**Project Reports for the GEWEX GHP Meeting**

**Full Panel, Project or Working Group Name (Acronym): Near 0°C Precipitation**
**Reporting Period: August 2018 – October 2019**
**Starting date: December 2014**
**End date: 2019**
**URL:**
**Chair(s) and term dates: P Groisman and R Stewart**

## 1. Regional Hydroclimate Project (RHP) or Cross-Cut (CC) activities over the last year

### *Science Issues:*

The overarching issue being addressed is improving our understanding of future changes in hazardous cold/shoulder season precipitation, especially occurring near 0°C.

Achieving this requires:

- understanding past and present changes as well as considering future conditions.

Addressing these issues requires an examination of several sub-issues including:

- data requirements and availability
- climatology of key variables and phenomena
- simulation and understanding of key driving processes
- assessment of projections and their shortcomings

Studies of near-0°C precipitation should also include assessments of their impact and suggest mitigation measures. Now, after we found that the freezing events frequency has been recently increased at high latitudes (from Alaska to Northern Europe) and in some mountainous regions (Tian Shan), these assessments are especially needed.

### *Science and Technical Highlights:*

Significant progress has been made in the sub-topics mentioned above as summarized here:

Data:

- An ongoing effort is still being devoted to producing reliable datasets in different regions that can be used for the analysis of near 0°C precipitation. It is difficult to have reliable consistent datasets within this temperature range with changing observational methods and standards.
- In regards to data across the northern extratropics, we compiled a data set of more than 1,500 long-term time series (40 years of data) of synoptic observations with freezing precipitation information (Figure 1).

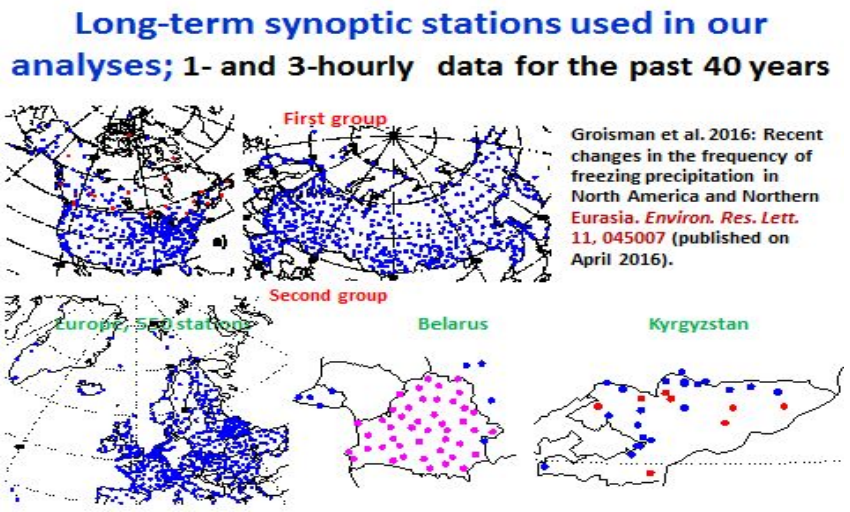



**Figure 1:** Long-term synoptic stations that have been currently accumulated (1 and/or 3-horly data during the past 40 years) and their freezing precipitation (rain and drizzle) information were used in our analyses (a) to build climatology of freezing events over the largest part of the northern extratropics and (b) to estimate the changes in occurrences of these events in the last decade and their trends (where they are present).

Climatology and the tendencies:

- The regions of the world in which climatology studies have either been finished or are underway have been increased and coincide with Figure 1, where we calculated the long-term mean values of annual occurrence of the days with freezing events, their trends and changes in the past decade (compared to the previous 30 years).
- We are continuing to document near 0°C precipitation features across Canada. Figure 2 is one example and it shows the variation in the occurrence of (any type of) precipitation when the surface temperature is near 0°C ($-2 \le T \le 2$°C) over the 1981-2011 period. There are distinct patterns across the country in terms of the total number of hours of precipitation (and freezing rain alone) as well as the fraction of hours near 0c with precipitation (and freezing rain alone).

