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ICEREG

Report on the climate change modelling in Latvia and Lithuania

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LVĢMC

LIETUVOS ENERGETIKOS INSTITUTAS

Lietuvos hidrometeorologijos tarnyba

Contents

Abbreviations

CMIP	Coupled Model Intercomparison Project
ICEREG	Project LL-00136 “Ice-jam flood risk management in Latvian and Lithuanian regions with respect to climate change”
LEGMC	Latvian Environment, Geology and Meteorology Centre
NDD	Negative degree day
PDD	Positive degree day
SSP2-4.5	Moderate climate change scenario
SSP3-7.0	Significant climate change scenario

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1. Introduction

In the frame of the project “Ice-jam flood risk management in Latvian and Lithuanian regions with respect to climate change” (ICEREG, LL-00136) financed by the Interreg V-A Latvia–Lithuania Programme 2021–2027, the "Report on climate change modelling in Latvia and Lithuania" was developed on the basis of historical climate information and the CMIP6 models based on the following climate model scenarios:

- SSP2-4.5 – a scenario representing "moderate" climate change,
- SSP3-7.0 – a scenario representing "significant" climate change.

ICEREG project generated ensemble climate simulations of future climate with direct applications to the impacts on river ice regime, namely to the ice-jam formation for local communities and decision-making in Latvia and Lithuania.

The most detailed simulations of the project area future climate were generated.

ICEREG project used a dynamic downscaling method to generate climate projections over the pilot regions.

2. Data and methodology

In the analysis of past climate change, daily homogenized air temperature and precipitation data from LEGMC and Lithuanian meteorological stations were used. To assess changes over time, two climate normal periods were compared: the reference period from 1961 to 1990, and the current climate norm period from 1991 to 2020.

In the analysis of the future climate change, a numerical model analysis was conducted using CMIP6 (CMIP Overview – Coupled Model Intercomparison Project, 2023) models based on the following climate model scenarios:

- SSP2-4.5 – a scenario representing "moderate" climate change,
- SSP3-7.0 – a scenario representing "significant" climate change.

Initially, 47 models for mean air temperature and 48 models for atmospheric precipitation were downloaded. Models that did not have available data for both past and future climate changes, or whose examined time period was shorter than required (e.g., not extending to the end of the 21st century), were excluded.

To determine which downloaded models could successfully characterize future climate changes, data-driven conclusions were made about their ability to represent past climate. Model selection was based on a comparative analysis between the results of climate models for the past and data from the meteorological observation station network. Key evaluation criteria included:

- Data distributions,
- Differences between the climate reference period (1961–1990) and the current climate norm (1991–2020),
- Trend coefficients in the data,
- Annual and decadal moving averages,
- Consistency between past and future numerical climate models.

In the final ensemble, 24 models were used for mean air temperature and 13 for precipitation.

Each institution developing global climate models selects the resolution for their calculations based on their resources, capabilities, and needs. As a result, the downloaded models have varying spatial resolutions.

To draw conclusions about future climate changes on a local scale, it was necessary to improve the spatial resolution of these models. All model data were bilinearly interpolated onto a 5x5 km rectangular grid covering the area.

Models also differ in temporal coverage. Some global climate models use a 365-day calendar, ignoring leap years and February 29, while others use a 360-day calendar with all months consisting of 30 days. To standardize the model calendars, missing values were linearly interpolated using data from the preceding and following days.

Climate models calculate not only future but also past climate conditions. By comparing model results with actual observations, it is possible to assess the accuracy of a model for a specific region. However, every climate model differs to some extent from observations.

Errors in model calculations arise due to factors such as low resolution, simplified thermodynamic and physical processes, or incomplete knowledge of the Earth's climate system. For instance, simulated air temperature values can differ from observed values by several degrees (Ruosteenoja et al., 2016), significantly impacting subsequent calculations.

Various algorithms exist for correcting systematic model errors (bias correction). These algorithms use observational data to adjust model results to align with local climatic conditions.

In this project, climate model outputs were adjusted to local climatic conditions using interpolated meteorological station data with the Kriging interpolation method on a 5x5 km grid. Historical observations were compared with the simulated historical values from climate models to estimate systematic model errors. These adjustments were then applied to improve future projections.

Several bias correction methods were used: detrended quantile mapping, quantile delta mapping and linear scaling (Cannon et al., 2015). In case of projections for Latvia, quantile delta mapping was applied to air temperature, while both methods were used for precipitation. Bias correction was applied on a monthly basis using the *BiasAdjustCXX* command-line tool (Schwertfeger et al., 2023). In the case of Lithuania, detrended quantile mapping was used for bias corrections on the day of the year basis for both air temperature and precipitation. Detrended quantile mapping was applied using Python package *xclim* (Bourgault et al., 2023).

Linear scaling aligns simulated historical monthly averages with observed ones by calculating the mean difference between observed and simulated historical values and adding this difference to simulated future values (Teutschbein & Seibert, 2012).

Quantile delta mapping is based on statistical distributions. Monthly correction functions align the quantile distributions of observed and simulated datasets. These functions are used to transform simulated future values, with projected quantile differences between the historical (calibration) and future periods added to the transformed values (Tong et al., 2021).

To describe climate change processes and assess potential impacts on the river ice regime and ice-jam formation, the following climate indices were calculated for the selected river areas:

- Mean monthly air temperature,
- Mean air temperature for the November–April season,
- Negative degree day (NDD – days with daily average air temperature below 0 °C) count in November–April,
- NDD temperature sum in November–April,

- Positive degree day (PDD – days with daily average temperature above 0 °C) count in November–April,
- PDD temperature sum in November–April,
- Mean monthly precipitation amount,
- Mean precipitation amount for the November–April season.

Each climate index based on future climate models is represented by the ensemble mean value of the climate models used in the project.

3. Projections of air temperature indices and precipitation amount

Long-term regime changes in region rivers indicate that due to climate change, the ice season is becoming shorter (Stonevicius et al., 2008; Šarauskienė et al., 2024), indicating that climate change plays a significant role in river ice regime and ice-jam formation.

The projection for both Latvian and both Lithuanian river sections analyzed in this report shows similar tendencies because the rivers analyzed are located in relatively close proximity. But even so, the values of precipitation amount and air temperature indices are different; consequently, we present the projections of main factors for the ice-jam formation process in all four river sections separately.

3.1. Daugava River: between river tributaries Nereta and Aiviekste

3.1.1. Mean air temperature

Comparing the reference period (1961–1990) with the climatic norm period (1991–2020), the average November–April air temperature in Daugava River (between tributaries Nereta and Aiviekste) has increased by 1.6 °C, from –2.0 °C to –0.4 °C.

Future climate model projections show that air temperature will continue to rise throughout the 21st century (Fig. 3.1.1.1), reaching +1.9 [±1.0] °C and 3.1 [±0.8] °C under moderate (SSP2-4.5) and significant (SSP3-7.0) climate change by the end of the century, which would be an 2.3 °C or 3.5 °C increase relative to 1991–2020.

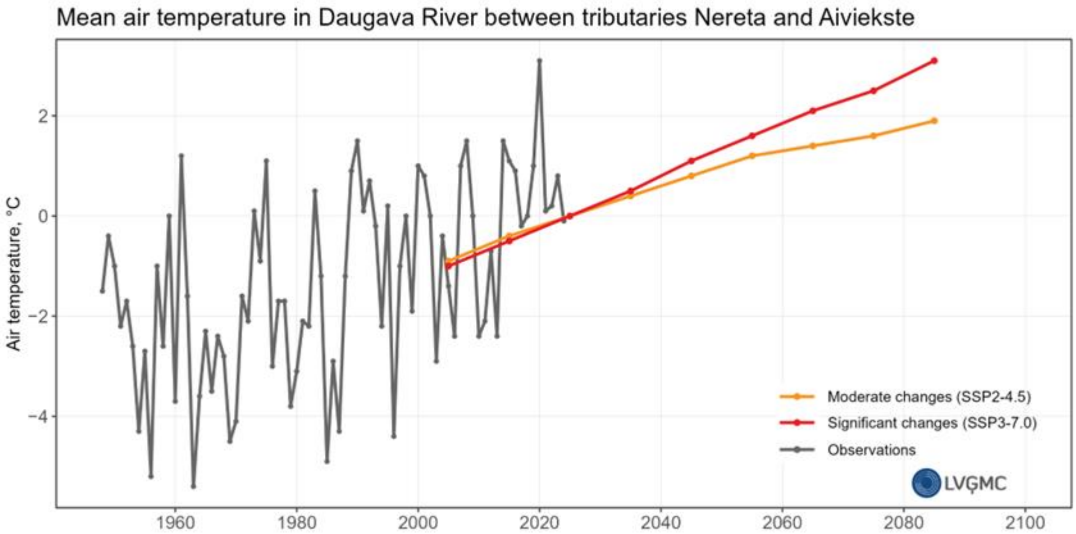

Figure 3.1.1.1. The average November–April air temperature in Daugava River between tributaries Nereta and Aiviekste from 1948 (observational data) to 2100 (climate model scenarios SSP2-4.5 and SSP3-7.0 data)

Mean air temperature of all months except November and April are negative in both the reference and the climate normal period, the coldest months being January and February. Monthly air temperatures increased by 0.7–2.5 °C between 1961–1990 and 1991–2020, with January experiencing the largest increase and November – the smallest.

Mean monthly air temperature will increase under both climate change scenarios, with only January and February remaining negative on average by the end of the century. The largest increase relative to 1991–2020 is predicted for November under moderate climate change (2.5 °C increase), and for December and February under significant climate change (3.8 °C increase) (Fig. 3.1.1.2).

The warming trend observed in seasonal mean temperature is also apparent when looking at only the coldest of winters (Fig. 3.1.1.3). The mean temperature of the coldest 25% and 10% winters has increased by 1.6 °C and 1.9 °C respectively.

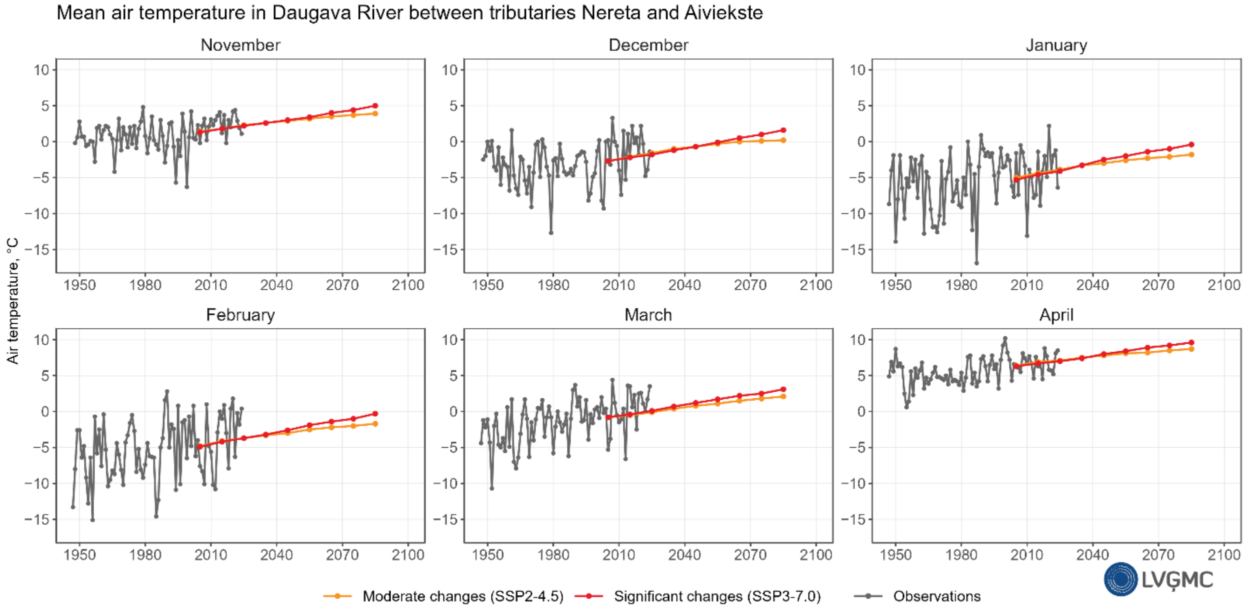

Figure 3.1.1.2. The average monthly air temperature in Daugava River between tributaries Nereta and Aiviekste from 1948 (observational data) to 2100 (climate model scenarios SSP2-4.5 and SSP3-7.0 data)

Future climate model projections suggest that warming will continue. The coldest 25% of winters are expected to warm by 2.8–4.0 °C, while the coldest 10% by 2.6–3.7 °C. In any scenario, the coldest of winters in the future will be warmer than typical winters now, and their mean temperature will be positive.

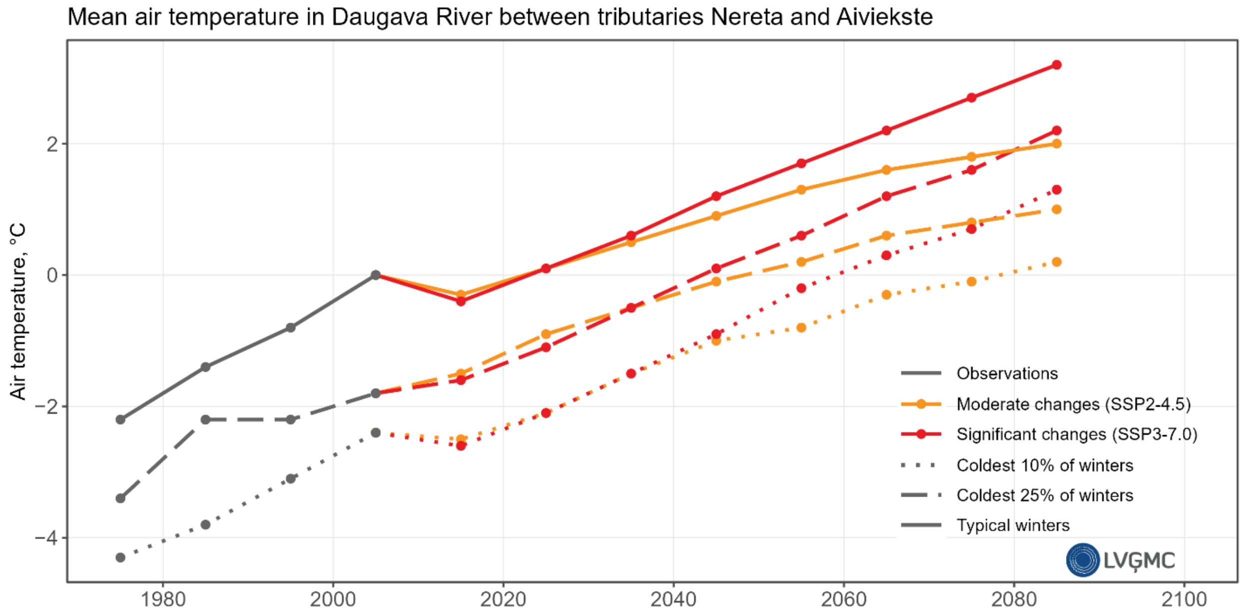

Figure 3.1.1.3. The average November–April air temperature of typical, coldest 25% and coldest 10% of winters in Daugava River between tributaries Nereta and Aiviekste from 1948 (observational data) to 2100 (climate model scenarios SSP2-4.5 and SSP3-7.0 data)

While climate models suggest a long-term warming trend, natural variability will continue to result in occasional colder winters. However, the frequency and intensity of extremely cold winters are projected to decline, reinforcing the observed trend towards a milder winter climate in the Daugava River region between Nereta and Aiviekste.

3.1.2. Negative degree days (NDDs)

The November–April negative degree days (NDDs), an indicator of winter severity and ice formation in the Daugava River region, have shown a significant decline over time, reflecting ongoing warming trends. During the normal period of 1991–2020, the average NDD sum was 469.7 °C, a substantial decrease compared to the reference period of 1961–1990, which recorded an average NDD of 657.8 °C. This represents a reduction of 188.1 °C due to the overall warming trend.

Future climate projections under the SSP2-4.5 and SSP3-7.0 scenarios suggest an even more dramatic decline in NDDs (Fig. 3.1.2.1). By 2071–2100, the projected declines result in an average NDD of 260.5 [±73.5] °C under moderate and 177.5 [±55.7] °C under significant climate change, representing reductions of 209.2 °C and 292.2 °C relative to the normal period, respectively.

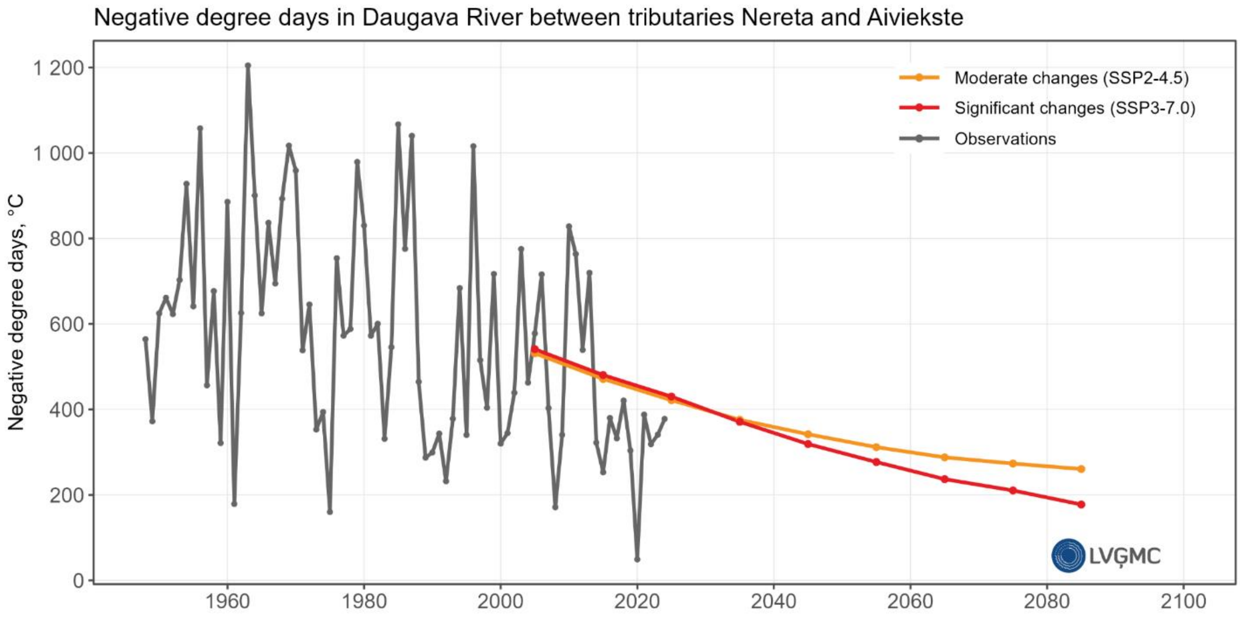

Figure 3.1.2.1. The November–April negative degree days (NDD) in Daugava River tributaries Nereta and Aiviekste from 1948 (observational data) to 2100 (climate model scenarios SSP2-4.5 and SSP3-7.0 data)

The monthly breakdown reveals the most significant reductions in NDDs occur in the coldest months – December, January, and February (Fig. 3.1.2.2). January, historically the coldest month, saw a decrease from 214.4 °C during 1961–1990 to 144.6 °C in 1991–2020. Projections indicate further declines to 89.3 [±27.1] °C under moderate and 63.8 [±18.9] °C under significant climate change by the end of the century.

February exhibits similar reductions, with NDDs decreasing from 173.8 °C in 1961–1990 to 132.3 °C in 1991–2020. By 2071–2100, values are projected to decline further, reaching 81.7 [±22.1] °C under moderate and 57.6 [±16.2] °C under significant climate change.

December also experiences notable declines, with NDDs dropping from 136.3 °C during the reference period to 98.8 °C in 1991–2020. Projections indicate further reductions to 49.9 [±19.2] °C and 31.5 [±16.9] °C under moderate and significant climate change by 2071–2100.

The transitional months—March, November, and April—also experience declines, but less drastic, while November and April, which already have low NDDs, are expected to see negligible values, particularly under significant change.

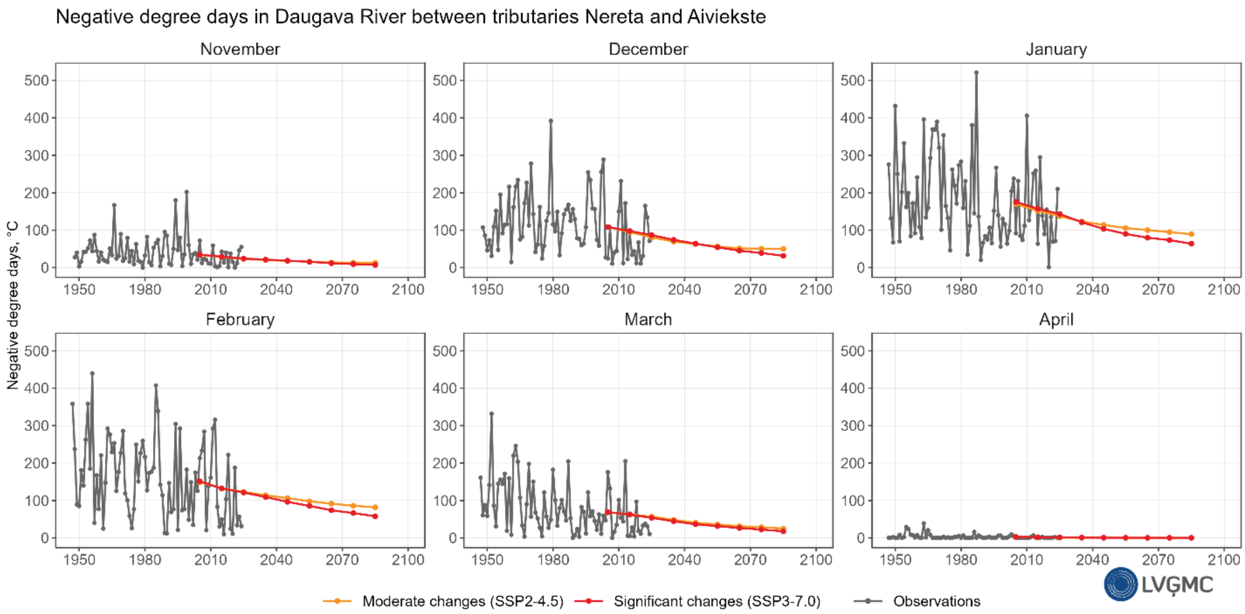

Figure 3.1.2.2. The monthly negative degree days (NDD) in Daugava River tributaries Nereta and Aiviekste from 1948 (observational data) to 2100 (climate model scenarios SSP2-4.5 and SSP3-7.0 data)

Historical records indicate that typical winters in the Daugava River region experienced an average NDD of 625.2 °C during 1961–1990, dropping to 403.6 °C by 1991–2020, a reduction of 221.6 °C. The coldest 25% of winters recorded an average NDD of 882.1 °C in the reference period, decreasing to 657.4 °C in 1991–2020, marking a decline of 224.7 °C. The coldest 10% of winters showed the most significant reduction, from 1019.3 °C to 764.6 °C, a decline of 254.7 °C (Fig. 3.1.2.3).

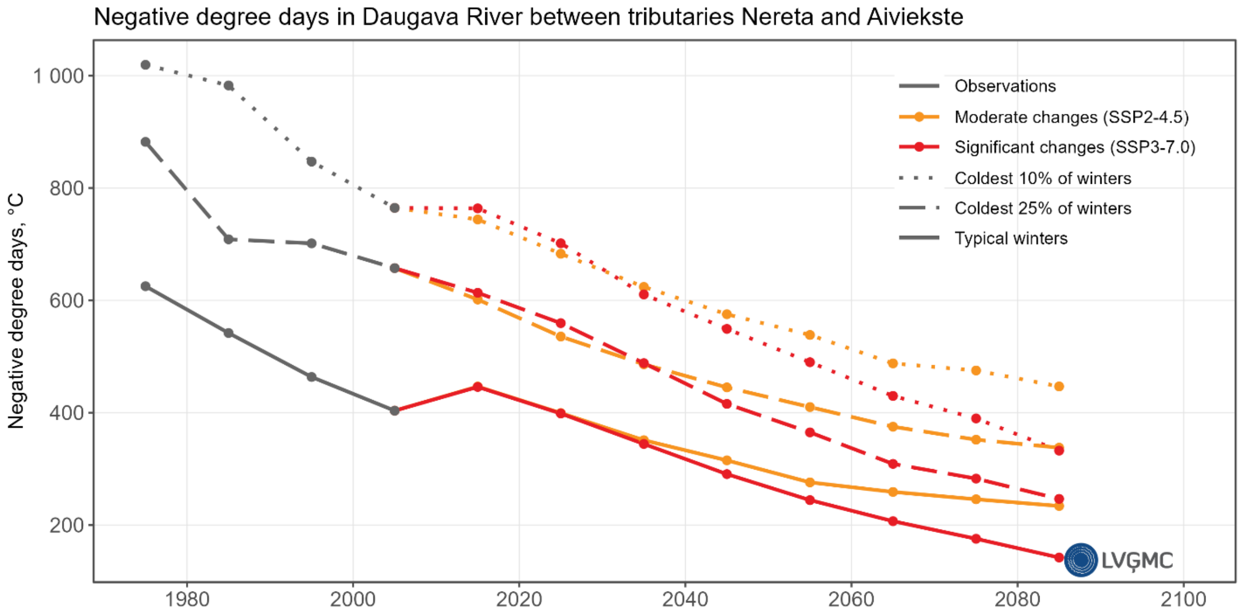

Figure 3.1.2.3. The November–April negative degree days (NDDs) of typical, coldest 25 % and coldest 10 % of winters in Daugava River tributaries Nereta and Aiviekste from 1948 (observational data) to 2100 (climate model scenarios SSP2-4.5 and SSP3-7.0 data)

Projections indicate that by 2071–2100, under SSP2-4.5, typical winters will experience an NDD decline to 234.0 [±74.0] °C, while the coldest 25% and 10% of winters will decrease to 337.8 [±100.9] °C and 446.8 [±118.3] °C, respectively. This represents reductions of 169.6 °C, 319.6 °C, and 317.8 °C compared to the normal period (1991–2020). Under significant climate change, these values are projected to decrease further, reflecting an even more pronounced warming trend.

These findings highlight a significant reduction in winter severity in the Daugava River region. The declining NDDs suggest a shift toward shorter and milder winters, reducing ice accumulation and altering the river's winter hydrology in the coming decades.

3.1.3. Number of days with negative mean air temperature

The number of days with mean air temperature below 0 °C in the Daugava River region has significantly declined due to warming trends. The seasonal average dropped from 99 days in 1961–1990 to 83 days in 1991–2020, a decrease of 16 days.

Future projections indicate further reductions (Fig. 3.1.3.1). By 2071–2100, the number of sub-zero days is expected to decline to 61 [±12] days under moderate and 46 [±11] days under significant climate change, respectively.

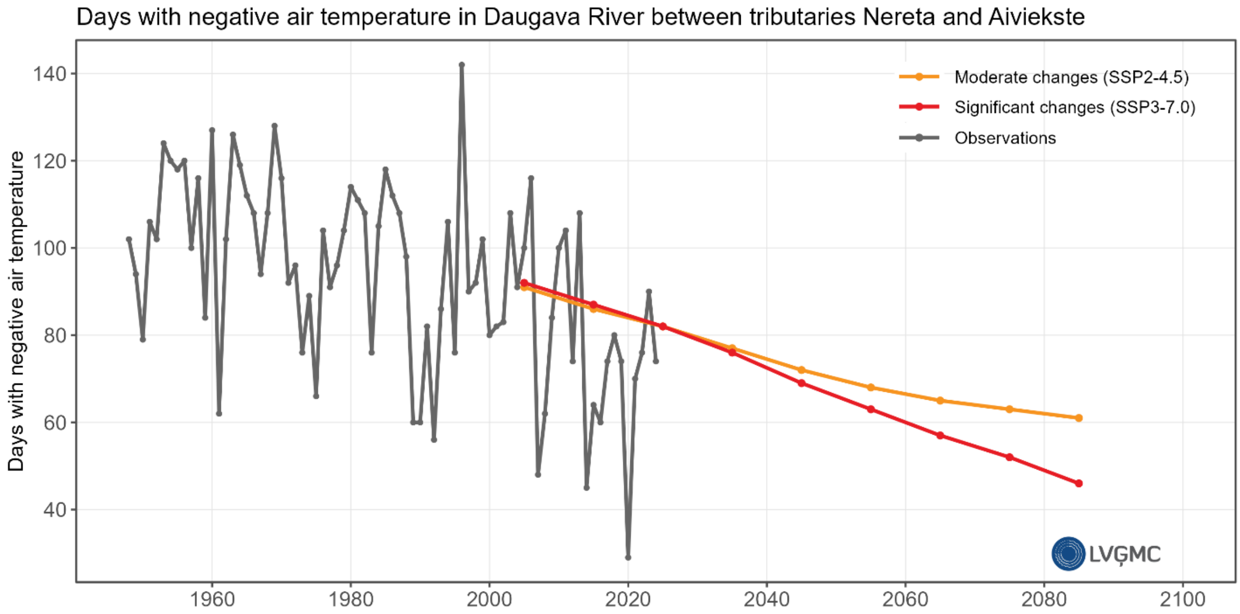

Figure 3.1.3.1. The November–April number of days with negative mean air temperature in Daugava River tributaries Nereta and Aiviekste from 1948 (observational data) to 2100 (climate model scenarios SSP2-4.5 and SSP3-7.0 data)

Monthly trends reveal the most significant declines in winter months (Fig. 3.1.3.2).

