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Quantile mapping bias adjustment of the NEX-GDDP-CMIP6 climate data for Iceland

The Meteorological Society fall meeting
October 29, 2024

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Skrifstofustjóri loftslagsþjónustu og aðlögunar

Introduction

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- Climate change poses significant challenges and may affect the ecosystem, economy, infrastructure, and most importantly the Icelandic society as a whole
- The ability to adapt to the continuous, and unescapable, changes requires extensive knowledge of the changes themselves
- To carry out impact studies on a regional scale, more information need to be added to global climate models (GCMs)

Urban Flood Management (Zevenbergen et al., 2010)

NEX-GDDP-CMIP6 dataset

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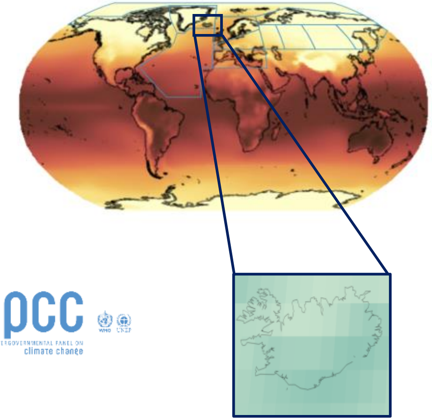
Global Models ~100 km



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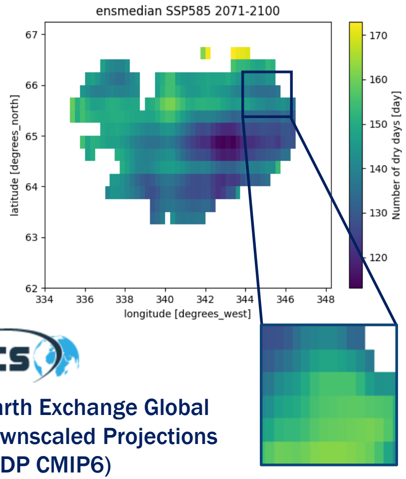
Downscaled Models ~25 km



NCCS

NASA Earth Exchange Global Daily Downscaled Projections (NEX-GDDP CMIP6)

- NASA Earth Exchange Global Daily Downscaled Projections (NEX-GDDP-CMIP6)
- Statistically-downscaled and bias-adjusted GCM output
  - The data is interpolated to a high-resolution of ~ 25 km
  - The Global Meteorological Forcing Dataset (GMFD) for Land Surface Modeling was used to bias-correct the data
- The goal of this work is to produce high resolution, bias-adjusted climate data for Iceland (Climate Atlas of Iceland)

NEX-GDDP-CMIP6 dataset

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- At daily timesteps for
  - historical period (1950-2014), and future projections (2015-2100)
  - for three Shared Socioeconomic Pathways (SSP2-4.5, SSP3-7.0, and SSP5-8.5)

- Available variables include
  - Precipitation (pr) [mm d^{-1}]
  - Mean, maximum, and minimum near-surface temperature (tas, tasmax, tasmin) [°C]
  - Near-surface relative humidity (hurs) [%]
  - Near-surface specific humidity (huss) [-]
  - Surface downwelling longwave radiation (rlds) [W m^{-2}]
  - Surface downwelling shortwave radiation (rlds) [W m^{-2}]
  - Near-surface wind speed (sfcWind) [m s^{-1}]

15 models out of 35 were chosen from the NEX-GDDP CMIP6 for the Climate Atlas

Model	Variant	pr	tas	tasmax	tasmin
ACCESS-CM2	r1i1p1f1				
BCC-CSM2-MR	r1i1p1f1				
CESM2	r4i1p1f1				
CMCC-CM2-SR5	r1i1p1f1				
CMCC-ESM2	r1i1p1f1				
CNRM-ESM2-1	r1i1p1f2				
FGOALS-g3	r3i1p1f1				
GFDL-ESM4	r1i1p1f1				
IITM-ESM	r1i1p1f1				
INM-CM5-0	r1i1p1f1				
MIROC-ES2L	r1i1p1f2				
MIROC6	r1i1p1f1				
MPI-ESM1-2-HR	r1i1p1f1				
MPI-ESM1-2-LR	r1i1p1f1				
MRI-ESM2-0	r1i1p1f1				

Note: Green = historical & all SSPs available; red = no data available. pr = precipitation (kg m^{-2} s^{-1}); tas = mean near-surface air temperature (K), tasmax and tasmin = maximum and minimum near-surface air temperature (K).

Quantile mapping bias adjustment

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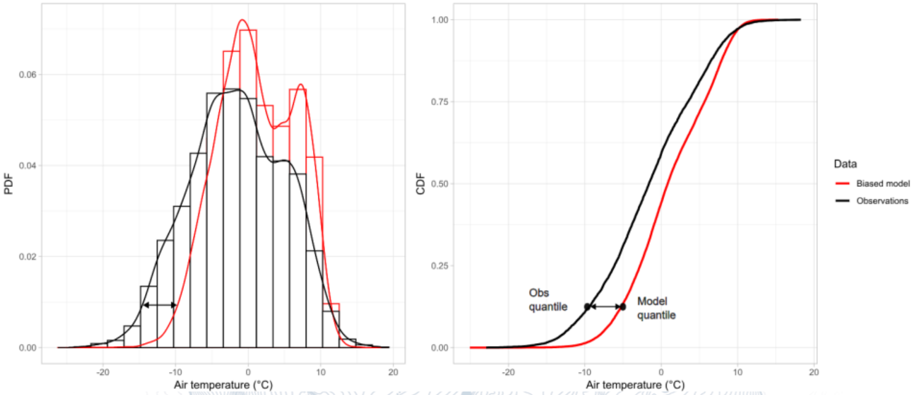
- The NEX-GDDP-CMIP6 data can still have biases
- Statistical bias adjustment techniques have been introduced, that use statistical transformations (quantile mapping)
  - Distribution-derived transformations (fitting a theoretical distribution to the data)
  - Empirical quantile mapping (EQM)



