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

IPCC-AR5: CMIP5 models

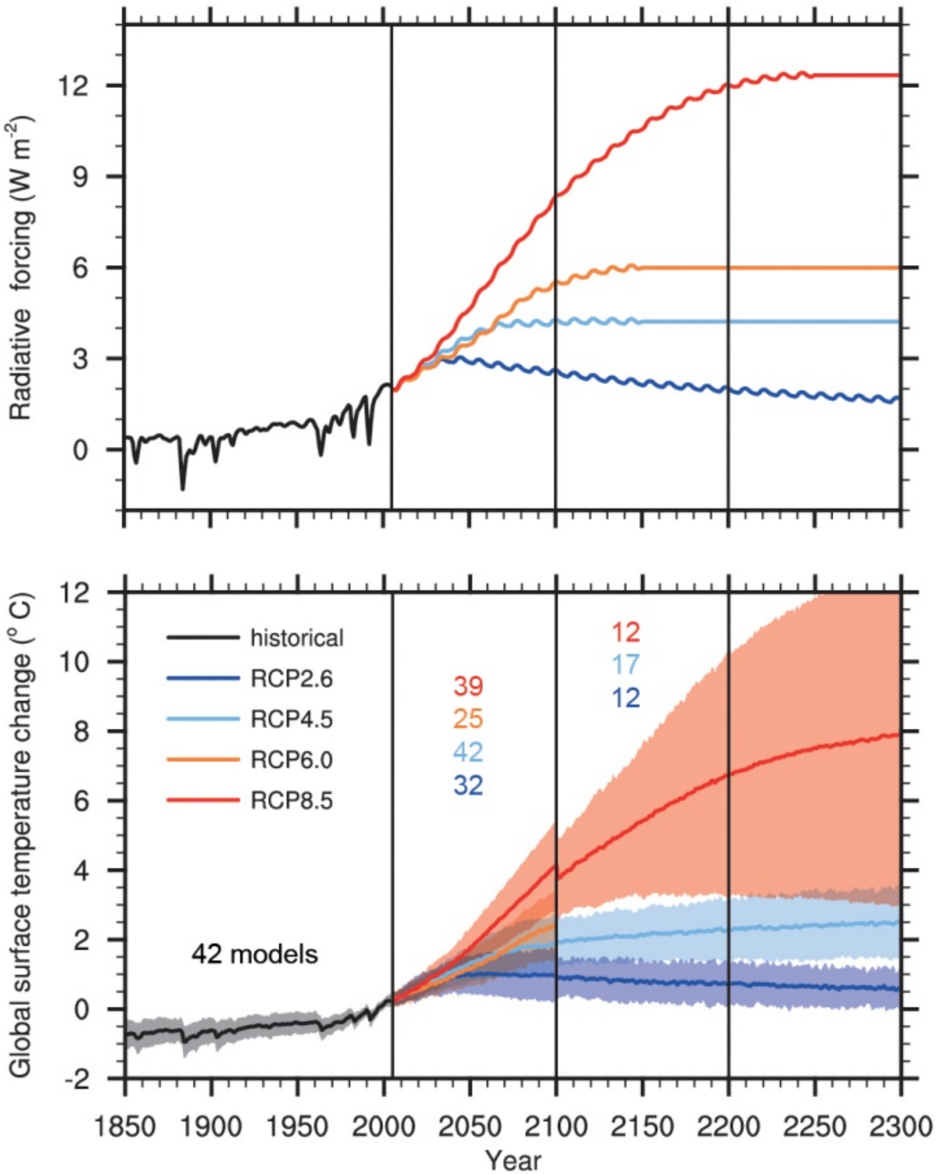
	Model name		Atmos	Land Surface	Ocean	Sea-Ice	FC	Aerosol	Atmos Chem	Land Carbon	Ocean BGC
			AOGCM				ESM				
CMIP5	ACCESS1.0, ACCESS1.3	Australia									
	BCC-CSM1.1, BCC-CSM1.1(m)	China									
	BNU-ESM	China									
	CanCM4	Canada									
	CanESM2										
	CCSM4										
	CESM1 (BGC)										
	CESM1 (WACCM)	USA	HT								
	CESM1 (FASTCHEM)										
	CESM1 (CAM5)										
	CESM1 (CAM5.1-FV2)	USA									
	CMCC-CM, CMCC-CMS	Italy	HT								
	CMCC-CESM		HT								
	CNRM-CM5	France									
	CSIRO-Mk3.6.0	Australia									
	EC-EARTH	Europe									
	FGOALS-g2	China									
	FGOALS-s2										
	FIO-ESM v1.0	China									
	GFDL-ESM2M, GFDL-ESM2G										
	GFDL-CM2.1	USA									
	GFDL-CM3		HT								
	GISS-E2-R, GISS-E2-H	USA	HT					p2,p3*	p2, p3*		
	GISS-E2-R-CC, GISS-E2-H-CC		HT					p2,p3*	p2, p3*		
	HadGEM2-ES										
	HadGEM2-CC	UK	HT								
	HadCM3										
	HadGEM2-AO	Korea									
	INM-CM4	Russia									
	IPSL-CM5A-LR / -CM5A-MR / -CM5B-LR	France	HT								
	MIROC4h, MIROC5		HT								
	MIROC-ESM	Japan	HT								
	MIROC-ESM-CHEM		HT								
	MPI-ESM-LR / -ESM-MR / -ESM-P	Germany	HT								
	MRI-ESM1	Japan	HT								
	MRI-CGCM3		HT								
	NCEP-CFSv2	USA									
	NorESM1-M	Norway									
	NorESM1-ME										
AMIP	GFDL-HIRAM C180 / -HIRAM C360	USA									
	MRI-AGCM3.2S / -AGCM3.2H	Japan									

