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# How different sources of climate databases influence assessment of growth response in dendroclimatic analyses – case study from Lapland

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## Abstract

The paper deals with the comparison of the time series from different climate databases. We compared the measured data with the modelled data of monthly and seasonal temperature means and precipitation totals. Reliable and as long as possible time series of such data represent the basic starting point of dendroclimatic analyses. We evaluated the differences in the growth response of spruce derived using different databases of the stated climatic characteristics. The stem cores used to derive the cross-correlation function were taken from Hårås locality situated in the boreal zone of the Swedish part of Lapland. We compared the measured records from the nearest meteorological stations situated 18 and 40 km away from the locality with the interpolated values from CRU TS 3.21 climate database and with the reconstructed 502-year-long database. The spatial resolution of the modelled databases was $0.5^{\circ} \times 0.5^{\circ}$ of latitude and longitude. We found a systematic error of different magnitudes in the modelled values, and we also quantified a random error and the overall accuracy of the data. The temperature model underestimated the data in comparison with the measured values, while the precipitation model overestimated the data. We also found that the radial increments of spruce correlated more strongly with the temperature than with the precipitation. Hence, in the conditions of the boreal zone, temperature is a more important factor affecting tree-ring formation. We found significantly higher correlations between the radial increment and the modelled precipitation data than with the data measured at the precipitation station situated 18 km from the locality of interest.

## 1 Introduction

Dendroclimatology as a branch of dendrochronology uses dated ring series to reconstruct the current and past climate. Currently, its main potential is to provide the information about the growth responses of tree species on the currently ongoing climate change.

One of the currently greatest challenges is to understand and predict climate change impacts on the development of forest ecosystems. This covers systematic monitoring and detection of climate change, evaluation of climate models, their calibration and creation of climate scenarios, while climate variability affects many natural and anthropogenic systems. Due to this, the need has arisen to create standard climate databases for different climate elements that would cover the whole land area of the Earth. In dendroclimatology, monthly and seasonal databases of climate elements are mainly used. Climate databases are usually created for the basic period of reference climate of 1961–1990 defined by the World Meteorological Organisation (WMO) and are annually updated. Several databases have been created for different primary and secondary climate variables (Mitchell and Jones, 2005).

In dendroclimatological works (e.g. Babst et al., 2013; Büntgen et al., 2007; Gouirand et al., 2007; Wang et al., 2013), the world-wide database created by Climatic Research Unit (hereafter as CRU), which belongs to University of East Anglia, is frequently used. Main data sources for this database are (Harris et al., 2013):

- international monthly data of CLIMAT swopped between the countries within WMO (around 2400 meteorological stations);
- Monthly Climatic Data for the World (MCDW), created by National Climatic Data Center (NCDC) for WMO (around 2500 meteorological stations);
- World Weather Records (WWR) – 10 year-long databases, which are swopped between the National Meteorological Services (NMSs) and NCDC
- the Australian Bureau of Meteorology (BoM).

In dendroclimatological applications the selection of climate data is necessary for the unambiguous explanation of climate impact on the creation of tree radial increment. It is important that these data reflect real conditions under which the increment was created. However, considering the density of meteorological stations and the variability of meteorological elements conditioned mainly by the morphological roughness





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of the Earth surface, this condition cannot always be met. Therefore, the main goal of this work is to compare the interpolated data of temperature and precipitation from the database of CRU TS 3.21 and from the database comprising more than 500 year-long series created by Luterbacher et al. (2004) and Pauling et al. (2006), with directly measured data from the nearest meteorological and precipitation stations. The essential question was to analyse the influence of different sources of climatic data on explaining the formation of radial increment of spruce.

## 2 Materials and methods

The area of interest, where the data were collected, was the locality called Hårås situated in the Swedish part of Lapland. Hårås is located 60 km north of polar circle border in Norrbotten region, 70 km west from Jokkmokk town. Its elevation is around 585 m a.s.l. From the geomorphological point of view, Hårås belongs to the Scandinavian Mts. Pedologically, podsol soils dominate.

Regarding tree species composition, *Pinus* sp. and *Picea* sp. dominate in the stands at the locality. As the elevation increases, crown canopy becomes released and the share of *Betula* sp. in species composition increases. The upper tree line at an elevation of around 715 m a.s.l. is formed by pure birch stands.

