Heat waves in Florida and their future from high-resolution regional climate model integrations

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Abstract
This study examines the simulation of the heatwave events over Florida from the integration of two regional climate models (RCMs) at comparatively high resolution (at 10 km grid spacing) for two decades of the current climate (1986–2005) followed by their projection in the mid-21st century (2041–2060). The two RCMs are coupled ocean–atmosphere (CRSM) and atmosphere only (URSM), which are forced at the lateral boundaries by the corresponding simulation of the Community Climate System Model v4 (CCSM4) for both the atmosphere and the ocean. The analysis reveals a reasonable simulation of the frequency, intensity and characteristic kinematic and thermodynamic features of the heatwave events over Florida from both the RCMs with the differences between URSM and CRSM being insignificant. The future projections (2041–2060) are presented only for URSM since the projected differences from CRSM were insignificant. We found the projected change of higher frequency ranging between 20 to over 50% increase relative to the late 20th-century frequency of heatwave events. Similarly, the projections suggest a broadening of the season of their occurrence by over 2 months. These projected changes are associated with a projected increase in the mean surface temperature, a slight increase of surface humidity but with a mean reduction of surface relative humidity, and a westward dislocation of the North Atlantic Subtropical High.

KEYWORDS
heatwave, North Atlantic Subtropical High, regional climate model

1 INTRODUCTION

This study examines the fidelity of the heatwaves in the late 20th-century simulation over Florida and the projection in the mid-21st century from unprecedented 10 km grid resolution regional climate model (RCM) integrations. In the United States, the National Weather Service (NWS) recognizes heat as the leading cause of weather-related deaths with nearly 200 occurrences in 2021 (NWS, 2021). Heatwaves increase the ambient heat level of work environments and can cause heat stress which then increases the risk of occupational accidents and injuries (Rameezdeen & Elmualim, 2017). Wald (2019) notes that heat-related illnesses from extreme events are also rising as documented by visits to emergency rooms across the United States both in rural and urban settings, which is raising the economic burden of health care.

Across Florida, pronounced changes in heatwave frequency have occurred throughout the state, most notably in southern Florida and along the I-4 corridor that
expands from Tampa to the east of Orlando (Keellings & Waylen, 2014; Leary et al., 2015). Some studies note that areas close to water bodies have an increased probability of extremely high temperatures given that water bodies can regulate daytime maximum and nighttime minimum temperature ranges (Behrens et al., 2019; Raghavendra et al., 2019; Schär et al., 2004). Marine heatwaves have shown a positive trend around the coasts of Florida and are linked to a general increase in sea surface temperature (SST; Androulidakis & Kourafalou, 2022). Therefore, terrestrial Florida is vulnerable to heatwaves from the warming surrounding oceans. Additionally, a modelling study involving dynamically downscaling the Community Earth System Model (Gent et al., 2011) to 4 km × 4 km grids on the future of the eastern United States estimates an increase in heatwave frequency (Wu et al., 2014). Wu et al. (2014) note that heatwaves in 2057–2059 will be 3.5–6.4 times more frequent than in 2002–2004, and mortality will be 7.5–19.0 times higher than in 2002–2004. A study on heat-related illnesses resulting in death or provision of medical services among Florida residents found that the highest mortality rates are observed in the panhandle or northern Florida, whereas the lowest mortality rates are in the southern counties (Morano et al., 2016). Morano et al. (2016) also found that average summer temperatures are higher and more variable in northern Florida compared to other regions of the state. Furthermore, they also suggest that high rates of heat-related illnesses in South Central Florida are due to the larger outdoor workforce.

Heatwaves are becoming longer and more frequent across regions of Florida which raises concerns about the future climate (Cloutier-Bisbee et al., 2019). In a study conducted with reanalysis datasets, Thomas et al. (2020) indicate that the Southeastern US shows a significant incidence of compound heatwaves (that are a combination of daytime and nighttime heatwaves) which is exceeded in frequency by only the Northwest region in the continental US. Thomas et al. (2020) found that mechanisms associated with nighttime heat waves differ by region. In the Southeast US, nighttime heatwave days are associated with anomalous low-level southerly flow leading to warm air advection into the region. In another related modelling study, Rastogi et al. (2020) indicate that despite the relative humidity exhibiting insignificant projected change, the future humid heatwaves in the Southeastern US are going to intensify owing to the increase in the daily maximum temperature. Similarly, Lau and Nath (2012) indicate that the duration and frequency statistics of the heatwaves in the mid-21st century generated by a global model at 50 km over Florida can be reproduced by adding the projected warming trend to the daily temperature for the late twentieth century and then diagnosing the heatwaves. More recently, Horowitz et al. (2023) suggest that the heatwaves in the United States with the exception of the mid-western US are significantly modulated by circulation anomalies and less so by soil moisture deficits. They find that the circulation anomalies account for over 85% of the heat wave temperature anomalies unlike the strong positive land-atmosphere feedbacks prevalent in the Central US heatwave events.

