Potential Impact of Climate Variability on the Intra-Americas Sea

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Abstract

This study examines the potential impact of anthropogenic greenhouse warming (AGW) on the Intra-Americas Sea (IAS, Caribbean Sea and Gulf of Mexico) by downscaling the Coupled Model Intercomparison Project phase-5 (CMIP5) model simulations under historical and two future emission scenarios using an eddy-resolving resolution regional ocean model. The simulated volume transport by the western boundary current system in the IAS, including the Caribbean Current, Yucatan Current and Loop Current (LC), is reduced by 20-25% during the 21st century, consistent with a similar rate of reduction in the Atlantic Meridional Overturning Circulation (AMOC). The effect of the LC in the present climate is to warm the Gulf of Mexico (GoM). Therefore, the reduced LC and the associated weakening of the warm transient LC eddies have a cooling impact in the GoM, particularly during boreal spring in the northern deep basin, in agreement with an earlier dynamic downscaling study. In contrast to the reduced warming in the northern deep GoM, the downscaled model predicts an intense warming in the shallow (≤ 200 m) northeastern shelf of the GoM especially during boreal summer since there is no effective mechanism to dissipate the increased surface heating. Potential implications of the regionally distinctive warming trend pattern in the GoM on the marine ecosystems and hurricane intensifications during landfall are discussed. This study also explores the effects of 20th century warming and climate variability in the IAS using the regional ocean model forced with observed surface flux fields. The main modes of sea surface temperature variability in the IAS are linked to the Atlantic Multidecadal Oscillation and a meridional dipole pattern between the GoM and Caribbean Sea. It is also shown that variability of the IAS western boundary current system in the 20th century is largely driven by wind stress curl in the Sverdrup interior and the AMOC.

Model Experiments

Ocean model: GFDL Modular Ocean Model (MOM4p1)

Domains: Atlantic Ocean (20°S – 65°N), 25 vertical layers.

Horizontal grid: High resolution (0.1° in IAS, 0.25° elsewhere),

1. Force Climate Variability Run

Surface forcing: Ensemble weighted CMIP5 atmospheric forcing with bias correction.

IC & BC: CMIP5 salinity and temperature with bias correction

Run periods (high resolution): 1900-2098

- 1900-2005 under Historical Scenario
- 2006-2098 under RCP4.5 & RCP8.5

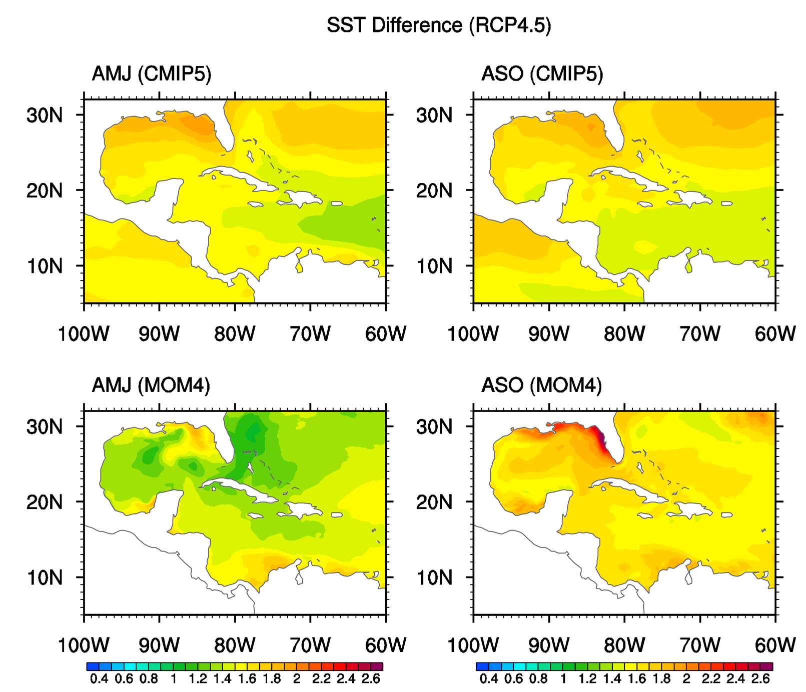
2. Natural Climate Variability Run

Surface forcing: 20th Century Reanalysis (20CR) surface flux

IC & BC: SODA v2.2.6 salinity and temperature

Run periods (high resolution): from 1871-2008.

