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Environments conductive to tropical transitions in the North Atlantic: Anthropogenic climate change influence study

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ABSTRACT

Tropical cyclones can have different precursors, but most of them affecting Europe have a tropical transition origin and develop in autumn. This research focuses on analyzing changes on favorable environments for tropical transition development in the North Atlantic (NATL) basin for this season under the Anthropogenic Climate Change (ACC) effect. Comparisons between the climatology of some relevant variables related to tropical cyclogenesis have been computed for different periods, considering the ACC effect. For this purpose, the SSP5–8.5 scenario from an adapted version of the EC-Earth3 climatic model has been used. The combination of the obtained results is indicative of a NATL environment tropicalization in response to ACC, weightier for the end of the XXI century. Therefore, the NATL environment will be more prone to tropical transition development in the future, which is of particular concern since tropical cyclones are notorious for their lethality and economic impact worldwide.

Key points:

1. To enhance the knowledge of how the ACC could influence the NATL environment behavior to favor tropical transition development.
2. To deepen on the understanding of how the ACC could have impacts on the NATL environment to promote tropical cyclones intensification.

1. Introduction

Tropical cyclones (TCs) are well known for their impact on ecosystems and the general population since they rank among the deadliest and most economically damaging weather catastrophes worldwide (Emanuel, 2005; Peduzzi et al., 2012). TCs typically have a barotropic origin (McTaggart-Cowan et al., 2013). Nevertheless, under suitable baroclinic atmospheric conditions, a sequence of precursor disturbances can potentially lead to TC development. Tropical cyclogenesis develops when a preexisting cyclonic vorticity centered in the lower troposphere interacts favorably with an upper-tropospheric trough (Molinari et al., 1995), but another form is via the tropical transition (TT) from an extratropical precursor (Davis and Bosart, 2003; Davis and Bosart, 2004; González-Alemán et al., 2015; Quitián-Hernández et al., 2016; Bentley et al., 2016; Bentley et al., 2017; Quitián-Hernández et al., 2021). TTs are defined by the evolve and mutation of a baroclinic cyclone into a tropical cyclone when affected by un upper tropospheric disturbance originating in midlatitudes (Davis and Bosart, 2003; Davis and Bosart, 2004; McTaggart-Cowan et al., 2015). In fact, Calvo-Sancho et al. (2022) demonstrate that most TCs affecting Europe recently have a TT origin; such is the case of Vince [2005], Ophelia [2017] or Leslie [2018].

High sea surface temperature (SST), decreased stability, high lower-troposphere moisture content, and low wind shear, among other characteristics, are required for a tropical cyclogenesis environment (Riehl, 1954; Miller, 1958; Gray, 1968; DeMaria and Connell, 2001). Several studies on TTs in the North Atlantic (NATL) basin have found that a large

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quantity of latent heat is released in the seconds leading up to the occurrence. This causes a surge in low-level potential vorticity (PV; Cammas et al., 1994; Hulme and Martin, 2009), which intensifies circulation around the cyclone's center in the lower troposphere. On the other hand, there is a PV decrease in the upper troposphere as a TT event occurs (Hulme and Martin, 2009; Calvo-Sancho et al., 2022). The wind shear at 800–300 hPa (WSH) shows a decline when a TT develops, which is due to the extratropical cyclone occlusion process, being a direct consequence of the vertical PV redistribution (Calvo-Sancho et al., 2022). The coupling index (CI; Eq.1; Bosart and Lackmann, 1995) characterizes the bulk column stability, showing a decrease when a TT develops due to the environment losing stability (McTaggart-Cowan et al., 2015). Therefore, introducing a CI predictor enhance the sensitivity of seasonal forecasts to systems influenced by baroclinic effects, bolstering the ability to predict the occurrence frequency of tropical cyclogenesis on seasonal timescales (McTaggart-Cowan et al., 2015).

Recent studies conclude that the ongoing Anthropogenic Climate Change (ACC) may have already affected the frequency and intensity of TCs (Villarini and Vecchi, 2013; Murakami et al., 2020; Chand et al., 2022; Wu et al., 2022), although there is no agreement on whether it has increased or decreased, due to the reanalysis limitations for detecting TCs trends (Emanuel, 2023). The lack of consensus surrounding the ACC effect on TCs intensity and frequency is an important topic reflected in the reports of the Intergovernmental Panel on Climate Change and some other studies (Stocker, 2014; Knutson et al., 2020; Wu et al., 2022; Sainsbury et al., 2022). However, satellite-based intensity measurements show that the frequency of category 3 to 5 cyclones has increased globally by approximately 5% each year since 1979, including the NATL (Holland and Bruyère, 2014; Kossin et al., 2020). Bhatia et al. (2019) demonstrate that the recent increase of NATL TC rapid intensification (TC intensity boosting >18 m s^{-1} in 24 h) is quite unusual when compared with natural variability, allowing to conclude that it may be caused by ACC. Moreover, it has been revealed a poleward expansion of the TC activity due to a changing global climate in both hemispheres due to the tropicalization of the environment at higher latitudes (Kossin et al., 2014; Walsh et al., 2019), exposing regions that are further from the equator.

