Phenomena of Intense Climatic Changes over the Territory of Ukraine and a Vision for the Extension of the Climatic Monitoring System

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Goal and objectives

- Based on the spatio-temporal analysis of meteorological parameters for the period from 1901 to 2021, present evidence of dramatic changes of climatic conditions over the territory of Ukraine.

- The following metrics of meteorological and water balance parameters was analyzed: temperature, precipitation, Aridity Index, Potential and Actual evapotranspiration (ET), Standard Precipitation Index (SPI), and Standard Precipitation Evapotranspiration Index (SPEI).

- Hierarchical and Principal Component Analysis (PCA) clustering for periods prior and post temporal structural breaks/breakthroughs were used for mapping and zonation of the territory of Ukraine.

According to the Koppen-Geiger classification, climate of Ukraine is mostly humid continental with hot summer


Köppen-Geiger Climate Classification, 1991-2020
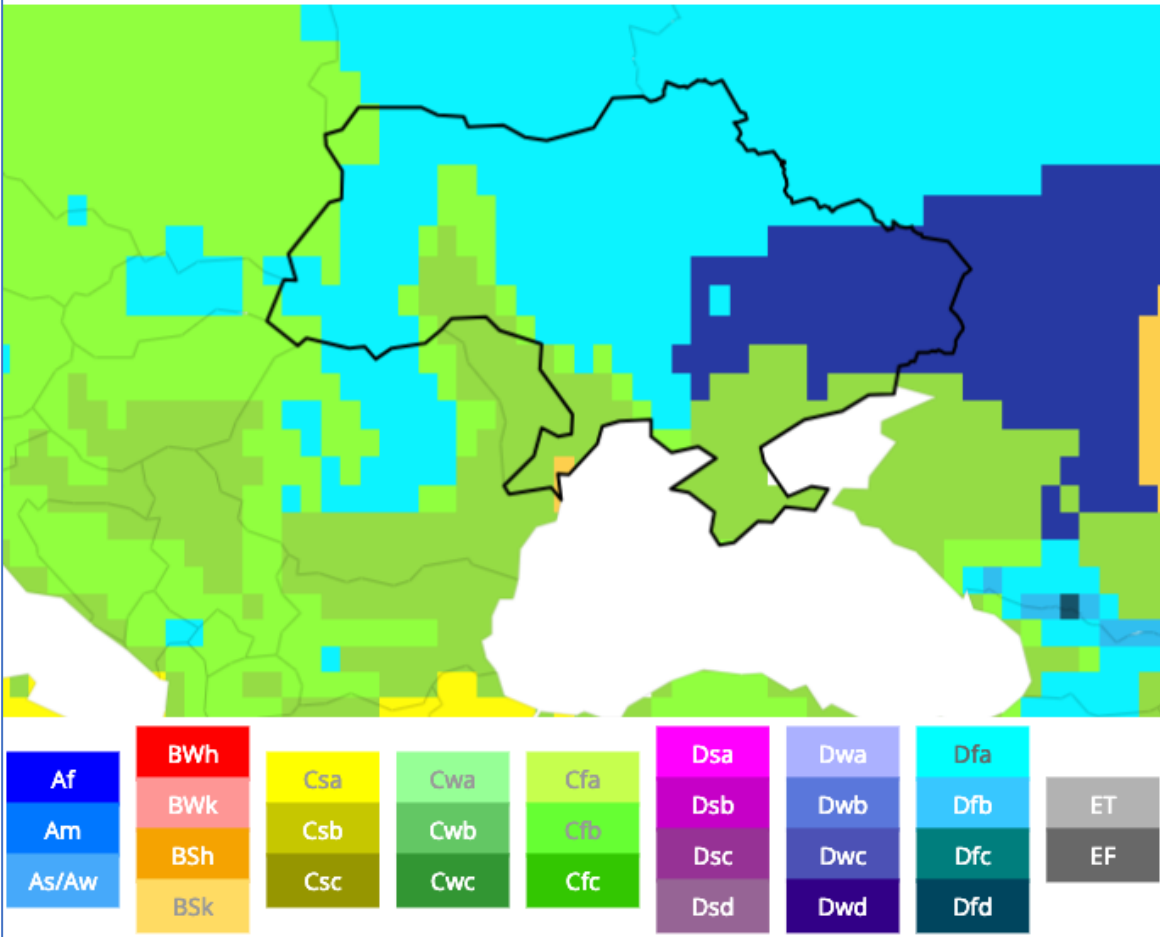
| Code	Description	Group	Precipitation Type	Level of Heat
Af	Tropical rainforest climate	Tropical	Rainforest	
Cwa	Monsoon-influenced humid subtropical climate	Temperate	Dry winter	Hot summer
Cwb	Subtropical highland climate or temperate oceanic climate with dry winters	Temperate	Dry winter	Warm summer
Cwc	Cold subtropical highland climate or subpolar oceanic climate with dry winters	Temperate	Dry winter	Cold summer
Dfa	Hot-summer humid continental climate	Cold (continental)	Without dry season	Hot summer

Data sources and methods

- Data were downloaded from the Climate Change Knowledge Portal https://climateknowledgeportal.worldbank.org/country/ukraine/climate-data-historical
- Historical data at a resolution of 0.5°x0.5° (50km x 50km) were produced by the Climatic Research Unit (CRU) of University of East Anglia
  - 25 regions of Ukraine were analyzed

- Calculations were conducted with the application of the Rstudio platform using libraries:
  - zoo, xts. caTools, HydroTSM, pals, anytime, SPEI, dplyr, strucchange, ecdfHT, factoextra, maps, hydroTools,

Time series of yearly temperature (black lines) and 30–year averaged temperature (blue lines)
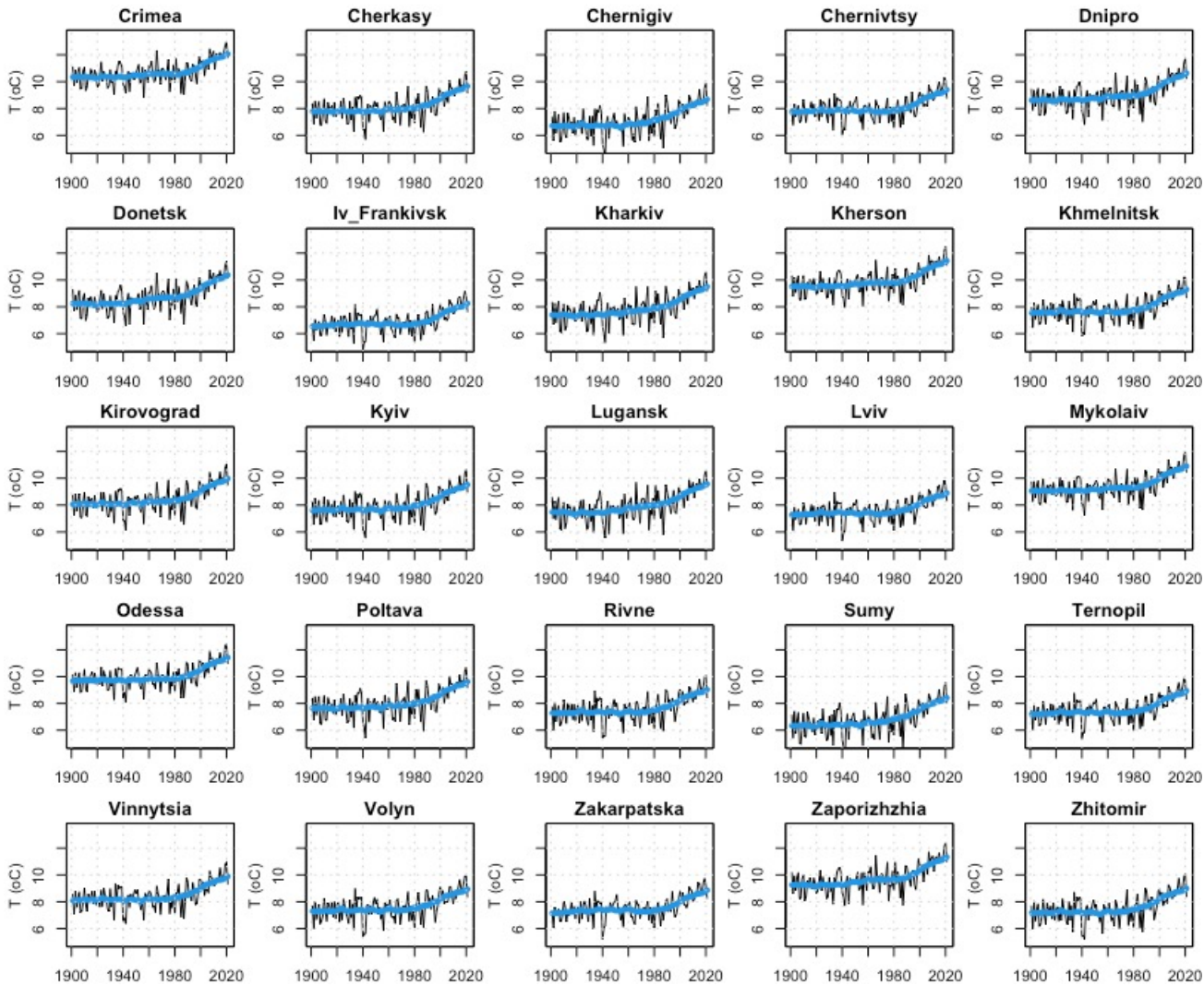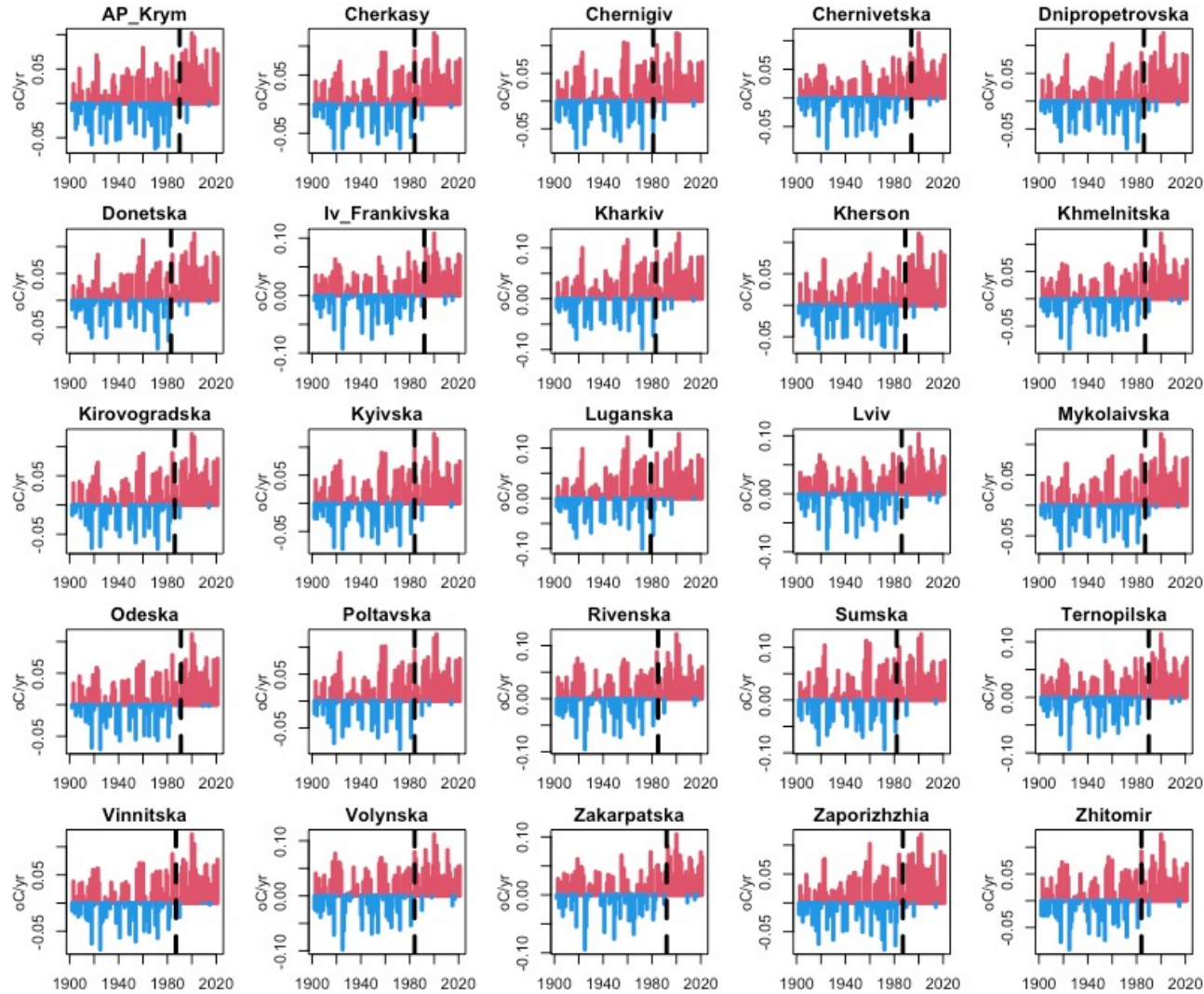