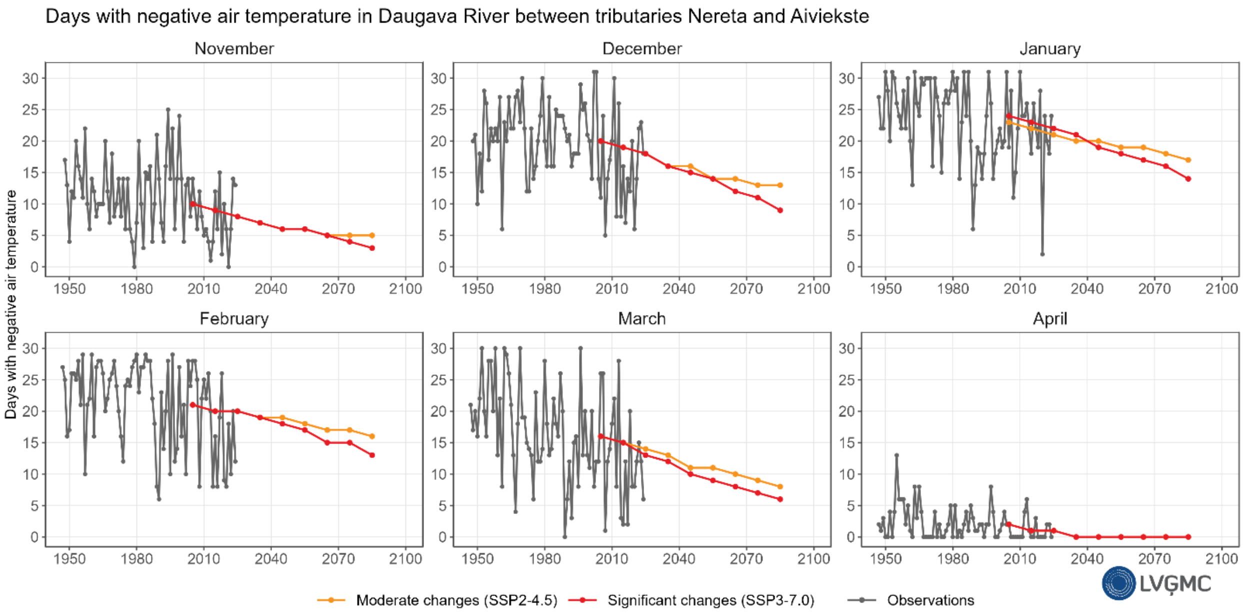

Figure 3.1.3.2. The monthly number of days with negative mean air temperature in Daugava River tributaries Nereta and Aiviekste from 1948 (observational data) to 2100 (climate model scenarios SSP2-4.5 and SSP3-7.0 data)

January and February, which previously averaged 24 and 23 sub-zero days in 1961–1990, dropped to 21 and 19 days in 1991–2020. Projections for 2071–2100 suggest further decreases to 17 and 16 days under SSP2-4.5 and 14 and 13 days under SSP3-7.0. March, which averaged 17 days in 1961–1990, is expected to drop to

8 days under moderate and 6 days under significant climate change. By the end of the century, sub-zero days in April will become nearly absent.

The decline in cold days is also reflected in winter severity. Typical winters experienced a drop from 104 days in 1961–1990 to 83 days in 1991–2020, with projections for 2071–2100 indicating a further reduction to 59 [±13] and 44 [±12] days, depending on the climate change scenario. The coldest 10% of winters are expected to decline from 108 days in the 1991–2020 period to 85 [±14] days and 71 [±12] days under moderate and significant climate change (Fig. 3.1.3.3).

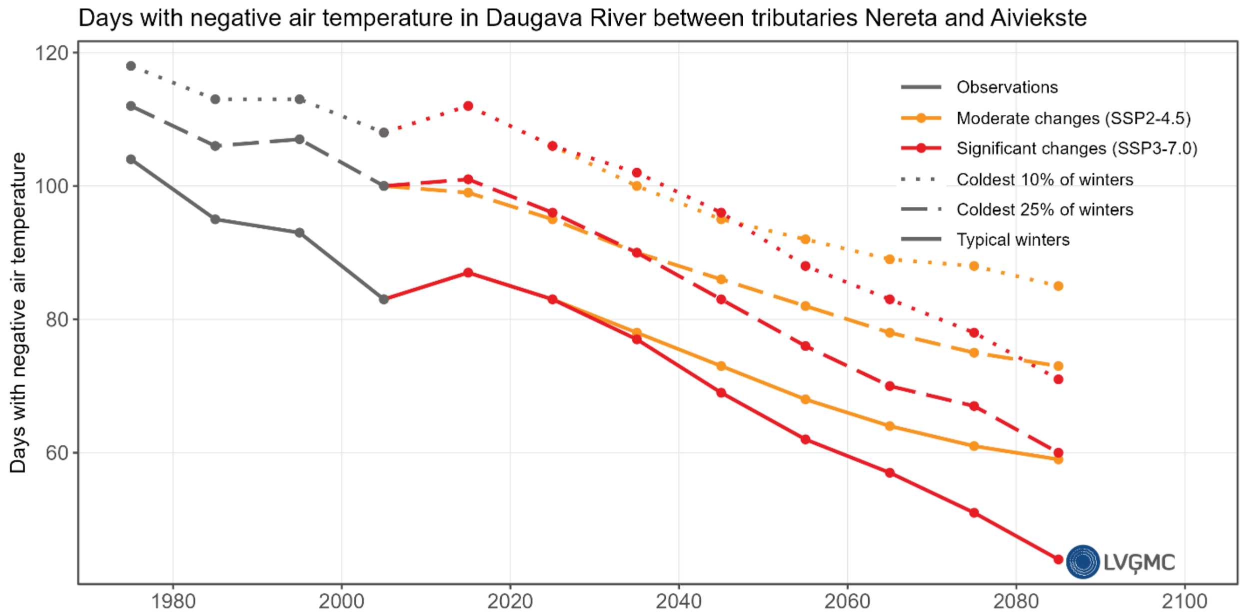

Figure 3.1.3.3. The November–April number of days with negative mean air temperature of typical, coldest 25 % and coldest 10 % of winters in Daugava River tributaries Nereta and Aiviekste from 1948 (observational data) to 2100 (climate model scenarios SSP2-4.5 and SSP3-7.0 data)

These findings highlight a continued shift towards shorter, milder winters, reducing ice accumulation and altering the winter hydrology of the Daugava River in the coming decades.

3.1.4. Positive degree days (PDDs)

Positive Degree Days (PDDs), an indicator of accumulated warmth, have significantly increased in the Daugava River region, reflecting ongoing warming trends. During the reference period (1961–1990), the average November–April PDD sum was 286.0 °C, rising to 400.3 °C in 1991–2020, an increase of 114.3 °C.

Future projections indicate continued increases under both climate scenarios (Fig. 3.1.4.1). PDDs are projected to cross 500.0 °C by mid-century, rising further to 596.6 [±129.2] °C and 737.8 [±110.5] °C under moderate and significant climate change, respectively, by the end of the century.

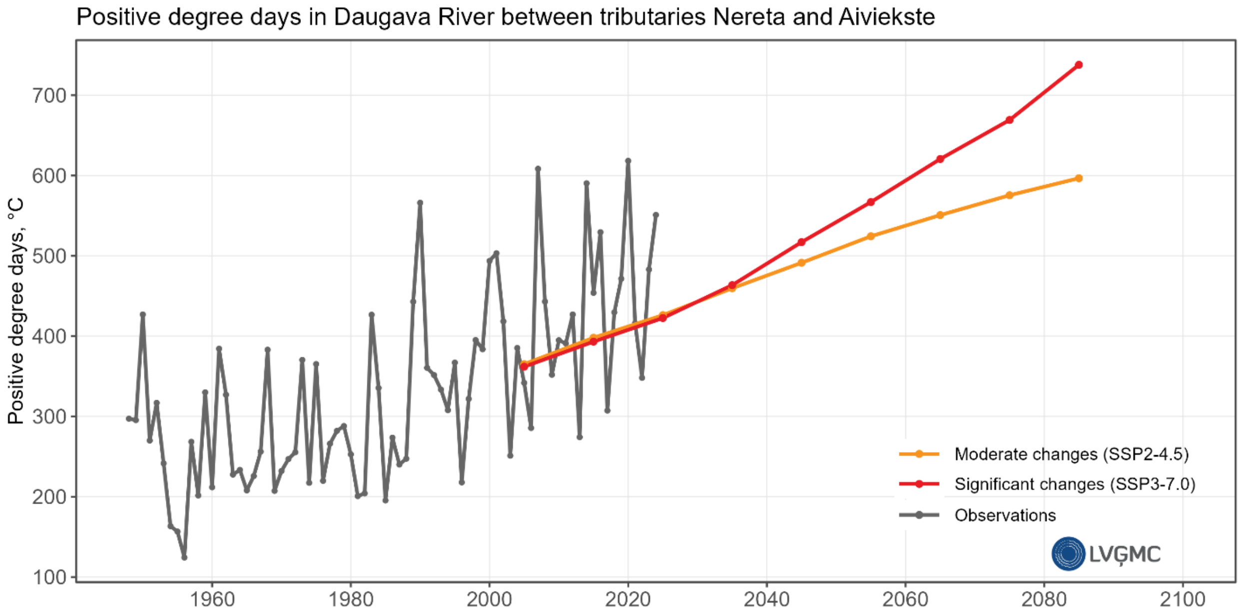

Figure 3.1.4.1. The November–April positive degree days (PDD) in Daugava River tributaries Nereta and Aiviekste from 1948 (observational data) to 2100 (climate model scenarios SSP2-4.5 and SSP3-7.0 data)

Monthly trends show the most significant increases in early spring (Fig. 3.1.4.2). April PDDs rose from 154.2 °C in 1961–1990 to 202.1 °C in 1991–2020 and are projected to reach 288.6 [±23.3] °C by the end of the century under significant climate change. March follows a similar pattern, with PDDs expected to more than double compared to the normal period. Even traditionally cold months, January and February, show notable increases, with February PDDs projected to rise from 8.0 °C in 1961–1990 to 48.0 [±14.3] °C by 2071–2100 under significant climate change.

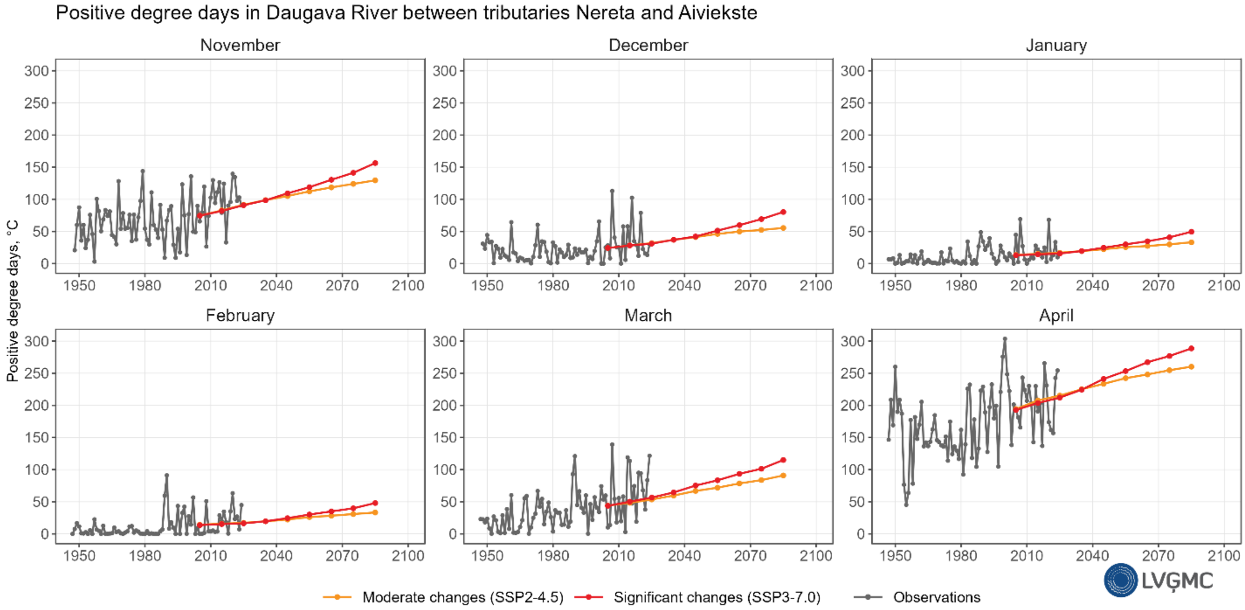

Figure 3.1.4.2. The monthly positive degree days (PDD) in Daugava River tributaries Nereta and Aiviekste from 1948 (observational data) to 2100 (climate model scenarios SSP2-4.5 and SSP3-7.0 data)

The rise in PDDs is evident across all winter severity categories (Fig. 3.1.4.3). Typical winters recorded an average of 255.4 °C during 1961–1990, increasing to 388.0 °C in 1991–2020. By 2071–2100, this is projected to reach 740.3 [±110.5] °C under significant climate change.

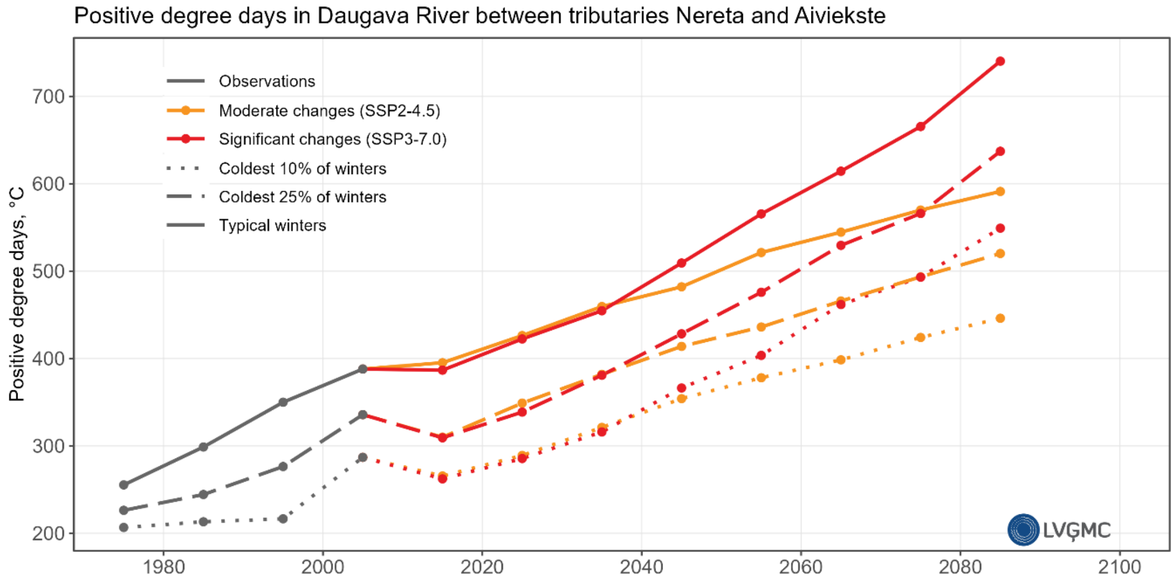

Figure 3.1.4.3. The November–April positive degree days (PDD) of typical, coldest 25 % and coldest 10 % of winters in Daugava River: between tributaries Nereta and Aiviekste from 1948 (observational data) to 2100 (climate model scenarios SSP2-4.5 and SSP3-7.0 data)

3.1.5. Precipitation amount

Seasonal precipitation during the November–April period in the Daugava River region has increased over time, reflecting a trend toward wetter conditions. The reference period (1961–1990) recorded an average of 244.6 mm, rising to 255.0 mm in 1991–2020, an increase of 4%. The greatest increases were observed in January and February, with precipitation rising by 22% and 43%, respectively.

Future projections indicate further increases in both climate scenarios (Fig. 3.1.5.1). By 2071–2100, precipitation is projected to rise to 350.3 [±31.2] mm under moderate and 363.6 [±35.6] mm under significant climate change, reflecting increases of 37% and 43%, respectively.

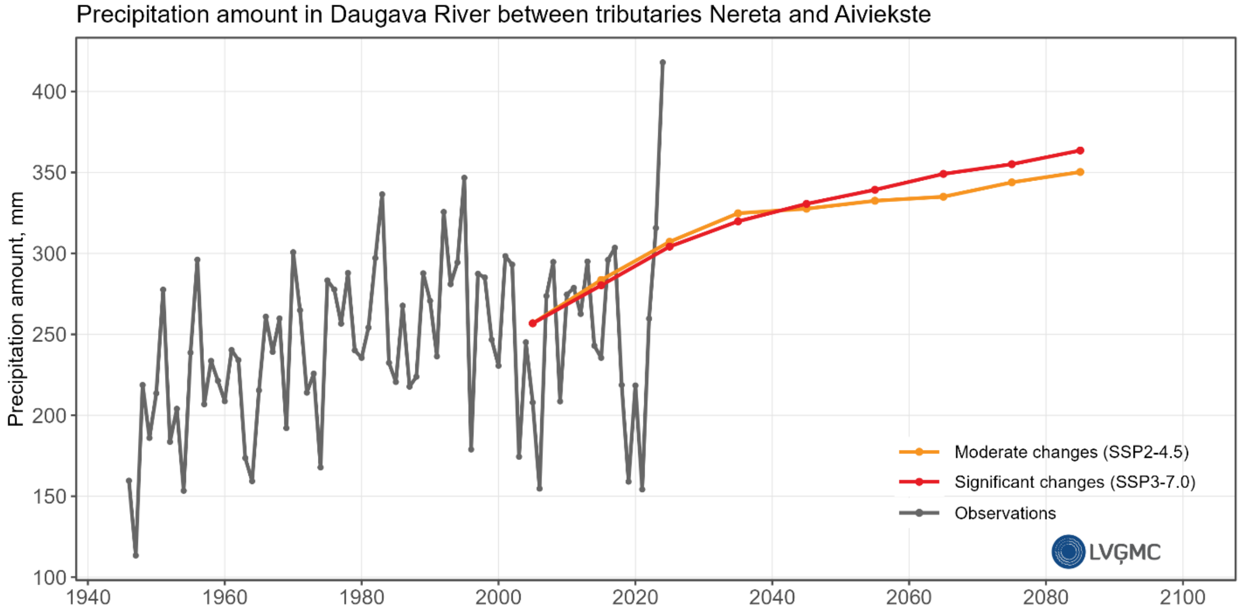

Figure 3.1.5.1. The November–April precipitation amount in Daugava River tributaries Nereta and Aiviekste from 1948 (observational data) to 2100 (climate model scenarios SSP2-4.5 and SSP3-7.0 data)

Monthly precipitation changes vary (Fig. 3.1.5.2). The largest increases are expected in April, with precipitation projected to rise from 35.5 mm in 1991–2020 to 62.0 [±8.5] mm under moderate and 62.3 [±6.4] mm under significant climate change by the late 21st century. January and February will also see notable increases, though not as large as other months, with February precipitation reaching 51.9 [±8.3] mm under significant climate change – 32% more than in 1991–2020.

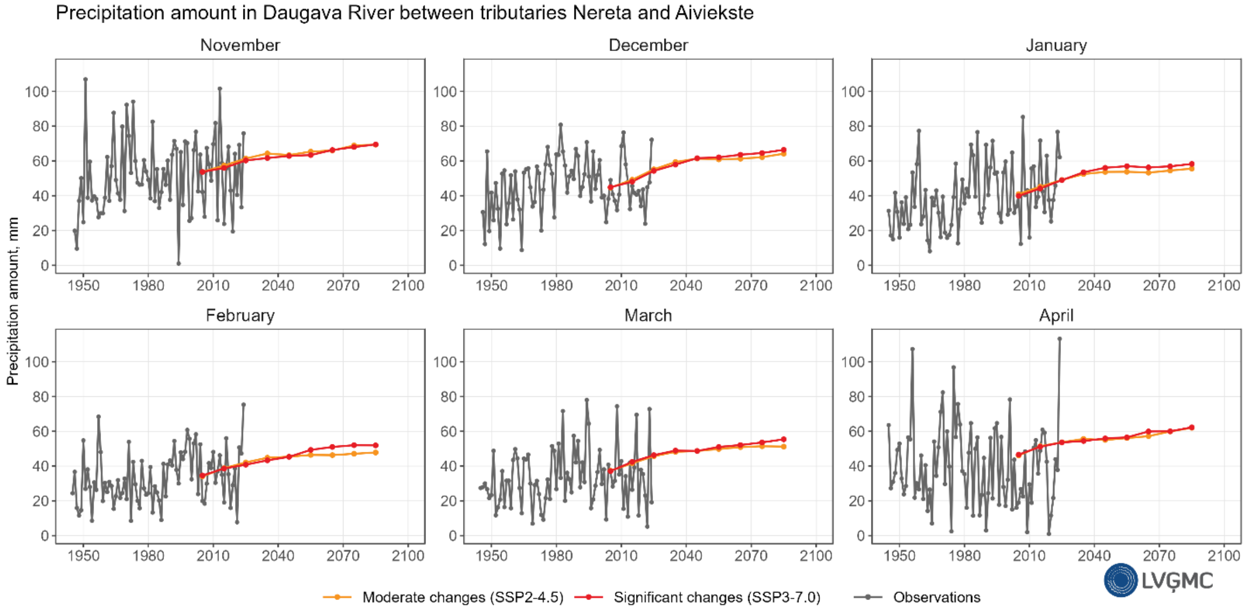

Figure 3.1.5.2. The monthly precipitation amount in Daugava River tributaries Nereta and Aiviekste from 1948 (observational data) to 2100 (climate model scenarios SSP2-4.5 and SSP3-7.0 data)

Overall, precipitation trends indicate a wetter future, with both climate scenarios suggesting a continued rise in total precipitation throughout the cold season. The increase is most evident in late winter and early spring, which may contribute to higher river discharge and altered hydrological conditions in the Daugava River region. These changes highlight the importance of considering increased winter precipitation in future water management and flood risk planning.

3.2. Lielupe River: from the confluence of Musa and Memele rivers to the junction with Sesava River

3.2.1. Mean air temperature

Comparing the reference period (1961–1990) with the climatic normal period (1991–2020), the average November–April air temperature in Lielupe River from the confluence of Mūsa and Mēmele rivers to the junction with Sesava River has increased by 1.5 °C, from –1.0 °C to +0.5 °C.

Future climate projections indicate continued warming (Fig. 3.2.1.1), reaching 2.6 [±1.0] °C under moderate and 3.8 [±0.8] °C under significant climate change by the end of the century, an increase of 2.1 °C and 3.3 °C, respectively, relative to 1991–2020.

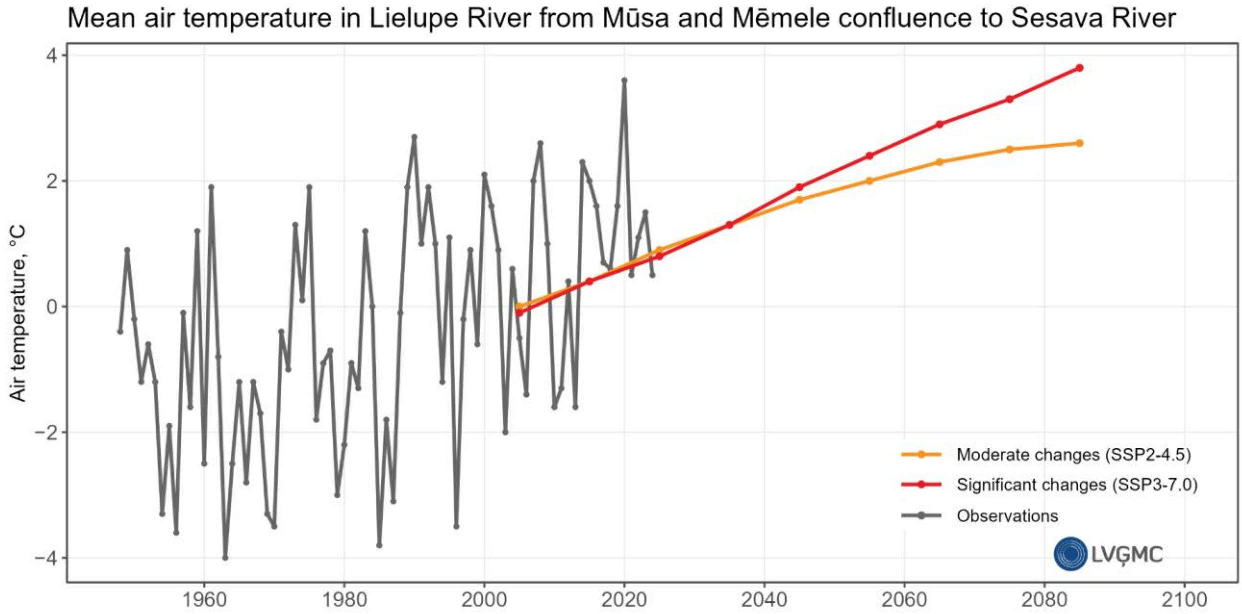

Figure 3.2.1.1. The average November–April air temperature in Lielupe River from the confluence of Musa and Memele rivers to the junction with Sesava River from 1948 (observational data) to 2100 (climate model scenarios SSP2-4.5 and SSP3-7.0 data)

Mean air temperatures in December–February were negative in both the reference and normal periods, with January and February being the coldest months. Monthly temperatures increased by 0.7–2.3 °C from 1961–1990 to 1991–2020, with January experiencing the largest increase. By 2071–2100, under moderate climate change, only January and February will remain negative, while under significant climate change, all months on average will be above 0 °C. The largest increase relative to 1991–2020 is expected for December under significant warming (3.7 °C increase) (Fig. 3.2.1.2).

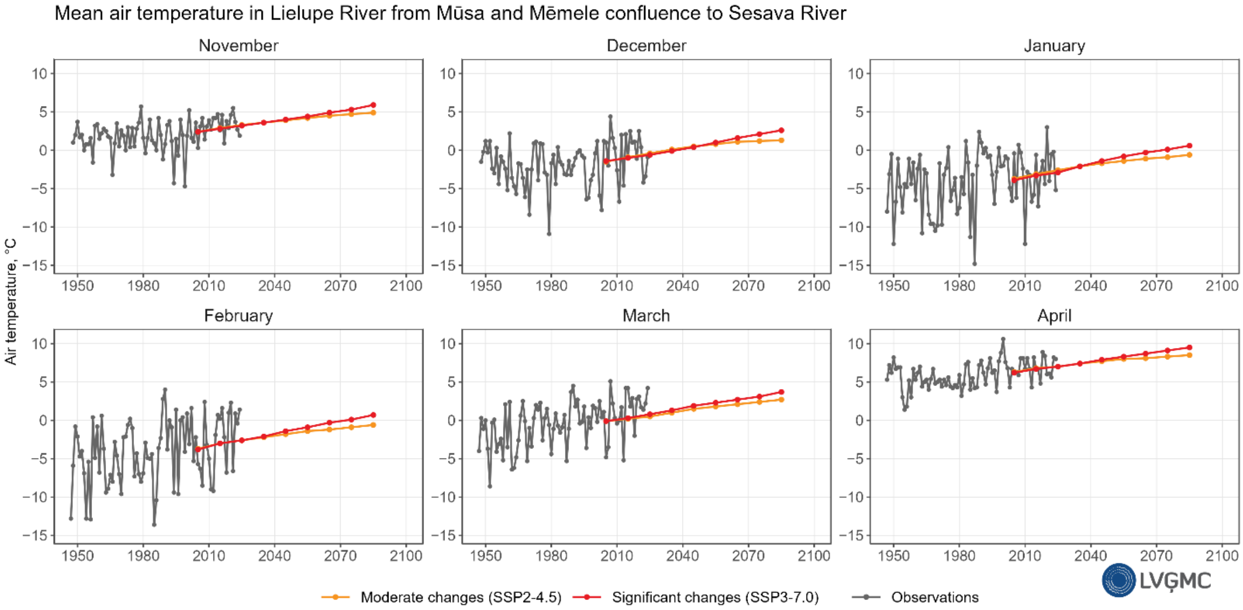

Figure 3.2.1.2. The average monthly air temperature in Lielupe River from the confluence of Musa and Memele rivers to the junction with Sesava River from 1948 (observational data) to 2100 (climate model scenarios SSP2-4.5 and SSP3-7.0 data)

The warming trend is also evident in coldest winters. The coldest 10% of winters warmed by 1.8 °C between the reference and normal periods, from −3.4 °C to −1.6 °C. By 2071–2100, these will warm to +1.0 [±1.2] °C under moderate and to +2.1 [±0.8] °C under significant climate change relative to 1991–2020. The coldest 25% of winters in the Lielupe River region have so far warmed by 1.9 °C and are also expected to warm by 2.5–3.6 °C by the end of the century, becoming positive (Fig. 3.2.1.3).

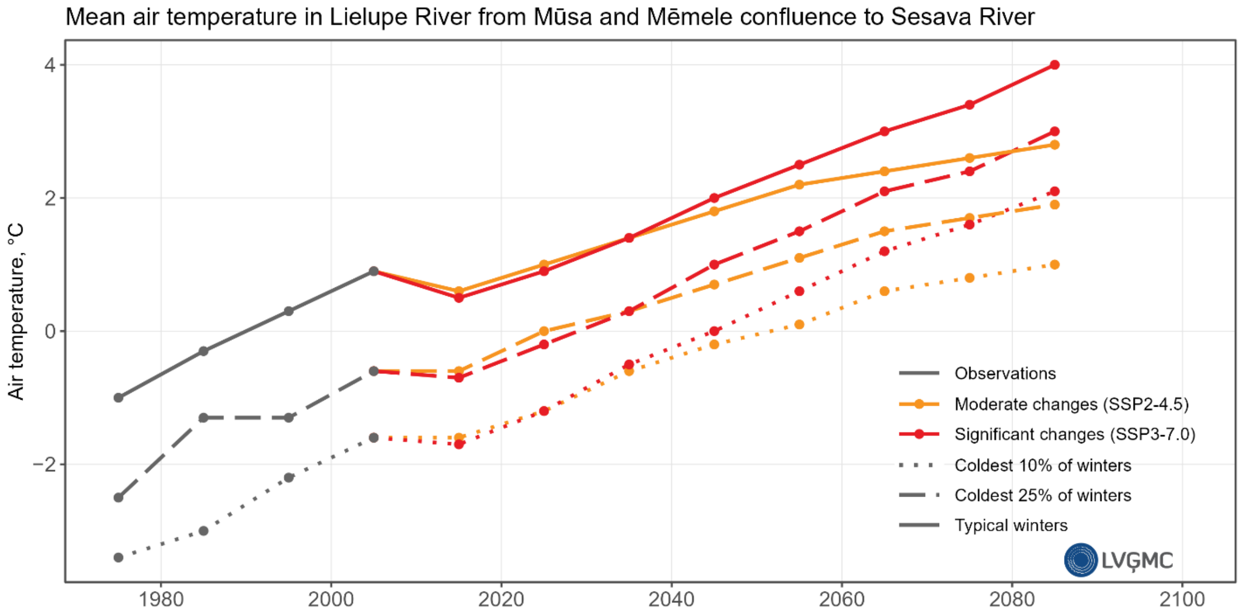

Figure3.2.1.3. The average November–April air temperature of typical, coldest 25 % and coldest 10 % of winters in Lielupe River: from the confluence of Musa and Memele rivers to the junction with Sesava River from 1948 (observational data) to 2100 (climate model scenarios SSP2-4.5 and SSP3-7.0 data)

While natural variability will still bring occasional colder winters, their frequency and intensity will decrease, reinforcing the trend towards milder winters in the Lielupe River region.

3.2.2. Negative degree days (NDDs)

The November–April negative degree days (NDDs), an indicator of winter severity and ice formation, have declined significantly in the Lielupe River region. The average NDD dropped from 526.1 °C (1961–1990) to 366.4 °C (1991–2020), a reduction of 159.7 °C.

By 2071–2100, NDDs are projected to decline further to 194.1 [±60.2] °C under moderate and 129.2 [±44.5] °C under significant climate change, marking a significant reduction compared to historical values (Fig. 3.2.2.1).

