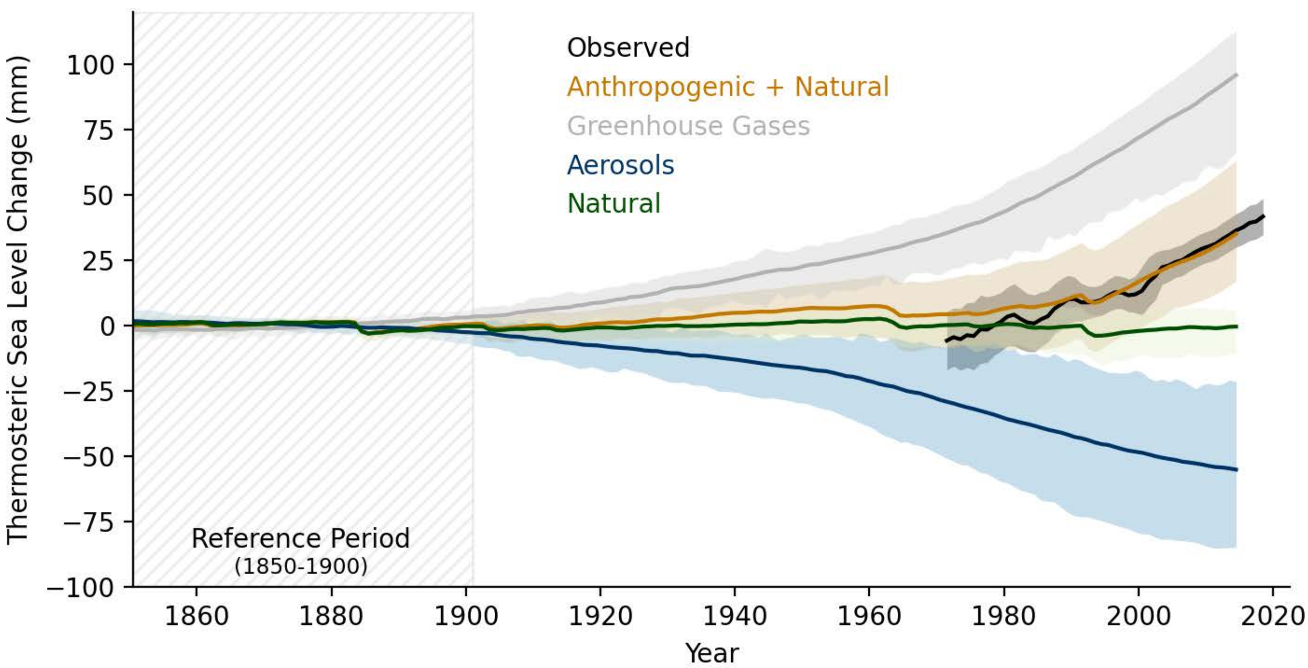


Figure 3: Simulated and observed global mean sea level change due to thermal expansion relative to the reference period 1850 - 1900. The graph shows the thermosteric (due to ocean temperature change) sea level change due to different forcings. Source: IPCC, https://www.ipcc.ch/report/ar6/wg1/figures/chapter-3/figure-3-29

The history of detection and attribution

Detection and attribution science began with the theory that the composition of the atmosphere can impact the climate. This idea goes back more than a century. Before formal methods of detection and attribution existed, scientists were aware that the climate system was sensitive to variations in the amount of energy received from the sun and how that was distributed across the land, ocean and atmosphere and back out into space. In 1856, experiments by the pioneering American scientist, Eunice Newton Foote found that CO_2 absorbs heat. She concluded that an atmosphere with higher concentrations of CO_2 would cause Earth's temperature to increase[3]. This is known as the greenhouse effect, where greenhouse gases warm the climate (see: The greenhouse effect).

Formal methods of detection and attribution, known as 'fingerprinting' were first established in the 1990s. Fingerprinting was used to identify the causes of the observed warming trend in global temperatures and informed the Intergovernmental Panel on Climate Change's (IPCC) Second Assessment Report in 1995.

