On considering the annual cycle of air temperature in climate trend analysis based on quantile regression methodology

Lavrov A.S., Sterin A.M.
RIHMI-WDC, Obninsk, Russia

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- In a changing climate, it is necessary to have the most complete information about the statistical characteristics of the distribution of meteorological parameters, which include both long-period trends in average values and estimates of extreme values and their trends.

- The traditional method of linear regression is the OLS Ordinary Least Squares method. However, its application is correct only if the conditions of homoscedasticity (constancy of the error on the interval of changes in predictors) and uncorrelation of the series are met, which is far from the case for the task of assessing climate trends.

- The OLS gives a picture of changes in average values only, it does not give anything for the characteristics of changes in the "tails" of distributions (predictor values close to extreme), the estimates of OLS are very sensitive to outliers!

- Quantile regression (Koenker and Bassett, 1978) is a robust nonparametric regression analysis tool that provides estimates of the regression coefficient values for an arbitrary quantile value of τ (0 < τ < 1) values of the predictor..

- The solution of the linear quantile regression problem for an arbitrary value of τ (0 < τ < 1) is carried out by optimizing the following expression:

- $$\hat{\beta} = argmin\left[\sum_{i\in\{i:\, y_i \geq x_i'\beta\}} \tau|y_i - x_i'\beta| + \sum_{i\in\{i:\, y_i < x_i'\beta\}} (1-\tau)|y_i - x_i'\beta|\right]$$

Quantile regression for upper-air temperature:

- analysis of temperature trends for about 350 aerological stations around the globe;
- trend analysis at altitudes of 850-30 hPa;
- trend analysis for quantile values from 0.05 to 0.95 in 0.01 increments.

Quantile regression for surface temperature:

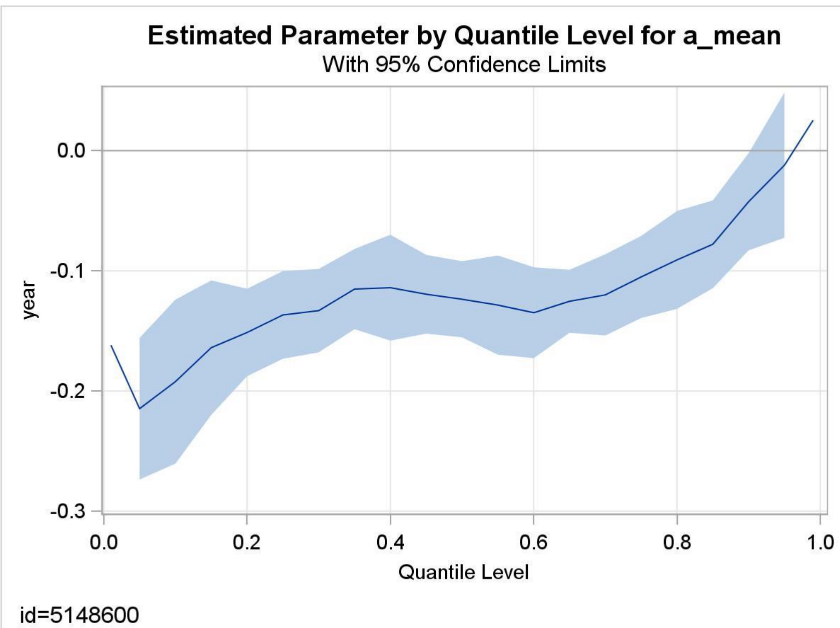
- analysis of temperature trends for more than 1400 stations in Russia;
- trend analysis for the values of the quantiles 0.01, 0.05-0.95 in increments of 0.05 and 0.99;
- trend analysis for minimum, maximum and mean daily temperature.

In both cases, calculations were carried out at stations with a sufficient number of observations.

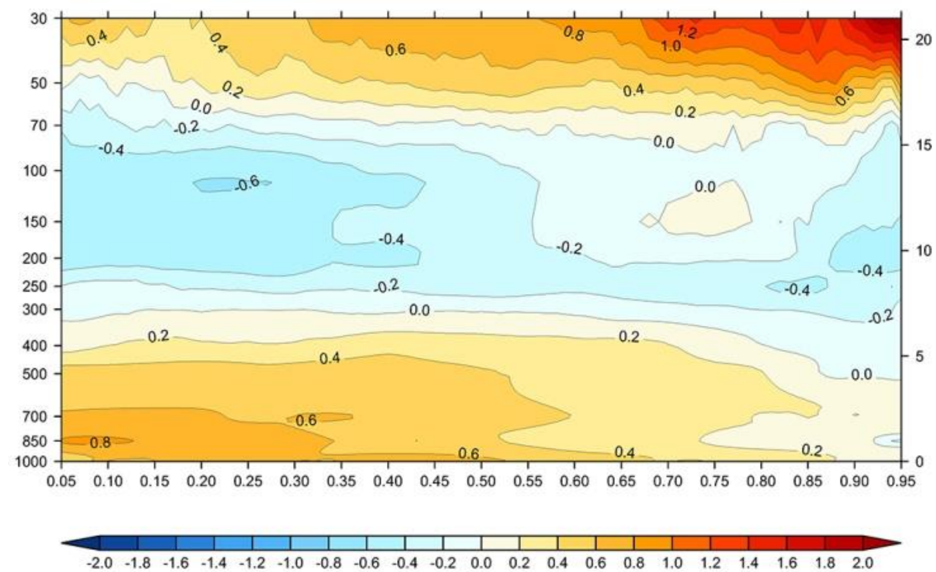
Results of trend estimation by the quantile regression method.

Quantile process

Vertical-quantile distributions



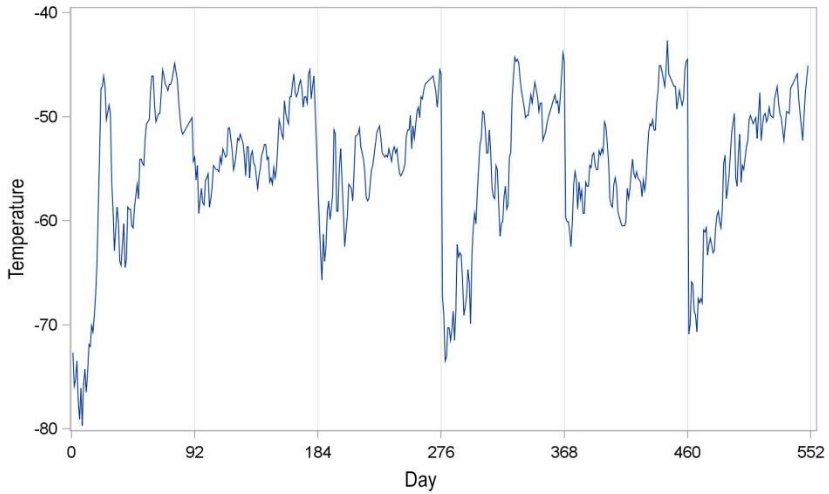
Station 36058, Chemal, Altay. Winter Mean daily temperature