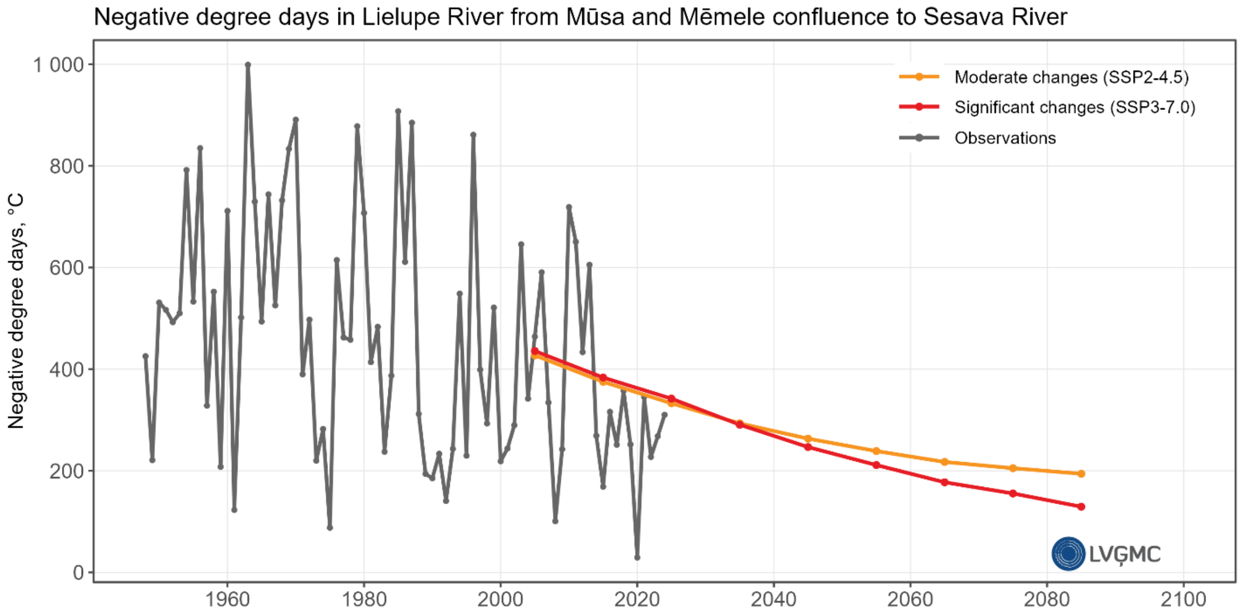

Figure 3.2.2.1. The November–April negative degree days (NDD) in Lielupe River from the confluence of Musa and Memele rivers to the junction with Sesava River from 1948 (observational data) to 2100 (climate model scenarios SSP2-4.5 and SSP3-7.0 data)

The largest reductions occur in December, January, and February. January NDDs declined from 172.8 °C (1961–1990) to 115.8 °C (1991–2020), with projections falling to 67.3 [±23.1] °C (SSP2-4.5) and 47.2 [±15.3] °C (SSP3-7.0) by 2071–2100. February follows a similar trend, decreasing from 145.3 °C to 105.0 °C, with projections dropping further to 42.9 [±15.1] °C (SSP3-7.0). December NDDs are also projected to decline significantly (Fig. 3.2.2.2).

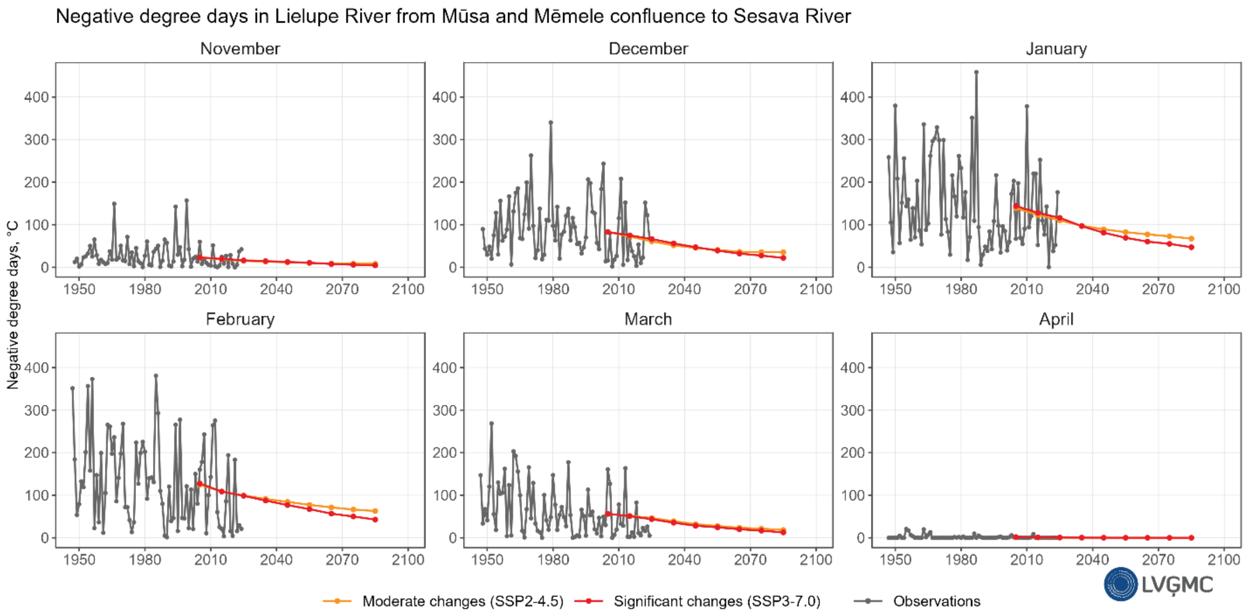

Figure 3.2.2.2. The monthly negative degree days (NDD) in Lielupe River from the confluence of Musa and Memele rivers to the junction with Sesava River from 1948 (observational data) to 2100 (climate model scenarios SSP2-4.5 and SSP3-7.0 data)

The coldest 10% of winters saw NDDs drop from 883.5 °C (1961–1990) to 646.0 °C (1991–2020). Projections for 2071–2100 under the most severe climate change scenario SSP3-7.0 indicate a decline to 260.2 [±80.5] °C. The coldest 25% of winters show a similar trend, dropping from 727.6 °C to 506.8 °C, with further declines projected under significant climate change (Fig. 3.2.2.3).

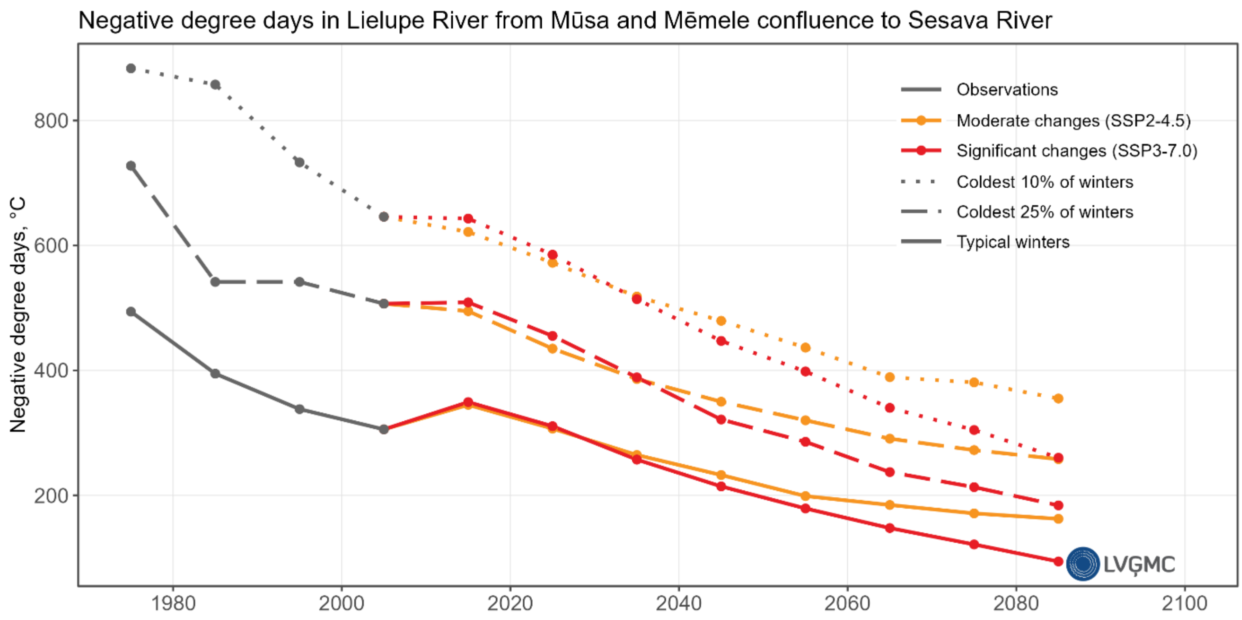

Figure 3.2.2.3. The November–April negative degree days (NDDs) of typical, coldest 25 % and coldest 10 % of winters in Lielupe River from the confluence of Musa and Memele rivers to the junction with Sesava River from 1948 (observational data) to 2100 (climate model scenarios SSP2-4.5 and SSP3-7.0 data)

The Lielupe River region is experiencing shorter, milder winters, with reductions in key winter months by late century. These changes will significantly impact ice cover formation and winter hydrology, reinforcing the ongoing warming trend.

3.2.3. Number of days with negative mean air temperature

The number of days with mean air temperature below 0 °C in the Lielupe River region has declined due to warming trends. The seasonal average dropped from 86 days in 1961–1990 to 71 days in 1991–2020, a loss of 15 days.

Future projections indicate continued reductions (Fig. 3.2.3.1). By 2071–2100, the number of sub-zero days is expected to decline to 47 [±10] days (moderate change) and 35 [±9] days (significant change), a decrease of up to 36 days from the normal period.

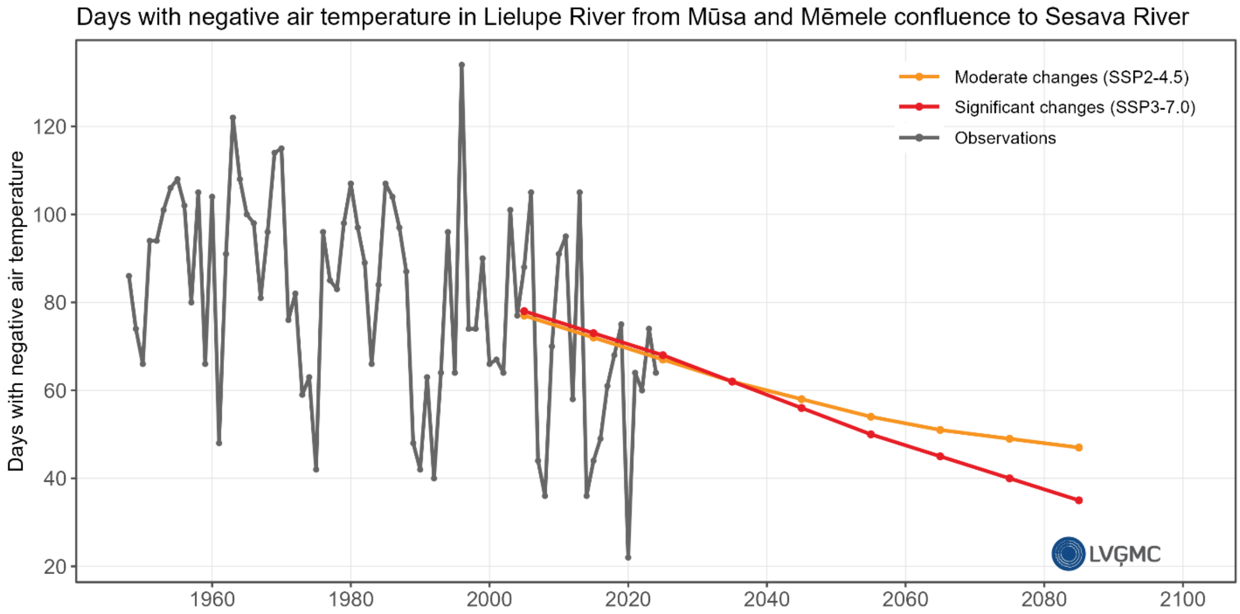

Figure 3.2.3.1. The November–April number of days with negative mean air temperature in Lielupe River from the confluence of Musa and Memele rivers to the junction with Sesava River from 1948 (observational data) to 2100 (climate model scenarios SSP2-4.5 and SSP3-7.0 data)

The largest declines occur in December–February. January decreased from 22 days (1961–1990) to 18 days (1991–2020), with projections for 2071–2100 showing a further decrease to 14 [±3] days (moderate change) and 11 [±2] days (significant change). February follows a similar trend, decreasing from 21 days to 17 days, with projections reaching 13 [±3] days (moderate change) and 10 [±3] days (significant change) by 2071–2100. Other months see similar declines, but April has no sub-zero days in the future at all (Fig. 3.2.3.2).

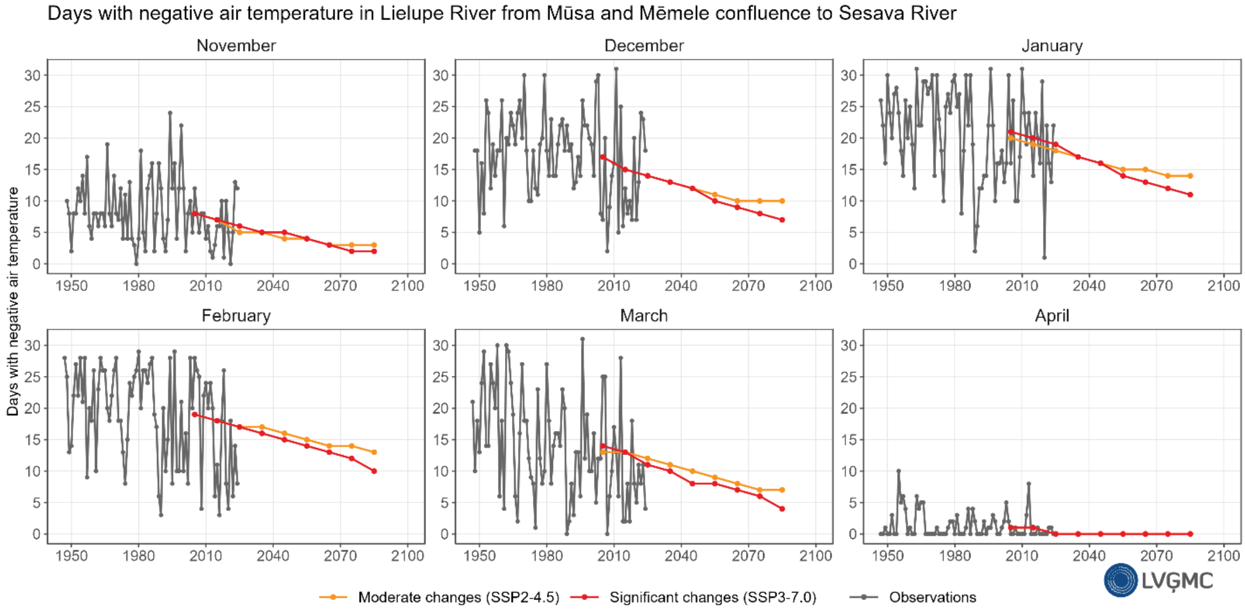

Figure 3.2.3.2. The monthly number of days with negative mean air temperature in Lielupe River from the confluence of Musa and Memele rivers to the junction with Sesava River from 1948 (observational data) to 2100 (climate model scenarios SSP2-4.5 and SSP3-7.0 data)

The coldest 10% of winters saw a reduction from 109 days (1961–1990) to 101 days (1991–2020), with projections for 2071–2100 under significant climate change dropping to 59 [±12] days. The coldest 25% of winters also declined from 100 days to 89 days, with projections under significant climate change showing further reductions to 47 [±11] days (Fig. 3.2.3.3).

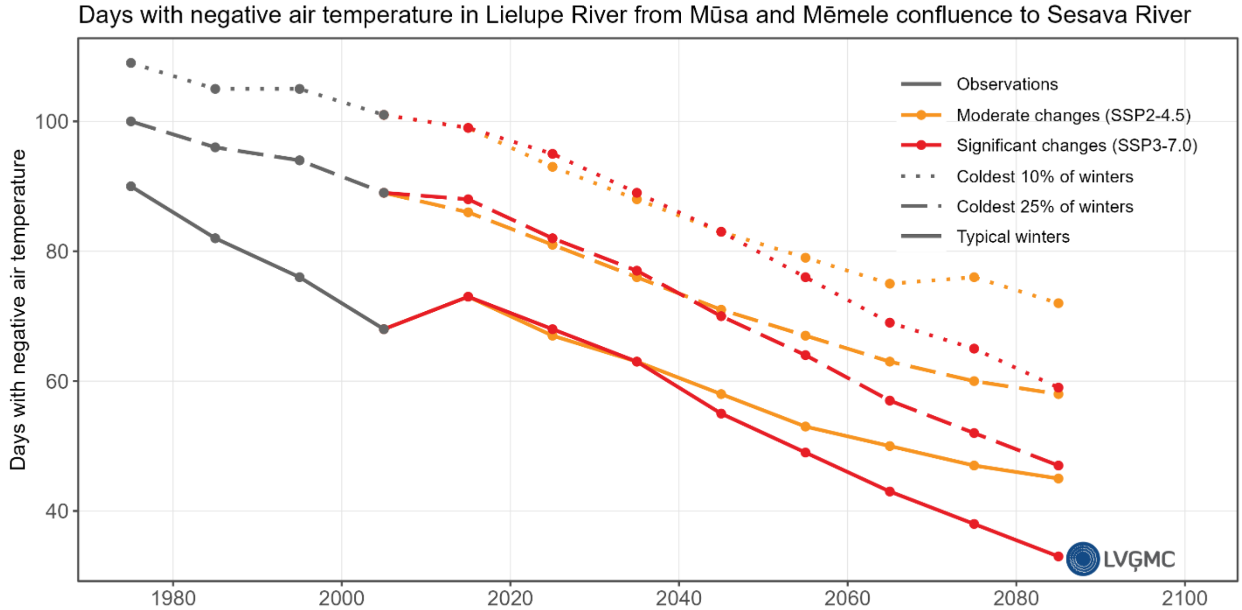

Figure 3.2.3.3. The November–April number of days with negative mean air temperature of typical, coldest 25 % and coldest 10 % of winters in Lielupe River from the confluence of Musa and Memele rivers to the junction with Sesava River from 1948 (observational data) to 2100 (climate model scenarios SSP2-4.5 and SSP3-7.0 data)

The Lielupe River region is experiencing shorter, milder winters, with more sub-zero days by the late century. The declining number of cold days will also contribute to a reduction in negative degree days (NDDs), limiting ice accumulation and altering seasonal freeze-thaw cycles in the river system.

3.2.4. Positive degree days (PDDs)

The Positive Degree Days (PDDs) in the Lielupe River region have increased significantly, reflecting the ongoing warming trend. During the 1961–1990 reference period, the mean PDDs for November–April averaged 339.6 °C. By 1991–2020, this value had risen to 461.5 °C, an increase of 121.9 °C.

Future projections suggest continued increases under both climate change scenarios (Fig. 3.2.4.1). By 2071–2100, PDDs are projected to increase to 674.7 [±134.2] °C (SSP2-4.5) and 825.1 [±112.5] °C (SSP3-7.0), marking a rise of 363.6°C from the normal period.

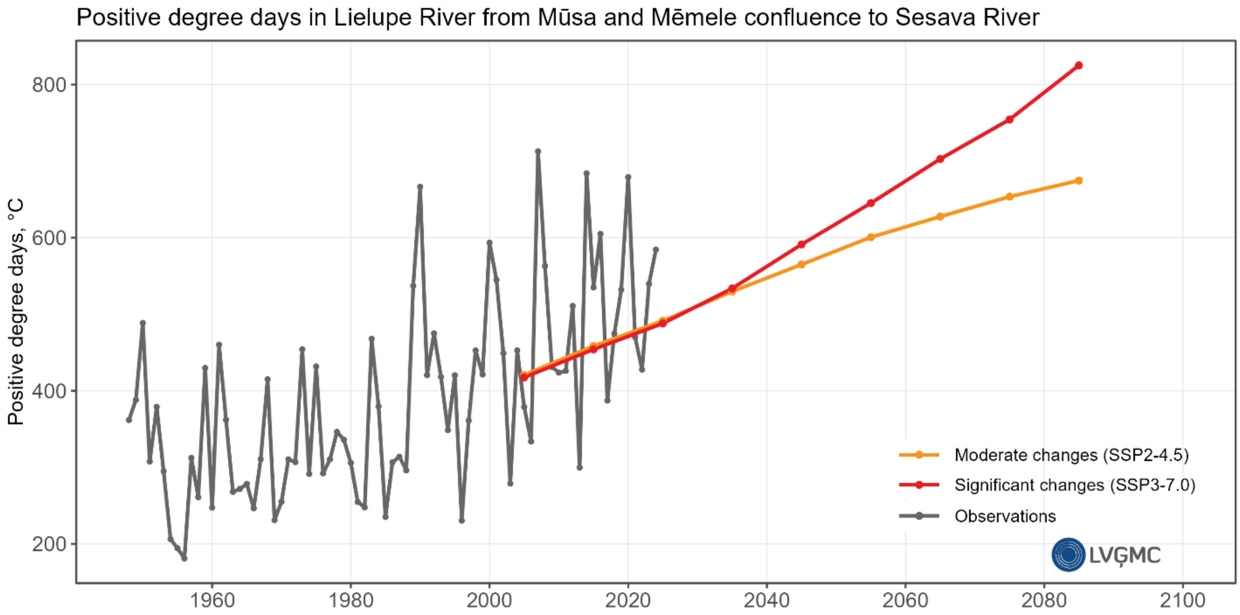

Figure 3.2.4.1. The November–April positive degree days (PDD) in Lielupe River from the confluence of Musa and Memele rivers to the junction with Sesava River from 1948 (observational data) to 2100 (climate model scenarios SSP2-4.5 and SSP3-7.0 data)

Monthly PDDs have increased across all cold-season months. November rose from 80.9 °C (1961–1990) to 96.6 °C (1991–2020), with projections reaching 153.9 [±28.9] °C and 181.0 [±32.5] °C under moderate and significant climate change by 2071–2100. January and February saw respective increases from 15.5 °C and 13.2 °C (1961–1990) to 27.8 °C and 26.1 °C (1991–2020), with further projected rises to 48.4 [±17.6] °C and 44.9 [±16.8] °C (moderate change), and 67.5 [±15.5] °C and 62.9 [±15.6] °C (significant change) by 2071–2100 (Fig. 3.2.4.2).

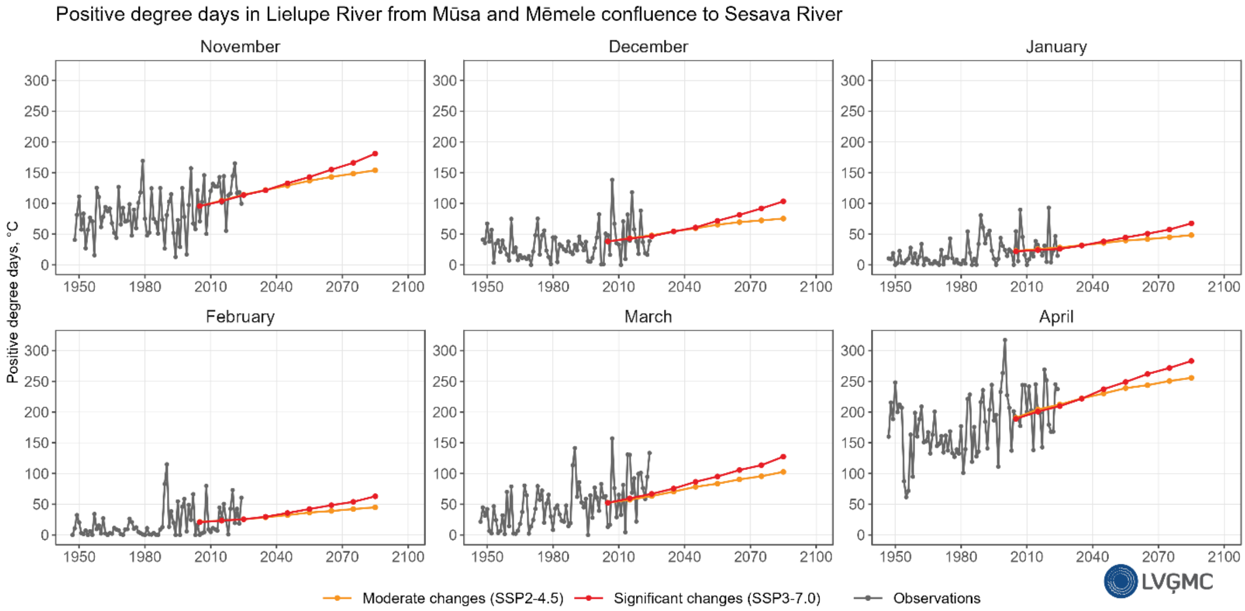

Figure 3.2.4.2. The monthly positive degree days (PDD) in Lielupe River from the confluence of Musa and Memele rivers to the junction with Sesava River from 1948 (observational data) to 2100 (climate model scenarios SSP2-4.5 and SSP3-7.0 data)

PDDs have increased significantly even in cold winters (Fig. 3.2.4.3). The coldest 10% of winters had a mean PDD of 248.3 °C in 1961–1990, rising to 330.4 °C in 1991–2020, an increase of 82.1 °C. By 2071–2100, this value is projected to reach 549.2 [±87.8] °C under significant climate change, marking an additional rise of 218.8 °C. The coldest 25% of winters followed a similar trend, increasing from 273.4 °C in 1961–1990 to 394.0 °C in 1991–2020, with projections reaching 637.2 [±101.2] °C by 2071–2100 under significant climate change.

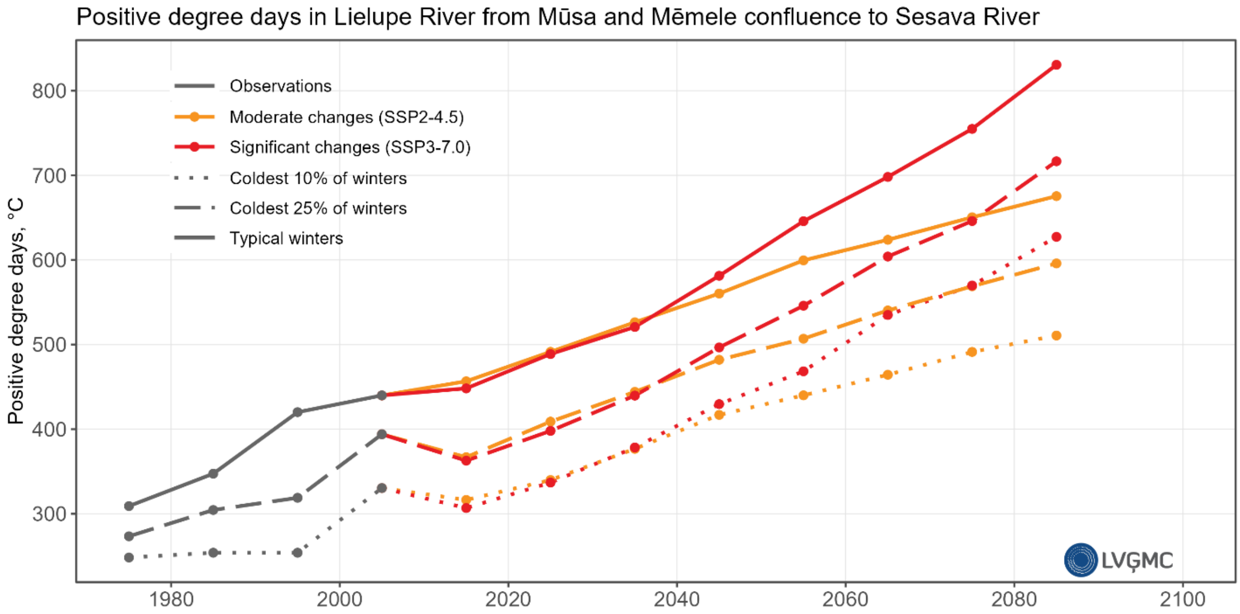

Figure 3.2.4.3. The November–April positive degree days (PDD) of typical, coldest 25 % and coldest 10 % of winters in Lielupe River from the confluence of Musa and Memele rivers to the junction with Sesava River from 1948 (observational data) to 2100 (climate model scenarios SSP2-4.5 and SSP3-7.0 data)

The Lielupe River region is undergoing substantial warming. This trend will lead to fewer frost days, earlier snowmelt, and changes in river hydrology, further accelerating climate-driven seasonal shifts.

3.2.5. Precipitation amount

The total precipitation in the Lielupe River region during the November–April season has increased over time. During 1961–1990, seasonal precipitation averaged 231.6 mm, while in 1991–2020, it rose to 236.4 mm, marking a 2% increase.

Future projections suggest a continued upward trend (Fig. 3.2.5.1). By 2071–2100, precipitation is projected to rise to 353.2 [±40.7] mm (moderate change) and 365.6 [±45.5] mm (significant change), indicating increases of 49% and 55%, respectively.

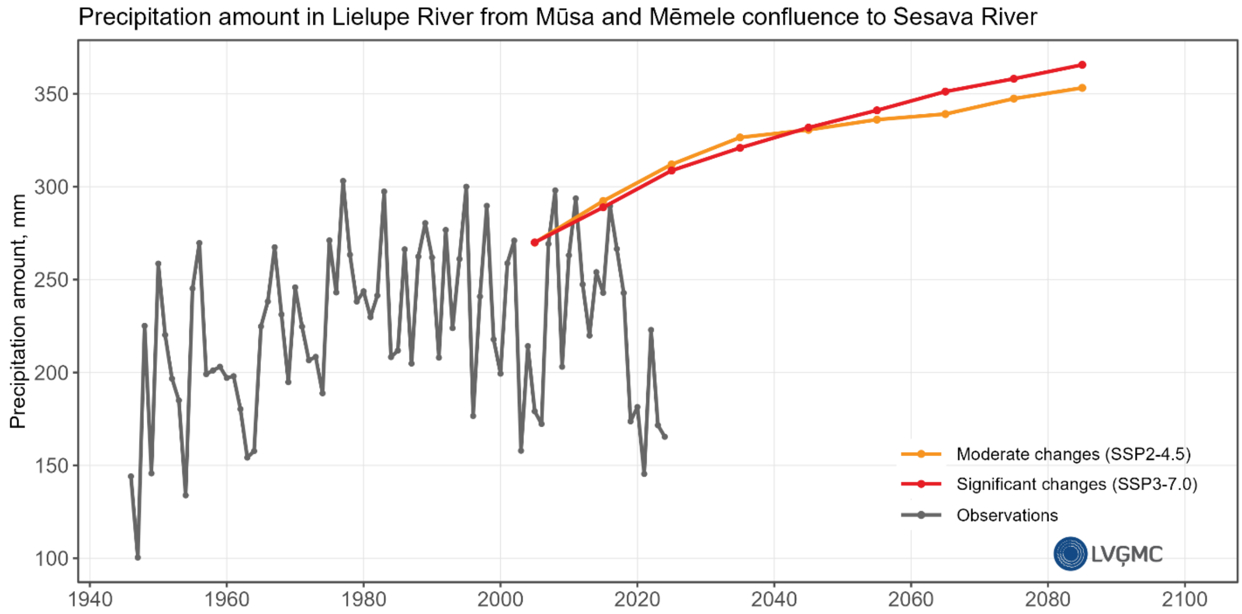

Figure 3.2.5.1. The November–April precipitation amount in Lielupe River from the confluence of Musa and Memele rivers to the junction with Sesava River from 1948 (observational data) to 2100 (climate model scenarios SSP2-4.5 and SSP3-7.0 data)

The largest relative increases are expected in January and February. January precipitation rose by 25% from 32.9 mm (1961–1990) to 41.1 mm (1991–2020). Projections for 2071–2100 indicate further increases to 57.4 [±9.0] mm (moderate change) and 60.5 [±9.9] mm (significant change), marking increases of 40% and 47% compared to the climate normal. Similarly, February precipitation increased by 30%, rising from 26.0 mm (1961–1990) to 33.7 mm (1991–2020), with projections reaching 47.8 [±7.7] mm (moderate change) and 51.6 [±9.6] mm (significant change), indicating 42% and 53% increases, respectively.