Temperature increase since 1901
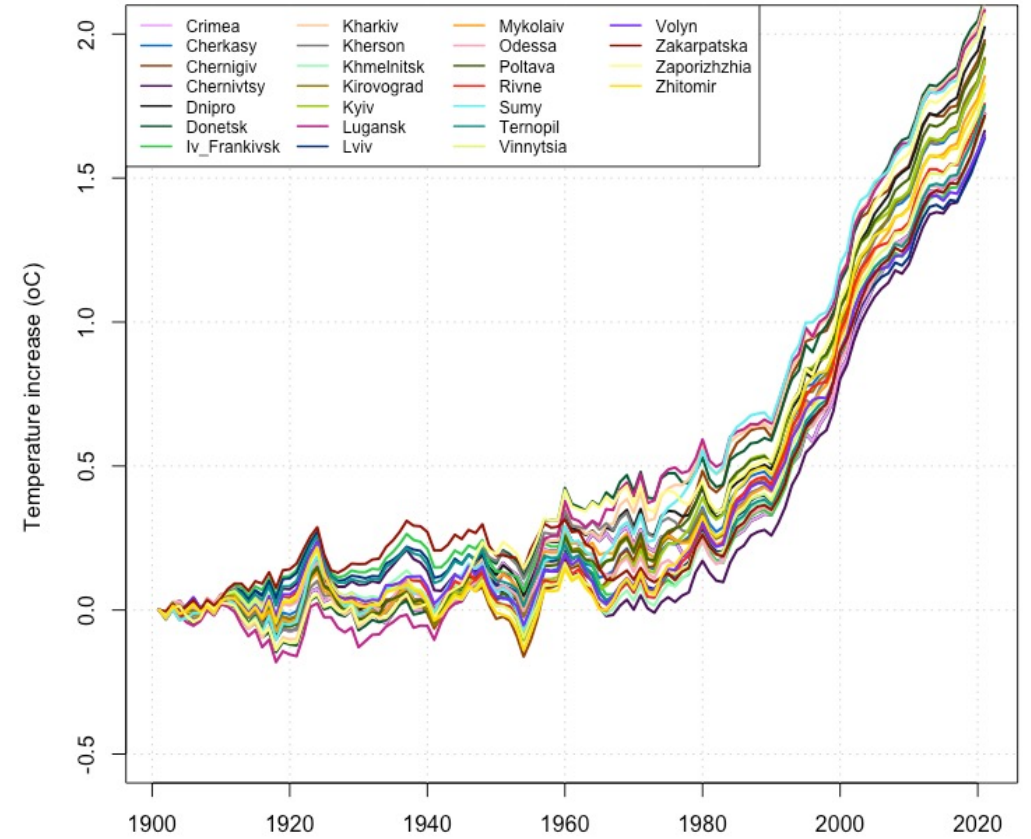
Z-score of temperature indicates that climate warming began in 1940s, and the "hot" phase of climate changes started in 1979-1994
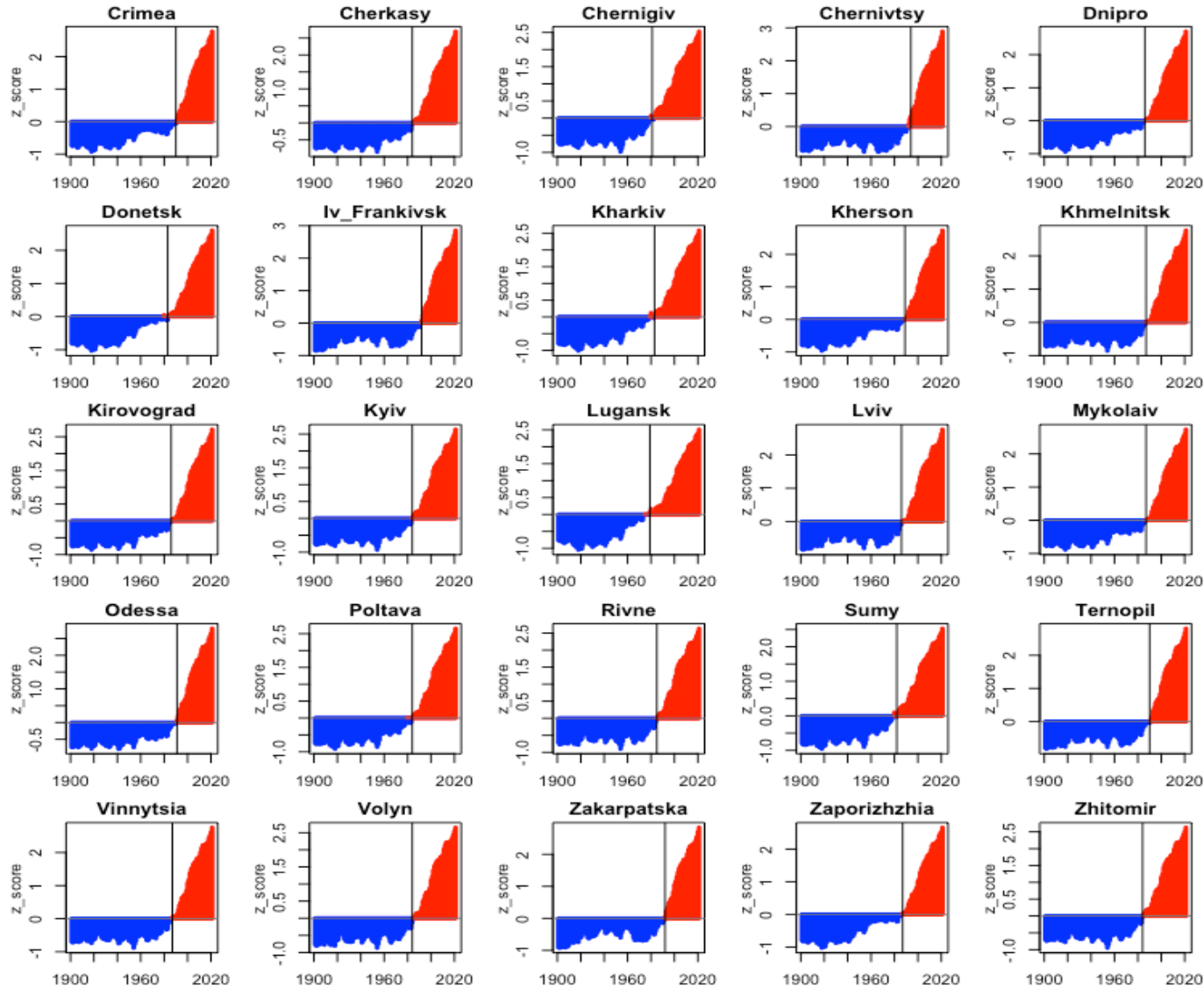

Region	Year
Crimea	1990
Cherkasy	1984
Chernigiv	1981
Chernivtsy	1994
Dnipro	1986
Donetsk	1983
Iv_Frankivsk	1992
Kharkiv	1983
Kherson	1989
Khmelnitsk	1987
Kirovograd	1986
Kyiv	1984
Lugansk	1979
Lviv	1986
Mykolaiv	1987
Odessa	1991
Poltava	1984
Rivne	1985
Sumy	1982
Ternopil	1990
Vinnytsia	1987
Volyn	1984
Zakarpatska	1992
Zaporizhzhia	1987
Zhitomir	1984

