



Australian  
Centre for  
Disease  
Control

# Guidance on climate risk assessment and adaptation planning for Australian health system organisations

**Climate and Health Hazard Data – Methodological Report**

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# Introduction

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## About this Methodological Report

This *Methodological Report* accompanies the *Climate and Health Hazard Data*, providing detailed descriptions of the concepts, datasets, and analytical methods used to assess climate-related hazards relevant to population health across Australia. The report serves as a technical companion to the main manual, offering transparency about data sources, modelling techniques, and indicator development.

The report begins by outlining the historical baseline conditions and the climate scenarios applied to model future climate hazards. It then describes the climate models and time horizons adopted for the analysis, ensuring consistency across hazard assessments. Subsequent sections present the analytical frameworks, data sources, and outputs for each of the 6 key climate-related hazards examined: heat and humidity, fire, drought, rainfall and flood, storm and coastal inundation. Each section defines the indicators used, summarises the methods of calculation, and explains how results are aggregated and reported at the health district level.

Finally, the Methodological Report provides references for the data products, modelling frameworks, and scientific literature underpinning the analysis. Together, these sections ensure that the methodological foundations of the *Climate and Health Hazard Data* are clearly documented, reproducible, and aligned with current climate science and health impact assessment practices.

# Health district methodology

The *Climate and Hazard Data* provides climate information for 53 health districts across Australia. The 53 health districts are based on [Local Hospital Networks \(LHN\)](#), organisations that provide public hospital services in accordance with the National Health Reform Agreement. LHN is the national term for these networks, with some states and territories using different terms. Some of the 53 health districts are formed by merging adjacent LHNs in urban areas with similar climatic characteristics. A breakdown of this methodology is provided below for each jurisdiction:

**Australian Capital Territory (ACT)** has a single eponymous LHN and is treated as a single health district.

**New South Wales (NSW)** is divided into 15 Local Health Districts (LHDs), 5 of which are in Sydney. We construct 12 NSW health districts, corresponding to the 15 LHDs except that:

- South Eastern Sydney LHD, Sydney Local LHD and Northern Sydney LHD are merged into a single 'Eastern Sydney health district'.
- Western Sydney LHD and South Western Sydney LHD are merged into a single 'Western Sydney health district'.

**Northern Territory (NT)** is covered by a single LHN, Northern Territory Regional Health Services. To provide more granular climate hazard data, 5 health districts are constructed using NT Health's 5 service delivery regions.

**Queensland** is divided into 16 Hospital and Health Services (HHSs), 15 of which are geographically defined and one of which is a state-wide service for children. We construct 12 Queensland health districts, corresponding to the geographically defined HHSs except that the four south east Queensland HHSs (Gold Coast, Metro North, Metro South and Sunshine Coast) are combined into a single South East health district.

**South Australia (SA)** is divided into 10 Local Health Networks, 9 of which are geographically defined and one of which is a state-wide service for women and children. We construct 7 SA health districts, corresponding to the geographically defined Local Health Networks except that the three Adelaide Local Health Networks (Central Adelaide, Northern Adelaide and Southern Adelaide) are combined into a single Adelaide health district.

**Tasmania** is covered by a single LHN, the Tasmanian Health Service. To provide more granular climate hazard data, 3 health districts are constructed using the 4 Tasmanian Statistical Divisions (SDs) used by we split Tasmania into four health districts using the Australian Bureau of Statistics (these also correspond to the 3 regions used by Ambulance Tasmania).

- The West & North SD is the North-West health district.

- The Launceston & North East SD is the North-East health district.
- The South East SD and Hobart SD are merged to form the South health district.

**Victoria** established 12 [Local Health Service Networks](#) (LHSNs) on 1 July 2025. As preparation of the Climate and Health Hazard Data commenced before the LHSNs were established, a different approach to constructing health districts was adopted. 5 health districts correspond to the Victorian Department of Health's former rural health regions (Barwon South Western, Gippsland, Grampians, Hume and Loddon Mallee), while a sixth health district was constructed by merging the Department's former regions covering Melbourne (Northern Metropolitan, Southern Metropolitan, Eastern Metropolitan and Western Metropolitan). These 6 health districts correspond to the LHSNs as follows:

- The Gippsland, Grampians, Hume and Loddon Mallee health districts broadly align with their respective LHSNs.
- Barwon South-West health district encompasses areas now principally covered by the Barwon and South West LHSNs.
- Melbourne health district combines the metropolitan Melbourne LHSNs.
- Some LHSNs also cross the metropolitan-rural interface (North Metro and Mitchell LHSN, East Metro and Murrindindi LHSN).

Future updates to the Climate and Health Hazard data will seek to align the health districts used for Victoria to current LHSN boundaries.

**Western Australia (WA)** is divided into 6 Health Services, 4 of which are geographically defined – 3 in Perth and the other, the WA Country Health Service, covering the rest of the state. We construct 8 health districts as follows:

- The 3 Perth Health Services (North Metropolitan Health Service, South Metropolitan Health Service, and East Metropolitan Health Service) to form Perth health district.
- The WA Country Health Service is divided into 7 regions: Goldfields, Great Southern, Kimberley, Mid West, Pilbara, South West and Wheatbelt.