March and April also show notable increases. March precipitation declined slightly by 3% from 32.3 mm (1961–1990) to 31.3 mm (1991–2020) but is projected to rise by 60% under moderate and 71% under significant climate change by 2071–2100. April precipitation decreased by 12% from 40.5 mm (1961–1990) to 35.5 mm (1991–2020), yet projections indicate increases of 66% (moderate change) and 64% (significant change) by late 21st century (Fig. 3.2.5.2).

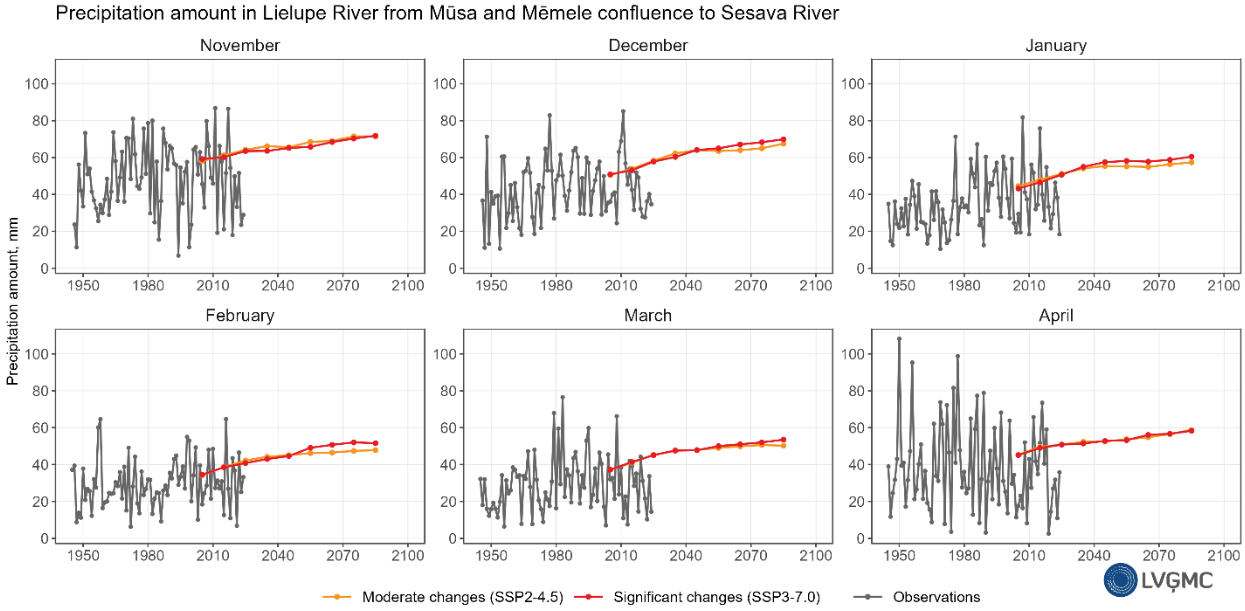

Figure 3.2.5.2. The monthly precipitation amount in Lielupe River from the confluence of Musa and Memele rivers to the junction with Sesava River from 1948 (observational data) to 2100 (climate model scenarios SSP2-4.5 and SSP3-7.0 data)

Precipitation in the Lielupe River region is projected to increase substantially throughout the 21st century, with the highest increases occurring in winter and early spring months. These changes indicate a shift toward wetter conditions, potentially affecting river hydrology, seasonal flooding risks, and water availability in the region.

3.3. Muša River: between settlements Gustoniai to Ustukiai

3.3.1. Mean air temperature

Comparing the reference period (1961–1990) with the climatic normal period (1991–2020), the average November–April air temperature in Muša River between settlements Gustoniai to Ustukiai has increased by 1.6 °C, from –1.1 °C to +0.5 °C.

Future climate model projections suggest that air temperature will continue to rise throughout the 21st century (Fig. 3.3.1.1). The steepest upward trend is projected under a significant changes climate model scenario (SSP3-7.0), predicting that by the end of the century (2071–2100), the average November–April air temperature in Muša River between settlements Gustoniai to Ustukiai will reach +5.0 [±1.1] °C, an increase of 4.5 °C compared to the current climatic normal period and 6.1 °C compared to the reference period. Under a moderate climate change scenario (SSP2-4.5), the average annual air temperature by the end of the century is expected to be +3.6 [±1.0] °C—an increase of 3.1 °C and 4.7 °C compared to the current normal and reference periods, respectively. Climate scenario differences become more significant after 2050 (Fig. 3.3.1.1).

In the reference period (1961–1990), the mean monthly air temperature was negative in December – March, with the lowest monthly mean in January –5.4 °C and February –5.2 °C. In the climate normal period (1991–2020), air temperature increased in all months, and the season with negative mean monthly air temperature shortened to December – February. The part of the year with the lowest mean monthly air temperature remained the same, but the mean temperature increased in January by 2.3 °C to –3.1 °C and February by 2.1 °C to the same value of –3.1 °C. The increase in January and February mean temperatures was the most significant in comparison to the increase in other months 0.7–1.8 °C.

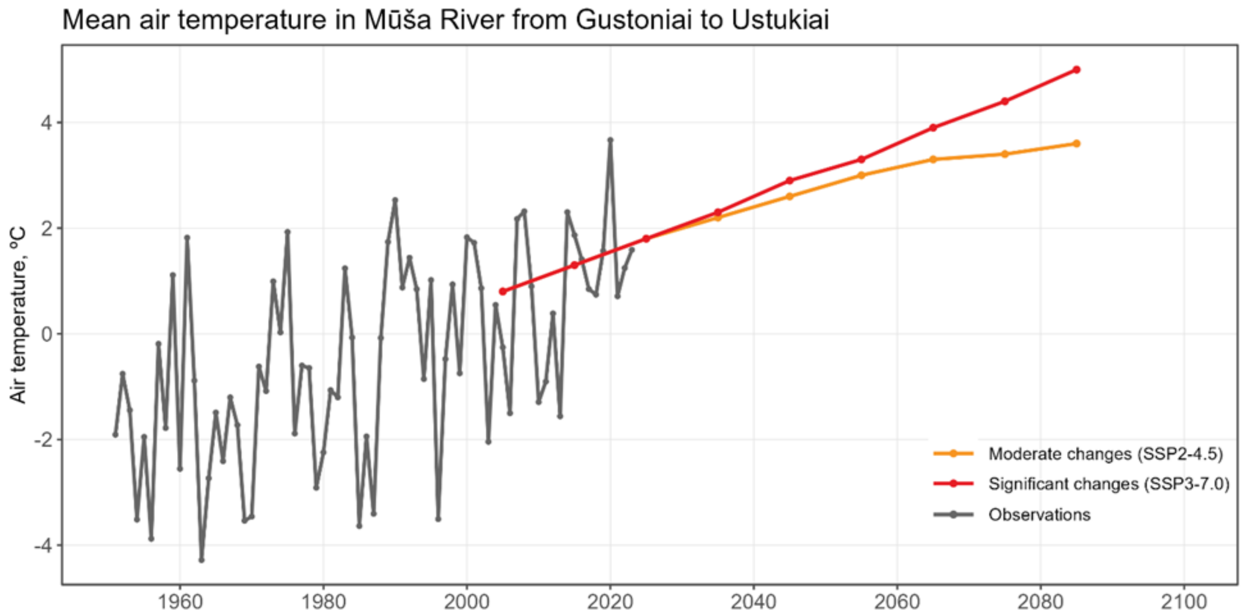

Figure 3.3.1.1. The average November–April air temperature in Muša River between settlements Gustoniai to Ustukiai from 1951 (observational data) to 2100 (climate model scenarios SSP2-4.5 and SSP3-7.0 data)

Mean monthly air temperature projected under a significant changes climate model scenario (SSP3-7.0) predicts that in the middle of the century (2041–2070), the mean monthly air temperature is likely to increase in all cold season months (Fig. 3.3.1.2) by 2.3–3.5 °C in comparison to the normal period. The largest increase is expected in the coldest months of January and February when the mean air temperature will be respectively +0.4 [±1.1] °C and +0.2 [±1.31] °C. If climate changes according to the moderate change scenario (SSP2-4.5, the average annual air temperature in the middle of the century (2041–2170) will increase in all cold season months by 1.9–3.0 °C compared to the normal period. According to the SSP2-4.5 scenario, the largest changes will be in the coldest December–February period. The mean monthly air temperature will remain lower than 0 °C in January –0.1 [±1.0] °C and February –0.3 [±0.8] °C.

Mean monthly air temperature projected under a significant changes climate model scenario (SSP3-7.0) predicts that by the end of the century (2071–2100), the mean monthly air temperature is likely to increase in all cold season months by 4.6–7.7 °C in comparison to the normal period. The largest increase is expected in January and February when the mean air temperature will be respectively +2.3 [±1.4] °C and +1.9 [±1.5] °C.

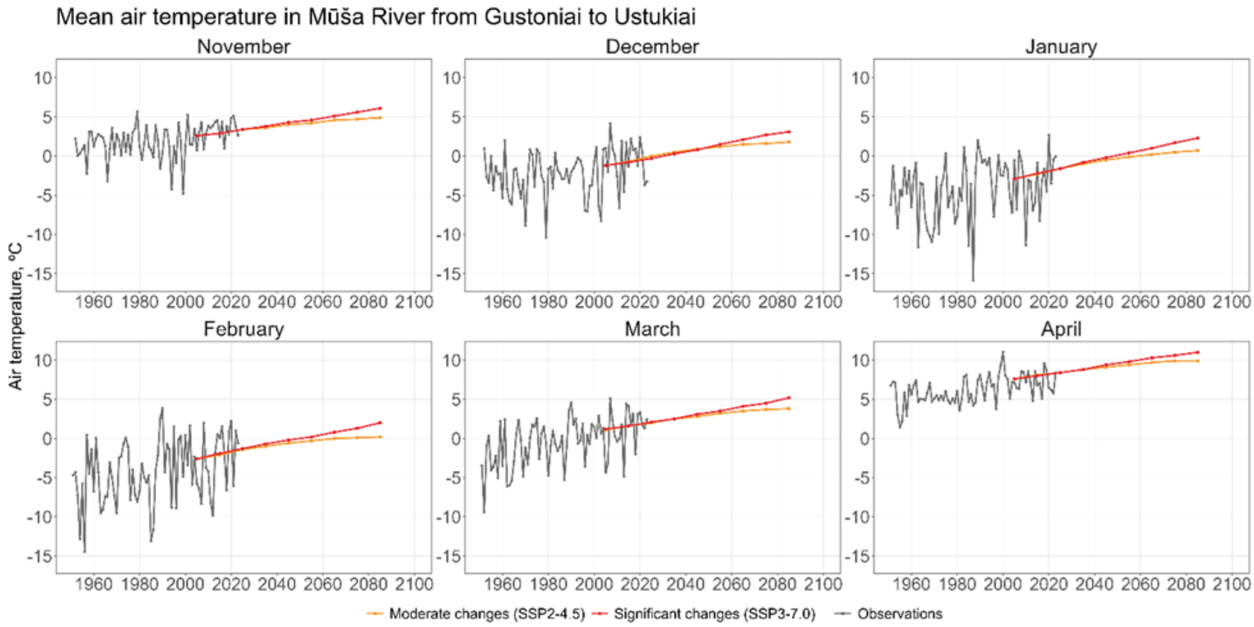

Figure 3.3.1.2. The average monthly air temperature in Muša River between settlements Gustoniai to Ustukiai from 1951 (observational data) to 2100 (climate model scenarios SSP2-4.5 and SSP3-7.0 data)

Presume climate would change according to the moderate change scenario (SSP2-4.5). In that case, the average annual air temperature by the end of the century (2071–2100) will increase in all cold season months by 2.6–3.8 °C compared to the normal period. The largest changes, according to the SSP2-4.5 scenario, will be in the coldest December–February period, resulting that even according to the moderate climate change at the end of the 21st century, the mean monthly air temperature will be higher than 0 °C during all months of the year.

While the climate models project a significant increase in mean air temperature, resulting in mean cold season positive air temperature, due to natural variability, there will be colder winters with lower mean air temperature.

The cold winters become warmer even in the observation period. There was a significant warming trend during November–April when comparing the reference period of 1961–1990 to the climate normal of 1991–2020. For the coldest 10% of winters, the mean temperature increased from −3.5°C to −1.5°C, reflecting a rise of 2.0 °C. Similarly, for the coldest 25% of winters, the mean temperature rose from −2.4 °C to −0.7 °C, a change of 1.7 °C. Typical winters show the most similar increase as the coldest winters, with temperatures rising from −1.1 °C to +0.9 °C. These changes underscore the warming trend across all winter categories, particularly in typical winters and the coldest 10% of winters (Fig. 3.3.1.3).

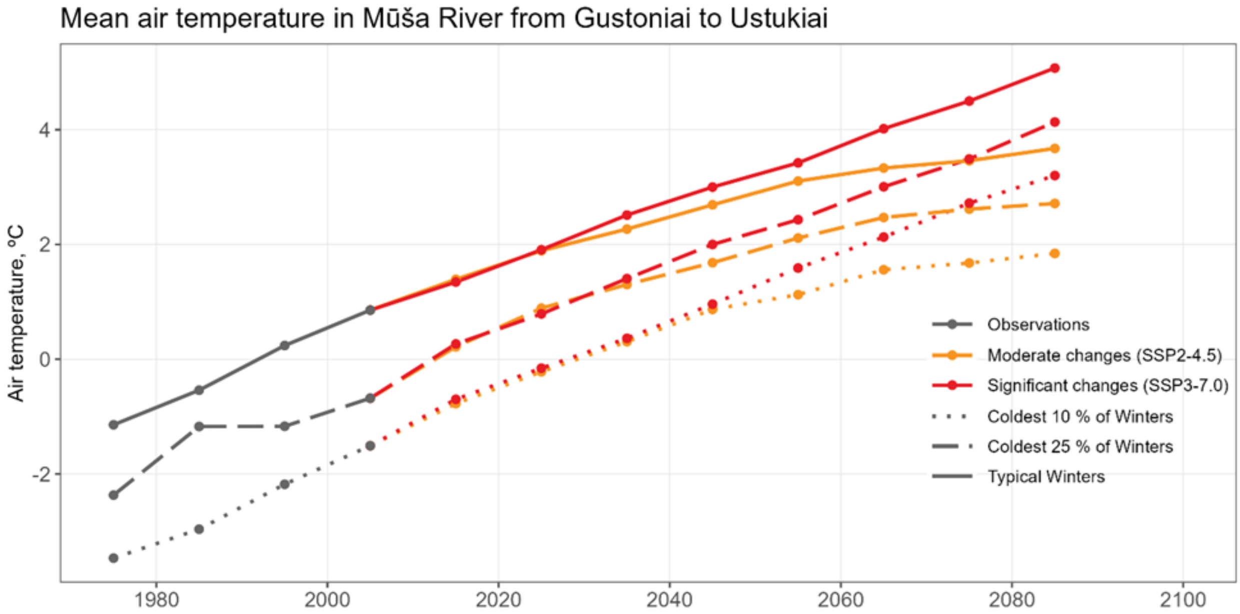

Figure 3.3.1.3. The average November–April air temperature of typical, coldest 25 % and coldest 10 % of winters in Muša River between settlements Gustoniai to Ustukiai from 1951 (observational data) to 2100 (climate model scenarios SSP2-4.5 and SSP3-7.0 data)

Projections under two climate scenarios, SSP2-4.5 and SSP3-7.0, indicate continued warming, with more significant increases expected under the high-emission SSP3-7.0 scenario. During the period 2041–2070, for the coldest 10% of winters, the mean temperature is projected to be +1.1 [±1.06] °C under SSP2-4.5, marking an increase of 4.6 °C relative to 1961–1990 and 2.6 °C relative to 1991–2020. This temperature will be 0.2 °C warmer than the 1991–2020 typical winter. Under SSP3-7.0, the mean temperature is expected to reach +1.6 [±0.8] °C, an increase of 5.1 °C relative to 1961–1990 and 3.1 °C relative to 1991–2020, making it 0.7 °C warmer than the 1991–2020 typical winter. For the coldest 25% of winters, the mean temperature under SSP2-4.5 is projected to be +2.1 [±0.8] °C, with increases of 4.5 °C and 2.8 °C relative to 1961–1990 and 1991–2020, respectively. This is 1.2 °C warmer than the 1991–2020 typical winter. Under SSP3-7.0, the mean temperature is projected to be +2.4 [±0.8] °C, reflecting increases of 4.8 °C and 3.1 °C relative to the same periods, making it 1.5 °C warmer than the 1991–2020 typical winter. Typical winters are projected to experience a mean temperature of +3.1 [±0.7] °C under SSP2-4.5, an increase of 4.2 °C relative to 1961–1990 and 2.2 °C relative to 1991–2020. Under SSP3-7.0, the mean temperature for typical winters is expected to reach +3.4 [±0.8] °C, reflecting increases of 4.5 °C and 2.5 °C relative to the same periods.

Looking further into the future, during the period 2071–2100, the coldest 10% of winters are projected to have a mean temperature of +1.8 [±1.2] °C under SSP2-4.5, an increase of 5.3 °C relative to 1961–1990 and 3.3 °C relative to 1991–2020. This would be 0.9 °C warmer than the 1991–2020 typical winter. Under SSP3-7.0, the mean temperature for the coldest 10% of winters is expected to reach +3.2 [±1.2] °C, reflecting increases of 6.7 °C and 4.7 °C relative to the same periods, making it 2.3 °C warmer than the 1991–2020 typical winter. For the coldest 25% of winters, the mean temperature under SSP2-4.5 is projected to be +2.7 [±1.1] °C, marking increases of 5.1 °C and 3.4 °C relative to 1961–1990 and 1991–2020, respectively. This is 1.8 °C warmer than the 1991–2020 typical winter. Under SSP3-7.0, the mean temperature is expected to be +4.1 [±1.1] °C, reflecting increases of 6.5 °C and 4.8 °C relative to the same periods, making it 3.2 °C warmer than the 1991–2020 typical winter. Typical winters during 2071–2100 are projected to have a mean temperature of +3.7 [±1.0] °C under SSP2-4.5, with increases of 4.8 °C and 2.8 °C relative to 1961–1990 and 1991–2020. Under SSP3-7.0, typical winters are expected to reach a mean temperature of +5.1 [±1.1] °C, representing increases of 6.2 °C and 4.2 °C relative to the same periods.

3.3.2. Negative degree days (NDDs)

The November–April negative degree days (NDDs), an indicator of cold severity and linked to formation of ice cover and accumulation of ice mass in the river, averaged 376.9 °C during the observed period of 1991–2020. During the reference period of 1961–1990, the NDDs were 542.0 °C, highlighting the significant reduction that occurred by 1991–2020 due to warming.

Future projections under two climate scenarios, SSP2-4.5 and SSP3-7.0, indicate a dramatic decline in NDDs (Fig. 3.3.2.1), further emphasizing the expected warming trends. For the period 2041–2070, under SSP2-4.5, the average NDD is projected to drop to 195.2 [±45.2] °C, reflecting a reduction of 346.8 °C relative to the 1961–1990 reference period and 181.7 °C compared to 1991–2020. Under SSP3-7.0, the decline is even more pronounced, with NDDs averaging 175.6 [±46.32] °C, representing reductions of 366.4 °C relative to the reference period and 201.3 °C compared to the climate normal. Looking further ahead to the period 2071–2100, the NDD under SSP2-4.5 is expected to decline further to 166.0 [±56.4] °C, marking a reduction of 376.0 °C relative to 1961–1990 and 210.9 °C compared to 1991–2020. Under SSP3-7.0, the NDD is projected to plummet to 103.1 [±42.8] °C, representing reductions of 438.9 °C and 273.8 °C relative to the reference period and the climate normal, respectively. This highlights a much warmer winter season under the significant climate change scenario.

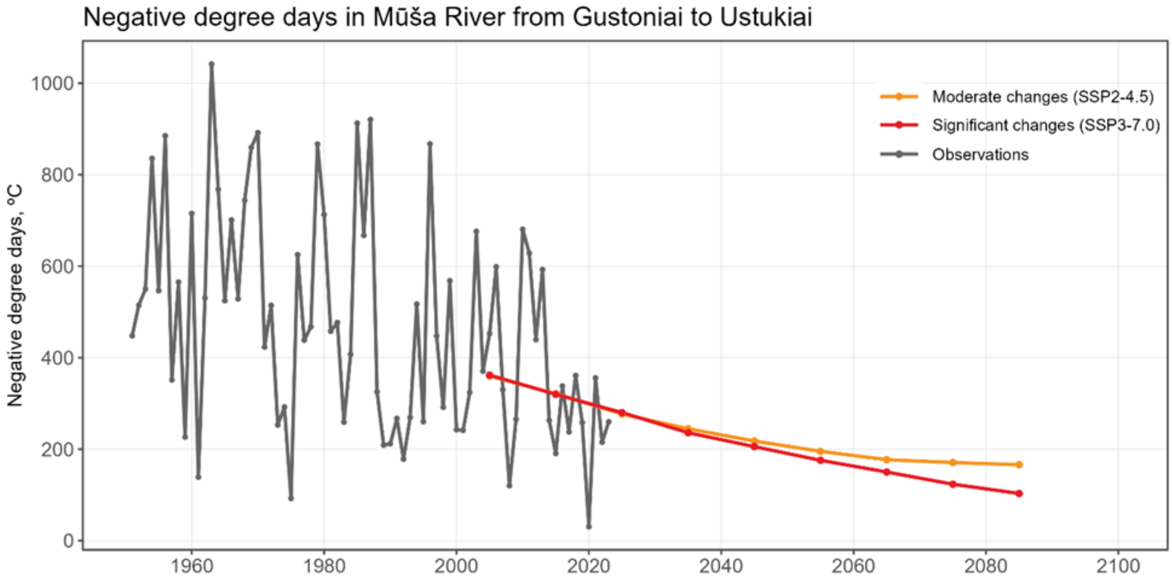

Figure 3.3.2.1. The November–April negative degree days (NDD) in Muša River between settlements Gustoniai to Ustukiai from 1951 (observational data) to 2100 (climate model scenarios SSP2-4.5 and SSP3-7.0 data)

The monthly analysis reveals that the most substantial changes occur in the core winter months of December, January, and February. January (Fig. 3.3.2.2), traditionally the coldest month, shows the largest reductions, with NDDs dropping from 180.9 °C in 1961–1990 to 122.8 °C in 1991–2020. By 2041–2070, values are projected to fall to 65.3 [±17.6] °C under SSP2-4.5 and 58.5 [±15.4] °C under SSP3-7.0. By 2071–2100, the decline continues to 55.4 [±19.5] °C under SSP2-4.5 and 36.5 [±14.1] °C under SSP3-7.0. Similarly, February exhibits marked decreases, with NDDs projected to drop to 54.1 [±17.7] °C under SSP2-4.5 and 34.0 [±15.2] °C under SSP3-7.0 by the end of the century.

December also shows significant changes, with NDDs declining from 113.6 °C in 1961–1990 to 82.1 °C in 1991–2020 and further to 34.2 [±17.2] °C under SSP2-4.5 and 22 [±12.7] °C under SSP3-7.0 by 2071–2100. In contrast, the transitional months of March, November, and April experience less dramatic but still notable declines. March NDDs decrease from 71.7 °C in 1961–1990 to 41.7 °C in 1991–2020 and are projected to drop further to 11.6 [±7.4] °C under SSP2-4.5 and 5.6 [±4.6] °C under SSP3-7.0 by the end of the century. November and April, which already have low NDDs, are expected to approach negligible values, particularly under SSP3-7.0.

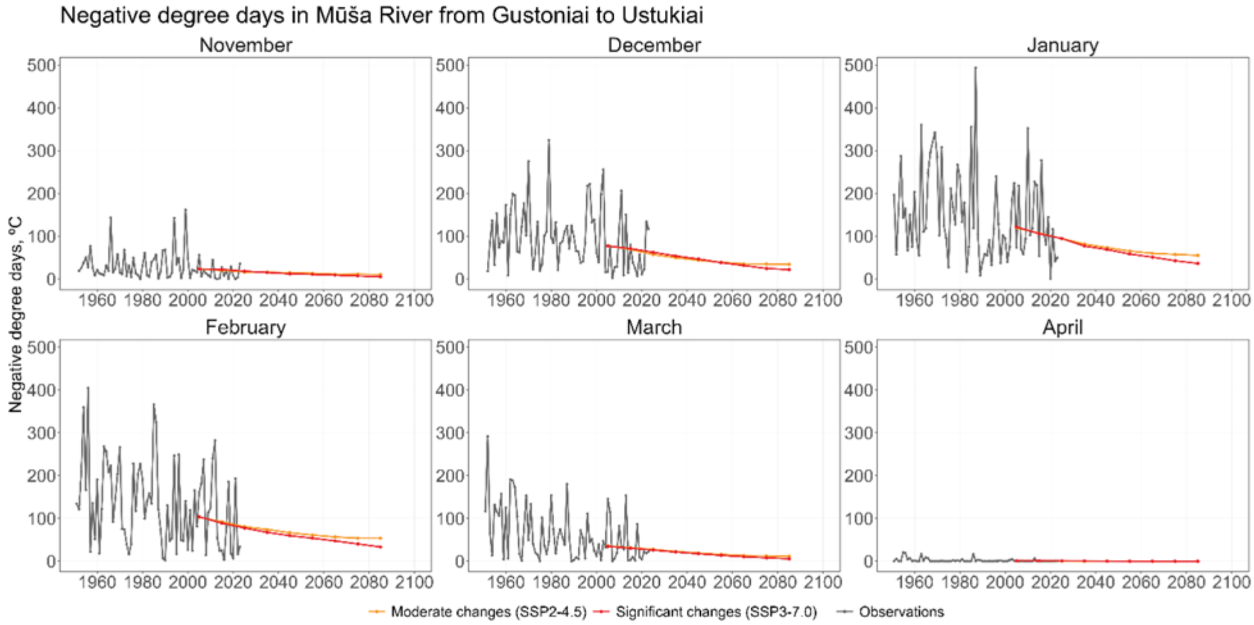

Figure 3.3.2.2. The monthly negative degree days (NDD) in Muša River between settlements Gustoniai to Ustukiai from 1951 (observational data) to 2100 (climate model scenarios SSP2-4.5 and SSP3-7.0 data)

During the earlier reference period, typical winters recorded a mean NDD of 519.5 °C, while by the 1991–2020 climate normal, this value had dropped to 327.2 °C—a significant reduction of 192.3 °C. Similarly, the coldest 25% of winters experienced a decline from 736.1 °C to 501 °C, marking a reduction of 235.1 °C, and the coldest 10% of winters saw a drop from 894.1 °C to 633.1 °C, a total decrease of 261.0 °C. These substantial reductions underscore the notable warming of winters even within the observed historical data (Fig. 3.3.2.3).

Under two distinct scenarios, SSP2-4.5 and SSP3-7.0, projections for the future indicate that this warming trend will continue to intensify. Under the SSP2-4.5 scenario, which assumes moderate mitigation efforts, the mean NDD for typical winters is projected to decline to 163.9 [±30.1] °C during the mid-21st century (2041–2070). For the coldest 25% and 10% of winters, the projected mean NDDs are 258.4 [±66.2] °C and 356.0 [±92.4] °C, representing reductions of 242.6 °C and 277.1 °C, respectively, compared to the 1991–2020 climate normal. By the late 21st century (2071–2100), the declines become even more pronounced, with typical winters expected to have a mean NDD of 142.4 [±58.6] °C, a reduction of 184.8 °C, while the coldest 25% and 10% of winters are projected to decline to 224.7 [±79.9] °C and 318.0 [±98.4] °C, respectively, corresponding to decreases of 276.3 °C and 315.1 °C.

Under the SSP3-7.0 scenario, the projected reductions in NDDs are even more dramatic. By 2041–2070, typical winters are expected to record a mean NDD of 154.5 [±44.8] °C, a decrease of 172.7 °C compared to the 1991–2020 normal. For the coldest 25% of winters, the mean NDD is projected to fall to 236.5 [±59.7] °C, a reduction of 264.5 °C, and the coldest 10% of winters are expected to decline to 327.3 [±77.1] °C, a decrease of 305.8 °C. Looking further to the late century (2071–2100), the changes are even starker: typical winters are projected to have a mean NDD of 78.5 [±39.4] °C, which represents a dramatic reduction of 248.7 °C compared to the 1991–2020 normal. Meanwhile, the coldest 25% and 10% of winters are expected to decline to 143.9 °C [±51.2] and 217.1 [±84.1] °C, respectively, amounting to reductions of 357.1 °C and 416 °C. These projections illustrate the profound impact of the SSP3-7.0 scenario on winter temperatures.

