Proposal of the *GEWEX/GHP Cross-Cut Project*:
"Cold/Shoulder Season Precipitation near 0°C"

Objective: To improve our understanding of future changes in hazardous cold/shoulder season precipitation and storms, especially occurring near 0°C.

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1. Background

Many regions of the world are subjected to precipitation occurring near 0°C during the cold and shoulder (spring/autumn) seasons (hereafter, near 0°C precipitation). Major snowstorms obviously occur but a wide variety of precipitation types (including freezing rain, freezing drizzle, ice pellets and wet snow) do as well. Several types often occur simultaneously and rain occurring on top of snow is a critical, related phenomenon.

Small changes in atmospheric conditions lead to major changes in the types or amount of near 0°C precipitation. For example, if near-surface temperatures are slightly above (below) 0°C, rain or wet snow (snow) occurs; if a slightly above-freezing inversion occurs (or not) aloft, freezing rain (snow) can reach the surface. It also needs to be recognized that solid precipitation amounts near 0°C (such as wet snow) can be the highest in a winter storm.

There are many impacts of near 0°C precipitation. Heavy snowfall generates hazards for infrastructure and transportation. Wet snow and freezing rain may create hazardous traffic conditions and icing on communication lines (Changnon 2003), and they can have major effects on ecosystems and wildlife (Millward and Kraft 2004; Zhou et al. 2011). Rainfall on mountainous terrain covered by melting snowpack (rain-on-snow events) may initiate intense snowmelt with flash flooding (Groisman et al. 2003; McCabe et al. 2007).

Near 0°C precipitation affects large regions of the world. Higher latitude areas such as Russia, Fennoscandia, Canada and United States are particularly prone but, on occasion, lower latitude regions are as well. For example, an ice storm in 1998 (Henson et al., 2011) remained the most costly natural disaster affecting Canada until rain-on-snow enhanced 2013 flooding in Alberta. Eastern portions of North America suffered from such an event at Christmas 2013 with infrastructure losses in the billions of dollars, a number of fatalities, and inconvenience for millions of people. Shanghai suffered a devastating 2008 freezing rain event (Zhou et al., 2011). In Germany, Frick and Wernli (2012) pointed out the many consequences on infrastructure and transportation of a devastating 2005 wet snow event.

With global climate change in the extratropics, the 0°C isotherm will not disappear and associated precipitation events will continue to occur. Rain should fall farther upslope in mountainous regions, thereby increasing the risk of flooding. Alterations in temperatures, storm intensity and track will alter the likelihood and occurrence of near 0°C precipitation including freezing rain (e.g. Lambert and Hansen 2011; Qian et al. 2014). Weakening of the atmospheric circulation in the extratropical regions (e.g., Tilinina et al. 2013; Wang et al. 2012) may lead to more polar jet stream meandering (e.g., Francis and Vavrus 2012) that can lead to more persistent near 0°C events. The overall warming, together with a larger influx of the water vapour in the winter atmosphere from the oceans (including ice-free portions of the Arctic Ocean) will allow more water vapour in the winter atmosphere that can increase the amount of near 0°C precipitation. And, near 0°C temperatures should generally move poleward and arrive at many locations earlier in spring or later in autumn. This could potentially affect the seasonal cycle of near 0°C precipitation.

Despite significant progress in addressing near 0°C precipitation, it remains a challenging issue. Kunkel et al. (2013) indicated that freezing precipitation was associated with the lowest level of understanding for both detection and attribution amongst several types of hazardous weather conditions affecting the U.S.

2. Rationale

Cold/shoulder season precipitation near 0°C is of interest to several components of GEWEX. It is certainly an important issue in some of GHP's (GEWEX Hydroclimatology Panel) regional projects such as CCRN (Changing Cold Regions Network) over western Canada, Baltic Earth and NEESPI (Northern Eurasian Earth Science Partnership Initiative). Such precipitation is also important for GDAP (GEWEX Data and Applications Panel) as it seeks to characterize precipitation globally, including its phase.

Cold/shoulder season precipitation issues have justifiably been recognized by GEWEX in its Science Questions. One of the activities identified in Science Question 4 (Extremes) is to examine "cold season extremes such as snowstorms, rain-on-snow episodes, freezing precipitation". Such an activity is undoubtedly of interest to CliC and is within the scope of the WCRP Grand Challenge on Extremes that is being developed.

3. Objective

Given the importance of this issue and its contributions to GEWEX and WCRP, it is proposed that a GHP cross-cut be developed to **improve our understanding of future changes in hazardous cold/shoulder season precipitation, especially occurring near 0°C.**

This requires understanding past and present changes and as well as considering future conditions. Addressing these requires an examination of several issues including data requirements and availability, climatology of key variables and phenomena, simulation and understanding of key driving processes, and assessment of projections and their shortcomings. Assessing the current situation in these various categories will undoubtedly lead to the identification of specific gaps.

Studies of near 0°C precipitation should also include assessments of their impact and suggest mitigation measures.

4. Phenomena

The overall issue of near 0°C precipitation is linked with several phenomena. These include blizzards (just snow), rain-on-snow (both phases with a particularly importance of the precipitation interaction with pre-existed snowpack), and freezing rain and drizzle (just liquid). The specific hazards associated with these events include:

4.1. Heavy snowfall/rainfall transition around °C

In the cold season (when surface air temperatures are less than approximately 1°C) precipitation occurs more frequently on days when surface air temperature is near 0°C and, because of the larger water holding capacity of the atmosphere compared todays with colder temperatures, the amount of this precipitation is also higher. When this precipitation occurs, it is also often linked with some rain and a transition between rain and snow may disrupt many human activities. Regional studies have been carried out in Norway, Canada, and Russia on the relationship between the fraction of precipitation falling in the solid phase (snow) as a function of surface air temperature (cf., Førland and Hanssen-Bauer, 2003). These studies show that ongoing climate change (warming in the high latitudes) has already affected this fraction causing numerous repercussions for the environment, terrestrial hydrology, and societal wellbeing (agriculture, housing, transport, and recreation).

