# Dynamical Downscaling Projections of 21st Century Atlantic Hurricane Activity: CMIP3 and CMIP5 Model-based Scenarios


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## Summary


**Twenty-first century projections of Atlantic climate change are downscaled to explore potential changes in hurricane activity. Multi-model ensembles using the CMIP3/A1B (Late 21st century) and CMIP5/RCP4.5 (Early and Late 21st century) scenarios are examined. Storm cases from an 18 km-grid regional model (Zetac) are further downscaled into the GFDL hurricane model (9 km inner-grid spacing, with ocean coupling) to explore intense hurricanes.**

**A significant reduction in tropical storm frequency is projected for the CMIP3 (-27%), CMIP5-Early (-20%) and CMIP5-Late (-23%) ensembles. Lifetime-maximum hurricane intensity increases significantly in the high-resolution experiments--by 4 to 6% for CMIP3 and CMIP5 ensembles. A significant increase (+87%) in the frequency of very intense (Category 4-5) hurricanes (winds >= 59 m s$^{-1}$) is projected using CMIP3, but smaller, marginally significant increases are projected (+45% and +39%) for the CMIP5-Early and CMIP5-Late scenarios. Hurricane rainfall rates increase robustly for the CMIP3 and CMIP5 scenarios. For the late 21st century, this increase amounts to +20 to +30% in the model hurricane's inner core, with a smaller increase (order 10%) for averaging radii of 200 km or larger. The fractional increase in precipitation at large radii (200-400 km) approximates that expected from environmental water vapor content scaling, while increases for the inner core exceed this level.**


