HUMAN-ASSOCIATED EXTREME EVENTS: FREEZING PRECIPITATION

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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.

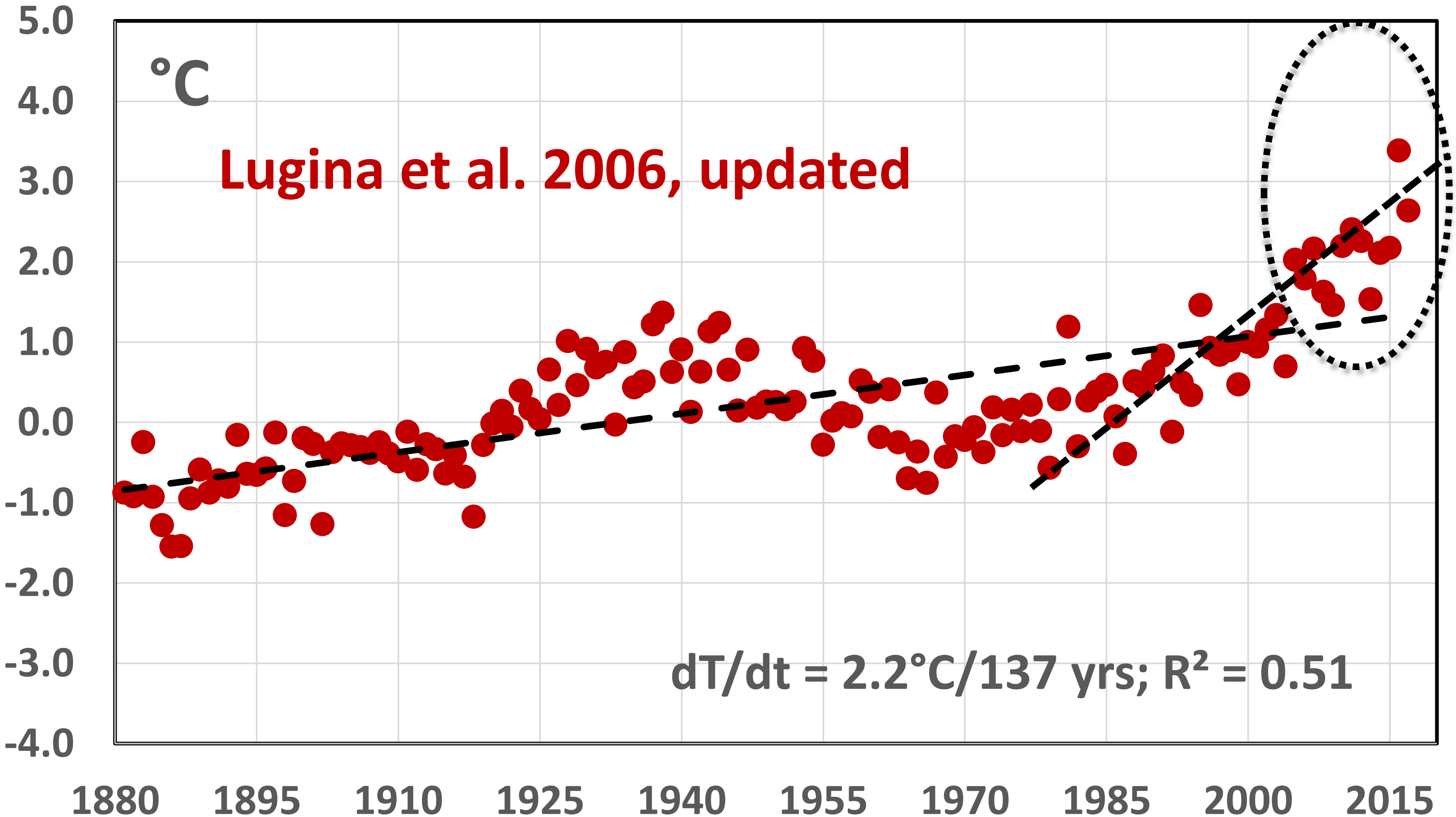
Rationale

Global changes in the last decades (in particular, in the 21st century) were already too large. They do not allow us to ignore their potential consequences in extreme events frequency and intensity.

Data and Brief Summary of Results

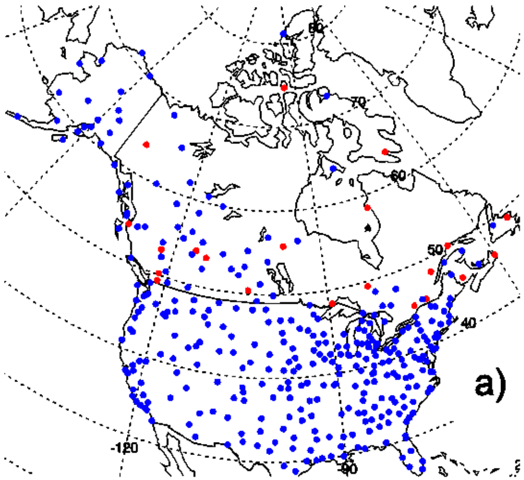
The Arctic Warming

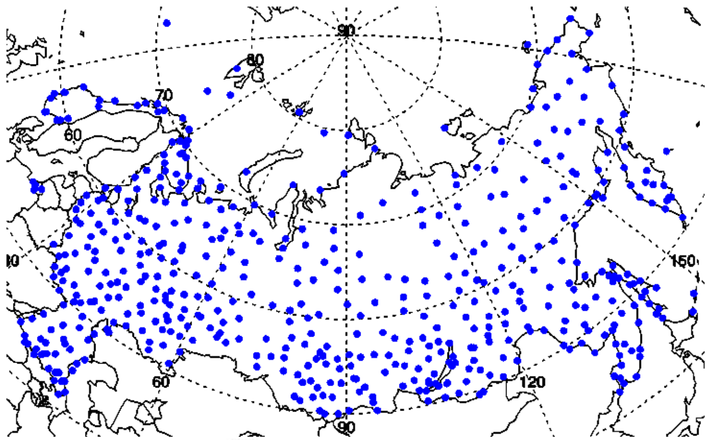
Annual surface air temperature anomalies area-averaged over the 60°N - 90°N latitudinal zone, °C



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

First group

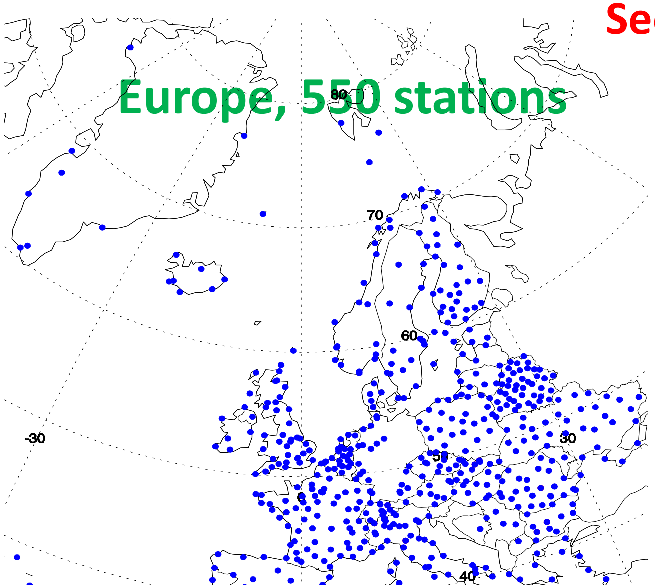




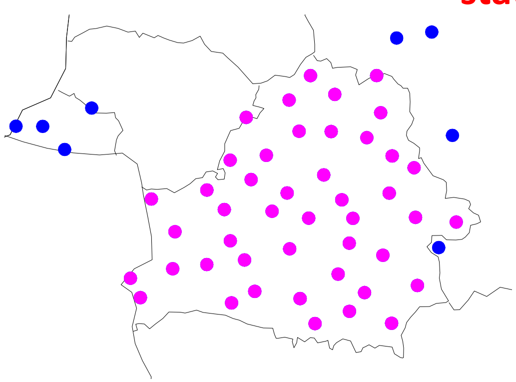
First group are station data collected for Groisman et al. 2016. **The second group** includes the station data that we are currently using to cover the entire extratropics. **The third group** includes also the upper air data for further studies of the freezing events phenomena and reanalyses.

Second group

Europe, 550 stations

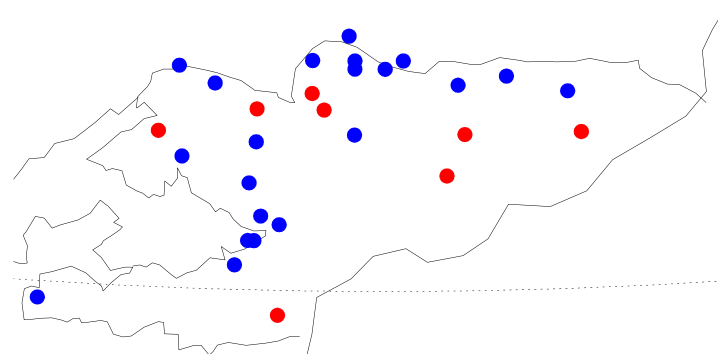


Belarus



Kyrgyzstan

stations at 2 km or above are shown in red



Changes of freezing events in the last decade. 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, Belarus, 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 northern Canada, Alaska, Europe and North Atlantic north of 60°N, Eastern Belarus, 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.
- Occurrence of freezing drizzle over Russia has decreased nationwide.

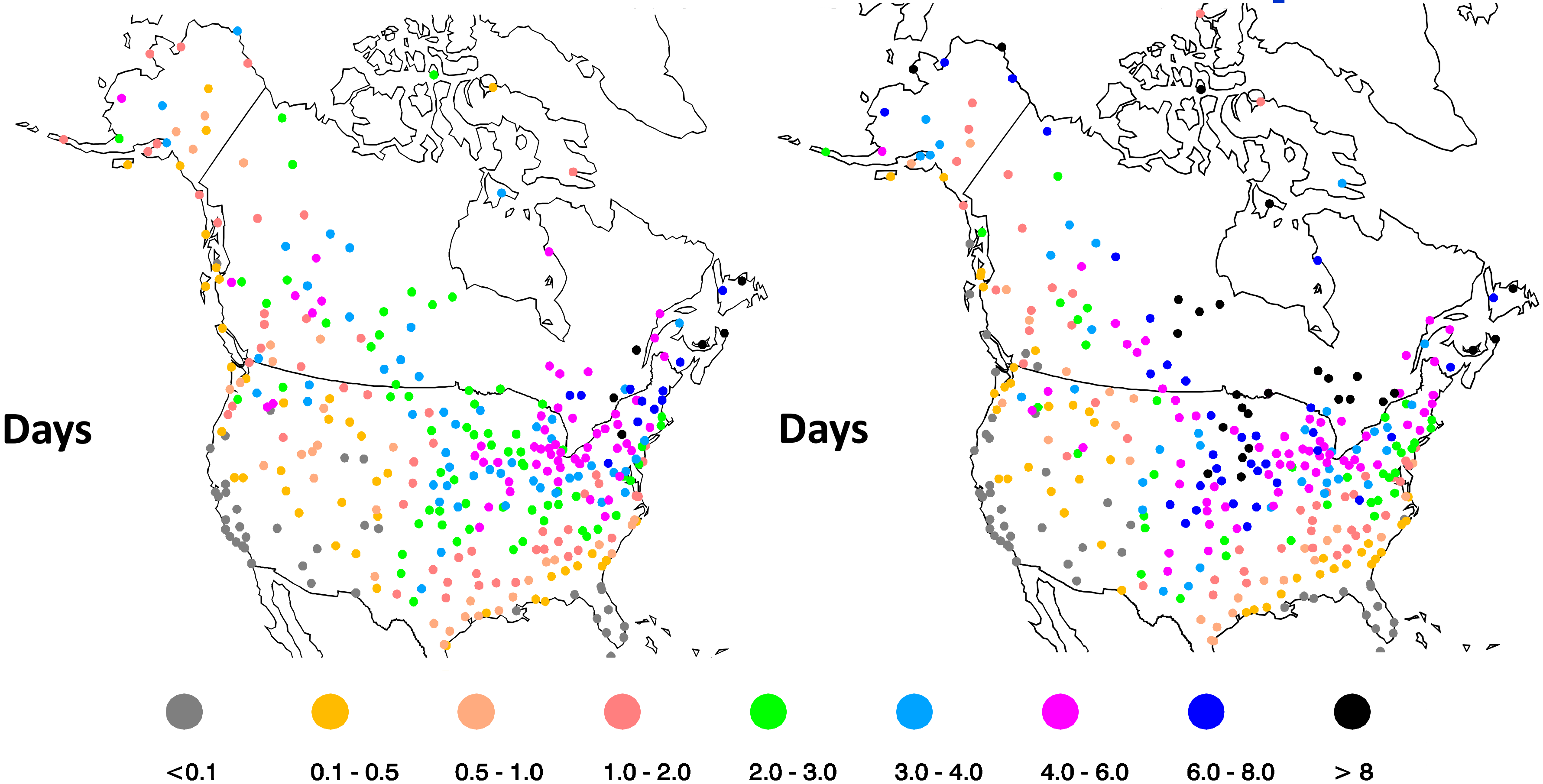
Long-term regional mean values of freezing rain frequency northern Europe and selected regions of North America and Russia for 1975-2014 and differences between the mean values for the last decade (2005-2014) and the previous 30-yr-long period (1975-2004)