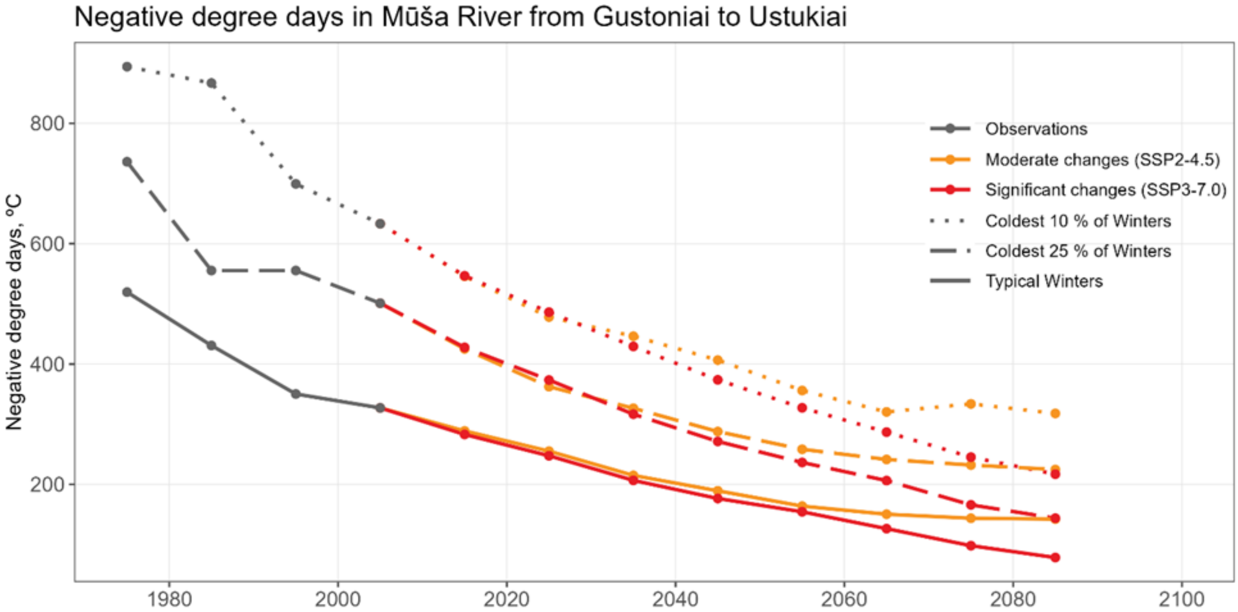

Figure 3.3.2.3. The November–April negative degree days (NDDs) of typical, coldest 25 % and coldest 10 % of winters in Muša River: between settlements Gustoniai to Ustukiai from 1951 (observational data) to 2100 (climate model scenarios SSP2-4.5 and SSP3-7.0 data)

The warming of the coldest winters, in particular, provides valuable insights into how extreme cold events are likely to change in the coming decades. For the period 2041–2070, the coldest 10% of winters are projected to warm by 277.1 °C under SSP2-4.5 and 305.8 °C under SSP3-7.0, relative to the 1991–2020 climate normal. Similarly, the coldest 25% of winters are expected to warm by 242.6 °C and 264.5 °C under SSP2-4.5 and SSP3-7.0, respectively. By 2071–2100, the warming trends intensify even further. The coldest 10% of winters are projected to warm by 315.1 °C under SSP2-4.5 and by an extraordinary 416 °C under SSP3-7.0, while the coldest 25% of winters are expected to warm by 276.3 °C and 357.1 °C, respectively. These changes suggest a profound reduction in the frequency and severity of traditionally extreme cold winters.

3.3.3. Number of days with negative mean air temperature

The negative degree days show the potential to accumulate ice in the rivers but do not indicate how long this accumulation can take place. The number of days with mean air temperature below 0 °C during the November–April season has shown a significant decline over time (Fig. 3.3.3.1), reflecting the effects of warming trends. Observations from 1991–2020 indicate a seasonal average of 74 days, which is a decrease of 15 days compared to the 1961–1990 period when the average was 89 days.

Future projections under two climate scenarios, SSP2-4.5 and SSP3-7.0, forecast further reductions. For the period 2041–2070, the average number of days is projected to drop to 45 [±8] days under SSP2-4.5 and 42 [±9] days under SSP3-7.0, representing declines of 28 and 32 days, respectively, compared to 1991–2020. By 2071–2100, these figures are expected to decrease further to 40 [±11] days under SSP2-4.5 and 28 [±10] days under SSP3-7.0, reflecting reductions of 34 and 45 days, respectively, relative to the climate normal period.

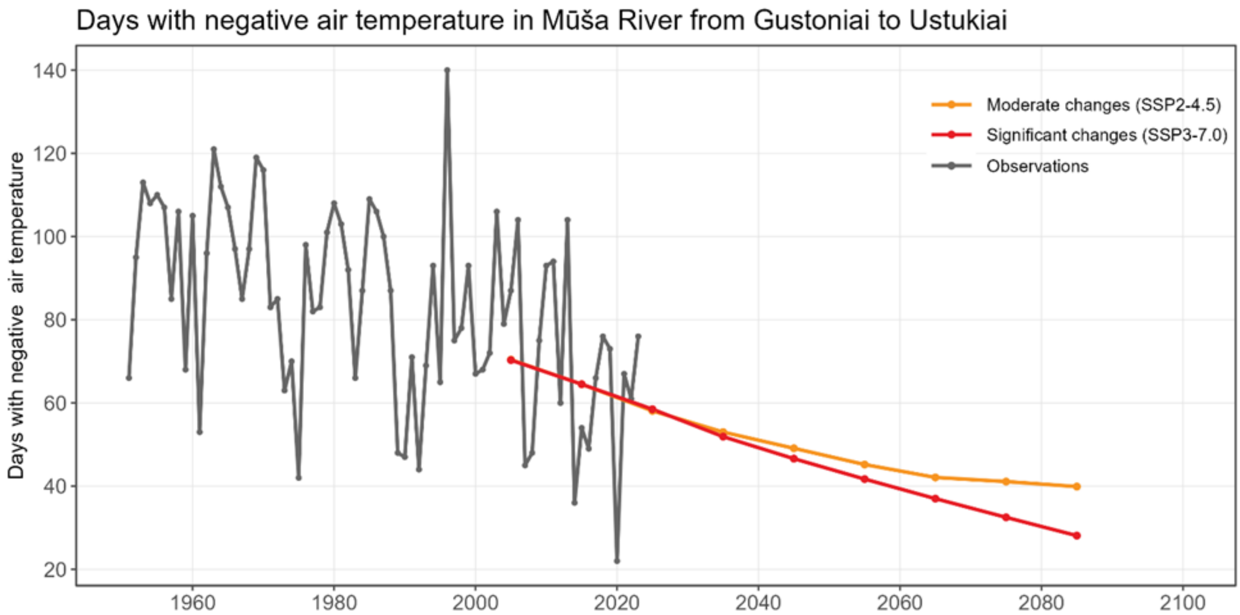

Figure 3.3.3.1. The November–April number of days with negative mean air temperature in Muša River: between settlements Gustoniai to Ustukiai from 1951 (observational data) to 2100 (climate model scenarios SSP2-4.5 and SSP3-7.0 data).

The monthly trends also highlight notable changes (Fig. 3.3.3.2). For November, the number of days did not change between 1961–1990 and 1991–2020. Projections for 2041–2070 estimate values of 5 [±2] days under SSP2-4.5 and 4 [±1] days under SSP3-7.0, with further decreases to 4 [±1] and 2 [±1] days, respectively, by 2071–2100. December, traditionally colder, shows a decline from 20 days in 1961–1990 to 16 days in 1991–2020. Future projections for 2041–2070 estimate 10 [±3] days under both scenarios, decreasing to 9 [±3] and 7 [±3] days, respectively, by 2071–2100.

In January, the number of days decreased from 23 in 1961–1990 to 19 in 1991–2020. Projections for 2041–2070 estimate a further reduction to 13 [±2] days under SSP2-4.5 and 12 [±3] days under SSP3-7.0. By 2071–2100, the numbers are projected to drop to 11 [±3] days under SSP2-4.5 and 8 [±3] days under SSP3-7.0. February follows a similar trajectory, with the number of days decreasing from 22 in 1961–1990 to 18 in 1991–2020. For 2041–2070, the values are projected to decline to 12 [±2] days under SSP2-4.5 and 11 [±3] days under SSP3-7.0, and to 11 [±2] and 8 [±3] days, respectively, by 2071–2100.

March shows a marked decline, with the number of days dropping from 15 in 1961–1990 to 12 in 1991–2020. Future projections for 2041–2070 estimate 6 [±2] days under SSP2-4.5 and 6 [±2] days under SSP3-7.0, with further reductions to 5 [±2] and 3 [±2] days, respectively, by 2071–2100. In April, the number of days with negative mean air temperature was 1 day in the reference period 1961–1990, and with the warming climate, the occurrence of such days became less likely even in the climate normal period.

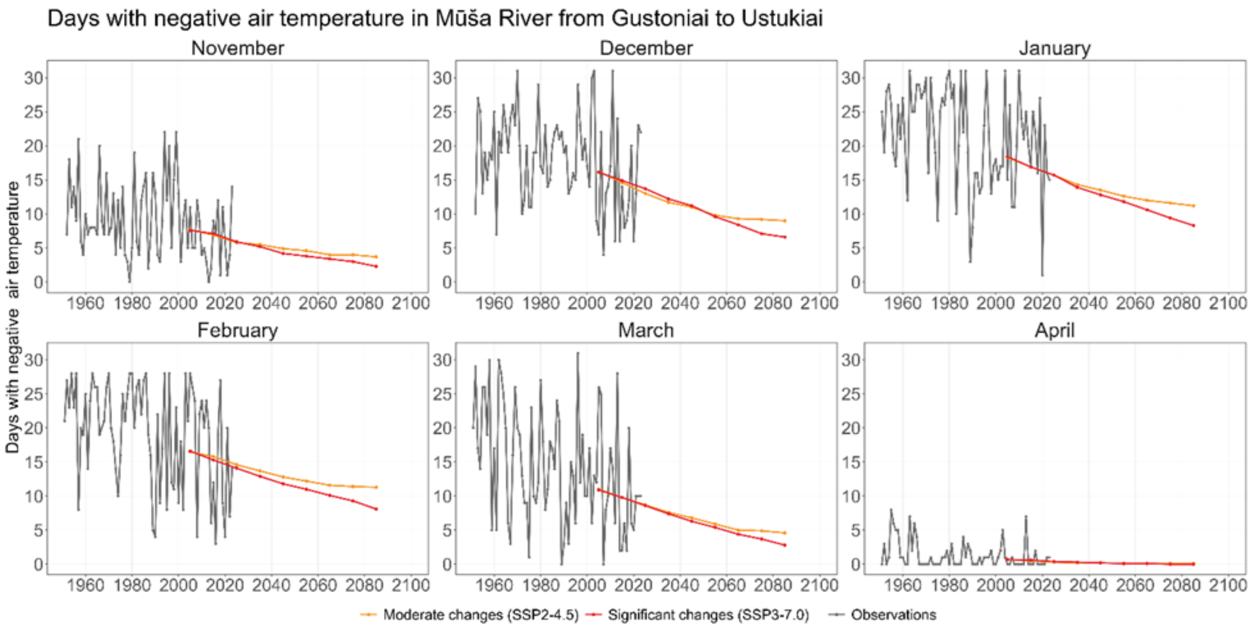

Figure 3.3.3.2. The monthly number of days with negative mean air temperature in Muša River between settlements Gustoniai to Ustukiai from 1951 (observational data) to 2100 (climate model scenarios SSP2-4.5 and SSP3-7.0 data)

The number of days with mean air temperature below 0 °C during the November–April season in cold winters has significantly decreased between the 1961–1990 reference period and the climate normal of 1991–2020 (Fig. 3.3.3.3). For typical winters, the mean value declined from 94 days to 73 days, a reduction of 21 days. Similarly, the coldest 25% and 10% of winters saw reductions of 14 and 8 days, respectively, during the same interval.

Projections under SSP2-4.5 indicate a continued decline in the number of such days by the middle and end of the 21st century. For the period 2041–2070, typical winters are projected to have a mean of 45 [±8] days, a reduction of 28 days compared to the 1991–2020 climate normal. The coldest 25% and 10% of winters are expected to have 57 [±10] and 68 [±12] days, representing decreases of 35 and 36 days, respectively. Under SSP3-7.0, the reductions are even more pronounced. By 2041–2070, typical winters are projected to have 41 [±10] days, while the coldest 25% and 10% of winters will experience 52 [±10] and 64 [±9] days, representing declines of 32, 39, and 41 days, respectively.

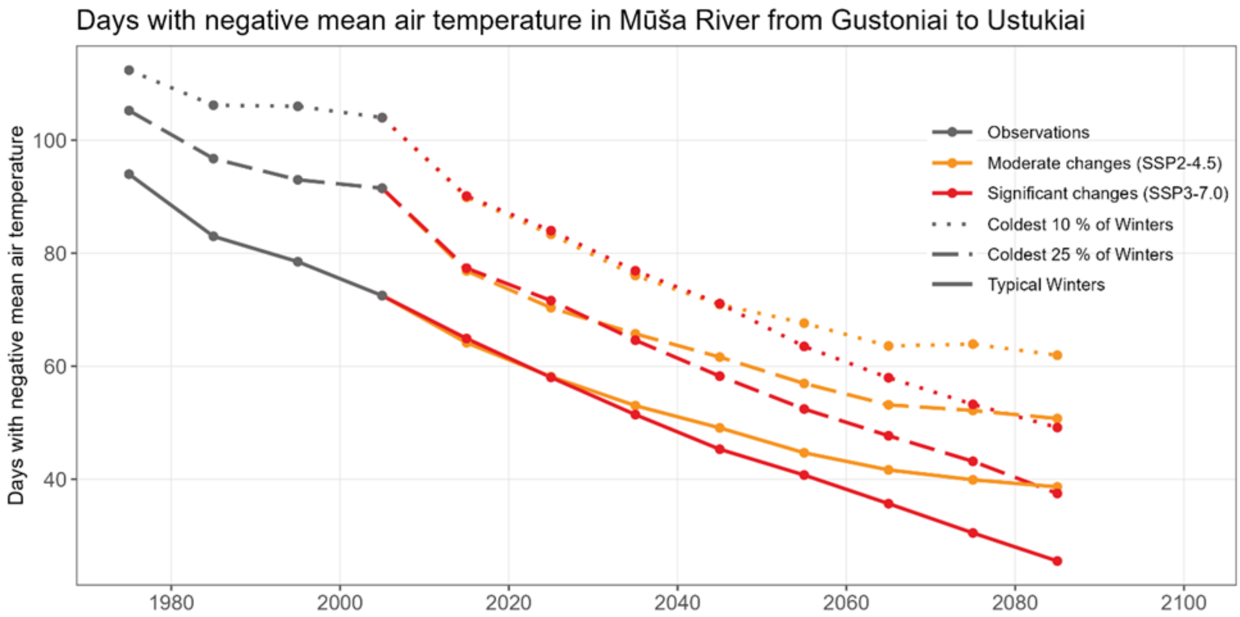

Figure 3.3.3.3. The November–April number of days with negative mean air temperature of typical, coldest 25 % and coldest 10 % of winters in Muša River between settlements Gustoniai to Ustukiai from 1951 (observational data) to 2100 (climate model scenarios SSP2-4.5 and SSP3-7.0 data)

By the end of the century (2071–2100), under SSP2-4.5, the number of days for typical winters is projected to decline to 39 [±12], while coldest 25% and 10% of winters drop to 51 [±13] and 62 [±14] days, representing decreases of 34, 41, and 42 days, respectively. In SSP3-7.0, these reductions are extreme, with typical winters at 26 [±11] days and coldest 25% and 10% of winters at 38 [±12] and 49 [±14] days, showing reductions of 47, 54, and 55 days, respectively.

3.3.4. Positive degree days (PDDs)

During the observation period, the mean November–April PDDs for the reference period 1961–1990 were 343.8 °C. In the climate normal period (1991–2020), PDDs increased to 468.0 °C, reflecting an absolute rise of 124.2 °C. This substantial increase indicates a warming trend of the November–April season over the observed decades (Fig. 3.3.4.1).

Looking toward the future, under the SSP2-4.5 scenario, PDDs are projected to reach 732.7 [±90] °C for the period 2041–2070, representing an increase of 388.9 °C from the reference period and 264.7 °C from the 1991–2020 climate normal. For 2071–2100, the PDDs are expected to rise further to 813.3 [±126.4] °C.

Under the SSP3-7.0 scenario, the projected changes are even more pronounced. For 2041–2070, the mean PDDs are expected to be 779.1 [±90.1] °C, which is 435.3 °C higher than the reference period and 311.1 °C above the 1991–2020 normal. By 2071–2100, PDDs are projected to climb to 1001.5 [±157.3] °C, representing an overwhelming increase of 657.7 °C compared to the reference period and 533.5 °C from the 1991–2020 climate normal.

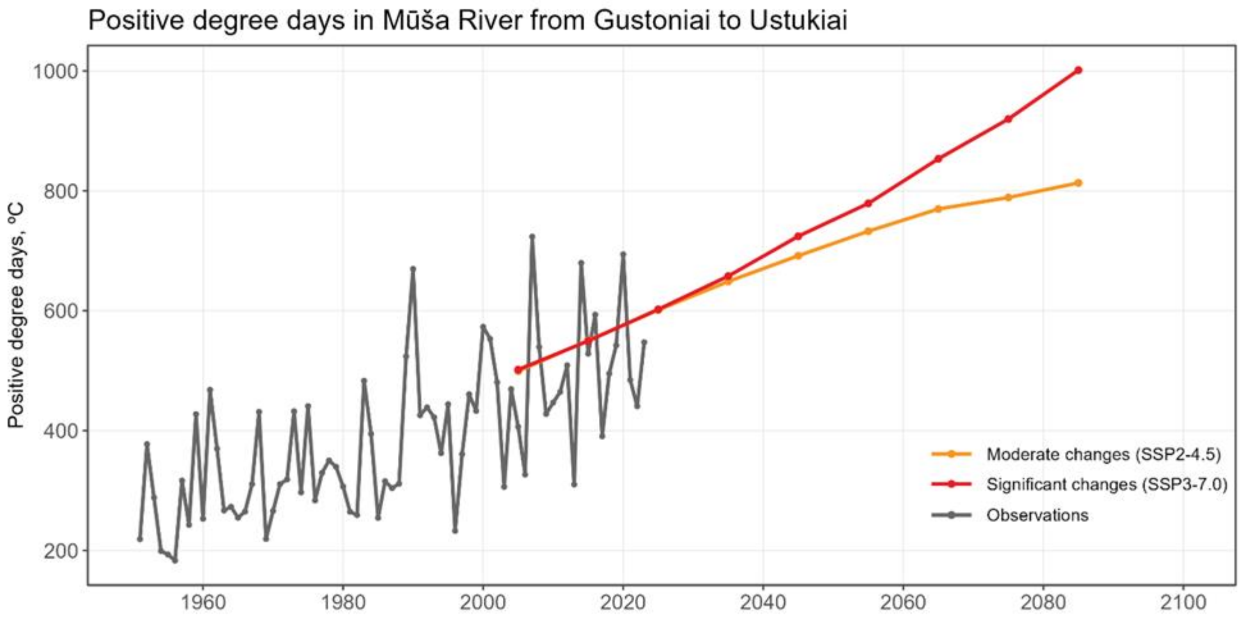

Figure 3.3.4.1. The November–April positive degree days (PDD) in Muša River between settlements Gustoniai to Ustukiai from 1951 (observational data) to 2100 (climate model scenarios SSP2-4.5 and SSP3-7.0 data)

The seasonal changes in Positive Degree Days (PDDs) during November–April can be explained in greater detail by examining the monthly data for each month within this period.

During the reference period of 1961–1990, the monthly mean PDDs for November–April was relatively low, reflecting cooler temperatures. For November, the mean PDD was 80.6 °C, decreasing slightly in December to 23.3 °C. The coldest months, January and February, recorded mean PDDs of only 13.6 °C and 8.6 °C, respectively. PDDs increased notably in March to 39.4 °C and peaked in April at 167.2 °C.

In the subsequent climate normal period of 1991–2020, all months within this season experienced increases in mean PDDs, indicating a warming trend (Fig. 3.3.4.2). For example, November rose to 95.9 °C, representing an increase of 15.3 °C. Similarly, December increased to 38.9 °C, a rise of 15.6 °C. January and February recorded PDDs of 25.6 °C and 22.8 °C, reflecting increases of 12.0 °C and 14.2 °C, respectively. In March, PDDs reached 63.9 °C, an increase of 24.5 °C, while April rose to 219.0 °C, showing a substantial increase of 51.8 °C compared to the reference period.

Under the SSP2-4.5 scenario, significant increases in monthly PDDs are projected for 2041–2070. November is expected to reach 140.3 [±28.1] °C, while December will increase to 77.7 [±24.9] °C, reflecting substantial warming of these early winter months. January and February will rise to 62.5 [±15.8] °C and 53.4 [±11.1] °C, respectively. These changes represent marked increases in the coldest months. March is projected to reach 115.3 [±18.1] °C, and April is expected to increase dramatically to 283.1 [±22.5] °C, indicating continued substantial warming during late winter and early spring.

For 2071–2100, under the SSP2-4.5 scenario, these trends intensify further. November is projected to reach 158.9 [±33.5] °C, while December will rise to 89.1 [±31.9] °C. January and February will increase further to 76.6 [±23.5] °C and 59.7 [±17.9] °C, respectively. March is expected to reach 130.6 [±21.4] °C, and April will rise to 298.5 [±19.2] °C, continuing the trend of a warming season.

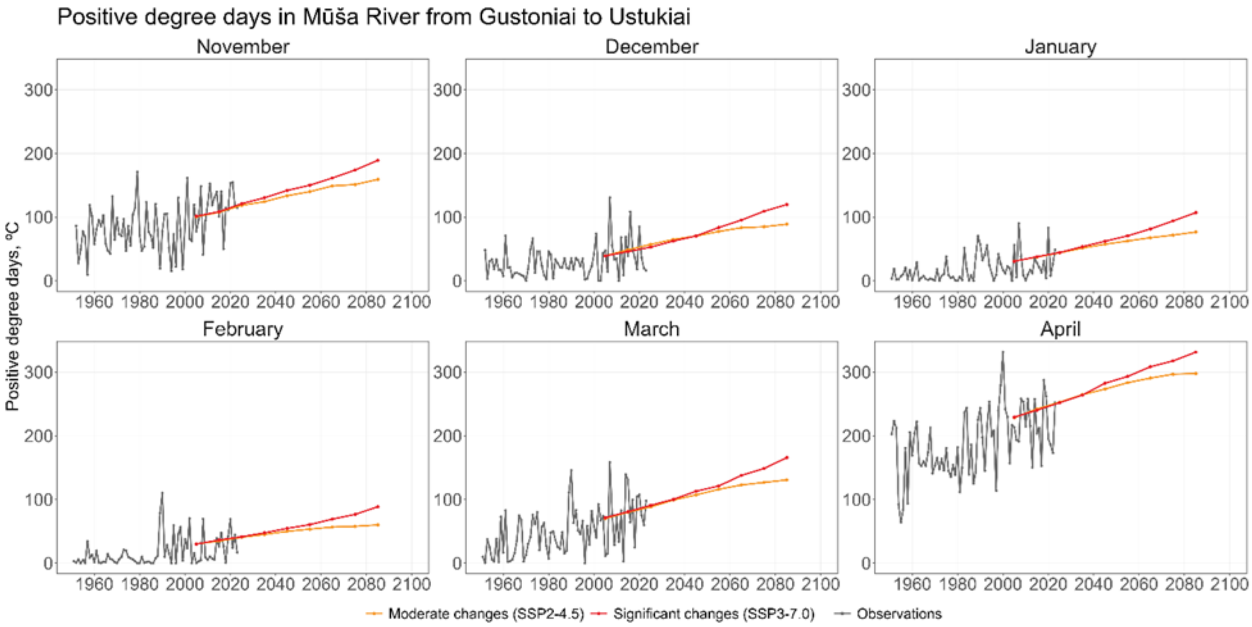

Figure 3.3.4.2. The monthly positive degree days (PDD) in Muša River between settlements Gustoniai to Ustukiai from 1951 (observational data) to 2100 (climate model scenarios SSP2-4.5 and SSP3-7.0 data)

Under the SSP3-7.0 scenario, the warming is more pronounced. For 2041–2070, November is projected to reach 150.2 [±29.4] °C, while December will increase to 83.9 [±22.1] °C. January and February will rise to 70.6 [±19.7] °C and 60.3 [±19.5] °C, respectively. March will increase significantly to 120.8 [±20.3] °C, while April will reach 292.9 [±18.3] °C, marking dramatic warming, particularly in spring.

By 2071–2100, under SSP3-7.0, the monthly PDDs reach their highest levels. November is projected to rise to 189.8 [±42.6] °C, while December will increase to 120.4 [±39.2] °C. January and February will experience PDDs of 107.0 [±32.6] °C and 87.7 [±27.4] °C, respectively. March is expected to reach 166.3 [±25.2] °C, and April will see the highest value of 331.8 [±25.7] °C, illustrating the strongest warming during late winter and early spring.

Positive Degree Days (PDDs) during cold winters have experienced a notable upward trend from the reference period of 1961–1990 to the climate normal of 1991–2020 (Fig. 3.3.4.3). During the reference period, typical winters recorded a mean PDD of 311.1 °C, while the coldest 25% and 10% of winters had PDDs of 268.3 °C and 258.8 °C, respectively. By 1991–2020, these values increased to 453.7 °C, 410.3 °C, and 325.1 °C, representing a substantial rise that aligns with warming trends.

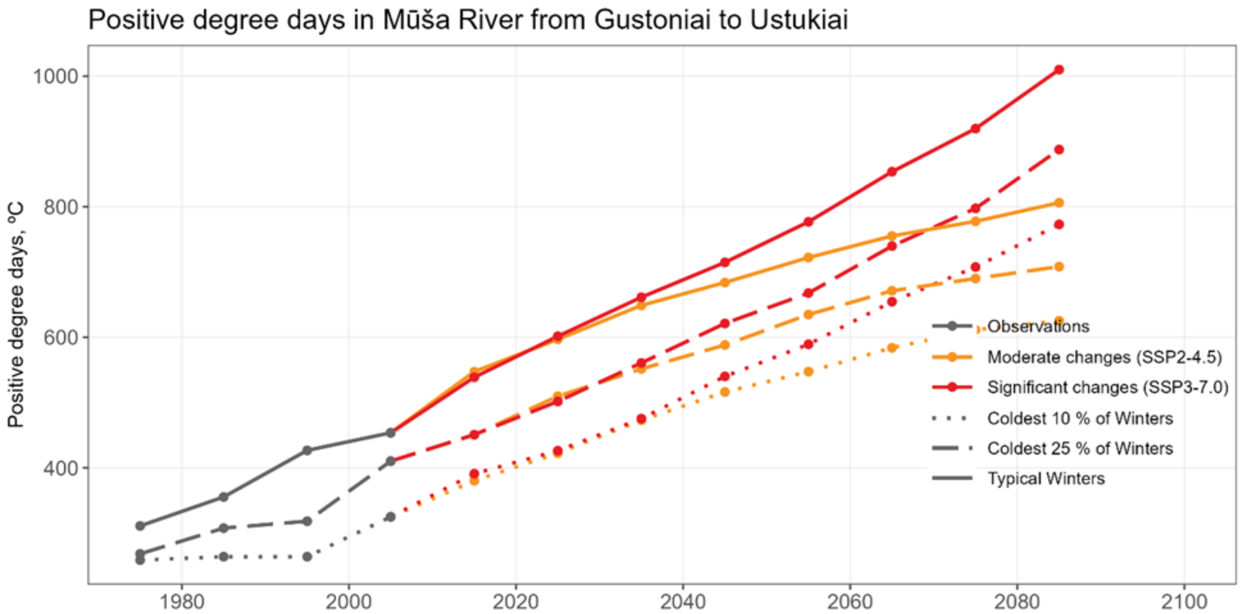

Figure 3.3.4.3. The November–April positive degree days (PDD) of typical, coldest 25% and coldest 10 % of winters in Muša River between settlements Gustoniai to Ustukiai from 1951 (observational data) to 2100 (climate model scenarios SSP2-4.5 and SSP3-7.0 data)

Projections under SSP2-4.5 indicate continued increases in PDDs by the mid-century (2041–2070), with typical winters reaching 722.1 [±98.5] °C, the coldest 25% of winters 634.8 [±89.5] °C, and the coldest 10% of winters 547.4 [±98.8] °C. By the end of the century (2071–2100), typical winters are projected to further rise to 806.1 [±122.2] °C, the coldest 25% to 708.2 [±127.3] °C, and the coldest 10% to 625.3 [±119.8] °C.

Under SSP3-7.0, a more extreme scenario, PDD increases are even more pronounced. For 2041–2070, typical winters are expected to reach 776.9 [±91.6] °C, while the coldest 10% and 25% of winters will reach 589.3 [±77.1] °C and 667.7 [±82.3] °C, respectively. By 2071–2100, typical winters are projected to rise to 1010.0 [±165.0] °C, with the coldest 25% reaching 887.5 [±142.4] °C and the coldest 10% – 773.0 [±128.5] °C.

3.3.5. Precipitation amount

Observations during the reference period (1961–1990) highlight notable changes from the climate normal of 1991–2020. Seasonal precipitation during 1961–1990 amounted to 223 mm, which was 18 mm or 8% lower than the 1991–2020 climate normal of 241 mm (Fig. 3.3.5.1). Monthly variations were also evident, with November recording slightly higher precipitation (50.3 mm, a 2% increase), while January and February showed significant decrease of 30% and 41%, respectively. In contrast, the climate normal period (1991–2020) exhibited greater stability in precipitation, with increases particularly evident in January and February, reflecting a general trend toward wetter conditions.

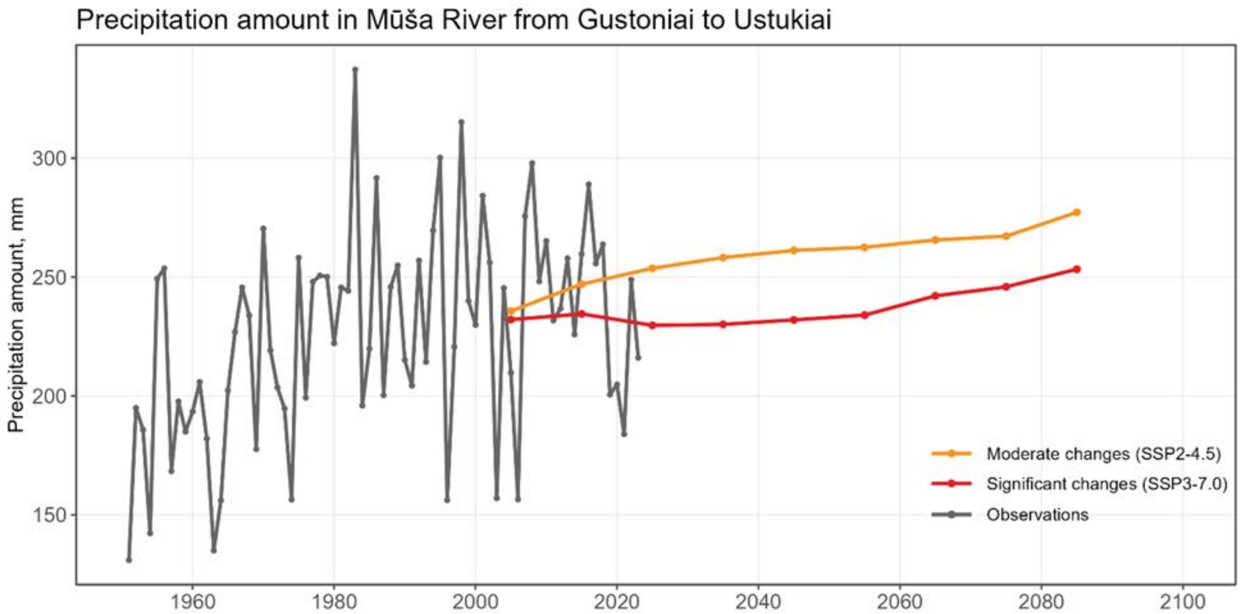

Figure 3.3.5.1. The November–April precipitation amount in Muša River between settlements Gustoniai to Ustukiai from 1951 (observational data) to 2100 (climate model scenarios SSP2-4.5 and SSP3-7.0 data)

Looking ahead, projections under SSP2-4.5 and SSP3-7.0 scenarios illustrate contrasting outcomes for precipitation patterns. In the mid-21st century (2041–2070), SSP2-4.5 projects a notable rise in total seasonal precipitation to 262.5 [±19.2] mm, an increase of 9% relative to the climate normal. Monthly precipitation under this scenario also shows consistent growth (Fig. 3.3.5.2). For example, November is expected to receive 50.4 [±5.8] mm, a slight increase of 3.5%, while December is projected to experience a rise to 53.4 [±5.0] mm, an increase of 15%. Similarly, March and April are anticipated to see increases of 11%, reaching 37.6 [±5.2] mm and 41.4 [±4.7] mm, respectively.

