Impact of Intraseasonal Oscillations on the Tropical Cyclone Activity Over the Gulf of Mexico and Western Caribbean Sea in GFDL HiRAM

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Abstract The tropical cyclones (TCs) that form over the warm waters in the Gulf of Mexico region pose a major threat to the surrounding coastal communities. Skillful subseasonal prediction of TC activity is important for early preparedness and reducing the TC damage in this region. In this study, we evaluate the performance of a 25 km resolution Geophysical Fluid Dynamics Laboratory (GFDL) High Resolution Atmospheric Model (HiRAM) in simulating the modulation of the TC activity in the Gulf of Mexico and western Caribbean Sea by the intraseasonal oscillation (ISO) based on multiyear retrospective seasonal predictions. We demonstrate that the HiRAM faithfully captures the observed influence of ISO on TC activity over the region of interest, including the formation of tropical storms and (major) hurricanes, as well as the landfalling storms. This is likely because of the realistic representation of the large-scale anomalies associated with boreal summer ISO over Northeast Pacific in HiRAM, especially the enhanced (reduced) moisture throughout the troposphere during the convectively enhanced (suppressed) phase of ISO. The reasonable performance of HiRAM suggests its potential for the subseasonal prediction of regional TC risk.

1. Introduction

The intraseasonal oscillation (ISO or the Madden-Julian Oscillation) is a large-scale atmospheric oscillation with a typical period of 30–60 days and characterized by eastward propagating convection and circulation anomalies (Madden & Julian, 1971, 1972). It has been well known that ISO modulates the basin-wide tropical cyclone (TC) activity by affecting the large-scale environment (e.g., Camargo et al., 2009; Vitart, 2009). Generally, the likelihood of TC genesis is increased (decreased) in the ocean basin where ISO is in the convectively enhanced (suppressed) phase (e.g., Indian Ocean: Kikuchi & Wang, 2010; North Atlantic Pacific: Li & Zhou, 2013; Northeastern Pacific: Maloney & Hartmann, 2000a; North Atlantic Ocean: Klotzbach, 2010). Moreover, the ISO exerts significant impact on the TC activity in subbasins with densely populated coastal communities, such as the Gulf of Mexico. During the peak of TC season in the Northern Hemisphere (NH, June–November), the magnitude of ISO is enhanced over the Northeast Pacific warm pool (Maloney & Esbensen, 2003) and characterized by northward propagation between 5°N and 25°N in additional to the eastward propagation (Jiang & Waliser, 2008). The ISO in the Northeast Pacific not only modulates the genesis location and number of TCs formed locally (Jiang et al., 2012; Maloney & Hartmann, 2000a) but also significantly influences the TC activity in the Gulf of Mexico and western Caribbean Sea (Maloney & Hartmann, 2000b; MH00 hereafter). Particularly, MH00 showed that the number of hurricanes formed during the convectively enhanced ISO phase is nearly 3 times more than the convectively suppressed ISO phase based on historical observations.

Considering the long-range predictability of ISO in dynamical models (Lee et al., 2015; Neena et al., 2014; Xiang et al., 2015), the significant modulation of ISO on TC activity has important implications on the subseasonal (loosely defined as the time scale from 2 weeks to less than a season) prediction of TCs. Belanger et al. (2010) indicated that the prediction of subseasonal TC activity over North Atlantic was affected by the phase and intensity of the ISO at the time of model initiation in the European Centre for Medium-Range Weather Forecasts (ECMWF) Monthly Forecast System. Li et al. (2016) suggested that the subseasonal TC prediction skill tended to be better during the years with strong ISO activity by examining the results from the National Centers for Environmental Prediction (NCEP) Global Ensemble Forecasting System.
The TCs that form over the Gulf of Mexico have high probability in making landfall at the surrounding coastal regions and causing severe life and property damages. Skillful subseasonal prediction of TC activity is undoubtedly of great importance for early preparation and reducing the TC damage in this region. In order to have skillful prediction of the subseasonal TC activity, it is important for dynamical models to faithfully capture the ISO characteristics and also its impact on TC statistics, such as the frequency of TC formation and landfall.

