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

The "Great Appalachian Storm" of 1950 in Reanalyses and Historical Weather Charts

Kathrin Burkart and Angela-Maria Wyss*

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

Abstract

On the Thanksgiving weekend of 24-27 November 1950, the eastern United States were struck by one of the most damaging and meteorologically unique winter storms ever recorded. Forming over North Carolina, the storm quickly moved north, striking western Pennsylvania, eastern Ohio and West Virginia. These areas were covered with several feet of snow for multiple days. An accompanying windstorm covered a far greater area. The storm was unique, mainly, because it featured not only extremely strong winds and heavy snow, but also included both high and low temperatures. The focus of this paper lays on an analysis to establish whether the 20CRv2c, ERA-20C, NCEP/NCAR and CERA-20C reanalyses are able to reproduce the historical measurements and weather charts with respect to pressure, wind speed, 500 hPa geopotential height, and precipitation rate. The results show that 20CRv2c, ERA-20C, NCEP/NCAR and CERA-20C are able to reproduce all important large-scale characteristics of the "Great Appalachian Storm". The comparison between the four datasets shows that the reanalysis datasets ERA-20C and CERA-20C, which have a higher spatial resolution, are able to represent more detailed features than 20CRv2c and NCEP/NCAR reanalysis.

1. Introduction

Extreme events are particularly relevant for society as they are often associated with large damages and losses. At the same time, they are rare and hence long time series are required to study extreme events in detail. This requires comprehensive high-resolution data going back

* Corresponding author: Angela-Maria Wyss, University of Bern, Institute of Geography, Hallerstr. 12, CH-3012 Bern, Switzerland. E-mail: angela-maria.wyss@students.unibe.ch

in time. New surface-only reanalysis datasets are able to reconstruct atmospheric conditions of the past based on surface pressure or wind only. These include the “Twentieth Century Reanalysis” versions 2 and 2c (20CRv2 and 20CRv2c; Compo et al., 2011), the European Centre for Medium-Range Weather Forecasts (ECMWF) Twentieth Century Reanalysis (ERA-20C; Poli et al., 2016), and the coupled European reanalysis (CERA-20C; Laloyaux et al., 2017). However, before these products can be used for statistical analyses of extreme events, it is important to assess their ability to reproduce individual historical extreme events. A previous *Geographica Bernensia* book (Brönnimann and Martius, 2013) focused on the 20CRv2 dataset and its ability to reproduce severe storm and flood events of the past 140 years. For most of the events, a relatively good performance was found, but there were also events that 20CRv2 missed. This work can now be expanded to compare several products.

The focus of this paper lays on the investigation of the “Great Appalachian Storm” in 1950. On the Thanksgiving weekend on 24-27 November 1950, the eastern United States were confronted with one of the most damaging and meteorologically interesting winter storms ever recorded (Fig. 1). The storm became known as the “Great Appalachian Storm”. It caused 353 fatalities and a huge amount of damages. An analysis will be conducted to establish whether the reanalyses data sets 20CRv2c, ERA-20C and CERA-20C represent the storm. Additionally, the extreme events is analysed with the full-input reanalysis NCEP/NCAR (Kistler et al., 2001) for comparison. In this context the following question is addressed in this paper: To what extent are the datasets 20CRv2c, ERA-20C, NCEP/NCAR and CERA-20C able to reproduce the “Great Appalachian Storm” with its distinct features described in historical weather records from November 1950? An overall goal of this study is to help assess the quality of the available data for the time frame of the storm.

Figure 1. A woman digs out after the blizzard. Photo courtesy Boston Public Library, Leslie Jones Collection.

The paper is organized as follows: Section 2 describes the data used for the eventual comparison, *i.e.,* all reanalysis data sets and the historical observations. In Section 3, we present our analysis of the specific event. Section 4 discusses the results. Finally, conclusions are drawn in Section 5.

2. Data and Methods

20CR is an atmospheric data set which is solely based on the assimilation of surface and sea-level pressure observations (Compo et al., 2011). The NCEP CFS Model is used to generate background fields, with monthly sea-surface temperature and sea ice as boundary conditions. The new version of 20CR, termed 20CRv2c, was released in 2015 and covers a timespan of more than 150 years, going back to 1851. It is based on surface pressure data from the International Surface Pressure Databank (ISPD; Cram et al., 2015) and produces three-dimensional state estimates of the atmosphere every six hours using an Ensemble Kalman Filter-based approach. The model is run at T62 spectral truncation (corresponding to a horizontal resolution of 2° x 2°) and 24 levels in the vertical. The data set has a six-hourly temporal resolution, but three-hourly forecasts are provided for several variables. Compared to 20CRv2, 20CRv2c uses new sea ice and sea-surface temperature fields and an updated version of ISPD (for further details and differences between the reanalyses see Brönnimann, 2017). As 20CRv2, 20CRv2c is an ensemble product, with 56 equally likely members. In this study only the ensemble mean is considered. The data assimilated into 20CRv2c for the analysis of 6 UTC, 25 November 1950 is shown in Figure 2. The figure also shows the model topography, which is relatively coarse.

ERA-20C is an atmospheric reanalysis dataset of the 20th century, from 1900-2010. In addition to observations of surface pressure, the data set also assimilates surface marine winds (see Brönnimann, 2017, for details). It uses a different assimilation scheme than 20CRv2c (4D-VAR). The ERA-20C products describe the spatio-temporal evolution of the atmosphere, the land-surface, and ocean waves. The horizontal resolution is approximately 125 km (spectral truncation T159). The assimilation step is 24 hours (all forecasts are integrated from 06 UTC, Poli et al., 2016), and three-hourly output is provided. ERA-20C is a deterministic reanalysis (no ensemble, although an ensemble was used to generate the background covarience).