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*
Greenland and Iceland	1.1	**0.49**	*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
Baltic Sea Basin	2.0	**0.60**	all three tests
Russian Atlantic Arctic	1.4	***-0.20***	*L- & R_s- tests*
Great East European Plain, northwest	1.3	0.28	none
Great East European Plain, northeast	2.2	***0.77***	*L- & R_s- tests*

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

CLIMATOLOGY

Climatology of freezing events over North America for the 1975-1994 period

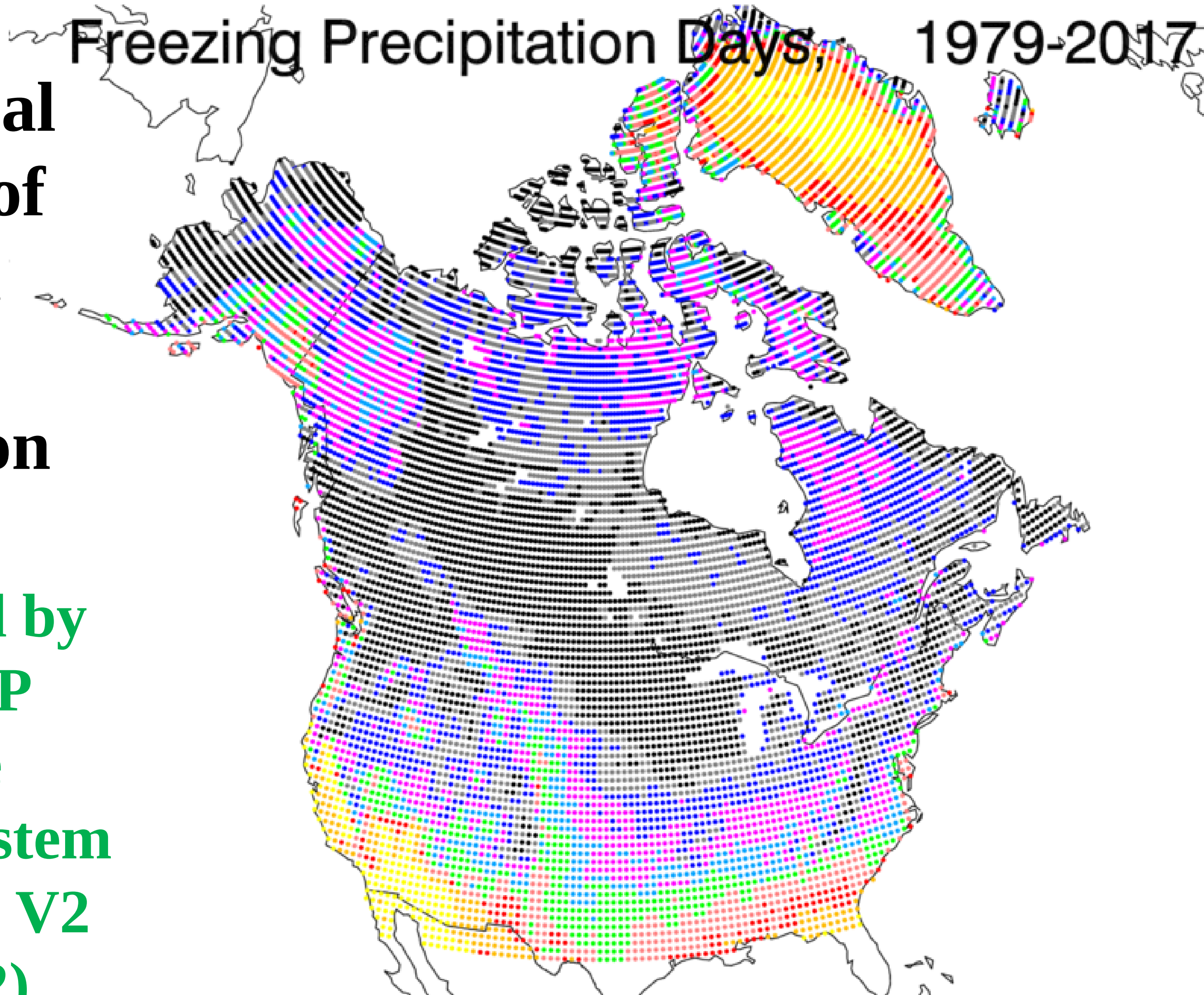


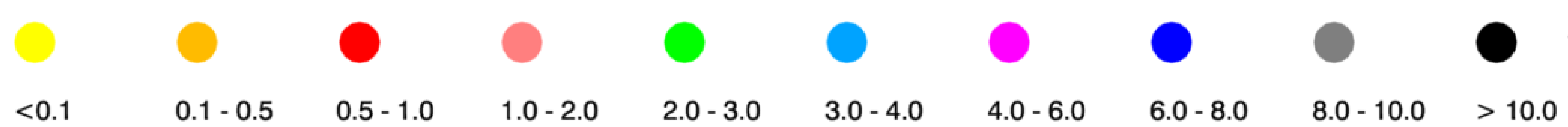
Annual freezing rain frequency

Annual freezing drizzle frequency

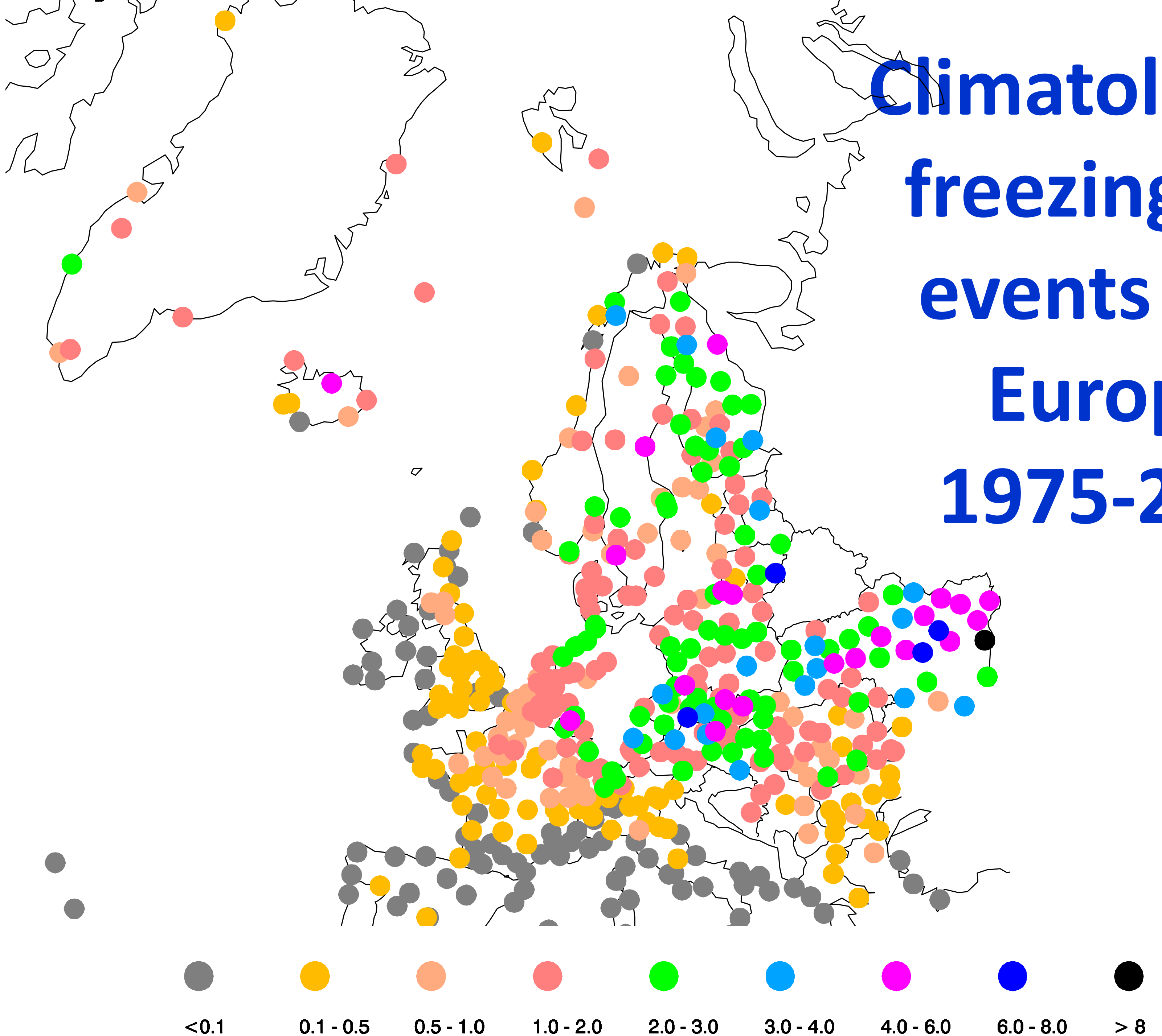
Mean annual frequency of days with freezing precipitation d ×(yr)$^{-1}$

as reported by the NCEP Climate Forecast System Reanalysis. V2 (CFSRv2)



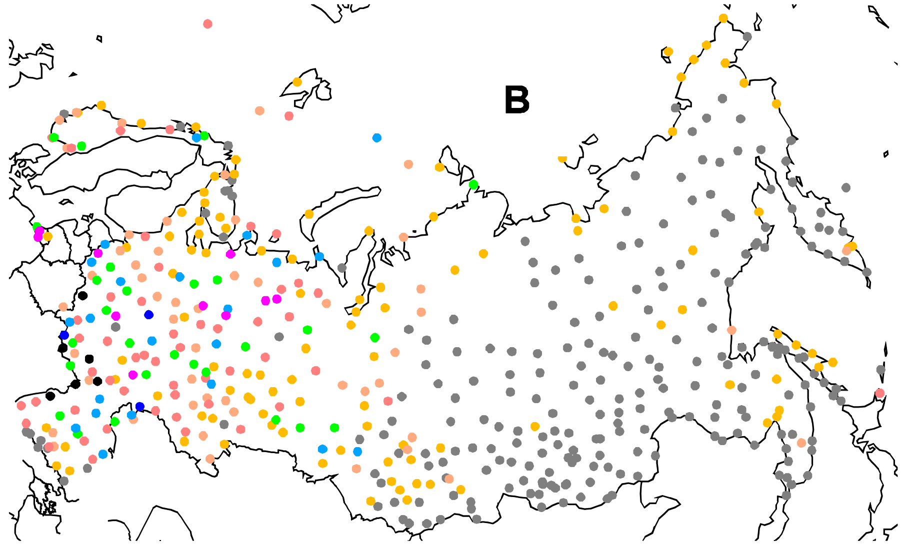


Climatology of freezing rain events over Europe, 1975-2014



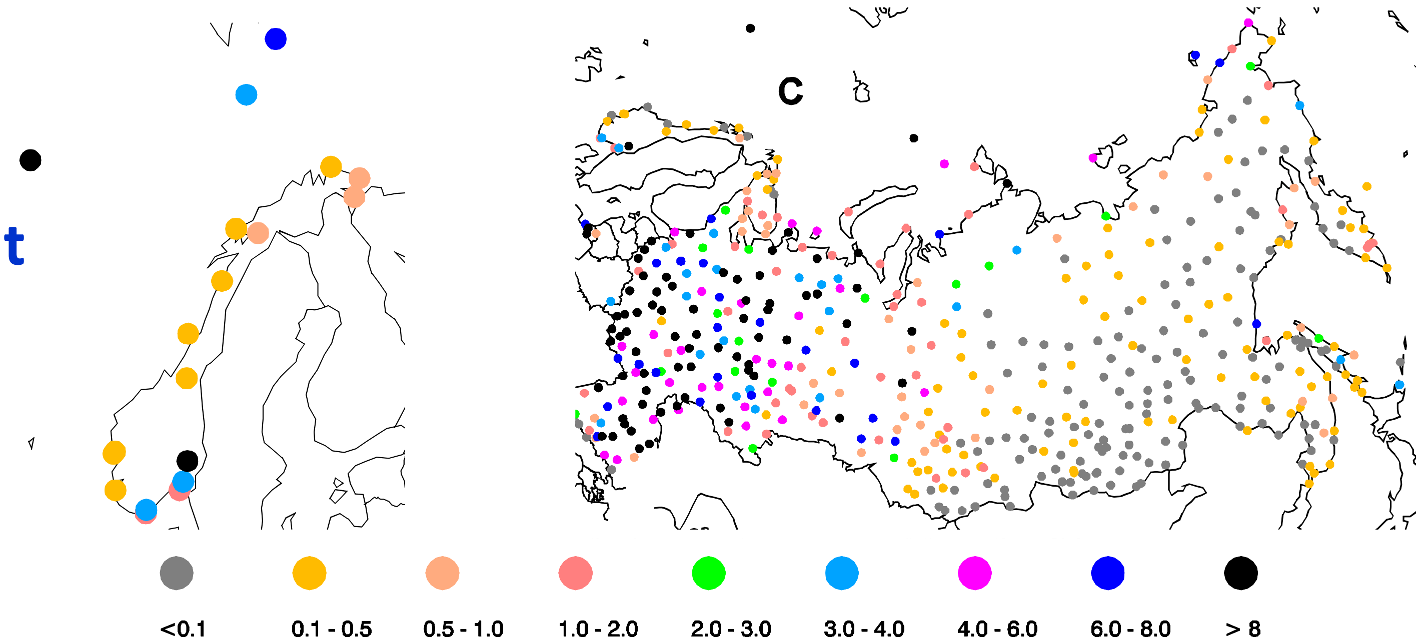
Climatology of freezing events over Russia and Norway