Since there is a large uncertainty associated to the complex life cycle of the systems (Sainsbury et al., 2022; Emanuel, 2023), this study is focused on analyzing climatologies of favorable environments for their development, instead of studying each cyclone separately. The main purpose of this research is to gain a deeper understanding of how changes in the NATL environments favorable for TT development could be affected by ACC. This is based on the following facts: most TCs affecting Europe have a TT origin (Calvo-Sancho et al., 2022) and develop during the autumn season (September, October, November; SON), as described by McTaggart-Cowan et al. (2013), Bentley et al. (2016) and Sainsbury et al. (2022). Thus, comparisons between the SON climatology of the variables linked to tropical cyclogenesis and systems intensification, described in the next section, are computed for different periods. The SSP5–8.5 (Shared Socioeconomic Pathways; Tebaldi et al., 2020) scenario of a modified version of the EC-Earth climatic model third generation (EC-Earth3) is considered. Ideally, it would be better to use several models from the Coupled Model Intercomparison Project Phase 6 (CMIP6; Eyring et al., 2016) repository for a more exhaustive analysis. However, all the models in this repository lack some indispensable variables needed for the analysis of TT. The potential temperature at dynamic tropopause (2 PVU, i.e., $2 \cdot 10^{-6}$ m^2 s^{-1} K kg^{-1}; θ_{DT}) and the PV are not included in the official CMIP6 repository, and they are essential variables for the methodology used in this study. θ_{DT} is needed to compute the CI, along with the equivalent potential temperature at 850 hPa ($\theta_{E,850}$; Eq. 1), which is a crucial parameter when analyzing TCs and TTs since it describes the overall stability of the air column, increasing the sensitivity of seasonal forecasts to systems affected by baroclinic effects (McTaggart-Cowan et al., 2015; Bentley et al., 2016; Bentley et al., 2017; Calvo-Sancho et al., 2022). On the other hand, TTs are characterized by a PV redistribution when they develop. Therefore, the PV is also an essential variable for their analysis (Hulme and Martin, 2009; Calvo-Sancho et al., 2022). As a result, we are forced to produce these variables. Considering the computational resources at our disposal, a single model is chosen as per the reasons stated in the next section. This way, we expect to have an insight into the changes in environments favorable for TTs due to the ACC in the NATL basin employing a methodology that has not been used before for this purpose.

2. Data and methodology

The EC-Earth3 model is a complex global climate model widely used for climate change and variability predictions and projections. It is one of the models that compound the CMIP6. It is a suitable model for climate prediction and research for several reasons (Doblas Reyes et al., 2018; Döscher et al., 2022): i) it ensures accuracy conserving mass and energy, ii) it is useful for different timescales (ranging from the weather forecast to long-term studies on climate or even paleoclimate scenarios), iii) it is coupled with other state-of-the-art components (e.g., the LIM3 sea-ice model or the LPJG vegetation model), which introduce more complexity into the system, iv) it has portability, which has a price in terms of computational costs, but allows the participation in very ambitious experiments, and v) it employs atmosphere-ocean coupling, which is essential in the heat and momentum distribution at local and short time scales. Moreover, the EC-Earth climate sensitivity has been enhanced from CMIP5 to CMIP6, where the main features are the introduction of a new cloud microphysics scheme and a radiation scheme (EC-Earth3; Prodhomme et al., 2016; Wyser et al., 2019), thus being among the models with higher climate sensitivity of CMIP6 (Huusko et al., 2021). This model is regularly used for extreme events attributions (Doblas Reyes et al., 2018; Otto et al., 2018). However, it has never been used for TCs analysis before, this research being the first using EC-Earth3 model for this purpose to the authors' knowledge, although using a new version of it due to the additional outputs needed (θ_{DT} and PV).

The EC-Earth3 climate model from CMIP6 has been adapted (hereafter EC-Earth3-BSC) in order to obtain all the needed variables, which has been done in collaboration with the Barcelona Supercomputing Center (BSC; Massonnet et al., 2020). The BSC generated a database of those variables needed using the EC-Earth3-BSC model for this study. The horizontal resolution is 0.7° x 0.7° with 91 vertical hybrid levels, from 1000 hPa to 1 hPa and it has a six–hourly temporal resolution (Döscher et al., 2022). The domain of study is 00°N - 70°N, 90°W - 00°E.

