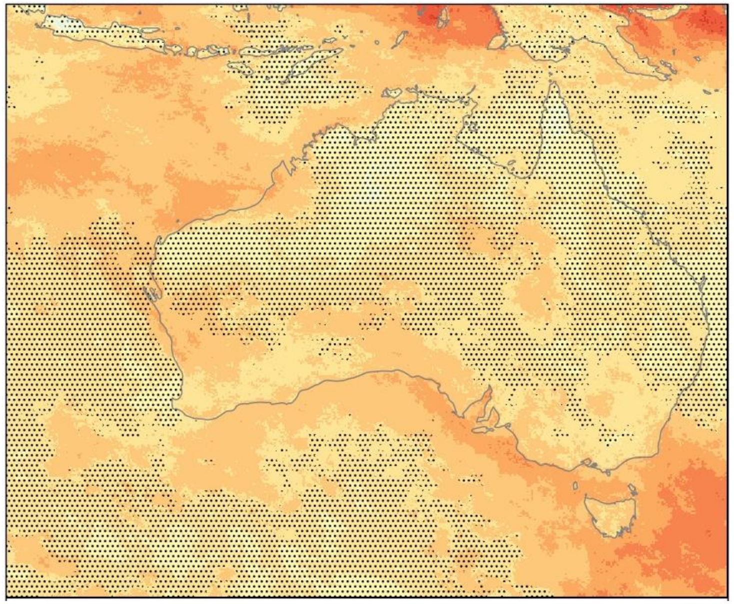
The Bureau of Meteorology

Compound heat events – Extreme, impactful, and unknown

Cass Rogers, Climate Scientist, cassandra.rogers@bom.gov.au

Humid-heat trends



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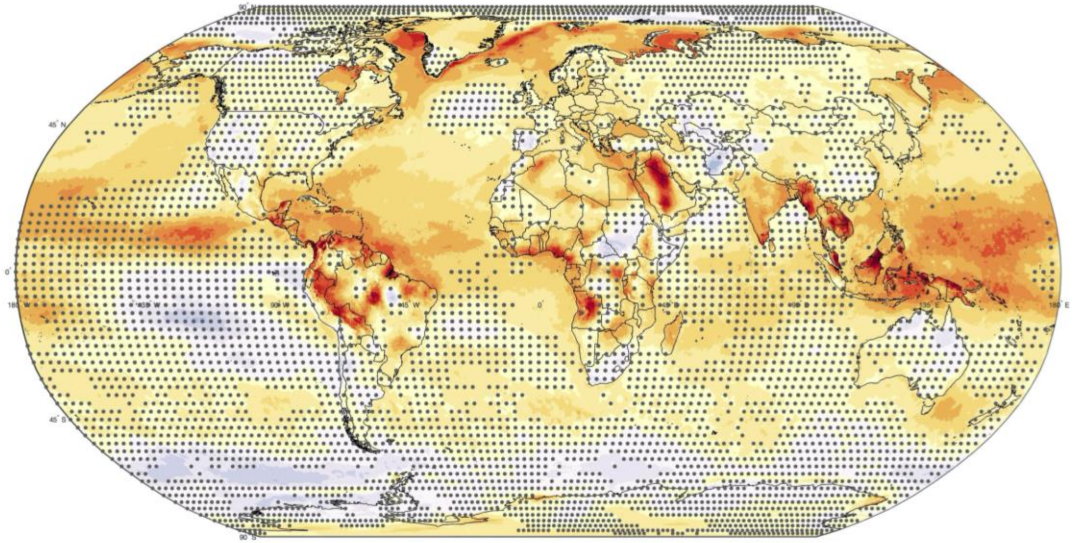

Stand alone heat events ➔ well-understood

Extreme heat is well-researched

- Heatwaves hotter, longer, more frequent
  (Perkins-Kirkpatrick & Lewis, 2020)
- Mean temperatures increasing
- Extreme temperatures increasing

Perkins-Kirkpatrick, S.E. and Lewis, S.C., 2020. Increasing trends in regional heatwaves. *Nature communications*, *11*(1), pp.1-8.

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Typically examine dry-bulb temperature

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- Heatwaves hotter, longer, more frequent
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- Mean temperatures increasing
- Extreme temperatures increasing

Typically examine dry-bulb temperature

However, we have a limited understanding of compound extreme heat events and their impacts

Perkins-Kirkpatrick, S.E. and Lewis, S.C., 2020. Increasing trends in regional heatwaves. *Nature communications*, *11*(1), pp.1-8.

Compound events

A combination of multiple drivers and/or hazards that contribute to societal or environmental risk

Zscheischler, J., Martius, O., Westra, S., Bevacqua, E., Raymond, C., Horton, R.M., van den Hurk, B., AghaKouchak, A., Jézéquel, A., Mahecha, M.D. and Maraun, D., 2020. A typology of compound weather and climate events. *Nature reviews earth & environment*, *1*(7), pp.333-347.

Compound events

A combination of multiple drivers and/or hazards that contribute to societal or environmental risk

Four categories:

1. Preconditioned
2. Multivariate
3. Temporally compounding
4. Spatially compounding

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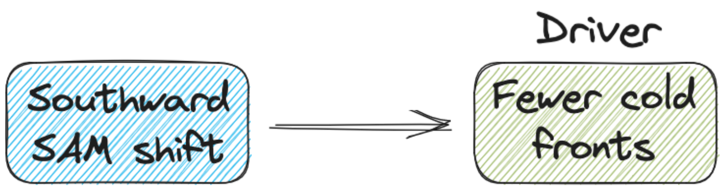
Multivariate compound events

Extreme events with multiple hazards and/or multiple drivers
➔ Same time, same place

Example 1
Multiple hazards
Single driver



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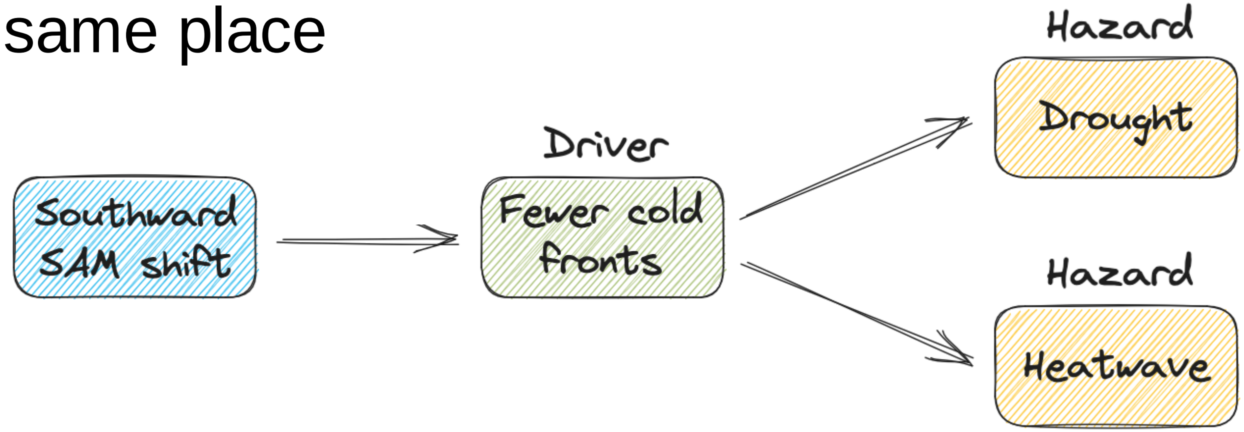

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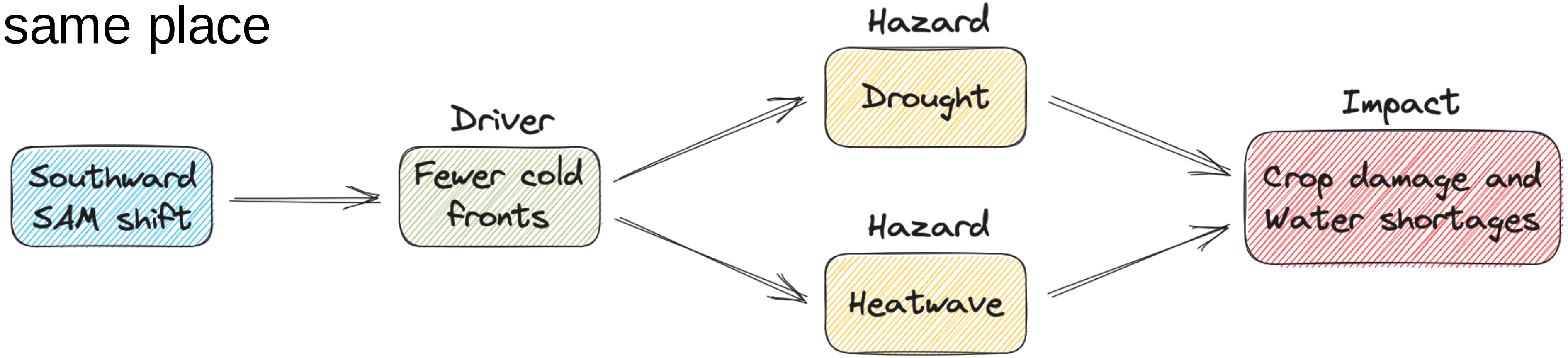

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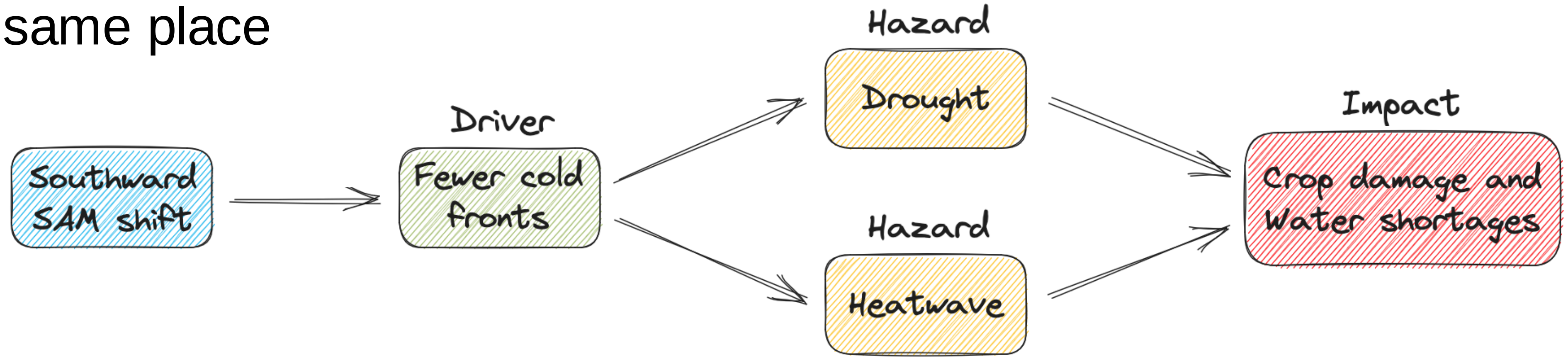
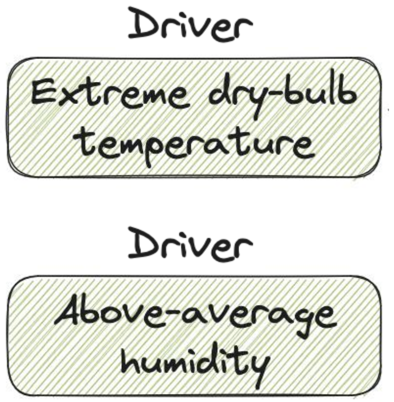


<u>Example 2</u>

Multiple drivers

Single hazard



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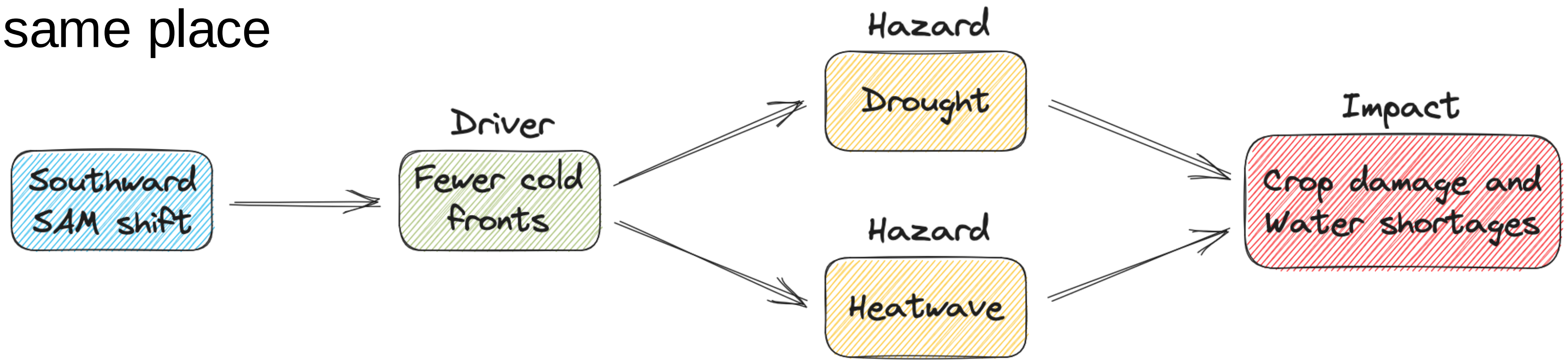

<u>Example 2</u>
Multiple drivers
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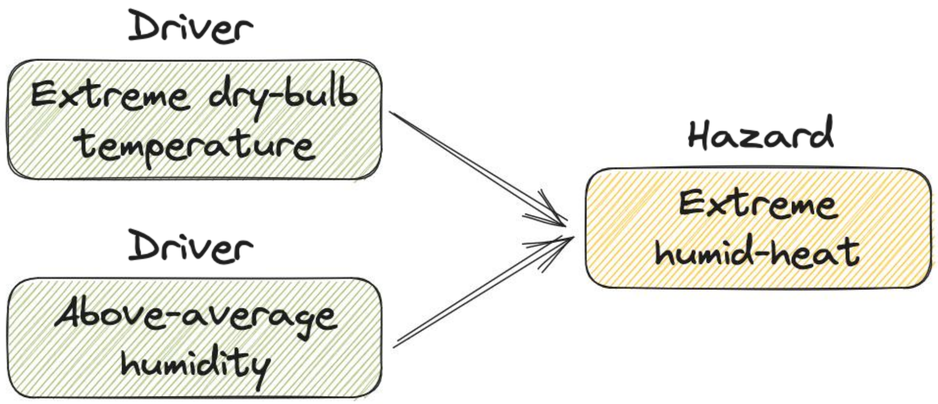