## 1. Substantial changes in conditions affecting Atlantic hurricanes are projected for the 21st century.

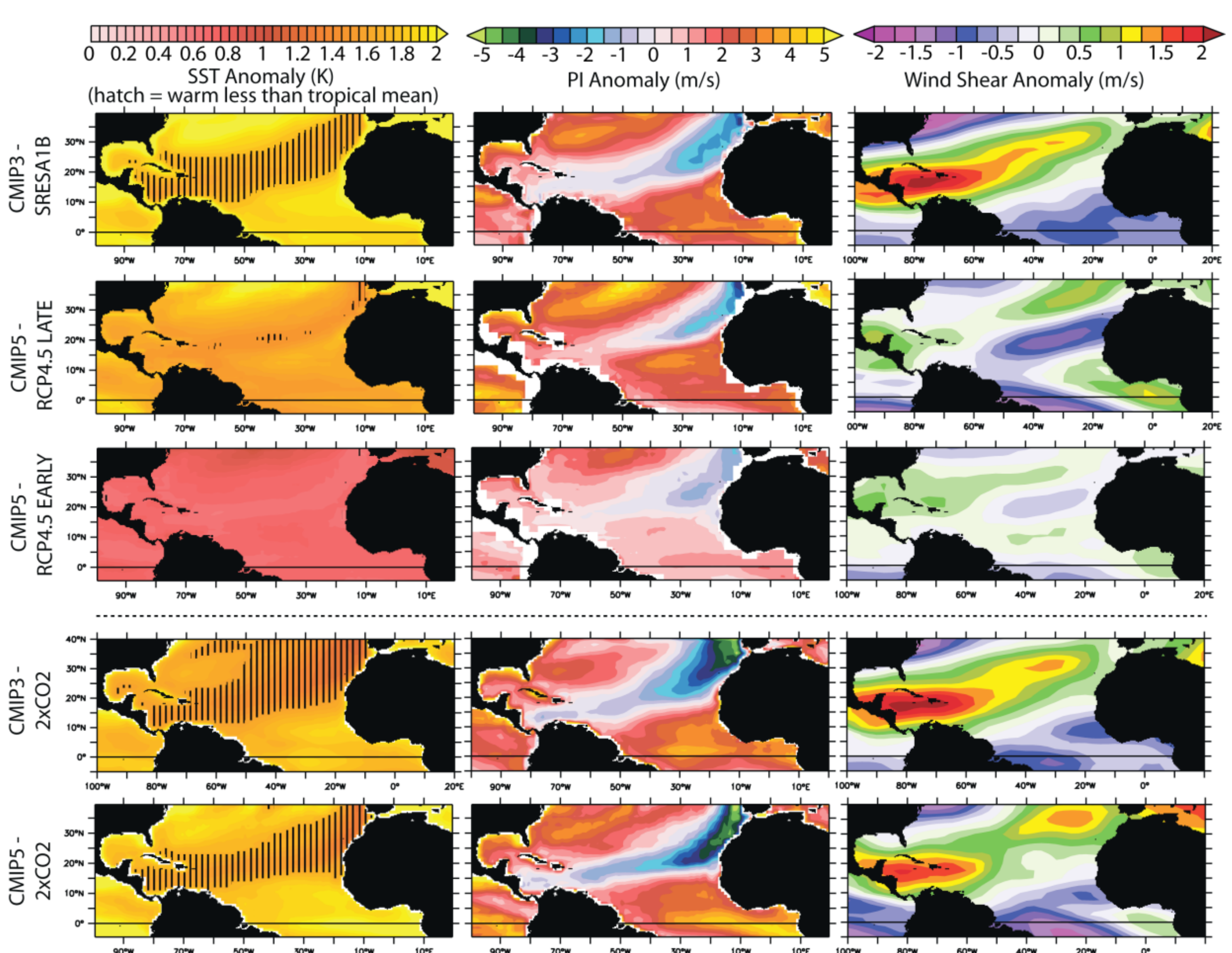


*Fig. 1. Changes (warm climate minus control; Aug-Oct. season) in large-scale environmental fields for various CMIP3 and CMIP5 experiments and time periods. Left column: SST change (color shading) and the "relative SST change field" computed as local SST change minus the tropical mean (30°N-30°S) SST change in Kelvin (contour, with hatching indicating where the SST warming is less than the tropical mean SST warming); middle column: tropical cyclone potential intensity change (m s$^{-1}$); right column: vertical wind shear change (200 HPa vs. 850 HPa; in m s$^{-1}$). Bottom two rows labeled "CMIP3-2xCO2" and "CMIP5-2xCO2" were computed from linear trends (years 1-70) of +1%/yr CO2 experiments.*

