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Characteristics of different convective parameterization schemes on the simulation of intensity and track of severe extratropical cyclones over North Atlantic

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ABSTRACT

The role of the convective parameterization schemes (CPSs) in the ARW-WRF (WRF) mesoscale model is examined for extratropical cyclones (ETCs) over the North Atlantic Ocean. The simulation of very severe winter storms such as Xynthia (2010) and Gong (2013) are considered in this study. Most popular CPSs within WRF model, along with Yonsei University (YSU) planetary boundary layer (PBL) and WSM6 microphysical parameterization schemes are incorporated for the model experiments. For each storm, four numerical experiments were carried out using New Kain Fritsch (NKF), Betts-Miller-Janjic (BMJ), Grell 3D Ensemble (Gr3D) and no convection scheme (NCS) respectively. The prime objectives of these experiments were to recognize the best CPS that can forecast the intensity, track, and landfall over the Iberian Peninsula in advance of two days. The WRF model results such as central sea level pressure (CSLP), wind field, moisture flux convergence, geopotential height, jet stream, track and precipitation have shown sensitivity CPSs. The 48-hour lead simulations with BMJ schemes produce the best simulations both regarding ETCs intensity and track than Gr3D and NKF schemes. The average MAE and RMSE of intensities are least that (6.5 hPa in CSLP and 3.4 ms^{-1} in the 10-m wind) found in BMJ scheme. The MAE and RMSE for and intensity and track error have revealed that NCS produces large errors than other CPSs experiments. However, for track simulation of these ETCs, at 72-, 48- and 24-hour means track errors were 440, 390 and 158 km respectively. In brevity, BMJ and Gr3D schemes can be used for short and medium range predictions of the ETCs over North Atlantic. For the evaluation of precipitation distributions using Gr3D scheme are good agreement with TRMM satellite than other CPSs.

1. Introduction

The extratropical cyclones (ETCs) occurs over subtropical North Atlantic Ocean causes one of the most expensive losses of life, property at the place of their landfall at coastal regions of Europe. The dangerous character of ETCs are associated with strong winds, heavy precipitation and storm surges during the winter season have produced significant damages and substantial economic loss over the southwestern of Europe (Swiss Re, 2008). Due to very low pressure at the core of ETCs that produces violent winds and torrential precipitation evenly distributed around the centre and thus, categorised as wind and precipitation storms (Karremann et al., 2016). Most of the ETCs formed over mid-latitude of North Atlantic region are cold core systems associated with baroclinic instability and North Atlantic Oscillations (NAO) as discussed in Ulbrich et al. (2009); Pinto et al. (2008). In recent decades, there were five severe storms viz., Kyrill (Fink et al., 2009), Klaus (Liberato et al., 2011), Xynthia (Liberato et al., 2013), Gong (Liberato, 2014), and Stephanie (Ferreira et al., 2014), that caused intensive damage and substantial economic losses over Iberian Peninsula and adjoining European region. With a continuous supply of moisture from North Atlantic, the storms reached the maximum intensity and passed through the coast of the Europe, even though they were originated at unusual lower latitudes. Moreover, the occurrence of cold spells in the winter season is related to low storm track activity over the part of mid-latitude continental regions, and therefore, storm tracks and their intensities are influenced by continental temperature as well as moisture

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(Lehmann and Coumou, 2015). Most of these storms have made landfall in Iberian Peninsula with an anomalous intensity and consequently, with high wind speed and precipitation are considered in this study. Since the 17th century, the most destructive wind storms are experienced in Portugal caused huge loss of life (Domínguez-Castro et al., 2013). Two historical events occurred in November (1724) and another in February (1941) (Muir-Wood, 2011; Freitas and Dias, 2013) were the most destructive storms ever experienced, due to lack of early warning about these storms. The numerical prediction of ETCs with at least 48-hour lead time, could give the administrators to take necessary precautionary measures like evacuating the people, protecting the properties etc. lead to minimize the damage. The present study focuses on providing the genesis, movement and estimation of its damage precursors like wind and precipitation with at least 2 days lead time by identifying the best suitable combination of physical parameterization schemes in predicting the ETCs in real time.

The movement of ETCs is known from the knowledge of upper air jet stream and prevailing conditions. However, prediction of intensity and position of landfall a few days in advance would be highly advantageous for planning and execution of the mitigation measures effectively. Thus, to understand the dynamical mechanisms which are a favourite for the development and significant intensification of these extratropical storms that landfall near the Iberian Peninsula. Studies reveal that using mesoscale model certainly possible because of recent advancement of computer resources. Mesoscale numerical models are sophisticated and essential tools for complementing the traditional study of atmospheric dynamics, controlling the life cycle of mid-latitude extreme storms. A recent survey by Kumar and Krishnamurti (2016) documented that the movement of rain bands from southeast to northwest directions termed as the onset of monsoonal isochrones were well simulated with WRF model at 25 km resolution and agreeing with TRMM 3B42 satellite data. The impacts connected to severe weather events, the surface wind fields play an important role, and their generation mechanisms are much related to local factors such as topography (Luna et al., 2011), and surface moisture as well as temperature (Seneviratne et al., 2010; Jerez et al., 2012). The simulation studies also report that for extreme weather events, higher resolution models have enhanced concurrence with observations than coarser resolution over tropical regions (Mailhot et al., 1989; Bhaskar Rao et al., 2009; Srinivas et al., 2013).

