Gassner, S., L. Frigerio, M. Schwander, and C. Dizerens (2017) The "Great White Storm" of 1913.
In: Brönnimann, S. (Ed.) *Historical Weather Extremes in Reanalyses.* Geographica Bernensia G92, p. 123-131, DOI: 10.4480/GB2017.G92.11

The "Great White Storm" of 1913

Sylvia Gassner, Luca Frigerio, Mikhaël Schwander*, and Céline Dizerens

Oeschger Centre for Climate Change Research and Institute of Geography, University of Bern, Switzerland

Abstract

The "Great White Storm" of 1913 was one of the strongest storms to hit the Great Lakes region, and likely one of the most devastating natural disasters in the whole of the United States. The intensity of the storm led to many deaths and important economic damage. The recent development of reanalysis data sets such as version 2c of the "Twentieth Century Reanalysis" (20CRv2c) and the ECMWF reanalyses ERA-20C and CERA-20C provide valuable information to analyse extreme events such as the "Great White Storm" of 1913. It can be used to study the atmospheric mechanisms leading to such intense storms, which might contribute to better assess similar weather events in the future. The "Great White Storm" of 1913 is well reproduced in 20CRv2c. The reanalysis captures the key ingredient responsible for the development of the storm. However, it fails to give a good estimate of smaller scale parameters such as snow depth. Further analyses are required concerning precipitation, as prolonged snowfall was one of the major problems for people during the storm. Although it appears that 20CRv2c better captures the storm than ERA-20C, such conclusions depend critically on the variables studied.

1. Introduction

The Great Lake Region in North America has been subject to many strong snow storms in the past. Many of them occurred at the beginning of winter when the thermal contrast between the warm lakes and low air temperatures is pronounced. Evaporation from the lakes can lead to increased humidity, which in some cases can significantly increase the precipitation in the Great Lakes basin (Angel and Isard, 1998). One of the most devastating winter cyclones in

* Corresponding author: Mikhael Schwander, University of Bern, Institute of Geography, Hallerstr. 12, CH-3012 Bern, Switzerland. E-mail: mikhael.schwander@giub.unibe.ch

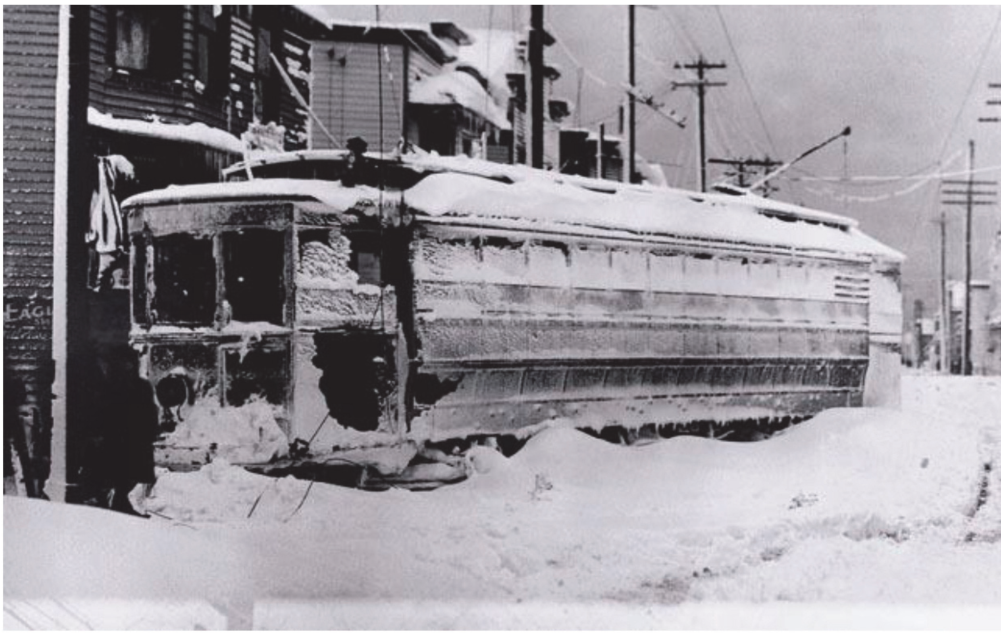

Figure 1. Impact of the “Great White Storm” in Cleveland on 10 November 1913 (Western Reserve Historical Society, 2016).

the Great Lakes region certainly was the “Great White Storm” that occurred from 7 to 11 November 1913 (see Burkart and Wyss, 2017, in this volume for another snow storm). The storm led to more than 250 fatalities, approximately 12 sinking ships, and power outages that lasted for several days (Wagenmaker et al., 2014). The city of Cleveland was particularly affected by this storm (Fig. 1). In this paper, we analyse the meteorological situation that led to the disastrous storm event in three historical reanalyses, namely the “Twentieth Century Reanalysis” version 2c (20CRv2c, Compo et al., 2011) and the European reanalyses ERA-20C (Poli et al., 2016) and CERA-20C (Laloyaux et al., 2017).