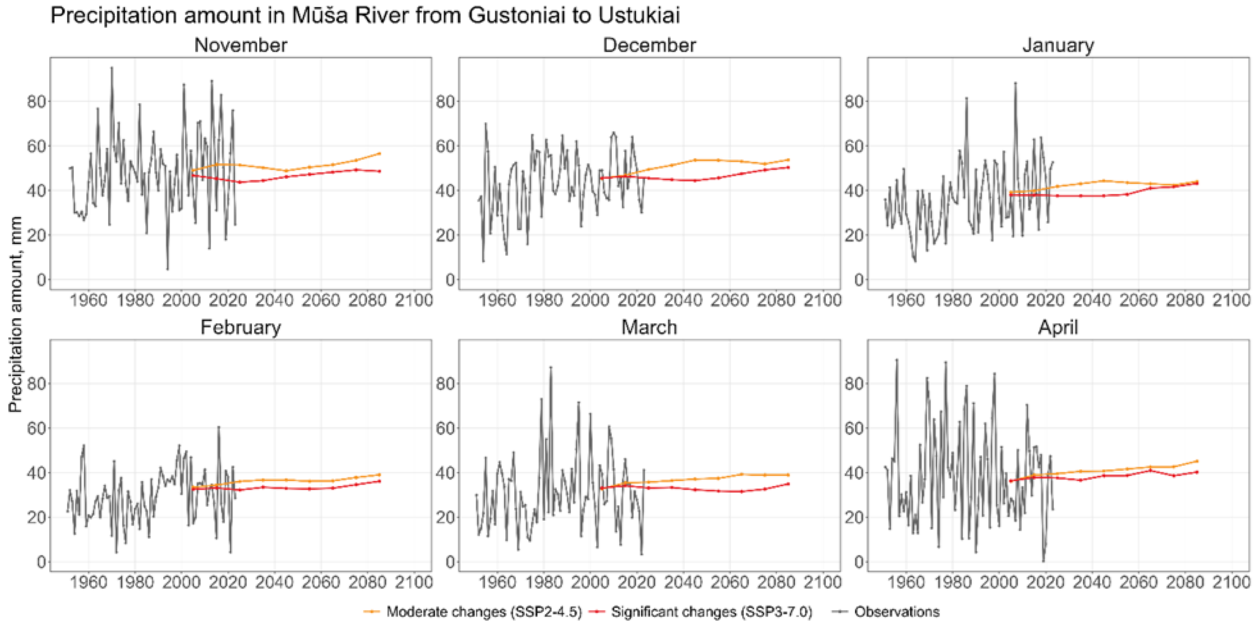

Figure 3.3.5.2. The monthly precipitation amount in Muša River between settlements Gustoniai to Ustukiai from 1951 (observational data) to 2100 (climate model scenarios SSP2-4.5 and SSP3-7.0 data)

Under SSP3-7.0 for the same period, total seasonal precipitation is expected to decrease to 234 [±89.0] mm, a deficit of 3% compared to the climate normal. Monthly patterns indicate declines in February and March, with reductions of 6% and 8%, respectively, while April exhibits a modest increase of 5%, reaching 39.0 [±16.0] mm. These results underscore the variability and overall reductions in precipitation expected under higher-emission scenarios.

By the late 21st century (2071–2100), SSP2-4.5 continues to predict increases in precipitation, with the total seasonal amount projected to reach 277.2 [±12.4] mm, a significant increase of 15%. Monthly increases become more pronounced during this period. November is projected to receive 56.7 [±6.0] mm and December – 54.0 [±4.3] mm, representing an 16% increase for both. April precipitation is anticipated to reach 45.5 [±5.3] mm, reflecting an increase of 22%.

In contrast, SSP3-7.0 suggests a modest increase in seasonal precipitation to 253.3 [±97.1] mm, an increase of 5% compared to the climate normal. Monthly variability remains pronounced, with November and December showing relatively stable precipitation amounts of 48.7 [±19.4] mm and 50.2 [±19.5] mm, respectively, while April shows a slight increase to 40.2 [±16.7], representing a gain of 8%.

Overall, the SSP2-4.5 scenario consistently projects higher and more stable precipitation amounts compared to SSP3-7.0, reflecting the benefits of moderate mitigation efforts. The wetter conditions under SSP2-4.5 highlight the influence of increased atmospheric moisture, particularly during the winter months of November and December. Conversely, SSP3-7.0 indicates greater variability and less pronounced changes, with some months experiencing declines or minimal increases, reflecting the uncertainty associated with high-emission pathways.

3.4. Lėvuo River: from Pamarliškiai to Bridge in Skaistgiriai

3.4.1. Mean air temperature

Comparing the reference period (1961–1990) with the climatic normal period (1991–2020), the average November–April air temperature in the Lėvuo River region (from Pamarliškiai to Skaistgiriai Bridge) rose by 1.7 °C, from –1.3 °C to +0.4 °C. Climate model projections suggest continued warming throughout the 21st century (Fig. 3.4.1.1). Under the significant climate change scenario (SSP3-7.0), by 2071–2100, the November–April average temperature is projected to reach +4.9 [±1.1] °C, 4.5 °C higher than the current normal. In a moderate scenario (SSP2-4.5), this temperature will increase to +3.5 [±1.0] °C, 3.1 °C higher than the climate normal period.

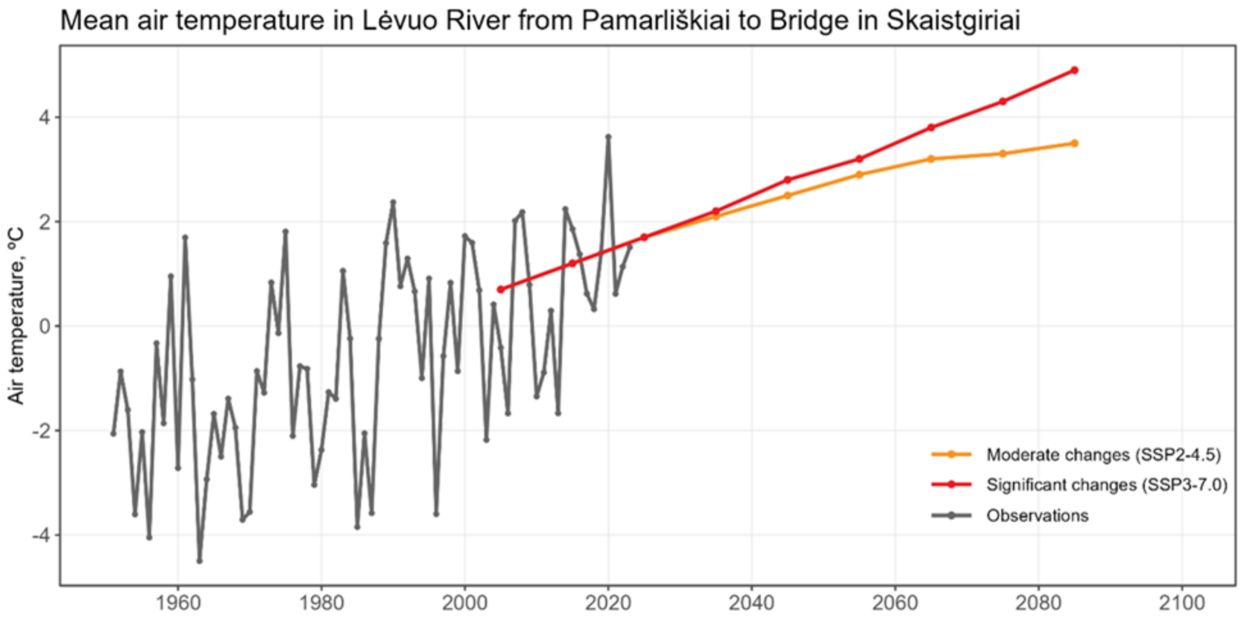

Figure 3.4.1.1. The average November–April air temperature in Lėvuo River from Pamarliškiai to Bridge in Skaistgiriai from 1951 (observational data) to 2100 (climate model scenarios SSP2-4.5 and SSP3-7.0 data)

In the reference period (1961–1990), mean monthly air temperatures were negative from December to March, with January and February the coldest (−5.6 °C and −5.4 °C). By the normal period (1991–2020), these months warmed by 2.3 °C and 2.2 °C to −3.3 °C and −3.2 °C. The largest changes occurred in these two coldest months (Fig. 3.4.1.2) reducing the seasonal variations.

Projections under SSP3-7.0 show mid-century (2041–2070) monthly temperatures increasing by 2.4–3.6 °C compared to the normal, with January and February showing the largest increases. The air temperature during these months is projected to be +0.3 [±1.1] °C and +0.1 [±1.3] °C. Under SSP2-4.5, mid-century monthly temperatures would rise by 1.9–3.1 °C, particularly in December–February. However, January and February mean temperatures remain below 0 °C, at −0.2 [±1.0] °C and −0.4 [±0.2] °C, respectively.

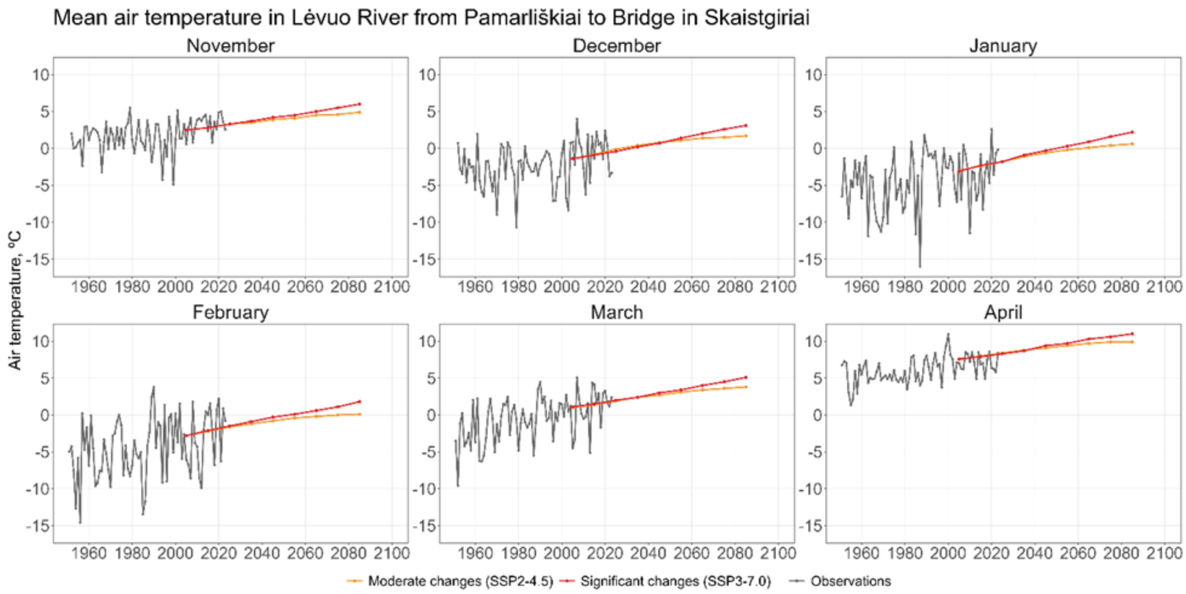

Figure 3.4.1.2. The average monthly air temperature in Lėvuo River from Pamarliškiai to Bridge in Skaistgiriai from 1951 (observational data) to 2100 (climate model scenarios SSP2-4.5 and SSP3-7.0 data)

By 2071–2100, SSP3-7.0 projects monthly temperatures to rise by 3.9–5.5 °C, with January and February increasing to +2.2 [±1.4] °C and +1.8 [±1.5] °C. Under SSP2-4.5, monthly temperatures would rise by 2.6–3.9 °C, with December–February seeing the largest changes, resulting in mean monthly temperatures above 0 °C year-round.

The warming trend is evident even in extreme winters. During November–April, the coldest 10% of winters in climate normal period were warmer by 1.9 °C changing from −3.6 °C in reference period to −1.5 °C. Typical winters experienced similar warming, rising by 2.0 °C (from −1.3 °C to +0.7 °C). These trends highlight significant temperature increases across all winter categories (Fig. 3.4.1.3).

Projections under SSP2-4.5 and SSP3-7.0 scenarios indicate continued warming of cold winters, with greater increases under the high-emission SSP3-7.0 scenario. In 2041–2070, for the coldest 10% of winters, the mean temperature is expected to rise to +1.0 [±1.1] °C under SSP2-4.5, 2.7 °C above 1991–2020, exceeding the typical 1991–2020 winter by 0.3 °C. Under SSP3-7.0, it will reach +1.5 [±0.8] °C, a 3.2 °C increase over 1991–2020, 0.8 °C warmer than the typical winter in climate normal period.

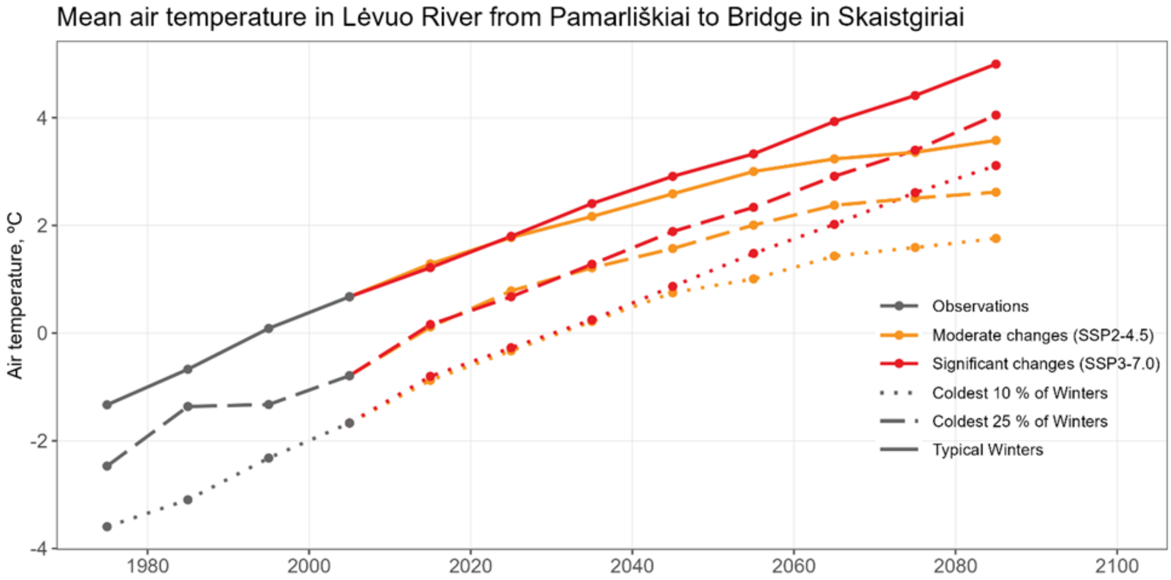

Figure 3.4.1.3. The average November–April air temperature of typical, coldest 25 % and coldest 10 % of winters in Lėvuo River from Pamarliškiai to Bridge in Skaistgiriai from 1951 (observational data) to 2100 (climate model scenarios SSP2-4.5 and SSP3-7.0 data)

By 2071–2100, the coldest 10% of winters will reach +1.8 [±1.2] °C under SSP2-4.5, 3.5 °C above 1991–2020, 1.1 °C warmer than a typical 1991–2020 winter. Under SSP3-7.0, this will rise to +3.1 [±1.1] °C, which is 4.8 °C above the climate normal and 2.4 °C warmer than the typical winter. Typical winters will warm to +3.6 [±1.0] °C under SSP2-4.5 and +5.0 [±1.1] °C under SSP3-7.0, reflecting increases of 2.9 °C and 4.3 °C from 1991–2020.

3.4.2. Negative degree days (NDDs)

The November–April negative degree days (NDDs) averaged 387.9 °C during the observation period of 1991–2020. In comparison, the reference period of 1961–1990 recorded NDDs of 563.0 °C, illustrating a significant reduction by 1991–2020 because of warming trends.

Future projections under the SSP2-4.5 and SSP3-7.0 climate scenarios suggest a substantial further decline in NDDs (Fig. 3.4.2.1), reinforcing expectations of continued warming. For 2041–2070, under SSP2-4.5, the average NDD is projected to decrease to 202.2 [±45.8] °C, marking a reduction of 185.7 °C relative to 1991–2020. Under SSP3-7.0, the decline is even more pronounced, with average NDDs of 181.4 [±46.8] °C, representing a reduction of 206.5 °C compared to the recent climate normal. By 2071–2100, the NDD under SSP2-4.5 is projected to decline further to 171 [±57.8] °C, corresponding to a reduction of 216.3 °C relative to 1991–2020. Under SSP3-7.0, the NDD is projected to drop to 106.7 [±43.8] °C, a decrease of 281.2 °C compared to both the reference and the more recent periods, indicating significantly warmer winter seasons under a severe climate change scenario.

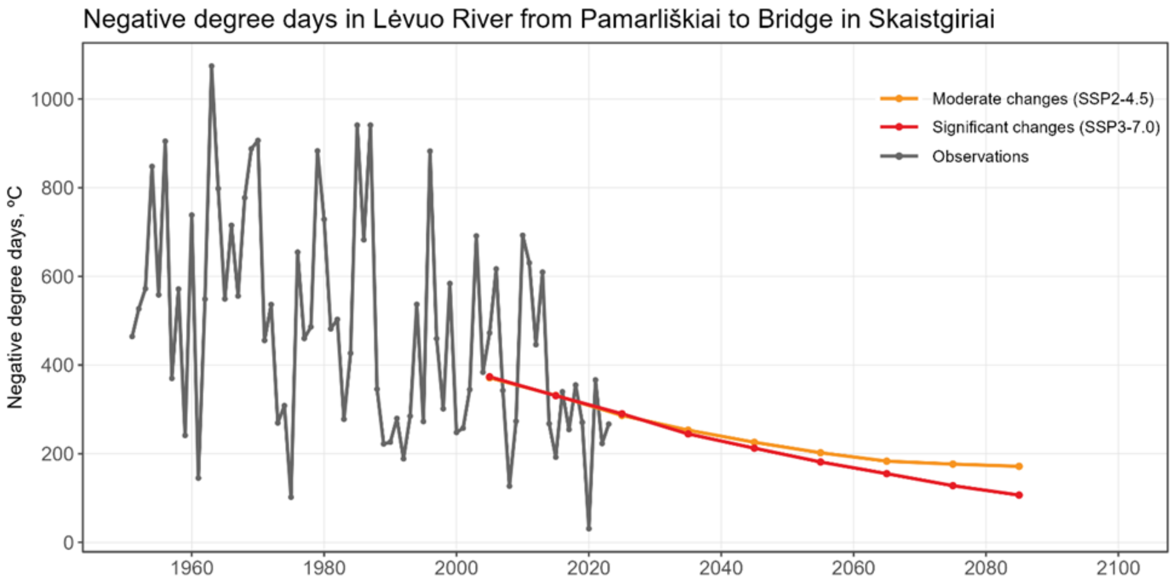

Figure 3.4.2.1. The November–April negative degree days (NDD) in Lėvuo River from Pamarliškiai to Bridge in Skaistgiriai from 1951 (observational data) to 2100 (climate model scenarios SSP2-4.5 and SSP3-7.0 data)

Monthly analyses indicate that the most substantial changes occur during the coldest winter months of December, January, and February. January, traditionally the coldest month (Fig. 3.4.2.2), exhibits the largest reductions, with NDDs declining from 187.2 °C during 1961–1990 to 125.6 °C during 1991–2020. For 2041–2070, January NDDs are projected to decrease to 67.0 [±17.7] °C under SSP2-4.5 and 59.7 [±15.6] °C under SSP3-7.0. By 2071–2100, NDDs are anticipated to fall further to 56.5 [±20.1] °C under SSP2-4.5 and 37.4 [±14.3] °C under SSP3-7.0. February exhibits similar trends, with NDDs projected to decline to 56.6 [±18.1] °C under SSP2-4.5 and 35.8 [±15.7] °C under SSP3-7.0 by the century's end.

December also demonstrates notable changes, with NDDs decreasing from 118.6 °C during 1961–1990 to 84.0 °C during 1991–2020 and further to 35.0 [±17.5] °C under SSP2-4.5 and 22.3 [±12.9] °C under SSP3-7.0 by 2071–2100. Conversely, the transitional months of March, November, and April show less pronounced but still significant declines. March NDDs reduced from 74.9 °C during 1961–1990 to 43.0 °C during 1991–2020 and are projected to decline further to 12.3 [±7.6] °C under SSP2-4.5 and 6.0 [±4.8] °C under SSP3-7.0 by the century's close. November and April, which already record low NDDs, are projected to approach negligible levels, particularly under SSP3-7.0.

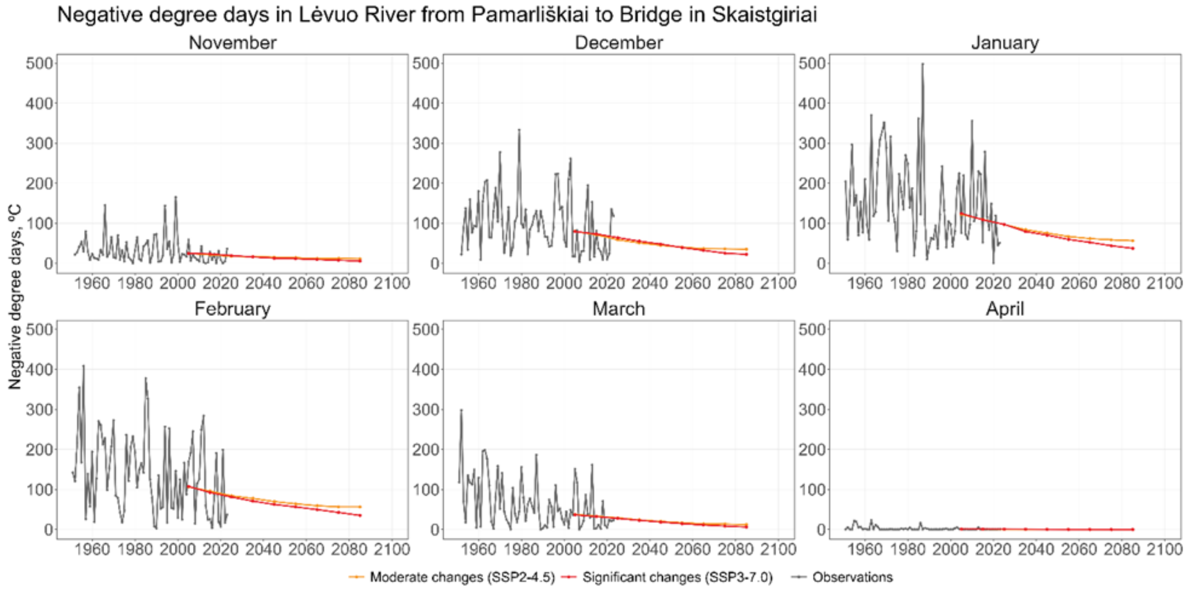

Figure 3.4.2.2. The monthly negative degree days (NDD) in Lėvuo River from Pamarliškiai to Bridge in Skaistgiriai from 1951 (observational data) to 2100 (climate model scenarios SSP2-4.5 and SSP3-7.0 data)

During the earlier reference period, typical winters had a mean NDD of 542.6 °C, which declined to 341.2 °C during 1991–2020, representing a reduction of 201.4 °C. Similarly, the coldest 10% of winters saw a decrease from 910.0 °C to 636.5 °C, a total reduction of 273.5 °C. These significant decreases underscore the pronounced warming of winters observed even in historical data (Fig. 3.4.2.3).

Projections under SSP2-4.5 and SSP3-7.0 indicate that this warming trend will intensify in the future. Under SSP2-4.5, the mean NDD for typical winters is projected to decline to 171.3 [±30.8] °C during the mid-21st century (2041–2070). For the coldest 10% of winters, the mean NDD is projected to decrease to 369.5 [±94.3] °C. By the late 21st century (2071–2100), typical winters are expected to record a mean NDD of 148.4 [±60.4] °C, a reduction of 192.6 °C, while the coldest 10% of winters are projected to drop to 327.2 [±101.0] °C, representing a decrease of 309.3 °C.

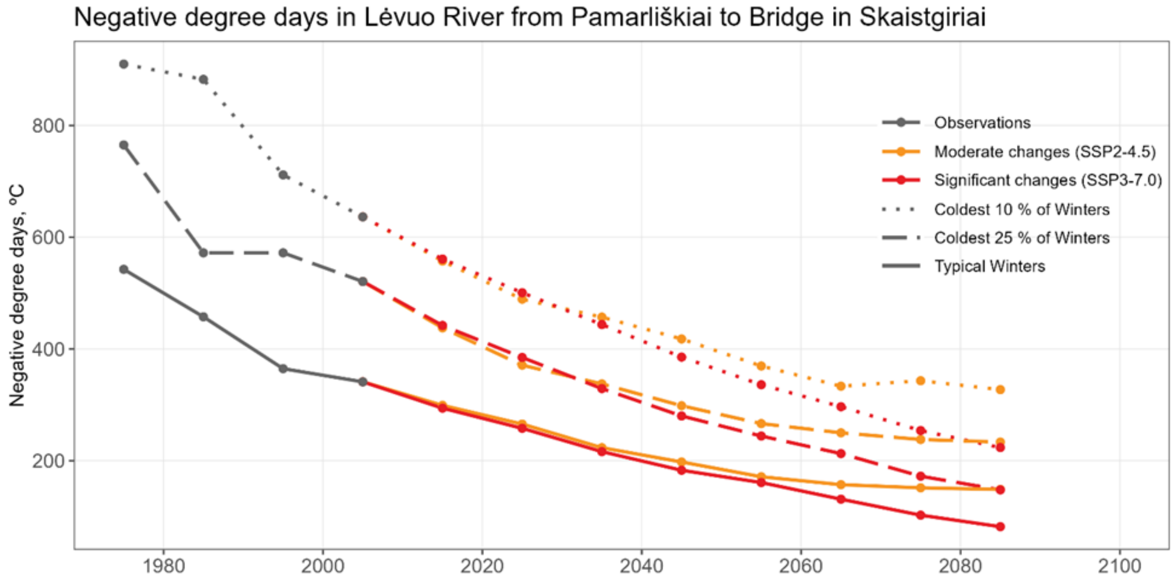

Figure 3.4.2.3. The November–April negative degree days (NDDs) of typical, coldest 25% and coldest 10% of winters in Lėvuo River from Pamarliškiai to Bridge in Skaistgiriai from 1951 (observational data) to 2100 (climate model scenarios SSP2-4.5 and SSP3-7.0 data)

Under the SSP3-7.0 scenario, projected reductions in NDDs are even more substantial. By 2041–2070, typical winters are expected to record a mean NDD of 160.9 [±44.9] °C, a decrease of 180.3 °C relative to the 1991–2020 climate normal. For the coldest 10% of winters, NDDs are projected to decline to 336.0 [±77.8] °C, a decrease of 300.5 °C. By the late 21st century (2071–2100), typical winters are anticipated to record a mean NDD of 81.9 [±41.3] °C, representing a dramatic reduction of 259.3 °C compared to 1991–2020. For the coldest 10% of winters, NDDs are projected to decline to 223.6 [±86.3] °C, corresponding to a reduction of 412.9 °C.

3.4.3. Number of days with negative mean air temperature

The number of days with mean air temperatures below 0 °C during the November–April season has exhibited a notable decline over time (Fig. 3.4.3.1), indicative of the ongoing warming trend. Observations from the 1991–2020 period reveal a seasonal average of 75 days, reflecting a reduction of 15 days compared to the 1961–1990 baseline, when the average stood at 91 days.

Future projections under the SSP2-4.5 and SSP3-7.0 climate scenarios anticipate further reductions. For the period 2041–2070, the average number of days is forecasted to decline to 47 [±8] days under SSP2-4.5 and 43 [±0] days under SSP3-7.0, representing decreases of 29 and 32 days, respectively, compared to the 1991–2020 period. By 2071–2100, these averages are expected to drop further to 41 [±11] days under SSP2-4.5 and 29 [±10] days under SSP3-7.0.

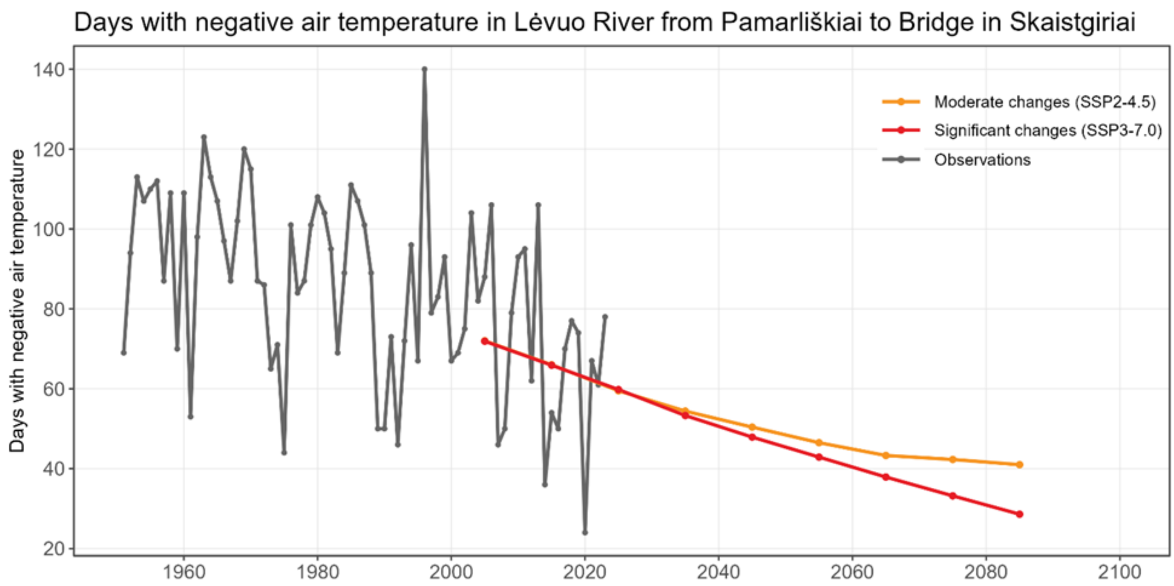

Figure 3.4.3.1. The November–April number of days with negative mean air temperature in Lėvuo River from Pamarliškiai to Bridge in Skaistgiriai from 1951 (observational data) to 2100 (climate model scenarios SSP2-4.5 and SSP3-7.0 data)

Monthly trends also underscore significant changes (Fig. 3.4.3.2). December shows a reduction from 20 days in 1961–1990 to 17 days in 1991–2020. Projections for 2041–2070 estimate 10 [±3] days under SSP2-4.5 and 10 [±3] days under SSP3-7.0, with further declines to 9 [±4] and 7 [±3] days, respectively, by 2071–2100.