The report concluded that "the balance of evidence suggests a discernible human influence on global climate". The report noted that to achieve greater confidence, more evidence was required. Across each subsequent IPCC report (2001, 2005, 2009, 2013), confidence in the impact of anthropogenic greenhouse gases on climate change has increased, with improved models, better observational and paleoclimate datasets and new techniques in detection and attribution. By the Sixth Assessment Report in 2021, the IPCC declared "it is unequivocal that human influence has warmed the atmosphere, ocean and land."

The science of detection and attribution has progressed to look at changes in variables other than temperature, including rainfall, snow and ice cover, storms, cyclones and wildfires. Detection and attribution now looks at regional and local scales, as well as individual extreme events. These methods continue to advance and the ARC Centre of Excellence for Climate Extremes (the Centre) is actively contributing to the evolution of detection and attribution science.

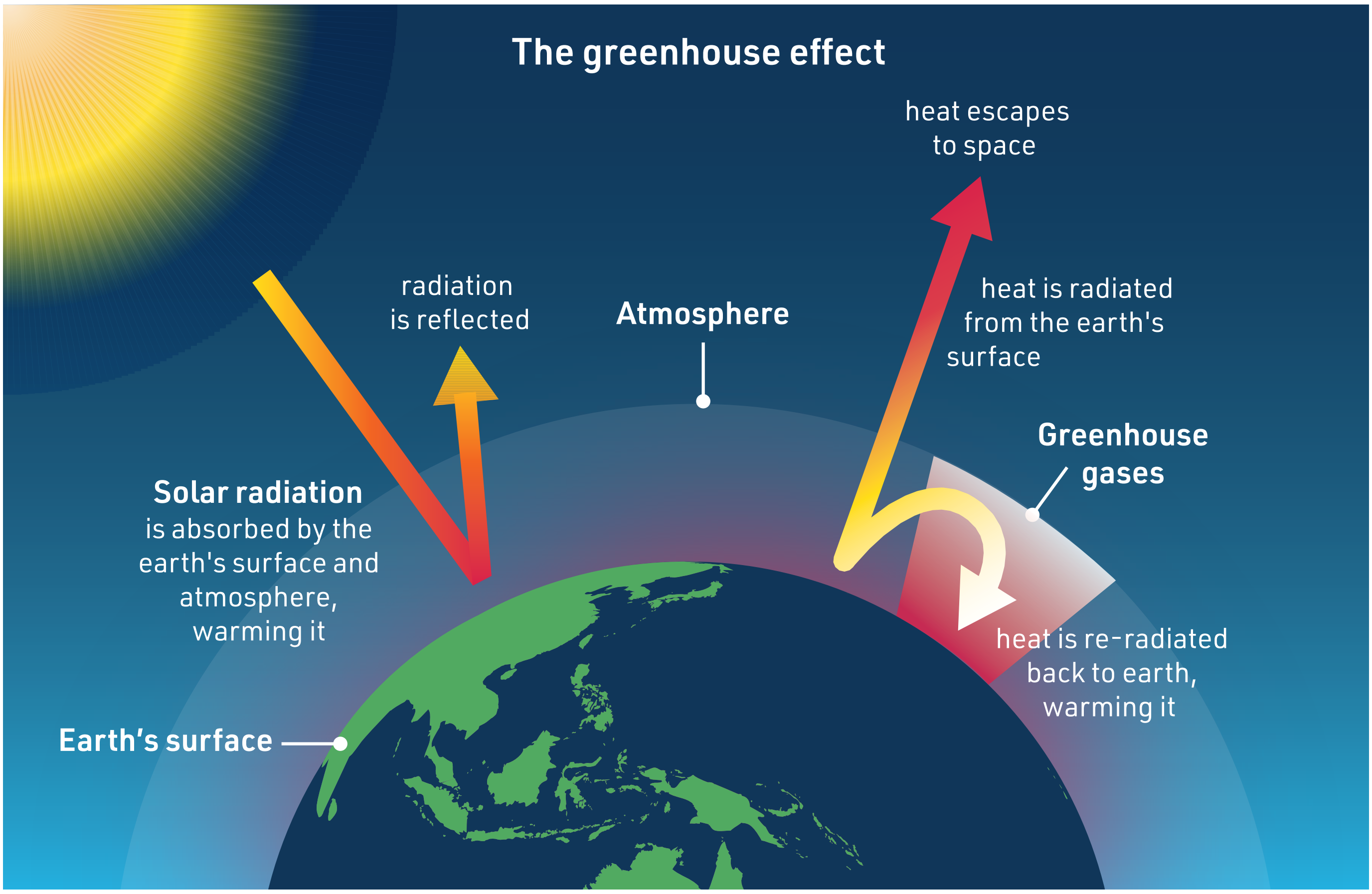


Figure 4: The greenhouse effect is the warming of the earth's surface caused by greenhouse gases in the atmosphere, which interrupt the radiation of heat away from earth and back out to space. When radiation leaving earth hits greenhouse gases in the atmosphere, the gases cause it to re-radiate in all directions, with some of it heading back to earth causing warming.
Source: ARC Centre of Excellence for Climate Extremes.

How is detection and attribution possible?

Usually, three elements are required for a robust detection and attribution study:

- High quality observational data over adequate spatial and time scales (needed for detection).
- An understanding of the physical processes behind the climate variable of interest (needed for attribution).
- The ability to model the climate variable, underpinning processes, and the observed changes (needed for attribution).

Detection: How do we detect a change in the climate?

High quality observational data over adequate spatial and time scales is essential for detecting whether a change in the climate has occurred. To detect a trend, scientists examine the observational record of the variable in question and assess whether significant changes have occurred. This involves comparing recent observations to an earlier time period, or calculating a trend over the whole time period.

Statistical analysis is used to determine whether there has been a statistically significant change in the variable over the time period in question i.e. a change that cannot be explained by chance alone. The choice of statistical tests is chosen based on the variable in question. Statistical analysis allows us to determine if:

- a statistically significant change (not explainable by chance alone) in a climate variable has occurred; or
- there is no significant change and so natural variations in the climate cannot be ruled out.

For example, recent research by the Centre detected that heatwave trends have been increasing across most of Australia since 1951[4] (Figure 5). This study used high quality observational data over Australia and analysed temperature over the 1951-2020 time period to understand how heatwaves have changed. The study detected statistically significant trends across much of Australia, concluding that heatwaves are intensifying, becoming hotter, longer and more frequent. Figure 5 shows areas where the number of heatwave days has been increasing in red, with the black hatching indicating statistically significant trends (i.e. unlikely to be due to chance).

