

SPECIAL PROJECT PROGRESS REPORT

All the following mandatory information needs to be provided. The length should *reflect the complexity and duration* of the project.

Reporting year 2024

Project Title: High-Resolution Downscaled RCM-CMIP6 Simulations

Computer Project Account: spienola

Principal Investigator(s): Paul Nolan

Affiliation: Irish Centre for High-End Computing (ICHEC), IT Building, South Campus, National University of Ireland Galway (NUIG), Galway, Ireland

Name of ECMWF scientist(s) collaborating to the project
(if applicable) N/A

Start date of the project: Jan 2022

Expected end date: Dec 2024

Computer resources allocated/used for the current year and the previous one (if applicable)

Please answer for all project resources

		Previous year		Current year	
		Allocated	Used	Allocated	Used
High Performance Computing Facility	(units)	70 million	70 million	60 million	60 million
Data storage capacity	(Gbytes)	30,000	30,000	30,000	30,000

Summary of project objectives (10 lines max)

The scientific objectives of the project are to dynamically downscale CMIP6 data to provide high resolution regional climate projections for Europe and Ireland using both standard atmosphere-only (WRF and COSMO-CLM) and coupled atmosphere-ocean-wave (COAWST) Regional Climate Models (RCMs). The resulting datasets will add to a larger ensemble of RCM data currently being produced at a national and European scale (EURO-CORDEX). The future climate is simulated under all four “tier-1” SSP (SSP1-2.6, SSP2-4.5, SSP3-7.0 and SSP5-8.5) scenarios.

Summary of problems encountered (10 lines max)

The problems encountered were minimal. The implementation and running of the WRF & COSMO-CLM RCMs on the Atos system presented no issues. The only minor issues were the transferring of the large climate datasets from atos to local servers which resulted in some delays.

Summary of plans for the continuation of the project (10 lines max)

The PI will analyse the simulations outlined in Tables 1 during year 4. In addition, the COAWST RCM will be completed (on the ICHEC supercomputer). The PI will collaborate with the project team to complete the RCM-CMIP6 analysis and complete four papers which are currently in preparation: the physical climate changes, impacts (e.g., heatwaves, photovoltaic, growing season), the wind energy resource, and regional Global Warming Thresholds.

List of publications/reports from the project with complete references

- Nolan, P. (2024). *Updated High-resolution Climate Projections for Ireland*. Environmental Protection Agency, Ireland (in Press, [draft](#)).
- O’Brien, E., Ryan, P., Holloway, P., Wang, J., Nowbakht, P., Phillips, C., Fitton, J., O’Dwyer, B. and Nolan, P. (2024) TRANSLATE Research Report. Prepared for Met Éireann by University of Galway, Irish Centre for High-End Computing, University College Cork, and MaREI, the SFI Research Centre for Energy, Climate, and Marine. ISBN: 978-1-917198-00-4.
- O’Brien, E., and P. Nolan. TRANSLATE: standardised climate projections for Ireland. *Front. Clim.* 5, 4 May 2023. <https://doi.org/10.3389/fclim.2023.1166828>
- Murphy, C., Nolan, P., Quinn, T. and Heaphy, L., 2024. *Ireland’s Climate Change Assessment 2023. Volume 3: Being prepared for Ireland’s Future Climate*.

Summary of results

During the period under review (July 2023 to June 2024), the PI completed the RCM-CMIP6-SSPs simulations highlighted in blue in Table 1. The simulations highlighted in green were completed in year 1 and 2 of the project, while white shading shows simulations currently running.

RCM	CMIP6 ESM	ESM Ensemble Members	RCM Nesting Strategy	Historical (# RCM Runs)	SSP1-2.6 (# RCM Runs)	SSP2-4.5 (# RCM Runs)	SSP3-7.0 (# RCM Runs)	SSP5-8.5 (# RCM Runs)
WRF	EC-Earth AOGCM (× 1)	r11i1p1f1	20km → 4km	1980-2014 (1)	2015-2100 (1)	2015-2100 (1)	2015-2100 (1)	2015-2100 (1)
WRF	EC-Earth-Veg (× 2)	r12i1p1f & r14i1p1f1	20km → 4km	1980-2014 (2)	2015-2100 (2)	2015-2100 (2)	2015-2100 (2)	2015-2100 (2)
WRF	MPI-ESM1-2-HR (× 2)	r1i1p1f1 & r2i1p1f1	20km → 4km	1980-2014 (2)	2015-2100 (2)	2015-2100 (2)	2015-2100 (2)	2015-2100 (2)
COSMO-CLM5	EC-Earth-Veg (× 2)	r12i1p1f & r14i1p1f1	12km → 4km	1980-2014 (2)	2015-2100 (2)	2015-2100 (2)	2015-2100 (2)	2015-2100 (2)
COSMO-CLM5	MPI-ESM1-2-HR (× 2)	r1i1p1f1 & r2i1p1f1	12km → 4km	1980-2014 (2)	2015-2100 (2)	2015-2100 (2)	2015-2100 (2)	2015-2100 (2)
COSMO-CLM5	MIROC6 (× 1)	r1i1p1f1	12km → 4km	1980-2014 (1)	2015-2100 (1)	2015-2100 (1)	2015-2100 (1)	2015-2100 (1)
COSMO-CLM5	CMCC-CM2-SR5 (× 1)	r1i1p1f1	12km → 4km	1980-2014 (1)	2015-2100 (1)	2015-2100 (1)	2015-2100 (1)	2015-2100 (1)
COSMO-CLM5	CNRM-ESM2-1 (× 1)	r1i1p1f2	12km → 4km	1980-2014 (1)	2015-2100 (1)	2015-2100 (1)	2015-2100 (1)	2015-2100 (1)
COSMO-CLM5	NorESM2-MM (× 1)	r1i1p1f1	??	1980-2014 (1)	2015-2100 (1)	2015-2100 (1)	2015-2100 (1)	2015-2100 (1)
COSMO-CLM5	EC-Earth-Veg (× 1)	r1i1p1f1	12km → 4km	1980-2014 (1)	2015-2100 (1)	2015-2100 (1)	2015-2100 (1)	2015-2100 (1)

Table 1. Details of the completed ensemble of RCM-CMIP6 simulations run as part of the current study. The columns present information on the RCM, CMIP6 ESM (number in bracket indicates number of separate ESM realisations downscaled), ESM realization ensemble id's, nesting strategy, historical (1980-2014) and future SSP-RCP (2015-2100) number of simulations. Green shading; complete, blue: completed during the period under review, white: currently running.

Projections of numerous variables (e.g., temperature, precipitation, 10m wind, snowfall, specific & relative humidity, MSLP, surface solar radiation, cloud cover, air density, 10cm soil temperature) and derived products (e.g., heatwaves, frost & ice days, growing & grazing season, growing degree days for crops & pests, heavy rainfall days, dry days, turbine height wind power, solar photovoltaic power, heating degree days, driving rain, evapotranspiration) were analysed. To quantify the uncertainty in the projections, the 33rd, 50th and 66th percentiles of the ensemble of projections are calculated. To highlight areas of uncertainty, for each figure, hatching is included where the P33 & P66 projections have different signs. An overview of the preliminary projections can be seen in the previous (2023) progress report.

During the period under review, the SSP-RCP scenario-based RCM projections were supplemented with global warming threshold (GWT) scenario projections. These alternative scenarios have garnered substantial interest since the 2015 Paris Agreement (a UN treaty in which 195 nations

pledged to tackle climate change) which aims to limit global warming to "well below" 2°C by the end of the century, and "pursue efforts" to keep warming within the safer limit of 1.5°C (UN, 2015).

Figure 1 presents preliminary 2m temperature projections for Ireland for various GWTs (1.5, 2, 2.5, 3, 3.5 and 4°C). For example, the projections under the "2°C GWT Scenario" show temperature projections over Ireland in a world which is 2°C warmer with respect to 1850-1900. Similarly, seasonal GWT scenario projections are presented in Figure 2. The GWT scenario projections were assessed using the RCM-CMIP6-SSP scenario projections of the current research as well as the ensemble of RCM-CMIP5-RCP projections of Nolan and Flanagan (2020). As such, the ensemble size is considerably larger (up to 58 members) and allows for a better quantification of uncertainty. This increased ensemble size allows for the IPCC AR6 "Approach C" (discussed in Section 1.4.2) to be implemented where robustness/certainty is based on both model agreement ($\geq 80\%$ agreement of ensemble members in the sign of projected change) and significance (in this case, the 'signal to noise ratio' test). Furthermore, the enhanced ensemble size allows for assessment of a larger range of "likelihood" projections. Figure 3 presents various percentiles of the ensemble of projections of annual 2m temperature for five GWT scenarios; the 10th (very likely), 33rd (likely), 50th (as likely as not), mean, 66th (unlikely) and 90th (very unlikely) projections. Similarly, the seasonal likelihood projections are presented in Figures 4 to 7. The preliminary GWT scenario projections for precipitation (%) presented in Figure 8 (annual), Figures 9 (seasonal) and Figures 10 to 14 (annual and seasonal likelihood projections), show substantial less areas of uncertainty (compared to the SSP-based projections), underpinning the importance of analysing large ensembles in the assessment of climate change.