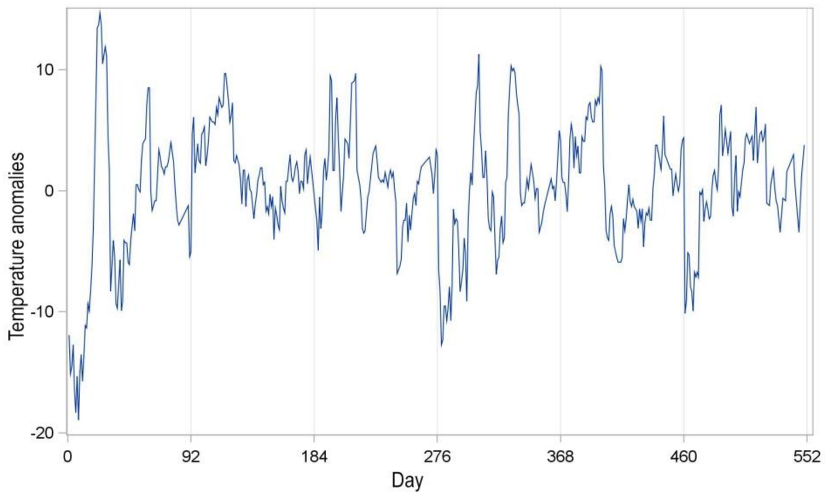


Station 23205, Naryan-Mar. Winter 850-30 hPa

Time series. Station 23205, Naryan-Mar, 2000-2005 spring

Temperature	**Temperature anomalies**

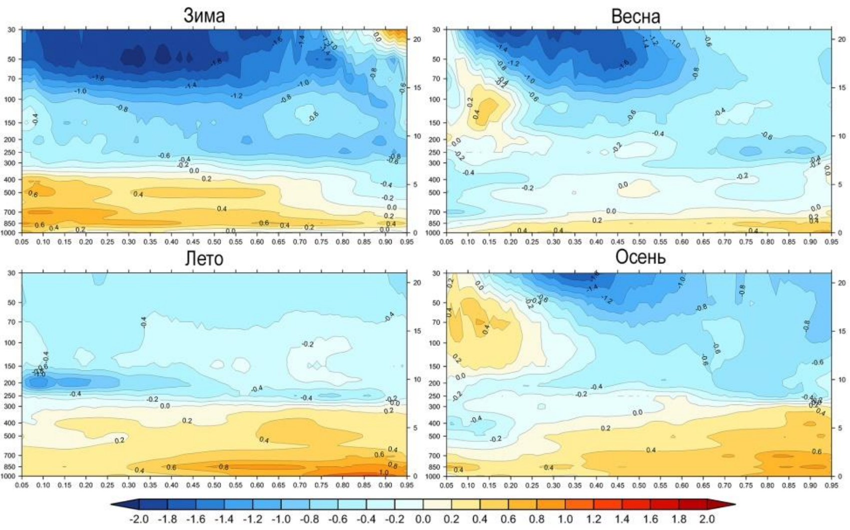




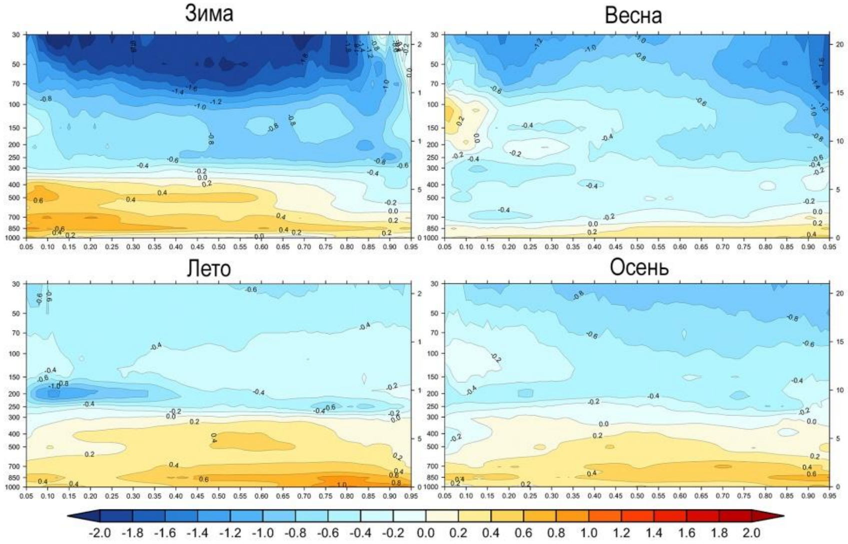
100 hPa

The difference between temperature trends and anomaly trends

Temperatures



Anomalies (monthly norms)



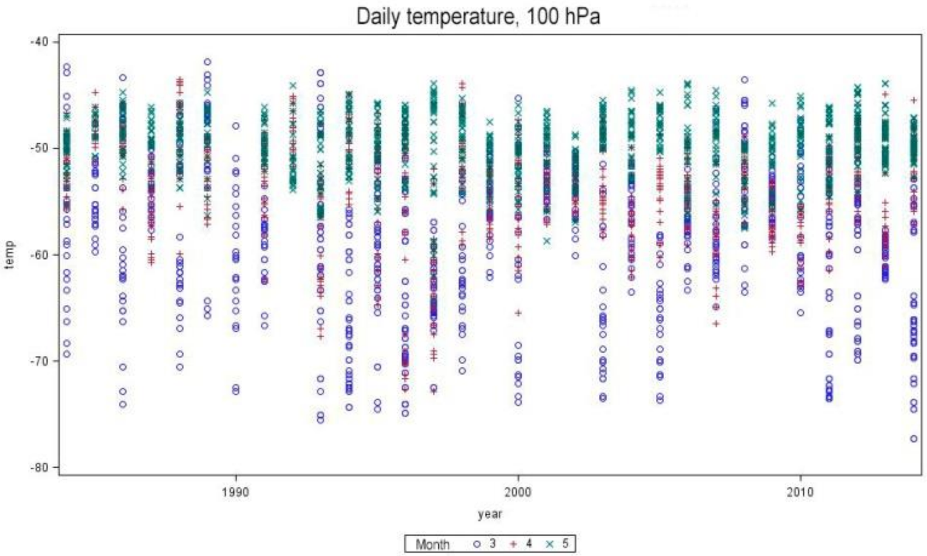
Station 1152, Bodo Vi, Norway

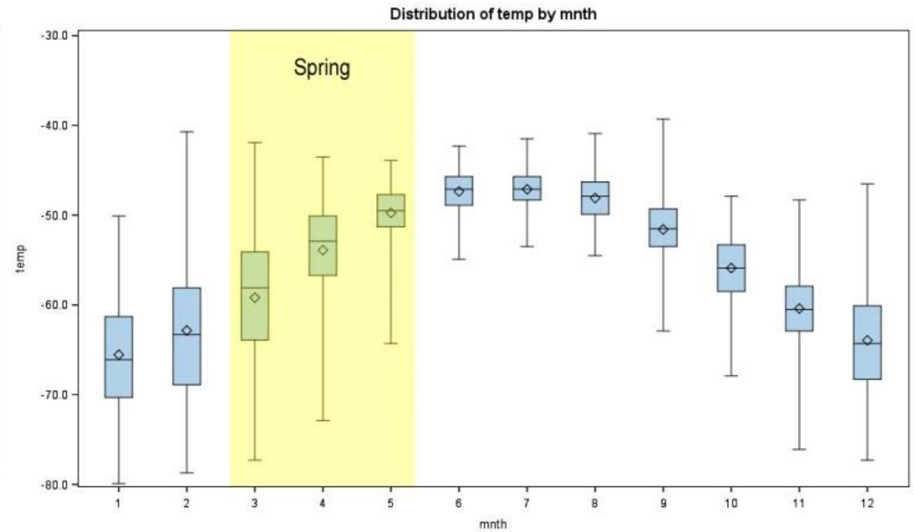
Daily temperature values
Station 1152, Bodo Vi, Norway, Spring

Daily temperatures by year

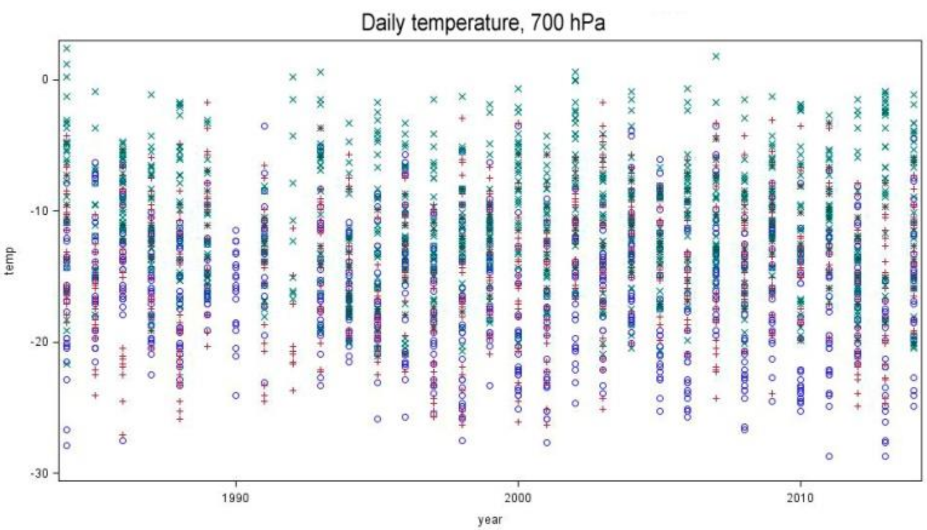
The spread of daily temperatures by month

