Characterisation of synoptic conditions and cyclones associated with top ranking potential wind loss events over Iberia

Article

Karremann, M. K., Liberato, M. L. R., Ordóñez, P. and Pinto, J. G. (2016) Characterisation of synoptic conditions and cyclones associated with top ranking potential wind loss events over Iberia. Atmospheric Science Letters, 17 (6). pp. 354-361. ISSN 1530-261X doi: https://doi.org/10.1002/asl.665 Available at https://centaur.reading.ac.uk/62700/

To link to this article DOI: http://dx.doi.org/10.1002/asl.665

Publisher: John Wiley & Sons

ATMOSPHERIC SCIENCE LETTERS
OPEN
Now fully open access
RMetS
Royal Meteorological Society
WILEY

Characterisation of synoptic conditions and cyclones associated with top ranking potential wind loss events over Iberia

Journal:	*Atmospheric Science Letters*
Manuscript ID	ASL-15-131.R2
Wiley - Manuscript type:	Research Article
Date Submitted by the Author:	08-Mar-2016
Complete List of Authors:	Karremann, Melanie; Karlsruher Institut fur Technologie - Campus Nord, Institute of Meteorology and Climate Research (IMK); University of Cologne, Institute for Geophysics and Meteorology Liberato, Margarida; Instituto Dom Luiz, Faculdade de Ciências, Universidade de Lisboa,; Universidade de Trás-os-Montes e Alto Douro (UTAD), Escola de Ciências e Tecnologia Ordóñez, Paulina; Universidade de Trás-os-Montes e Alto Douro (UTAD), Escola de Ciências e Tecnologia; Universidad Nacional Autónoma de México, Mexico City, Mexico, Centro de Ciencias de la Atmósfera Pinto, Joaquim; University of Reading, Department of Meteorology; University of Cologne, Institute for Geophysics and Meteorology
Keywords:	windstorms, Iberia, cyclones, multi-decadal variability, impacts, potential wind losses

Characterisation of synoptic conditions and cyclones associated with top ranking potential wind loss events over Iberia

Melanie K. Karremann[1,2,*], Margarida L. R. Liberato[3,4], Paulina Ordóñez[3,5], Joaquim G. Pinto[2,6]

1) Institute of Meteorology and Climate Research, Karlsruhe Institute of Technology, Karlsruhe, Germany

2) Institute for Geophysics and Meteorology, University of Cologne, Cologne, Germany

3) Escola de Ciências e Tecnologia, Universidade de Trás-os-Montes e Alto Douro, Vila-Real, Portugal

4) Instituto Dom Luiz (IDL), Universidade de Lisboa, Lisboa, Portugal

5) Centro de Ciencias de la Atmósfera, Universidad Nacional Autónoma de México, Mexico City, Mexico

6) Department of Meteorology, University of Reading, Reading, United Kingdom

Short title: Characterisation of top ranking potential wind losses over Iberia

Submitted to *Atmospheric Science Letters*

19 October 2015

Revised 8 March 2016

[*] *Corresponding author address:* Melanie K. Karremann, Institute of Meteorology and Climate Research (IMK), Karlsruhe Institute of Technology, Hermann-von-Helmholtz-Platz 1, 76344 Eggenstein-Leopoldshafen, Germany

E-mail: melanie.karremann@kit.edu, Tel. +49-721 608-24793, Fax: +49-721-608-24377

Abstract

Intense extra-tropical cyclones are often associated with strong winds, heavy precipitation and socio-economic impacts. Over southwestern Europe, such storms occur less often, but still cause high economic losses. We characterise the large-scale atmospheric conditions and cyclone tracks during the top-100 potential losses over Iberia associated with wind events. Based on 65 years of reanalysis data, events are classified into four groups: (i) cyclone tracks crossing over Iberia on the event day ("Iberia"), (ii) cyclones crossing further north, typically southwest of the British Isles ("North"), (iii) cyclones crossing southwest to northeast near the northwest tip of Iberia ("West"), and (iv) so called "Hybrids", characterised by a strong pressure gradient over Iberia due to the juxtaposition of low and high pressure centres. Generally, "Iberia" events are the most frequent (31% to 45% for top-100 vs. top-20), while "West" events are rare (10% to 12%). 70% of the events were primarily associated with a cyclone. Multi-decadal variability in the number of events is identified. While the peak in recent years is quite prominent, other comparably stormy periods occurred in the 1960s and 1980s. This study documents that damaging wind storms over Iberia are not rare events, and their frequency of occurrence undergoes strong multi-decadal variability.

Keywords: windstorms, Iberia, cyclones, impacts, potential wind losses, multi-decadal variability

1. Introduction

Extra-tropical cyclones are determinant for the weather conditions in the mid-latitudes. Embedded in the westerly flow, cyclones typically undergo a strong intensification over the North Atlantic Ocean while travelling towards Europe. Intense cyclones are often associated with strong winds and heavy precipitation (e.g. Pfahl, 2014), thus often leading to large socio-economic impacts (e.g. Swiss Re, 2008). Over southwestern Europe, such intense cyclones occur less often (e.g., Trigo, 2006; Pinto et al., 2009). This can be explained by the cyclone track climatology (Fig. 1a), which features a reduced number of systems near Iberia. Intense cyclones affecting Iberia typically cause high amounts of precipitation and flooding in that area (Ramos et al., 2014). Still, recent storms like "Klaus"† (Liberato et al., 2011) were primarily characterised by very strong winds, leading to €541m insured losses in Spain due to wind gusts (CCS, 2015). In winter 2013/2014, several storms affected the Iberian Peninsula, including storm "Dirk" (20131224‡), which caused €30.3m insured losses in Spain due to both wind gusts and floods (CCS, 2015). While previous studies analysed single storms (e.g., "Klaus" and "Xynthia"; Liberato et al., 2011; 2013), a climatological assessment is missing. Based on 65 years of reanalysis data, we characterise the large-scale atmospheric conditions and cyclone tracks associated with the top-100 potential losses over Iberia due to strong wind events (windstorms).