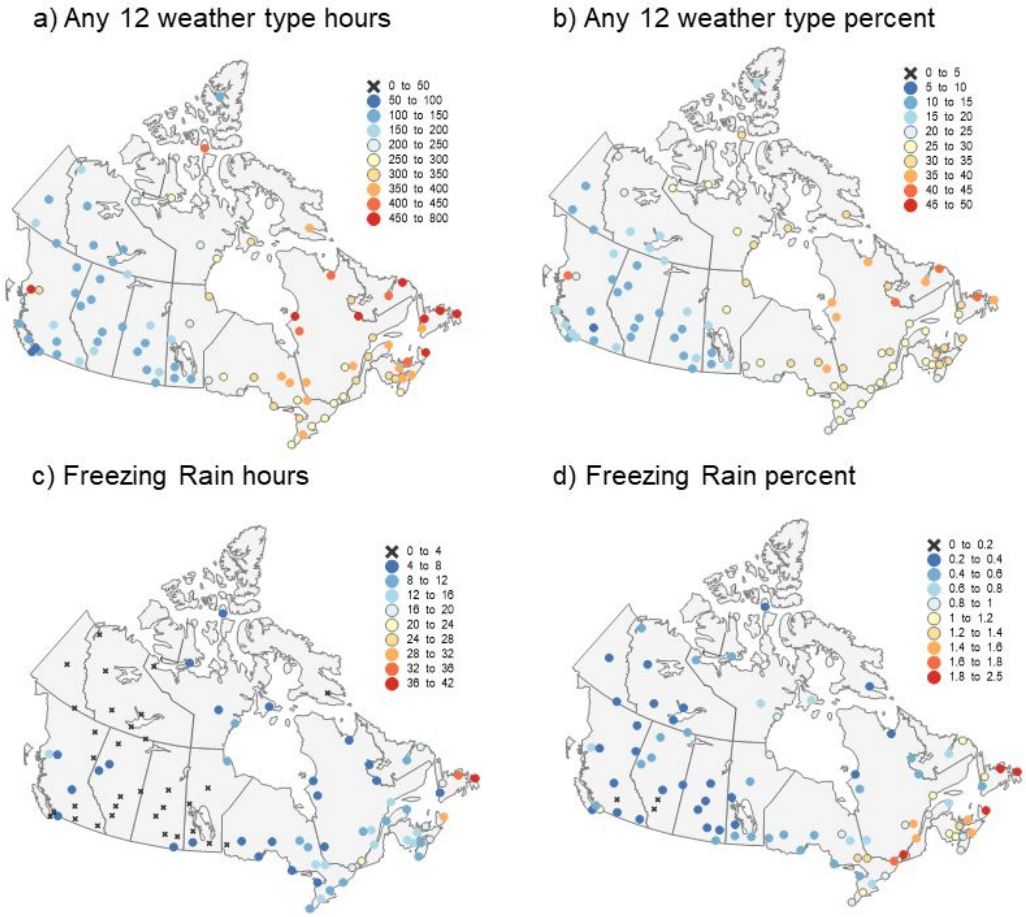



**Figure 2**: Precipitation type occurrences during near 0°C (-2°C ≤ T ≤ 2°C) conditions over the 1981-2011 period. (a) average annual number of hours with reported precipitation types (any of the 12), (b) percentage of near 0°C conditions associated with reported precipitation types (any of the 12), (c) average annual number of hours with freezing rain, and (d) percentage of near 0°C conditions associated with freezing rain.

Simulation and understanding:

- The WRF (Weather Research and Forecasting) model and CRCM5 Canadian Regional Climate Model (using the empirical technique of Bourgouin, 2000) were utilized to simulate precipitation type transitions over the western Cordillera of Canada (Almonte and Stewart, 2019).
- A parameterization using a new microphysics scheme has been developed to simulate freezing rain and ice pellets. It considers gradual melting and freezing of precipitation without adding significant computing time (Cholette et al., 2019).

Projections and shortcomings:

- Examination of many CMIP5 models over North America has illustrated that the near 0°C region will move northward but there is large variation in the actual displacement across the country (Stewart et al., 2019).
- Projections have been made on changes to ice loading on infrastructure across North America in association with changing freezing rain patterns (Jeong et al., 2019).

***New Projects/Activities Put in Place:***

- From in situ and upper air data, we characterized the occurrence of freezing events using other meteorological variables. We found a quite narrow intervals of the surface air and low troposphere temperatures associated with freezing events. The first were close or below to 0°C, while the lower tropospheric temperatures were unusually warm with frequent temperature inversions at low levels (Figure 3).