Annual frequency of freezing rain days

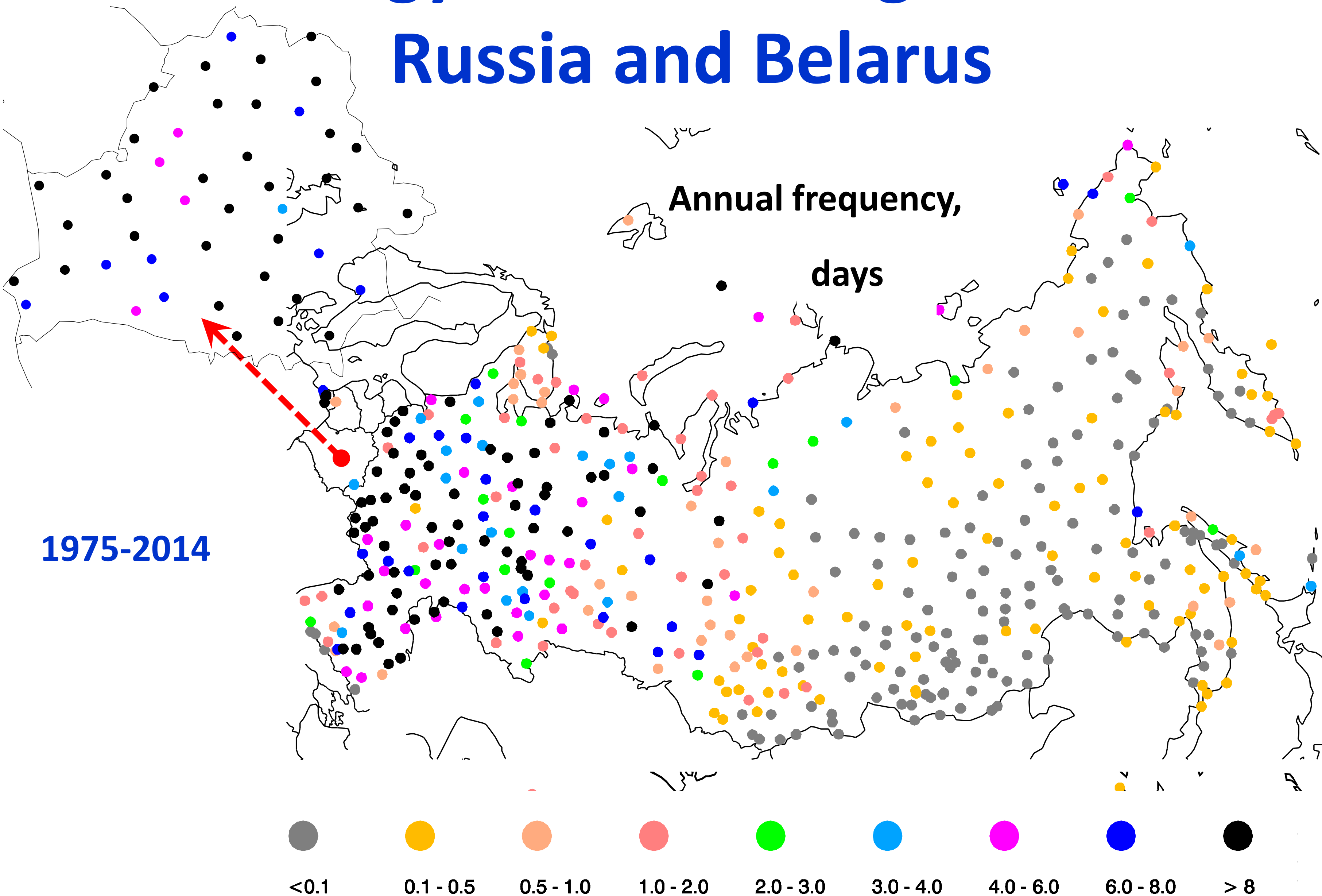


1975-2014

The same, but for freezing drizzle days

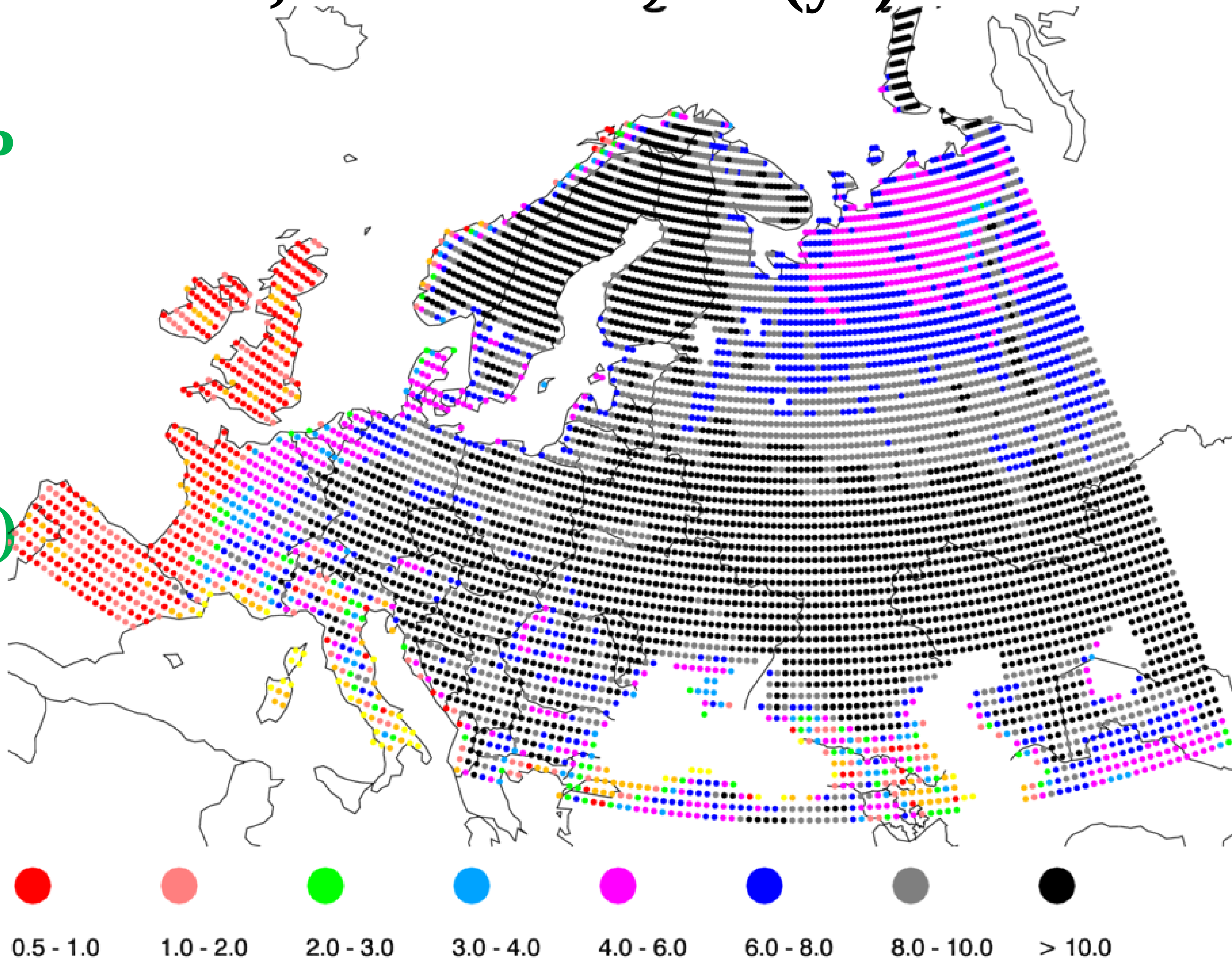


Climatology of all freezing events over Russia and Belarus



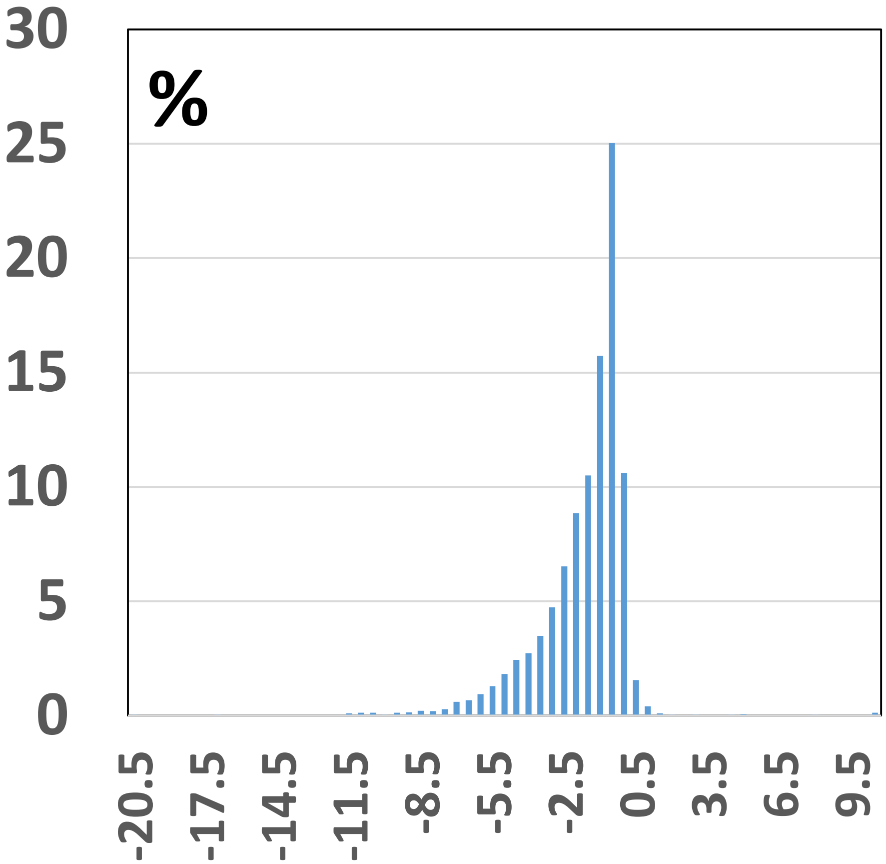
Mean annual frequency of days with freezing precipitation over Eurasia west of the Ural Mountains; 1979-2017; d ×(yr)$^{-1}$

As reported by the NCEP Climate Forecast System Reanalysis. V2 (CFSRv2)