2. Data

The analysis of potential wind loss events over Iberia is performed based on the National Centre for Environmental Prediction/National Centre for Atmospheric Research reanalysis (hereafter NCEP; Kistler et al., 2001). As no gust wind speed is available for this dataset, 6-hourly instantaneous 10m-wind speeds (hereafter wind) are analysed. NCEP reanalysis is provided on a T62 resolution (Fig. 1b; 1.875°). For each grid point *ij*, daily maximum wind speeds (largest values for each day between 00, 06, 12 and 18 UTC, denoted v_{ij}) for the extended winter (October to March) 1948/49 to 2014/15 are selected. Winters are named by the second year, e.g. winter 2014/15 is named 2015. Based on the climatology, 98th wind percentiles ($v_{98_{ij}}$) are

† Cyclone names after Freie Universität Berlin database, www.met.fu-berlin.de/adopt-a-vortex/historie/

‡ All dates in yyyymmdd

calculated, and are used as a threshold for the loss model. The 6-hourly mean sea level pressure (MSLP) data is used for cyclone tracking and computation of the MSLP gradient over Iberia [10°W-2.5°E; 35°N-45°N].

Potential loss event rankings may differ between reanalysis datasets (Karremann et al., 2014a). This is also true for cyclone characteristics (e.g., Trigo, 2006). A preliminary analysis revealed a similar list of top events for NCEP and ERA-Interim (cf. Table S1). Our focus on NCEP is motivated by the longer time series, which enables a better representation of long term variability of events affecting Iberia.

3. Methodology

Event identification

The present study uses a simplified approach of previous empirical models (e.g., Klawa and Ulbrich, 2003; Pinto et al., 2012; Karremann et al., 2014a) considering only meteorological parameters to estimate potential losses based on gridded data. The main assumptions are: (i) a critical wind speed needs to be exceeded to cause any loss. In most parts of Europe, this threshold corresponds to $v_{98_{ij}}$ (e.g. Klawa and Ulbrich, 2003), (ii) a strong non-linearity in the wind – loss relation is assumed as the kinetic energy flux is proportional to the cube of wind speed (Mills, 2005). Following Pinto et al. (2012), the potential wind loss (MI) over Iberia (Fig. 1b) per day is defined as:

$$MI(day) = \sum_{i=1}^{N} \sum_{j=1}^{M} \left(\frac{v_{ij}}{v_{ij}^{98}} \right)^3 * I\left(v_{ij}, v_{ij}^{98} \right) \quad \text{Eq. (1)}$$

$$I(v_{ij}, v_{ij}^{98}) = \begin{cases} 0 & v_{ij} < v_{ij}^{98} \\ 1 & v_{ij} > v_{ij}^{98} \end{cases}$$

The number of analysed grid points in the longitudinal and latitudinal directions is given by M and N respectively. Based on all identified MI events, a ranking is established. The top-100 MI events between October 1948 and March 2015 are selected for detailed analysis.

Cyclone tracking

Cyclone tracks are derived with a cyclone tracking algorithm (Murray and Simmonds, 1991; Pinto et al., 2005). The Laplacian of MSLP is used as proxy for the relative geostrophic vorticity and is used for cyclone identification. Cyclone tracks are compiled by considering the most probable trajectory of the systems between subsequent time frames (estimated from MSLP gradients, past cyclone speed and intensity).

Assignment of top loss events with cyclone tracks

The top-100 MIs are characterised in terms of large-scale atmospheric conditions and the presence of low pressure centres using NCEP data and weather charts[§]. If cyclone tracks are located on the event day within 30ºW-20ºE, 30ºN-65ºN (blue box in Fig.1a), they are preliminary assigned to the event. These cyclone tracks and associated windstorm footprints are analysed: the cyclone which matches best with the windstorm footprint in terms of timing and overlap with Iberia is subjectively selected as potentially responsible for MIs over Iberia.

If potential loss event days are identified on subsequent dates and both events are associated with the same cyclone, the dates are combined as one event. In this case, MI is recalculated by summing up the maximum exceedance of the 98th percentile within these subsequent days at each grid point ij. Thus, the following MI events (below top-100) are added to the list until the top-100 is complete again. The final list of top-100 MIs is shown in Table S1.

4. Analysis of the top-100 events

The time distribution of top-100 MIs over the 65-year period is displayed in Fig. 1c. About 84% of the events occurred between December and February, and only 2% in October, 6% in November, and 8% in March. Colours indicate the ranking of storms. A clear dependency between the ranking of events and the seasonality is not found (Fig. 1c). On the one hand, the number of events changes strongly from year to year. The largest number of events is identified for 2001 (6 events) and 2014 (5 events), while for other periods a maximum of 2 events per winter is found, e.g., in most of the 1970s, 1990s and 2000s. Decadal variability is analysed using a 10-year running average of the number of events per winter for different intensities (Fig. 1d). Periods with a reduced number of events include 1957-1960, the 1970s and 1994-2004,

[§] Berliner Wetterkarte, published by Society Berliner Wetterkarte e.V., Freie Universität Berlin and German Weather Service. ISSN:0177-3984, www.berliner-wetterkarte.de while periods in the 1960s, 1980s and after 2005 display more events than average. While this result is largely independent from the intensity of events (colours in Fig. 1d), the peak in recent years is very prominent for the top-20 MIs (red curve). Longer periods with a low number of top-20 MIs are identified in the 1970s, 1990s and early 2000s. Thus, decadal variability in the number of events is identified for all intensities.

For each event, synoptic conditions and associated cyclone tracks are characterised following the methodology described in section 3. The location of the pressure minima for the top-100 events is depicted in Fig. 2a. The pressure minima of the top-20 MIs (red colours in Fig. 2a) are mostly identified close to the north of Iberia, roughly between 15°W-5°E and 38°N-58°N. For lower ranking events, the region is wider. It is notable that only four events from the extreme windstorms database (XWS; Roberts et al., 2014; their Table 1[**]) are present in our event list, revealing that the top events for Iberia (Table S1) are largely different from those affecting other parts of Europe (cf. also Karremann et al., 2014b).

The identified cyclones were grouped based on their characteristics. 70% of the analysed events are strongly influenced by cyclones:

(i) Cyclone tracks crossing over Iberia at the event day (box "Iberia" in Fig. 2a) and thus with a direct influence (group *"Iberia"*, cf. Fig. 2b).

(ii) Cyclone tracks crossing north of Iberia on a zonal track, mostly southwest from the British Isles (region "North" in Fig. 2a), and influencing Iberia primarily due to their extended fronts (group *"North"*, Fig. 2c).

(iii) Cyclone tracks crossing from southwest to northeast, but west of Iberia (cf. grey area "West" in Fig. 2a) and not intersecting the *Iberia* box (group *"West"*, Fig. 2d).

