Projected future climate changes in Altai Mountains

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Photo: A. Litvinov

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Photo: A. Litvinov

Contents

Introduction

Here we present some overview of projected climate changes in Altai Mountains. It is found that high mountain areas are experiencing the earliest and greatest impacts of climate change.As well as, the mountains play an important role in regulating the climate in Asia. Thus, the problem of climate changes in Altai is of current interest. For more details, one should address to The Fifth Assessment Report that presents the main results on climate change in Asia: warming trends (including higher extremes, whichare strongest over the continental interiors of Asia) and warming in the period 1979 onward which was strongest over China in winter, but in northern and eastern Asia -spring and autumn. It is noted that from 1900 to 2005, precipitation increased significantly in northern and central Asia but declined in parts of southern Asia. Finally, it is supposed that future climate change is likely to affect water resource scarcity with enhanced climate variability and more rapid melting of glaciers [IPCC, 2014].
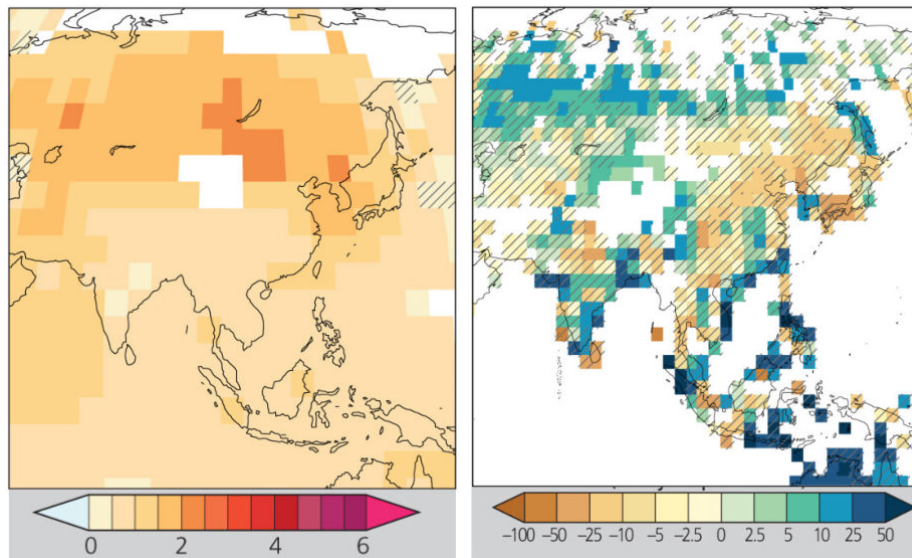
Map of observed annual average temperature changes from 1901–2012, derived from a linear trend (left panel), and map of observed annual precipitation change from 1951–2010, derived from a linear trend (right panel) [IPCC, 2014; Hijioka et al., 2014].

Observed changes in annual average temperature and precipitation in Asia are shown in map, but , knowledge of how the climate will change in the future is needed to develop adaptations to these changes.

1.   *Study area*

Climate change affects the world's mountain regions and limits the services provided by mountains. This is especially important for mountain regions located within the boundaries of several countries, and the Altai Mountains shows very spectacular example of such region: it stretches over Mongolia, Russia, China and Kazakhstan. The Altai mountains is a big region ($85-92^0$E and $48-52^0$N) located in the Northern Asia, that is extended for more than 1200 km from the north to the south and can be divided into two areas: Russian Altai at north and Mongolian Altai at south.

The Altai Mountains acts as a barrier for most of the humid air masses transported by the Westerlies, resulting in a strong northwest to southeast precipitation gradient. These mountain areas have a high seasonal temperature range (from $+41^o$C in summer to $-47°$C in winter). The Siberian High is an anticyclone centered over Eurasia ($40-65°$N, $80-120°$E) that controls the winter weather in the Altai Mountains. The Siberian High is maintained by radiative cooling over snow-covered Asia, associated with large-scale descending motion. The anticyclone prevents winter precipitation in the Mongolian part of the Altai Mountains, whereas few intrusions of Westerlies can result in precipitation in the Russian part of the Altai Mountains. In summer, most of the precipitation is transported by humid air masses of the Westerlies [Malygina et al., 2017].

2. Data and methods

From the experience of numerousstudies of Altai climate,a set of more representative data andeffective methods was chosen. Below we list the mostly used ones. For the projected future one needs to use the climate scenarios - the chosen ones are described below in this section too.

2.1. Atmospheric reanalysis

 NCAR climate data guide

[https://climatedataguide.ucar.edu/data-type/atmospheric-reanalysis]

Reanalysis a systematic approach to produce data sets for climate monitoring and research. Reanalysis are created via an unchanging ("frozen") data assimilation scheme and model(s) which ingest all available observations every 6-12 hours over the period being analyzed.

Reanalysis NCEP-NCAR[https://climatedataguide.ucar.edu/data-type/atmospheric-reanalysis]

NCEP-NCAR (R1) is the original reanalysis effort. It uses a frozen global state-of-the-art global data assimilation system (as of 11 January 1995). The original database was enhanced (additional, quality checked datasets) by NCAR's Data Support Section.

KEY STRENGTHS: 1) Global Data Set; 2) Longest running reanalysis that uses rawindsonde data; 3) Used in many publications so it can be used as a baseline reference for many computations.

KEY LIMITATIONS: 1)Antiquated (1994) data assimilation/model; 2) Low spatial and temporal moisture variability over oceans relatively poor Southern Hemisphere.

Reanalysis ERA-Interim[https://climatedataguide.ucar.edu/data-type/atmospheric-reanalysis]

ERA-Interim. Using a much improved atmospheric model and assimilation system from those used in ERA-40, ERA-Interim represents a third generation reanalysis. ERA-Interim now extends back to 1979 and the analysis is expected to be continued forward until the end of 2018.

KEY STRENGTHS: 1) Spatially and temporally complete data set of multiple variables at high spatial and temporal resolution; 2) Improved low-frequency variability; 3) Improved stratospheric circulation (compared to ERA-40).

KEY LIMITATIONS: 1) Too intense of a water cycling (precipitation, evaporation) over the oceans; 2) In the Arctic: positive biases in temperature and humidity below 850hPA compared to radiosondes; does not capture low-level inversions.
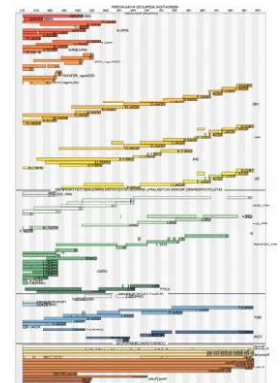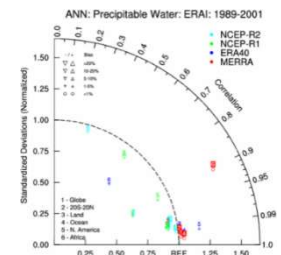
2.2. Extremes temperature and precipitation indices
Climdex indices
[https://www.climdex.org/about/project/]

The Climdex indices can help us understand patterns in temperature and precipitation extremes: how they change from year to year or from place to place.Climdex offers 27 indices, all derived from daily temperature and precipitation data. These indices are a standardised set recommended by the CCI/WCRP/JCOMM Expert Team on Climate Change Detection and Indices. The standardisation of these indices allows researchers to compare results across time periods, regions and source datasets.

Definitions of extreme temperature and precipitation indices used in IPCC
[https://www.ipcc.ch/; Zhang et al., 2011]

Index	Descriptive name	Definition	Units
TXx	Warmest daily Tmax	Seasonal/annual maximum value of daily maximum temperature	^0C
TNx	Warmest daily Tmin	Seasonal/annual maximum value of daily minimum temperature	^0C
TXn	Coldest daily Tmax	Seasonal/annual minimum value of daily maximum temperature	^0C
TNn	Coldest daily Tmin	Seasonal/annual minimum value of daily minimum temperature	^0C
TN10p	Cold nights	Days (or fraction of time) when daily minimum temperature<10th percentile	days (%)
TX10p	Cold days	Days (or fraction of time) when daily maximum temperature <10th percentile	days (%)
TN90p	Warm nights	Days (or fraction of time) when daily minimum temperature >90th percentile	days (%)
TX90p	Warm days	Days (or fraction of time) when daily maximum temperature >90th percentile	days (%)
RX1day	Wettest day	Maximum 1-day precipitation	mm
SDII	Simple daily intensity index	Ratio of annual total precipitation to the number of wet days (≥1 mm)	mm day^{-1}
R95p	Precipitation from very wet days	Amount of precipitation from days >95th percentile	mm
CDD	Consecutive dry days	Maximum number of consecutive days when precipitation<1 mm	days

2.3. Climate scenarios

### Intergovernmental Panel on Climate Change (IPCC)

[https://www.ipcc.ch/]

For the Fifth Assessment Report (AR5) of IPCC, the scientific community has defined a set of four new scenarios. The CMIP5 simulations were performed with prescribed CO_2 concentrations reaching:421 ppm (RCP2.6),538 ppm (RCP4.5), 670 ppm (RCP6.0) and 936 ppm (RCP 8.5) by the year 2100.

Projected change in global mean surface air temperature for the mid- and late 21st century relative to the reference period of 1986–2005

Scenario	Global Mean SurfaceTemperature Change(^{0}C) mean (likely range)	
	2046-2065	2081-2100
RCP2.6	1.0 (0.4 — 1.6)	1.0 (0.3 — 1.7)
RCP4.5	1.4 (0.9 — 2.0)	1.8 (1.1 — 2.6)
RCP6.0	1.3 (0.8 — 1.8)	2.2 (1.4 — 3.1)
RCP8.5	2.0 (1.4 — 2.6)	3.7 (2.6 — 4.8)

Change in average surface temperature(1986–2005 to 2081–2100)[https://www.ipcc.ch/]
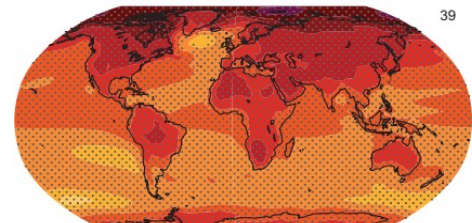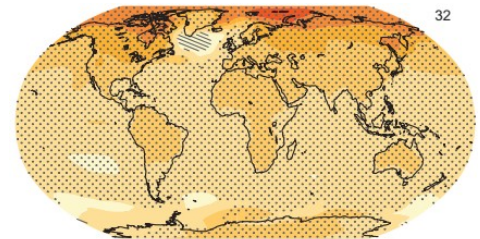
Change in average precipitation (1986–2005 to 2081–2100)
[https://www.ipcc.ch/]

6
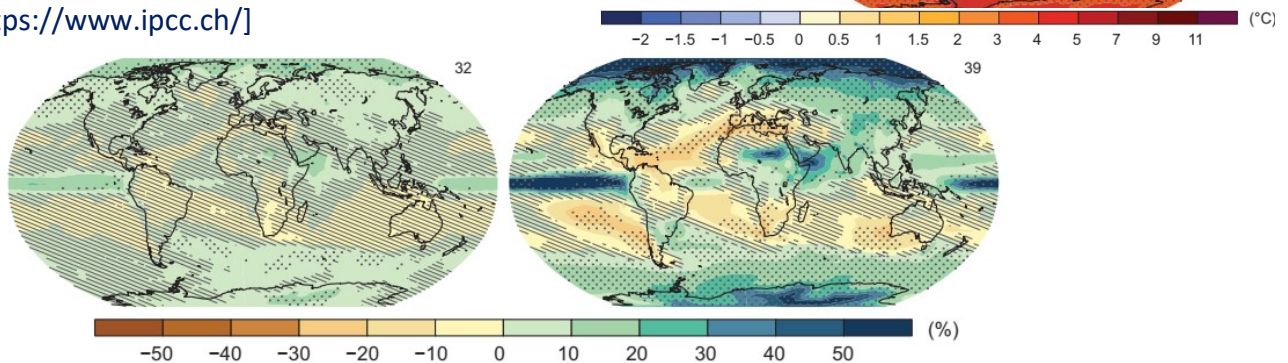
Speaking about climate change in Altai we would like to concentrate more on the tempe-rature and precipitation anomalies. Below we show some spectacular results on their variations including some mostly representative indices characterizing these parameters.