We analyse different parameters such as sea-level pressure, geopotential height, temperature, and snow depth to assess the quality of the three reanalyses to reproduce the “Great White Storm”. For this purpose, the three reanalyses are compared to historical weather charts. Another focus lies on the question whether the 20CRv2c dataset is able to represent the role of the lakes as moisture source, which might have influenced the effect of this particular storm.

The paper is organized as follows. Section 2 describes the data and methods used to compare the historical data with the data of the reanalysis. The results are presented in Section 3 and discussed in Section 4. Finally, the conclusions are drawn in Section 5.

2. Data and Methods

Currently four historical reanalyses reach back long enough to study the “Great White Storm” of 1913: 20CRv2, 20CRv2c, ERA-20C and CERS-20C. In our study we compare the latter three. All three assimilate surface pressure; two also assimilate marine winds (see Brönnimann, 2017, for a more detailed description of all reanalyses).

20CRv2c was chosen to examine the role of moisture sources. This reanalysis provides 3-dimensional, 6-hourly data with a 2° x 2° latitude-longitude grid and 28 layers vertically

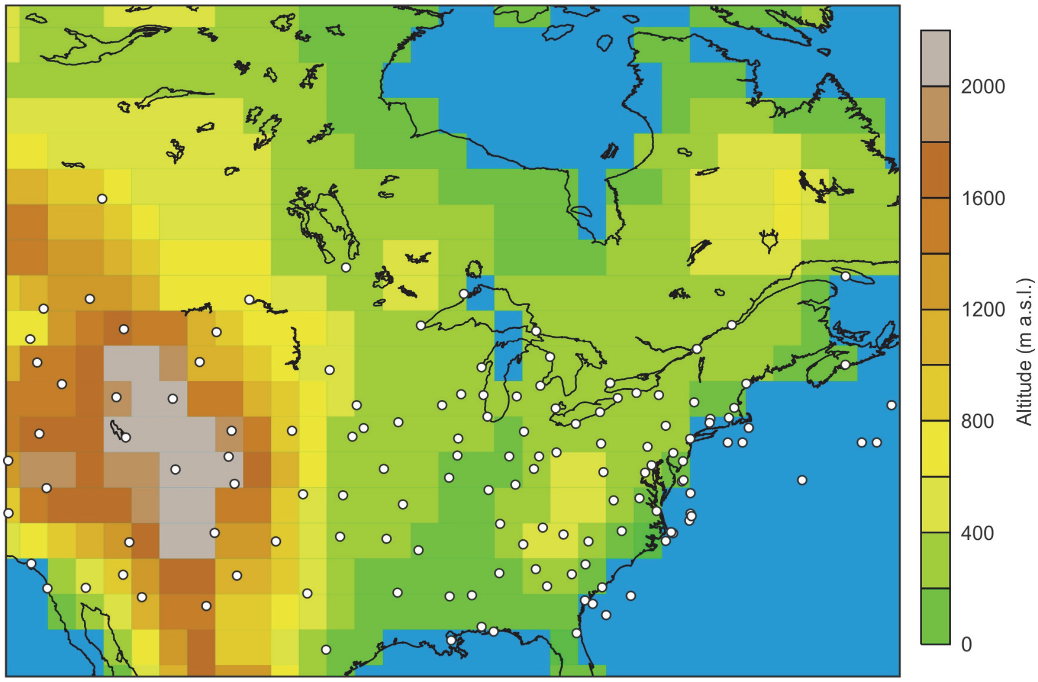

Figure 2. Topography and location of assimilated surface pressure data in 20CRv2c for the analysis of 10 November 1913, 6 UTC. The Great Lakes are represented by three water grid cells.

over a time frame of 137 years, starting in 1851. It uses the NCEP/CFS model, with the boundary conditions set by monthly sea-surface temperature and sea-ice extent measurements. 20CRv2c uses the same model as version 2 (see Compo et al., 2011), with new sea ice boundary conditions for high latitudes from the COBE-SST2 (Hirahara et al., 2014), new pentad Simple Ocean Data Assimilation with sparse input (SODAsi.2, Giese et al., 2015) sea-surface temperature fields and additional observations from ISPD version 3.2.9 (Cram et al., 2015). 20CRv2s is an ensemble product with 56 members. In this paper we analyse the ensemble mean.

