UPPER-AIR CLIMATE MONITORING: DATA SOURCES, TECHNOLOGICAL ASPECTS, SOME RESULTS

LAVROV A.S., STERIN A.M., KHOHLOVA A.V.

All-Russian Research Institute of Hydrometeorological Information - *World Data Centre*

STATE OF THE GLOBAL CLIMATE

WMO Statement on the state of the global climate in 2017:

"The years 2015, 2016 and 2017 were clearly warmer than any year prior to 2015, with all pre-2015 years being at least 0.15 °C cooler than 2015, 2016 or 2017."

2017 was the year with the highest documented economic losses associated with severe weather and climate events.

CLIMATE MONITORING

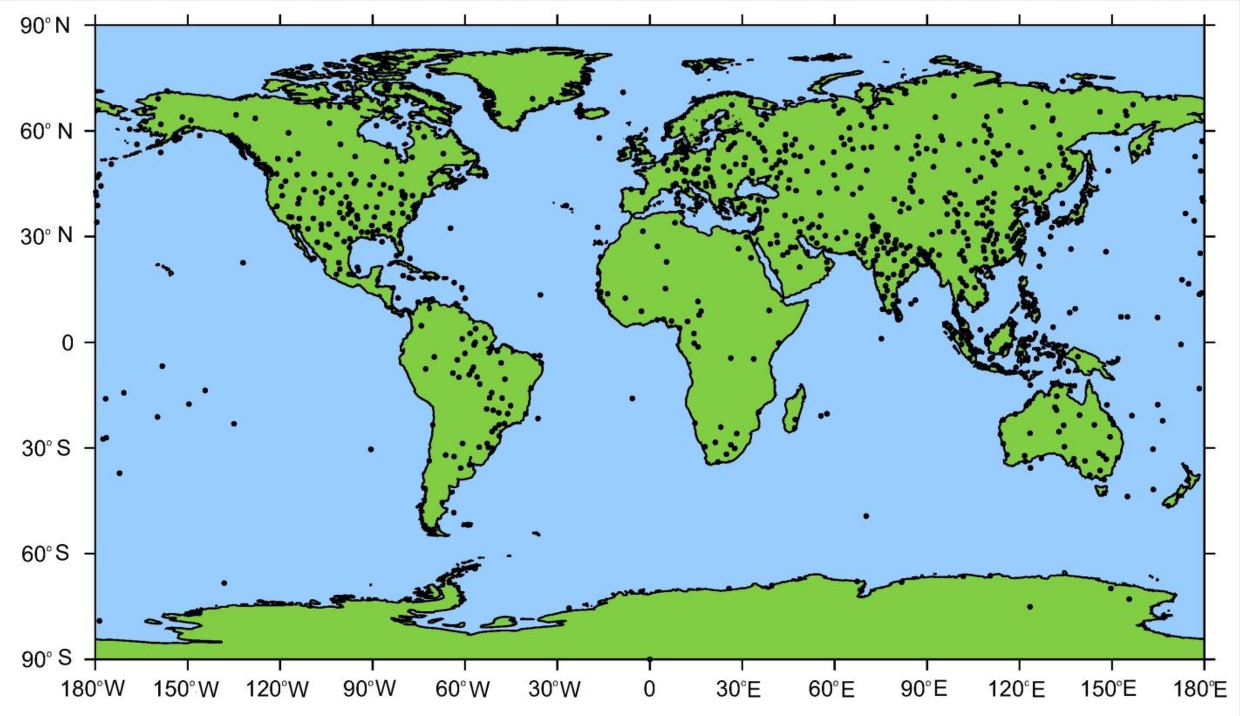
- Roshydromet annually publishes “A report on climate features on the territory of the Russian Federation“.
- Sections “temperature in free atmosphere" and “wind in free atmosphere" are prepared by RIHMI-WDC
- Source data - long-term global upper-air sounding data from more than 900 aerological stations. The dataset is updated monthly and contains data from 1958 to the present.

TEMPERATURE AND WIND MONITORING

- Receiving monthly statistical characteristics for each station.
- Temporal and spatial (vertical and horizontal) averaging.
- Analysis of temperature and wind in the analyzed year, evaluation of year's rank and of trends.
- Presentation of the results.

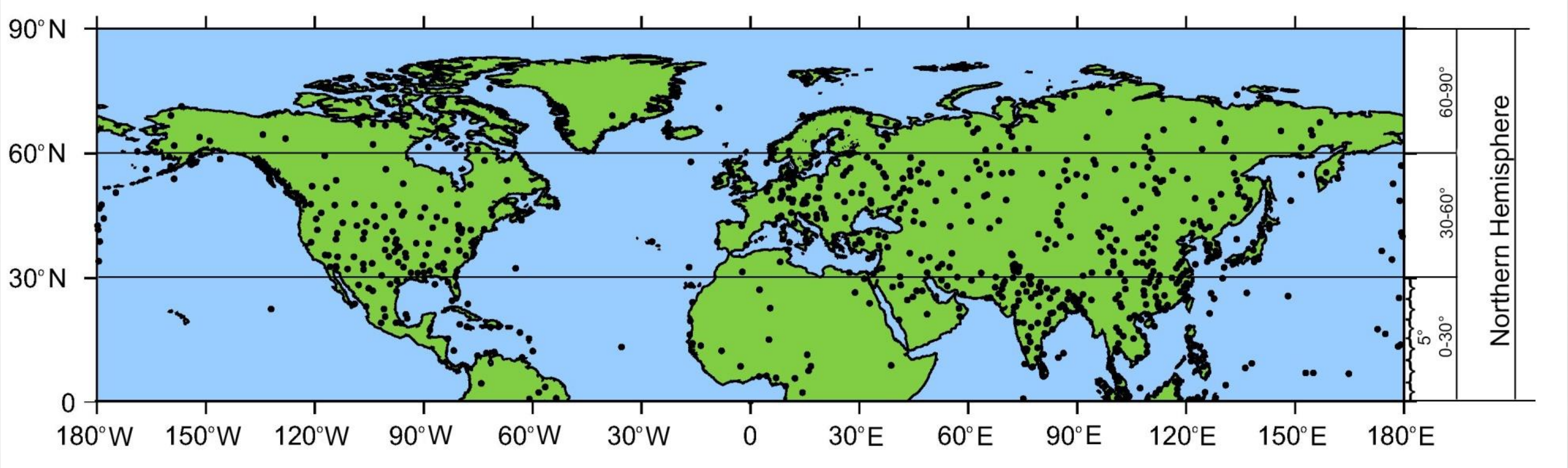
PROCESSING, ANALYSIS AND VISUALIZATION OF DATA

Network of upper-air stations.



- Calculations of the norms for 1981-2010 (standard pressure levels, averaged in vertical layers (850-300 and 100-50 hPa)) at individual stations.
- Calculations of monthly statistics for individual years.
- Calculations of monthly, seasonal and annual anomalies.

PROCESSING, ANALYSIS AND VISUALIZATION OF DATA



- Construction of latitudinal-vertical sections (for temperature).
- Construction of maps (for the territory of the Russian Federation, for wind characteristics).
- Analysis of trends.
- Comparative analysis of climatic characteristics with other independent regularly updated sources.

ESTIMATES OF THE TEMPERATURE REGIME ACCORDING TO THE DATA OF RIHMI-WDC

Estimation of the seasonal and annual temperature anomalies in the troposphere and lower stratosphere, 2017

SEASON	0-30 N.		30-60 N.		60-90 N.		Northern Hemisphere	
TROPOSPHERE, 850-300 hPa								
	ΔT_{2017}	-R	ΔT_{2017}	-R	ΔT_{2017}	-R	ΔT_{2017}	-R
WINTER	0,71	2	0,70	4	0,32	14	0,68	2
SPRING	0,27	11	0,59	5	-0,03	28	0,44	5
SUMMER	0,37	3	0,56	5	0,27	18	0,48	3
AUTUMN	0,79	1	0,47	7	0,41	11	0,57	2
YEAR	0,50	3	0,54	3	0,37	11	0,52	3
LOWER STRATOSPHERE, 100-50 hPa								
	ΔT_{2017}	R	ΔT_{2017}	R	ΔT_{2017}	R	ΔT_{2017}	R
WINTER	-2,29	1	-1,37	3	-0,42	24	-1,61	1
SPRING	-1,33	3	-1,19	4	-0,73	11	-1,20	2
SUMMER	-1,11	5	-0,83	5	-0,92	1	-0,92	3
AUTUMN	-1,83	3	-0,60	8	-0,38	9	-0,95	4