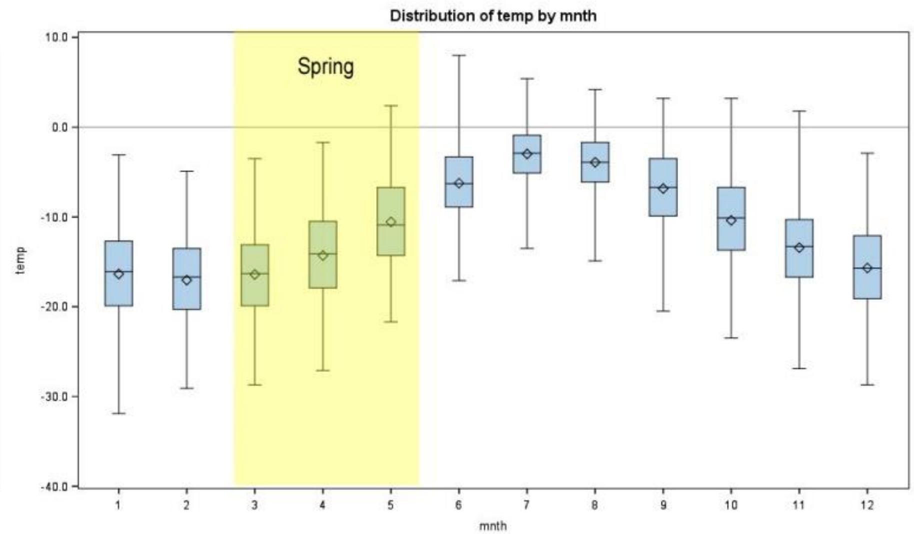
100 hPA





700 hPa

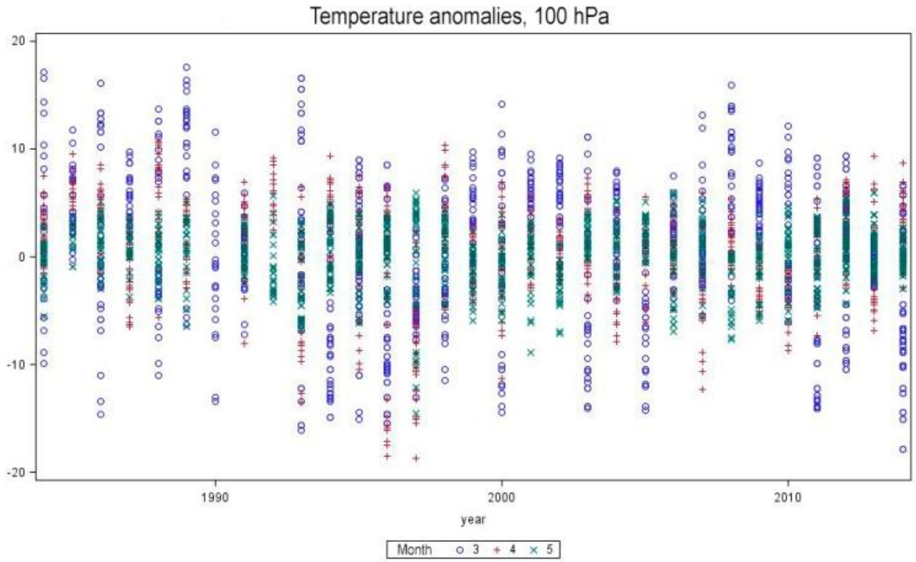




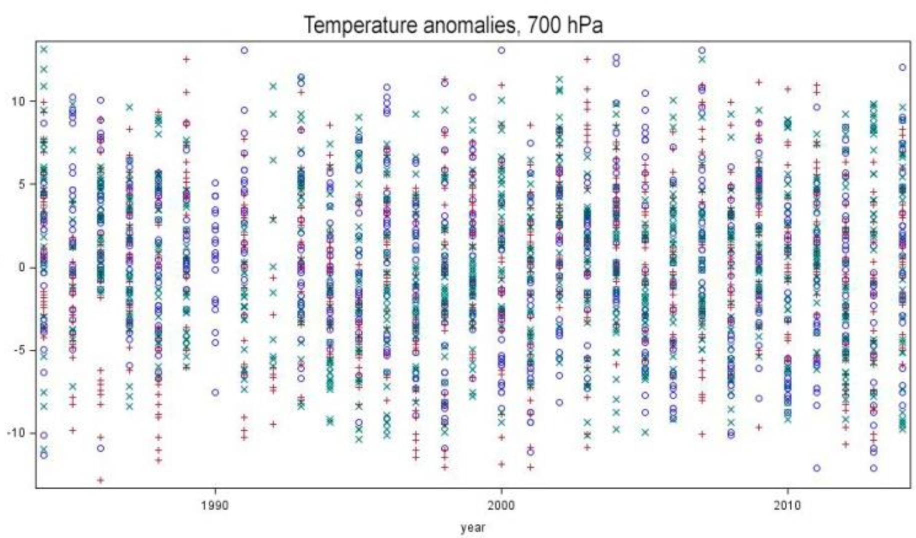
Daily anomaly values
Station 1152, Bodo Vi, Norway, Spring