20CRv2c is used to analyse the evolution of the storm on 8, 9, 10 and 11 November at 06 UTC for sea-level pressure, geopotential height, temperature, and snow depth. The 20CRv2c output is then compared with historical daily weather charts obtained from the NOAA Central Library. These weather maps are based on observational data from weather stations in the northeastern part of the United States. Measured parameters include air temperature (degrees Fahrenheit, °F), air pressure (inches Hg), wind speed (m s^{-1}) and precipitation (mm).

In addition, sea-level pressure, geopotential height and snow depth are compared with the ERA-20C reanalysis (and with CERA-20C only for snow depth). ERA-20C is a reanalysis from the European Centre for Medium-Range Weather Forecasts (ECMWF). It covers the period 1900-2010 and assimilates observations of surface pressure and surface marine winds only. It has a 125 km horizontal resolution, 91 levels in the vertical, and a 6-hourly temporal resolution (see Brönnimann, 2017, in this volume for details about the data set). CERA-20C is available from 1901 to 2010 and assimilates surface pressure and marine wind observations as well as ocean temperature and salinity profiles. It has also a 125 km horizontal resolution, 91 vertical levels, a 6-hourly temporal resolution. CERA-20C is a 10-member ensemble.

3. Results

We first describe the “Great White Storm” based on historical weather charts, displayed in Figure 3, and based on the work of Wagenmaker et al. (2014), who used Version 2 of 20CR combined with a dynamical downscaling using the WRF model. The “Great White Storm” is a cyclonic storm that resulted from two converging storm fronts (known as a “November gale”) hitting the Great Lakes region between 7 and 11 November 1913. The two storm fronts

