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The Iberian Storm of 1941 in the Twentieth Century Reanalysis

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Abstract

In the night from 15 to 16 February 1941, a disastrous storm hit the Iberian Peninsula and caused devastation across the peninsula. Historical reports and sparse observational data show the exceptional strength and impact of the storm. No comparable event has been recorded since. Therefore, studying this specific historical storm event is important from a present-day perspective in order to better understand storm risks in the Iberian Peninsula. The focus of this paper is to assess whether the Twentieth Century Reanalysis Version 2c (20CRv2c) is able to reproduce this unique storm. We compare the ensemble mean reanalysis fields with historical observations with respect to mean sea-level pressure and wind. The comparison shows that the Iberian Storm of 1941 is well reproduced in 20CRv2c. Mean sea-level pressure is reproduced better than wind. Discrepancies can be due to measurement errors in the historical observations as well as inaccuracies in the reanalysis. Our results suggest that 20CRv2c is a good tool to reproduce and analyse historical storm events.

1. Introduction

Wind storms represent one of the major perils in Europe. Extreme storms are rare, and hence the past record of events is important for improving our understanding of extreme weather events. Meteorological station data and weather reports reach back to the middle of the 19th century. They can help to estimate the occurrence of heavy storms. However, they are not sufficient in quality and quantity to provide a comprehensive, quantitative depiction of storms directly from the data. When assimilated in a weather prediction model, however, they are sufficient to enable detailed meteorological analyses back into the 19th century. The

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“Twentieth Century Reanalysis” Version 2c (20CRv2c, Compo et al., 2011) is one of these data sets. It reaches back 160 years, thus covering many extreme events. Nevertheless, it remains to be established for each case whether or not this reanalysis product is suitable for studying extremes.

This article focuses on the Iberian Storm in February 1941. This windstorm was formed by a meteorological setup that is unique until today (Freitas and Dias, 2013). The basis was the strong negative North Atlantic Oscillation (NAO) in the winter of 1940/41 (Viñas Rubio, 2001). A weak North Atlantic Subtropical High and Icelandic Low allowed the westerlies to dislocate further south and pass over the Mediterranean area instead over Northern Europe (Viñas Rubio, 2001). Days before the storm, a major Atlantic low with a strong jet stream to its South was situated to the West of England (Muir-Wood, 2011). This allowed the formation of a rapidly intensifying daughter storm that was propelled to the East by the jet. Storms and cold surges occur relatively frequently under such circumstances (see also Ernst et al., 2017, in this volume). However the path and the intensity of the Iberian Storm were a rare occurrence this far south as they usually occur over the Northeast Atlantic (Muir-Wood, 2011; Viñas Rubio, 2001).

On Saturday, 15 February 1941, a cyclone moved from the Azores to the East and reached the Portuguese coast in the early afternoon (Viñas Rubio, 2001). The cyclone intensified and passed northern Portugal and Galicia on the night of 15 February. This was accompanied by strong winds and heavy rainfall all over the Iberian Peninsula. Wind gusts reached up to 200 km h^{-1} (Viñas Rubio, 2001). Garnier et al. (2017) report an observed pressure of 948 hPa and wind speeds of 35 m s^{-1} on 15 February. Impacts of the windstorm included floods, high waves and a storm tide. At least 130 people lost their lives. Woods, coasts, factories and other buildings were destroyed (Muir-Wood, 2001; Cereceda, 1941). The historic centre of Santander was destroyed by a fire during the storm (Fig. 1).

Figure 1. Devastation in Santander. The ‘Calle Menéndez Núñez’ in Santander after the windstorm in February 1941. Picture courtesy: Colección Samot.

The 1941 storm has been revisited recently as a study case with respect to impacts of extreme storms. Garnier et al. (2017) study the storm and its human impacts based on historical sources. The storm was the first major event after a long storm-less period and caused massive destruction. Fortunato et al. (2017) focus on waves, storm surge and the inundation a similar storm could produce today. They used the Weather Research and Forecasting Model (WRF) to downscale 20CRv2c, then they used a suite of regional and local wave, tide and surge models. They were able to reproduce the storm, which opens new perspectives to investigate historical extreme events. However, their study does not assess the quality of 20CRv2c directly.