Quantile mapping relies on deriving a transfer function that “maps” the CDF of the modeled data onto the CDF of the observed (reference) data

$$x_{corrected} = CDF^{-1}_{reference}\left(CDF_{modeled}\left(x_{raw}\right)\right)$$

Copernicus Arctic Regional Reanalysis (CARRA)

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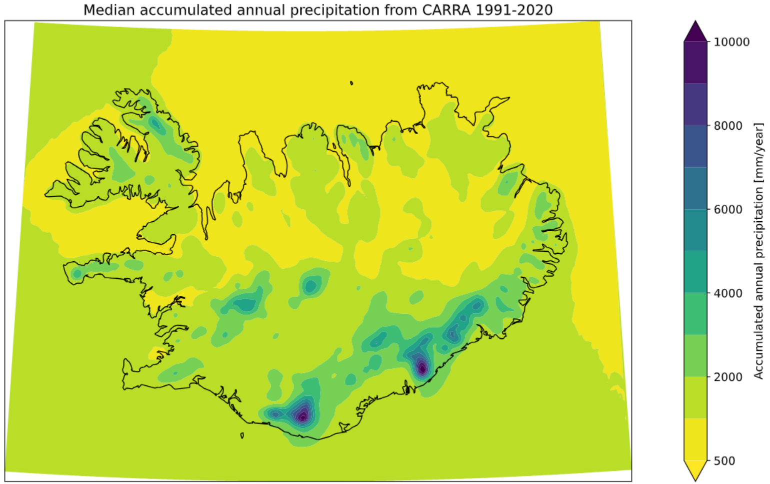
Reference data

- The high-resolution (2.5 km), gridded CARRA data was chosen as reference
- The CARRA covers the period from September 1990 to present (> 30 years)
- A reference period (1991–2014) was selected overlaping with the historical period of NEX-GDDP-CMIP6 (1950–2014)
- The data is available at 3-hr temporal resolution, which was then used to calculate the daily mean, maximum, and minimum air temperature at 2-m height, and the accumulated daily precipitation



Bias adjustment of temperature and precipitation

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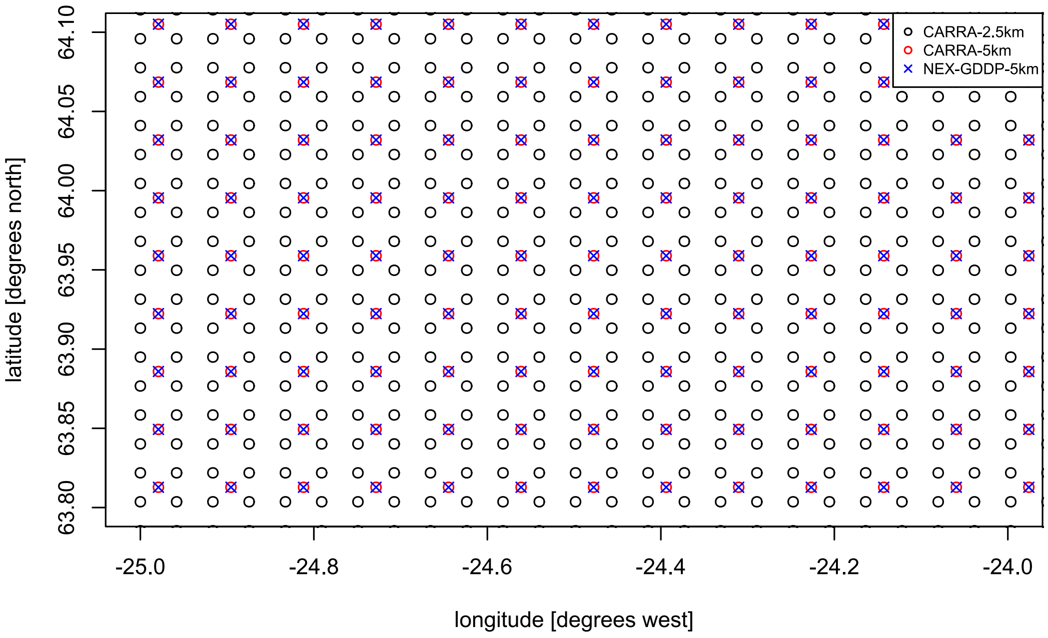
Pre-processing of the data

- Both datasets (NEX-GDDP-CMIP6 and CARRA) were regridded to a common, 5-km resolution
  - The new grid was centered in between the original 2.5 km of the CARRA data
  - Bilinear interpolation was carried out to calculate the new values at 5-km resolution

- The calendars of both datasets were unified (365-day) before bias-adjustment



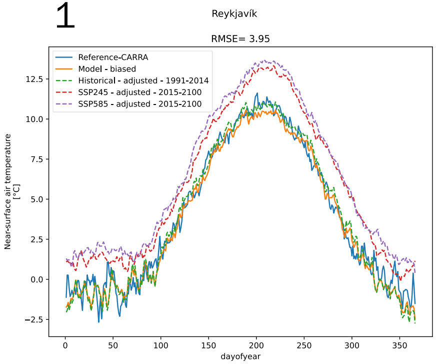
Bias adjustment approaches

Temperature

Four methods were tested and compared

1. Simple quantile mapping (constant adjustment factors for all years)
2. Monthly-varying adjustment factors for each month (e.g., for the 1st of May is the average of those for both April and May)
3. The scaling factors were computed separately for each day of the year, using a ± 15-day moving window over all years in the reference period creating two CDFs; one for the observation and one for the historical simulated value being corrected
4. The bias adjustment was carried out by first detrending all projected future quantiles from a model and then applying quantile mapping to the detrended series