In January, the number of days decreased from 23 in 1961–1990 to 20 in 1991–2020. For 2041–2070, projections estimate further reductions to 13 [±2] days under SSP2-4.5 and 12 [±2] days under SSP3-7.0. By 2071–2100, these figures are projected to decrease to 11 [±3] days under SSP2-4.5 and 8 [±3] days under SSP3-7.0. A similar pattern is observed in February, where the number of days declined from 22 in 1961–1990 to 18 in 1991–2020. Projections for 2041–2070 indicate values of 12 [±2] days under SSP2-4.5 and 11 [±3] days under SSP3-7.0, with the number of days staying the same by 2071–2100 under SSP2-4.5, but reducing to 8 [±3] days.

March shows a substantial decline, with the number of days falling from 16 in 1961–1990 to 12 in 1991–2020. Future estimates for 2041–2070 predict 6 [±2] days under both scenarios, with further decreases to 5 [±2] and 3 [±2] days by 2071–2100. In April, the occurrence of days with negative mean air temperatures, which averaged 1 day in 1961–1990, are expected to become obsolete in the future.

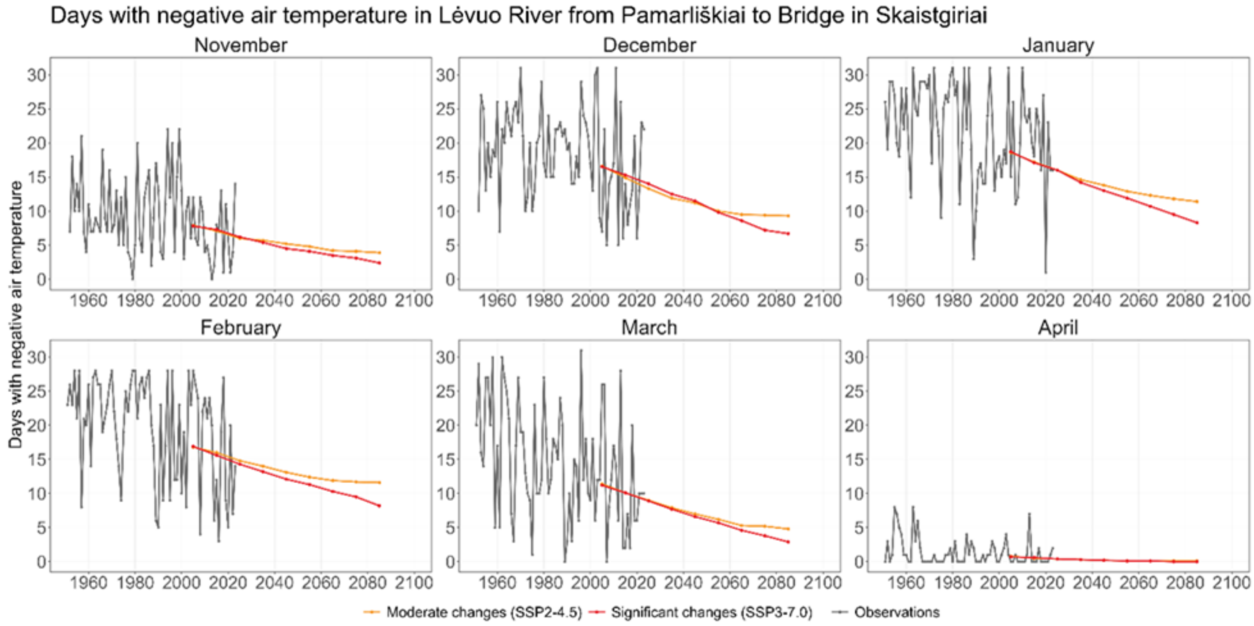

Figure 3.4.3.2. The monthly number of days with negative mean air temperature in Lėvuo River from Pamarliškiai to Bridge in Skaistgiriai from 1951 (observational data) to 2100 (climate model scenarios SSP2-4.5 and SSP3-7.0 data)

The number of days with mean air temperatures below 0 °C during the November–April season has also significantly declined in cold winters between the 1961–1990 baseline and the 1991–2020 climate normal (Fig. 3.4.3.3). For typical winters, the average decreased from 96 days to 75 days, a reduction of 21 days. Similarly, the coldest 25% and 10% of winters experienced reductions of 14 and 9 days, respectively, over this period.

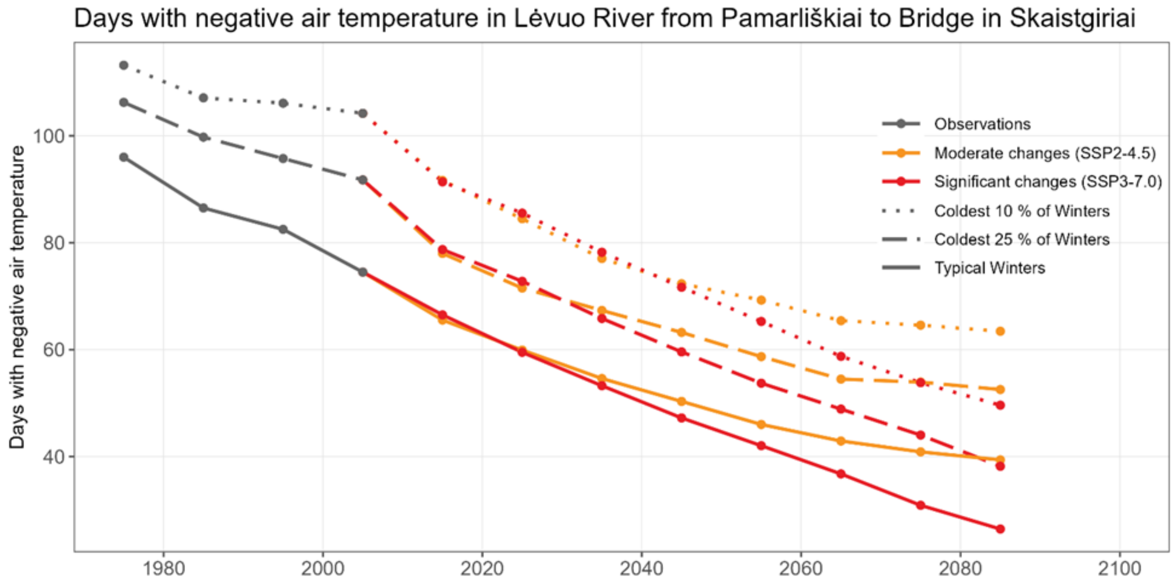

Figure 3.4.3.3. The November–April number of days with negative mean air temperature of typical, coldest 25 % and coldest 10 % of winters in Lėvuo River from Pamarliškiai to Bridge in Skaistgiriai from 1951 (observational data) to 2100 (climate model scenarios SSP2-4.5 and SSP3-7.0 data)

Projections under SSP2-4.5 suggest a continued decline by the mid- and late 21st century. Between 2041 and 2070, typical winters are projected to average 46 [±8] days, a reduction of 29 days relative to the 1991–2020 normal. For the coldest 10% of winters, the average is expected to decrease to 69 [±12] days, representing a decline of 36 days. Under SSP3-7.0, these reductions are even more pronounced. By 2041–2070, typical winters are projected to average 42 [±10] days, while the coldest 10% of winters are expected to average 65 [±9] days, reflecting decreases of 33 and 39 days, respectively.

By the late century (2071–2100), SSP2-4.5 projections indicate a further decline, with typical winters averaging 39 [±11] days and the coldest 10% of winters averaging 63 [±14] days, reductions of 35 and 40 days, respectively. Under SSP3-7.0, these figures drop even more sharply, with typical winters projected at 26 [±11] days and the coldest 10% of winters at 50 [±14] days, corresponding to declines of 48 and 55 days, respectively.

3.4.4. Positive degree days (PDDs)

During the observation period, the mean Positive Degree Days (PDDs) for the November–April season in the reference period 1961–1990 averaged 334.4 °C. In the subsequent climate normal period (1991–2020), PDDs increased to 456.7 °C, reflecting an absolute rise of 122.3 °C. This significant increase highlights the warming trend observed during the November–April season over recent decades (Fig. 3.4.4.1).

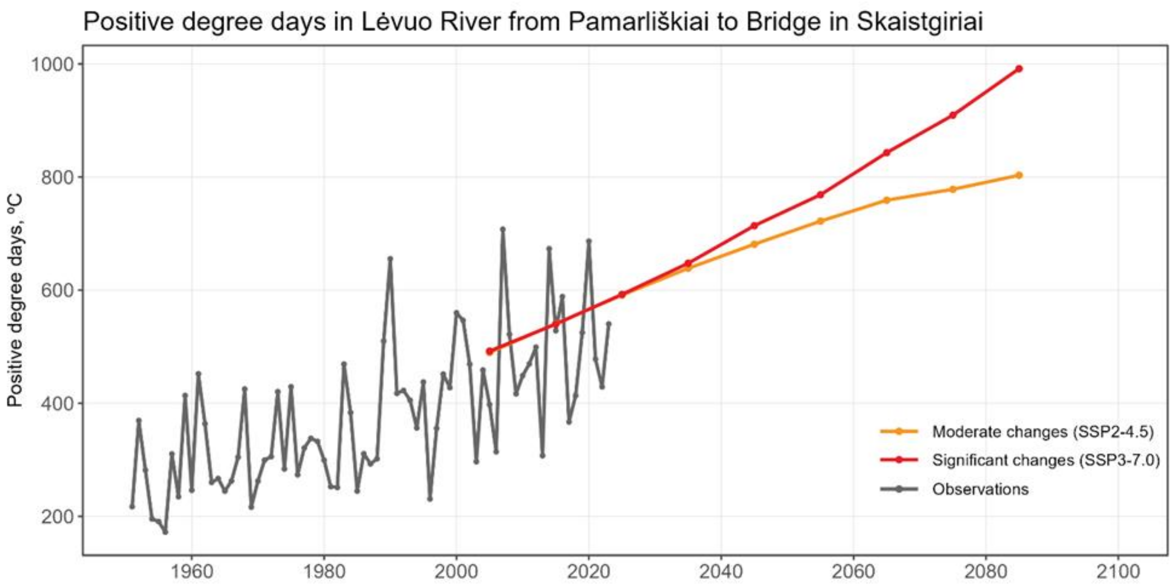

Figure 3.4.4.1. The November–April positive degree days (PDD) in Lėvuo River from Pamarliškiai to Bridge in Skaistgiriai from 1951 (observational data) to 2100 (climate model scenarios SSP2-4.5 and SSP3-7.0 data)

Future projections indicate continued increases in PDDs under both the SSP2-4.5 and SSP3-7.0 climate scenarios. Under SSP2-4.5, PDDs are projected to reach 722.0 [±89.1] °C during the 2041–2070 period, representing an increase of 265.3 °C from the 1991–2020 climate normal. By 2071–2100, PDDs are expected to rise further to 803.2 [±126.1] °C. Projections under SSP3-7.0 show even greater increases, with mean PDDs for 2041–2070 reaching 768.7 [±89.9] °C, an increase of 312.0 °C above the 1991–2020 normal. By the end of the century (2071–2100), PDDs are projected to rise to 991.6 [±157.1] °C, representing an extraordinary increase of 534.9 °C compared to the 1991–2020 normal.

During the 1961–1990 reference period, monthly mean PDDs for November–April were relatively low, reflecting cooler temperatures. November recorded a mean PDD of 78.0 °C, while December had a lower value of 21.6 °C. The coldest months, January and February, recorded mean PDDs of 12.6 °C and 7.9 °C, respectively. In contrast, PDDs increased in March to 37.6 °C and peaked in April at 165.8 °C.

In the 1991–2020 climate normal period, all months in this season experienced an increase in mean PDDs, reflecting a clear warming trend (Fig. 3.4.4.2). For instance, November's PDD rose to 94.4 °C, while December increased to 37.3 °C. January and February recorded PDDs of 24.4 °C and 21.6 °C, respectively. March's PDD rose to 62.0 °C, and April's PDD increased substantially to 215.2 °C, demonstrating notable warming compared to the reference period.

Under SSP2-4.5, substantial increases in monthly PDDs are projected for 2041–2070. November is expected to reach 138.1 [±28.1] °C, while December is projected to rise to 75.8 [±25.2] °C. January and February are forecasted to reach 60.7 [±15.7] °C and 51.6 [±10.7] °C, respectively. March's PDD is projected to rise to 113.1 [±22.9] °C, and April is expected to increase dramatically to 282.3 [±22.9] °C, illustrating pronounced warming in late winter and early spring. By 2071–2100, these trends intensify further under SSP2-4.5, with November projected to reach 156.7 [±33.4] °C and December rising to 87.2 [±32.0] °C. January and February are forecasted to increase to 75.2 [±23.6] °C and 57.9 [±17.3] °C, respectively. March's PDD is expected to reach 128.3 [±21.3] °C, while April will rise to 298.0 [±19.3] °C, continuing the warming trend.

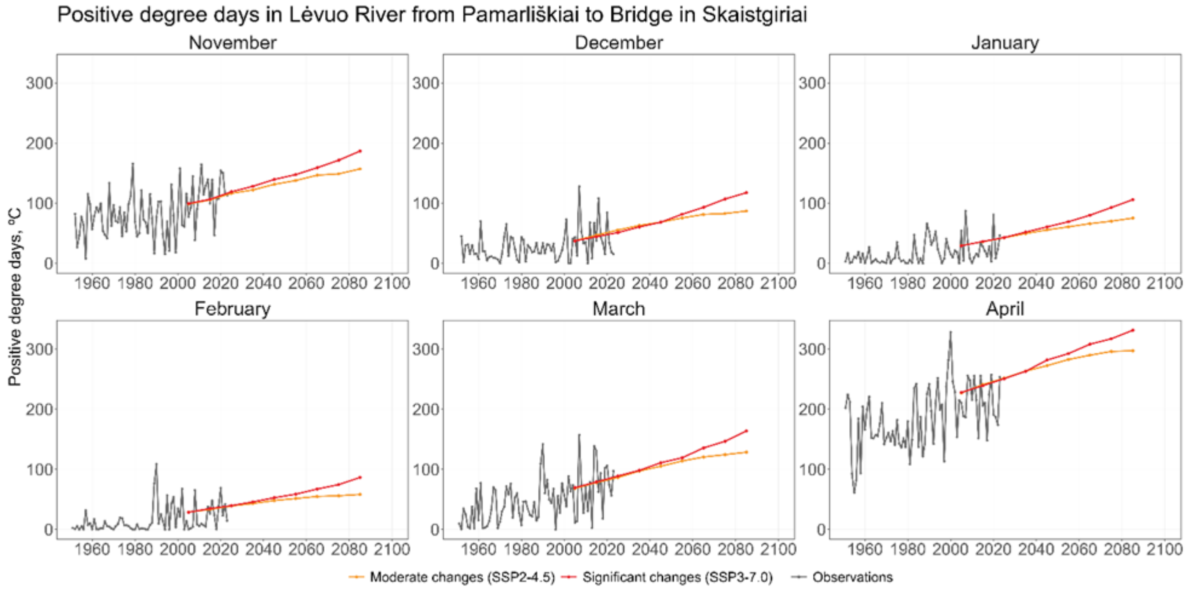

Figure 3.4.4.2. The monthly positive degree days (PDD) in Lėvuo River from Pamarliškiai to Bridge in Skaistgiriai from 1951 (observational data) to 2100 (climate model scenarios SSP2-4.5 and SSP3-7.0 data)

The SSP3-7.0 scenario shows even more pronounced warming. For 2041–2070, November is projected to reach 147.8 [±29.6] °C, and December is expected to rise to 81.8 [±22.3] °C. January and February are projected to reach 69.2 [±19.5] °C and 58.6 [±19.0] °C, respectively. March's PDD is forecasted to rise to 118.7 [±20.4] °C, and April will reach 292.2 [±18.6] °C, illustrating pronounced warming, particularly in spring. By 2071–2100, November is projected to reach 187.5 [±42.6] °C, and December is expected to rise to 118.2 [±39.4] °C. January and February are forecasted to reach 105.9 [±32.6] °C and 85.6 [±26.9] °C, respectively. March is expected to rise to 164.3 [±25.5] °C, while April will peak at 331.8 [±26.3] °C, marking the strongest warming during late winter and early spring.

Positive Degree Days during cold winters have shown a significant upward trend from the 1961–1990 reference period to the 1991–2020 climate normal (Fig. 3.4.4.3). Typical winters recorded a mean PDD of 303.1 °C during the reference period, while the coldest 25% and 10% of winters averaged 263.6 °C and 250.4 °C, respectively. By 1991–2020, these values increased to 443.2 °C, 399.5 °C, and 313.6 °C, representing a substantial rise consistent with observed warming trends.

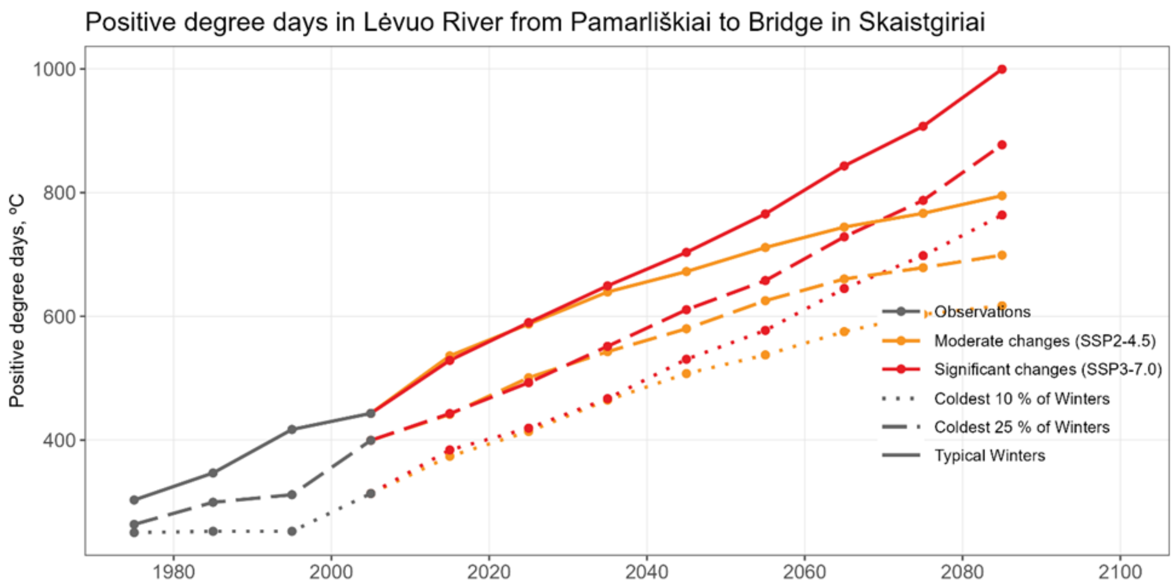

Figure 3.4.4.3. The November–April positive degree days (PDD) of typical, coldest 25% and coldest 10 % of winters in Lėvuo River from Pamarliškiai to Bridge in Skaistgiriai from 1951 (observational data) to 2100 (climate model scenarios SSP2-4.5 and SSP3-7.0 data)

Projections under SSP2-4.5 indicate continued increases in PDDs by mid-century (2041–2070), with typical winters reaching 711.3 [±88.9] °C and the coldest 10% of winters reaching 537.6 [±98.1] °C. By the late century (2071–2100), typical winters are expected to rise further to 795.0 [±122.3] °C, and the coldest 10% to 617.0 [±119.1] °C. Under SSP3-7.0, the warming trend is even more pronounced. For 2041–2070, typical winters are projected to reach 765.6 [±90.9] °C, while the coldest 10% of winters will rise to 577.3 [±76.8] °C. By 2071–2100, typical winters are expected to reach 999.6 [±165.5] °C, while the coldest 10% are projected to rise to 763.8 [±127.5] °C, reflecting dramatic increases in PDDs under this scenario.

3.4.5. Precipitation amount

Observations from the reference period (1961–1990) reveal notable changes in precipitation compared to the climate normal of 1991–2020. Seasonal precipitation during 1961–1990 totalled 230.6 mm, which was 10% lower than the 1991–2020 climate normal of 253.6 mm (Fig. 3.4.5.1). The climate normal period (1991–2020) exhibited a more even distribution of precipitation compared to the reference period. The increase in precipitation between the reference and climate normal periods was particularly pronounced in January and February, reflecting a general trend toward wetter conditions.

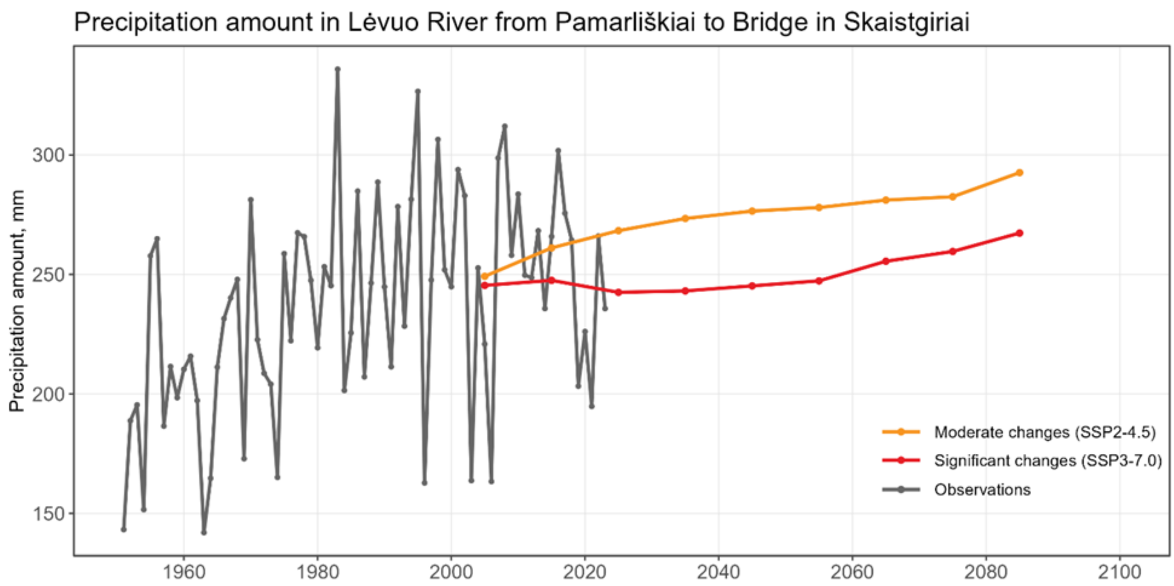

Figure 3.4.5.1. The November–April precipitation amount in Lėvuo River from Pamarliškiai to Bridge in Skaistgiriai from 1951 (observational data) to 2100 (climate model scenarios SSP2-4.5 and SSP3-7.0 data)

Projections under the SSP2-4.5 and SSP3-7.0 scenarios indicate contrasting trajectories for future precipitation patterns. During the mid-21st century (2041–2070), SSP2-4.5 forecasts a notable rise in total seasonal precipitation to 278.0 [±19.6] mm, an increase of 10% relative to the climate normal. Monthly precipitation under this scenario also shows consistent growth (Fig. 3.4.5.2), with the most substantial increase projected for December, where precipitation is expected to rise to 56.9 [±5.0] mm, representing an increase of 18%. In other months, the projected increases are milder, ranging between 4% and 12%.

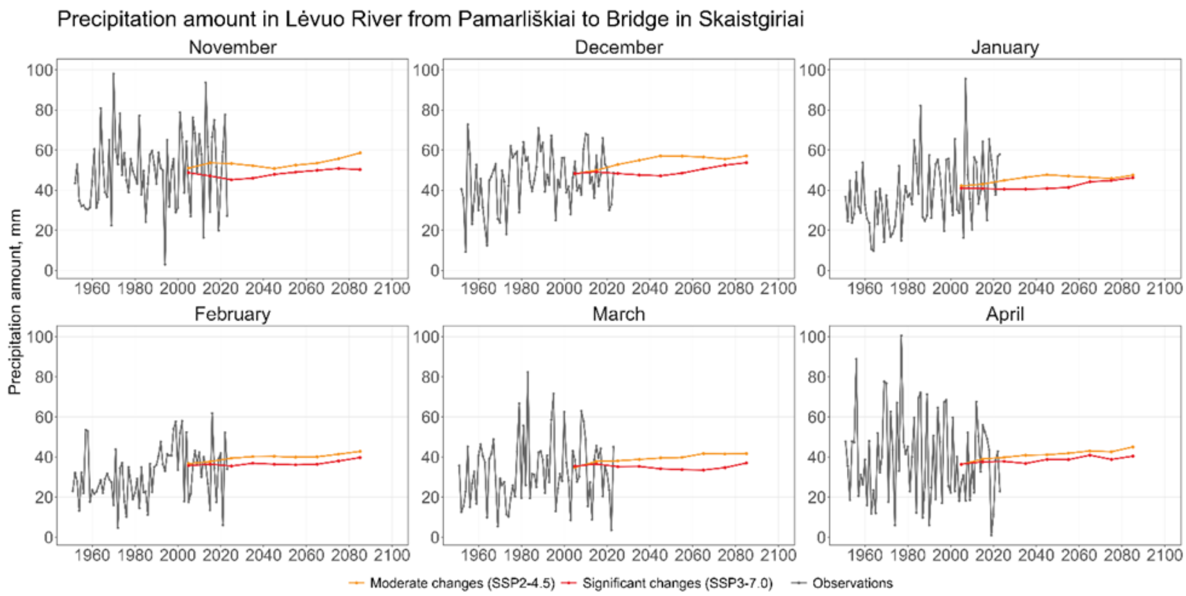

Figure 3.4.5.2. The monthly precipitation amount in Lėvuo River: from Pamarliškiai to Bridge in Skaistgiriai from 1951 (observational data) to 2100 (climate model scenarios SSP2-4.5 and SSP3-7.0 data)

Conversely, under SSP3-7.0, total seasonal precipitation during the same period is projected to decline to 247.4 [±94.1] mm, representing a decrease of 2% compared to the climate normal. Monthly patterns suggest no significant changes for December and April, while the remaining months are expected to experience declines of 4% to 7%.

By the late 21st century (2071–2100), SSP2-4.5 continues to project increases in precipitation, with total seasonal amounts expected to rise to 292.6 [±12.4] mm, an increase of 15% relative to the climate normal. Monthly increases become more pronounced during this period, with November projected to receive 58.9 [±6.2] mm, an increase of 17%, and December rising to 57.5 [±4.5] mm, representing a 19% increase. April precipitation is anticipated to reach 45.3 [±5.2] mm, reflecting a 19% increase. January and February are also projected to see increases of 8% and 12%, respectively.

In contrast, SSP3-7.0 for the late 21st century suggests a modest increase in total seasonal precipitation to 267.3 [±100.3] mm, an increase of 5% compared to the climate normal. Monthly variability remains similar to that observed during the climate normal period, with the most significant monthly increase of 11% occurring in December.

Overall, as observed in the case of the Muša River, the SSP2-4.5 scenario consistently projects higher and more stable precipitation amounts compared to SSP3-7.0. The wetter conditions under SSP2-4.5 underscore the influence of increased atmospheric moisture, particularly during the winter months of November and December. In contrast, SSP3-7.0 is characterized by greater variability and less pronounced changes, with some months experiencing declines or minimal increases, reflecting the inherent uncertainties of high-emission pathways.

4. Conclusions

The historical and projected climate changes along the Muša River (between Gustoniai and Ustukiai) and the Lėvuo River (from Pamarliškiai to the bridge in Skaistgiriai) in Lithuania and Daugava River (between tributaries Nereta and Aiviekste) and Lielupe River (from Mūsa and Mēmele confluence to Sesava River) in Latvia follow similar trends. Air temperature and analyzed indices show only marginal differences, suggesting that climate change will affect the primary factors influencing ice-jam formation in similar ways for both areas.

The historical warming trend is evident when comparing the reference period (1961–1990) to the climate normal (1991–2020). During this time, **mean seasonal (November–April) air temperature** increased by 1.5–1.7 °C across the four river basins, whereas monthly air temperatures increased by 0.7–2.5 °C. November air temperature has increased the least, the difference between the reference and climate normal being 0.7 °C for all rivers, but January has experienced the highest increase of 2.3–2.5 °C. Future projections show continued warming across all rivers and scenarios. Seasonal air temperature is expected to rise by 2.1–4.5 °C relative to 1991–2020, with Lithuania experiencing a larger increase. At the end of the century, even the coldest 10% and 25% of winters are expected to be 0.1–2.4 °C warmer than the typical winters now (Figures 3.1.1.3, 3.2.1.3, 3.3.1.3, 3.4.1.3).

This significant warming indicates that while ice-jams may still form, their probability will likely decrease, especially towards the end of the 21st century. Mitigation policies will play a critical role in determining the extent of these changes, as SSP3-7.0 projects significantly greater warming from mid-century onward compared to the more moderate SSP2-4.5 scenario.

Negative degree days (NDDs), which are indicative of ice formation and thickening, are projected to decline substantially. Larger NDD values historically contributed to the accumulation of thicker ice covers, increasing the likelihood of ice-jams when the ice cover broke. Thicker ice transported by rivers typically leads to the formation of more resistant ice jams and more severe flooding. NDDs have already decreased seasonally by 159.7–188.1 °C from 1961–1990 to 1991–2020, mostly due to reductions in January and February. Substantial reductions in NDDs are projected in the future for the November–April period, with seasonal NDDs at the end of the century reaching values below 200 °C and even close to 100 °C, almost the same as the current normal for January (~120 °C), for example (Figures 3.1.2.1, 3.2.2.1, 3.3.2.1, 3.4.2.1).

The **number of days with mean air temperatures below 0 °C**, crucial for frazil ice formation and freeze-up jams, will also decline significantly. Historically, such events occurred primarily at the start of the cold season, but with rising temperatures, frazil ice formation has become more sporadic, even during the current climate norm period (1991–2020). Projections show a consistent reduction in the number of days with mean temperatures below 0 °C across all scenarios, though Lithuanian rivers are projected to experience a larger decrease of days with negative air temperature. While in Latvian river regions the number of days with negative air temperature by the end of the century will decrease by 22 or 37 days, which is a reduction of less than half from the normal period, Lithuanian river regions are expected to see a larger reduction – more than half compared to the normal period. These reductions in freezing days, especially consecutive ones, imply a significant decline in the likelihood of frazil ice formation and associated ice-jams.