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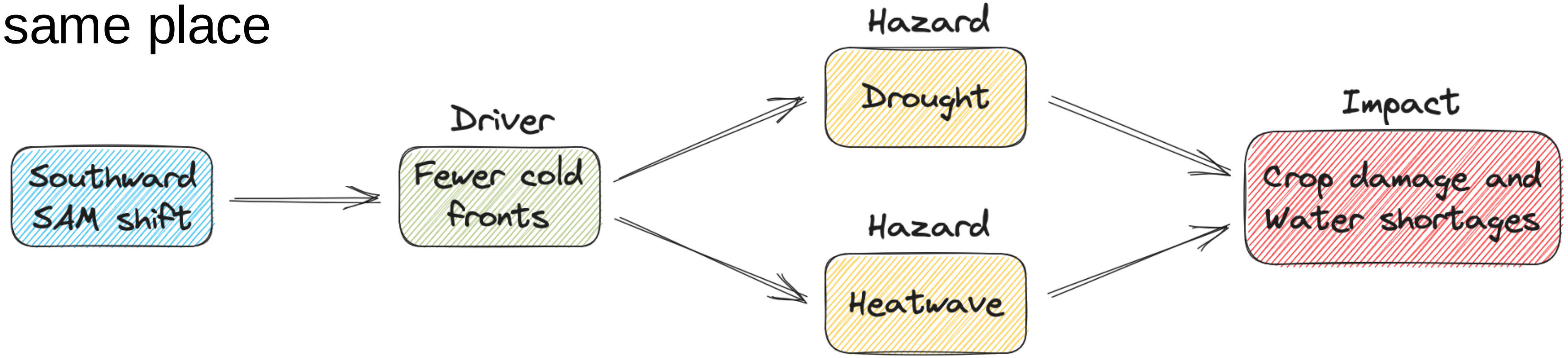

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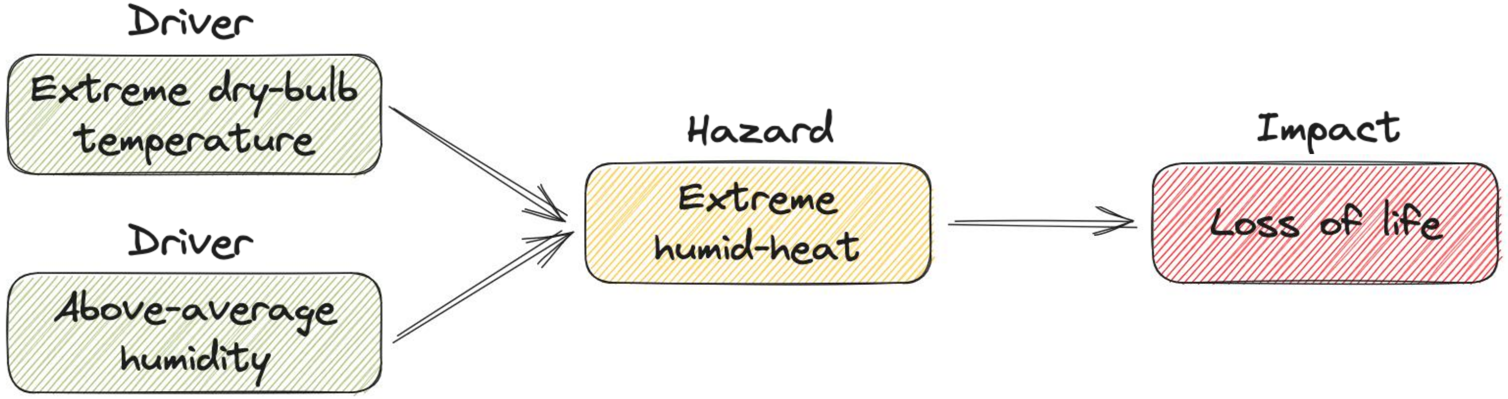

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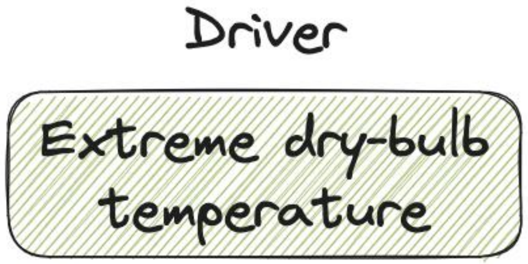
Why should compound events research be a priority?

If we only consider isolated extremes, we risk *underestimating* highly impactful and unprecedented future extremes



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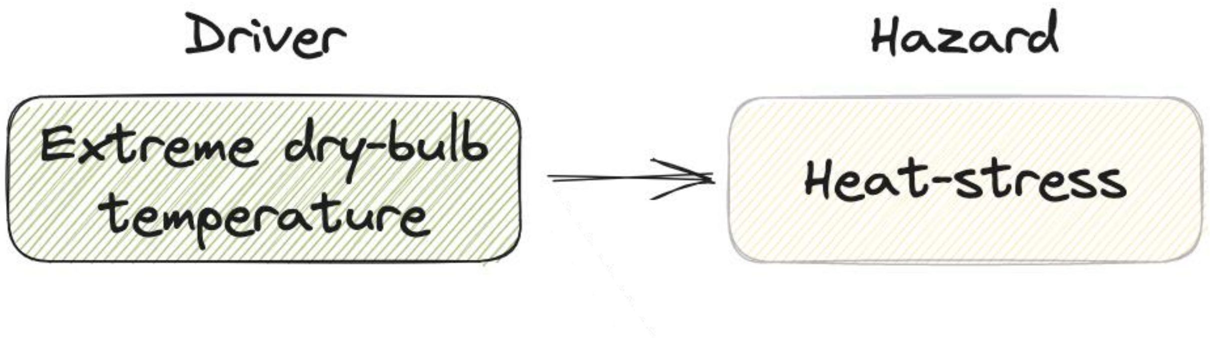

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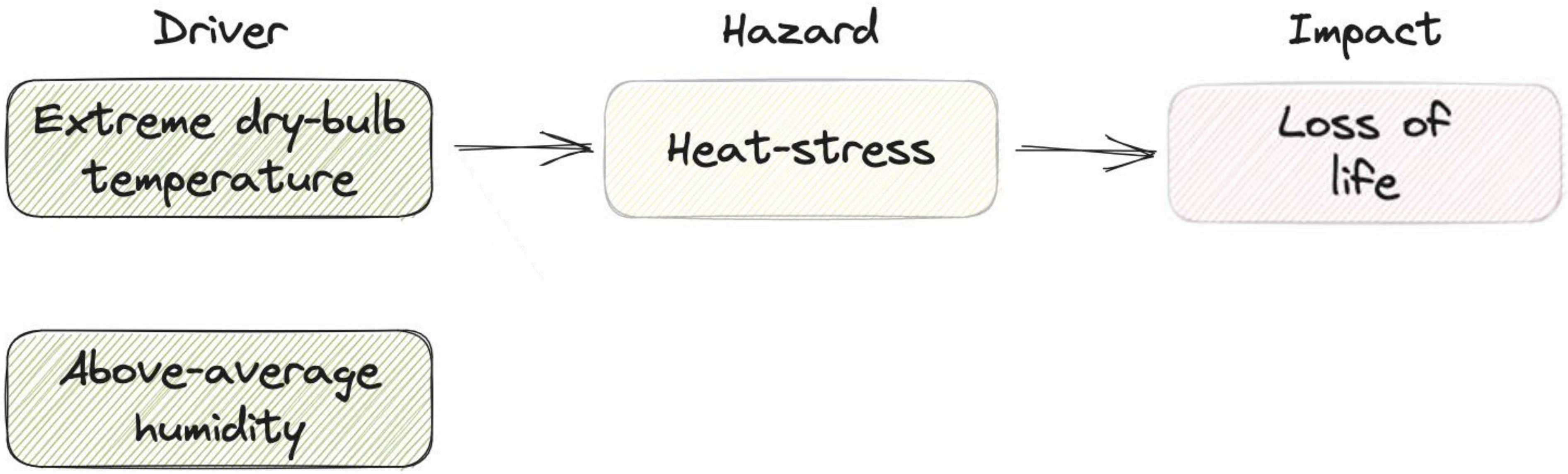

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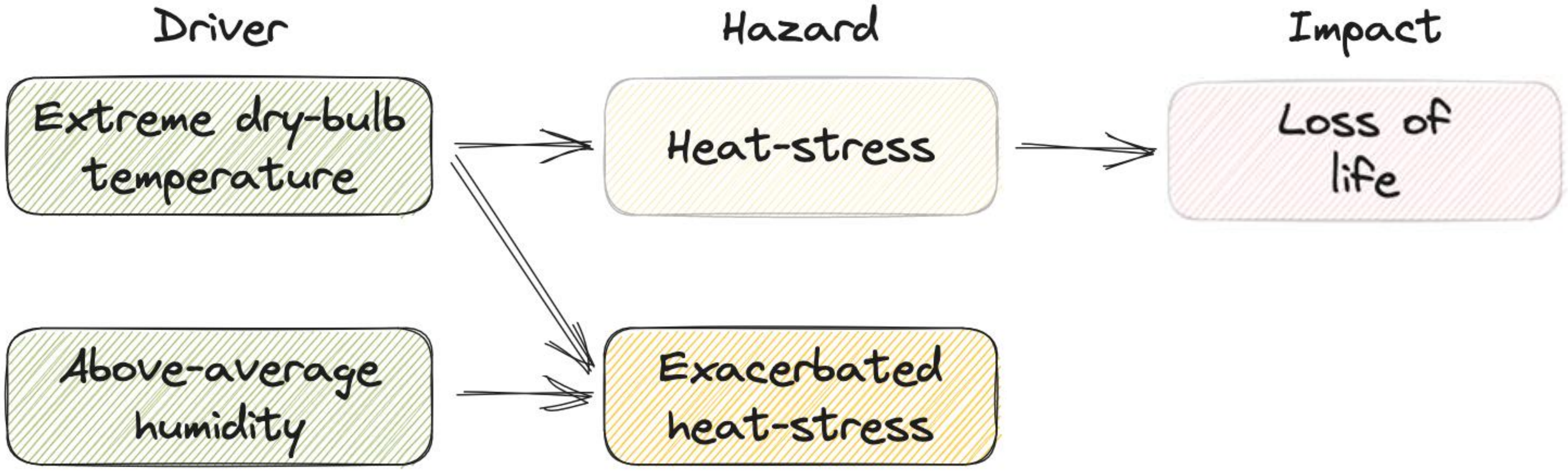

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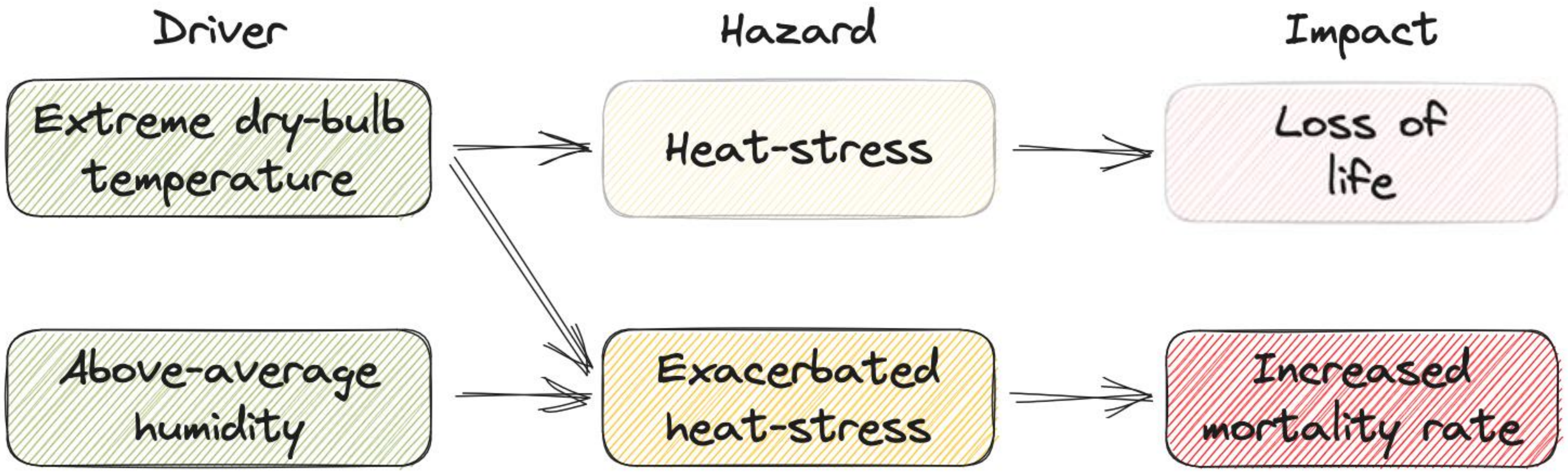

Compound extreme humid-heat is more hazardous than dry-heat

➔ Reduced ability to cool via sweating

Sherwood & Huber (2010)

Sherwood, S.C. and Huber, M., 2010. An adaptability limit to climate change due to heat stress. *Proceedings of the National Academy of Sciences*, *107*(21), pp.9552-9555.