In this paper we assess how 20CRv2c reproduces the 1941 Iberian Storm (Compo et al., 2011). We compare the reanalysis with historical observations of the Iberian Storm of 1941. The paper is organised as follows. Section 2 describes data and methods, Section 3 shows the results of our analysis and in Section 4 we discuss our results. A short conclusion is drawn in Section 5.

2. Data and Methods

In order to get an overview of the intensity and pathway of the storm, several sources have been used to document the course of the windstorm. Historical weather maps of the German Reichswetterdienst (Täglicher Wetterbericht) and the US Weather Bureau (Air Ministry, Meteorological Office, Daily Weather Report. British Section) were taken from the NOAA Central Library, weather charts form the British Meteorological Office were taken from the Met Office Digital Library. The maps provide sea-level pressure, wind speed, and rainfall data of the Iberian Peninsula. In the following we focus on wind speed and direction as well as mean sea-level pressure. For the direct comparison with the reanalysis, the German weather maps provide the best coverage, with maps four times a day within one hour difference to the reanalysis. For the wind speed we use data from the British Meteorological Office and the American Weather Bureau from the same sources. We use data from the stations Lisbon, Porto/Vigo, San Sebastian and Gibraltar.

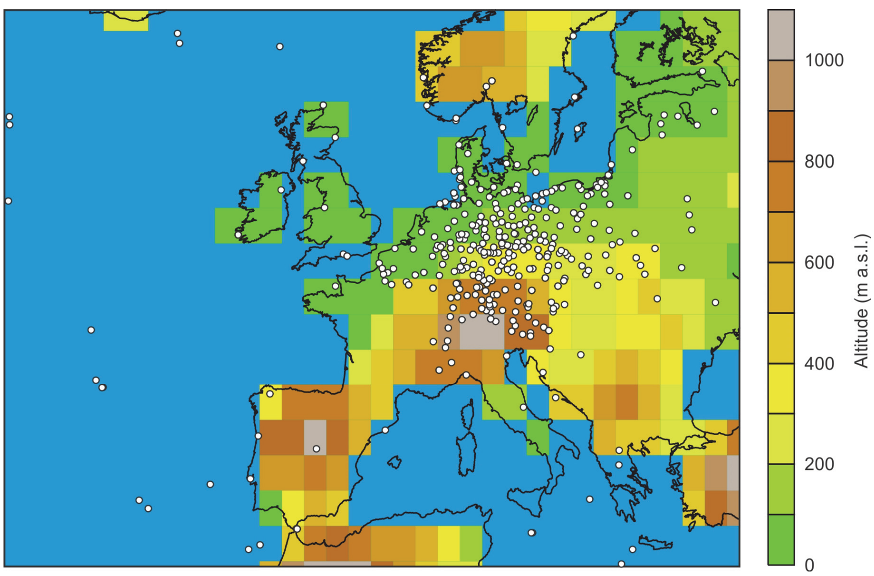

Figure 2. Topography and location of assimilated surface pressure data in 20CRv2c for the analysis of 15 February 1941, 12 UTC.

The reanalysis data of sea-level pressure and wind are taken from 20CRv2c (Compo et al., 2011). The reanalysis provides 3 dimensional, 6-hourly data back to 1851 from the assimilation of surface and sea-level pressure into the CFS model (Saha et al., 2010) using an Ensemble Kalman Filter method. The model is driven by monthly sea-surface temperatures and sea ice (Giese et al., 2016; Hirahara et al., 2014) at its boundaries (see Brönnimann, 2017, for details). Note that 10-m wind speeds were calculated from the ensemble mean vectorial winds. Hence, they are weaker than the ensemble mean wind speeds by definition.

Figure 2 shows the model topography, land-sea mask, and the data assimilated for the peak of the storm. The number of assimilated observations is low in some countries, possibly due to the Second World War (Fig. 2). In particular, the Iberian Peninsula is not well covered, but there are some ship data from the North Atlantic.