Z-score = (x − μ)/ σ   Z-score > 0 – "hot" phase of temperature increase

# Temporal gradient of temperature increased during the "hot" phase of climate change

Cumulative distribution function of temporal gradient of temperature in the "hot" phase: average is 0.045 ºC/year
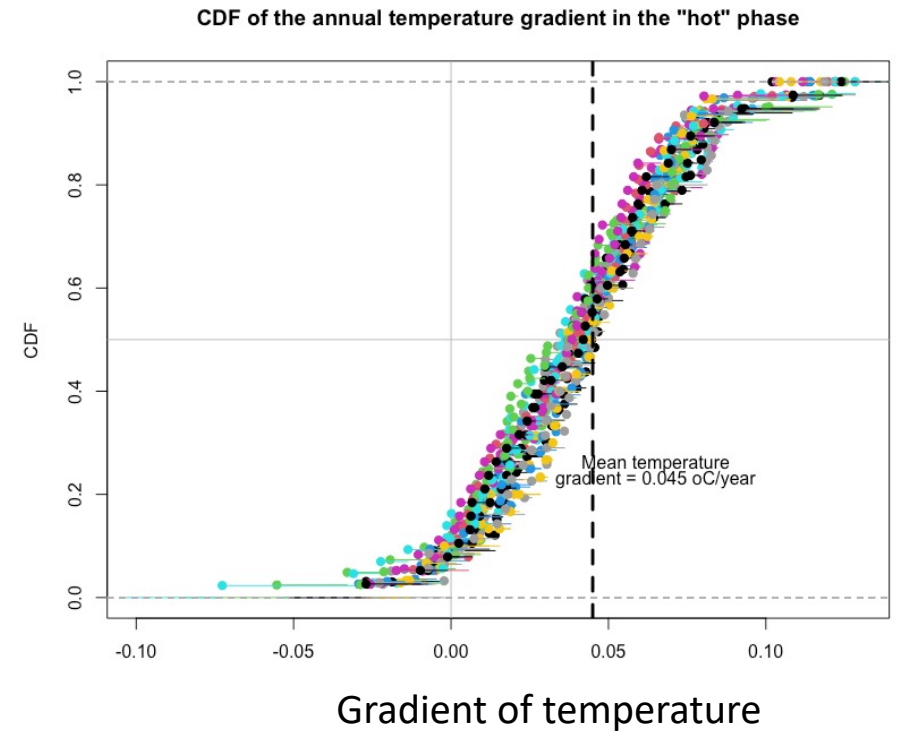
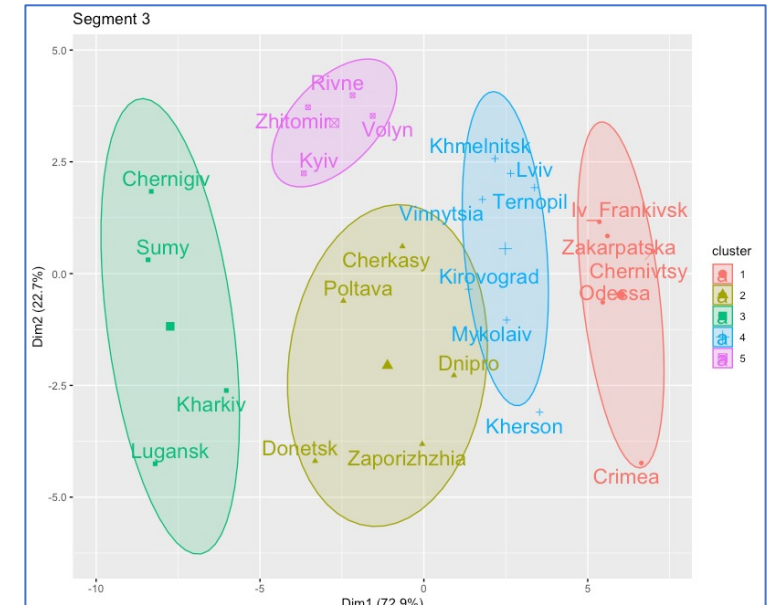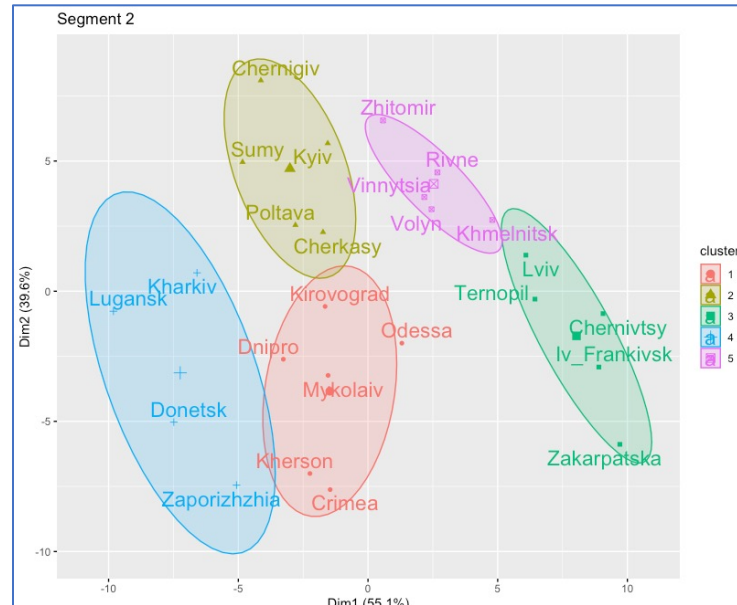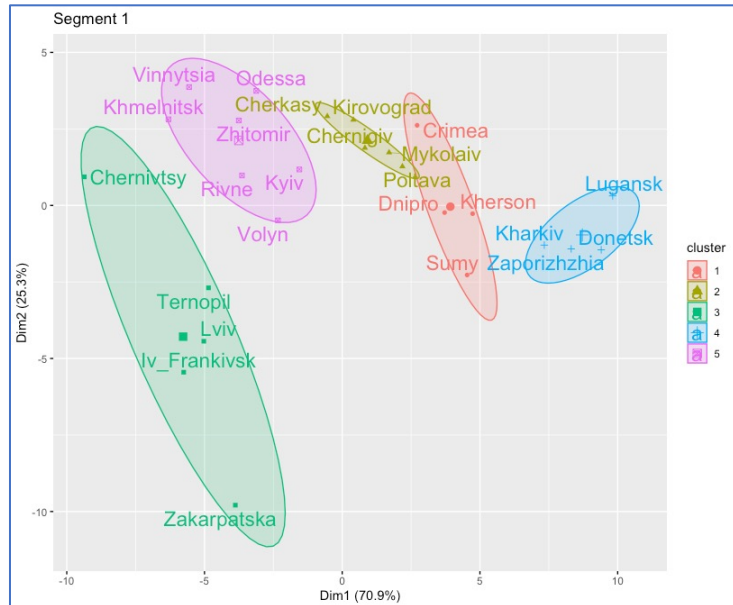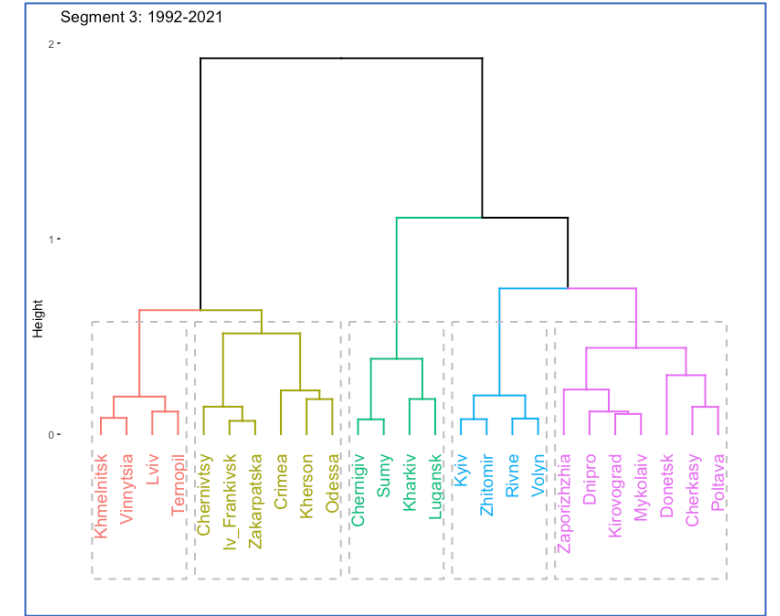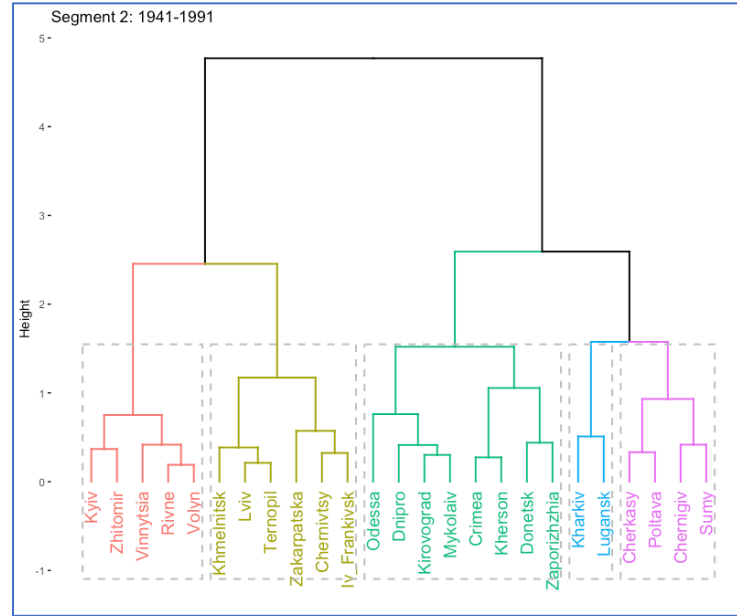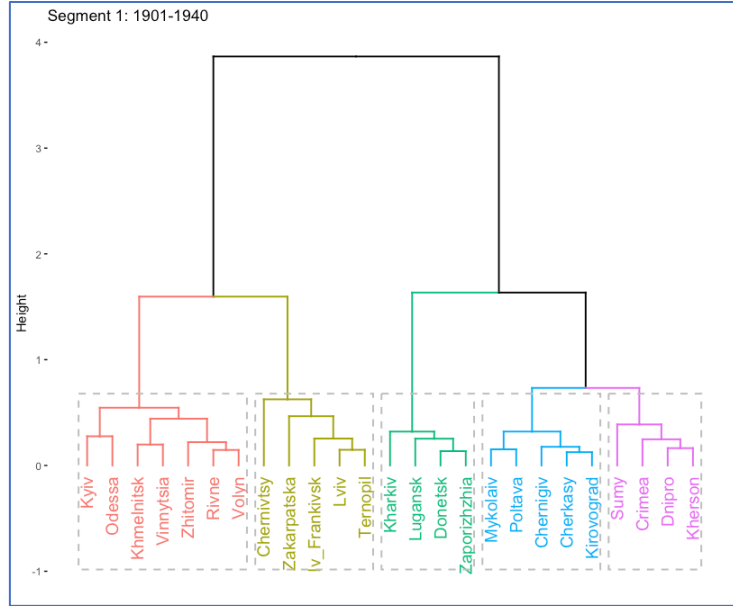Vertical dashed lines are thresholds of time series of temperature—beginning of the "hot" phase

Temperature increased more significantly in winter and summer (Kyiv region)
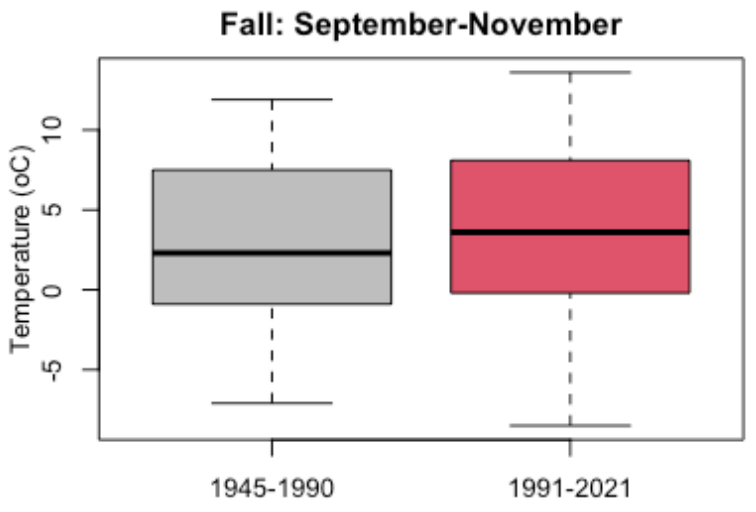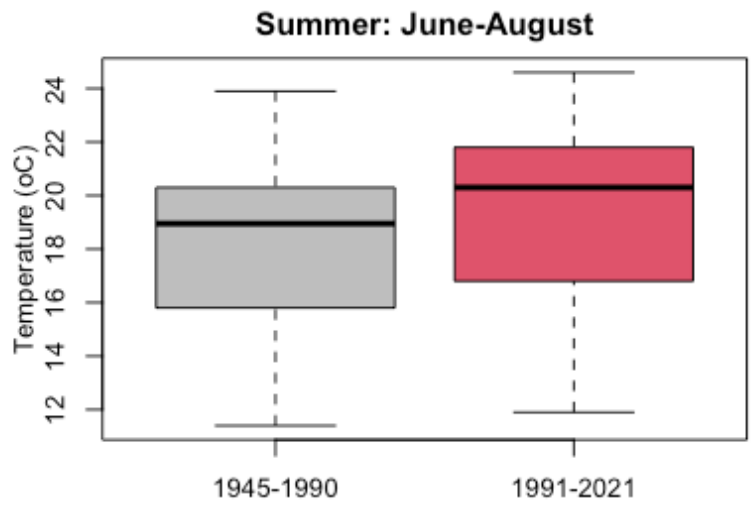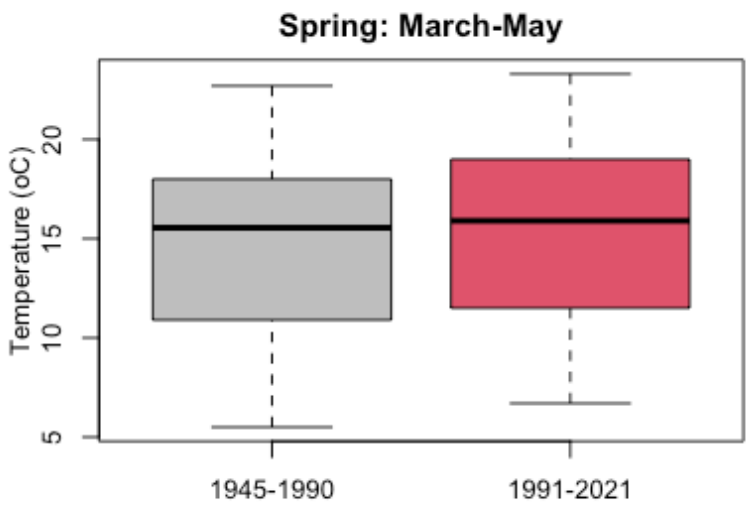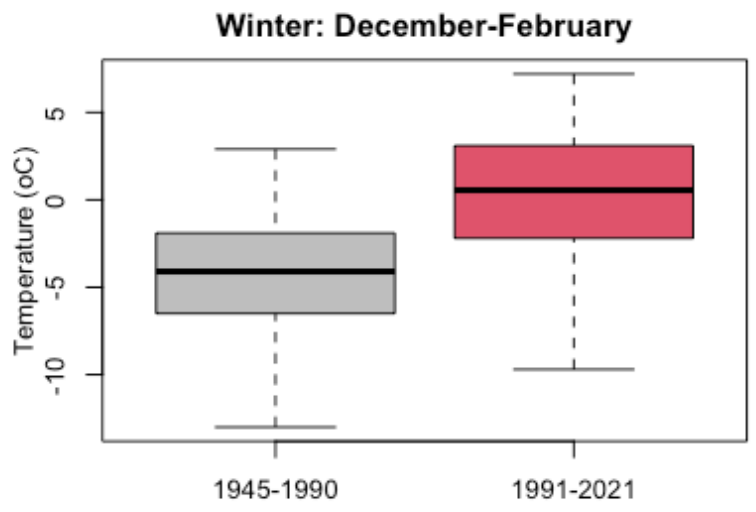
Hierarchical and PCA clustering of Ukraine based on temperature