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We also risk *underpreparing* for extreme events

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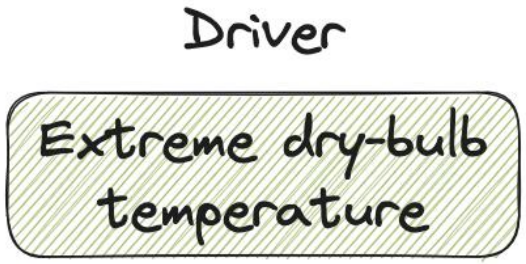

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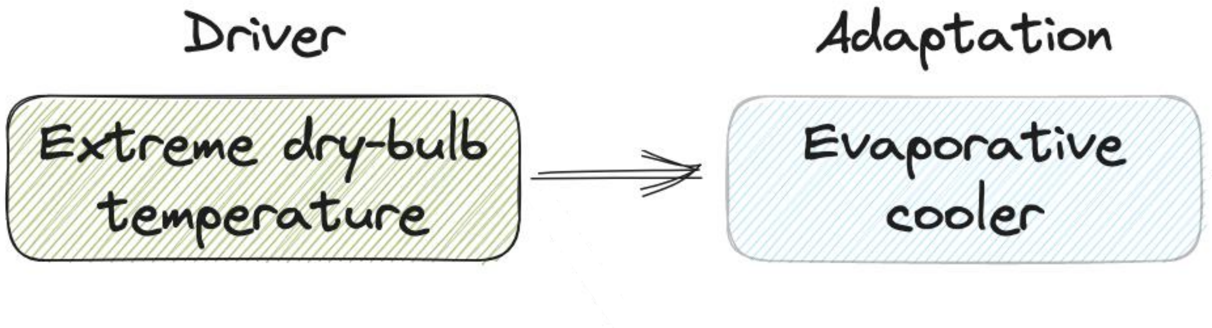

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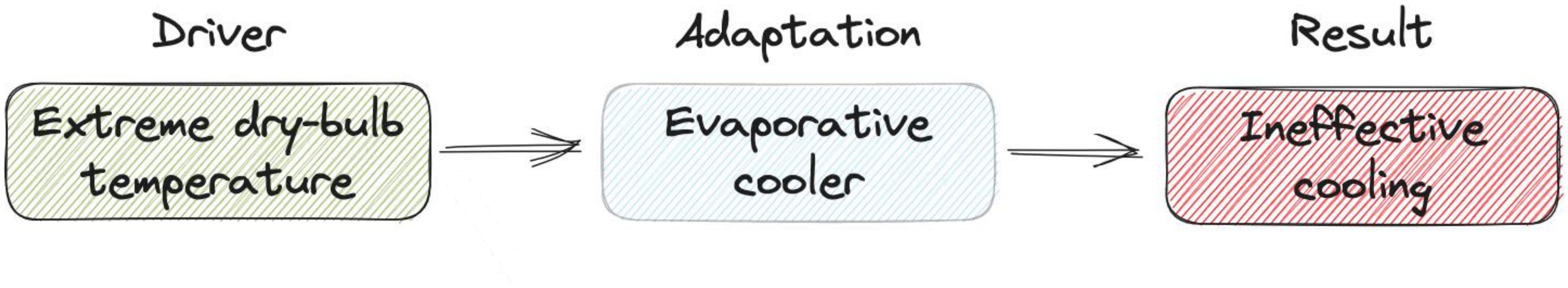

Evaporative coolers depend on latent cooling to reduce air temperature

➔ Less effective latent cooling with high humidity

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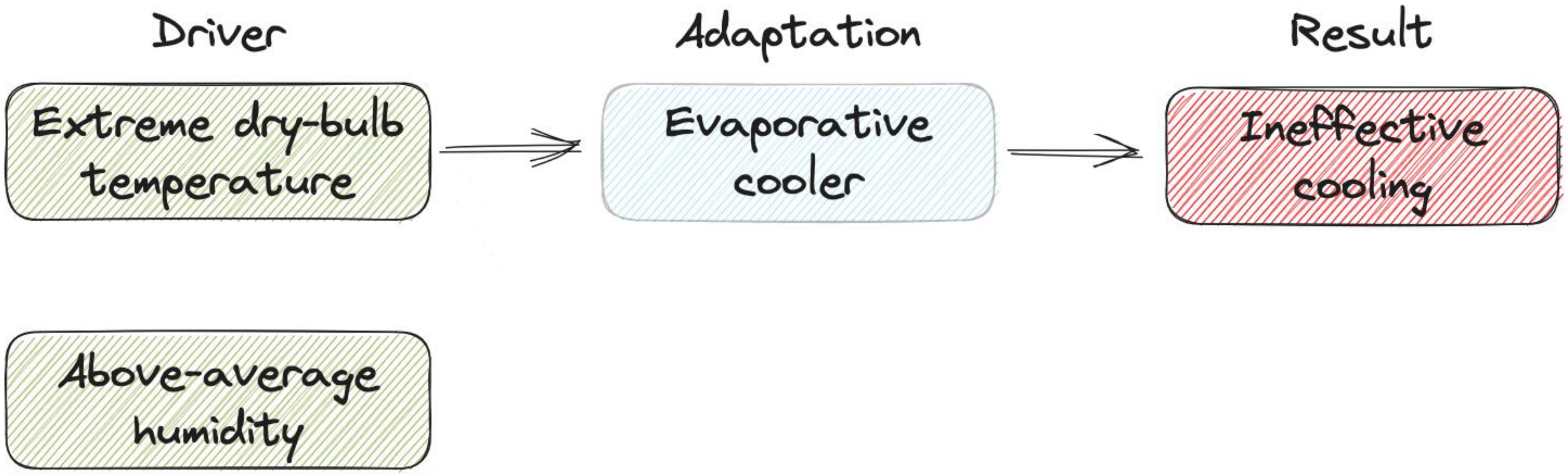

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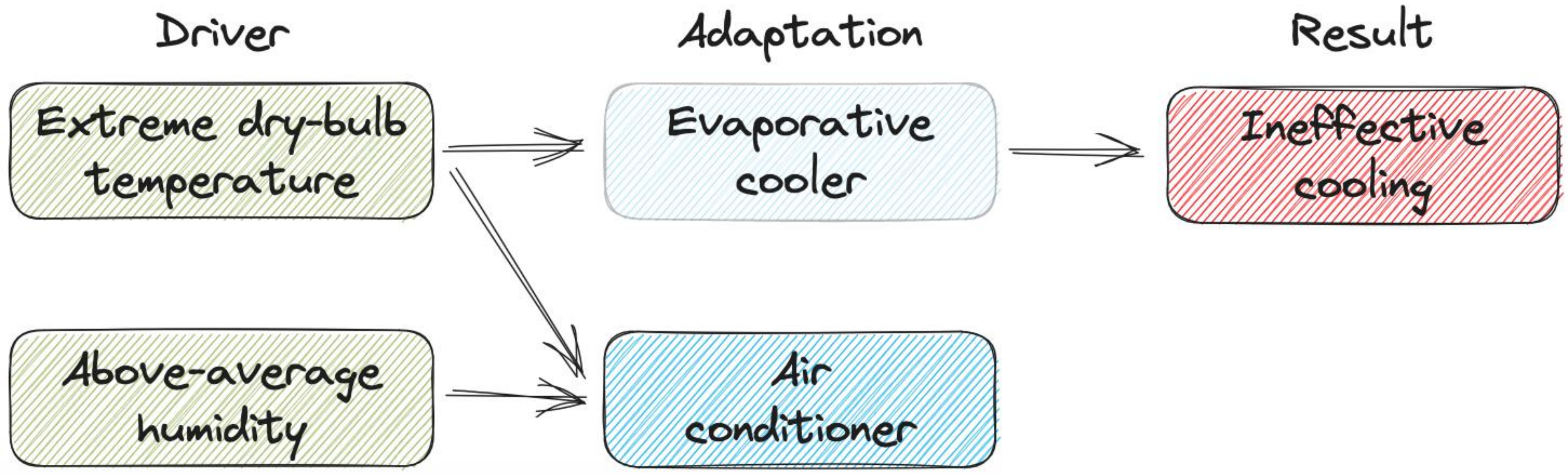

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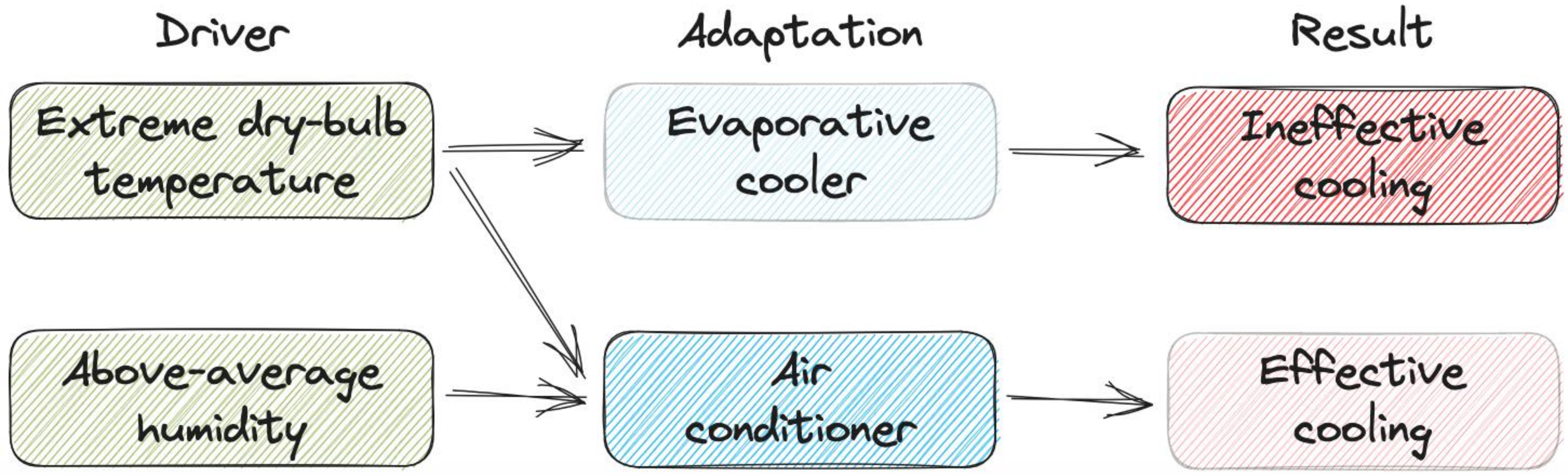


Evaporative coolers depend on latent cooling to reduce air temperature

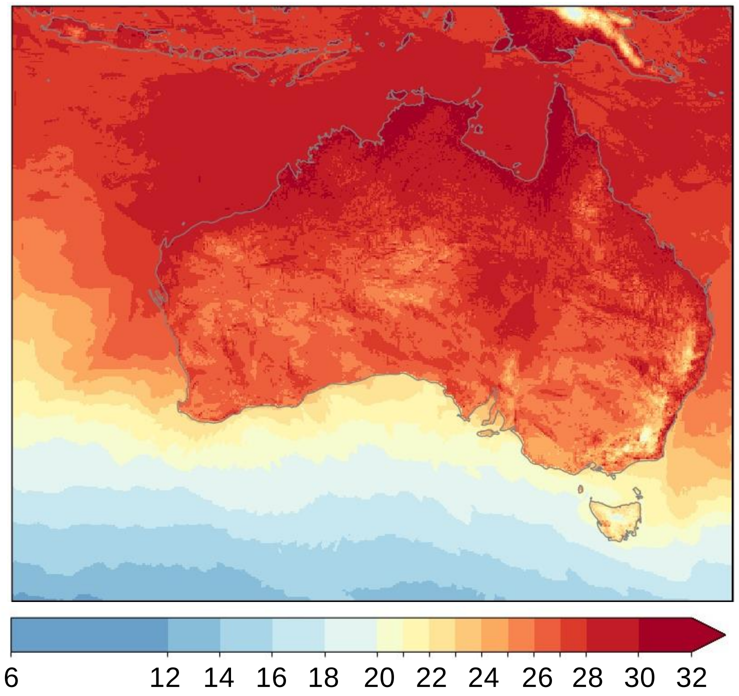
➔ Less effective latent cooling with high humidity

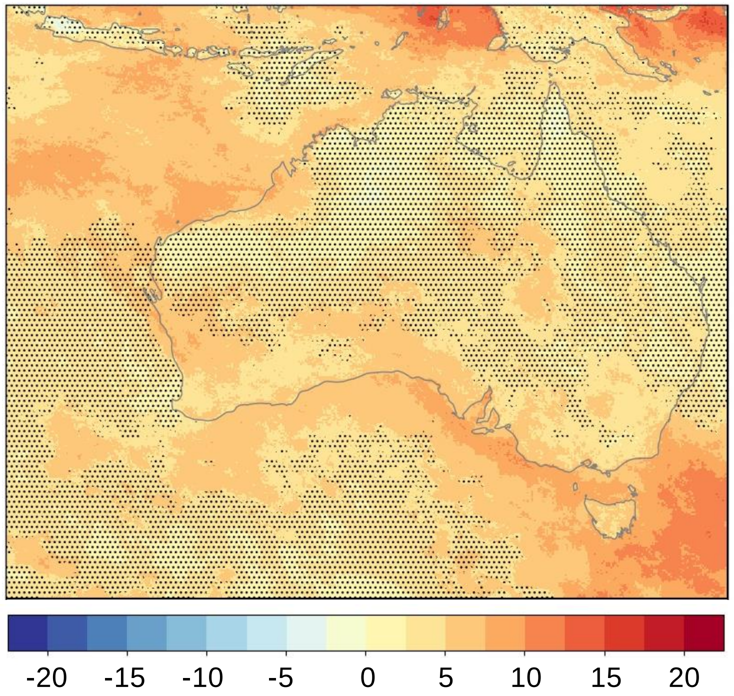
Air conditioners remove moisture from the air

➔ Effective when humidity is high

Understanding extreme humid-heat trends over Australia

Collaborators: Mitch Black and Rob Warren





Stippling = no significant trend

How has dry- and humid-heat changed?

