Jozef Syktus – Research Professor

School of the Environment, The University of Queensland, Brisbane, Australia

Contribution from Ralph Trancoso, Sarah Chapman, Rohan Eccles and others

Climate Projections and Services, Department of Energy and Climate, Qld Government

- Overview of Queensland Future Climate Programme & Climate Projections and Services

- Analysis of projected precipitation trends from CMIP5/CMIP6 projections

University of Warsaw – 24 May 2024
Poland

Poland vs Queensland

Size: 321 mil km2
Population: 36.8 mil
GDP: 688 mild USD

Emissions: EU legally binding target of a 55% reduction by 2030, target 90% by 2040 relative to 1990 emission levels.
Poland ??

Size: 1729 mil km2
Population: 5.2 mil
GDP: 334 mild USD

Emissions: Legislation – requiring Queensland to cut emissions by 30 per cent on 2005 levels by 2030, 75 per cent by 2035, and reach net zero by 2050

Queensland Future Climate Science Program in 2024: *climate modelling, analysis, and services*

Ralph Trancoso[1], Jozef Syktus[2], Sarah Chapman[1], Nathan Toombs[1], David Ahrens[1], David Owens[1], Hong Zhang[1], David Putland[1], Ryan McGloin[1], Rohan Eccles[1]

[1] Department of Energy and Climate, Queensland Government, Brisbane, Australia.

[2] The University of Queensland, School of The Environment, Brisbane, Australia.

The University of Queensland Australia — Create Change

Queensland Government

Background

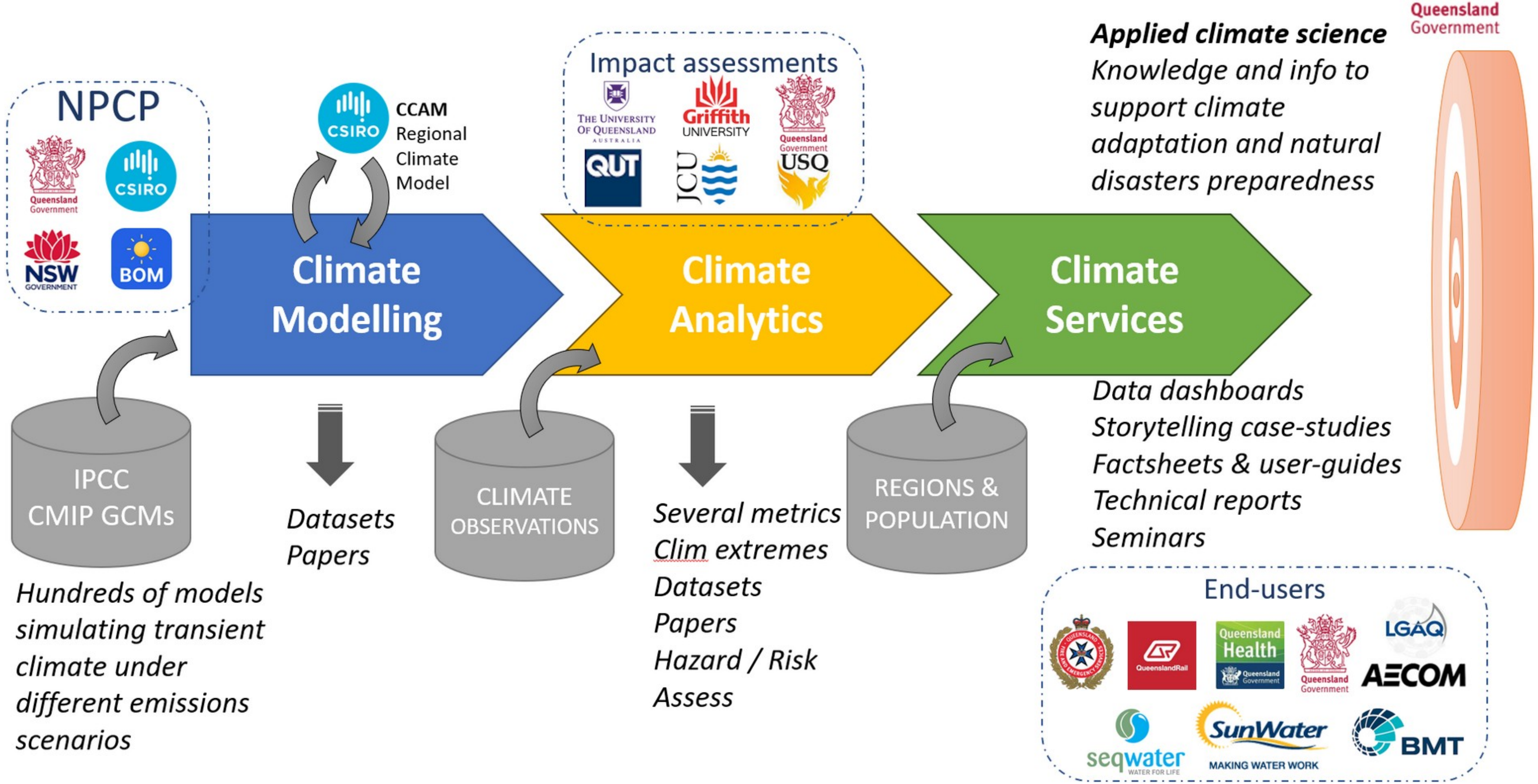
The *Queensland Future Climate Science Program*

- Collaboration between Queensland Government and University of Queensland;
- Dynamically downscaling of future climate simulations;
- Translation of climate projections into climate services to underpin adaptation and preparedness for natural disasters;
- Phase 1: 11 CMIP5 GCMs under 2 RCPs with 10 km of resolution over Queensland.
- Phase 2: 11 CMIP6 GCMs (15 ensembles) under 4 SSPs with 10 km of resolution over Australia.

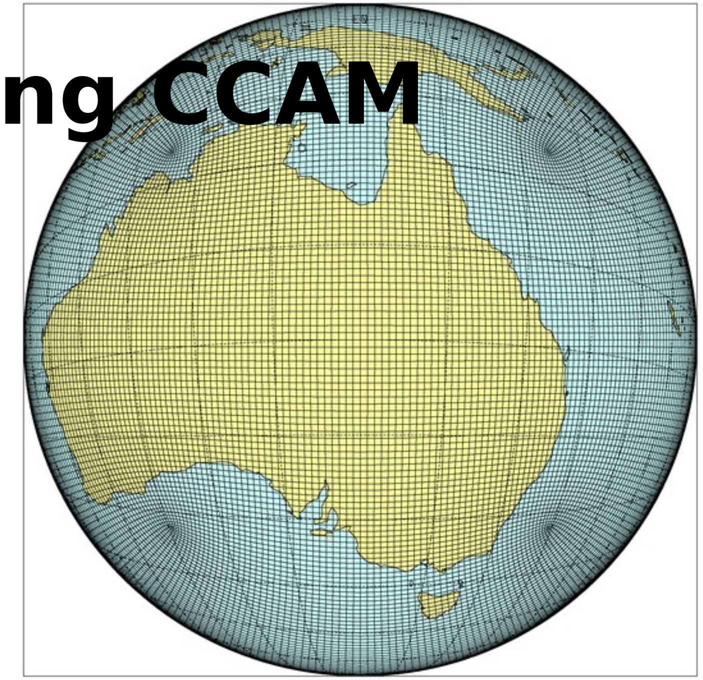
Team expertise and niche

- **Climate modelling**
  - Regional climate modelling
  - Convection Permitting modelling
  - Statistical downscaling (to develop)
- **Climate extremes and hazards**
  - Heatwaves
  - Extreme Temperature
  - Extreme Precipitation
  - Drought
  - Wetness and Floods
  - Fire Weather
  - Tropical Cyclones
  - Convective Extremes
  - Compound extremes
  - Marine hazards
- **Climate analytics**
  - Global Climate Models analysis
  - Regional Climate Models analysis
  - Data visualization
  - Bias correction
  - Generalized Extreme Value
  - Machine Learning (to develop)
- **Climate services**
  - Data portals
  - Regionalization portals
  - Translation of knowledge (storytelling case studies and storyline approach)
  - GWL approach services
  - Documentation and communication products
  - Knowledge brokerage

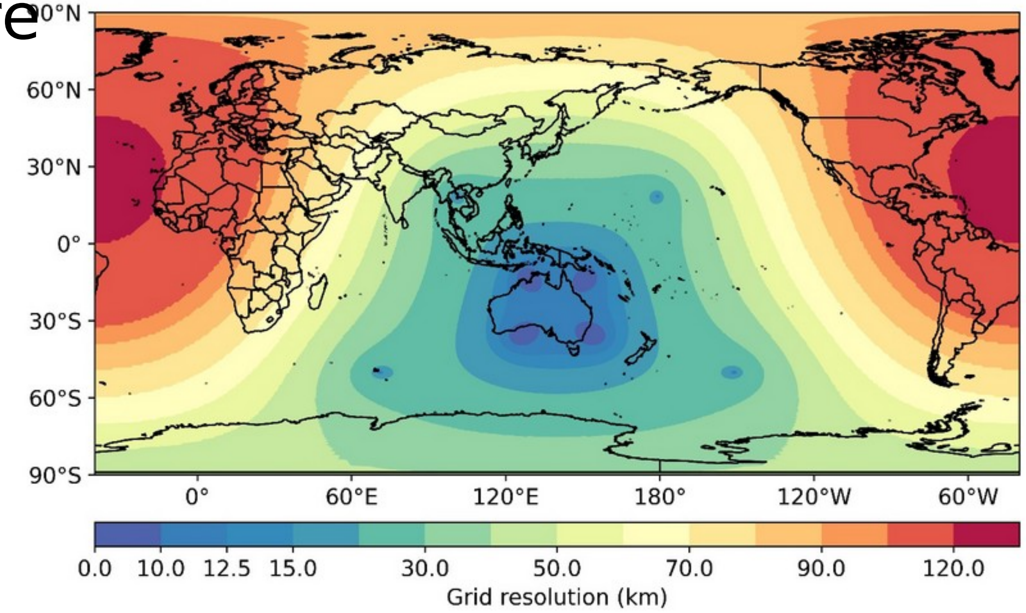
Climate Projections & Services workflow



CMIP6 downscaling approach using CCAM



- Conformal Cubic Atmospheric Model (CCAM) CSIRO
- Global model with stretched grid (C288 grid) and maximum resolution over Australia (**10km**)
- Bias-corrected SSTs and sea ice
- 35 vertical levels in the atmosphere and 30 in the ocean, parameterization scale aware
- 15 ensemble runs (**5 ocean coupled**)
- Forced using the CMIP6 radiative forcings for 4 SSPs, **64 simulations in total, +6718 years**
  - **SSP1-2.6**: Sustainability
  - **SSP2-4.5**: Middle of the road
  - **SSP3-7.0**: Regional rivalry
  - **SSP5-8.5:** Fossil-fuelled development (stress testing)



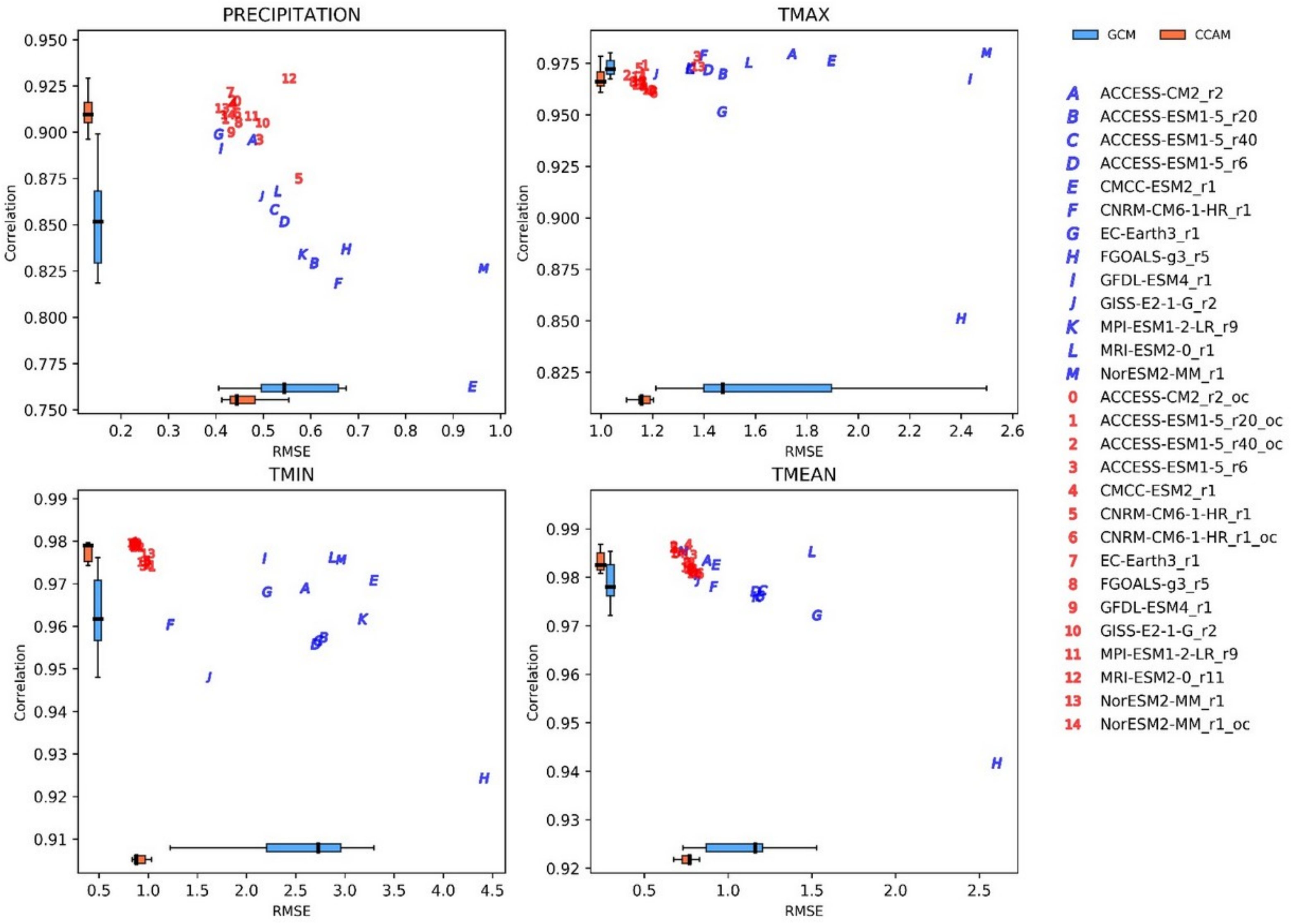
Dynamically downscaling of CMIP6 models using CCAM