# Timelines and scenarios

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## Historical baseline conditions

The historical baseline refers to observed data for the dates 1985–2014.

## Climate scenarios

A climate scenario is a plausible representation of future climate. A climate scenario considers a set of driving factors to estimate the expected impacts of climate change. Shared Socioeconomic Pathways (SSPs) are climate scenarios that represent plausible future levels of global warming. The SSPs consider various socioeconomic factors (such as population, economic growth, education, urbanisation and technology development) that could change over the next century and influence future greenhouse gas emissions. Scientists have developed SSP scenarios based on 5 narratives describing a range of potential future socioeconomic trends. The most recent iteration of SSPs also incorporate information from what were previously called Representative Concentration Pathways (RCPs) – SSP2-4.5 denotes what would previously have been called a scenario involving SSP2 and RCP4.5, the reasoning being that SSP2 describes socioeconomic conditions likely to give rise to RCP4.5.

The *Climate and Health Hazard Data* provides climate projections for 2 SSPs:

- **SSP2-4.5:** This scenario has emissions steady at roughly the same as current levels before starting to fall in the middle of the century and net zero is not reached by 2100, with temperatures rising by about 2.7°C by the end of the century. This is referred to as a 'middle of the road scenario', representing a moderate emissions reduction from 2040.
- **SSP3-7.0:** Under this scenario, both emissions and temperatures continue to rise, the latter by about 3.6°C by 2100. Based on more recent data and an improved understanding of how the main drivers of future emissions are likely to change over time, there is a common view among climate scientists that the SSP5-8.5 scenario is unlikely to be realised. Therefore, SSP3-7.0 is now considered the 'reasonable worst-case scenario' representing delayed and minimal emissions reduction.

Fire Hazard projections are not available for SSP2-4.5, so SSP1-2.6 is used as the lower emission scenario for this hazard instead of SSP2-4.5. Under SSP1-2.6, global emissions are reduced but don't reach net zero until after 2050 and warming stabilises at about 1.8°C by 2100. This document refers to SSP1-2.6 as the 'sustainability' scenario.

## Climate models and time horizons

The impact of the SSPs on climate is assessed using Global Climate Models (GCMs). The Climate and Health Hazard Data uses projected climate changes from 9 CMIP6 GCMs: (ACCESS-CM2, ACCESS-ESM1-5, CESM2, CMCC-ESM2, CNRM-ESM2-1, EC-Earth3, MPI-ESM1-2-HR, NorESM2-MM, UKESM1-0-LL).

These 9 models are used to project hazards under different SSPs for 3 time horizons:

- **1985–2014** (presented as the baseline)
- **2035–2064** (presented as '2050')
- **2070–2099** (presented as '2085').

This assessment is done for each SSP and summarised in the below table.

| Time                | Years                        | Description                                               | Using this time horizon                                                                                                         |
|---------------------|------------------------------|-----------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------|
| Baseline            | Observed data from 1985–2014 | This represents the historical baseline position for each | Undertake a risk assessment to ensure these risks are understood and being managed now.                                         |
| Mid-century (2050)  | 2035–2064                    | This represents the medium-term climate projections.      | Identify and manage emergent risks to health systems and populations.                                                           |
| Late century (2085) | 2070–2099                    | This represents the long-term climate projections.        | If planning infrastructure or policy with long-lasting consequences, then this time horizon should be used in risk assessments. |

## Comparing observed and future scenarios

The reported baseline results are actual recorded values that reflect the weather conditions observed during the stated period. These historical conditions are then replicated within the GCM, acknowledging that modelled data can never perfectly match observed data. When comparing hazards between the baseline and future scenarios, both are based on modelled conditions. This ensures that any differences reflect the effects of climate change alone.

If observed baseline data were used instead, it would be unclear whether changes arose from climate change or from differences between observed and modelled data. Using modelled data for both the baseline and future scenarios ensures consistency within the model, allowing changes to be reliably attributed to the influence of climate change.

# Heat and humidity hazard methods

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## Data source

The heat and humidity hazard uses daily projections of maximum and minimum near-surface temperature and mean relative humidity from application-ready climate projections based on observations, adjusted through a quantile-delta-change method to incorporate projected climate changes from CMIP6 GCMs (Irving et al. 2024). Results were calculated using the 8 GCMs with the necessary emissions scenarios and variables available: ACCESS-CM2, ACCESS-ESM1-5, CMCC-ESM2, CNRM-ESM2-1, EC-Earth3, MPI-ESM1-2-HR, NorESM2-MM, UKESM1-0-LL. The GCM CESM2 was not included as it did not contain the variables required for analysis of the heat and humidity indicators.

## Analytical approach

Daily projections of maximum and minimum near-surface temperature and mean relative humidity are used to calculate 8 heat and humidity indicators.

- average temperature (°C)
- maximum temperature on hot days (°C)
- minimum temperature on hot nights (°C)
- average apparent temperature on hot days (°C)
- average heatwave duration in days
- number of heatwaves per year
- number of days per year > 35°C
- number of days per year > 40°C.

## Population-weighted averaging

As the CMIP6 daily time series projections (Irving et al. 2024) are provided as a gridded dataset with a regular spatial resolution of 11 kilometres across Australia, each data point corresponds to the centre of a grid cell that represents the average projected climate conditions for that area.

