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	2022
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)	N/A	N/A	60 million	60 million
Data storage capacity	(Gbytes)	N/A	N/A	30,000	20,000

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 (Euro-CORDEX) 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 new Atmos system presented no issues.

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

The PI will continue to run the simulations outlined in Table 2 during years 2 & 3. In addition, the COAWST RCM will be run. Furthermore, the RCM work will contribute to the CORDEX project by running the required outer domain of selected RCM simulations on the Euro-CORDEX domains, conforming to the CORDEX standards, and extending the simulation period to 1950-2100 (for the outer domain).

List of publications/reports from the project with complete references

No publications - the project started in January 2022.

Summary of results

The choice of CMIP6 data for downscaling was informed by a careful review carried by Euro-CORDEX partners. This study identified an initial set of CMIP6 datasets based on many factors, e.g., model level data availability, SSP coverage (SSP1-2.6, SSP2-4.5, SSP3-7.0 & SSP5-8.5), model resolution, Equilibrium Climate Sensitivity (ECS; low, medium & high), model skill, e.g., JJA/DJF Extratropical Storm Track, Transient Climate Response, Circulation and sea surface temperature validations. Informed by this study, and with particular weight given to ensuring a plausible spread of ECS, the CMIP6 datasets presented in Table 1 (white shading) were chosen for initial downscaling over the Irish domain. The choice of CMIP6 data is further confirmed by a separate 2021 study carried out by the Finnish Meteorological Institute (Ruosteenoja, K., 2021). This filtering of CMIP6 models results in a high-quality, representative, and manageable ensemble for downscaling over Ireland. The progress of the initial RCM simulations is presented in Table 2 (note that some of these simulations are run as part of a separate ICHEC HPC project). These simulations will be updated over time to include downscaling of additional CMIP6 datasets from the international community.

CMIP6 Model	Ensemble id	ECS	Atmospheric resolution
MIROC6	r1i1p1f1	2.61	200 km
MPI-ESM1-2-HR	r1i1p1f1 r2i1p1f1	2.98	100 km
EC-Earth3	r11i1p1f1	4.2	79 km
EC-Earth3-Veg	r1i1p1f1 r12i1p1f1 r14i1p1f1	4.31	79 km
NorESM2-LM	r1i1p1f1	2.54	250 km
MPI-ESM1-2-LR	r1i1p1f1	3	250 km
CMCC-ESM2	r1i1p1f1	??	100 km
CMCC-CM2-SR5	r1i1p1f1	3.52	100 km
ACCESS-ESM1-5	r1i1p1f1	3.87	250 km
CNRM-ESM2-1	r1i1p1f1	4.76	110 km

Table 1. Initial CMIP6 data selected for downscaling over Ireland (white shading). The datasets shaded in orange are suitable CMIP6 datasets highlighted for future downscaling research.

RCM	CMIP6 ESM Ensemble id	Historical Progress	SSP1-2.6 Progress	SSP2-4.5 Progress	SSP3-7.0 Progress	SSP5-8.5 Progress
WRF (20 & 4km)	EC-Earth AOGCM r11i1p1f1	1980-2014 Complete	2015-2100 Complete	2015-2100 Complete	2015-2100 Complete	2015-2100 Complete
WRF (20 & 4km)	EC-Earth-Veg r12i1p1f1	1980-2014 Complete	2015-2100 Complete	2015-2100 Complete	2015-2100 Complete	2015-2100 Complete
WRF (20 & 4km)	EC-Earth-Veg r14i1p1f1	1980-2014 Complete	2015-2100 Complete	2015-2100 Complete	2015-2100 Complete	2015-2100 Complete
COSMO-CLM5 (12 & 4km)	EC-Earth-Veg r12i1p1f1	1980-2014 Complete	2015-2100 Complete	2015-2100 Complete	2015-2100 Complete	2015-2100 Complete
COSMO-CLM5 (12 & 4km)	EC-Earth-Veg r14i1p1f1	1980-2014 Complete	2015-2100 Complete	2015-2100 Complete	2015-2100 Complete	2015-2100 Complete
COSMO-CLM5 (12 & 4km)	MPI-ESM1-2-HR r1i1p1f1	1980-2014 Complete	2015-2100 Complete	2015-2100 Complete	2015-2100 Complete	2015-2100 Complete
COSMO-CLM5 (12 & 4km)	MPI-ESM1-2-HR r2i1p1f1	1980-2014 Complete	2015-2100 Complete	2015-2100 Complete	2015-2100 Complete	2015-2100 Complete
COSMO-CLM5 (12 & 4km)	MIROC6 r1i1p1f1	10% Complete	10% Complete	10% Complete	10% Complete	10% Complete
WRF (20 & 4km)	MPI-ESM1-2-HR r1i1p1f1	1980-2014 Complete	40% Complete	40% Complete	40% Complete	40% Complete
WRF (20 & 4km)	MPI-ESM1-2-HR r2i1p1f1	20% Complete	5% Complete	10% Complete	10% Complete	5% Complete

Table 2. Details of the progress of the initial ensemble of RCM-CMIP6 simulations. The rows present information on the RCM used, nesting strategy, CMIP6 ESM ensemble id, historical (1980-2014) simulation progress, future (2015-2100) simulation progress for each SSP.

The RCM configurations were validated by downscaling ECMWF ERA5 reanalyses for multi-decadal time periods and comparing the output with observational data. See Figures 1 for validations of 2m temperature as resolved by the COSMO-CLM5-ERA5 4km simulation.

Figure 2 presents preliminary projections of 2m temperature under four SSPs emission scenarios. We also compare downscaled CMIP5 (RCP4.5 & RCP8.5) with CMIP6 (SSP245 and SSP585) projections for the middle of this century (2041–2060 vs. 1981-2000). It is found that for most fields analysed, the downscaled CMIP5 and CMIP6 projections are similar (Figures 3-16). This agreement adds a measure of confidence to the projections.