ΔT_{2017} – anomaly; R – rank in the row of the coldest (warmest) years

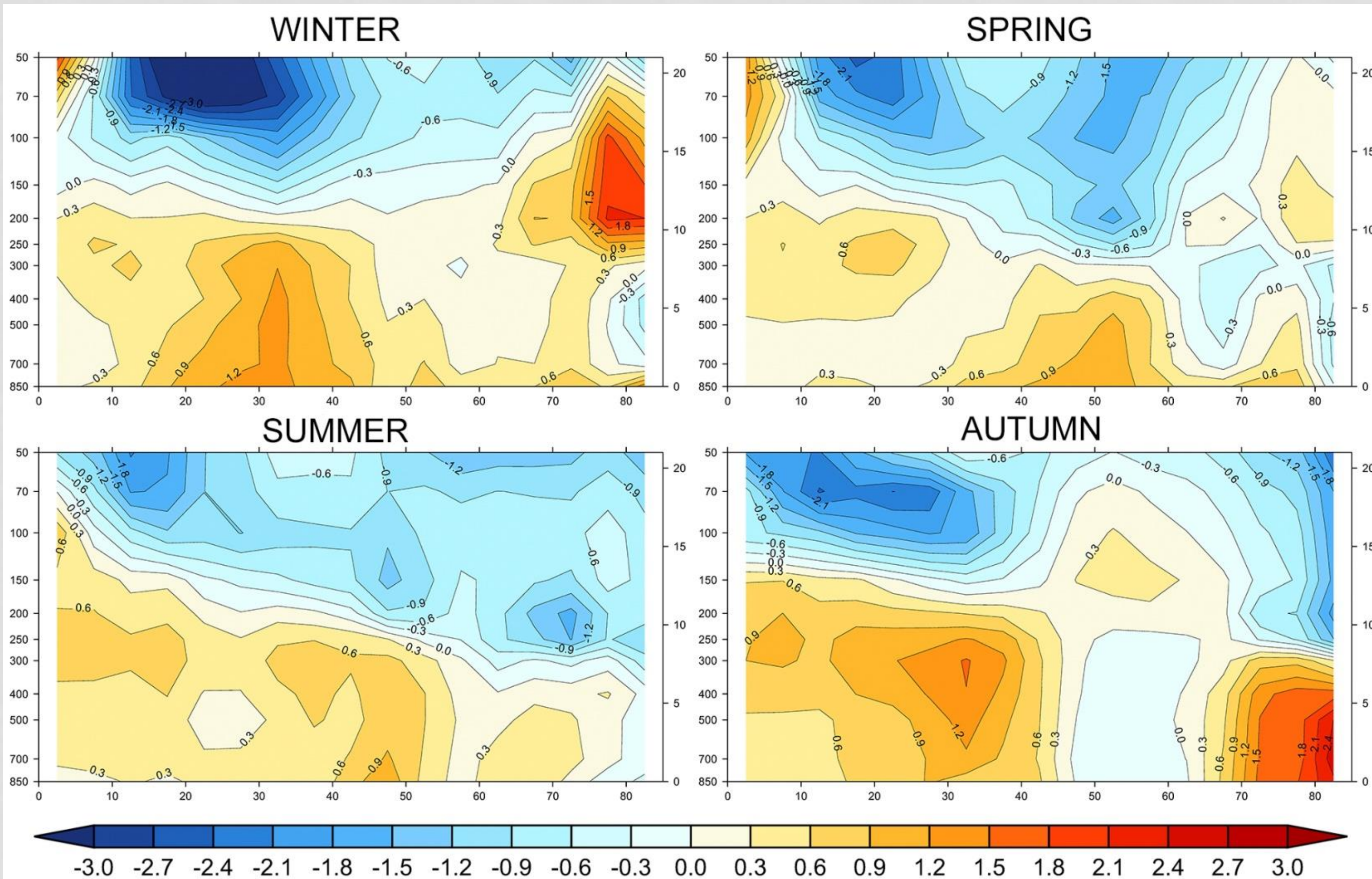
ESTIMATES OF THE TEMPERATURE REGIME ACCORDING TO THE DATA OF RIHMI-WDC

Estimation of the linear trend of temperature in the troposphere and lower stratosphere, 2017.

SEASON	0-30 N.		30-60 N.		60-90 N.		Northern Hemisphere	
	b	D	b	D	b	D	B	D
TROPOSPHERE, 850-300 hPa								
WINTER	0,18	28	0,11	7	0,16	22	0,14	19
SPRING	0,09	10	0,20	35	0,17	16	0,16	36
SUMMER	0,06	8	0,22	36	0,23	30	0,17	34
AUTUMN	0,13	19	0,22	39	0,24	30	0,20	45
YEAR	0,12	23	0,19	44	0,20	39	0,17	44
LOWER STRATOSPHERE, 100-50 hPa								
WINTER	-0,66	45	-0,33	19	-0,08	0	-0,41	38
SPRING	-0,55	53	-0,38	38	-0,35	11	-0,43	55
SUMMER	-0,52	48	-0,37	42	-0,24	32	-0,40	49
AUTUMN	-0,60	43	-0,35	47	-0,20	30	-0,41	53

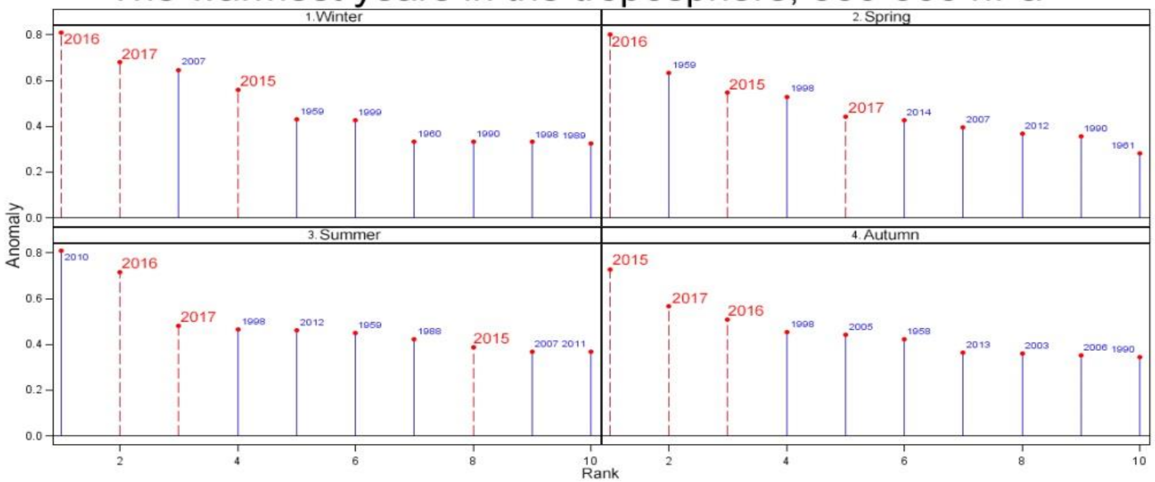
ESTIMATES OF THE TEMPERATURE REGIME ACCORDING TO THE DATA OF RIHMI-WDC

Latitudinal-vertical structure of seasonal upper-air temperature anomalies in 2017.

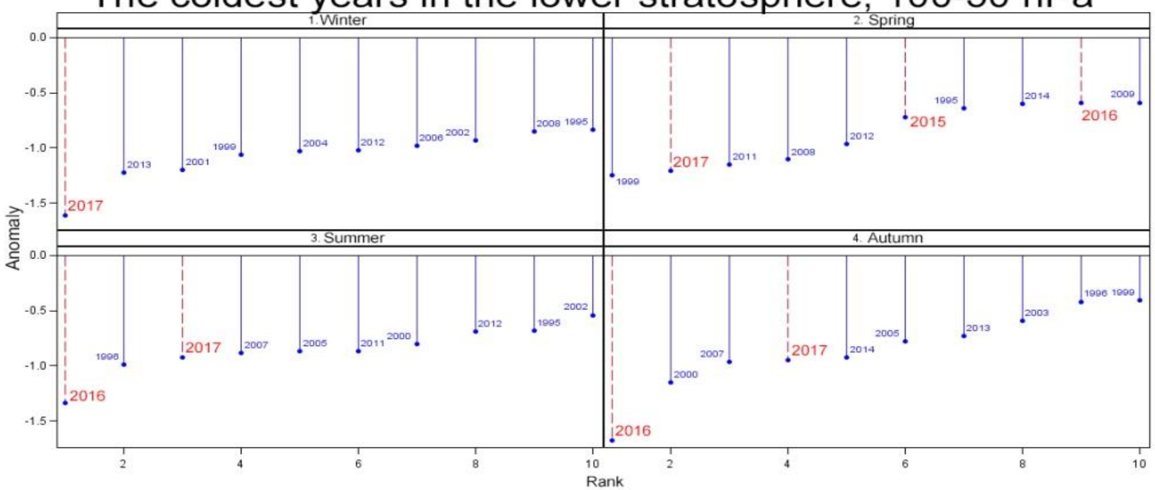


ESTIMATES OF THE TEMPERATURE REGIME ACCORDING TO THE DATA OF RIHMI-WDC

The warmest years in the troposphere, 850-300 hPa



The coldest years in the lower stratosphere, 100-50 hPa



The ranks of the most significant seasonal temperature anomalies in the free atmosphere of the northern hemisphere during the period 1958-2017.