Impact of AGW Variability



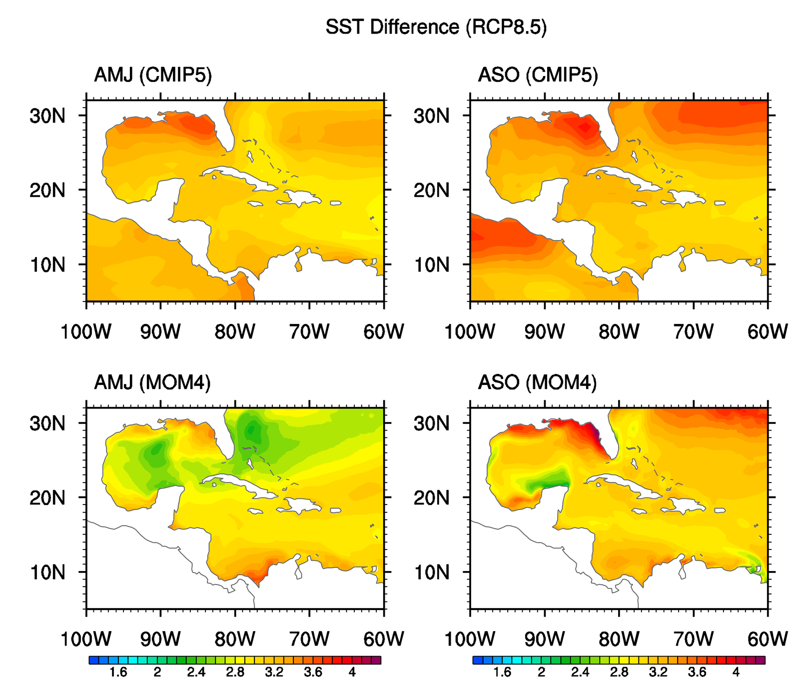


Fig. 1: SST difference between the late 21st century and late 20th century during AMJ obtained from (a) CMIP5 models, and (b) high-resolution MOM4 experiment under the RCP4.5 scenario. (b) is same as (a) but for the ASO season, and (d) is same as (b) but for the ASO season.

Fig. 2: Same as Fig. 1, except that the differences are from the CMIP5 RCP8.5 scenario. The color bar is different with that in Fig.1. SST increase is more severe under RCP8.5 scenario.

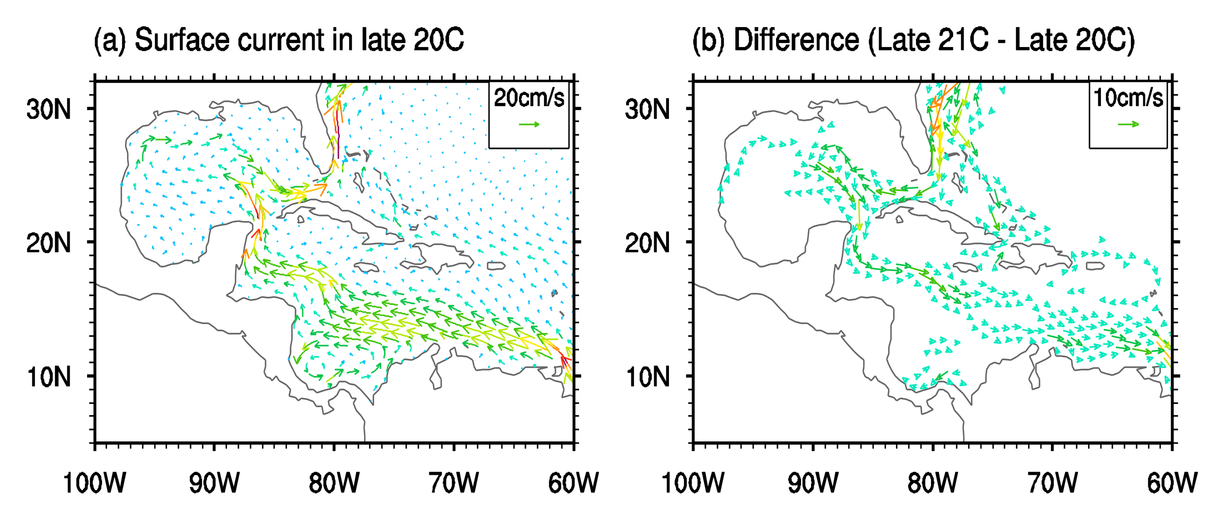


Fig. 3:(a) Long-term annual mean surface current in the late 20th century obtained from EXP_HIS. (b) Anomalous (i.e., late 21st century to late 20th century) surface current in the IAS obtained from EXP_RCP8.5 and EXP_HIS.