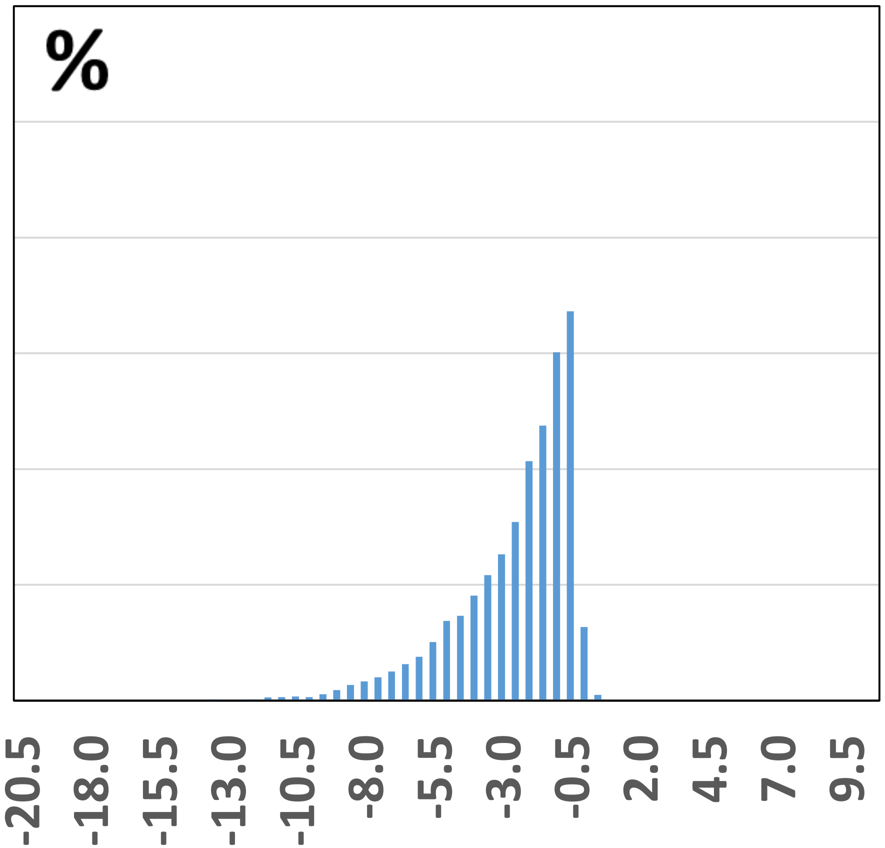


PILOT CHARACTERIZATION OF FREEZING EVENTS USING OTHER METEOROLOGICAL VARIABLES

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



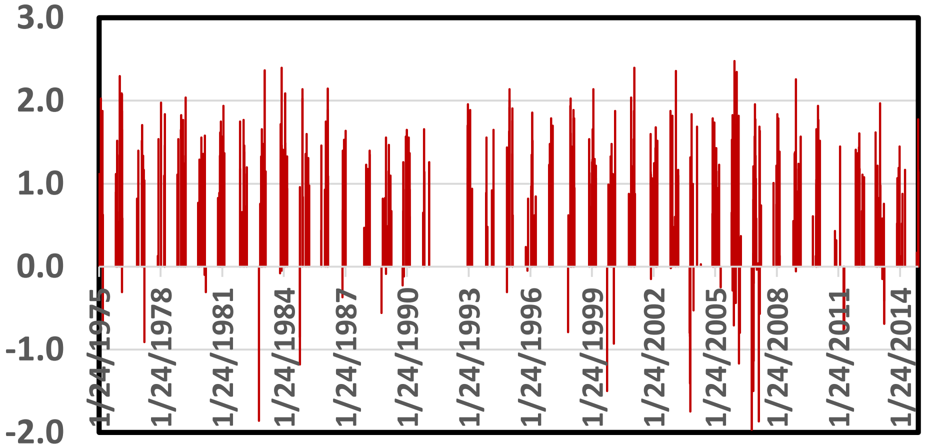
Freezing rain by T_a



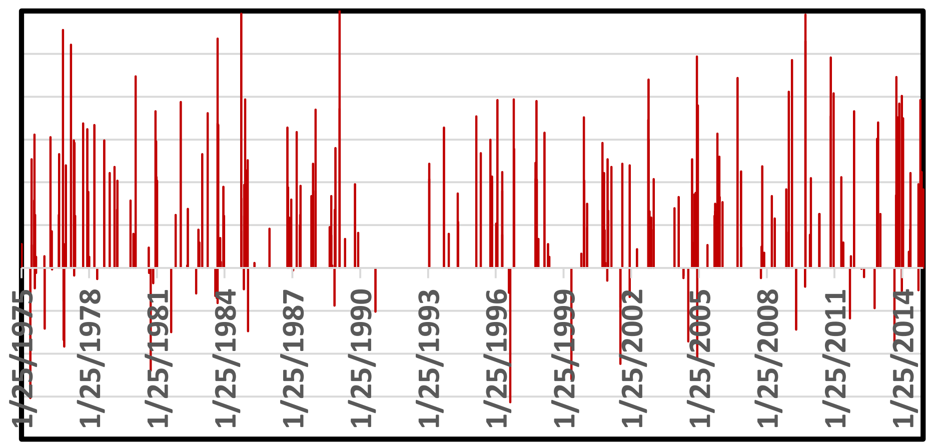
Freezing drizzle by T_a

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

Three CONUS stations



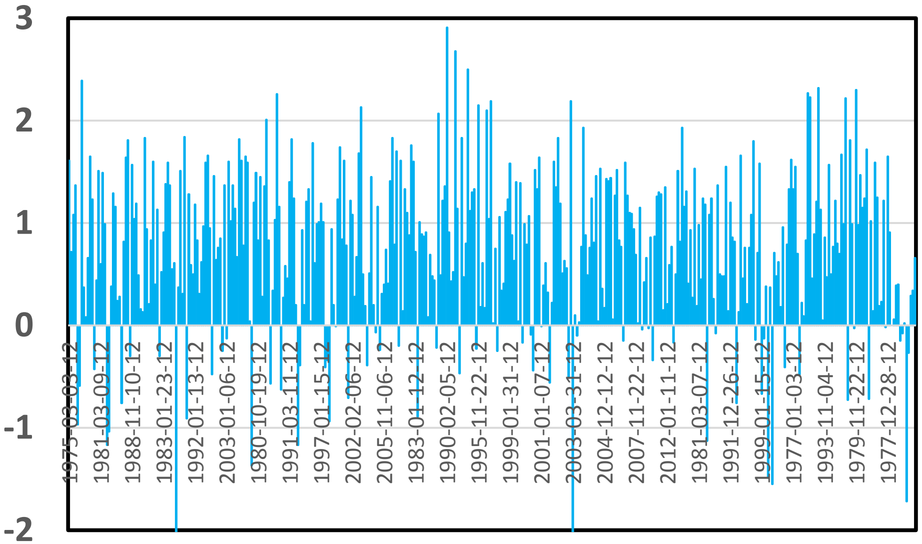
Two Alaskan stations



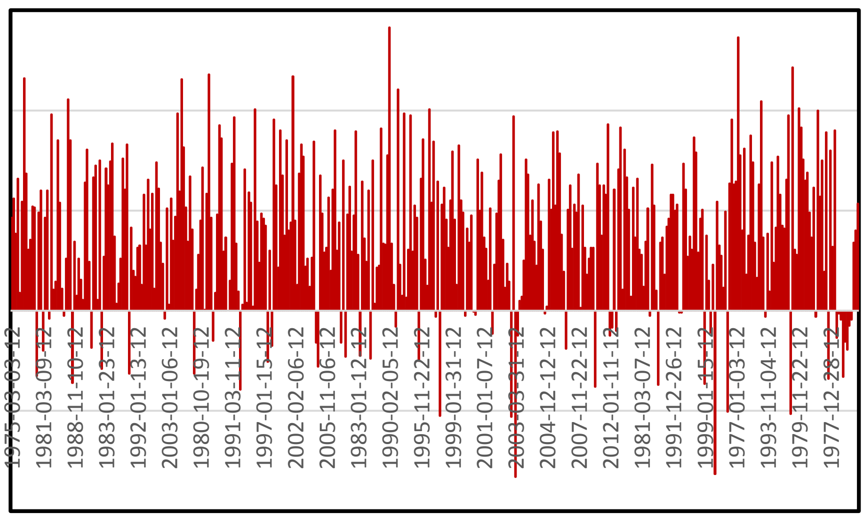
Anomalies are expressed in fractions of standard deviations of "normalized" daily temperature values at 12 UTC. Seasonal cycle variability of mean daily values and variances are eliminated by normalizing. CONUS = Contiguous U.S.

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

850 hPa Northern Europe



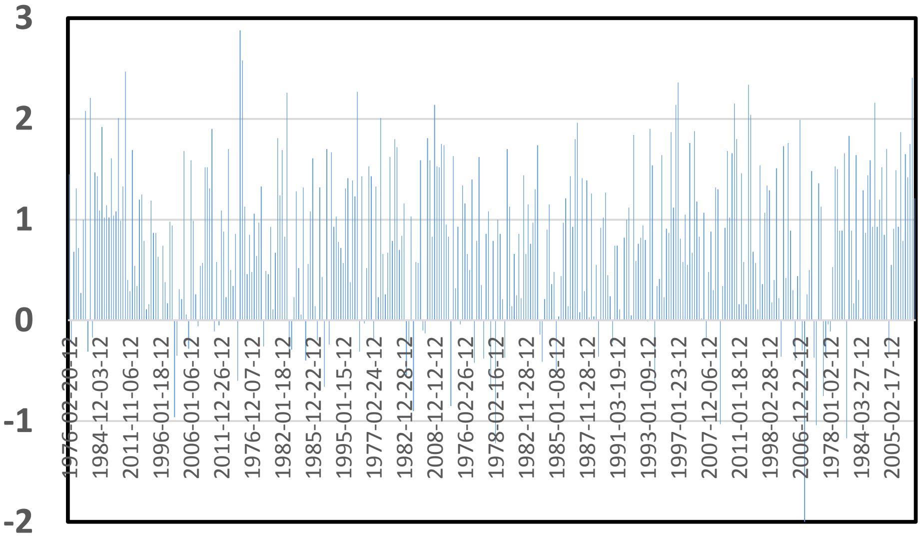
700 hPa Northern Europe



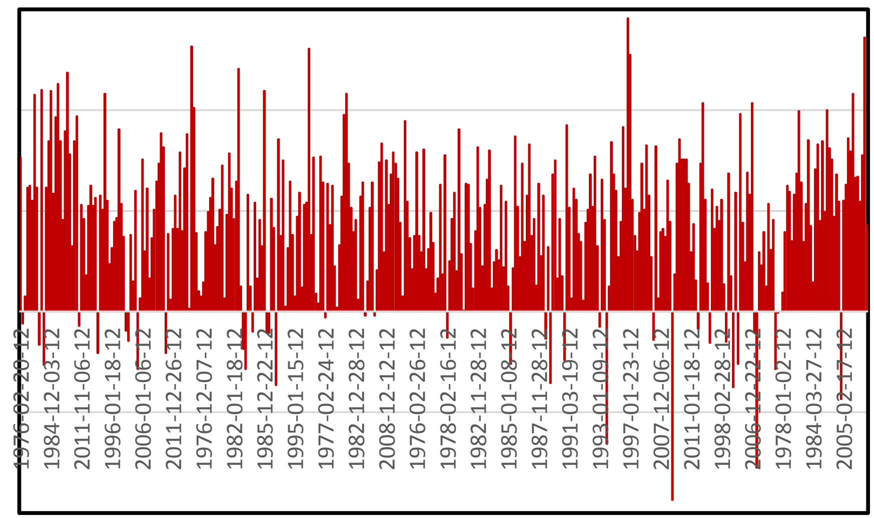
Anomalies are expressed in fractions of standard deviations of "normalized" daily temperature values at 12 UTC. Seasonal cycle variability of mean daily values and variances are eliminated by normalizing. Stations from Finland, Sweden, Norway, and Iceland.

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

850 hPa North European Russia



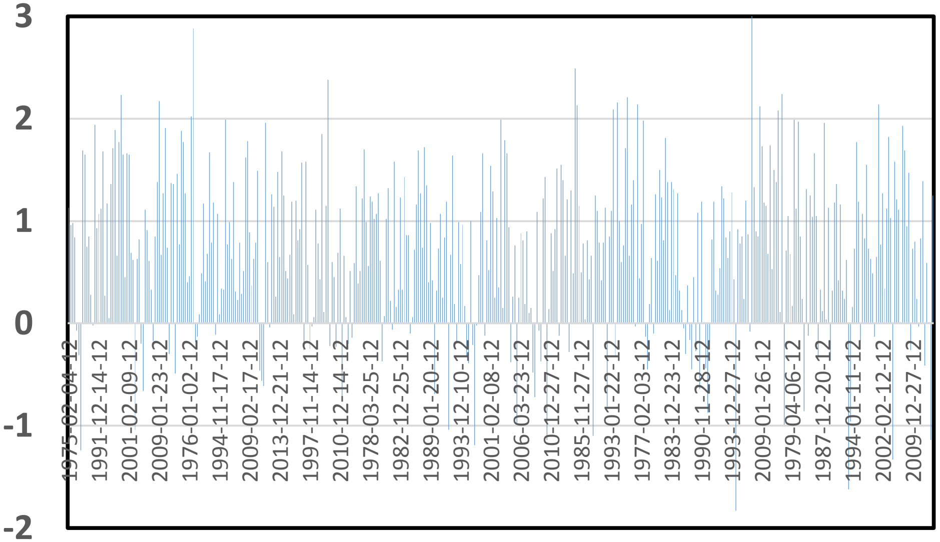
700 hPa North European Russia



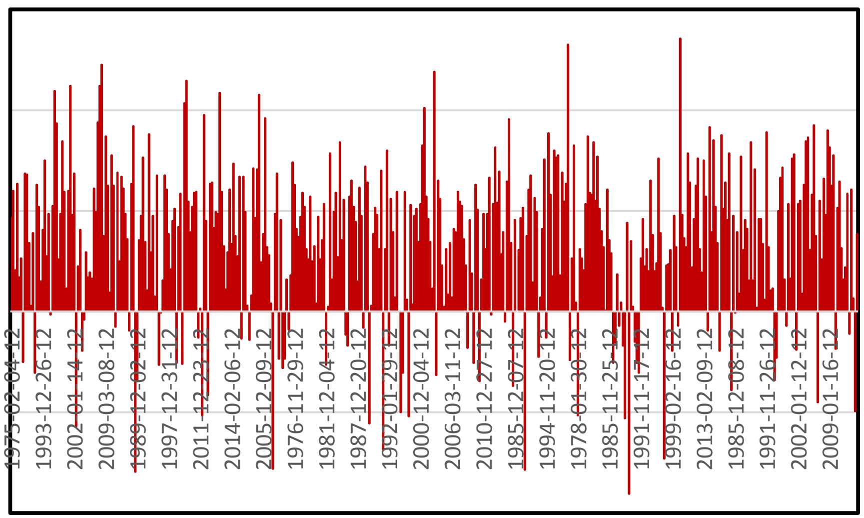
Anomalies are expressed in fractions of standard deviations of "normalized" daily temperature values at 12 UTC. Seasonal cycle variability of mean daily values and variances are eliminated by normalizing. Russian stations from 55°N to 62°N west of the Urals.