To show the effect of ACC on environments favorable for TT development in the NATL region, the EC-Earth3-BSC SSP5–8.5 scenario is considered, since it is the most extreme ACC scenario and it has been already used in similar research (Xi and Lin, 2021; Delfino et al., 2023). This scenario provides a robust framework for analyzing the potential impacts on climate patterns and, due to their extreme nature, allows researchers to explore the upper bounds of environmental changes, making it a critical tool for understanding future climate shifts and their broader implications. Three different periods are selected: historical (1981–2010), near future (2021–2050) and far future (2071–2100), since the available data provided by the BSC covers from 1980 to 2100, and we need periods whose length is statistically significant (30 years - long) and represent the historical climate and two future climates sufficiently spaced in time. Similar periods have been used in other climatic research, such as Tomozeiu et al. (2014) and Lorenzo et al. (2021), among others. Near and far future SON anomalies with respect to the SON historical period are computed, and the Mann – Whitney U test (Mann and Whitney, 1947) is used to determine whether these anomalies are significant ($\alpha = 0.05$). Table 1 shows the variables from the EC-Earth3-BSC model used for this study. SST, Z300, TCW and WSH are indicative of TC development, intensity and/or maintenance, regardless of the TC origin (TT or not). On the other hand, $APV_{925,800}$, $APV_{300,200}$,

Table 1
Variables analyzed from the EC-Earth3-BSC model.

Variable	Acronym	Units
Geopotencial Height at 300 hPa	Z300	gpm
Mean Sea Level Pressure	MSLP	hPa
Sea Surface Temperature	SST	°C
Averaged Potential Vorticity (925–800 hPa)	$APV_{925,800}$	PVU
Averaged Potential Vorticity (300–200 hPa)	$APV_{300,200}$	PVU
Total Column Water	TCW	mm
Vertical Wind Shear (850–300 hPa)	WSH	m s^{-1}
Coupling Index	CI	°C

$\theta_{E,850}$ and CI are important variables when studying those TC whose origin is a TT. It must be noted that, when computing the seasonal mean values of WSH and CI in SON, the results are smoothed and do not contribute to the understanding of their behavior in response to ACC. Therefore, since a decrease of the higher WSH and lower CI values are indicative of tropical cyclogenesis in the NATL, the 99th (P99) and 1st (P1) percentiles of WSH and CI, respectively, have been computed to emphasize the possible future development of the systems.

The CI is a useful parameter for determining the environmental stability, thus being critical when studying tropical cyclogenesis. Considering the poleward expansion of tropical cyclogenesis (Kossin et al., 2014), the CI is useful as a tool for assessing the impacts of a changing environment due to ACC on the thermodynamic limits for tropical cyclogenesis at higher latitudes. A low CI requires high $\theta_{E,850}$,

