# Future winter extreme temperature and precipitation events in the Arctic

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[1] This study investigates the possible changes in future winter temperature and precipitation extremes in the Arctic using the regional climate model HIRHAM4. Under the B2 emission scenario conditions, frequency and intensity of future (2037–2051) extremes have changed significantly compared to the present-day (1981–1995) extremes. Extreme precipitations have intensified and the number of extreme events has changed significantly over East Siberia and Barents Sea. Extreme warm and extreme cold temperatures have become warmer with maxima over Barents Sea and Central Eurasia. Changes in the mean climate and its variability are modulating the future winter extreme events. **Citation:** Saha, S. K., A. Rinke, and K. Dethloff (2006), Future winter extreme temperature and precipitation events in the Arctic, *Geophys. Res. Lett.*, *33*, L15818, doi:10.1029/2006GL026451.

## 1. Introduction

[2] Instrumental records show an increase in global averaged annual surface air temperature by 0.6°C in the 20th century [*IPCC*, 2001]. Coupled Atmosphere-Ocean General Circulation Models (AOGCMs) project an increase in global mean annual surface temperature by 1.4–5.8°C over the period 1990 to 2100. Since the projected surface temperature increase in the Arctic is much higher than the global average increase [*ACIA*, 2005], the Arctic permafrost regions [*Zhang et al.*, 2000] may decrease rapidly in the future [*Lawrence and Slater*, 2005] as they are very sensitive to the temperature increase. It has been seen that the economy, human health and the natural environment are increasingly becoming vulnerable to the extreme climate events [*Kunkel et al.*, 1999; *Easterling et al.*, 2000]. There is growing evidence that the extreme events will also change in the future along with the rapid increase in mean climate [*Kharin and Zwiers*, 2004; *Meehl et al.*, 2005; *Barnett et al.*, 2006; *Boo et al.*, 2006].

[3] AOGCMs have been used to study the regional scale extreme climate change [e.g., *Weisheimer and Palmer*, 2005]. But their application to study regional scale climate processes is limited due to the coarse resolution. On the other hand high resolution regional climate models (RCMs), driven by AOGCMs boundary condition are able to resolve small scale climate processes. *Christensen and Christensen* [2003] have pointed out the increase in extreme summer precipitation over Europe using a RCM which covers parts of the Arctic. So far there is no further study of future extreme events using a RCM applied over the circumpolar Arctic region. We have investigated the future change in extreme 2 m air temperature and precipitation by using RCM HIRHAM4, applied over the Arctic.

[4] Aim of this paper is to illustrate possible changes in extreme precipitation and temperature events during the middle of 21st century in the Arctic under IPCC B2 emission scenario conditions.

## 2. Model and Simulation Setup

[5] The RCM HIRHAM4 has been applied in the circumpolar Arctic region first by *Dethloff et al.* [1996] and afterward it has been used for several Arctic applications [e.g., *Dorn et al.*, 2003; *Rinke et al.*, 2004]. The model horizontal grid resolution of 0.5 degree in rotated latitude, longitude has been applied over all north of ~65°N. Further details of the model dynamical and physical configurations are given in *Christensen et al.* [1996] and *Dethloff et al.* [1996].

[6] HIRHAM4 has been used to simulate climate for two time slices each of 15 years, where the first time slice (1981–1995) represents the present day climate and the second time slice (2037–2051) represents the possible future climate. The lower and lateral boundary conditions of HIRHAM4 are provided in every 12 hours from the AOGCM ECHO-G [*Legutke and Voss*, 1999] with T30 atmospheric resolution. For the first time slice simulations, boundary conditions from control ECHO-G run [*González-Rouco et al.*, 2003] and for the second time slice simulations IPCC B2 scenario run made by ECHO-G have been used. The ECHO-G control run used past three external forcing factors: solar variability, atmospheric greenhouse gas (GHG) concentrations and stratospheric volcanic aerosols whereas the B2 scenario run used fixed external forcing except for the future GHG concentrations. Aerosol forcing is not considered in the B2 scenario run.

## 3. Results

[7] We have followed the definition of extreme events used by *Sánchez et al.* [2004], where extremes are the 90th and 10th percentile of daily mean within a season. We used daily data of each 15 years long time slices, where 15 × 90 data at each model grid point during one season are used for calculating percentiles. Only daily precipitations above 0.1 mm are used for percentile calculation. Our analysis showed that maximum change in future extreme temperature and precipitation are during winter (DJF). We have presented here the results of winter season only.