ECMWF has further developed its assimilation system into an ocean-atmosphere coupled data assimilation system (CERA) that aims at producing a self-consistent estimate of the climate system, *i.e.,* a climate reanalysis. The product, termed CERA-20C (Laloyaux et al., 2017), covers the period from 1901 to 2010 at moderate resolution using similar input as ERA-20C (see Brönnimann, 2017). In CERA-20C, three-hourly estimates of the coupled ocean-atmosphere state are available as an ensemble of 10 members. In this study we use ensemble member #0.

The NCEP/NCAR Reanalysis data set (Kistler et al., 2001) is a continuously updated (1948–present), global gridded data set that represents the state of the Earth's atmosphere every six hours. All observations (including radiosonde and satellites) are assimilated. Even today, this 20-year old data set remains one of the most widely used data sets in atmospheric science, hence a comparison of this data in its early years with surface-only reanalyses set is useful. The resolution of the global reanalysis model is T62 (209 km) with 28 levels.

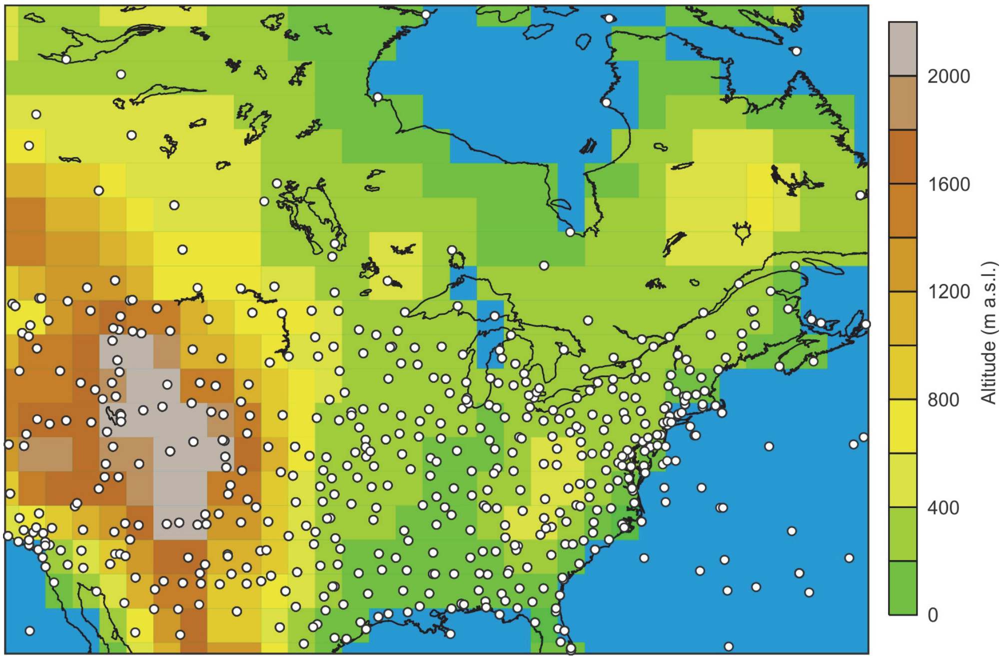

Figure 2. Topography of the 20CRv2c dataset. White dots show all observations assimilated into 20CRv2c from 0 to 6 UTC on 25 November 1950.

The four reanalysis products are compared with historical weather data and weather charts (Smith, 1950; Smith and Roe, 1952) for the period 24-27 November, over the domain 20-60° N and 100-50° W. The same time steps as well as levels are used for the analysis and thus allow qualitative and quantitative comparison of the data sets. The following variables were analysed:

- geopotential height (500 hPa) at 03:00 UTC
- wind (500 hPa) at 03:00 UTC
- reduced see level pressure at 12:00 UTC
- precipitation rate (mm h^{-1})
- minimum 2-m temperature on 25 November

3. Results and Discussion

3.1 Description of the event

The "Great Appalachian Storm" in November 1950 was a very severe storm that caused more than 30 inches (about 76 cm) of snow in many areas along the eastern United States, record breaking temperatures, and hurricane-force winds (NOAA, www.noaanews.noaa.gov/stories/s334c.htm, www.weather.gov/jkl/appalachianstorm1950). The "Great Appalachian Storm" is an atypical "nor'easter" (because of the unusual southeasterly surface winds, the storm is also called "southeaster"). These are extratropical storms that develop along the North American east coast (New England, Canada) partly due to strong temperature contrasts. They are often accompanied by heavy rain or snow, and can lead to severe coastal flooding, coastal erosion, hurricane-force winds, or blizzard conditions. Nor'easters are most intense during winter. The cold polar air mass converges with the warmer oceanic air over the Gulf Stream (see Fischer et al., 2013, for a more typical nor'easter; see also Gassner et al., 2017, in this volume).