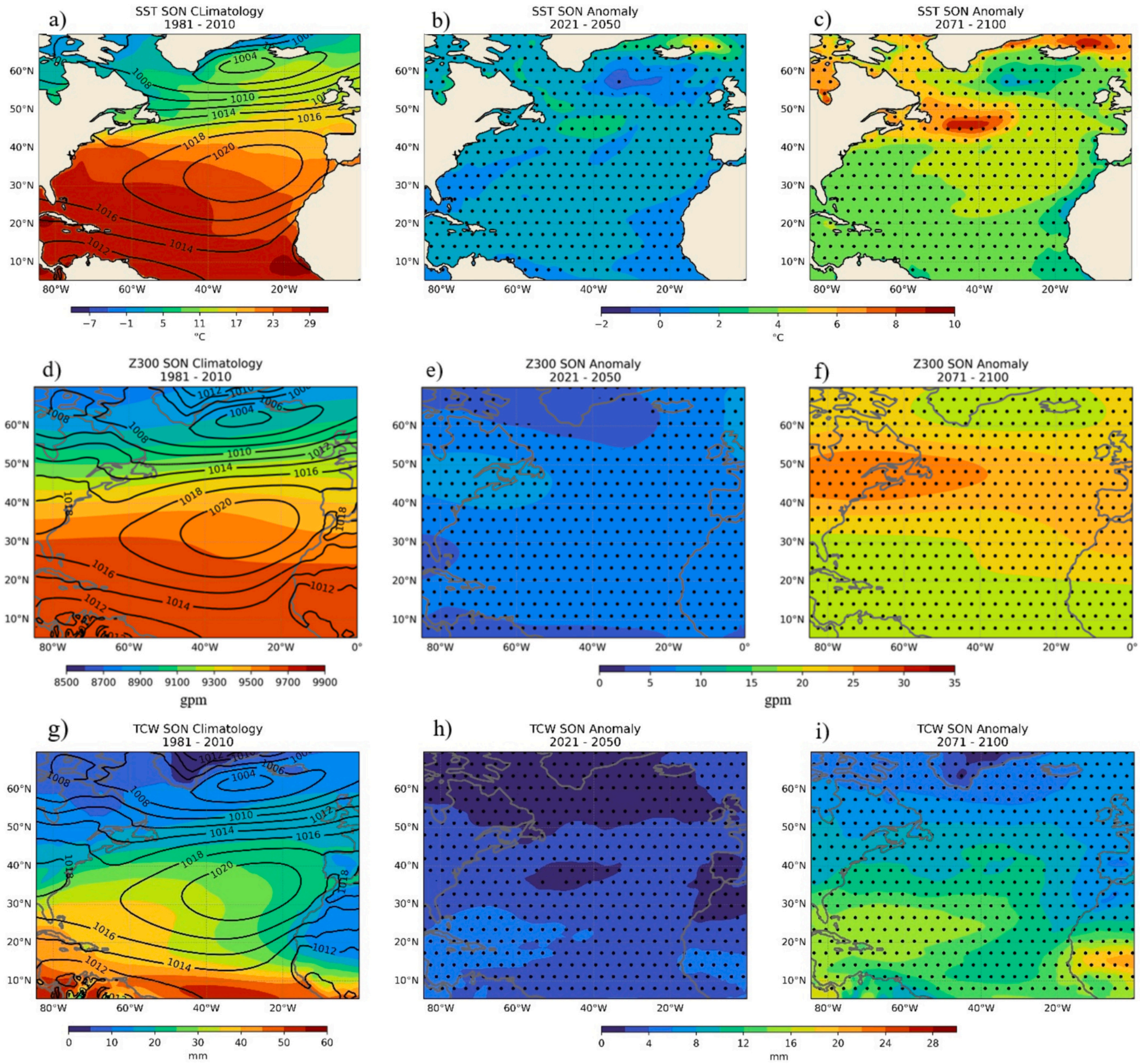

Fig. 1. Seasonal climatological values in SON for the 1981–2010 period of a) SST (°C) and MSLP (hPa; black contours), d) Z300 (gpm) and MSLP (hPa; black contours), g) TCW (mm) and MSLP (hPa; black contours). Seasonal anomaly values in SON with respect to the climatology of SST (°C) for the b) near and c) far future period; of Z300 (m) for the e) near and f) far future period; of TCW (mm) for the h) near and i) far future period. Black dots indicate where the anomalies computed are statistically significant (Mann – Whitney U test; $\alpha = 0.05$).

associated to the enhanced surface latent heat fluxes, and a steep tropospheric lapse rate (Eq.1; McTaggart-Cowan et al., 2015). It is defined by Bosart and Lackmann (1995) as:

$$CI = \theta_{DT} - \theta_{E,850} \tag{1}$$

where θ_{DT} is the potential temperature at dynamic tropopause and $\theta_{E,850}$ is the potential temperature at 850 hPa.

3. Results

In tropical cyclogenesis, the SST is one of the most relevant variables (Davis and Bosart, 2004; Camargo et al., 2007; Zhang et al., 2008; McTaggart-Cowan et al., 2015). In the absence of a warm SST and oceanic mixed layer, most emerging tropical disturbances are unable to extract the necessary surface heat energy to support active convection and to promote the formation of self-sustaining circulation. Kang and Elsner (2015) show the relationship between an increase in SST and TC intensity and frequency, revealing an average increase in TC intensity worldwide per year for the 1984–2012 period, being the NATL contribution impressive. They confirm that an increasing SST brings about an environment which is more unstable and with a higher moisture content in the lower troposphere, while also leading to stronger high-pressure conditions aloft. This combination reduces the occurrence of TCs but provokes their intensification, which is consistent with the results revealed by Holland and Bruyère (2014) since they show that the increase in occurrence of intense TCs caused by the ACC is accompanied by a similar decrease of weaker TCs.

Figure 1a shows the SST climatology for the historical period in SON. It displays higher values in the western NATL than in the eastern NATL, due to the oceanic currents configuration (Rossby, 1996; Stramma et al., 2001; Alexander et al., 2020). Fig. 1b reveals slightly positive values of the SST anomaly for the near future (statistically significant for the whole domain), while Fig. 1c shows very high positive SST anomaly values for the far future period in SON with respect to the climatology, particularly in the northeast coast of USA, which is in line with Shearman and Lentz (2010), and east coast of Canada. This sharp increase, when compared with the rest of the NATL basin, can be a result of the proximity and interaction among various ocean currents such as the Labrador current, Gulf stream and Loop current, as well as complex underwater features like the Gulf of Maine and Georges Bank (Alexander et al., 2020). It should be noted that the SST behavior in response to ACC constitutes a broad study area, which is not the aim of this research but the SST influence on TC intensification and TT development.

