Potential Impact of climate change and variability on the Intra-Americas Sea (IAS)

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Outline

- Brief summary IPCC-AR5 (The physical science basis)
- Impact of natural climate variability on the IAS
- Climate change impact on the IAS
42 fully coupled climate models participated the Coupled Model Intercomparison Project-5 (CMIP5).

These models were integrated for the pre-industrial period (before 1850) and then the historical period (1851-2006).

At the end of the historical run (2006), these models were further integrated until 2100 and beyond under the four RCP scenarios.

**IPCC-AR5** mainly describes the ensemble-mean of the 42 model projections.

19 models simulate ocean biogeochemistry.

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**IPCC-AR5. Table. 9.1**

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**AOGCM** = Atmosphere-Ocean Global Circulation Model, **ESM** = Earth System Model
IPCC-AR5: Future greenhouse gas (GHG) concentration scenarios and temperature

- **Representative Concentration Pathways (RCPs)** are four greenhouse gas concentration (RCP2.6, 4.5, 6.0 and 8.5) time trajectories adopted by the IPCC.

- RCP2.6 is the lowest GHG concentration scenario: 2.6 Wm$^{-2}$ of GHG-induced net heat flux into the Earth system by 2100.

- RCP8.5 is the highest GHG concentration scenario: 8.5Wm$^{-2}$ of GHG-induced net heat flux into the Earth system by 2100.

- Global-mean surface (ocean, land and sea-ice) temperature is projected to increase by 1°C (RCP2.6) ~ 4°C (RCP8.5) by 2100.
A Note on Climate Variability vs. Change

- The anthropogenic warming signal is superimposed on significant natural variability
- What we observe will be a combination of both processes
- The best match to historical observations is obtained from running climate models with both natural and anthropogenic forcing
"With high confidence", ocean uptake of anthropogenic CO₂ will continue with all four RCP scenarios until 2100.

Increasing CO₂ storage in the ocean will “virtually certainly” increase the acidification in the future, continuing the observed trend during the past decades.

Under RCP8.5, the global ocean surface pH will decrease by 0.31 through to 2100.
Aragonite Saturation State

- With increasing acidity in the ocean, the carbonate ions ($CO_3^{2-}$) decreases, and thus the Aragonite saturation state ($\Omega$) decreases.
- When $\Omega$ becomes undersaturated (< 1), $CaCO_3$ starts dissolving.
- Under RCP8.5, the surface $\Omega$ becomes undersaturated by 2050 in the Arctic and Southern Ocean and by 2150 in the tropics.
- Coral and other calcifying organisms (e.g. foraminifera, pteropods) will suffer as $\Omega$ decreases.

$Ca^{2+} + CO_3^{2-} \leftrightarrow CaCO_3$
- $\rightarrow$: calcification ($\Omega > 1$)
- $\leftarrow$: dissolution ($\Omega < 1$)

$\Omega = ([Ca^{2+}] + [CO_3^{2-}]) / [CaCO_3]$
Impacts of the Ocean Environment: Oxygen Depletion

- Dissolved Oxygen (DO) will decline by up to 4% during the 21st century due to (1) warming-induced reduction of O₂ solubility and (2) increased ocean stratification (i.e., reductions in convective mixing and deep water convection).

- Largest reduction is expected around 200 - 400m. However, in some regions (e.g., tropical Atlantic and Indian Oceans) DO may increase in the future.

- Significant model variability for DO projections

IPCC-AR5. Fig. 6.30
Largely due to (1) thermal expansion, (2) glaciers and (3) Greenland ice sheet melting, the global mean sea level will rise up to 60cm by 2100 under RCP8.5 scenario.

There will be some regional variations due to ocean dynamics.

May lead to loss of shallow nursery habitats, changing estuary and marsh dynamics.
Impacts on the Ocean Environment: Precipitation

- With increasing temperature, the atmosphere can hold more moisture.
- This may lead to a large reduction of the rainfall in the future, particularly in the subtropical regions.
- In the North Atlantic, a slowing AMOC may also contribute to reduced rainfall.
- As a result, sea surface salinity will be greatly reduced in the North Atlantic (up to 1 psu by 2100 under RCP8.5).
- Implications for river discharge, estuarine dynamics, nutrient inputs
Dynamic Downscaling of IPCC-AR5 projections

- Spatial resolution of global climate models is usually too coarse to resolve regional and local-scale processes
- The following slides describe results for the IAS from a downscaled regional model
- Dynamic downscaling model used:
  NOAA GFDL’s Modular Ocean Model version 4 (MOM4) was used to downscale the CMIP5 model projections for the IAS region.
- CMIP5 model weighting:
  Used the sea surface, 100m and 200m temperature averaged in GoM and CBN, and AMOC at 30°N to weight the CMIP5 models. If a particular model has large errors, the weight will be very small.
- Surface and boundary conditions and initial conditions:
  Derived the weighted ensemble means of the surface and boundary conditions from the CMIP5 model runs
- Downscaling simulations:
  Conducted dynamic downscaling simulations for the IAS region under RCP4.5 and RCP8.5 scenarios for 1901-2100.
The downscaled model reproduced SST (anomaly) variability in the GoM and CBN during the 20th century reasonably well.