One group of climate data used in the analysis consists of the monthly series measured at the nearest meteorological stations. From Kvikkjokk meteorological station (66°57′58.28″ N, 17°44′27.35″ E) we used the data about air temperature. The data about monthly precipitation totals were taken from Tjåmotis precipitation station (66°55′57.06″ N, 18°32′31.04″ E). The positions of Hårås locality and both meteorological stations are shown in Fig. 1.

Kvikkjokk meteorological station is situated at an elevation of 337 m a.s.l., approximately 40 km from Hårås. Tjåmotis station is located at an elevation of 300 m a.s.l., approximately 18 km from Håråsu. The region is characterised by subarctic climate with short, cold summers and long, cold winters.





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The measured climate data of temperature and precipitation at Kvikkjokk and Tjåmotis stations were obtained from NORDKLIM database, which was prepared by the Swedish Meteorological and Hydrobiological Institute (SMHI, 2014) for Scandinavia. The monthly mean temperatures at Kvikkjokk station were available for the period from 1890 to 2001, while the monthly precipitation totals at Tjåmotis were available for the years from 1909 to 1997. For simplification we will call the data from NORDKLIM database as "measured" data.

The second group of the climate databases encompassed interpolated time series. For the position of both weather stations and Hårås locallity we generated the data using the web application of the Royal Netherlands Meteorological Institute called KNMI Climate Explorer, which was created in order to enable the analysis of time series of climate data (CLIMEX.KNMI, 2014). The data about temperature and precipitation were generated at the level of monthly and seasonal (three monthly) temperature means and precipitation totals. For monthly data we used CRU TS 3.21 database, from which the temperature and precipitation data were available for the periods 1901–2012, and 1901–2009, respectively.

The database of CRU TS 3.21 (hereafter as CRU) has been created by interpolating the data from a large number of meteorological and precipitation stations. The values have been interpolated on a regular square grid with resolution of 0.5, 1.0 and 2.5° of latitude and longitude. The data are available only for terrestrial areas including ocean islands (excluding Antarctica). The method of interpolating climate data (gridding), which results in the creation of temperature grid, is thoroughly described in Harris et al. (2014). For the purposes of this work we used the data with the smallest available grid spacing, i.e. $0.5^\circ \times 0.5^\circ$.

From the same web service (KNMI Climate Explorer) and with the same grid resolution ($0.5^\circ \times 0.5^\circ$) we also obtained the seasonal means of temperatures for 502-year-long series from the period between 1500 and 2002, and seasonal precipitation totals for the period from 1500 and 2000. The database of temperatures is named as Luterbachet et al. Temperature (hereafter as LT), as the work by Luterbacher et al. (2004)





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deals with the methodology of creating such a long time series. The database of precipitation in the given web application is named Pauling et al. Precipitation (hereafter as PP) after the work of Pauling et al. (2006) devoted to its creation. For simplification, we call all four databases generated from the application of KNMI Climate Explorer as "modelled" climate data.

At Hårås locality, 20 increment cores were taken from spruce tree stems at a height of 1.3 m. After pre-processing of samples, they were analysed in WinDENDRO computer image analysis system. The analysis consisted of measuring tree ring widths and their dating. The created tree-ring series were synchronised with the regional curve derived from the tree-ring curves, which showed each other the closest correlation (highest values of coefficients of correlation). We used visual synchronisation supported by a graphical method of "skeleton plot" (Cropper, 1979). The series was considered to be satisfactorily synchronised if the value of the Gleichläufigkeit score ($G$) exceeded 70 %. Tree ring series, which did not exceed this threshold, were excluded from further analyses. With regard to the open crown canopy of the stands, the tree ring series were standardised using a modified negative exponential function. The final tree ring chronology was performed with the method of robust double-weighted-averaging of tree ring indices that included the removal of temporal autocorrelation. The values of tree ring indices were calculated using the formula of Cook and Kairiukstis (1990).

The impact of climate on increment was evaluated by deriving the cross-correlation function between monthly or seasonal values of climate characteristics (temperature, precipitation) and tree-ring indices within 18 month-long (April preceding year to September) or 7 season-long (March, April, May preceding year to September, October, November) dendroclimatic year. Student $t$ test was used to evaluate the significance of the coefficients of correlation at 5 and 1 % significance level.

With regard to the goal of the work, we compared the results of growth response derived from the measured climate data and from the modelled climate data. We wanted to reveal the cases in the results with different statistical significance of correlation coefficients caused by different climate databases (measured vs. modelled data).