1



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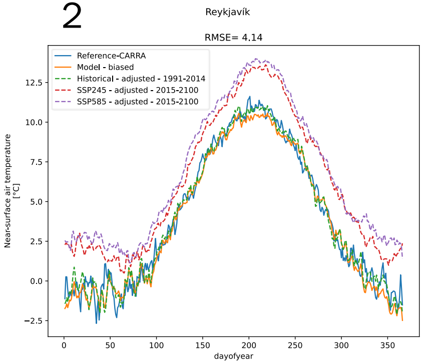

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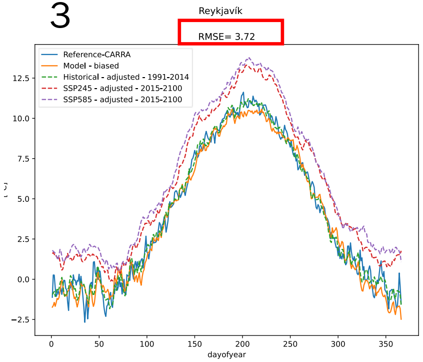

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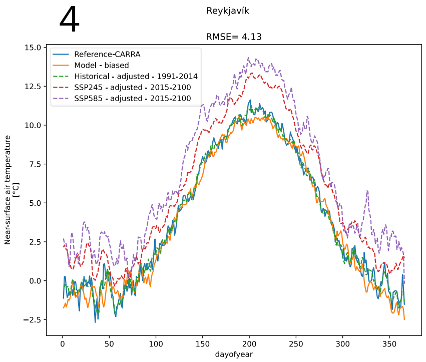
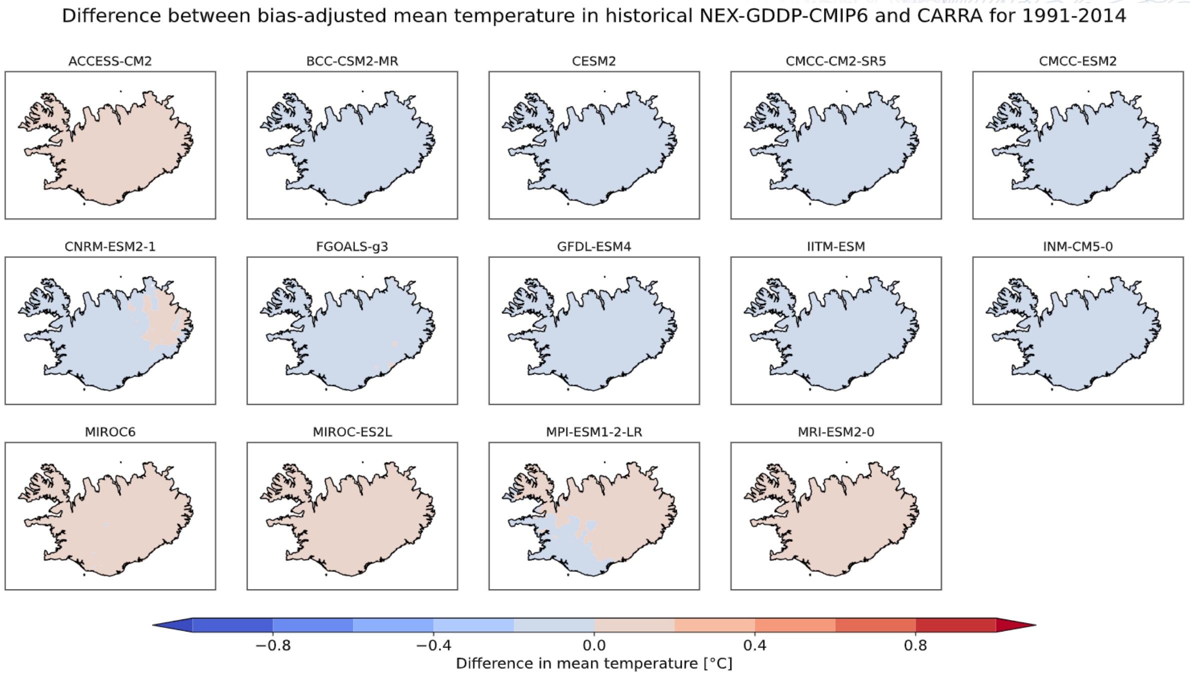


Bias-adjusted NEX-GDDP-CMIP6 data

Mean daily temperature (tas)