Positive degree days (PDDs), which are linked to thawing events that could trigger thermal or physical ice cover breaks, are projected to increase. Very high PDD values may indicate conditions too warm for ice cover to form or significant limitations on ice accumulation. PDDs could be associated with ice-jam formation only after substantial NDD accumulation and a preceding period of below-freezing days. This combination would result in thicker ice and greater snow melt flow, leading to a higher potential for ice-jams. However, with much warmer cold seasons even by the mid-21st century the PDDs would reach ~720–770 °C, which is a significant increase in comparison to climate norm period (Figures 3.1.4.1, 3.2.4.1, 3.3.4.1, 3.4.4.1).

Precipitation indirectly affects ice-jams through runoff formation and can directly weaken ice cover during extended rain spells. Seasonal precipitation has increased by 2–10% since the reference period (1961–1990), though there are notable monthly variations. Future projections indicate increased precipitation for all river regions, though a smaller increase in Lithuanian regions (up to 15%) compared to Latvia (up to 43%). Comparatively large projected increases of precipitation amount in December could create more favourable conditions for ice-jam formation, substantial warming during the cold season will likely offset this effect.

In summary, climate change can significantly reduce the frequency and severity of ice-jams due to warmer temperatures, fewer freezing days, shorter accumulation periods for NDDs, and declining frazil ice formation. The moderate climate change scenario (SSP2-4.5) projects more stable conditions, while the significant climate change scenario (SSP3-7.0) suggests greater variability throughout the century and a more extreme reduction of ice-jam risk in the late 21st century.

References

1. Ruosteenoja, K., Kämäräinen, M., Aņiskeviča, S., Mäkelä, A., & Pirinen, P. (2016). Development of climate change scenarios for Latvia for the period until the year 2100. Finnish Meteorological Institute. https://helda.helsinki.fi/server/api/core/bitstreams/8218532a3227-4422-af9e-7c82d937ecea/content
2. Cannon, A. J., Sobie, S. R., & Murdock, T. Q. (2015). Bias Correction of GCM Precipitation by Quantile Mapping: How Well Do Methods Preserve Changes in Quantiles and Extremes? Journal of Climate, 28(17), 6938–6959. https://doi.org/10.1175/JCLI-D-14-00754.1
3. Schwertfeger, B. T., Lohmann, G., & Lipskoch, H. (2023). Introduction of the *BiasAdjustCXX* command-line tool for the application of fast and efficient bias corrections in climatic research. SoftwareX, 22. https://doi.org/10.1016/j.softx.2023.101379
4. Bourgault et al., (2023). *xclim*: xarray-based climate data analytics. Journal of Open Source Software, 8(85), 5415. https://doi.org/10.21105/joss.05415
5. Teutschbein, C., & Seibert, J. (2012). Bias correction of regional climate model simulations for hydrological climate-change impact studies: Review and evaluation of different methods. Journal of Hydrology, 456–457, 12–29. https://doi.org/10.1016/j.jhydrol.2012.05.052
6. Tong, Y., Gao, X., Han, Z., Xu, Y., Xu, Y., & Giorgi, F. (2021). Bias correction of temperature and precipitation over China for RCM simulations using the QM and QDM methods. Climate Dynamics, 57(5–6), 1425–1443. https://doi.org/10.1007/s00382-020-05447-4
7. Stonevicius, E., Stankunavicius, G., Kilkus, K. (2008) Ice Regime Dynamics in the Nemunas River, Lithuania. Clim. Res. 36, 17–28
8. Šarauskienė, D., Jakimavičius, D.; Jurgelėnaitė, A.; Kriaučiūnienė, J. (2024) Warming Climate Induced Changes in Lithuanian River Ice Phenology. Sustainability 16, 725. https://doi.org/10.3390/su16020725

Mean air temperature

River basin	Period	Reference; 1961–1990	Normal; 1991–2020	Normal vs. reference	Future; 2071–2100 [± model standard deviation]		Future vs. normal period	
					SSP2-4.5	SSP3-7.0	SSP2-4.5	SSP3-7.0
Daugava River	Season	−2.0 °C	−0.4 °C	↑ +1.6 °C	+1.9 [±1.0] °C	+3.1 [±0.8] °C	↑ +2.3 °C	↑ +3.5 °C
	Nov	+0.7 °C	+1.4 °C	↑ +0.7 °C	+3.9 [±1.1] °C	+5.0 [±1.2] °C	↑ +2.5 °C	↑ +3.6 °C
	Dec	−3.8 °C	−2.2 °C	↑ +1.6 °C	+0.2 [±1.2] °C	+1.6 [±1.1] °C	↑ +2.4 °C	↑ +3.8 °C
	Jan	−6.6 °C	−4.1 °C	↑ +2.5 °C	−1.8 [±1.1] °C	−0.4 [±0.9] °C	↑ +2.3 °C	↑ +3.7 °C
	Feb	−5.9 °C	−4.1 °C	↑ +1.8 °C	−1.7 [±1.1] °C	−0.3 [±0.8] °C	↑ +2.4 °C	↑ +3.8 °C
	Mar	−1.7 °C	−0.1 °C	↑ +1.6 °C	+2.1 [±1.2] °C	+3.1 [±1.0] °C	↑ +2.2 °C	↑ +3.2 °C
	Apr	+5.0 °C	+6.7 °C	↑ +1.7 °C	+8.7 [±0.9] °C	+9.6 [±0.8] °C	↑ +2.0 °C	↑ +2.9 °C
Lielupe River	Season	−1.0 °C	+0.5 °C	↑ +1.5 °C	+2.6 [±1.0] °C	+3.8 [±0.8] °C	↑ +2.1 °C	↑ +3.3 °C
	Nov	+1.7 °C	+2.4 °C	↑ +0.7 °C	+4.9 [±1.1] °C	+5.9 [±1.2] °C	↑ +2.5 °C	↑ +3.5 °C
	Dec	−2.6 °C	−1.1 °C	↑ +1.5 °C	+1.3 [±1.1] °C	+2.6 [±1.1] °C	↑ +2.4 °C	↑ +3.7 °C
	Jan	−5.1 °C	−2.8 °C	↑ +2.3 °C	−0.6 [±1.1] °C	+0.6 [±0.8] °C	↑ +2.2 °C	↑ +3.4 °C
	Feb	−4.7 °C	−2.8 °C	↑ +1.9 °C	−0.6 [±1.1] °C	+0.7 [±0.8] °C	↑ +2.2 °C	↑ +3.5 °C
	Mar	−0.8 °C	+0.7 °C	↑ +1.5 °C	+2.7 [±1.1] °C	+3.7 [±0.9] °C	↑ +2.0 °C	↑ +3.0 °C
	Apr	+5.3 °C	+6.8 °C	↑ +1.5 °C	+8.5 [±0.9] °C	+9.5 [±0.7] °C	↑ +1.7 °C	↑ +2.7 °C
Muša River	Season	−1.1 °C	+0.5 °C	↑ +1.6 °C	+3.6 [±1.0] °C	+5.0 [±1.1] °C	↑ +3.1 °C	↑ +4.5 °C
	Nov	+1.6 °C	+2.3 °C	↑ +0.7 °C	+4.9 [±1.3] °C	+6.2 [±1.5] °C	↑ +2.6 °C	↑ +3.9 °C
	Dec	−2.9 °C	−1.4 °C	↑ +1.5 °C	+1.8 [±1.6] °C	+3.2 [±1.6] °C	↑ +3.2 °C	↑ +4.6 °C
	Jan	−5.4 °C	−3.1 °C	↑ +2.3 °C	+0.7 [±1.3] °C	+2.3 [±1.4] °C	↑ +3.8 °C	↑ +5.4 °C
	Feb	−5.2 °C	−3.1 °C	↑ +2.1 °C	+0.2 [±1.2] °C	+1.9 [±1.5] °C	↑ +3.3 °C	↑ +5.0 °C
	Mar	−1.0 °C	+0.7 °C	↑ +1.7 °C	+3.8 [±0.9] °C	+5.2 [±0.9] °C	↑ +3.1 °C	↑ +4.5 °C
	Apr	+5.5 °C	+7.3 °C	↑ +1.8 °C	+10.0 [±0.6] °C	+11.1 [±0.9] °C	↑ +2.7 °C	↑ +3.8 °C
Levuo River	Season	−1.3 °C	+0.4 °C	↑ +1.7 °C	+3.5 [±1.0] °C	+4.9 [±1.1] °C	↑ +3.1 °C	↑ +4.5 °C
	Nov	+1.5 °C	+2.2 °C	↑ +0.7 °C	+4.8 [±1.3] °C	+6.1 [±1.5] °C	↑ +2.6 °C	↑ +3.9 °C
	Dec	−3.1 °C	−1.5 °C	↑ +1.6 °C	+1.7 [±1.6] °C	+3.1 [±1.6] °C	↑ +3.2 °C	↑ +4.6 °C
	Jan	−5.6 °C	−3.3 °C	↑ +2.3 °C	+0.6 [±1.4] °C	+2.2 [±1.4] °C	↑ +3.9 °C	↑ +5.5 °C
	Feb	−5.4 °C	−3.2 °C	↑ +2.2 °C	0 [±1.2] °C	+1.8 [±1.5] °C	↑ +3.2 °C	↑ +5.0 °C
	Mar	−1.2 °C	+0.6 °C	↑ +1.8 °C	+3.7 [±0.9] °C	+5.1 [±0.9] °C	↑ +3.1 °C	↑ +4.5 °C
	Apr	+5.4 °C	+7.1 °C	↑ +1.7 °C	+9.9 [±0.7] °C	+11.1 [±0.9] °C	↑ +2.8 °C	↑ +4.0 °C

Seasons span from the previous year's November until April.
For example, reference period values are calculated for November 1960–April 1990.

SSP2-4.5 Moderate climate change scenario
SSP3-7.0 Significant climate change scenario

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Negative degree days (NDDs)

River basin	Period	Reference; 1961−1990	Normal; 1991−2020	Normal vs. reference	Future; 2071−2100 [± model standard deviation]		Future vs. normal period	
					SSP2-4.5	SSP3-7.0	SSP2-4.5	SSP3-7.0
Daugava River	Season	657.8 °C	469.7 °C	↓ −188.1 °C	260.5 [±73.5] °C	177.5 [±55.6] °C	↓ −209.2 °C	↓ −292.2 °C
	Nov	42.6 °C	38.3 °C	↓ −4.3 °C	12.6 [±7.2] °C	7.0 [±4.7] °C	↓ −25.7 °C	↓ −31.3 °C
	Dec	136.3 °C	98.8 °C	↓ −37.5 °C	49.9 [±19.2] °C	31.5 [±16.9] °C	↓ −48.9 °C	↓ −67.3 °C
	Jan	214.4 °C	144.6 °C	↓ −69.8 °C	89.3 [±27.1] °C	63.8 [±18.9] °C	↓ −55.3 °C	↓ −80.8 °C
	Feb	173.8 °C	132.3 °C	↓ −41.5 °C	81.7 [±22.1] °C	57.6 [±16.2] °C	↓ −50.6 °C	↓ −74.7 °C
	Mar	86.7 °C	54.0 °C	↓ −32.7 °C	24.9 [±10.8] °C	17.5 [±9.0] °C	↓ −29.1 °C	↓ −36.5 °C
	Apr	4.0 °C	1.7 °C	↓ −2.3 °C	0.2 [±0.3] °C	0.1 [±0.1] °C	↓ −1.5 °C	↓ −1.6 °C
Lielupe River	Season	526.1 °C	366.4 °C	↓ −159.7 °C	194.1 [±60.2] °C	129.2 [±44.5] °C	↓ −172.3 °C	↓ −237.2 °C
	Nov	30.3 °C	26.1 °C	↓ −4.2 °C	8.1 [±5.1] °C	4.4 [±3.1] °C	↓ −18.0 °C	↓ −21.7 °C
	Dec	107.8 °C	76.8 °C	↓ −31.0 °C	35.5 [±14.5] °C	22.0 [±12.2] °C	↓ −41.3 °C	↓ −54.8 °C
	Jan	172.8 °C	115.8 °C	↓ −57.0 °C	67.3 [±23.1] °C	47.2 [±15.3] °C	↓ −48.5 °C	↓ −68.6 °C
	Feb	145.3 °C	105.0 °C	↓ −40.3 °C	63.0 [±19.0] °C	42.9 [±15.1] °C	↓ −42.0 °C	↓ −62.1 °C
	Mar	67.8 °C	41.9 °C	↓ −25.9 °C	18.4 [±9.6] °C	12.7 [±7.5] °C	↓ −23.5 °C	↓ −29.2 °C
	Apr	2.2 °C	0.8 °C	↓ −1.4 °C	0.1 [±0.2] °C	0 [±0] °C	↓ −0.7 °C	↓ −0.8 °C
Muša River	Season	542.0 °C	376.9 °C	↓ −165.1 °C	166.0 [±56.4] °C	103.1 [±42.8] °C	↓ −210.9 °C	↓ −273.8 °C
	Nov	31.9 °C	27.2 °C	↓ −4.7 °C	11.1 [±6.4] °C	5.4 [±3.3] °C	↓ −16.1 °C	↓ −21.8 °C
	Dec	113.6 °C	82.1 °C	↓ −31.5 °C	34.2 [±17.2] °C	22.0 [±12.7] °C	↓ −47.9 °C	↓ −60.1 °C
	Jan	180.9 °C	122.8 °C	↓ −58.1 °C	55.4 [±19.5] °C	36.5 [±14.1] °C	↓ −67.4 °C	↓ −86.3 °C
	Feb	153.3 °C	108.4 °C	↓ −44.9 °C	54.1 [±17.7] °C	34.0 [±15.2] °C	↓ −54.3 °C	↓ −74.4 °C
	Mar	71.7 °C	41.7 °C	↓ −30.0 °C	11.6 [±7.4] °C	5.6 [±4.6] °C	↓ −30.1 °C	↓ −36.1 °C
	Apr	2.3 °C	0.7 °C	↓ −1.6 °C	0.1 [±0.2] °C	0 [±0] °C	↓ −0.6 °C	↓ −0.7 °C
Levuo River	Season	563.0 °C	387.9 °C	↓ −175.1 °C	171.6 [±57.8] °C	106.7 [±43.8] °C	↓ −216.3 °C	↓ −281.2 °C
	Nov	33.5 °C	28.5 °C	↓ −5.0 °C	11.6 [±6.6] °C	5.6 [±3.5] °C	↓ −16.9 °C	↓ −22.9 °C
	Dec	118.6 °C	84.0 °C	↓ −34.6 °C	35.0 [±17.5] °C	22.3 [±12.9] °C	↓ −49.0 °C	↓ −61.7 °C
	Jan	187.2 °C	125.6 °C	↓ −61.6 °C	56.5 [±20.0] °C	37.4 [±14.3] °C	↓ −69.1 °C	↓ −88.2 °C
	Feb	158.3 °C	112.3 °C	↓ −46.0 °C	56.6 [±18.1] °C	35.8 [±15.7] °C	↓ −55.7 °C	↓ −76.5 °C
	Mar	74.9 °C	43.0 °C	↓ −31.9 °C	12.3 [±7.6] °C	6.0 [±4.8] °C	↓ −30.7 °C	↓ −37.0 °C
	Apr	2.6 °C	0.7 °C	↓ −1.9 °C	0.1 [±0.2] °C	0 [±0] °C	↓ −0.6 °C	↓ −0.7 °C

Seasons span from the previous year's November until April.
For example, reference period values are calculated for November 1960−April 1990.

SSP2-4.5 Moderate climate change scenario

SSP3-7.0 Significant climate change scenario

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Number of days with negative mean air temperature

River basin	Period	Reference; 1961–1990	Normal; 1991–2020	Normal vs. reference	Future; 2071–2100 [± model standard deviation]		Future vs. normal period	
					SSP2-4.5	SSP3-7.0	SSP2-4.5	SSP3-7.0
Daugava River	Season	99 days	83 days	↓ −16 days	61 [±12] days	46 [±11] days	↓ −22 days	↓ −37 days
	Nov	11 days	10 days	↓ −1 day	5 [±2] days	3 [±2] days	↓ −5 days	↓ −7 days
	Dec	21 days	18 days	↓ −3 days	13 [±3] days	9 [±4] days	↓ −5 days	↓ −9 days
	Jan	24 days	21 days	↓ −3 days	17 [±3] days	14 [±3] days	↓ −4 days	↓ −7 days
	Feb	23 days	19 days	↓ −4 days	16 [±3] days	13 [±2] days	↓ −3 days	↓ −6 days
	Mar	17 days	13 days	↓ −4 days	8 [±2] days	6 [±3] days	↓ −5 days	↓ −7 days
	Apr	2 days	2 days	⇕ 0 days	0 [±0] days	0 [±0] days	↓ −2 days	↓ −2 days
Lielupe River	Season	86 days	71 days	↓ −15 days	47 [±10] days	35 [±9] days	↓ −24 days	↓ −36 days
	Nov	9 days	8 days	↓ −1 day	3 [±2] days	2 [±1] days	↓ −5 days	↓ −6 days
	Dec	19 days	15 days	↓ −4 days	10 [±3] days	7 [±3] days	↓ −5 days	↓ −8 days
	Jan	22 days	18 days	↓ −4 days	14 [±3] days	11 [±2] days	↓ −4 days	↓ −7 days
	Feb	21 days	17 days	↓ −4 days	13 [±3] days	10 [±3] days	↓ −4 days	↓ −7 days
	Mar	14 days	12 days	↓ −2 days	7 [±2] days	4 [±2] days	↓ −5 days	↓ −8 days
	Apr	1 day	1 day	⇕ 0 days	0 [±0] days	0 [±0] days	↓ −1 day	↓ −1 day
Muša River	Season	89 days	74 days	↓ −15 days	40 [±11] days	28 [±10] days	↓ −34 days	↓ −45 days
	Nov	9 days	9 days	⇕ 0 days	4 [±2] days	2 [±1] days	↓ −5 days	↓ −6 days
	Dec	20 days	16 days	↓ −4 days	9 [±3] days	7 [±3] days	↓ −7 days	↓ −9 days
	Jan	23 days	19 days	↓ −4 days	11 [±3] days	8 [±3] days	↓ −8 days	↓ −11 days
	Feb	22 days	18 days	↓ −4 days	11 [±3] days	8 [±3] days	↓ −6 days	↓ −9 days
	Mar	15 days	12 days	↓ −3 days	5 [±2] days	3 [±2] days	↓ −7 days	↓ −9 days
	Apr	1 day	1 day	⇕ 0 days	0 [±0] days	0 [±0] days	↓ −1 day	↓ −1 day
Levuo River	Season	90 days	75 days	↓ −15 days	41 [±11] days	29 [±10] days	↓ −34 days	↓ −47 days
	Nov	9 days	9 days	⇕ 0 days	4 [±2] days	2 [±1] days	↓ −5 days	↓ −6 days
	Dec	20 days	16 days	↓ −4 days	9 [±4] days	7 [±3] days	↓ −7 days	↓ −10 days
	Jan	23 days	20 days	↓ −4 days	11 [±3] days	8 [±3] days	↓ −8 days	↓ −11 days
	Feb	22 days	18 days	↓ −4 days	12 [±3] days	8 [±3] days	↓ −6 days	↓ −10 days
	Mar	16 days	12 days	↓ −3 days	5 [±2] days	3 [±2] days	↓ −7 days	↓ −9 days
	Apr	1 day	1 day	⇕ 0 days	0 [±0] days	0 [±0] days	↓ −1 day	↓ −1 day

Seasons span from the previous year's November until April.
For example, reference period values are calculated for November 1960–April 1990.

SSP2-4.5 Moderate climate change scenario
SSP3-7.0 Significant climate change scenario

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Positive degree days (PDDs)

River basin	Period	Reference; 1961–1990	Normal; 1991–2020	Normal vs. reference	Future; 2071–2100 [± model standard deviation]		Future vs. normal period	
					SSP2-4.5	SSP3-7.0	SSP2-4.5	SSP3-7.0
Daugava River	Season	286.0 °C	400.3 °C	↑ +114.3 °C	596.6 [±129.2] °C	737.8 [±110.5] °C	↑ +196.3 °C	↑ +337.5 °C
	Nov	64.5 °C	79.6 °C	↑ +15.1 °C	129.5 [±27.4] °C	156.4 [±32.3] °C	↑ +49.9 °C	↑ +76.8 °C
	Dec	17.6 °C	30.2 °C	↑ +12.6 °C	55.4 [±21.4] °C	80.3 [±22.8] °C	↑ +25.2 °C	↑ +50.1 °C
	Jan	8.8 °C	18.4 °C	↑ +9.6 °C	33.1 [±15.4] °C	49.5 [±14.7] °C	↑ +14.7 °C	↑ +31.1 °C
	Feb	8.0 °C	17.8 °C	↑ +9.8 °C	33.3 [±15.1] °C	48.0 [±14.3] °C	↑ +15.5 °C	↑ +30.2 °C
	Mar	32.8 °C	52.2 °C	↑ +19.4 °C	90.9 [±29.2] °C	115.0 [±25.5] °C	↑ +38.7 °C	↑ +62.8 °C
	Apr	154.2 °C	202.1 °C	↑ +47.9 °C	260.2 [±28.0] °C	288.6 [±23.3] °C	↑ +58.1 °C	↑ +86.5 °C
Lielupe River	Season	339.6 °C	461.5 °C	↑ +121.9 °C	674.7 [±134.2] °C	825.1 [±112.5] °C	↑ +213.2 °C	↑ +363.6 °C
	Nov	80.9 °C	96.6 °C	↑ +15.7 °C	153.9 [±28.9] °C	181.0 [±32.5] °C	↑ +57.3 °C	↑ +84.4 °C
	Dec	27.0 °C	41.8 °C	↑ +14.8 °C	75.3 [±23.4] °C	103.3 [±25.0] °C	↑ +33.5 °C	↑ +61.5 °C
	Jan	15.5 °C	27.8 °C	↑ +12.3 °C	48.4 [±17.6] °C	67.5 [±15.5] °C	↑ +20.6 °C	↑ +39.7 °C
	Feb	13.2 °C	26.1 °C	↑ +12.9 °C	44.9 [±16.8] °C	62.9 [±15.6] °C	↑ +18.8 °C	↑ +36.8 °C
	Mar	42.1 °C	63.4 °C	↑ +21.3 °C	102.6 [±28.7] °C	127.4 [±23.9] °C	↑ +39.2 °C	↑ +64.0 °C
	Apr	161.0 °C	205.7 °C	↑ +44.7 °C	255.6 [±25.3] °C	283.1 [±21.6] °C	↑ +49.9 °C	↑ +77.4 °C
Muša River	Season	343.8 °C	468.0 °C	↑ +124.2 °C	813.3 [±126.4] °C	1001.5 [±157.3] °C	↑ +345.3 °C	↑ +533.5 °C
	Nov	80.6 °C	95.9 °C	↑ +15.3 °C	158.9 [±33.5] °C	189.8 [±42.5] °C	↑ +63.0 °C	↑ +93.9 °C
	Dec	23.3 °C	38.9 °C	↑ +15.6 °C	89.1 [±31.9] °C	120.4 [±39.1] °C	↑ +50.2 °C	↑ +81.5 °C
	Jan	13.6 °C	25.6 °C	↑ +12.0 °C	76.6 [±23.5] °C	107.0 [±32.6] °C	↑ +51.0 °C	↑ +81.4 °C
	Feb	8.6 °C	22.8 °C	↑ +14.2 °C	59.7 [±17.9] °C	87.7 [±27.4] °C	↑ +36.9 °C	↑ +64.9 °C
	Mar	39.4 °C	63.9 °C	↑ +24.5 °C	130.6 [±21.4] °C	166.3 [±25.2] °C	↑ +66.7 °C	↑ +102.4 °C
	Apr	167.2 °C	219.0 °C	↑ +51.8 °C	298.5 [±19.2] °C	331.8 [±25.7] °C	↑ +79.5 °C	↑ +112.8 °C
Levuo River	Season	334.4 °C	456.7 °C	↑ +122.3 °C	803.2 [±126.1] °C	991.6 [±157.1] °C	↑ +346.5 °C	↑ +534.9 °C
	Nov	78.0 °C	94.4 °C	↑ +16.4 °C	156.7 [±33.4] °C	187.5 [±42.6] °C	↑ +62.3 °C	↑ +93.1 °C
	Dec	21.6 °C	37.3 °C	↑ +15.7 °C	87.2 [±32.0] °C	118.2 [±39.4] °C	↑ +49.9 °C	↑ +80.9 °C
	Jan	12.6 °C	24.4 °C	↑ +11.8 °C	75.2 [±23.6] °C	105.9 [±32.6] °C	↑ +50.8 °C	↑ +81.5 °C
	Feb	7.9 °C	21.6 °C	↑ +13.7 °C	57.9 [±17.3] °C	85.6 [±26.9] °C	↑ +36.3 °C	↑ +64.0 °C
	Mar	37.6 °C	62.0 °C	↑ +24.4 °C	128.3 [±21.3] °C	164.3 [±25.4] °C	↑ +66.3 °C	↑ +102.3 °C
	Apr	165.8 °C	215.2 °C	↑ +49.4 °C	298.0 [±19.3] °C	331.8 [±26.3] °C	↑ +82.8 °C	↑ +116.6 °C

Seasons span from the previous year's November until April.
For example, reference period values are calculated for November 1960–April 1990.

SSP2-4.5 Moderate climate change scenario
SSP3-7.0 Significant climate change scenario

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Precipitation amount

River basin	Period	Reference; 1961–1990	Normal; 1991–2020	Normal vs. reference	Future; 2071–2100 [± model standard deviation]		Future vs. normal period	
					SSP2-4.5	SSP3-7.0	SSP2-4.5	SSP3-7.0
Daugava River	Season	244.6 mm	255.0 mm	↑ +4.3%	350.3 [±31.2] mm	363.6 [±35.5] mm	↑ +37.4%	↑ +42.6%
	Nov	55.0 mm	53.4 mm	↓ −2.9%	69.4 [±7.4] mm	69.5 [±8.7] mm	↑ +30.0%	↑ +30.1%
	Dec	50.2 mm	46.4 mm	↓ −7.6%	64.2 [±8.9] mm	66.4 [±11.4] mm	↑ +38.4%	↑ +43.1%
	Jan	36.3 mm	44.2 mm	↑ +21.8%	55.6 [±6.8] mm	58.3 [±7.6] mm	↑ +25.8%	↑ +31.9%
	Feb	27.5 mm	39.3 mm	↑ +42.9%	47.8 [±6.7] mm	51.9 [±8.3] mm	↑ +21.6%	↑ +32.1%
	Mar	34.6 mm	36.1 mm	↑ +4.3%	51.2 [±7.7] mm	55.4 [±6.9] mm	↑ +41.8%	↑ +53.5%
	Apr	41.0 mm	35.5 mm	↓ −13.4%	62.0 [±8.5] mm	62.3 [±6.3] mm	↑ +74.6%	↑ +75.5%
Lielupe River	Season	231.6 mm	236.4 mm	↑ +2.1%	353.2 [±40.7] mm	365.6 [±45.5] mm	↑ +49.4%	↑ +54.7%
	Nov	53.9 mm	49.8 mm	↓ −7.6%	71.5 [±10.4] mm	71.8 [±12.5] mm	↑ +43.6%	↑ +44.2%
	Dec	45.9 mm	45.0 mm	↓ −2.0%	67.5 [±10.6] mm	69.9 [±14.1] mm	↑ +50.0%	↑ +55.3%
	Jan	32.9 mm	41.1 mm	↑ +24.9%	57.4 [±9.0] mm	60.5 [±9.9] mm	↑ +39.7%	↑ +47.2%
	Feb	26.0 mm	33.7 mm	↑ +29.6%	47.8 [±7.7] mm	51.6 [±9.6] mm	↑ +41.8%	↑ +53.1%
	Mar	32.3 mm	31.3 mm	↓ −3.1%	50.2 [±8.4] mm	53.5 [±6.3] mm	↑ +60.4%	↑ +70.9%
	Apr	40.5 mm	35.5 mm	↓ −12.3%	58.8 [±8.3] mm	58.3 [±6.7] mm	↑ +65.6%	↑ +64.2%
Muša River	Season	223.0 mm	241.0 mm	↑ +8.1%	277.2 [±12.4] mm	253.3 [±97.1] mm	↑ +15.0%	↑ +5.1%
	Nov	50.3 mm	48.7 mm	↓ −3.2%	56.7 [±6.0] mm	48.7 [±19.4] mm	↑ +16.4%	↕ 0%
	Dec	43.5 mm	46.4 mm	↑ +6.7%	54.0 [±4.3] mm	50.2 [±19.5] mm	↑ +16.4%	↑ +8.2%
	Jan	31.9 mm	41.3 mm	↑ +29.5%	44.0 [±3.7] mm	43.2 [±17.0] mm	↑ +6.5%	↑ +4.6%
	Feb	24.6 mm	34.7 mm	↑ +41.1%	38.8 [±3.2] mm	35.6 [±13.8] mm	↑ +11.8%	↑ +2.6%
	Mar	31.6 mm	33.8 mm	↑ +7.0%	39.2 [±4.3] mm	34.4 [±13.4] mm	↑ +16.0%	↑ +1.8%
	Apr	41.8 mm	37.3 mm	↓ −10.8%	45.5 [±5.3] mm	40.2 [±16.7] mm	↑ +22.0%	↑ +7.8%
Levuo River	Season	230.6 mm	253.6 mm	↑ +10.0%	292.6 [±12.4] mm	267.3 [±102.3] mm	↑ +15.4%	↑ +5.4%
	Nov	51.2 mm	50.3 mm	↓ −1.8%	58.9 [±6.2] mm	50.4 [±20.0] mm	↑ +17.1%	↑ +0.2%
	Dec	45.8 mm	48.4 mm	↑ +5.7%	57.5 [±4.5] mm	53.7 [±20.8] mm	↑ +18.8%	↑ +11.0%
	Jan	33.2 mm	43.9 mm	↑ +32.2%	47.4 [±3.9] mm	46.2 [±18.1] mm	↑ +8.0%	↑ +5.2%
	Feb	25.3 mm	38.0 mm	↑ +50.2%	42.6 [±3.3] mm	39.1 [±15.1] mm	↑ +12.1%	↑ +2.9%
	Mar	32.9 mm	35.8 mm	↑ +8.8%	41.9 [±4.9] mm	36.4 [±14.2] mm	↑ +17.0%	↑ +1.7%
	Apr	42.7 mm	38.1 mm	↓ −10.8%	45.3 [±5.2] mm	40.4 [±16.7] mm	↑ +18.9%	↑ +6.0%

Seasons span from the previous year's November until April.
For example, reference period values are calculated for November 1960–April 1990.

SSP2-4.5 Moderate climate change scenario
SSP3-7.0 Significant climate change scenario

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