On the other hand, positive Z300 anomaly values can be seen in Figs. 1e, f, displaying larger ones for the far future period, being indicative of TC intensification in the future according to Kang and Elsner (2015). It worth to mention that not all the domain is statistically significant for the near future, and the largest anomalies in the far future are presented over Nova Scotia, close to the SST anomaly maxima. This higher Z300 increase in that region could be related to strong *El-Niño Southern Oscillation* (ENSO) events (Toniazzo and Scaife, 2006), which are expected to become increasingly frequent in the future (Cai et al., 2014). Fig. 1g shows that the maxima TCW value reached is about 50 mm near the equator and that the higher values are over the southwestern region of the NATL basin, being in concordance with the higher SST climatological values (Fig. 1a). Figs. 1h, i present significant positive anomaly values for the whole domain. It should be noted that TCW values around 30–45 mm are reached for the far future period in most of the domain of study (Fig. 1i), which is in line with the TCW values that Calvo-Sancho et al. (2022) show when a TT occurs. The combination of the three variables behavior shown in Fig. 1 in response to ACC lead to environments that promote TT development and TC intensification in the NATL region (Davis and Bosart, 2004; McTaggart-Cowan et al., 2013; Kang and Elsner, 2015; Calvo-Sancho et al., 2022).

The APV is also a crucial variable to analyze in TT development. When introducing a differential diabatic heat source into the air column, the PV can be redistributed vertically (Cammas et al., 1994; Hulme and Martin, 2009). The diabatic heating forcing is explained by Hoskins et al. (1985) in terms of the Lagrangian tendency of PV, which holds when advective processes dominate frictional and diabatic ones. Baroclinic systems often involve tilting and stretching of air masses along isentropic surfaces, which can alter the potential temperature, vorticity and density profiles of the air parcels, leading to changes in their PV. Studies, such as Hulme and Martin (2009) and Calvo-Sancho et al. (2022), show that in moments previous to a TT, the releases of large amounts of latent heat lead to an increase of PV at low-levels, which is accompanied by an increase of circulation intensity, as high PV air concentration in the center of a TC contributes to its intensification in the lower troposphere. Indeed, they also demonstrate that the PV decreases in the upper troposphere when a TT approaches. This different behavior between high and low level APV when a TT occurs is explained by the non-advective PV tendency (Cammas et al., 1994; Hulme and Martin, 2009; Calvo-Sancho et al., 2022).

The seasonal mean in SON of $APV_{300,200}$ and $APV_{925,800}$ provide relevant information since the PV behavior in climatological terms is also an important fact for understanding cyclogenesis. The near future period shows widespread negative values of the $APV_{300,200}$, which are statistically significant only for some areas of the domain (Fig. 2b). On the other hand, Fig. 2c reveals significant negative $APV_{300,200}$ anomaly values in many parts of the NATL basin for the far future. In the lower troposphere, the $APV_{925,850}$ presents significant positive anomaly values in some regions (Figs. 2e, f), although they are not as high (in absolute value) as the decrease shown for $APV_{300,200}$ (Figs. 2b, c). It should be noted that Figs. 2d, e, f reveal punctual locations with the lowest climatological values (Fig. 2d) and greatest anomalies for the near (Fig. 2e) and far (Fig. 2f) future periods, respectively, which may be partially caused by the orography (Thorpe et al., 1993; Scherrmann et al., 2023).

The far future APV behavior is in line with the result obtained in Fig. 1f, as it can be appreciated mayor increases of Z300 where the decreasing anomalies for $APV_{300,200}$ and the increase of $APV_{925,850}$ are statistically significant in Figs. 2c, f. This can be explained by the geopotential tendency equation for the quasigeostrophic approximation, which indicates that positive vorticity increases the geopotential Laplacian, resulting in a geopotential decrease (Holton, 1973). Based on this, it can be concluded that the region enclosed by 30°N - 50°N and 60°W - 10°W for the far future period could become prone to TT development in terms of the APV due to its redistribution inducing an increasing divergence in the upper troposphere (not shown), i.e., rising of the air masses.