There were only a few studies that examined the relationship between ISO and the TC activity over the Gulf of Mexico in dynamical models, summarized as follows. Aiyyer and Molinari (2008) investigated the influence of ISO on TC genesis in the Gulf of Mexico and the Northeast Pacific, but they only performed idealized simulations using a barotropic model with prescribed large-scale flow. Vitart (2009) showed that ECMWF atmospheric model captured the TC track difference between the active and inactive ISO phases in the North Atlantic based on a 20 year subseasonal (46 days) prediction data set, but the statistics of tropical storms (TSS) and hurricanes that formed locally in the Gulf of Mexico were not explicitly discussed. Barnston et al. (2015) analyzed the performance of a high-resolution (approximately 37 km) version of the NCEP Climate Forecast System (CFS) and found that the CFS can approximately reproduce the observed relationship between ISO and TC activity in different subsectors of the North Atlantic. But they noted that there were noticeable biases in the Gulf of Mexico: the CFS had a large negative bias in the climatological TC activity in the Gulf of Mexico and also underestimated the local TC activity during the active ISO phase. Similarly, Halperin et al. (2013) indicated that the global models generally underrepresented the TC genesis over Gulf of Mexico by examining the genesis forecasts in five global models, and they also pointed out that the models had relatively poor performance in predicting the genesis event over Gulf of Mexico. In summary, to the best of our knowledge, there has been no reported study showing that any dynamical model is capable of satisfactorily capturing the modulation of TC statistics in the Gulf of Mexico region by ISO, as illustrated in MH00.

In this work, we evaluate the performance of the latest nonhydrostatic version of NOAA/Geophysical Fluid Dynamics Laboratory (GFDL) High Resolution Atmospheric Model (HiRAM) in simulating the response of TC activity in the Gulf of Mexico and western Caribbean Sea region to ISO based on a multiyear seasonal prediction data set. We aim to demonstrate that HiRAM is able to realistically capture the influence of ISO on TC statistics in the Gulf of Mexico and western Caribbean Sea and thus has potential for subseasonal prediction of the regional TC activity.

2. Model and Data

The model data set used in this study is a series of seasonal predictions for a 25 year period from 1990 to 2014 based on the HiRAM with approximately 25 km horizontal resolution (Chen & Lin, 2016). Compared to a previous version of HiRAM used in Chen and Lin (2013), the current version has the following main upgrades: (1) the use of nonhydrostatic version of the GFDL Finite Volume Cubed-Sphere Dynamical Core (FV3) and (2) the replacement of the single plume convection scheme used in Zhao et al. (2009) with the double plume convection scheme (Zhao et al., 2016).

Each hindcast run covered a 5 month period from July to November (153 days in total). The sea surface temperature (SST) field used for each hindcast period was the monthly SST climatology plus the SST anomalies on the initial forecast time based on observations (the SST anomalies are assumed persistent throughout each model run) (Chen & Lin, 2013). The data set consisted of five forecast ensemble members for each hurricane season, which were created by using 1 day lagged initial conditions (the first member initialized on 0000 UTC 1 July, the second on 0000 UTC 30 June, etc.). The model TCs were tracked by the same algorithm as in Harris et al. (2016). Briefly, the TC tracking scheme detects all long-lived warm-core sea level pressure minima (see the appendix in Harris et al., 2016 for details). The definitions of TS and hurricane are as follows. A TS must have a lifetime of at least 72 h (including the early tropical depression stage), maintain a warm core and maximum wind of at least 17.5 m s\(^{-1}\) for no less than 36 consecutive h, and have a warm core for at least 48 h (not necessarily consecutive). A hurricane is defined as a TS that obtains a maximum wind of 32.5 m s\(^{-1}\) or greater while centered equatorward of 40° latitude. The TC records were saved every 6 h.