In some cases, the cyclone was not found to be determinant per se for the windstorm footprint from the selected event, but rather its co-occurrence with a high pressure centre on the opposite side of Iberia, which led to a strong pressure gradient over the region and consequently strong winds (cf. also Pfahl, 2014). Thus a final category is defined as follows:

(iv) Synoptic situation with the juxtaposition of a cyclone and an anticyclone, leading to a pronounced MSLP gradient over Iberia and thus strong winds (group *"Hybrid",* cyclone tracks shown in. Fig. S1). Events are marked with a black circle in Fig. 2a.

[**] cf. http://www.europeanwindstorms.org for updates on the XWS database.

The assignment of events into the four groups is shown in Table S1, and composite MSLP fields in Fig. S2. For the top-100 MIs, most events are classified as *Iberia* (31%), closely followed by *Hybrid* (30%), *North* (28%) and *West* (11%, Table 1). The relative importance of the *Iberia* group increases with intensity of MI, reaching 45% for top-20 MIs. Conversely, the percentage of *North* storms decreases with intensity, reaching 15% for top-20 MIs. Top ranking events typically affect a larger area (more grid points; Table S1), although the relationship is not strong. While all four groups show a dichotomous pattern with a high and a low pressure system (cf. Pfahl, 2014), the analysis provides evidence that in 70% (all but *Hybrid* group) the cyclones are primarily responsible for the strong winds over Iberia and thus the MI event.

5. Characterisation of the four groups

The general characteristics of each group are presented in this section including a representative case study. Like many East Atlantic cyclones, most of the systems considered here are secondary cyclones, which develop on the trailing cold fronts of "parent" cyclones located further North (e.g. Dacre and Gray, 2013).

Group Iberia:

The cyclones in this group cross over Iberia (Fig. 2b), leading to a direct impact. This group includes named storms like "Klaus" (20090123), "Xynthia" (20100227) and "Gong" (20130119). Storm "Stephanie" (Top#1, 20140209) is selected as representative example. A high pressure at 500hPa is identified over the subtropical North Atlantic, and a low pressure system north of Scotland (not shown). The corresponding surface low pressure centre ("Ruth", Fig. 3a) is below 970hPa, and the Azores high is above 1025hPa, leading to an intense westerly flow towards West- and Central Europe. "Stephanie" is a secondary low developing in this strong westerly flow, and is located over the Bay of Biscay on 10 January, 00 UTC (Fig. 3a). The associated windstorm footprint affected the whole Iberian Peninsula (Fig. 3b). Hurricane-force winds, snow and rain were reported, causing the strongest damage in western regions where wind uprooted numerous trees, broke windows and blew roofs away while high waves and flooding disrupted roads.

Group North:

This group is characterised by cyclones crossing north of Iberia in a zonal track, typically over the British Channel (Fig. 2c). Such cyclones usually feature extended cold fronts, leading to strong winds further south over Iberia. This group includes named storms “Martin” (19991227) and “Anne” (20140104). Storm “Joachim” (Top#62, 20111216) is selected as representative case. High pressure at 500hPa is identified over the subtropical North Atlantic, while the mid-level low pressure system is located west of Iceland (not shown). The corresponding surface low pressure centre (“Hergen”, Fig. 3c) is below 970hPa, and the Azores high is above 1030hPa. Strong westerly flow dominates at upper levels, in which cyclone “Joachim” is embedded (not shown). Beside the difference of air masses, a short wave trough influenced its explosive development. The core pressure deepened from 1008hPa to 980hPa within 24h bringing severe wind gusts and heavy rainfall to many parts of northern Iberia, causing numerous incidents such as falling trees, fences and streetlights or landslides.

Group West:

This group is characterised by cyclones crossing from the southwest to the northeast, typically close to the northwestward tip of Iberia (Fig. 2d), and includes storms like the “Great Storm of 1987” (19871015). Storm “Qumaira” (Top#59, 20140206) is selected as a representative example. A blocking high pressure system is located over the subtropical North Atlantic and mid-level low pressure centres are located between Greenland and Scotland (not shown). The surface steering low “Petra” is located over Scotland (Fig. 3e), while the secondary pressure system “Qumaira” (980hPa) moves northeastward towards southern England. “Qumaira” led to important disruption to all forms of transport in Iberia, together with power cuts and building and tree damage.

Group Hybrids:

This group is characterised by a co-occurrence of a high and a low pressure centre on opposite sides of Iberia, leading to a pronounced MSLP gradient and strong winds over the region. A prominent example is 20090305 (Top#21). A low pressure system is located north of Scotland, while a blocking high is found over the North Atlantic (not shown). The juxtaposition of both systems is associated with an intense jet stream from southern Greenland towards Iberia (not shown). At lower levels, the surface high pressure system is above 1040 hPa, while cyclone “Andreas” located between Scotland and the Faroese has a core pressure of 975hpa (Fig. 3g). Further south, over the English Channel, an unnamed low below 985hPa is found. This example shows that the cyclone over southern England cannot be primarily responsible for the potential loss event over Iberia; only the combination of the different systems led to a strong pressure gradient and thus strong surface winds. The impacts were severe: many trees were uprooted and a great number of buildings were damaged, also in southern Spain and even Morocco.

6. Comparison of cyclone characteristics

The difference of cyclone characteristics between the groups are now explored. In terms of the minimum core pressure, the lowest minimum mean value for the event day (± one day) was found for *West* (966hpa), followed by *North* (976hpa), *Iberia* and *Hybrid* (both 983hpa; Table 2). Given the small samples and large spread, the differences between groups are not statistically significant at the 90% significance level. Results are similar for the maximum vorticity, with largest values found for *West* and the lowest for *Hybrid* (1.95 and 1.28 hPa/deg.lat^2, respectively). The intensification rates per 24hours, in terms of vorticity, are highest for *West* and *Iberia* (1.13 and 0.95hPa/deg.lat^2.day^{-1}) and lowest for *North* and *Hybrid* (both 0.84hPa/deg.lat^2.day^{-1}), while core pressure evolution is highest for *North* (14.8hpa/day) and lowest for *West* (12.7hpa/day). Results are similar when analysing the 24hour peak intensity change irrespective of the event day (not shown). Unlike other types, the deepening cyclone phase associated with *Hybrid* events does not often coincide with the event day (± one day). This indicates that cyclones contributing to *Hybrid* events are not necessarily very intense and their development does not always have a clear impact on the events. The mean MSLP gradient around Iberia is lowest for *Iberia* (1.64hpa/100km) and largest for *North* and *West* (1.83 and 1.81 hpa/100km, respectively). The gradient for *Hybrid* is in between (1.72hpa/100km). This confirms that despite the weaker cyclones in the *Hybrid* group, the co-occurrence of a high pressure centre on the opposite side of Iberia effectively creates a strong pressure gradient leading to strong winds.