Comparison of clusters of temperature for different regions

| Column1	1901-1941	1941-1991	1992-2021
Crimea	1	1	1
Cherkasy	2	2	2
Chernigiv	2	2	3
Chernivtsy	3	3	1
Dnipro	1	1	2
Donetsk	4	4	2
Iv_Frankivsk	3	3	1
Kharkiv	4	4	3
Kherson	1	1	4
Khmelnitsk	5	5	4
Kirovograd	2	1	4
Kyiv	5	2	5
Lugansk	4	4	3
Lviv	3	3	4
Mykolaiv	2	1	4
Odessa	5	1	1
Poltava	2	2	2
Rivne	5	5	5
Sumy	1	2	3
Ternopil	3	3	4
Vinnytsia	5	5	4
Volyn	5	5	5
Zakarpatska	3	3	1
Zaporizhzhia	4	4	2
Zhitomir	5	5	5

Time series of yearly precipitation (black lines) and 30–year averaged temperature (blue lines)
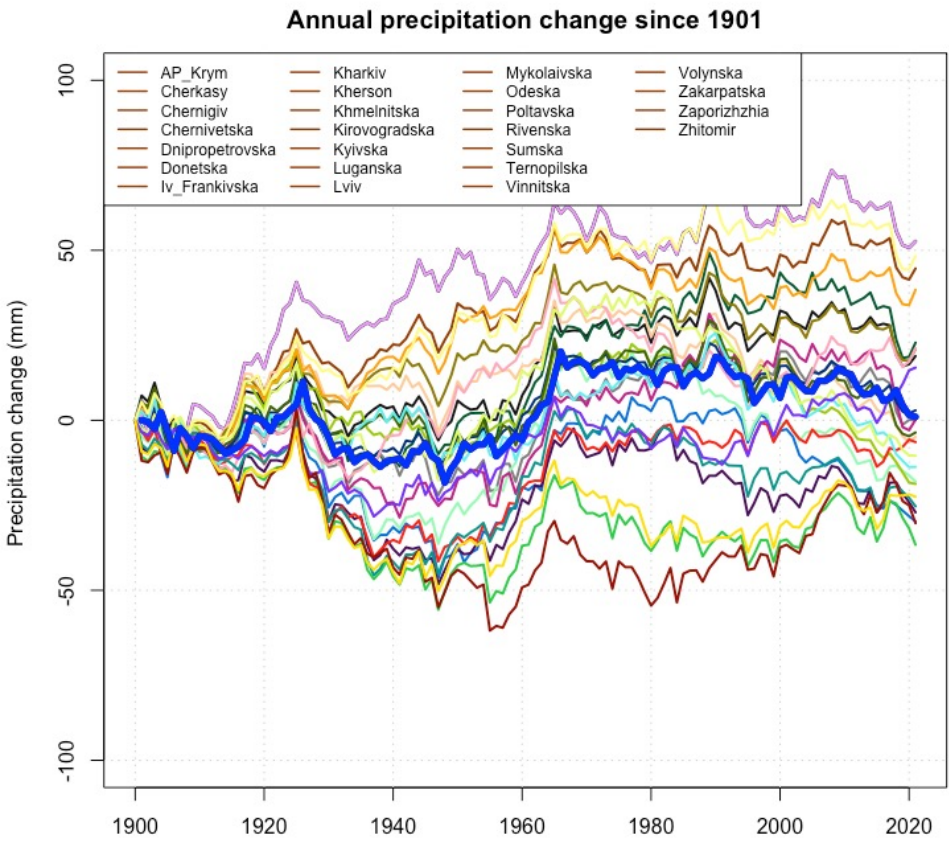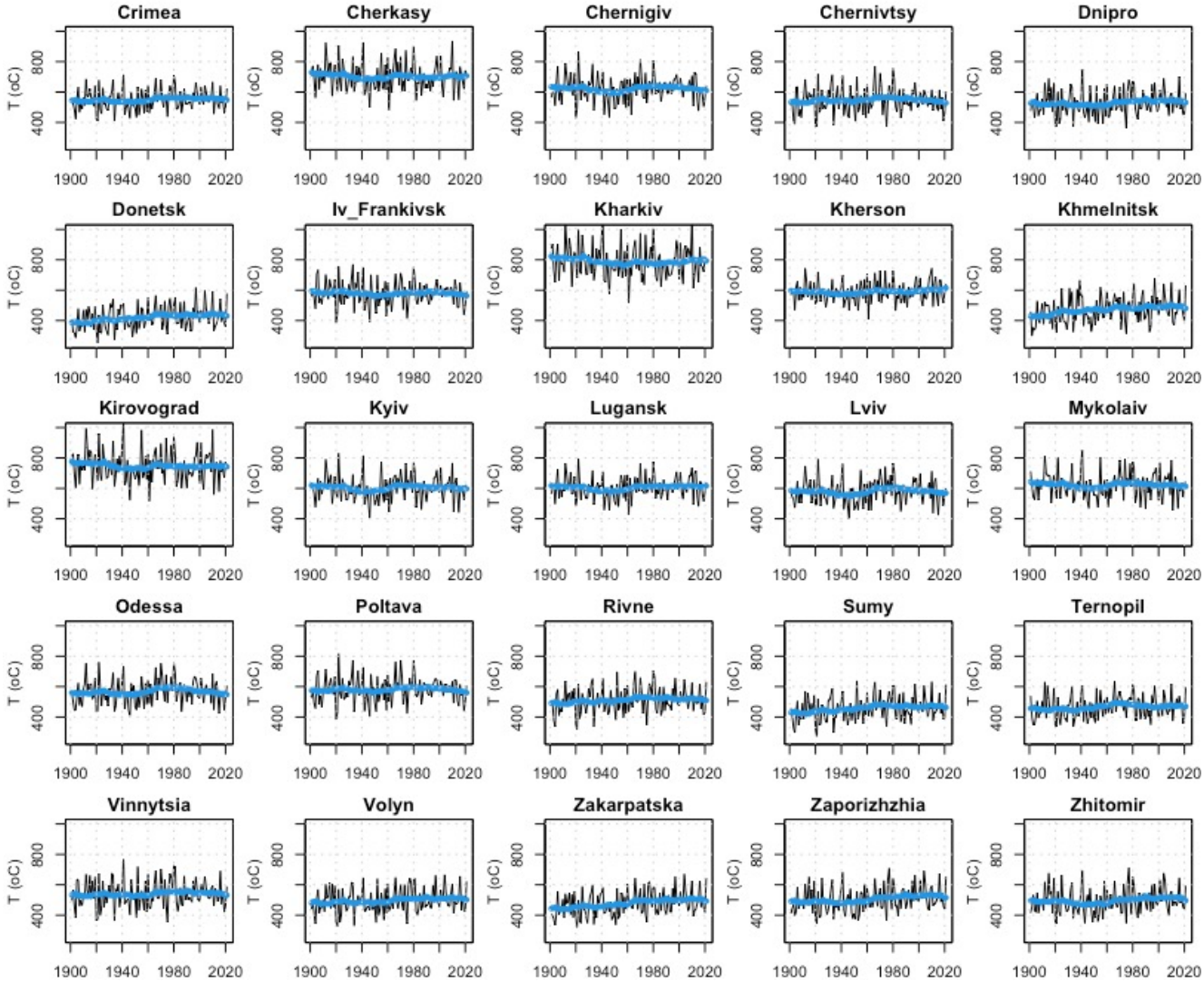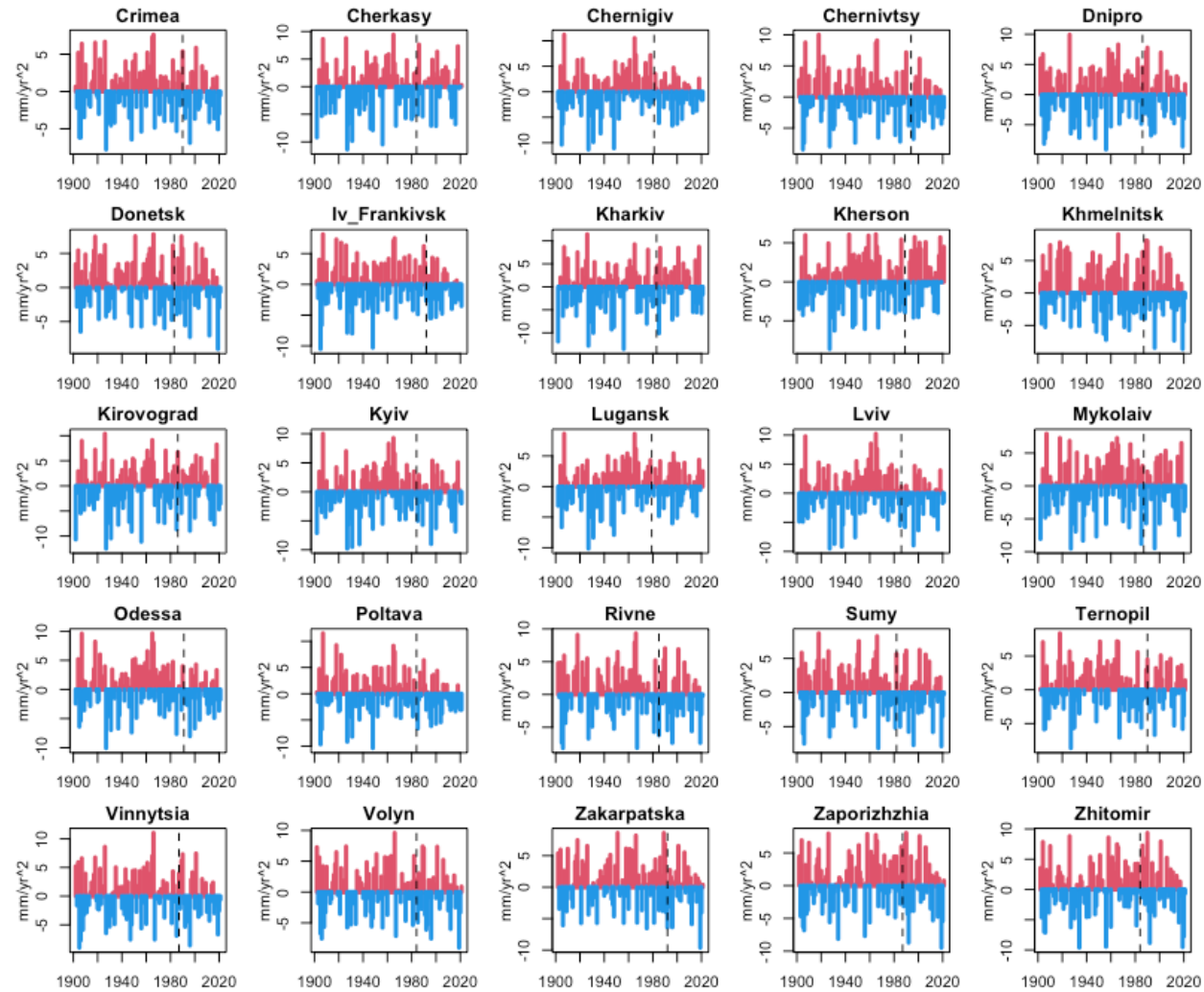
z-score of precipitation vs. time
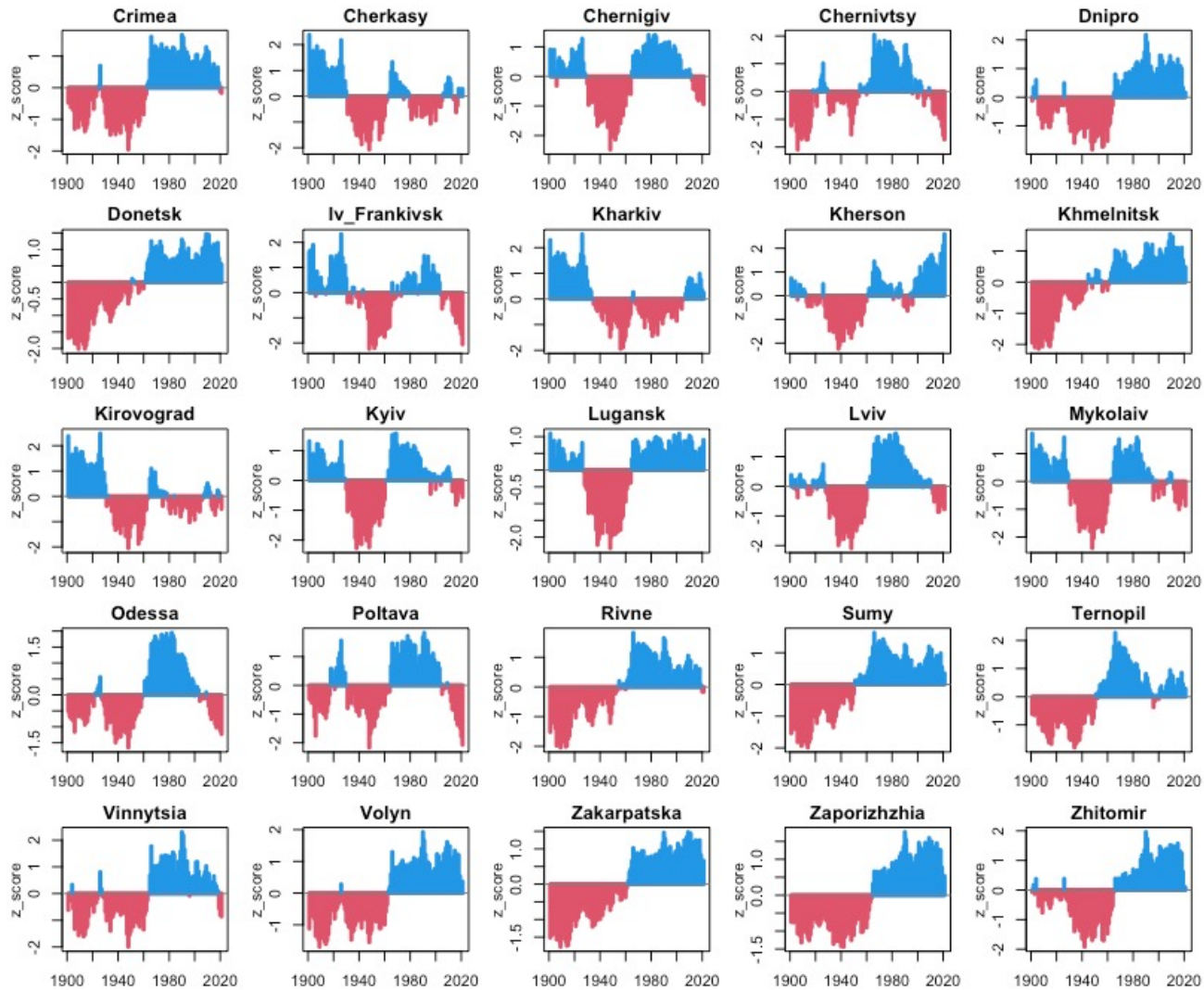
Z-score of precipitation is practically the same as Standard Precipitation Index
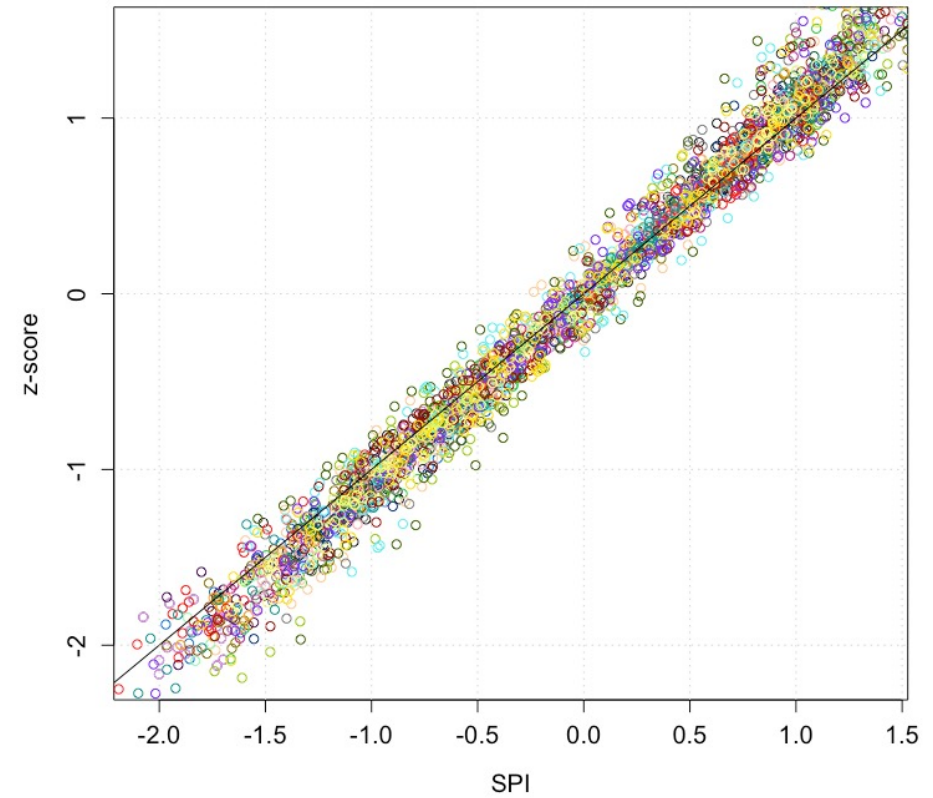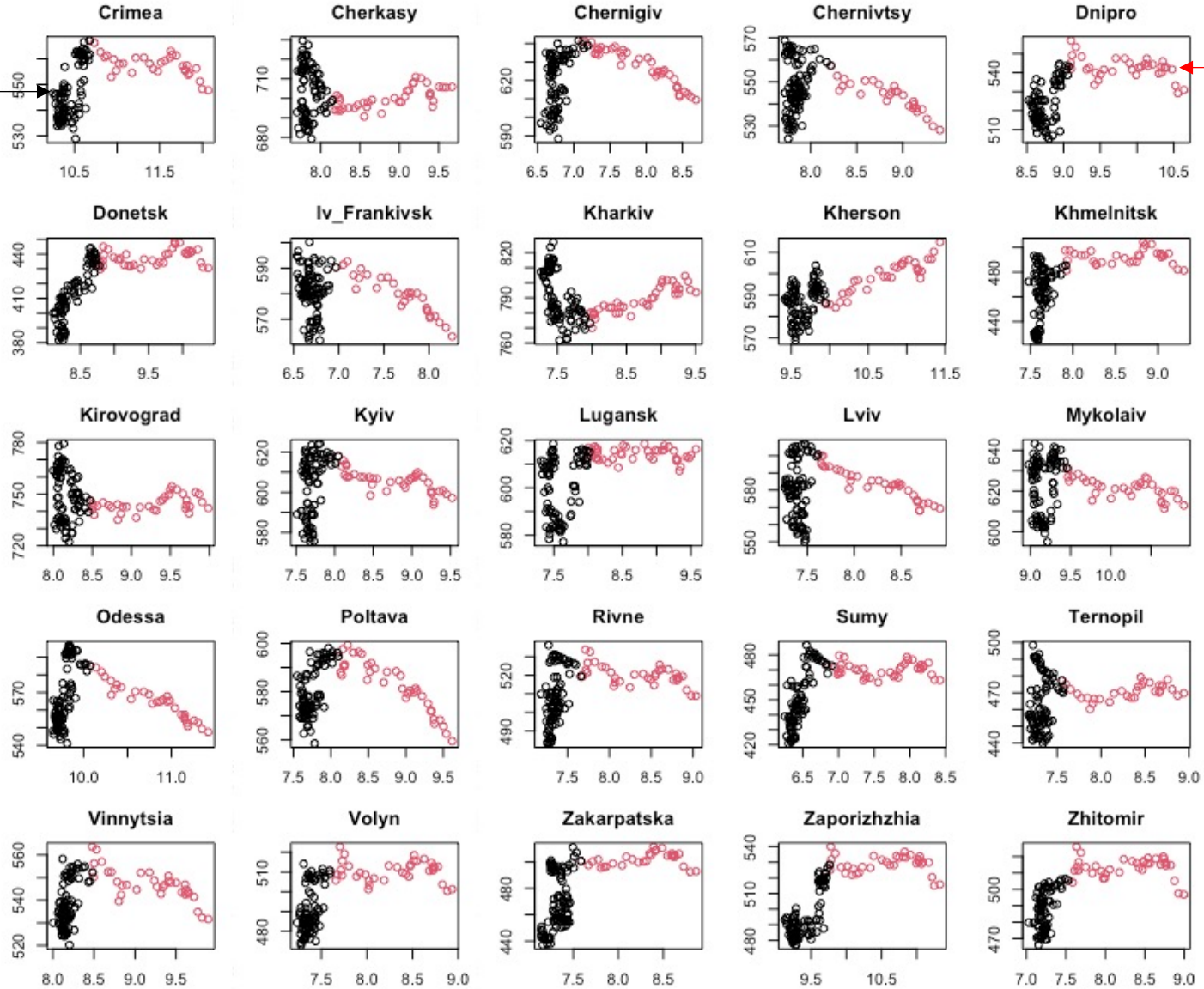
Temporal gradient of precipitation decreases during the hot phase of warming