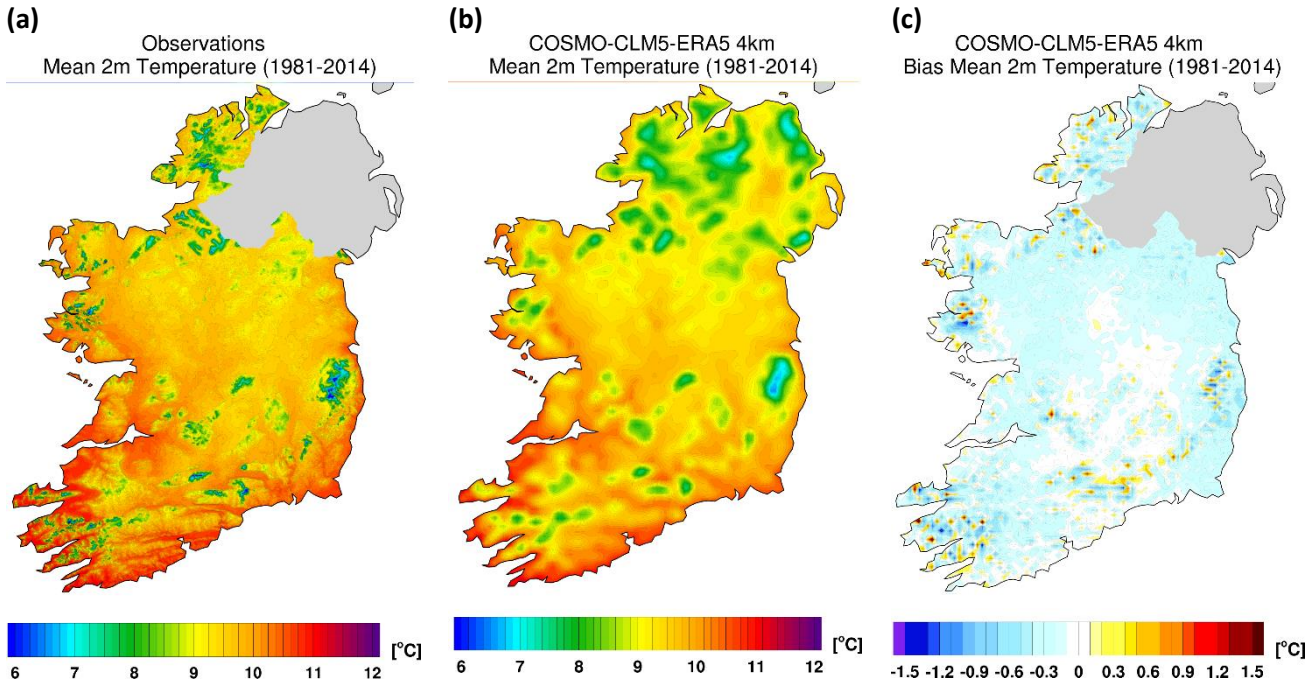

Figure 1. COSMO-CLM5 Validation of Mean 2m Temperature (1981-2014); **(a)** Met Eireann Observations, **(b)** COSMO-CLM5-ERA5 4km and **(c)** Bias

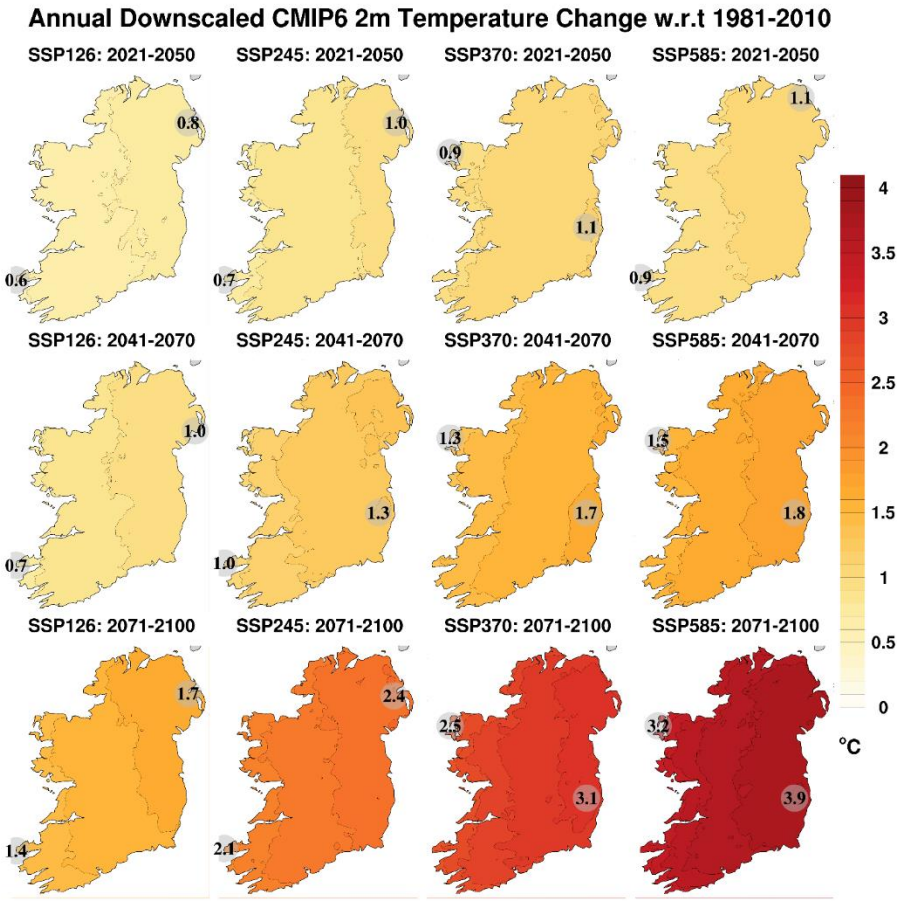

Figure 2. Preliminary 21st-century Regional Climate Model (RCM) projections of annual 2-m temperature for SSP1-2.6, SSP2-4.5, SSP3-7.0 & SSP5-8.5. All RCM ensemble members were run with 4-km grid spacing. In each case, the future 30-year period is compared with the past period 1981–2010. The numbers included on each plot are the minimum and maximum projected changes, displayed at their locations.