CMIP6 Model	Model full name	Resolution	Ensemble member	CCAM setup
ACCESS-ESM1.5	Australian Community Climate and Earth System Simulator, v. 1.5, CCAM atmospheric	1.875 x 1.25°	r6i1p1f1	atmospheric
			r20i1p1f1	atm-ocean coupled
			r40i1p1f1	atm-ocean coupled
ACCESS_CM2	Australian Community Climate and Earth System Simulator, version 2	1.875 x 1.25°	r2i1p1f1	atm-ocean coupled
CMCC-ESM2	Centro Euro-Mediterraneo sui Cambiamenti Climatici	0.9 x 1.25°	r1i1p1f1	atmospheric
CNRM-CM6-1-HR	Centre National de Recherches Météorologiques Coupled Global Climate Model, version 6.1, high-resolution	0.5 x 0.5°	r1i1p1f2	atmospheric
			r1i1p1f2	atm-ocean coupled
EC-Earth3	European Community Earth-System Model, version 3	0.8 x 0.8°	r1i1p1f1	atmospheric
FGOALS-g3	Flexible Global Ocean-Atmosphere-Land System Model, grid point version 3	2.5 x 2.5	r4i1p1f1	atmospheric
GFDL-ESM4	Geophysical Fluid Dynamics Laboratory Earth System Model, version 4	1 x 1°	r1i1p1f1	atmospheric
GISS-E2-2-G	Goddard Institute for Space Studies Model E2.2G	2. x 2.5°	r2i1p1f2	atmospheric
MPI-ESM1-2-LR	Max Planck Institute Earth System Model, version 1.2, low resolution	1.9 x 1.9	r9i1p1f1	atmospheric

RESULTS – AUSTRALIA CMIP6 GCMS & CCAM VS OBSERVATION CORRELATION AND RMSE

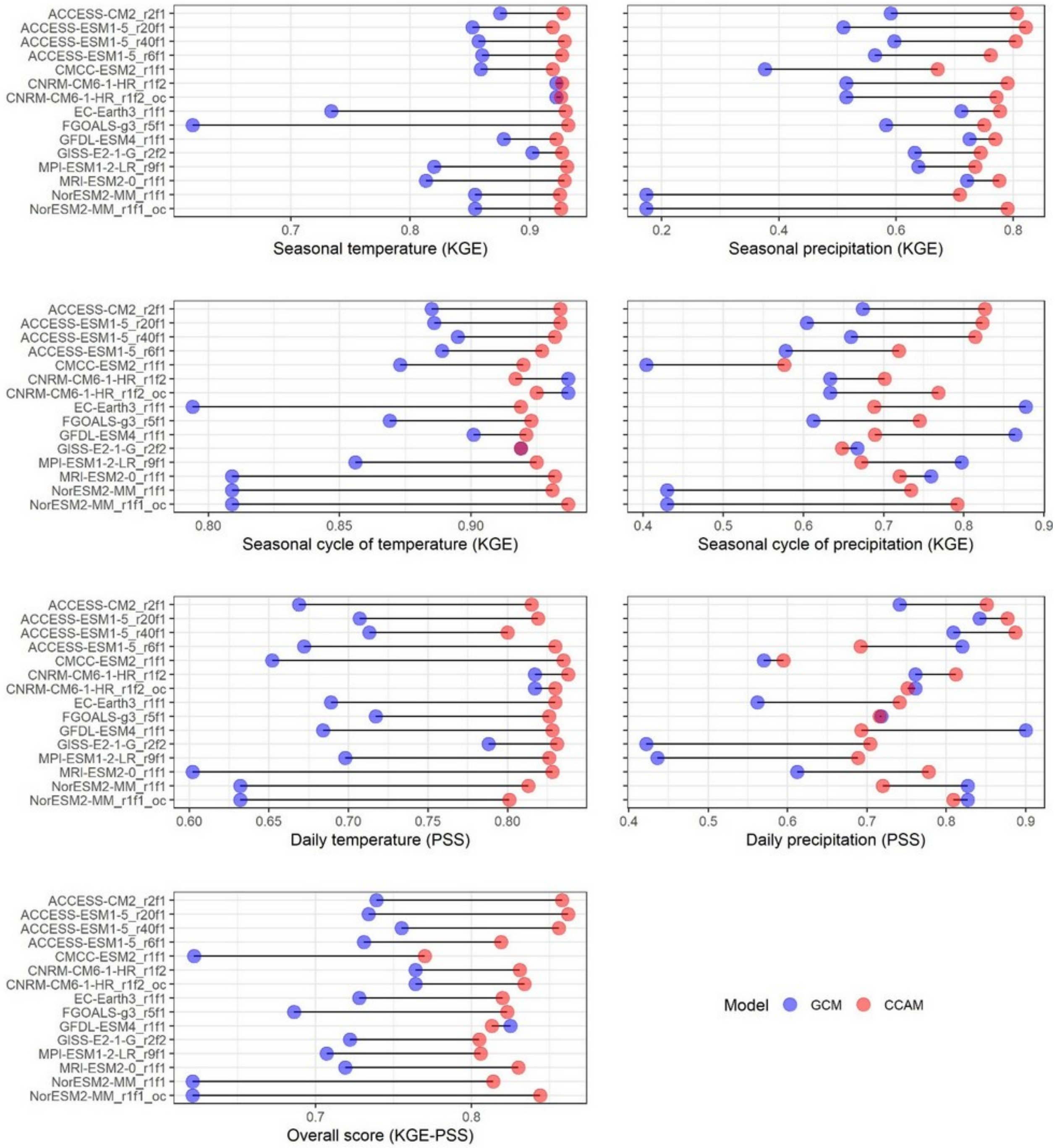
- Less spread in CMIP6-CCAM than in CMIP6 (due to bias correction of SSTs)
- Downscaling improves RMSE for all variables
- Correlation improved fo all variables

Chapman et al., 2023 Earth's Future, v.11(11) e2023EF003548

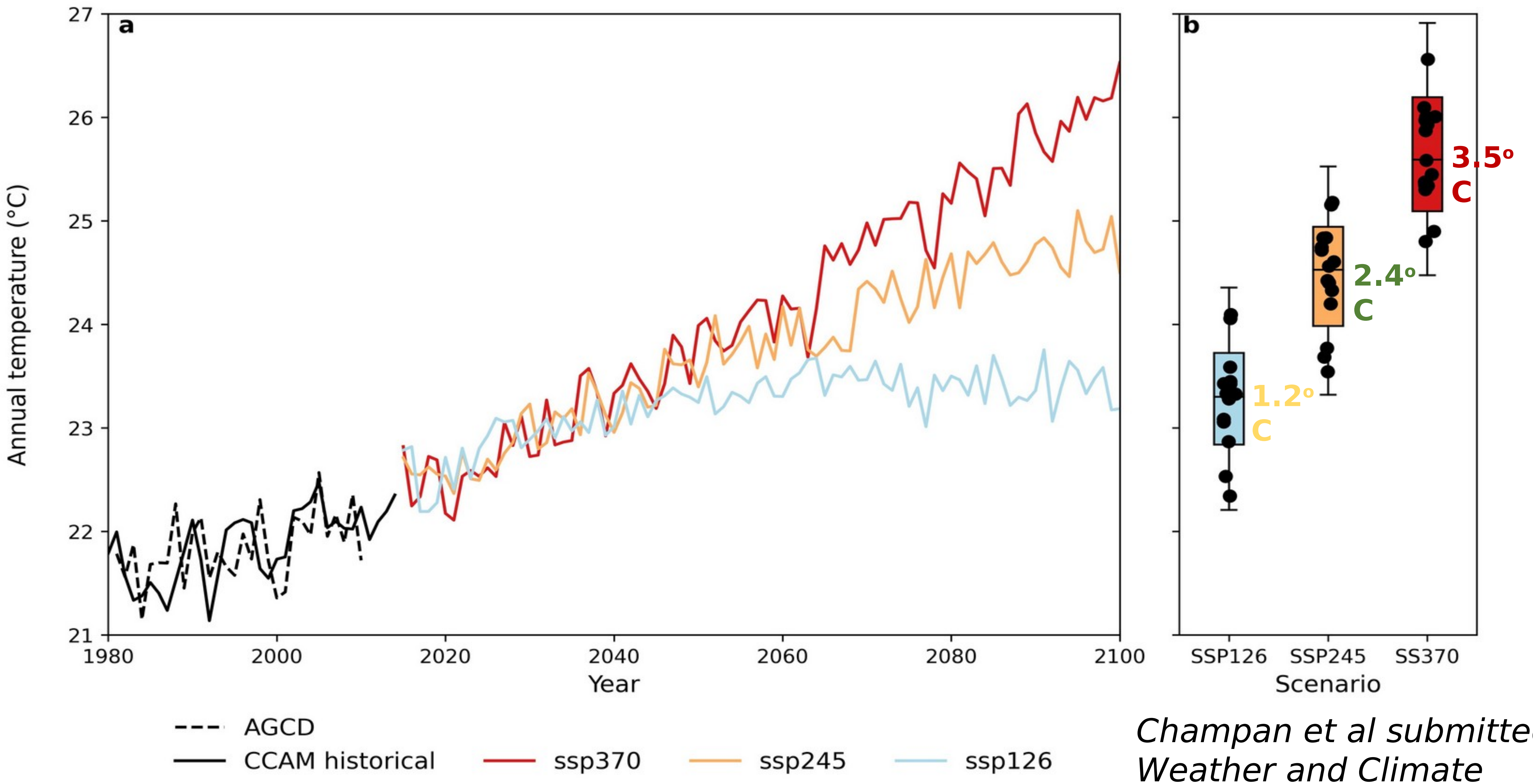


RESULTS – AUSTRALIA WIDE

- For majority of metrics and models, downscaling improves results
  - KGE and Perkins for seasonal and daily temp, and seasonal precip improves all models
  - Seasonal cycle temp improves all models except 1
  - Seasonal cycle precip improves for all except 4
- Overall model score improves for all models except GFDL-ESM4