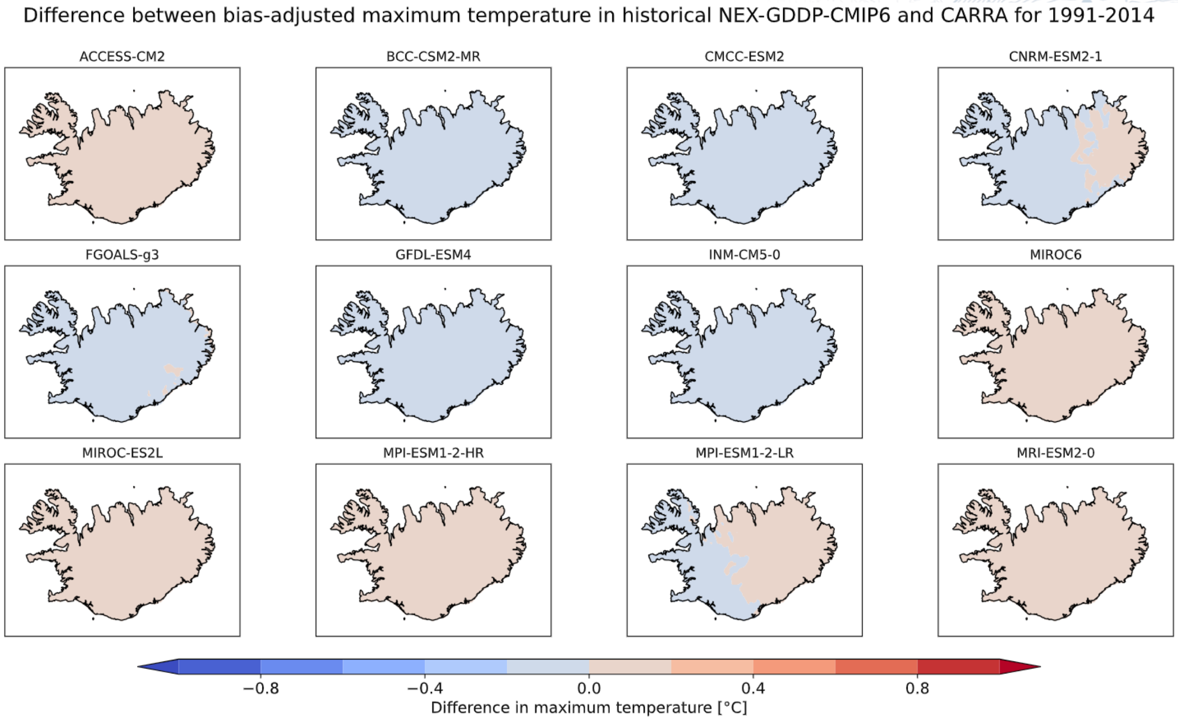
- Substantial improvement around all Iceland compared to CARRA



Bias-adjusted NEX-GDDP-CMIP6 data

Max daily temperature (tasmax)

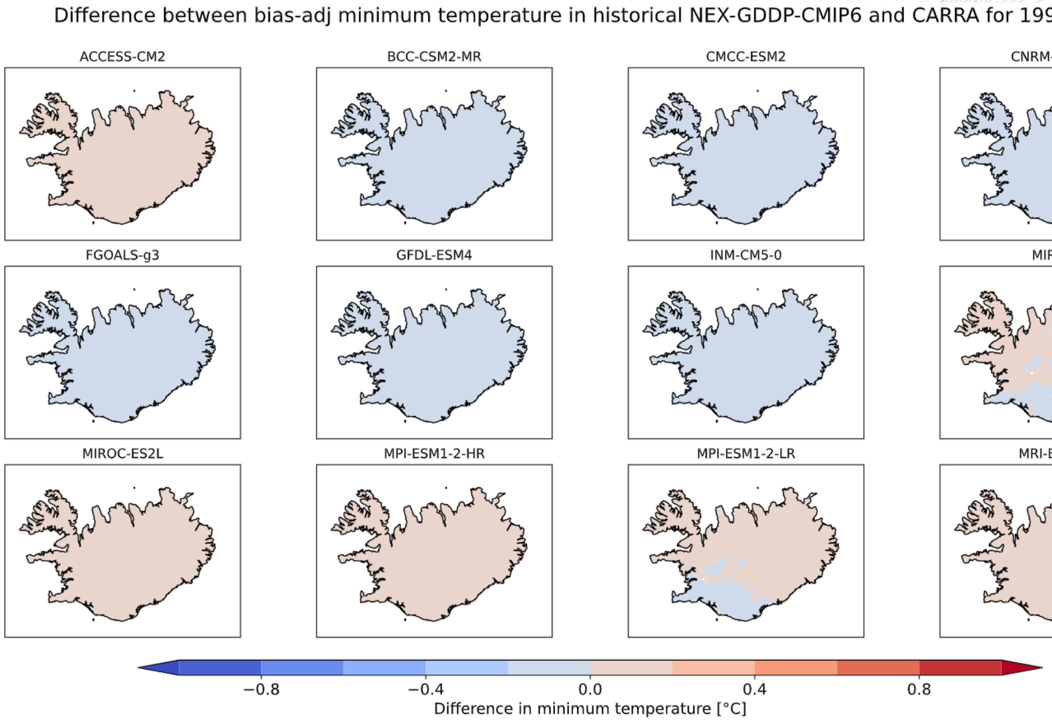
- Substantial improvement around all Iceland compared to CARRA



Bias-adjusted NEX-GDDP-CMIP6 data

Min daily temperature (tasmin)

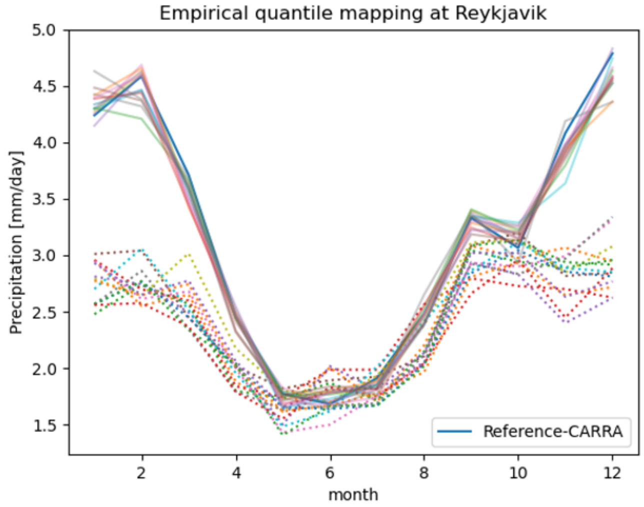
- Substantial improvement around all Iceland compared to CARRA



Bias-adjustment approaches

Precipitation

- Empirical quantile mapping (EQM) was used
- With frequency adaptation and new extremes
  - Frequency adaptation of dry-to-wet days (< 0.05 mm/day)
  - Generating new extreme values using constant extrapolation
  - 31-day rolling window was used