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

850 hPa South European Russia

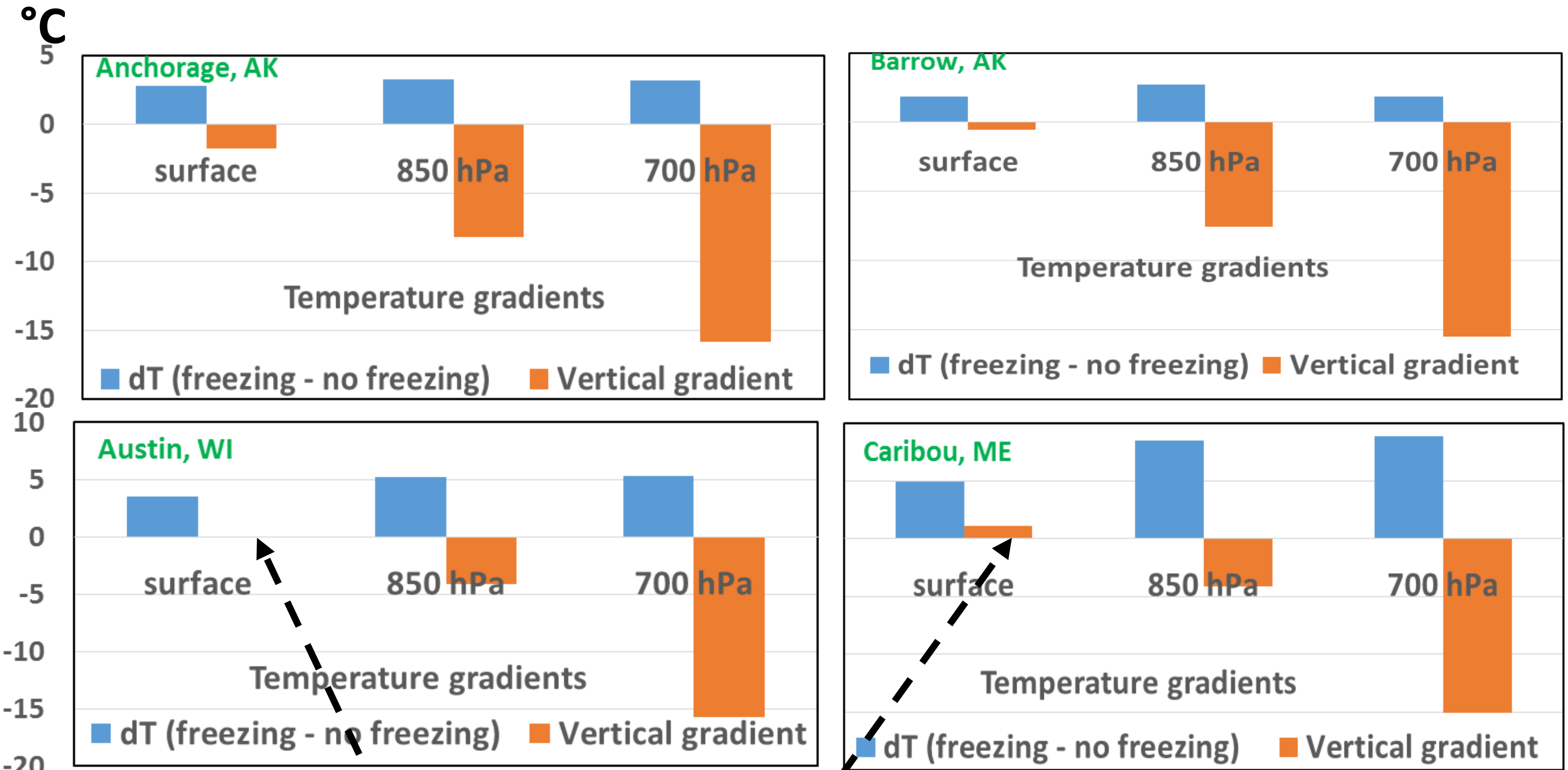


700 hPa South European Russia



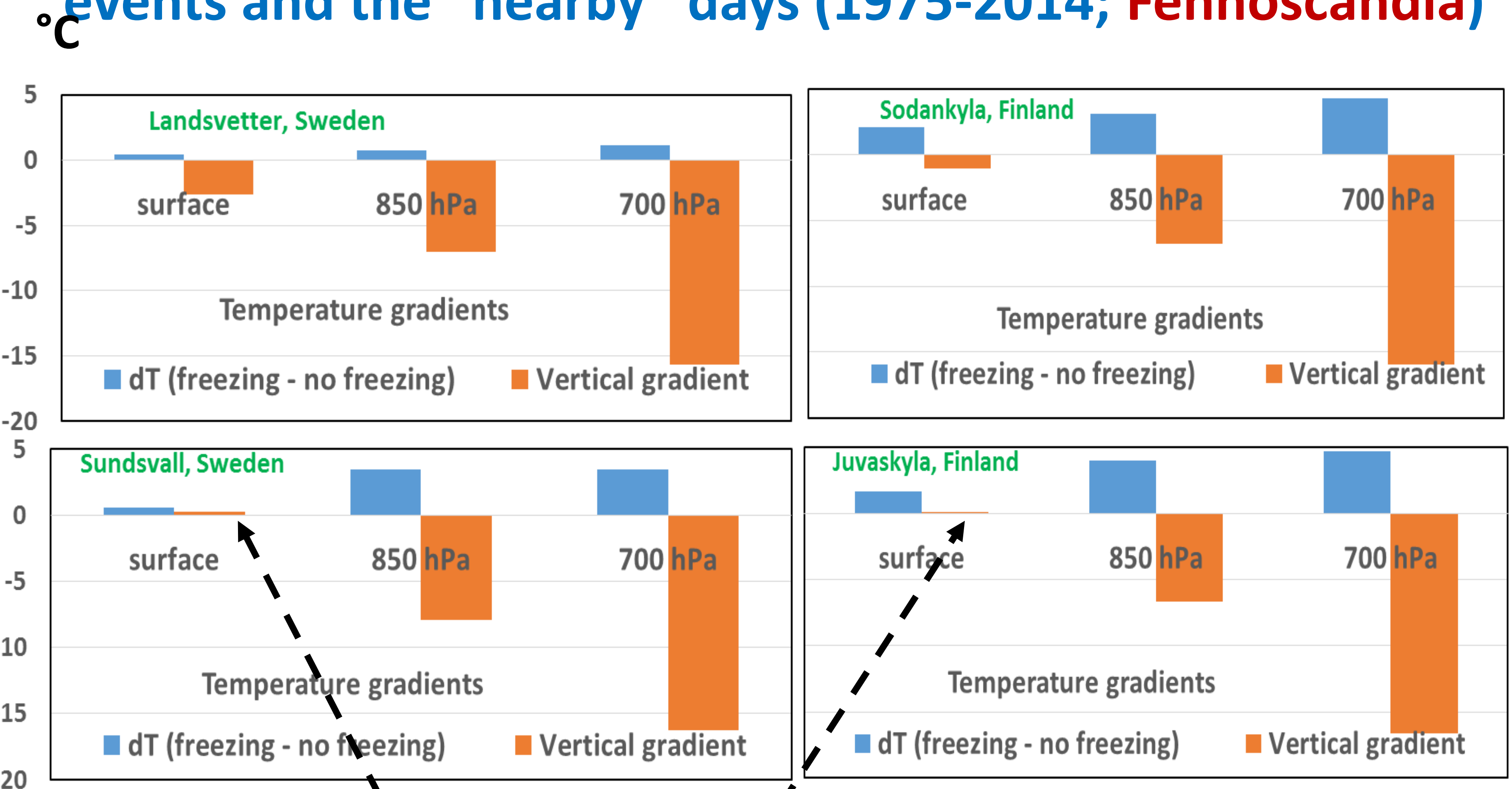
Anomalies are expressed in fractions of standard deviations of "normalized" daily temperature values at 12 UTC. Seasonal cycle variability of mean daily values and variances are eliminated by normalizing. Russian stations from 50°N to 54.5°N west of the Urals.

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



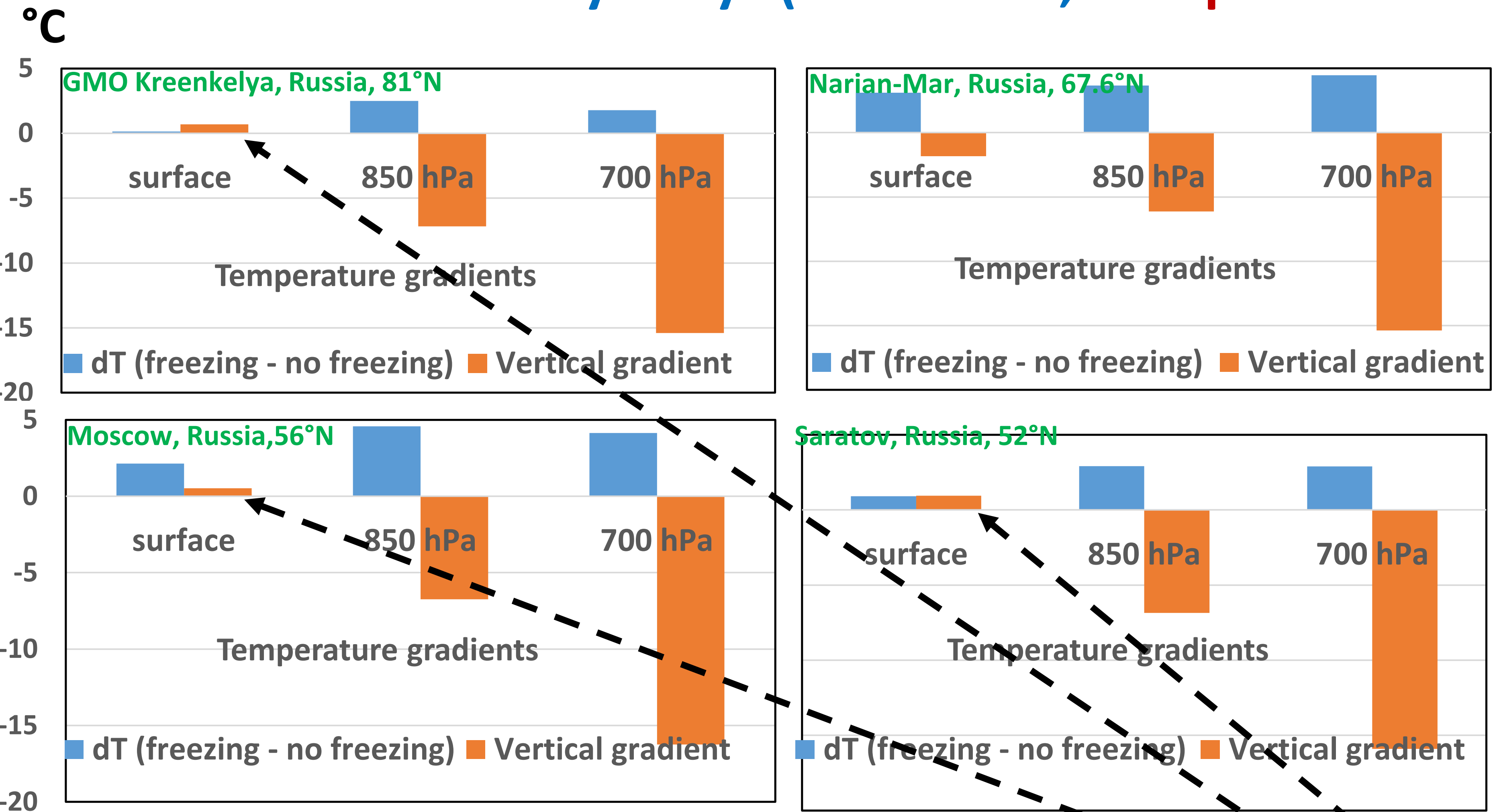
Vertical temperature differences during the days with freezing events (850 hPa – surface; 700 hPa – 850 hPa; 500 hPa – 850 hPa). ***inversions***

