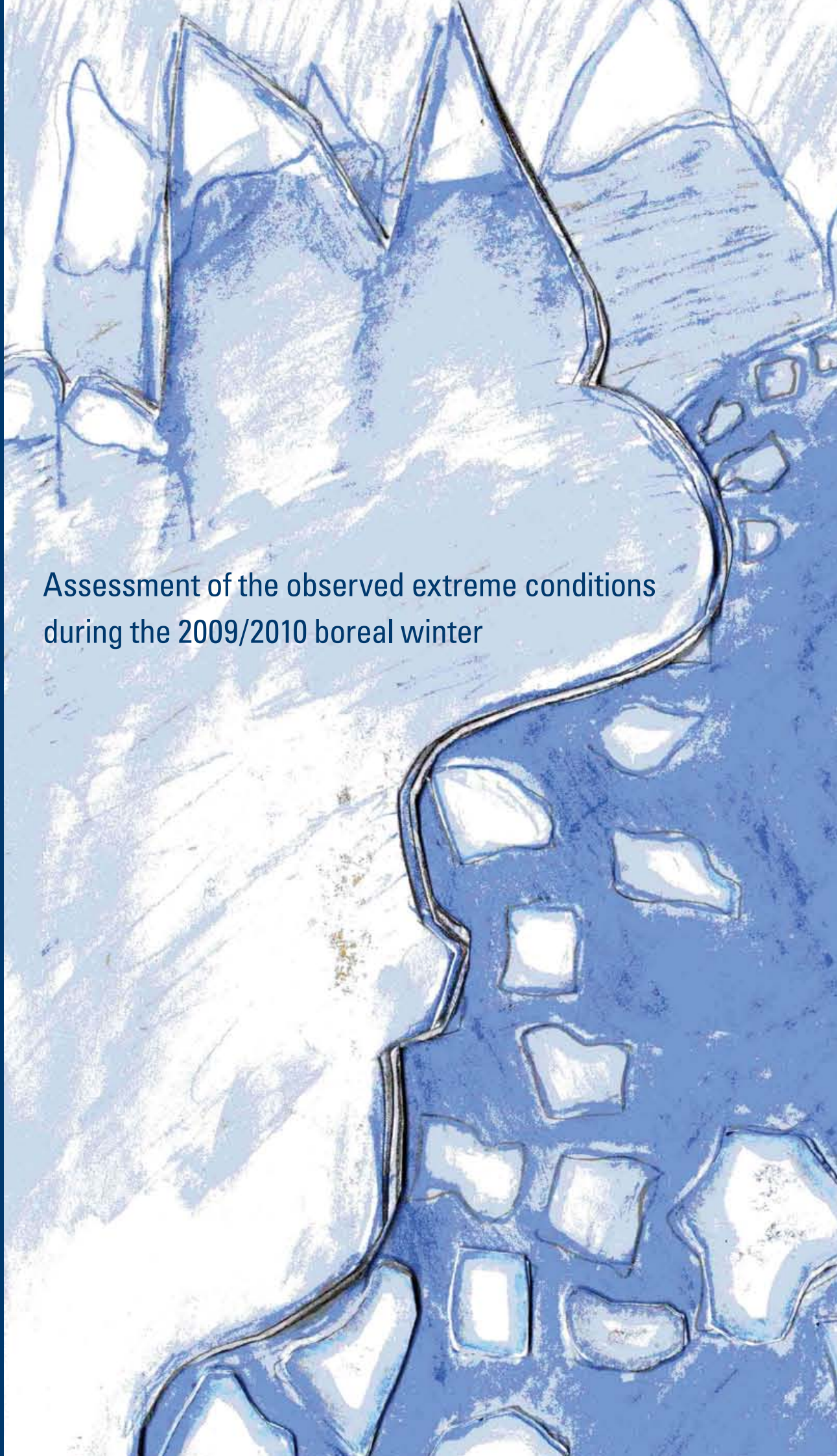

Assessment of the observed extreme conditions during the 2009/2010 boreal winter

World Meteorological Organization
Weather • Climate • Water

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Contributions by: Peter Bissolli, Deutscher Wetterdienst (DWD), German Meteorological Service, WMO Regional Association VI Pilot Regional Climate Centre on Climate Monitoring, Germany; Christophe Cassou, European Centre for Research and Advanced Training in Scientific Computation, France; Lijuan Chen, Beijing Climate Centre, China; Dmitry Kiktev, Hydrometeorological Centre of the Russian Federation; Vladimir Kryjov, Hydrometeorological Research Centre of the Russian Federation; D.R. Pattanaik, India Meteorological Department; Michel Schneider, Météo-France; and François Vinit, Météo-France