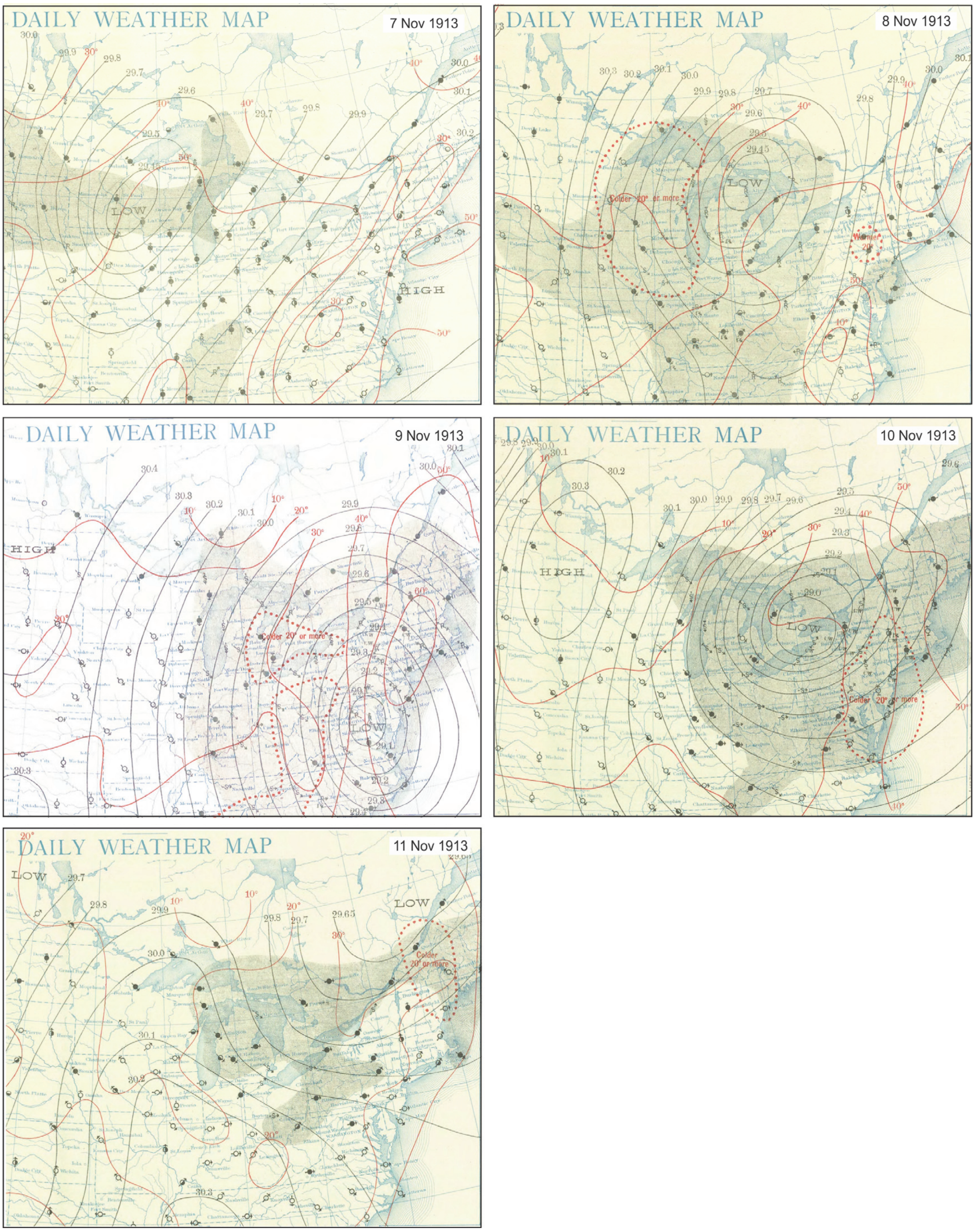

Figure 3. Daily weather maps (sea-level pressure, temperature, wind) for 7-11 November 1913 from the Department of Agriculture (NOAA Central Library Data).

merged into one low-pressure system on 8 November. The depression first brought warm air across the Great Lakes followed by a cold front with strong winds over Lake Superior. On 8 November, the storm weakened while the associated fronts moved eastward across the Great Lakes region, enhancing northerly strong winds and descending cold air. At the same time, a new low-pressure system started to develop along the Gulf Coast region. Between 8 and 9 November, the new storm rapidly intensified and moved quickly towards the North along the US East Coast. On 9 November, the remaining low-pressure system on the Great Lakes merged with this new low into one large storm called, the “Great White Storm”. The pressure dropped dramatically from Sunday night to early Monday, 10 November, reaching a pressure value of 970 hPa, centred between Lake Ontario and Lake Huron. The system then barely moved before the evening of 10 November, maintaining its strength and spreading very strong winds. Heavy precipitation fell in the region during the event and due to very low temperatures registered (approximately 258 K / –15°C), most of it as snow. In the evening of 10 November, the storm began to weaken and moved to a north to north-easterly direction. This movement continued on Tuesday, 11 November 1913, ending the event but leaving behind an arctic air descent (Wagenmaker et al., 2014).

In 20CRv2c we observe a similar evolution with first a trough and a low-pressure system (probably also resulting from the merging of two lows) over the Great Lakes on 8 November (Fig. 4). Whilst moving towards the east, a new low-pressure centre developed on the south-east coast and deepened quickly on 9 November leading to the advection of cold with a north to north-easterly flow over the region. The temperature at 850 hPa dropped from 7 °C over