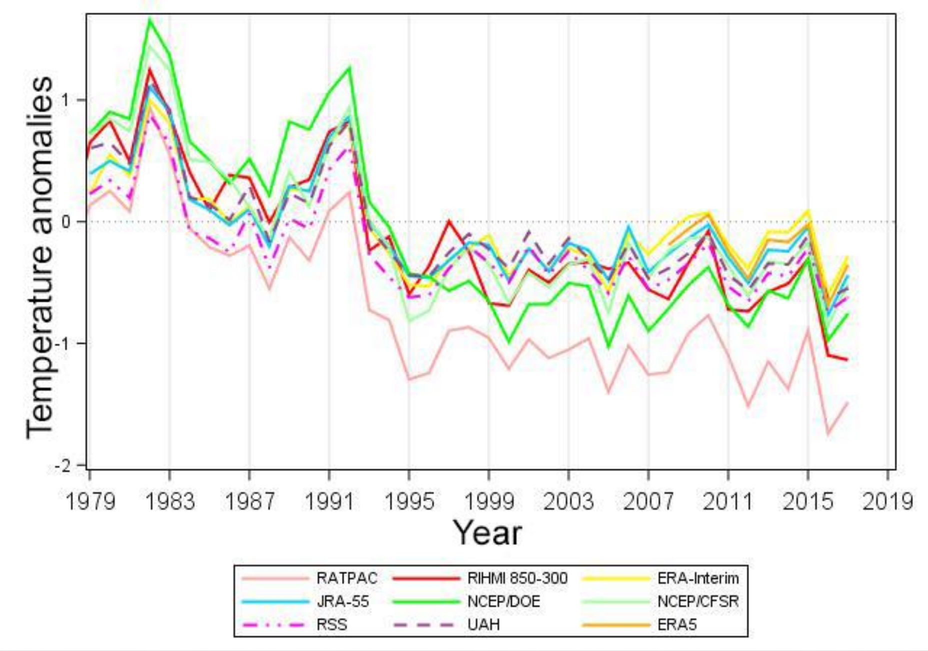
Highlighted in red 2015, 2016 and 2017.

DATA SOURCES

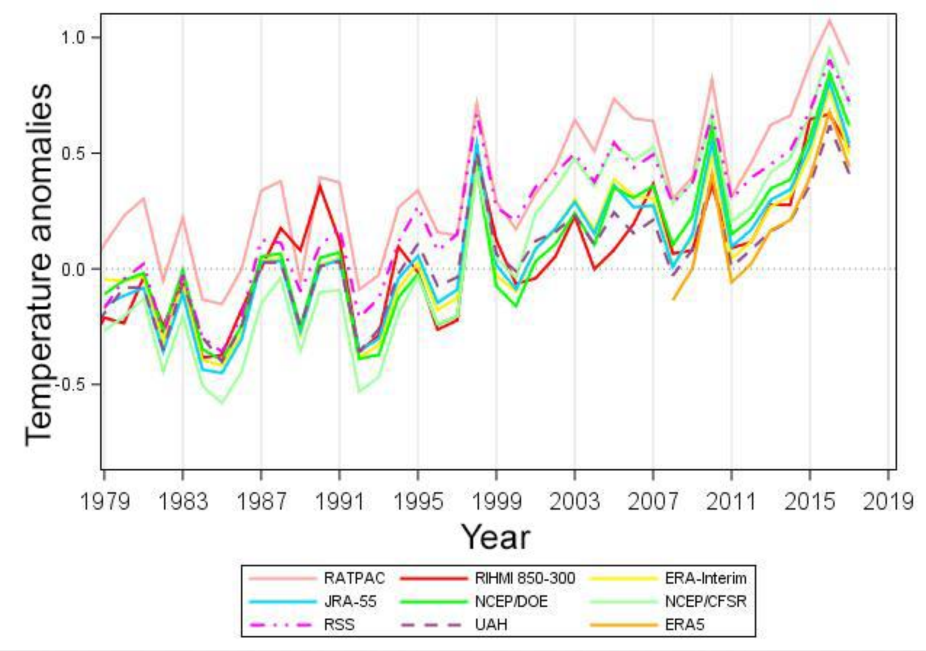
- **Radiosonde observations:**
  - **RATPAC** (National Climatic Data Center - https://www.ncdc.noaa.gov/);
  - **RIHMI** (All-Russian Research Institute of Hydrometeorological Information - http://meteo.ru/);
- **Satellite observations:**
  - **RSS** (Remote Sensing Systems, Inc. - http://www.remss.com/);
  - **UAH** (University of Alabama, Huntsville, USA - https://www.nsstc.uah.edu/);
- **Reanalysis:**
  - **ERA-Interim** (The European Centre for Medium-Range Weather Forecasts - https://www.ecmwf.int/);
  - **ERA5** (The European Centre for Medium-Range Weather Forecasts - https://www.ecmwf.int/);
  - **JRA-55** (Japan Meteorological Agency - http://jra.kishou.go.jp/);
  - **NCEP/DOE** (National Centers for Environmental Prediction - http://www.ncep.noaa.gov/);
  - **NCEP/CFSR** (National Centers for Environmental Prediction - http://www.ncep.noaa.gov/);