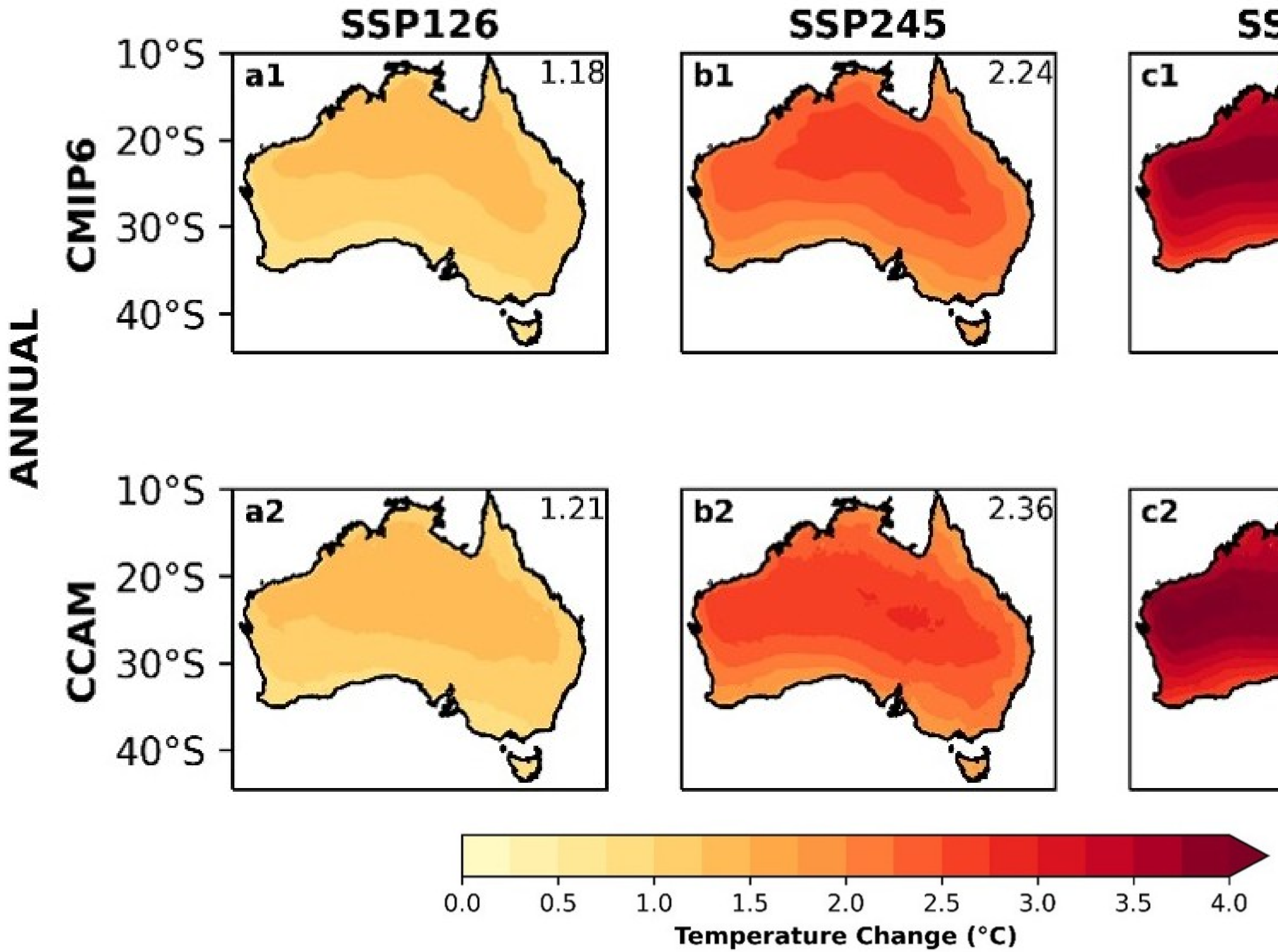


Projected Change – Temperature Australia

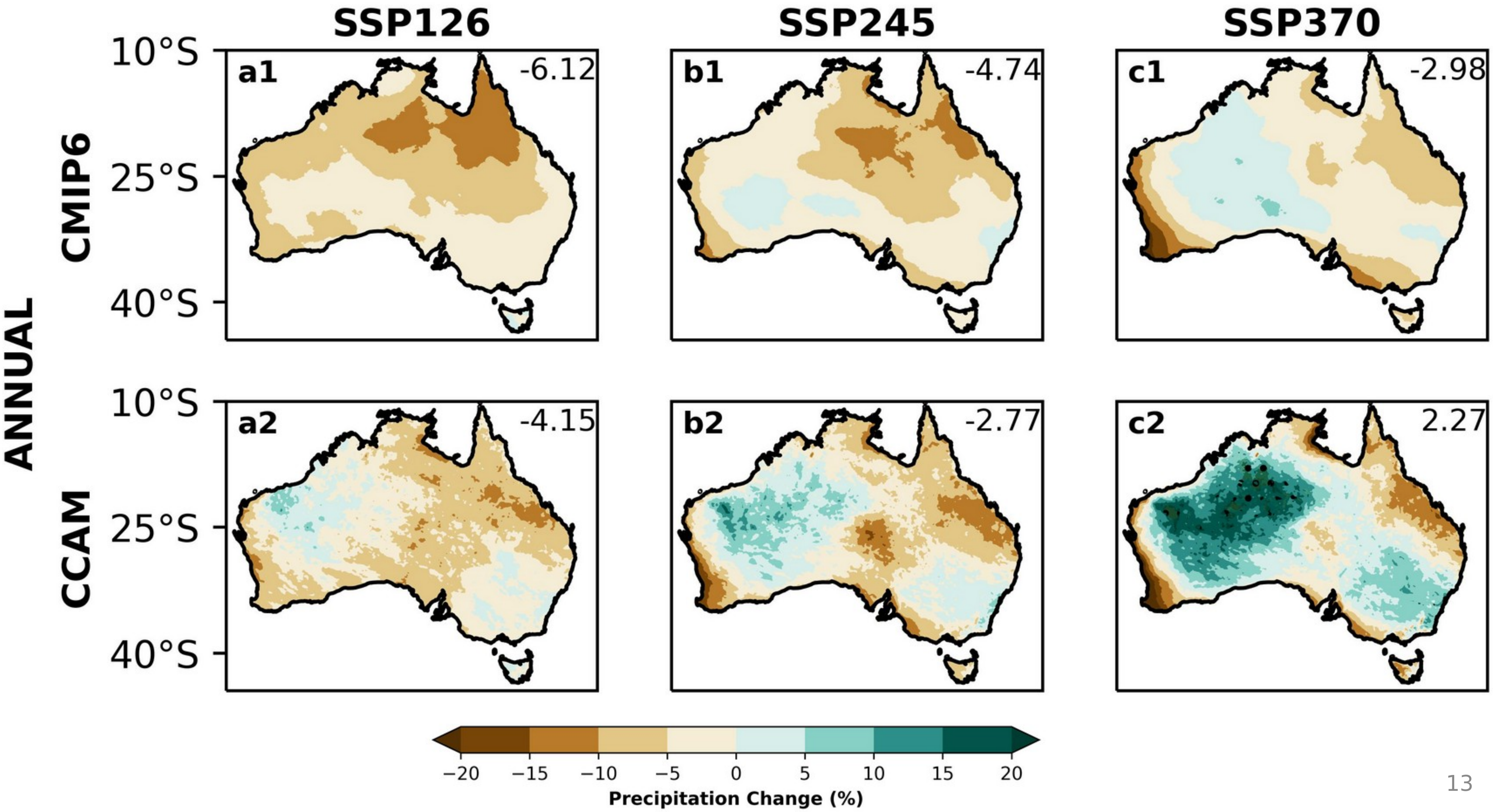


Champan et al submitted Weather and Climate Extremes

Projected Temperature Change - 2090 CMIP6 vs CCAM

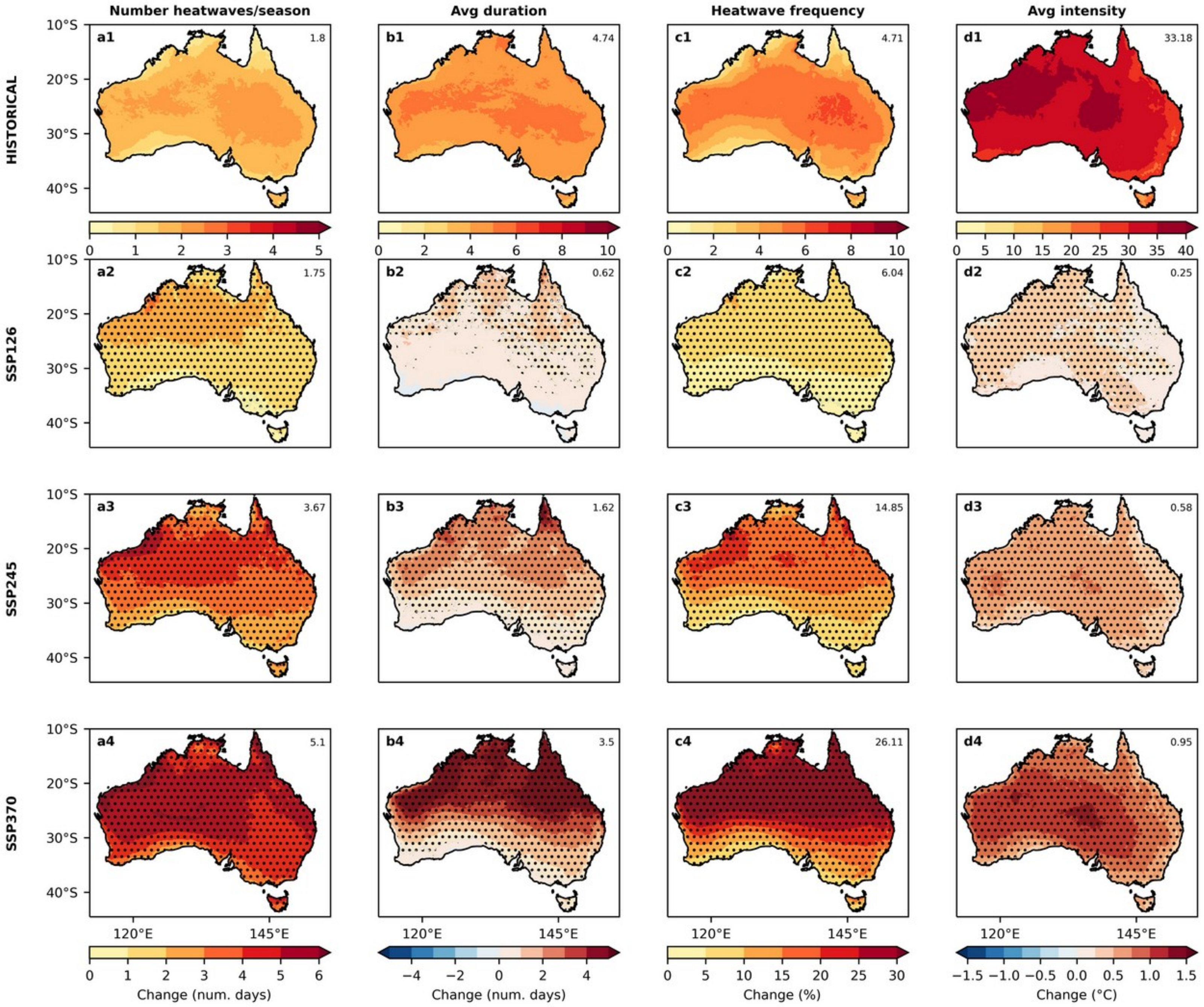


Projected Precipitation Change - 2090 CMIP6 vs CCAM

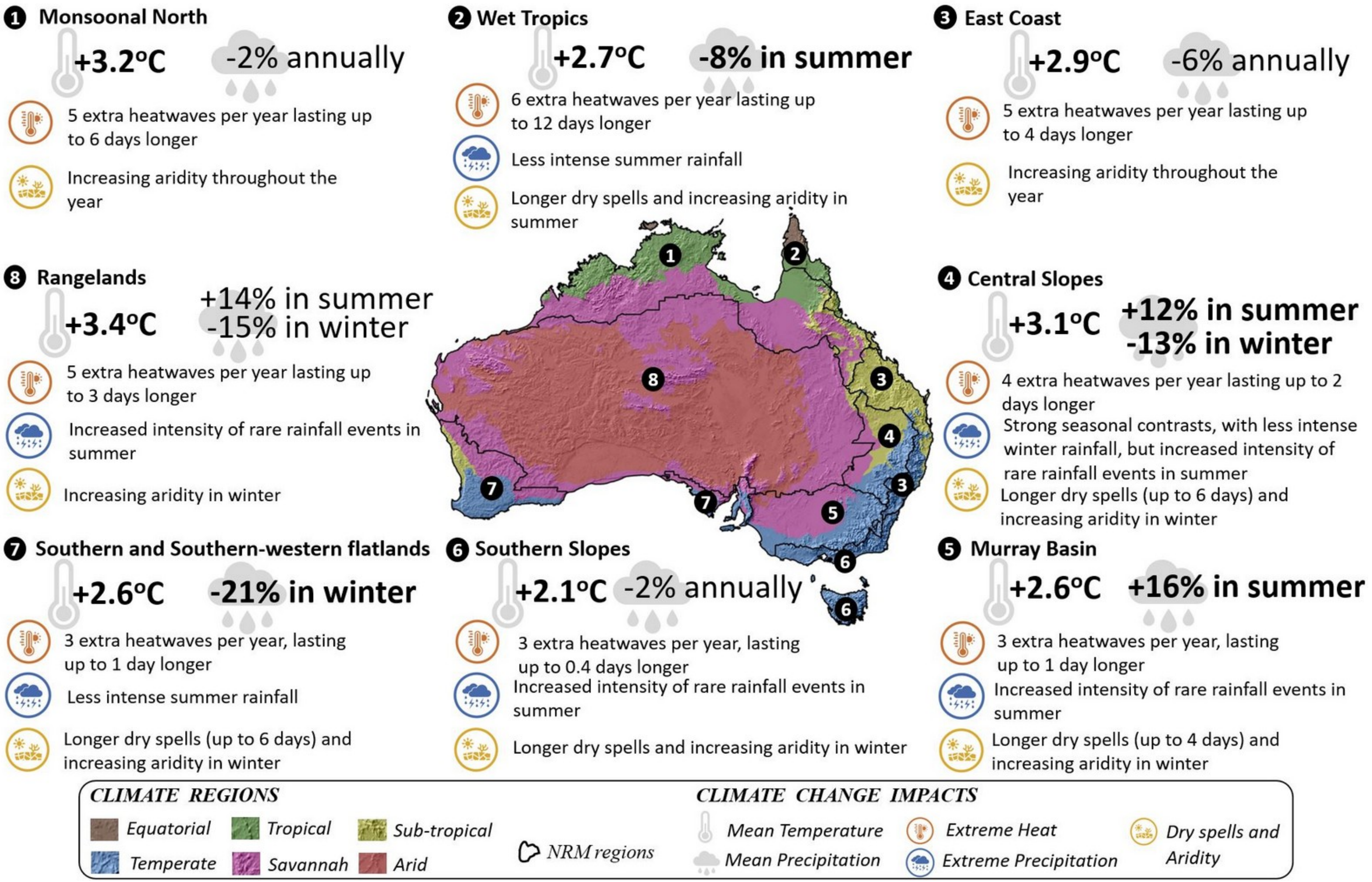


Projected Heatwave Change – 2090 CCAM

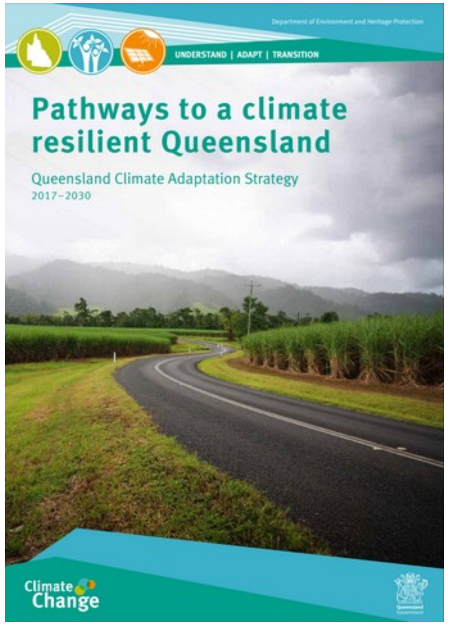
Consistent increased in number, duration, frequency and intensity



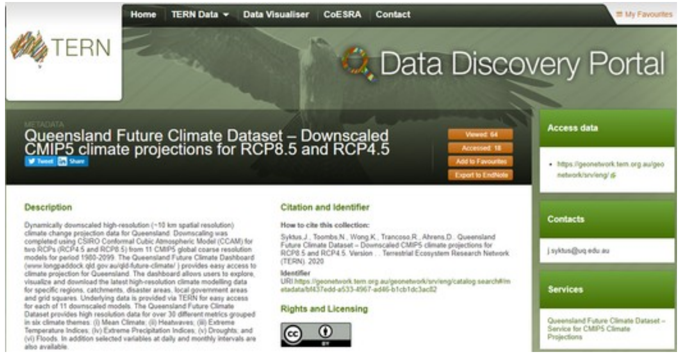
Climate change impacts over Australia under high emissions by end of century



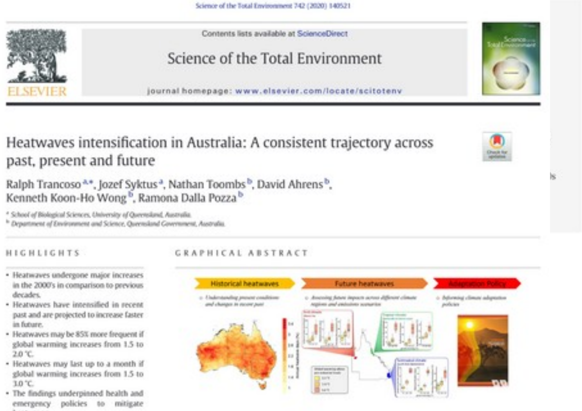
The Queensland *Future Climate Science* Program