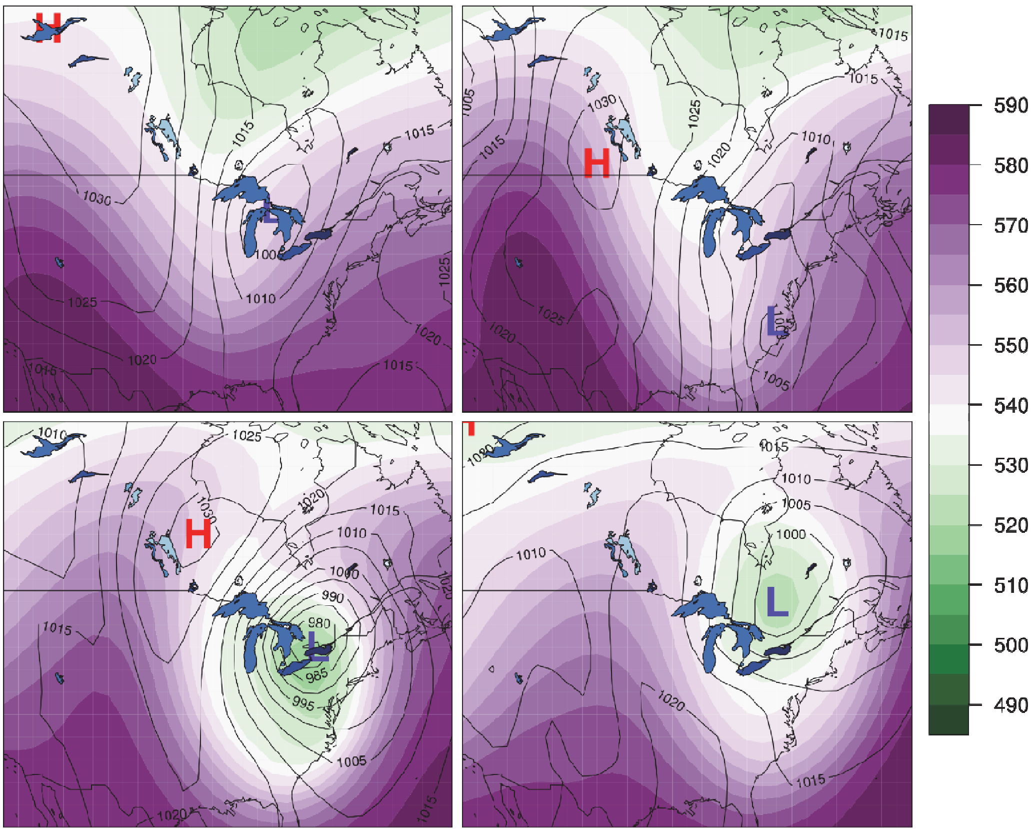

Figure 4. 20CRv2c 500 hPa geopotential height (gpdm) in colour and sea-level pressure (hPa) in contour on 7-10 November 1913, 06 UTC (from top left to bottom right).

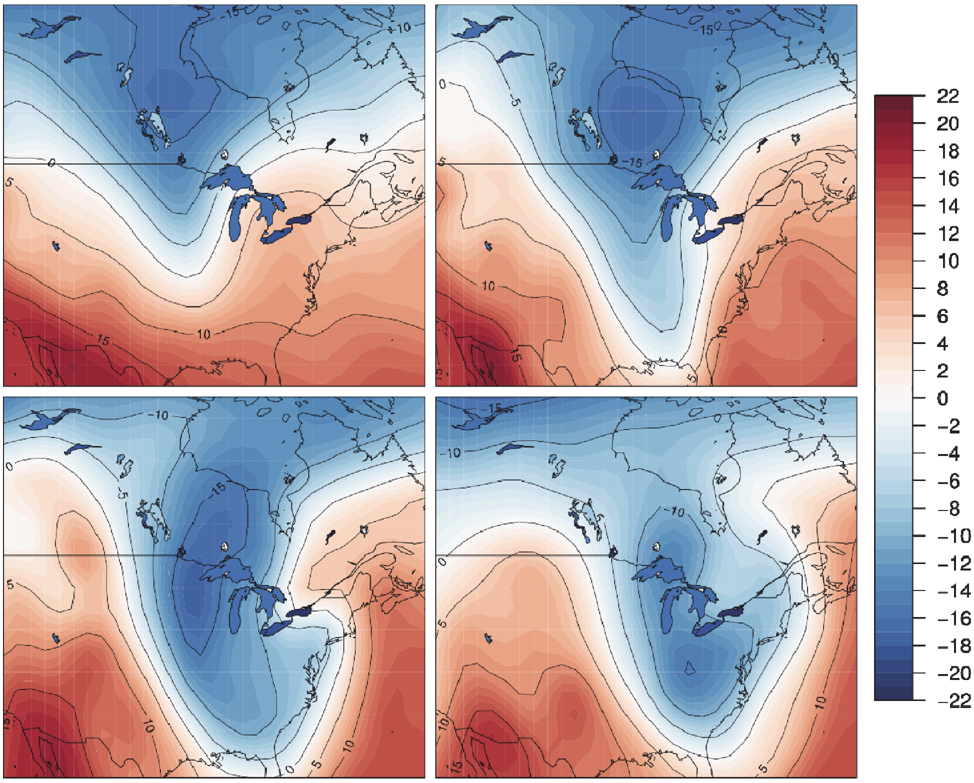

Figure 5. 20CRv2c 850 hPa temperature (°C) on 7-10 November 1913, 06 UTC (from top left to bottom right).