Reviewed by: Pierre Bessemoulin and Philippe Dandin, Météo-France; John Kennedy, Met Office, United Kingdom of Great Britain and Northern Ireland; Lucie Vincent, Environment Canada; Arndt Derk, National Oceanic and Atmospheric Administration/National Climatic Data Center (NOAA/NCDC), United States of America; and Manola Brunet, University of Rovira i Virgili, Spain

Web information sources include: NOAA/ NCDC, United States; NOAA/Climate Prediction Centre, United States; Met Office, United Kingdom; National Aeronautics and Space Administration (NASA), United States; and National Snow and Ice Data Center (NSIDC), United States

Chair, Publications Board
World Meteorological Organization (WMO)
7 bis, avenue de la Paix
P.O. Box 2300
CH-1211 Geneva 2, Switzerland

Tel.: +41 (0) 22 730 84 03
Fax: +41 (0) 22 730 80 40
E-mail: publications@wmo.int

Cover: Pollution of the seas (detail). Illustration by Caitlin Harrison, 11 years old, South Africa

Foreword

At its fifteenth session, held in Antalya, Turkey, in February 2010, the WMO Commission for Climatology decided that climate monitoring activities would henceforth include, inter alia, information gathering and analyses on extreme weather and climate events that might be considered especially relevant in terms of major societal impacts.

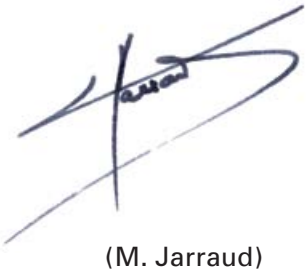
In this respect, the Commission agreed on a new approach to facilitate, whenever possible, an appropriate scientific description of causes and effects specifically associated with these key events, as a complement to the more general Statements on the Status of the Global Climate, which WMO regularly publishes on a yearly basis in collaboration with its Members.

The 2009/2010 winter was characterized by cold to extremely cold temperatures over large extensions of the northern hemisphere, including parts of Europe, Asia and North America, where the associated cold spells caused exceptional snowfall and contributed to making this winter an outstanding case study.

In particular, these conditions were found to be associated with large-scale atmospheric disturbances connected to the Arctic and North Atlantic Oscillations, as well as the El Niño event, which commenced in summer 2009 and continued throughout the first quarter of 2010.

It is noteworthy, however, that regardless of these exceptionally cold and widespread conditions, other parts of the northern hemisphere, including the Arctic region and Canada, recorded mild to very mild winter conditions. In addition, the combined global land and ocean average surface temperature for the period between December 2009 and February 2010 has been determined to be above the long-term average over the reference period 1961–1990 as compiled on the basis of Members' datasets under the international coordination of WMO.

I am indeed confident that, in addition to climate watch activities, the present report will also contribute to further progress in the climate knowledge base.



(M. Jarraud)
Secretary-General

Introduction

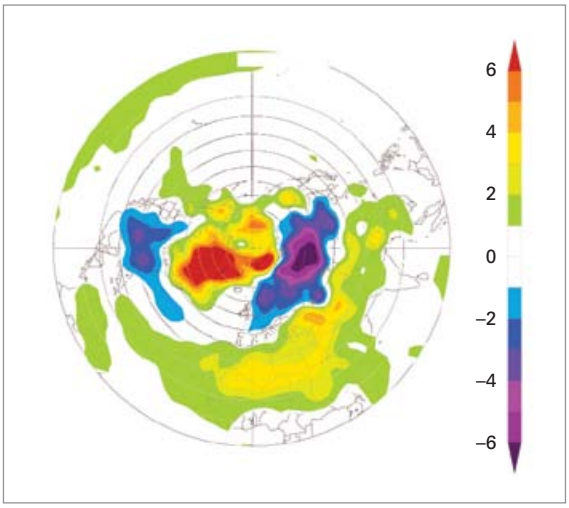


Figure 1. Winter 2009/2010 temperature anomaly for December–January–February at 1 000 mb based on NCEP–NCAR reanalysis, with 1968–1996 as a reference period *(Source: NOAA, Earth System Research Laboratory, Physical Sciences Division)*

During boreal winter 2009/2010 (the period from December 2009 to February 2010), extreme conditions were recorded in many places. Strong negative temperature anomalies and heavy and prolonged snow conditions occurred over Europe, the Russian Federation and parts of North America, particularly the United States, and Asia (Figures 1 and 2). Though winter is naturally a cold season in the northern hemisphere, the persistence of cold spells and heavy snowfall over large areas made boreal winter 2009/2010 one of the harshest winters in the past three decades in some places.