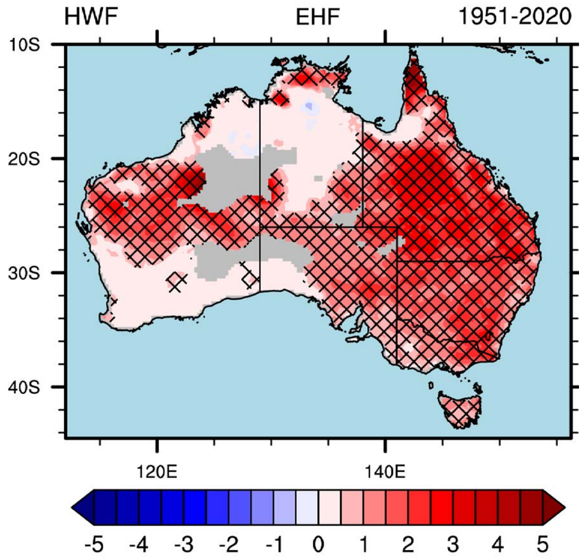
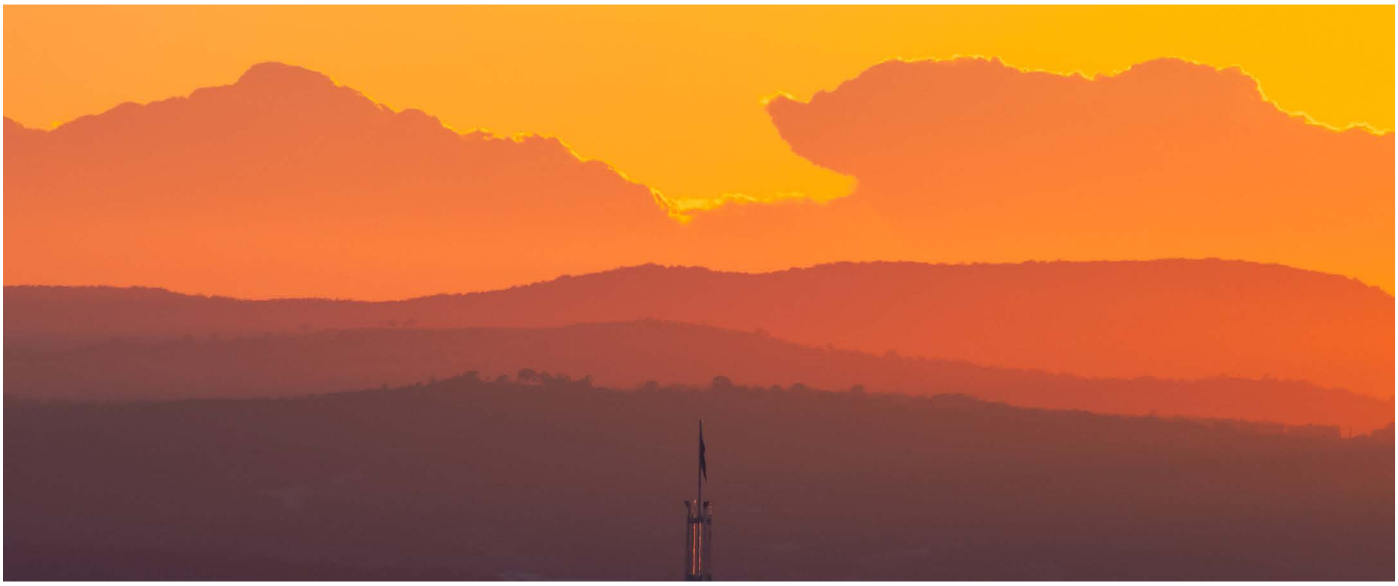


Figure 5: Decadal trends in the number of heatwave days experienced during November-March over Australia for the period 1951-2020. For example, a value of 5 indicates that, on average, an extra 5 heatwave days occur at that location per decade compared to a 1961-1990 baseline. Hatching indicates where trends are significant. Grey areas have limited data for trend detection[4].



Attribution: How do we attribute a change in the climate?

We use climate models to understand more about what causes changes in our climate. Climate models allow us to run experiments where we can study the climate with or without potential causal factors present and see which factors reproduce our observations.

The first step is to evaluate:

1. Do we have a good understanding of the physical processes that impact the climate variable in question?

If climate models do not simulate processes realistically, they cannot provide reliable information on the processes driving the variable.

2. Can climate models simulate this process accurately?

If the model simulates the process of interest well, we can proceed to analyse further simulations. This generally involves running two types of model experiments over the recent historical period (say the last 100-200 years):

- one which includes natural variability and human impacts, accounting for greenhouse gases, aerosols and land use changes (the 'world that was') and
- one which includes only natural variability which demonstrates the climate we would expect to occur without human impacts (the 'world that might have been').

Comparing the two experiments allows researchers to see how human activities have impacted the climate system. Researchers repeat the same experiment multiple times to account for the variability within the models themselves. The results are tested for statistical significance which allows us to formally attribute the observed changes to human activities.