To support health district-level analysis, it is necessary to aggregate the gridded data that spatially overlap with the district to produce a single value.

Conceptually, this means summarising multiple values, potentially with significant variation across the district into a representative value. By using a population-weighted average, the aggregation process ensures that climate conditions in more populous parts of a district have

a proportionally greater influence on the final value yielding a result that better reflects the actual exposure of the population within that district.

To achieve this, the Australian Bureau of Statistics (ABS) [Australian Population Grid 2024](#) is resampled to match the 11-kilometre resolution of the CMIP6 climate grids. For example, if a health district contains 50 climate grid cells with projected 95<sup>th</sup> percentile maximum temperatures ranging from 30°C to 38°C, the aggregation will give more weight to cells where more people live.

## Average temperature (°C)

The average temperature indicator is calculated as the mean of daily average temperatures for the entire time horizon, defined as the midpoint between daily maximum and minimum temperatures.

This was computed for each grid cell in the CSIRO CMIP6 11 km gridded dataset (Irving et al. 2024) using the *tasmax* (daily maximum temperature) and *tasmin* (daily minimum temperature) functions, separately for each GCM, emissions scenario and time horizon. The results were aggregated to health districts using population-weighted averaging.

## Maximum temperature on hot days (°C)

This indicator represents the 95<sup>th</sup> percentile of daily maximum temperatures. To calculate this value, all daily maximum temperatures (*tasmax*) for each grid cell are ordered from lowest to highest. The 95th percentile temperature represents the value near the top of the ordered list of daily maximum temperatures — it is hotter than 95% of all other days within the selected time period. This means only about 5% of days are hotter. It is not the single highest temperature (which could be an outlier or anomaly), but a more typical extreme that occurs often enough to be meaningful.

This value is used as a threshold for identifying very hot days that can pose risks to human health and well-being. The 95th percentile maximum temperature value was calculated for each GCM, emissions scenario and time horizon and aggregated to health districts using population-weighted averaging.

## Minimum temperature on hot nights (°C)

Daily minimum temperature is commonly used as a proxy for overnight temperature, as it typically occurs in the early morning hours and reflects the coolest point of the 24-hour cycle. Elevated minimum temperatures indicate poor overnight cooling, which can compound heat stress by limiting the body's ability to recover from daytime heat, particularly during

heatwave events. This indicator represents the 95th percentile of daily minimum temperatures.

To calculate this value, all daily minimum temperatures (*tasmin*) for each grid cell are ordered from lowest to highest. The 95th percentile minimum temperature represents the value near the top of the ordered list of daily minimum temperatures — it is warmer than 95% of all other nights within the selected time period. This means only about 5% of nights are warmer.

It is not the single warmest night (which could be an anomaly), but a more typical extreme that occurs often enough to be meaningful. This value serves as a threshold for identifying unusually warm nights that can affect comfort, sleep quality, and health.

This 95th percentile minimum temperature value was calculated separately for each GCM, emissions scenario, and time horizon, and aggregated to health districts using population-weighted averaging.

## Average apparent temperature on hot days (°C)

This indicator represents the average apparent temperature—accounting for the combined effects of air temperature and relative humidity—on days with a maximum temperature of 27°C or higher, averaged over the entire time horizon. It uses the United States National Oceanic and Atmospheric Administration (NOAA) Heat Index methodology. It is used as a proxy for human-perceived heat-stress and is particularly important for northern Australia, especially during the wet season (typically November to April). When temperature and relative humidity are both high, even moderate increases in temperature can result in significantly higher apparent temperatures, intensifying heat stress and limiting the effects of evaporative cooling.

Daily maximum temperature (*tasmax*) is converted to Fahrenheit and the official NOAA multiple regression formula is applied (National Weather Service 2022), with daily maximum relative humidity (*hursmax*) as an additional input to derive Heat Index.

Additional adjustments are applied for low and high humidity extremes, per NOAA guidelines (National Weather Service 2022), before the results were converted back to Celsius and averaged across the time horizon.

Daily maximum temperature and daily maximum relative humidity do not necessarily occur simultaneously; as a result, this approach may overestimate apparent temperature relative to calculations based on coincident sub-daily observations. However, sub-daily humidity-temperature pairs are not consistently available across the historical and projected gridded datasets used, and the use of daily maxima represents a consistent and conservative approximation of potential peak heat stress conditions, particularly relevant for population-level risk assessment in humid climates.

The calculation was performed at each grid cell and repeated for each GCM, emissions scenario, and time horizon and were aggregated to health districts using population-weighted averaging.

| Heat      | Notes                                                                                                               |
|-----------|---------------------------------------------------------------------------------------------------------------------|
| 27–32°C   | Caution: fatigue is possible with prolonged exposure and activity. Continuing activity could result in heat cramps. |
| 33–41°C   | Extreme caution: heat cramps and heat exhaustion are possible. Continuing activity could result in heat stroke.     |
| 42–54°C   | Danger: heat cramps and heat exhaustion are likely; heat stroke is probable with continued activity.                |
| over 54 C | Extreme danger: heat stroke is imminent.                                                                            |

### Average heatwave duration in days

The average heatwave duration in days indicator is calculated using the Excess Heat Factor (EHF) method developed by the Bureau of Meteorology (Nairn & Fawcett 2015). This approach captures periods of heat that are both statistically significant relative to historical extremes and intense relative to recent conditions.