Dry-heat

Heatwaves hotter, longer, more frequent
(Perkins-Kirkpatrick & Lewis, 2020)

Mean temperatures increasing

Extreme temperatures increasing

Changes are generally well understood

Perkins-Kirkpatrick, S.E. and Lewis, S.C., 2020. Increasing trends in regional heatwaves. *Nature communications*, *11*(1), pp.1-8.
Raymond, C., Matthews, T. and Horton, R.M., 2020. The emergence of heat and humidity too severe for human tolerance. *Science Advances*, *6*(19), p.eaaw1838.
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Wet-bulb temperature extremes have increased in many locations

- Station analyses (Raymond et al., 2020)
- Gridded analyses (Rogers et al., 2021)

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Extreme heat frequency trends

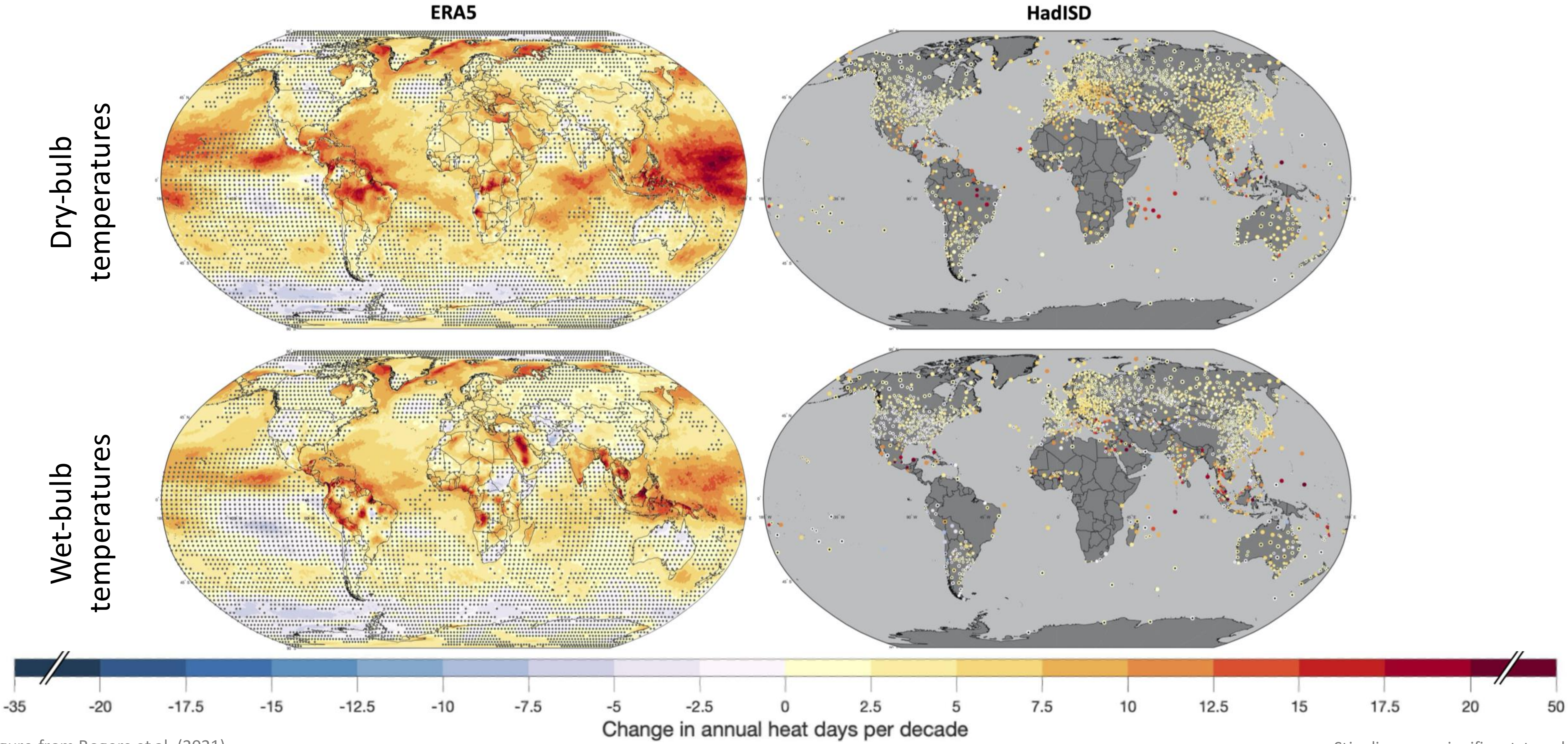
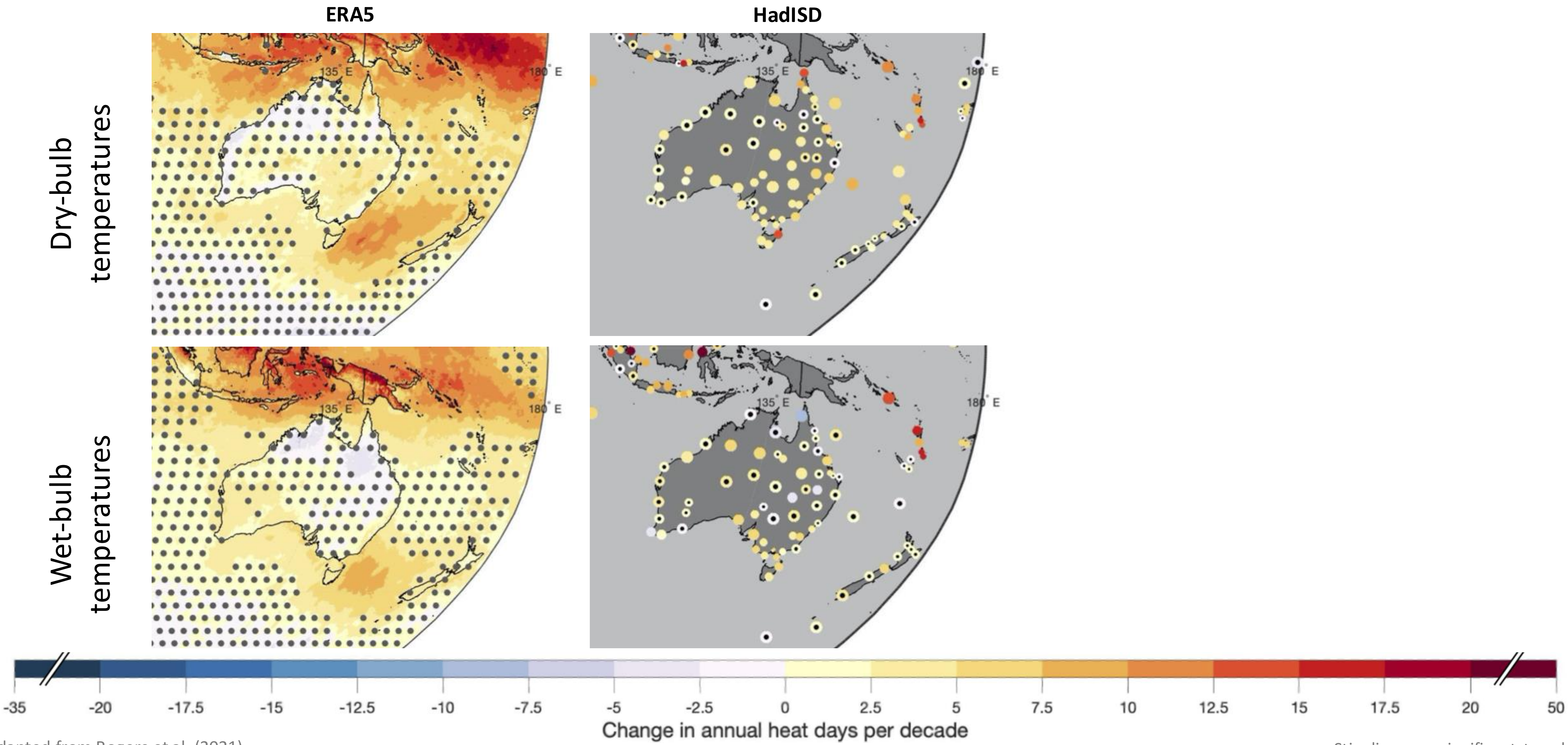


Figure from Rogers et al. (2021)

Stippling = no significant trend

All plots use Jan-Dec data for 1979-2019

Extreme heat frequency trends over Australia



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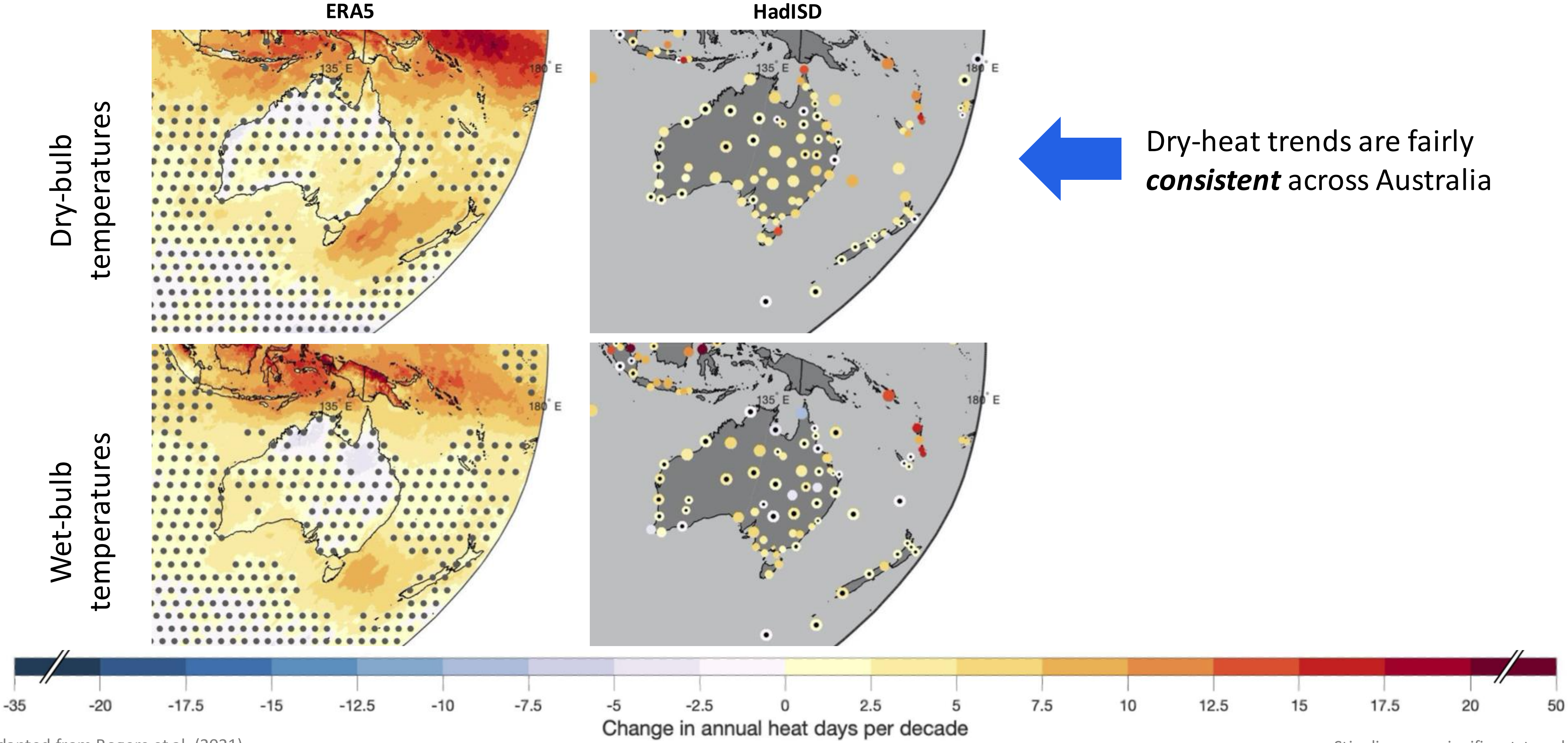

Dry-heat trends are fairly ***consistent*** across Australia

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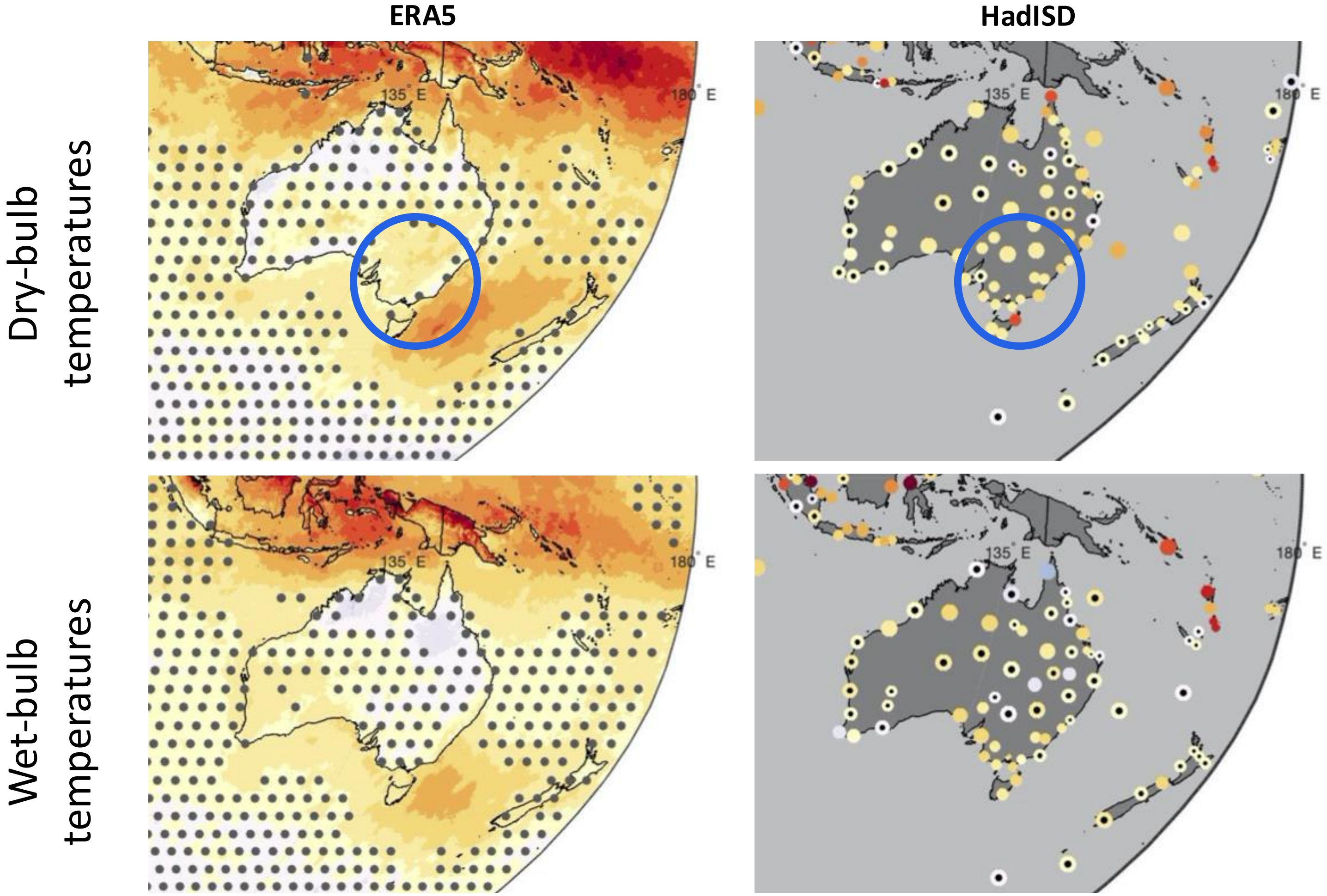
Extreme heat frequency trends over Australia