However, while the apparent extreme winter conditions affected densely populated areas and had a great impact on the daily lives of millions of people, other large areas in the northern hemisphere recorded above normal temperatures for the season. This was the case particularly in the Arctic region and Canada, where temperatures reached +6°C above the long-term average in some locations.

For the period December 2009–February 2010 the combined land and ocean average surface temperature over the northern hemisphere is estimated to be about half a degree above the seasonal long-term average, which is estimated at +8.6°C based on the reference period 1961–1990. According to the dataset of the United Kingdom Met Office, the northern hemisphere surface temperature anomaly for December–January–February was +0.47°C above the long-term average. The United States NOAA/NCDC dataset shows a temperature anomaly of +0.51°C.

The following sections describe the extreme winter conditions observed in many areas of the northern hemisphere and provide an insight into existing knowledge for the explanation of the mechanisms behind these conditions, based on sound scientific research studies. More detailed global aspects, including major climatic features in all regions, will be provided in the WMO Statement on the Status of the Global Climate,

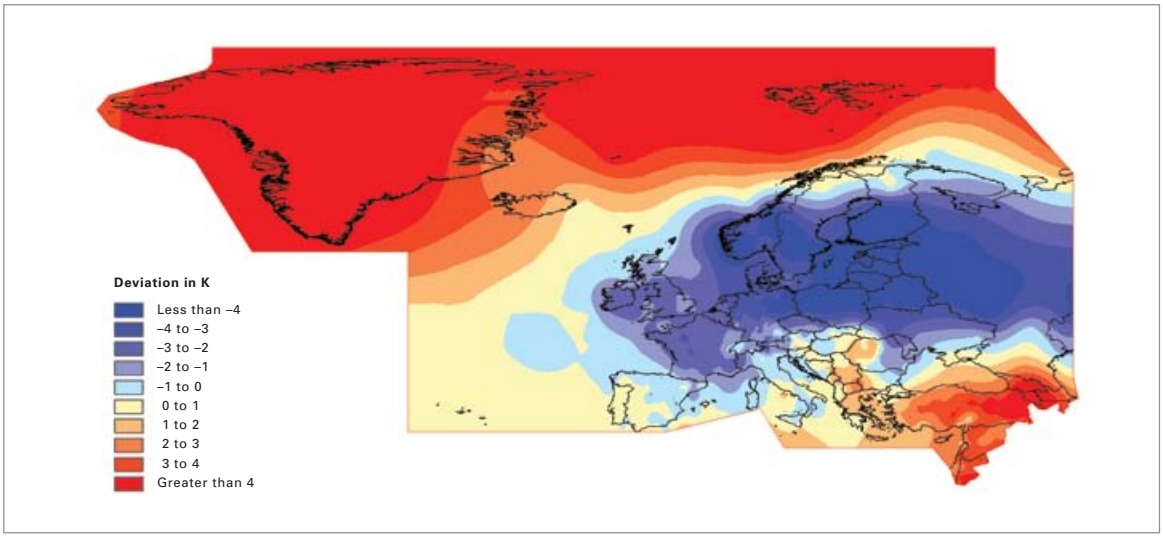


Figure 2. Monthly mean temperature anomalies in Europe for January 2010 (reference period 1961–1990) *(Source: DWD, Germany)*