AOGCM = Atmosphere-Ocean Global Circulation Model,
ESM = Earth System Model

IPCC-AR5. Table. 9.1

- 42 fully coupled climate models participated the Coupled Model Inter-comparison 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.

IPCC-AR5: Future greenhouse gas (GHG) concentration scenarios and temperature

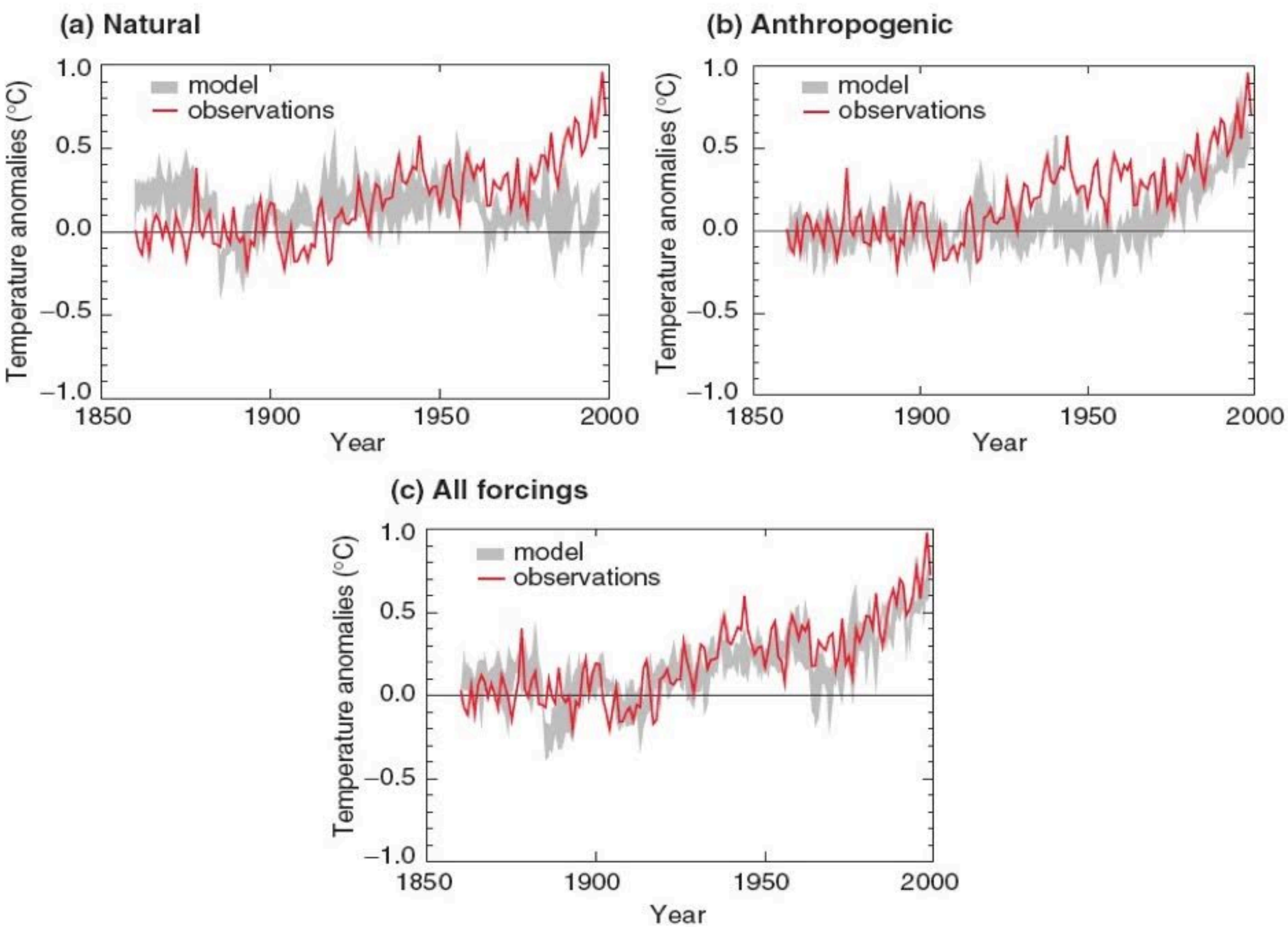


IPCC-AR5. Fig. TS.15