3.1. Temperature Anomalies

Altai Mountains (85^0E – 92^0E, 48^0N – 52^0N)
January-December (1896-2018)

[https://www.ncdc.noaa.gov/data-access/land-based-station-data/land-based-datasets]

Global temperature anomaly data come from the Global Historical Climatology Network-Monthly (GHCN-M) data set and International Comprehensive Ocean-Atmosphere Data Set (ICOADS), which have data from 1880 to the present.
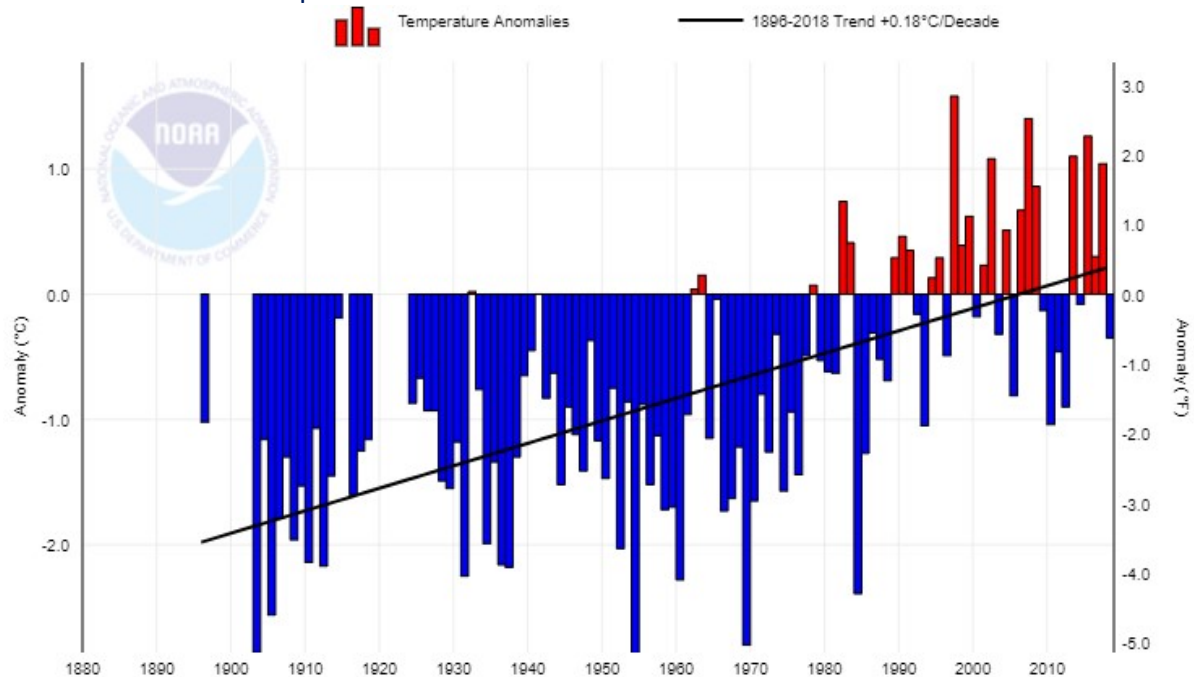
The temperature in Altai Mountains has increased significantly over the last century and the trend was + 0.18^0C / decade, the greatest increase was noted in the last thirty years.

3.2. Coordinate anomalies temperature

Altai Mountains (85^{0}E – 92^{0}E, 48^{0}N – 52^{0}N)
Coordinate anomalies are with respect to the 1981 to 2010 average
[https://www.ncdc.noaa.gov/data-access/land-based-station-data/land-based-datasets]

Global temperature anomaly data come from GHCN-M data set and ICOADS, which have data from 1880 to the present.
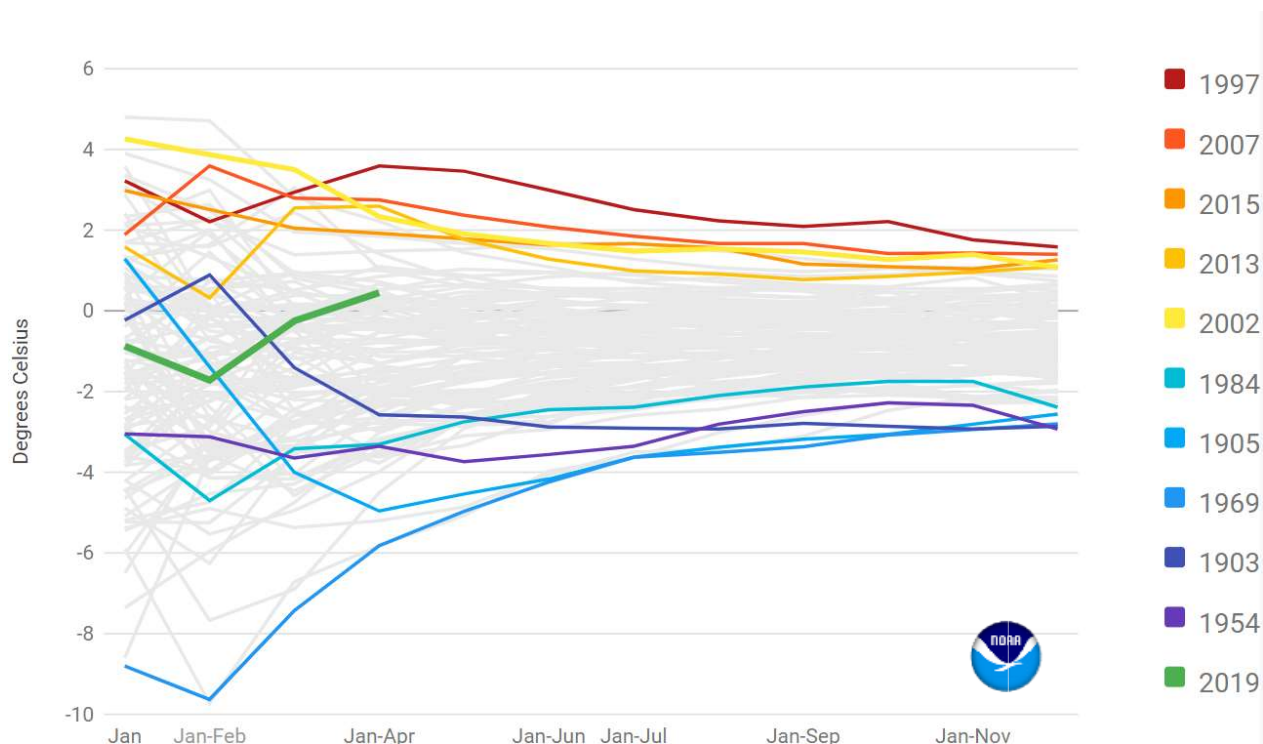
The warmest years were in the last 30 years, and the coldest ones - earlier, with the exception of 1984. The trends for 2019 are still unclear, however, the beginning of the year shows that it is essentially a year marking the beginning of the warmer years.

3.3. Extreme climate indices

Annual maximum value of daily maximum temperature
Warmest daily Tmax (TXx)[www.climdex.org]
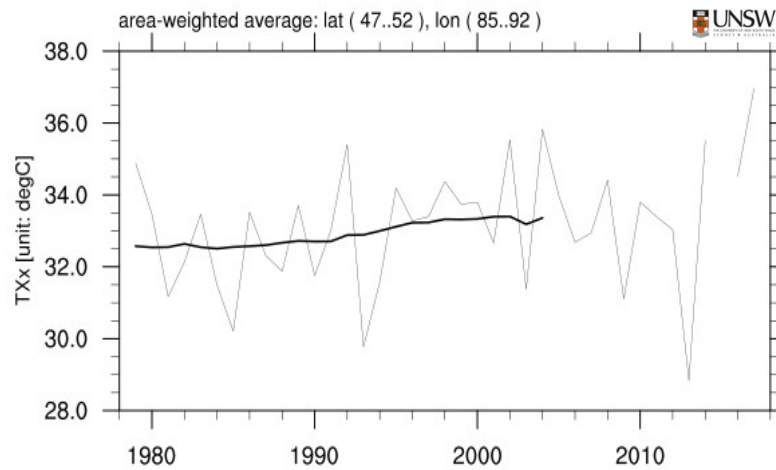
Warmest days with maximum temperature (about $+36^0C$) was in 1992, 2002 and 2005.

Annual maximum value of daily minimum temperature
Warmest daily Tmin (TNx)[www.climdex.org]
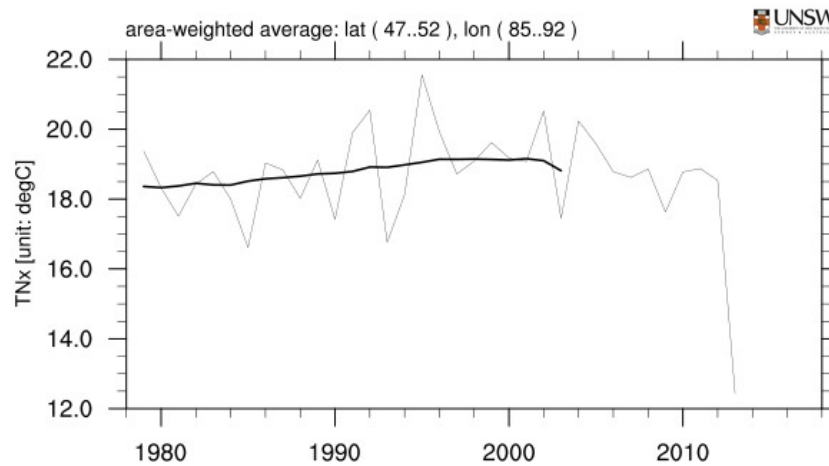
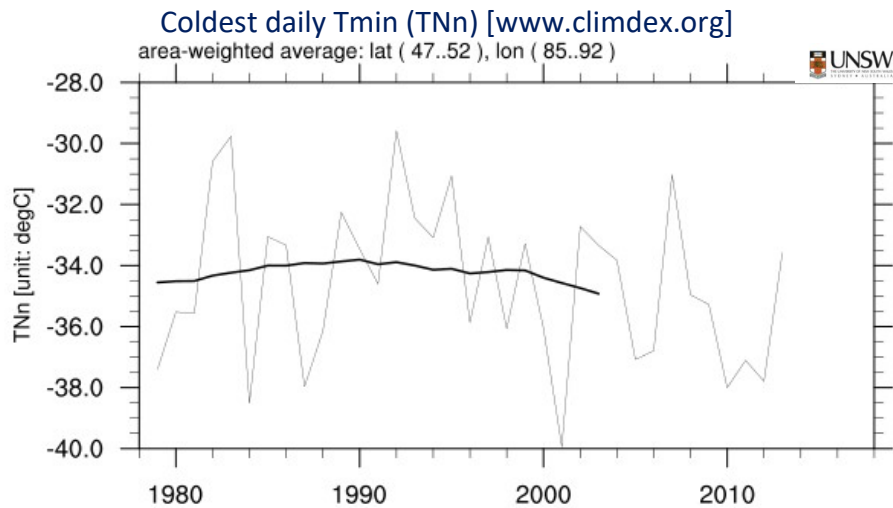*Warmest days with minimum temperature (about $+17^0C$) was in 1993 and 2015 ($+12.5^0C$).*

Annual minimum value of daily maximum temperature

Coldest daily Tmax (TXn)[www.climdex.org]
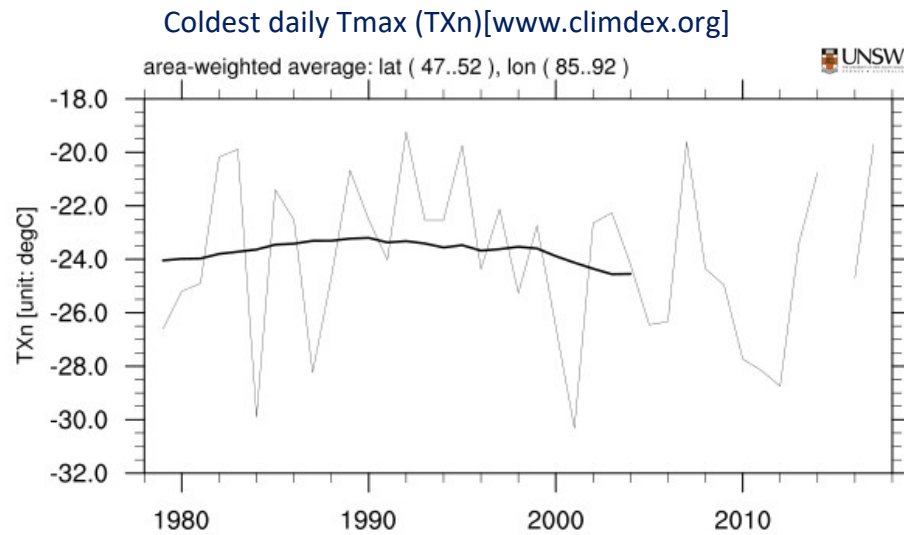
The annual minimum value of the daily maximum temperature (about -30⁰C) was in 1984 and 2001, at this time Mongolia (Mongolian Altai, Hovd aimag) was experiencing drought and dzud.

## Annual minimum value of daily minimum temperature

Coldest daily Tmin (TNn) [www.climdex.org]

The annual minimum value of daily minimum temperature (about -40⁰C) was in 2001, when observed dzud in Mongolia with significant losses livestock.

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Days when daily minimum temperature<10th percentile
Cold nights (TN10p) [www.climdex.org]

area-weighted average: lat (47..52), lon (85..92)
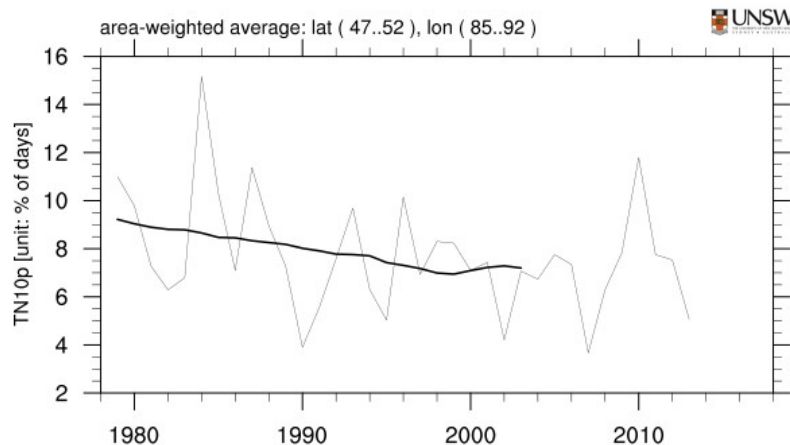
Maximum number of days when daily minimum temperature <10th percentile (cold nights) was in 1984 (drouth in Mongolian Altai) and 2010 (dzud in Hovd aimag).