7. Summary and Conclusions

The top ranking potential wind loss events affecting Iberia were classified into four groups based on cyclone tracks and large-scale atmospheric conditions: *(i)* cyclone tracks crossing Iberia on the event day (*Iberia*), *(ii)* cyclones crossing further north, mostly southwest of the British Isles (*North)*, *(iii)* tracks crossing southwest to northeast to the northwest of Iberia (*West)*, and *(iv)* so called *Hybrids*, days with a large pressure gradient over Iberia due to the juxtaposition of a low and a high pressure centre. Generally, *Iberia* events are the most frequent, ranging from 31% (top-100 MIs) to 45% (top-20 MIs). However, other types like *North and Hybrid* are also frequent (28% and 30% respectively for top-100 MIs). The number of *North* storms decreases considerably with intensity (15% for top-20 MIs). *West* type storms are rare (10-12%). 70% of the MIs can be primarily attributed to cyclones. Cyclones associated with *Hybrid* events (30%) are typically weaker than for other cases, but the mean MSLP gradient over Iberia is comparable to other types. Although we have focussed on a single reanalysis dataset, the results would be comparable for others given our focus on large-scale features like MSLP gradients, cyclone tracks, and windstorm footprints. Multi-decadal variability of events is identified for all intensities. The peak in recent years is quite prominent in terms of the number of top-20 MIs. Other periods with a large number of storms occurred in the 1960s and 1980s. This study documents that windstorms affecting Iberia may have different characteristics, they are not rare events, and their frequency of occurrence undergoes strong multi-decadal variability.

Acknowledgements

This work was supported through project STORMEx FCOMP-01-0124-FEDER-019524 (PTDC/AAC-CLI/121339/2010) by FEDER funds (COMPETE) and Portuguese national funds (FCT). We thank NCEP/NCAR for reanalysis, the Berliner Wetterkarte for weather charts, Helen Dacre for comments and Sven Ulbrich for cyclone computations. We thank the three anonymous reviewers for their helpful suggestions.

References:

CCS 2015. Estadística - Riesgos extraordinarios. Serie 1971-2014. Consorcio Compensación de Seguros. Ministerio de Economía y Competitividad, Madrid. 146 pp. NIPO: 720-15-101-5. (Spanish) www.consorseguros.es.

Dacre HF, Gray SL. 2013. Quantifying the climatological relationship between extratropical cyclone intensity and atmospheric precursors, *Geophys Res Lett* **40**: 2322–2327. doi:10.1002/grl.50105.

Karremann MK, Pinto JG, Von Bomhard PJ, Klawa M. 2014a. On the clustering of winter storm loss events over Germany. *Nat Hazards Earth Syst Sci* **14**: 2041-2052. doi:10.5194/nhess-14-2041-2014.

Karremann MK, Pinto JG, Reyers M, Klawa M. 2014b. Return periods of losses associated with European windstorm series in a changing climate. *Environ Res Lett* **9**: 124016. doi:10.1088/1748-9326/9/12/124016

Klawa M, Ulbrich U. 2003. A model for the estimation of storm losses and the identification of severe winter storms in Germany. *Nat Hazards Earth Syst Sci* **3**: 725−732. doi:10.5194/nhess-13-2239-2013.

Kistler R, et al. 2001. The NCEP/NCAR 50-year reanalysis: monthly-means CDROM and documentation. *Bull Amer Meteorol Soc* **82**: 247−267. doi:10.1175/1520-0477(2001)082.

Liberato MRL, Pinto JG, Trigo IF, Trigo RM. 2011. Klaus – an exceptional winter storm over Northern Iberia and Southern France. *Weather* **66**: 330–334. doi:10.1002/wea.755.

Liberato MLR, Pinto JG, Trigo RM, Ludwig P, Ordoñez P, Yuen D, Trigo IF. 2013. Explosive development of winter storm Xynthia over the subtropical North Atlantic Ocean. *Nat Hazards Earth Syst Sci* **13**: 2239–2251. doi:10.5194/nhess-13-2239-2013.

Mills E. 2005. Insurance in a climate of change. *Science*. **309**: 1040-1044. doi:10.1126/science.1112121.

Murray RJ, Simmonds I. 1991. A numerical scheme for tracking cyclone centres from digital data. Part I: Development and operation of the scheme. *Aust Meteorol Mag* **39**: 155–166.

Pfahl S. 2014. Characterising the relationship between weather extremes in Europe and synoptic circulation features. *Nat Hazards Earth Syst Sci* **14**: 1461–1475. doi:10.5194/nhess-14-1461-2014.

Pinto JG, T Spangehl, Ulbrich U, Speth P. 2005. Sensitivities of a cyclone detection and tracking algorithm: Individual tracks and climatology. *Meteorol Z* **14**: 823–838. doi:10.1127/0941-2948/2005/0068.

Pinto JG, Zacharias S, Fink AH, Leckebusch GC, Ulbrich U. 2009. Factors contributing to the development of extreme North Atlantic cyclones and their relationship with the NAO. *Clim Dyn* **32**: 711–737 doi:10.1007/s00382-008-0396-4.

Pinto JG, Karremann MK, Born K, Della-Marta PM, Klawa M. 2012. Loss potentials associated with European windstorms under future climate conditions. *Clim Res* **54**: 1-20. doi:10.3354/cr01111.

Ramos AM, Trigo RM, Liberato MLR. 2014. A ranking of high-resolution daily precipitation extreme events for the Iberian Peninsula. *Atmos Sci Lett* **15**: 328–334. doi:10.102/asl2.507.

Roberts JF et al. 2014. The XWS open access catalogue of extreme windstorms from 1979-2012. *Nat Hazards Earth Syst Sci* **14**: 2487-2501. doi:10.5194/nhess-14-2487-2014.

Swiss Re 2008 Natural catastrophes and man-made disasters in 2007: high losses in Europe. Sigma, Nr. 1/2008. Swiss Re publishing. www.swissre.com/sigma/?year=2008#.