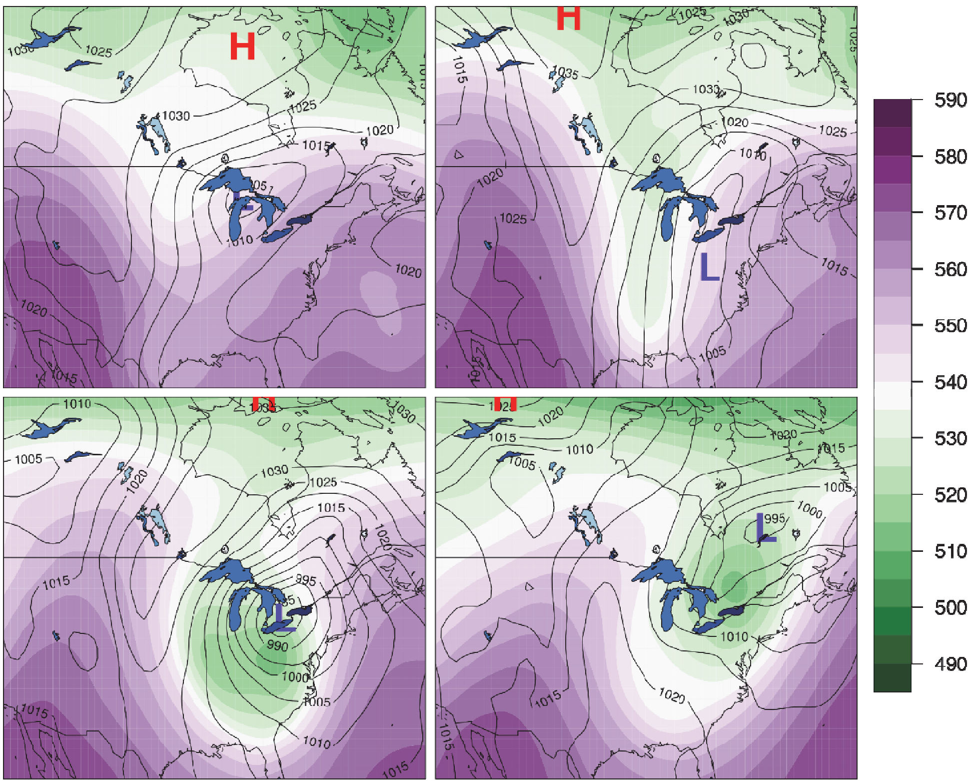

Figure 6. ERA-20C 500 hPa geopotential height (gpdm) in colour and sea-level pressure (hPa) in contour on 7-10 November 1913, 06 UTC (from top left to bottom right).

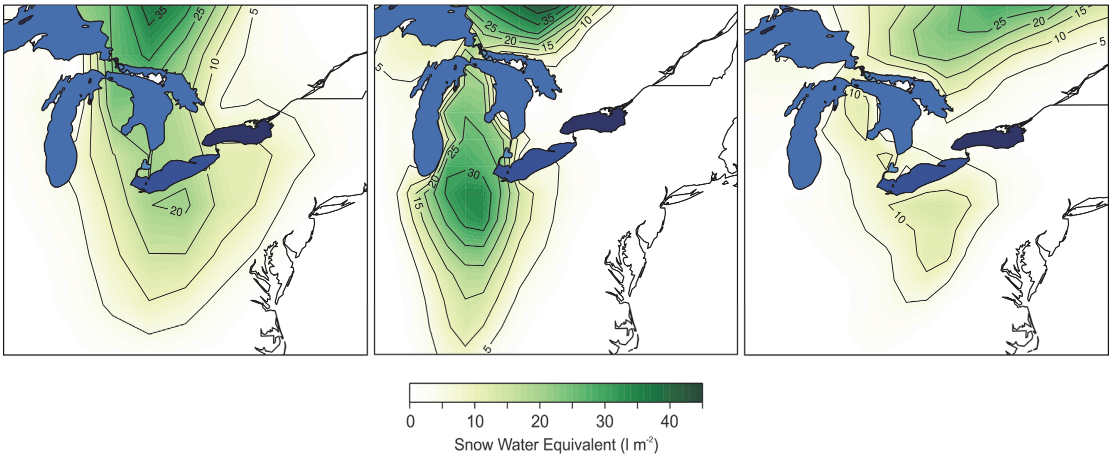

Figure 7. Snow water equivalent (l m^{-2}) for 20CR (left), ERA-20C (centre) and CERA-20C (right) on 11 November 1913, 18 UTC.

the region of Cleveland on 8 November to -12 °C on 11 November (Fig. 5). The low-pressure system moved northward whilst strengthening on 10 November. It reached its minimum (~980 hPa) over the Lake Ontario on 10 November in the morning before weakening the next day over Québec.

The ERA-20C reanalysis shows a similar pattern and evolution of the low-pressure system as 20CR from 8 to 11 November (Fig. 6). However, the trough on the 500 hPa geopotential level is stronger in ERA-20C and also slightly located more west compared to 20CRv2c. The pressure low on 10 November is ~5 hPa higher than in 20CRv2c and located more to the west (over the Lake Erie).