Vertical dashed lines are thresholds of time series of temperature—beginning of the "hot" phase
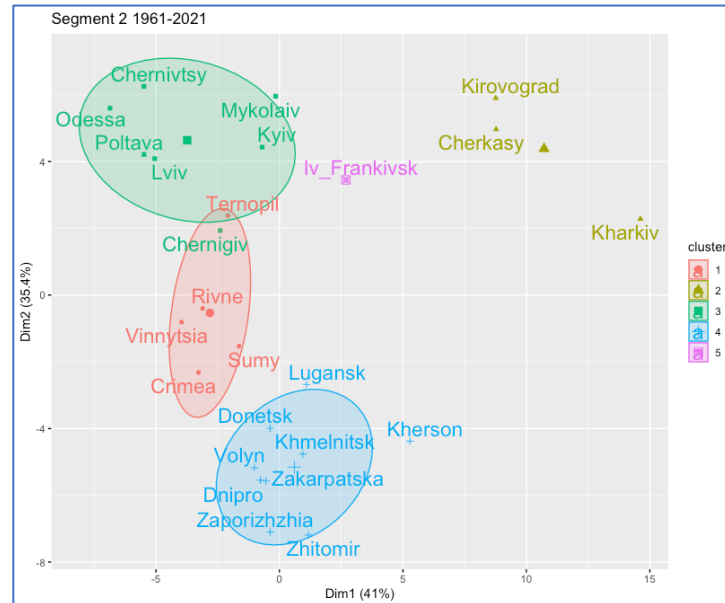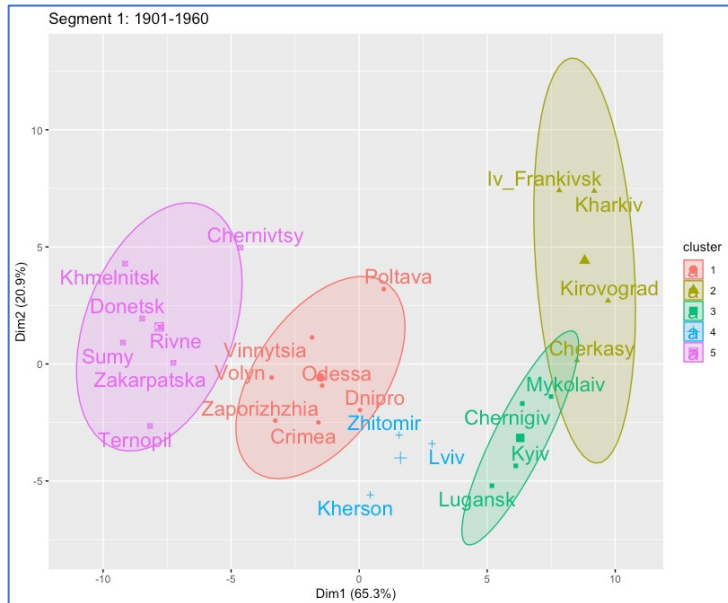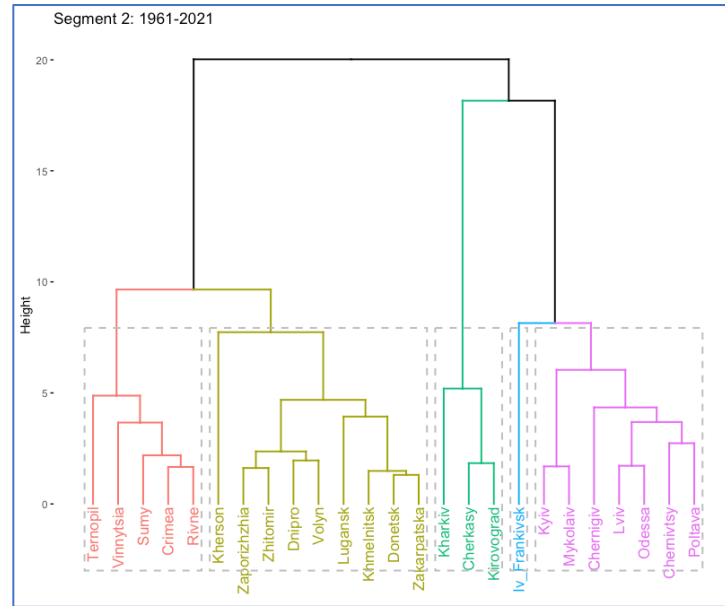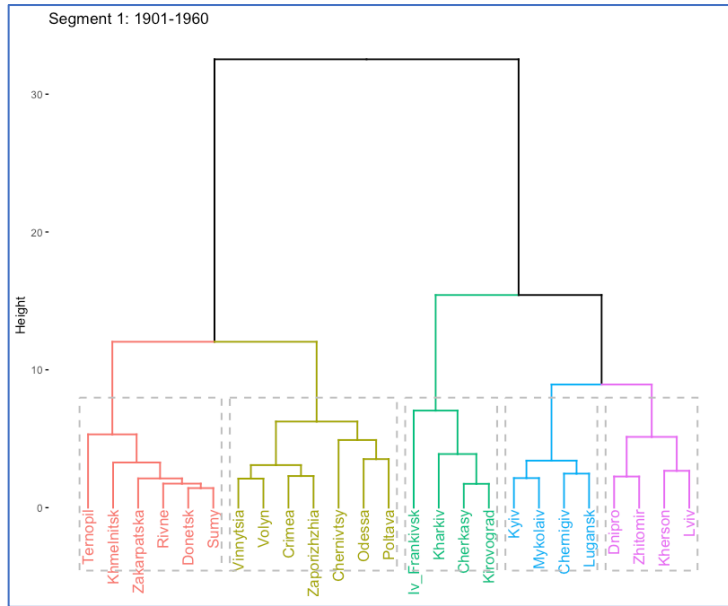
Relationship between temperature vs precipitation changes with time