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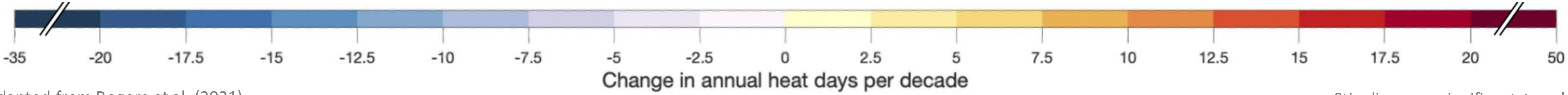

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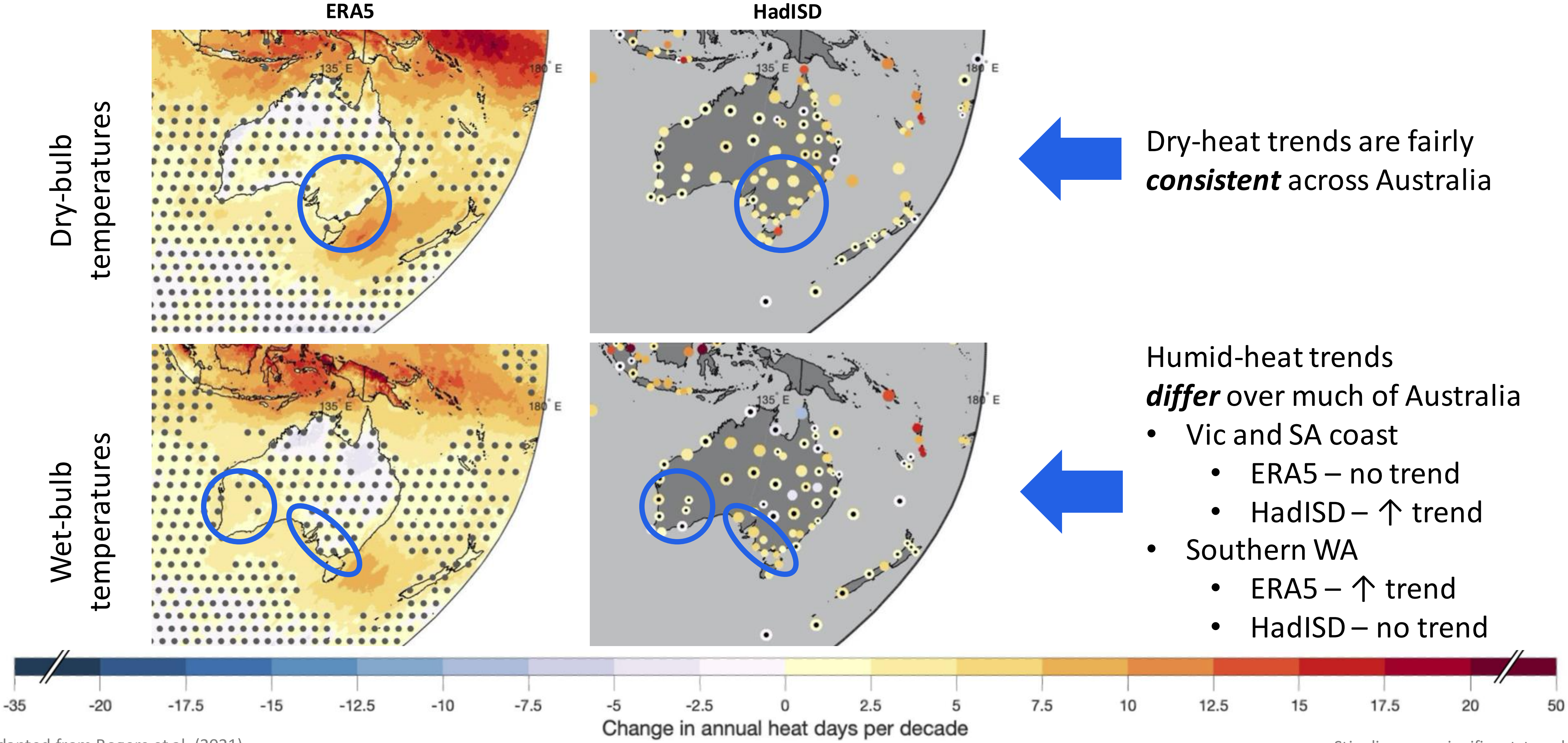

Dry-heat trends are fairly ***consistent*** across Australia

Humid-heat trends ***differ*** over much of Australia

- Vic and SA coast
  - ERA5 – no trend
  - HadISD – ↑ trend
- Southern WA
  - ERA5 – ↑ trend
  - HadISD – no trend

Adapted from Rogers et al. (2021)

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Aim: How has humid-heat changed over Australia?

Calculation of wet-bulb temperature

- Dry-bulb temperature
- Pressure
- A humidity metric (specific humidity, relative humidity, or dew-point temperature)

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Examination of wet-bulb temperature trends over Australia using multiple datasets

- ERA5
    - Global data
- BARRA1
    - Higher resolution than ERA5
    - Data only available over Australia and surrounding regions
- The Bureau's automatic weather station data
    - Including some actual (not derived) wet-bulb temperature observations

Calculating wet-bulb temperature – our new fast and accurate method

Commonly used methods in the literature

- Davies-Jones (2008)
  - A highly-accurate iterative method
  - Slow and computationally intensive to run
- Stull (2011)
  - Fast to run
  - Large errors for extremely hot temperatures (>1˚C)

Davies-Jones, R., 2008. An efficient and accurate method for computing the wet-bulb temperature along pseudoadiabats. *Monthly Weather Review*, *136*(7), pp.2764-2785.

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We are developing a new method to calculate wet-bulb temperature

- NEWT – The Noniterative Evaluation of Wet-bulb Temperature method
- We implement equations from Romps (2017) and Moisseeva and Stull (2017)
- Our method should produce *highly accurate* data (similar to Davies-Jones, 2008), but much *faster*

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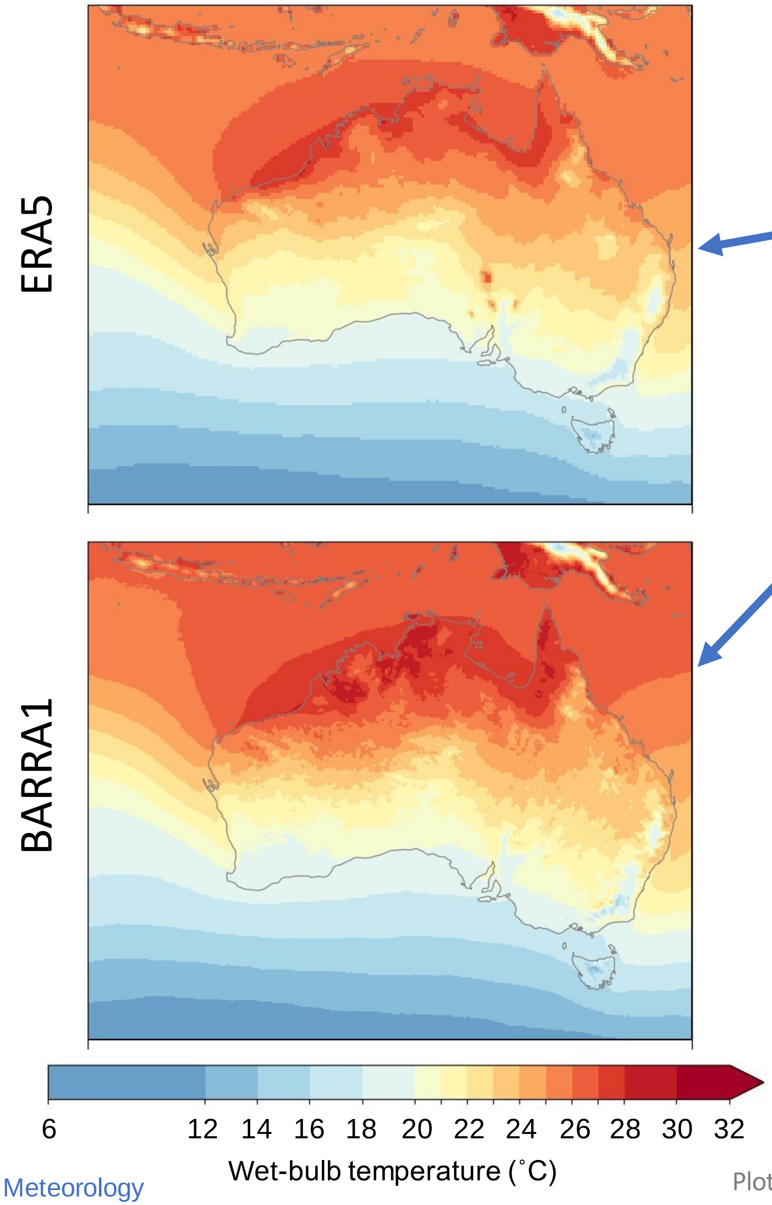
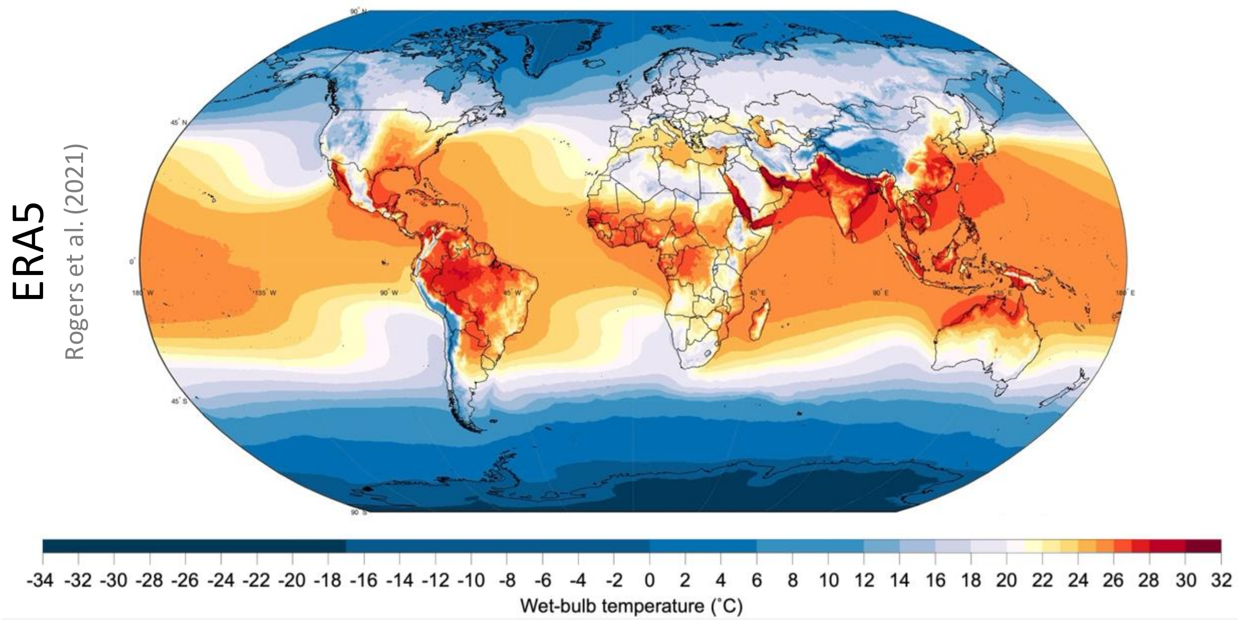
95th percentile of maximum daily wet-bulb temperature (Jan-Dec)



ERA5 and BARRA1 results using NEWT method are similar to ERA5 results using Davies-Jones method