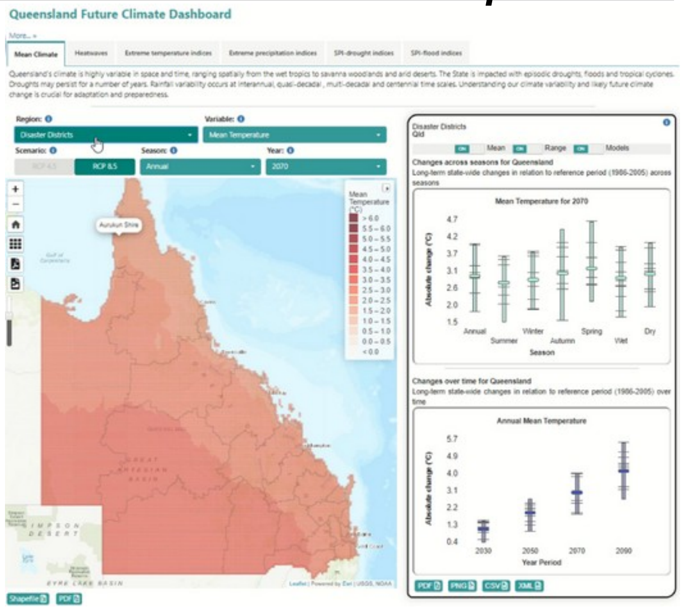
Datasets



Papers

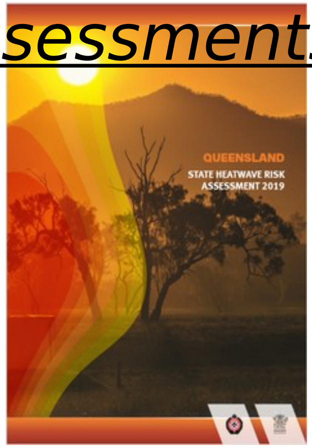


Future climate portal

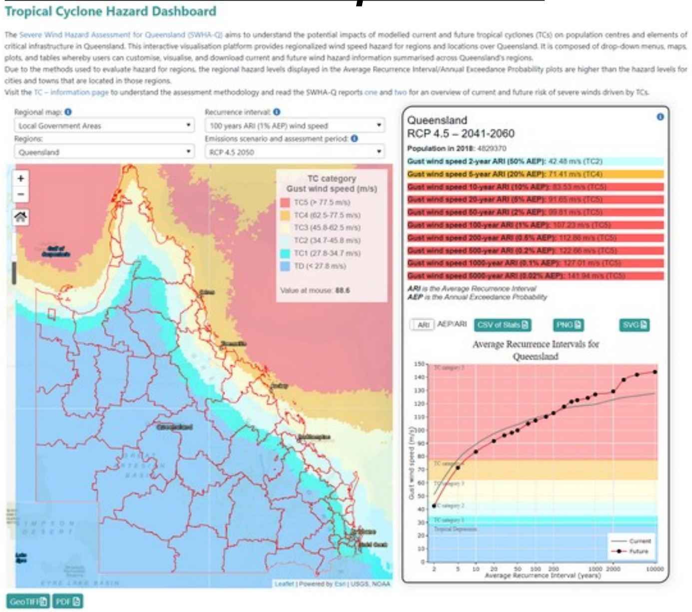


Case studies

Risk/Hazard assessments

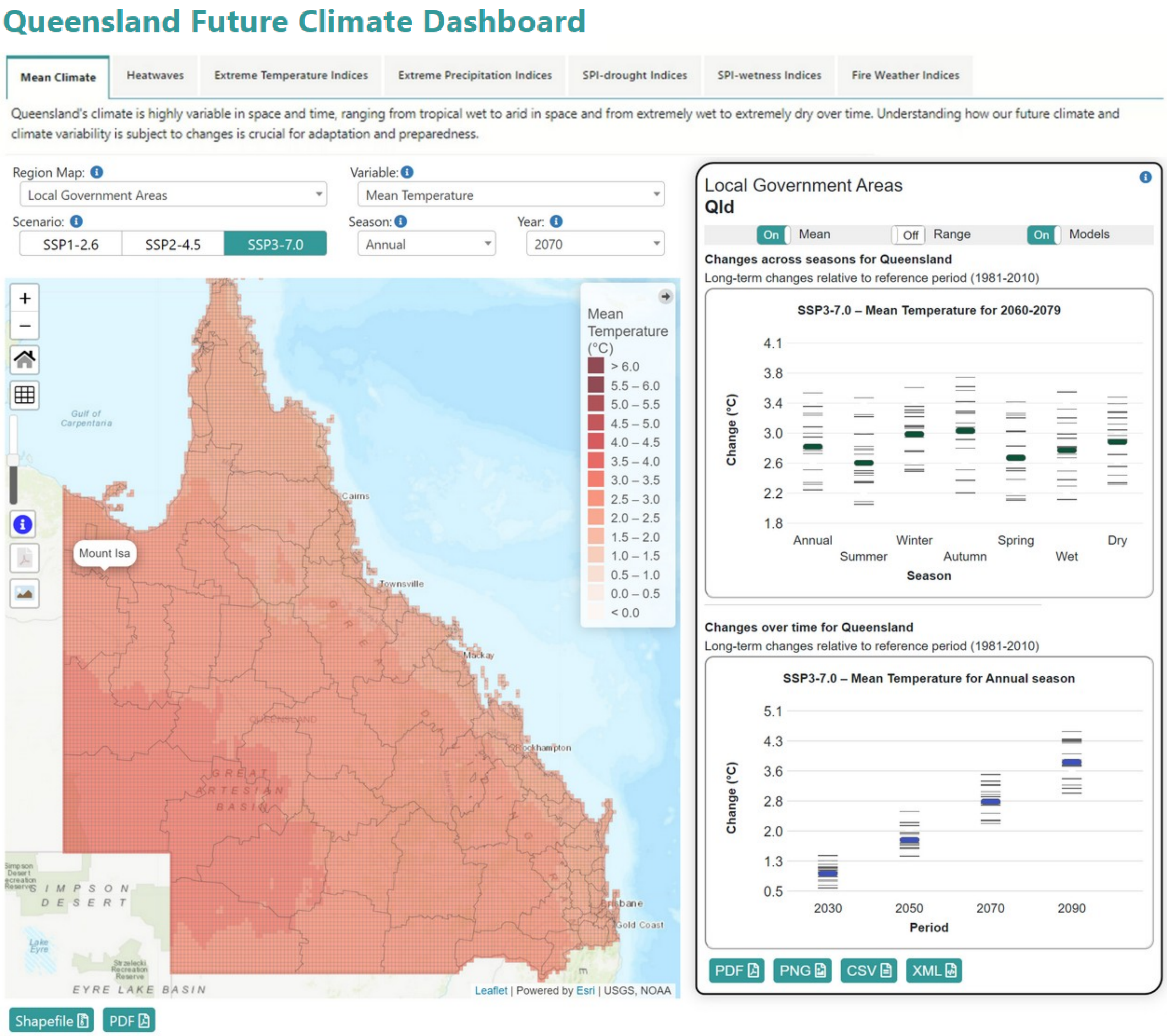


TC Hazard portal



CMIP6 dashboard

- 3 emissions scenarios (new!)
- 15 ensemble runs (new!)
- 50+ metrics
- 200+ regions
- Point-based locations (new!)



Data Publication - CORDEX-CMIP6 Regional Projections from the Queensland Future Climate Science Program

NCI
NATIONAL COMPUTATIONAL INFRASTRUCTURE
nci.org.au

Catalog https://dapds00.nci.org.au/thredds/catalogs/ig45/catalog.html

Dataset

- CORDEX-CMIP6 Data from the Queensland Future Climate Science Program
  - QldFCP-2/
  - licence/

Dataset

- ACCESS-CM2
  - historical/
  - ssp126/
  - ssp245/
  - ssp370/

Dataset

- UQ-DES
  - ACCESS-CM2/
  - ACCESS-ESM1-5/ X 3
  - CMCC-ESM2/
  - CNRM-CM6-1-HR/ X 2
  - EC-Earth3/
  - ERA5/
  - FGOALS-g3/
  - GFDL-ESM4/
  - GISS-E2-1-G/
  - MPI-ESM1-2-LR/
  - MRI-ESM2-0/
  - NorESM2-MM/ X 2

- 20km resolution CORDEX domain
- 102 variables, 170Tb size ~498,127 files
- 3 emissions scenarios
- 15 simulations each, 5 fully coupled atmosphere-ocean

THE CONVERSATION

Academic rigour, journalistic flair

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Up to 5 billion people to be hit by rainfall changes this century if CO_2 emissions are not curbed, research shows

Published: January 17, 2024 1.38pm AEDT

original. Idrees Mohammad/EPA

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Three to five billion people – or up to two-thirds of the world's population – are set to be affected by projected rainfall changes by the end of the century unless the world rapidly ramps up emissions reduction efforts, according to new research by myself and colleagues.

Author

Ralph Trancoso
Adjunct Associate Professor in Climate Change, The University of Queensland

THE CONVERSATION

Academic rigour, journalistic flair

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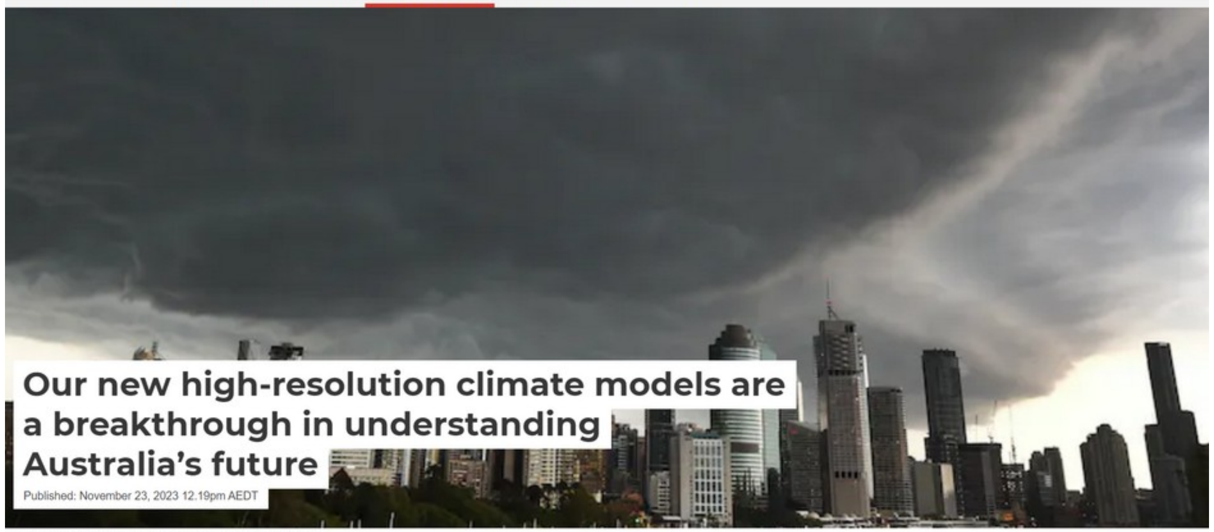

Our new high-resolution climate models are a breakthrough in understanding Australia's future

Published: November 23, 2023 12.19pm AEDT

A storm cell over Brisbane in 2014. (AAP Image/Dan Peled)

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Australia's climate, already marked by extremes with bushfires, heatwaves, storms and coastal flooding, is only set to worsen with the growing effects of climate change.

Disasters like the Black Summer bushfires of 2019–20 and the 2022 eastern Australian floods are likely to become more frequent and intense.

If carbon emissions continue at the current rate, climate change may make Australia unbearable for future generations. It's a confronting outlook, and we need better tools to understand future impacts so we can adapt to them.

Authors

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Disclosure statement

nature communications

Article | Open access | Published: 11 January 2024

Significantly wetter or drier future conditions for one to two thirds of the world's population

Ralph Trancoso, Jozef Syktus, Richard P. Allan, Jacky Croke, Ove Hoegh-Guldberg & Robin Chadwick

Nature Communications **15**, Article number: 483 (2024) | Cite this article

20k Accesses 5 Citations 273 Altmetric

https://www.nature.com/articles/s41467-023-44513-3


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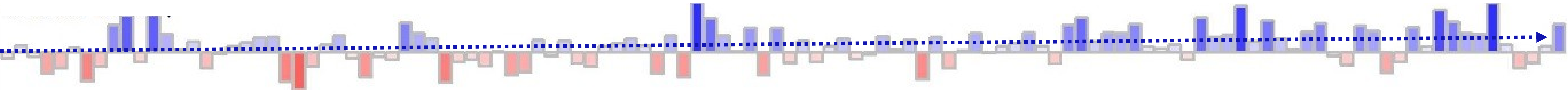
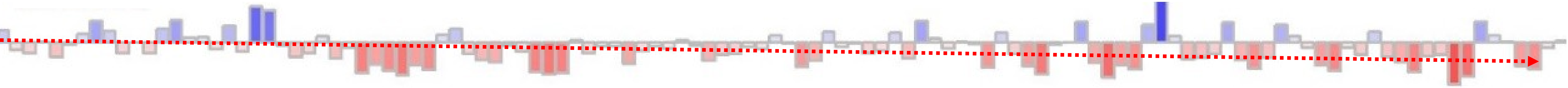


Significantly wetter or drier future conditions for one to two thirds of the world's population



Jozef Syktus – School of the Environment, The University of Queensland

Ralph Trancoso (paper lead author) - Department of Energy and Climate/UQ Adjunct A/Prof

Richard P. Allan – University of Reading

Jacky Croke – Queensland University of Technology

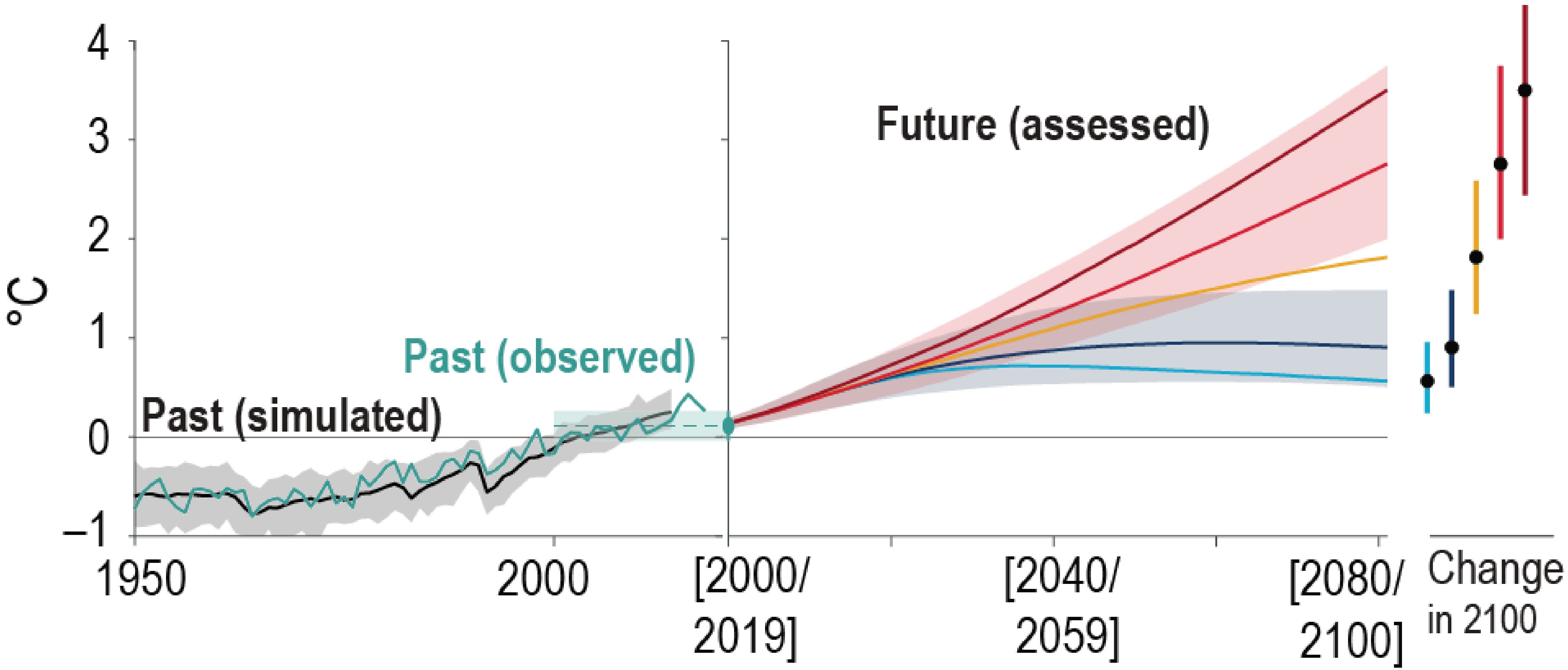
Ove Hoegh-Guldberg - The University of Queensland

Robin Chadwick - University of Exeter & UK Met Office

THE UNIVERSITY OF QUEENSLAND AUSTRALIA — CREATE CHANGE | Queensland Government | University of Reading | QUT | University of Exeter | Met Office

Background

Global climate models project temperature to rise under increased emissions with consensual agreement



(IPCC 2023)

Background

Precipitation is complex to simulate due to various influencing factors, including:
•diverse physics represented by GCMs (Knutti et al 2013),
•their sensitivity to radiative forcing, rate of warming (Meehl et al 2023; Hausfather et al 2022) and to aerosols radiative cooling (Salzman 2016; Baek & Lora 2021),
•sea surface temperature variability (Wang et al 2014) and patterns (Good et a 2021),
•internal climate fluctuations operating at timescales varying from intra-seasonal to multi-decadal – e.g., the El Niño (Cai et al 2021), the IOD (Kent et al 2015), PDO (Li et al 2020), SAM (Gillet & Fyfe 2013) and NAM (Thompson & Wallace, 2001)

Future projections from GCMs do not align over time, amplifying the heterogeneity of multiple projections (McSweeney & Jones 2013; Rowell 2012),

More ensembles over time along with computational power tends to expand the spread of the climate change signal of precipitation and increase uncertainty.
To reconcile the wide range of precipitation projections from multiple GCMs, new approaches are needed (Trenberth & Dai 2003; Maher et al 2021).