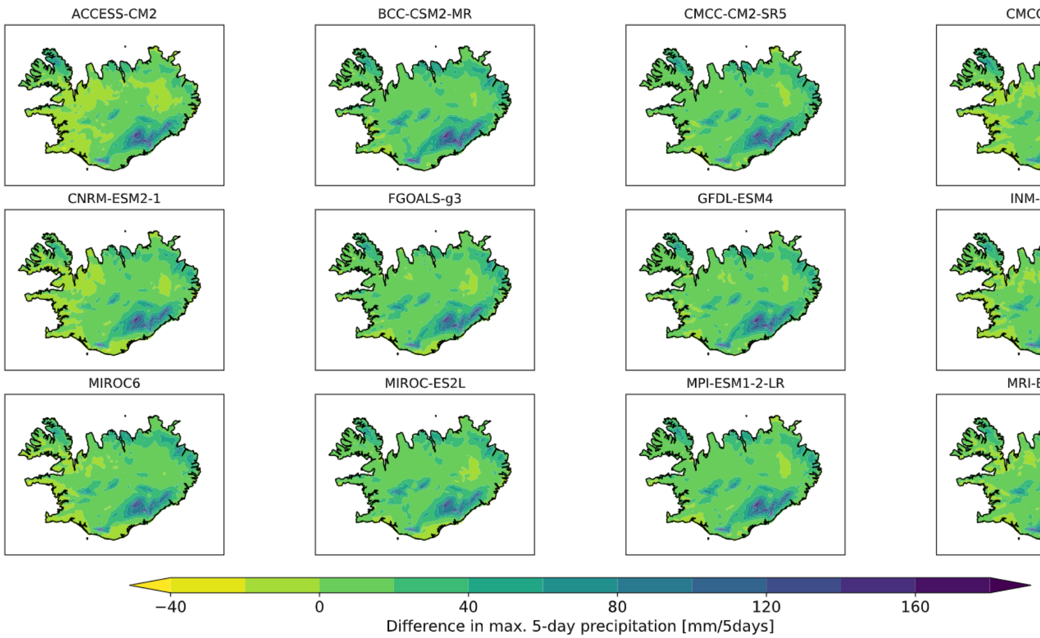


Bias-adjusted NEX-GDDP-CMIP6 data

Precipitation

- Substantial improvement around all Iceland compared to CARRA

Difference between bias-adjusted mean maximum 5-day precipitation (RX5D) in historical NEX-GDDP-CMIP6 and CARRA for 1991-2014



Bias-adjusted temperature and precipitation

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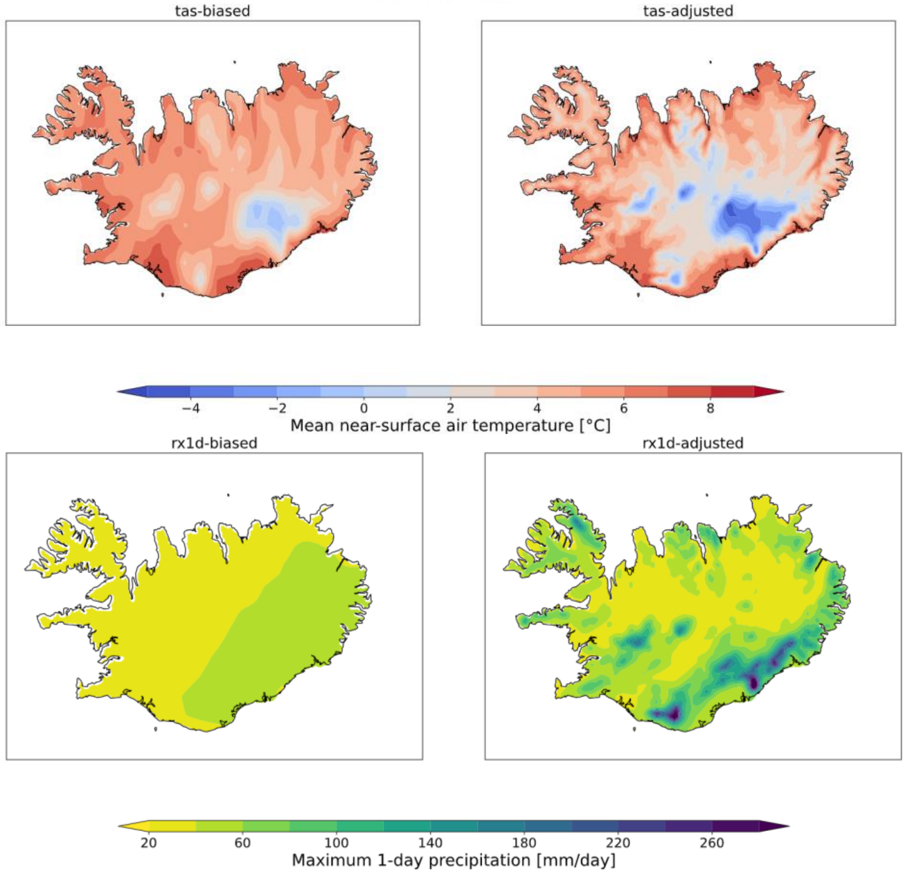
NEX-GDDP-CMIP6

- The final output is a bias-adjusted, high-resolution (5-km) NEX-GDDP-CMIP6 dataset
  - Four variables (i.e., tas, tasmax, tasmin, and pr)
  - Historical period (1950–2014)
  - Future projections (2015–2100) for 3 scenarios (SSP2-4.5, SSP3-7.0, and SSP5-8.5)
  - 12–14 models



Conclusions

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- Climate change adaptation requires reliable climate-related information at regional and local scales

- Empirical-statistical bias-adjustement methods are robust and effective methods that can minimize systematic biases in GCMs

- Empirical quantile mapping (EQM) has the advantage of not requiring specific assumptions on the distribution of the reference data

- Empirical quantile mapping can be adjusted to overcome shortcomings related to producing new extremes and offers more flexibility

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Thank you!

