New ensemble of regional climate projections for Europe

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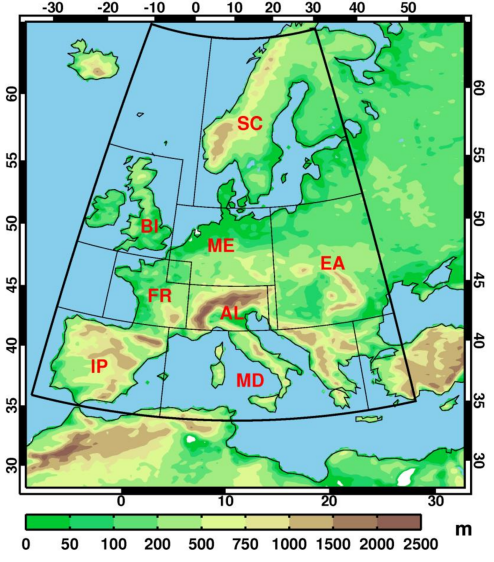
Introduction

- Regional dynamical climate downscaling – regional climate model (RCM) with boundary conditions from a global climate model (GCM; 'driving model')
- CORDEX is an international project for dynamical climate downscaling on regional domains together covering all continents
- We contribute to the EURO-CORDEX-CMIP6 ensemble on the CORDEX European domain, among other groups
- HARMONIE-Climate (HCLIM) – a regional climate model developed by a consortium of European meteorological institutes
- ALADIN—a mesoscale regional weather model optimised for 10–50 km resolution
- Ensemble of HCLIM43–ALADIN simulations driven by multiple CMIP6 models
- Regional HCLIM simulations produced by SMHI, DMI, and MetNo
- CMIP6 models have spatial resolutions of ~100 km
- The HCLIM43–ALADIN ensemble has a spatial resolution of 12.5 km
- Support for adaption planning, which requires higher spatial resolutions than CMIP6

Simulations, domain, and PRUDENCE regions

The HCLIM ensemble has 6 driving models:

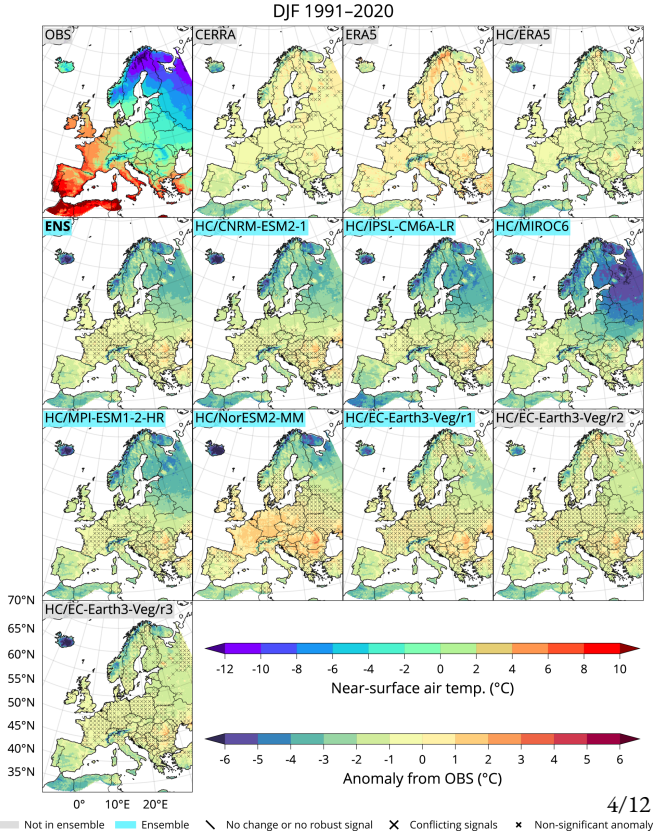
Institute	Driving model	Variant	Resolution (km)	ECS (K)	TCR (K)
SMHI	CNRM-ESM2-1	r1i1p1f2	150	4.76	1.86
SMHI	EC-Earth3-Veg	r1i1p1f1	70	4.31	2.62
SMHI	EC-Earth3-Veg	r2i1p1f1	70	4.31	2.62
SMHI	EC-Earth3-Veg	r3i1p1f1	70	4.31	2.62
SMHI	MIROC6	r1i1p1f1	130	2.61	1.55
SMHI	MPI-ESM1-2-HR	r1i1p1f1	90	2.98	1.66
DMI	IPSL-CM6A-LR	r1i1p1f1	160	4.56	2.32
MetNo	NorESM2-MM	r1i1p1f1	100	2.50	1.33