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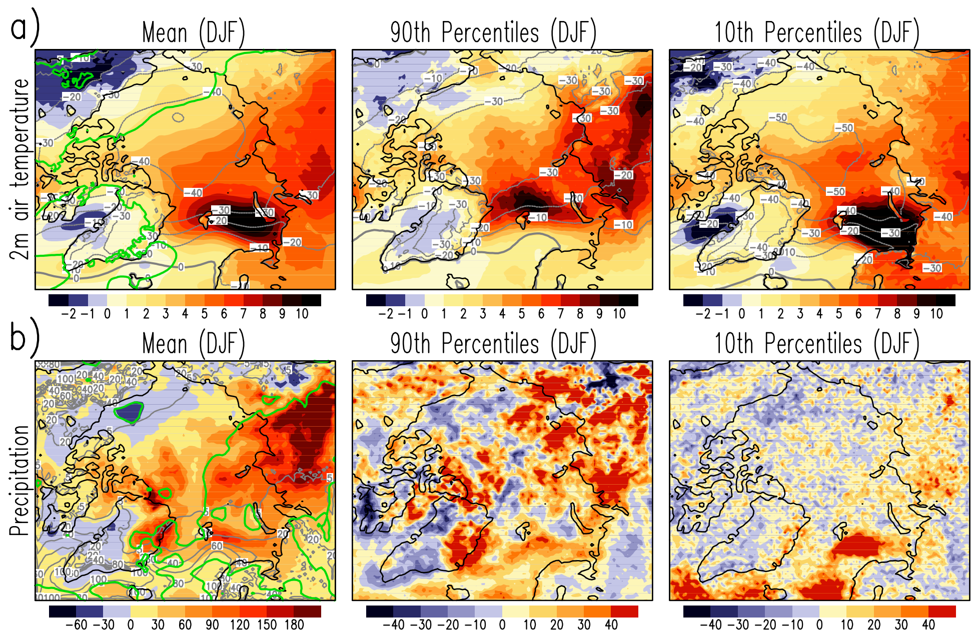


**Figure 1.** Changes (shaded color) in winter (DJF) mean, 90th percentile and 10th percentile (a) 2 m air temperature (in °C) and (b) precipitation (in percentage) between control (1981–1995) and B2 scenario (2037–2051) simulations. Positive and negative values indicate increase and decrease respectively in the future time slice. Gray contours represent the corresponding actual winter temperature (°C) and precipitation (mm month$^{-1}$) for the time slice 1981–1995. Green contours represent the 95% significance level.

### 3.1. Temperature

[8] Shaded color plot in Figure 1a shows the changes in future (2037–2051) mean and extreme winter 2 m air temperature compared to the present day (1981–1995) climate simulations. The isolines show the mean and extreme temperature for the present day climate simulations. Maxima of mean warming are over central Eurasia and Barents Sea, which is in agreement with the projections made by several global models [*ACIA*, 2005]. Mean future winter air temperature is warmer by 8°C over central Eurasia and by more than 10°C over the Barents Sea with 95% significance level. Like most of the AOGCMs, ECHO-G predicts a maximum winter sea-ice retreat over the Barents Sea in the middle of this century, which causes largest winter warming over this region.

[9] Future winter extreme warm temperature is warmer by a maximum of 8–10°C over Barents Sea, central Eurasia and East Siberia. Extreme cold temperature is warmer in the future time slice with maximum over Barents Sea by more than 10°C. There is a clear indication of shifts in extreme cold and warm events toward warmer conditions along with the mean change. Additionally there are much regional variations in the extreme temperature change. The locations of maxima of extreme changes are not necessarily always coincided with the maxima of mean air temperature increase. *Mearns et al.* [1984] has shown from observations that the frequency of extreme temperature changes nonlinearly with the changes in mean. Our model also shows that the extreme temperature does not change linearly with the mean temperature change.

### 3.2. Precipitation

[10] Figure 1b shows the change in winter mean and extreme precipitation. In the warmer climate, mean precipitation has been increased over Scandinavia, Barents Sea, Kara Sea, Laptev Sea and East Siberia by 30–180% and are significant at 95% level. HIRHAM4 is able to reproduce winter Siberian High pressure pattern quite realistically for the present climate [*Saha*, 2005], which results in a very low precipitation. The absolute increase in winter precipitation is highest over north Atlantic storm track region. Isolines over the mean precipitation change show the monthly mean winter precipitation for the present day climate. The model is able to reproduce the winter precipitation maxima associated with storm tracks in the right place. Nevertheless the percentage of precipitation increase in the model is found highest over East Siberia. The domain averaged convective precipitation during winter has increased by 1.21 mm month$^{-1}$ (14%) with main contribution from the north Atlantic Ocean and the Barents Sea region. The sub-domains D1 and D2 have showed an increase in convective precipitation by 2.27 mm month$^{-1}$ (70%) and 0.026 mm month$^{-1}$ (134%) respectively.