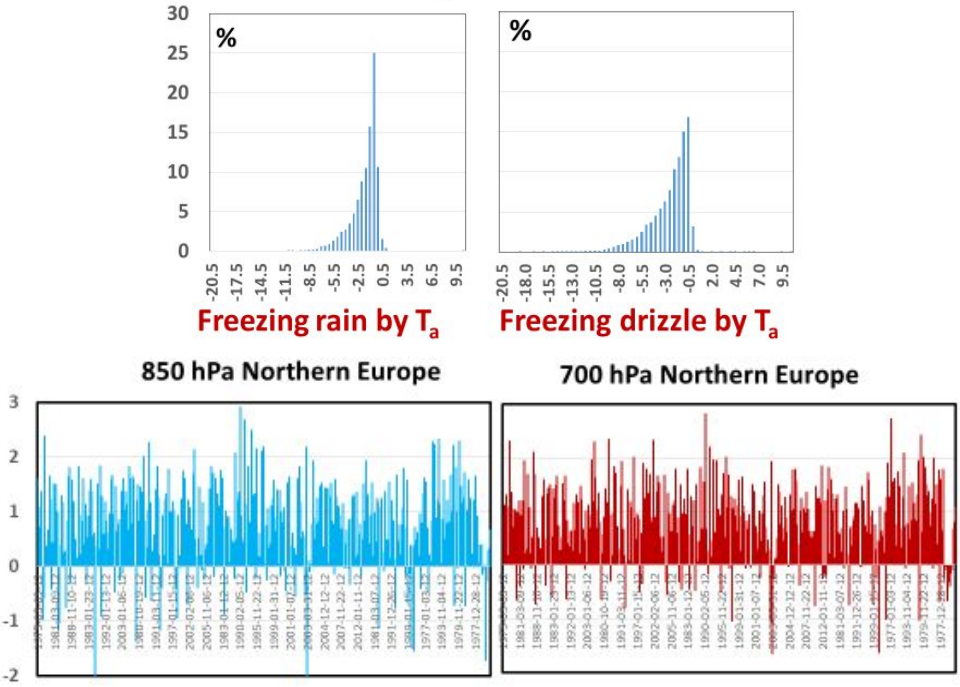



**Figure 3: Upper diagrams.** Freezing precipitation distribution (%) by associated surface air temperature, $T_a$ (over entire Russia). **Lower diagrams.** Upper air normalized temperature anomalies at 850 and 700 hPa for freezing events at eight stations in Fennoscandia. Similar anomalies were found over Russia, Alaska, and Canada.

- Using combinations of in situ (Figure 1), co-located upper air, and reanalysis data (specifically, the NCEP Climate Forecast System Reanalysis V2, CFSRv2 was used), we introduced the term "weather conditions conducive to freezing rain, WCCFR", when (with a high probability) precipitation occurs in the form of freezing rain. Thereafter, we built a climatology of WCCFR for North America and Northern Eurasia at the plain terrain with elevation below 1200 m asl (Figure 4) and estimated the latest WCCFR changes after 2005 (i.e., in the last third of the massive satellite era reports used in modern reanalyses; Figure 5).

Analysis of Figure 4 shows that weather conditions conducive to freezing rain (WCCFR) are most frequent in eastern and northern Europe, southwest Siberia, southern Canada, and northeastern and midwestern U.S. (can be 10 days/year or more). These conditions are more frequent over North America than over Northern Eurasia