Annual Temperature Change Global Warming Thresholds

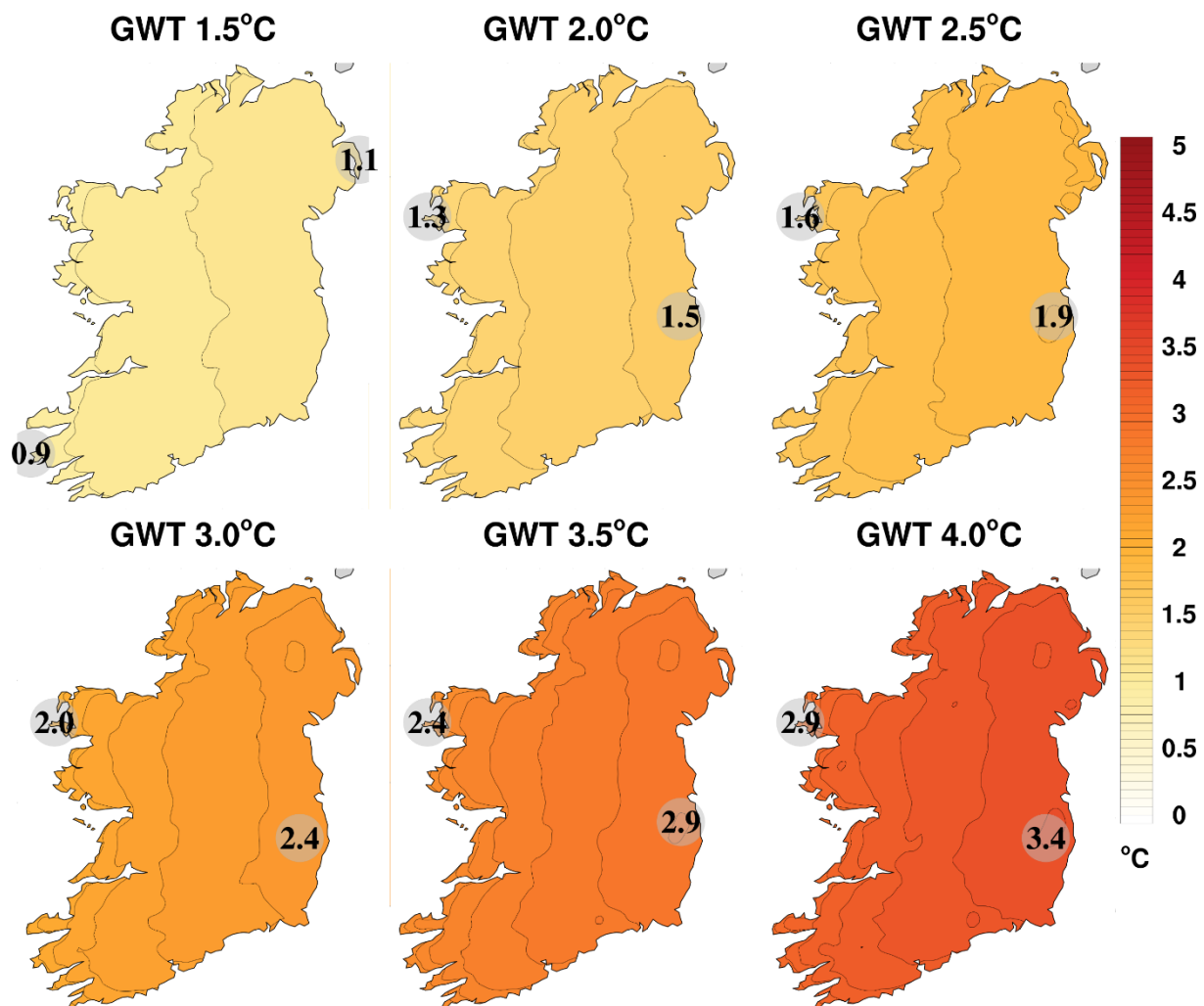


Figure 1. RCM 2m Temperature Projections for Ireland for Global Warming Thresholds (GWTs) w.r.t. 1850-1900; GWT = 1.5°C (58 ensemble members), GWT = 2.0°C (49 members), GWT = 2.5°C (40 members), GWT = 3.0°C (31 members), GWT = 3.5°C (22 members), GWT = 4.0°C (13 members). The projections were produced using an ensemble of high-resolution (4km) downscaled CMIP5-RCP and CMIP6-SSP GCMs. Hatchings are included to highlight areas of ‘uncertainty’; “+” highlights areas where $|\mu_{ensemble}| - \sigma_{ensemble} < 0$, “x” highlights areas where the 20th and 80th percentile of ensemble projections have different signs and “*” highlights areas where both conditions occur¹.

¹ Note that for the annual and seasonal temperature projections, no such areas of uncertainty were identified over Ireland.
June 2024