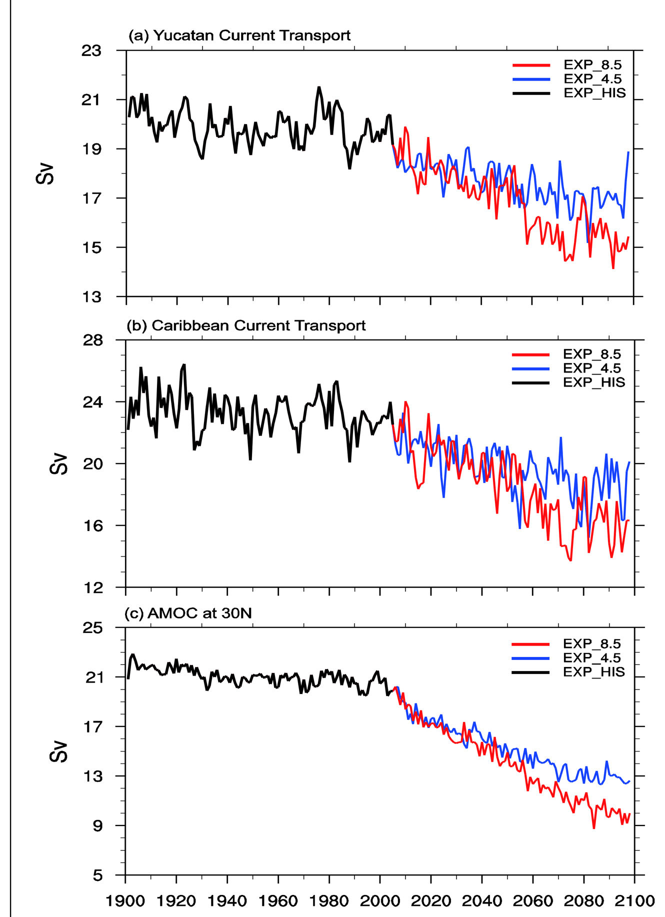


Fig. 4:Variability of (a) the annual mean volume transport (Sv) across the Yucatan Channel and (b) Caribbean Current volume transport for the period 1900-2098 obtained from EXP_HIS, EXP_4.5 and EXP_8.5. (c) Variability of the AMOC at 30N (Sv) for the period 1900-2098 obtained from EXP_HIS, EXP_4.5 and EXP_8.5.