Trigo IF. 2006. Climatology and interannual variability of storm-tracks in the Euro-Atlantic sector: a comparison between ERA-40 and NCEP/NCAR reanalyses. *Clim Dyn* **26**: 127–143. doi:10.1007/s00382-005-0065-9.

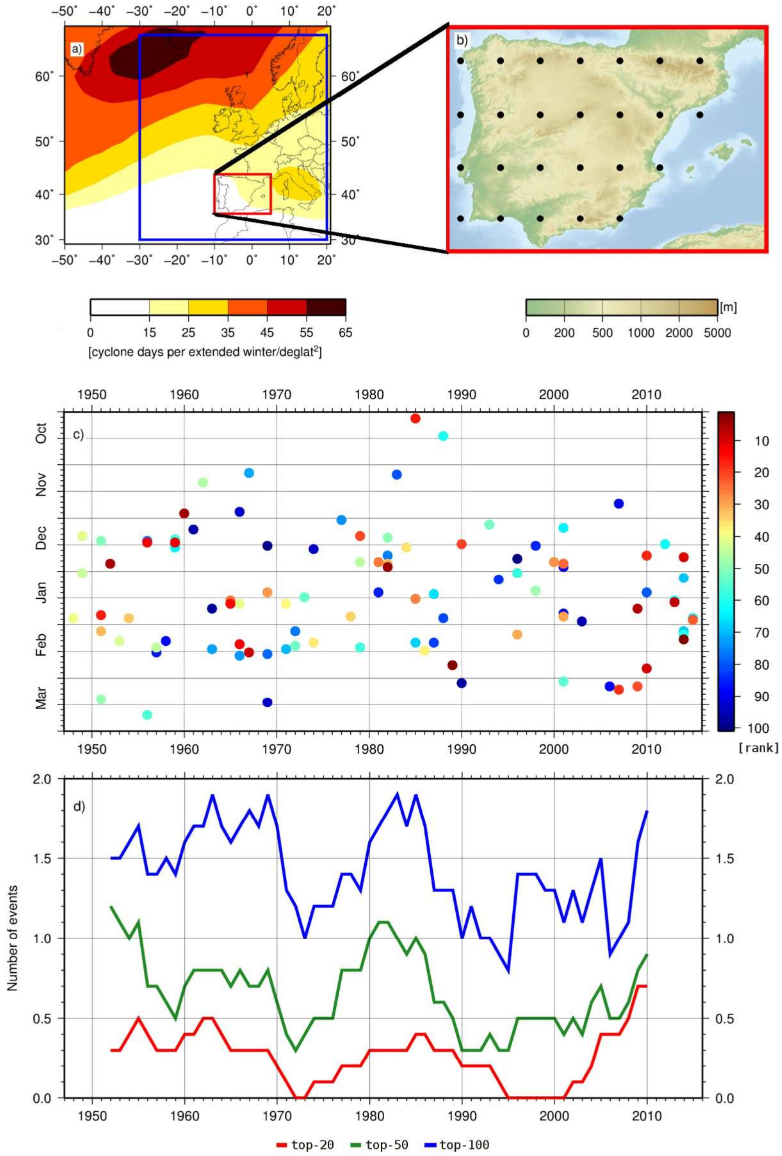

Fig. 1 (a) Cyclone track density [cyclone days per extended winter season per deg.lat^2; red box: geographical location of Iberian Peninsula; blue box: area for identification of cyclone tracks (b) orography and NCEP grid points of investigated region (c) time distribution of top-100 potential wind loss events for winters 1949-2015. Year corresponds to January, e.g. 1990: winter 1989/90. Colours: rank of event (d) 10-year running mean of the number of events for each winter; red: top-20 potential wind losses; green: top-50, blue: top-100 wind loss events; e.g. 1953: running mean of 1949-1958. Average number of events per winter: top-100 potential wind losses: 1.5; top-50: 0.75; top-20: 0.3.
225x329mm (300 x 300 DPI)

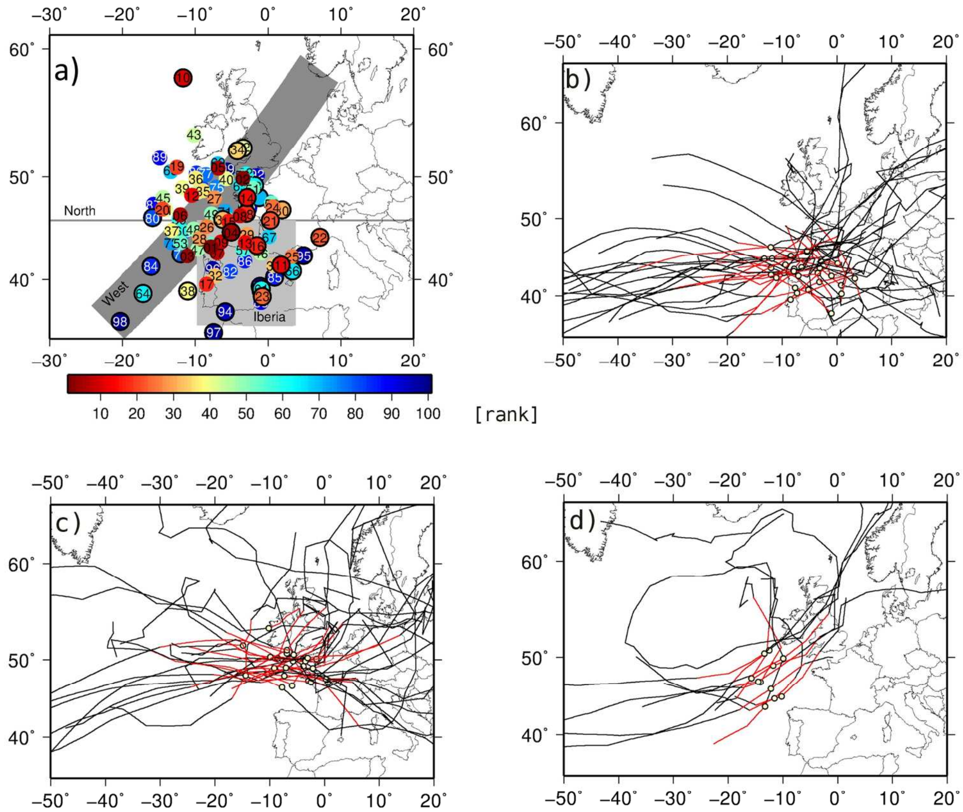

Fig. 2 (a) Position of minimum pressure of identified cyclones responsible for potential wind losses over the Iberian Peninsula at the event day. Colours/numbers: rank of event; black circle: cyclones associated with Hybrid type. Identification of regions of the different groups: Iberia (light grey shaded region): cyclones crossing this area during the event day; North: cyclones crossing from west to east in a zonal path within this region during the event day; West (dark grey shaded region): cyclones crossing from southwest to northeast along the dark grey shaded region. (b) cyclone tracks of group Iberia (31 events) (c) cyclone tracks within North (28 events) (d) cyclone tracks for West group (11 events). (b)-(d) red: cyclone track during the event day; circles: corresponding to a).
201x193mm (300 x 300 DPI)