[11] The 90th percentile precipitation has increased most noticeably over Siberia and north Atlantic by 30–50%. Increase in 90th percentile precipitation indicates that the extreme high precipitation will further intensify in the warmer climate and the intensity is regionally distributed. There are no big changes in 10th percentile precipitation, except over part of Barents Sea and north Atlantic Ocean, where a tendency to more wet condition has occurred. Retreat of Barents Sea sea-ice enables additional moisture supply to the winter cyclones, which increases the 10th percentile precipitation.

[12] We have defined the consecutive days including single day precipitation with 90th percentile or above as a "wet event" and the consecutive days including single day precipitation with 10th percentile or below as a "dry event".

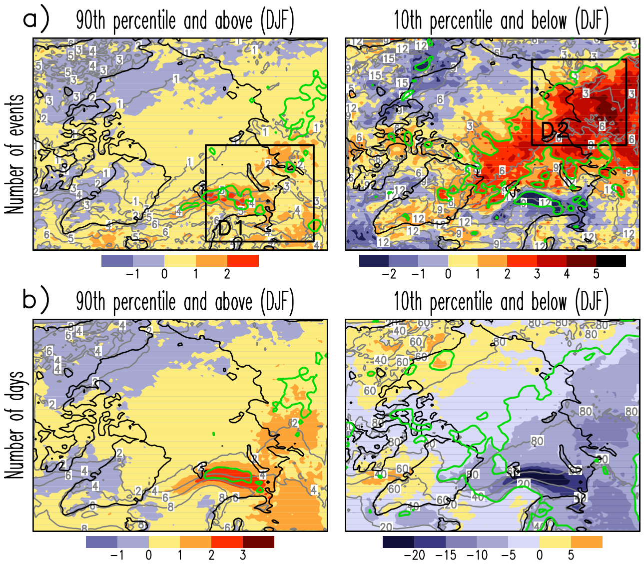


**Figure 2.** (a) Projected change (shaded color) in number of precipitation events with 90th percentile or above and 10th percentile or below precipitation. Isolines show the number of extreme events during 1981–1995. (b) Projected change in number of days associated with 90th percentile or above and 10th percentile or below precipitation. Gray contours represent the number of extreme event days during 1981–1995 and green contours represent the 95% significance level.

We have also calculated the total number of days associated with wet events and dry events in a season. Figure 2a shows the change in precipitation events during winter. Though the extreme high precipitations in the East Siberia have intensified (Figure 1b), there are very few precipitation events which cross the 90th percentile. In the future climate scenario, the high precipitation regions connected with storm track has extended further to the north and north-east (Figure 2). Therefore, the number of wet event has increased by 100% in north of Spitsbergen and part of Kara Sea. Dry events over East Siberia and central Arctic have increased by about 70–100%. This indicates that there are frequent precipitation events in the future warmer climate, which may not necessarily exceed the 90th percentile.

[13] Figure 2b shows the change in cumulative number of days associated with wet and dry events. A consistent increase in the cumulative number of days associated with wet events is seen over the region where future wet events have increased. The decrease in cumulative days associated with dry event over Barents Sea is also consistent with the decrease in number of dry events. Furthermore the decrease in number of cumulative days associated with dry event over Siberia and central Arctic is due to the increase in precipitation events that are above the 10 percentile of daily precipitation. An increase in precipitation events also reduces the average day-length of dry events. A large percentage of increase in monthly mean winter precipitation (Figure 1b) over Siberia, Barents Sea, Kara Sea and Laptev Sea is due to more frequent wet events as well as due to increase in moderate precipitation events. These changes result into an increase in number of dry events and decrease in cumulative days associated with dry events.