To calculate EHF, daily mean temperature was first derived as the average of daily maximum (*tasmax*) and minimum (*tasmin*) temperatures. From this, a 3-day running average was compared against 2 benchmarks: a fixed, historical 95<sup>th</sup> percentile value (representing historical long-term extremes), and a rolling 30-day average (representing recent conditions). These comparisons form the 2 components of EHF and are multiplied to produce the final EHF value.

In the original station-based formulation of EHF, Nairn and Fawcett (2015) derive daily mean temperature by pairing a day’s maximum temperature with the following day’s minimum temperature to align with Australia’s 9am–9am observing-day convention and to emphasise overnight heat stress. Gridded climate datasets, however, may assign daily minimum and maximum temperatures to a given calendar date based on dataset-specific construction and observing conventions, such that these values can originate from different 24-hour periods (Irving et al. 2024). Accordingly, for gridded GCM outputs used in this study, daily mean temperature was calculated using same-day *tasmax* and *tasmin* to provide a consistent and transparent implementation of the EHF methodology suitable for large-area, multi-decadal analyses.

A heatwave day is defined as a day where the EHF value is positive (i.e.  $EHF > 0$ ). A heatwave event is defined as a sequence of 3 or more consecutive heatwave days, in line with the

Bureau of Meteorology's operational definition (Hudson & Marshall 2016). Once these events were identified, their individual durations (i.e., number of consecutive heatwave days) were recorded for each year. The average heatwave duration was then calculated by taking the mean duration of all such events within each year. This process was repeated independently for each GCM, emissions scenario, and time horizon.

While this method provides a consistent and physiologically relevant measure of heatwave exposure, it is important to note a key limitation related to the underlying climate data. The GCM-based projections used in this analysis are generated using a quantile–delta change (QDC) scaling approach, where future changes in climate variables are applied as adjustments to historical observed weather patterns (Irving et al. 2024). As a result, while projected future changes in temperature magnitude and variability are represented, future changes in the frequency, intensity, or behaviour of synoptic-scale drivers—such as blocking highs, monsoonal intrusions, or changes to large-scale circulation patterns—are not captured. The resulting heatwave indicators, including event frequency and duration, are therefore conditioned on historical weather sequences, which may underestimate or misrepresent changes in the processes that physically drive extreme heat events under future climate conditions.

## Number of heatwaves per year

The number of heatwaves per year indicator uses the same EHF-based detection method described above. A heatwave is defined as any period of 3 or more consecutive days with EHF > 0, indicating that both the short-term temperature (3-day mean) exceeds the long-term extreme threshold (historical 95th percentile), and is also higher than the recent 30-day average.

The number of distinct heatwave events was counted annually for each grid cell. These counts were then spatially aggregated to health districts using population-weighted averaging. This process was repeated independently for each GCM, emissions scenario, and time horizon.

## Number of days per year > 35°C

The number of days per year > 35°C indicator is calculated using daily maximum temperature (*tasmax*) from the CSIRO CMIP6 11 km gridded dataset (Irving et al. 2024). For each grid cell, the number of days each year where the daily maximum temperature exceeded 35.0°C was counted. This process was repeated for each GCM, emissions scenario and time horizon.

These counts were aggregated to health districts using population-weighted averaging.

## Number of days per year > 40°C

The number of days per year > 40°C indicator is calculated in the same way as the > 35°C indicator but applies a higher threshold of 40.0°C. For each grid cell and year, the number of days where daily maximum temperature exceeded 40°C was counted, using *tasmax* from the CSIRO CMIP6 dataset. These counts were calculated for each GCM, emissions scenario, and time horizon and were aggregated to health districts using population-weighted averaging.

## Data outputs

The heat and humidity hazard uses climate projections from the CMIP6 Global Climate Models reported across 3 time horizons:

- **mid-21<sup>st</sup> century** (represented by the 30-year window 2035–2064)
- **late-21<sup>st</sup> century** (represented by the 30-year window 2070–2099)
- **historical baseline** data for 1985–2014.

8 CMIP6 models (ACCESS-CM2, ACCESS-ESM1-5, CMCC-ESM2, CNRM-ESM2-1, EC-Earth3, MPI-ESM1-2-HR, NorESM2-MM, UKESM1-0-LL) are used to calculate climate changes between a 1985–2014 baseline period and the 2 future projection periods for each SSP. The average of each indicator is reported along with the maximum and minimum values across climate models reported in square brackets.

# Fire hazard methods

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## Data source

The Fire Hazard uses the National Bushfire Intelligence Capability Stage 2 Fireline Intensity (FLI) data products based on CMIP6 data (Opie et al. 2023). FLI considers slope, vegetation and weather to produce a rate of heat output per unit length (kW/m) along a bushfire's front. It is a measure of a fire's heat output and provides data-driven insights into bushfire hazard under baseline and future scenarios. The data have been generated by CSIRO to support national and state-level decision-making for bushfire management, relevant across a broad range of scales – from individual properties through to continental.

