Freezing Precipitation, Characterization of Weather Conditions Associated with it, and Changes of the Frequency of its Occurrence Pavel Groisman^{1,4,6}, Xungang Yin², Olga Bulygina³, and Irina Danilovich (Partasenok)⁵

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Objective

(GEWEX Cross-Cut project):

To improve our understanding of future changes in hazardous cold/shoulder season precipitation and storms, especially occurring near 0°C. These extremes can be devastating and are subject to changing climate.

Long-term synoptic stations used in our analyses; 1- and 3-hourly data for the past 40 years



First group are station data collected for Groisman et al. 2016. The second group includes the station data that we are currently using to cover the entire extratropics. The third group includes also the upper air data for further studies of the freezing events phenomena.

urope, 550 statio **Belarus** stations at 2 km or above are shown in red

Second group

Kyrgyzstan



Percent of the surface air temperature observations within the [-2°C, 2°C] interval over latitudinal zones of Russia



ETR – European territory of the Russian Federation

CLIMATOLOGY OF FREEZING EVENTS



Annual freezing rain frequency

Annual freezing drizzle frequency

Inhomogeneity issues due to automation

Top. Average number of days with freezing drizzle reported by the U.S. and Canadian stations.

Bottom. Average number of days with freezing drizzle (blue dots) and freezing rain (red dots) for the United States only.





... and reporting

Region-wide mean changes in the frequency of **moderate and heavy freezing rain events** (days year⁻¹) that followed the introduction of METAR reporting formats in August 1996 over Northeastern U.S. (east of 80°W and north of 40°N).

Climatology of freezing events over Russia and Norway



Climatology of all freezing events over





CHANGES IN THE LAST DECADE

Possible cause: The Arctic temperature increase/Annual surface air temperature anomalies area-averaged over the 60°N - 90°N latitudinal zone



Recent changes in the freezing precipitation frequency

Climate conditions in the last decade have been very different from the past decades. For example, each year the Arctic (60°- 90°N) surface air temperature was warmer than any year during the period of instrumental observations.

Therefore, we conducted change assessment in the freezing precipitation characteristics by comparing them in the last decade (2005-2014) with those for the previous three decades (1975-2004). We show these changes in day yr⁻¹ for freezing rain, freezing events (Northern Eurasia), freezing drizzle (for Russia only), and separately for occurrences of intense freezing rain and drizzle over Russia. Thereafter, we present a Table with regional climatologies and the estimates of the last decade change for selected climatic regions of Russia, Europe, and North America.







Annual Freezing Drizzle Frequency area-averaged over Russia



Light and intense freezing drizzle event frequency arithmetically averaged over the long-term stations of the Russian federation. Light freezing drizzle occurrence (LFD) is approximately 10 times larger than this occurrence for intense freezing drizzle (IFD).

Changes of the mean annual numbers of days with all freezing events between 2005-2015 and 1977-2004 periods over Belarus



Changes in the annual number of freezing precipitation-hours over Belarus between 2004-2015 and 1977-2003 periods 120 Station changes sorted by longitude % 80 40 0 Lon.,°E -40 <u>23.4 24.5 25.4 26.0 26.4 26.9 27.5 27.9 28.3 28.8 29.2 29.6 30.1 30.3 31.0</u> 40 Average change within longitude ranges 30 Percent, changes %, Number of stations count 20 10 0 Lon. Range °E 23-26 26-29 29-32

Annual freezing rain frequency, FRF, area-averaged over



North America, zone 50°- 60°N **NE of East-European Plain**

2005 2010

2015



Annual freezing rain frequency, FRF, areaaveraged over the Steppe Zone of European Russia and the southern West Siberia



 Note the order of magnitude scale difference between the continental Siberian region and the Steppe Region of European Russia Annual frequency of all freezing precipitation events (freezing rain, freezing drizzle, and ice rain) over Kyrgyzstan during the 1966-1990 period and recent changes in this frequency during the 21st century

Freezing events at	below	from 1 to	above
different elevation	1 km	2 km	2 km
Climatology, days(yr)-1	0.98	0.61	0.25
Changes between two	-0.31	-0.16	0.50
periods, days(yr) ⁻¹			

Data of 26 synoptic stations. For the 2009-2011, the data were not available for analysis

Long-term regional mean values of freezing rain frequency northern Europe and selected regions of North America and Russia for 1975-2014 and differences between the mean values for the last decade (2005-2014) and the previous 30-yr-long period (1975-2004)

Region	Regional mean values days yr ⁻¹	Diff. days yr ⁻¹	Significant changes by following tests
North America north of 66.7°N	1.8	1.06	t- & L- tests
North America, between 50°N and 60°N	2.5	0.28	L- & R _s - tests
Norway south of 66.7°N	1.1	1.05	all three tests
Norway north of 66.7°N	1.1	1.10	all three tests
Russian Atlantic Arctic	1.4	-0.20	L- & R _s - tests
Northwest of the Great East European Plain	1.3	0.28	none
Northeast of the Great East European Plain	2.2	0.77	L- & R _s - tests
Greenland and Iceland	1.1	0.49	L- & R _s - tests
Baltic Sea Basin	2.0	0.60	all three tests

Statistically significant changes at the 0.05 level are in bold and at the 0.10 level are in bold italic.