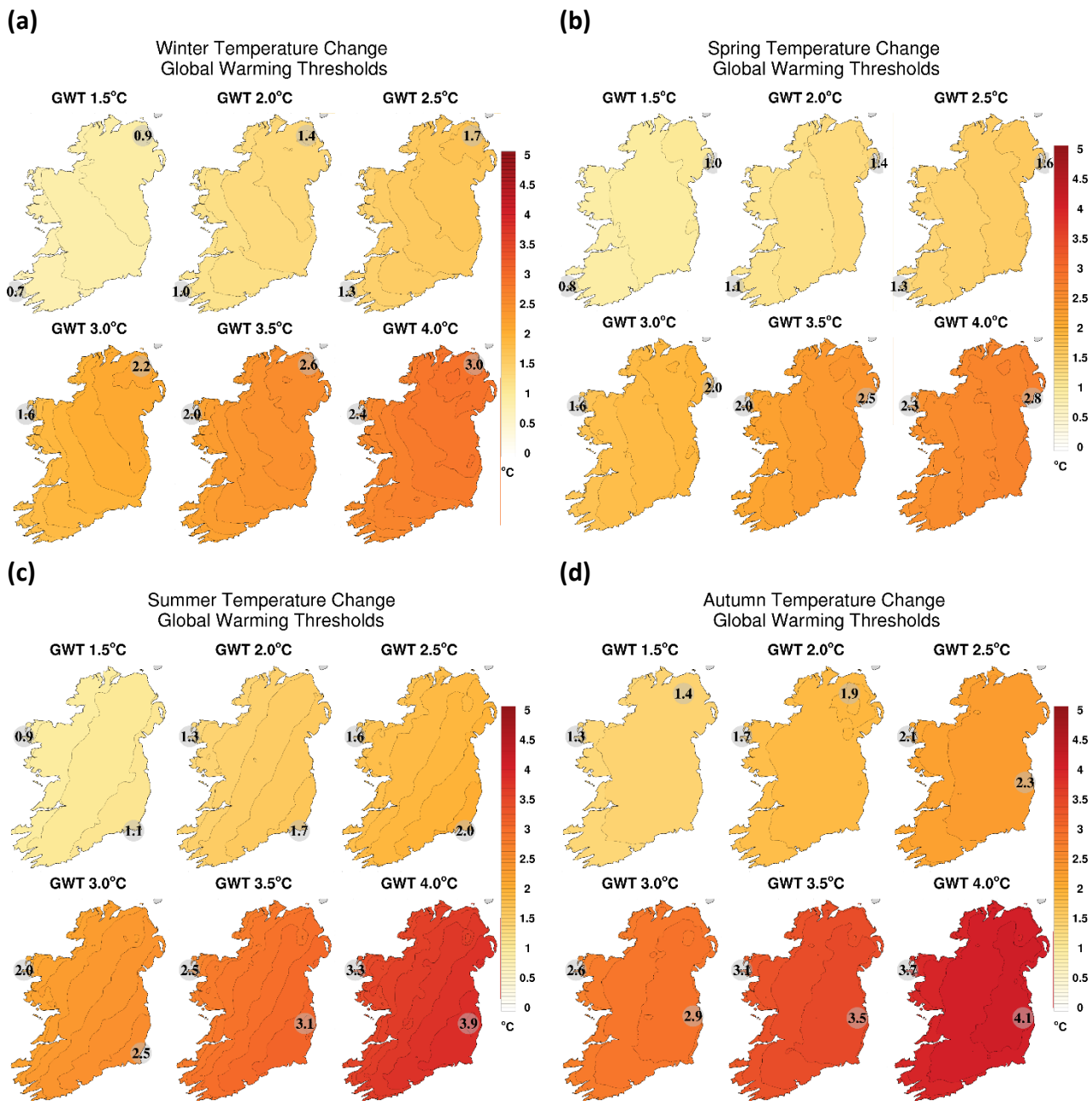


Figure 2. RCM Seasonal 2m Temperature GWT Projections for Ireland w.r.t. 1850-1900; GWT = 1.5°C (58 ensemble members), GWT = 2.0°C (49 members), GWT = 2.5°C (40 members), GWT = 3.0°C (31 members), GWT = 3.5°C (22 members), GWT = 4.0°C (13 members). The projections were produced using an ensemble of high-resolution (4km) downscaled CMIP5-RCP and CMIP6-SSP GCMs.

Annual Global Warming Thresholds Percentiles of Ensemble Temperature Projections

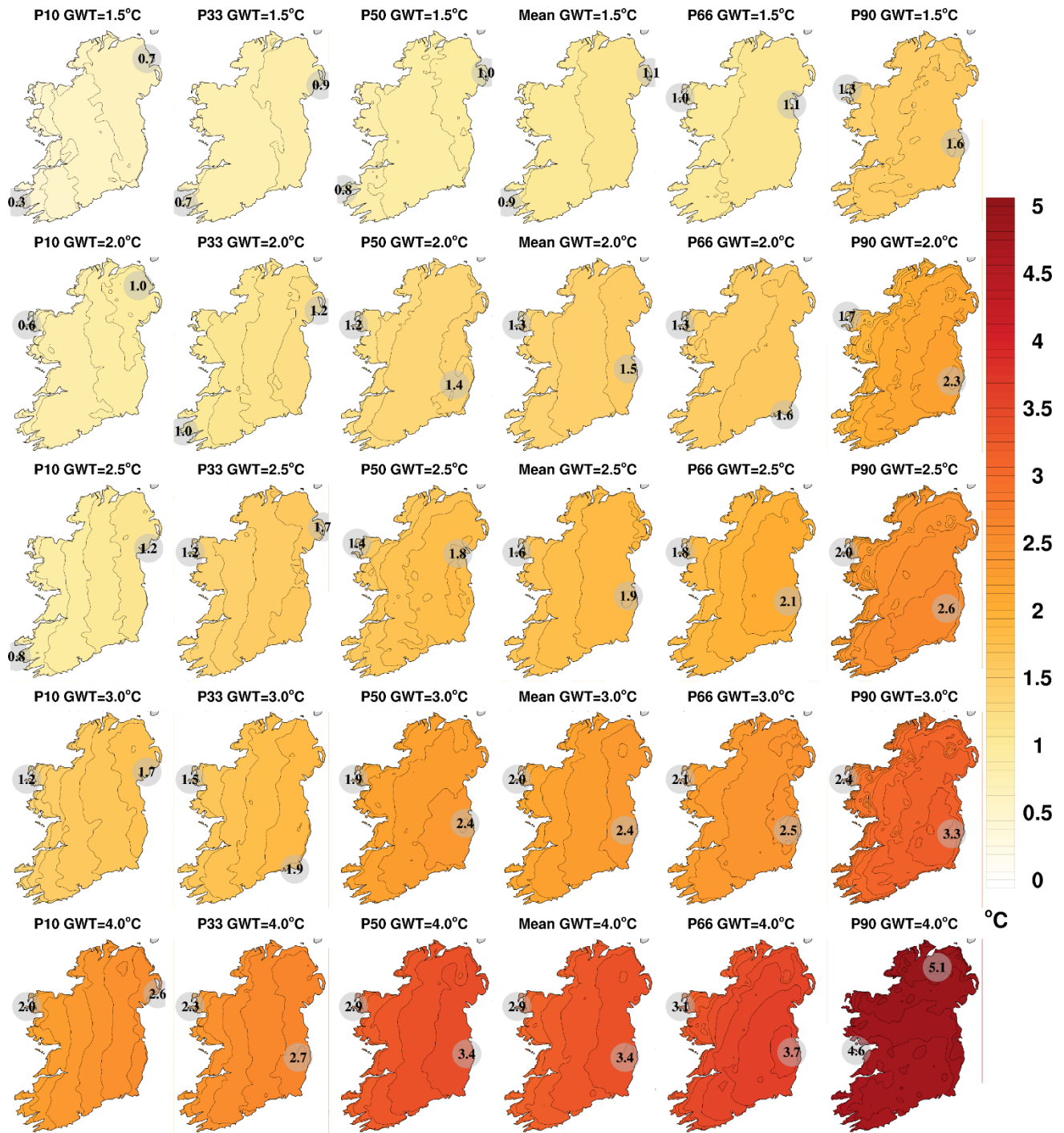


Figure 3. Percentiles of Ensemble of RCM Annual 2m Temperature GWT Projections (°C) w.r.t. 1850-1900; GWT = 1.5°C (58 ensemble members), GWT = 2.0°C (49 members), GWT = 2.5°C (40 members), GWT = 3.0°C (31 members) and GWT = 4.0°C (13 members). The projections were produced using an ensemble of high-resolution (4km) downscaled CMIP5-RCP and CMIP6-SSP GCMs.