WSH is an important environmental dynamical parameter in the TC development, intensity and structure (McTaggart-Cowan et al., 2015; Davis and Bosart, 2004; Calvo-Sancho et al., 2022). DeMaria (1996) shows that there is a strong, nearly linear relationship, between WSH and how quickly TCs weaken over a period of 12–36 h after the highest WSH value. There are many mechanisms that can help determine how WSH modifies the TC intensity, such as translation speed, shear depth or ventilation effects (DeMaria, 1996; Zeng et al., 2010; Wu et al., 2022). In any case, WSH is generally unfavorable for TC boosting. Fig. 3a shows the seasonal climatological P99 WSH values for the historical period in SON, and it can be appreciated that the maximum ones are reached over the area of Nova Scotia. The P99 WSH anomalies for the near future period (Fig. 3b) present almost no significative values in the domain of study. However, the P99 WSH anomaly values for the far future period reveal a significant reduction in response to the ACC (Fig. 3c). This can lead to conclude that the climatological P99 WSH values are considerably lowered for the far future period, which favors the TC development and maintenance (DeMaria, 1996; Calvo-Sancho et al., 2022). These results are in concordance with the behavior appreciated in Fig. 2 for the $APV_{300,200}$ and $APV_{925,850}$, since the PV redistribution leads to a WSH decrease (Davis and Bosart, 2004; Calvo-Sancho et al., 2022). The

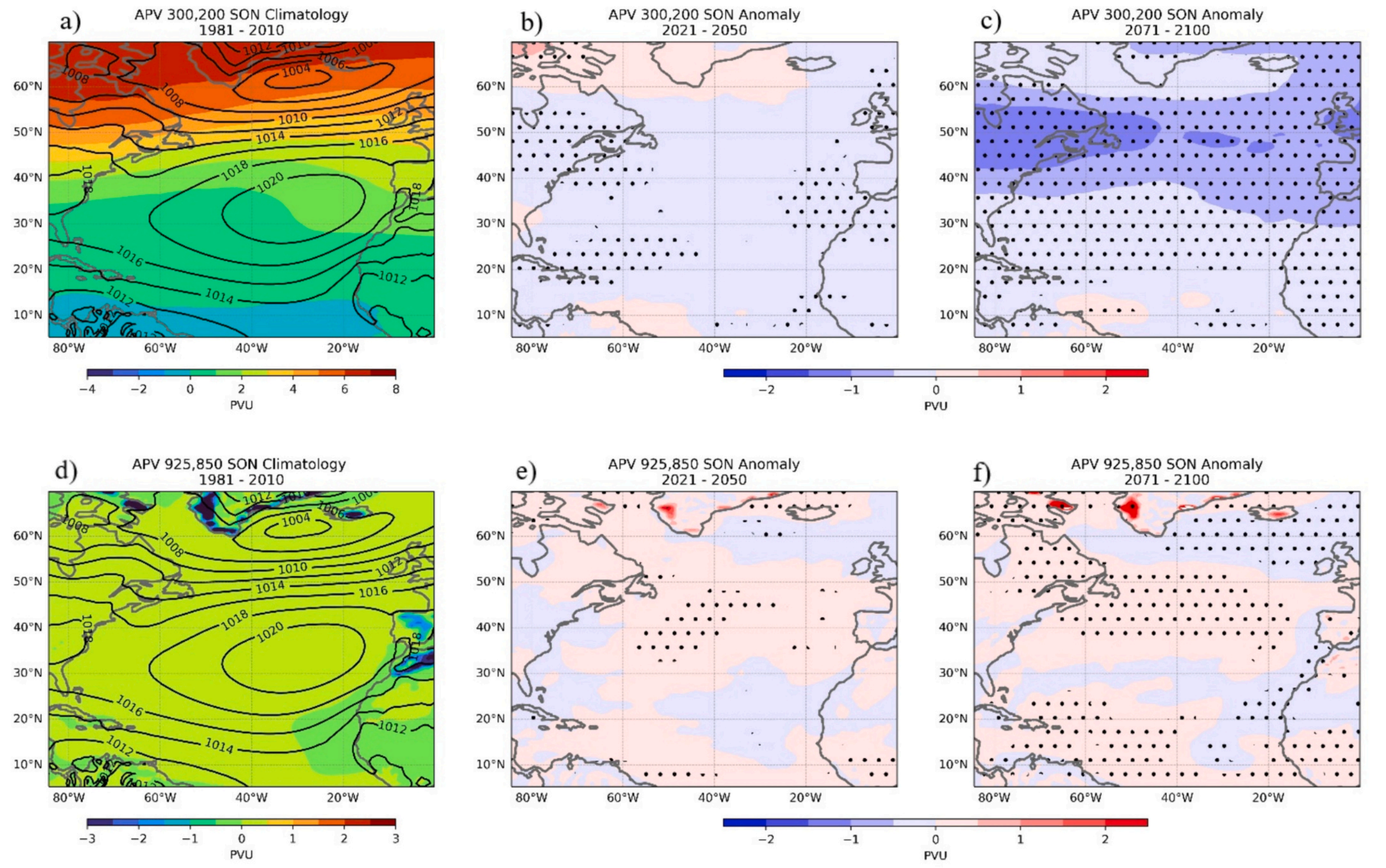

Fig. 2. Seasonal climatological values in SON for the 1981–2010 period of a) $APV_{300,200}$(PVU) and MSLP (hPa; black contours), d) $APV_{925,850}$(PVU) and MSLP (hPa; black contours). Seasonal anomaly values in SON with respect to the climatology of $APV_{300,200}$(PVU) for the b) near and c) far future period; of $APV_{925,850}$(PVU) for the e) near and f) far future period. Black dots indicate where the anomalies computed are statistically significant (Mann – Whitney U test; $\alpha = 0.05$).