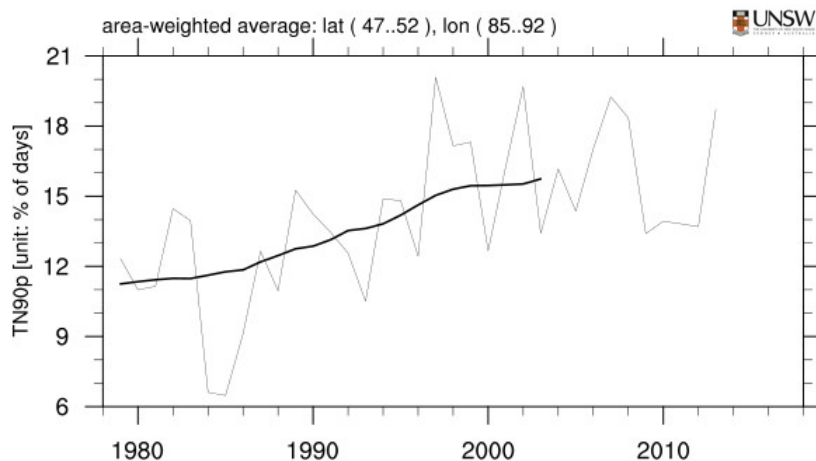## Days when daily maximum temperature <10th percentile
Cold Days (TX10p) [www.climdex.org]

area-weighted average: lat (47..52), lon (85..92)
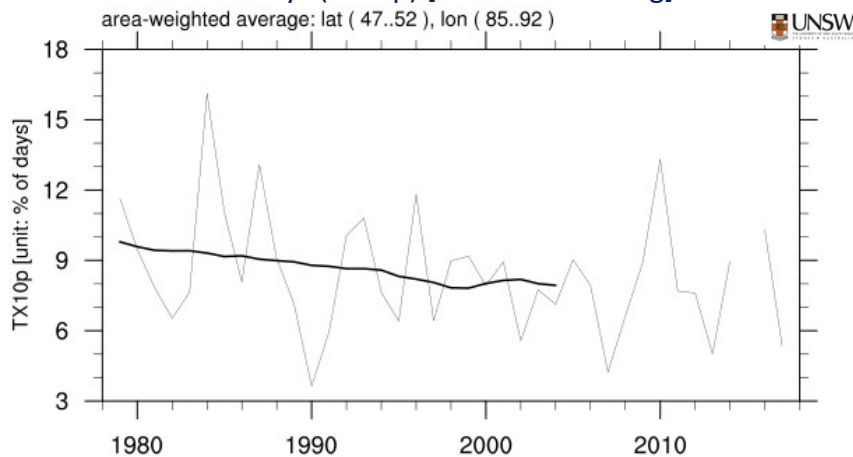
Maximum number of days when daily maximum temperature <10th percentile (cold days) was in 1984 and 2010 (extreme events in Mongolian Altai).
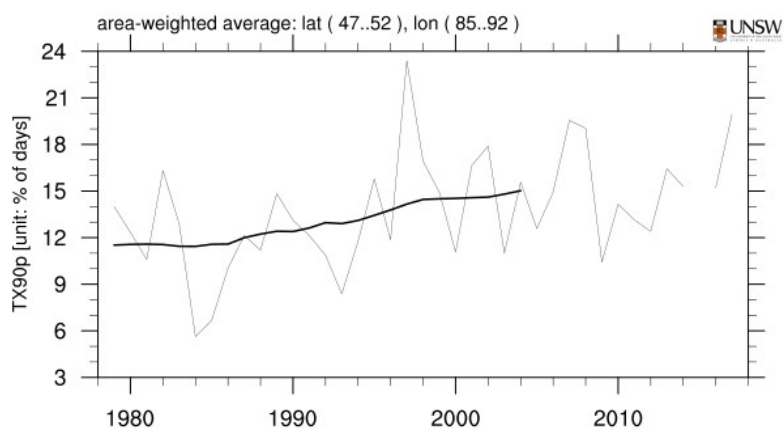
Days when daily minimum temperature >90thpercentile
Warm nights (TN90) [www.climdex.org]

area-weighted average: lat (47..52), lon (85..92)

Maximum number of days when daily minimum temperature >90th percentile was in 1997 (about 20%) and there is a tendency to increase.

Days when daily maximum temperature >90th percentile
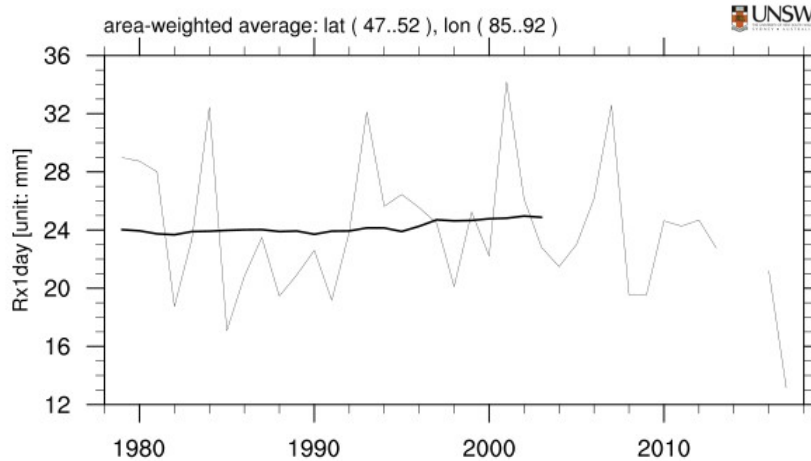### Warm days(TX90p) [www.climdex.org]

area-weighted average: lat (47..52), lon (85..92)

Maximum number of days when daily maximum temperature >90 th percentile was in 1997.

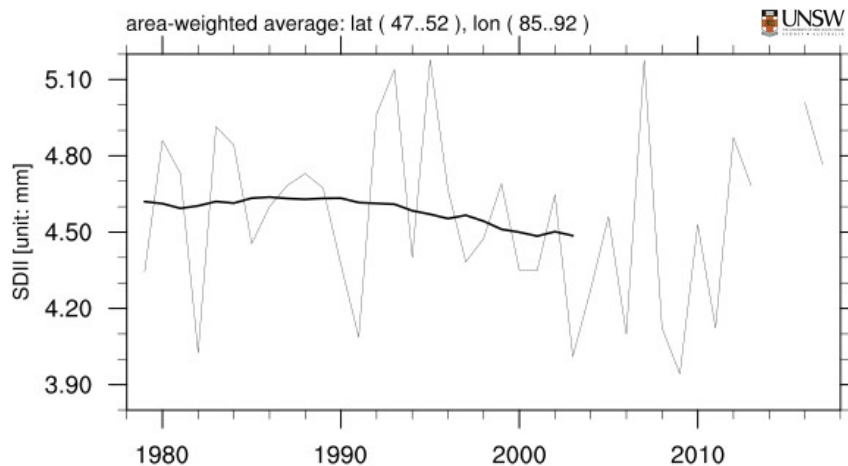## *Maximum 1-day precipitation*
Wettest day (RX1day) [www.climdex.org]

Wettest day (maximum 1-day precipitation) was in 2001, when in Mongolia due to snowstorms observed dzud.

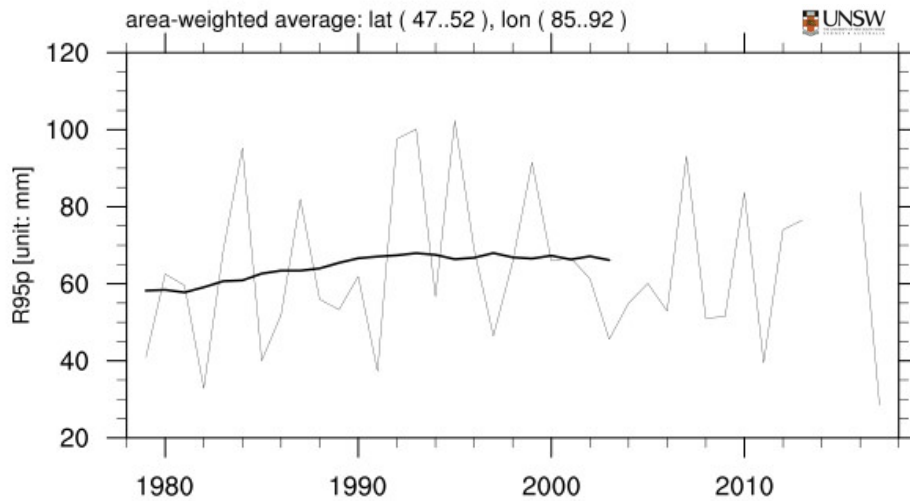## *Ratio of annual total precipitation to the number of wet days (≥1 mm)*
Simple daily intensity index (SDII)[www.climdex.org]

Maximum ratio of annual total precipitation to the number of wet days (≥1 mm) was in 2007.

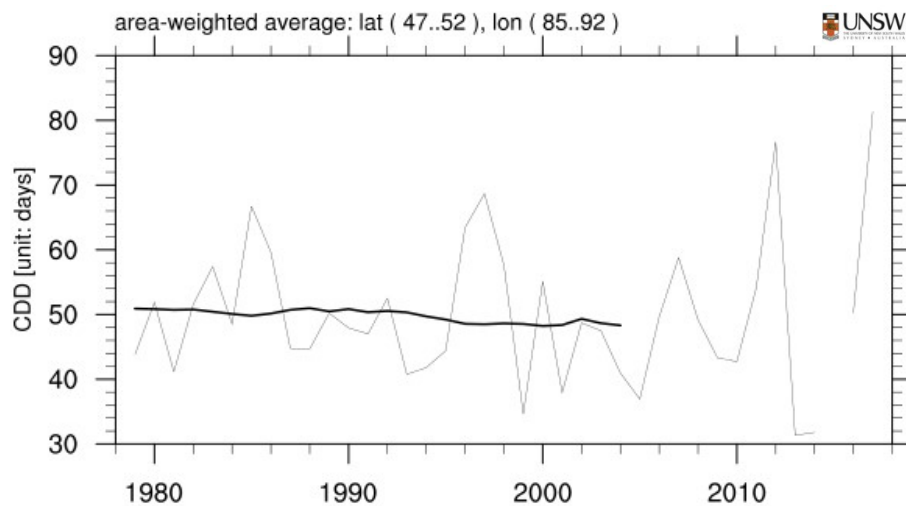## Amount of precipitation from days >95th percentile
Precipitation from very wet days (R95p) [www.climdex.org]

Most precipitation from very wet days was in 1990s (1991, 1993 and 1995).

Maximum number of consecutive days when precipitation<1 mm
Consecutive dry days (CDD) [www.climdex.org]

Maximum number of consecutive days when precipitation <1 mm was in 2012 (about 77 days).

4. Projected future climate changes in Altai Mountains

In this section we present some results on the projected climate changes in Altai. The shown estimations are based on four climate scenarios listed above in the corresponding section (subsection 2.3).
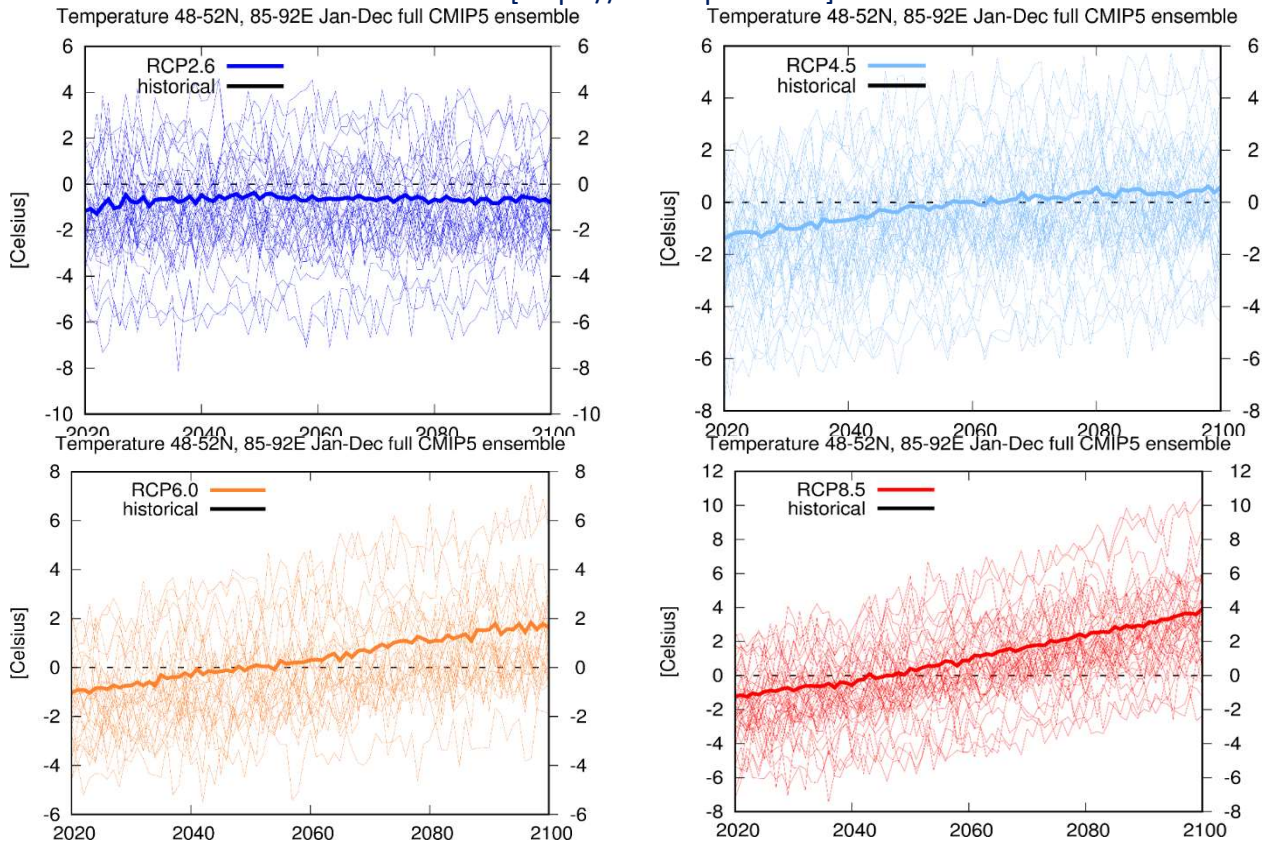
4.1. Temperature and precipitation