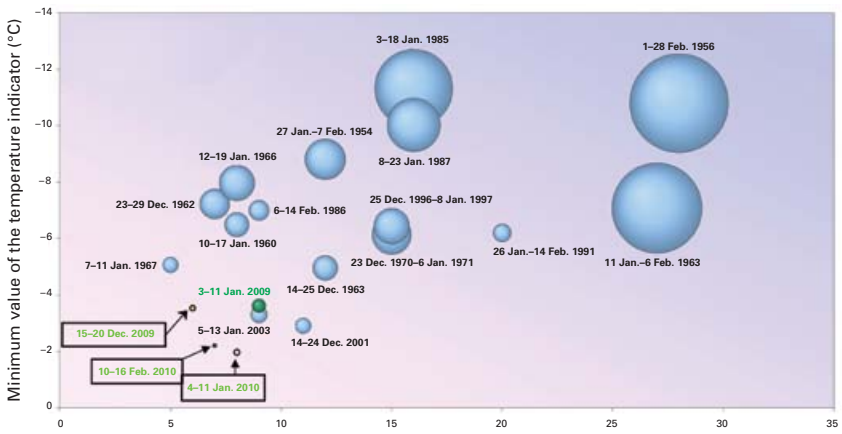


Figure 3. Major cold waves in France for the period 1950–2010; x-axis: duration of the cold spell in days; y-axis: minimum value of the temperature indicator (average of daily mean temperatures in °C measured at 30 meteorological stations evenly distributed over France). The diameter of circles symbolizes the intensity of cold waves; the largest are the most severe. Only major cold waves are plotted, except the recent cold waves of 2009 and 2010 for comparison purposes. *(Source: Météo-France).*

which is published annually on the occasion of World Meteorological Day, which is celebrated on 23 March each year.

Extreme cold and snowfall conditions

During the period December 2009–February 2010, several places in the northern hemisphere recorded extended cold spells associated with very low temperatures, at times together with heavy and prolonged snowfall. In Europe, the United Kingdom experienced its most prolonged spell of freezing temperatures and snowfall across the country since winter 1981/1982. In France several stations recorded cold to very cold spells. The Châtillon-sur-Seine station in Côte d'Or recorded –20.1°C on the night of 19–20 December 2009, breaking the previous December record of –17.5°C recorded in 1946. The country as a whole, however, has experienced considerably more intense and persistent cold spells in the past 60 years (Figure 3). Central and Eastern Europe were severely hit in late January by an extremely cold weather outbreak affecting Poland, Hungary, Romania, Ukraine and Turkey. About a dozen stations in the European part of the Russian Federation and Siberia registered new absolute temperature minima for this time of year (Figure 4). These cold spells caused more than 450 casualties in Europe.

Most of north-eastern China recorded very cold conditions; some stations recorded temperatures as low as –32°C and low temperature records were broken at 26 meteorological stations. In India, a cold wave in December caused a drop in both minimum and maximum temperatures in the northern and eastern parts of the subcontinent. During the period 2–17 January, the mean maximum daily temperature dropped 4°C below the long-term average over many parts of northern India. The Himalayan states of Jammu and Kashmir and Himachal Pradesh were the worst hit by icy cold winds and sub-zero temperatures.

Hundreds of records for daily minimum temperatures were broken across the eastern two thirds of the United States. In Key West, Florida, the thermometer dipped to 6°C on the morning of 11 January. This was the second lowest temperature ever recorded at the southernmost weather station in

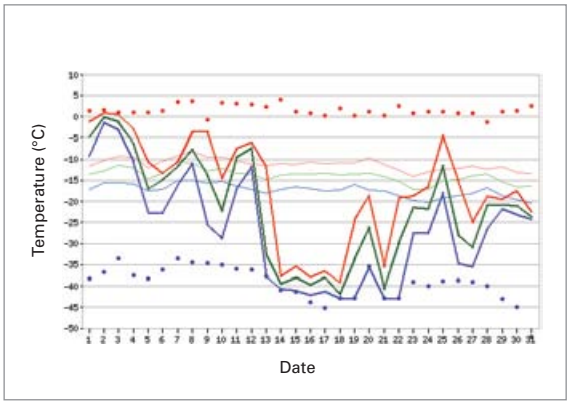


Figure 4. Daily temperatures in Ukhta (Komi Republic, Russian Federation) in December 2009; daily Tmin, Tmax and Tmean in blue, red and green, respectively, with bold curves and their long-term averages with thin curves. Red (blue) dots represent previous daily multi-year temperature maxima (minima) . *(Source: Hydrometeorological Centre of the Russian Federation)*

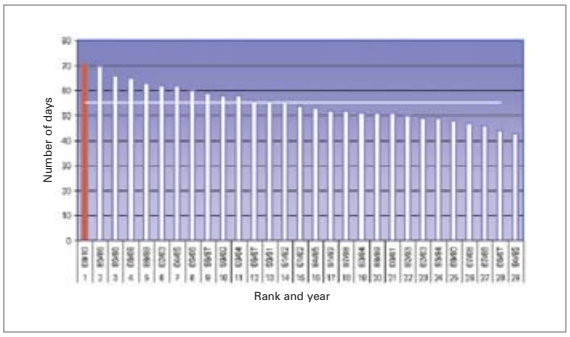


Figure 5. Number of days with a snow depth >= 1 cm in winter (December 2009–February 2010) in Germany, averaged over all elevations > 1 000 m above mean sea level *(Source: DWD, Germany).*

the contiguous United States. The coldest temperature ever observed at the station was 5°C in both January 1981 and 1886.

