

II. HURRICANE GONZALO AND ITS EXTRATROPICAL TRANSITION TO A STRONG EUROPEAN STORM

FRAUKE FESER, MONIKA BARCIKOWSKA, SUSANNE HAESELER, CHRISTIANA LEFEBVRE, MARTINA SCHUBERT-FRISIUS, MARTIN STENDEL, HANS VON STORCH, AND MATTHIAS ZAHN

After transitioning from a hurricane to an extratropical storm, Gonzalo tracked unusually far, achieving exceptional strength over Europe; however, it was within the historical range of such transforming storms.

Introduction. Recent studies simulating continued anthropogenic climate change provide evidence that extratropically transitioning tropical cyclones (TCs) will become more frequent and will hit western Europe more often (Baatsen et al. 2015; Haarsma et al. 2013). Mokhov et al. (2014) asserted, “Under the tendency towards global warming, we can expect an increase in the number of intensive cyclones in the warmer and more humid troposphere.” We saw Hurricane Gonzalo of 2014 as an occasion to assess if these aforementioned properties of extratropically transitioned storms—frequency, intensity, and tracks—have changed.

East of the Leeward Islands a tropical depression formed on 12 October 2014. On its way it passed through the northern Leeward Islands and intensified to a category 4 hurricane (Saffir-Simpson hurricane wind scale) on 16 October, known as “Gonzalo”. After changing its direction to northeast, Gonzalo weakened and crossed Bermuda with gusts of more than 200 km h⁻¹ and heavy rains of about 70 mm within 24 hours. On 19 October, the storm transitioned to an extratropical cyclone off the coast of Newfoundland (Brown 2015). While continuing its path across the North Atlantic towards northwestern Europe, the cyclone was absorbed by a cold front and strengthened again. Afterwards, it hit the northern part of the United Kingdom on 21 October. It crossed the North Sea and then central parts of Europe, and went down to the Balkans. On 23 October ex-Gonzalo

merged with another low pressure system that led to heavy precipitation for several days in this region. Maximum wind gusts between 100 and 180 km h⁻¹, causing North Sea storm surges, were reported from several countries^{1,2,3}. In addition, ex-Gonzalo triggered regional precipitation amounts of 50–100 mm in 24 hours, while the advection of cold air led to a sudden temperature drop with snowfall in some areas. Gonzalo and its remnants caused several fatalities, storm surges, structural damage, and power outages on both sides of the Atlantic^{4,5}. Gonzalo attracted strong media attention as it affected many countries along its path⁶.

There is no general definition of extratropical transition (ET) of TCs (Malmquist 1999). Basically, it is a gradual transformation of a TC into a system with extratropical characteristics while moving poleward into a more baroclinic environment with higher wind shear, a larger Coriolis parameter, and lower sea surface temperatures (Jones et al. 2003). The ET storm may interact with upper-level troughs or extratropical low pressure systems. Evans and Hart (2003) describe ET as the transition of a warm-core TC that interacts with a baroclinic midlatitude environment and then develops a cold core. Forty-six percent of the Atlantic TCs transitioned into extratropical cyclones between 1950 and 1996 (Hart and Evans 2001). This result was supported by Jones et al. (2003) for 1970–99 and Mokhov et al. (2014) for 1970–2012 who found 45% of North Atlantic TCs underwent ET. But only very few

AFFILIATIONS: FESER, SCHUBERT-FRISIUS, VON STORCH, AND ZAHN—Institute for Coastal Research, Helmholtz-Zentrum Geesthacht, Centre for Materials and Coastal Research, Geesthacht, Germany; BARCIKOWSKA—Princeton Environmental Institute, Princeton University, New Jersey; HAESELER, AND LEFEBVRE—Deutscher Wetterdienst (DWD), Hamburg, Germany; STENDEL—Danish Climate Centre, Danish Meteorological Institute, Copenhagen, Denmark

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¹www.bsh.de/de/Meeresdaten/Vorhersagen/Sturmfluten/Berichte/Sturmflut_nordsee_22_10_2014.pdf (in German)

²<http://blog.metoffice.gov.uk/2014/10/21/top-uk-wind-speeds-as-gonzalos-remnants-felt/>

³www.meteofrance.fr/actualites/15846766-retour-de-la-fraicheur-sur-l-hexagone (in French)