Winter Global Warming Thresholds Percentiles of Ensemble Temperature Projections

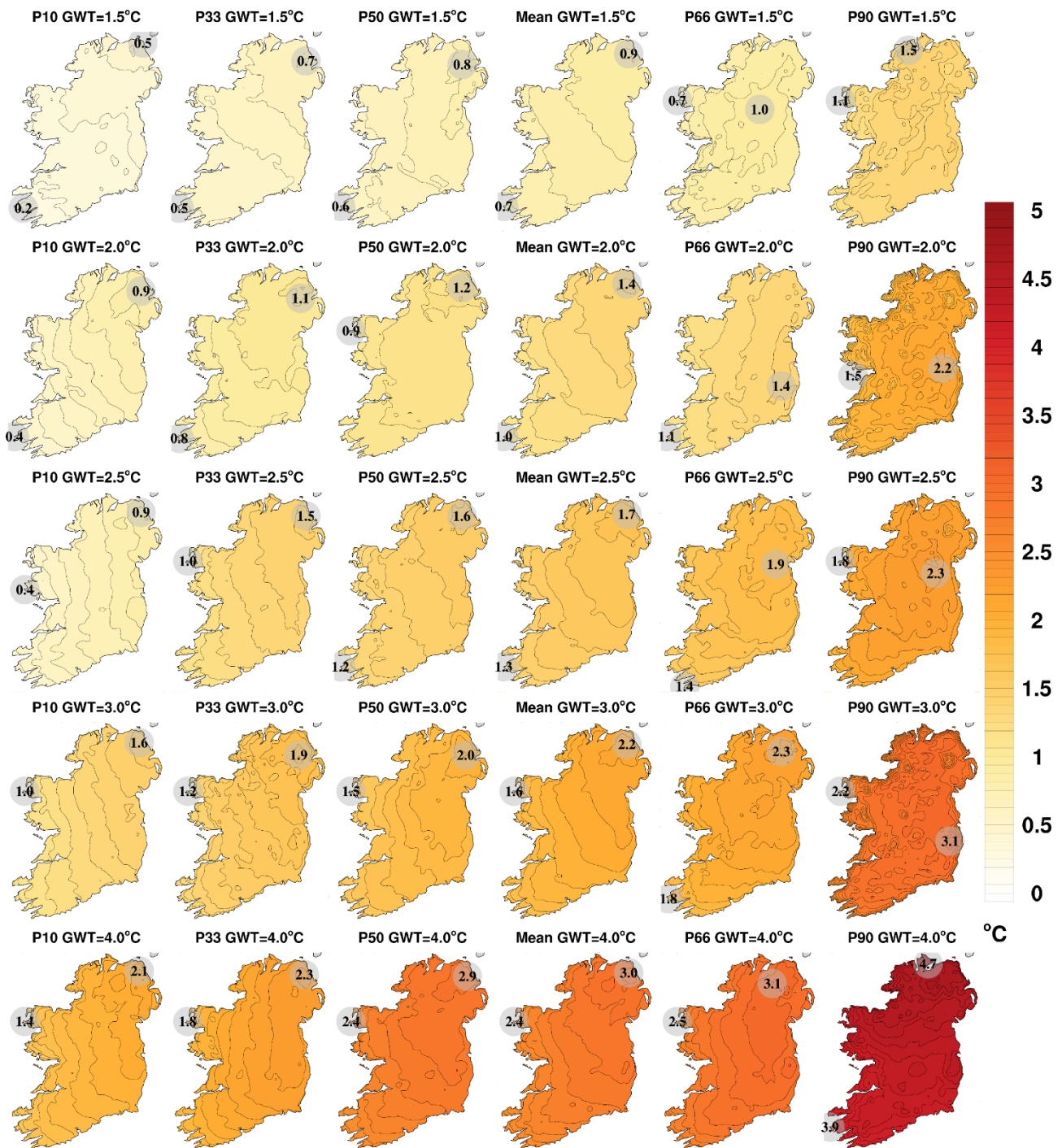


Figure 4. Percentiles of Ensemble of RCM Winter 2m Temperature GWT Projections (°C) w.r.t. 1850-1900; GWT = 1.5°C (58 ensemble members), GWT = 2.0°C (49 members), GWT = 2.5°C (40 members), GWT = 3.0°C (31 members) and GWT = 4.0°C (13 members). The projections were produced using an ensemble of high-resolution (4km) downscaled CMIP5-RCP and CMIP6-SSP GCMs.

Spring Global Warming Thresholds Percentiles of Ensemble Temperature Projections

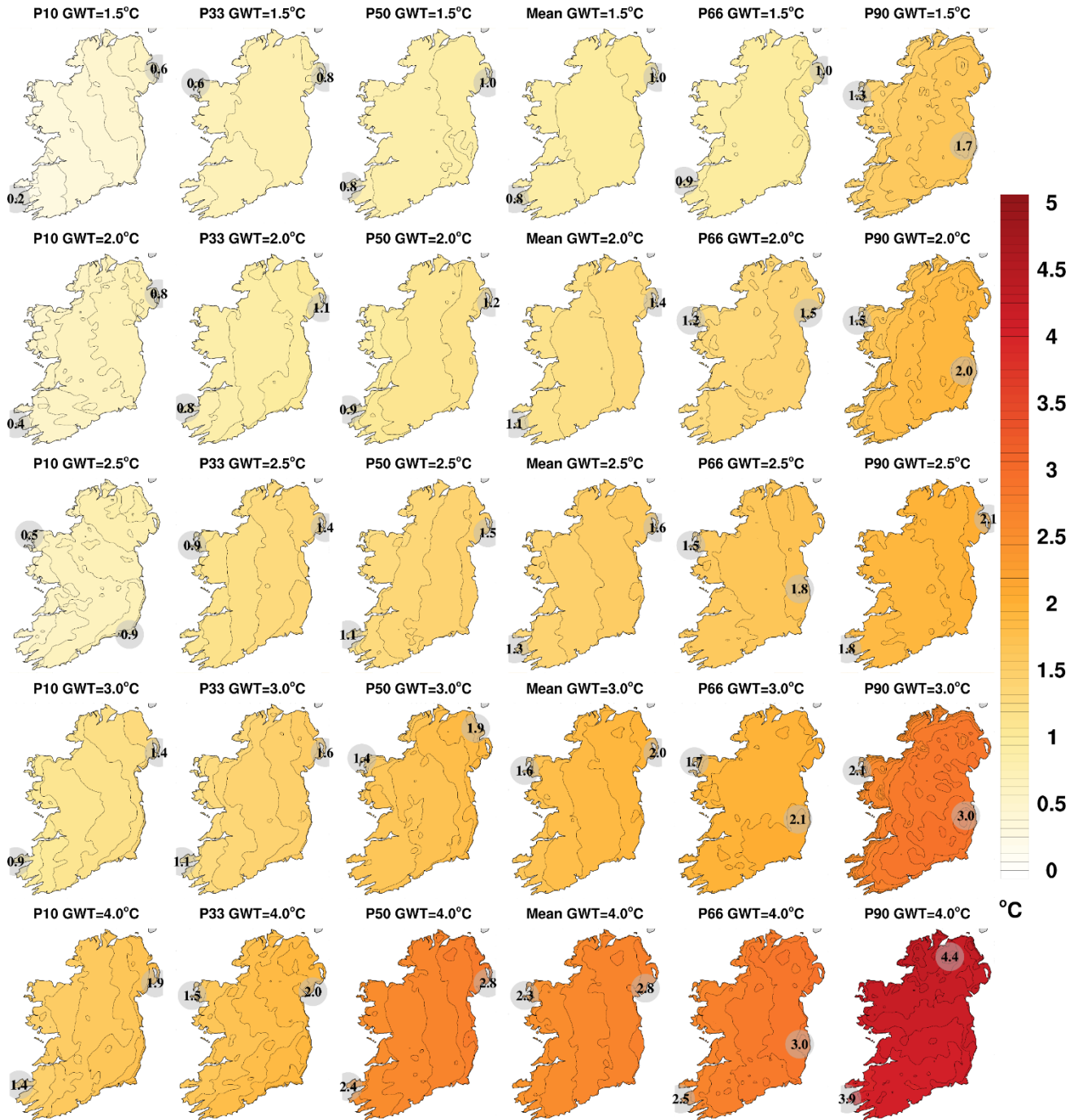


Figure 5. Percentiles of Ensemble of RCM Spring 2m Temperature GWT Projections (°C) w.r.t. 1850-1900; GWT = 1.5°C (58 ensemble members), GWT = 2.0°C (49 members), GWT = 2.5°C (40 members), GWT = 3.0°C (31 members) and GWT = 4.0°C (13 members). The projections were produced using an ensemble of high-resolution (4km) downscaled CMIP5-RCP and CMIP6-SSP GCMs.