Combined with these cold conditions, heavy snowfall in many places caused severe disturbances to ground and air traffic. The extent and duration of snow events were unusual in several places in Europe, including southern locations such as in Spain and Italy. Based on the frequency of snowfalls in France, the winter was likely one of the country's snowiest in the past 30 years. Likewise, many places in Germany experienced their longest duration of snow in at least 30 years (Figure 5). The Estonian capital of Tallinn reported an all-time snow depth record of 62 cm. In late January, the cold spell was particularly intense in many parts of Central and Eastern Europe, including Poland, Ukraine, Hungary and Turkey.

In the United States, the meteorological station at the Ronald Reagan Washington National Airport in Arlington, Virginia, reported 55.9 inches (~142 cm) of snow accumulation through 11 February 2010. This broke the record set in 1898 and represented nearly 3.5 times the long-term average of 15.2 inches (38.6 cm) of snow (Figure 6). Widespread snow and sleet were also reported across Florida, including the city of Orlando, a very rare event for the state.

In China, central Beijing received 11 mm of water equivalent of snow on 2 January, the most for a single day since January 1951, while a snow depth of 33 cm was reported in its suburbs. In Seoul, Republic of Korea, 28 cm of snow fell on 3 January, marking the greatest snowfall amount for the city since records began in 1937.

Daily life was affected; air, rail and road transport links were disrupted, schools and many other public services were closed and crops were damaged by frost. For example, 655 flights were cancelled at Beijing Capital International Airport and 10 highways were closed.

Mild winter over the Arctic and other places

The most striking warm winter condition was the very high temperature recorded over the Arctic region, and extending to most of Canada, where significant positive temperature

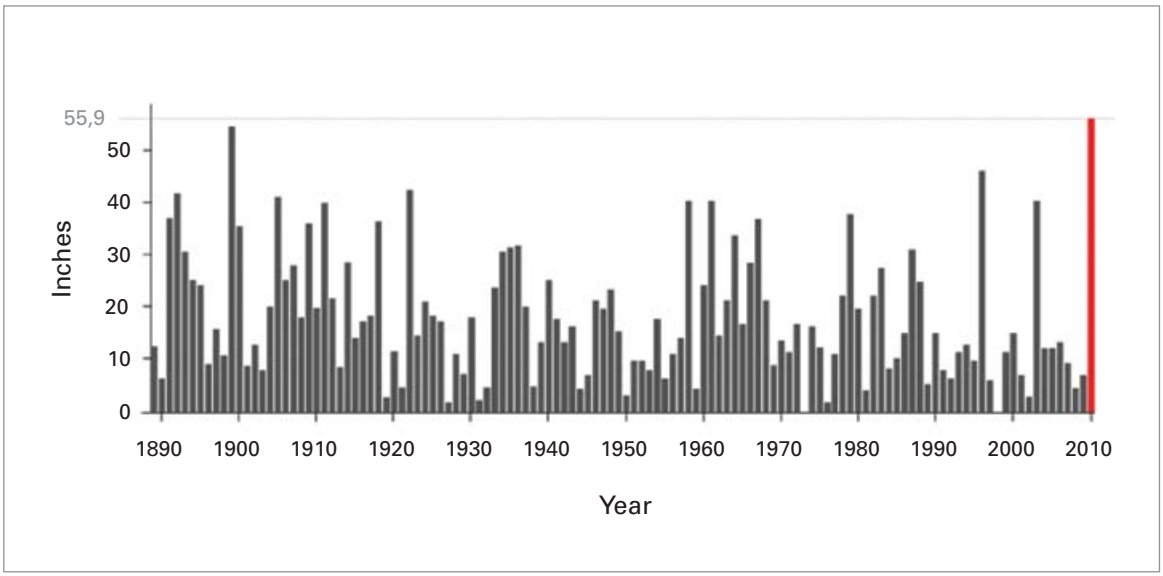


Figure 6. Annual snowfall at the Ronald Reagan Washington National Airport meteorological station for 1888–1889 through 2009–2010. The red bar shows the 55.9 inches (~142 cm) accumulated through 11 February 2010 that broke the previous record from 1898–1899. *(Source: NOAA National Weather Service)*