COMPARISON OF DIFFERENT DATA SOURCES

Lower stratosphere



Troposphere



The series of annual temperature anomalies in the northern hemisphere

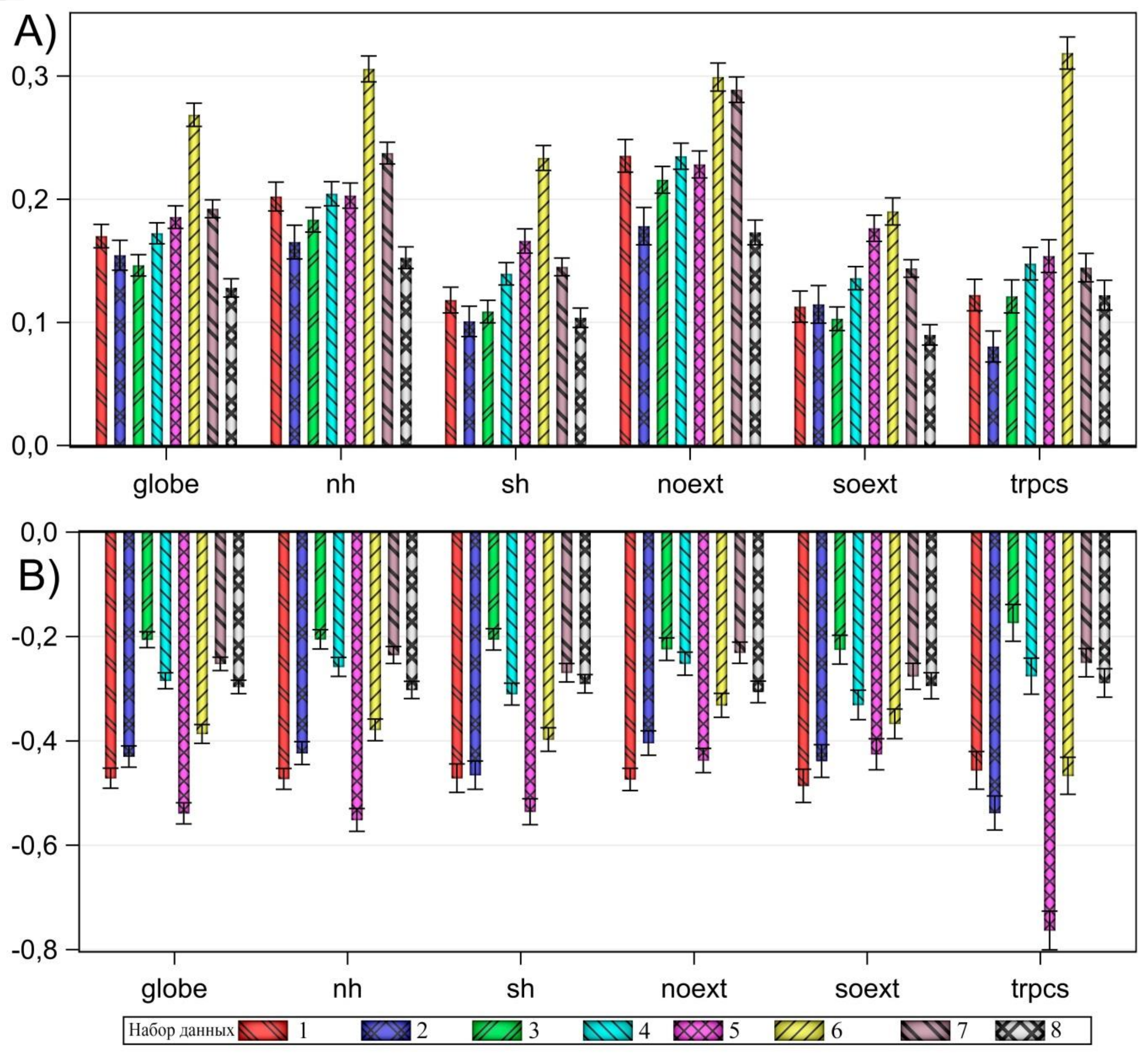
PEARSON BIVARIATE CORRELATION

	RATPAC	RIHMI	ERA-Interim	JRA-55	NCEP/DOE	NCEP/CFSR	RSS	UAH
Troposphere								
RATPAC	1	0,68	0,88	0,87	0,87	0,84	0,84	0,82
RIHMI	0,80	1	0,67	0,67	0,67	0,61	0,63	0,64
ERA-Interim	0,98	0,76	1	0,99	0,97	0,95	0,92	0,92
JRA-55	0,97	0,80	0,99	1	0,96	0,93	0,93	0,94
NCEP/DOE	0,74	0,63	0,76	0,74	1	0,93	0,86	0,88
NCEP/CFSR	0,91	0,69	0,95	0,91	0,71	1	0,88	0,87
RSS	0,91	0,74	0,93	0,95	0,66	0,90	1	0,95
UAH	0,92	0,76	0,94	0,97	0,68	0,87	0,98	1
Lower stratosphere								
RATPAC	1	0,80	0,88	0,88	0,83	0,88	0,86	0,87
RIHMI	0,86	1	0,70	0,73	0,68	0,69	0,72	0,73
ERA-Interim	0,96	0,85	1	0,98	0,90	0,96	0,93	0,94
JRA-55	0,95	0,87	0,98	1	0,90	0,95	0,95	0,95
NCEP/DOE	0,71	0,64	0,72	0,72	1	0,89	0,86	0,87
NCEP/CFSR	0,95	0,82	0,97	0,94	0,69	1	0,90	0,92
RSS	0,93	0,86	0,93	0,93	0,66	0,89	1	0,99
UAH	0,94	0,87	0,94	0,94	0,68	0,91	0,99	1

Yellow - monthly anomalies

Blue - annual anomalies

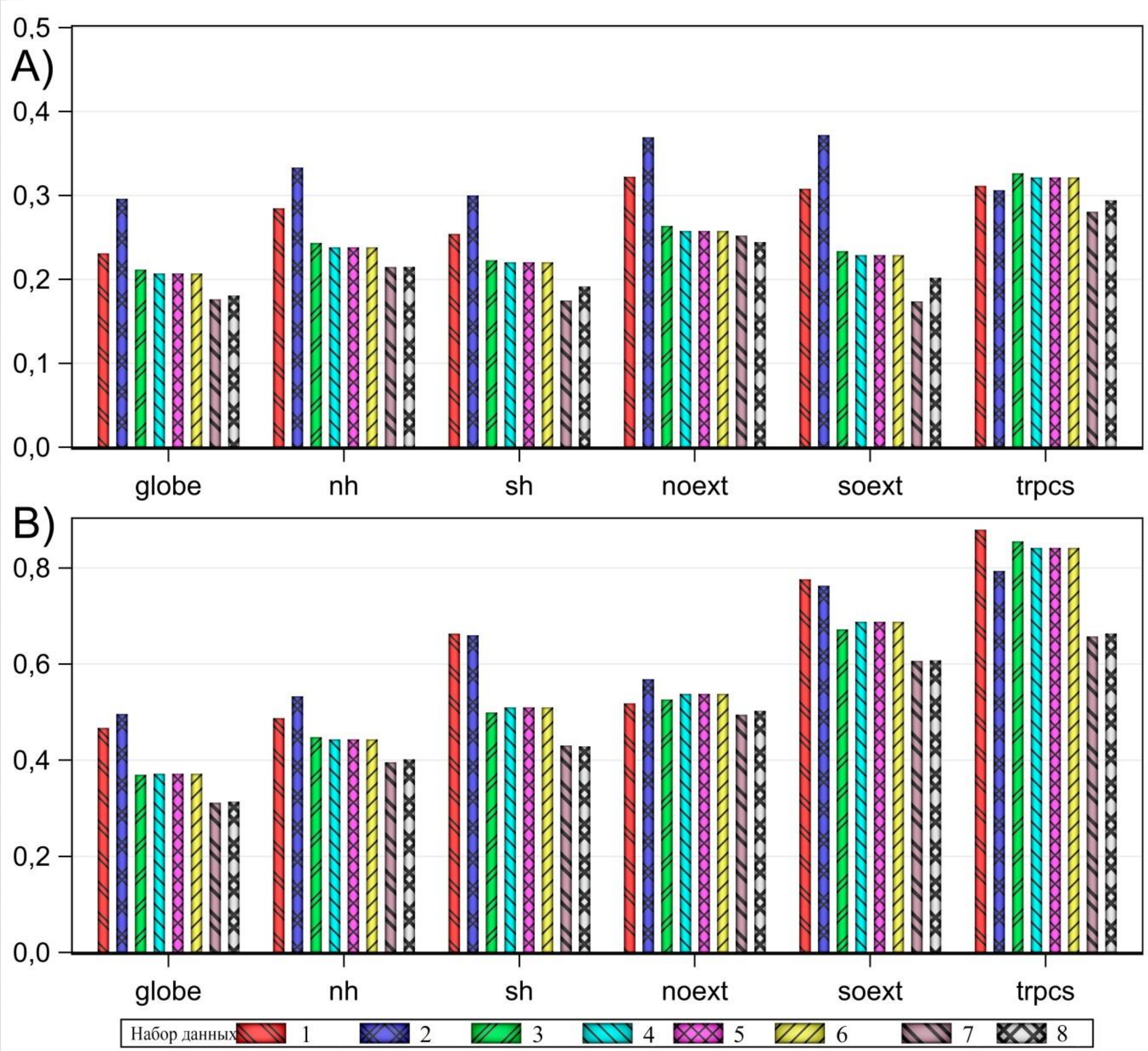
TRENDS ESTIMATES



Trends of the series of temperature anomalies (°C in 10 years) in the troposphere (A) and in the lower stratosphere (B) for the period 1979-2017.

1 - RATPAC;
2 - RIHMI;
3 - ERA-Interim;
4 - JRA-55;
5 - NCEP/DOE;
6 - NCEP/CFSR;
7 - RSS;
8 - UAH

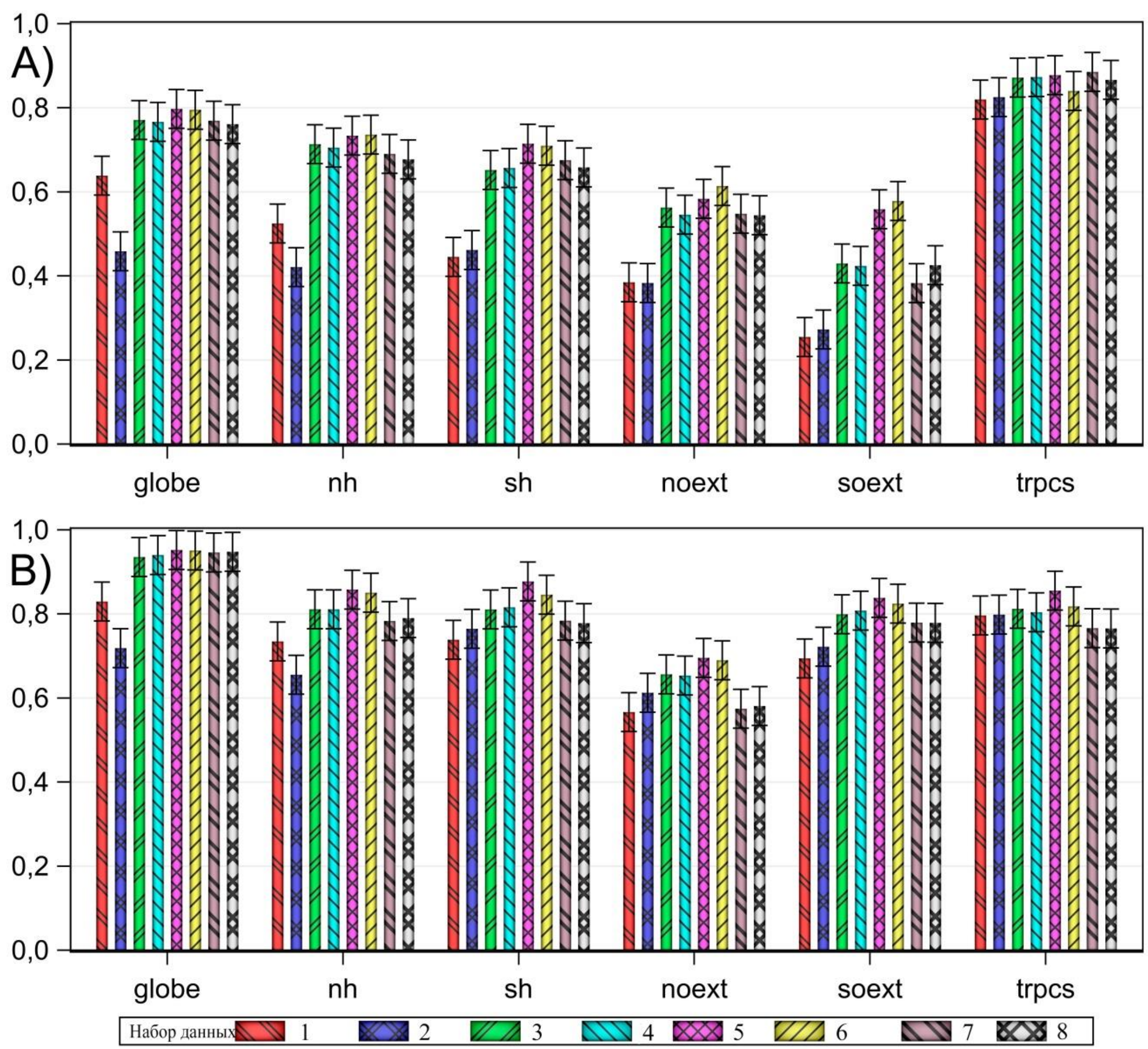
STANDARD DEVIATIONS



Standard deviations of the series of temperature anomalies (°C) after the removal of trends in the troposphere (A) and in the lower stratosphere (B) for the period 1979-2017.