Summer Global Warming Thresholds Percentiles of Ensemble Temperature Projections

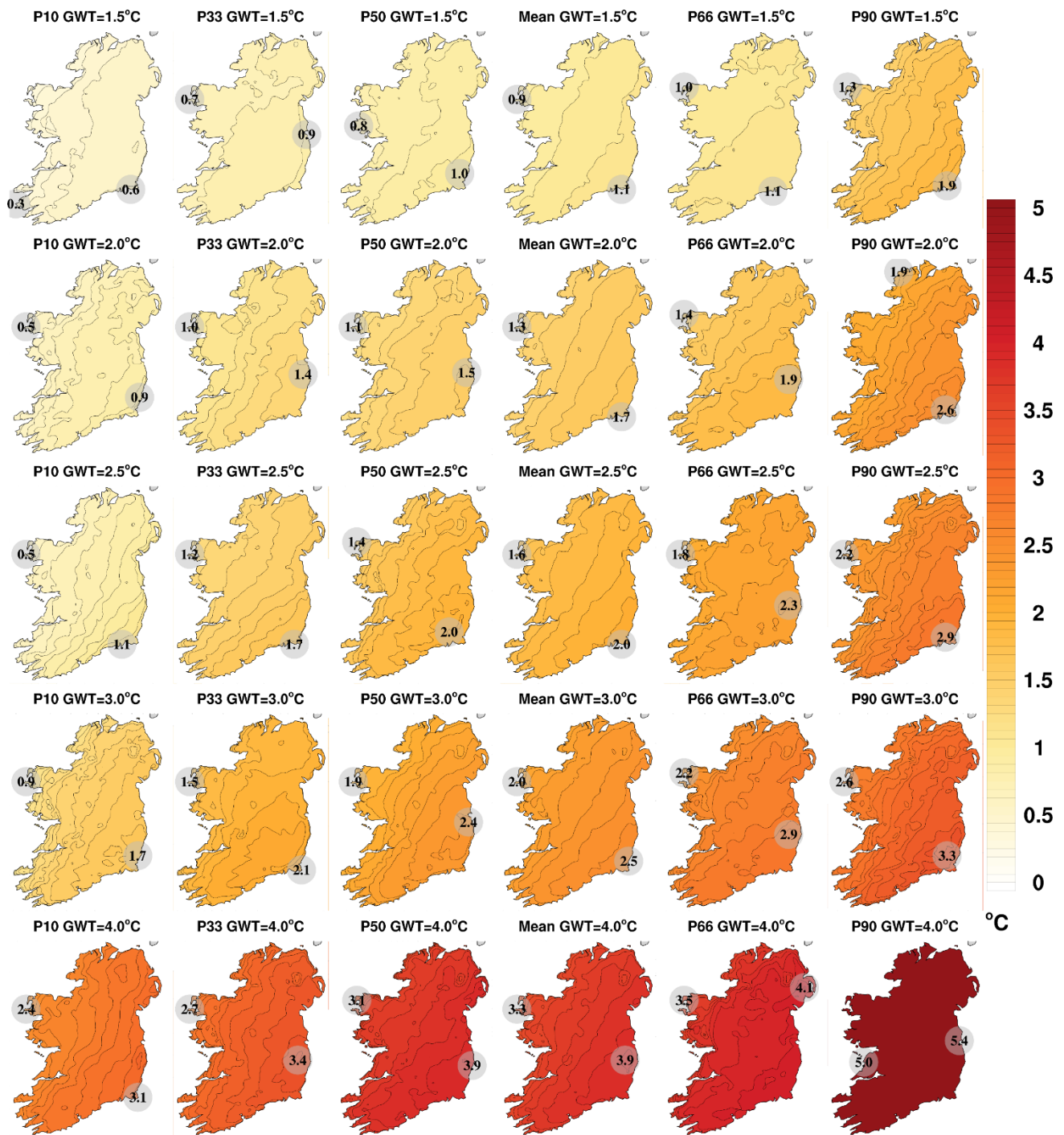


Figure 6. Percentiles of Ensemble of RCM Summer 2m Temperature GWT Projections (°C) w.r.t. 1850-1900; GWT = 1.5°C (58 ensemble members), GWT = 2.0°C (49 members), GWT = 2.5°C (40 members), GWT = 3.0°C (31 members) and GWT = 4.0°C (13 members). The projections were produced using an ensemble of high-resolution (4km) downscaled CMIP5-RCP and CMIP6-SSP GCMs.

Autumn Global Warming Thresholds Percentiles of Ensemble Temperature Projections

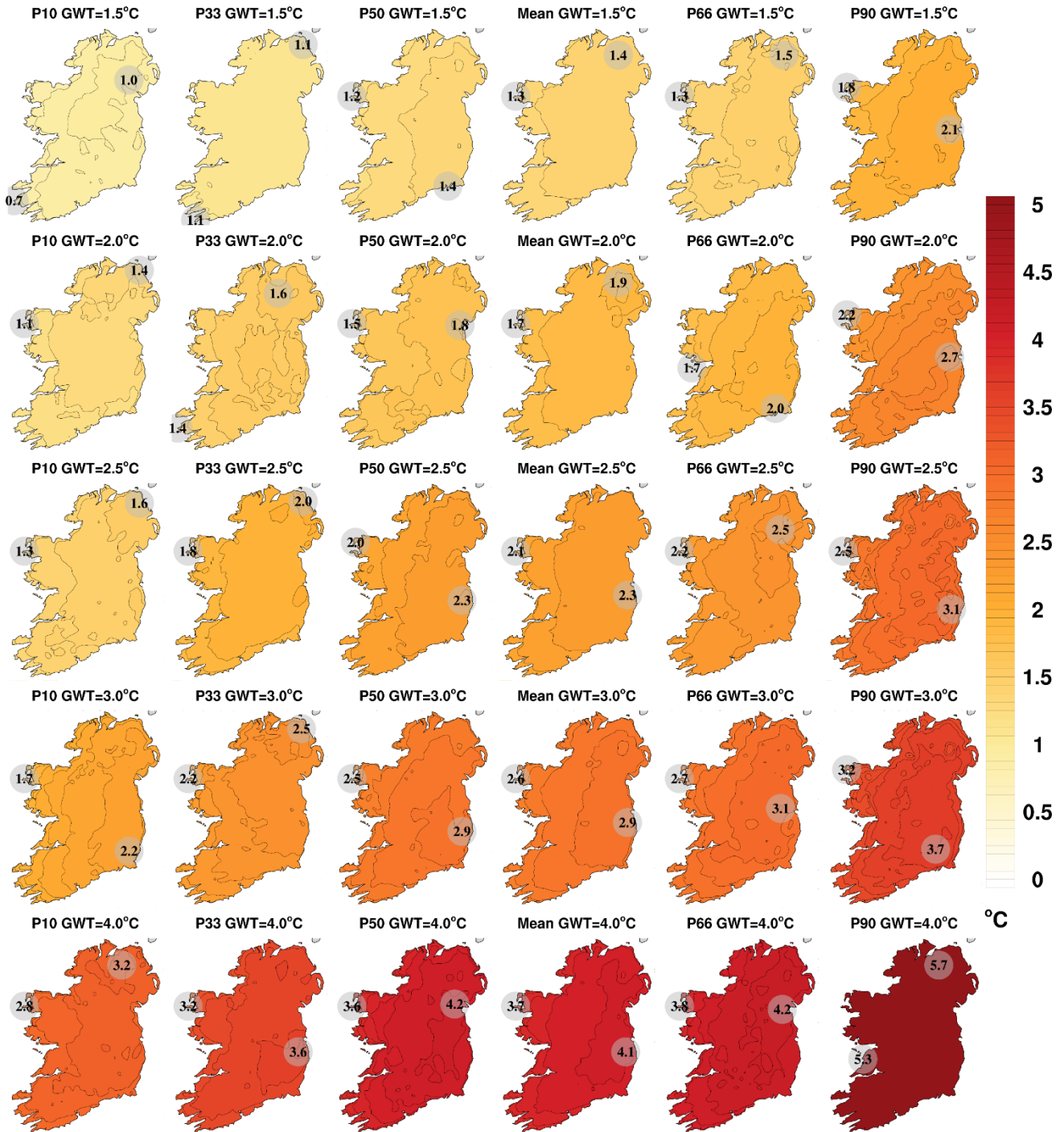


Figure 7. Percentiles of Ensemble of RCM Autumn 2m Temperature GWT Projections (°C) w.r.t. 1850-1900; GWT = 1.5°C (58 ensemble members), GWT = 2.0°C (49 members), GWT = 2.5°C (40 members), GWT = 3.0°C (31 members) and GWT = 4.0°C (13 members). The projections were produced using an ensemble of high-resolution (4km) downscaled CMIP5-RCP and CMIP6-SSP GCMs.