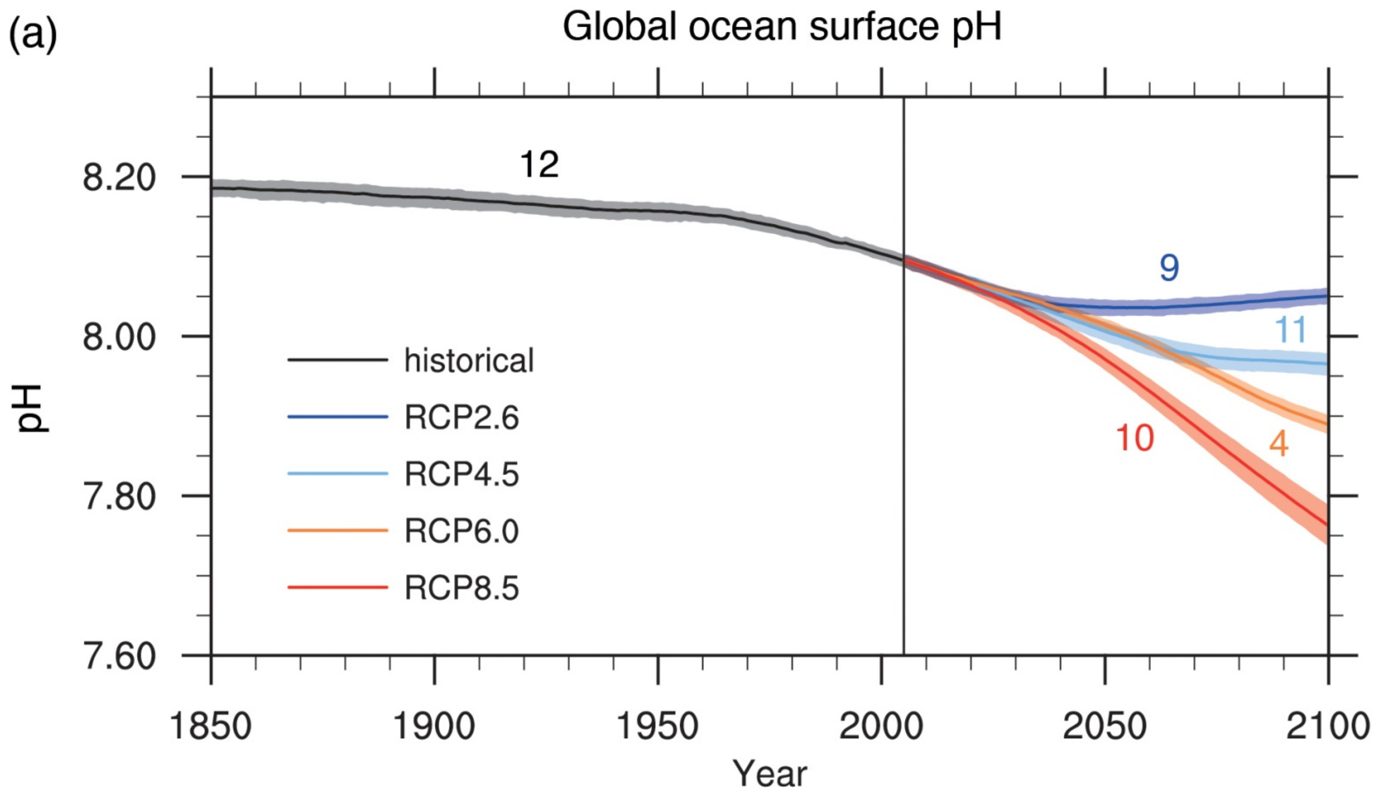
- Representative Concentration Pathways (RCPs) are four greenhouse gas concentration (RCP2.6, 4.5, 6.0 and 8.5) time trajectories adopted by the IPCC.
- RCP2.6 is the lowest GHG concentration scenario: 2.6 Wm^{-2} of GHG-induced net heat flux into the Earth system by 2100.
- RCP8.5 is the highest GHG 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