1 - RATPAC;
2 - RIHMI;
3 - ERA-Interim;
4 - JRA-55;
5 - NCEP/DOE;
6 - NCEP/CFSR;
7 - RSS;
8 - UAH

AUTOCORRELATIONS



Autocorrelations with a lag of one month of series of temperature anomalies (° C) after the removal of trends in the troposphere (A) and in the lower stratosphere (B) for the period 1979-2017.

1 - RATPAC;
2 - RIHMI;
3 - ERA-Interim;
4 - JRA-55;
5 - NCEP/DOE;
6 - NCEP/CFSR;
7 - RSS;
8 - UAH

5 WARMEST YEARS IN THE TROPOSPHERE

Rank	Globe		NH		Noext		SH		Trpcs	
	T	Year	T	Year	T	Year	T	Year	T	Year
Ratpac										
1	**0,97**	**2016**	**1,07**	**2016**	**1,08**	**2016**	**0,78**	**2016**	**1,03**	**2016**
2	**0,81**	**2017**	**0,89**	**2015**	**0,95**	**2017**	0,69	1998	0,76	1998
3	**0,77**	**2015**	**0,88**	**2017**	**0,94**	**2015**	**0,69**	**2017**	0,76	2010
4	0,73	2010	0,82	2010	0,83	2010	0,59	2010	**0,71**	**2015**
5	0,70	1998	0,73	2005	0,74	2005	**0,53**	**2015**	**0,70**	**2017**
Rihmi										
1	**0,66**	**2016**	**0,65**	**2016**	**0,69**	**2015**	**0,72**	**2016**	**0,72**	**2016**
2	**0,59**	**2015**	**0,65**	**2015**	**0,64**	**2016**	**0,52**	**2017**	0,50	1998
3	**0,52**	**2017**	**0,52**	**2017**	**0,54**	**2017**	0,49	1998	0,46	2010
4	0,50	1998	0,50	1998	0,51	1959	0,40	2010	**0,42**	**2017**
5	0,37	2010	0,44	1959	0,50	1998	0,29	2014	0,37	1987
NCEP/DOE										
1	**0,78**	**2016**	**0,85**	**2016**	**0,85**	**2016**	**0,72**	**2016**	**0,84**	**2016**
2	0,60	2010	**0,62**	**2017**	**0,66**	**2017**	0,58	2010	0,59	2010
3	**0,59**	**2017**	0,62	2010	0,63	2010	**0,55**	**2017**	**0,55**	**2015**
4	**0,49**	**2015**	**0,57**	**2015**	**0,57**	**2015**	**0,41**	**2015**	**0,54**	**2017**
5	0,39	1998	0,44	1998	0,41	2014	0,38	2014	0,53	1998

5 WARMEST YEARS IN THE TROPOSPHERE

Rank	Globe		NH		Noext		SH		Trpcs	
	T	Year	T	Year	T	Year	T	Year	T	Year
NCEP/CFSR										
1	**0,84**	**2016**	**1,07**	**2016**	**0,93**	**2016**	**0,74**	**2016**	**1,00**	**2016**
2	**0,69**	**2017**	**0,89**	**2015**	**0,71**	**2017**	**0,67**	**2017**	0,78	2010
3	0,62	2010	**0,88**	**2017**	**0,65**	**2015**	0,57	2010	**0,72**	**2017**
4	**0,56**	**2015**	0,82	2010	0,62	2010	**0,46**	**2015**	**0,72**	**2015**
5	0,48	2007	0,73	2005	0,55	2007	0,44	2007	0,60	2005
ERA-Interim										
1	**0,66**	**2016**	**0,78**	**2016**	**0,77**	**2016**	**0,56**	**2016**	**0,78**	**2016**
2	**0,47**	**2017**	**0,50**	**2015**	**0,53**	**2017**	**0,44**	**2017**	0,60	1998
3	0,43	2010	**0,50**	**2017**	0,52	2010	0,37	2010	**0,50**	**2015**
4	0,42	1998	0,50	2010	**0,50**	**2015**	0,36	1998	0,45	2010
5	**0,38**	**2015**	0,48	1998	0,42	1998	**0,27**	**2015**	**0,43**	**2017**
JRA-55										
1	**0,70**	**2016**	**0,81**	**2016**	**0,82**	**2016**	**0,59**	**2016**	**0,79**	**2016**
2	**0,51**	**2017**	0,55	2010	**0,60**	**2017**	**0,48**	**2017**	0,69	1998
3	0,50	1998	**0,54**	**2017**	0,58	2010	0,47	1998	**0,51**	**2015**
4	0,49	2010	0,54	1998	**0,54**	**2015**	0,43	2010	0,50	2010
5	**0,42**	**2015**	**0,53**	**2015**	0,47	1998	**0,31**	**2015**	**0,45**	**2017**