## 2. Downscaling methodology: A two-step approach using dynamical models:

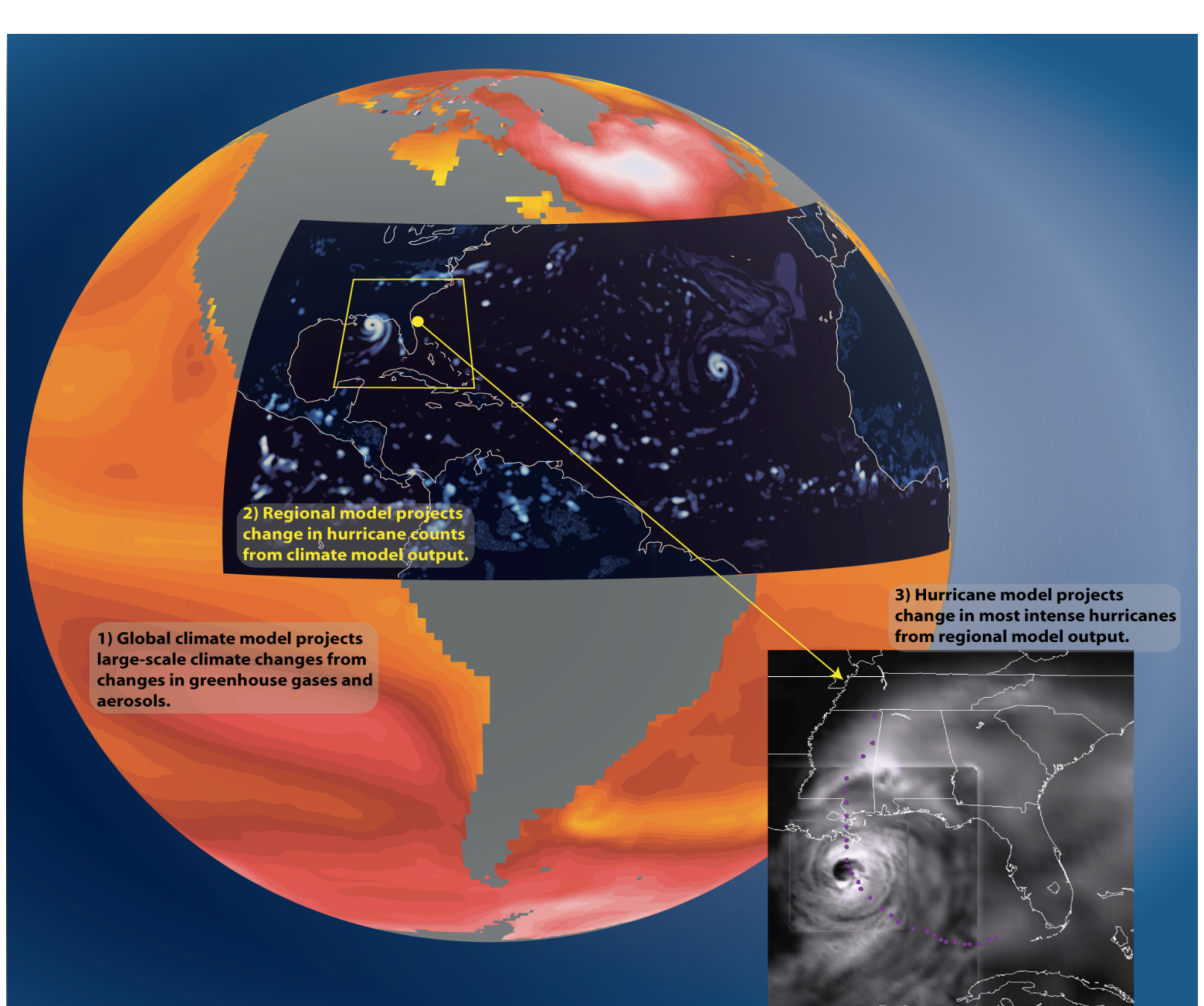


*Fig. 2. Methodology: A two-step downscaling method is used for hurricane and tropical storm simulations. Twenty seven full seasons are simulated using the Zetac regional model (18 km grid) forced by NCEP Reanalyses. For the warm climate scenarios, a climate change signal (summarized in Fig. 1) is added to the Reanalysis fields. The individual tropical storms and hurricanes from the Zetac model are then re-simulated using the GFDL hurricane model (grid-spacing as fine as 9 km), which can simulate very intense (up to category 5) hurricanes.*

## 3. Model-projected changes in late 21st century Atlantic tropical storm counts can be anticipated if we know the relative SST used in the projection.