In this study, the focus is to understand the heatwave events from two unique 20-year integrations of two RCMs centered over Florida for the current (1986–2005) and estimate the projected changes of heatwave events during the mid-21st century (2041–2060). These RCM integrations were conducted at an unprecedented 10 km grid spacing centered over Florida with one of them coupled to a regional ocean model at the same 10 km grid spacing while the other is just the regional atmospheric model with prescribed SST from the driving global model. This is one of the first studies that examines heat waves from a dynamically downscaled climate at 10 km grid resolution centered over Florida. This resolution offers a reasonable depiction of the geography of Florida that is otherwise poorly represented in global climate models that have grid resolutions usually >100 km (Misra et al., 2019; Narotsky & Misra, 2022).

2 | MODEL DETAILS

The RCMs used in this study are the regional spectral model (RSM; Juang & Kanamitsu, 1994) and RSM-regional ocean modelling system (ROMS; Haidvogel et al., 2000; Shchepetkin & Mc Williams, 2005). RSM is the atmosphere-only, uncoupled model (URSM) and RSM-ROMS is the coupled ocean–atmosphere (CRSM) RCM. Both these models have been extensively used for regional climate studies (Han & Roads, 2004; He et al., 2015; Li et al., 2012; Li et al., 2014). Both the URSM and CRSM have been run at 10 km grid resolution with the atmospheric and the oceanic components in the latter sharing identical grids. Since the RCM integrations used in this study have been extensively analysed in earlier studies, we refer the readers to them for more details on the models (e.g., Bhardwaj & Misra, 2019; Misra et al., 2019; Misra & Bhardwaj, 2021; Misra & Bhardwaj, 2022). Both the URSM and CRSM have been forced at the lateral boundaries with integrations of the Community Climate System Model version 4 (CCSM4; Gent et al., 2011), which was part of the Coupled Model Intercomparison Project version 5 (CMIP5; Taylor et al., 2012). It has been shown that the CCSM4 model that participated in CMIP5 was one of the five top-ranked models in simulating the present-day global climate.
(Sheffield et al., 2013) and is widely used for dynamical downscaling over various regions (Bhardwaj & Misra, 2019; Jayasankar et al., 2023). The atmospheric component of the RCM is forced at 6-h intervals while the oceanic component of the RCM is forced at monthly intervals with the boundary conditions provided by the corresponding components of CCSM4. The late 20th-century simulations (1986–2005) from the RCMs are referred to as URSM20 and CRSM20 while the mid-21st-century simulations (2041–2060) are referred to as URSM21 and CRSM21.

It should be noted that Florida has a near-flat terrain with elevation under 50 m. The land cover, south of the Tampa-Orlando corridor is largely bare soil/broadleaf shrubs while north of this corridor it is largely evergreen needleleaf vegetation (Selman & Misra, 2015). The RCMs use the NOAH land surface model following Ek et al. (2003). Although, urbanization in Florida seems to have an impact on secular trends of temperature (Misra et al., 2012) and precipitation (Misra et al., 2018), their impact on heat wave events is likely to be highly local and unresolved at 10 km grid resolution. Furthermore, the details of land cover and land use change for the simulation of the humid heat waves over Florida may not be as critical given the relatively weaker role of land-atmosphere coupling (e.g., Horowitz et al., 2023; Rastogi et al., 2020).