Plots on left use Jan-Dec data for 1990-2018

Plot on right uses Jan-Dec data for 1979-2019

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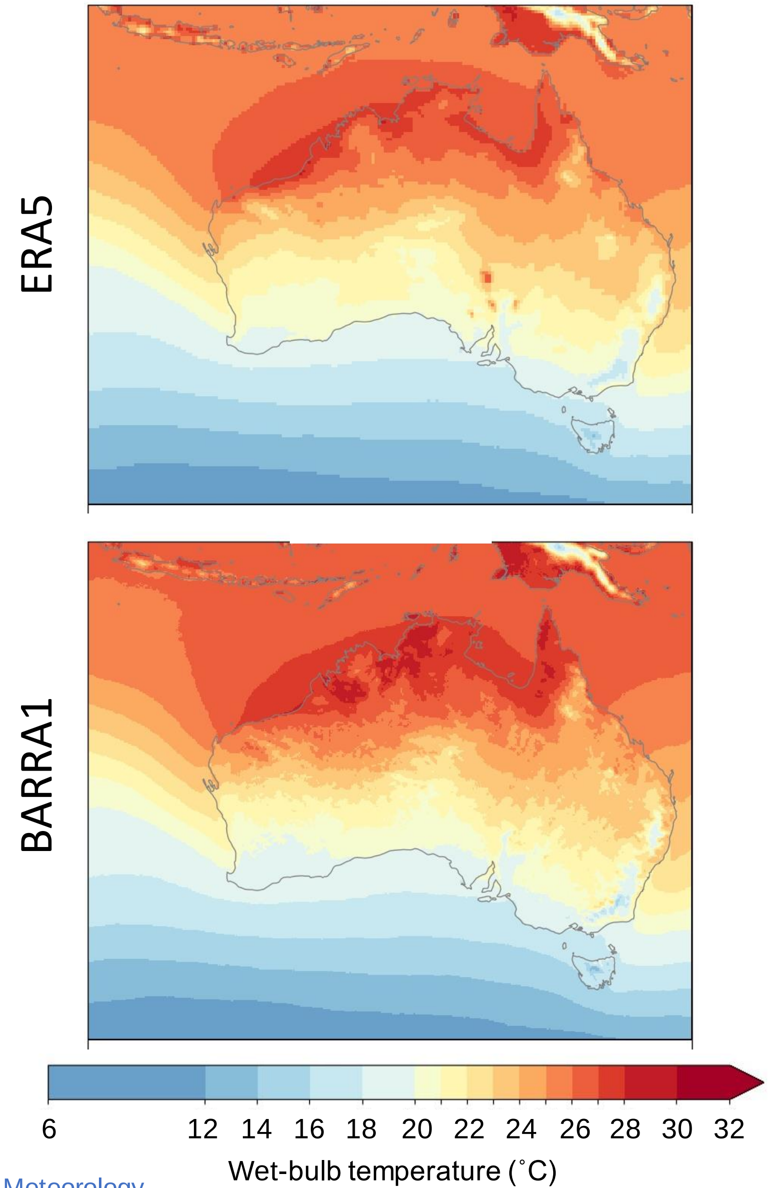
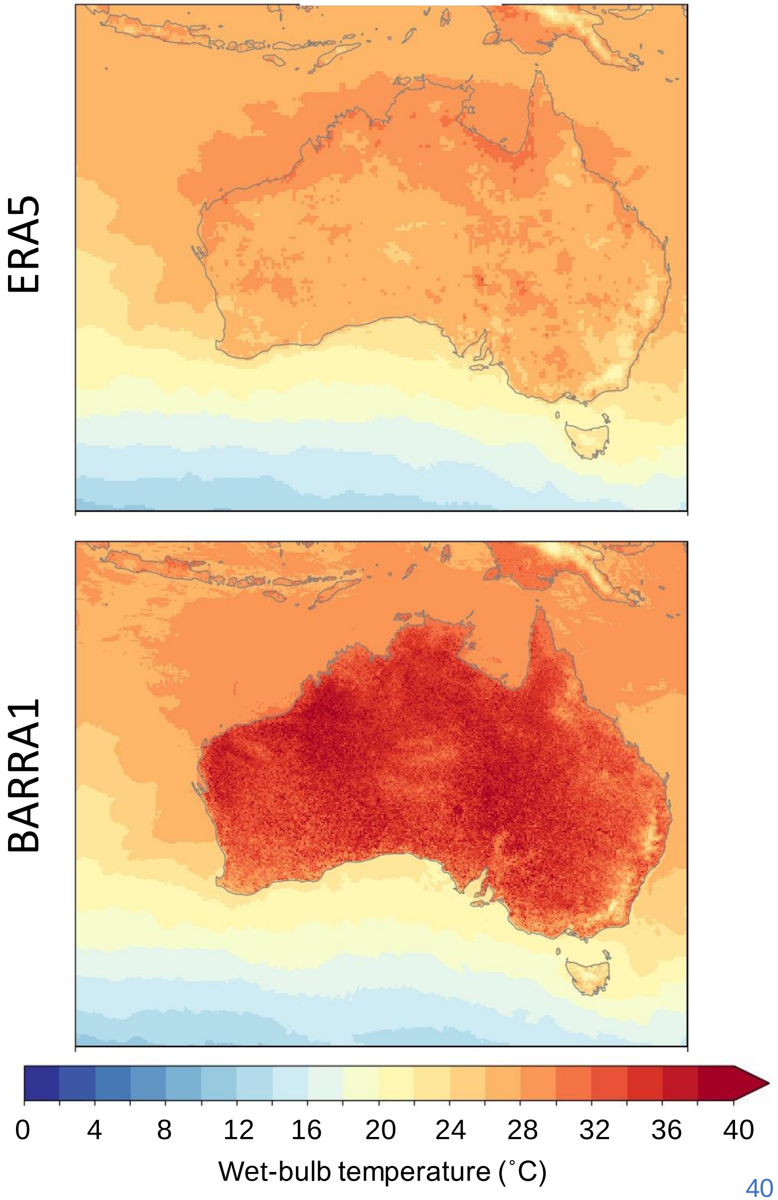
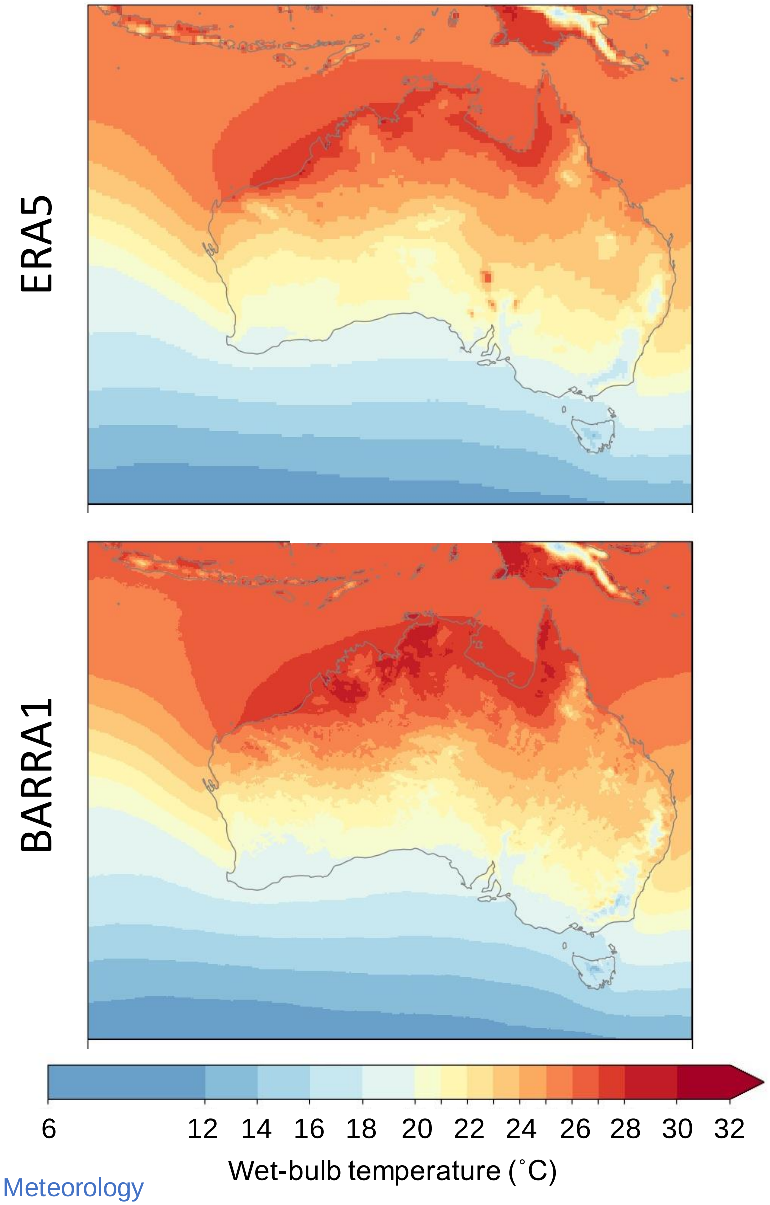


Maximum daily wet-bulb temperature

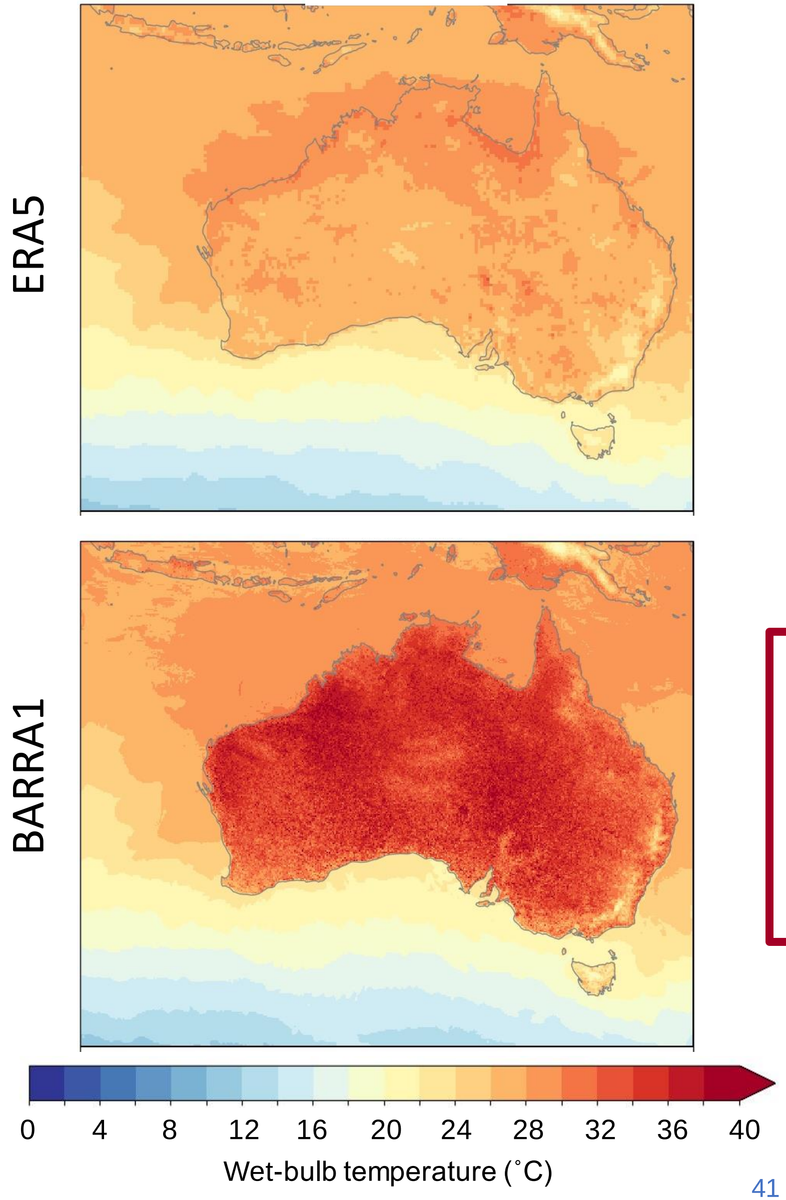


All plots use Jan-Dec data for 1990-2018

95th percentile of maximum daily wet-bulb temperature



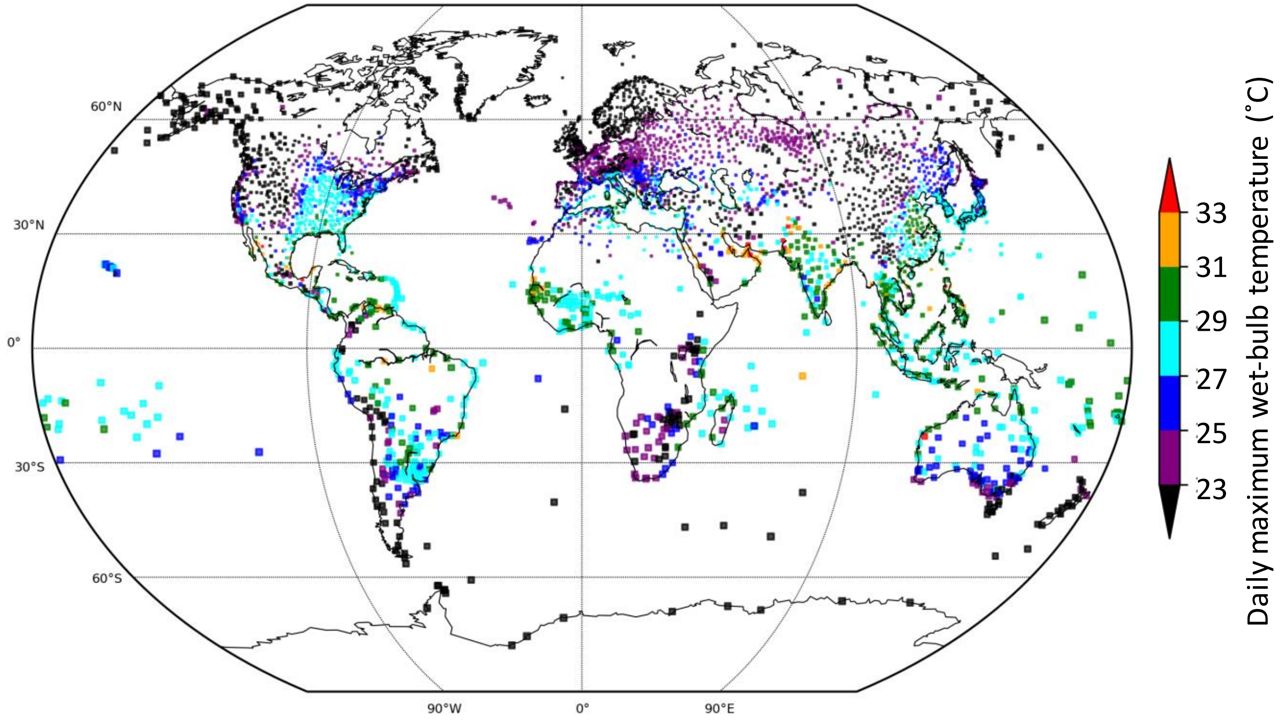
Maximum daily wet-bulb temperature



Maximum wet-bulb temperatures are too high in BARRA1

All plots use Jan-Dec data for 1990-2018

BARRA1 wet-bulb temperature is ***much*** greater than in other studies



99.9th percentile of maximum daily wet-bulb temperature

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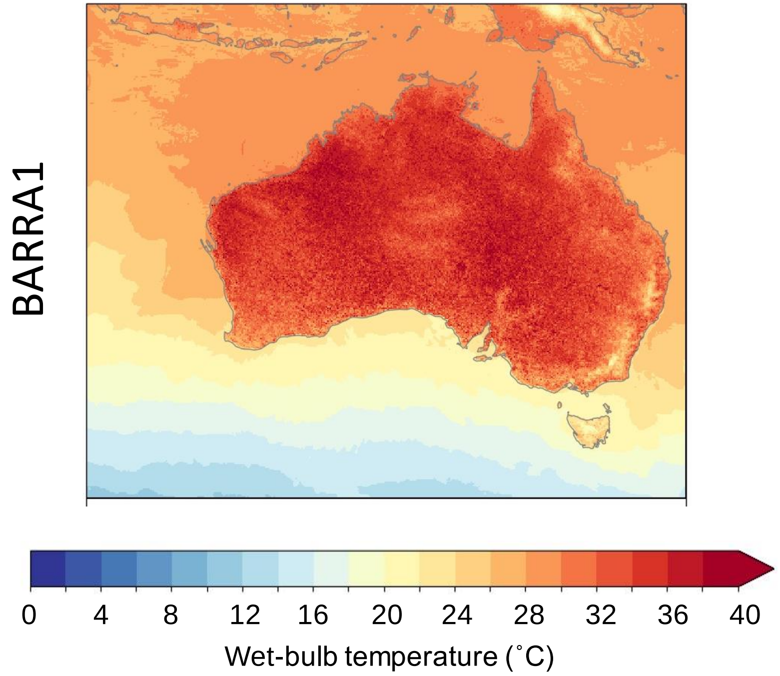

Raymond et al. (2020)

> "While our analysis of weather stations indicates that [wet-bulb temperature] has already been reported as having ***exceeded 35°C in limited areas for short periods***, this has not yet occurred at the regional scale represented by reanalysis data"

Left figure from Raymond et al. (2020)

Raymond, C., Matthews, T. and Horton, R.M., 2020. The emergence of heat and humidity too severe for human tolerance. *Science Advances*, 6(19), p.eaaw1838.