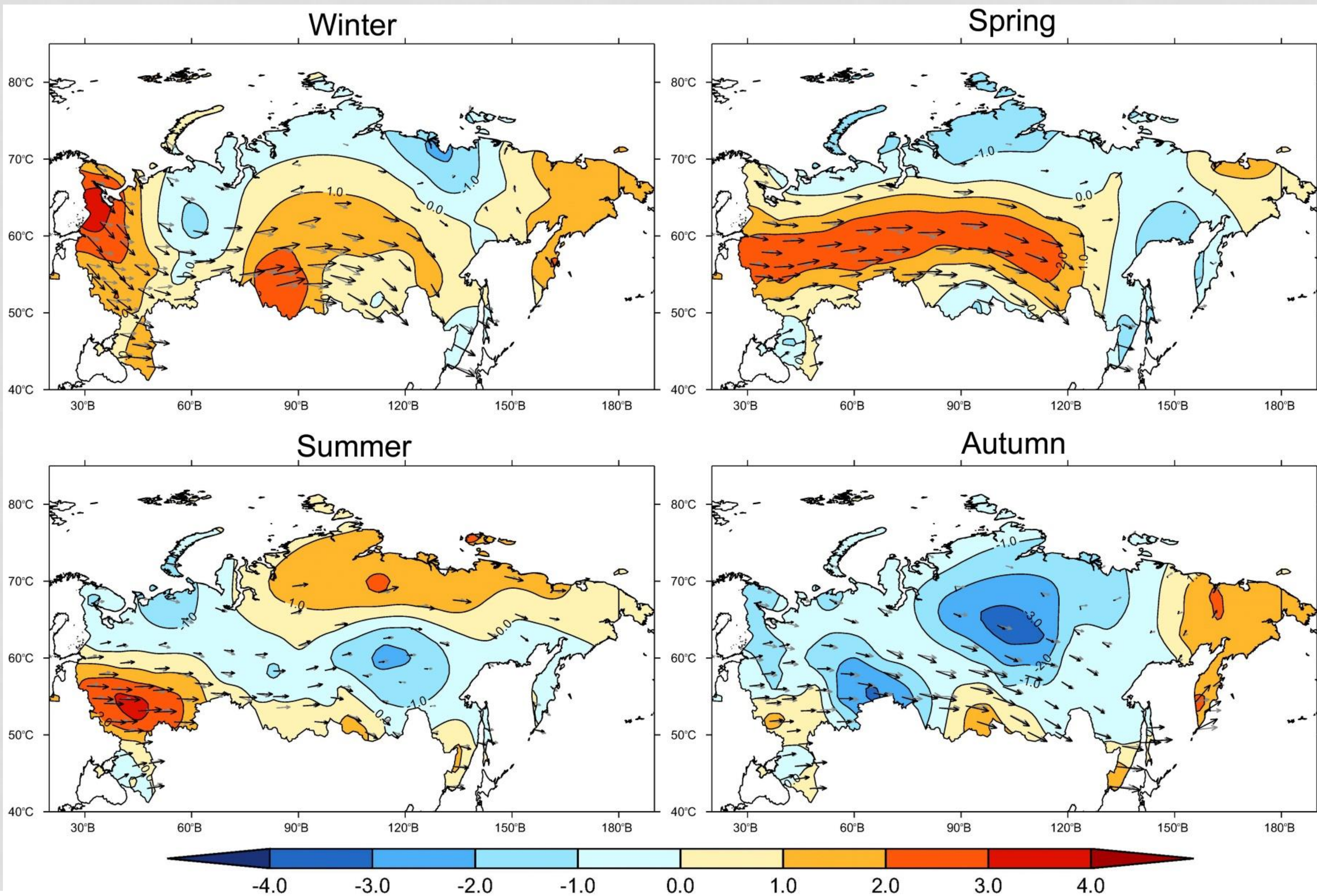
5 WARMEST YEARS IN THE TROPOSPHERE

Rank	Globe		NH		Noext		SH		Trpcs	
	T	Year	T	Year	T	Year	T	Year	T	Year
Rss										
1	**0,75**	**2016**	**0,90**	**2016**	**1,00**	**2016**	**0,59**	**2016**	**0,73**	**2016**
2	**0,64**	**2017**	**0,72**	**2017**	**0,87**	**2017**	**0,54**	**2017**	0,68	1998
3	0,58	1998	**0,69**	**2015**	**0,79**	**2015**	0,49	2010	**0,50**	**2015**
4	0,58	2010	0,67	1998	0,76	2010	0,48	1998	0,49	2010
5	**0,55**	**2015**	0,66	2010	0,68	1998	**0,41**	**2015**	**0,46**	**2017**
Uah										
1	**0,51**	**2016**	**0,62**	**2016**	**0,63**	**2016**	0,46	1998	0,68	1998
2	0,48	1998	0,51	1998	**0,47**	**2017**	**0,41**	**2016**	**0,62**	**2016**
3	**0,38**	**2017**	**0,41**	**2017**	0,42	2010	**0,34**	**2017**	0,36	2010
4	0,34	2010	0,40	2010	0,42	1998	0,27	2002	**0,35**	**2015**
5	**0,27**	**2015**	**0,36**	**2015**	**0,38**	**2015**	0,27	2010	**0,31**	**2017**