This model data set contains 125 five month hindcast runs in total and provides large samples of simulated ISO events and TCs (will be shown in section 4), which allows for obtaining a robust estimate of the impact of
ISO on TC statistics in HiRAM. To minimize the impact of the initial condition on the results, and in particular
the impact of the initialized ISO state, we exclude the model simulations in the first two weeks of July in our
following analysis.

The ERA-Interim (ERA-I) reanalysis (Dee et al., 2011) with 0.75° resolution from July to November during years
1979–2015 is used to assess the large-scale simulations in HiRAM. The TC observations are the 6-hourly “best
track” data from July to November during years 1979–2015 over the North Atlantic in the HURDAT2 data set
provided by the National Hurricane Center (Landsea & Franklin, 2013). We use all the available ERA-I reanaly-
sis and the TC observations in the corresponding periods to obtain the most robust estimate of observed
impact of ISO on the TC statistics.

In our analysis, the atmospheric variables from both ERA-I reanalysis and the HiRAM simulations are daily
averaged and mapped to 1° × 1° grids. The daily climatology in both reanalysis and HiRAM is calculated as
the average of the daily fields during all available years, and the daily anomalies are calculated as the total
daily fields minus the corresponding climatological field.

3. Regional ISO Index

To facilitate a direct comparison with the results in MH00, we use the same method to obtain an index that
describes the magnitude and phase of the ISO signal in the Northeast Pacific. Consistent with MH00, we apply
the empirical orthogonal function (EOF) analysis of the zonal wind anomalies at 850 hPa over the Northeast
Pacific and Gulf of Mexico (Equator–30°N; 130°W–80°W). The wind anomalies used in the EOF analysis are
20–80 day band-pass filtered to retain the ISO band signal.

EOF analysis reveals that the leading EOF mode (Figures 1a and 1b) is the largest contributor to the total var-
iance, explaining ~35%, while each of other modes contributes less than 10% (not shown). The spatial struc-
ture of the first EOF is characterized by a zonal jet structure centered on 10°N that is associated with the local
ISO. As shown in Jiang and Waliser (2008), the convectively enhanced (suppressed) ISO phase in Northeast
Pacific is characterized by westerly (easterly) 850 hPa zonal wind anomalies. The spatial structure of the first
EOF and its contribution in HiRAM are in good agreement with the ERA-I reanalysis, suggesting that HiRAM
captures the ISO signal in the Northeast Pacific. Similar to MH00, the principal component (PC) of the first EOF
mode is used as an index of the Northeast Pacific ISO in this study and will be referred to as PC1 hereafter. A
positive (negative) value of PC1 corresponds to westerly (easterly) 850 hPa zonal wind anomalies. The
regression coefficients of the outgoing longwave radiation (OLR) anomalies onto the standardized PC1 in both the ERA-I reanalysis and HiRAM simulations are shown in Figures 1c and 1d, respectively. The regression pattern of OLR anomalies in Northeast Pacific (east of 120°W) is negative, suggesting that an increase of PC1 is associated with an increase of convection in this region. It is worth noting that the negative regression pattern extends to the Gulf of Mexico, indicating that the convection in the Gulf of Mexico is under the influence of the Northeast Pacific ISO.

4. Modulation of Tropical Cyclone Activity by ISO

In this section, we examine the impact of ISO on TC activity in the region west of 75°W and south of 30°N in the North Atlantic basin, which include the entire Gulf of Mexico, western Caribbean Sea, and part of the northwest Atlantic. From here on, we will refer to the selected region as the Gulf of Mexico (GoM) region.