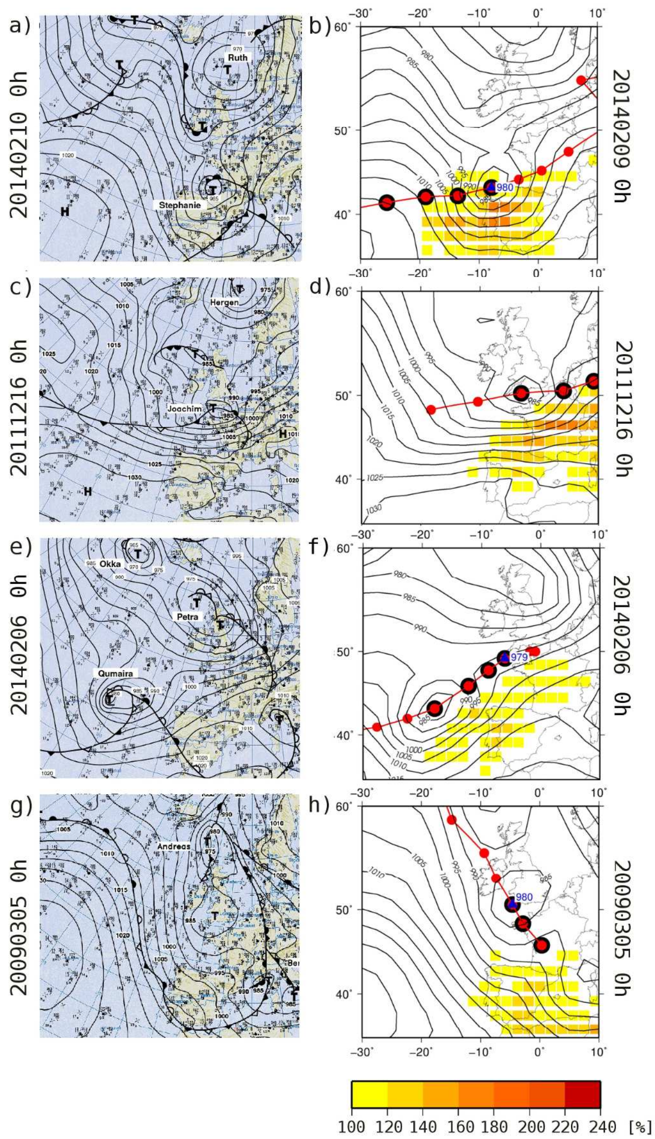

Fig. 3 Case study for (a, b) group Iberia, (c, d) group North, (e, f) group West, (g, h) group Hybrid. Left panels: surface weather charts adapted with courtesy of Berliner Wetterkarte e.V.; right panels: windstorm footprints and responsible cyclone tracks; black circle: time frames corresponding to event day, blue triangle: pressure minimum at event day (for (d) outside shown area); colours: exceedance of v_(98_ij) in [%]; date: yyyymmdd time in UTC.
202x355mm (300 x 300 DPI)

	Iberia	North	West	Hybrid
Top-20	45	15	10	30
Top-50	36	24	12	28
Top-100	31	28	11	30

Table 1: Number of events [%] per group and intensity. Top-20, top-50 and top-100 potential wind loss events between October 1948 and March 2015.

	IBERIA	NORTH	WEST	HYBRID
Pressure minimum (event day)	983±9.31	976±13.1	966±13.3	983±15.8
Laplace maximum (day)	1.63±0.68	1.51±0.67	1.95±0.95	1.28±0.76
MSLP gradient (day)	1.64±0.46	1.83±0.39	1.81±0.44	1.72±0.44
Pressure evolution (24h)	13.5±8.46	14.8±8.26	12.7±9.46	13.2±8.93
Laplace evolution (24h)	0.95±0.60	0.84±0.51	1.13±0.64	0.84±0.64

Table 2: Mean value and standard deviation for different characteristics for the four groups: pressure minimum at the event day (hpa); Laplace maximum at the event day (hPa/deg.lat^2); MSLP gradient at the event day (hpa/100km); pressure evolution (hpa/24h) and Laplace evolution (hPa/deg.lat^2/24h) with 24hours.

Characterisation of synoptic conditions and cyclones associated with top ranking potential wind loss events over Iberia

Melanie K. Karremann, Margarida L. R. Liberato, Paulina Ordóñez, Joaquim G. Pinto