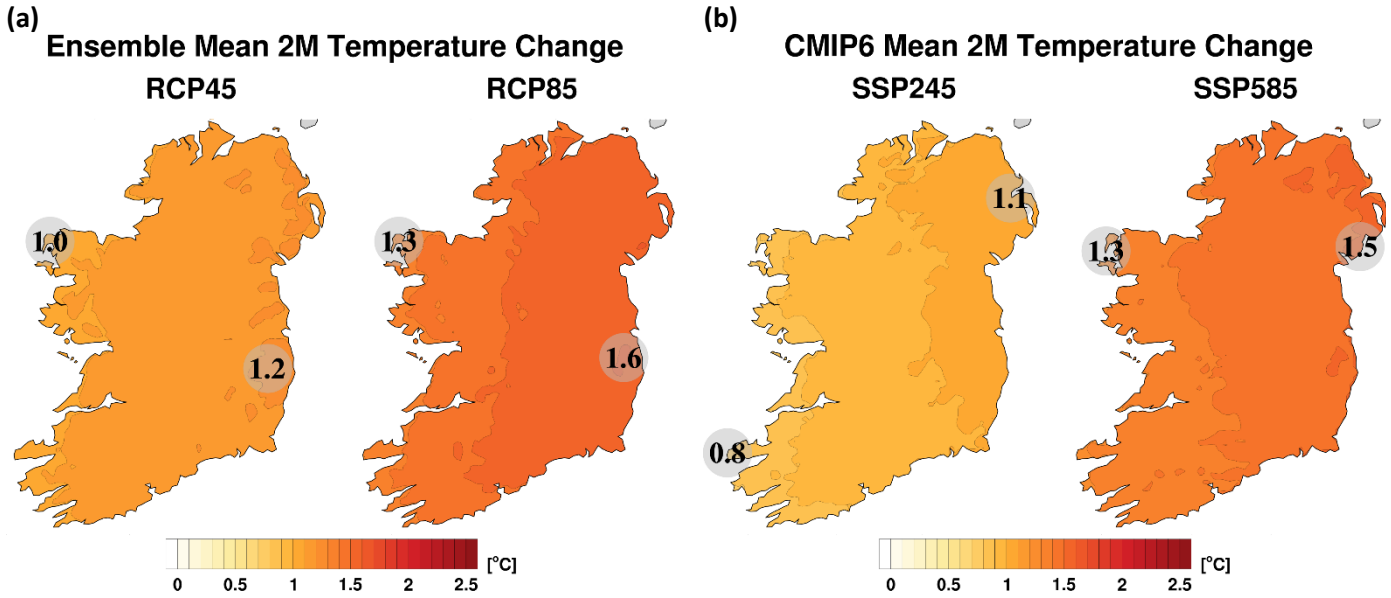

Figure 3. Projections of 2-m temperature change of downscaled **(a)** CMIP5 and **(b)** CMIP6 data. In each case, the future period 2041–2060 is compared with the past period 1981–2000. The numbers included on each plot are the minimum and maximum projected changes, displayed at their locations.

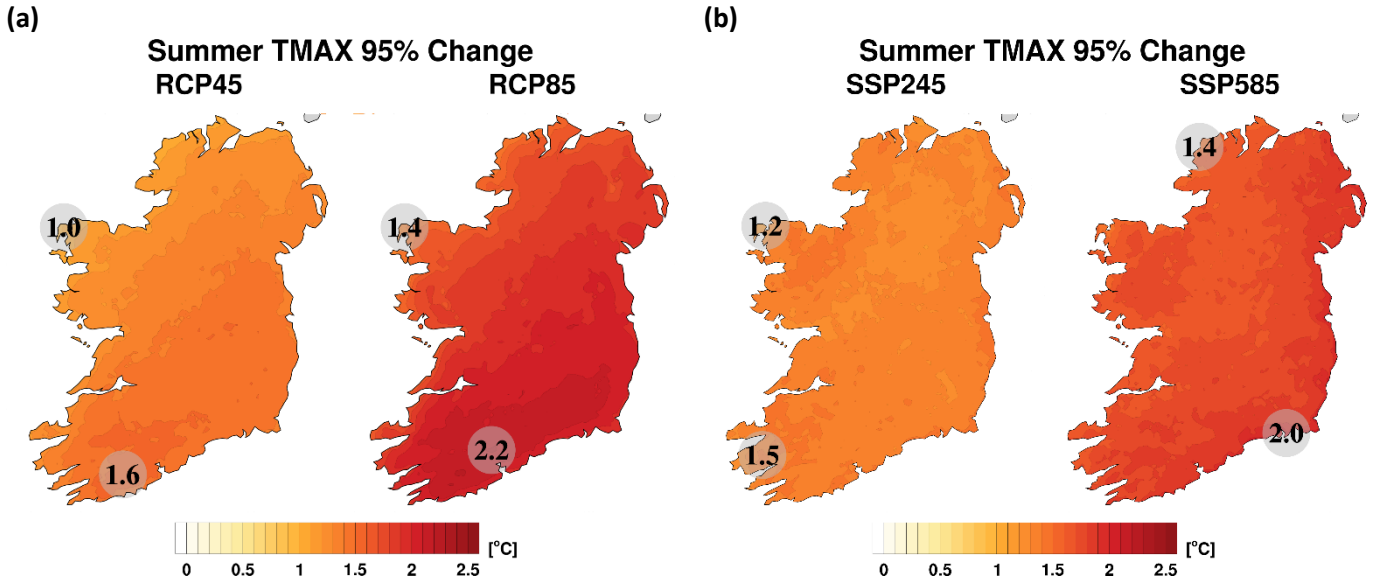

Figure 4. Projected changes in mid-century top 5% of daily maximum temperatures (warm summer days) for **(a)** CMIP5 and **(b)** CMIP6. In each case, the future period, 2041–2060, is compared with the past period, 1981–2000.

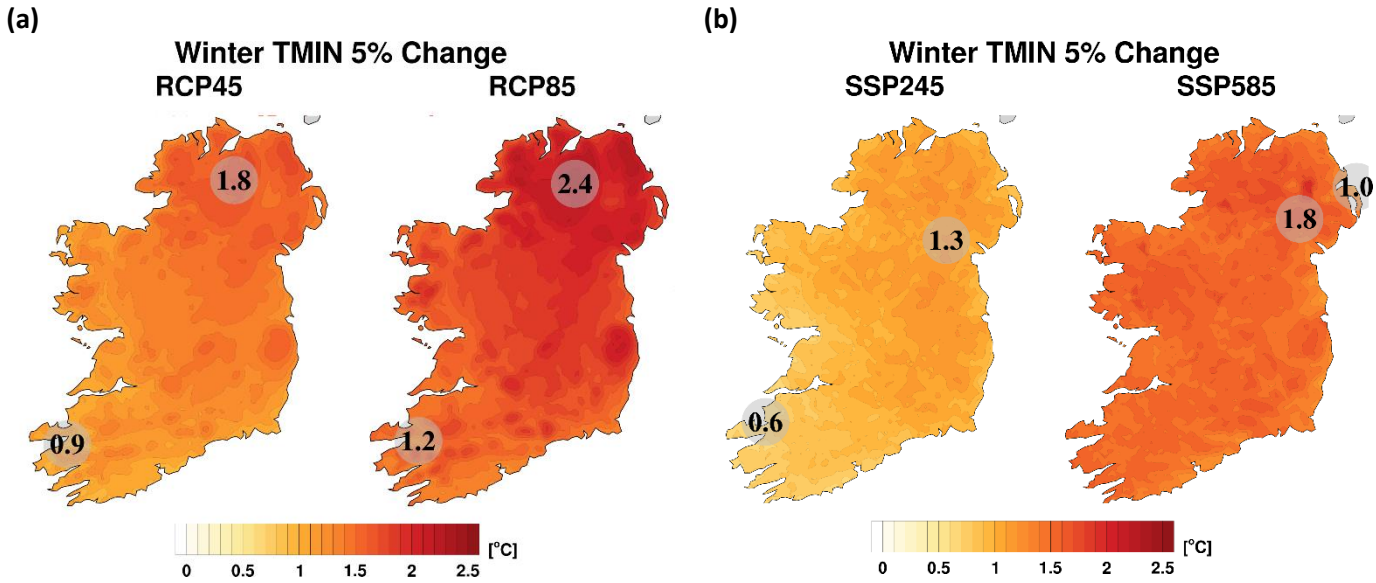

Figure 5. Projected changes in mid-century bottom 5% of daily minimum temperatures (cold winter nights) for **(a)** CMIP5 and **(b)** CMIP6. In each case, the future period, 2041–2060, is compared with the past period, 1981–2000.