For example, Figure 6 shows the global surface temperature change since 1850 showing observations and model simulations:

- The grey band shows the model simulations of the response in global surface temperature to human and natural forcings.
- The red band shows the model simulations of the response in global surface temperature to greenhouse gases only.
- The blue band shows the model simulations of the response in global surface temperature to aerosols and other human drivers (except greenhouse gases).
- The green band shows the model simulations of the response in global surface temperature to natural forcings only.
- The solid black line shows the observations and the other coloured lines show the multi-model mean.

Figure 6 shows the observational record cannot be reproduced by only natural processes, but models including both human and natural forcing reproduce the warming trend that has been observed over this period.

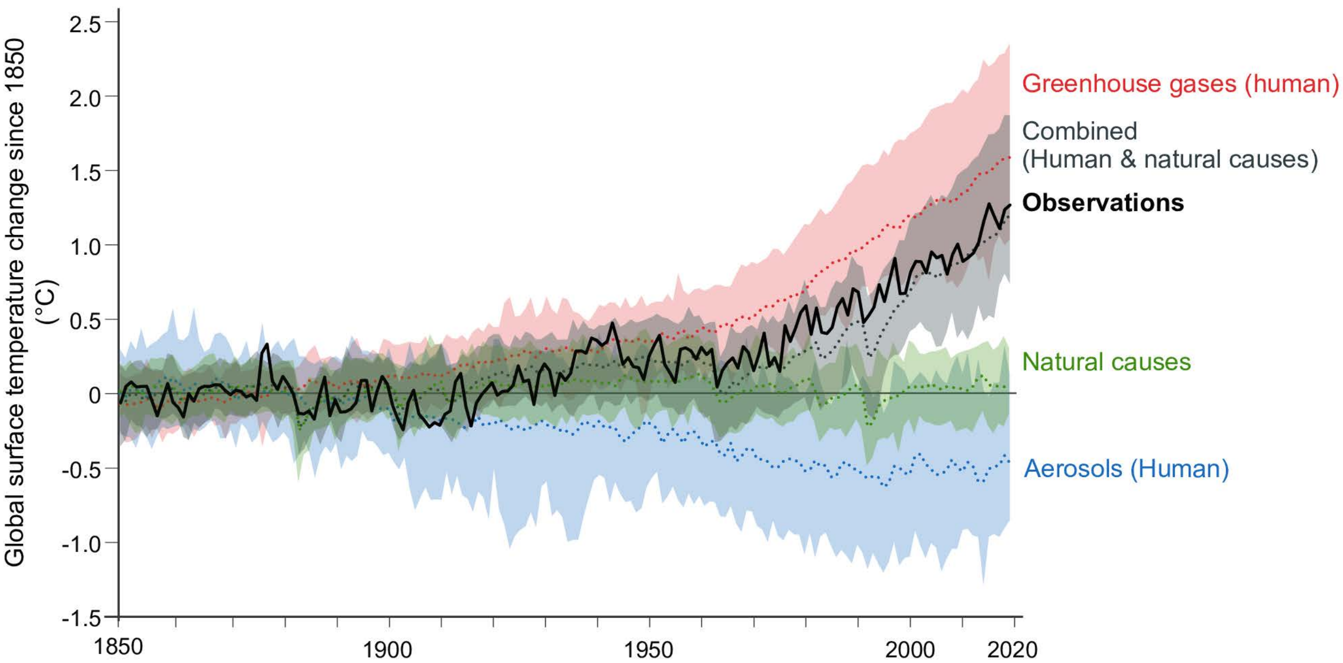


Figure 6: The global surface temperature change since 1850.
Source: IPCC, https://www.ipcc.ch/report/ar6/wg1/figures/chapter-3/faq-3-1-figure-1/

Fingerprinting[5], as described earlier, is used to quantify the influence of each human activity or 'climate forcing'. We create experiments where we isolate individual factors (e.g. greenhouse gases, aerosols or land use change) to see how the climate responds. Each different human activity causes a distinct global warming pattern, or fingerprint. We can compare the fingerprint created by each human activity with observations. This will determine whether the fingerprint from that particular forcing is noticeable in the observations. This allows us to measure the impact of each forcing on the observed variable of interest.