Annual Precipitation Change Global Warming Thresholds

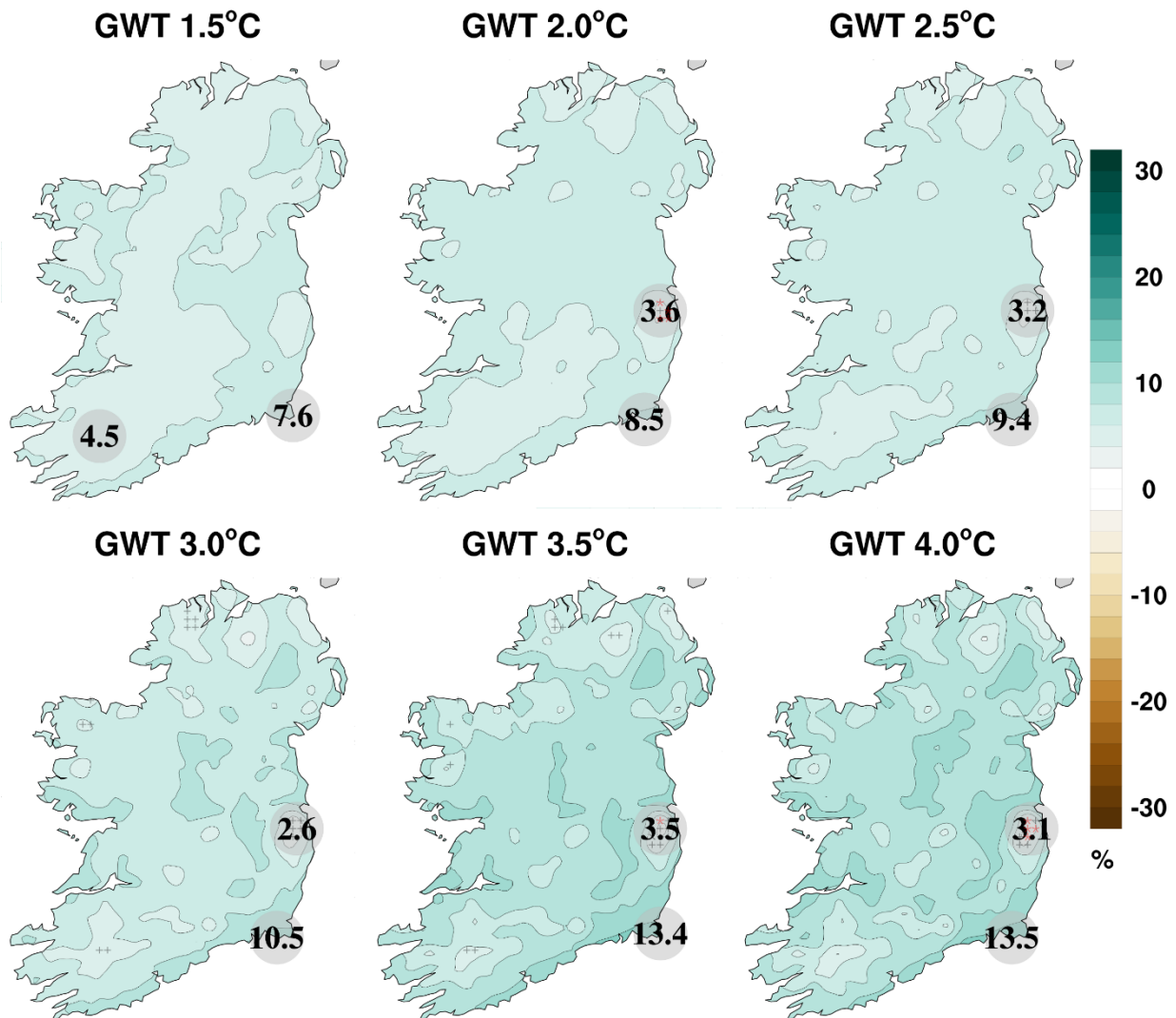


Figure 8. Annual RCM Precipitation GWT Projections (%) for Ireland w.r.t. 1850-1900; GWT = 1.5°C (58 ensemble members), GWT = 2.0°C (49 members), GWT = 2.5°C (40 members), GWT = 3.0°C (31 members), GWT = 3.5°C (22 members), GWT = 4.0°C (13 members). The projections were produced using an ensemble of high-resolution (4km) downscaled CMIP5-RCP and CMIP6-SSP GCMs. Hatchings are included to highlight areas of ‘uncertainty’; “+” highlights areas where $|\mu_{ensemble}| - \sigma_{ensemble} < 0$, “x” highlights areas where the 20th and 80th percentile of ensemble projections have different signs and “*” highlights areas where both conditions occur.

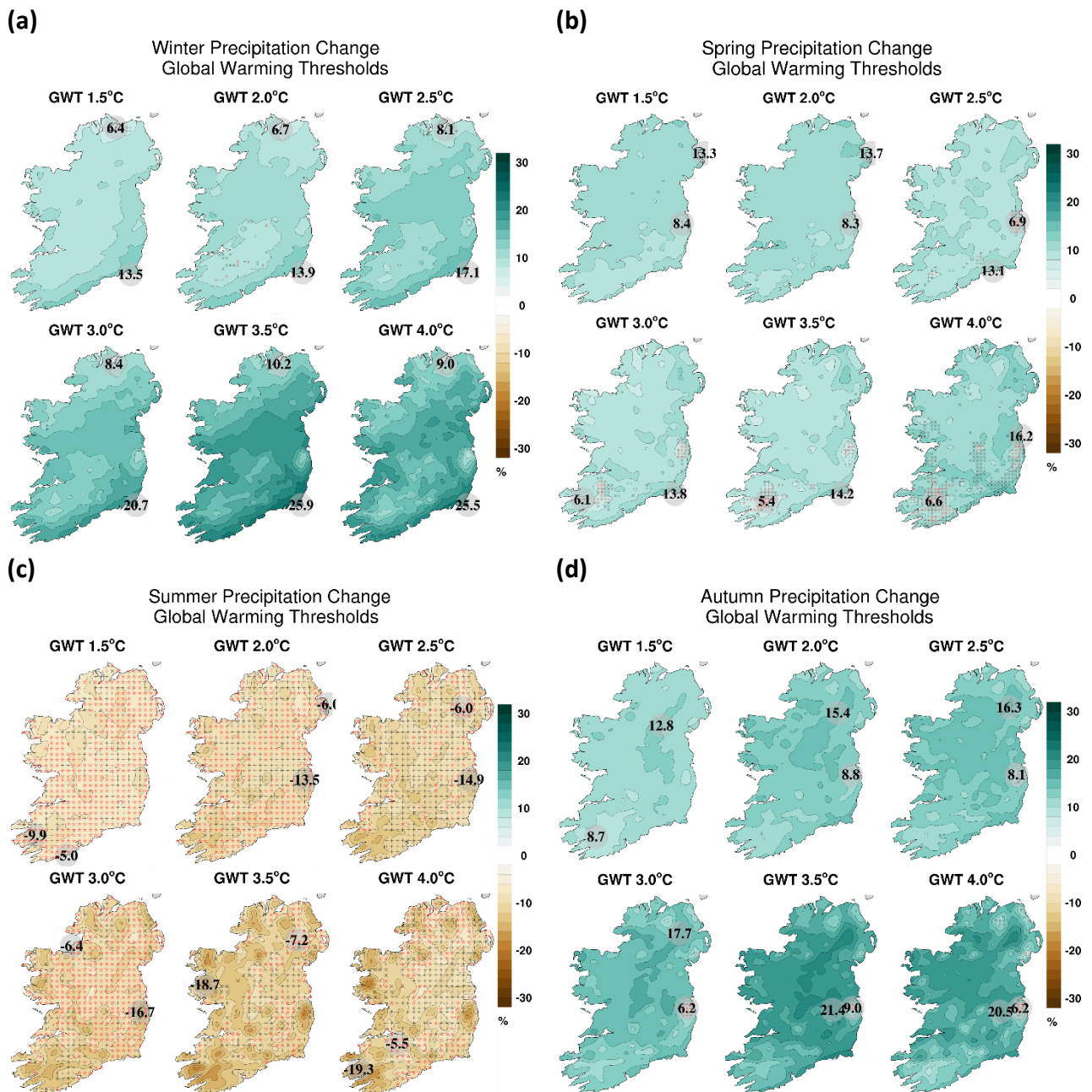


Figure 9. Seasonal RCM Precipitation GWT Projections (%) for Ireland w.r.t. 1850-1900; GWT = 1.5°C (58 ensemble members), GWT = 2.0°C (49 members), GWT = 2.5°C (40 members), GWT = 3.0°C (31 members), GWT = 3.5°C (22 members), GWT = 4.0°C (13 members). The projections were produced using an ensemble of high-resolution (4km) downscaled CMIP5-RCP and CMIP6-SSP GCMs. Hatchings are included to highlight areas of ‘uncertainty’; “+” highlights areas where $|\mu_{ensemble}| - \sigma_{ensemble} < 0$, “x” highlights areas where the 20th and 80th percentile of ensemble projections have different signs and “*” highlights areas where both conditions occur.

Annual Global Warming Thresholds Percentiles of Ensemble Precipitation Projections