⁴www.munichre.com/site/corporate/get/documents/_E1520419191/mr/assetpool.shared/Documents/5_Touch/_Publications/302-08605_de.pdf (in German)

⁵www.deutscherueck.de/fileadmin/user_upload/Sturmdoku_2014_WEB.pdf (in German)

⁶www.gdacs.org/media.aspx?eventid=1000112&episoidid=30&eventtype=TC

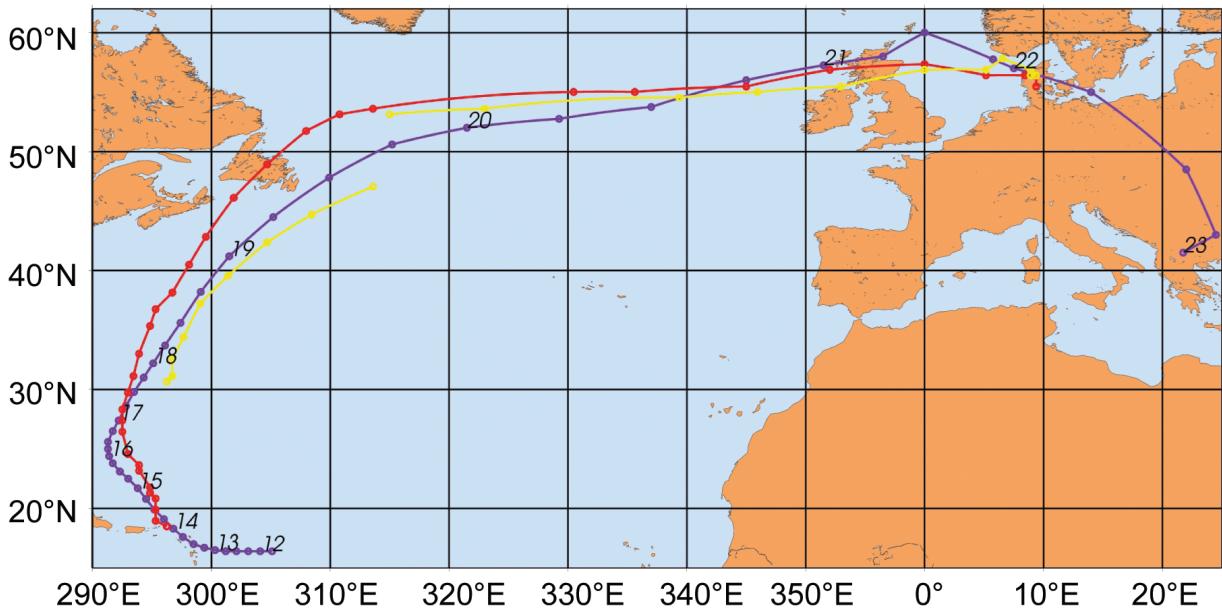


FIG. 11.1. Tracks of Hurricane Gonzalo in the GCM long-term (yellow) and short-term (red) simulations. Observed tracks of surface pressure from NOAA (Brown 2015) and the Deutscher Wetterdienst global weather forecast model assimilation fields, interpolated to a 0.25° grid (purple, numbers represent days in October 2014 at 0:00 UTC).

transitioned storms continue tracking into Europe; most extratropically transitioning cyclones decay west of 10°W over the Atlantic (Hart and Evans 2001).

Climate perspective. To answer the question whether the characteristics of ET have changed over the past decades, homogeneous datasets are necessary in order to derive long-term statistics. Mokhov et al. (2014) estimated changes of ET of TCs between 1970 and 2012 over the North Atlantic and found an increase in the number of transformed cyclones by 1 in 10 to 11 years. A climatology of ET of Atlantic TCs was given by Hart and Evans (2001). The annual frequency of transitioning TCs from 1950 to 1996 showed some year-to-year variability, but no trend was described. Hart and Evans (2001) analyzed best track data, which provide TC track location and intensity information. These are based on various meteorological measurements, aircraft reconnaissance, and satellite data in more recent decades. Since best track data often do not depict the storm after transition to an extratropical storm, reanalysis data was added to complete the climatology. But reanalysis data may contain inhomogeneities due to changes in observational density or instrumentation (Krueger et al. 2013; Landsea 2007). For instance, the addition of satellite data in November 1978 provided better observational coverage and thus improved statistics (Truchelut et al. 2013; Vecchi and Knutson 2011).