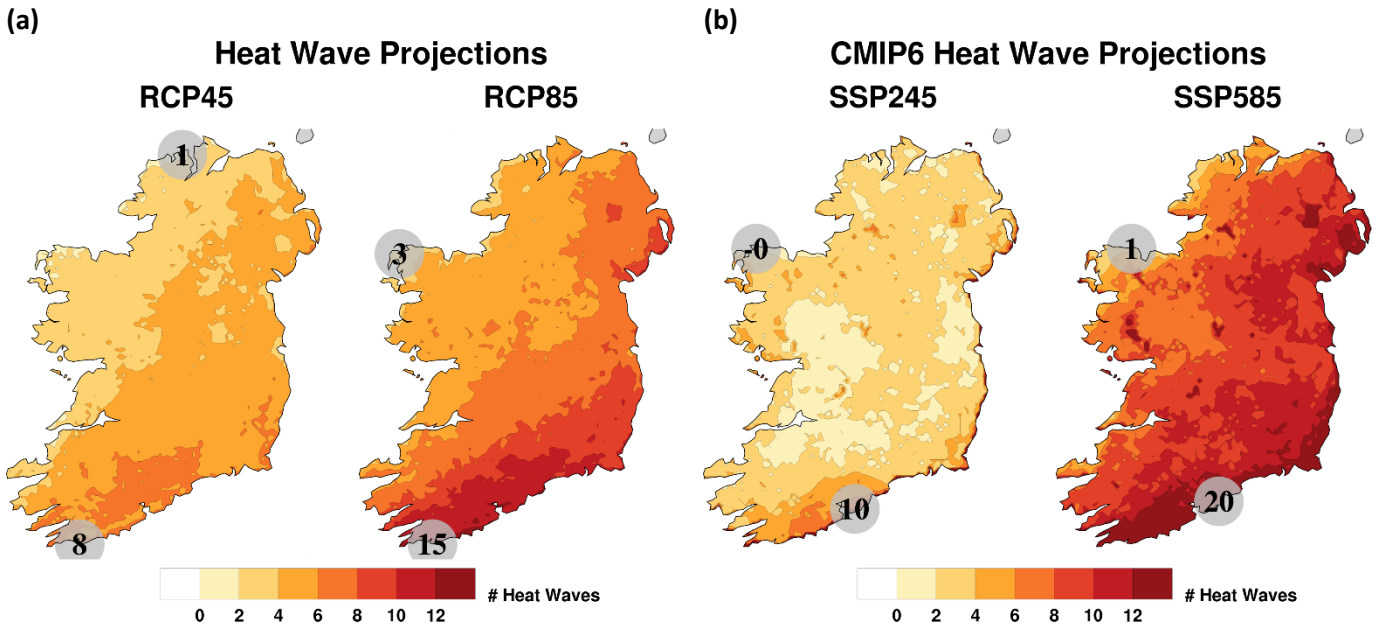

Figure 6. The projected change in the number of heat waves events over the 20-year period 2041–2060 for **(a)** CMIP5 and **(b)** CMIP6. In each case, the future period 2041–2060 is compared with the past period 1981–2000.

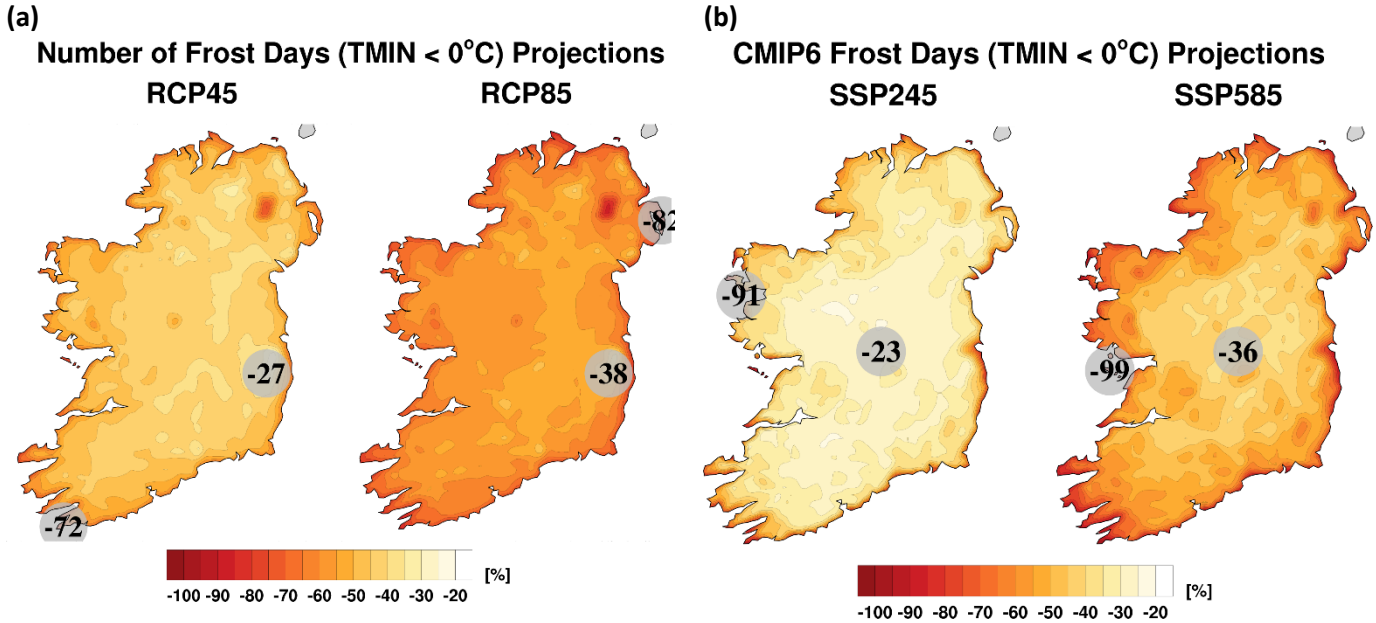

Figure 7. Projected changes in mid-century numbers of frost days and for **(a)** CMIP5 and **(b)** CMIP6. In each case, the future period 2041–2060 is compared with the past period 1981–2000. *Frost Day Definition: a day when the minimum daily temperature is lower than 0°C.*