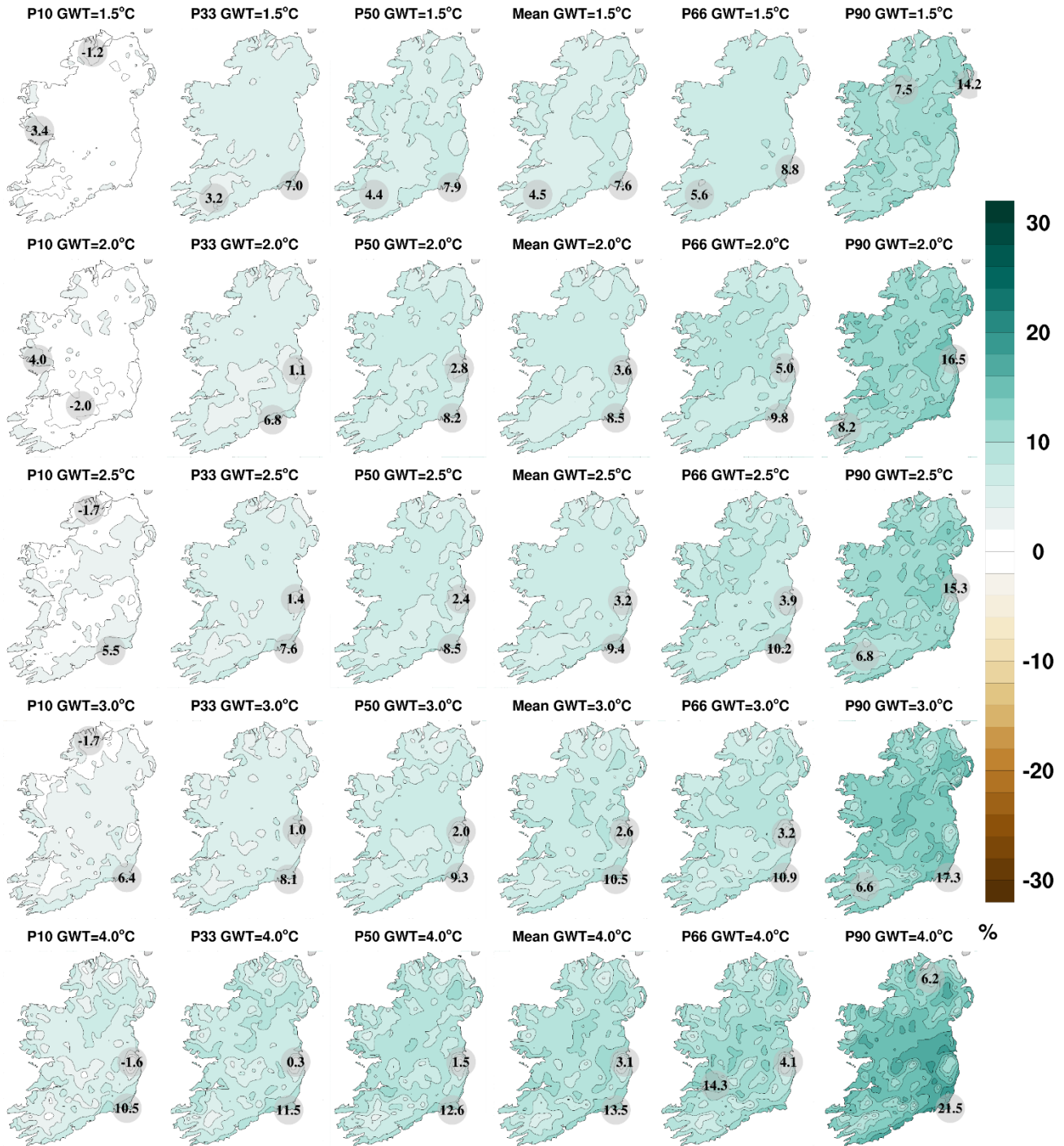


Figure 10. Percentiles of Ensemble of RCM Annual Precipitation GWT Projections (%) w.r.t. 1850-1900; GWT = 1.5°C (58 ensemble members), GWT = 2.0°C (49 members), GWT = 2.5°C (40 members), GWT = 3.0°C (31 members) and GWT = 4.0°C (13 members). The projections were produced using an ensemble of high-resolution (4km) downscaled CMIP5-RCP and CMIP6-SSP GCMs.

Winter Global Warming Thresholds Percentiles of Ensemble Precipitation Projections

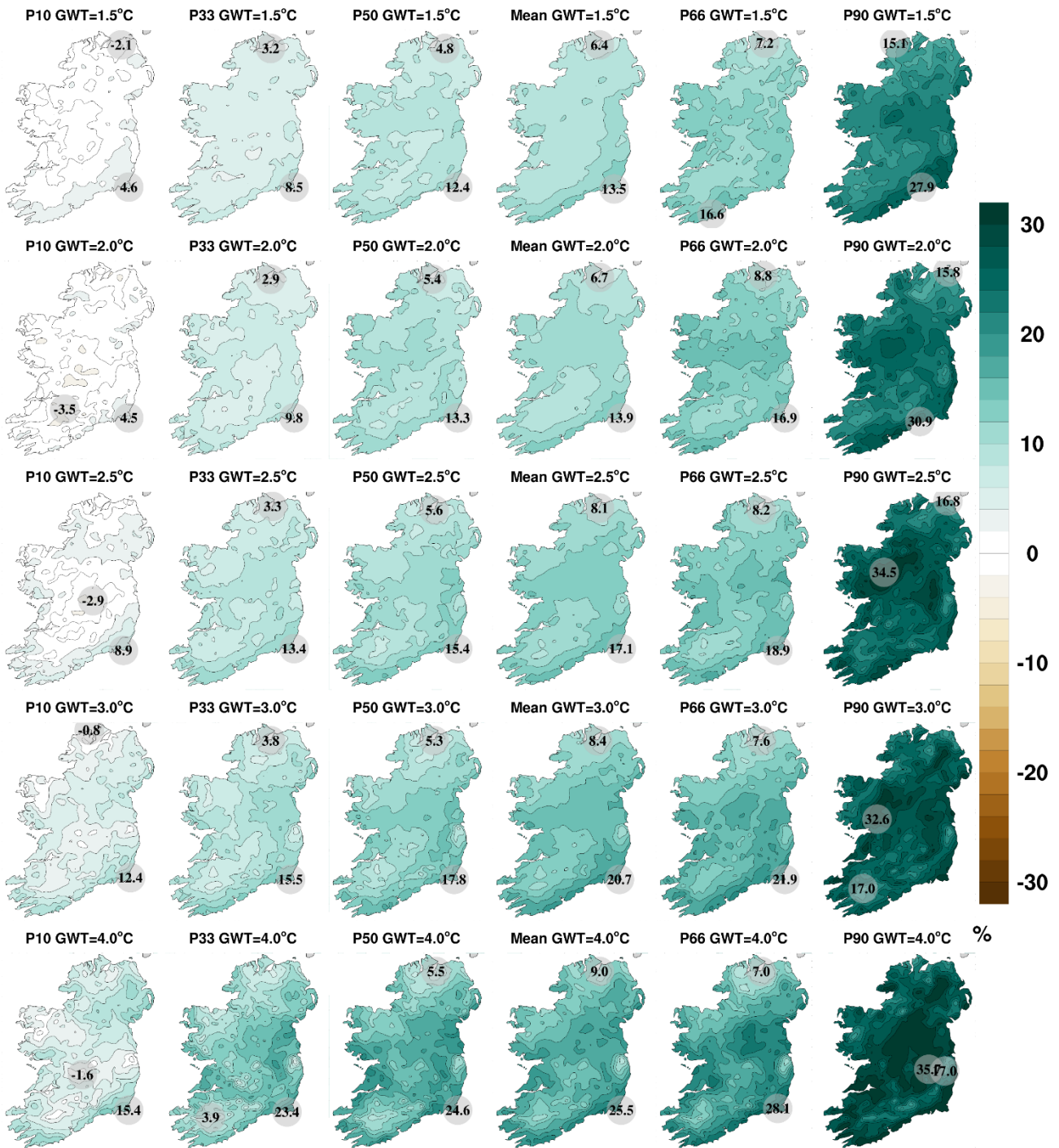


Figure 11. Percentiles of Ensemble of RCM Winter Precipitation GWT Projections (%) w.r.t. 1850-1900; GWT = 1.5°C (58 ensemble members), GWT = 2.0°C (49 members), GWT = 2.5°C (40 members), GWT = 3.0°C (31 members), GWT = 3.5°C (22 members), GWT = 4.0°C (13 members). The projections were produced using an ensemble of high-resolution (4km) downscaled CMIP5-RCP and CMIP6-SSP GCMs.

Spring Global Warming Thresholds Percentiles of Ensemble Precipitation Projections



Figure 12. Percentiles of Ensemble of RCM Spring Precipitation GWT Projections (%) w.r.t. 1850-1900; GWT = 1.5°C (58 ensemble members), GWT = 2.0°C (49 members), GWT = 2.5°C (40 members), GWT = 3.0°C (31 members) and GWT = 4.0°C (13 members). The projections were produced using an ensemble of high-resolution (4km) downscaled CMIP5-RCP and CMIP6-SSP GCMs.