The inputs into the calculation of FLI are obtained from the following sources:

- **Vegetation** classification is defined by the Australian Fire Danger Rating System (AFDRS) National Fuel Map and parameter table.
- **Weather** is defined by both a historical weather reanalysis dataset BARRA-R2 (baseline scenario) drawing on hourly concurrent data and a climate biased future weather dataset (based on 6 Global Climate Models for SSP1-2.6 and SSP3-7.0 from CMIP6, projected scenarios).
- **Terrain** is represented by Geoscience Australia's Shuttle Radar Topographic Mission (SRTM) Smoothed Digital Elevation Model.

These are ingested into 8 select fire behaviour models in alignment with the current Australian Fire Danger Rating System and VESTA Mark 2. The data are generated as rasters (20m resolution), which show the Fireline Intensity for given fire weather return period intervals of 20, 50 and 100 years. The SSP1-2.6 represent a sustainability scenario, and SSP3-7.0 represents the reasonable worst-case scenario.

The FLI provides spatial information on the intensity with which a fire would burn in the event of a bushfire. It does not represent the likelihood or frequency of a fire occurring. This means that the future fire hazard assessment considers how climate change will impact the intensity at which future fires will burn. The future fire hazard assessments do not consider how climate change will affect the ignition frequency of future fires. This approach is consistent with the scientific understanding of fire hazard in that the impacts of climate change are largely about how a fire burns when there is fire in the landscape (rather than how frequently fire events occur).

# Analytical approach

The analytical approach addresses the following question: 'In the event of a major bushfire, what is the likely impact of that fire in terms of likelihood of containment, danger to assets and smoke emissions'? Major bushfires are defined as those which occur at intervals of every 20 to 100 years. For fire with those return intervals, the area that is subject to different levels of fire hazard is calculated for each health district. Different levels of fire severity are defined based on published data on the likely consequences from fires burning at different FLI (Hollis et al. 2024).

| Category                | FLI Range    | Fire type                                                                                                                        |
|-------------------------|--------------|----------------------------------------------------------------------------------------------------------------------------------|
| Low hazard              | 0–4,000      | Fires can typically be managed but smoke hazard may persist.                                                                     |
| Moderate to high hazard | 4,000–27,500 | Suppression and containment difficult. Upper limit for 'offensive' fire management strategies. Community losses may be expected. |
| Very high hazard        | ≥ 27,500     | Increased likelihood of community loss and significant consequences.                                                             |

For each health district, the percentage area subject to different hazards was estimated for all the climate models represented in the data. For reporting purposes, the mean of all models is calculated along with estimates of the minimum and maximum.

## Data outputs

Tables are provided for each health district showing the proportion (percentage) of each district that is expected to experience each hazard level under the 1-in-20- and 1-in-100- year events. Charts are also provided to help visualise the extents of the changes.

# Drought hazard methods

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## Data source

The drought hazard uses daily projections of precipitation from application-ready climate projections based on observations, adjusted through a quantile-delta-change method to incorporate projected climate changes from CMIP6 Global Climate Models (Irving et al. 2024).

## Analytical approach

Precipitation data is used to create one indicator for the drought hazard – ‘number of months per year in drought’. The drought indicator uses the Standardised Precipitation Index (SPI). SPI is a widely used index to characterise meteorological drought on a range of timescales. SPI quantifies observed precipitation as a standardised departure from a selected probability distribution function that models the raw precipitation data. In other words, SPI estimates the deviation of precipitation from the long-term probability function at different time scales (e.g. 1, 3, 6, 9, or 12 months). The drought indicator uses the Standardised Precipitation Index with a rolling window of 12 months (SPI-12), a 12-month SPI compares the precipitation for 12 months against the same period in a long-term historical record and any deviation from the distribution towards negative values indicates a decline in rainfall and thus indicates drought (World Meteorological Organization, 2012). The SPI-12 can range from extremely wet ( $SPI \geq 2$ ) to extremely dry ( $SPI \leq -2$ ). This assessment considers moderate dry events ( $SPI \leq -1$ ), which are described as moderate droughts.

## Data outputs

The drought hazard uses climate projections from the CMIP6 Global Climate Models reported across 3 time horizons:

- **mid-21<sup>st</sup> century** (represented by the 30-year window 2035–2064)
- **late-21<sup>st</sup> century** (represented by the 30-year window 2070–2099)
- **historical baseline** data for 1985–2014.

9 CMIP6 models (ACCESS-CM2, ACCESS-ESM1-5, CESM2, CMCC-ESM2, CNRM-ESM2-1, EC-Earth3, MPI-ESM1-2-HR, NorESM2-MM, UKESM1-0-LL) are used to calculate climate changes between a 1985–2014 baseline period and the 2 future projection periods for each SSP. The average of each indicator is reported along with the maximum and minimum values across climate models reported in square brackets.

# Storm hazard methods

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## Data source

The storm hazard uses daily projections of maximum surface wind speed from application-ready climate projections based on observations, adjusted through a quantile-delta-change method to incorporate projected climate changes from CMIP6 Global Climate Models (Irving et al. 2024).