Background

Temporal aggregations are inadequate for heterogeneous variables like precipitation. Excessive temporal averaging (e.g., 20 years) does not retain critical information and may obscure insights into the direction of changes. Typically, **ensemble average** is presented to express projected changes.

We present a novel approach that analyses trends in continuous, long-term time-series from multiple GCM ensembles and quantifies the agreement of wetter or drier conditions from all available model simulations.

Objectives

- detect global warming-induced wetting and drying patterns,
- understand differences between CMIP5/6 GCM generations,
- determine seasonal dominance, and
- identify “hotspots” of drier and wetter conditions with potential global human impacts.

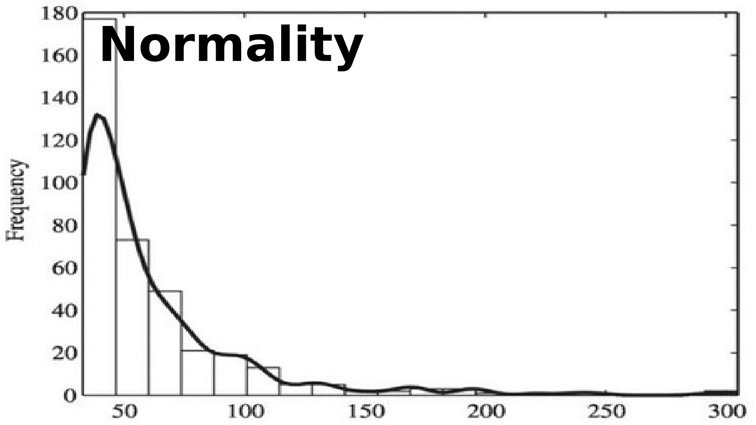
Data and approach

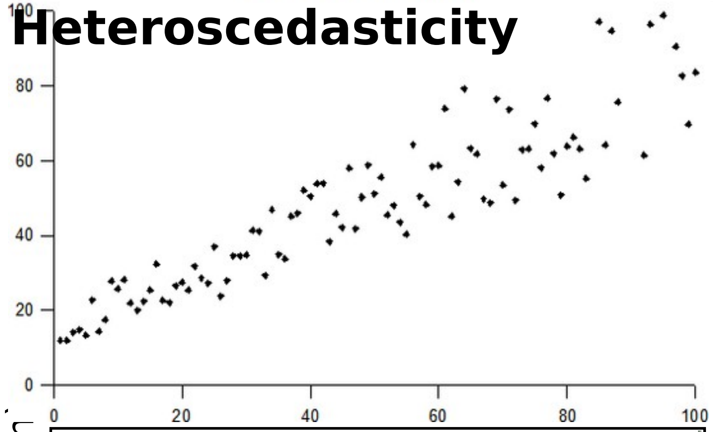
Data

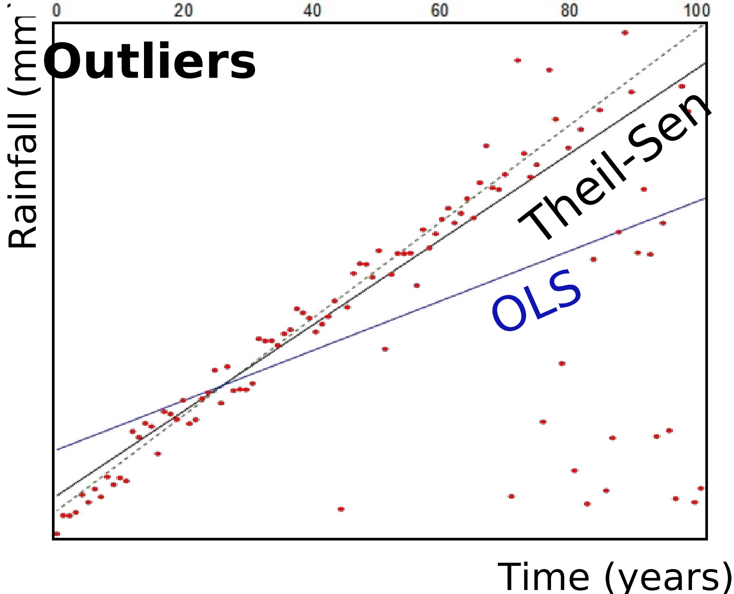
- 146 GCMs: 67 CMIP5 and 79 CMIP6 resampled to 1.5 °
- Intermediate (RCP4.5 / SSP2-4.5) and very high (RCP8.5 / SSP5-8.5) emissions scenarios
- Period 1981-2100 (120 years) – constrain natural variability
- Annual, DJF, MAM, JJA, SON

Long-term monotonic trends

- Non-parametric statistics – Rainfall time-series do not meet parametric stats assumptions.
- Mann-Kendall (significance) and Theil-Sen slope estimator (trend slope). Method account for autocorrelation.

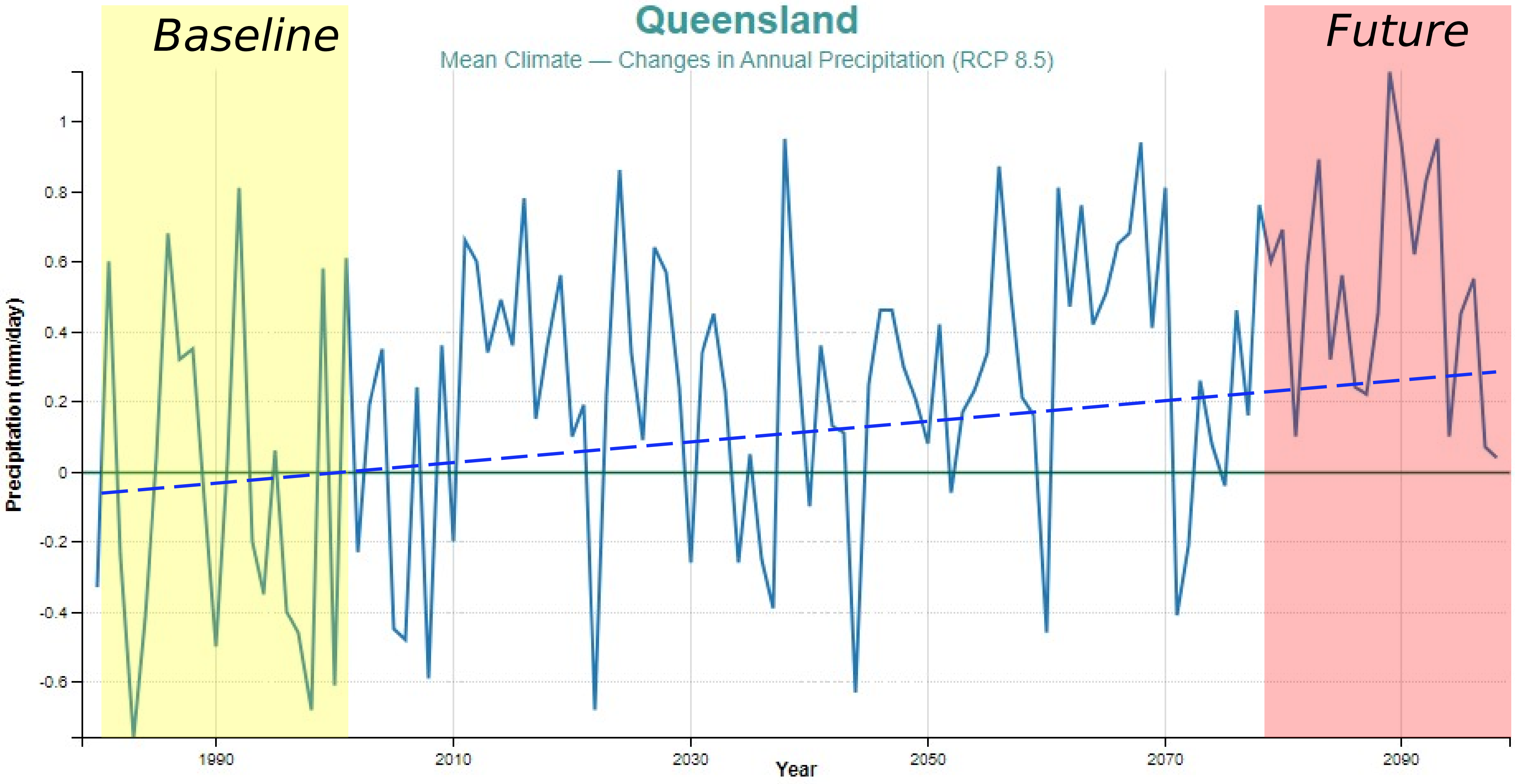






Approach

- The assessment of continuous trends in time-series is a more comprehensive way to understand how global warming affects precipitation totals because it samples the entire time-series, aligns with the nature of radiative forcing, and does not employ temporal averaging.
- All pairs of points are factored in (T_2-T_1, T_3-T_2 …T_n-T_{n-1}) instead of T_{future} – $T_{baseline}$.



Approach

Multi-model agreement

•Percentage of GCMs with a robust long-term drying and wetting signal.

•Assesses the time-series of **individual** models and produces **an integrated multi-model agreement** quantification.

It utilised 120-year time-series of annual and seasonal precipitation totals of the 146 GCMs, interrogating the time-series of individual grid-cells as follows:

1)Whether statistically significant trends ($p < 0.05$) have been detected;
2)The direction of trends (slope) to determine if it was undergoing wetting or drying;
3)Whether the cumulative trend over the 120-year period (slope) shifted by at least 10% the local regime (or whether the 120-year change is at least 10% as large as the mean).

Country- and state-scale impacts

•Spatial masks of wetting and drying agreement (50 e 66% agreement thresholds)

•Affected population – current (Tatem 2017) and future (Wang et al 2022) gridded data (1km)

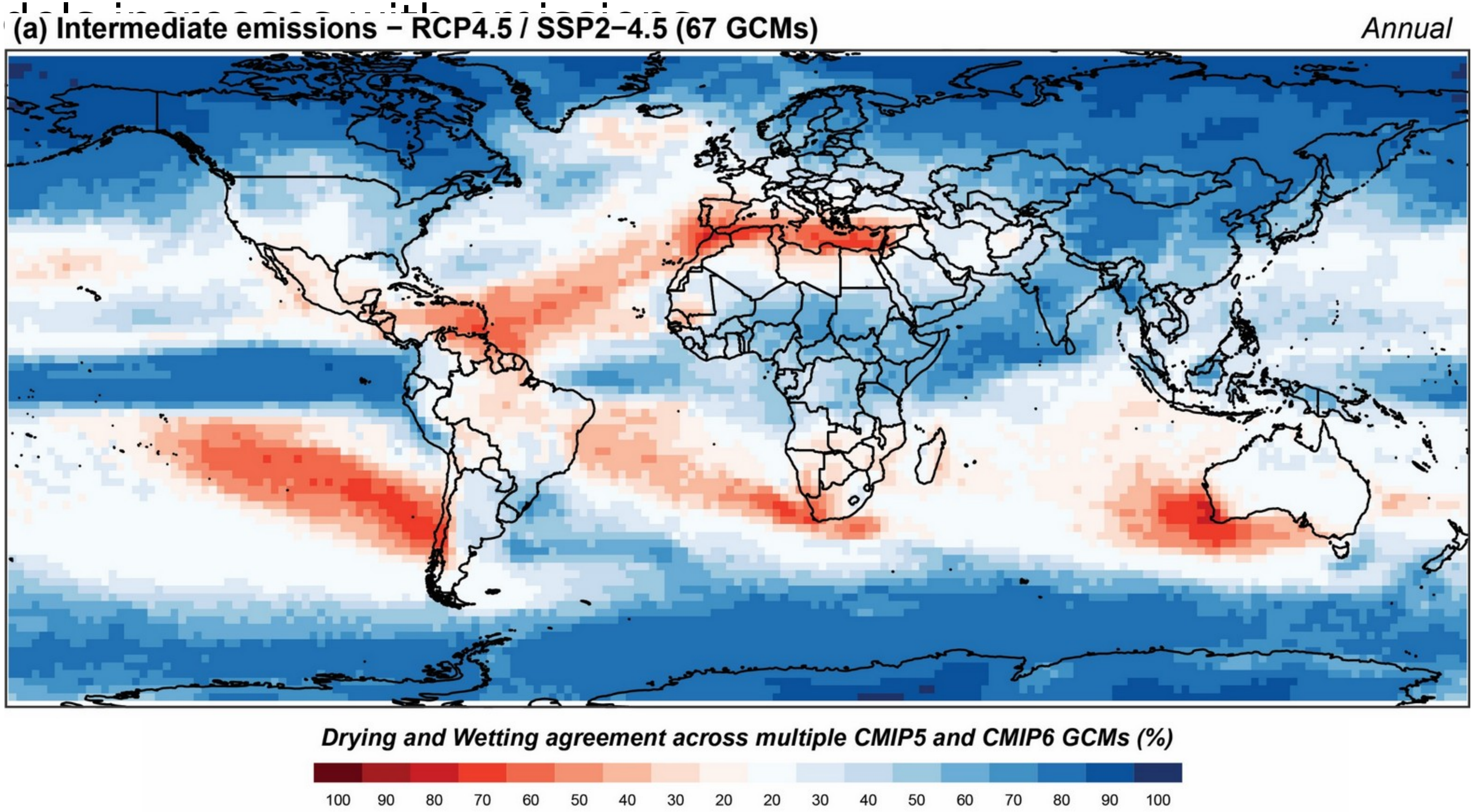
•Regionalization by country and states globally