Summer Global Warming Thresholds Percentiles of Ensemble Precipitation Projections

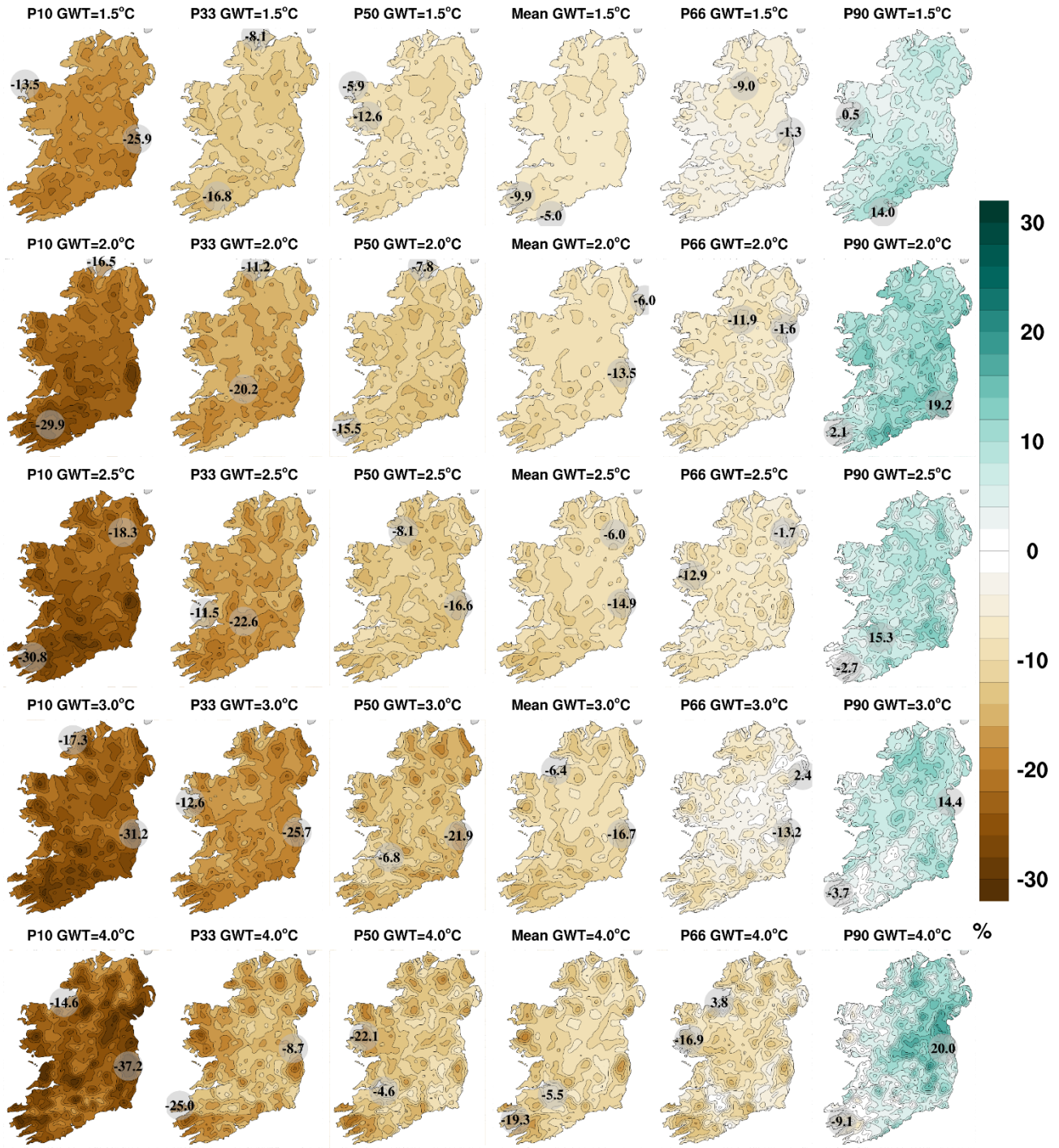


Figure 13. Percentiles of Ensemble of RCM Summer Precipitation GWT Projections (%) w.r.t. 1850-1900; GWT = 1.5°C (58 ensemble members), GWT = 2.0°C (49 members), GWT = 2.5°C (40 members), GWT = 3.0°C (31 members) and GWT = 4.0°C (13 members). The projections were produced using an ensemble of high-resolution (4km) downscaled CMIP5-RCP and CMIP6-SSP GCMs.

Autumn Global Warming Thresholds Percentiles of Ensemble Precipitation Projections

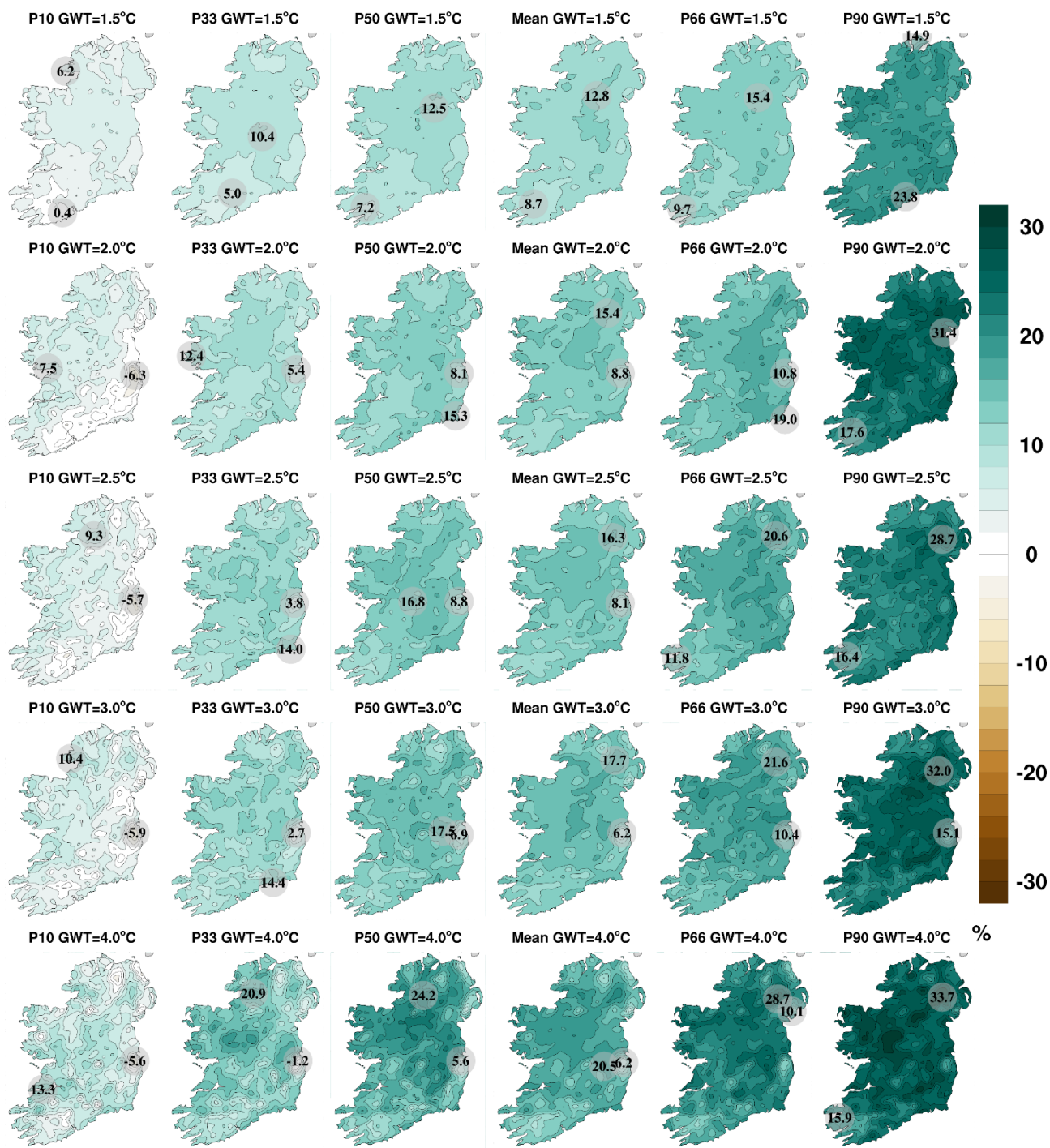


Figure 14. Percentiles of Ensemble of RCM Autumn Precipitation GWT Projections (%) w.r.t. 1850-1900; GWT = 1.5°C (58 ensemble members), GWT = 2.0°C (49 members), GWT = 2.5°C (40 members), GWT = 3.0°C (31 members) and GWT = 4.0°C (13 members). The projections were produced using an ensemble of high-resolution (4km) downscaled CMIP5-RCP and CMIP6-SSP GCMs.

References:

- Nolan, P., Flanagan, J. (2020). *High-Resolution Climate Projections for Ireland – A Multi-model Ensemble Approach*. EPA Research Report, 339. <http://epa.ie/pubs/reports/research/climate/researchreport339/> (accessed 30/06/24)
- UN 2015. Conference of the Parties, Adoption of the Paris Agreement, Dec. 12, 2015 U.N. Doc. FCCC/CP/2015/L.9/Rev/1