The small differences in the location of the low-pressure system are visible in the snow cover. 20CRv2c and ERA-20C do not show the same location of maximum snow depth (expressed in snow water equivalent, l m^{-2}, Fig. 7 left and centre). In 20CRv2c, the maximum snow depth is located south of the Lake Erie in the region of Cleveland (~20 l m^{-2}), whereas the maximum snow depth in ERA-20C is situated further west between the Lake Erie and the Lake Michigan but with values above 30 l m^{-2}. The CERA-20C reanalysis (Fig. 7 right) has a similar location of the maximum snow depth as 20CRv2c (south of the Lake Erie) but with lower values (~10 l m^{-2}).

A comparison with historical pressure maps from 1913 (Fig. 7) shows a similar evolution and location of the storm as found in 20CRv2c: a first low-pressure centre over the Great Lakes on November 8 and the development of another one further south on the next day.

4. Discussion

The fast development of the low-pressure system associated to the humidity released from the Great Lakes led the exceptional storm of November 1913 (the storm is often also called the “White Hurricane”, which is meteorologically wrong, even though wind speeds on 10 November over Lake Huron reached hurricane strength, *i.e.,* ~70 miles per hour; Wagenmaker et al., 2014). The analysis of 20CRv2c and the comparison with other reanalysis data set and historical data allows us to assess its quality and ability to reproduce the atmospheric conditions that led to the “Great White Storm” of 1913.

Compared with historical charts, 20CRv2c provides a good reconstruction of the storm with an evolution from 8 to 11 November very similar to historical daily weather charts. A similar location of the depression at different time steps as well as a similar development is found. ERA-20C agrees somewhat worse with the historical charts.

Some differences between ERA-20C and 20CRv2c in snow water equivalent are noteworthy. In ERA-20C, maximum snow depth is located too far west in ERA-20C. The maximum snow depth found south of Lake Erie in all analyses (most pronounced in ERA-20C) suggests a potential influence of the lakes on the intensity of the precipitation (known as the lake-effect). However, the snow depth seems to be underestimated by 20CRv2c. In Cleveland, 56 cm of snow were measured, whereas the snow water equivalent in 20CRv2c suggests a depth of approximately 20 cm (assuming that 1 l m^{-2} of water is equivalent to 1 cm of snow). In ERA-20C, the amount of snow is closer to the measured values but the location does not match the historical data. Although 20CRv2c might capture some of the influence of the Great Lakes, the 2° degrees resolution is too coarse to capture the real intensity, spread and quantity of the precipitation. It can provide an idea of the location of precipitation but no exact values.

5. Conclusions

We have analysed the weather conditions and evolutions of the atmospheric circulation in 20CRv2c that led to the “Great White Storm” of November 1913 in the Great Lakes region. The combination between an intense, fast developing low-pressure system and relatively warm lakes brought heavy snow fall over the region. 20CRv2c provides a good reconstruction of the event. A comparison with historical charts shows a similar evolution of the storm. However, the intensity of the low-pressure system is slightly underestimated by 20CRv2c and the resolution of the reanalysis too coarse to provide a good estimation of the snow depth. Compared with historical charts, 20CRv2c captures the sea-level pressure fields and its evolution better than ERA-20C.

Acknowledgements

The Twentieth Century Reanalysis Project dataset was obtained courtesy of the NOAA/OAR/ESRL PSD, Boulder, Colorado, USA, from their web page at http://www.esrl.noaa.gov/psd/. Support for the 20CR dataset is provided by the U.S. Department of Energy, Office of Science Innovative and Novel Computational Impact on Theory and Experiment program, Office of Biological and Environmental Research and by the National Oceanic and Atmospheric Administration Climate Program Office. The work was supported by FP7 project ERA-CLIM2, H2020 project EUSTACE, and the Swiss National Science Foundation project EXTRA-LARGE.

References

Angel, J. R. and S. A. Isard (1998) The frequency and intensity of Great Lake cyclones. *J. Climate,* **11,** 61-71.

Brönnimann, S. (2017) Weather Extremes in an Ensemble of Historical Reanalyses. In: Brönnimann, S. (Ed.) *Historical Weather Extremes in Reanalyses.* Geographica Bernensia G92, p. 7-22, DOI: 10.4480/GB2017.G92.01.