•Seasonal dominance – which season has contributed the most to the annual trends

Findings

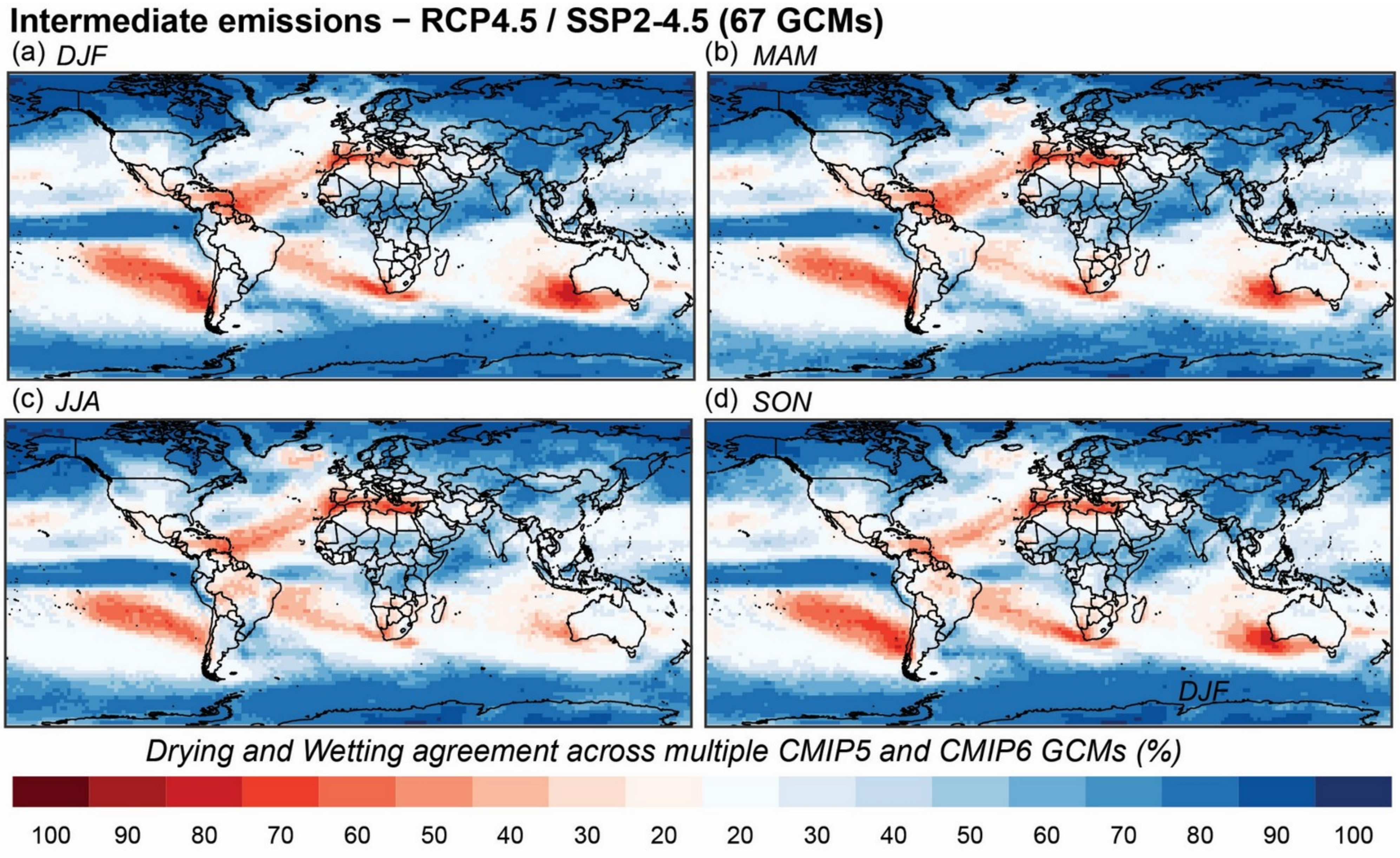
Global hotspots of wetter and drier conditions

Hotspots of wetter and drier future conditions – consistent across CMIP generations, seasons and scenarios and the agreement across models increases with emissions



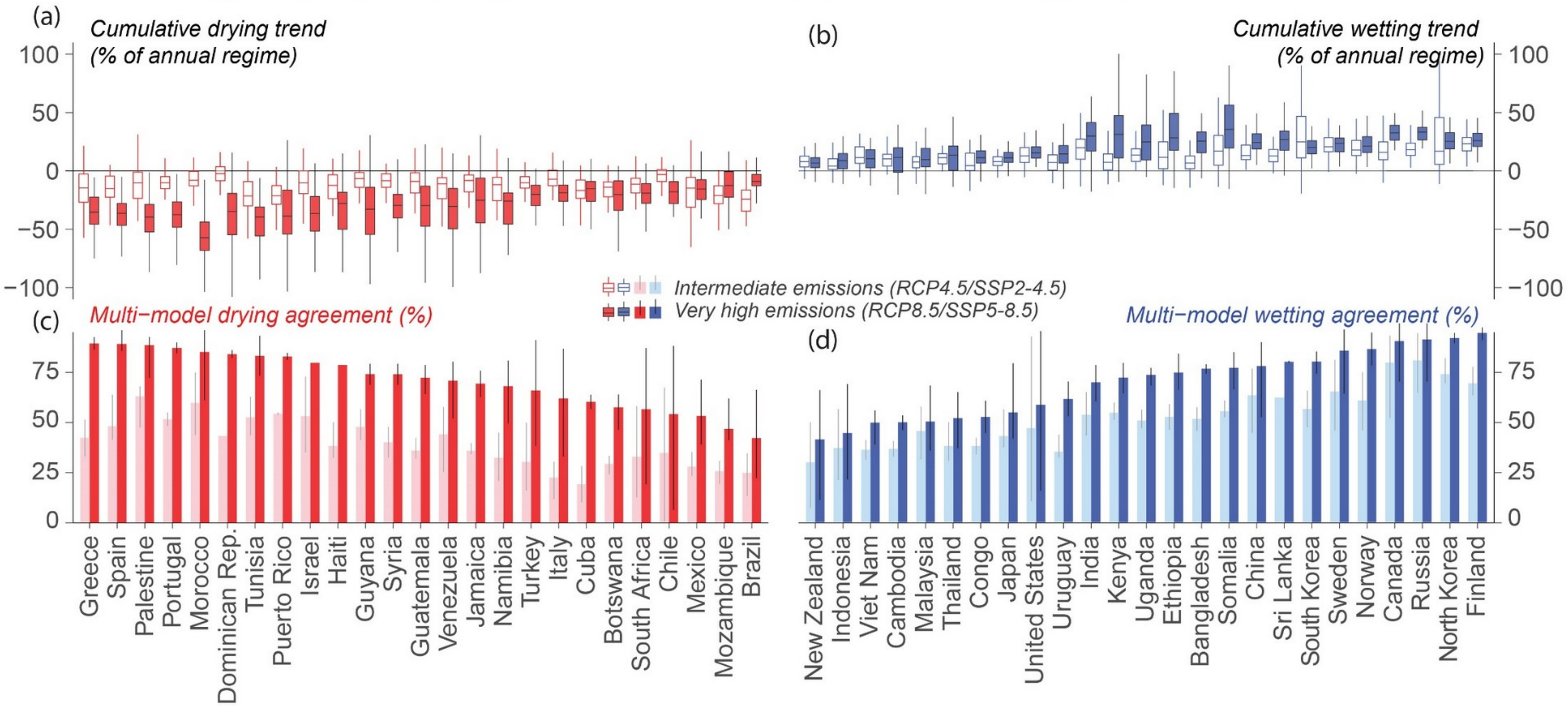
Findings

Global hotspots of wetter and drier conditions across seasons



Findings

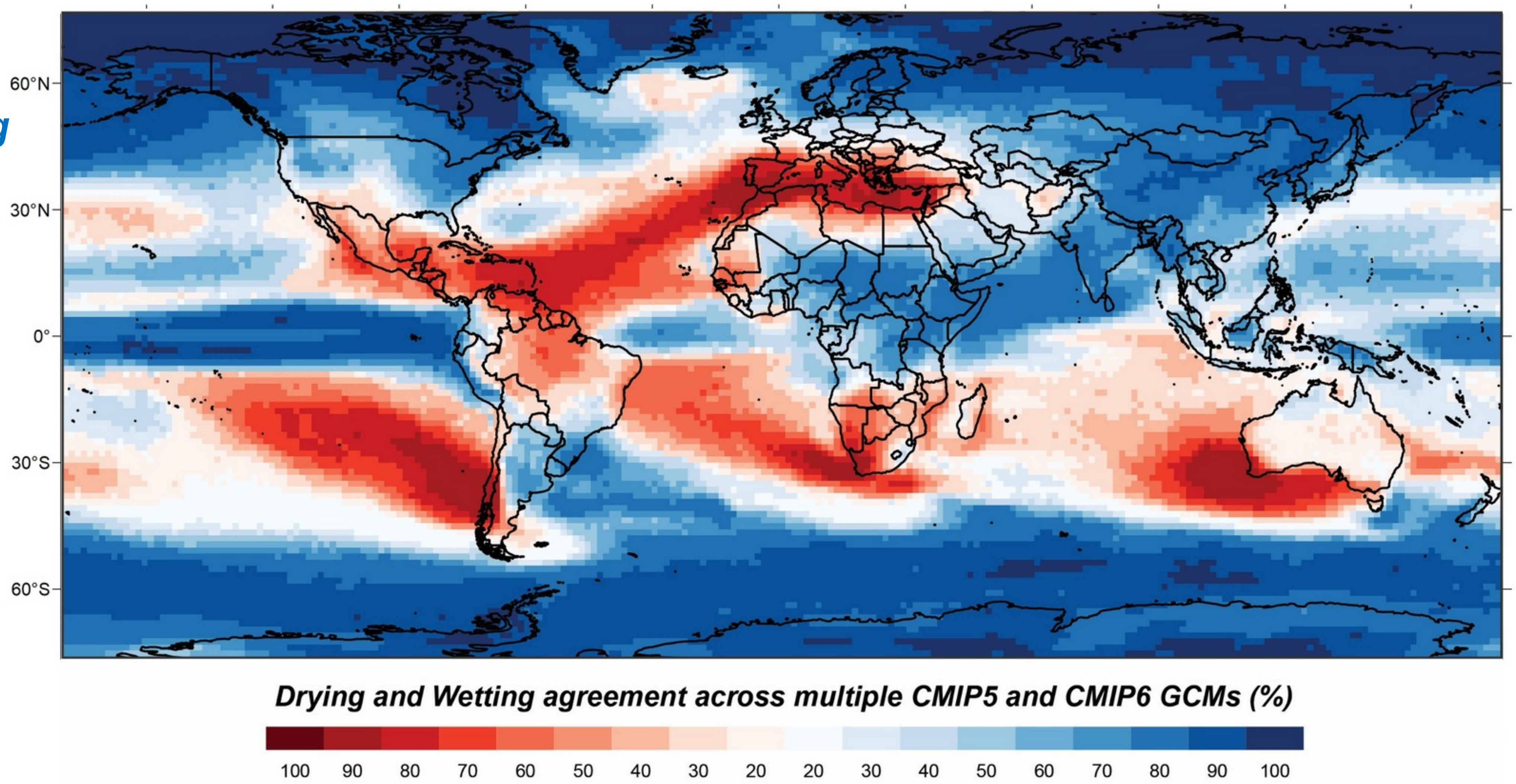
Country and state-level impacts – Annual scale



Findings

Drying and wetting agreement masks

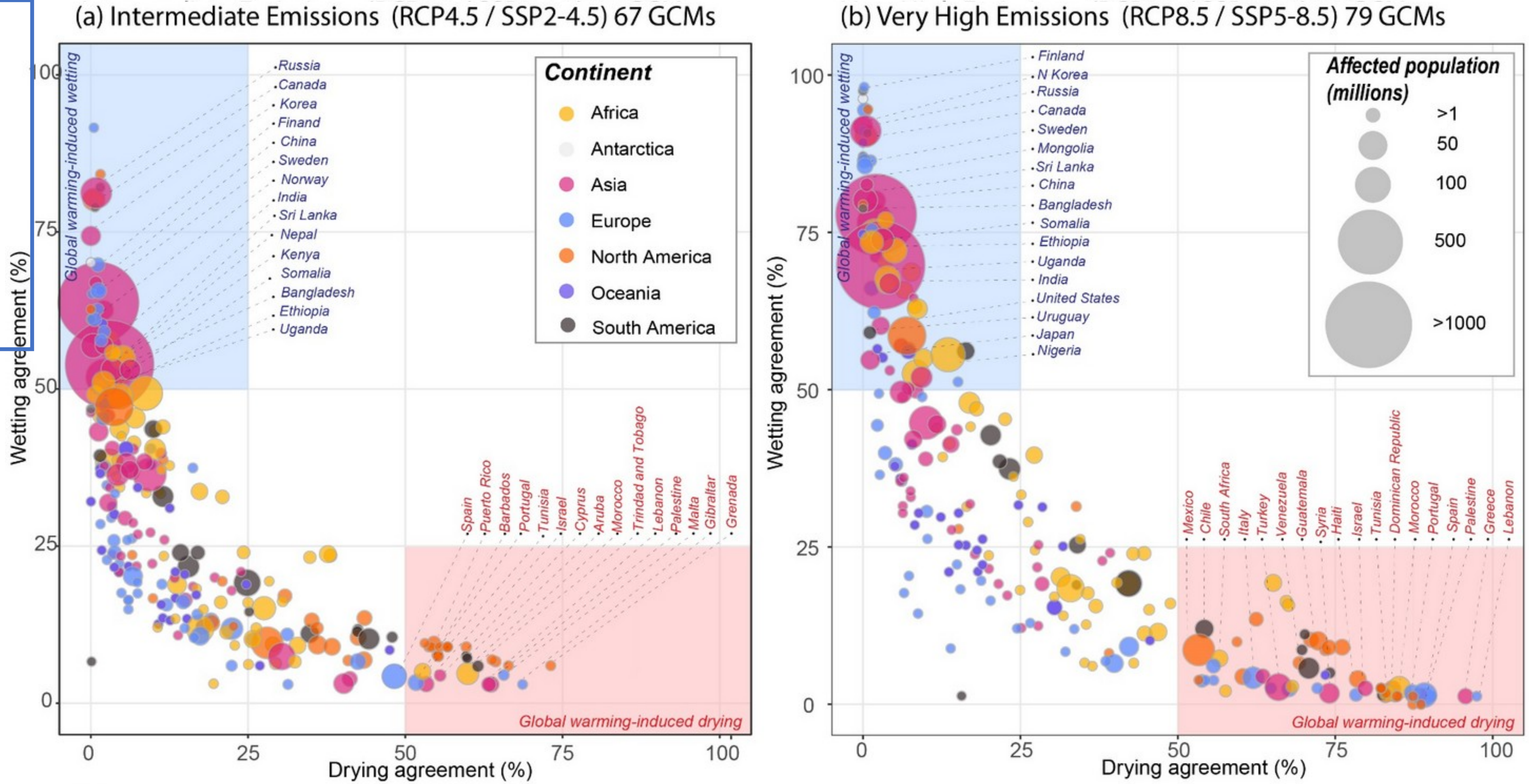
Country-scale impacted population



Findings *Impacts on global population by country*

Three billion people are projected to be impacted by changes in precipitation **under intermediate emissions**. However, if emissions are not curbed, **five billion people** or two thirds of world’s population could be affected.