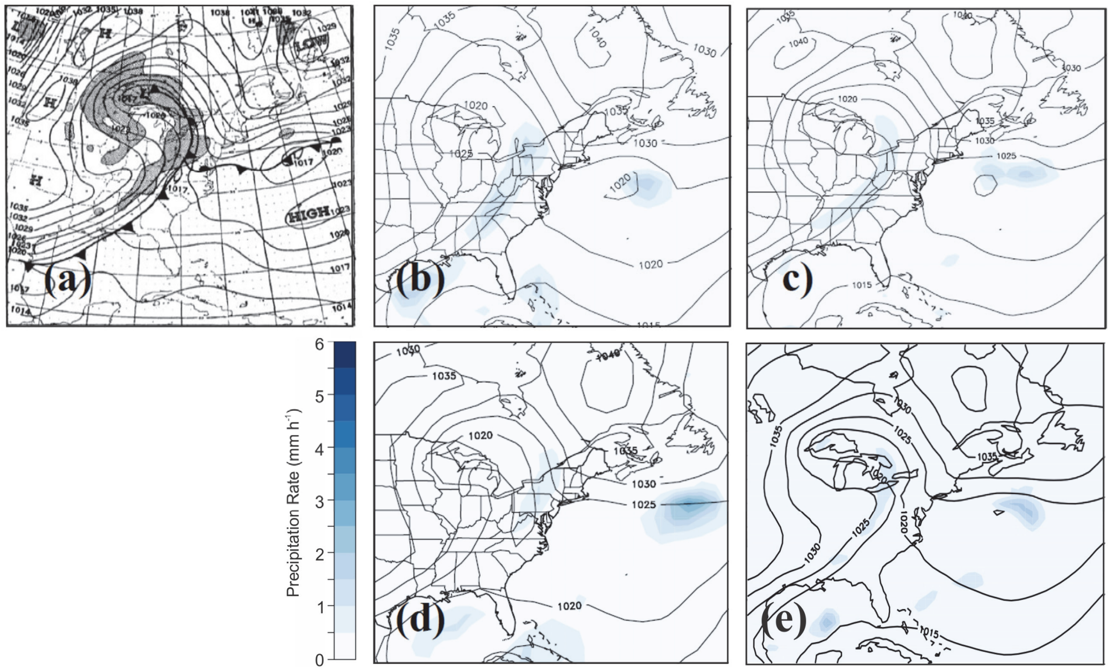

Figure 3: Pressure (contour lines) and precipitation rate (shading) on 24 November 1950 at 12 UTC based on (a) Smith (1950), (b) 20CRv2c, (c) ERA-20C, (d) NCEP/NCAR and (e) CERA-20C.

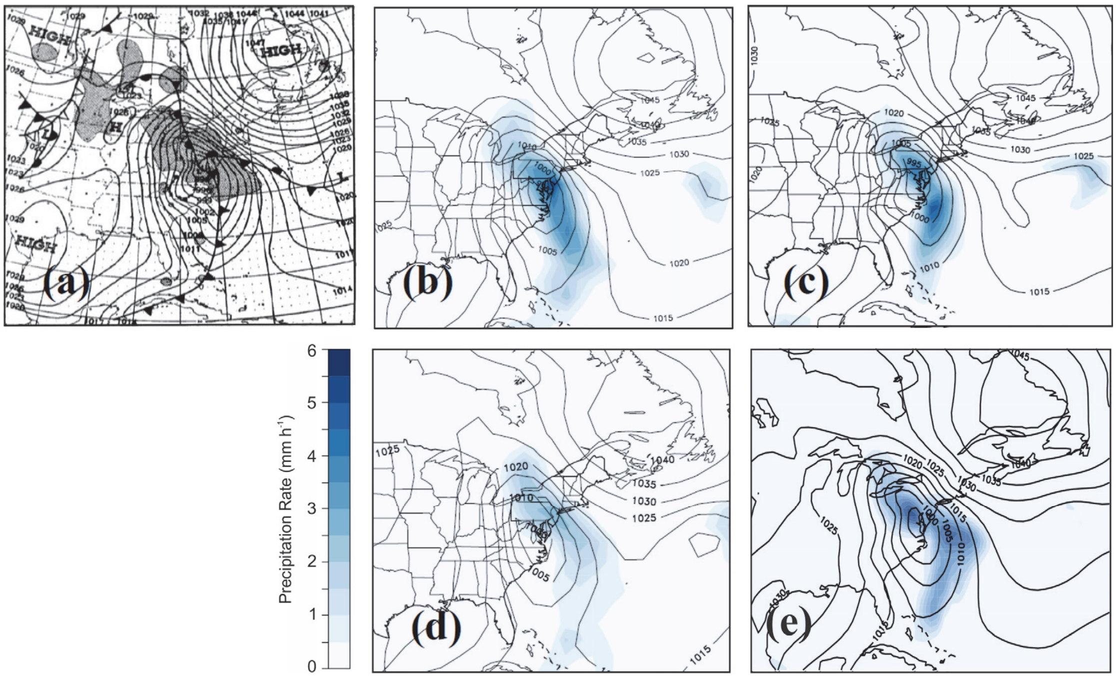

Figure 4: Pressure (contour lines) and precipitation rate (shading) on 25 November 1950 at 12 UTC based on (a) Smith (1950), (b) 20CRv2c, (c) ERA-20C, (d) NCEP/NCAR and (e) CERA-20C.