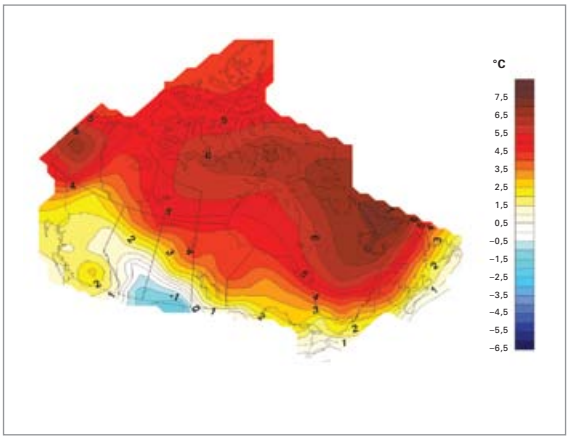


Figure 7. Warmest winter in Canada: temperature departures from normal in °C for December 2009–February 2010 *(Source: Environment Canada, Science and Technology Branch, Climate Research Division)*

anomalies for the period December 2009–February 2010 were recorded. The Canada national average temperature for winter 2009/2010 was +4.0°C above normal, making it the warmest winter on record since nationwide records began in 1948. The previous record was set in 2005/2006 with +3.9°C above normal. As shown in the mean temperature departures map (Figure 7), temperatures across the entire the country were above normal, except for a small area over the southern Prairies, with some areas of the Arctic and northern Quebec showing a more than +6°C temperature anomaly.

Most of China and India, despite the cold conditions observed in parts, recorded temperatures above the long-term average (Figures 8 and 9, respectively). Similar conditions were observed in the Middle East and Northern Africa.

Driest winter in Canada

Overall, Canada had its driest winter in 63 years of records, with 9 of the country's 11 climatic regions ranking in the top 10 driest winters. Southern British Columbia had the driest winter followed by northern British Columbia with the second driest winter on record. This had a negative impact on snow conditions for the 2010 Winter Olympics, which were held in Vancouver.

Observed atmospheric and climate patterns

Atmospheric oscillations

Despite the rare occurrence of the observed northern hemisphere cold conditions in relatively large areas combined with the very mild conditions over the Arctic and Canada, meteorologists are nevertheless familiar with a number of associated atmospheric patterns. The most evident of these patterns is the large-scale abnormal distribution of air pressure systems that control the general circulation and the associated winter disturbances in the northern hemisphere. This anomaly is generally associated with atmospheric oscillations and stationary planetary atmospheric waves that are triggered by internal or external forcing. As a result of these oscillations, weather conditions are significantly altered. Usual west–east storm tracks become marked with strong meridional components allowing cold air masses from the Arctic to migrate further south.

The Arctic Oscillation (AO) represents the surface pressure and geopotential height difference between the mid-latitudes of the northern hemisphere and the Arctic. The Arctic Oscillation index was extremely negative this winter, with unusually high surface pressure

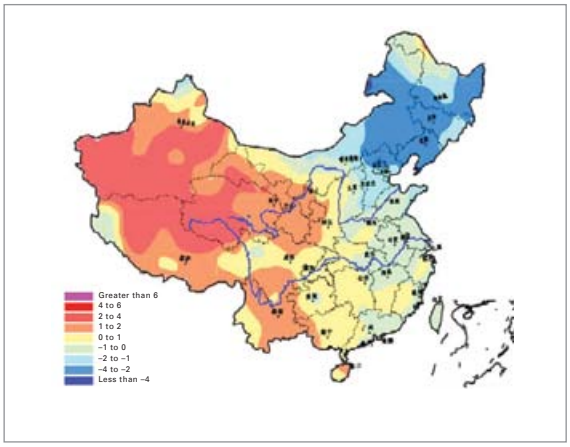


Figure 8. Mean temperature anomalies over China for the period 1 December 2009–20 January 2010 *(Source: China Meteorological Administration)*