Prior to "hot" phase: mostly precipitation increases as temperature increases

"Hot" phase: precipitation remains the same or decreases

# Hierarchical and PCA clustering and zonation of Ukraine based on precipitation

Cluster numbers

	1901-1960	1961-2021
Crimea	1	1
Cherkasy	2	2
Chernigiv	3	3
Chernivtsy	5	3
Dnipro	1	4
Donetsk	5	4
Iv_Frankivsk	2	5
Kharkiv	2	2
Kherson	4	4
Khmelnitsk	5	4
Kirovograd	2	2
Kyiv	3	3
Lugansk	3	4
Lviv	4	3
Mykolaiv	3	3
Odessa	1	3
Poltava	1	3
Rivne	5	1
Sumy	5	1
Ternopil	5	1
Vinnytsia	1	1
Volyn	1	4
Zakarpatska	5	4
Zaporizhzhia	1	4
Zhitomir	4	4

Aridity Index increased during the "hot" phase
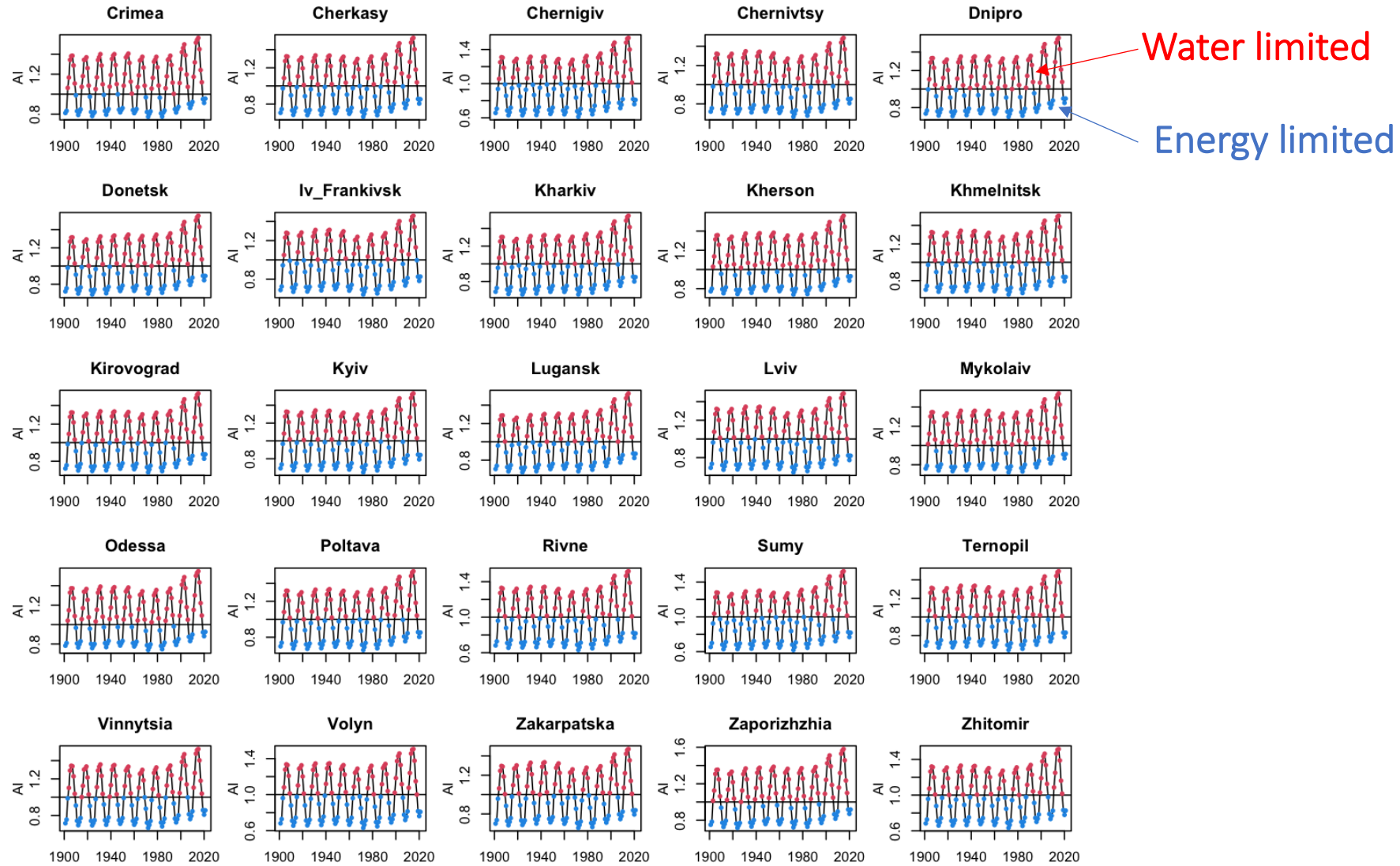
Hierarchical and PCA clustering of Ukraine based on SPEI
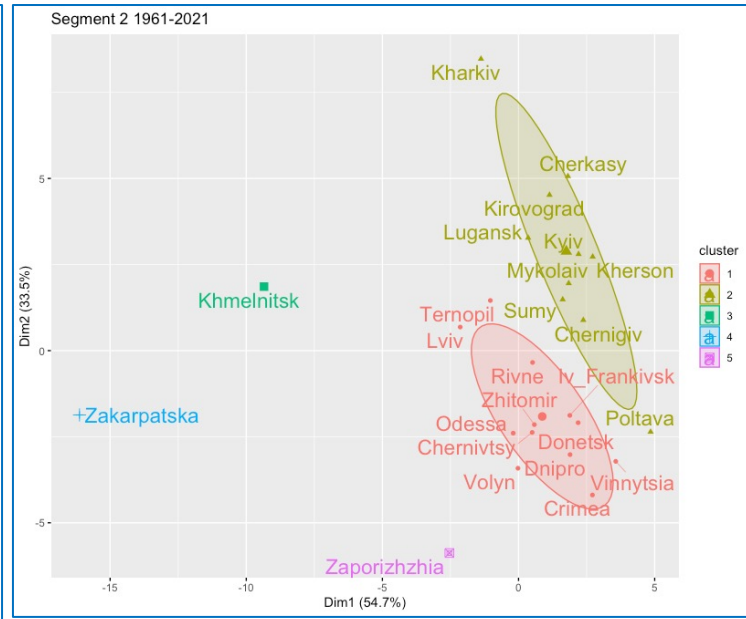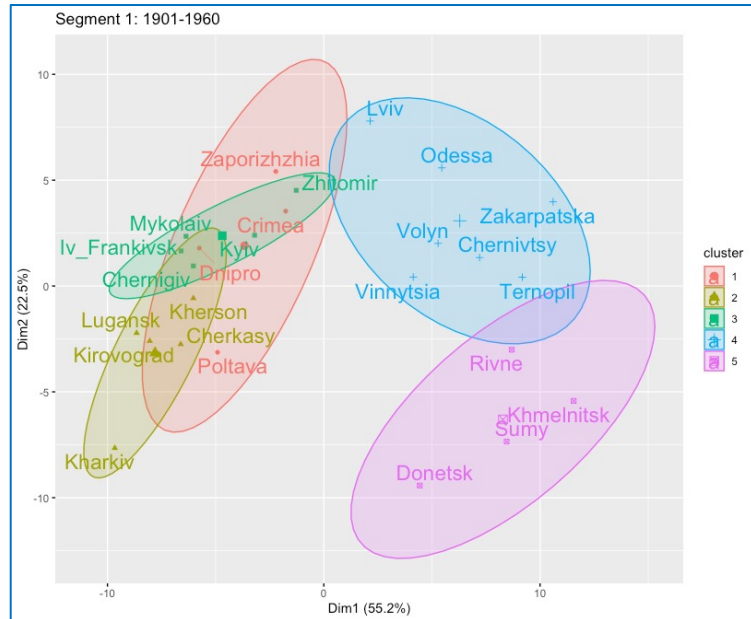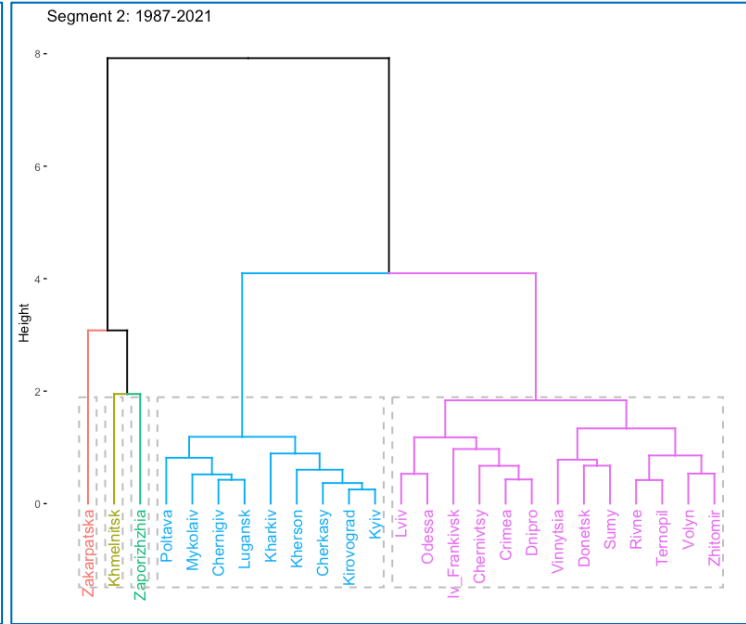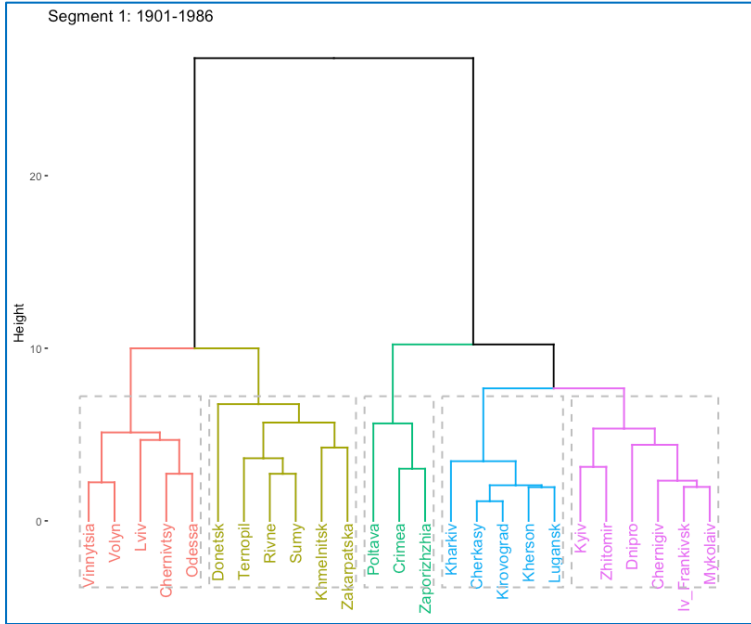
Clusters