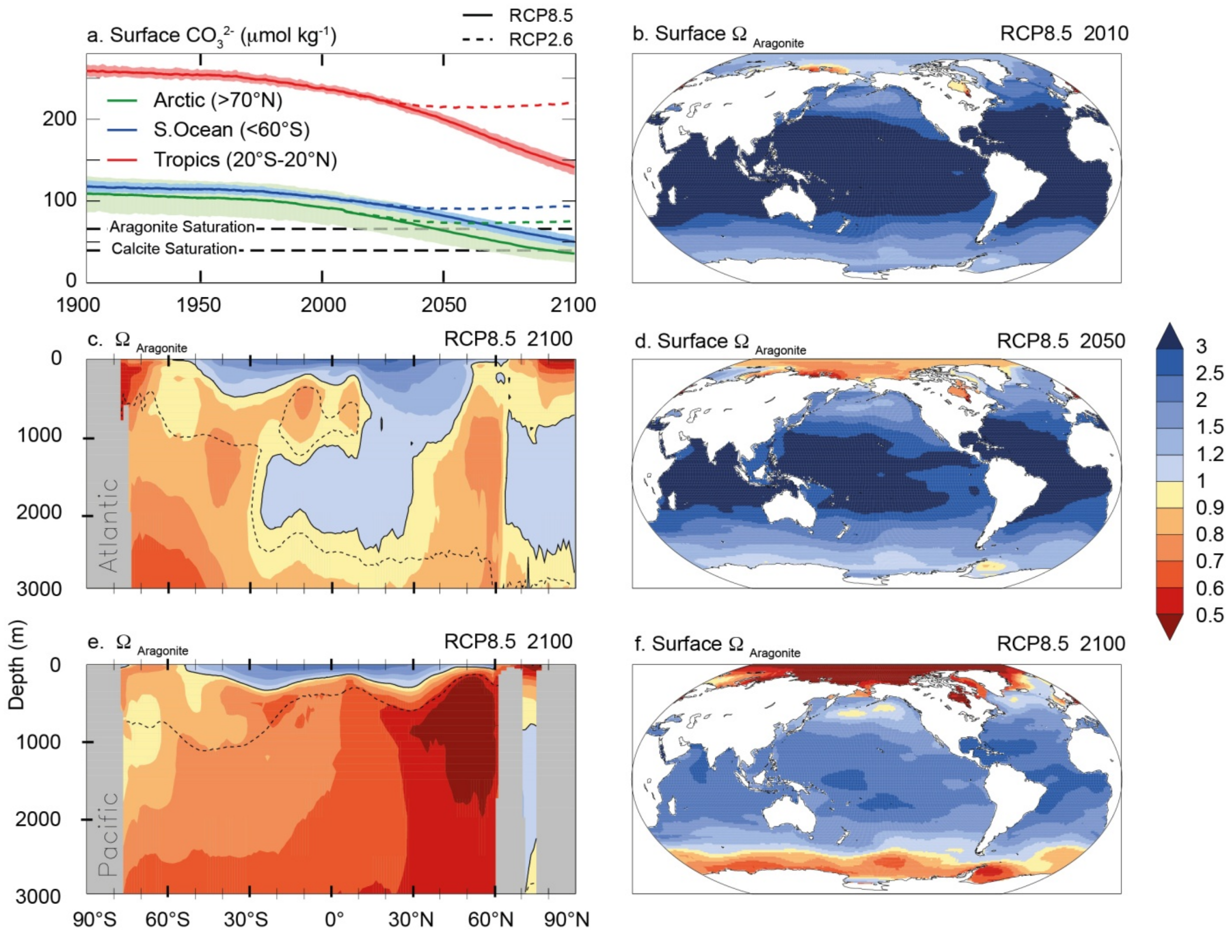
Impacts on the Ocean Environment: Ocean Acidification



IPCC-AR5. Fig. TS.20

- "***With high confidence***", ocean uptake of anthropogenic CO_2 will continue with all four RCP scenarios until 2100.
- Increasing CO_2 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



$Ca^{2+} + CO_3^{2-} \leftrightarrow CaCO^3$

→: calcification (Ω > 1)