3. Results

3.1. Sea-level pressure from historical maps

Days before the windstorm event, the atmospheric situation was characterized by a pronounced low-pressure system over the Atlantic Ocean 1000 km to the South of Iceland (Muir-Wood, 2011). In the historical maps, on the night of 13 February 1941, the cyclone was located at the coast southwest of England (Fig. 3, bottom left). The pressure at the cyclone centre was 984 hPa. The cyclone reached up to the southern coast of the Iberian Peninsula where sea-level pressure reached 1012 hPa. This low-pressure system was stable throughout the day while moving slightly to the East. In the night the cyclone intensified and further in the South, a daughter cyclone with 988 hPa in the centre emerged. It was located between the Azores and the Portuguese coast (Fig. 3, bottom middle). Throughout 15 February, the cyclone in the South intensified and moved towards the northwest of the Iberian Peninsula (Fig. 3, bottom right). In the afternoon the centre with 975 hPa reached the coast of Portugal between Porto and Lisbon. In the early evening the centre of the cyclone was over Galicia and reached up to the western-centre of the Iberian Peninsula. In the North, the cyclone extended to Iceland with two more minima to the west of Great Britain. The pressure in those minima reached around 980 hPa.

On 16 February 1941, 01 UTC, the daughter cyclone was situated over the Atlantic Ocean in the historical maps, while the more northern cyclone no longer was detectable. Sea-level pressure in the centre of the cyclone was 960 hPa with a strong gradient to the South. In southern Portugal sea-level pressure reached 1000 hPa (Fig. 4, bottom left). During the day the cyclone moved in north-easterly direction towards England. At 07 UTC the centre of the cyclone (with a sea-level pressure of 960 hPa) was near the coast of Brittany and reached the southern coast of England before 01 UTC on 17 February (Fig. 4, bottom right). At this time the pressure was 970 hPa.

3.2. Wind in historical weather charts

On 14 February, 00 UTC, the wind blew from a westerly direction with gusts of 21 m s^{-1} over Portugal, according to historical weather charts. In Gibraltar, the winds were noticeably weaker. At noon the winds flattened in the whole region and reached maximum gusts of 14 m s^{-1}.

In the night to 15 February the wind was about 6 m s^{-1} and from a southerly direction in the historical weather charts. In Gibraltar the winds were from the West. At noon the wind speed increased in the region and reached up to 21 m s^{-1}. The winds at the Portuguese coast were from South/Southeast whilst in San Sebastian the winds blew from the West. With 8 m s^{-1} they were weaker than elsewhere. The winds on 16 February blew from western direction and reached a velocity up to 21 m s^{-1} throughout the region.

Table 1: Wind direction and wind speed at 10 m for different regions (chosen because of their location and their availability of data) in observations (US Weather Bureau and British Meteorological Office, from NOAA Central Library, Air Ministry, Meteorological Office 1941) and 20CRv2c (based on ensemble mean *u* and *v* components)

	Observations		**20CRv2c**	
	wind direction	speed [m s^{-1}]	wind direction	speed [m s^{-1}]
14 February 1941, 00:00 UTC				
Region Lisbon	south-southwest	17-21	southwest	16-20
Region Porto/Vigo	west-southwest	17-21	southwest	16-20
Region Gibraltar	west	3-6	south-southwest	4-8
14 February 1941, 12:30 UTC (historical observations)/12:00 (Reanalysis)				
Region Lisbon	west	3-6	west	12-16
Region Porto/Vigo	west	5-14	west	12-16
Region Gibraltar	west	11-14	west-southwest	4-8
Region San Sebastian	west	3-6	southwest	4-8
15 February 1941, 00:00 UTC				
Region Lisbon	south	3-6	south	4-8
Region Porto/Vigo	south	3-6	south	8-12
Region Gibraltar	west	2-3	south	0-4
15 February 1941, 12:30 UTC (historical observations)/12:00 (Reanalysis)				
Region Lisbon	south	17-21	south	24-28
Region Porto/Vigo	southeast	11-14	southeast	20-24
Region Gibraltar	west	17-21	southwest	8-12
Region San Sebastian	east	5-8	southeast	8-12
16 February 1941, 00:00 UTC				
Region Lisbon	west	17-21	west	16-20
Region Porto/Vigo	-	-	west	20-24
Region Gibraltar	-	-	southwest	4-8
16 February 1941, 12:30 UTC (historical observations)/12:00 (Reanalysis)				
Region Lisbon	west	17-21	west	8-12
Region Port/Vigo	west	14-21	west	8-12
Region Gibraltar	west	11-14	southwest	4-8
Region San Sebastian	west	17-21	south	4-8