In the following the storm is analysed in the weather charts of Smith (1950), which are reproduced in Fig. 3a to Fig. 6a. The storm on 24-27 November 1950 was first noted on the surface weather map of 12:30 UTC, 24 November as a small low developing over North Carolina and western Virginia. By 00:30 UTC, 25 November, it was obvious that the

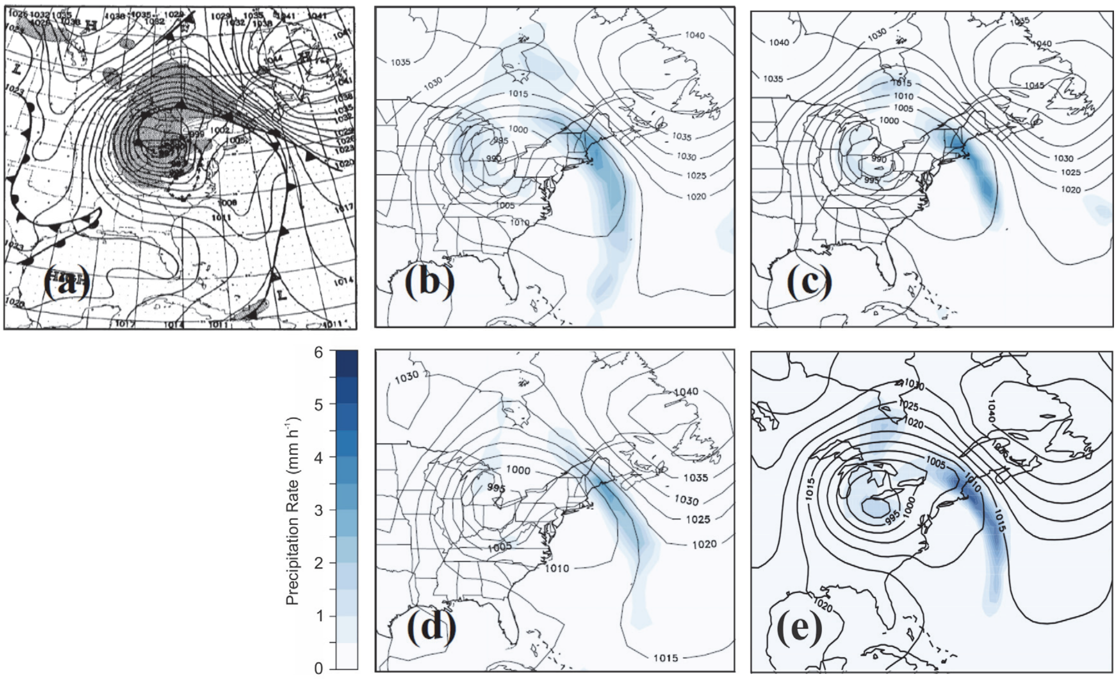

Figure 5: Pressure (contour lines) and precipitation rate (shading) on 26 November 1950 at 12 UTC based on (a) Smith (1950), (b) 20CRv2c, (c) ERA-20C, (d) NCEP/NCAR and (e) CERA-20C.

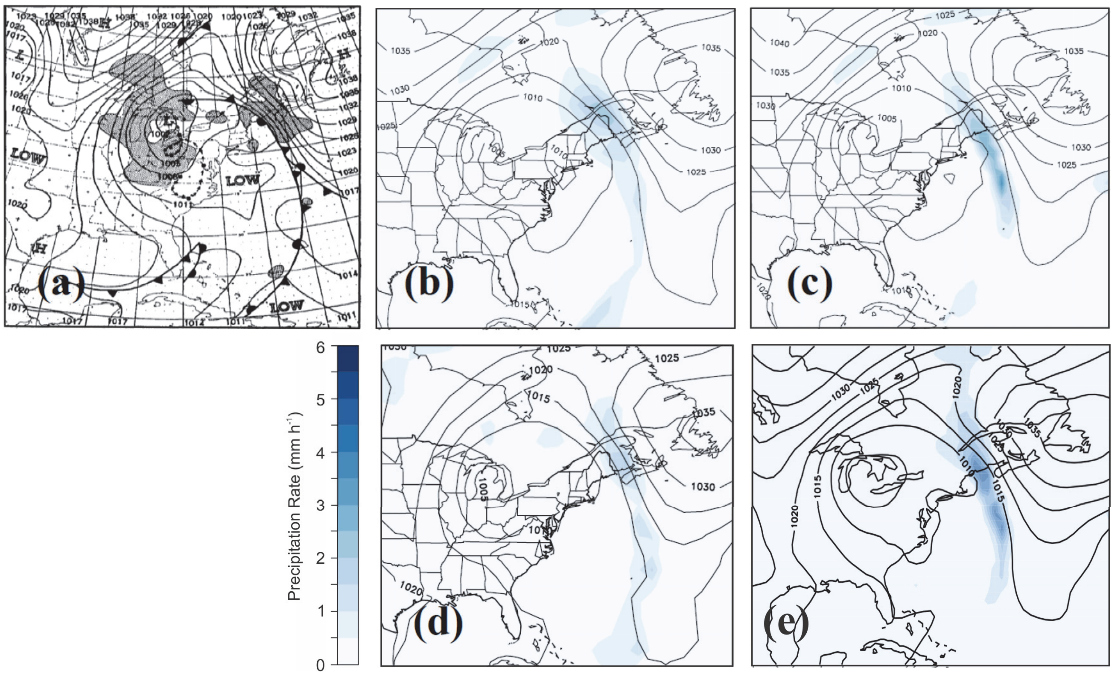

Figure 6: Pressure (contour lines) and precipitation rate (shading) on 27 November 1950 at 12 UTC based on (a) Smith (1950), (b) 20CRv2c, (c) ERA-20C, (d) NCEP/NCAR and (e) CERA-20C.

deepening low over North Carolina had completely captured a place of prominence over another small low developing in the Great Lakes region. The cold air was swept rapidly around the low over North Carolina and was associated with a sudden southward elongation of the centre. By 12:30 UTC, 25 November, the surface low had deepened by 26 hPa. Surface winds behind the former occlusion through Pennsylvania and New York had changed to a northerly direction with a somewhat easterly component, the occlusion transforming into a warm front. By 00:30 UTC on 26 November, the new centre was located near Cleveland, Ohio. While the surface low reformed and deepened over Ohio, the 500 hPa low reached its lowest central value. At 03:00 UTC, 26 November, the low was circling north-wards (Smith, 1950).