Atmospheric Science Letters

Supplementary Material

Date	GP	rk	G	rE	Date	GP	rk	G	rE	Date	GP	rk	G	rE	Date	GP	rk	G	rE
19480129	20	39	W	x	***19650120***	***19***	***14***	***H***	x	19811212	11	49	N	-	20001206	17	64	H	12
19481211	17	41	W	x	19651129	11	92	N	x	19811223	14	75	N	-	20001228	20	23	H	-
19490101	18	43	N	x	19660120	17	40	N	x	19811228	18	32	I	-	20001230	11	90	I	24
19501214	14	50	N	x	***19660212***	***18***	***13***	***I***	x	***19811230***	***22***	***3***	***I***	3	20010126	16	91	N	-
19510127	***23***	***16***	***H***	x	19660219	13	73	W	x	19821106	23	80	H	31	20010128	20	29	I	8
19510204	21	31	H	x	19661105	14	71	N	x	19831218	20	35	N	26	20010302	16	54	I	5
19510313	17	48	W	x	***19670217***	***23***	***8***	***I***	x	***19841004***	***21***	***15***	***I***	4	20030131	8	95	H	-
19511228	***22***	***5***	***N***	x	19681217	13	99	N	x	19850117	23	26	I	-	20060305	13	88	I	21
19530210	17	42	H	x	19690113	18	28	I	x	19850211	16	67	I	9	20061124	12	89	N	25
19540129	17	33	I	x	19690218	14	78	H	x	19860216	17	37	I	33	***20070307***	***19***	***18***	***H***	27
19551214	16	77	N	x	19690315	12	93	H	x	19870114	10	66	H	34	***20090123***	***19***	***6***	***I***	2
19551215	***21***	***12***	***N***	x	19710120	18	38	H	x	19870211	11	82	I	-	20090305	22	21	H	7
19560323	14	55	I	x	19710215	16	70	H	x	19871015	13	60	I	11	***20091223***	***14***	***17***	***I***	18
19570214	14	44	N	x	19720204	16	76	W	x	19880129	15	81	N	39	20100113	17	79	I	20
19570217	12	86	I	x	19720213	13	52	N	x	***19890225***	***24***	***2***	***N***	1	***20100227***	***20***	***9***	***I***	13
19580210	14	87	W	x	19730116	16	53	I	x	***19891216***	***20***	***19***	***W***	6	20111216	14	62	N	-
19581213	18	56	N	x	19731219	14	94	H	x	19900303	11	97	H	-	20130118	11	61	H	38
19581215	***21***	***11***	***H***	x	19740211	18	36	W	x	19921204	17	51	N	37	***20130119***	***21***	***7***	***I***	-
19581218	14	63	H	x	19761201	16	74	N	x	19940105	14	83	N	30	***20131224***	***21***	***10***	***H***	-
19591130	***20***	***4***	***H***	x	19780128	20	34	H	x	19951225	12	100	H	41	20140104	17	69	N	49
19601207	9	96	I	x	***19781211***	***19***	***20***	***W***	x	19960101	14	58	I	17	20140204	13	68	W	-
19611111	18	46	I	x	19781227	16	45	N	x	19960206	16	30	H	22	20140206	15	59	W	-
19630123	9	98	H	x	19790214	15	57	I	14	19971217	12	84	H	-	***20140209***	***24***	***1***	***I***	45
19630215	15	72	H	x	19801227	15	25	I	-	19980112	12	47	I	-	20150129	14	65	N	x
19650118	20	24	N	x	19810113	13	85	H	-	19991227	17	27	N	36	20150130	20	22	H	x

Table S1: List of top-100 potential wind loss events including information on the date, the number of grid points exceeded (GP), the rank (rk) and the corresponding group (G): *Iberia* (I), *North* (N), *West* (W), *Hybrid* (H) for NCEP data. Date format is yyyymmdd. The top-20 events are in bold and italic. Rank of events also featured in the ERA-Interim top-50 (rE) for the period 1979-2014 are added in the last column for comparison. "-" indicates the event was not found within the top-50 for ERA-Interim. "x" indicates date outside the analysed ERA-Interim period.

Table S1 includes a list of top-100 potential wind loss events based on NCEP reanalysis data and the period 1948-2015. For comparison, the rank of events featured within the top-50 of ERA-Interim reanalysis for the period 1979-2015 are also indicated (rE). The agreement between the identified top events for the two datasets is generally good. The top-10 events are identified for both datasets as well as most of the other events in the common time period. Thus, the basic set of events remains the same for ERA-Interim. The events marked with "-" were also identified for ERA-Interim but their rank in below the top-50. The agreement between the NCEP and ERA-interim datasets is comparable to that identified for Germany in Karremann et al. (2014a; their Table 1). In spite of the known sensitivity of the identified cyclone tracks depending from the chosen methodology and reanalysis datasets (e.g., Raible et al., 2008; Allen et al., 2010; Neu et al., 2013; Tilinina et al., 2013), our focus on the large-scale features of the events and the similar basic pool of events leads to a similar characterisation of synoptic situations and the cyclone tracks. Therefore, the resulting separation into four groups is similar (not shown).

References:

Allen JT, Pezza AB, Black MT (2010) Explosive cyclogenesis: A global climatology comparing multiple reanalyses. *J Climate*, **23**: 6468–6484.

Neu U, Akperov MG, Bellenbaum N, Benestad R, Blender R, Caballero R, Cocozza A, Dacre HF, Feng Y, Fraedrich K, Grieger J, Gulev S, Hanley J, Hewson T, Inatsu M, Keay K, Kew SF, Kindem I, Leckebusch GC, Liberato MLR, Lionello P, Mokhov II, Pinto JG, Raible CC, Reale M, Rudeva I, Schuster M, Simmonds I, Sinclair M, Sprenger M, Tilinina ND, Trigo IF, Ulbrich S, Ulbrich U, Wang XL, Wernli H (2013) IMILAST – a community effort to intercompare extratropical cyclone detection and tracking algorithms. *Bull Amer Meteorol Soc* **94:** 529–547.

Raible CC, Della-Marta P, Schwierz C, Wernli H, Blender R (2008) Northern Hemisphere extratropical cyclones: A comparison of detection and tracking methods and different reanalyses. *Mon Wea Rev,* **136:** 880-897.

Tilinina N, Gulev SK, Rudeva I, Koltermann P (2013) Comparing cyclone life cycle characteristics and their interannual variability in different reanalyses. *J Clim,* **26:** 6419-6438.

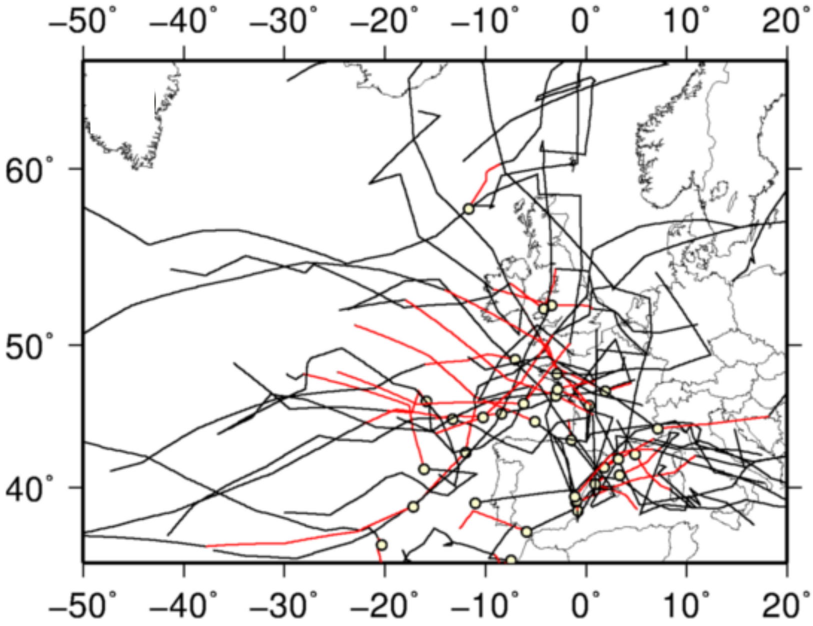

Fig S1: As Fig. 2b but for group *Hybrid*.