- CMIP6 experiments: historical (1950–2014) and future scenarios (2015–2100)
- Future scenarios: SSP1-2.6, SSP3-7.0, and SSP5-8.5 (NorESM2-MM only)
- EC-Earth3-Veg runs with 3 different initial conditions (internal variability)
- An evaluation simulation driven by the ERA5 reanalysis
- The EURO-CORDEX-CMIP6 has transient aerosols as in the driving GCM—update from static aerosols in EURO-CORDEX-CMIP5, which caused biases

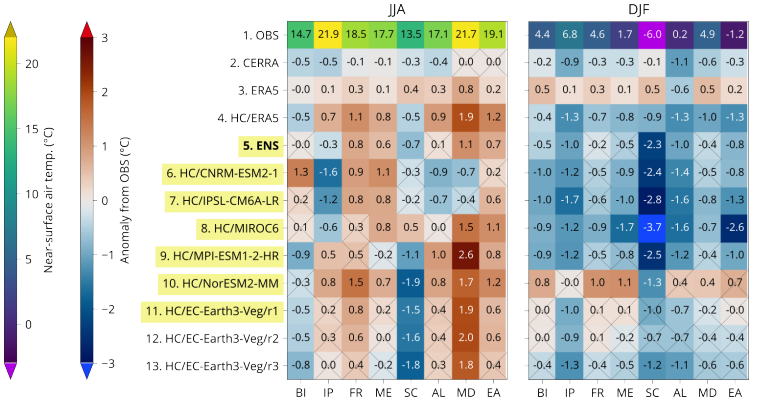
Evaluation

- Reference evaluation of historical and future projections
- Historical experiment compared to observations (E-OBS gridded dataset), regional reanalyses (CERRA and CERRA-Land for precip.), and the global reanalysis ERA5 in 1991–2020 [*manuscript in preparation*]
- Future projections SSP1-2.6 and 3-7.0 in 1971–2100 relative to 1991–2020 [*manuscript in preparation*]
- Variables: near-surface air temperature (T), precipitation (R), daily minimum (T_{min}) and maximum (T_{max}) near-surface air temperature, surface-level pressure (p_{SL})
- Seasons: annual (ANN), winter (DJF), spring (MAM), summer (JJA), and autumn (SON)



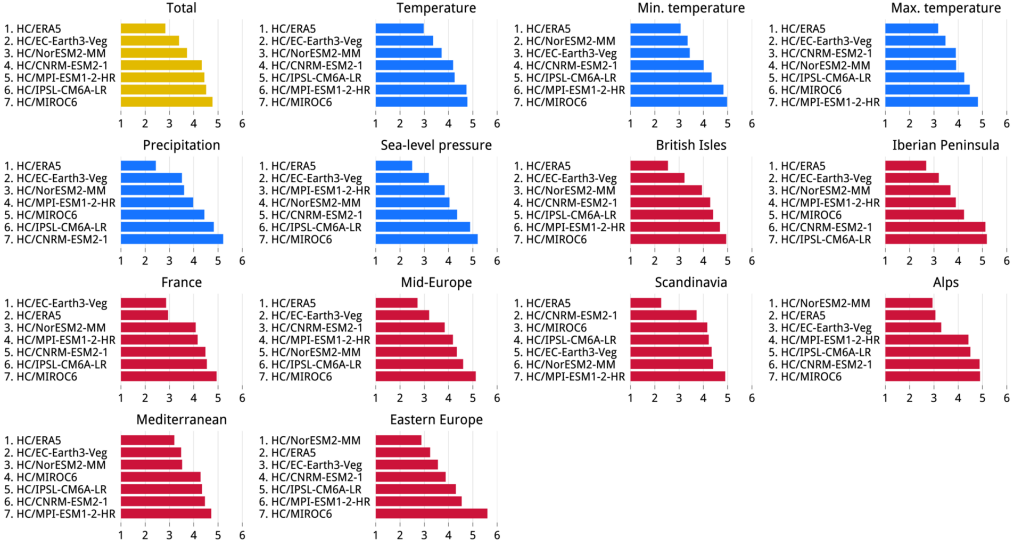
Bias relative to E-OBS in 1991–2020

- The reanalyses are very close to E-OBS
- Significant temperature biases only about 1/2 of the regions and models
- Biases in temperature mostly within 1°C, except Scandinavia in winter (~-2.5°)
- In summer, mostly positive temperature bias; in winter mostly negative bias
- Both positive and negative biases in precipitation in summer, especially large and positive over the Mediterrannean
- Positive biases in precipitation in winter