3  |  METHODOLOGY

The seminal work of developing heatwave indices by Steadman (1979) as a continuous function of temperature and humidity for a certain range of their values has been commonly adopted. However, the National Weather Service (NWS) has refined the Steadman heat index to include a broader range of temperatures and relative humidity following Rothfusz (1990), which is adopted in this study. This heat index takes the following form:

$$I_{\text{NWS}} = -42.379 + 2.04901523T + 10.14333127R - 0.22475541TR - 0.00683738T^2 - 0.05481717R^2 + 0.00122874T^2R + 0.00085282T^2R^2 - 0.0000199T^2R^2$$  \hspace{1cm} (1)

where $I_{\text{NWS}}$, $T$, and $R$ represent heat index in °F, temperature in °F, and relative humidity in %, respectively. $I_{\text{NWS}}$ is ideally calculated each hour throughout the day and the daily maximum $I_{\text{NWS}}$ is classified into one of four categories of heat indices (HIs), HI13 through HI16 that correspond to heat index ranging from 80 to 130°F (Smith et al., 2013). An adjustment to $I_{\text{NWS}}$ ($I_{\text{NWS}}^*$) computed from Equation (1) is made when $R$ is less than 13% and $T$ is between 80 and 112°F as:

$$I_{\text{NWS}}^* = I_{\text{NWS}} - B$$  \hspace{1cm} (2)

where,

$$B = \frac{(13 - R)}{4} \sqrt{\frac{17 - |T - 95|}{17}}$$  \hspace{1cm} (3)

However, if $R$ is greater than 85% and $T$ is greater than 80°F but less than 87°F then $B$ takes the form:

$$B = \frac{(R - 85)}{10} \times \frac{(87 - T)}{5}$$  \hspace{1cm} (4)

The adjustments made to $I_{\text{NWS}}$ ($I_{\text{NWS}}^*$) are applied to compute a maximum heat index using the Weather Prediction Center (WPC) or Model Output Statistics (MOS) forecast daily maximum temperature and the 0000 UTC dewpoint temperature at each forecast grid point for each day (https://www.wpc.ncep.noaa.gov/heat_index/details_hi.html). Equation (1) is not appropriate for use when temperature and humidity conditions do not warrant a heat index value below 80°F, and is not valid for extreme cases of temperature and relative humidity beyond specific ranges of values (https://www.wpc.ncep.noaa.gov/heat_index/details_hi.html).

We define heat index HI13 following Smith et al. (2013), which is defined when $I_{\text{NWS}}$ or $I_{\text{NWS}}^*$ exceeds 80°F. We are somewhat limited in the choice of HI13 because it gives us the largest sample of heat wave events compared to heatwaves defined at higher thresholds from our rather limited number of model integrations over a 20-year period.

4  |  RESULTS

4.1  |  Verification of the late 20th-century RCM simulations

As mentioned earlier, both URSM20 and CRSM20 have been extensively verified in earlier studies (e.g., Bhardwaj & Misra, 2019; Misra et al., 2019; Misra & Bhardwaj, 2021; Misra & Bhardwaj, 2022). However, in this study, we specifically verify the heatwave simulation of the late 20th-century integration of URSM20 and CRSM20 forced by CCSM4 with the corresponding heatwave rendition in ERA5. The climatological distribution of the total number of 1-day heat wave events across Florida is shown in Figure 1. The ERA5 reanalysis dataset
shows a maximum in the number of 1-day heatwave events for south Florida, and a decrease in the total number of 1-day heatwave days with increasing latitude to panhandle Florida (Figure 1a). In comparison, the uncoupled (URSM20; Figure 1b) and coupled (CRSM20; Figure 1c) models can capture the observed meridional gradient in the frequency of the 1-day heatwave events (Figure 1a) across Florida showing similar meridional gradient with a maximum in south Florida. Figure 1d shows that the differences between URSM20 and CRSM20 are negligible. Furthermore, both models overestimate the frequency of the 1-day heatwave events
across Florida except in a major part of south Florida (Figure 1e, f).

The meridional gradient of the frequency of the 2-, 3-, 4-, and 5-day heatwave events in ERA5 is like the 1-day heatwave event as seen in Figures S1a, S2a, S3a, and S4a (supplementary material), respectively. We observe that for these longer heatwave events, South Florida displays the highest frequency than the rest of Florida, which the models can simulate (Figures S1-S4; CRSM20 is not shown because it is like URSM20). As the duration of the heatwave event increases, their frequency of occurrence gradually decreases from the panhandle region towards south Florida in ERA5 (Figures S1a, S2a, S3a and S4b). However, the RCMs tend to overestimate their frequency. That is, the systematic errors in the frequency of these longer-duration events are higher and more widespread than for the 1-day heatwave events (Figures S1-S4). However, an interesting feature is that the likelihood of longer duration heatwave events (>2 days) is highly likely if the 1-day event occurs. For example, in both ERA5 and URSM20, the likelihood of 2-day heatwave events is over 75% in South Florida (Figures S1a, b), which diminishes to just over 50% for 5-day heatwave events (Figure S4a, b). Nonetheless, URSM tends to overestimate the likelihood of the longer-duration heatwave events in Panhandle and Central Florida.