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

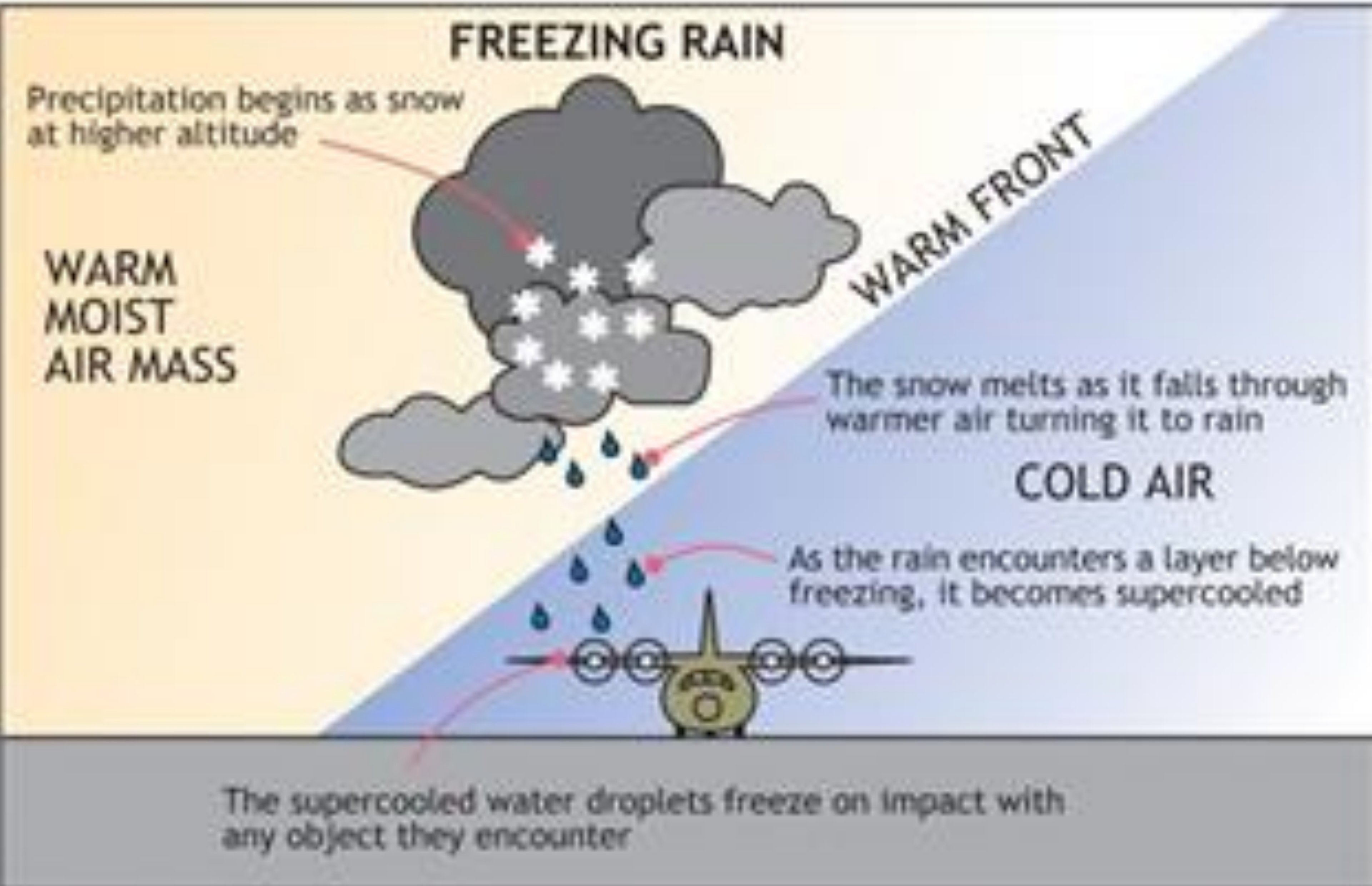


Vertical temperature differences during the days with freezing events (850 hPa – surface; 700 hPa – 850 hPa; 500 hPa – 700 hPa). ***Inversions.***

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.***


FREEZING RAIN
Precipitation begins as snow
at higher altitude
WARM
MOIST
AIR MASS
WARM FRONT
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

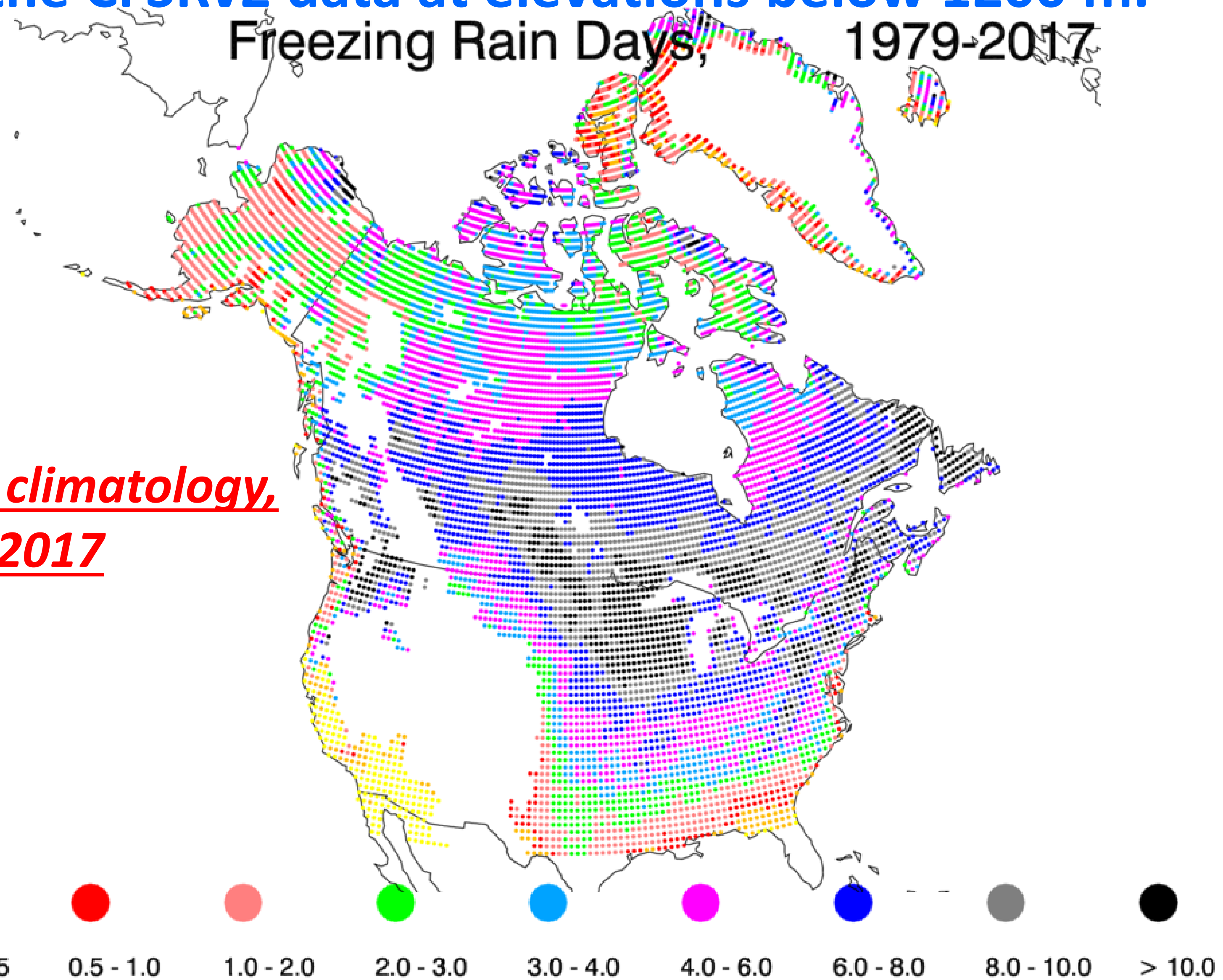
Generalized definition of weather conditions conducive to freezing rain (WCCFR) with P.

Meteorological variable	Boundary (ies)
Near-surface air temperature, $T_{surface}$	$T_{surface} \in [-5.0°C, 0.2°C]$
Air temperature at 850 hPa	T_{850hPa} > -0.4°C
Air temperature at 700 hPa	T_{700hPa} > -6°C

Relationship was derived from synoptic and aerologic observations in the U.S., Canada, Russia, and Northern Europe and is valid at elevations below 1200 m

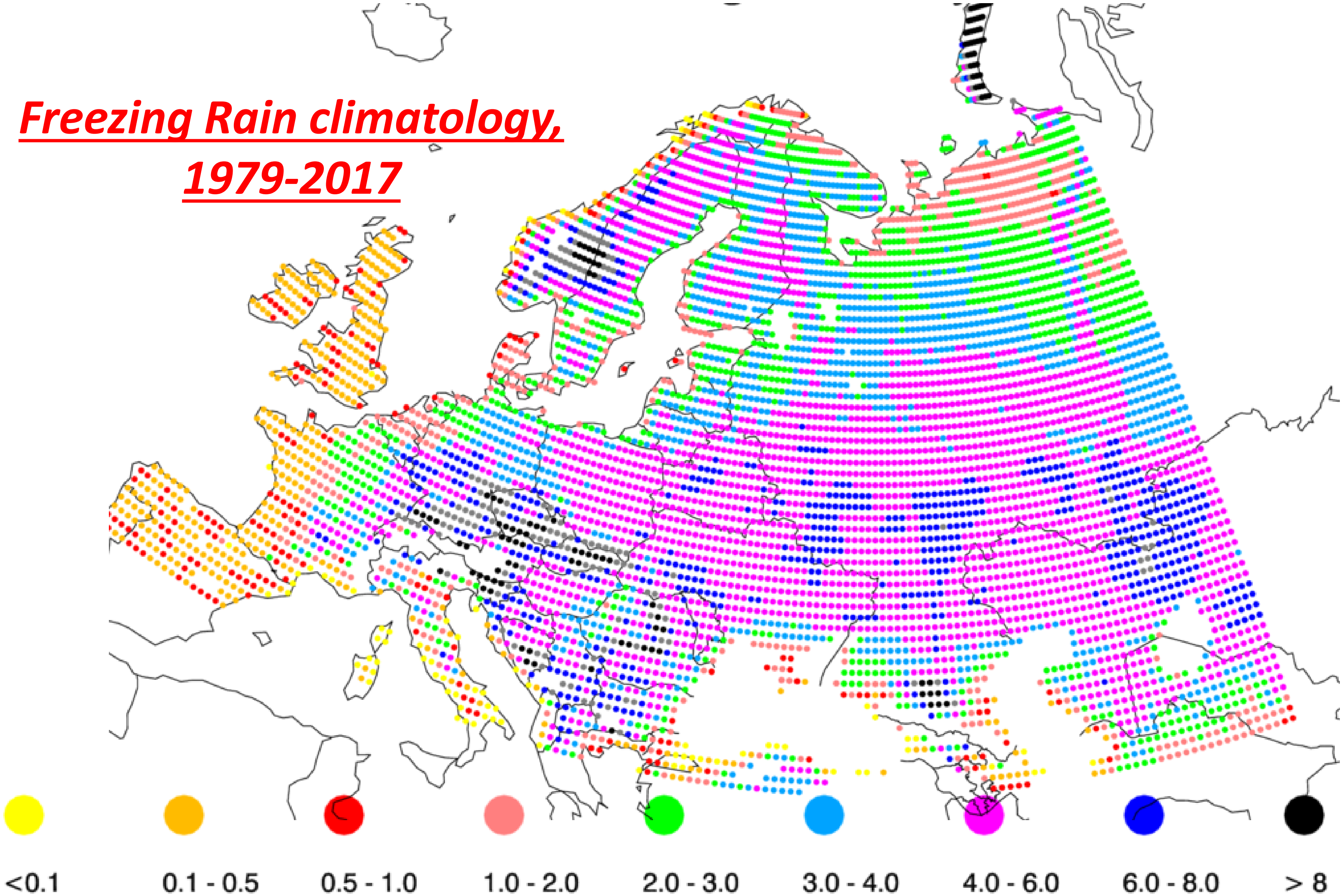
Weather conditions conducive to freezing rain (WCCFR) applied to the CFSRv2 data at elevations below 1200 m.