The 5 warmest years in the troposphere: 1998, 2010, 2015, 2016, 2017

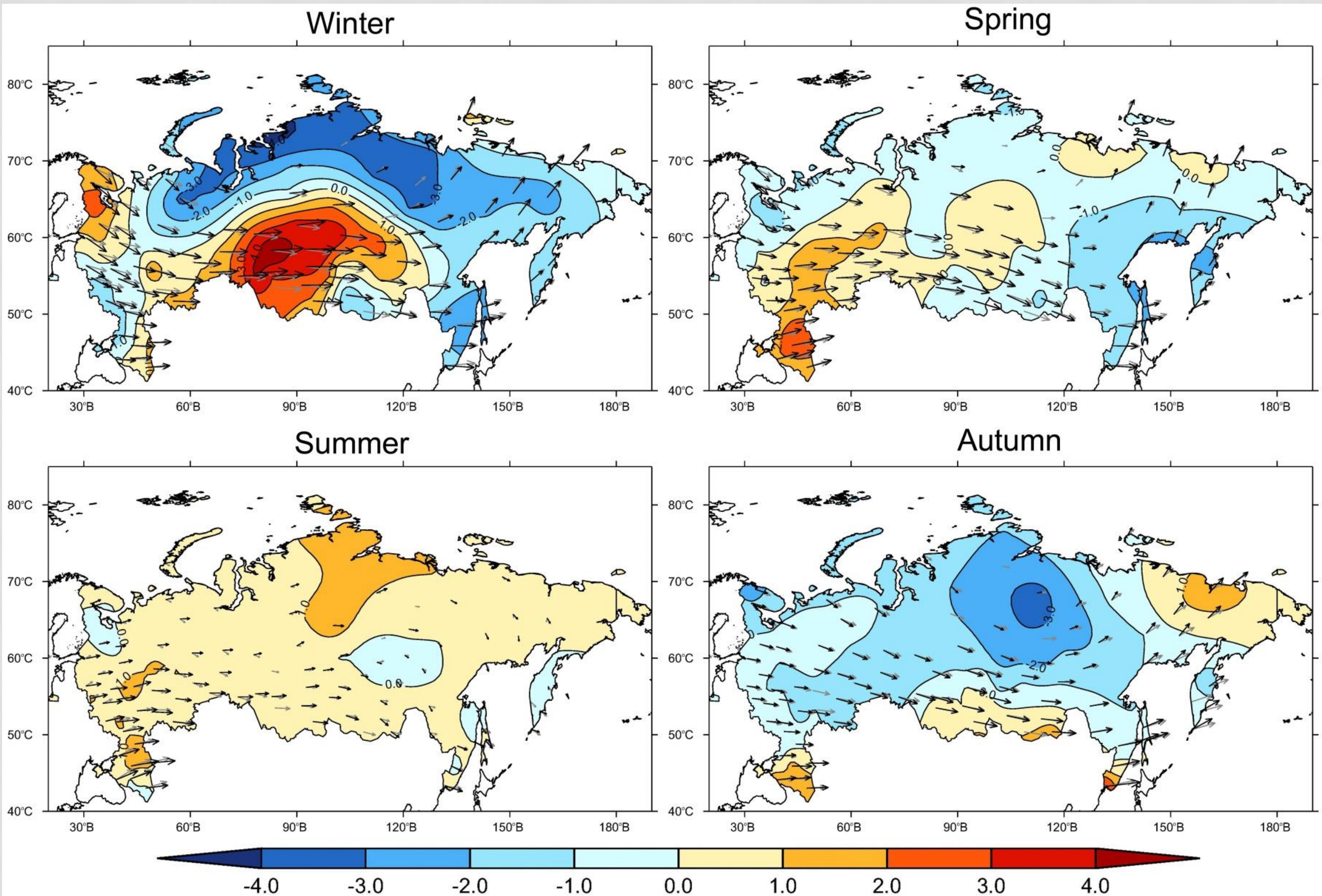
ANALYSIS OF WIND REGIME ESTIMATES

Anomalies of wind speed and direction in the troposphere in 2017



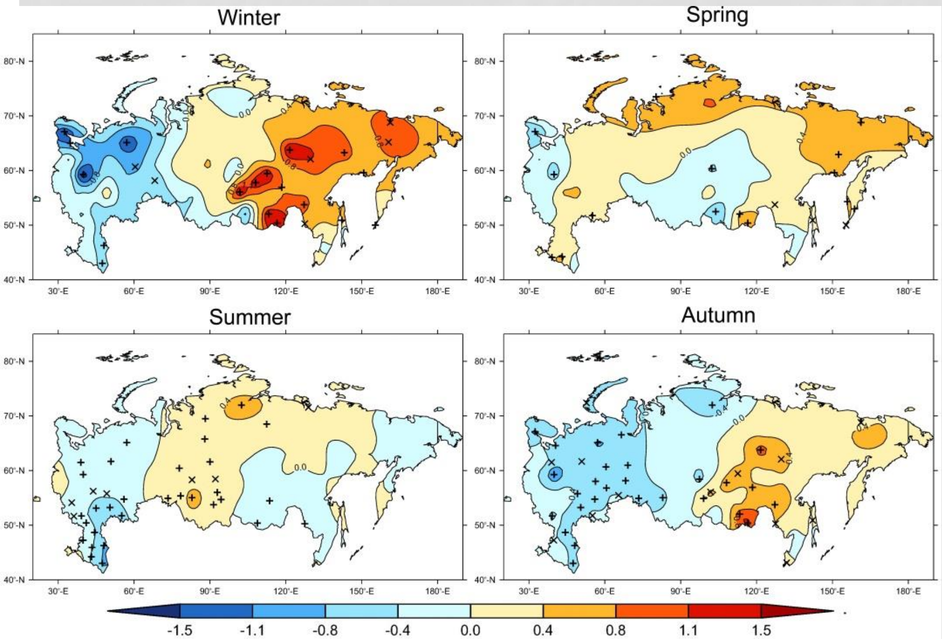
ANALYSIS OF WIND REGIME ESTIMATES

Anomalies of wind speed and direction in the stratosphere in 2017

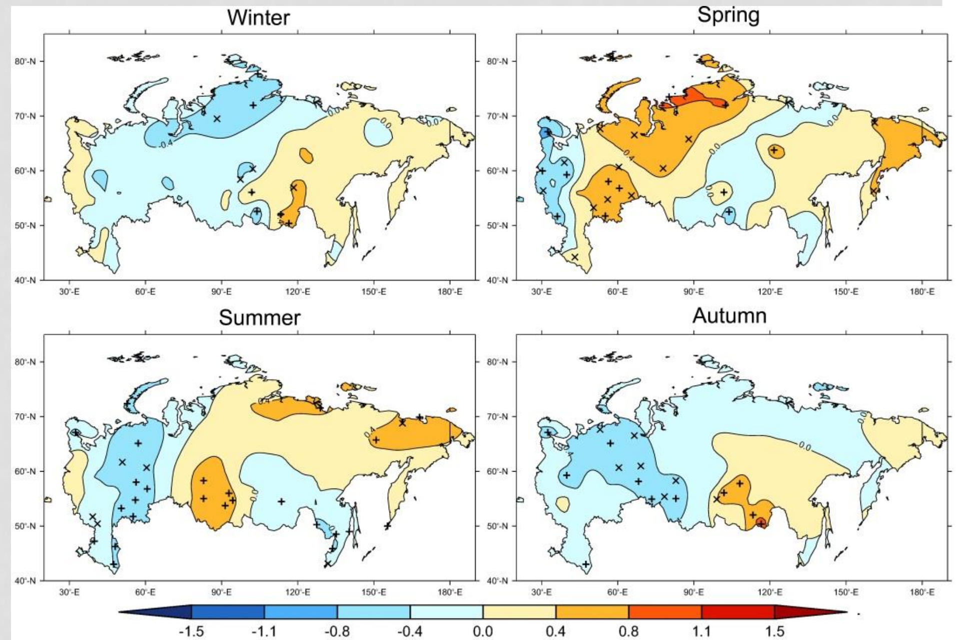


TRENDS OF THE MERIDIONAL WIND

Lower stratosphere



Troposphere

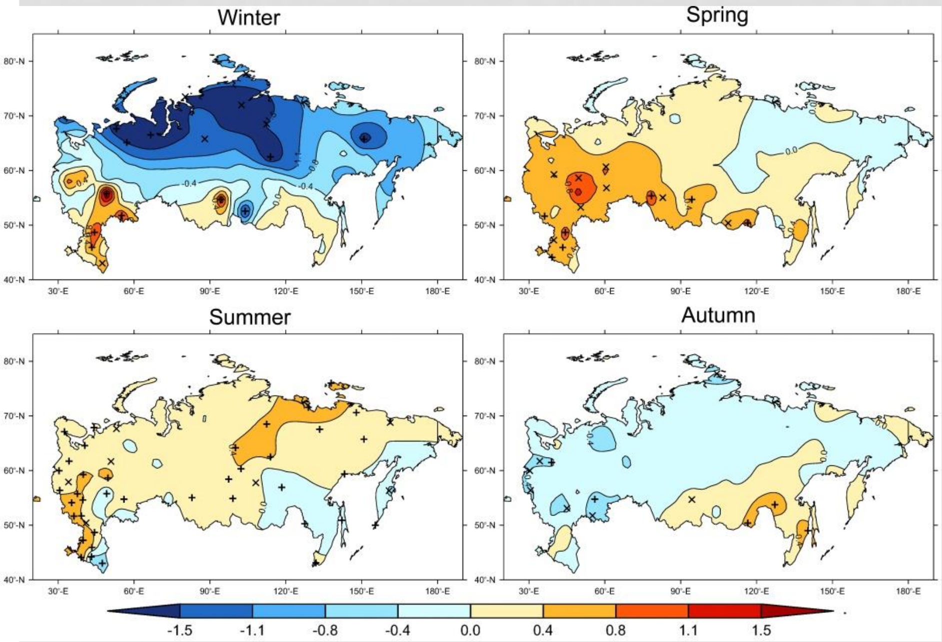


"+" - statistically significant trends with a probability of 0.9

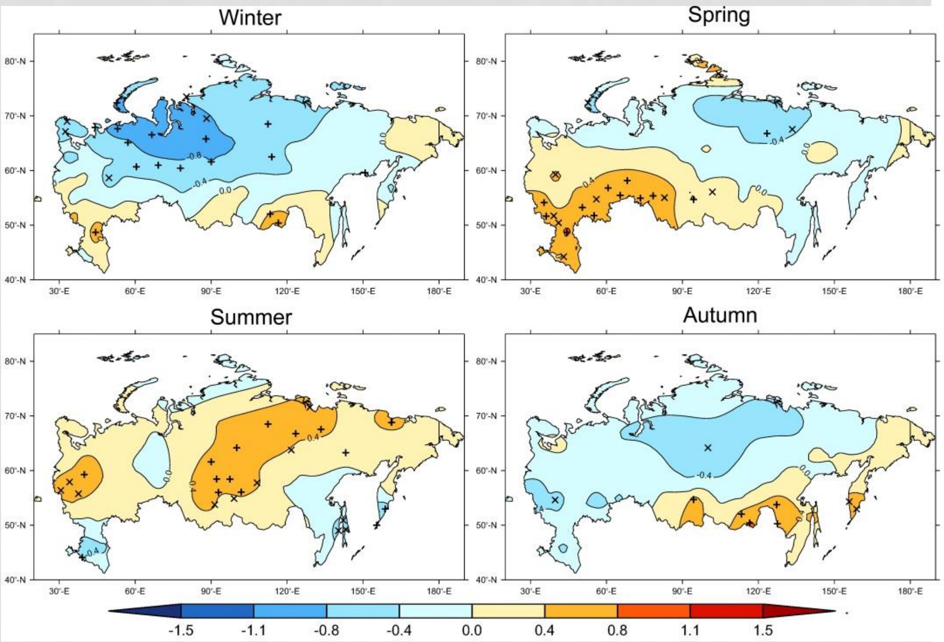
"x" - statistically significant trends with a probability of 0.85

TRENDS OF THE ZONAL WIND

Lower stratosphere



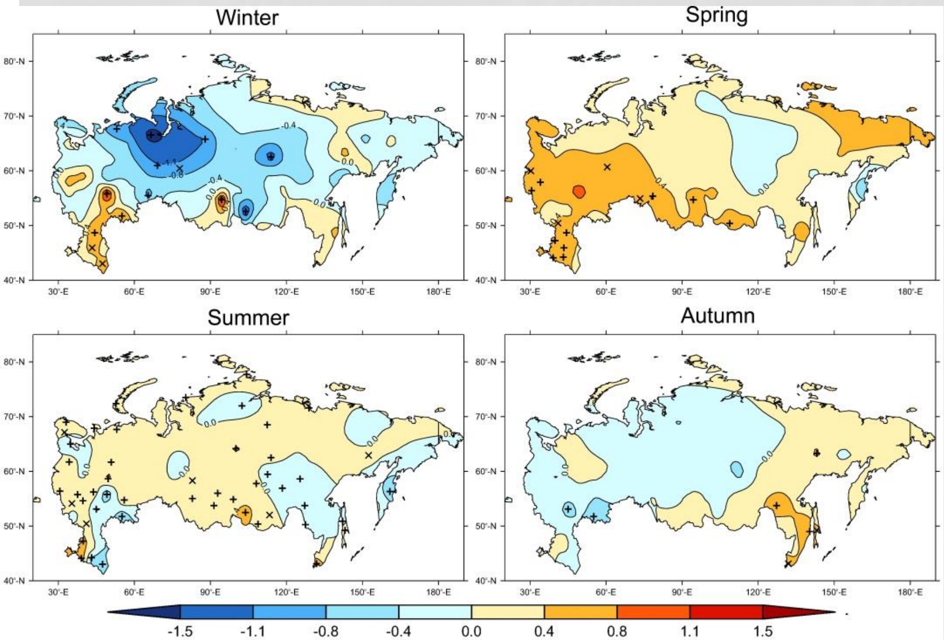
Troposphere



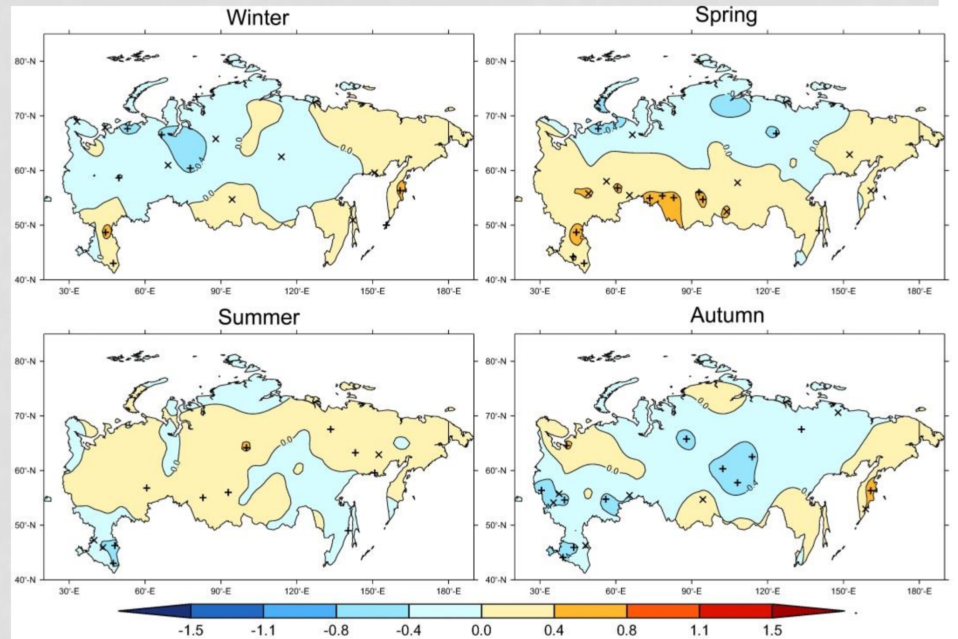
"+" - statistically significant trends with a probability of 0.9
"x" - statistically significant trends with a probability of 0.85