## 4. Discussion

[14] Changes in future extremes with respect to present day extremes depend on the mean climate change as well as on the changes in climate variability [*Meehl et al.*, 2000]. The Gaussian distribution of daily 2 m air temperature shows that the mean of future temperature has shifted toward the warmer climate (Figures 3a, 3d) and the variability has decreased and increased respectively over subdomains West Russia-Scandinavia and East Siberia (areas D1 and D2 respectively in Figure 2). These two changes (mean and variability) together have modified the future temperature extremes (tails). Future mean precipitation has increased and the variability has changed (Figures 3b and 3e), which have modified the future precipitation extremes.

[15] Increase in the future high latitude precipitation intensity is connected with the atmospheric moisture content, which has been advected from low latitude [*Barnett et al.*, 2006]. According to Clausius-Clapeyron equation, saturation vapor pressure increases with temperature and therefore, the water holding capacity of atmosphere increases. So the winter storm track which brings warm and moist air into Scandinavia and Western Russia can intensify precipitation under warmer conditions. Release of more latent heat can facilitate future weaker storm to grow into a vigorous one than those in the present climate. Such development may increase the future number of precipitation events. During winter heat and moisture are transported to higher latitudes by cyclones and anticyclones, whereas during summer this heat transfer from the ocean into the atmosphere is mainly due to convection. In the RCM simulations the heat and moisture increase is partly by inflow through the boundaries and partly by additional heat and moisture supply connected with the reduced sea-ice

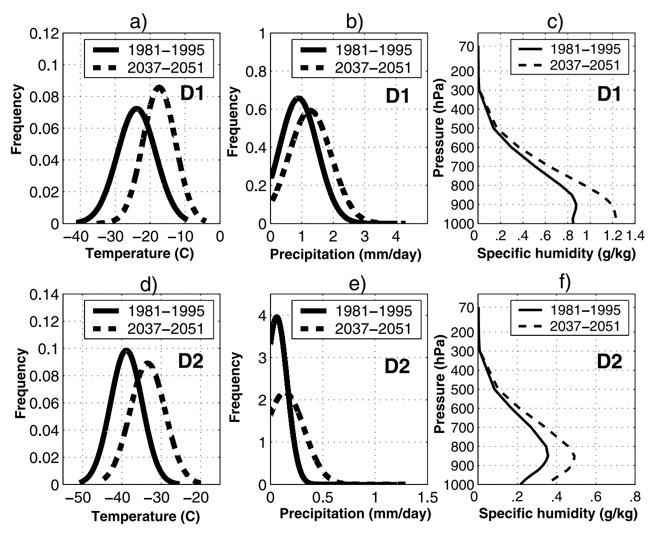


**Figure 3.** (a and d) Gaussian distribution of daily winter temperature (in °C) and (b and e) winter precipitation (in mm day$^{-1}$) averaged over areas D1 and D2 (shown in Figure 2). (c and f) Area averaged (D1 and D2) vertical profile of monthly mean specific humidity (g kg$^{-1}$) during winter.

cover over the Arctic Ocean. However it is difficult to say which one of the above two processes will be more relevant or to distinguish their individual impact. In the described scenario simulations the temperature of the troposphere increases but there is also a pronounced increase of moisture at the lower levels implying an increase in moist instability over winter storm track region as shown in Figure 3c. The increase in future convective precipitation (section 3.2) is an indication of increased convection which is probably connected with the higher convective available potential energy (CAPE). An increase of CAPE in the $CO_2$ climate was explained by *Rennó and Ingersoll* [1996], who showed that the increase in surface temperature lead to an increase in CAPE. Therefore the total CAPE value is larger in a warmer and moister climate regime. As a result of strong convection, more moisture is transported to the further east along with the storm movement. The larger increase in low level specific humidity over D1 region compared to D2 region is connected with the Barents Sea sea-ice retreat.

## 5. Conclusion

[16] Extreme events are very sensitive to the climate change in the model. The model shows very significant changes in the frequency and intensity of extreme temperature and precipitation in the Arctic in 3–5 decades from now due to GHG increase. Additionally the changes are highly regional dependent. The location of changed maxima and minima of extreme temperature and precipitation does not always coincide with the location of the mean maxima, minima changes. There are significant changes in the future extremes with respect to the present day extremes. However the shape (frequency, intensity) of extremes defined by the respective climate could also change.

[17] The RCM results can vary depending on the driving AOGCMs. In particular, the ECHAM models are sensitive in terms of large-scale atmospheric circulation patterns and their teleconnection [*Stephenson and Pavan*, 2003]. The presented results are based on only one specific AOGCM and are for the B2 scenario. A multimodel ensemble approach could further increase the confidence about these future projections of extreme climate.

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