Temperature
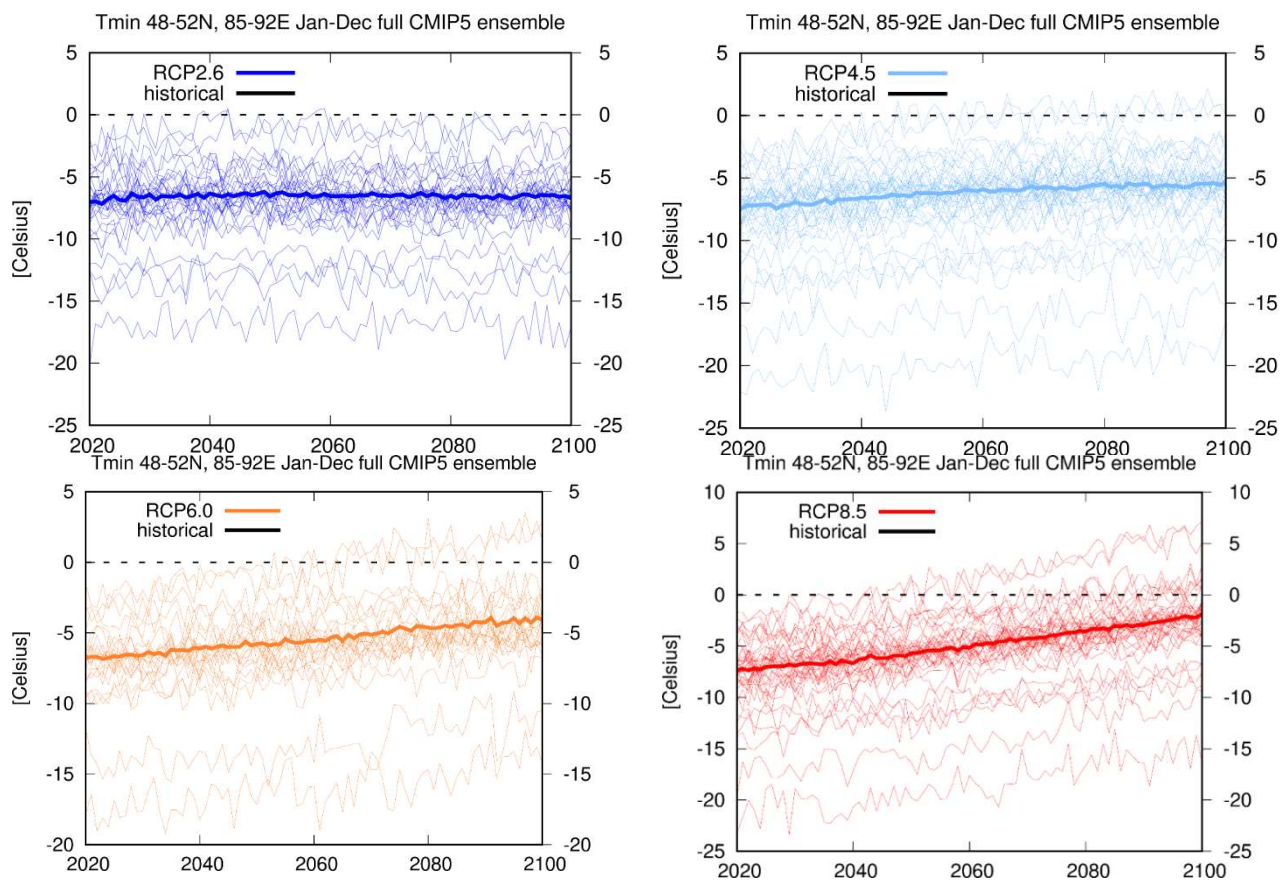
KNMI Climate ExplorerCMIP5 (IPCC AR 5) (2020-2100)
[https://climexp.knmi.nl]

According to scenario RCP 2.6, the temperature in Altai Mountains does not increase by more than 0.5^0C, but in the other three scenarios it will increase significantly. Maximum increases (by almost 5^0C) temperatures by 2100 are possible with scenario RCP 8.5.

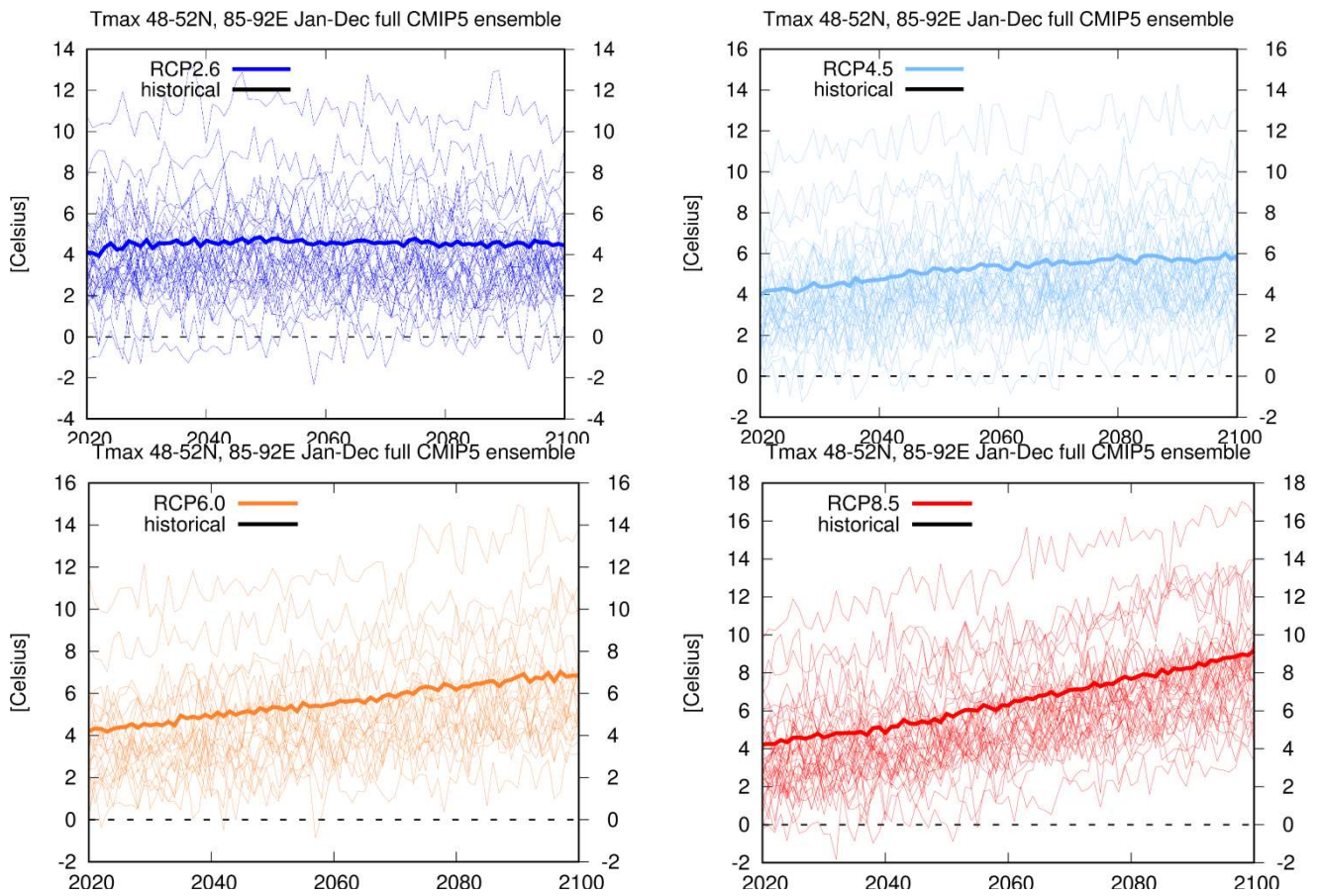KNMI Climate Explorer CMIP5 (IPCC AR 5) (2020-2100)
[https://climexp.knmi.nl]

Changes close to the temperature are predicted to change the minimum temperature in Altai Mountains: from 0.5 to 5 ^{0}C, with «soft» (RCP 2.6) and «hard» (RCP 8.5) scenarios.

KNMI Climate Explorer CMIP5 (IPCC AR 5) (2020-2100)
[https://climexp.knmi.nl]

Changes in the maximum temperature are projected by the year 2100 in Altai Mountains as for the minimum temperature, i.e. from 0.5^{0}C (RCP 2.6) to 5^{0}C (RCP 8.5).
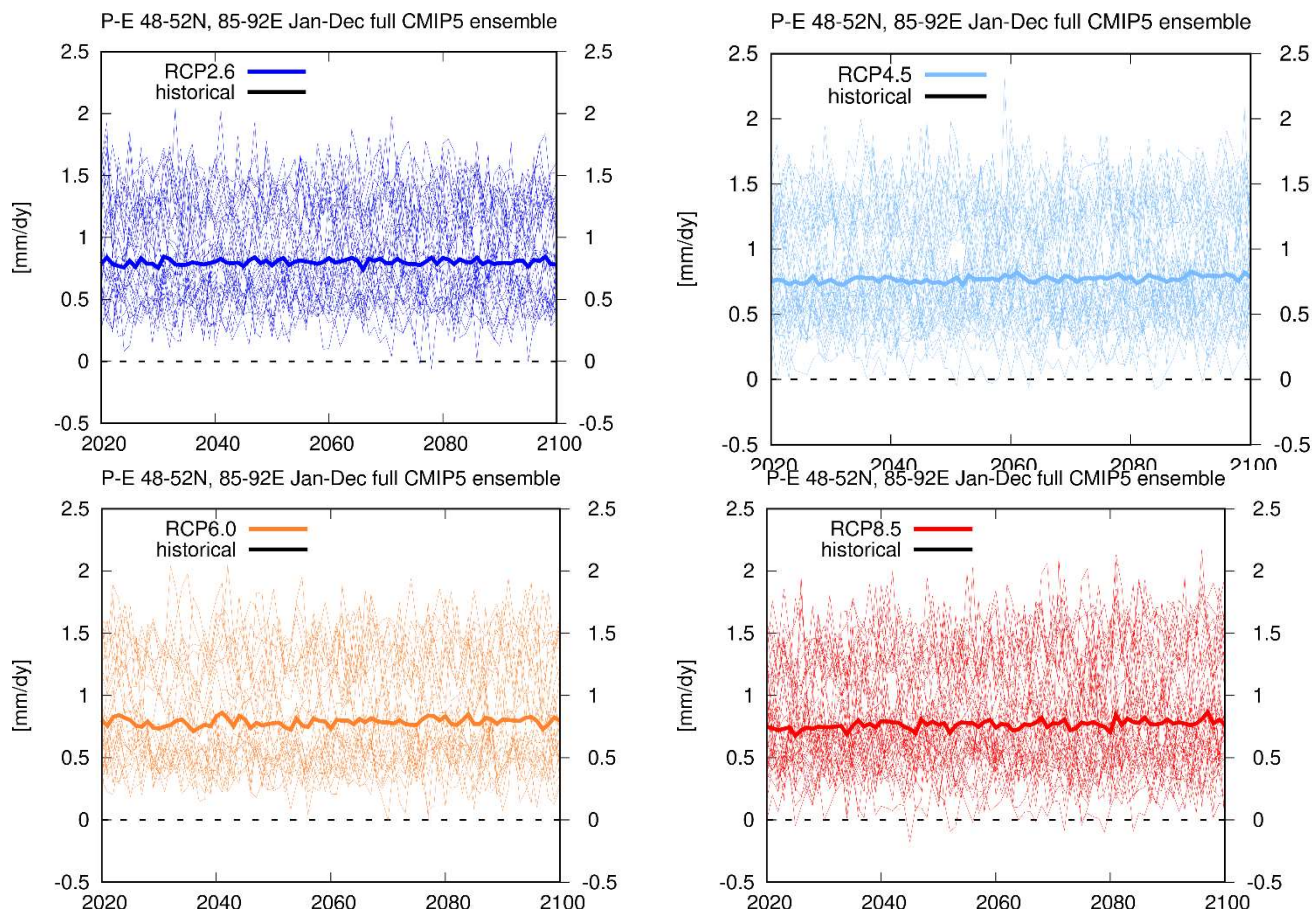
KNMI Climate Explorer CMIP5 (IPCC AR 5) (2020-2100)
[https://climexp.knmi.nl]