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The comparison of climate data from climate databases gives us information about the systematic and random error of the modelled climate data. From the differences between the modelled and measured data we calculated the average difference ($\bar{e}$) and the standard deviation of differences ($S_e$). Student $t$ test was applied to test the significance of the systematic error at 5 and 1 % significance levels. The final accuracy of the modelled data was quantified by mean quadratic error ($m_e$). The above-described evaluation was performed separately for the mean temperature and precipitation totals. For each climatic characteristic we also analysed the differences in monthly and seasonal climatic series. The differences were calculated for the overlapping intervals, in which both the modelled and the measured data were available. Hence, in the case of monthly temperature, the overlapping time interval was 1901–2001, while for the seasonal values the period was 1890–2001. In the case of precipitation, the overlapping period was the same for both monthly and seasonal data (1909–1997). The measured seasonal data were derived by aggregating the measured monthly values.

# 3 Results

## 3.1 Evaluation of errors in modelled climate databases

The differences between the modelled and measured climate data were calculated separately for monthly and seasonal data of mean temperatures and precipitation totals. We analysed the deviation of the modelled data from the measured values, the presence of the random error, and the overall accuracy of the modelled data. The final values of the errors of the analysed databases are presented in Tables 1 and 2.

In the case of mean temperature, the model underestimated the monthly data by 1.43 °C, and seasonal data by 1.39 °C, as documented by the values of average deviation ($\bar{e}$) in Table 1. The significance of bias was proved with the statistical test at $\alpha = 1\,\%$ significance level.

The random error was quantified with the mean error of differences ($s_e$). It describes the variation of the differences around the average difference $\overline{e}$ and is considered a measure of precision of the modelled values of temperature. The precision of the modelled monthly temperatures was found to be ±0.69 °C (±27.26 %), while the precision of the seasonal data was ±1.19 °C (±46.49 %). The comparison of the relative mean errors shows that the monthly temperature data were approximately half as more precise than the seasonal data. However, this results from the fact that $s_e$ of the seasonal data was calculated from the differences, the number of which was probably by two thirds smaller than the amount of the measured data. The advantage of the database of the modelled seasonal temperatures is that it encompasses the time series of more than 500 years (starting in the year 1500). If it had been possible to calculate the differences for such a long time series, the mean error of the seasonal data would have probably decreased.

The overall accuracy of the modelled monthly temperature data was ±1.59 °C, and of the modelled seasonal temperature was ±1.83 °C.

Table 2 presents the statistical comparison of the differences between the measured and the modelled data of monthly and seasonal precipitation totals.

Similarly to temperature, the results of the statistical test proved systematic deviation of the modelled data from the measured data. On the contrary to temperature, the precipitation model overestimated the measured values. In the monthly database, the model overestimated the values by 4.46 mm on average, while in the case of seasonal data the overestimation was 15.75 mm. Greater deviation of the seasonal data results from the nature of the data, since they were calculated as a sum of precipitation of three months in one season. Relative average differences were almost equal (11 or 12.5 %).

The precision of the monthly and seasonal precipitation was ±5.12 mm (±11 %), and ±31.84 mm (±22 %), respectively, which is very similar to temperature. This means that the variability of the differences in monthly precipitation was approximately half of the variability of the differences of the seasonal data. However, similarly to temperature,





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we have to account for the fact that the result is influenced by a shorter series of the measured seasonal data in comparison to the model, as for Tjåmotis station the available series encompassed only 88 years.

The final accuracy of the modelled monthly and seasonal precipitation totals was ±6.90 and ±35.52 mm, respectively (Table 3).

On the base of the obtained results we can say that with 99 % confidence the modelled data of both climatic characteristics were significantly different from the measured data. This bias can be eliminated from the data by extracting the value of the mean bias from every value of the modelled climatic series.

### 3.2 Comparing the suitability of the climatic databases for dendroclimatic analyses

In the first step of evaluating the suitability of the climatic databases for dendroclimatic analyses we examined the correlation between the data measured at the nearest meteorological stations (Kvikkjokk and Tjåmotis) and the modelled data generated using the KNMI Climate Explorer application for the position of Hårås with the resolution of 0.5°.