We first demonstrate that HiRAM can realistically capture the observed distribution of TS formation that occurred over the GoM region under all conditions. The formation of TS refers to the event when the TC reaches TS intensity (maximum surface wind speed reaching 17.5 m s\(^{-1}\)). Figure 2 shows the histograms of days and TS formation with respect to the standardized PC1 from both observations and HiRAM simulations. The model distributions are generally consistent with these in observations. A significant portion (greater than 70%) of days in both observations and HiRAM simulations have PC1 less than 1 standard deviation (SD; Figures 2a and 2b), and most storms form during these periods (Figures 2c and 2d). It is noticeable that TS formation is overall favored in the periods when PC1 is positive in both observations and HiRAM, which is consistent with MH00.

Figure 2. Histograms of days with respect to the standardized PC1 in (a) observations and (b) HiRAM, respectively. The total number of days is shown in the parenthesis. The frequency shown is the percentage of total days in each bin. (c, d) Same as Figures 2b and 2d but for the TS genesis events.
We then focus on the TS formation in the days when the amplitude of PC1 exceeds 1 SD. Similar to MH00, we define the days with positive (negative) PC1 that exceeds 1 SD as the westerly (easterly) phase hereafter. Figure 3 illustrates the tracks of the TSs (including the ones later reaches hurricane intensity), formed locally over the GoM region during the westerly and easterly phases from both observations and HiRAM simulations. The results are generally consistent with MH00, despite the difference in temporal coverage of the data. Remarkably, HiRAM captures well the large contrast between the two phases: the number of TS formed during the westerly phase is nearly four times as large as during the easterly phase.

It should be noted that the TSs formed in the model are nearly 3 times as many as in the observations during both the westerly and easterly phases, which is because there are more days in the model than in observations during these two phases.

As noted by MH00, ISO influences all TCs over the GoM region, not only those formed locally (as shown in Figure 3). We next show that the geographic distribution of all the 6-hourly TC records identified during the two ISO phases to demonstrate that HiRAM captures the modulation of all TCs by ISO. Note that the TC records considered here include both TCs formed over the GoM region (shown in Figure 3) and those formed remotely but later propagated into the GoM region. Here we define the track density as the number of 6-hourly TC records per day within a 5° × 5° box centered on each 1° grid point. The climatological track density in HiRAM (observations) is calculated as the track density averaged over all days in the model simulations (observations).

The anomalies of the track density for all TC records with at least TS intensity during the westerly and easterly phases (with climatological track density subtracted) are shown in Figure 4. Similarly, the anomalies of the
track density for the TC records with at least hurricane intensity are shown in Figure 5. During the westerly (easterly) phase, there is an increase (decrease) in the TC (including both TSs and hurricanes) track density over almost the entire selected region (including the coastal areas), indicating an overall increase (decrease) in the TC risk. The track density anomalies in HiRAM (Figures 4b and 4d and Figures 5b and 5d) are overall in good agreement with these in observations (Figures 4a and 4c and Figures 5a and 5c).

We further quantify the change of the frequencies of four events that occurred over the GoM region during the two ISO phases relative to the climatological state: the formations of TSs, hurricanes, and major hurricanes (categories 3 to 5 based on Saffir-Simpson hurricane wind scale), as well as TC landfall. The landfall event considered here refers to the landfall of TCs with at least TS intensity (maximum surface wind no less than 17.5 m s\(^{-1}\)) that occurred at the entire coastal areas over the GoM region (south of 30°N and west of 75°W). The occurrence frequency of each event is calculated as the total number of the events divided by the total number of days. Figure 6 shows the climatological occurrence frequencies of the four events over the GoM region and the changes in the two ISO phases. HiRAM is generally in good agreement with the observations in the climatological frequencies of the TS and hurricane formations, as well as the TC landfall, although small negative biases exist (an ~11% negative bias in TS formation, ~5% in hurricane formation, and ~10% in TC landfall). There is a relatively large (~50%) negative bias in the occurrence of major hurricanes in HiRAM, which could be attributed to the relatively coarse horizontal resolution the model uses. The 25 km horizontal resolution is likely not high enough to realistically resolve the inner core TC structure and thus limit the occurrence of the most intense hurricanes (i.e., the major hurricanes). Nevertheless, HiRAM shows good agreement with the observations in terms of the change of all the four events in the two ISO phases relative to the climatology. Specifically, HiRAM captures the significant increase of TC activity in the westerly phase: the occurrence frequency of TS increases by more than 75% relative to the climatology and occurrence.