Precipitation 48-52N, 85-92E Jan-Dec full CMIP5 ensemble
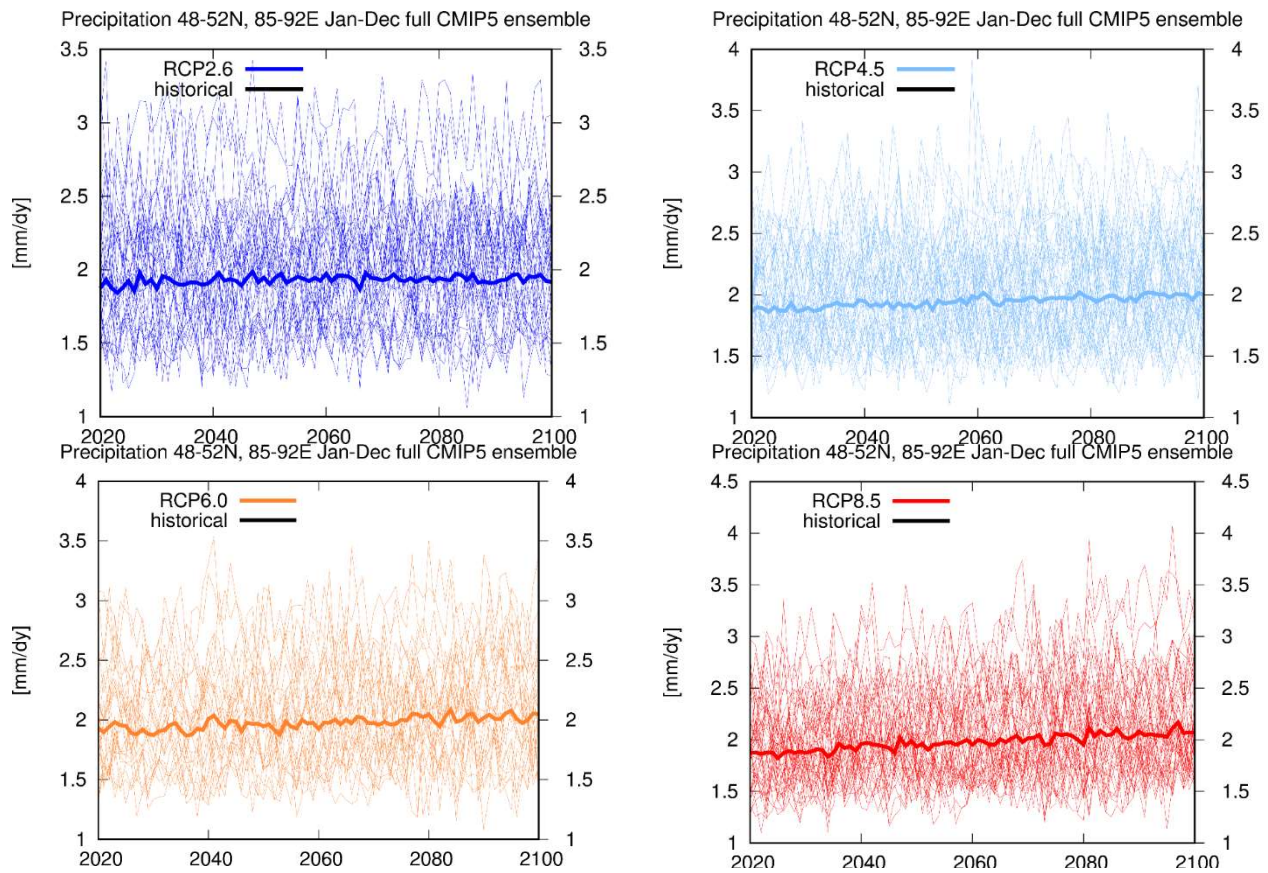
In contrast to temperature, no significant changes in precipitation are expected: from 0 mm/day change for scenario RCP 2.6 to 0.2 mm/day for scenario RCP 8.5.

P-E 48-52N, 85-92E Jan-Dec full CMIP5 ensemble

Under all four scenarios (RCP 2.6, RCP 4.5, RCP 6.6 and RCP 8.5) Precipitation-Evaporation by 2100 in Altai Mountains will be at the same level.

4.2. Extreme climate
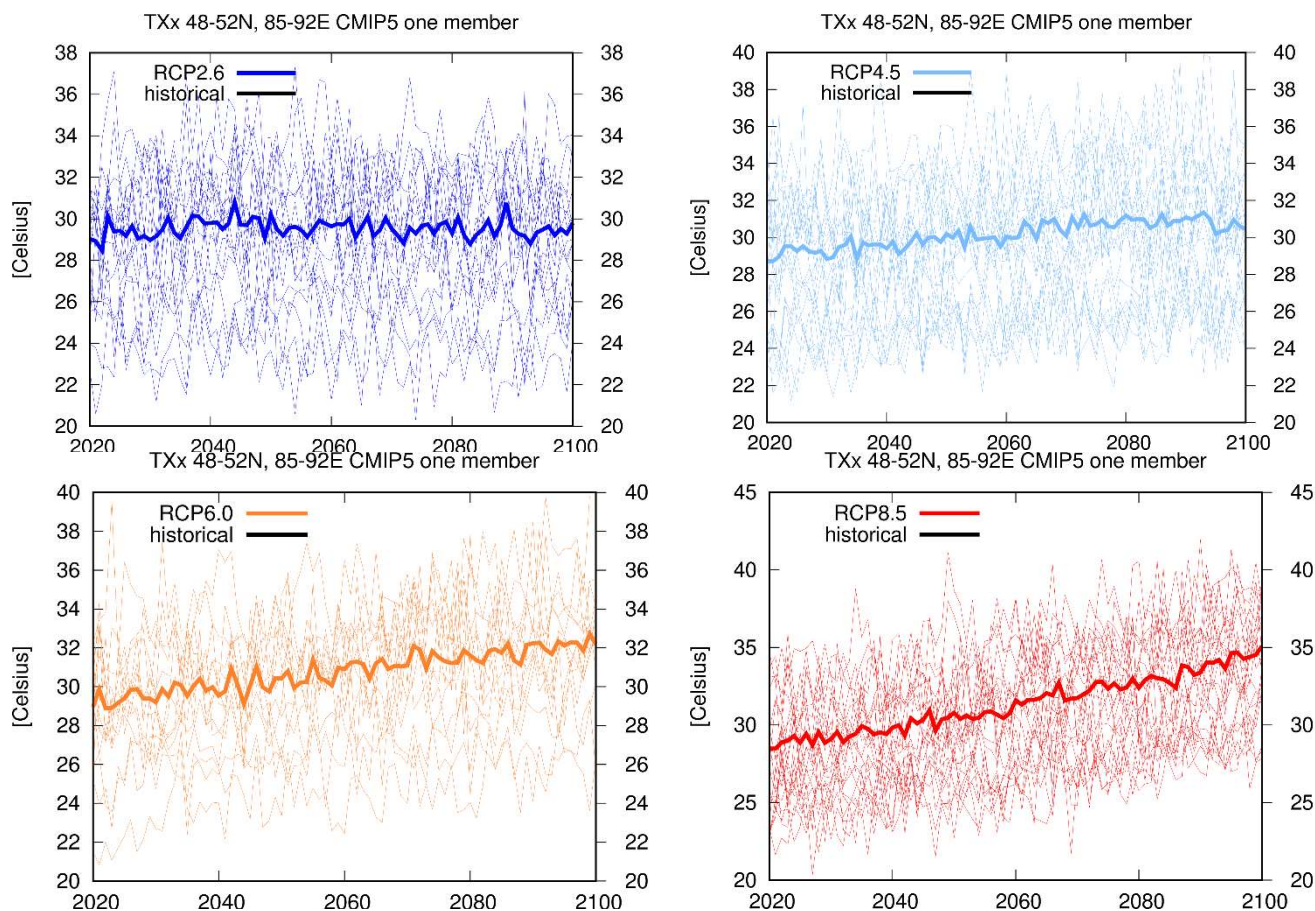### Annual maximum value of daily maximum temperature

KNMI Climate Explorer CMIP5 (IPCC AR 5) (2020-2100)
[https://climexp.knmi.nl]
Warmest daily Tmax (TXx)

Projections of future changes (RCP 2.6, RCP 4.5, RCP 6.6 and RCP 8.5) show that annual maximum value of daily maximum temperature (or warmest daily Tmax) by 2100 will hardly change with RCP 2.6 and will increase to the maximum (5^0C) with RCP 8.5.

KNMI Climate Explorer CMIP5 (IPCC AR 5) (2020-2100)
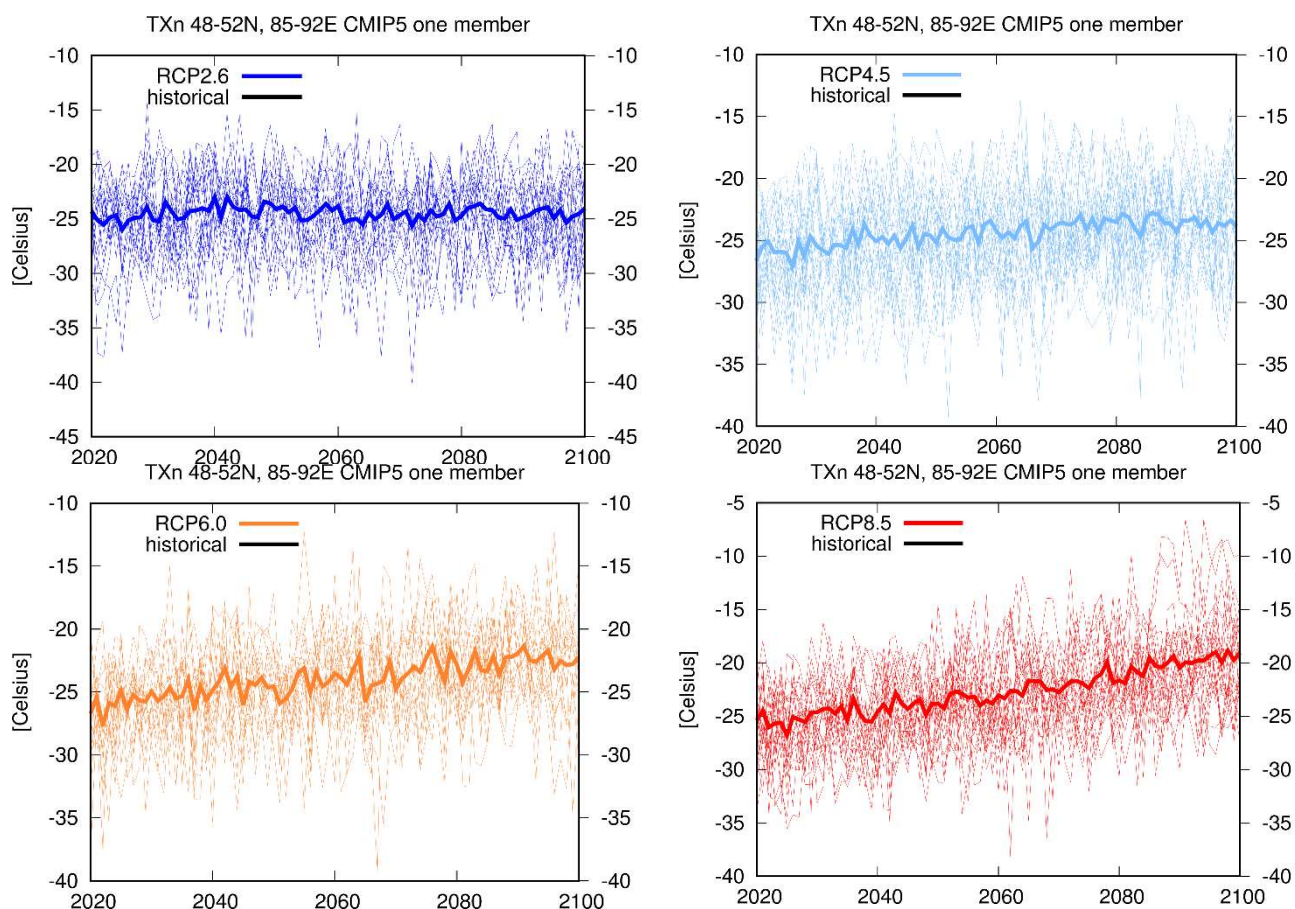[https://climexp.knmi.nl]
Warmest daily Tmin (TNx)
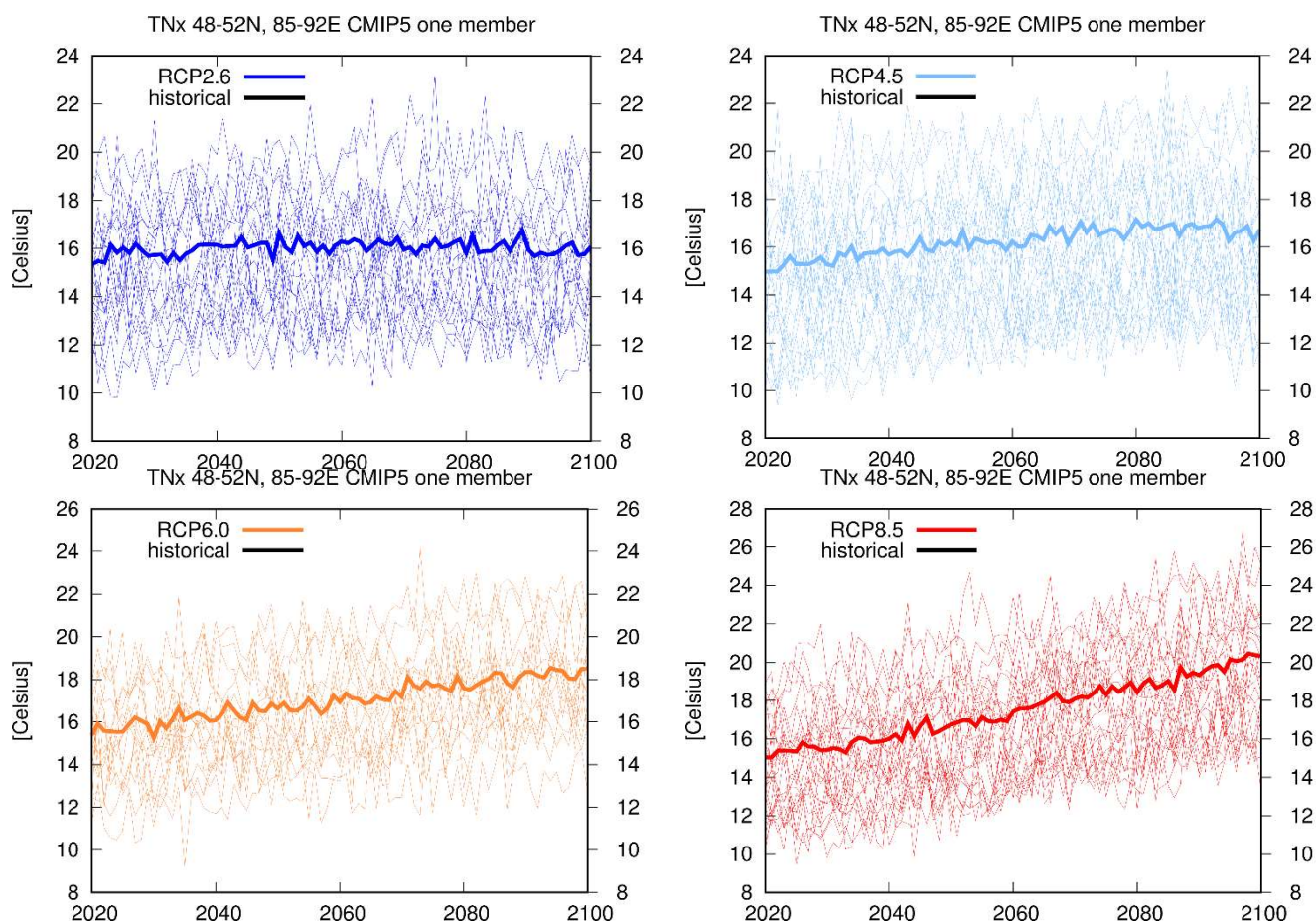
Changes in Annual maximum value of daily minimum temperature (Warmest daily Tmin) will be the same as the changes in warmest daily Tmax, namely the temperature rise in RCP 8.5 by 5^0C.