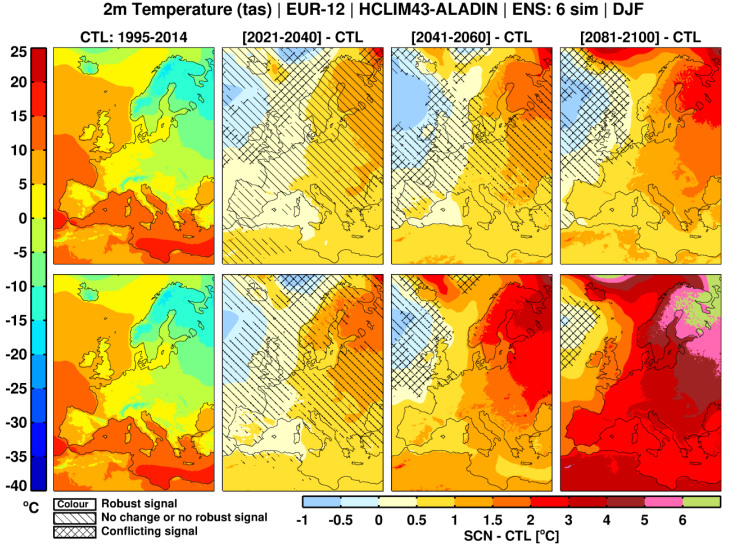
Model performance

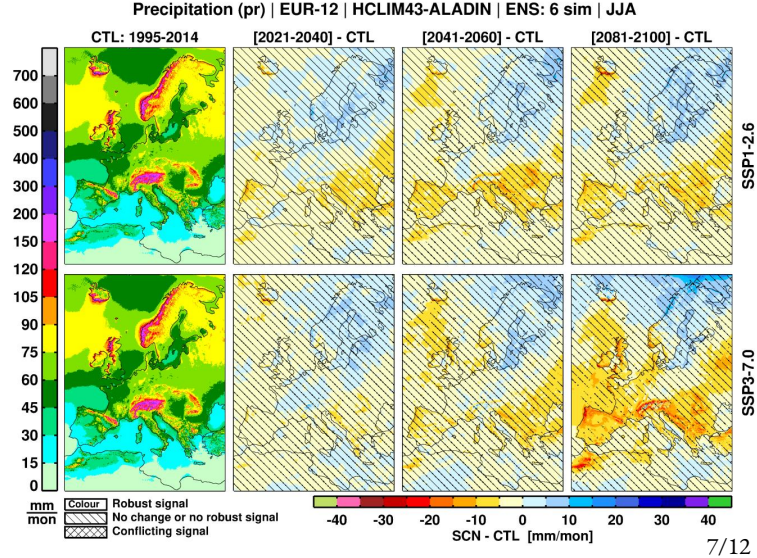
- Based on T, T_{min}, T_{max}, R, and p_{SL}
- Ranks based on mean and standard deviation relative to E-OBS and ERA5 (p_{SL}) in the PRUDENCE regions and seasons
- Best-performing model HC/EC-Earth3-Veg; worst HC/MIROC6 (not counting the evaluation HC/ERA5)
- HC/CNRM-ESM2-1 the best-performing model for Scandinavia



Projected temperature and precipitation change

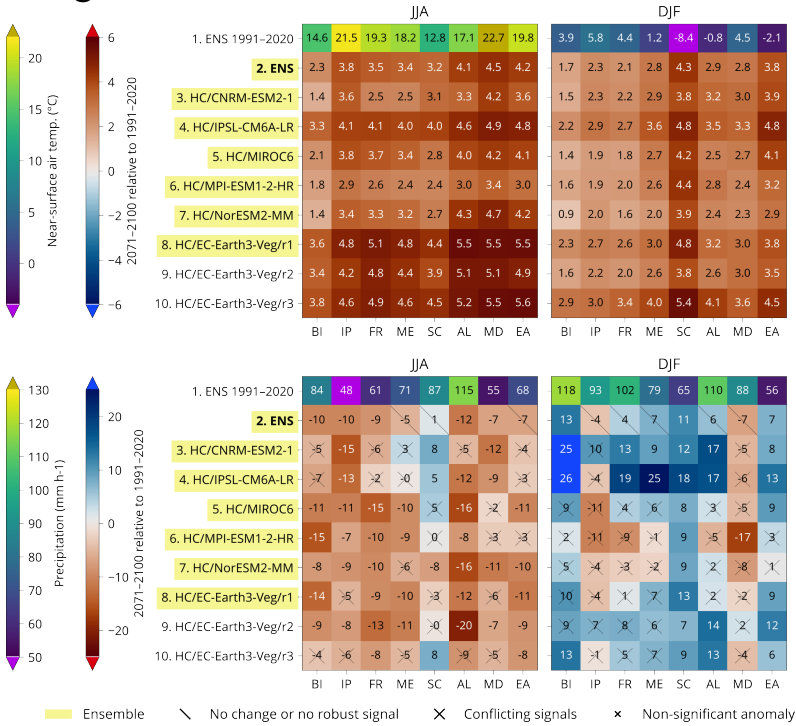
- Temperature change of 0.5–3°C in SSP1-2.6 and 2–7°C in SSP3-7.0 by the end of the century
- Greater temperature increase in Northern and Eastern Europe, especially Scandinavia
- No robust change in precipitation, although a tendency to drier conditions in southern Europe