## Analytical approach

Daily maximum surface wind speed is used to calculate the number of annual storms across 4 storm intensity categories (low, medium, high and very high), producing 4 storm hazard indicators:

- number of low-intensity storms (40–62 km/hr) per year
- number of medium-intensity storms (63–87 km/hr) per year
- number of high-intensity storms (88–117 km/hr) per year
- number of very-high-intensity storms (> 117 km/hr) per year.

Storm intensity categories identified based on the weatherzone wind damage guide ([www.weatherzone.com.au](http://www.weatherzone.com.au)).

## Data outputs

The storm hazard uses daily maximum surface wind speed data obtained from the Bureau of Meteorology's Atmospheric high-resolution Regional Reanalysis of Australia (BARRA) project to analyse storms hazards for the historical baseline period (1985–2014).

In some locations where high-wind speed events are common (e.g. where tropical cyclones are experienced in northern Australia, where East Coast Lows are experienced in eastern Australia etc.) the BARRA data underestimates the maximum wind speeds on days when an extreme wind event is occurring. This issue was addressed by comparing BARRA data with actual observed maximum wind speeds at places and times when an extreme wind event was known to occur, calculating the typical error, and 'bias correcting' the BARRA data accordingly so that the BARRA-based maximum wind speeds were more realistic and the frequency of high- and very-high-intensity storms was consistent with what is known to have occurred during the historical baseline period.

Climate projections from the CMIP6 Global Climate Models are then used to quantify the impacts of climate of climate change on storm hazards for 2 future time horizons:

- **mid-21<sup>st</sup> century** (represented by the 30-year window 2035–2064)
- **late-21<sup>st</sup> century** (represented by the 30-year window 2070–2099).

9 CMIP6 models (ACCESS-CM2, ACCESS-ESM1-5, CESM2, CMCC-ESM2, CNRM-ESM2-1, EC-Earth3, MPI-ESM1-2-HR, NorESM2-MM, UKESM1-0-LL) are used to estimate the impacts of climate change for the 2 future time horizons under 2 SSPs (SSP2-4.5 and SSP3-7.0). The average, maximum and minimum across the 9 CMIP6 models is reported for each of the 4 storm hazard indicators.

# Rainfall and flood hazard methods

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## Data source

The rainfall hazard uses daily projections of precipitation from application-ready projections based on observations, adjusted through a quantile-delta-change method to incorporate projected climate changes from CMIP6 Global Climate Models (Irving et al. 2024).

The flood hazard uses climate change considerations from the draft update to the Climate Change Considerations chapter in 'Australian Rainfall and Runoff: A Guide to Flood Estimation' (Wasko et al. 2024).

## Analytical approach

### Rainfall indicators

Precipitation data is used to create one rainfall hazard indicator – 'average number of extreme rainfall days per year'. Extreme rainfall is based on a precipitation value that exceeds the 95th percentile of precipitation for that health district. This 95th percentile is used to determine the frequency of days in a year of extreme rainfall where rainfall may exceed (future climate change scenario) or has exceeded (observed baseline data) this threshold.

The average annual threshold was determined from the observed dataset, calculating the 95<sup>th</sup> percentile per gridded cell within the observed precipitation data and averaging this value across the health district. Independent thresholds were calculated for each health district. The average number of extreme rainfall days per year is reported along with the maximum and minimum values across climate models reported in square brackets.

### Flood indicators

#### Key principles

This assessment is only intended to provide **an approximation of the change in frequency of flooding, suitable for** a national assessment examining broad trends in flooding. The assessment **does not consider specific flooding risks to individual waterways and locations**. For more detailed information about flooding at a local scale, please refer to state or local government information for site specific flood modelling and flood mapping information.

Future changes in flooding revolve around several factors:

- **Future changes in rainfall** (a warmer climate tends to be associated with more intense rainfall)
- **Future changes in soil dryness** (a warmer climate will lead to drier soils which absorb more rainfall prior to a flood)
- **The duration of a rainfall event** (short events tend to affect small catchments such as small creeks and local streets, while longer events tend to affect large river systems as well as local creeks and streets)
- **The context of the flooding** (urban areas with high proportion of paved areas flood more often than rural catchments with grassland or forest).

Climate change is likely to lead to higher rainfall intensity in most locations across Australia, but there is also expected to be drier soils across most areas, absorbing more of the rainfall. The balance between these 2 factors will vary from region to region. Consequently, in some areas there may be more rainfall contributing to flooding, while in some areas there may be less.

The amount of rainfall absorbed by dry soil varies significantly between seasons and locations. After some rainfall has been absorbed, and the soil profile becomes saturated, any further rainfall contributes to flooding. This remainder is called the 'rainfall excess' or 'flood runoff'.

Whether flooding increases or decreases with climate change depends on the balance between the increase in rainfall and the dryness of the soil.

In urban areas, the ground is mostly covered with asphalt, concrete, or roofing. This means that almost all rainfall is converted into runoff. Consequently, drier soils make little difference to future flooding in urban areas, and flooding will increase over time as rainfall intensities increase. In rural areas, drier soils in future will absorb more of the rain which may make a significant difference to flooding.