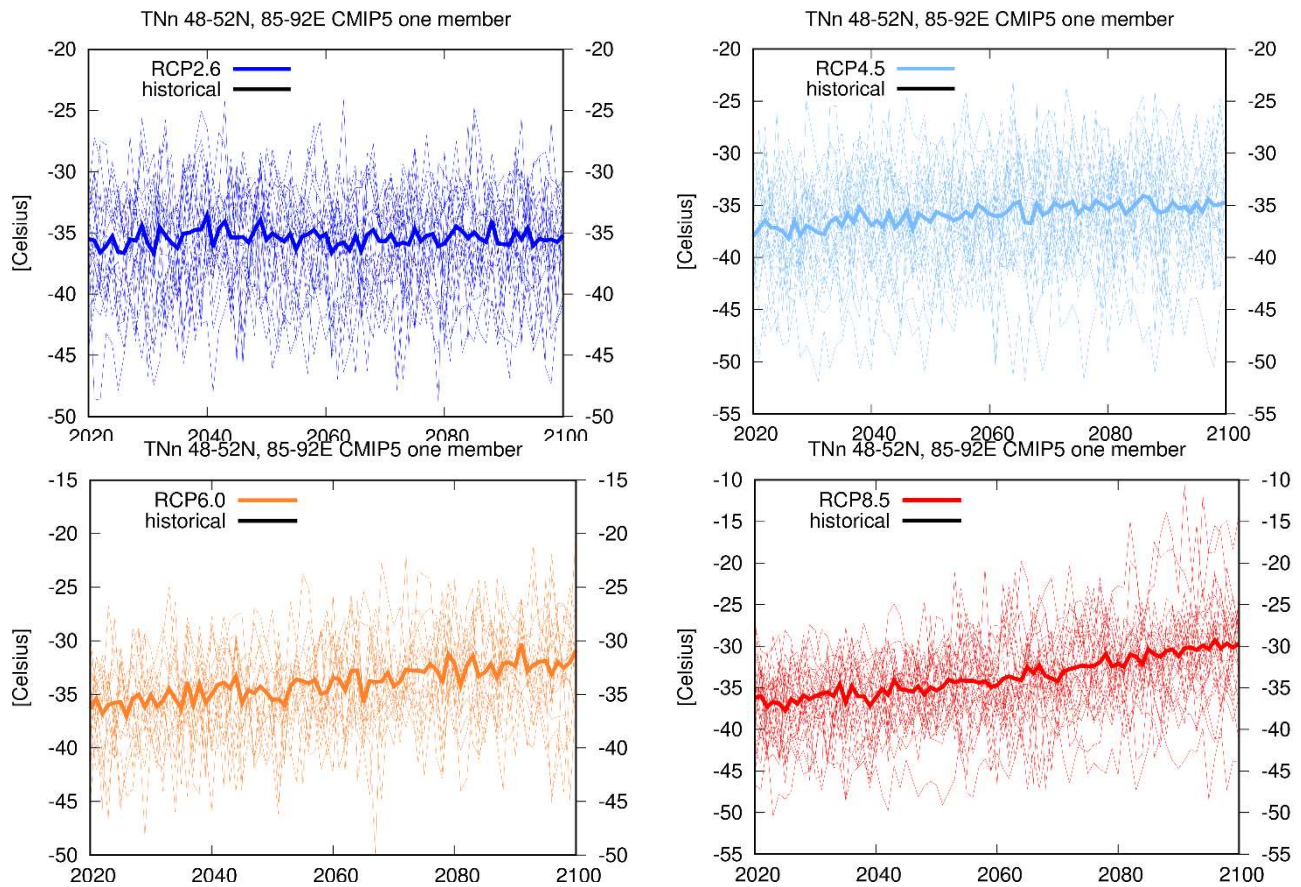KNMI Climate Explorer CMIP5 (IPCC AR 5) (2020-2100)
[https://climexp.knmi.nl]
Coldest daily Tmax (TXn)

As with increasing temperatures (Tmax and Tmin) with warmest daily, the temperature rise will also be at an annual minimum value of daily maximum temperature, and will be less than a degree at RCP 2.6 and about 5^0C degrees at RCP 8.5.
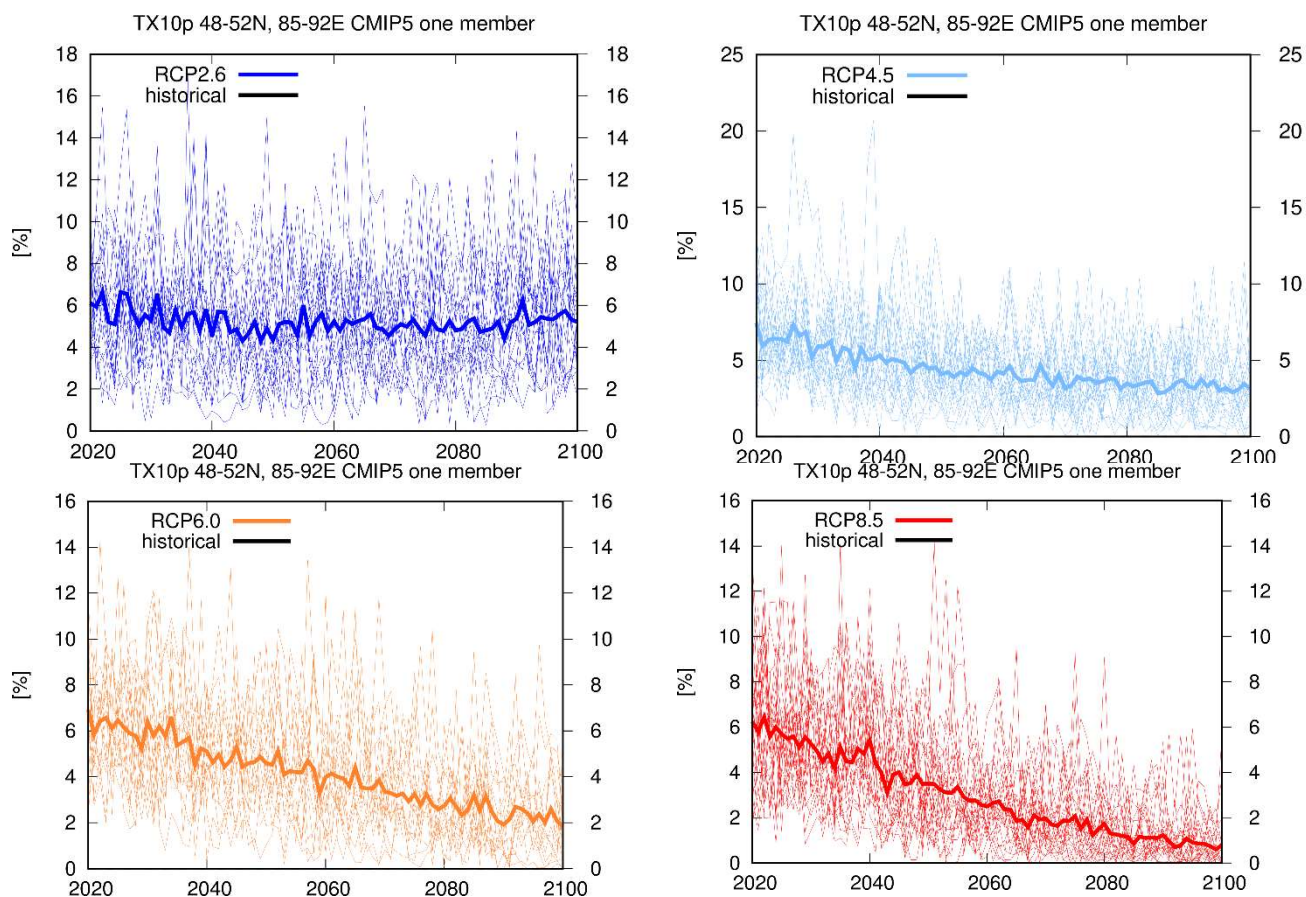
KNMI Climate Explorer CMIP5 (IPCC AR 5) (2020-2100)
[https://climexp.knmi.nl]
Coldest daily Tmin (TNn)

Annual minimum value of daily minimum temperature will be changed in the same way as coldest daily (Tmax).

KNMI Climate Explorer CMIP5 (IPCC AR 5) (2020-2100)
[https://climexp.knmi.nl]
Cold nights (TN10p)
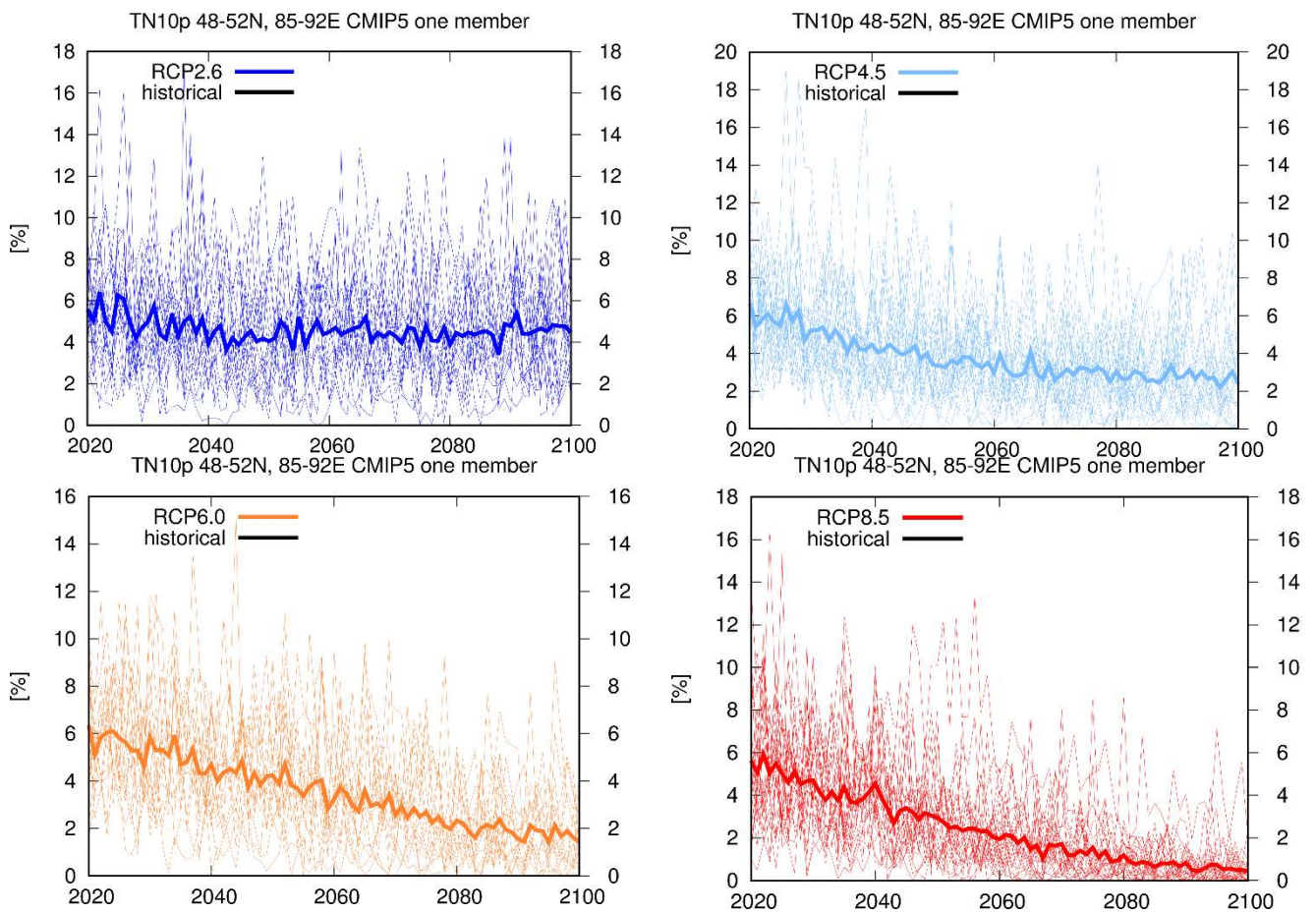
The number of days when the daily minimum temperature <10th percentile at RCP 2.6 decreases by less than 1%, while at RCP 8.5 more than 5% and becomes less than 1%.