Figure 4. Track density anomalies (counts per day; multiplied by a factor of 1,000) of all TCs (including both TSs and hurricanes) during the (a, c) westerly and (b, d) easterly phases, respectively. The anomalies refer to the departure from the climatological track density. Only the anomalies with magnitude larger than 15% of the local climatological mean are shown.
frequencies of hurricane, major hurricane, and TC landfall increase by more than 100%. HiRAM also captures the significant reduction (nearly 50%) of the occurrence frequencies of the four events in the easterly phase. The above analyses indicate that HiRAM faithfully reproduces the observed modulation of TC activity over the GoM region by ISO, including not only the local TC genesis but also the occurrences of the (major) hurricanes and the TC landfalls over the surrounding coastal regions.

5. Large-Scale Anomalies Associated With ISO

In this section, we quantify the large-scale anomalies during the two ISO phases that affect TC genesis frequency, with a focus on examining the performance of HiRAM in representing those anomalies. Several studies (e.g., Camargo et al., 2009; Jiang et al., 2012) indicated that the genesis potential index (GPI) proposed by Emanuel and Nolan (2004) was useful in explaining the effect of ISO on TC genesis. We therefore use this index to understand how the environment changes associated with ISO affect the TC genesis over the GoM region.

The GPI empirically incorporates four important variables that affect the probability of TC genesis and defined as follows:

\[
\text{GPI} = \left(10^5 |\eta|^{3/2}\right) \left(\frac{\text{RH}}{50}\right)^3 \left(\frac{\text{PI}}{70}\right)^3 \left(1 + 0.1S\right)^{-2},
\]

where \( \eta \) is the 850 hPa absolute vorticity, RH is the 600 hPa relative humidity, PI is the potential intensity of the TC in term of the maximum surface wind speed (Bister & Emanuel, 2002), and S is the magnitude of the vertical wind shear between 200 hPa and 850 hPa. The variables used to calculate the GPI in both ERA-I reanalysis and HiRAM simulations are the daily averaged fields described in section 2. Furthermore, similar to

Figure 5. Same as Figure 4 except for track density anomalies of hurricanes only (counts per day; multiplied by a factor of 1,000).
Camargo et al. (2009), we calculate the GPI using the actual values of one variable in equation (1) and the climatological values of the other three to quantify the relative importance of four variables in contributing to the total GPI anomalies during the westerly and easterly phases. These GPI anomalies are labeled as GPI-RH, GPI-η, GPI-S, and GPI-PI, respectively; for example, GPI-η is calculated using the actual daily η fields and the climatological daily RH, PI, and S fields (without interannual variations). The composites of the large-scale fields in the westerly and easterly phases are obtained by averaging all the daily fields in the corresponding phase.

The composite GPI anomalies and the anomalies of the individual components during the westerly and easterly phases are shown in Figures 7 and 8, respectively. Potential intensity only has minor contribution to the total GPI anomalies in the two phases (not shown), which is consistent with previous studies (Camargo et al., 2009; Jiang et al., 2012). In both ERA-I reanalysis and HiRAM simulations, the GPI has positive (negative) anomalies during the westerly (easterly) phase over the entire GoM region, which provides an explanation for the difference in the TS formation frequency in the two phases. The reason for the realistic representation of the anomalous GPI patterns in HiRAM is that it reasonably captures the spatial distributions of the anomalies of each GPI component. Although there are biases in the wind shear and relative humidity anomalies over the Northeast Pacific, the sign and the pattern of the anomalies are largely consistent with the observations both here and over the GoM.