Daily anomalies by year

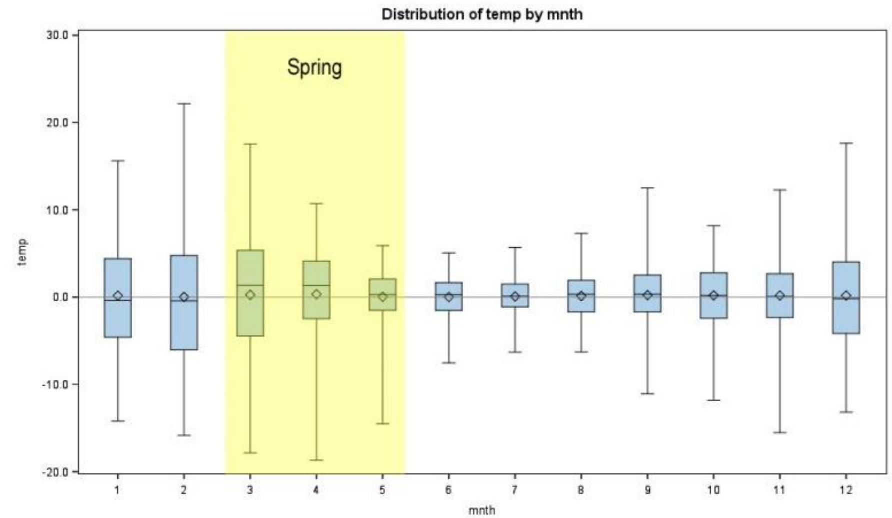
100 hPA

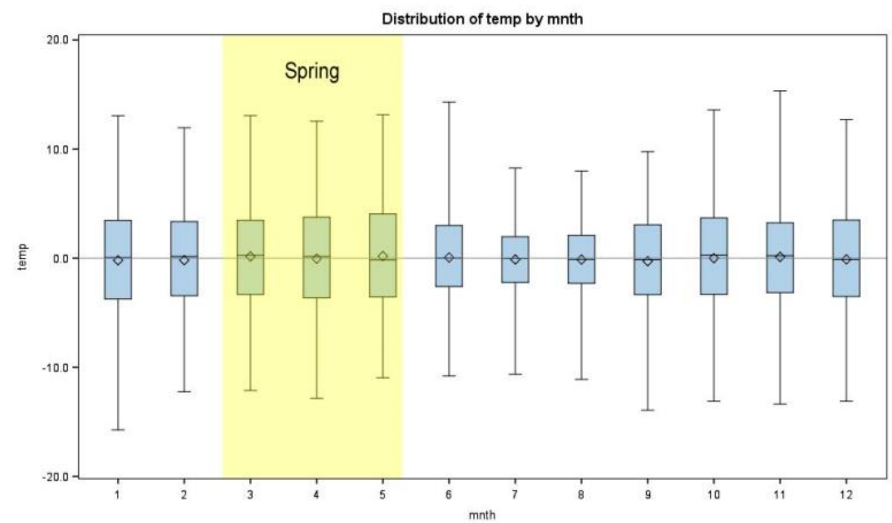


700 hPa



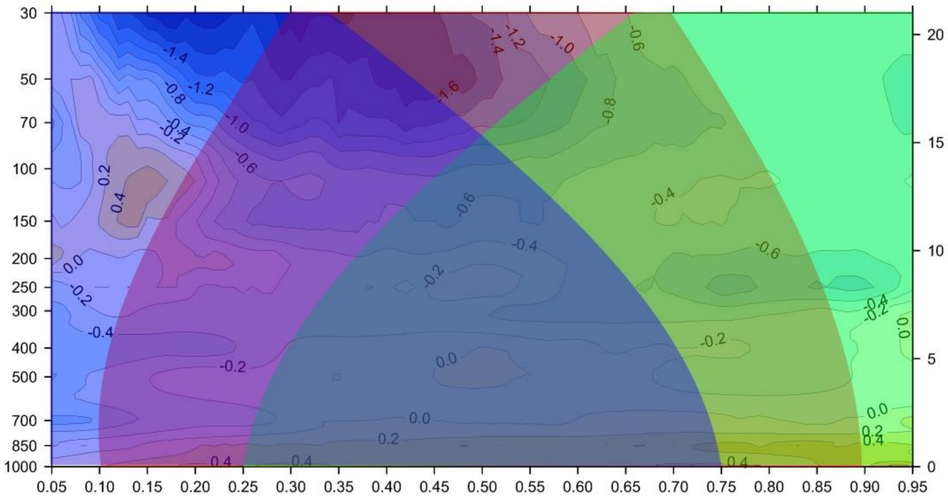
The spread of daily anomalies by month

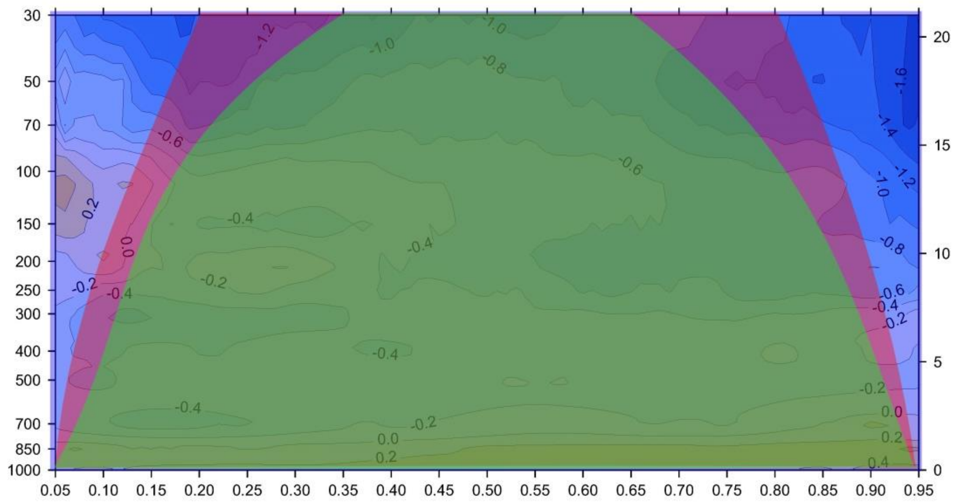




Distribution of daily temperature/anomaly values over the quantile range

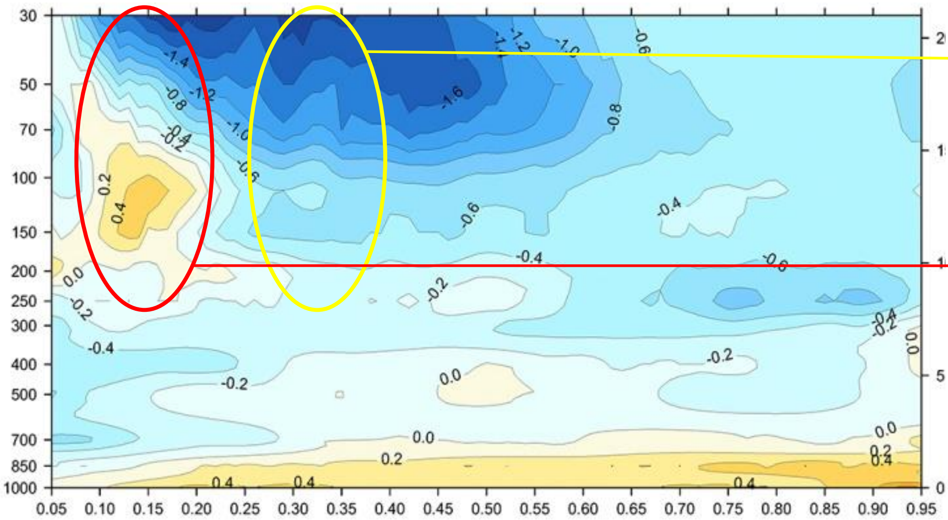
Temperatures	**Anomalies (monthly norms)**



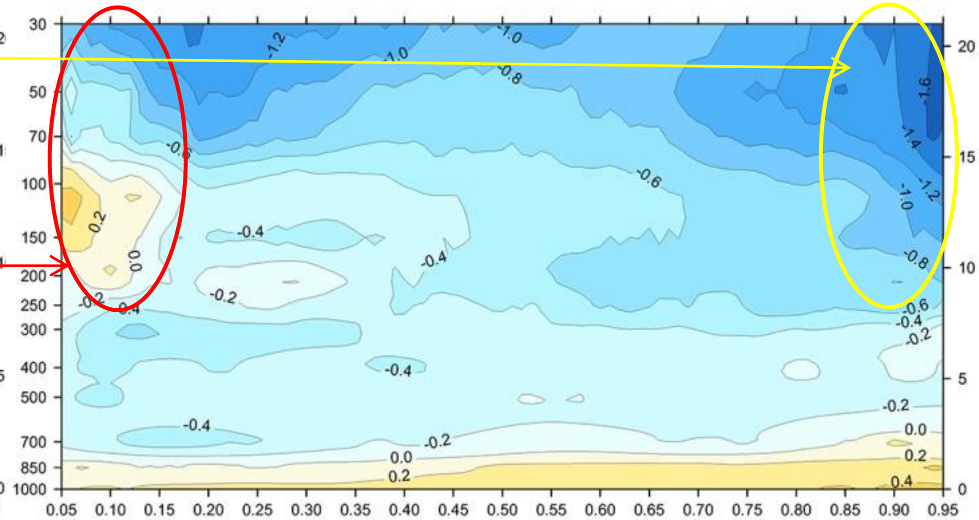


Transition from temperatures to anomalies

Temperatures

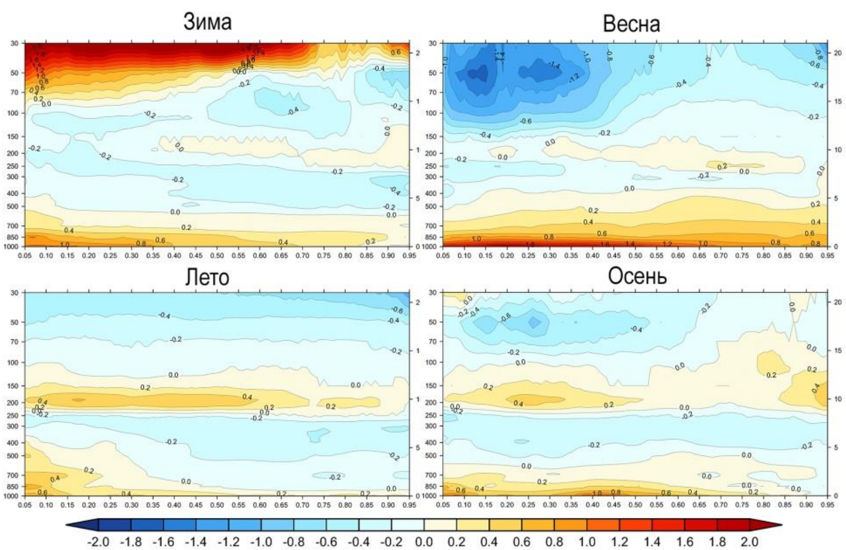


Anomalies (monthly norms)