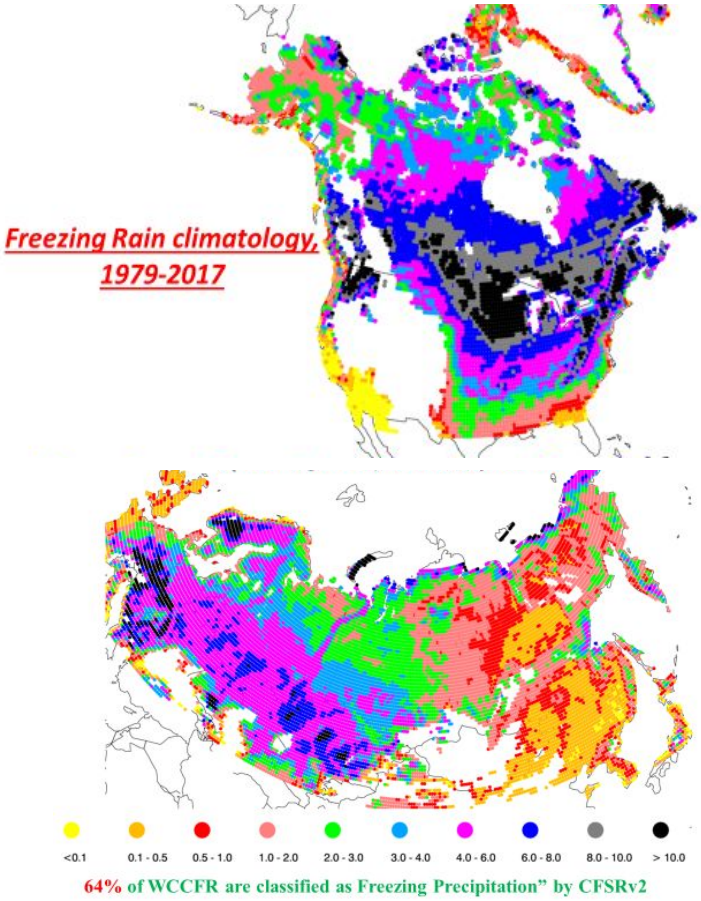
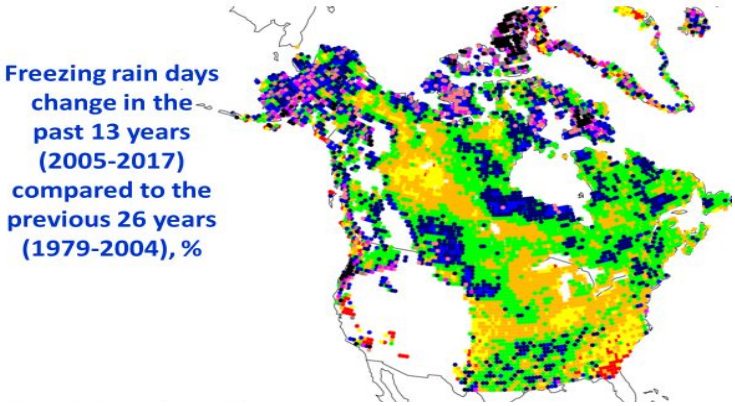



**Figure 4:** Annual number of days with weather conditions conducive to freezing rain.

The analysis of Figure 5 shows that since 2005, the frequency of WCCFR:

- increased over northern and eastern Europe, the Canadian Arctic, Alaska, and northern Great Plains, and
- decreased over western Europe, the boreal zone of western Canada as well as southeastern and midwestern U.S.



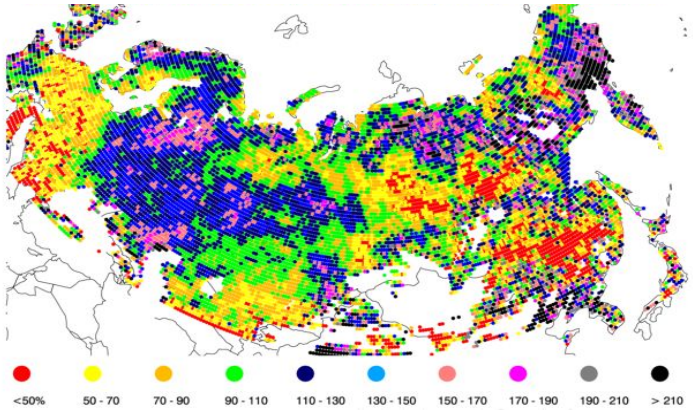



**Figure 5:** Freezing rain days change (%) in the past 13 years (2005-2017) compared to the previous 26 years (1979-2004) over North America (upper) and northern Europe/Asia (lower).

We were able to analyze the changes of the *freezing drizzle frequency* only over the countries where no automation was introduced in the weather type observations during the post-WWII period (e.g., the former USSR countries). There, we found a systematic decrease in the drizzle frequencies during the past 40 years (Figure 6).