The relationship between the temperatures is shown in Fig. 2a and b. In both cases, we revealed close correlations between the compared databases of temperatures documented by high values of coefficients of correlation. The comparison of 100 year-long series of the monthly temperature means obtained from the CRU database ($T\_CRU_{HARAS}$) and the measured data from Kvikkjokk meteorological station situated 40 km away ($T\_MONTH_{KVIKJOK}$) revealed that the coefficient of correlation reached the value of 0.99 (Fig. 2a). Similarly, 111-year-long series of the modelled seasonal temperature means ($T\_LT_{HARAS}$) and of the measured seasonal means ($T\_SEASON_{KVIKJOK}$) also showed to be tightly correlated with the coefficient of correlation equal to 0.98 (Fig. 2b).

The correlation between the databases of precipitation totals was lower than that of temperature, particularly in the case of seasonal data. The coefficient of correlation between the seasonal precipitations had a value of 0.84, which indicates that the variability of the modelled seasonal precipitation at Hårås ($P\_PP_{HARAS}$) least corresponded with the variability of precipitation measured at Tjåmotis precipitation station ($P\_SEASON_{TJAMOTIS}$) situated 18 km from Hårås (Fig. 2d). The correlation between the modelled monthly precipitation ($P\_CRU_{HARAS}$) and the measured precipitation totals ($P\_MONTH_{TJAMOTIS}$) was tighter ($r = 0.93$) as documented in Fig. 2c. The comparison of the databases was performed using 88-year-long climatic series of precipitation.

The next step was to evaluate the cross-correlation functions derived from the data of spruce radial increments and individual climate databases. For this analysis, we selected such periods from the databases of both climatic characteristics, within which the measured time series were available. Hence, the period for temperature and precipitation was 1902–2001, and 1910–1997, respectively.

The values of coefficients of correlation presented in the graph (Fig. 3) quantify the strength and the sign of the relationship between the indices of radial increment and the mean of monthly (Fig. 3a) or seasonal (Fig. 3b) temperatures within the 18 month-long or 7 season-long dendroclimatic year. The values of the correlation coefficients were tested at $\alpha = 1$ or 5 % significance level.

From Fig. 3a we can see that the annual increment was significantly negatively correlated with the temperatures in April, July and August of the preceding year, or its summer season (JJA_pre). In July of the preceding year, the values of the coefficient of correlation were significant at 1 % significance level for both measured and modelled data. This means that with 95 % confidence, high values of temperatures in July of the preceding year negatively affected increment formation in the next year. On the other hand, temperatures in the summer season in the year of increment formation were positively correlated with increment. Particularly June and July were the months that significantly promoted the formation of the radial increment at 1 % significance level. However, the differences between the growth response of spruce depending on the database used were not revealed in any period.





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Overall, the coefficients of correlation derived from the databases of the measured and modelled temperature data did not significantly differ in their values and in the trend of the correlation. The only exception was found for December of the preceding year. The value of $r = 0.20$ for the measured temperature data was proven to be significant at $\alpha = 5\,\%$, while in the case of the modelled data the statistical test did not confirm the value of coefficient of correlation equal to $r = 0.17$ to be significant.

The evaluation of the growth response of spruce to precipitation showed an opposite trend as in the case of temperature. The increasing amount of precipitation in the spring season (MAM_pre) of the year preceding the increment formation positively correlated with the increment formation (Fig. 3d), and its impact on increment formation was confirmed with 95 % confidence. In the database of the monthly data, we found that the month May had a significant effect on increment formation at 5 % significance level (Fig. 3c). In the year of the increment formation, the amount of precipitation in the summer season (JJA) had a significant negative impact on increment formation (Fig. 3d). If we used the database of monthly precipitation totals, we revealed that May was a significant month at 5 % significance level (Fig. 3c).

From the graphs in Fig. 3c and d we can see that the significant influence of precipitation on increment was confirmed only for the cross-correlation function derived from the database of precipitation modelled in a square grid of $0.5^{\circ} \times 0.5^{\circ}$. The coefficients of correlation derived from the measured precipitation data were significantly lower than those from the modelled data ($\Delta r \geq 0.05$) in the case of three out of 18 months of the dendroclimatic year, namely May of the preceding year, and May and June of the year of increment formation (Fig. 3c). In both cases concerning the month May we confirmed statistical significance of coefficients of correlation at $\alpha = 5\,\%$ significance level, while the significant correlations were derived from the modelled precipitation data.