KNMI Climate Explorer CMIP5 (IPCC AR 5) (2020-2100)
[https://climexp.knmi.nl]
Cold days(TX10p)

Changes to days (or fraction of time) when daily maximum temperature <10th percentile will be the same as changes to cold nights.

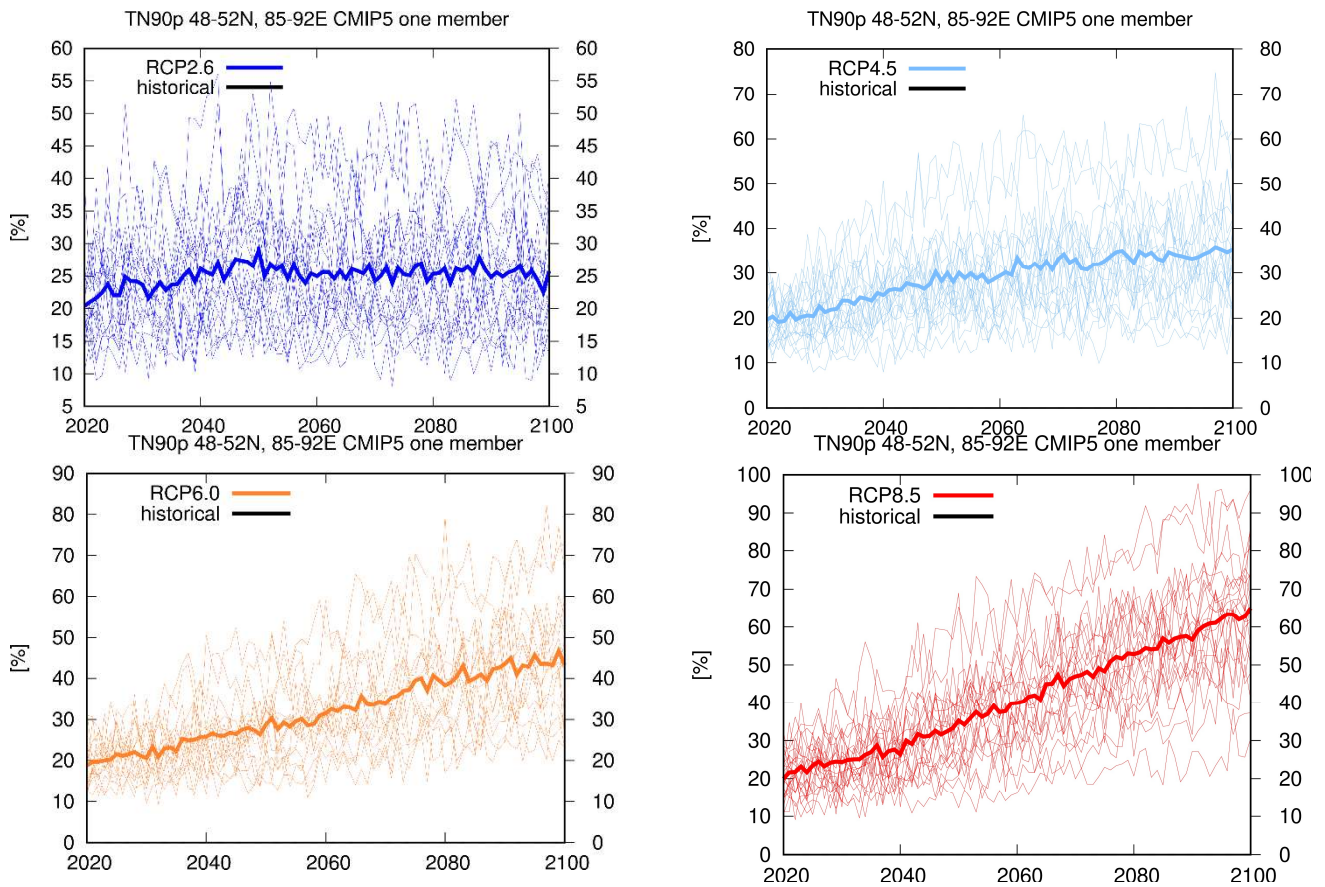KNMI Climate Explorer CMIP5 (IPCC AR 5) (2020-2100)
[https://climexp.knmi.nl]
Warm nights (TN90p)

The number of days when the daily minimum temperature> 90t percentile under RCP 2.6 does not increase significantly, while for RCP 8.5 it will grow by 45% and will be about 65% of the total number of days per year, and will be almost 240 days per year.
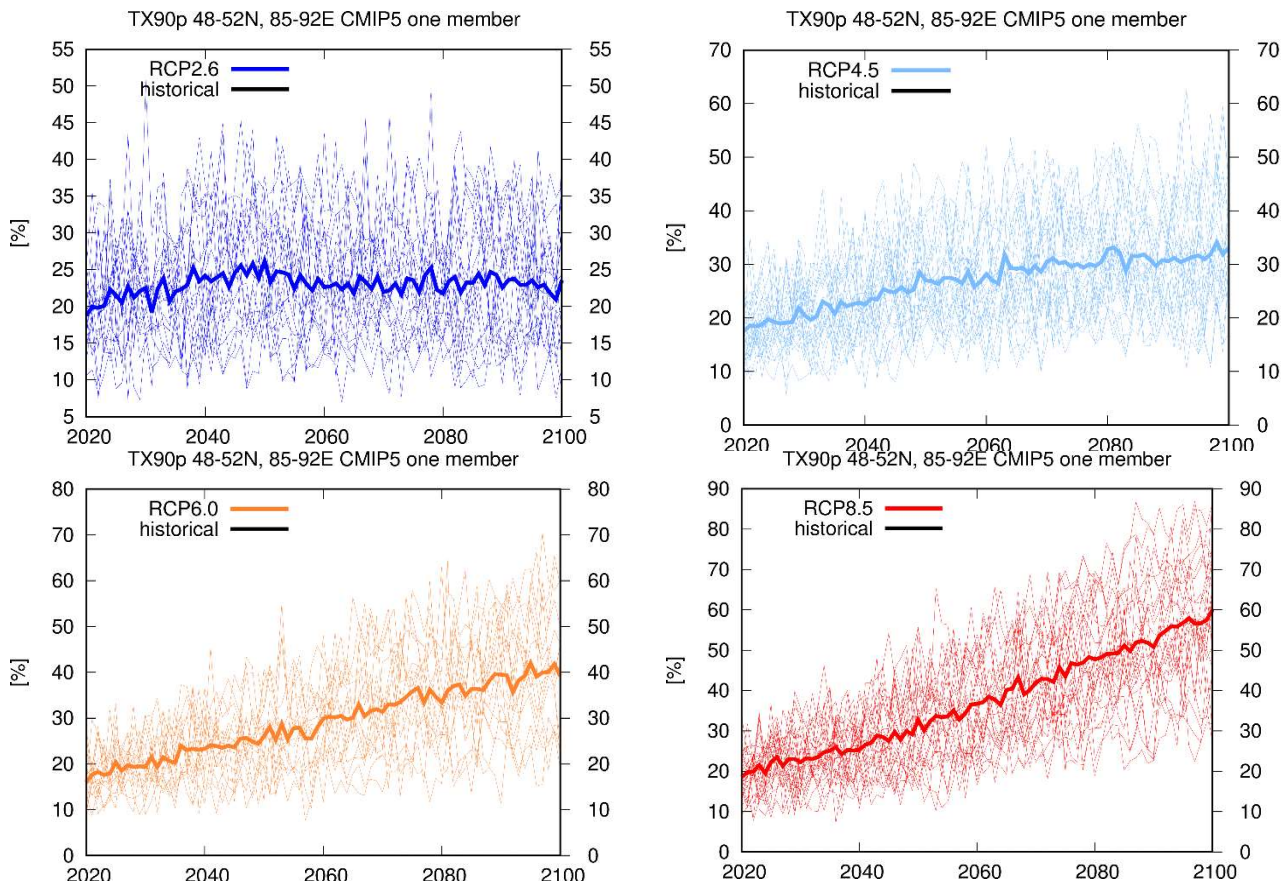
KNMI Climate Explorer CMIP5 (IPCC AR 5) (2020-2100)
[https://climexp.knmi.nl]
Warm days (TX90p)

The number of days when the daily maximum temperature> 90th percentile does not greatly increase under RCP 2.6 and will increase by more than 40% under RCP 8.5.
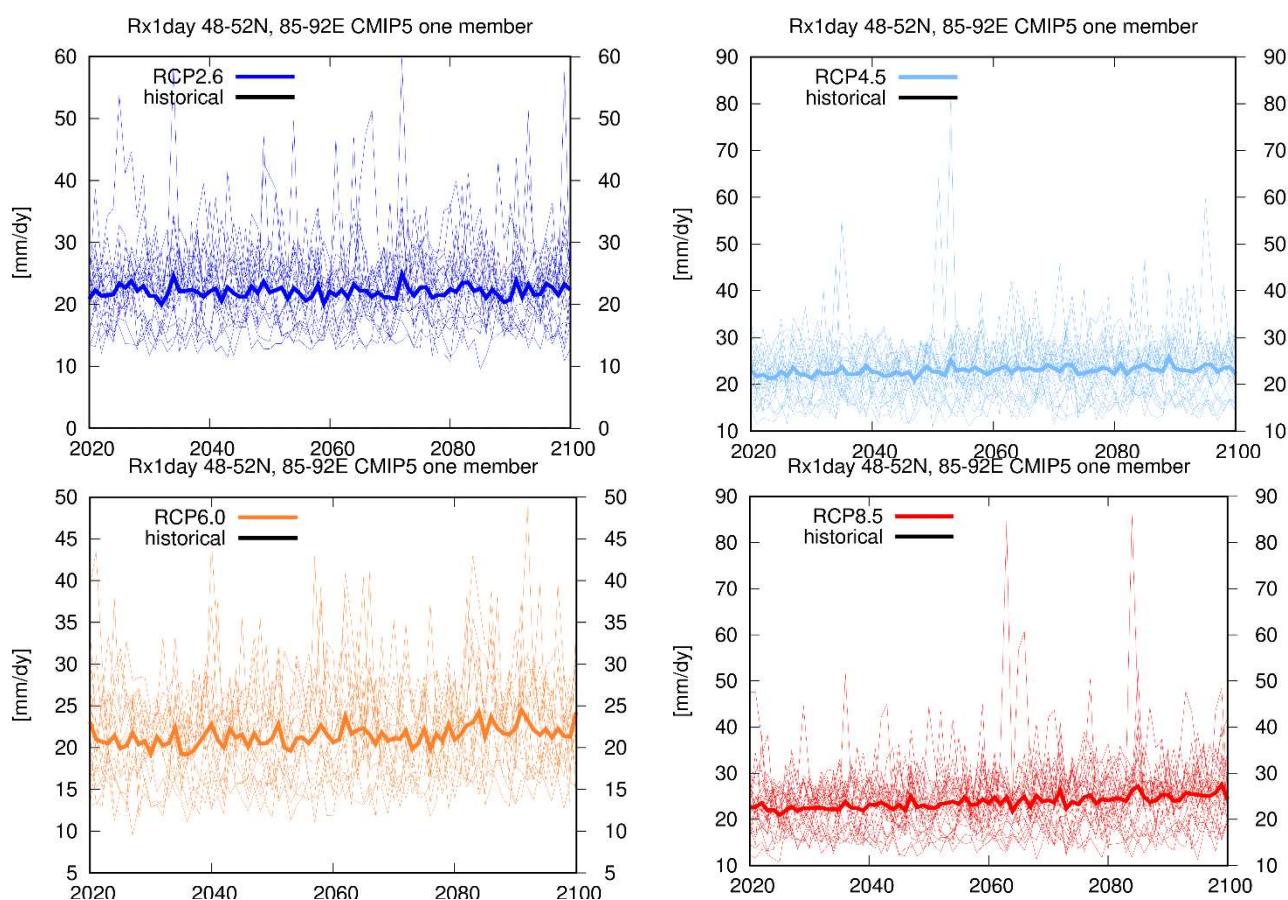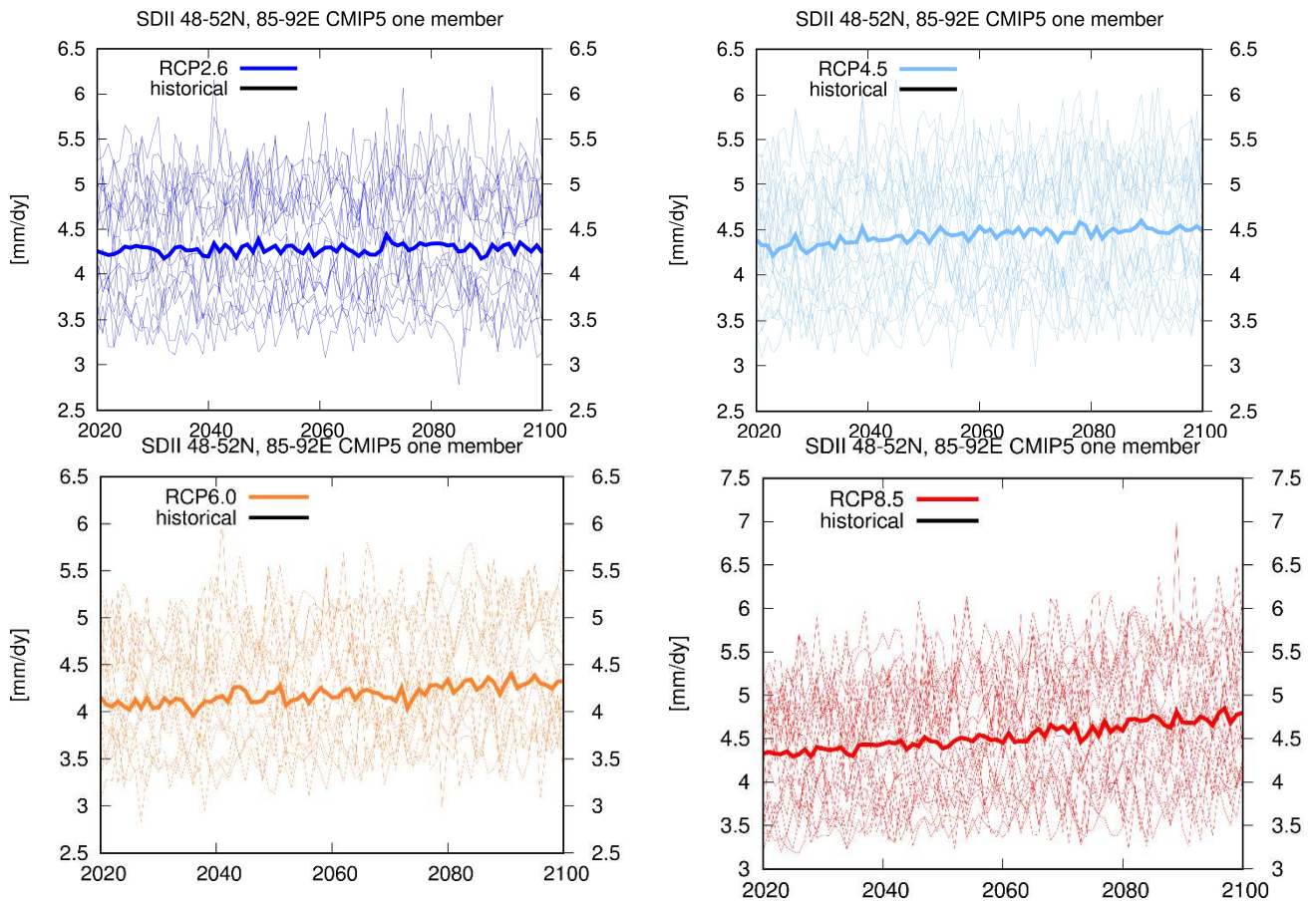
Maximum 1-day precipitation