Sc4.5 - 34.5% 2.7bil
Sc8.5 - 54.6% 4.35bil

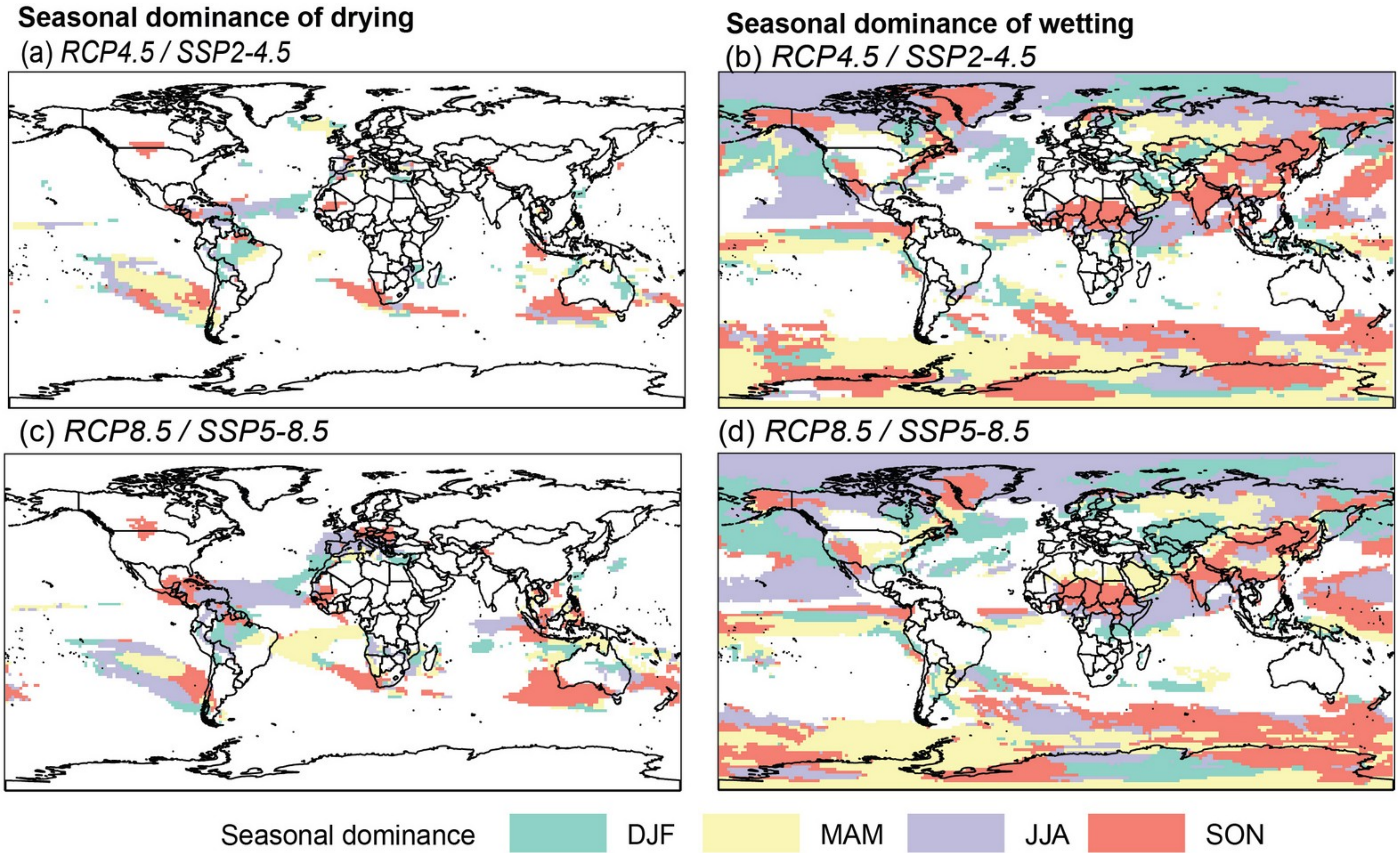


CURRENT POPULATION

Sc4.5 - 3.3% - 266mil
Sc8.5 - 11% - 875mil

Findings

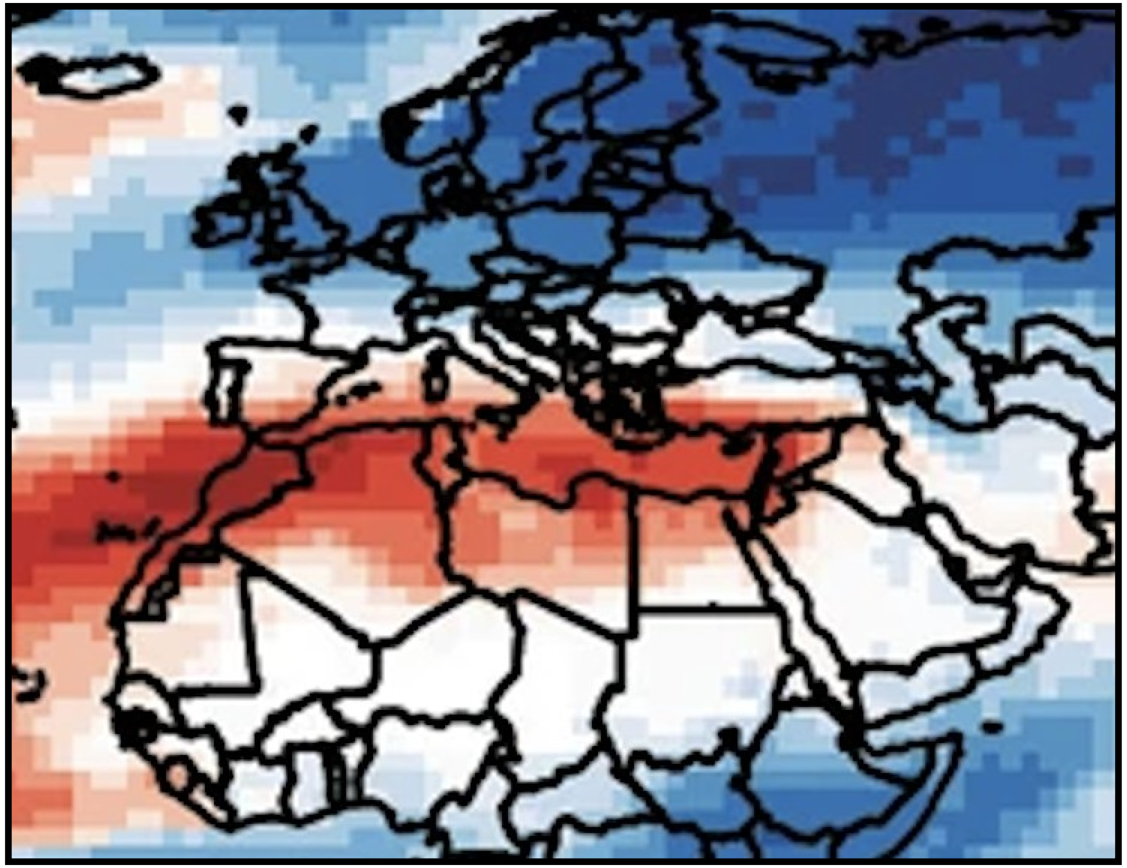
Seasonal dominance of drying and wetting patterns



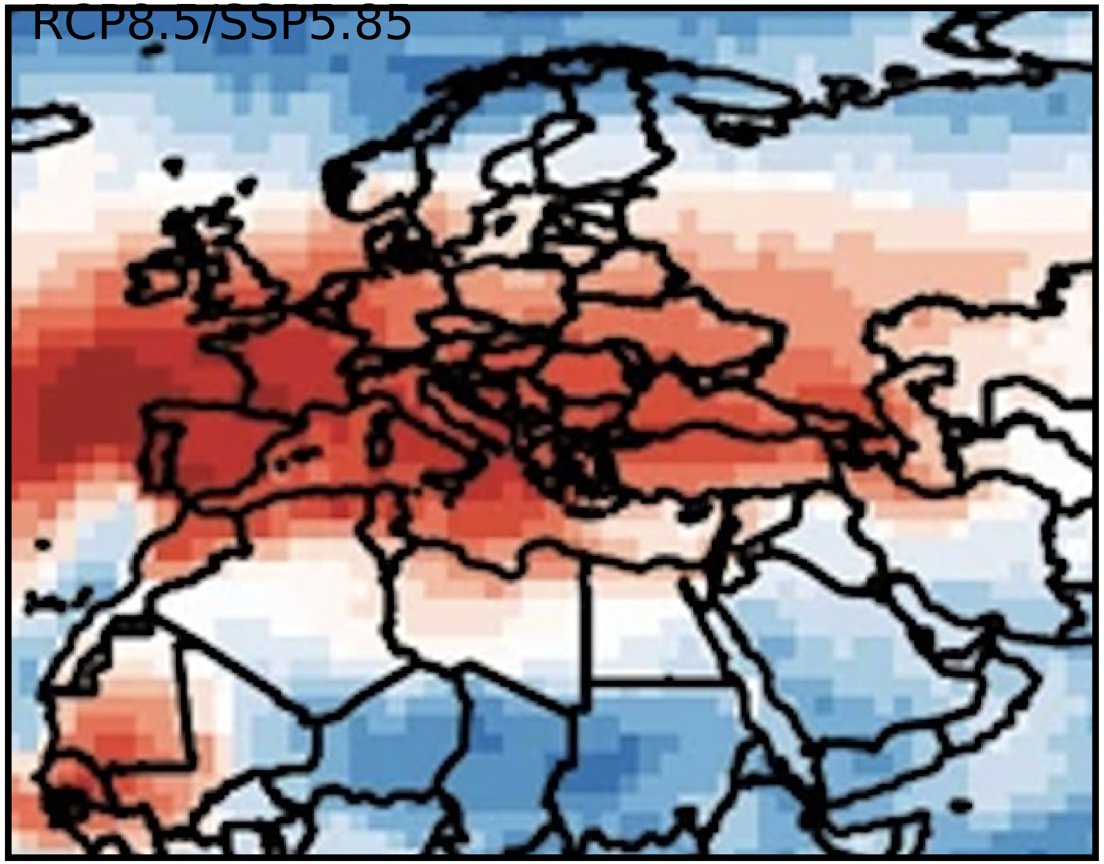
Findings *European region*

Significant hotspot of drying over the southern Europe & wetting over Scandinavia.
Poland tendency towards wetter winter and drier summer

DJF –



JJA – RCP8.5/SSP5.85



Drying and wetting agreement masks

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R
				Drying agreement (%)					Wetting agreement (%)					median % change in P	Affected population (current)		Affected population (future)	
	ID	*NAME*	*COUNTRY*	ann	djf	mam	jja	son	ann	djf	mam	jja	son	over 120-year	wet	dry	wet	dry
2416	2414	Dolnoslaskie	Poland	6.5	0.7	0.7	60.8	10.8	30.4	72.0	46.8	7.5	28.5	3.0	0.0	0.0	0.0	0.0
2417	2415	Kujawsko-pomorskie	Poland	6.2	0.0	0.8	51.6	8.4	44.7	79.4	54.4	7.1	33.0	8.9	160829.3	0.0	143937.4	0.0
2418	2416	Lubuskie	Poland	5.9	1.0	0.2	59.5	10.5	34.2	72.5	47.1	8.8	32.0	4.7	0.0	0.0	0.0	0.0
2419	2417	Lódzkie	Poland	3.9	0.0	1.3	55.7	9.1	32.7	79.9	52.9	5.5	24.2	6.0	0.0	0.0	0.0	0.0
2420	2418	Lubelskie	Poland	6.1	0.5	0.8	59.6	11.8	30.6	85.1	56.2	2.7	15.0	5.0	0.0	0.0	0.0	0.0
2421	2419	Malopolskie	Poland	7.6	0.7	1.6	62.4	13.9	24.3	80.0	48.9	2.9	19.1	2.0	0.0	0.0	0.0	0.0
2422	2420	Mazowieckie	Poland	3.2	0.0	0.7	52.8	9.1	37.1	85.6	57.2	5.8	24.9	7.1	0.0	0.0	0.0	0.0
2423	2421	Opolskie	Poland	4.1	1.1	1.2	60.3	10.1	27.4	74.9	47.4	5.5	24.4	1.8	0.0	0.0	0.0	0.0
2424	2422	Podlaskie	Poland	1.4	0.0	0.1	51.8	6.5	43.7	89.5	61.6	7.6	30.7	9.3	90258.7	0.0	79645.9	0.0
2425	2423	Podkarpackie	Poland	11.6	1.3	1.1	63.0	15.2	25.9	80.8	48.5	2.7	13.2	1.5	0.0	0.0	0.0	0.0
2426	2424	Pomorskie	Poland	2.6	0.0	0.3	47.0	5.1	64.2	87.6	56.5	11.5	41.2	13.2	2345659.6	0.0	2216720.4	0.0
2427	2425	Swietokrzyskie	Poland	6.5	0.9	1.2	60.6	13.3	25.6	81.8	52.7	2.8	18.2	3.3	0.0	0.0	0.0	0.0
2428	2426	Slaskie	Poland	4.8	0.3	1.3	60.0	12.1	26.5	80.2	48.6	3.2	23.1	1.9	0.0	0.0	0.0	0.0
2429	2427	Warminsko-mazurskie	Poland	3.0	0.0	0.0	47.0	5.8	54.2	88.9	61.3	9.2	37.3	11.3	1160728.3	0.0	1100352.3	0.0
2430	2428	Wielkopolskie	Poland	6.1	0.0	0.9	55.9	9.9	36.2	76.0	50.5	8.4	28.5	5.6	2637.4	0.0	1870.7	0.0
2431	2429	Zachodniopomorskie	Poland	6.5	0.7	0.0	55.6	10.0	46.8	77.8	52.2	9.5	34.6	9.2	588110.6	0.0	534446.6	0.0
166	164	Poland	Europe	2.0	2.1	2.1	2.1	2.0	45.3	43.5	45.1	42.9	45.1	8.9				

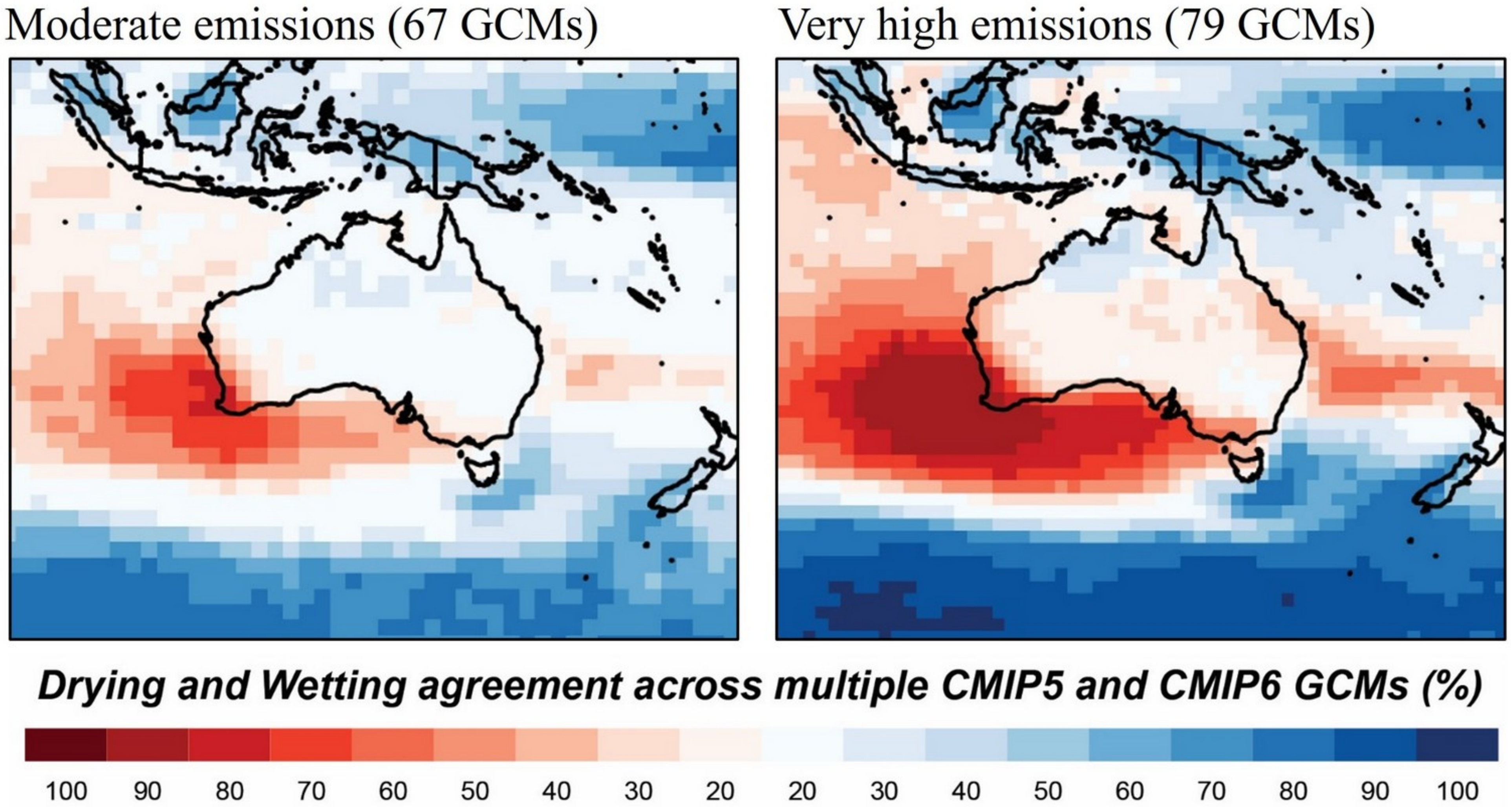
Supplementary material – regionalization at sub-country level