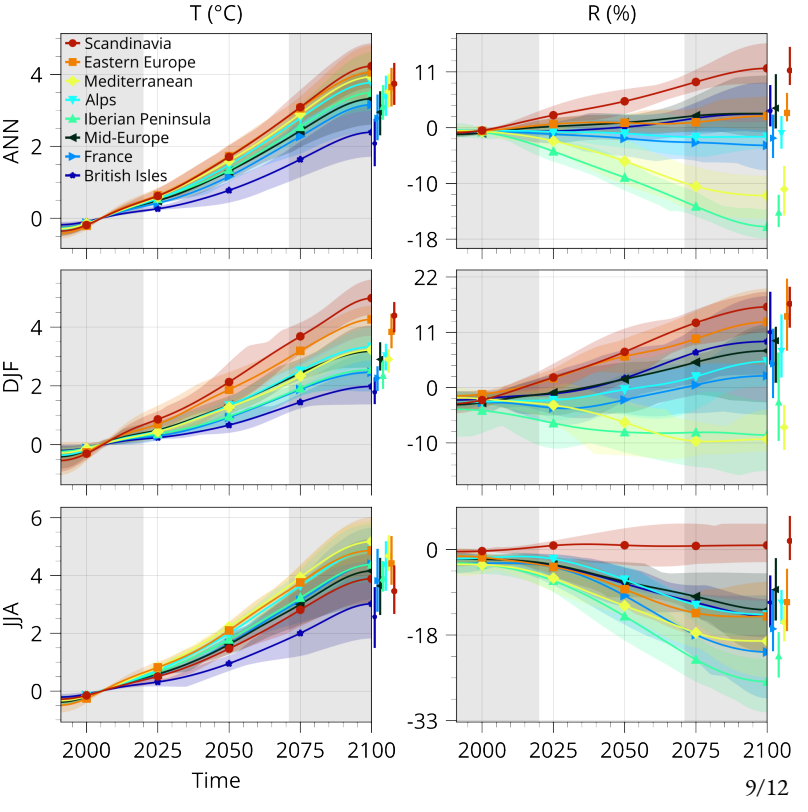
Projected changes for the PRUDENCE regions

- 2071–2100 under SSP3-7.0 relative to 1991–2020
- Larger temperature change in summer (+1.4–5.6°C) than winter (+0.9–5.4°C)
- Temperature increase in winter largest in Scandinavia (~+4°C)
- Temperature increase in summer largest in the Mediterranean (~+4.5°C)
- Precipitation change is significant only in about 1/2 of the regions and models
- Drier summers (~-10%) in most regions except Scandinavia (might become wetter)
- Wetter winters (~+10%) in most regions (uncertain), except for the Mediterranean (might become drier)



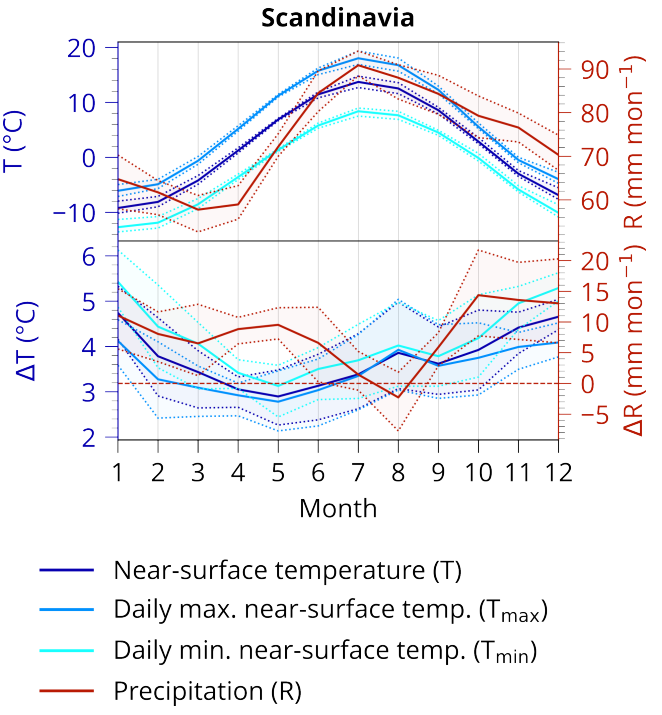
Projected time series (SSP3-7.0)

