North Atlantic Hurricane Potential Intensity in CMIP5 Models: Anthropogenic Forcing versus Atlantic Multidecadal Variability

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Motivation: How does Atlantic hurricane intensity respond to climate change versus AMV?

$PDI \equiv \int_0^\tau V_{\text{max}}^3 \, dt$

$r^2 = 0.75$

Emanuel, 2005: Increasing destructiveness of tropical cyclones over the past 30 years. Nature
Questions:

• Can we understand the 20th Century PDI & SST relationship by natural climate variability such as the AMV?

• How does hurricane intensity change (rather than PDI) associated with AMV and climate change?

• How much of the hurricane PI changes in the late 20th Century can be attributed to climate change versus AMV?
Hurricane Potential Intensity in AGCM with Prescribed Global Observed SST

\[ V_{pot}^2 = \frac{C_k}{C_D} \frac{T_s}{T_0} (CAPE^* - CAPE^b) \]

- $C_k$: exchange coefficient for enthalpy
- $C_D$: drag coefficient
- $T_s$: SST
- $T_0$: outflow temperature
- CAPE: Convective Available Potential Energy
- CAPE*: saturated CAPE at maximum wind radius
- CAPE^b: CAPE for the ambient boundary layer

Camargo, Ting, Kushnir, 2012, Climate Dynamics
Mean anomalous PI (m/s) in the North Atlantic main development region (MDR) for JJASON hurricane season

Camargo, Ting, Kushnir, 2012, Climate Dynamics
Tropical North Atlantic Anomalous PI (m/s) and Relative SST in ASO

(a) Mean Anom. PI Tropical North Atlantic

(b) Mean Anom. Relative SST Tropical North Atlantic

GOGA: AGCM with prescribed observed SST over global oceans

TAGA: AGCM with prescribed observed SST over the tropical Atlantic domain

IOPOGA: AGCM with prescribed observed SST over the tropical Indian and Pacific Oceans

Camargo, Ting, Kushnir, 2012, Climate Dynamics
AMO vs Climate Change

(a) CC and AMV indices

(b) Regression SST and AMV

(c) Regression SST and CC

(a) Anom. PI Reg. AMV & CC

(b) Anom. PI Reg. AMV

(c) Anom. PI Reg. CC

Camargo, Ting, Kushnir, 2012, Climate Dynamics
Summary of AGCM results

• Late 20th Century PI changes in the Atlantic MDR is dominated by AMV (~2m/s), and the climate change signal is rather weak, about .5 m/s increase over the past Century.

• Given that AMV is local to the Atlantic, local SST (TAGA) depicts well the PI changes due to AMV. But for Climate Change signal, local SST (TAGA) tends to exaggerate the PI changes (approximately doubling the amplitude) compared to that with global SST (GOGA), consistent with previous studies using PDI (e.g., Vecchi et al., 2008).

• How hurricane PI may change in the 21st century, when anthropogenic influence increases in amplitude while the AMV continue to slowly swing between negative and positive phases with presumably the same amplitude as during the 20th Century?
CMIP5 Models and Ensembles

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<th>rcp8.5</th>
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24 models, 85 ensemble members for historical, 47 members for rcp4.5 and 50 members for rcp8.5
Atlantic PI Climatology ASO – Multi-model mean

PI ASO ENSM Clim Hist

PI ASO ENSM Clim rcp4.5

PI ASO ENSM Clim rcp8.5

(b) NCEP Rean.

(d) Interim ECMWF Rean.
Atlantic PI ASO 21C and 20C – Multi-Model Mean
Atlantic MDR PI ASO Anomalies

- **rcp4.5**: ~2.5 m/s
- **rcp8.5**: ~5 m/s
MDR Absolute vs. Relative SST in CMIP5 Models

Absolute SST Anomalies

Relative SST Anomalies

Black: Observations; Think pink: individual models; Thick pink: multi-model mean

By the end of this century, absolute MDR SST increases reach about 2°C for rcp4.5, and 3.8°C for rcp8.5, while relative SST barely changed.
Atlantic MDR PI ASO Anomalies

Atlantic MDR PI Anomalies – Historical and rcp4.5

(c) Anom. PI Reg. CC

~2.5 m/s

~5 m/s

Atlantic MDR PI Anomalies – Historical and rcp8.5

(b) Anom. PI Reg. AMV

~5 m/s
Climate Change indices

Time-series of Climate Change index for Historical

Time-series of Climate Change index for Scenarios

Legend:
- rcp4.5
- rcp8.5
AMV in CMIP5 models (historical, rcp4.5 and rcp8.5)

**AMV indices**

- **historical**
- **rcp4.5**
- **rcp8.5**

**AMV and CC (thick red) indices**

- **historical**
- **rcp4.5**
- **rcp8.5**
PI Regression Patterns – Historical Multi-Model Mean

AMO Reg. Hist. Multi-model Mean

CC Reg. Hist. Multi-model Mean

(a) GOGA PI & AMV

(b) GOGA PI & CC
PI Regression patterns (Multi-model mean)
PI Regression Patterns – CC rcp8.5
SST regression onto Climate Change and AMO indices

Regression of SST onto AMO Index
(a) CMIP5/Historical
(b) rcp45
(c) rcp85

Regression of SST onto Forced Component
(d) CMIP5/Historical
(e) rcp45
(f) rcp85
Relative SST regression onto Climate Change and AMO indices
Relative vs. Absolute SST regression onto Climate Change and AMO indices
There is a clear resemblance between spatial patterns of PI and the relative (and absolute) SST for both the Climate Change and the AMO related patterns.
Summary

• Hurricane potential intensity (PI) changes in the tropical Atlantic main development region in the past few decades are dominated by natural SST variability known as the Atlantic Multidecadal Variability (Camargo et al., 2012)

• PI increases due to forced climate change signal by the end of the 21st Century will surpass the amplitude of the natural variability in both rcp4.5 (~2.5m/s) and rcp8.5 (~5m/s) scenarios based on CMIP5 multi-model means

• While the spatial pattern of the PI associated with climate change resembles both the absolute and the relative SST patterns, neither the absolute SST nor the relative SST change associated with climate change signal is a good indicator of the amplitude change of the hurricane potential intensity

• The PI changes associated with AMV does not change substantially as the radiative forcing amplitude changes (historical vs. rcp4.5 vs. rcp8.5)