Calculating wet-bulb temperature using BARRA1

- Wet-bulb temperature is too high in BARRA1
- Known high bias in screen level specific humidity
- Common solution is to replace screen level moisture with lowest model level moisture

ERA5

- Pressure (surface)
- Dry-bulb temperature (screen level)
- Dew-point temperature (screen level)

BARRA1 – screen level

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BARRA1 – screen level
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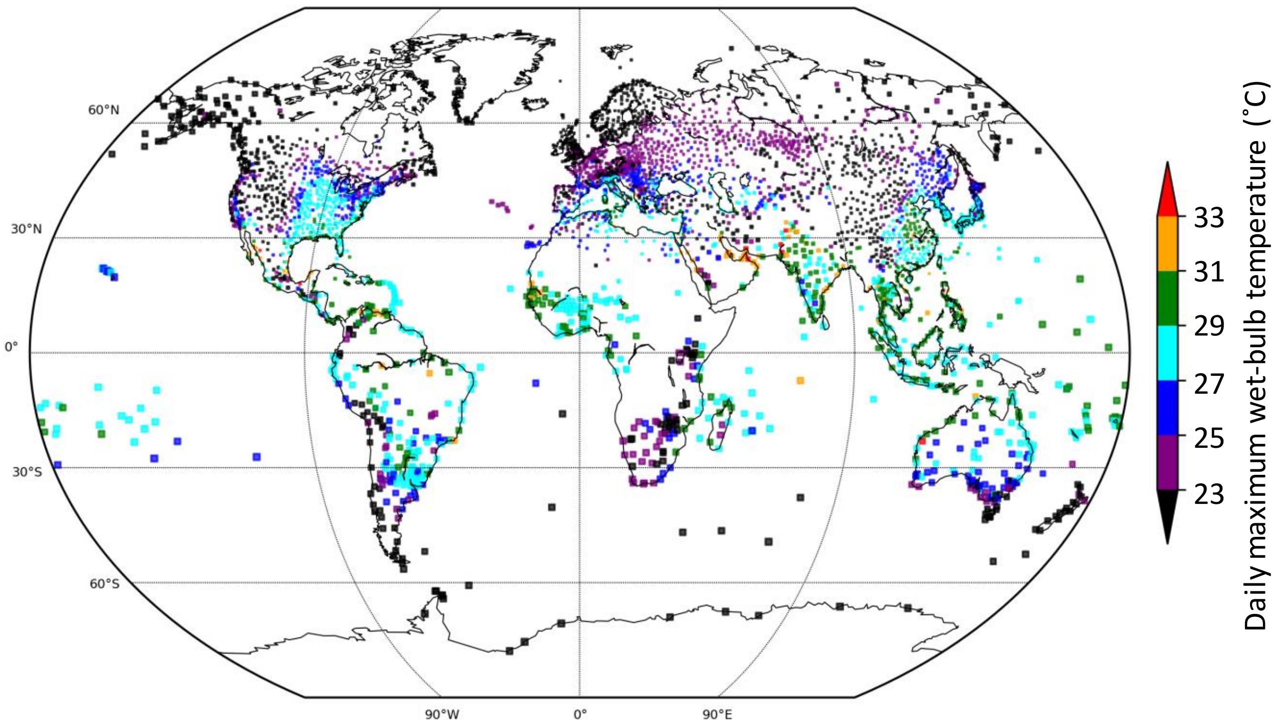
- Dry-bulb temperature (screen level)
- Dew-point temperature (screen level)

→

BARRA1 – lowest model level
- Pressure (surface)
- Dry-bulb temperature (screen level)
- Specific humidity (lowest model level)

Lowest model level moisture produces more realistic wet-bulb temperature than screen level moisture



99.9th percentile of maximum daily wet-bulb temperature

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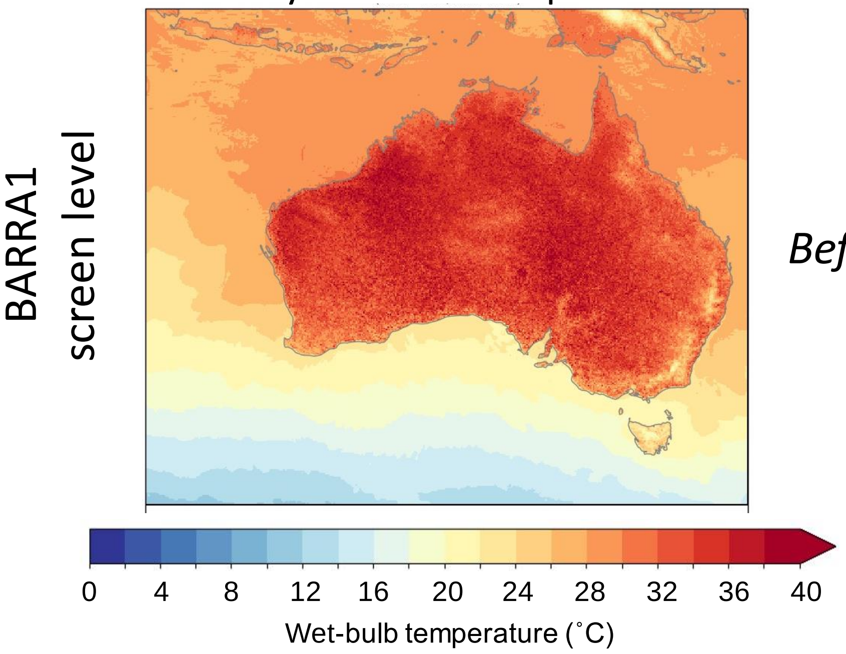

Before

Left figure from Raymond et al. (2020)

Raymond, C., Matthews, T. and Horton, R.M., 2020. The emergence of heat and humidity too severe for human tolerance. *Science Advances*, *6*(19), p.eaaw1838.

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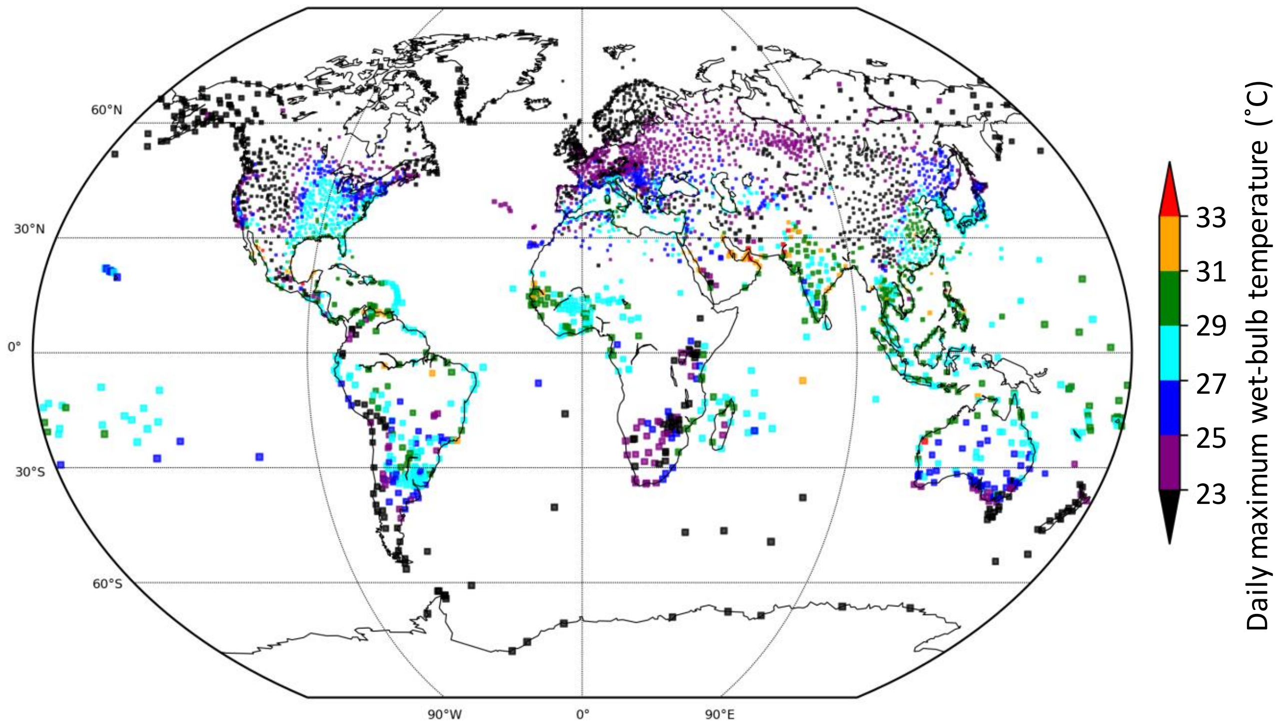

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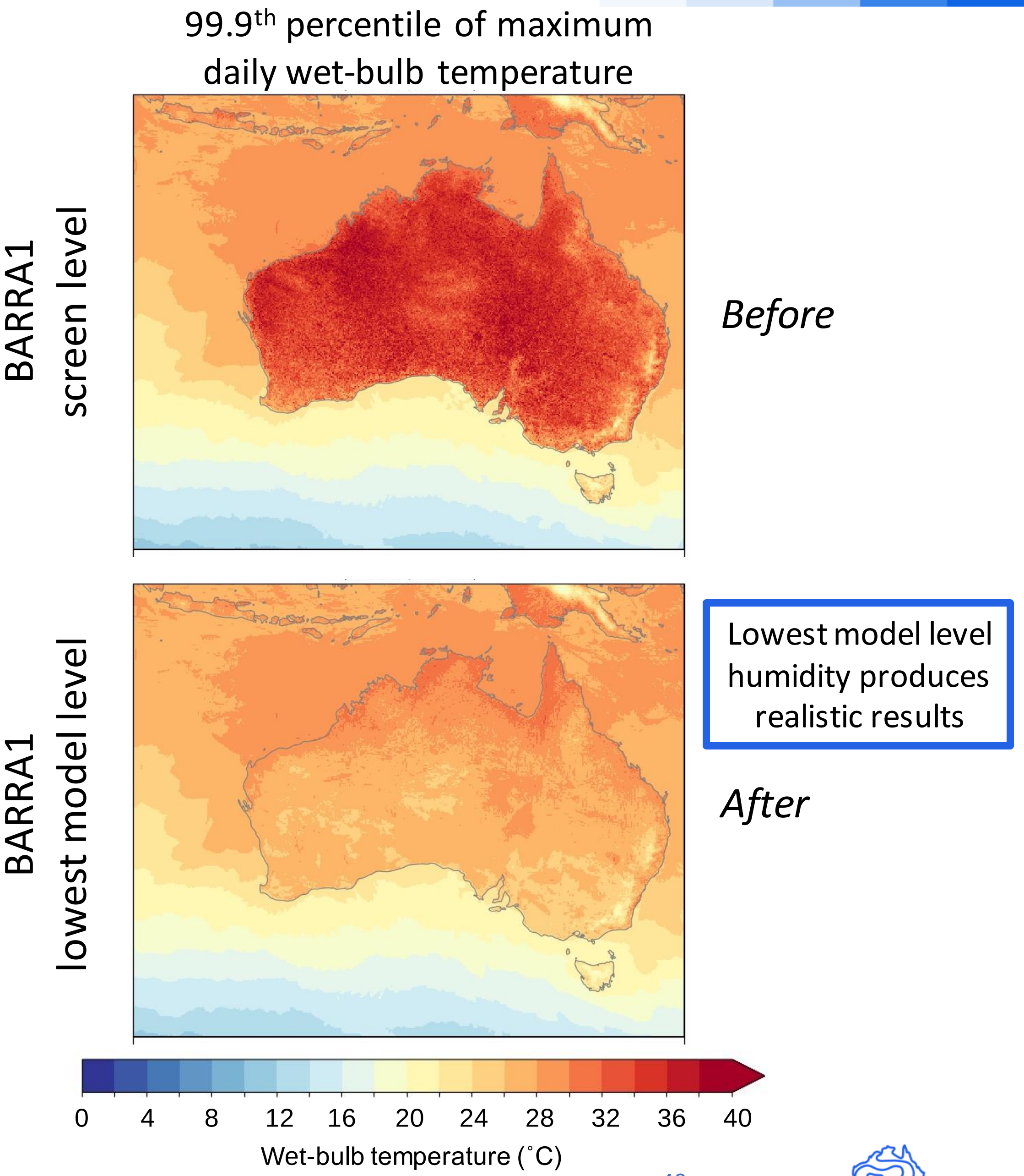