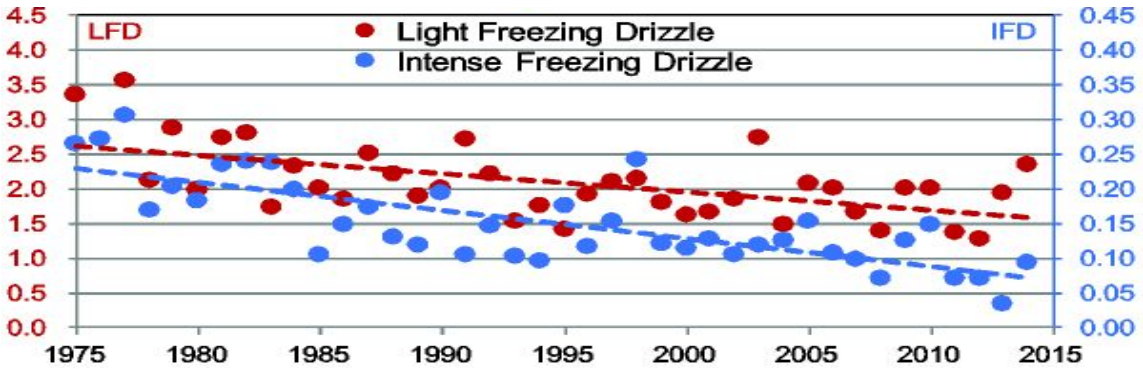



**Figure 6:** Annual Freezing Drizzle Frequency area-averaged over Russia. Light and intense freezing drizzle event frequency was averaged over the long-term stations of the Russian Federation. Occurrence of the light freezing drizzle occurrence (LFD) is approximately 10 times larger than the occurrence for intense freezing drizzle (IFD).

- We also submitted proposals to U.S. and Russian funding agencies to support our further activity on the Cross-cut Project keeping in mind that we shall need to (a) go into more details of near-0°C precipitation events and associated perils (changes in timing, intensity, and spatial pattern, handling the inhomogeneity in the data); (b) modify and complete our analyses for those countries, where synoptic information about freezing events is not readily available (first of all, for East Asia countries); and (c) assess the impact of perils associated with the near 0°C precipitation and project their changes in the next decades.
- A concerted effort continues to be made to quality control Canadian operational near 0°C regions and to utilize this information to characterize these regions. This includes the many types of precipitation as well as the associated state variables. It is intended that, once complete, this dataset will be made available to everyone via a web portal.

***Workshops and Meetings Held:***

- One in St. Petersburg, Russia (April 26-27, 2017) within the Annual Meeting of the Science Team of the BELMONT Forum International Project "The ARCTIC-ERA (**ARCTIC** climate change and its impact on **E**nvironment, infrastructures and **R**esource **A**vailability".

## 2. Planned activities for next year

This is the final report for this project. Over its 5-year period, significant accomplishments have been achieved:

- The topic itself has become better highlighted. Through, for example, presentations and research articles, there is an improved realization of the important issues associated with 0°C conditions.
- A substantial amount of progress has been made in connection with all the issues being addressed within this cross-cut.
- We have continued to deal with the shortcomings of observational information. Long-term records for precipitation near 0°C are difficult to access in some areas and this limits the extent to which climatologies and model evaluations can be carried out.
- We have carried out trend analyses using the best available information and have shown that, in some areas, there are significant shifts in the patterns of freezing precipitation.
- We have analyzed global and regional climate model information to examine future projections of freezing precipitation and have, for example, illustrated substantial increases in several regions of North America although we also pointed out that large variations occur between models.
- We have spurred on research to improve cloud microphysical parameterizations to better account for precipitation near 0°C which often undergoes full or partial melting and freezing.

We plan to submit a final summary of the project's progress for publication in GEWEX News.

It is recognized that much more needs to be done on the issue of hazardous precipitation near 0°C. We hope that future activities build on our progress on this important topic.

We would like to thank GHP for its support.

## 3. Contributions to the GEWEX Science Questions

GSQ1: Observations and Predictions of Precipitation

- Datasets are being carefully produced that document precipitation near 0°C.
- Initial assessments of projections are being made and limitations in model physics have been identified and steps have been and continue to be taken to rectify these.

GSQ2: Global Water Resource Systems

- Precipitation near 0°C represents a significant fraction of all precipitation over many regions and thus must be properly accounted for.
- Phase changes of melting and freezing near 0°C have significant hydrologic consequences and our progress in addressing this precipitation is therefore critical.