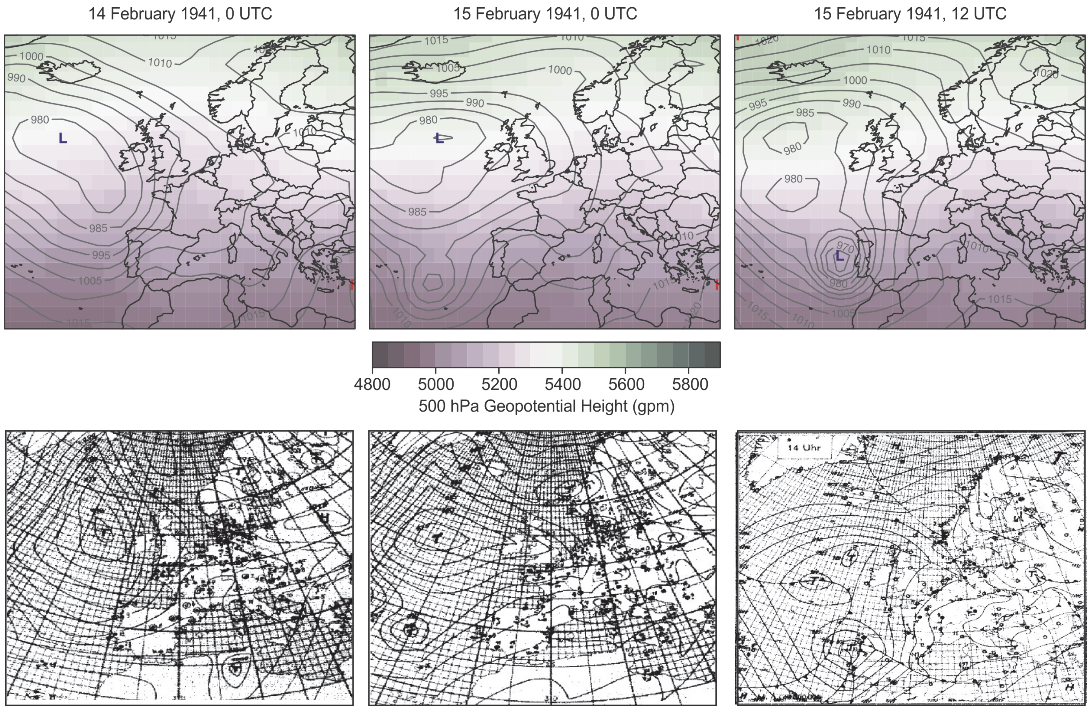

Figure 3. (top) Mean sea-level pressure in hPa (contour lines) and 500 hPa geopotential height (shaded colours) on 14 February 1941, 00 UTC (left), 15 February 1941, 00 UTC (middle) and 15 February, 12 UTC (right) in the ensemble mean of 20CRv2c. (bottom) Historical weather maps from the Deutsche Reichswetterdienst (NOAA Central Library) indicating mean sea-level pressure (contour lines) on 14 February 1941, 01 UTC (left), 15 February 1941, 01 UTC (middle) and 15 February, 01 UTC (right), source: Deutscher Wetterdienst.