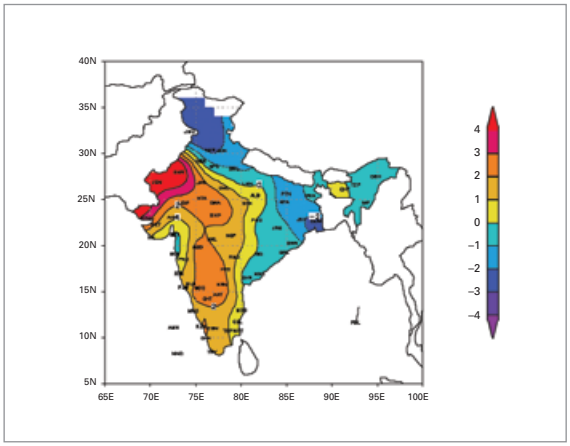


Figure 9. Anomaly of the minimum temperature (°C) in India during the period 26–31 December 2009 *(Source: India Meteorological Department)*

over the Arctic Ocean. Following a strong negative phase from mid-December through mid-January, the Arctic Oscillation briefly went positive, but then dipped again to a strongly negative phase during the remainder of January and February.

Monthly values of the AO index were extremely low for the three months with February recording the lowest monthly value (–4.2) since 1950. As a consequence of the negative AO phase a very stable meridional circulation was established over large parts of the northern hemisphere. While cold air persisted over most of Europe, warm air with higher-than-normal temperatures persisted over the Arctic region and Canada. A strong persistent surface pressure high over Scandinavia was the reason for an easterly flow of cold continental air masses especially into the northern regions of Central Europe. High pressure extended also over Siberia where an outstanding core pressure of 1 072 hPa was recorded in January.

The negative Arctic Oscillation continued throughout most of January and all of February with persisting high pressure conditions over the Arctic extending deeper into the upper atmosphere, indicating the high stability of the phenomenon.

Considering the values of the AO index (given in brackets below), the seven lowest monthly negative values for the winter (December–January–February) since 1950 were recorded in 1962/1963 (–3.3), 1965/1966 (–3.2), 1968/1969 (–3.1), 1976/1977 (–3.7), 1977/1978 (–3.0), 1984/1985 (–2.8) and 2009/2010 (–4.2). The AO index for winter 2009/2010 was the lowest on record, depicting the high intensity of the Arctic Oscillation and consequently its strong influence on winter pressure systems and the spatial temperature patterns. The North Atlantic Oscillation (NAO), which correlates very well with the Arctic Oscillation and affects mainly the Atlantic region, Europe and the Mediterranean, recorded its lowest winter value since 1950, which matched the 1963 record of –1.9. Research results show that a negative phase of the North Atlantic Oscillation is associated with a high probability of extreme cold and snowy conditions over northern France (Cassou, 2008; Slonosky and Yiou, 2001). Furthermore, several particularly cold winters in Eurasia in the recent 60 years coincided with a negative NAO index, but the temperature spatial anomaly patterns vary from case to case (Hirschi and Sinha, 2007).

2009/2010 El Niño episode

The major pattern that affected climate in late 2009 and the first quarter of 2010 was the moderate to strong El Niño episode. Previous studies show that direct impacts of the El Niño–Southern Oscillation (ENSO) are clearly established consistently over tropical areas. Research results show that ENSO can also affect extra-tropical regions through various mechanisms, including through influencing atmospheric oscillations (Baldwin and Dunkerton, 2005; Bell, et al., 2009; Crooks and Gray, 2005; Ineson and Scaife, 2009; Jia et al., 2008; Kodera and Kuroda, 2005; Kryjov and Park, 2007; L'Heureux and Thompson, 2005; Matthes et al., 2006). However, a consistent ENSO signal over these regions has not been clearly identified as in the case of the tropical regions.

The important role played by ENSO in the Northern American region has also been well established. Significant positive surface temperature anomalies spread eastward from the west coast of Canada to Labrador from the late fall to early spring following the onset of El Niño episodes (Shabbar and Khandekar, 1996). Recent analysis by NOAA scientists revealed good historical evidence of heavy snowstorms over the mid-Atlantic region of the United States whenever a combination of an El Niño episode and a negative North Atlantic Oscillation is observed (Hoerling et al., 2010).