Figure 7 shows the contributions of different climate forcings to the observed global temperature increase since the pre-industrial period using fingerprinting methods[2].

Greenhouse gases have contributed to 1.5°C of warming while other human drivers (e.g. aerosols and land-use change) have caused 0.4°C of cooling.

This has resulted in the net warming of 1.1°C. Solar and volcanic drivers, as well as the natural internal variability of the climate system have not impacted the change in global temperature over this long time period.

It is easier to attribute temperature than other variables

In general, we are more confident in attributing temperature to climate change than other variables. This is because we have a long record of high quality temperature observations covering most of the globe, heat extremes are well simulated by climate models and the physical processes around temperature are well understood.

In contrast, other extremes such as heavy rainfall are much harder to attribute as they:

- often occur on more local scales,
- are more intermittent,
- are more variable in time,
- are less well observed and
- are less well simulated by models.

Some phenomena, such as global trends in droughts or floods are the result of multiple processes occurring over varying periods of time. A drought can be influenced by many factors such as rainfall, evaporation, or changes in vegetation over timescales that might range from weeks to years. Trends in multifaceted phenomena can be hard to attribute to specific anthropogenic forcings and makes detection and attribution much more challenging.

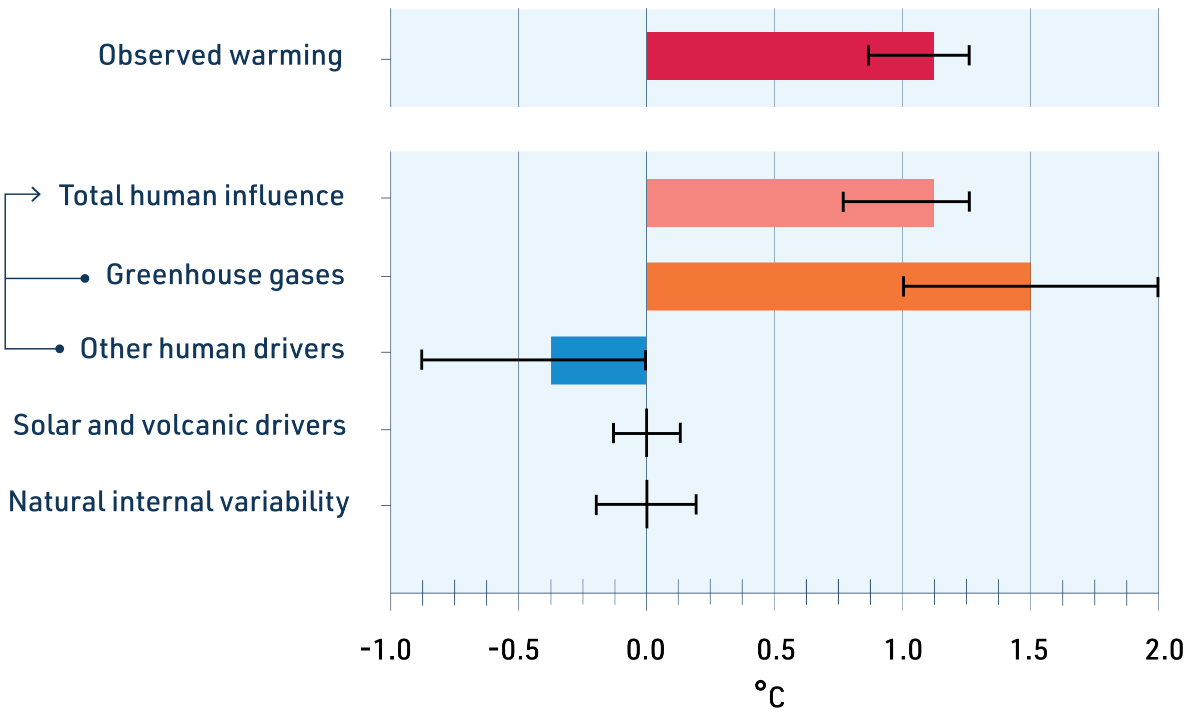


Figure 7: The contributions of different forcings to the observed warming of global surface temperatures. The whiskers on the graph show the very likely range of observed warming and the likely range of contributions from different forcings.
Source: adapted from https://www.ipcc.ch/report/ar6/wg1/figures/summary-for-policymakers/figure-spm-2

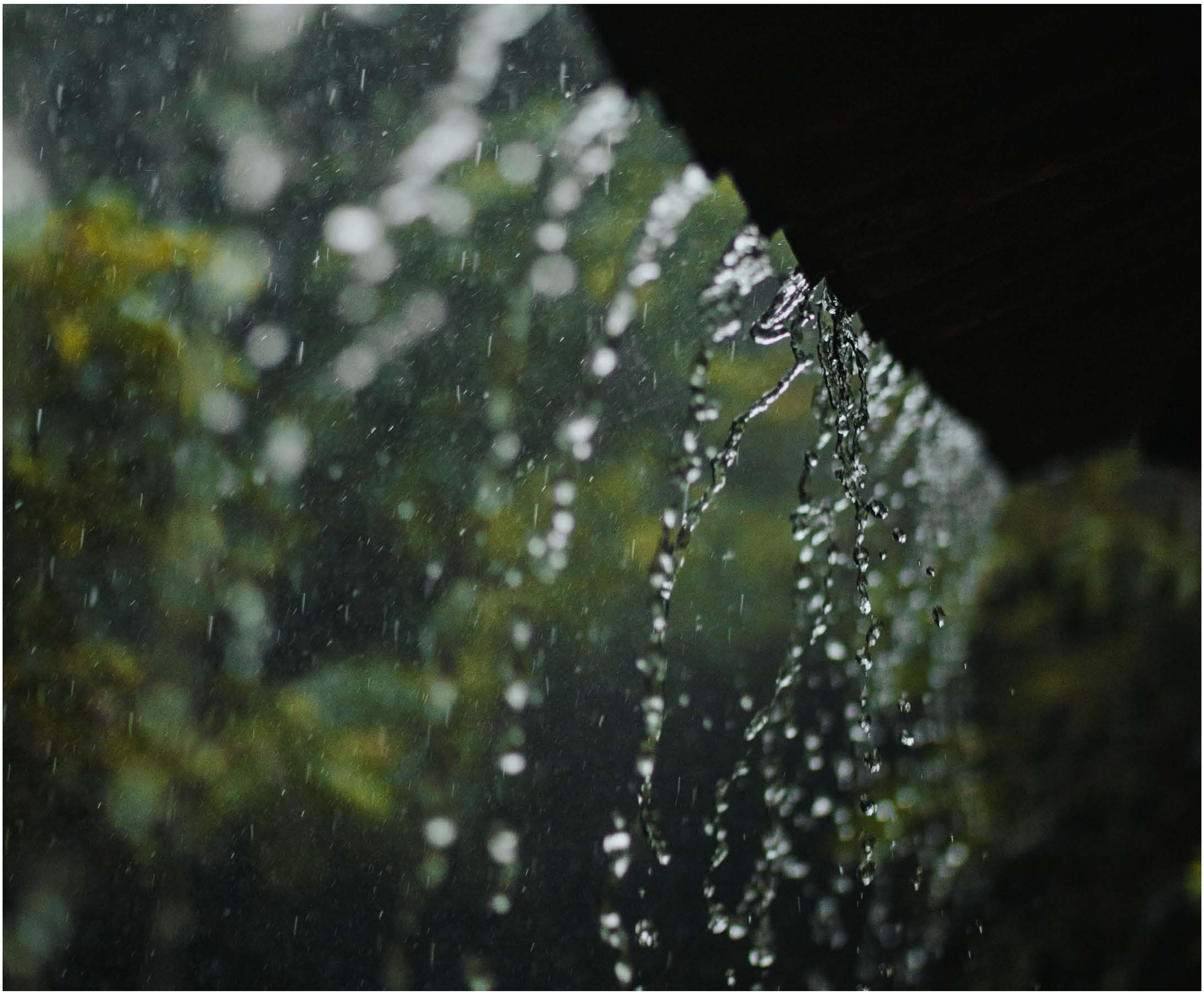
How does detection and attribution relate to risk?