Under RCP8.5, GoM SST will increase from 26°C to slightly above 29°C in 2100, and the CBN SST will increase from 27.5°C to about 31°C in 2100.
One of the major findings in the dynamic downscaling is that the entire boundary current system in the IAS (Caribbean Current, Yucatan Current, Loop Current and Florida Current) is significantly reduced by 20 ~ 25% by 2100 (RCP8.5).

CMIP5 models did not show this reduction clearly because the IAS boundary current system was not very well resolved in CMIP5 models (i.e., horizontal model resolution is about 100km).
The projected weakening of the ocean circulation in the Gulf of Mexico (GoM) suggests that the shallow (≤ 180 m) northern shelf of the GoM may experience lower rates of upwelling from deep cool water onto the shelf.

Consistent with this hypothesis, the downscaled model predicts an intense warming over the northern shelf of the GoM in boreal summer.

This warming trend may increase the chance for hurricane intensification during landfall in the northern and eastern Gulf.

The warming may also expose marine life in the northern GoM shelf regions to increasing frequency of thermal stress.
Global-mean surface (ocean, land and sea-ice) temperature is projected to increase by \(4^\circ C\) (RCP8.5) at 2100.

Global ocean surface pH will decrease by 0.31 through to 2100.

Surface Aragonite state (\(\Omega\)) becomes undersaturated by 2050 in the Arctic and Southern Ocean and by 2150 in the tropics. As such, coral and other calcifying organisms will suffer as \(\Omega\) deceasing to 1.

Dissolved Oxygen (DO) will decline by up to 4% during the 21st century. Largest reduction is expected around 200 – 400m.

The Arctic Sea in summer will be completely ice-free around 2050.

Global mean sea level will rise up to 60cm by 2010.

Evaporation minus precipitation will greatly increase in the IAS. As a result, the sea surface salinity will be greatly increased in the IAS (up to 1 psu by 2100)

Downscaled model results highlight a weakening AMOC and Loop Current

May result in heterogeneous warming across the Gulf of Mexico
Associated Publications

- **Impact of natural climate variability on the IAS**

- **Climate change impact on the IAS**

- **Implications for Atlantic bluefin tuna and skipjack tuna adult and larval habitats**


- **Implications for Caribbean coral bleaching**
Used IPCC-AR5 models, a dynamical downscaled model and a statistical downscaling to project the onset of annual coral bleaching conditions in the Caribbean.

The average year for the onset of annual severe bleaching is 2040–2047 for all three projections.

However, the dynamically downscaled projections suggests an earlier onset of annual severe bleaching linked to projected changes in regional currents, a feature not resolved in IPCC-AR5 models.

Statistically downscaled projections were similar to those from the dynamical model, except in the Bahamas and Florida Reef Tract.
Combined predictive habitat models with a downscaled climate model to examine potential impacts of climate change on adults and larvae of Atlantic bluefin tuna (*Thunnus thynnus*) and skipjack tuna (*Katsuwonus pelamis*) in the IAS.

Showed marked temperature-induced habitat losses for both adult and larval bluefin tuna on their northern Gulf of Mexico spawning grounds. In contrast, habitat suitability for skipjack tuna increased as temperatures warmed.
Under RCP8.5, the Arctic Sea in summer will be completely ice-free around 2050. This will lead to (1) sea water freshening, (2) sea level rise & (3) slowdown of Atlantic Meridional Overturning Circulation (AMOC), which will affect the Atlantic Ocean circulations.
First two EOF modes explain more than 60% of the total SST variance in the IAS during 1901-2010.

The first mode describes a multi-decadal oscillation of the SST in the entire IAS.

The second mode describes an interannual dipole oscillation between GoM and CBN.
The first EOF mode mainly describes the Atlantic Multi-decadal Oscillation (AMO).

There is no apparent seasonality in the first mode.

The second EOF (IAS dipole mode) mode has the peak in spring (February - April).
Impact of Natural Climate Variability on the IAS

- Net surface heat flux in winter very well explains the SST dipole variability between GoM and CBN.
- The IAS dipole mode is largely forced by surface latent heat flux associated with changes in surface winds.
- After the peak of El Nino in winter, cold SST anomalies usually develop in GoM and warm SST anomalies in CBN.
- Likewise, after the peak of La Nina in winter, warm SST anomalies usually develop in GoM and cold SST anomalies in CBN.
Atlantic Meridional Overturning Circulation (AMOC) is a part of the global thermohaline circulation, also known as global ocean conveyor.

IPCC-AR5 projected about 20 ~ 25% of the reduction in the strength of the AMOC by 2100 (RCP8.5).

The projected reduction of the IAS boundary current system is consistent with the projected slowdown of the AMOC.
The first (2007) and the second (2012) GOMECC cruises showed measurable temporal pH and aragonite saturation state ($\Omega_{ar}$) changes in the East and Gulf coast of the U.S.

The expected 2% average decrease in $\Omega_{ar}$ due to increasing atmospheric CO2 levels over the 5-year period was largely overshadowed by local and regional variability.

This study proposed to use a regional ocean-biogeochemistry model simulation to isolate seasonal cycle and other variability from the multi-annual trend between the 1st and 2nd GOMECC cruise data.