GSQ3: Changes in Extremes

- Precipitation near 0°C leads to many impacts and so the whole effort is contributing to the study of changing extremes.
- We found significant changes in the frequency of freezing rain precipitation occurrence over the extratropical regions of the Northern Hemisphere. In the Arctic and sub-Arctic, step-wise increases in their occurrence in the last decade have been found and in the south decreases have been observed (Groisman et al. 2016, *Environ. Res. Lett*.; see also Figure 4).

GSQ4: Water and energy cycles and processes

- Precipitation near 0°C occurs over many regions and is a significant component of the global water cycle that needs to be addressed. For example, more frequent switches from frozen to liquid forms of precipitation affect the seasonality of snowmelt and freshet.

**4. Activities contributing to the WCRP Grand Challenges as identified by the JSC**

This activity directly relates to the CLIMATE EXTREMES Grand Challenge. Freezing precipitation, for example, leads to enormous impacts and there continues to be major issues associated with its detection, change, understanding, and prediction and projection. This cross-cut is contributing to all these areas.

We do need to more closely link with the Grand Challenge leaders however. We are working somewhat in parallel that has traditionally not been addressed within the Grand Challenge itself.

**5. Cooperation with other GHP and WCRP projects (CLIVAR, CliC, SPARC), outside bodies (e,g. iLEAPS) and links to applications**

Much of this activity in Canada has been carried out in connection with the Canadian RHP GWF (Global Water Futures) and with Environment and Climate Change Canada. The near 0°C region has many hydrologic, ecological and societal impacts.

In the U.S., France, and the Russian Federation, this activity is carried out in close cooperation with the International Belmont Forum Project "The ARCTIC-ERA (**ARCTIC** climate change and its impact on **E**nvironment, infrastructures and **R**esource **A**vailability)."

Although this activity is relevant to CliC and CLIVAR as well, no formal linkage has been established.

## 6. List of key publications

The following is a list of some of the articles and presentations produced in association with this project over its full period.

### *Journal articles:*


Almonte, J. and R.E. Stewart, 2019: Precipitation transition regions over the southern Canadian Cordillera during January–April 2010 and under a pseudo-global warming assumption. Hydrol. Earth Syst. Sci., 23, 3665–3682, https://doi.org/10.5194/hess-23-3665-2019.

Barszcz, A., J. A. Milbrandt, J. M. Thériault, 2018: Improving the explicit prediction of freezing rain in a km-scale numerical weather prediction model. Weather and Forecasting, 33, 767-782.

Bresson, E, R. Laprise, D. Paquin, J.M. Thériault and R de Elia, 2017: Evaluating CRCM5 ability to simulate mixed precipitation, Atmos.-Ocean, 55, 79-93.

Bulygina, O.N., Arzhanova, N. M, and P. Ya. Groisman, 2015: Icing Conditions over Northern Eurasia in Changing Climate. Environ. Res. Lett. 10, 025003. doi:10.1088/1748-9326/10/2/025003

Cholette, M., H. Morrison, J. Milbrandt and J. Thériault, 2019: Parameterization of the bulk liquid fraction on mixed-phase particles in the Predicted Particle Properties (P3) scheme: Description and Idealized simulations, J. Atmos. Sci., 76, 561–582.

Groisman, P.Ya., O. N. Bulygina, X. Yin, R. S. Vose, S. K. Gulev, I. Hanssen-Bauer, and E. Førland 2016: Recent changes in the frequency of freezing precipitation in North America and Northern Eurasia. Environ. Res. Lett. 11, 045007.

Kochtubajda, B., C. Mooney and R.E. Stewart, 2017: Characteristics, atmospheric drivers and occurrence patterns of freezing precipitation and ice pellets over the Prairie Provinces and Arctic Territories of Canada: 1964 – 2005. Atmos. Res., 191, 115–127.

Jeong, D. I., A. Cannon, and X. Zhang, 2019: Projected changes to extreme freezing precipitation and design ice loads over North America based on a large ensemble of Canadian regional climate model simulations, Natural Hazards and Earth System Sciences Discussions, 1–23, doi:10.5194/nhess-2018-395.