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Backup

Assessment of the CARRA data

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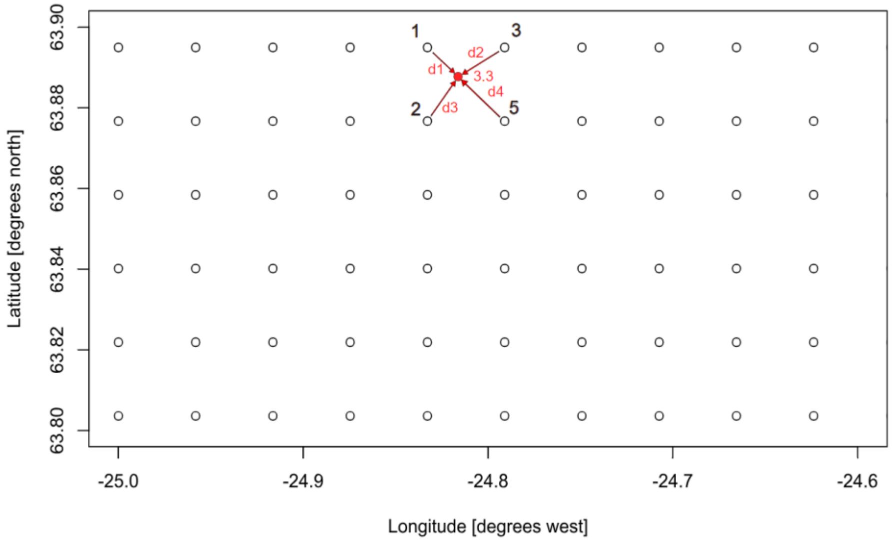
- The CARRA data was compared to observations at 49 automatic weather stations around Iceland (Massad et al., 2020)

- The stations' coordinates used to calculate the weighted average between the 4-nearest grid points

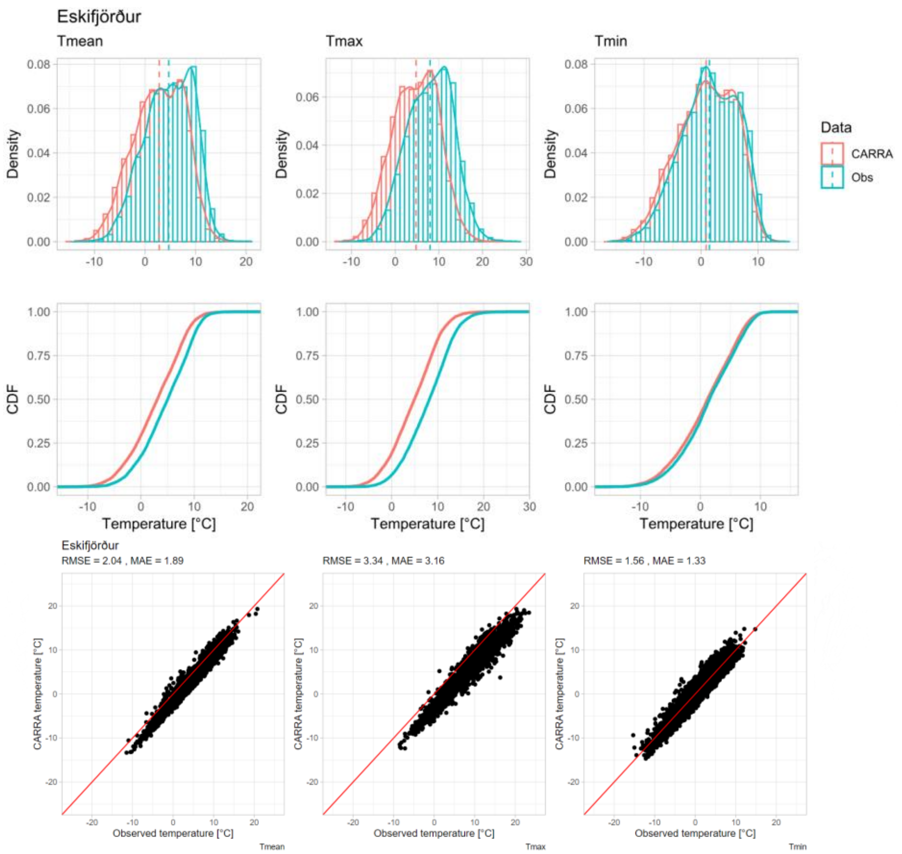


Schematic of the weighted average of the nearest four grid points interpolation of the CARRA gridded data to automatic stations' coordinates

Assessment of the CARRA data

Temperature

- The Copernicus Arctic Regional Reanalysis (CARRA) data was also compared to the observations at the 49 stations
- Good overall agreement was found between CARRA and observations
- Systematic biases were found in areas with complex orography