In the 7 season-long climatic year (Fig. 3d) we found significant differences in the growth response of spruce to precipitation in the spring season of the preceding year (MAM_pre) and in the summer of the increment formation year (JJA). The amount of precipitation in the spring of the preceding year promoted increment formation. Sum-



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mer precipitation in the year of increment formation decreased its formation. In the season of JJA, the difference between the coefficients of correlation derived from the measured and modelled precipitation was 0.16. For both seasons (MAM_pre, JJA) we confirmed significant influence of precipitation on increment formation at $\alpha = 5\,\%$ only when we used the database with the modelled precipitation values. The significant effect of precipitation data measured at a distance of 18 km (Tjåmotis) from the place of increment formation was not confirmed by the cross-correlation analysis using either seasonal precipitation database (PP) or monthly data (CRU).

## 4 Discussion and conclusion

The assessment of the suitability of using different climate databases for the purposes of dendroclimatic analyses performed within this paper revealed that the data in CRU TS 3.21 (CRU) database as well as those in the 502 year-long database of temperatures named Luterbacher et al. Temperature (LT) or in the 500-year-long database of precipitation named Pauling et al. Precipitation (PP) for the two meteorological stations situated in the Swedish part of Lapland (Kvikkjokk and Tjåmotis) had systematic errors of different magnitudes. The temperature databases of CRU and LT underestimated the values measured at Kvikkjokk station by 1.43 or 1.39 °C. On the contrary, the precipitation databases of CRU and PP overestimated the data measured at Tjåmotis precipitation station by 4.62, or by 15.75 mm in the case of three-monthly (seasonal) totals. The given systematic errors can be extracted from the data of the databases by subtracting the mean difference from every value in the database. We assume that spatial resolution of the modelled data is the main source of this error. The resolution determines that the values in the database represent uniform values for the whole grid square of $0.5^\circ \times 0.5^\circ$, although in reality there are differences in the values of climatic characteristics also inside such an area.

In order to avoid the bias in the data, in some updated databases it is preferred to express the data in the form of anomalies in spite of their absolute expression.

Anomaly for temperature is a difference between the absolute temperature value and the value of the long-term average determined from the period 1961–1990. In the case of precipitation, anomalies are relative values, i.e. they are given as a percentage of the deviation from the long-term average.

From the databases that prefer expressing the values in the form of anomalies we can name CRUTEM 4.2.0.0 (Osborn and Jones, 2014), and HadCRUT4 (Morice et al., 2012). The climate data expressed in this way enable the reduction or the complete elimination of systematic errors from the modelled data. Since the model of CRUTEM 4.2.0.0 is currently available only in a grid resolution of $5^{\circ} \times 5^{\circ}$, we decided to use the database of the modelled data from the version of CRU TS 3.21, which provides the data modelled in a grid of $0.5^{\circ} \times 0.5^{\circ}$. Here it is necessary to note that the systematic deviation (bias) of climate data does not affect the evaluation result of the growth response of spruce tree species. In order to correctly assess the impact of temperature and precipitation on the formation of radial increment it is important to ensure that the variability of the time series of the stated climatic characteristics corresponds with the variability of the climate at the place of increment formation.

Due to this fact, in the next part we analysed the agreement or the difference in the examined climate factors between the data measured at the nearest meteorological stations and the data interpolated for Hårås locality (modelled data). The comparison revealed that the precipitation data correlated less than the temperature data in spite of the fact that the precipitation station was only 18 km away from Hårås, while the station with the measured temperature was at a distance of 40 km. This confirms the long-term known fact that precipitation is more variable than temperature. This fact was also accounted for during the development of CRU model, in which the interpolation of precipitation values is performed within a smaller radius per one grid point than the interpolation of temperatures. In the case of precipitation, the correlation decreases faster as the distance increases, which is expressed by CDD (correlation decay distance) value during the selection of the stations for the interpolation of the grid point (Harris et al., 2014).





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Less agreement in the variability of the data from the precipitation databases also resulted in greater differences between the coefficients of correlation when evaluating the growth response of spruce using the measured and the modelled data. The obtained results of the cross-correlation function can be interpreted as follows. The statistically significant precipitation signal for the formation of the radial increment was revealed only in the case of the modelled precipitation data. In the case of measured data, the significance of the precipitation impact on increment could not be confirmed. Hence, the results showed that the selection of the precipitation database had an impact on explaining the growth response of spruce. A stronger correlation between the increment and precipitation was obtained if we used the modelled data from CRU and PP databases.