## Locations

For most regions, the centroid of each health district was adopted to represent the district for the purposes of obtaining rainfall intensity and soil loss information. However, in some cases the centroid was inappropriate. For example, the centroid for the Barossa Hills Fleurieu district in South Australia lies in the St Vincent Gulf. Also, the centroid for the Hume district in Victoria lies in the alps. In cases such as these, the rainfall and rainfall loss information at the centroid was not considered representative of where people are living or where health services are available. For these districts, manual adjustment was undertaken and an alternative location was selected nearer to a major urban centre within the district.

## Rainfall intensities and losses

Current rainfall intensity and rainfall losses information was extracted for each district. Rainfall intensity data at each location included all storm durations and frequencies. This data is provided as part of Australian Rainfall and Runoff (ARR) and is made available by the Bureau of Meteorology ([www.bom.gov.au/water/designRainfalls/](http://www.bom.gov.au/water/designRainfalls/)). This data was published in 2016, and is considered representative of the period from 1961 to 1990.

Initial loss and continuing loss data was extracted directly from ARR ([data.arr-software.org](http://data.arr-software.org)). Loss data was not available for some arid inland areas. In these cases, the initial loss and continuing loss were estimated to be 50mm and 4mm/h respectively.

## Climate change adjustments

Methods to adjust rainfall intensity data and rainfall loss data (initial loss and continuing loss) were adopted from draft update to the Climate Change Considerations chapter in 'Australian Rainfall and Runoff: A Guide to Flood Estimation' (Wasko et al. 2024). In short, a percentage change was applied to rainfall intensities and losses on a 'per degree of temperature rise' basis. The temperature increase for each location was available from ARR ([data.arr-software.org](http://data.arr-software.org)) for 2050 and 2085, and for representative socioeconomic pathways SSP2-4.5 and SSP3-7.0. For rainfall, the percentage change varied for events of different duration, with a lower percentage change applied to long events (>24 hours) and a higher percentage change applied to short events (<1 hour).

## Hydrograph calculation

To calculate the volume of rainfall excess ('flood runoff') from a given rainfall event, a simple hydrograph calculation was undertaken. The rainfall event was split into 60 timesteps, and the rainfall for the entire event was evenly distributed across these timesteps. The initial loss and continuing loss were subtracted from the rainfall using standard methods from Australian Rainfall and Runoff Book 5 Chapter 3. Any remaining rainfall was counted as flood runoff.

## Changes in flood frequency

Prior to any calculations, the rainfall and loss parameters were defined as follows:

- **For urban flooding**, the one-hour event duration was chosen because shorter events between 30 minutes and 4 hours are more likely to produce the most significant flooding in urban contexts.
- **For rural flooding**, the 24-hour event duration was chosen because longer events between 12 hours and 7 days are more likely to produce the most significant flooding in rural contexts.

- **Events which occur with a frequency** of once in one year, 10 years, and 100 years were selected to examine events across a range of frequencies.
- **In total**, this produced a set of 6 modelled events (3 frequencies x 2 durations).

The following steps were undertaken for each health district and for each of the 6 modelled events:

- **The *current* flood runoff** was calculated using *current* rainfall and loss parameters, giving a current flood runoff hydrograph and total flood runoff volume for the entire event.
- **The *future* flood runoff** was calculated using *climate adjusted* rainfall and losses for the same duration event (either one hour or 24 hours) for all possible frequencies (from 12 times per year to once per 2000 years).
- **The future flood runoff which provided the closest match** to the current flood runoff was identified. The frequency of this matching future event was adopted as the 'future flood frequency'. For example, if the flood runoff produced from the current 10-year event matched the flood runoff from the future 5-year event, then the future flood frequency was considered to have changed from one event every 10 years (current) to 2 events every 10 years (future).

## Data outputs

The rainfall hazard uses climate projections from the CMIP6 Global Climate Models reported across 3 time horizons:

- **mid-21<sup>st</sup> century** (represented by the 30-year window 2035–2064)
- **late-21<sup>st</sup> century** (represented by the 30-year window 2070–2099)
- **historical baseline** data for 1985–2014.

9 CMIP6 models (ACCESS-CM2, ACCESS-ESM1-5, CESM2, CMCC-ESM2, CNRM-ESM2-1, EC-Earth3, MPI-ESM1-2-HR, NorESM2-MM, UKESM1-0-LL) are used to calculate climate changes between a 1985–2014 baseline period and the 2 future projection periods for each SSP. The average of each indicator is reported along with the maximum and minimum values across climate models reported in square brackets. In cases where there is a large range between maximum and minimum values across climate models, users should use caution in interpreting these numbers, as this indicates that climate model projections diverge substantially, and the rainfall projections may not indicate a clear direction of how rainfall may change. This divergence represents higher uncertainty in the indicator and must be acknowledged in the users' decision-making process.

The flood hazard uses climate projections from Australian Rainfall and Runoff reported across 3 time horizons:

- **mid-21<sup>st</sup> century** (represented by the 30-year window 2035–2064)
- **late-21<sup>st</sup> century** (represented by the 30-year window 2070–2099)
- **historical baseline** data for approximately 1961–1990 (Wasko et al. 2024).

The climate projections from Australian Rainfall and Runoff do not use global climate models. Instead, they are based on extrapolations of observed rainfall changes from recent decades.