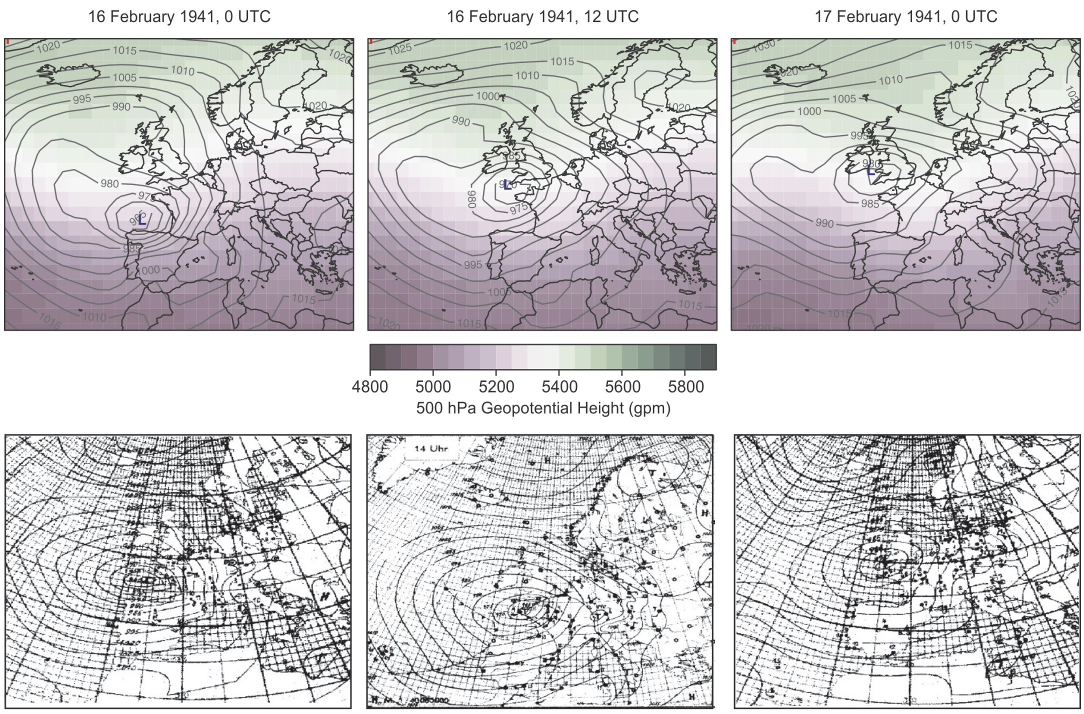

Figure 4. (top) Mean sea-level pressure in hPa (contour lines) and 500 hPa geopotential height (shaded colours) on 16 February 1941, 00 UTC (left), 16 February 1941, 12 UTC (middle) and 17 February, 00 UTC (right) in the ensemble mean of 20CRv2c. (bottom) Historical weather maps from the Deutsche Reichswetterdienst (NOAA Central Library) indicating mean sea-level pressure (contour lines) on 16 February 1941, 01 UTC (left), 16 February 1941, 13 UTC (middle) and 17 February, 01 UTC (right), source: Deutscher Wetterdienst.

3.3. Sea-level pressure in the 20CRv2c reanalysis

On 14 February, 00 UTC, the 20CRv2c ensemble mean shows a cyclone based west of the British Isles. In the centre the pressure was about 975 hPa. A strong pressure gradient was noticeable to the South (Fig. 3, top left). In the morning the cyclone moved slightly to the East, then remained stationary until the evening of that day.

On 15 February, 00 UTC, a second cyclone emerged in the South. Its centre was between the Azores and southern Portugal. In 20CRv2c, the pressure was still around 975 hPa in the northern centre and 988 hPa in the southern one (Fig. 3, top middle). During the morning the new cyclone intensified over the Atlantic west to Portugal. At noon the centre of the cyclone was just in front of the coast of Portugal and the pressure reached 960 hPa. The two cyclones merged and the new system reached from Portugal to Iceland. The strongest gradient was towards the South (Fig. 3, top right). In the evening the cyclone was situated over northern Portugal and Galicia, the pressure was 965 hPa.

On the night of 15 February the cyclone moved northeast, over the Bay of Biscay. The pressure in 20CRv2c increased slightly and was around 960 hPa at 00 UTC (Fig. 4, top left). In the morning the cyclone moved in the same direction and passed just to the West of the Bretagne. At noon the pressure decreased up to 965 hPa (Fig. 4, top middle). In the evening the centre of the cyclone was situated over south-western England and Wales, stretching to southern Ireland.

While Figures 3 and 4 show the ensemble mean, we also analysed the ensemble spread. During the period of the storm, the ensemble spread of sea-level pressure remained below 2 hPa over almost the entire analysis domain except towards the central North Atlantic (not shown).

3.4. Wind in the 20CRv2c reanalysis

On 14 February 1941, 00 UTC, the wind in 20CRv2c was from the West with a speed of 16-20 m s^{-1}. Around noon the winds became weaker, around 12-16 m s^{-1} (Fig. 5, top left and middle). On 15 February, 00 UTC, the wind blew from the South. In Portugal wind speeds in 20CRv2c were only 4-8 m s^{-1} (Fig. 4, top right). Around noon on 15 February strong winds advanced to the North and were located just off the Portuguese coast. In the South of Portugal those winds blew with at least 24 m s^{-1}. Further north, the winds were slower and from a southeasterly direction (Fig. 5, bottom left). Towards the evening the winds reached the inner parts of the peninsula. Spain was hit by winds of around 27 m s^{-1} speed. At the coast next to Porto winds were over 32 m s^{-1}.