When comparing both climatic characteristics, temperature signal was found stronger. Temperature was shown to be a more significant factor influencing the increment of spruce. This is in coincidence with the results of Babst et al. (2013), who evaluated the impact of precipitation and temperature on spruce increment in the boreal zone of the northern Scandinavia. The examined impact of mean temperatures in the individual months of the dendroclimatic year on the increment corresponds with the results of the cited work. The only difference was in the magnitude of the derived coefficients of correlation, which were in our case greater. This is probably caused by the fact that our growth responses represented only one locality (Håräs), while the cited paper analysed the growth responses of a larger area of the northern Scandinavia.

From the point of evaluating the utilisation of different temperature databases for the explanation of the growth response, we did not find any significant differences between the measured and the modelled data. A small difference was found only in the statistical interpretation of the coefficient of correlation ($r$) for December of the preceding year. In the case of the measured temperature at Kvikkjokk station, $r$ reached the value of 0.2, which was confirmed significant at $\alpha = 5\,\%$. However, the value of $r = 0.17$ derived from the modelled temperatures of CRU database was not confirmed significant.





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**Table 1.** Statistical evaluation of the differences between the measured and modelled data of monthly and seasonal temperatures.

| | Temperature | |
|---|---|---|
| | CRU | LT |
| Mean bias [°C] | −1.43* | −1.39* |
| Mean error [°C] | ±0.69 | ±1.19 |
| Mean quadratic error [°C] | ±1.59 | ±1.83 |

* significant value at $\alpha = 1\,\%$.





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**Table 2.** Statistical evaluation of the differences between the measured and modelled data of monthly and seasonal precipitation totals.

| | Precipitation | |
|---|---|---|
| | CRU | PP |
| Mean bias [mm] | 4.62* | 15.75* |
| Mean error [mm] | ±5.12 | ±31.84 |
| Mean quadratic error [mm] | ±6.90 | ±35.52 |

* significant value at $\alpha = 1\,\%$.





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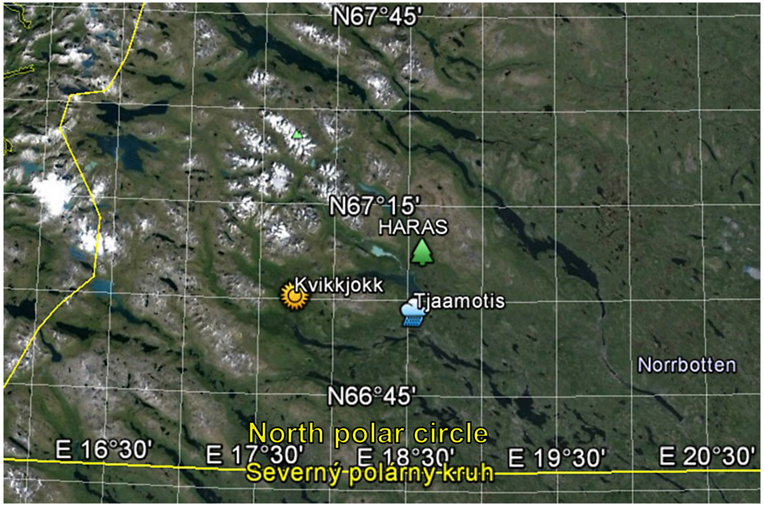