Pacific–North American pattern

The Pacific–North American pattern (PNA) is another prominent mode of low-frequency atmospheric variability in the northern hemisphere extra-tropics. This pattern is associated with strong fluctuations in the strength and location of the East Asian jet stream. In wintertime the positive phase of the PNA

is associated with above-average temperatures over western Canada and the extreme western United States, and below-average temperatures across the south-central and south-eastern United States. For this winter, the PNA index recorded positive values during the three months.

A positive phase of the Pacific–North American pattern tends to be associated with a warm ENSO episode (El Niño), consistent with the present winter, whereas a negative phase tends to be associated with a cold ENSO episode (La Niña).

Nevertheless, research results also show that a negative phase of the North Atlantic Oscillation during winter is compatible with a positive Pacific–North American pattern during an El Niño phase (Müller and Roeckner, 2006) and that the Pacific–North American pattern could play a connecting atmospheric factor between ENSO and the North Atlantic Oscillation (Cassou and Terray, 2001). Statistical composite analysis provides historical evidence of the combined influence of El Niño and the North Atlantic Oscillation on near-surface temperature during the boreal winter, which depicts well the winter 2009/2010 conditions (Figure 10).

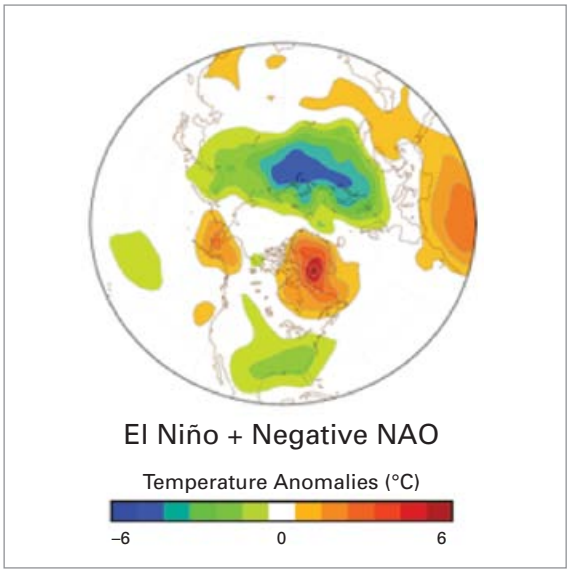


Figure 10. Long-term composite (from 1951–2010) illustrating typical wintertime combined influence of El Niño and the North Atlantic Oscillation on near-surface temperature anomaly in the northern hemisphere. This analysis compares well to the 2009/2010 winter conditions shown in Figure 1. *(Source: NOAA Climate Prediction Center)*

Conclusion

Winter 2009/2010 was characterized by cold to extremely cold temperatures over many and large areas in the northern hemisphere. The associated cold spells caused snowfall episodes with moderate to exceptional intensity and duration depending on geographical location. From a historical perspective, the comparison among past cold winters derived from time series indicates varying results depending on geographical location and the meteorological parameters, such as daily minimum temperature, duration of cold spell and snowfall intensity. For example, the 2009/2010 winter recorded the longest cold spell in the United Kingdom since 1981 while in the Baltic region snow accumulation broke the records in some places. In some other parts of Europe the cold spells were not very intense or unusual.

Several other places in the northern hemisphere recorded warmer conditions than the long-term average. Among these were the Arctic region and Canada, which recorded very strong positive temperature anomalies and the warmest winter since the beginning of the country's nationwide instrumental records in 1948. These opposing features depict a north–south type of dipole phenomenon that was associated with a strong and persisting Arctic Oscillation and a North Atlantic Oscillation. The El Niño event that started in the summer 2009 and continued through the first quarter of 2010 seems to have had some influence on the behaviour of these atmospheric patterns and the resulting winter conditions. However, due to the complexity of the interactions occurring within the climate system that are not linear types of relationships, thus far it is difficult to assess to which degree each of the described patterns had influenced the initiation, intensification or persistence of the observed cold/warm events in the northern hemisphere during winter 2009/2010.

Finally, a global assessment shows that for the northern hemisphere the combined land and ocean average surface temperature for December 2009–February 2010 remained warmer that the long-term average of the 1961–1990 reference period with about one-half degree centigrade anomaly.

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For more information, please contact:

World Meteorological Organization

Communications and Public Affairs Office

Tel.: +41 (0) 22 730 83 14 – Fax: +41 (0) 22 730 80 27

E-mail: cpa@wmo.int

7 bis, avenue de la Paix – P.O. Box 2300 – CH 1211 Geneva 2 – Switzerland

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