On 16 February, 00 UTC the wind speed in 20CRv2c was not as high as the evening before. At the north-western coast of the Iberian Peninsula the winds blew from the West with a speed of around 20 m s^{-1}. At noon the winds south of Lisbon were just 8-12 m s^{-1} and in the North the wind speed decreased to 8-12 m s^{-1} (Fig. 5, bottom middle and right).

4. Discussion

In this part the historical observations are compared to the results of the reanalysis. The former may however be inaccurate due to the instruments used at this time. Furthermore, there was no consensus about the location of the measurements (Muir-Wood, 2011).

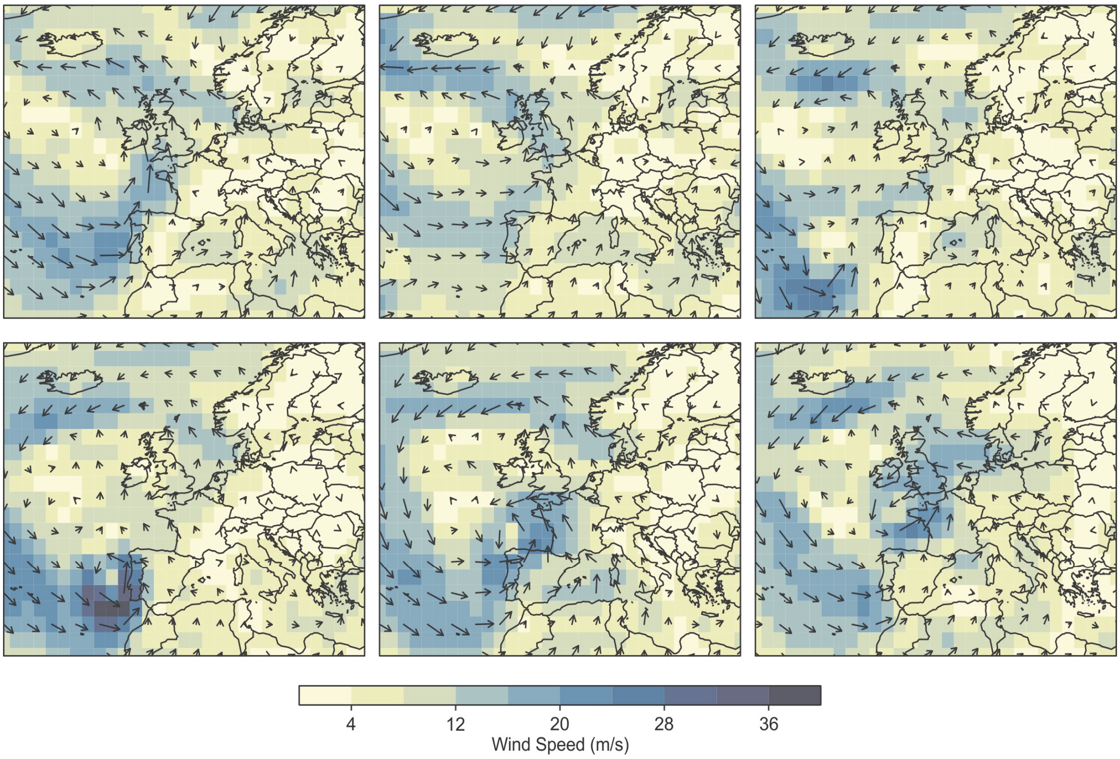

Figure 5. Ten-metre wind in the ensemble mean of 20CRv2c (note that wind speed, shown on colours, was calculated from ensemble mean *u* and *v*) 12 hourly from 14 February 1941, 00 UTC, to 16 February 1941, 12 UTC (top left to bottom right).

Concerning the reanalysis, it should be noted that we analysed the ensemble mean and not the 56 individual members. Ten-metre wind speed was calculated from ensemble mean *u* and *v*, which yields lower values than ensemble mean wind speeds.