Column1	1901-1986	1987-2021
Crimea	1	1
Cherkasy	2	2
Chernigiv	3	2
Chernivtsy	4	1
Dnipro	1	1
Donetsk	5	1
Iv_Frankivsk	3	1
Kharkiv	2	2
Kherson	2	2
Khmelnitsk	5	3
Kirovograd	2	2
Kyiv	3	2
Lugansk	2	2
Lviv	4	1
Mykolaiv	3	2
Odessa	4	1
Poltava	1	2
Rivne	5	1
Sumy	5	2
Ternopil	4	1
Vinnytsia	4	1
Volyn	4	1
Zakarpatska	4	4
Zaporizhzhia	1	5
Zhitomir	3	1

SPEI time series

Vertical dashed lines are the beginning of the "hot" phase
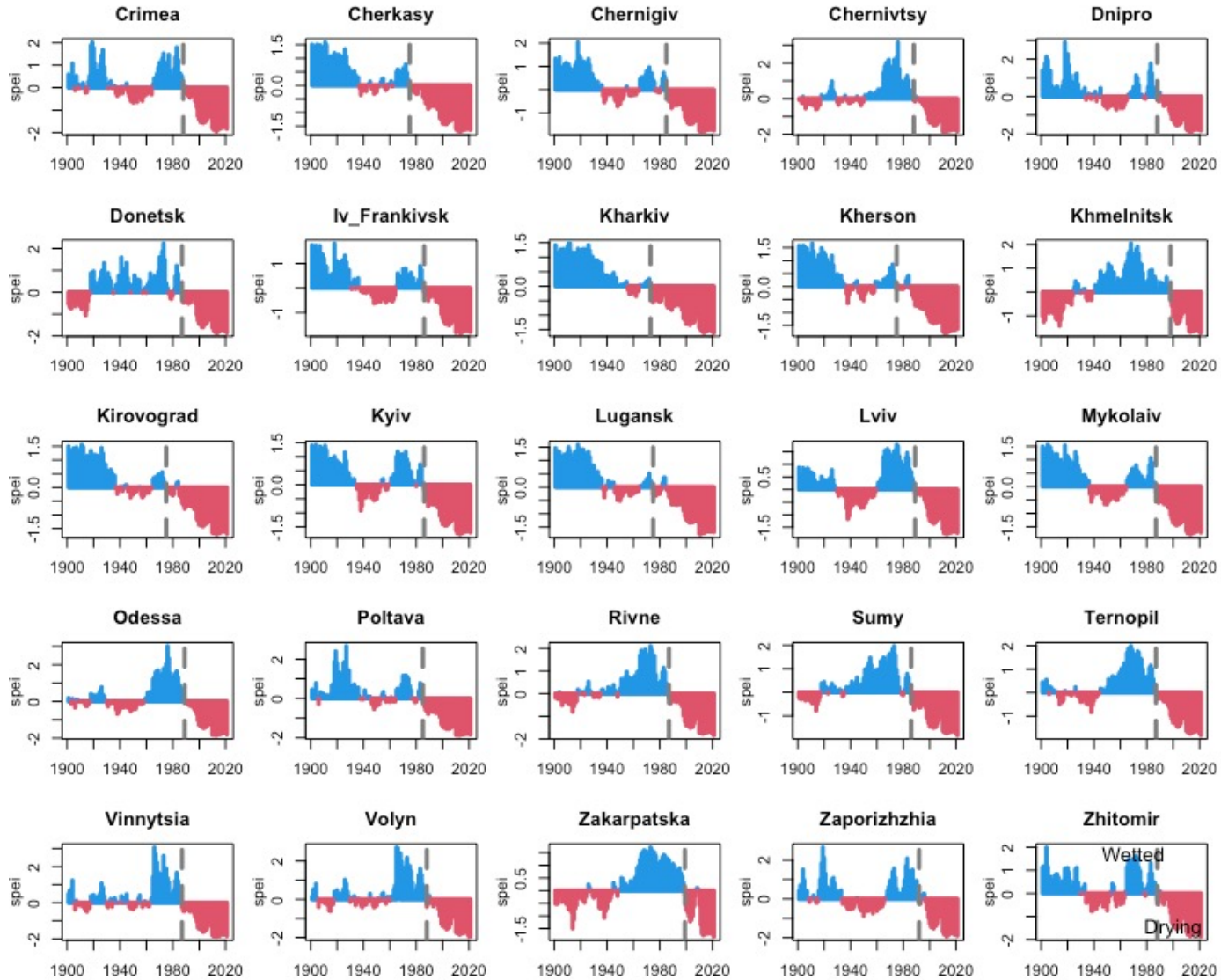
Beginning of the "hot" phase

Region	Year
Crimea	1988
Cherkasy	1975
Chernigiv	1985
Chernivtsy	1988
Dnipro	1988
Donetsk	1987
Iv_Frankivsk	1986
Kharkiv	1973
Kherson	1975
Khmelnitsk	1998
Kirovograd	1975
Kyiv	1986
Lugansk	1975
Lviv	1989
Mykolaiv	1987
Odessa	1989
Poltava	1985
Rivne	1987
Sumy	1986
Ternopil	1987
Vinnytsia	1987
Volyn	1988
Zakarpatska	1999
Zaporizhzhia	1992
Zhitomir	1988

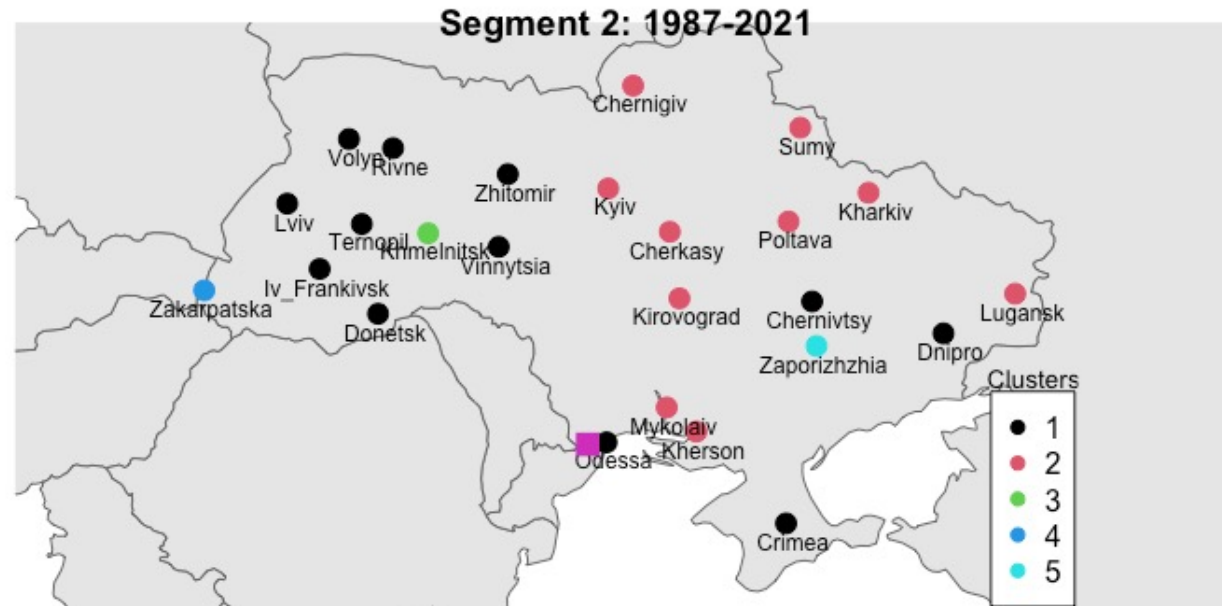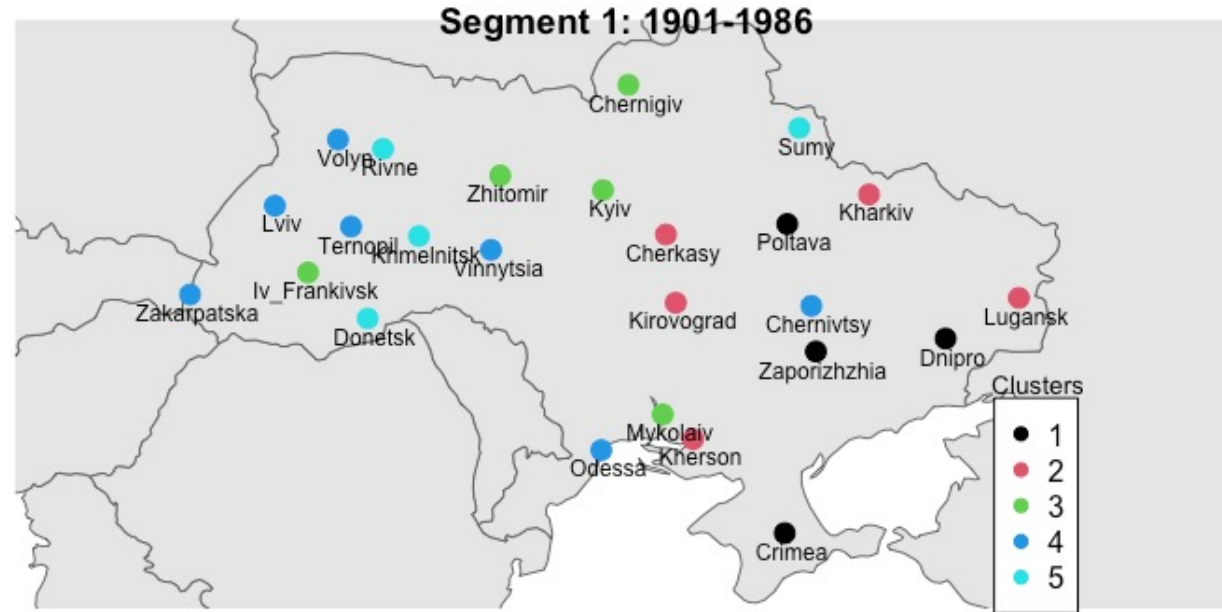# ET/P vs Aridity index plotted on the SOB curve
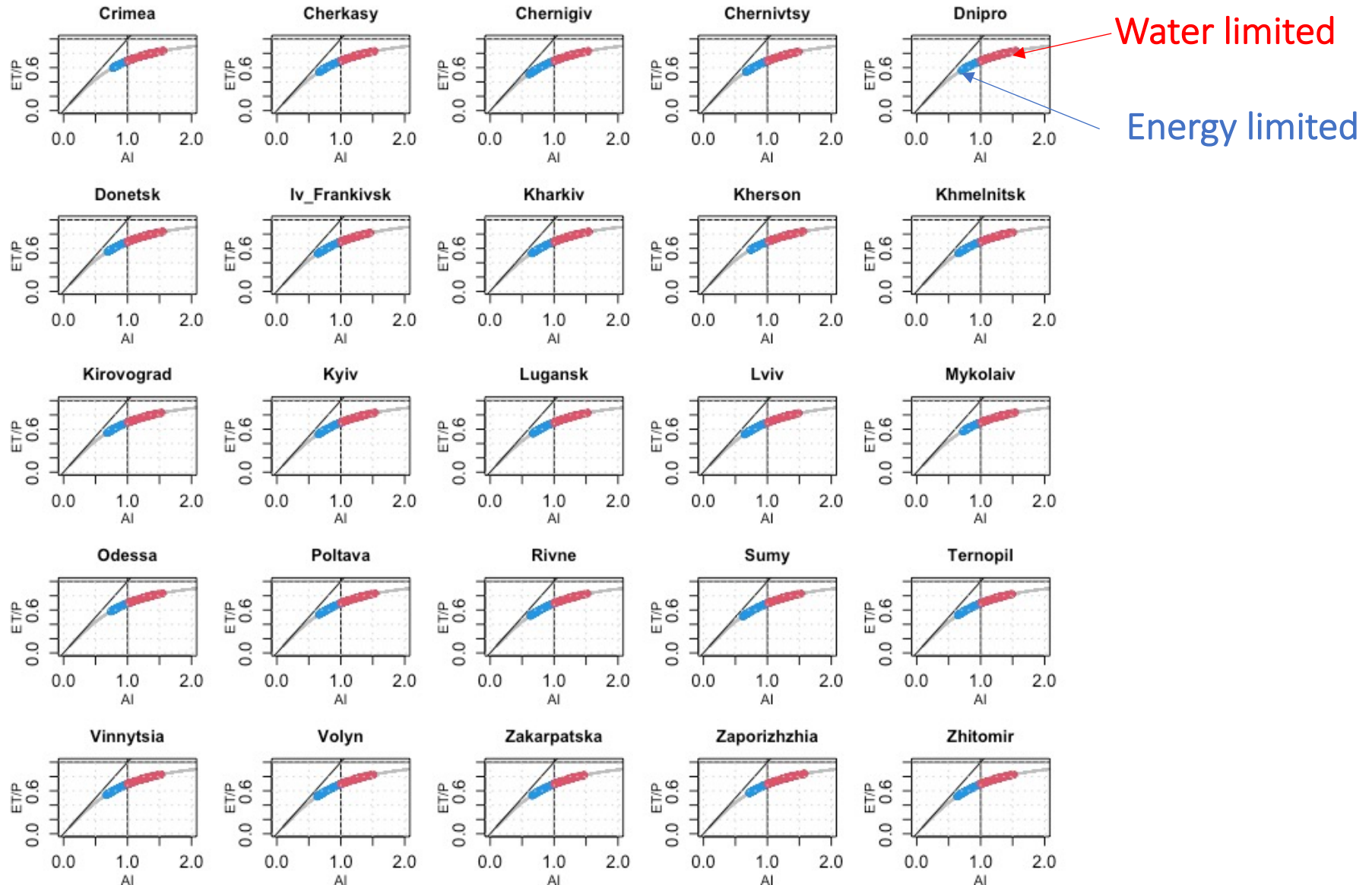
SOB -- Schreiber-Ol'dekop-Budyko curve