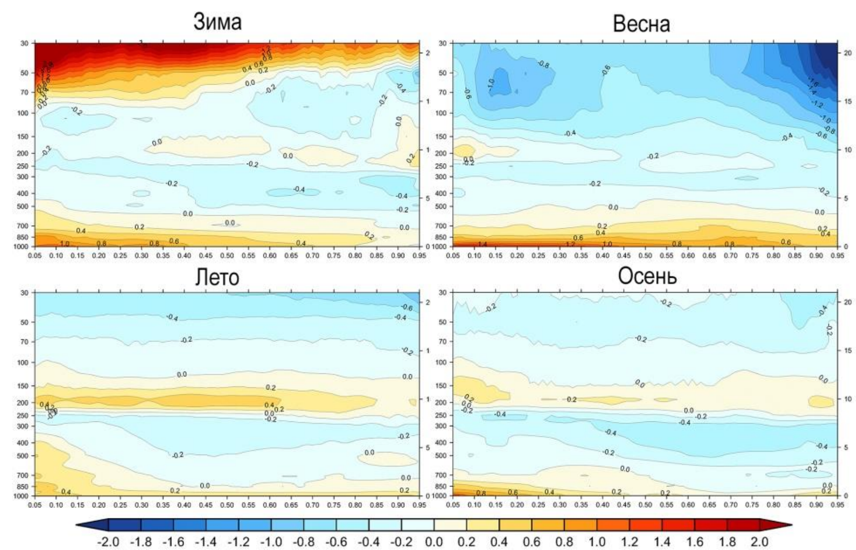


The difference between temperature trends and anomaly trends

Temperatures



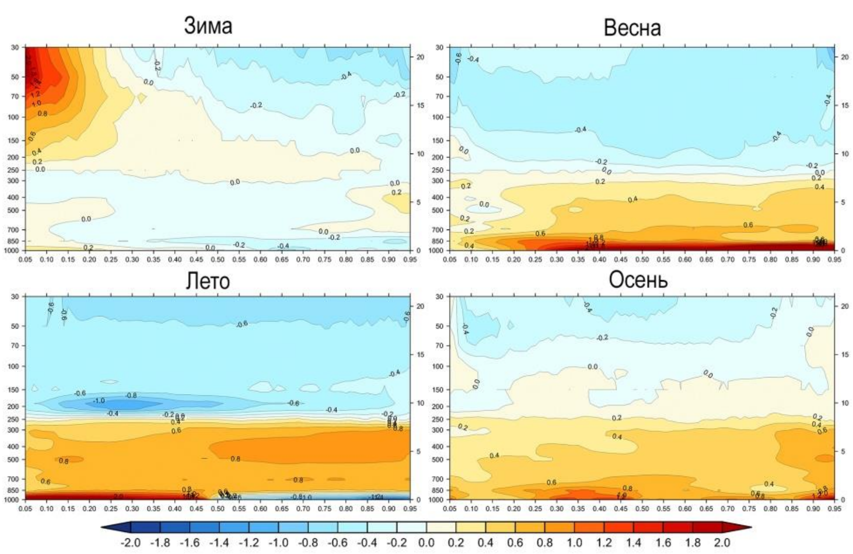
Anomalies (monthly norms)



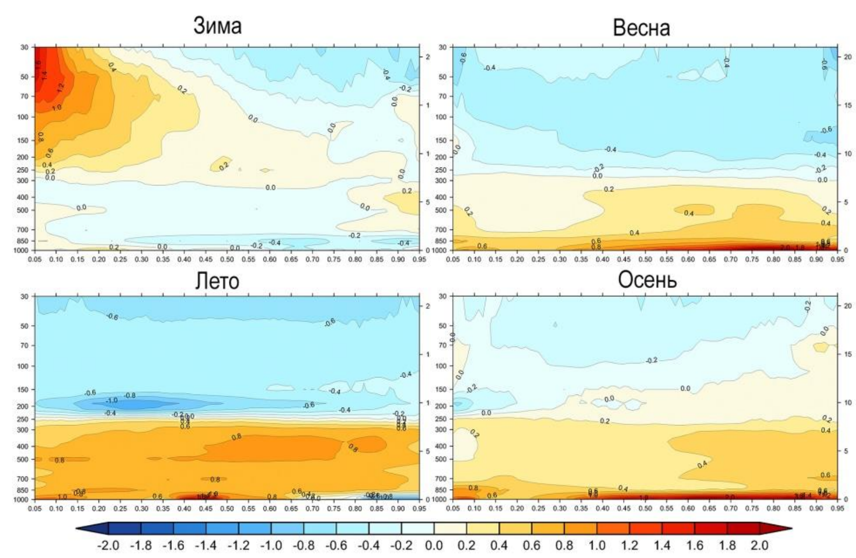
Station 23472, Turukhansk, Russia

The difference between temperature trends and anomaly trends

Temperatures



Anomalies (monthly norms)