A relatively new approach applies the well-established spectral nudging method to constrain global climate models with global large-scale reanalyses to derive a global high-resolution reconstruction for the atmosphere and the land surface (Yoshimura and Kanamitsu 2008; Kim and Hong 2012). The idea is to minimize the introduction of inhomogeneities as only very few meteorological variables at larger scales and higher atmospheric layers are nudged. Here we nudge only vorticity and divergence of the general circulation model (GCM) ECHAM6 (Giorgetta et al. 2013) towards the NCEP/NCAR reanalysis (Kalnay et al. 1996) for the time period 1948–2014. Reanalysis datasets tend to underestimate TC intensity and this underestimation cannot be attributed merely to the coarse resolution of the reanalysis data (Schenkel and Hart 2012). Underestimated TC intensities are also apparent in the forcing reanalysis of this study, which lead to weaker intensities also for the GCM simulation. Even though absolute TC intensity values can therefore not be directly compared to observations, the consistency and homogeneity of this dataset allows for a climatology and analysis of the number of storms and changes in intensity and tracks during the last decades.

The ECHAM6 data (about 78-km grid distance and 95 levels) was tracked with a relatively simple algorithm, which first localizes maxima in absolute values of spatially filtered 925-hPa vorticity fields, and

then joins these locations to tracks if the distance to the maximum of the next time step is less than 250 km. Finally three further criteria are applied: wind speed needs to exceed 15 m s^{-1} at least once along the track, tracks may not exist alongside land grid points in more than 50% of their positions, and they must evolve south of 32°N in the Atlantic and decay north of 40°N . In the long-term ECHAM6 simulation, Gonzalo is represented as a TC which weakens too much during ET so that it cannot be tracked as a single storm including the extratropical phase (Fig. 11.1). Nevertheless, a three-month test simulation using the same GCM settings showed a realistic representation of Gonzalo's track (Fig. 11.1). For regional climate simulations spectral nudging leads to similar large-scale weather systems, regardless when the simulation was started (Weisse and Feser 2003; Feser and von Storch 2008). Spectral nudging has less control in this GCM run. We therefore put Gonzalo from this short simulation into a climatological context with the long-term simulation. The ET climatology was found to be comparable to the one given by Hart and Evans (2001), though the GCM gives slightly higher storm

numbers (Fig. 11.2a, on average 5.4 to 4.1 storms per year). This is a result of the chosen wind speed tracking threshold of 15 m s^{-1} which we used throughout the study, a higher threshold would return smaller storm numbers. The GCM simulation shows a small increase of about one storm for the whole period of 67 years. For the entire time span 1979–93 the study of Hart and Evans (2001) shows an increase of 0.38 compared to an increase of 0.21 in ECHAM6. In the simulation, 220 ET storms are weaker than Gonzalo, 146 are stronger though. There is some year-to-year variability (between 0 and 7 storms stronger or weaker than Gonzalo) in intensity, no trend for storms weaker than Gonzalo, but a small trend (0.94 over the whole time period) for stronger ones was found (Fig. 11.2b). Baatsen et al. (2015) report that an expansion and eastward shift of the TC genesis region leads to more intense tropical cyclones and it increases their chances of reaching Europe for future climate conditions. In this study, the fixed tracking algorithm latitude constraints prevent any conclusions for a potential northward expansion of the genesis area, but an expansion towards lower latitudes was found. This