Freezing Rain climatology, 1979-2017



64% of WCCFR are classified as "Freezing Precipitation" by CFSRv2

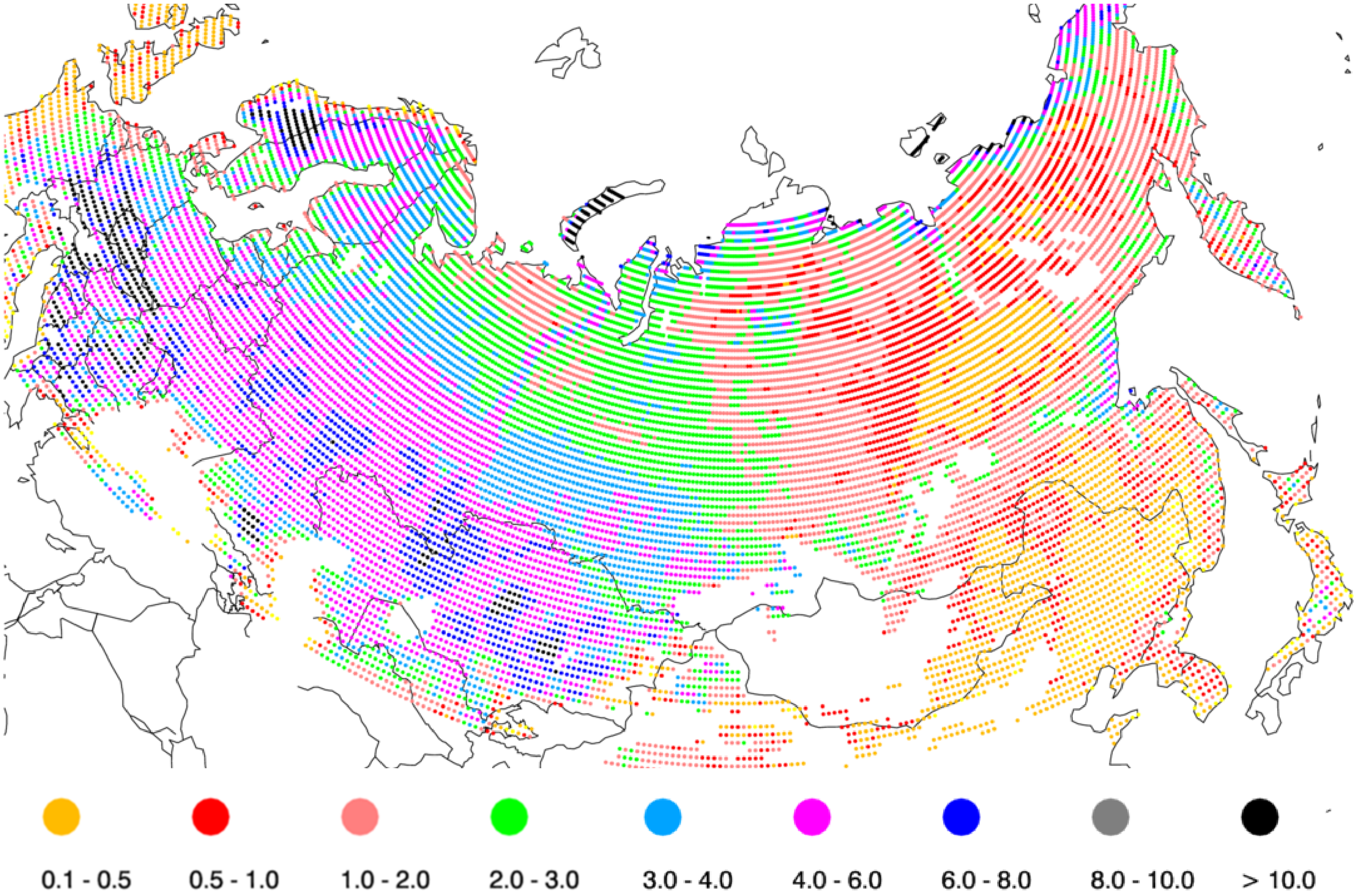
Weather conditions conducive to freezing rain (WCCFR) applied to the CFSRv2 data at elevations below 1200 m.



68% of WCCFR are classified as "Freezing Precipitation" by CFSRv2

Weather conditions conducive to freezing rain (WCCFR) applied to the CFSRv2 data at elevations below 1200 m.

<u>Freezing Rain climatology, 1979-2017</u>



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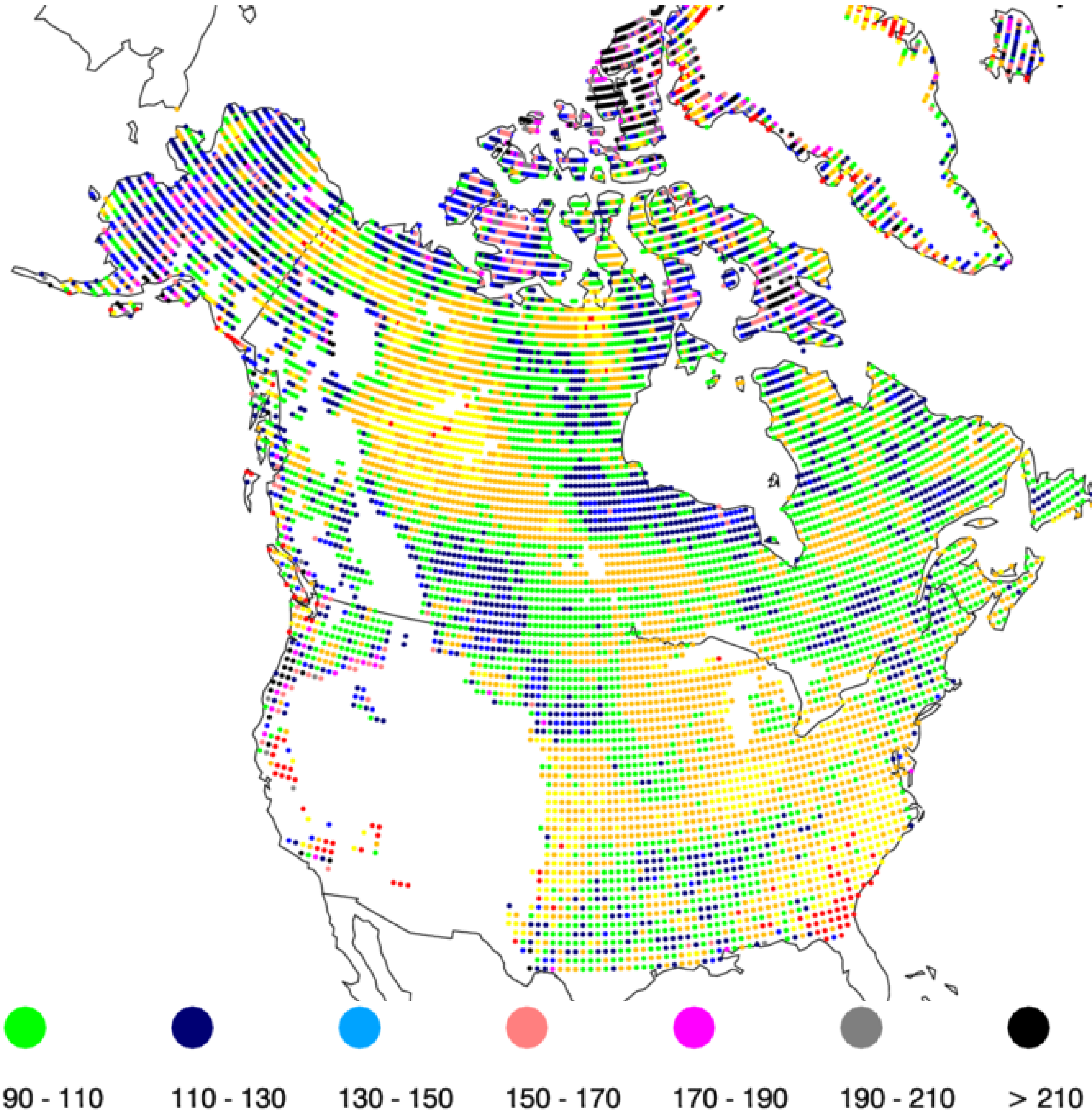
Freezing rain days change in the past 13 years (2005-2017) compared to the previous 26 years (1979-2004), %



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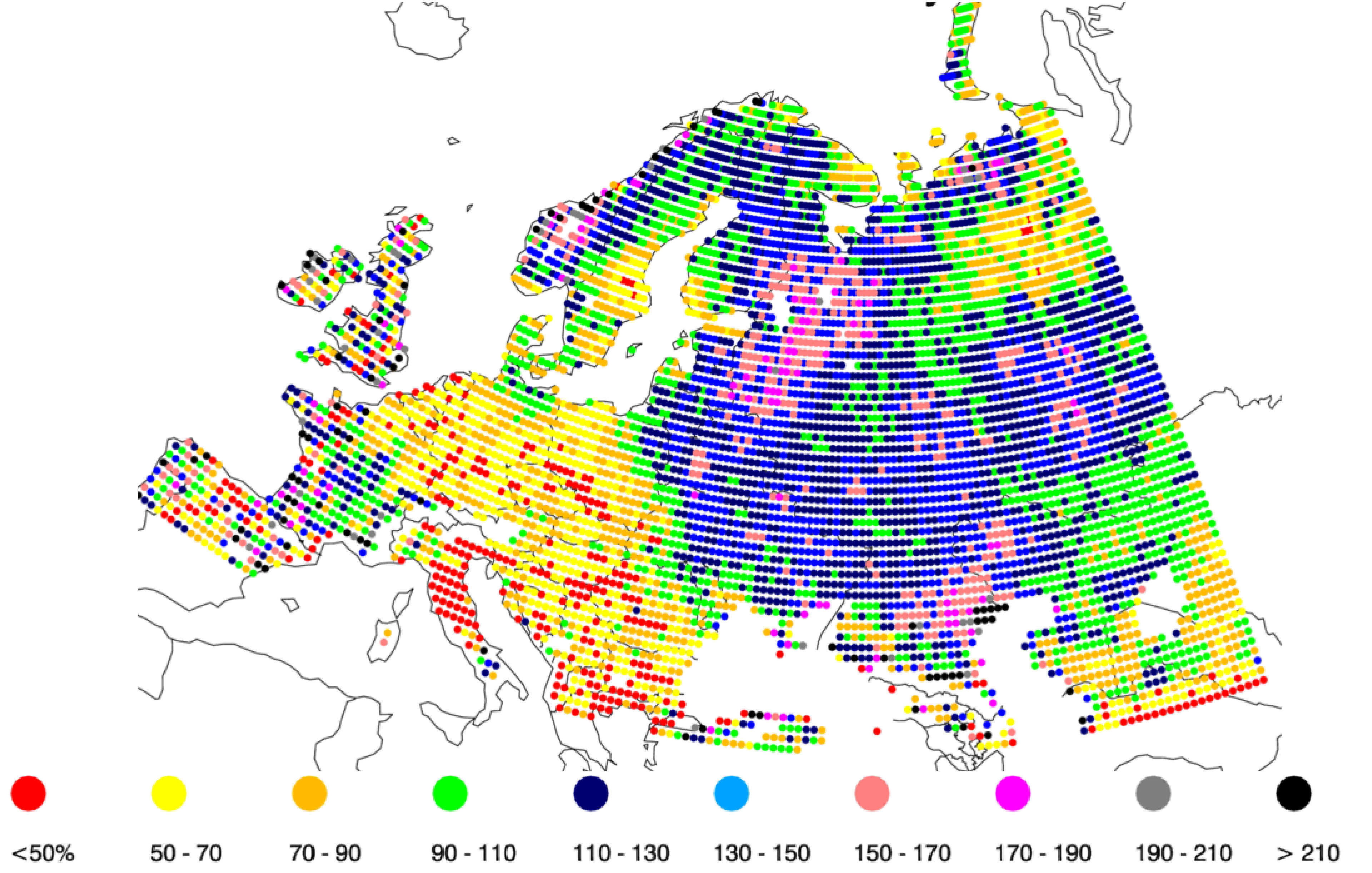
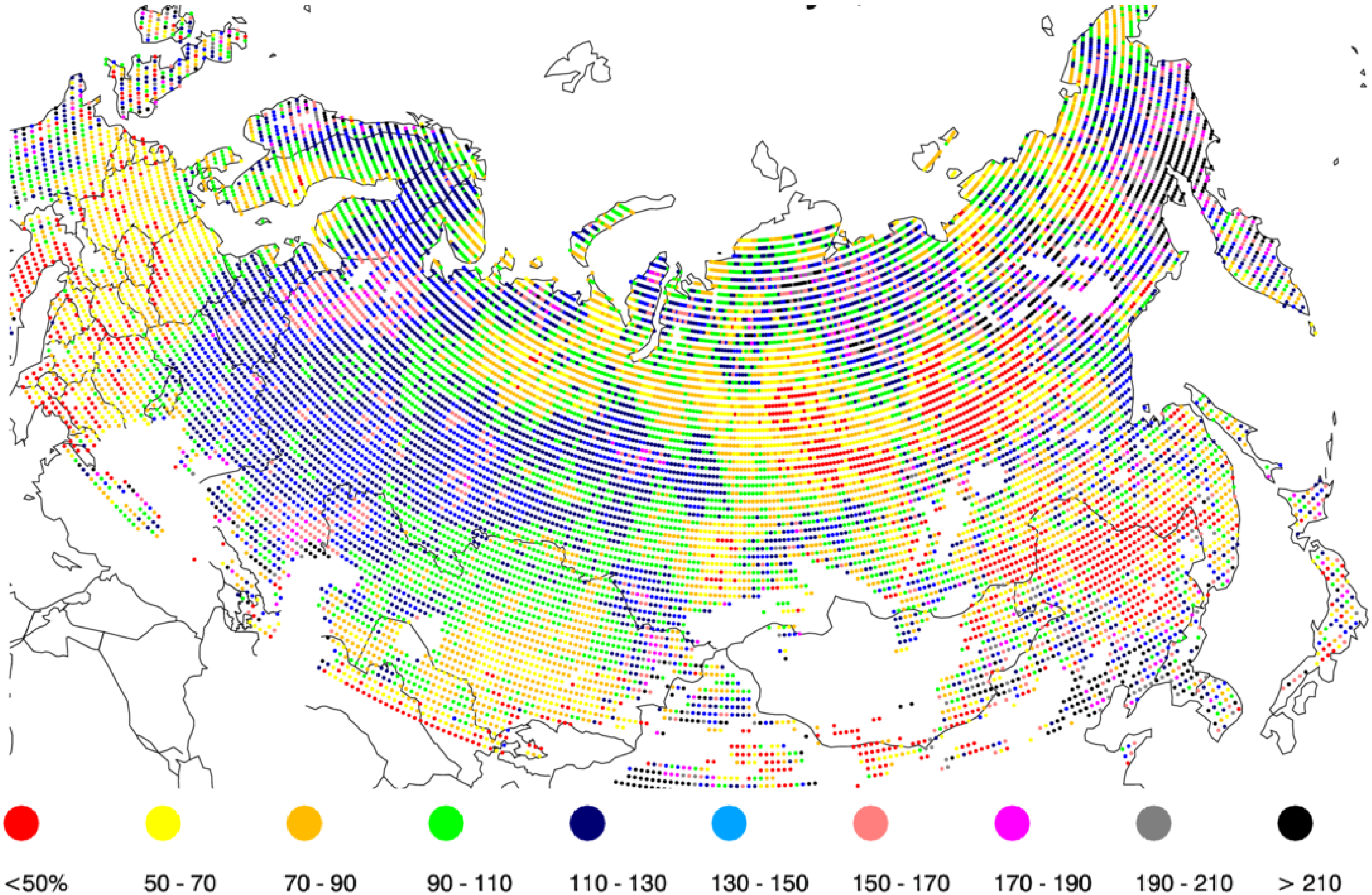
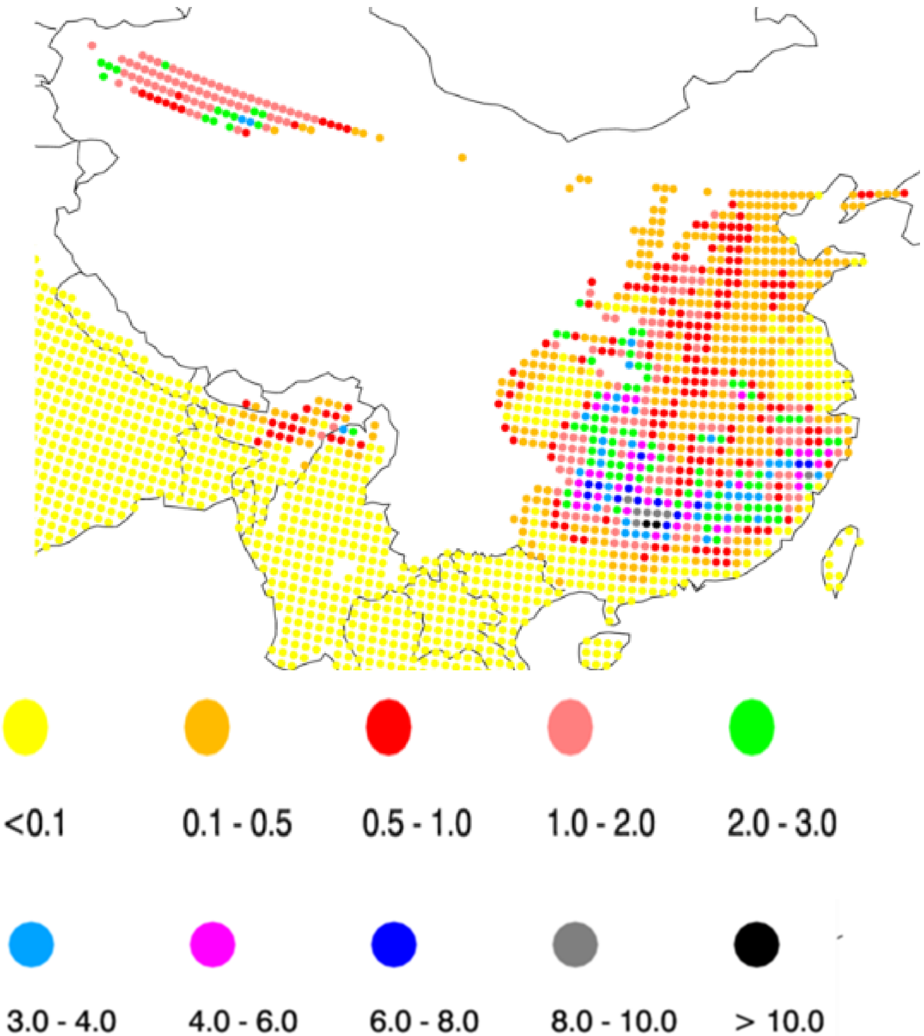