By 03:00 UTC, 27 November, the low was centred northeast of Toledo, Ohio. Subsequently, it moved slowly northwards, reformed over Lake Erie on 28 November, moved southwards over Washington D.C. and off towards the northeast. It filled rapidly in the following 24 hours and moved northwards over Lake Huron, though snow continued to fall in Indiana, Ohio and Pennsylvania. Before completely filling, the low circled southwards again through Ohio, further prolonging the snow showers (Smith, 1950).

3.2 Comparison of historical data with four reanalyses

In the following, the four days from 24-27 November 1950 will be analysed by comparing historical weather maps (made by Smith, 1950) with 20CRv2c. In order to further investigate the accuracy of 20CRv2c, the findings are compared with the additional reanalyses ERA-20C, NCEP/NCAR, and CERA-20C. As ERA-20C and CERA-20C display a higher spatial resolution than 20CRv2c and NCEP/NCAR, we expect a more detailed depiction of the event.

Surface Pressure and Precipitation

Since 20CRv2c is based on surface pressure data, the results of the pressure analyses are expectably good. 20CRv2c is able to reproduce all the characteristic features of the weather situation of the Thanksgiving weekend in 1950 (Fig. 3-6, b). There is a very good large-scale spatial correspondence as well as a correspondence of the pressure values.

The comparison with the ERA-20C reanalysis (Fig. 3-6, c) shows that ERA-20C reproduces an even more differentiated result. For example, ERA-20C allows to reproduce the small high-pressure cell northwest of the Great Lakes region (Fig. 3, c), which cannot be seen in the 20CRv2c reanalysis (Fig. 3, b). The NCEP/NCAR reanalysis (Fig. 3-6, d) shows less smooth lines due to its lower resolution. However, mean sea-level pressure is still very accurately displayed in comparison to the historical data. The same counts for the CERA-20C reanalysis (Fig. 3-6, e).

Precipitation fields from all four datasets (Fig. 3-6, b-e) agree relatively well along the Appalachians and the East Coast and the Atlantic in general. In the Great Lakes region, the agreement deteriorates. The convective precipitation along the cold front can be seen in all four datasets. The sharpest gradients are found in ERA-20C and CERA-20C, nicely tracking the fronts in the hand-analysed charts. In terms of precipitation rate, a direct comparison with the historical data cannot be done because the used historical data is not quantitative.

Geopotential Height and Wind

The analysis of the 500mb geopotential height in 20CRv2c corresponds well with the historical data. The magnitudes and the location of the troughs and ridges can be reproduced very accurately (Fig. 7-10, a-b). ERA-20C as well as CERA-20C show a slightly more precise positioning of the predominant cyclone (Fig. 7-10, c,e). The NCEP/NCAR reanalysis is very similar to the 20CRv2c, especially in the south.

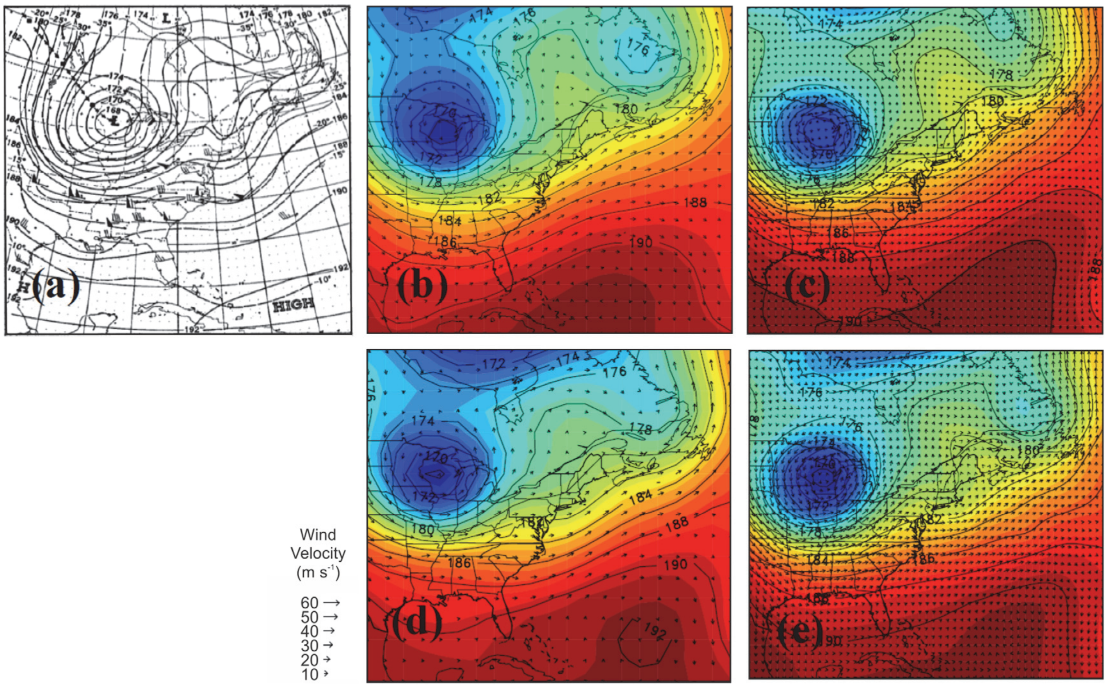

Figure 7. 500 hPa geopotential height (solid lined, in hundreds of geopotential feet) and wind (arrows) on 24 November 1950 at 3 UTC based on (a) Smith (1950), (b) 20CRv2c, (c) ERA-20C, (d) NCEP/NCAR and (e) CERA-20C.