Specifically, HiRAM reproduces the enhancement (reduction) in midlevel relative humidity over the entire GoM region and the lower-level vorticity immediately to the east of Mexico coast, as well as the reduction (enhancement) in the wind shear in western Caribbean Sea during the westerly (easterly) phase. These factors all contribute to the positive (negative) GPI anomalies in the westerly (easterly) phase and make the large-scale environment over the GoM region overall more (less) favorable for TC genesis.

Figure 6. (a) Climatological occurrence frequencies of TS formation, hurricane formation, major hurricane formation, and TC landfall occurred over the GoM region. (b) The change (in percentage) of the occurrence frequencies of the four events relative to their climatological frequencies in the westerly (W) and easterly (E) phases, respectively.
To quantify the relative importance of the four variables in (1) in contributing to the total GPI anomaly, we obtain the area-averaged anomalies of GPI, GPI-RH, GPI-$\eta$, GPI-$S$, and GPI-PI over GoM region (Figure 9). The results shown in Figure 9a indicate that the RH is the main contributor to the total GPI anomalies during the two phases, and the shear plays a secondary role in the ERA-I reanalysis. Same analysis applied to the model simulations indicates that HiRAM reasonably captures the relative importance of the four factors in contributing to the total GPI anomaly over the GoM region. The importance of midlevel relative humidity anomalies over the GoM region is consistent with the finding with Camargo et al. (2009), who showed that the midlevel humidity played a leading role in the modulation of the global TC genesis by ISO. It should be noted that the overall enhanced (reduction) moisture in the westerly (easterly) phase not only makes the large-scale environment more (less) favorable for TC genesis but also provides a more (less) favorable environment for TC intensification. This at least partially explains why the formations of hurricane and major hurricanes are enhanced (reduced) in the westerly (easterly) phase.

Figure 7. Composites of the anomalous atmospheric fields during the westerly phase in (Figures 7a, 7c, 7e, and 7g) ERA-I reanalysis and (Figures 7b, 7d, 7f, and 7h) HiRAM. (a, b) Genesis potential index, (c, d) 600 hPa relative humidity, (e, f) wind shear between 200 hPa and 850 hPa, and (g, h) 850 hPa vorticity.
Noticeably, the anomalous midlevel humidity over the GoM region is closely associated with that over the Northeast Pacific in both ISO phases (Figures 7c and 7d and 8c and 8d). Such patterns strongly suggest that the GoM region is under the influence of the ISO over the Northeast Pacific. Next we create the vertical-longitudinal composites of the large-scale anomalies averaged between 10°N and 30°N (the zonal bands where most TCs form over the region of interest) to understand the change of the atmospheric state in the two ISO phases (Figure 10). During the westerly (easterly) phase, the Northeast Pacific (east of 120°W) and GoM (100°W to 70°W) regions are characterized by positive (negative) moisture and upward (downward) vertical motion anomalies over the entire troposphere. Such result is consistent with Maloney and Esbensen (2003), which showed that enhanced (reduced) convection over the Northeast Pacific during NH summer was accompanied by positive (negative) moisture anomalies throughout the troposphere. According to Maloney and Esbensen (2003), such large-scale anomalies could be the result of a feedback loop between the circulation and convection. For example, during the westerly phase, the low-level westerly wind anomalies cause enhanced surface latent heat flux and low-level convergence, which contribute to the upward vertical motion and moisten the atmospheric column and help intensify the ISO convection, and thereby creating a feedback loop that leads to further enhancement of the anomalous circulation. Our analysis shows that

![Figure 8](image_url)

**Figure 8.** Same as Figure 7 except for the easterly phase.
Figure 9. Area-averaged GPI anomalies over the GoM region during (a) westerly and (b) easterly phases. The anomalies shown in each panel (from left to right) are the actual GPI anomalies (GPI) and the GPI anomalies obtained by only considering the daily-varying relative humidity (GPI-RH), shear (GPI-S), vorticity (GPI-η), and potential intensity (GPI-PI).