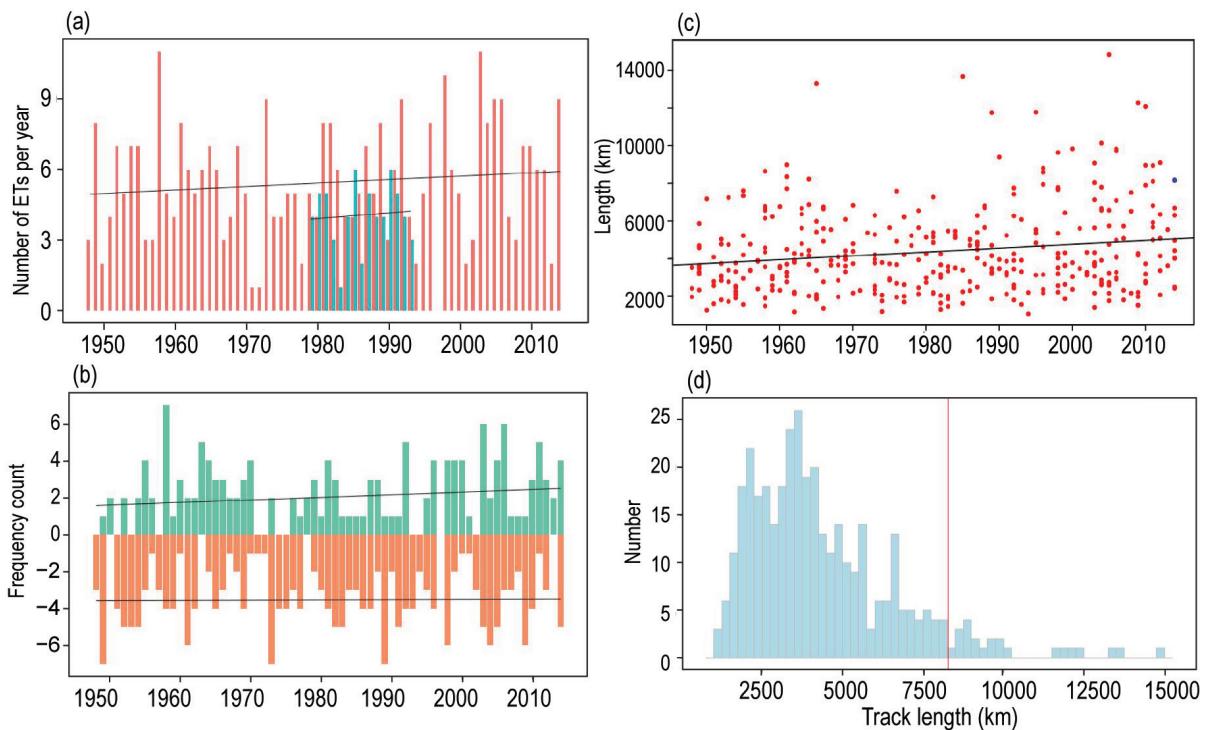


FIG. 11.2. Results from ECHAM6 multidecadal hindcast. (a) Annual numbers and trends of extratropically transitioning cyclones with a wind speed threshold of 15 m s^{-1} in the ECHAM6 simulation (red) and the study of Hart and Evans (2001) (blue); (b) numbers and trends of ET storms stronger (green) or weaker (orange) than Gonzalo (maximum simulated wind speed 22.6 m s^{-1}); (c) track lengths (km) of ET cyclones for the last decades and corresponding trend line (Gonzalo is marked as blue dot); and (d) histogram of ET cyclone track lengths in km (red line indicates Gonzalo).

change is caused by increasing numbers of cyclones which develop closer to the equator since the late 1980s. Track lengths (Fig. 11.2c) and durations (not shown) showed an increase of about 30% (1364.79 km) and of 2.4 days over the 67 years. Gonzalo ranks among the top 7% (23 out of 367 ET storms had longer tracks) in track length (Fig. 11.2d).

Conclusions. Gonzalo was a strong (category 4) hurricane in the Atlantic that underwent an ET and then headed for Europe. Within the last decades, the number of ET did increase marginally, both in the GCM simulation and the climatology of Hart and Evans (2001). The storm featured high intensities for most of its lifetime. The intensities of ET cyclones showed no trends for storms weaker than Gonzalo while a slight increase was deduced for storms that are stronger. The track of Gonzalo was also somewhat unusually long, ranking among the 7% longest-tracked of all extratropically transitioning TCs during the last 67 years. The simulated track lengths do show an increasing trend over time. For assessing if we may consider the present storm as an indication of a change, we can do two things: one is to assess if it is within the limits of what we have seen in the recent past, and the second, if certain characteristics are described in scenario simulations as more, or less, frequent than in control simulations. The latter would employ the methodology of event attribution (e.g., Stott et al. 2015, manuscript submitted to *Wiley Interdiscip. Rev.: Climate Change*), and the needed multiple high-resolution simulations do not exist at this time. Thus, we are attempting to answer the former “detection” question, by determining how anomalous the present event is given the cases of the past 67 years. It turns out the event is a rare event, albeit not an unprecedented one (similarly to the analysis of another European windstorm, see von Storch et al. 2014)

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