Impact of Natural Climate Variability

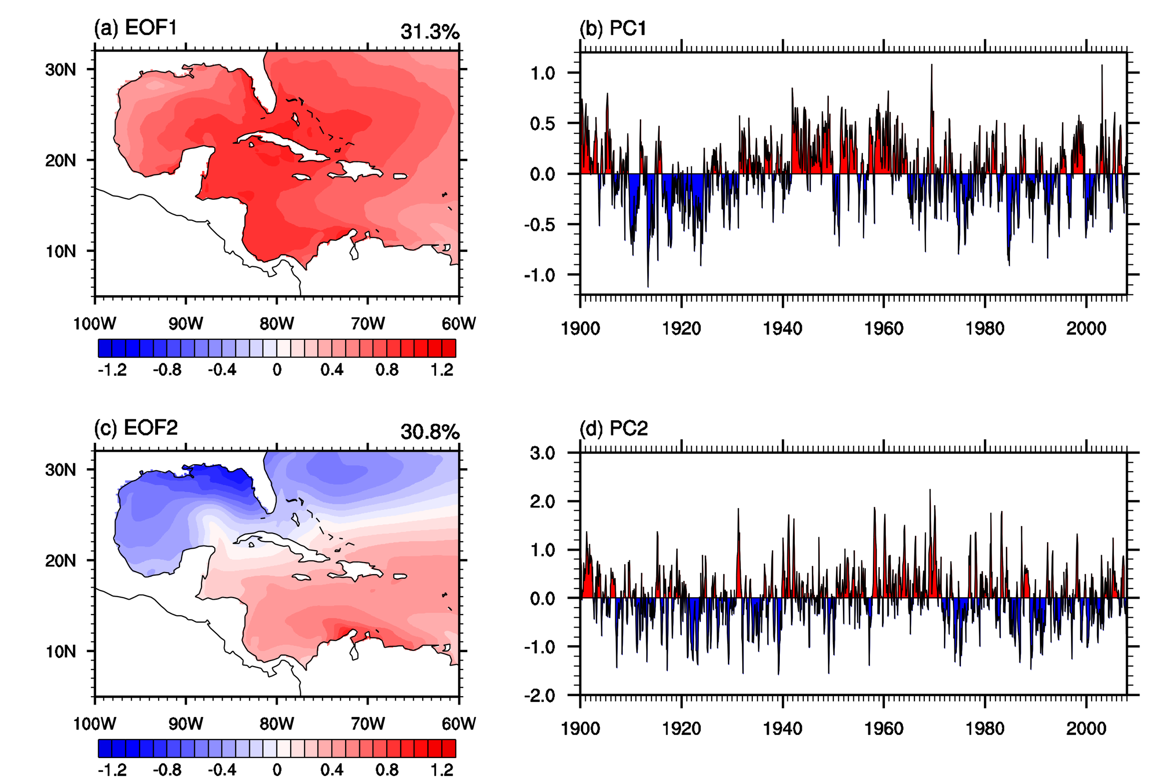


Fig 5: EOF analysis of the SST variability during 1900-2008 obtained from EXP_20CR. (a) The 1st mode of SST variability (EOF1), (b) the 2nd mode of SST variability (EOF2), and the time series of (c) PC1 and (d) PC2 (blue dashed) during 1900-2008. The leading two modes account for 31.3% and 30.8% of the total variance, respectively.