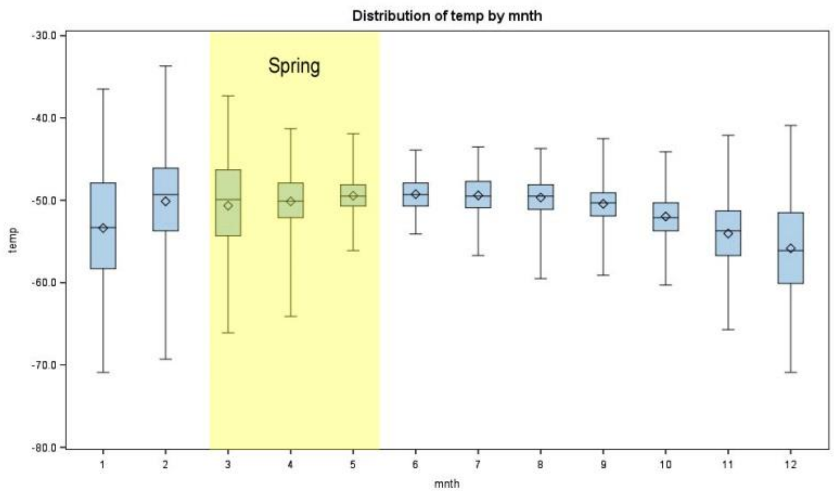


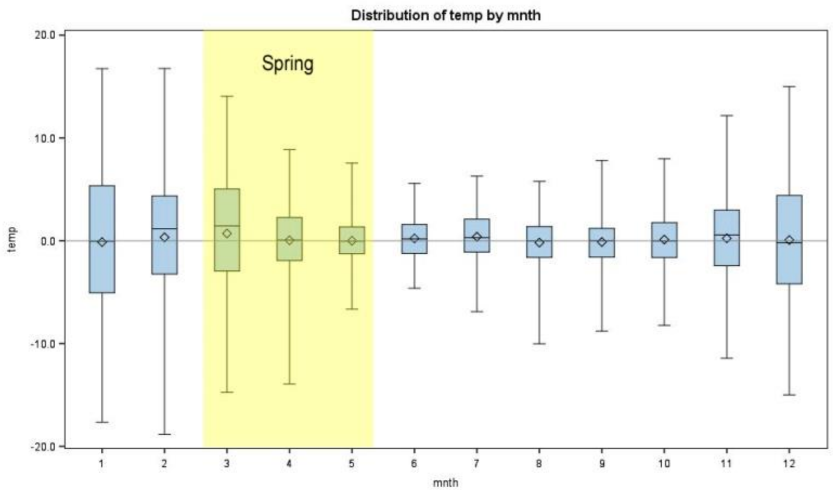
Station 25703, Seymchan, Russia

Temperature and anomaly values at 25703 station

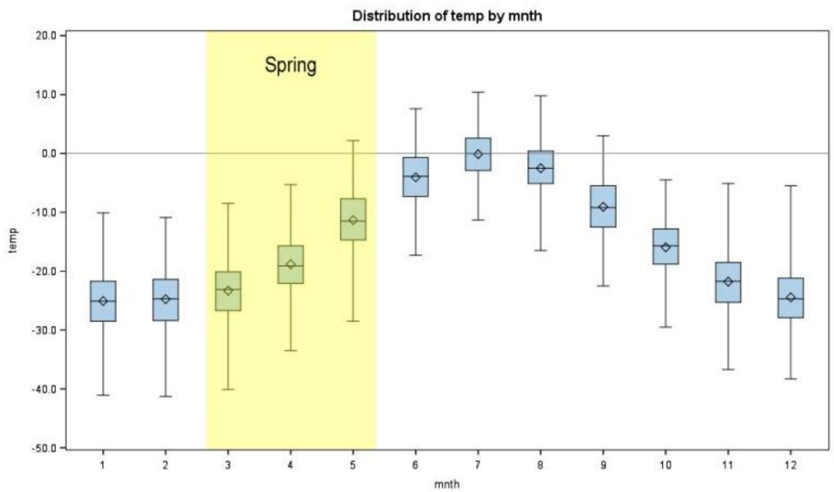
Temperatures	Anomalies (monthly norms)

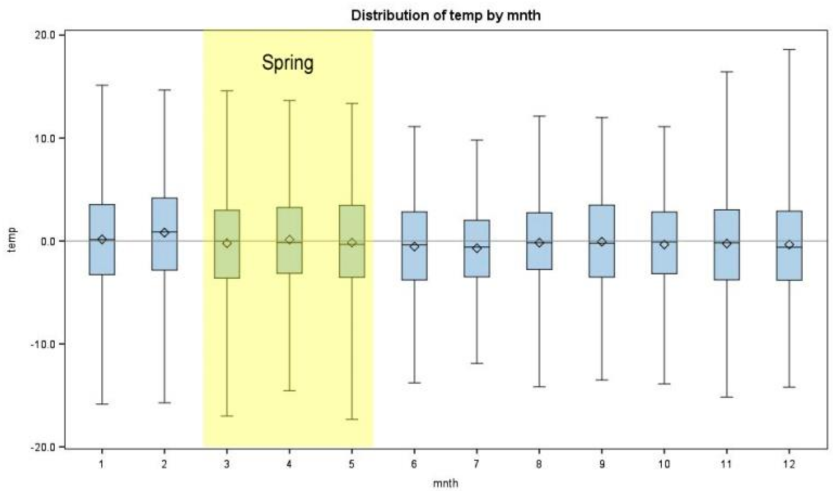
100 hPA





700 hPa

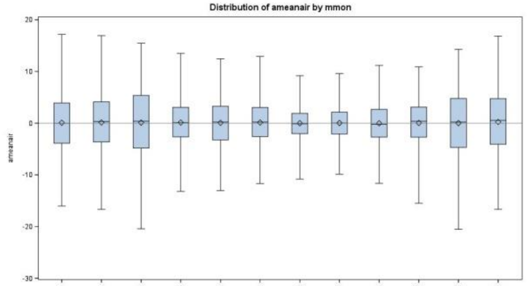


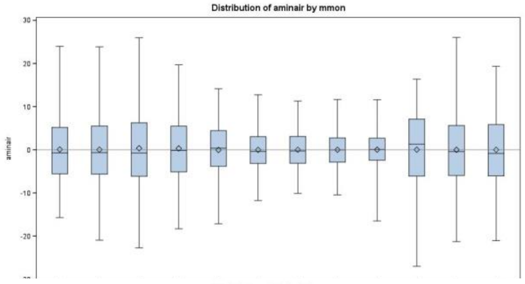


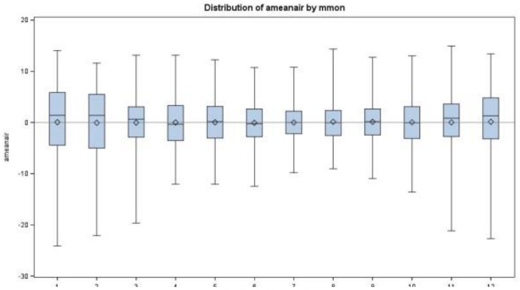
Surface temperature trends

Petropavlovka, 30924 | Dzhardzhan, 24143 | Maloyaroslavets, 27606

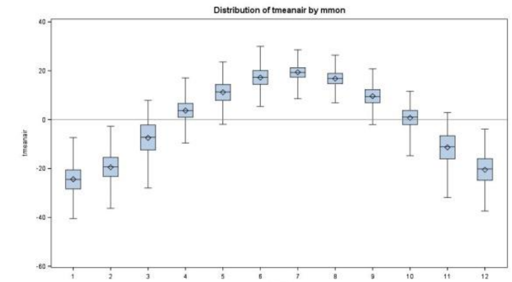
Anomalies

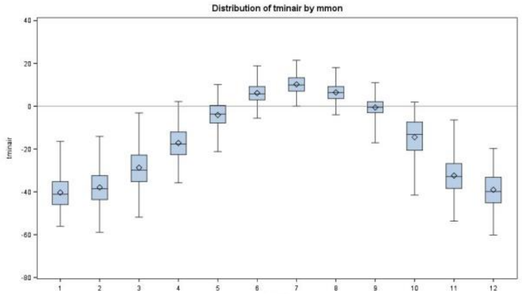


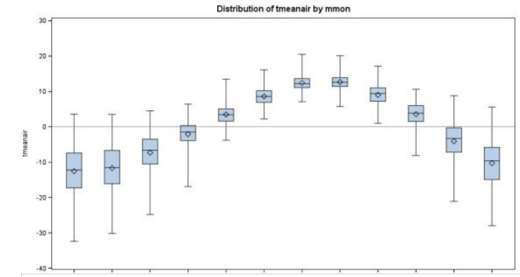




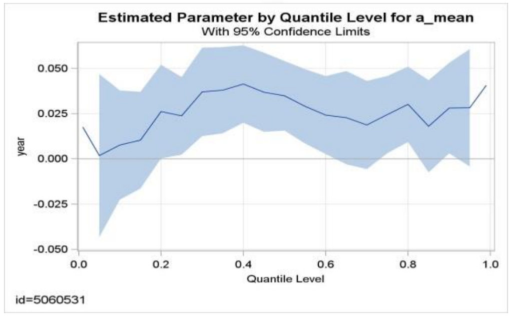
Temperature

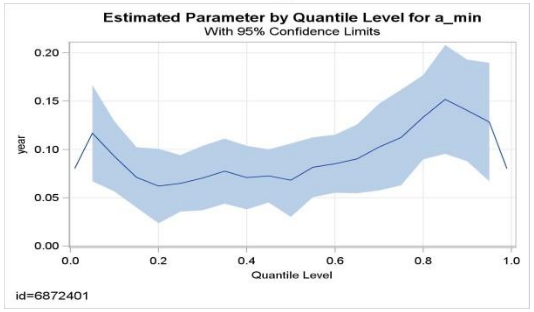


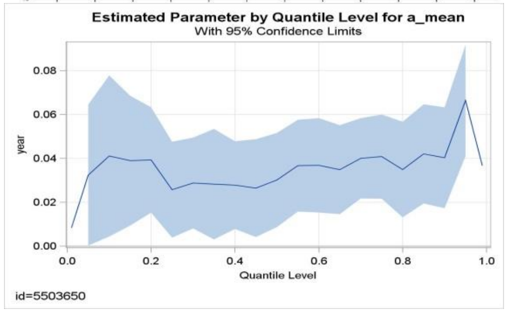




Trends







Clustering

For clustering, the characteristics of the quantile processes were calculated for each station:

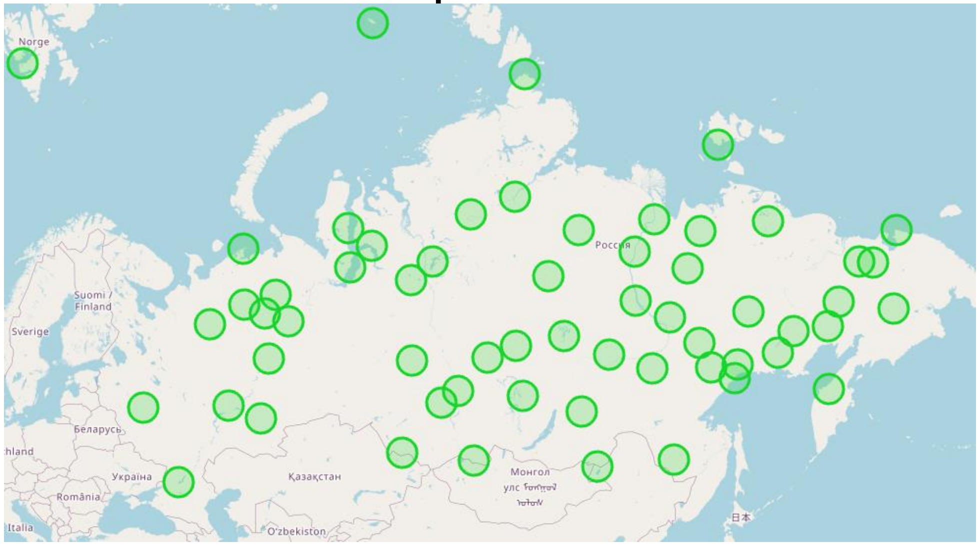
- The difference between trends at different quantile values:
  - t_25-t_5 - between quantiles τ =0.25 and 0.05 (characteristic of the "left tail of the distribution");
  - t_75-t_25 - between quantiles τ =0.75 and 0.25 (characteristic of the “middle part of the distribution");
  - t_95-t_75 - between quantiles τ =0.95 and 0.75 (characteristic of the “right tail of the distribution");
- Average trend value for all calculated quantiles.

Clustering was carried out for all variables (minimum, maximum and mean daily temperature) and all seasons at once.

There are 48 characteristics in total, each of them has undergone the standardization procedure.

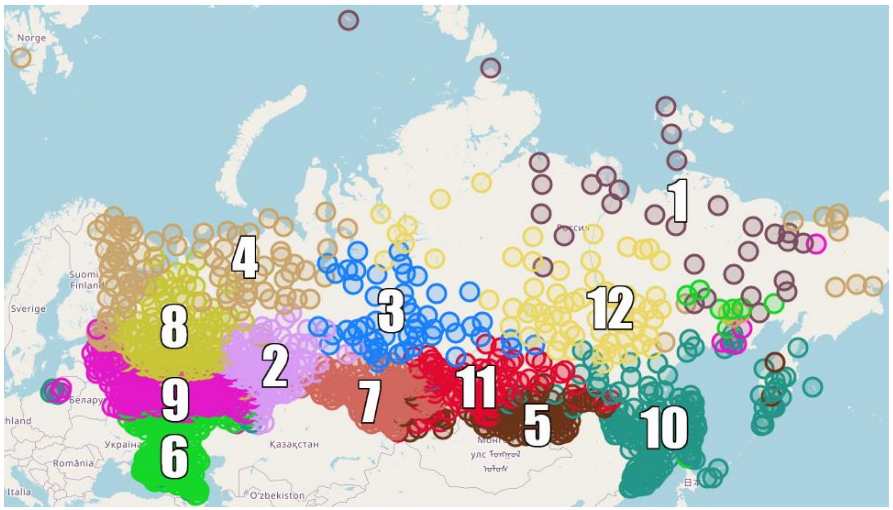
Initial seeds

- 60 stations most distant from each other in the space of 48 variables.
- No geographical information was used to determine the initial seeds.
- Initial seeds were determined for trends of temperature anomalies calculated relative to daily norms, and were used for trends of monthly anomalies and temperature trends.

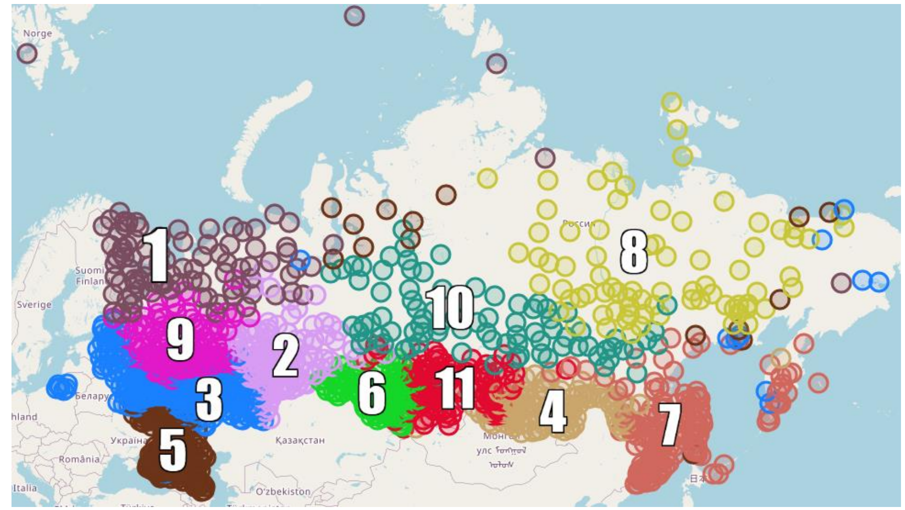


Initial seeds

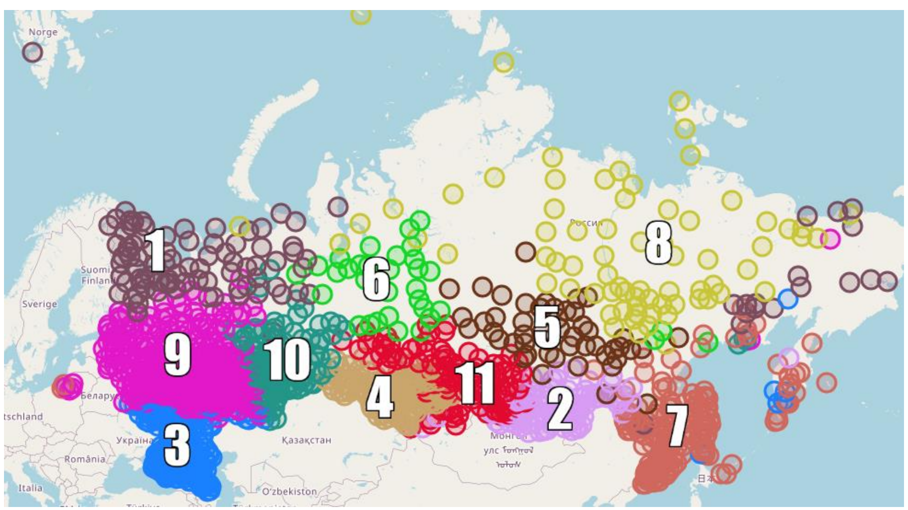
Clustering



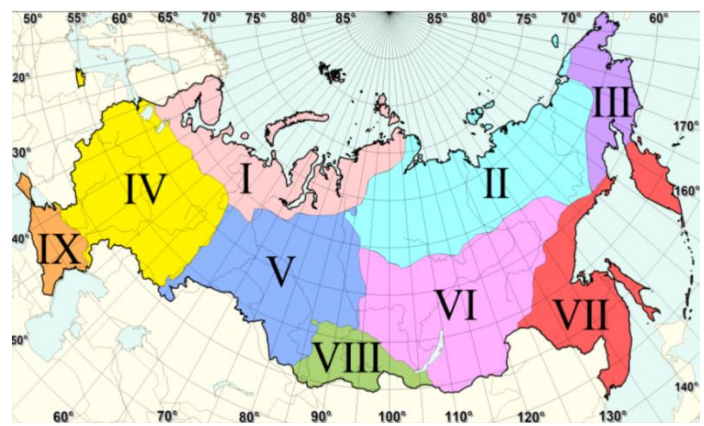
Temperature anomaly trends (daily norms)