The climatological mean of the first day of the year when the 1-day heatwave event occurs for the ERA5 dataset is early in the year over south Florida (~Julian day 100 or ~April 10), which is gradually delayed as you move further north to around Julian day 150 or May 30 over north Florida (Figure 2a). The model simulations, however, fail to show such a meridional gradient (Figure 2b, c). Furthermore, the differences between URSM20 and CRSM20 for the climatological mean of the first day of the heatwave event are insignificant (Figure 2d). But both models simulate the first day of the heatwave in the year almost a month later than ERA5 over south Florida while the simulation is reasonable in other parts of Florida (Figure 2e, f). It is interesting to note that the frequency of 1-day heatwave events in the RCM simulations is like ERA5 (Figure 1f) despite the first heatwave occurring nearly a month later over South Florida in URSM20 than in ERA5 (Figure 2f) because the daily variability of temperature and specific humidity in URSM20 is less compared to ERA5 (Figure S5). As a result, when the first day of the 1-day heatwave event in the year is reached then URSM20 more consistently produces these events than in ERA5 because of the reduced daily variability of temperature (Figure S5c). South Florida is exceptional in this feature because additionally, the daily variability of specific humidity in URSM20 is less compared to ERA5 (Figure S5f).

In contrast, the meridional gradient of the climatological mean of the last day of the 1-day heatwave event is reversed (Figure 3a) with south Florida displaying around ~Julian day 270 (~September 27) and the panhandle region showing around ~ Julian day 240 (~August 27). The models display a reasonable fidelity in simulating this metric of the heatwave event (Figure 3b, c) with the largest bias of later occurrence over the panhandle region in both RCMs (Figure 3e, f). A similar pattern of the first and the last day of occurrence of the longer (>1-day) duration heatwave patterns are observed in ERA5 and model simulations with similar bias as the 1-day heatwave events (not shown).

We also examined the bias of the 2 m air temperature and relative humidity in URSM20, which are the input parameters to compute the heat index. We chose to examine 2 m specific humidity instead of relative humidity because the former is an exclusive variable for moisture in the air. The composite mean of the 1-day heatwave events in ERA5 suggests ~28°C across Florida (Figure 4a). The corresponding mean temperature from URSM20 shows that it is ~29°C (Figure 4b) and the bias ranges from ~0.5 to 1.5°C (Figure 4c). The composite mean of the 2 m specific humidity for the 1-day heatwave event shows a rather uniform distribution of around 16 g/kg across Florida (Figure 4d). However, URSM20 underestimates this with the mean to be around 13 g/kg (Figure 4e), thereby depicting a uniform dry bias of around and over 3 g/kg (Figure 4f). The overlaid composite mean of the 850 hPa circulation for the 1-day heatwave event in ERA5 suggests ~28°C across Florida (Figure 4g). The models display a reasonable fidelity in simulating this metric of the heatwave event. However, URSM20 shifts the NASH further southwestward (Figure 4e) relative to ERA5 (Figure 4e), which produces a westerly and an easterly bias over south Florida and the rest of Florida (Figure 4f), respectively. The CRSM20 shows a similar distribution of the 2 m temperature and specific humidity as URSM20 (Figure S6). We also calculated the spatial root mean square error (RMSE) for both model simulations with respect to ERA5 over Florida (for only land points). We find the RMSE for the composite mean of 1-day heatwave event for temperature and specific humidity to be 1.18°C for URSM20, 1.53°C for CRSM20, 2.1 g/kg for URSM20, and 3.0 g/kg for CRSM20, respectively. These values are comparable between the two model simulations with CRSM20 showing a slight exacerbation of the warm and dry bias of URSM20. It may be noted that the differences shown in Figure S6 are however insufficient to change the threshold to be...
reached which defines HI13 events. We also found that the mid-21st century projection of the heatwave events like the late 20th-century simulations was very similar between URSM21 and CRSM21. Therefore, we ignore the mid-21st century projection of CRSM21 and use only URSM21 for the rest of the discussion.