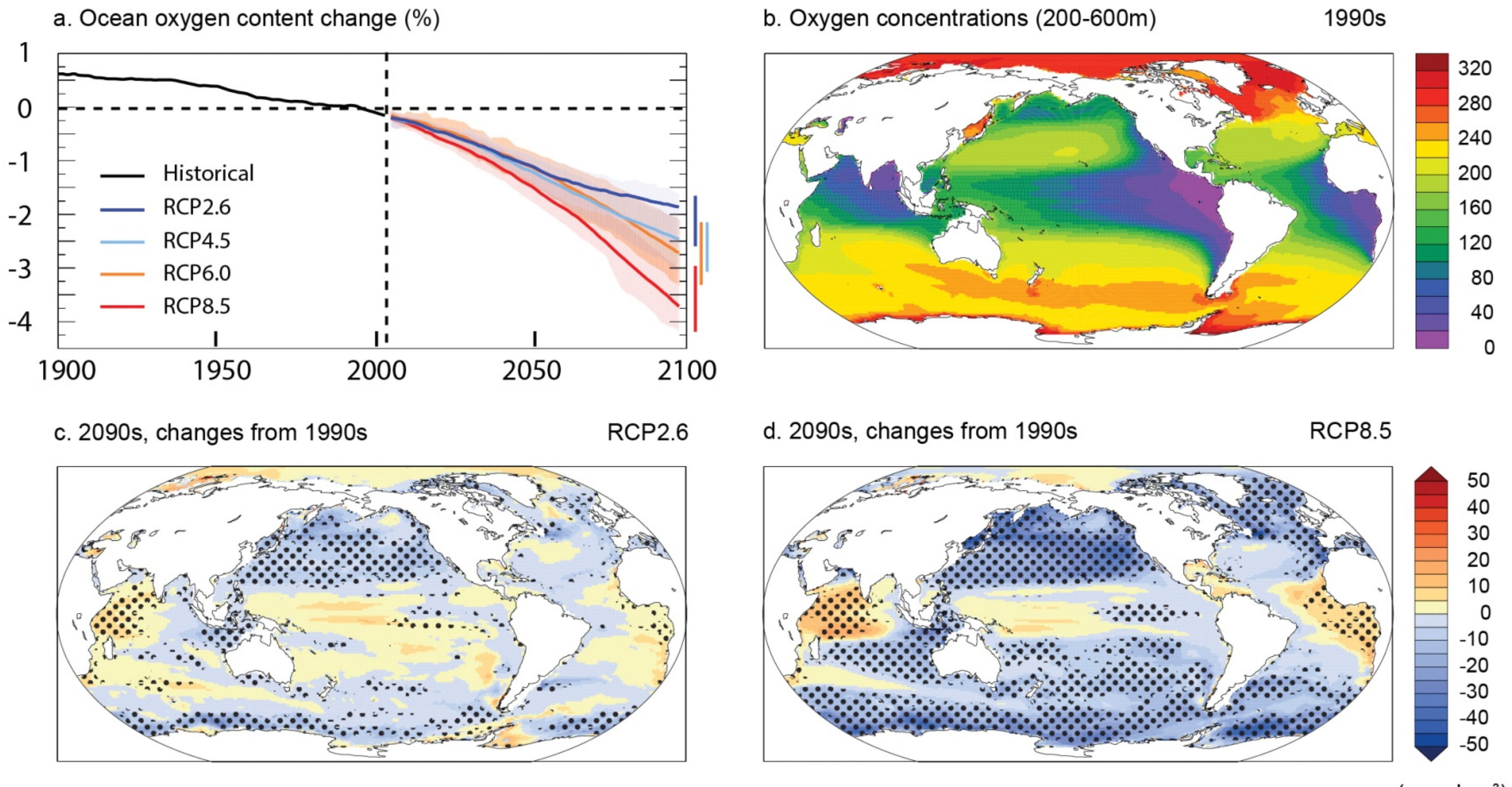
←: dissolution (Ω < 1)

$\Omega = ([Ca^{2+}] + [CO_3^{2-}]) / [CaCO^3]$

- With increasing acidity in the ocean, the carbonate ions (CO_3^{2-}) decreases, and thus the Aragonite saturation state (Ω) decreases.
- When Ω becomes undersaturated (< 1), $CaCO_3$ starts dissolving.
- Under RCP8.5, the surface Ω 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 Ω decreases