Kämäräinen, M., Hyvärinen, O., Jylhä, K., Vajda, A., Neiglick, S., Nuottokari, J. and Gregow, H., 2016: A method to estimate freezing rain climatology from ERA-Interim reanalysis over Europe. Natural Hazards and Earth System Sciences Discussions, 1–29, doi:10.5194/nhess-2016-225.

Kochtubajda, B., R.E. Stewart, M. Flannigan, B. Bonsal, C. Cuell and C. Mooney, 2019: An assessment of surface and atmospheric conditions associated with the extreme 2014 wildfire season in Canada's Northwest Territories. Atmos.-Ocean, 57, 73-90, doi: 10.1080/07055900.2019.1576023.

Matte, D., J. M. Thériault and R. Laprise, 2018: Climate change study of mixed precipitation over southern Quebec using a Regional Climate Model, Climate Dyn., https://doi-org.uml.idm.oclc.org/10.1007/s00382-018-4231-2.

Mekis, E., Donaldson, N., Reid, J., Zucconi, A., Hoover, J., Li, Q., Nitu, R. and Melo, S, 2018: An overview of surface-based precipitation observations at Environment and Climate Change Canada, Atmosphere-Ocean, 56(2), 71–95, doi:10.1080/07055900.2018.1433627.

Mekis, E., R.E. Stewart, J.M. Theriault, B. Kochtubajda, B.R. Bonsal and Z. Liu , 2019: Assessment of near 0°C temperature and precipitation characteristics across Canada. Hydrol. Earth Syst. Sci. (Submitted)

Partasenok, I.S. S.V. Povajnaya, E.V. Kamarouskaya and P.Ya. Groisman, 2017: Peculiarities of Precipitation near 0°C Regime and Freezing Events Occurrence over the Territory of Belarus. Natural Resources, 2017, No.1, 69-76. Minsk, Belarus. ISSN 1810-9810 (in Russian, with Belorussian and English abstracts).

Stewart, R.E., K.K. Szeto, B.R. Bonsal, J.M. Hanesiak, B. Kochtubajda, Y. Li, J.M. Theriault, C.M. DeBeer, B.Y. Tam, Z. Li, Z. Liu, J.A. Bruneau, P. Duplessis, S. Marinier and D. Matte, 2019: Summary and synthesis of Changing Cold Regions Network (CCRN) research in the interior of western Canada: Part I – Projected climate and meteorology. Hydrol. Earth Syst. Sci., 23, 3437–3455, https://doi.org/10.5194/hess-23-3437-2019.

Thériault, J., I. Hung, P. Vaquer, R.E. Stewart and J. Pomeroy, 2018: Precipitation characteristics and associated weather conditions on the eastern slopes of the Canadian Rockies during March-April 2015. Hydrol. Earth Syst. Sci., 22, 4491-4512.

***Conference Papers/Reports (GEWEX 2018 Conference shown separately):***

Cholette, M., J. M. Thériault, J. A. Milbrandt and H. Morrison, 2016: Microphysics parameterization of explicit partial melting of snow to study the formation of freezing rain and ice pellets. 2016 International Conference on Cloud and Precipitation, Manchester.

Groisman P. Ya. 2018: Freezing precipitation, characterization of weather conditions associated with it, and changes of the frequency of its occurrence. Presentation on July 5, 2018 at the ENVIROMIS International Conference, Tomsk, Russia, July 5-11, 2018.

Groisman P.Ya. 2019: Human-Associated Extreme Events. The III International Scientific Conference "Science of the Future" co-located with the IV All-Russia Forum "Science of the Future – Science of the Youth" (Sochi, Russia, 14-17 May, 2019; delivered on the 15th May, 2019).

Groisman, P., X. Yin, O. Bulygina, I. Partasenok, O. Zolina, E. Førland, and I. Hanssen-Bauer, 2016: Freezing Precipitation and Freezing Events over Northern Eurasia and North America. Paper presented three times with gradual additions of the latest results: (1) at the Annual JpGU Meeting, Makuhari, Chiba, Japan, May 22-26, 2016; (2) at the 33rd International Meeting of the International Geographical Congress Union, Beijing, August 21-25, 2916 and (3) at the All-Russian Conference "Science of the Future", Kazan', Russia, .20-23 Sept. 2016.