Infiltration/groundwater recharge+surface runoff decreased during the "hot" phase
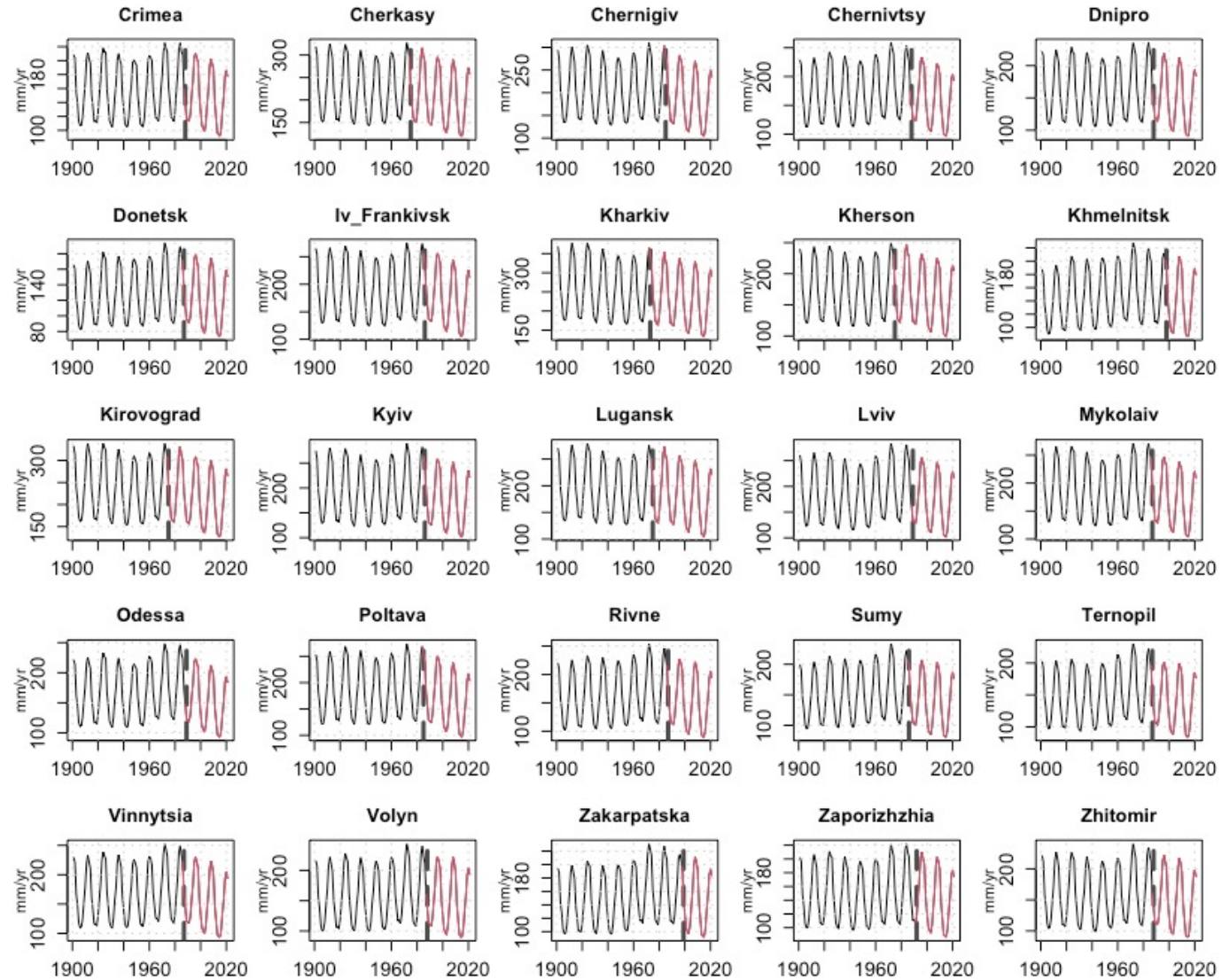
# Mapping/zonation of Ukraine based on SPEI

Conclusions

- Based on the statistical analysis of 25 regions of Ukraine, the country has been experiencing spatio-temporal changes of climatic conditions since the 1940s, with a drastic increase ('hot" phase) since the 1980s.
- Z-score and temporal gradient time series can be used as statistical tools to identify the temporal trends of climatic conditions of Ukraine.
- Clustering/zonation of the territory of Ukraine is different for the periods prior and during the 'hot' phase of the climatic changes, and it is different for temperature, precipitation and SPEI. The SPEI is an integrated climatic index to be used for the zonation and mapping of Ukraine.
- However, the obtained 2D spatio-temporal data are insufficient to explain the impact of climatic processes on land-atmosphere processes in Ukraine.

Examples of directions of future research

Hypothesis: an extension of the FLUXNET global network of eddy covariance towers over the territory of Ukraine will help construct reliable 3D climatic models and explain the impact of observed climatic changes on water cycle in Ukraine and surrounding European regions.

Compare meteorological parameters of Ukraine and other European coutries
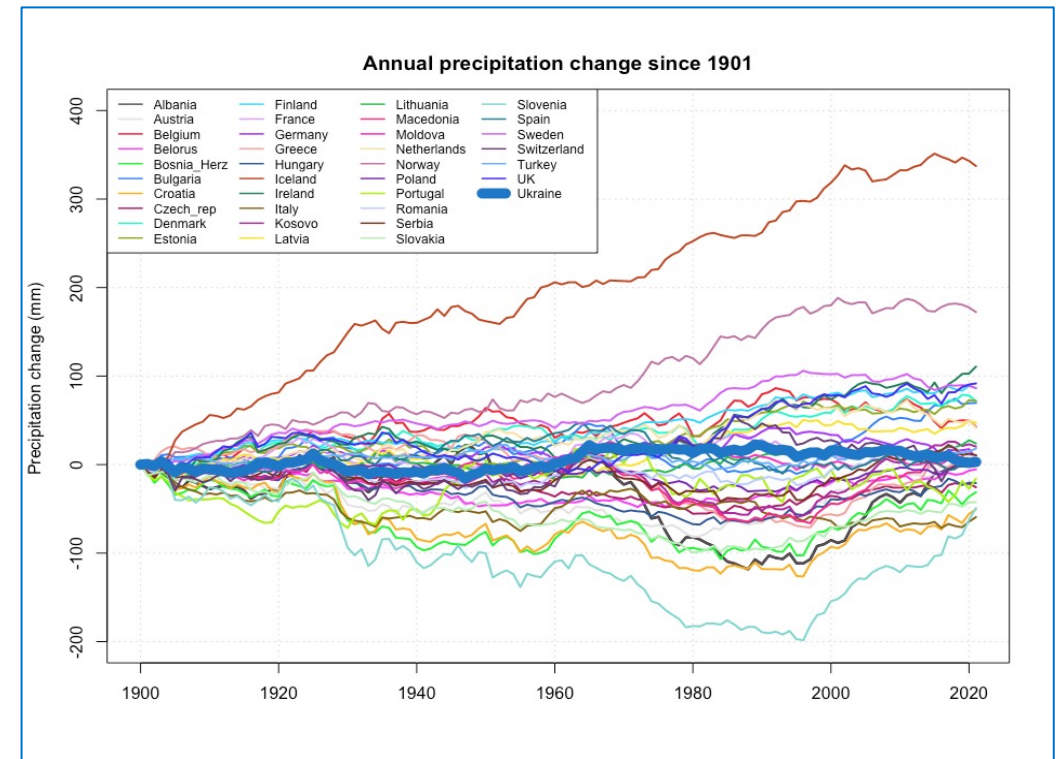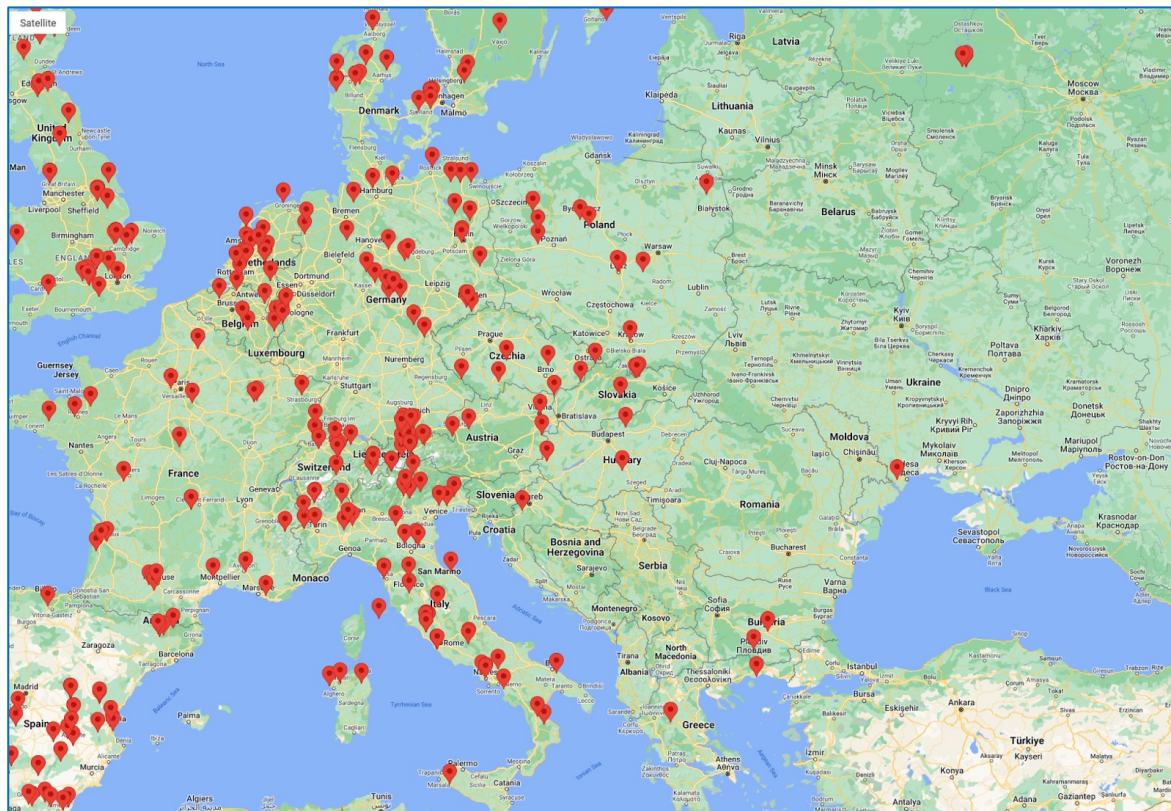
Examples of directions of future research

Compare meteorological parameters of Ukraine and Europe

Expand the European Eddy Covariance network of towers into Ukraine

Annual precipitation change since 1901