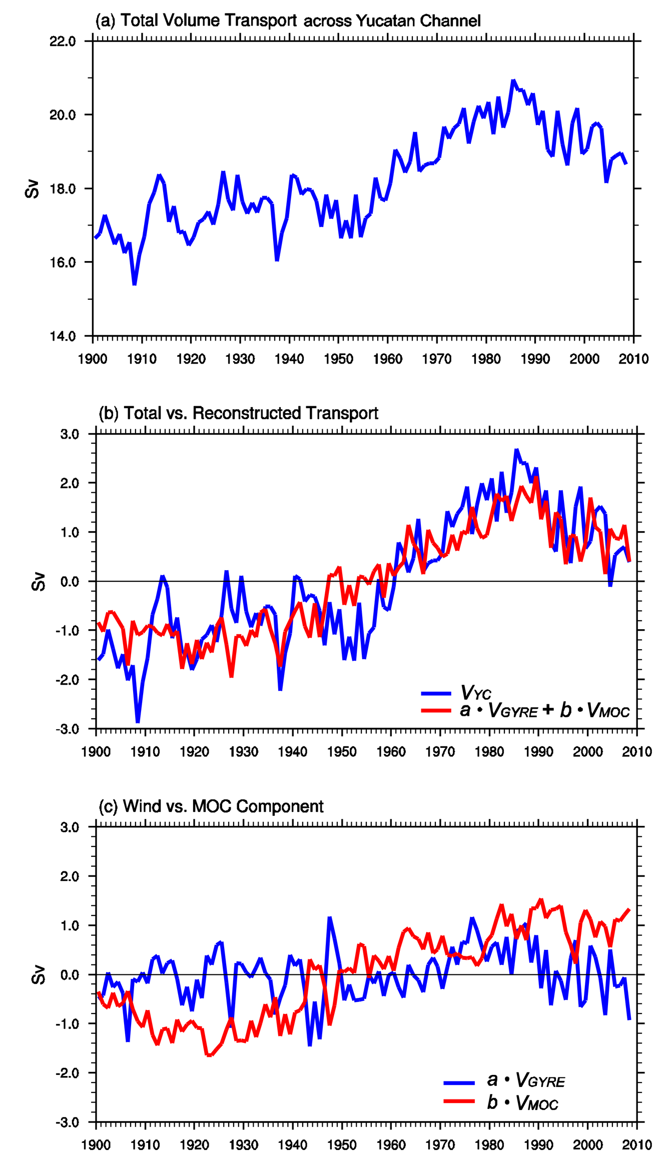


Fig 6: (a) Time series of the total volume transport across Yucatan Channel for the period of 1900 - 2008 obtained from EXP_20CR, (b) time series of the total (V_{YC}, blue) and reconstructed volume transport (red) during 1900-2008, and (c) time series of wind-driven gyre component ($a{\cdot}V_{GYRE}$, blue) and the AMOC component ($b{\cdot}V_{MOC}$, red) during the 1900-2008 obtained from EXP_20CR. V_{MOC} is defined as the maximum overturning stream function at 30°N.

Basin-averaged SST increase in GoM

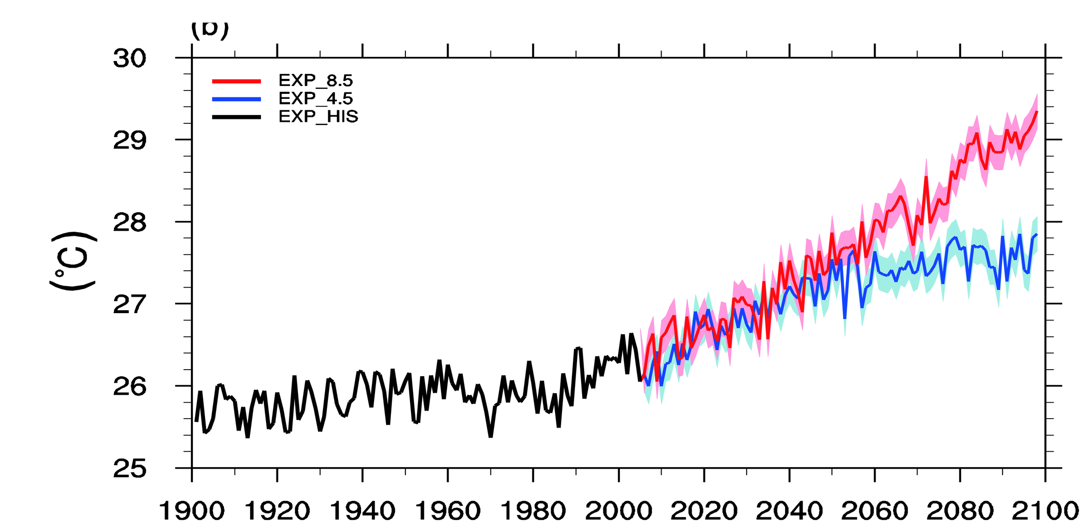


Fig 7. Time series of the annual mean SSTs averaged over the GoM during 1900-2098 obtained from EXP_HIS (black), EXP_4.5 (blue) and EXP_8.5 (red).

The standard deviation (STD) of the SST anomalies in the GoM for the period of 1900-2008 (EXP_20CR) is calculated (STD = 0.21) and the ± 0.21°C is added to each time point of the future SST projections (light color regions) obtained from EXP_4.5 and EXP_8.5.

Under RCP4.5 (RCP8.5), the GHG-induced SST increase in GoM over 26-year (13-year) period is statistically significant considering natural variability.

Conclusions

- Yucatan Current and Caribbean current transport will be reduced during 21st century (under both RCP4.5 and RCP8.5 scenarios). This is associated with the slowing down of the AMOC.
- In AMJ, there is minimal warming in northern GoM due to reduced LC.
- In ASO, there is increased warming in northeast Gulf coast and west Caribbean, which will increases chance of hurricane rapid intensification during landfall.
- For natural climate variability, SST main mode is AMO mode. 2nd mode is IAS dipole mode: latent heat flux is the main contributor.
- YC transport is largely driven by wind stress curl in the Sverdrup interior and the AMOC.
- The uncertainty due to natural climate variability is quite large and should be considered.

References:

Liu Y., S.-K. Lee, B. A. Muhling, J. T. Lamkin and D.B. Enfield, 2012: Significant reduction of the Loop Current in the 21st century and its impact on the Gulf of Mexico. J. Geophys. Res., 117, C05039, , doi:10.1029/2011JC007555

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