Temperature anomaly trends (monthly norms)



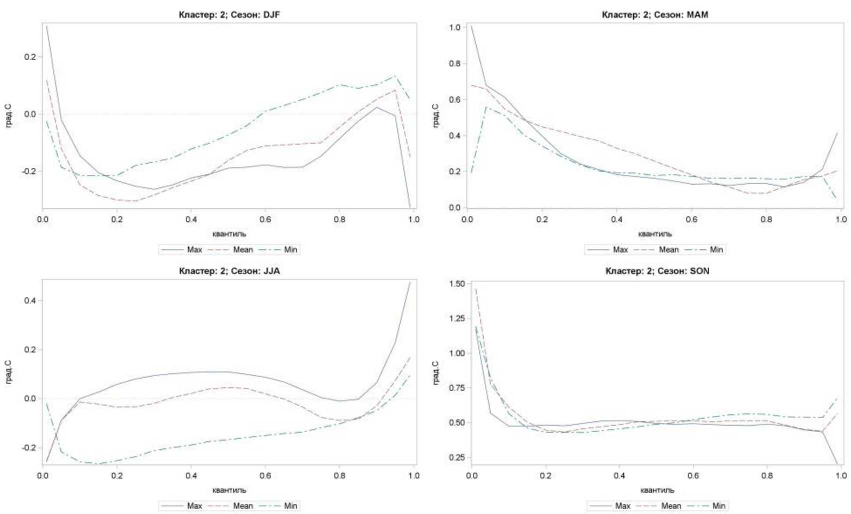
Temperature trends

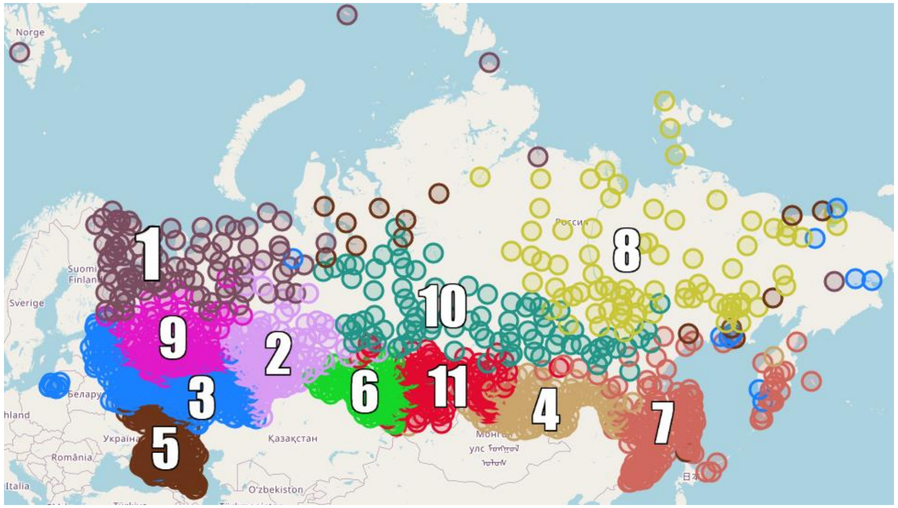


Quasi-homogeneous climatic regions
(A report on climate features on the territory of the Russian Federation in 2020)

Average quantile processes for the south of Ural Mountains (2)

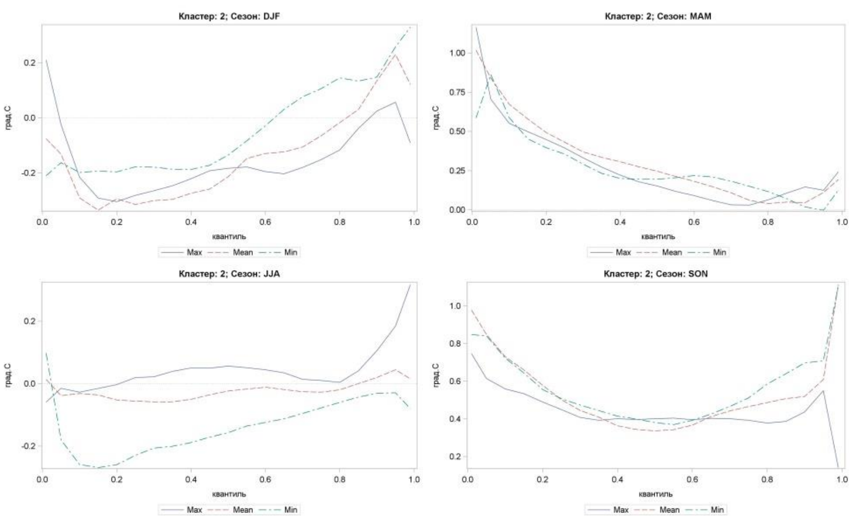
Anomalies (daily)



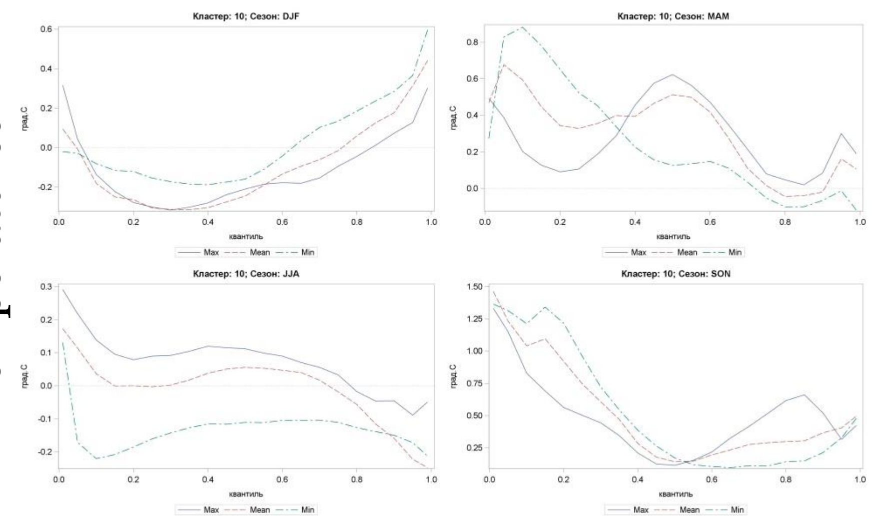


Temperature anomaly trends (monthly norms)

Anomalies (monthly)



Temperatures



Conclusions

- The quantile regression method is sensitive to the annual cycle of temperatures. The uneven distribution of temperatures of different months over the quantile range complicates the interpretation of quatile processes.
- This is most evident in the transitional seasons, spring and autumn, in the upper layers of the atmosphere.
- The transition to temperature anomalies simplifies the interpretation of quantile processes. In the transitional seasons, the trends of anomalies at small and large quantile values are determined mainly by the anomalies of the cold month (March/November). Trends in the rest of the quantile range are calculated based on mixed anomalies of all three months.
- This effect of the distribution of temperature anomalies over the quantile range decreases with decreasing altitude, but is more evident on the earth's surface than in the lower troposphere.

Thank you for your attention!