4.2. Blizzards

Blizzards occur on days with snowfall accompanied with strong winds. The presence of snow on the ground, especially of light non-compressed dry snow may serve an additional source for blizzards when blowing snow is raised from the surface into the air. Although they can occur with a variety of temperatures, they occur near 0°C as well. For example, about 40% of blizzards over Russia with precipitation above 10 mm occur when surface air temperatures are within 1°C of 0°C.

4.3. **Rain-on-snow events**

Rain falling on snow causes more rapid snowmelt and this may result in flash flooding. An analysis of such events was carried out for the Arctic Climate Impact Assessment (ACIA 2005) and this should be revisited with a more thorough analysis.

4.4. **Freezing rain and freezing drizzle**

The production of liquid precipitation or drizzle falling at temperatures below 0°C occurs over many regions. Fundamental issues are still not yet understood in connection with the production of this precipitation, such as ice nucleation, and model algorithms need to be improved to handle such events. In addition, national archives of each country affected by such events preserve the history of the largest events (e.g., Changnon 2002; Carriere et al. 2000; Changnon and Bigley 2005; Cortinas et al. 2004) but they were never put together and/or analyzed in a joint manner and this has to be rectified.

4.5. **Ice load on infrastructure**.

Related to freezing rain and drizzle above, ice loading represents a major impact. Given warming at higher latitudes, there are now indications of the effects of more open water on icing. Recently, Bulygina et al. (2014) used the Russian "Atmospheric Events" archive for the past 30 years to show a significant increase in the maximum icing quantities over the three Western Russia regions adjacent to the Barents, Baltic and Black Seas. Generally, such changes can be expected in all "humid" Arctic regions with significant open sea areas that are more and more experiencing regional warming.

5. Proposed Tasks

Given the importance of near 0°C precipitation, concern for its future occurrence, and the relative lack of coordinated research on this topic, it is proposed to collectively address this issue.

Task 1. Prepare a review article for the *Bulletin of the American Meteorological Society*. Its objective will be to assess our current understanding of near 0°C precipitation, its trends and future occurrence and it will also highlight key scientific uncertainties related to it. It will utilize selected examples of phenomena and impacts from several countries.

A number of other tasks are being considered after this review is completed or as it is in progress. In no particular order, initial ideas include the following.

Task 2. Compile the metadata for each large national and international archive that has synoptic information relevant to the near 0°C precipitation.

Task 3. Using contemporary reanalyses and RCM simulations, study the physics of atmospheric processes that can be potentially associated with near 0°C precipitation. In association with this, develop regional impact criteria of near 0°C precipitation events such as thresholds (if any) when each type of near 0°C precipitation events begins to represent specific hazards.

Task 4. Create contemporary climatology of each type of near 0°C precipitation phenomena.

Task 5. Merge (establish coherence/relationship/linkages) observed changes in characteristics of near 0°C precipitation events (in particular, the hazardous events) with physical processes that define them. Using these relationships and GCM projections (e.g., CMIP5), perform projections of future characteristics of these near 0°C precipitation events and their impact.

Task 6. Improve the model representation of near 0°C precipitation. A substantial issue for this precipitation is that its driving mechanisms are complex and small changes in environmental factors can tip the precipitation from one type to another with large consequences. The assumptions and parameterizations in current models need to be assessed and recommendations made for their improvement.

Task 7. Assess criteria for distinguishing the phase and characteristics of precipitation. In any climatological or modelling study, the type of precipitation must be clearly deciphered but this obvious issue still needs to be addressed in a comprehensive manner.

6. Timing

This proposal will be presented at the upcoming GHP meeting in December, 2014 in Pasadena. It is hoped that the effort will be formally endorsed as a cross-cut activity at that meeting.

The proposed BAMS review article has just been started. The initial task will be to write a proposal to BAMS to approve the concept. This should be done by January 2015 and a good draft should be completed by July 2015.

No formal meeting of the whole group is currently planned. Informal meetings will occur at other workshops and conferences (e.g., the Annual AGU Meeting (December 2014) and Annual EGU Assembly (Vienna, April 2015). We have proposed a dedicated Parallel Session on this cross-cut topic at the International Science Conference "Our Common Future under Climate Change", July 2015, Paris, France http://www.commonfuture-paris2015.org/ and will investigate an opportunity to use this venue for a topical side event. Much of the interaction within this cross-cut will nonetheless be through e-mails and conference calls.

7. Accomplishments over Last Year

This proposed cross-cut was first presented to GHP about a year ago. It was just an idea at that time and at least three significant advances have subsequently been made.

(a) Article in *GEWEX News*: An article was published and another manuscript was submitted to *Environment Research Letters* (Groisman and Stewart 2014; Bulygina et al. 2014);

(b) Meeting at GEWEX Conference 2014: Draft concepts discussed. Meeting was attended by Roy Rasmussen, Pavel Groisman, Ronald Stewart and Co-Chairs (Jason Evans and Jan Polcher);

(c) International Research Team was developed: A number of individuals have been contacted and who now appear as team members. This list of participants will undoubtedly grow as the cross-cut moves forward.

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