results obtained in Figs. 3b, c, along with those of Fig. 2, highlight the transition to a more barotropic environment in the far future period for the domain enclosed by 30°N - 50°N, which is a crucial fact for TT development and TC maintenance according to DeMaria (1996), Davis and Bosart (2004) and Calvo-Sancho et al. (2022), among others.

McTaggart-Cowan et al. (2015) analyze TC characteristics employing four global datasets covering from 1989 to 2013, thus studying 1757 TCs across all basins. They asses a CI global value of 22.5 °C as the upper limit for TT development since low CI values imply unstable environments. A decreasing CI favors deep convection development since the tropospheric stability is reduced. Indeed, Calvo-Sancho et al. (2022) reveal that the CI decreases when a TT occurs, reaching up values lower than 22.5 °C, which is consistent with the results obtained in the current study. Fig. 3d shows the seasonal climatological values in SON for the P1 of the CI and it reveals only a few spots in the domain (located around 0°N – 5°N, 60°W – 50°W) reaching the 22.5 °C upper limit aforementioned. Figs. 3e, f show negative P1 anomalies of the CI, especially in regions where the values are near the upper limit in Fig. 3d (southern region of the domain), highlighting a strong decrease of the CI value throughout the XXI century. Moreover, it should be noted that the far future period anomaly absolute values (Fig. 3f) are higher than those for the near future (Fig. 3e), and statistically significant in most parts of the domain, emphasizing that the TT development probability rises in terms of the CI especially for the far future period.

4. Summary and conclusions

Regarding the uncertainty in ACC effect on TC frequency and intensity (Stocker, 2014; Emanuel, 2023), this survey focusses on enhancing the knowledge of changes in favorable NATL environments for TT development and TC intensification under the ACC effect for the SON season, due to most TCs affecting western Europe having a TT origin and developing in SON (Calvo-Sancho et al., 2022). For this purpose, the SON anomalies with respect to the 1981–2010 climatology of some relevant variables, commonly used to evaluate the suitability of an environment for TT development and TC intensification, are analyzed for different periods (near and far future). The SSP5–8.5 scenario (Tebaldi et al., 2020) from the EC-Earth3-BSC climatic model has been used.

The SST results of this research reveals a significant increase for the whole domain. Moreover, the TCW and Z300 also present significant positive anomaly values for the future in almost the whole basin studied, being the anomaly values higher for the far future period. The combination of these three variables behavior contribute to an intensification of the systems (Kang and Elsner, 2015). On the other hand, large releases of latent heat lead to a low-level increase of PV and an upper-level PV decrease, which is appreciated in this research since it shows a significant decrease and increase of $APV_{300,200}$ and $APV_{925,800}$, respectively, for the far future period in many parts of the NATL basin. This is consistent with the Z300 results, which could favor air masses rising.

The PV redistribution induces a WSH decrease (Davis and Bosart, 2004; Calvo-Sancho et al., 2022), in agreement with the anomaly values obtained that show a significant P99 WSH decrease for the far future period in most of the domain of study. On the other hand, the CI, whose P1 presents significant negative anomaly values for the future periods in this study, highlights a stability reduction throughout the considered period.

The overall results show that, in general terms, the NATL environment will turn into a more barotropic one under the SSP5–8.5 scenario effects, i.e., the NATL environment will tropicalize in response to ACC.