- 2071–2100 relative to 1991–2020
- Greatest temperature increase in Scandinavia (~4°C), lowest in British Isles (~2°C)
- Polar amplification combined with maritime/continental influences
- Larger increases in summer (~4 ± 0.5°C) compared to winter (3 ± 0.5°C)
- The Mediterranean and Iberian Peninsula getting drier (~-15%) and Scandinavia getting wetter (~+10%), other regions neutral/noisy
- In summer all but Scandinavia getting drier (~-15%), esp. the Iberian Peninsula (~-25%)
- In winter all but the Mediterranean and Iberian Peninsula getting slightly wetter (~+5%), significantly Scandinavia and Eastern Europe (~+15%)
- In winter, the Mediterranean and Iberian Peninsula getting drier (~-10%)



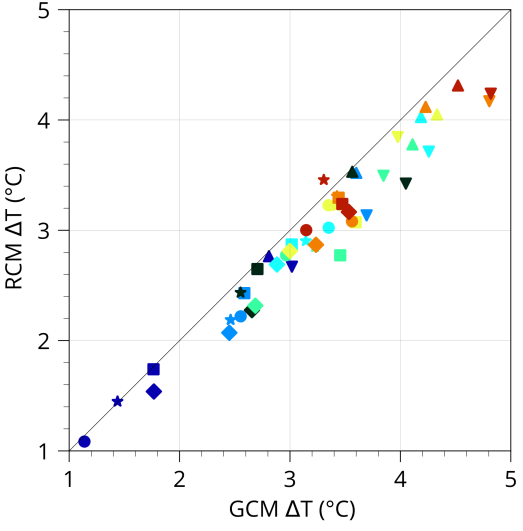
Projected annual cycle change

- Annual cycle in 1991–2020 and change in 2071–2100 (SSP3-7.0) relative to 1991–2020
- Temperature increase mostly in autumn and winter (~4.5°C) and less so in spring and summer (~3°C)
- Greater increase in daily minimum temperature (up to 0.5°C more than average temperature, esp. in winter)
- Smaller increase in daily maximum temperature (up to 0.5°C less than average temperature, esp. in winter)
- Increase in precipitation in most months except for August (neutral), esp. in autumn and winter (~+10 mm mon^{-1})



Global and regional climate model relationship

- The relationship between the driving GCM and the RCM
- Temperature change (ΔT) in 2071–2100 relative to 1991–2020
- The HCLIM ensemble projects a lower near-surface air temperature change in the PRUDENCE regions by about 10%
- Future investigation:
  - ΔT on the ground and at heights
  - Latent heat flux
  - Surface shortwave and longwave radiation
  - Precipitation differences between the RCM and GCMs
  - Missing processes in the RCM



Conclusions

- HCLIM contribution to EURO-CORDEX, to be available on ESGF later this year (delayed due to a transition to a new system)
- Relatively small regional biases in temperature (~1°C), precipitation bias usually <50%
- Best-performing model HC/EC-Earth3-Veg, worst HC/MIROC6
- Temperature projected to increase 2–4°C by 2100 in the SSP3-7.0 HCLIM simulations
- Precipitation projected to decrease in summer and increase in winter
- HCLIM projecting less temperature increase than the driving models by about 10%
- Scandinavia:
  - Regional-average negative temperature biases in winter (~-2.5°C), in summer within 1°C
  - Regional-average precipitation biases mostly within 15%
  - Best-performing model HC/CNRM-ESM2-1, worst HC/MPI-ESM1-2-HR
  - Largest increase of temperature (4°C) and precipitation (10%) of all regions
  - Most temperature increases in autumn and winter, all months wetter except for August
- Two reference manuscripts in preparation:
  - Historical evaluation (to be submitted to Geoscientific Model Development)
  - Future climate projections (probably to be submitted to Tellus A)