4.2 | Projections of the mid-21st century climate

Figure 5a–j show the climatological number of days of 1, 2, 3, 4, and 5-day heatwave events from URSM21 and its corresponding difference from URSM20, respectively.
There is a significant increase in the frequency of these heatwaves in the projected climate. For example, in northern Florida there is nearly 2 months of increase in the 1-day heatwave event notwithstanding nearly a month of increase in the rest of Florida (Figure 5f). In fact, northern Florida leads the increase for all other heatwave events with even the 5-day heatwave event showing almost an increase of well over a month in the projected climate (Figure 5j). This is consistent with other studies, which suggest an increase in the frequency and...
amplitude of heatwaves over Florida in a future climate (e.g., Androulidakis & Kourafalou, 2022; Cloutier-Bisbee et al., 2019; Keellings & Waylen, 2014).

Similarly, the first day of occurrence of the 1, 2, 3, 4 and 5-day heatwave events in the mid-21st century is occurring almost 15–25 days earlier than in the late 20th
century and even earlier in parts of Central and South Florida (Figure 6). For example, south of Lake Okeechobee, the first occurrence of the 1-day heatwave event is almost a month earlier in mid-21st century compared to the late 20th-century simulation (Figure 6f). Similarly, other heatwave events also occur earlier across Florida in
the mid-21st century and far earlier in Central and South Florida (Figure 6). Interestingly, the 5-day heatwave events seem to occur almost a month earlier in the mid-21st century compared to late-20th century simulation across peninsular Florida (Figure 6). Likewise, the last day of the occurrence of these heatwave events in the year are also comparatively delayed in the mid-21st century simulation (Figure 7). For instance, the last day of the 1-day heatwave is around Julian day 310 (~November 6) in South Florida (Figure 7a), which is delayed by over a month compared to the 20th century simulation (Figure 7b). But across Florida, the last day of all heatwave events are delayed by around 10–30 days in the mid-21st century projection from USRM21 (Figure 7f–j). Overall Figures 6 and 7 suggest that there is a significant lengthening of the season of occurrence of these heatwave events in the mid-21st century relative to the late 20th century simulations.

This increase in the frequency of the heatwaves in the mid-21st century projection from USRM21 is also associated with an increase in the mean 2 m air temperature.
The increase in the composite mean temperature of the 1, 2, 3, 4 and 5-day heatwave events for the projected climate is between 1 and 2°C across Florida and is largest in central and south Florida (Figure 8). Furthermore, the increase in projected temperature is similar for all heatwave events (Figure 8). But it should be noted that the differences in the composite mean temperature for the 1-day from 2- to 5-day heatwave events are less than 0.5°C in Figure 8. In addition, there is a reduction of the corresponding daily variability of temperature and specific humidity from the late 20th-century simulation (Figure S7). Likewise, the composite mean of the 2 m specific humidity shows a slight increase in the mid-21st century relative to the late 20th century period (Figure 9). The increase of surface humidity is rather uniform across Florida and is similar across all duration heatwave events. This projected increase in
the composite mean specific humidity implies a very modest projected increase in the composite mean of relative humidity of less than 1% for all heatwave events (Figure S8). This suggests that for the increase in the projected mean temperature, the increase in specific humidity is relatively small and the differences in the frequency and duration of the heatwave events in the RCM between the two epochs stem largely from the increase in temperature. So, the simulation from URSM21 implies that with the mean increase in surface temperature across Florida and a reduction of its daily variability in the mid-21st century, the threshold for longer-duration heatwave events is more easily reached in a longer season.

The composite mean 850 hPa circulation of the projected climate in Figure 10 suggests that NASH has
moved further westward relative to the corresponding 20th-century simulation leading to stronger northeasterly anomalies across Florida. This westward dislocation of NASH is consistent with other studies, which attribute this to anthropogenic warming (e.g., Cherchi et al., 2018; He et al., 2017; Li et al., 2011; Li et al., 2013). Misra and Bhardwaj (2021) suggest from detailed moisture budget calculations that in a future climate of the mid-21st century, the neighbouring ocean over the west Florida shelf becomes wetter and the net moisture flux from the Gulf of Mexico into Florida is reduced relative to the late 20th century period because of the westward dislocation of NASH. This is consistent with the higher frequency and a longer season of heatwaves in Florida from the projected mid-21st century simulation found in this study.