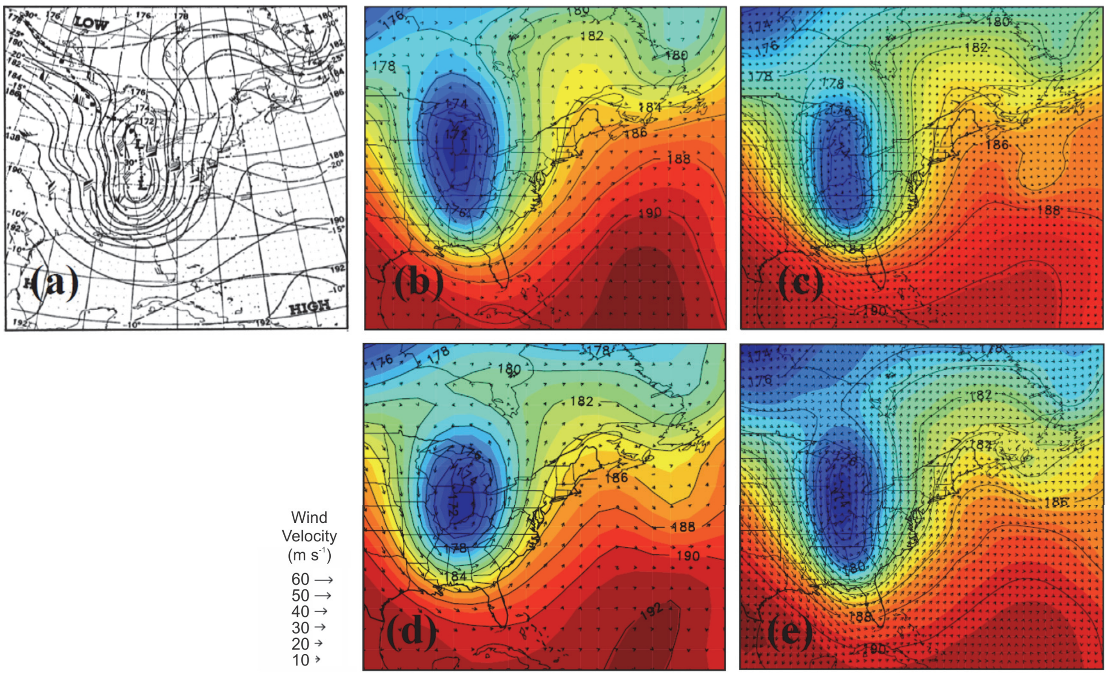

Figure 8. 500 hPa geopotential height (solid lined, in hundreds of geopotential feet) and wind (arrows) on 25 November 1950 at 3 UTC based on (a) Smith (1950), (b) 20CRv2c, (c) ERA-20C, (d) NCEP/NCAR and (e) CERA-20C.

In 20CRv2c, wind direction on the 500 hPa level corresponds well with the historical weather chart (Fig. 7-10, a-b). However, the wind speed is not reproduced well. Overall, the strongest winds occur along the southern part and are reproduced by 20CRv2c. Compared to the historical data, it can be recognized that the wind coming from a northwesterly direction is