IPCC-AR5. Fig. 6.29

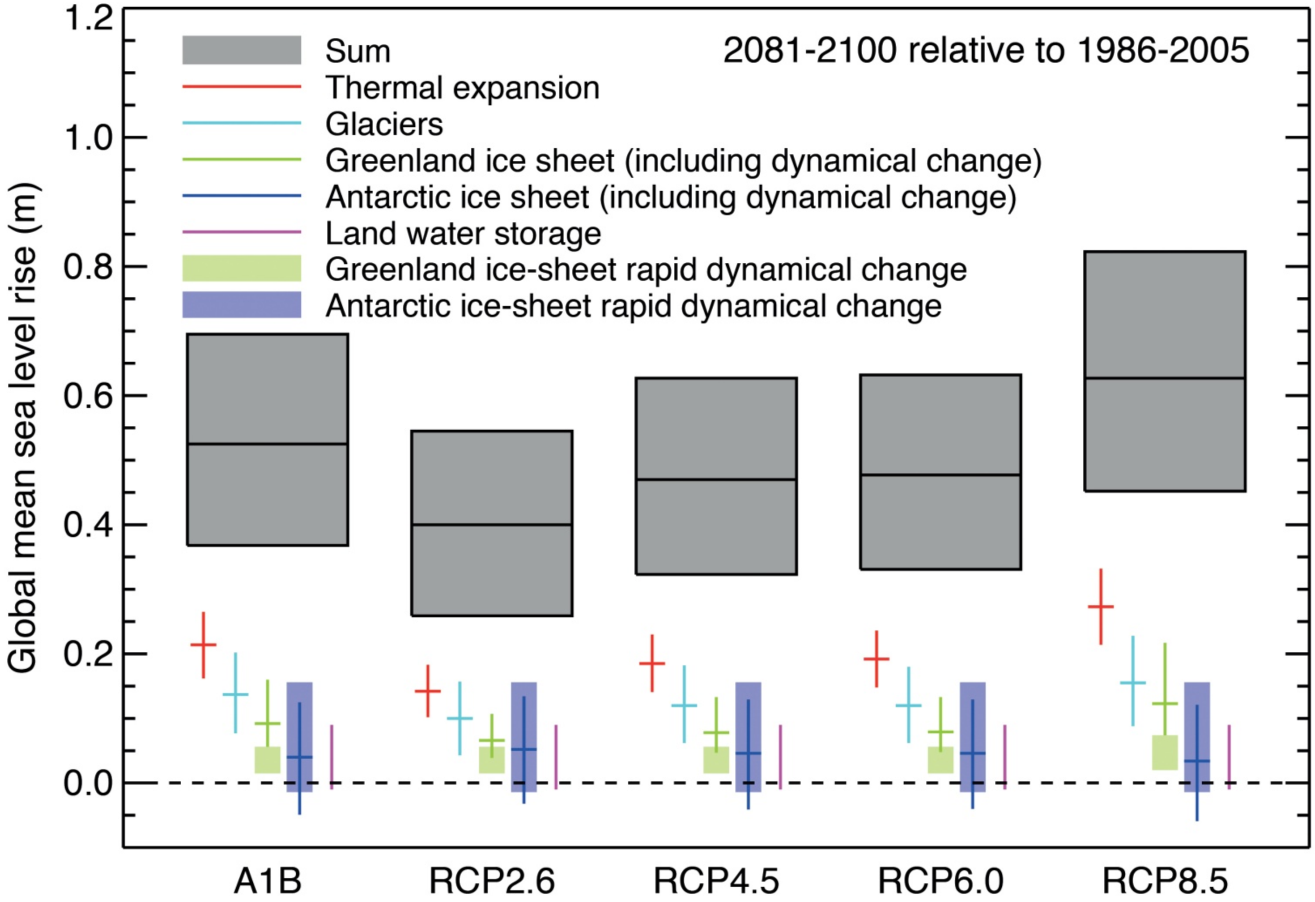
Impacts of the Ocean Environment: Oxygen Depletion



IPCC-AR5. Fig. 6.30

- Dissolved Oxygen (DO) will decline by up to 4% during the 21st century due to (1) warming-induced reduction of O_2 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

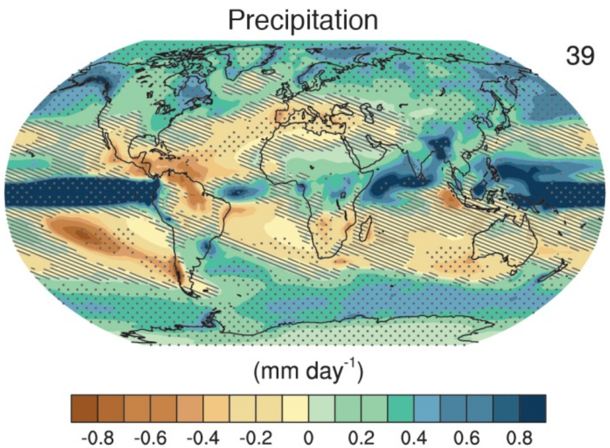
Impacts on the Ocean Environment: Sea Level Rise