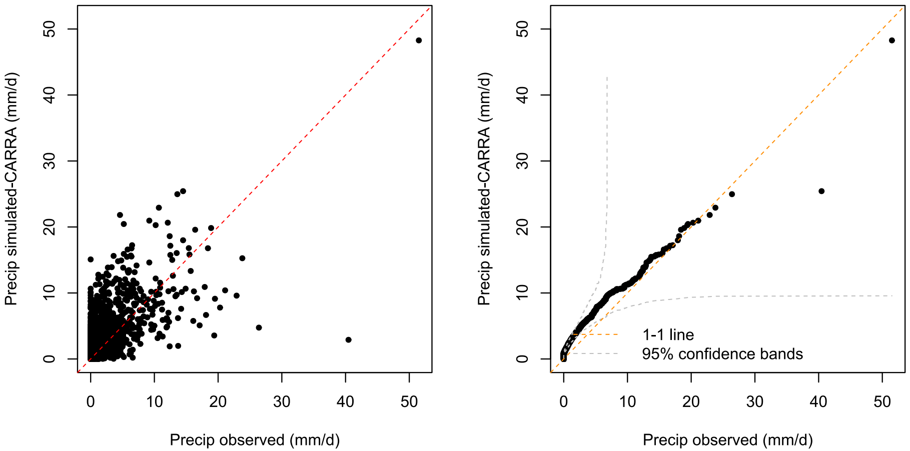
Assessment of the CARRA data

Precipitation

- Similarly, the CARRA data was compared to observations
- Found to agree well with observations

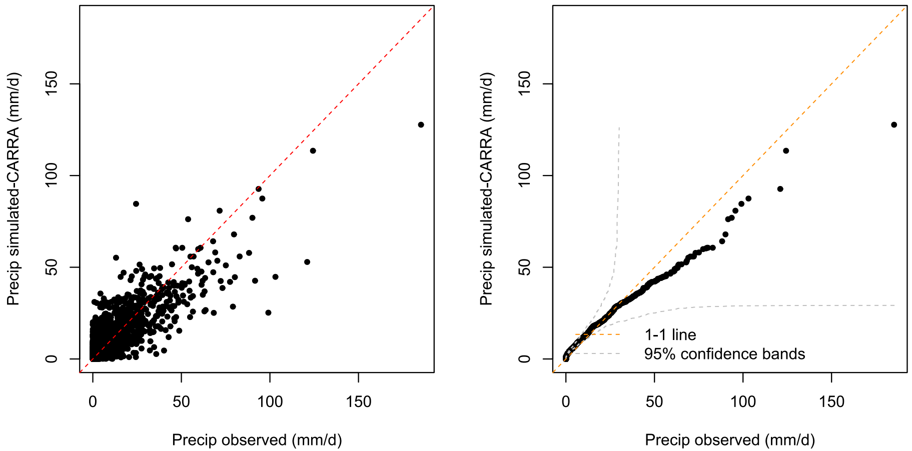
Akureyri

RMSE = 2.47, MAE = 1.26



Eskifjörður

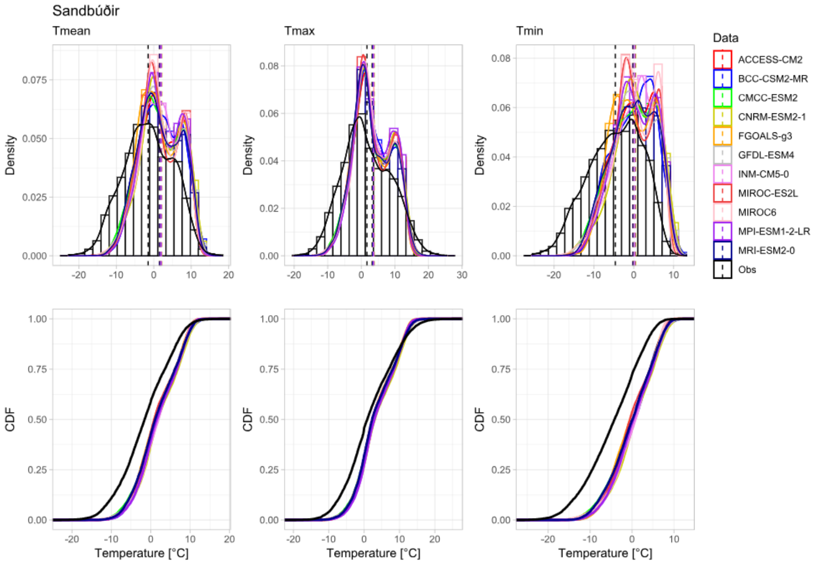
RMSE = 5.16, MAE = 2.44

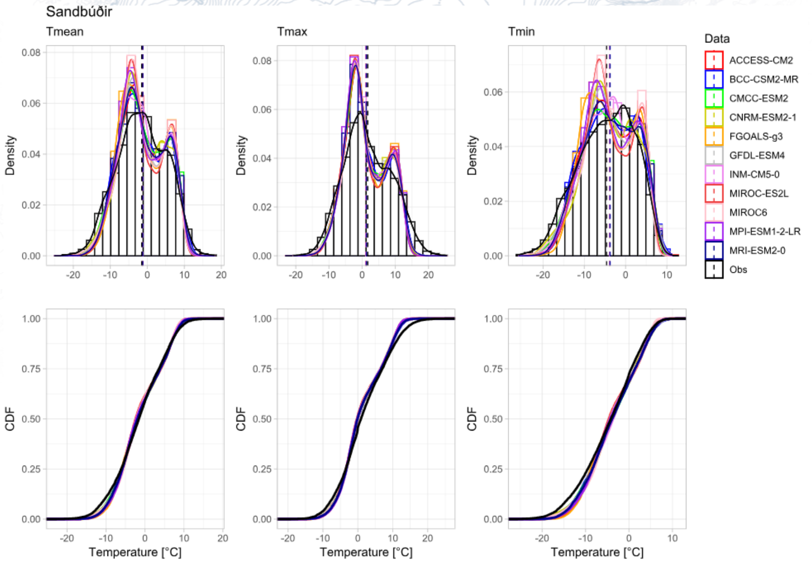


Bias-adjusted NEX-GDDP-CMIP6 data

Temperature

- The distributions of the climate models were also compared to the distribution of observations at 49 automatic stations around Iceland
- At certain locations, the bias-adjustment only a slight or no improvement was observed
- Substantial improvement was seen following the bias-adjustment in certain locations