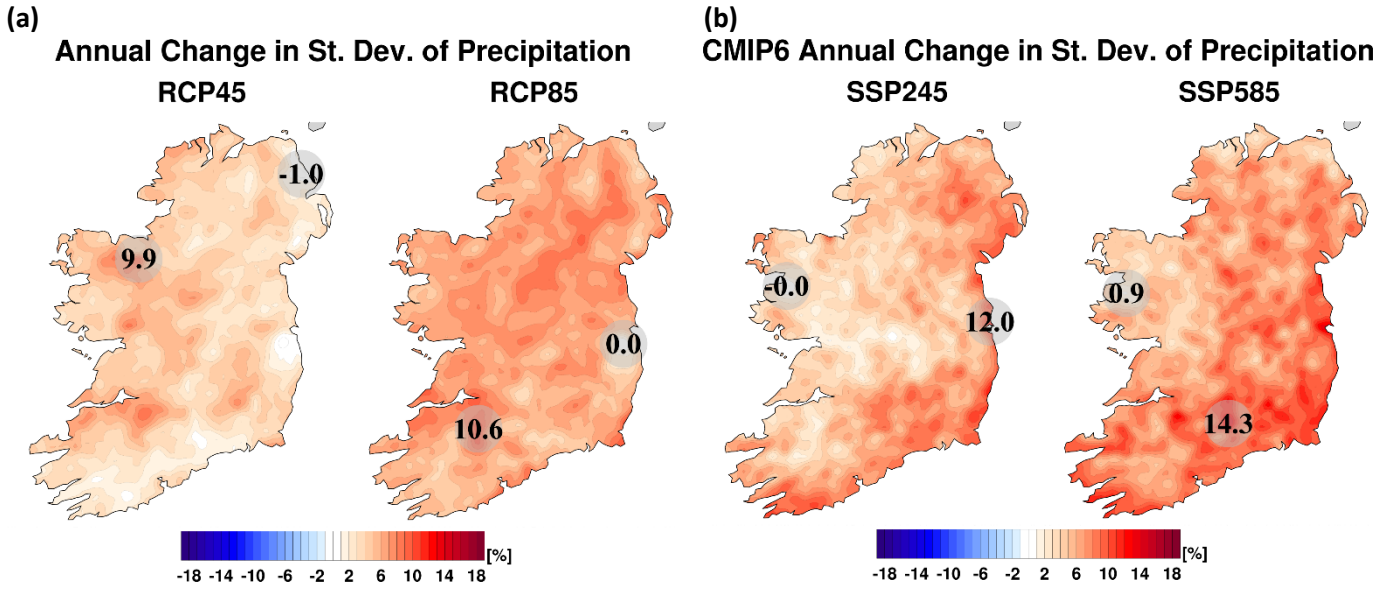

Figure 8. The projected change (%) in the standard deviation of mid-century precipitation for **(a)** CMIP5 and **(b)** CMIP6. In each case, the future period 2041–2060 is compared with the past period 1981–2000.

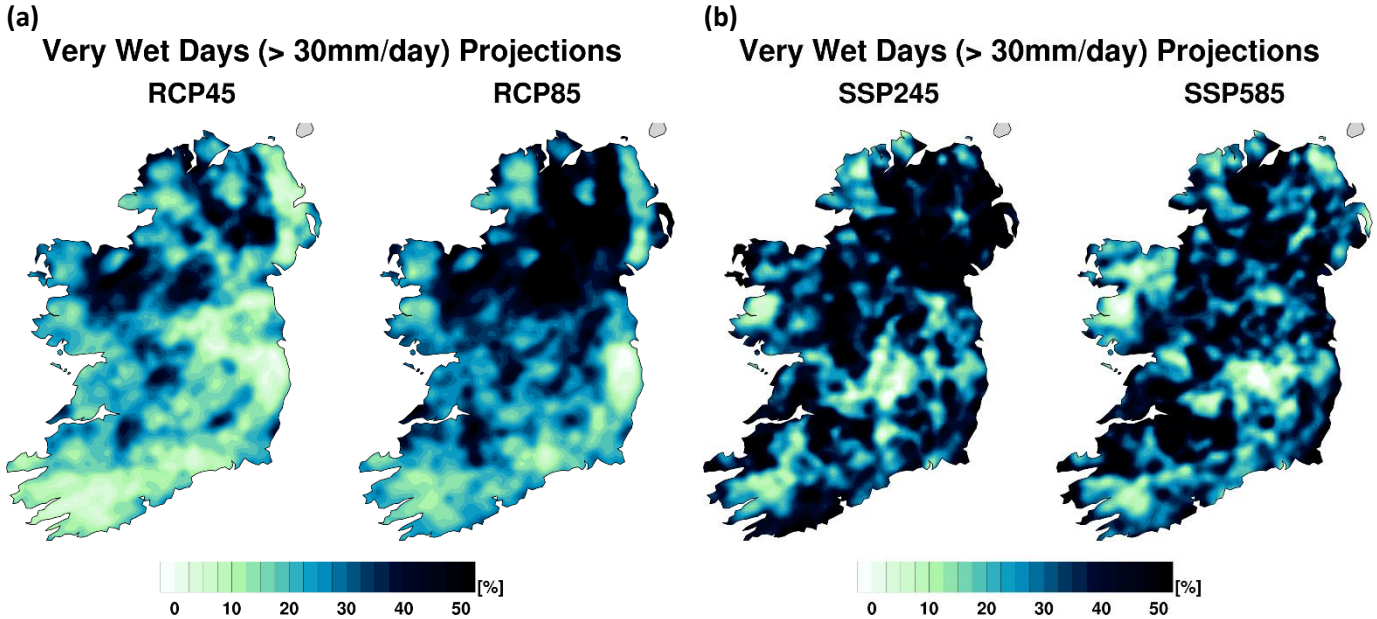

Figure 9. Projected change (%) in mid-century projections of very wet days (precipitation > 30 mm/day) for **(a)** CMIP5 and **(b)** CMIP6. In each case, the future period 2041–2060 is compared with the past period 1981–2000.