Drying and wetting agreement masks

	ID	NAME	Drying agreement (%) ann	djf	mam	jja	son	Wetting agreement (%) ann	djf	mam	jja	son	
2416	2414	Dolnoslaskie	6.5	0.7	0.7	60.8	10.8	30.4	72.0	46.8	7.5	28.5	
2417	2415	Kujawsko-pomorskie	6.2	0.0	0.8	51.6	8.4	44.7	79.4	54.4	7.1	33.0	
2418	2416	Lubuskie	5.9	1.0	0.2	59.5	10.5	34.2	72.5	47.1	8.8	32.0	
2419	2417	Lódzkie	3.9	0.0	1.3	55.7	9.1	32.7	79.9	52.9	5.5	24.2	
2420	2418	Lubelskie	6.1	0.5	0.8	59.6	11.8	30.6	85.1	56.2	2.7	15.0	
2421	2419	Malopolskie	7.6	0.7	1.6	62.4	13.9	24.3	80.0	48.9	2.9	19.1	* (red)
2422	2420	Mazowieckie	3.2	0.0	0.7	52.8	9.1	37.1	85.6	57.2	5.8	24.9	
2423	2421	Opolskie	4.1	1.1	1.2	60.3	10.1	27.4	74.9	47.4	5.5	24.4	
2424	2422	Podlaskie	1.4	0.0	0.1	51.8	6.5	43.7	89.5	61.6	7.6	30.7	* (blue)
2425	2423	Podkarpackie	11.6	1.3	1.1	63.0	15.2	25.9	80.8	48.5	2.7	13.2	* (red)
2426	2424	Pomorskie	2.6	0.0	0.3	47.0	5.1	64.2	87.6	56.5	11.5	41.2	* (blue)
2427	2425	Swietokrzyskie	6.5	0.9	1.2	60.6	13.3	25.6	81.8	52.7	2.8	18.2	
2428	2426	Slaskie	4.8	0.3	1.3	60.0	12.1	26.5	80.2	48.6	3.2	23.1	
2429	2427	Warminsko-mazurskie	3.0	0.0	0.0	47.0	5.8	54.2	88.9	61.3	9.2	37.3	* (blue)
2430	2428	Wielkopolskie	6.1	0.0	0.9	55.9	9.9	36.2	76.0	50.5	8.4	28.5	
2431	2429	Zachodniopomorskie	6.5	0.7	0.0	55.6	10.0	46.8	77.8	52.2	9.5	34.6	

Findings *Australian region*

Parts of Australia with strong drying agreement, large parts with poor model agreement impacted by model bias in Indo-Pacific tropical ocean ENSO impacted region.



Summary

This study estimates the **extent of the global population** to be affected by significant **long-term changes in precipitation due to human-caused global warming**.

The analysis provides an **intermediate to high emissions envelope** for how the global population is projected to be impacted by future changes in long-term precipitation totals based on the **agreement of precipitation projections from multiple climate models**.

The approach detected **agreement across multiple models in future wetting and drying trends**, revealing critical information on how precipitation is projected to change under scenarios associated with continued GHG emissions.

By examining the **time-series of individual models with flexible trend detection methods**, the approach provides a **more robust quantification of change, summarising critical multi-model information**

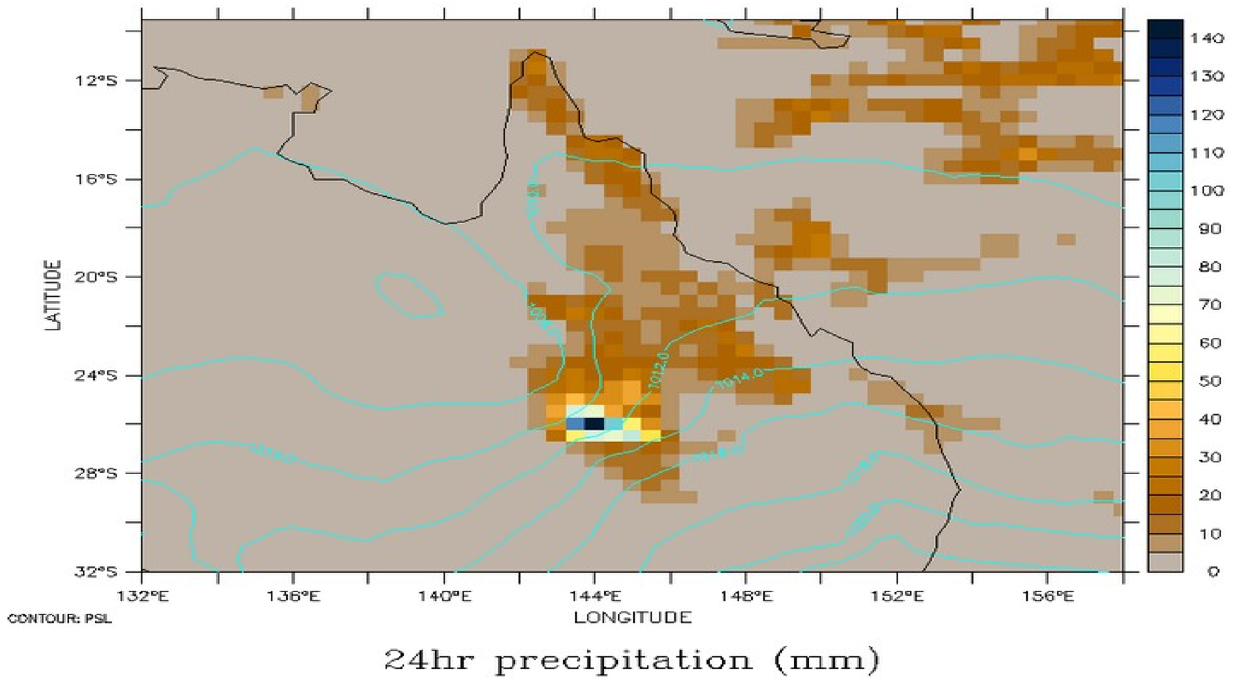
Further innovation is the **quantification of precipitation changes at country- and state-scale and their potentially exposed populations**. These findings can directly assist with designing 'fit for purpose' climate adaptation policies and **reduce uncertainty in which direction precipitation is projected to change globally** under different emissions levels.

Limitations

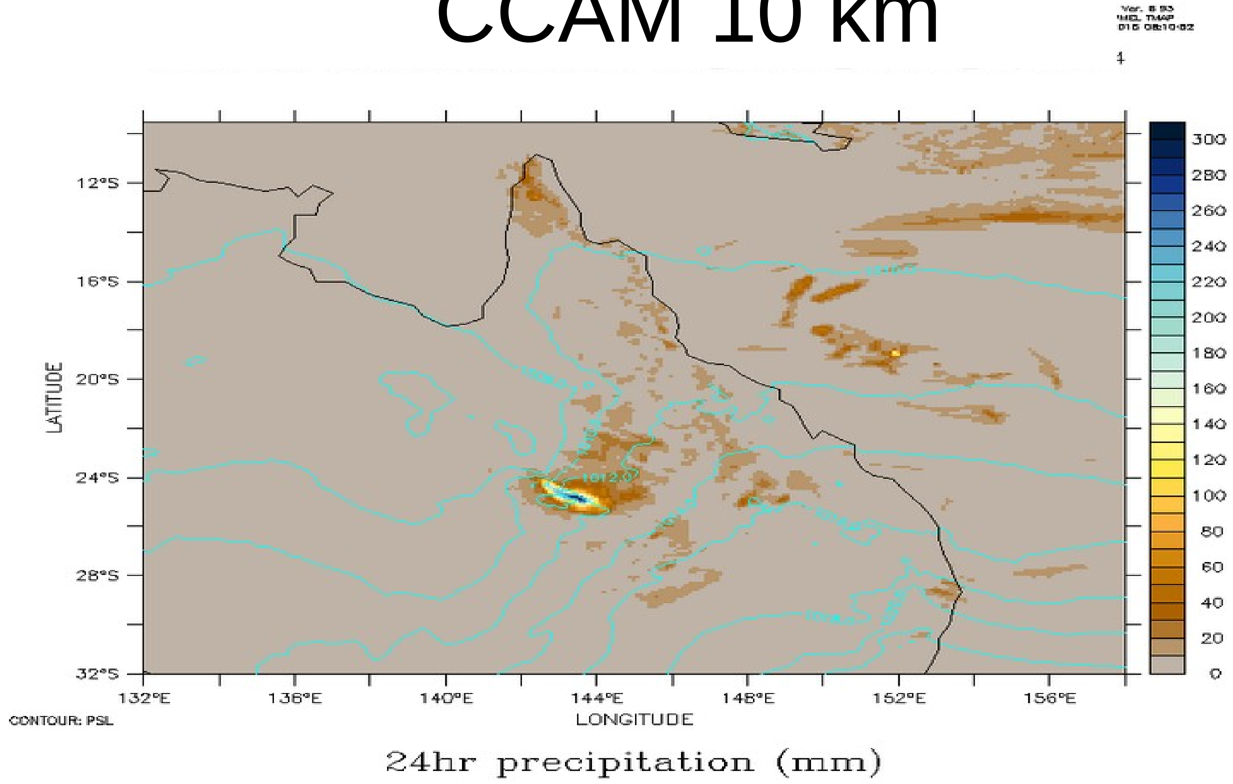
- Resolution – CMIP6 GCMs 50-250 km
- Parameterized clouds, convection, aerosols
- Models have spread in mean climate (historical baseline eg. 1981-2010)
- Model bias in SSTs i.e tropical Pacific cold tongue bias, Southern Ocean …
- Need for downscaling/km scale, convection permitting models, better physical processes especially related to hydrological cycle

Daily rainfall (colour fill) & pressure (contour line)

CCAM 50 km

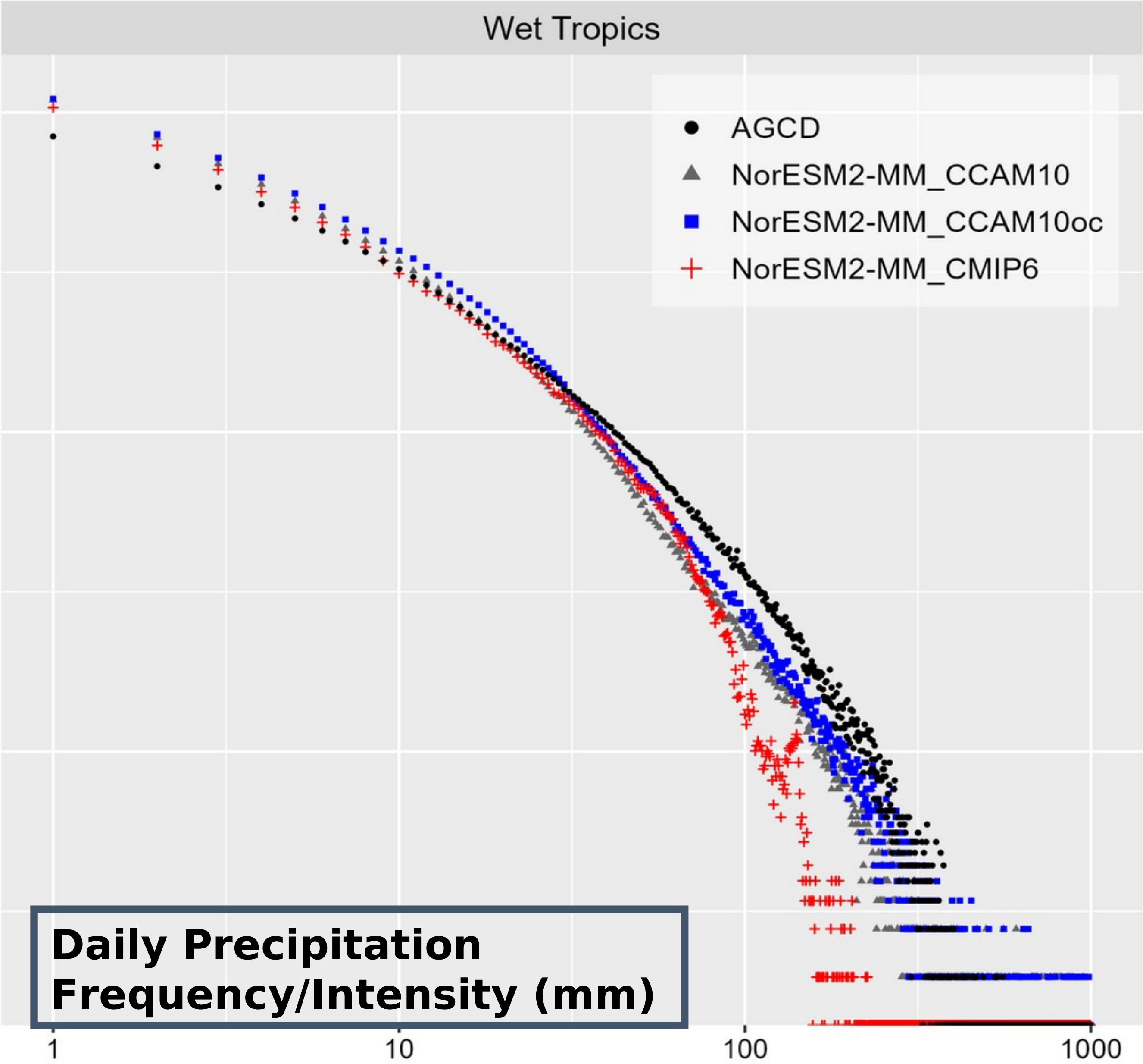


CCAM 10 km



Maximum daily rainfall amount more than twice greater in high resolution model & rainfall events more localised

WHY DOWNSCALING?



Daily Precipitation Frequency/Intensity (mm)