We can use detection and attribution methods to inform policymakers on future risks to humans and ecosystems under different scenarios of future climate change. Through detection and attribution research, it is unequivocal that human influence has warmed the atmosphere, ocean and land. Continued greenhouse gas emissions will cause further warming of the climate. We also know that the cooling effect caused by aerosols will decline over the coming decades, further adding to the warming. Other changes such as ocean warming, sea level rise, changes in rainfall extremes, drought and increased adverse fire weather have been detected[2]. Understanding these trends provides information to anticipate future risks from climate change and plan adaptation.

As detection and attribution methods develop, our capacity to establish causal links to observations are improving. The field of extreme event attribution is evolving, allowing researchers to determine whether specific extreme events have or will become 'more likely', 'more frequent' and/or 'more severe' due to human caused climate change.

Various extreme event attribution studies are now assessing how climate change has influenced the impacts of a specific extreme event, such as health impacts[6] or financial damages[7]. This extension of extreme event attribution is still in its infancy, with the potential to inform loss and damages in debate amongst the science community[8]. However, further developments in this new field have great potential in aiding discussions on the risks or negative consequences of climate change.

Understanding the role of climate change behind costly or deadly impacts allows for mitigation and response systems such as building codes or public health resources to be sufficiently bolstered[9], particularly as the risk of impacts increases.



What is the ARC Centre of Excellence for Climate Extremes doing to advance attribution science?

The ARC Centre of Excellence for Climate Extremes undertakes fundamental research that improves our scientific understanding of physical processes and the capability of climate models to simulate the processes. The Centre is also developing methods such as machine learning to produce faster, cost effective results to expand the information from model experiments.

Recent research at the ARC Centre of Excellence for Climate Extremes has shown:

- The overall intensity of the 2017/18 Tasman Sea marine heatwave was virtually impossible without anthropogenic forcing[10].
- Global average marine heatwave frequency and duration has increased by 34% and 17% respectively, resulting in a 54% increase in annual marine heatwave days[11]. Importantly, these trends can largely be explained by increases in mean ocean temperatures, suggesting that we can expect further increases in marine heatwave days under continued global warming.
- Rapid rain bursts have intensified over the past two decades by around 40% in Sydney[12]. This is an unexpected rate of change beyond anything that has been seen before and is the first time this phenomenon has been clearly documented anywhere in the world. This trend could not be attributed to natural variability, leaving climate change as a possibility, but further research is necessary to pinpoint the exact cause of this trend.
- More than 50% of the land surface has experienced robust changes in these hydrological cycle components since 1980[13]. Of particular concern is increasing water-resource stresses in key breadbasket regions, including in Australia, and in some densely populated areas. Using observations, data assimilation approaches and machine learning, the results support the general conclusion that over land "wet gets wetter but dry does not get drier".
- Evapotranspiration (the water evaporating from the soil, land surface and through plant leaves) shows an increasing trend since 1980 over most of the earth's surface[14].
- Currently the Centre is investigating the causes of the 2022 East Australian extreme rainfall events using observational analysis and high resolution climate models.
- The Centre is developing hypothetical experiments where we remove the influence of large-scale drivers like ENSO to understand teleconnections to Australian rainfall.

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