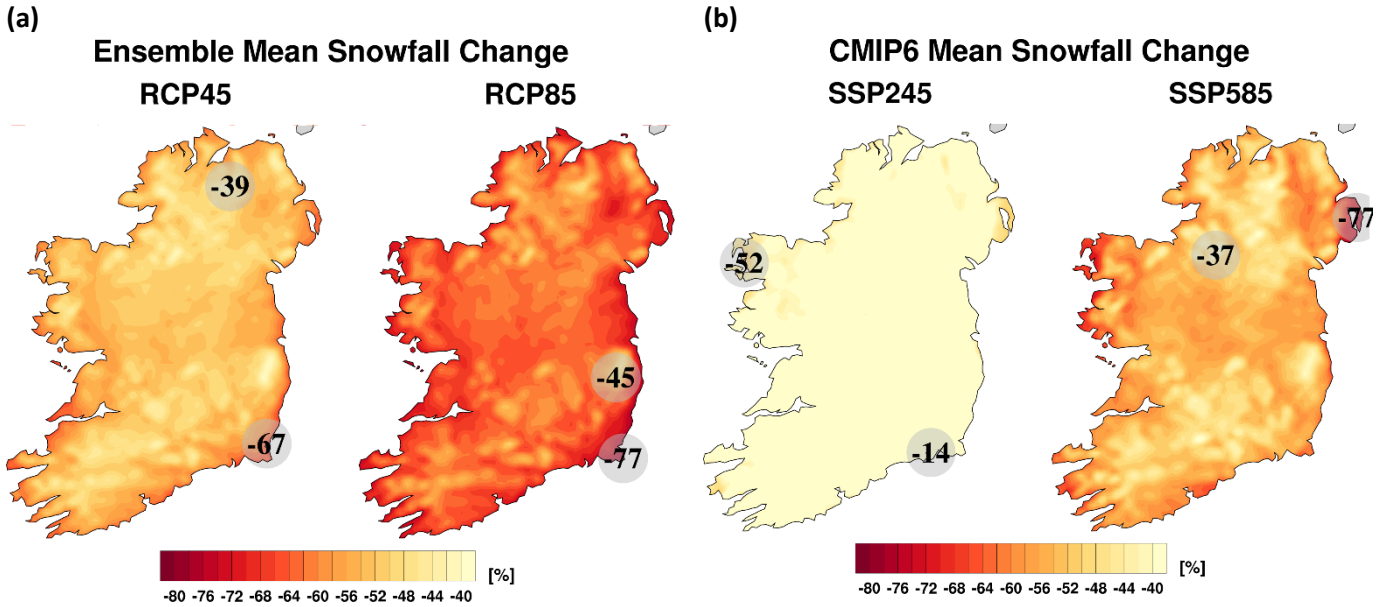

Figure 10. Projected change (%) in mid-century snowfall for **(a)** CMIP5 and **(b)** CMIP6. In each case, the future period 2041–2060 is compared with the past period 1981–2000.

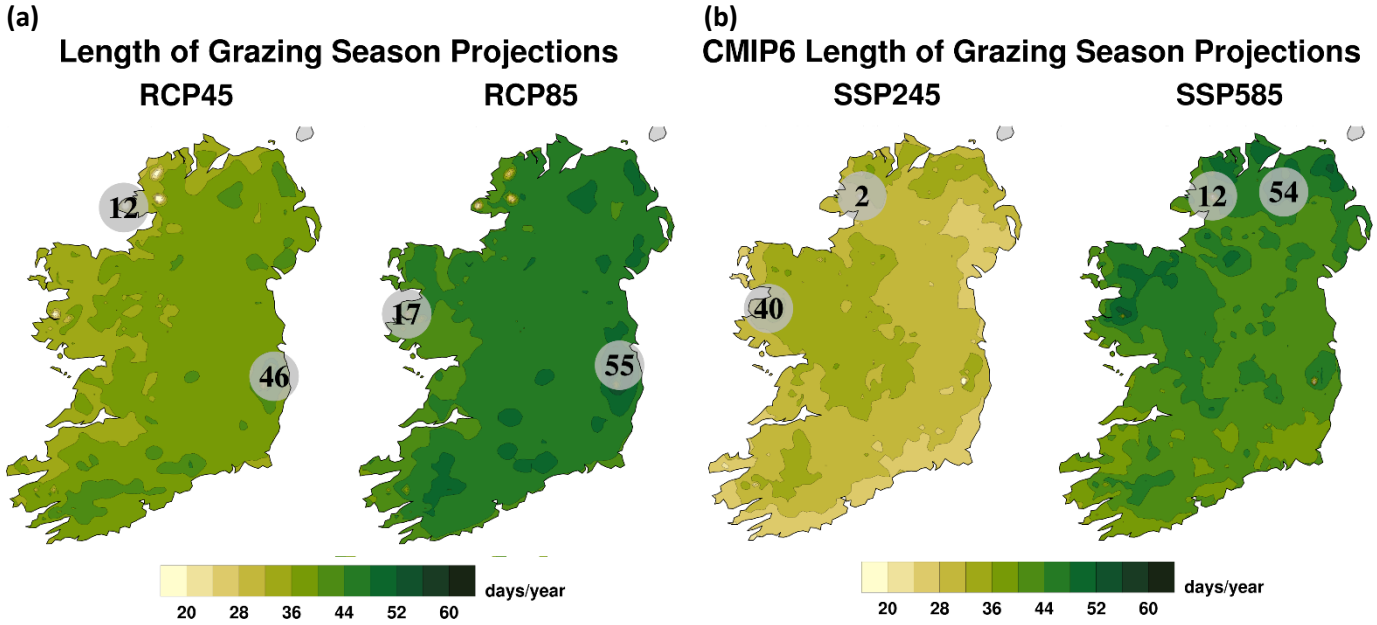

Figure 11. Projected change (%) in mid-century grazing season for **(a)** CMIP5 and **(b)** CMIP6. In each case, the future period 2041–2060 is compared with the past period 1981–2000.