Maximum 1-day precipitation in the Altai Mountains by 2010 for RCP 2.6, RCP 4.5 and RCP 6.0 almost does not change, while by RCP 8.5 it will increase by 5 mm/day.

Ratio of annual total precipitation to the number of wet days (≥1 mm)

KNMI Climate Explorer CMIP5 (IPCC AR 5) (2020-2100)
[https://climexp.knmi.nl]
Simple daily intensity index(SDII)

Changes in ratio of annual total precipitation to the number of wet days (≥1 mm) by the year 2100 will not exceed 0.5 mm/dy even in the most "hard" scenario RCP 8.5.

KNMI Climate Explorer CMIP5 (IPCC AR 5) (2020-2100)
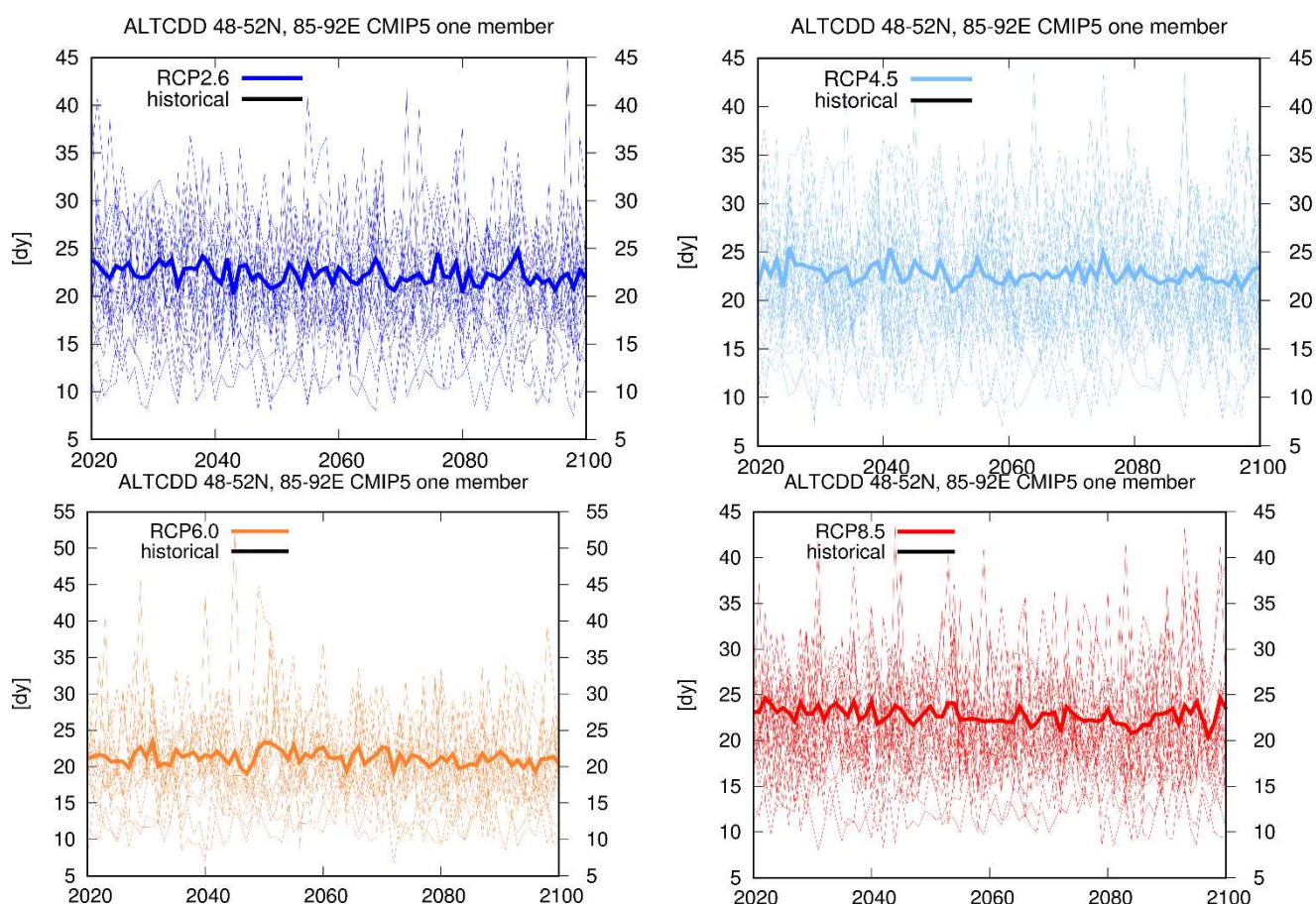[https://climexp.knmi.nl]
Precipitation from very wet days (R95p)
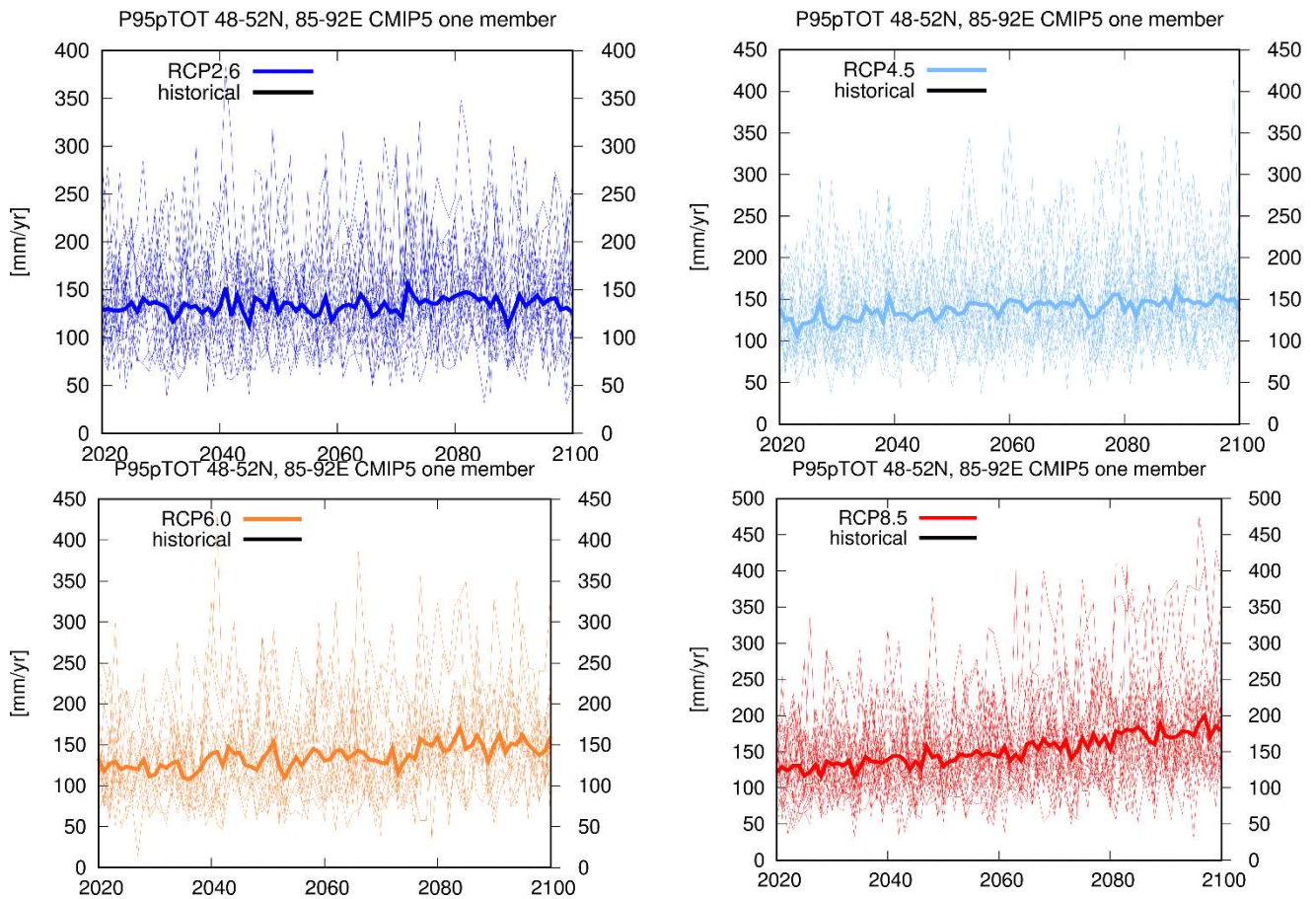
There will be almost no change in amount of precipitation from days> 95th percentile under RCP 2.6 by 2100, while by RCP 8.5 there will be an increase of almost 50 mm/year.

KNMI Climate Explorer CMIP5 (IPCC AR 5) (2020-2100)
[https://climexp.knmi.nl]
Consecutive dry days (CDD)

Maximum number of consecutive days when precipitation <1 mm to 2100 in Altai Mountains will not change, only with RCP 8.5 it will increase no more than 1-2 days.

Conclusions

In Altai Mountains the temperature has increased significantly over the last century and the trend was + 0.18^{0}C/decade, the greatest increase was noted in the last thirty years. The warmest years were in the last 30 years, and the coldest ones - earlier, with the exception of 1984. The trends for 2019 are still not completely clear, however, the first part of the year shows that it is essentially a year marking the beginning of the warmer years.

The results of analysis of changes in extreme climate indices in Altai Mountains (1979-2017) showed the following. The number of «Cold days» and «Cold nights» decreases, and the temperatures for these periods increase. All this happens against the background of an increase in the number of «Warm days» and «Warm nights» and an increase in their temperatures. At the same time, there are no uniform trends in the changes in the extreme indices of precipitation. It is important that during the years of maximum manifestation of some extreme climate indices in Altai Mountains, namely in Mongolian Altai (Hovd aimag), there were extreme climatic events that manifested themselves in catastrophic droughts and dzud.

In the Altai Mountains, by the end of the century, the mean temperature is projected to increase from 0.5^{0}C (RCP 2.6) to 5^{0}C (RCP 8.5), with no significant increase in precipitation (up to 0.2 mm for RCP 8.5), and the precipitation-evaporation rate will be the same.

Temperature increase at RCP 8.5 to 5^{0}C will be by 2100 in Altai Mountains in warmest days and on warmest nights. But, the number of cold days and nights will decrease and the number of warm days and warm nights to 2100 for RCP 8.5 will increase by 40-45%. At the same time, the wettest day can increase by 5 mm/day at RCP 8.5 and daily intensity index will be an increase of almost 50 mm/year by 2100.

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