Burkart, K. and A.-M. Wyss (2017) The ”Great Appalachian Storm” of 1950 in Reanalyses and Historical Weather Charts. In: Brönnimann, S. (Ed.) *Historical Weather Extremes in Reanalyses.* Geographica Bernensia G92, p. 47-58, DOI: 10.4480/GB2017.G92.04.

Compo, G. P., J. S. Whitaker, P. D. Sardeshmukh, N. Matsui, R. J. Allan, X. Yin, B. E. Gleason, R. S. Vose, G. Rutledge, P. Bessemoulin, S. Brönnimann, M. Brunet, R. I. Crouthamel, A. N. Grant, P. Y. Groisman, P. D. Jones, M. Kruk, A. C. Kruger, G. J. Marshall, M. Maugeri, H. Y. Mok, Ø. Nordli, T. F. Ross, R. M. Trigo, X. Wang, S. D. Woodruff, and S. J. Worley (2011) The Twentieth Century Reanalysis Project. *Q. J. R. Meteorol. Soc.,* **137,** 1-28.

Cram, T. A., G. P. Compo, X. Yin, R. J. Allan, C. McColl, R. S. Vose, J.S. Whitaker, N. Matsui, L. Ashcroft, R. Auchmann, P. Bessemoulin, T. Brandsma, P. Brohan, M. Brunet, J. Comeaux, R. Crouthamel, B. E. Gleason, Jr., P. Y. Groisman, H. Hersbach, P. D. Jones, T. Jonsson, S. Jourdain, G. Kelly, K. R. Knapp, A. Kruger, H. Kubota, G. Lentini, A. Lorrey, N. Lott, S. J. Lubker, J. Luterbacher, G. J. Marshall, M. Maugeri, C. J. Mock, H. Y. Mok, O. Nordli, M. J. Rodwell, T. F. Ross, D. Schuster, L. Srnec, M. A. Valente, Z. Vizi, X. L. Wang, N. Westcott, J. S. Woollen, and S. J. Worley (2015) The International Surface Pressure Databank version 2. *Geoscience Data Journal,* **2,** 31-46.

Giese, B. S., H. F. Seidel, G. P. Compo, and P. D. Sardeshmukh (2016) An ensemble of ocean reanalyses for 1815-2013 with sparse observational input. *J. Geophys. Res. Ocean.,* **121,** 6891–6910.

Hirahara S., I. Masayoshi, and Y. Fukuda (2014) Centennial-scale sea surface temperature analysis and its uncertainty. *J. Climate,* **27,** 57–75.

Laloyaux, P., E. de Boisséson, and P. Dahlgren (2017) CERA-20C: An Earth system approach to climate reanalysis. *ECMWF Newsletter,* **150,** 25–30.

Poli, P., H. Hersbach, D. Dee, P. Berrisford, A. Simmons, F. Vitart, P. Laloyaux, D. Tan, C. Peubey, J.-N. Thépaut, Y. Trémolet, E. Holm, M. Bonavita, L. Isaksen, and M. Fisher (2016) ERA-20C: An Atmospheric Reanalysis of the Twentieth Century. *J. Clim.,* **29,** 4085–4097.

Saha, S., S. Moorthi, H.-L. Pan, X. Wu, J. Wang, S. Nadiga, P. Tripp, R. Kistler, J. Woollen, D. Behringer, H. Liu, D. Stokes, R. Grumbine, G. Gayno, J. Wang, Y.-T. Hou, H.-Y. Chuang, H.-M. H. Juang, J. Sela, M. Iredell, R. Treadon, D. Kleist, P. Van Delst, D. Keyser, J. Derber, M. Ek, J. Meng, H. Wei, R. Yang, S. Lord, H. Van Den Dool, A. Kumar, W. Wang, C. Long, M. Chelliah, Y. Xue, B. Huang, J.-K. Schemm, W. Ebisuzaki, R. Lin, P. Xie, M. Chen, S. Zhou, W. Higgins, C.-Z. Zou, Qu. Liu, Y. Chen, Y. Han, L. Cucurull, R. W. Reynolds, G. Rutledge, and M. Goldberg (2010) The NCEP Climate Forecast System Reanalysis. *Bull. Amer. Meteorol. Soc.,* **91,** 1015-1057.

Wagenmaker, R., G. Mann, R. Pollman, D. Elliott, B. Smith, J. Keysor, J. Boris, M. Bardou, E. Brody, R. Green, S. Waters, K. Clark, S. Jamison, K. Lombardy, J. Levan, and K. Hintzen (2014) Reconstructing the Great Lakes “White Hurricane” Storm of 1913. *Mariners Weather Log,* **58,** 9-21.