Figure 10. Vertical-longitudinal cross sections of the composite anomalous humidity and wind fields averaged between 10°N and 30°N during the westerly and easterly phases in (a, c) ERA-I reanalysis and (b, d) HiRAM. Colors show the specific humidity anomalies (g kg⁻¹). Contours show the pressure velocity anomalies (Pa s⁻¹) multiplied by a factor of 100. Arrows show the zonal wind anomalies at 850 hPa and 200 hPa. The black bold line on each x axis indicates the longitudinal range of the GoM region.
HiRAM realistically simulates the large-scale circulation and moisture anomalies over the Northeast Pacific and GoM region during both the convectively enhanced and suppressed ISO phases, which is likely the main reason that HiRAM faithfully reproduced the change of the TC activity in the two ISO phases.

6. Summary

The tropical cyclones (TCs) formed in the Gulf of Mexico have high probability in making landfall at the surrounding coastal regions and causing severe damages. Skilful subseasonal prediction of TC activity is important for early preparedness and reducing the TC damage in this region. Previous studies (e.g., Maloney & Hartmann, 2000b) indicate that the ISO over the Northeast Pacific significantly modulates the likelihood of TS and hurricane formations in the Gulf of Mexico and western Caribbean Sea, which has important implications on the subseasonal predictability of the TC activity in this region.

In this study, we have evaluated the performance of the GFDL HiRAM in simulating the modulation of TC activity by ISO in the Gulf of Mexico and western Caribbean Sea region. A 25 year multiensemble retrospective seasonal prediction data set based on the nonhydrostatic version of HiRAM with approximately 25 km horizontal resolution is used. We have demonstrated that HiRAM faithfully captures observed influence of ISO on TC statistics in the Gulf of Mexico and western Caribbean Sea. Specifically, HiRAM not only captures the significantly enhanced TC genesis likelihood (more than 75%) in the westerly phase (convectively enhanced phase) but also reproduces the enhanced (more than 100%) occurrence frequencies of (major) hurricanes and landfalling storms. HiRAM also reasonably captures the reduced TC activity in the easterly phase (convectively suppressed phase).

Analysis of the large-scale environment indicates that HiRAM realistically reproduces the environment anomalies associated with the ISO that affect the TC activity. In particular, we find that HiRAM reasonably captures the enhancement (reduction) of moisture throughout the troposphere that is associated with the enhanced (reduced) ascending motion over the entire Gulf of Mexico and western Caribbean Sea region during the westerly (easterly) phase, which increases (decreases) the likelihood of TC genesis. The realistic representation of the large-scale anomalies associated with ISO serves as the precondition for the successful simulation of the impact of ISO on the regional TC activity in HiRAM.

Previous studies suggested that global models generally have deficiencies in simulating the climatology and the variability of TC activity over the GoM region (Barnston et al., 2015; Halperin et al., 2013; Li et al., 2016). The satisfactory performance of HiRAM over this region likely results from a combination of the use of relatively high horizontal resolution (~25 km), advanced nonhydrostatic dynamical core (FV3), and upgraded convection parameterizations. All these factors could contribute to the representation of the deep convective systems over tropics and thus the formation of TCs. However, it should be noted that it is hard to determine the key factor leading to the model’s good performance over GoM region.

The satisfactory performance of HiRAM presented in this study suggests its potential for the subseasonal prediction of regional TC activity. It is noticeable, however, that there is a relative large negative bias in the occurrence frequency of major hurricanes (categories 3–5), which is likely due to the relatively coarse horizontal resolution (~25 km) that may not be adequate to realistically resolve the TC eyewall structure. This could be improved by the use of higher resolution. The impact of model resolution on the hurricane structure and intensity simulation, as well as on subseasonal TC prediction skill, warrants future study.

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References