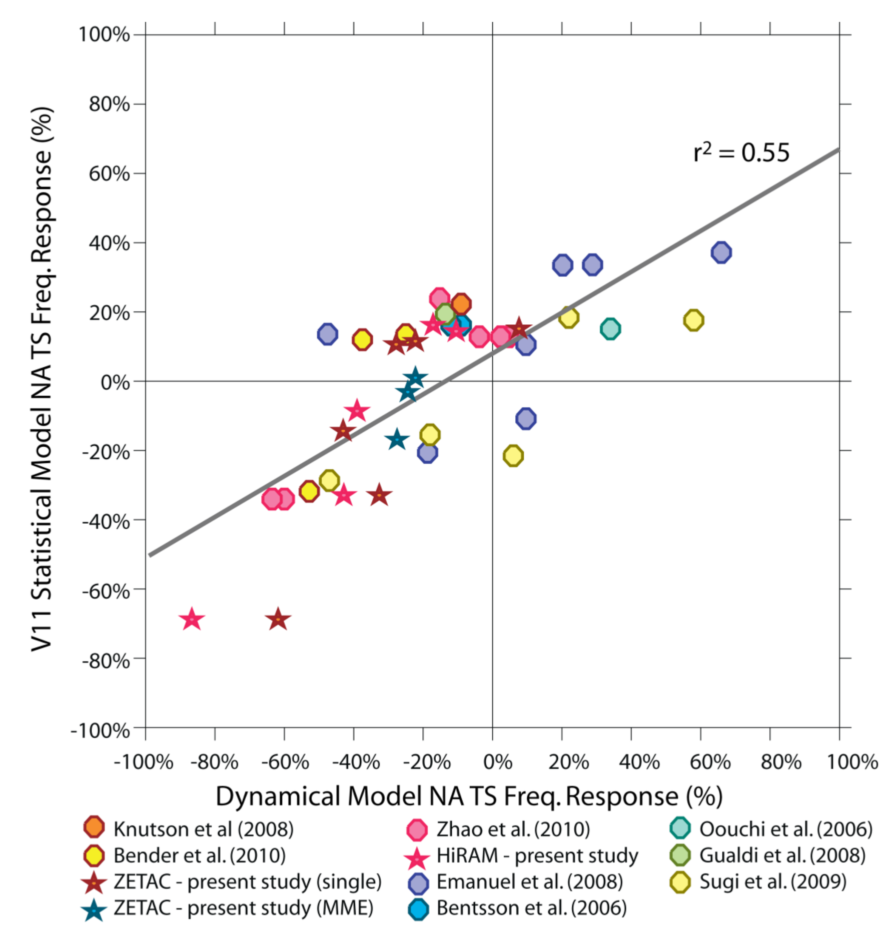


*Fig. 3. Comparison of published dynamical-model projections of Atlantic tropical storm frequency changes versus the statistical downscaling model of Villarini et al. (2011), which is based on relative SST changes. Relative SST is the SST in the tropical North Atlantic relative to SST averaged over the tropics (30°N-30°S). The figure shows that in most cases where the dynamical models projected increased tropical storm frequency, those models were usually being forced with--or had internally computed--relative SST increases. The blue stars depict the CMIP3, CMIP5-Early and CMIP5-Late multi-model ensemble results from the Zetac model.*

## 4. The GFDL hurricane model downscaling projects more Category 4-5 hurricanes for the 21st century, despite projections of fewer tropical storms and hurricanes overall.