Borkowski (2006) used WRF model to study the role of the boundary layer and upper-level processes on storm cyclogenesis. The surface flows before the development of surface cyclones in the instability conditions suggesting that net effect of the upper-level divergence patterns are very significant in the storm's development. Focusing on Otkin and Thomas (2008) in the case of mid-latitude cyclones over North Atlantic, WRF model is susceptible to the PBL and microphysical parameterisation schemes concerning model simulation of cloud properties. Marrero et al. (2008) showed when modelling the extratropical storm Delta which affected the Canary Islands during November 2005, the surface wind predicted by the WRF model has represented compassionate results with PBL scheme, surface layer scheme, horizontal resolution and nesting technique. The WRF model has also been used to simulate ETCs to provide the forcing for Ocean wave models (Heo et al., 2013). In WRF model, physics suites are combinations of schemes (e.g., microphysics, radiation, cumulus, PBL) that can be run together. However, these schemes that have been used any combinations as per the purpose of requirement and may be tuned based on characteristics of the weather events (Powers et al., 2017). Moreover, it is extremely crucial to the setting of WRF model experiments at a certain location with the aim of simulating extratropical storm episodes, an attention mostly given to the choice of the right physical parameterisation schemes (Heo et al., 2013).

The previous study of Xynthia has performed with Coupled Ocean-Atmosphere Mesoscale Prediction System (COAMPS) and results are discussed in Doyle et al. (2014). Also, Ludwig et al. (2013), simulated Xynthia with non-hydrostatic regional COSMO model forced with ERA-Interim datasets. Miglietta et al. (2015) have used WRF model for the simulation of tropical-like cyclones over the Mediterranean Sea and tested different cloud microphysics and convection schemes. Recently Ferreira et al. (2017) used WRF model for simulation of three severe winter storms such as Klaus, Gong and Stephanie and investigated the role of atmospheric water vapour on the intensification of these storms. Considering all the above a study has been undertaken to simulate and understand the mesoscale features and dynamic of severe winter storms through WRF model, but didn't appraisal of convection schemes over Iberian Peninsula.

As per the STORMEx project (Mid-latitude North Atlantic Extreme Storms Variability: Diagnosis, Modelling Dynamical Processes and Related Impacts on Iberia) main objectives of this project was to perform simulation using WRF modelling system for the assessment of extratropical storms that caused adverse impact mostly over the Iberian region. The purpose of this work is first, to setup and examine the WRF model performance on the unexpected development of Xynthia and Gong that consequent from wind and precipitation, secondly to identify imperfection of CPSs on intensity, track and moisture flux convergence (hereafter: MFC) during mature stage. Third, to perform the sensitivity analysis of widely used CPSs understand their dynamical mechanisms and suitability over Iberian region. This paper is organized as follows. In this article Section 2 discussed the synoptic features of Xynthia and Gong. The details of the model setup, description of CPSs, dynamical initialisations and model evaluations are reviewed in Section 3. The results are discussed in Sections 4 and 6. The key findings based on the results are presented in Section 7.

2. Synoptic features of Xynthia and Gong

2.1. Xynthia

Xynthia is a very severe cyclonic storm formed in the North Atlantic near Bermuda Island above the latitude of 30° N on 12 UTC of 25 February 2010. After 24-hour this low-pressure system got more intensified and moved steadily southeastward with the sea-level pressure of 988 hPa (www.met.fu-berlin.de). Due to southwesterly flow from the lower towards mid-latitudes, the surface and upper-level zonal flow and wave embedded in the westerlies that caused the vortex to cross through the south of the Azores. On 00 UTC 27 February, the vortex had dropped rapidly to 975 hPa and moved towards Iberian Peninsula. On 00 UTC 28 February (local time midnight) Xynthia reported as an explosive cyclonic storm with the lowest core pressure of 967 hPa and persisted over the Bay of Biscay and made first landfall over the west coast of France. Due to the strong pressure gradient within a very narrow space (gusts wind of 117 kmh^{-1}) persisted over northern coast of Spain and adjoined France. After post-landfall, it continued and moved to Belgium, Netherlands and Germany. The AVHRR satellite for mature stage of Xynthia valid on 21 UTC 27 February 2010 as illustrates in Fig. 1(a), shown dense cloud distributions over Iberian Peninsula. Mostly intense cloud bands are persisted over entire Iberian region and French coast. The explosive developments of Xynthia and its meteorological and socioeconomic impacts are discussed in Liberato et al. (2013). The storm have gust wind of 40 ms^{-1} as reported at low-level stations from the Atlantic Archipelagos of Madeira and Canary Islands characterized as a severe wind storm (Karremann et al., 2016) that induced storm surges of 8 mt height along the coastal locations of Portugal, Spain and France (Lumbroso and Vinet, 2011; Bertin et al., 2012; Liberato et al., 2013).

2.2. Gong

The low pressure system was originated over North Atlantic close to Newfoundland Island around longitude and latitude of 69° W and 40.5° N during 18 UTC 16 January 2013. This low pressure system along with