Freezing rain days change in the past 13 years (2005-2017) compared to the previous 26 years (1979-2004), %

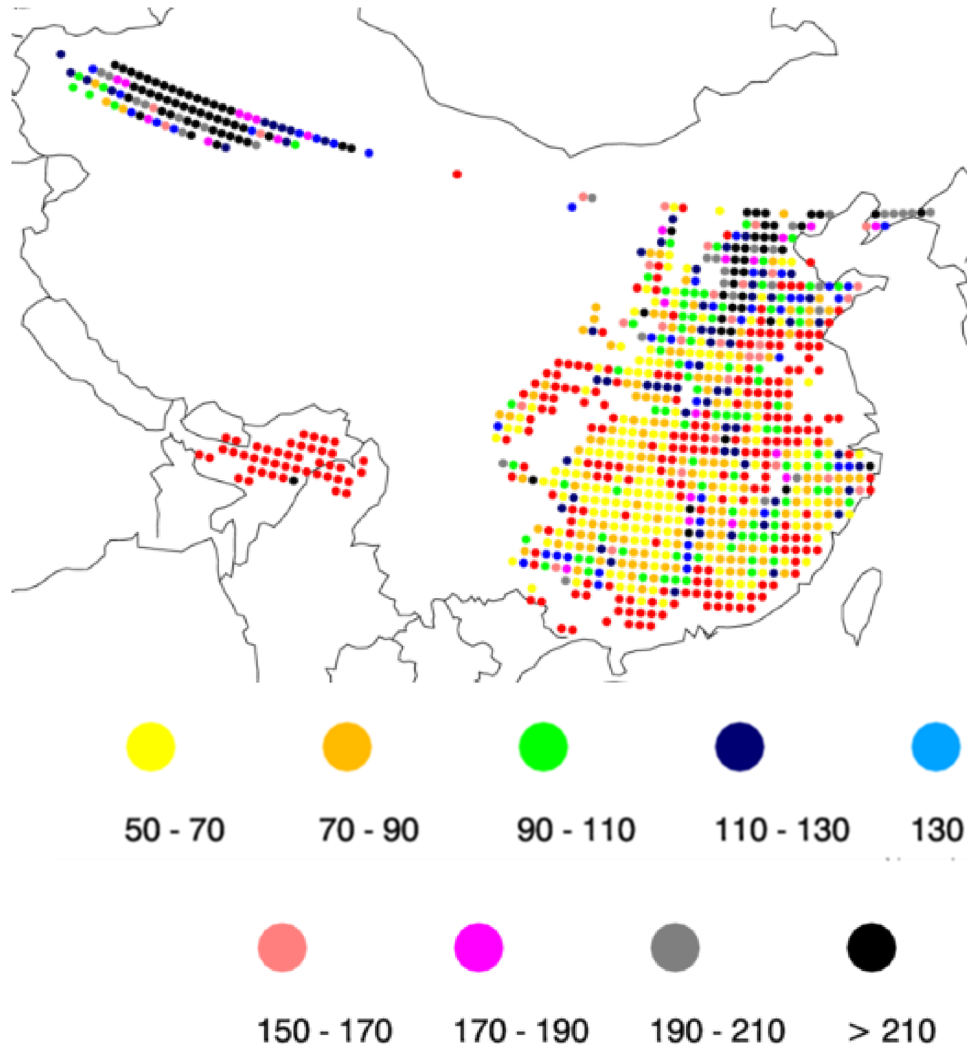


Freezing rain over China, south of 40°N

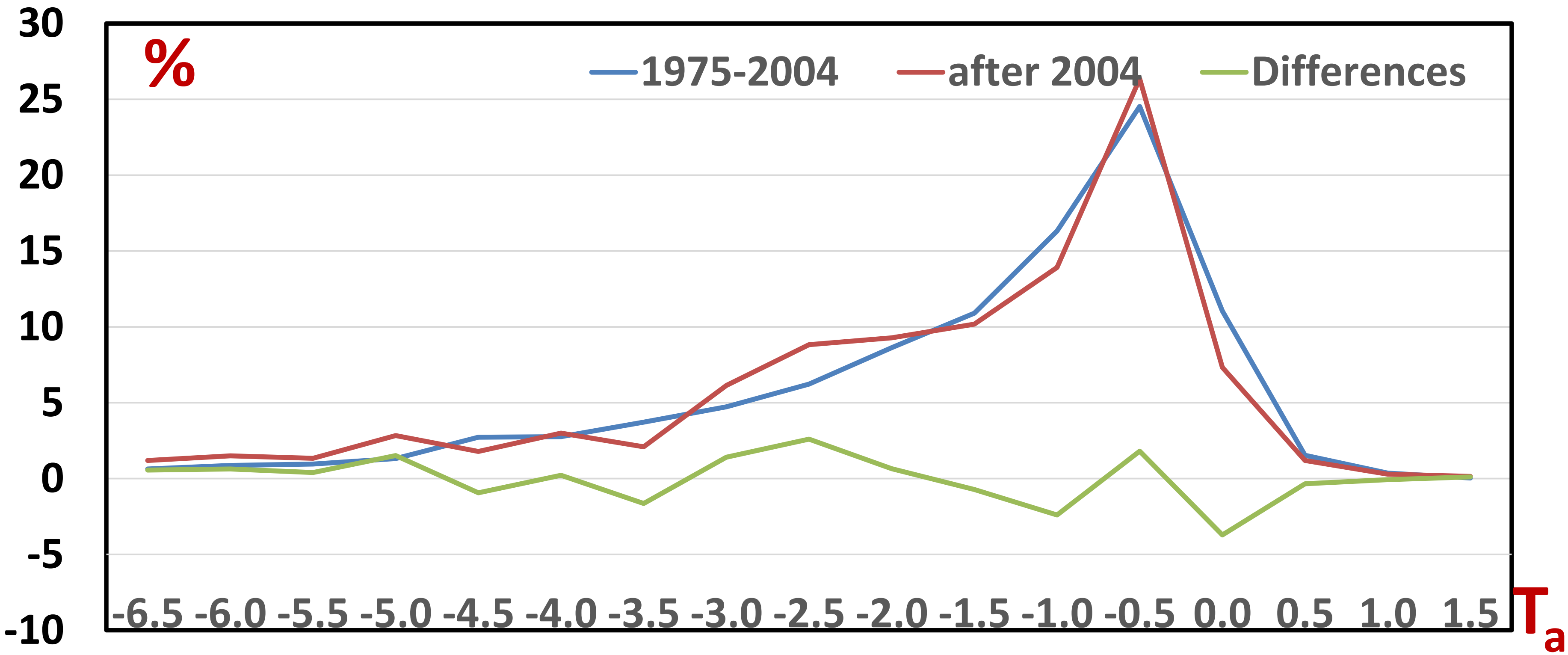
Climatology, 1979-2017; d yr^{-1}



Changes after 2004, %



Percent distribution of freezing rain events over Russia by associated surface air temperature T_a during the 1975-2004 and post 2004 periods



- Practically no differences with time in freezing rain distribution by T_a

Current achievements

- Using synoptic and aerologic data, we found the weather conditions that are mostly conducive to freezing rain (WCCFR)
- Now, these WCCFRs have been used to expand climatology of the freezing precipitation over the northern extratropics at low elevations.
- With the probabilities of 0.64 to 0.68 (depending upon the region), the WCCFRs characterize the "actual" freezing precipitation events reported by the CFSRv2 reanalysis.
- The algorithm of the WCCFR evaluation can be used for the FR spatial and future projections (e.g., within the reanalyses and future climate change scenarios).

Need to further study of freezing precipitation at high elevations

- **Changes here can be very different (cf., Kyrgyzstan, next slide)**

- **Freezing events here are quite frequent even in dry climates (cf., Western N. America and Tibetan Plateau, last slide)**

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 different elevation	below 1 km	from 1 to 2 km	above 2 km
Climatology, days(yr)$^{-1}$	0.98	0.61	0.25
Changes between two periods, days(yr)$^{-1}$	-0.31	-0.16	0.50

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

Mean annual frequency of days with freezing precipitation d $\times$(yr)$^{-1}$ as reported by the NCEP Climate Forecast System Reanalysis. V2 (CFSRv2)