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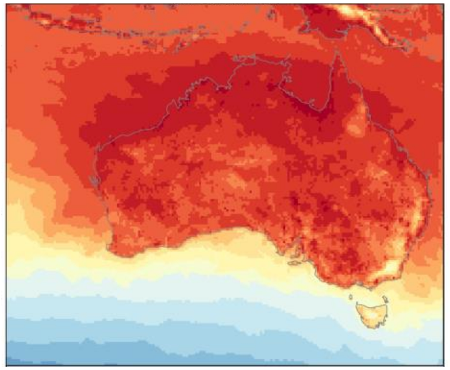
ERA5 vs BARRA1 (lowest model level)

Stippling = no significant trend

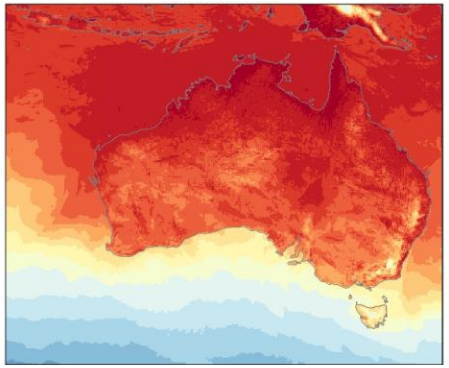
Maximum daily
wet-bulb temperature

ERA5



The hottest humid-heat events for ERA5 and BARRA1 are similar

BARRA1



Wet-bulb temperature (˚C)

All plots use Jan-Dec data for 1990-2018

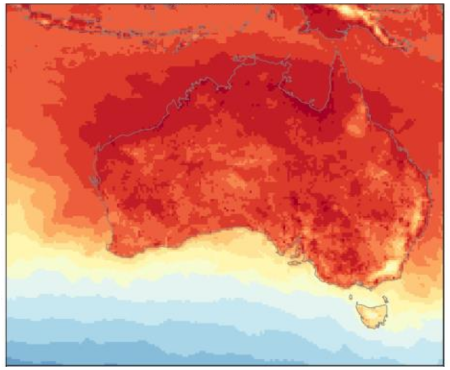
ERA5 vs BARRA1 (lowest model level)

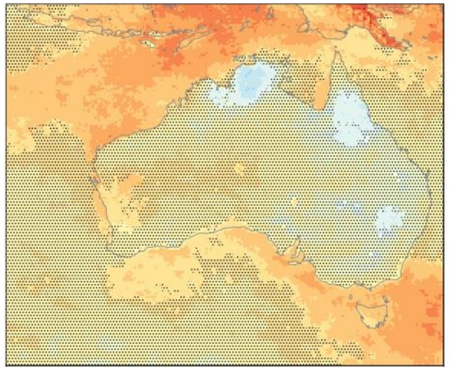
Stippling = no significant trend

Maximum daily
wet-bulb temperature

Trend in humid-heat days

ERA5

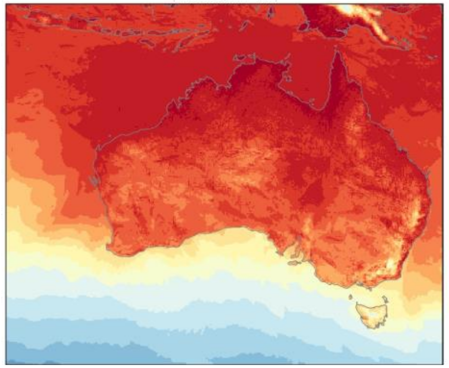


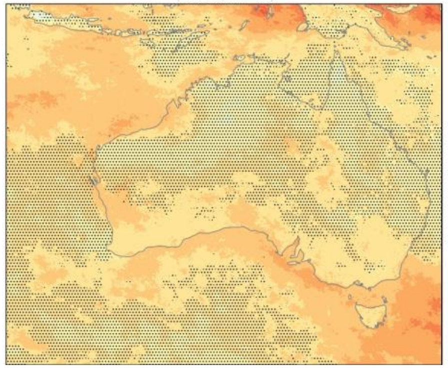


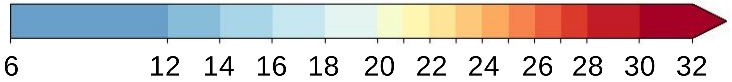
The hottest humid-heat events for ERA5 and BARRA1 are similar

Trends in humid-heat frequencies for ERA5 and BARRA1 are *inconsistent*

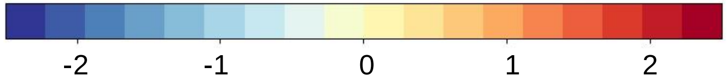
BARRA1







Wet-bulb temperature (˚C)

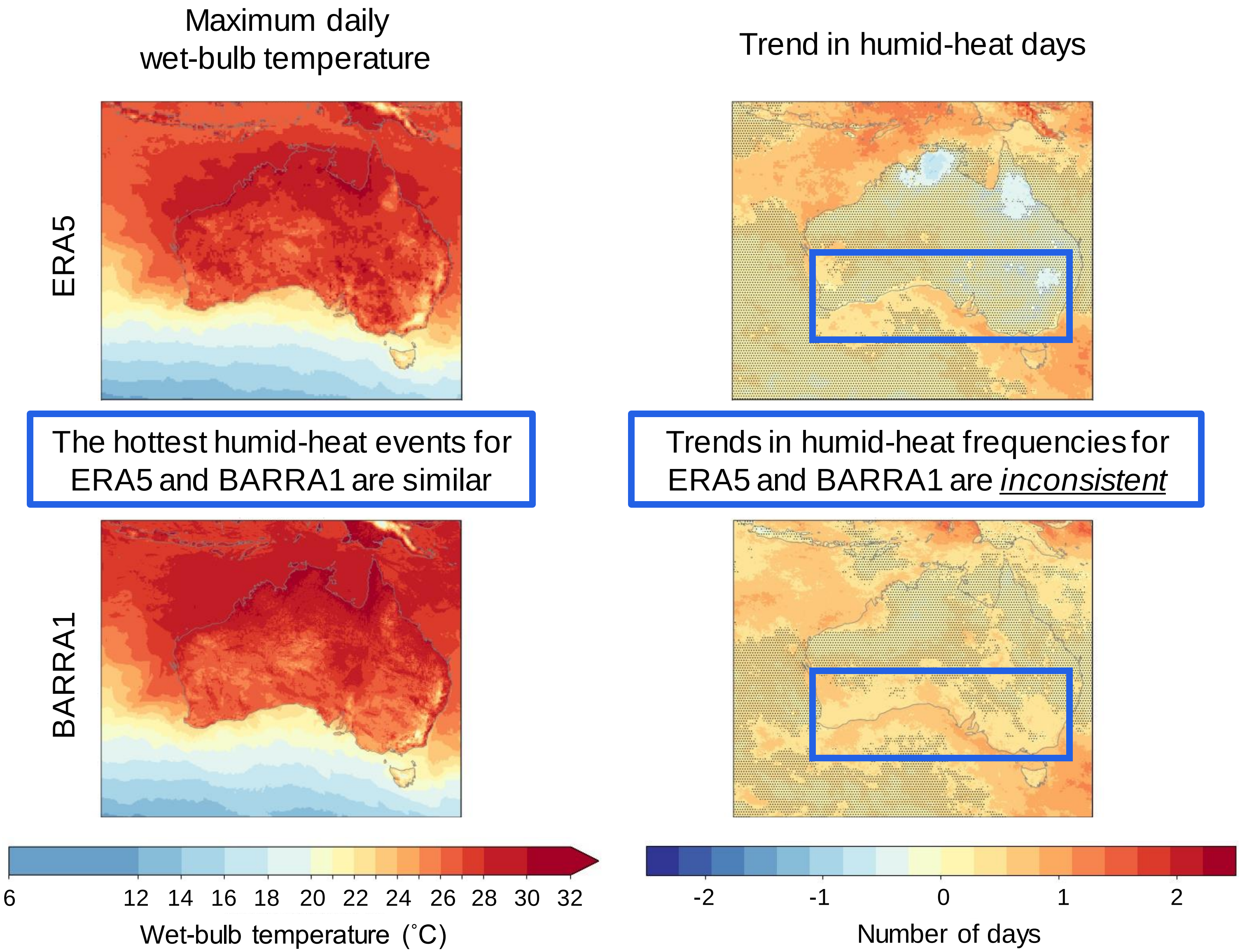


Number of days

All plots use Jan-Dec data for 1990-2018

ERA5 vs BARRA1 (lowest model level)

Stippling = no significant trend



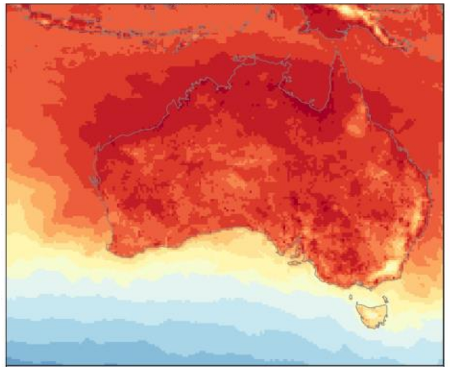
All plots use Jan-Dec data for 1990-2018

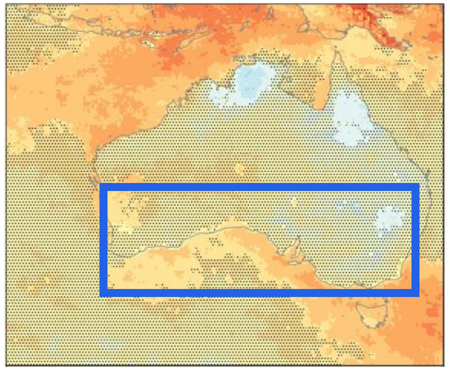
ERA5 vs BARRA1 (lowest model level)

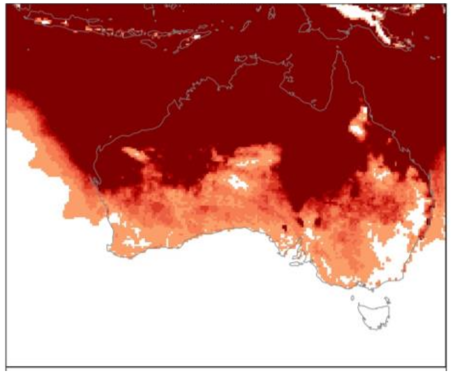
Stippling = no significant trend

Maximum daily wet-bulb temperature	Trend in humid-heat days	Number of days with wet-bulb temperatures > 26˚C

ERA5







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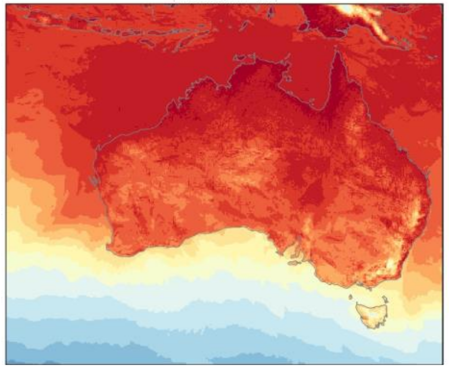
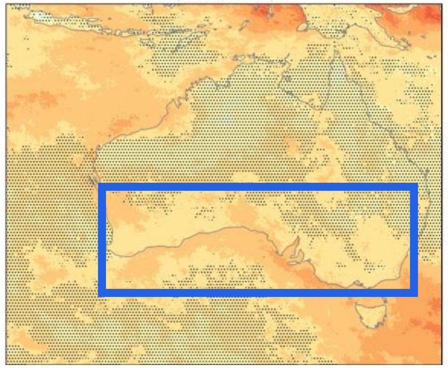
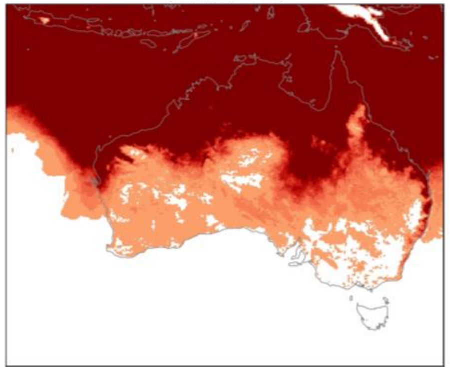
Trends in humid-heat frequencies for ERA5 and BARRA1 are *inconsistent*

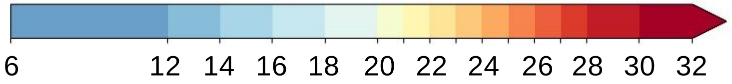
"Dangerous" humid-heat events occur over most of the mainland

BARRA1

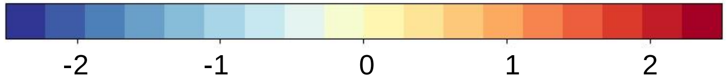




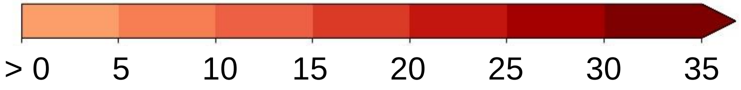




Wet-bulb temperature (˚C)



Number of days



Number of days

All plots use Jan-Dec data for 1990-2018

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www.researchgate.net/profile/Cassandra-Rogers-3

Summary

1. Compound events increase the threat posed by extremes
2. Without considering compound events, we risk underestimating extreme event impacts or underpreparing for these events
3. Humid-heat trends differ between datasets in some regions
4. Our new methodology has the potential to quickly produce highly accurate wet-bulb temperature data

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Future research

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- Compare reanalysis datasets to Bureau automatic weather station data
- Determine which datasets are suitable for humid-heat analysis
- Future projections
- Health impact of dry- and humid-heat ➔ which is most dangerous? (ABS)

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Want to know more about compound events research?
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Thank you!

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