4.1. Sea-level pressure comparison

On 14 February 1941 the cyclone to the West of England is shown very accurately in the reanalysis (Fig. 3, left). Pressure and pressure gradients are similar to the observations with only small deviations up to 5 hPa. The six-hourly data of the reanalysis show the same course of the cyclone. Small discrepancies are detected in the night to 15 February for the northern centre of the low pressure system, which is located to the west of Ireland. Mean sea-level pressure in 20CRv2c is around 5 hPa lower than in the historical observations (Fig. 3, middle). Other than that, the displacement of the pressure system to the East during the course of the 15 February is in agreement with observations (Fig. 3, right). At 15 February, 18 UTC the reanalysis places the centre of the cyclone slightly to the West compared to observations, but at the same latitude. On 16 February, 00 UTC the reanalysis and the observations agree well. The reanalysis shows the pressure field as well as the gradients precisely (Fig. 4, left). During the course of the day. The pressure gradient was weak to the West of the pressure centre. This gradient is shown more distinctly in the reanalysis data, which at 18 UTC even indicate a second small pressure centre. This feature is not seen in the historical charts (Fig. 4, middle).

4.2. Wind comparison

The historical observations and the reanalysis data have a time difference of 30 minutes each day at noon. On 14 February 1941, 00 UTC, 20CRv2c and the Daily Weather Report show almost identical wind directions and velocities (Table 1). Only in the region of Gibraltar the reanalysis shows a difference in the wind direction, which is more southerly in 20CRv2c. The same applies for noon where the wind in Gibraltar is more southerly and weaker in the reanalysis. Furthermore, 20CRv2c shows some deviations in the region around Lisbon where the wind force is stronger compared to observations. Other than that, 20CRv2c depicts the historical observations accurately.

In the morning of 15 February, the reanalysis depicts the observations very well, with a slight deviation in Gibraltar and a deviation for the wind speed in the region of Vigo/Porto. At noon all wind directions are almost identical in 20CRv2c and observations, although wind speeds are higher in 20CRv2c over the entire Iberian Peninsula. In the region of Porto/Vigo the difference reaches 10 m s^{-1}. In the region of Gibraltar neither wind speed nor direction coincide.

In the region of Lisbon on 16 February, 00 UTC, the wind direction in the reanalysis and the observations are in agreement. The wind speed differs only slightly. There are no historical observations available for the other regions. At noon the wind direction for Lisbon and Porto/Vigo agree between 20CRv2c and observations, but the wind speed is lower in the reanalysis for both regions. In the region of San Sebastian neither wind direction nor velocity in the reanalysis agree with the data from the U.S. Weather Bureau.

5. Conclusions

The mean sea-level pressure data in 20CRv2c depicts the Iberian Storm from 1941 very well quantitatively as well as with respect to its temporal development. Particularly, the comparisons on 14 and 15 February show very high agreement between reanalysis and historical weather charts. On 16 February some deviations appear, but the cyclone can still be recognized without difficulty. As 20CRv2c is based on the assimilation of surface observation of synoptic pressure, this good agreement was expected.

Wind velocity as well as wind direction in 20CRv2c are mostly in agreement with the historical observations. Especially in the region of Gibraltar there are some discrepancies, which however do not affect the storm. In summary, the Iberian Storm from 14 to 16 February 1941 is well reproduced in 20CRv2c. The reanalysis is suitable to analyse mean sea-level pressure as well as, to a slightly lesser extent, the wind evolution. One uncertainty in our comparison is the unknown precision of the measurements back in 1941. Part of the disagreement is likely also due to a lower quality of the observations as well as the fact that wind speeds were calculated from the ensemble mean.

The increased interest in the Iberian Storm of 1941 reflects the fact that until recently, only very few major storms could be studied quantitatively. The fact that 20CRv2c well represents the important features allows further modelling application such as shown by Fortunato et al. (2017). Nevertheless, as this book also shows, extreme events must be assessed individually.

With respect to the generation of the 1941 Iberian Storm, an interesting link concerns the possible relation to the strong El Niño during that winter (Brönnimann et al., 2004). The general setting (negative NAO) in which the storm developed was perhaps facilitated by the El Niño event. Further studies could address the cyclone track (see Karremann et al., 2016) and decadal variability in the frequency of occurrence of strong Iberian cyclones.

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