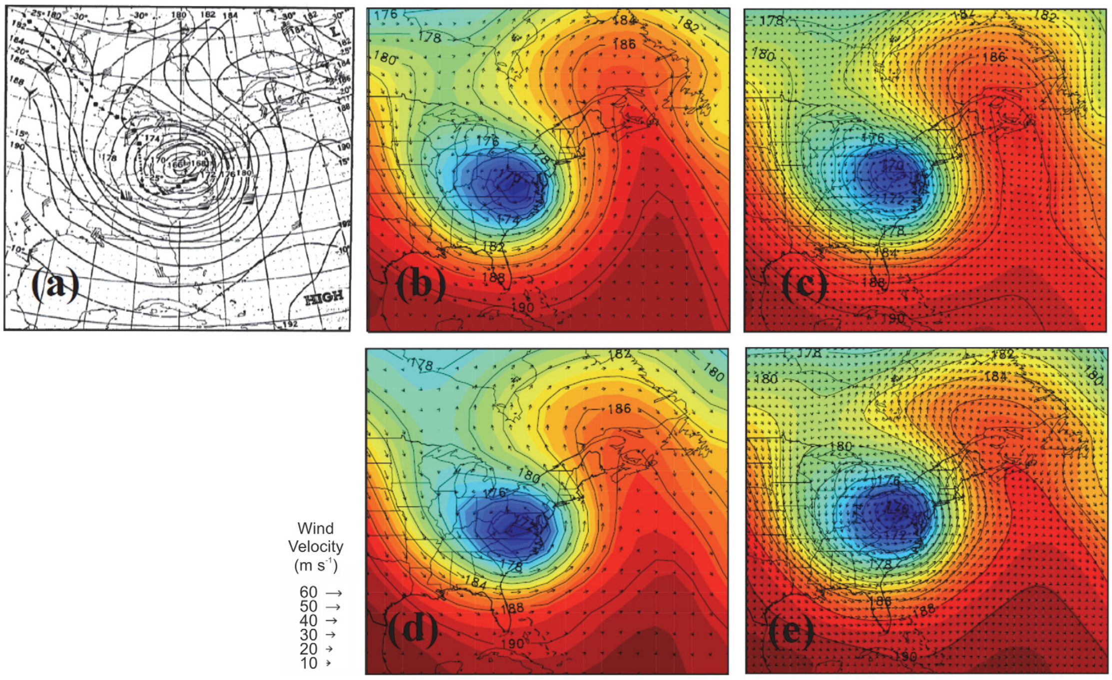

Figure 9. 500 hPa geopotential height (solid lined, in hundreds of geopotential feet) and wind (arrows) on 26 November 1950 at 3 UTC based on (a) Smith (1950), (b) 20CRv2c, (c) ERA-20C, (d) NCEP/NCAR and (e) CERA-20C.

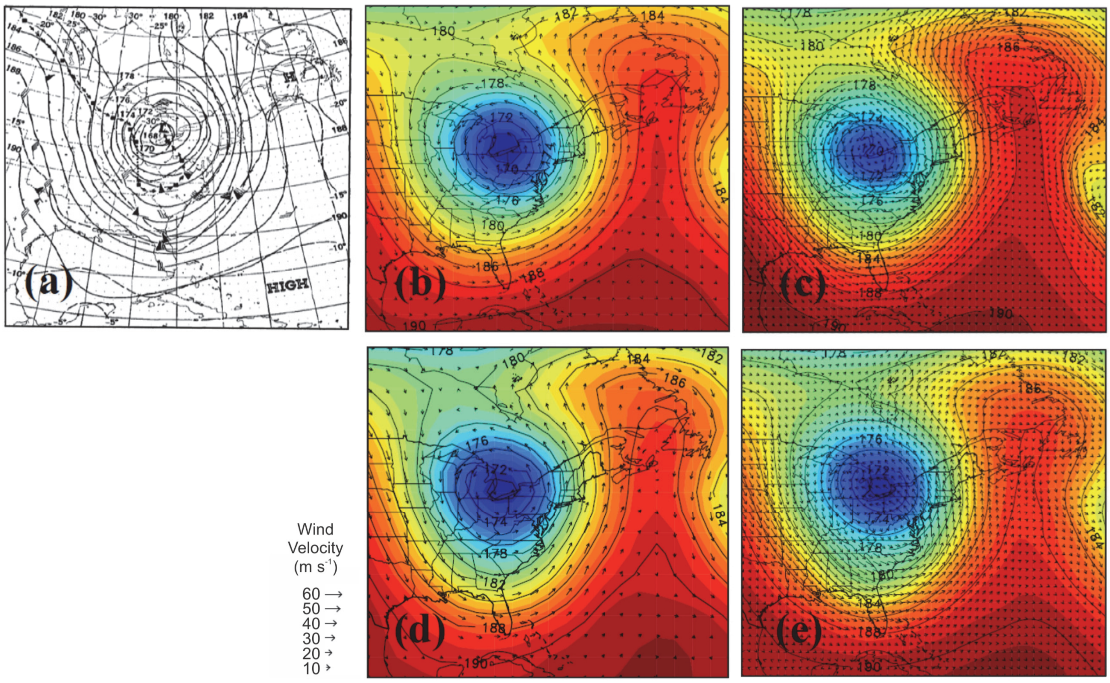

Figure 10. 500 hPa geopotential height (solid lined, in hundreds of geopotential feet) and wind (arrows) on 27 November 1950 at 3 UTC based on (a) Smith (1950), (b) 20CRv2c, (c) ERA-20C, (d) NCEP/NCAR and (e) CERA-20C.

underestimated in terms of strength. Despite this, the strength of the wind blowing northwards on the upper eastern side of the cyclone seems to be overestimated in 20CRv2c. Wind in ERA-20C, NCEP/NCAR and CERA-20C shows a very similar pattern and displays nicely the corresponding wind flow direction and wind strength. (Fig. 7-10, c-e).

Temperature

In order to further investigate the accuracy of the 20CRv2c for the Appalachian Storm of 1950, the variable 1000 hPa temperature is analysed. All reanalyses (Fig. 11, a-d) map the cold wave coming from northwest and are able to roughly replicate the recorded temperature minima. However, there are also large discrepancies in the accuracy: The 0 °F recorded in Cincinnati (OH) on 25 November or 7 °F in Pittsburgh (PA) on 26 November (from the *Monthly Weather Review*) are strikingly well reproduced by 20CRv2c. Other temperatures like -23 °F in Pellston (MI) or most of the temperature minima from cities at the coast can hardly be reproduced with 20CRv2c. Due to the 2° x 2° spatial resolution, a very precise reproduction cannot be expected. Especially around the Appalachians, where topography plays an important role in the temperature distribution, the reanalysis is not very accurate. Surprisingly, the coarse NCEP/NCAR dataset (2.5°x2.5°) shows an excellent performance (Fig. 11c). ERA-20C exhibits lower temperatures than 20CRv2c. Due to the higher spatial resolution, small scale features appear in more detail, *e.g.,* a slight warming in the Great Lakes region. Also, spatial gradients are more pronounced (Fig. 11b). The CERA-20C temperature agrees well with the other reanalyses, but it considerably overestimates the observed values (Fig. 11d).