Bias-adjusted NEX-GDDP-CMIP6 data

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Precipitation

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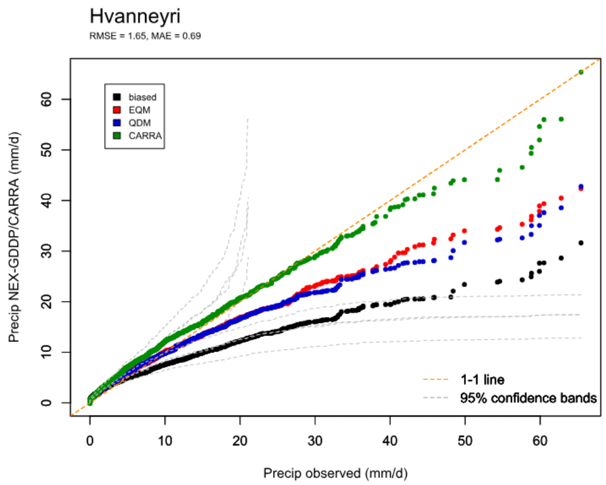
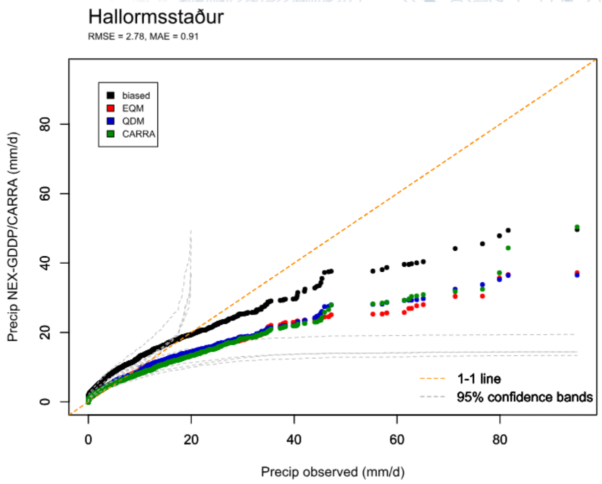


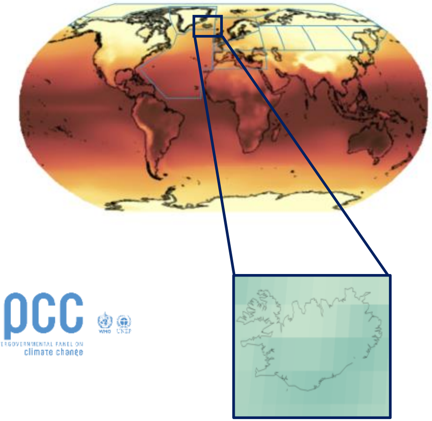


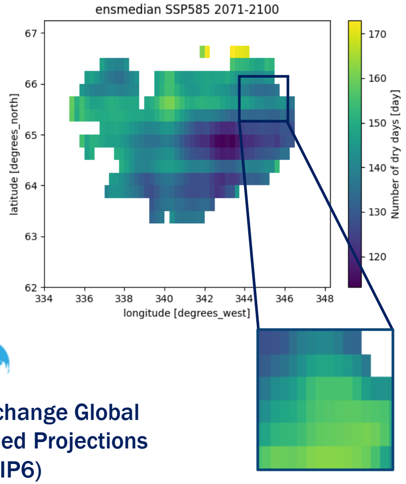
Climate Atlas of Iceland

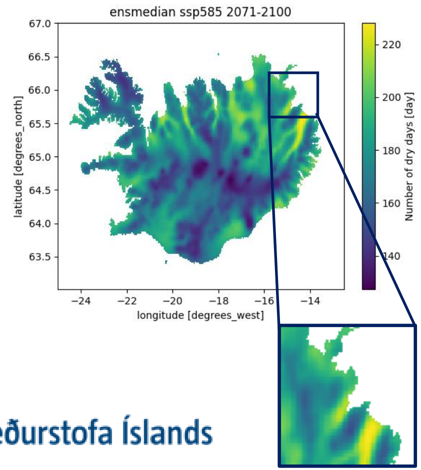
Global Models
~100 km

Downscaled Models
~25 km

Loftslagsatlas
~2.5 km







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Climate indicators for the Climate Atlas of Iceland

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The first phase of the project of the Climate Atlas of Iceland include with the following climate indicators (absolute value and change):

- Precipitation climate indicators
  - Annual
    - Mean annual daily precipitation (mm/d)
    - Accumulated annual precipitation (mm)
    - Max. 1-day precipitation – RX1D (mm/d)
    - Max. 5-day precipitation – RX5D (mm/5d)
    - Number of dry days (day & Δ change)
    - Dry spell total length (day & Δ change)
  - Seasonal (winter, spring, summer, and fall)
    - Mean seasonal daily precipitation (mm/d)
    - Accumulated seasonal precipitation (mm)
    - Max. 1-day precipitation (mm/d)
    - Max. 5-day precipitation (mm/5d)
    - Number of dry days (day)
    - Dry spell total length (day)

- Temperature climate indicators
  - Annual
    - Mean annual near-surface air temperature (°C)
    - Mean annual near-surface max. air temperature (°C)
    - Mean annual near-surface min. air temperature (°C)
    - Growing season length (day)
    - Number of frost days (day)
    - Daily freeze-thaw cycles (day)
    - Extreme temperature range (°C)
  - Seasonal (winter, spring, summer, and fall)
    - Mean near-surface air temperature (°C)
    - Max. near-surface air temperature (°C)
    - Min. near-surface air temperature (°C)
    - Extreme temperature range (°C)