**Figure 1.** Hårås locality and Kvikkjokk and Tjåmotis meteorological stations.





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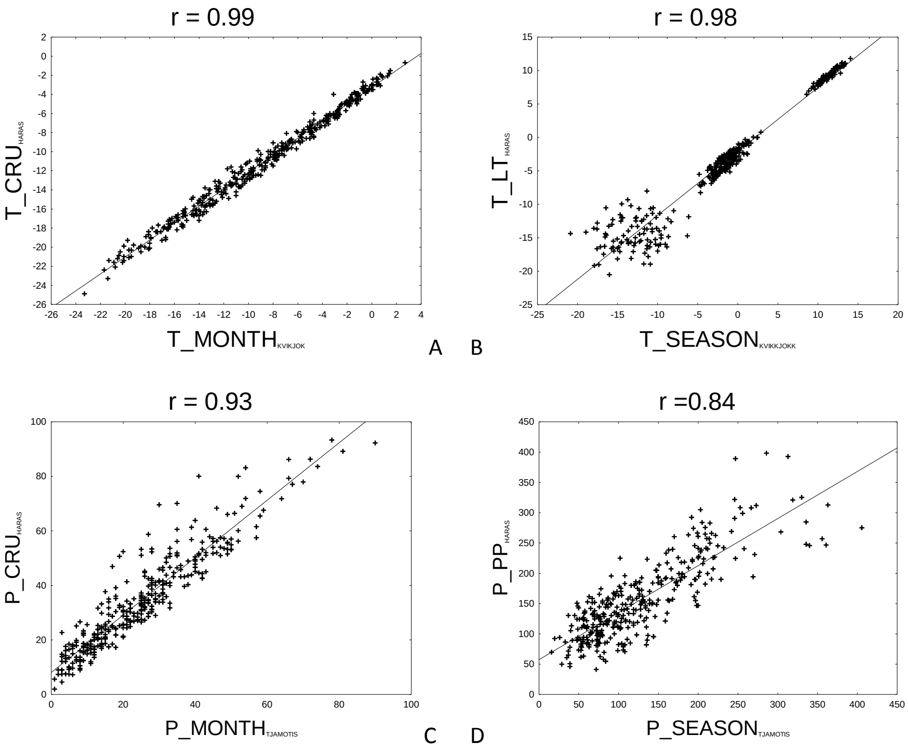


**Figure 2.** Graphs of correlation between **(a)** modelled monthly temperatures ($T\_CRU_{HARAS}$) and measured monthly temperatures ($T\_MONTH_{KVIKJOK}$), **(b)** modelled seasonal temperatures ($T\_LT_{HARAS}$) and measured seasonal temperatures ($T\_SEASON_{KVIKJOK}$), **(c)** modelled monthly precipitation ($P\_CRU_{HARAS}$) and measured monthly precipitation ($P\_MONTH_{TJAMOTIS}$), **(d)** modelled seasonal precipitation ($P\_PP_{HARAS}$) and measured seasonal precipitation ($P\_SEASON_{TJAMOTIS}$).





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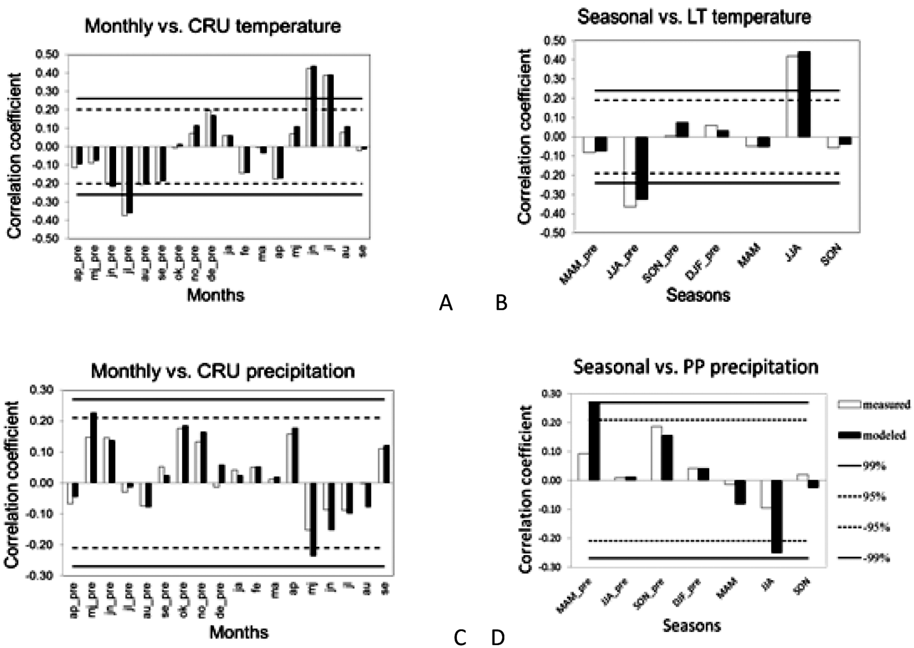


**Figure 3.** Coefficients of correlation derived from the relationship between the indices of spruce radial increment and **(a)** monthly temperature databases, **(b)** seasonal temperature databases, **(c)** monthly precipitation databases, **(d)** seasonal precipitation databases.





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