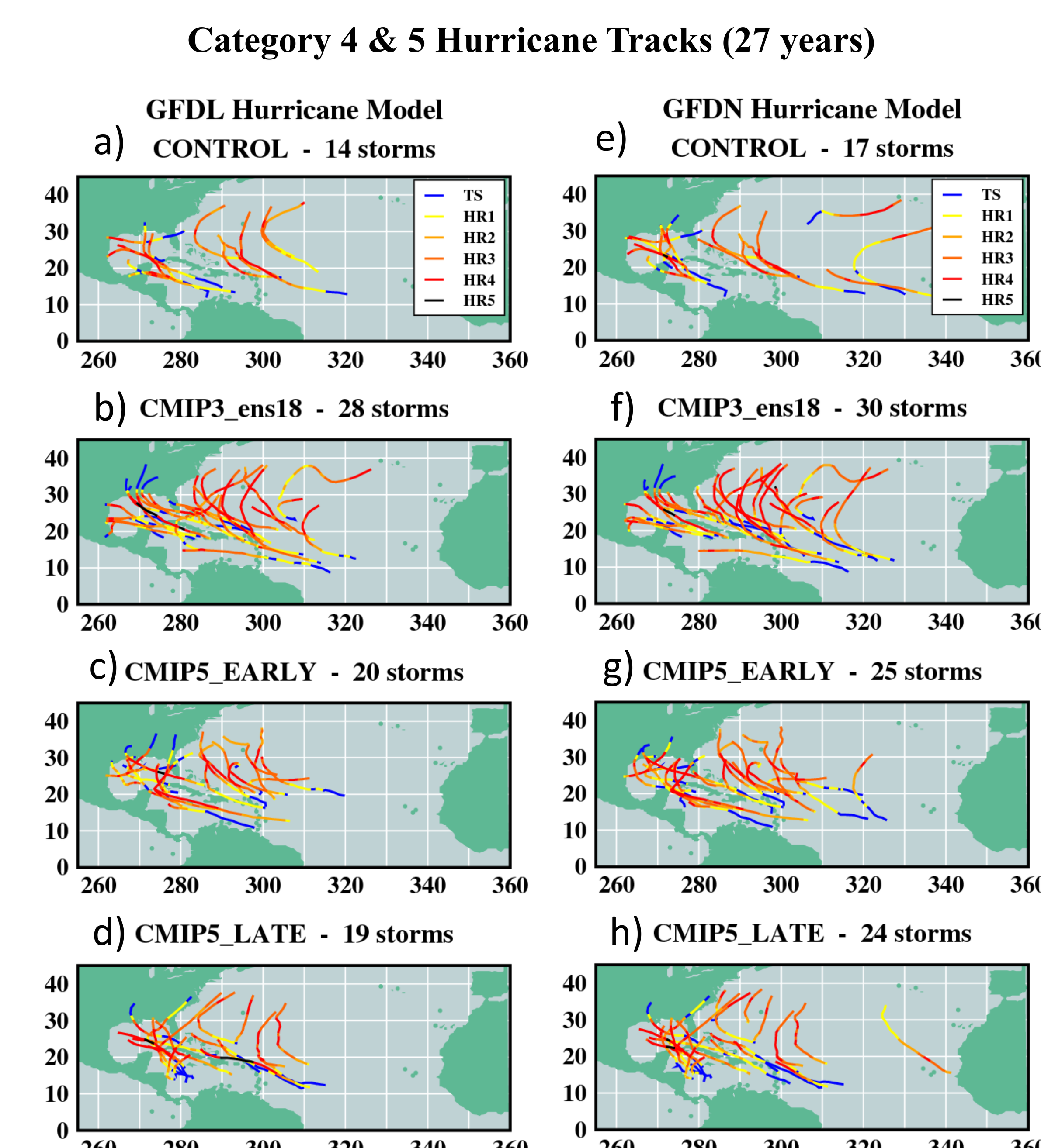


*Fig. 4. Tracks and intensities of all storms reaching category 4 or 5 intensity (>=59 m s$^{-1}$) in the GFDL hurricane model downscaling experiments (27 seasons), using two versions of the GFDL hurricane model [GFDL (a-d) and GFDN (e-h)]. Results shown for the control climate (a,e); CMIP3/A1B 18-model late 21st century ensemble climate change (b,f); CMIP5/RCP4.5 early 21st century ensemble (c,g); and CMIP5/RCP4.5 late 21st century ensemble (d,h).*

## 5. Projections of hurricane rainfall rates: an increase over the 21st century of +20-30% in the inner core, with a smaller increase (~+10%) for averaging radii of 200 km or larger.