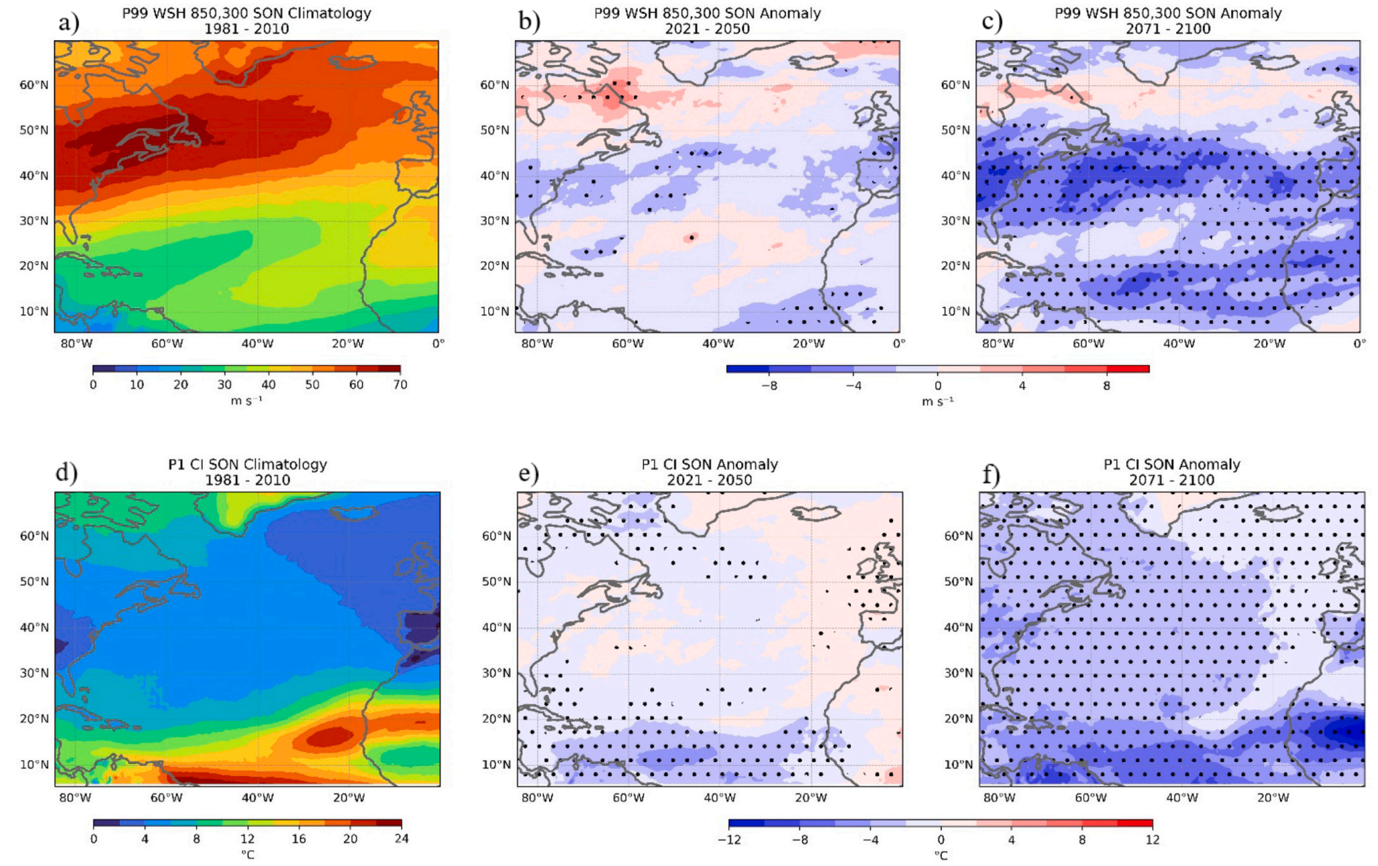

Fig. 3. Seasonal climatological values for the 1981–2010 period in SON of a) the P99 of WSH (m s^{-1}); d) the P1 of CI (°C). Seasonal anomaly values in SON with respect to the climatology of the P99 of WSH (m s^{-1}) for the b) near and c) far future period; of the P1 of CI (°C) for the e) near and f) far future period. Black dots indicate where the anomalies computed are statistically significant (Mann – Whitney U test; $\alpha = 0.05$).

Thus, it may become more prone to TT development and TC intensification in response to the ACC. It should be noted that the derived anomalies present less locations with significant values for the near future period than for the far future one, indicating a non-linear evolution of the NATL environment tropicalization due to it being significantly more pronounced for the furthest future period (2071–2100). These results are worrying due to the increasing probability of intense TCs reaching western Europe in the future, not being this region used to this type of phenomena. Accordingly, further study is required to enhance the knowledge of the topic.

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Open research

The EC-Earth3-BSC output files that support the findings of this study are available from the corresponding author, upon reasonable request.

CRediT authorship contribution statement

A. Montoro-Mendoza: Writing – original draft, Software, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **C. Calvo-Sancho:** Methodology, Data curation, Conceptualization. **J.J. González-Alemán:** Supervision, Methodology, Data curation, Conceptualization. **J. Díaz-Fernández:** Supervision, Conceptualization. **P. Bolgiani:** Supervision, Methodology, Data curation, Conceptualization. **M. Sastre:** Supervision, Conceptualization. **E. Moreno-Chamarro:** Resources, Data curation. **M.L. Martín:** Writing – review & editing, Validation, Supervision, Formal analysis, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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