Groisman, P.Ya., X. Yin, O. Bulygina, I. Partasenok, O.Zolina, E. Førland and I. Hanssen-Bauer, 2016: Freezing Precipitation and Freezing Events over Northern Eurasia and North America. 33rd International Geography Congress, Beijing, China, 21-25 August, 2016.

Groisman P.Ya, et al. 2017: Freezing Precipitation and Freezing Events over High Latitudes of the Northern Hemisphere: Climatology and the Last Decade Changes, Presented twice: at the ARCTIC ERA Workshop, April 26, 2017, St. Petersburg, Russia and at the AMAP Conference on Arctic Science: Bringing Knowledge to Action, Reston, VA, 24-27 April 2017

Groisman P.Ya., X. Yin, O. Bulygina, I. Danilovich, and O. Zolina. 2017: Understanding of Freezing Precipitation Processes and their Changes. The NEFI Workshop at the CITES Bi-annual Conf., Zvenigorod, Russia, September 3-7, 2017 (CITES = Internat. Conf. and Young Scientists School on Computational Information Technologies for Environmental Sciences").

Groisman P.Ya, Yin X., Bulygina O.N., Partasenok I., Gulev S.K., Zolina O.G. 2016: Freezing Precipitation and Freezing Events over the Northern Hemisphere Extratropics. XVI Glaciology Symposium, St. Petersburg, Russia, 24-27 May 2016.

Groisman, P.Ya., O. Bulygina, and A.I. Shiklomanov, 2016: Contemporary global climatic changes and their manifestation in the Dry Land Belt of Northern Eurasia. Paper presented twice: (1) at International Conference "Problems of Adaptation of Mountain Regions of Central Asia to Global Climate Change", Bishkek Kyrgyzstan, April 14-16, 2016; and (2) at the ENVIROMIS 2016 Conference, July 11-16, 2016, Tomsk, Russia.

Groisman, P.Ya., X. Yin, O. Bulygina, I. Partasenok, O.Zolina, E. Førland and I. Hanssen-Bauer, 2017: Freezing Precipitation and Freezing Events over Northern Eurasia and North America. 33rd International Geography Congress, Beijing, China, 21-25 August, 2016.

Groisman P.Ya, et al. 2017: Freezing Precipitation and Freezing Events over High Latitudes of the Northern Hemisphere: Climatology and the Last Decade Changes, Presented twice: at the ARCTIC ERA Workshop, April 26, 2017, St. Petersburg, Russia and at the AMAP Conference. on Arctic Science: Bringing Knowledge to Action, Reston, VA, USA, 24-27 April 2017

Groisman P.Ya., X. Yin, O. Bulygina, I. Danilovich, and O. Zolina. 2017: Understanding of Freezing Precipitation Processes and their Changes. The NEFI Workshop at the CITES Bi-annual Conf., Zvenigorod, Russia, September 3-7, 2017 (CITES = Internat. Conf. and Young Scientists School on Computational Information Technologies for Environmental Sciences").

Stewart, R.E., 2019: Near 0°C precipitation particles. Intl. Union Geodesy Geoph., Montreal.

Theriault J M, V Mcfadden, O Nikiema, R Laprise and D Paquin, 2016: Evaluation of the atmospheric conditions associated with freezing rain and ice pellets produced by regional climate model simulations, CMOS, Fredericton, N.-B., Canada.

Tropea, B. and R. Stewart, 2018: Freezing rain and wet snow affecting Manitoba. Prairie Division Canadian Assoc. Geographers, Hecla, Manitoba.

***Special Session at 8th (2018) GEWEX Open Science Conference:***

Groisman, P: Characterization of weather conditions associated with freezing precipitation and changes of the frequency of its occurrence.

Li, Y.: The characteristics of freezing rain over the Mount Nanyue.

Marinier, S. and J. Theriault: Precipitation characteristics during winter storms over eastern Canada using convection-permitting climate model simulations.

Matte, D., J. Theriault and R. Laprise: Projected changes of mixed precipitation over southern Quebec, Canada, using high-resolution regional climate simulations.

McCray, C. and J. Gyakum: Long-duration freezing rain events over North America: Regional climatology and maintenance mechanisms.

Mekis, E., R. Stewart, B. Bonsal, B. Kochtubajda and J. Theriault: An assessment of near 0°C temperature and precipitation characteristics across Canada.