FIGURE 9 The composite mean of the 2 m specific humidity (g/kg) for (a) 1-day, (b) 2-day, (c) 3-day, (d) 4-day, and (e) 5-day heat wave events for 2041–2060 from URSM21 and (f–j) its corresponding difference from URSM20 for the period of 1986–2005. [Colour figure can be viewed at wileyonlinelibrary.com]
CONCLUSIONS

In this study, we have conducted an analysis of heatwave events over Florida using two high-resolution RCMs. They are unique for the region because of their grid resolution of 10 km. Many of the global models are unable to resolve the peninsular geography and the complex ocean dynamics around Florida. The RCMs differ with one being just a regional atmospheric model to which SST is prescribed (URSM) from the global and the other being a regional coupled ocean–atmosphere model (CRSM).

Our analysis of the verification of the RCMs shows that the frequency and the seasonality of heatwave events over Florida are reasonably captured relative to ERA5. However, the bias of higher frequency and longer seasons of the heatwave events in the RCM simulation of the late

FIGURE 10 The composite mean of 850 hPa wind speed (shaded; m/s) and direction (vectors) for (a) 1-day, (b) 2-day, (c) 3-day, (d) 4-day, and (e) 5-day heat wave events for 2041–2060 from URSM21 and (f–j) its corresponding difference from URSM20 for the period of 1986–2005. [Colour figure can be viewed at wileyonlinelibrary.com]
20th century period (1986–2005) is apparent. This bias is associated with the warm and dry bias of 2 m air temperature and specific humidity, respectively, and a southward shift of NASH relative to ERA5. The two RCMs showed insignificant differences in their late 20th-century simulation of the heatwave events over Florida and hence CRSM was not further analysed for the projected climate. Furthermore, the differences in the mid-21st century simulations of the heatwave events between URSM and CRSM were also insignificantly small (not shown).

The projected climate for the 2041–2060 period from URSM indicates a significant increase in the frequency of the 1, 2, 3, 4, and 5-day heatwave events compared to the 1986–2005 period. Furthermore, all these heatwave events occur over a longer season with the occurrence of the first and last days of heatwaves occurring earlier (by over a month in some instances) and later (by over a month in some instances) in the year of the mid-21st century climate, respectively. This projected change in heatwaves is associated with an increase of 1 to 1.5°C warming of the 2 m air temperature with a slight increase in 2 m specific humidity and 2 m relative humidity, and a westward shift of NASH relative to the 1986–2005 period, resulting in easterly wind anomalies at 850 hPa across most of Florida. These projected changes on the large scale are consistent with earlier studies, which indicate that they are an impact of anthropogenic warming that results in the westward shift of NASH.

Given the rising population of Florida, and especially of the senior citizens, the threat of the increased frequency of heatwaves occurring over a longer period of the year must be taken seriously. Despite the reported model bias of the RCM, its uniquely high-resolution simulation at 10 km grid spacing adds more realism to the representation of Florida’s geography and the results of the study are consistent with the Fourth US National Climate Assessment for the Southeastern US (Carter et al., 2018). However, our study is limited by the period of integration (20 years for the current and future periods) and is from only two RCMs forced by only one global climate model. Furthermore, we are also looking at future projections from one emission pathway, the RCP8.5. Therefore, the uncertainty of the model projections is under-sampled in this study. Therefore, the results of this study must be robustly interrogated by sampling the uncertainty space more thoroughly.

**AUTHOR CONTRIBUTIONS**

**Parker Beasley:** Visualization; writing – review and editing; software; validation. **Vasubandhu Misra:** Conceptualization; supervision; methodology; writing – original draft; writing – review and editing; funding acquisition; resources. **C. B. Jayasankar:** Writing – review and editing; methodology; data curation; validation; software; supervision. **Amit Bhardwaj:** Software; writing – review and editing; data curation; supervision.

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**DATA AVAILABILITY STATEMENT**

The ERA5 reanalysis data were from https://www.ecmwf.int/en/forecasts/datasets/reanalysis-datasets/era5. The data from the RCM integrations and analysis scripts necessary to generate the figures in the manuscript are available from vmisra@fsu.edu.

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