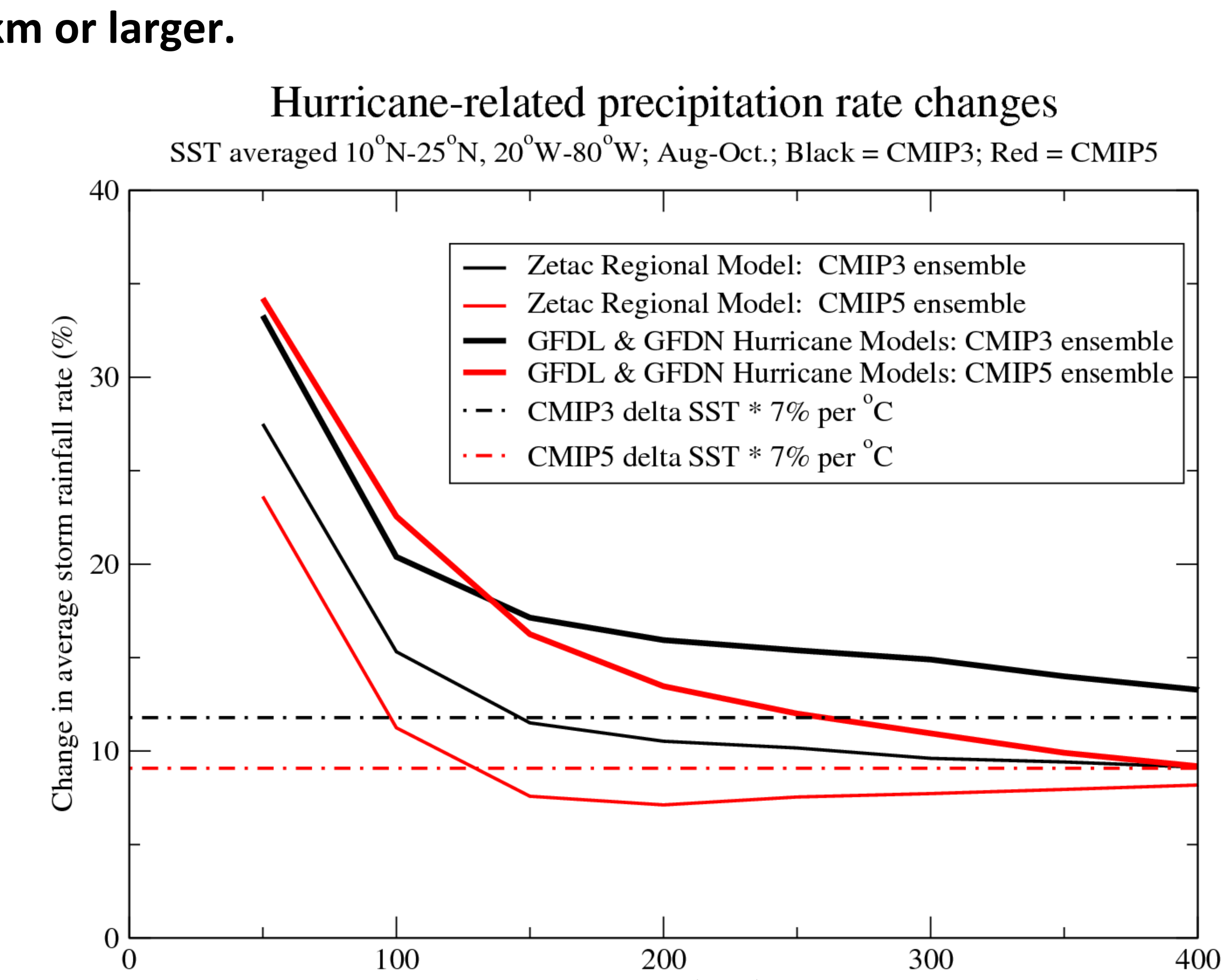


*Fig. 5 Change [%] between the control and warm climate in average hurricane rainfall rate for various averaging radii about the storm center [km] for the CMIP3/A1B (black) and CMIP5/RCP4.5 (red) late 21st century multi-model ensemble climate changes, based on the Zetac regional model (thin solid lines) or the GFDL/GFDN hurricane model ensemble (thick solid lines). The dashed lines illustrate idealized water vapor content scalings, obtained by multiplying the average SST change in the region 10-25°N, 20-80°W by 7% per degree C.*


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