The hazard metric is the 'change in flood frequency'. This is reported for the 2 future time horizons, and for the 3 flood frequencies: the one year, 10 year, and 100-year average recurrence interval rainfall events. In urban areas the one-hour rainfall event duration is used, while in rural areas the 24-hour event duration is used.

Data outputs from this assessment are only as individual estimates for each Health District. More detailed spatial information is not available from this analysis. For more detailed information about flooding at a local scale, please refer to state or local government information for site specific flood modelling and flood mapping information.

# Coastal inundation hazard methods

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## Data source

The coastal inundation hazard assessment adopted present day extreme sea level statistics derived from the University of Western Australia's 'Extreme Sea Levels in Australia' model (UWA 2018). This high-resolution hydrodynamic model produced a 59 year hindcast (1958–2016) of sea levels around the Australian coastline, which accounted for the effects of astronomical tides, storm surges due to wind and pressure, and seasonal and inter-annual mean sea level variability. However, it is important to note that the model did not account for wave setup or wave runup, which may contribute additional water levels in exposed coastal areas.

Extreme value analysis was applied to the sea level hindcast to estimate the probability of extreme events based on historical data. The probabilities are presented in terms of Average Recurrence Intervals or return periods (e.g., 1-in-100-year events) and are available at approximately 1km resolution along the Australian coastline.

Sea level rise projections utilised data from the NASA Sea Level Projection Tool (NASA 2021), which provides access to sea level projection datasets from the Intergovernmental Panel on Climate Change (IPCC) 6<sup>th</sup> Assessment Report (AR6). The 50<sup>th</sup> percentile (median) projections were adopted under 2 Shared Socioeconomic Pathways: SSP2-4.5, representing a stabilising emissions scenario, and SSP3-7.0, reflecting a higher emissions projection. These scenarios provide a robust basis for evaluating future sea level rise under both moderate and high greenhouse gas concentration pathways.

Ground elevation data was sourced from 2 primary datasets (Geoscience Australia 2025), depending on availability. Where available, 5m resolution Light Detection and Ranging (LiDAR) data from Geoscience Australia was used as the preferred dataset due to its high spatial resolution. In areas where LiDAR coverage was not available, elevation data was supplemented with the Shuttle Radar Topography Mission (SRTM) one-second (~30m) resolution dataset, a satellite-derived global digital elevation model. While SRTM provides broader coverage, its coarser resolution and reduced accuracy in urban areas are acknowledged limitations. Together, these datasets formed the ground elevation data for the coastal inundation hazard mapping.

It is important to note that the ground elevation data used in this assessment represents ground surface topography and is not reliable for accurately capturing the bathymetry of waterbodies or watercourses, such as rivers, creeks, or lakes. All waterbodies and

watercourses are hydraulically connected to the surrounding landscape and susceptible to inundation during tidal or storm tide events.

## Analytical approach

The coastal inundation hazard provides an indication of flooding in coastal areas that can be attributed to sea level rise and storm inundation. 3 indicators are reported as part of the coastal hazard:

- **tidal inundation** (ha inundated)
- **storm tide inundation** – '1-in-100 year' storm tide event (ha inundated)
- **storm tide inundation** – '1-in-1000 year' storm tide event (ha inundated).

To represent present day (baseline) coastal inundation conditions, tidal and storm tide inundation datasets were spatially interpolated across Australia using a Triangulated Irregular Network (TIN) surface. This method allowed for a continuous representation of water levels across the coastline, accounting for the spatial variability in extreme sea level statistics derived from the University of Western Australia's hindcast model.

Sea level rise projections for future planning horizons (2050 and 2085) were also interpolated as separate TIN surfaces across the Australian coastline. Sea level rise projections for 2100 have been adopted for the 2085 planning horizon for coastal hazards. 2100 was chosen to represent the 2085 time horizon as it conservatively represents near the end of this period and many states' planning regulations require consideration of sea level rise and storm tide to 2100. Consideration of 2100 will be most valuable for coastal health organisations, particularly when planning new health facilities. These projections were sourced from the IPCC AR6 dataset via the NASA Sea Level Projection Tool, based on the 50th percentile for SSP2-4.5 and SSP3-7.0 emissions scenarios.

To simulate future inundation extents, the sea level rise projection TINs were combined with the present day tidal and storm tide inundation TIN surfaces. This produced projected inundation surfaces for both 2050 and 2100, enabling spatial assessments of future hazard exposure under each emissions scenario. This approach assumes that the primary influence on future inundation is the increase in sea level, while other components (e.g. tides, storm surges) remain consistent with present day conditions.

An additional 0.1m has been included to account for 10% increase in storm intensity and frequency under the '1-in-1000-year storm tide event', which is considered as an extreme scenario. It is important to note that while increases in storm intensity/likelihood are likely to vary across regions, these increases to future inundation levels are generally minor compared to the influence of sea level rise.

Following the generation of these inundation TIN surfaces, inundation extents were calculated in hectares for each planning horizon and scenario. This allowed for a quantitative comparison of inundation exposure relative to the present-day baseline, providing insight into how coastal hazard extents may expand over time.

## **Data output**

The coastal inundation hazard is only reported for coastal health districts. The projected inundation levels in ha inundated are reported as well as the change from baseline conditions (in brackets).

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