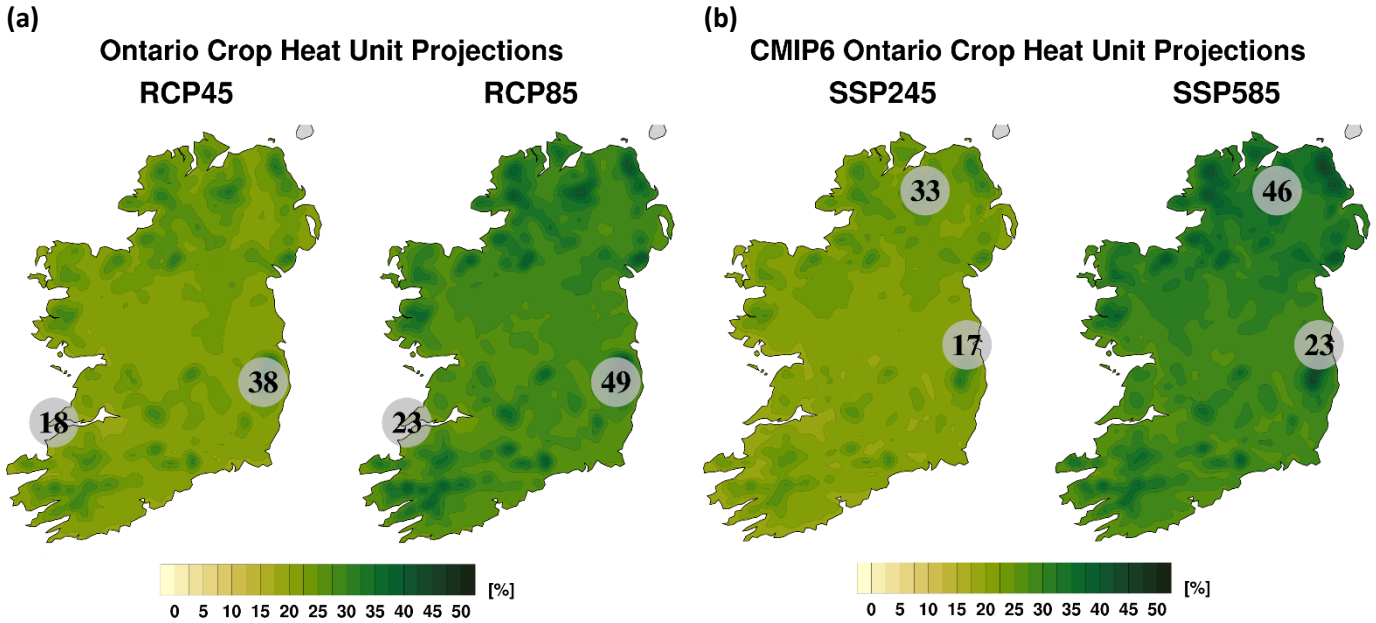

Figure 12. Projected change (%) in mid-century Ontario crop heat units for **(a)** CMIP5 and **(b)** CMIP6. In each case, the future period 2041–2060 is compared with the past period 1981–2000.

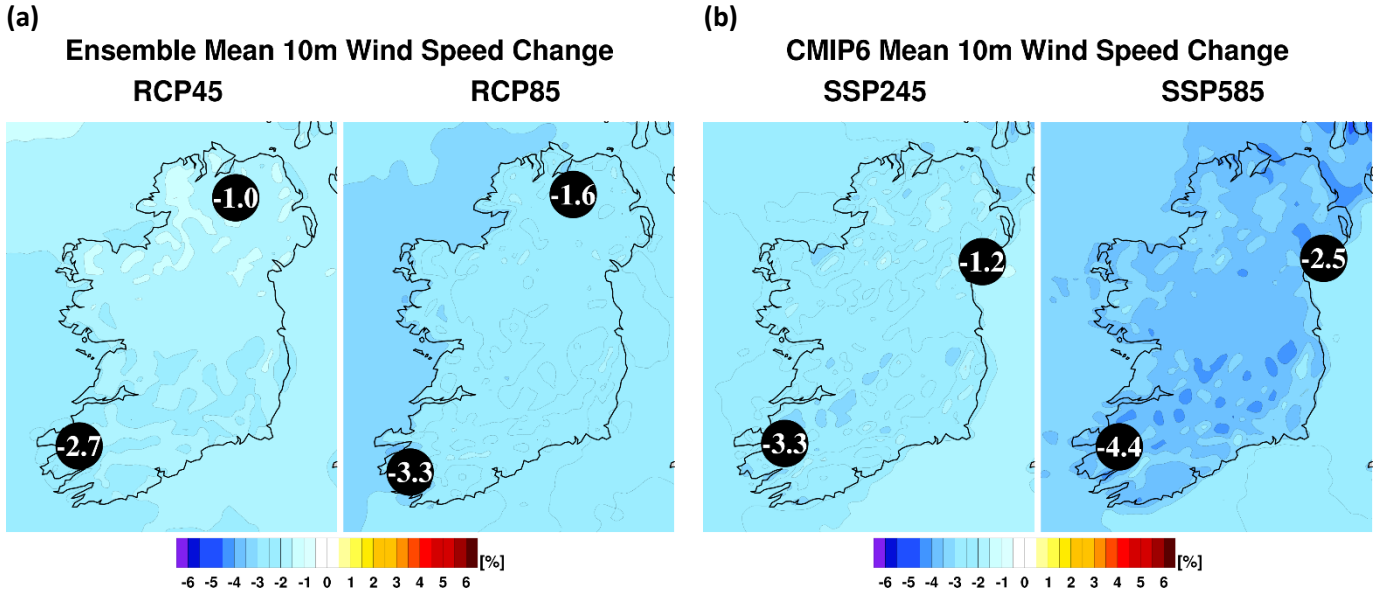

Figure 13. Projected change (%) in mid-century 10m wind speed for **(a)** CMIP5 and **(b)** CMIP6. In each case, the future period 2041–2060 is compared with the past period 1981–2000.

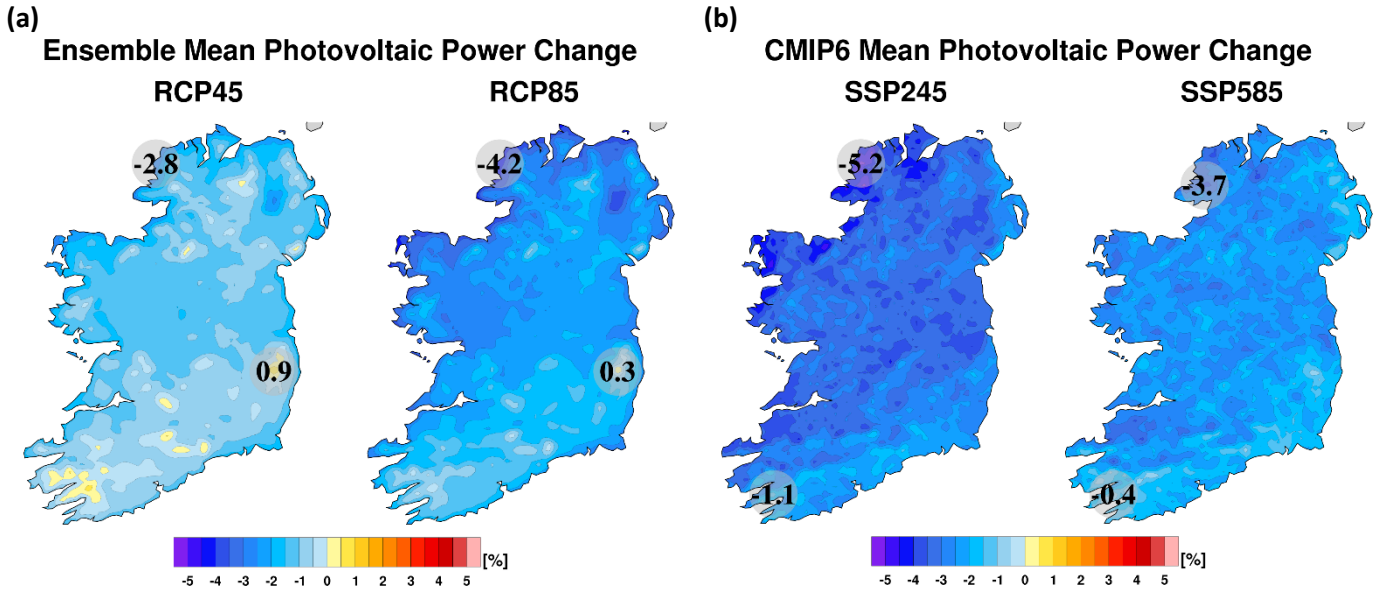

Figure 14. Projected change (%) in mid-century Solar Photovoltaic Power for **(a)** CMIP5 and **(b)** CMIP6. In each case, the future period 2041–2060 is compared with the past period 1981–2000.