Changes in the last decade of freezing events; results in a nutshell

- Using synoptic data for the past 40 years, we estimated the climatology of the frequency of freezing rain and drizzle occurrence for North America, Europe, Russia, and Kyrgyzstan and their changes in the past decade
- During the last decade, substantial changes in the annual freezing rain occurrence were found:
 - On the southern edge of our study domain (southeastern U.S., Central Europe, southern Russia) the frequencies of freezing events decreased along with the duration of the cold season;
 - In the Arctic (North America, Europe, and North Atlantic north of 60°N), in some taiga areas of Russia, and at high elevations (The Tian Shan Mountains), the frequencies of freezing events increased "following" the expansion of the short warm season.
 - Changes in the occurrence of freezing drizzle were estimated only for Russia. We found a statistically significant nationwide decrease in this element.

CHARACTERIZATION OF FREEZING EVENTS USING OTHER METEOROLOGICAL VARIABLES

Freezing precipitation distribution (%) by associated surface air temperature, T_a (over entire Russia)



Percent distribution of freezing rain events over Russia by associated surface air temperature T_a during the 1976-2004 and post 2004 periods



Practically no differences with time in freezing rain distribution by T_a

Fraction of freezing rain events for different near surface relative humidity ranges over the Russia





WARM MOIST AIR MASS

at higher altitude

The snow melts as it falls through warmer air turning it to rain COLD AIR

As the rain encounters a layer below freezing, it becomes supercooled

The supercooled water droplets freeze on impact with any object they encounter

Upper air normalized temperature anomalies at 700 hPa for freezing events at five US stations

Three CONUS stations

Two Alaskan stations



Anomalies are expressed in fractions of standard deviations of "normalized" daily temperature values at 12 UTC. Seasonal cycle variability of mean daily values and variances are eliminated by normalizing. CONUS = Contiguous U.S.

Upper air normalized temperature anomalies at 850 and 700 hPa for freezing events at eight stations of Fennoscandia



Anomalies are expressed in fractions of standard deviations of "normalized" daily temperature values at 12 UTC. Seasonal cycle variability of mean daily values and variances are eliminated by normalizing. Stations from Finland, Sweden, Norway, and Iceland.

Upper air normalized temperature anomalies at 850 and 700 hPa for freezing events at 7 stations of East European taiga



Anomalies are expressed in fractions of standard deviations of "normalized" daily temperature values at 12 UTC. Seasonal cycle variability of mean daily values and variances are eliminated by normalizing. Russian stations from 55°N to 62°N west of the Urals.

Upper air normalized temperature anomalies at 850 and 700 hPa for freezing events at 8 stations of East European forest-steppe and steppe



Anomalies are expressed in fractions of standard deviations of "normalized" daily temperature values at 12 UTC. Seasonal cycle variability of mean daily values and variances are eliminated by normalizing. Russian stations from 50°N to 54.5°N west of the Urals.

Air temperatures differences between the days with freezing events and the "nearby" days (1975-2014; USA)



Vertical temperature differences during the days with freezing events (850 hPa – surface; 700 hPa – 850 hPa; 500 hPa – 850 hPa). *inversions*

Air temperatures differences between the days with freezing events and the "nearby" days (1975-2014; Fennoscandia)



Air temperatures differences between the days with freezing events and the "nearby" days (1975-2014; European Russia)

Vertical temperature differences during the days with freezing events (850 hPa – surface; 700 hPa – 850 hPa; 500 hPa – 700 hPa). *Inversions.*

Initial freezing precipitation characterizations

- 60% of freezing rain and 55% of freezing drizzle events occur while surface air temperatures, T_a, are within [-1.5°C, 0.0°C] and [-2.0°C, -0.5°C] intervals respectively.
- 85% of freezing rain events occur when near surface relative humidity, RH, exceeds **90%**.
- Only 7% of meteorological observations were made when RH values exceed 90% and simultaneously T_a remain within the [-1.5°C, 0.0°C] interval. Over the entire Russian Federation, 80% of all freezing rain events are reported under these near-surface weather conditions.
- Using combined synoptic and upper air data during freezing events and in their absence over the USA, Northern Europe, and European Russia, we noticed that:
 - most of freezing rainfall occurs with warmer than usual lower troposphere (e.g., during warm fronts). For example, the $T_{700 hPa}$ anomalies over the U.S. are at $\Delta T_{700,normalized} = +1^{\circ}C$ (**p** = 0.16)
 - During freezing rain events, temperature inversions are quite frequent when temperature at 850 hPa is higher than at the surface.

Possible causes of increases of freezing event frequency at high latitudes

1. Large-scale meandering.

Figure 2b from Francis and Vavrus, 2012, *GRL*, 39, L06801. Schematic of ridge elongation (dashed vs. solid) in upper-level heights caused by enhanced warming in Arctic relative to mid-latitudes. Higher amplitude waves progress eastward more slowly, as indicated by arrows

2. Northward shift in Eurasian storm tracks (warm corner of cyclones can be more frequently found over the cold surfaces)

frequently found over the cold surfaces) 3. Increase in the number of days with Wangengheim-Girs circulation type W. This circulation type is associated with unobstructed water vapor transport from Atlantic towards Europe

4. Expansion of the short warm season 150

That's it!