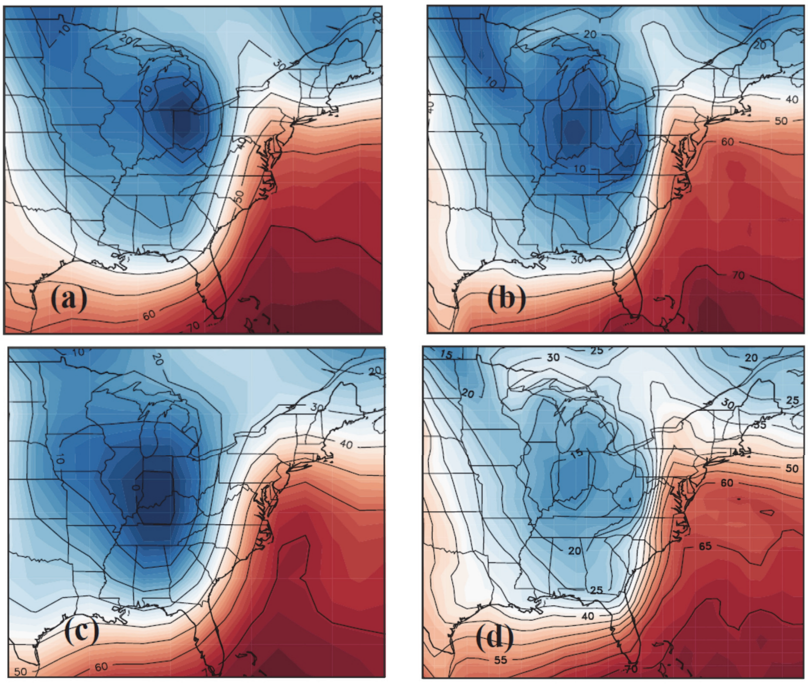

Figure 11. Minimum temperature (°F) at 1000 hPa level on 25 November in (a) 20CRv2c (b) ERA-20C (c) NCEP/NCAR 1950 (d) CERA-20C.

Meteorological stations in the central part of the study area show a rather accurate correspondence with the historical data, whereas stations in the north and along the coast show greater discrepancies. Generally, it can be shown that very low temperature are overestimated by all reanalyses. This is to be expected to some extent as minimum temperatures may be influenced by local factors such as cold-air pooling that are not captured in a coarse reanalysis. It should also be kept in mind that case studies typically suffer from a selection bias, *i.e.,* they were selected because of their extremeness in observations.

4. Conclusions

As presented above, the 20CRv2c data are able to reproduce all important large-scale characteristics of the "Great Appalachian Storm" including surface pressure, geopotential height and wind with good to very good accuracy. Also, temperature and precipitation qualitatively correspond with the historical data. However, these variables are strongly influenced by topography and other local factors and thus, they are difficult to reproduce with precision. The comparison with the reanalysis dataset ERA-20C, which has a higher spatial resolution, confirms the findings of the 20CRv2c reanalysis. The same is valid for the reanalyses NCEP/NCAR and CERA-20C. NCEP/NCAR, the dataset with the coarsest spatial resolution, agrees relatively well with the other reanalyses and with observations, especially with regards to temperature.

Overall, 20CRv2c seems to be capable of reproducing large-scale storm events, such as the "Great Appalachian Storm". It would be very interesting to further investigate the forecast variables of the dataset, *e.g.,* precipitation or snow depth. In combination with a downscaling, more accurate reconstructions could be achieved, especially for regions where topography plays a key role for synoptic weather activity. The newly coupled reanalysis dataset CERA-20C shows promising results and is thus worth further attention.

Acknowledgements

20CRv2c data were obtained courtesy of the NOAA/OAR/ESRL PSD, Boulder, Colorado, USA, from their Web site at http://www.esrl.noaa.gov/psd/. Support for the Twentieth Century Reanalysis Project dataset is provided by the U.S. Department of Energy, Office of Science Innovative and Novel Computational Impact on Theory and Experiment (DOE INCITE) program, and Office of Biological and Environmental Research (BER), and by the NOAA Climate Goal. The Project used resources of the National Energy Research Scientific Computing Center and of the National Center for Computational Sciences at Oak Ridge National Laboratory, which are supported by the Office of Science of the U.S. Department of Energy under Contract No. DE-AC02-05CH11231 and Contract No. DE-AC05-00OR22725, respectively. The work was supported by the Swiss National Science Foundation (Project "EXTRA-LARGE"), by the FP7 project ERA-CLIM2 and H2020 project EUSTACE.

References

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.

Brönnimann, S. and O. Martius (2013) *Weather extremes during the past 140 years.* Geographica Bernensia G89.

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.

Fischer, M., S. Lenggenhager, R. Auchmann, and A. Stickler (2013) Synoptic Analysis of the New York March 1888 Blizzard. In: Brönnimann, S. and O. Martius (Eds.) *Weather extremes during the past 140 years.* Geographica Bernensia G89, p. 45-52, DOI: 10.4480/GB2013.G89.05

Kistler, R., E. Kalnay, W. Collins, S. Saha, G. White, J. Woollen, M. Chelliah, W. Ebisuzaki, M. Kanamitsu, V. Kousky, H. van den Dool, R. Jenne, and M. Fiorino (2001) The NCEP-NCAR 50-year reanalysis: monthly means CD-ROM and documentation. *Bull. Amer. Meteorol. Soc.,* **82,** 247-267.

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.

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

Smith, C. D. (1950) The Destructive Storm of November 25-27, 1950. *Monthly Weather Review,* **78,** 204–209.

Smith, C. D. and C. Roe (1952) Comparison between the storms of November 20-22, 1952, and November 25-27, 1950. *Monthly Weather Review,* **80,** 227-231.