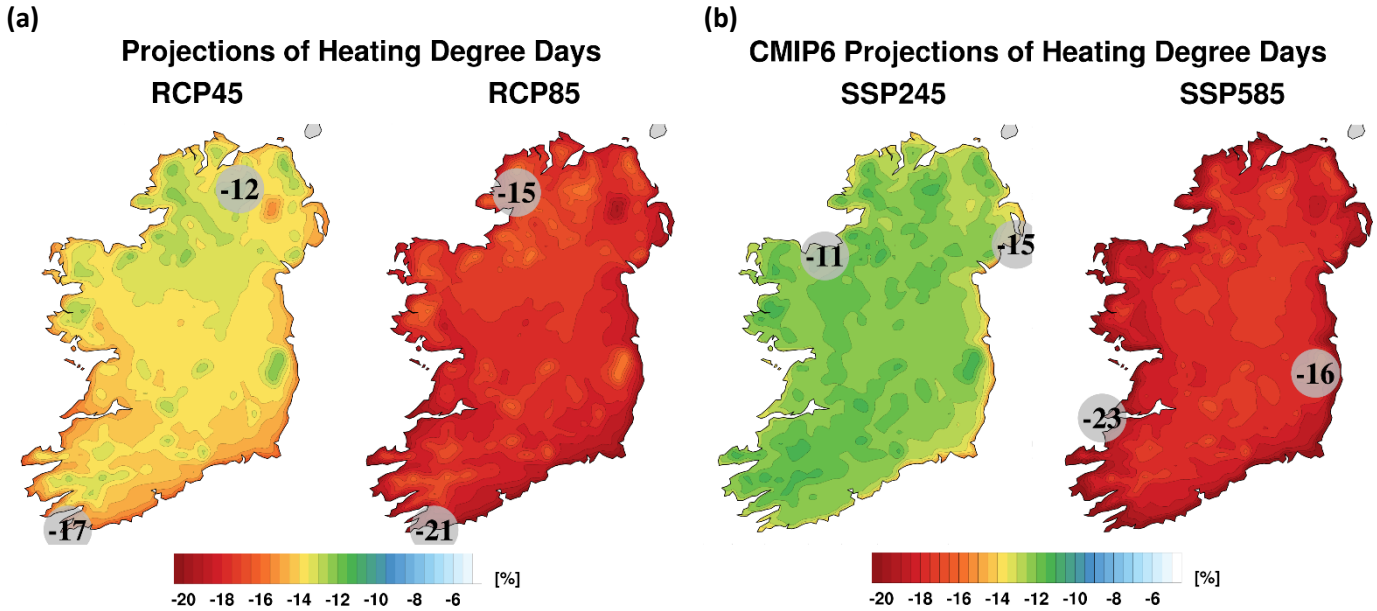

Figure 15. Projected change (%) in mid-century Heating Degree Days for **(a)** CMIP5 and **(b)** CMIP6. In each case, the future period 2041–2060 is compared with the past period 1981–2000.

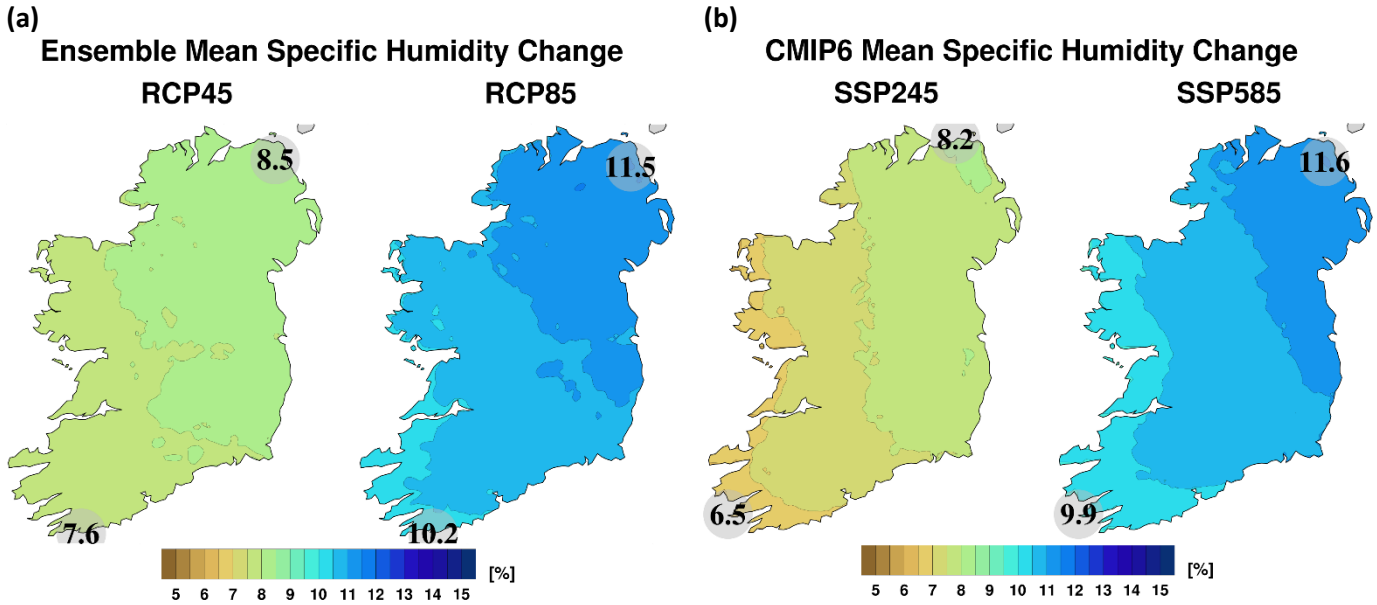

Figure 16. Projected change (%) in mid-century specific humidity for **(a)** CMIP5 and **(b)** CMIP6. In each case, the future period 2041–2060 is compared with the past period 1981–2000.