TRENDS OF THE WIND SPEED

Lower stratosphere



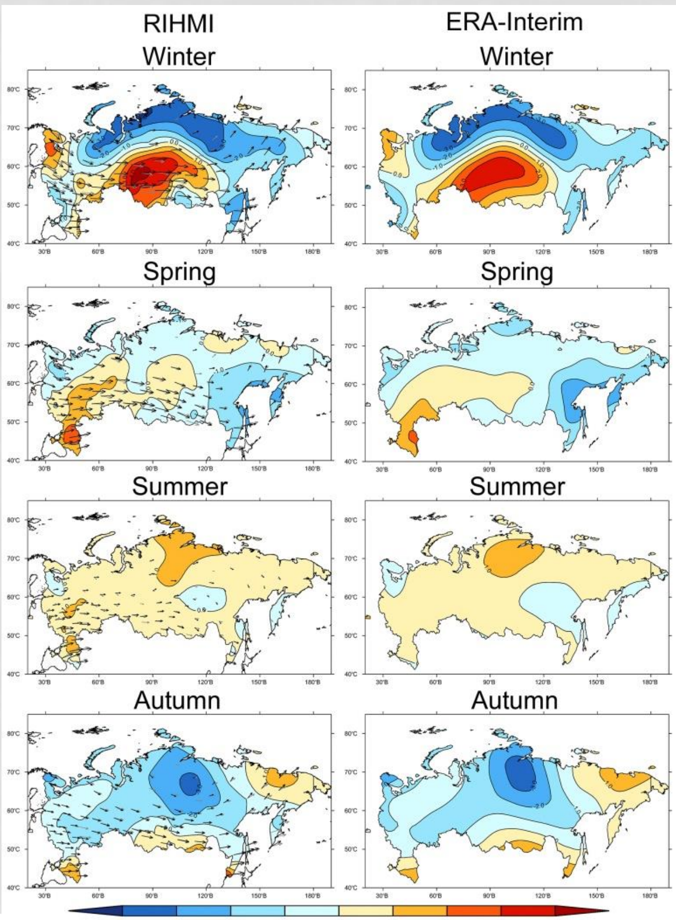
Troposphere



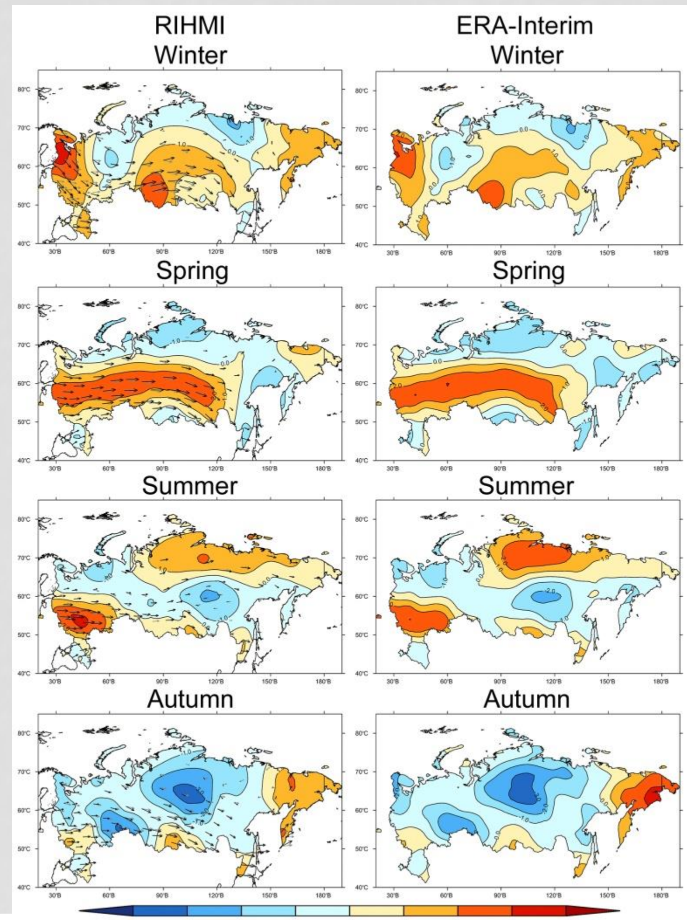
"+" - statistically significant trends with a probability of 0.9
"x" - statistically significant trends with a probability of 0.85

COMPARISON OF WIND MONITORING RESULTS.

Lower stratosphere

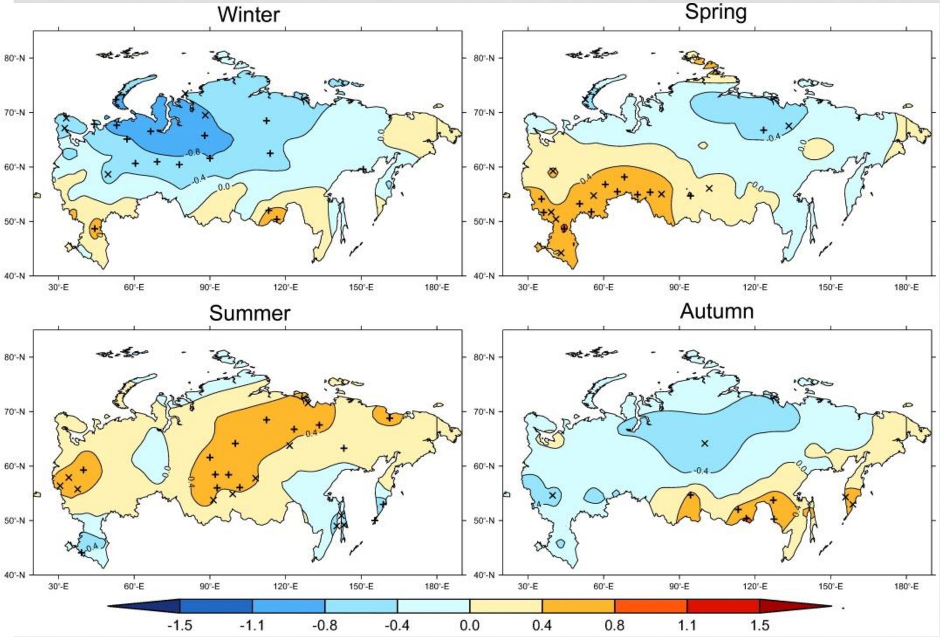


Troposphere

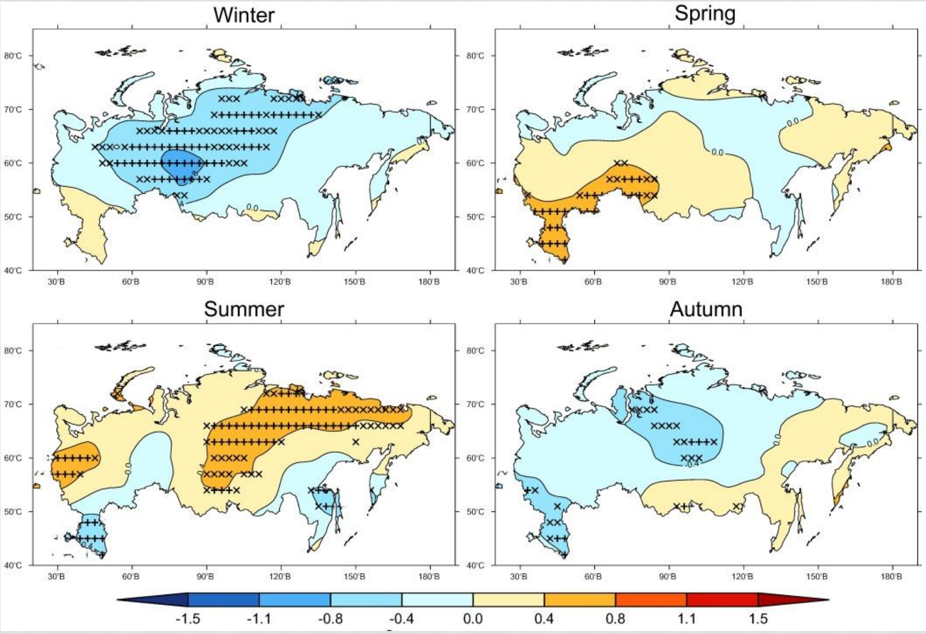


COMPARISON OF WIND MONITORING RESULTS.

RIHMI



ERA-Interim



"+" - statistically significant trends with a probability of 0.9
"x" - statistically significant trends with a probability of 0.85

CONCLUSIONS

- Results of tropospheric temperature monitoring are similar to those for surface temperature.
- 2015, 2016 and 2017 - the warmest years in the troposphere since 1958.
- In 2017 there were record low temperatures in the lower stratosphere.
- Above the territory of the Russian Federation there are areas of both positive and negative trends of the wind speed, zonal and meridional winds.
- The results of monitoring are confirmed by other independent data sources.