The group *Hybrid* is primarily characterised by a strong large-scale pressure gradient over Iberia due to the juxtaposition of a low and a high pressure centre. While the high pressure centre is often in the southwest of the domain, and the low pressure centre in the north/northeast of the domain, this is not always the case. Thus, this group includes a wide variety of tracks (cf. Fig. S1) and the MSLP composite is not very clear (cf. Fig. S2d). Some of the systems have apparently only a small contribution to the intensification of strong pre-existing large-scale pressure gradients (cf. discussion in Fink et al., 2009).

Reference:

Fink AH, Brücher T, Ermert V, Krüger A, Pinto JG (2009) The European storm Kyrill in January 2007: Synoptic evolution and considerations with respect to climate change. *Nat Hazards Earth Syst Sci* **9:** 405–423. doi:10.5194/nhess-9-405-2009

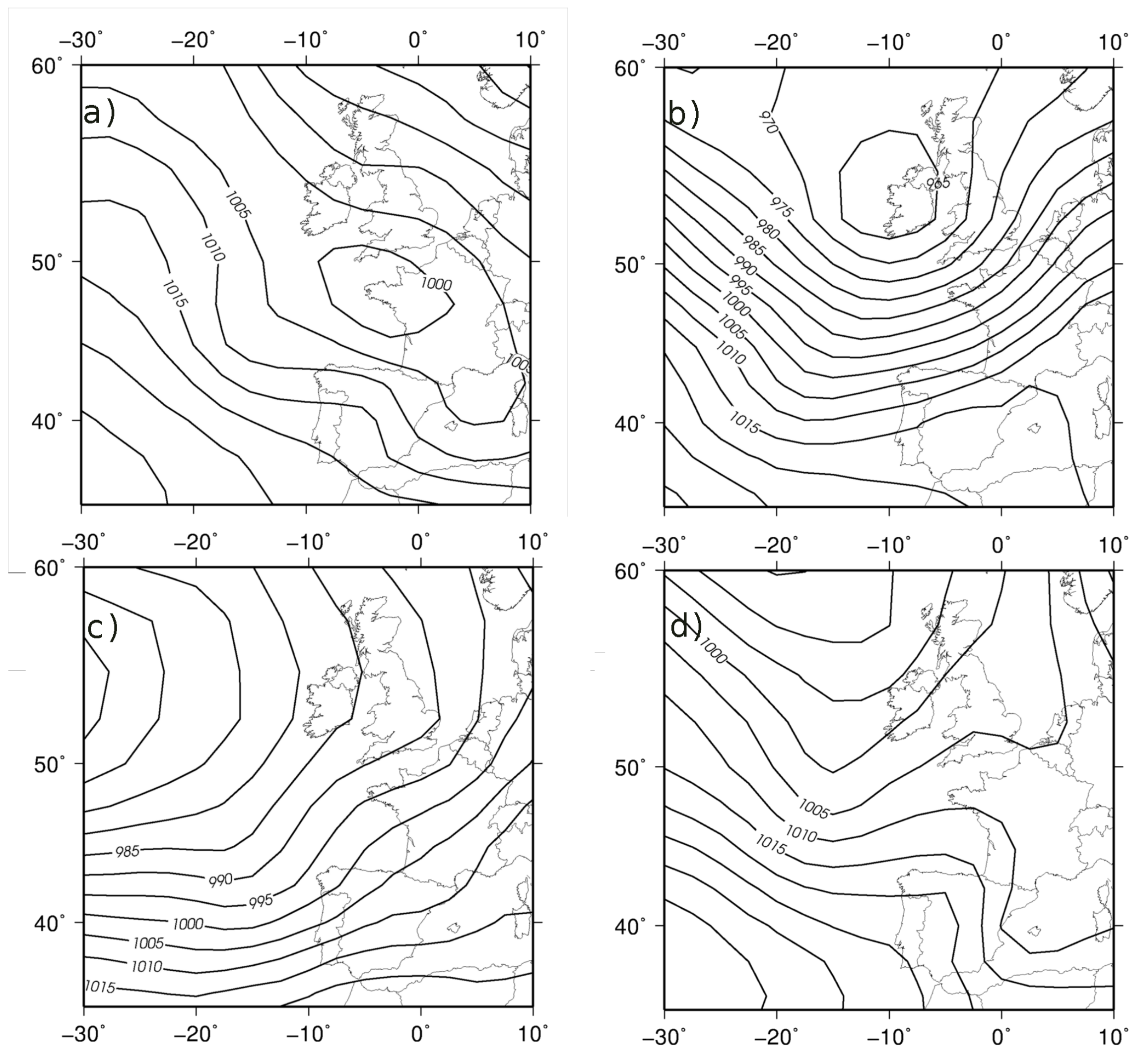

Fig S2: MSLP composites for (a) group *Iberia* (31 dates) (b) group *North* (28 dates) (c) group *West* (11 dates) (d) group *Hybrid* (30 dates). All four MSLP fields (00, 06, 12, 18 UTC) of each event day were included in the composites. For a list of dates see Table S1.

The MSLP composite fields are depicted in Figure S2. Results are similar than those presented in Fig. 3 for the case studies, but some characteristics are weakened by the compositing. For example, even though per definition all cyclones within the *Iberia* group cross over the Iberian Box during the event days (Fig. 1a), the lowest pressure for Iberia is found further north over Western France (Fig. S2a), as a result of the compositing. On the other hand, *North* group (Fig. S2b) clearly shows a low pressure centre over the British Isles, and a strong MSLP pressure gradient further south extending towards the Iberian Peninsula. The *West* group shows a southeast-northwest orientated pressure gradient (Fig. S2c), as expected. The pattern of Hybrid is weaker due to the very different cases included in this group (cf. Fig. S1), but still represents a largely southwest – northeast pressure gradient, also shown in Fig. 3g,h.