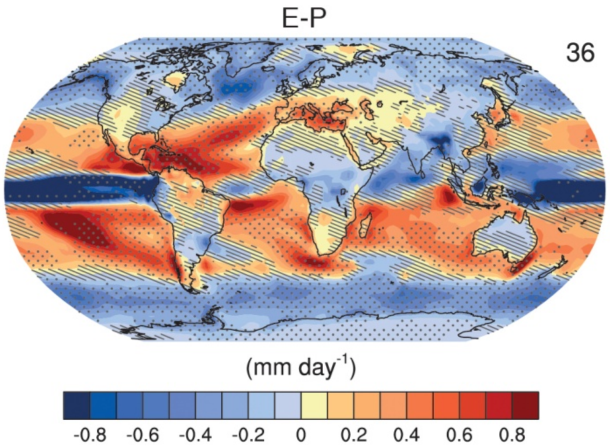


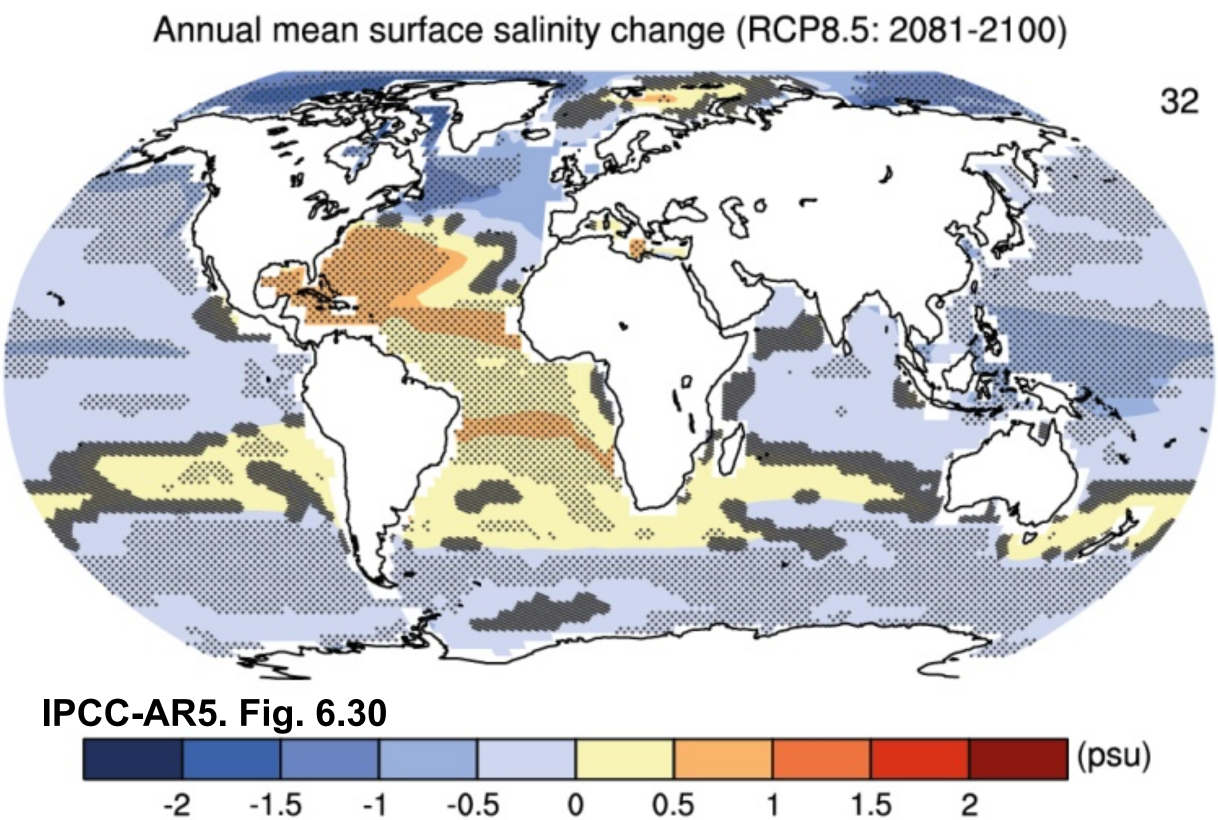
IPCC-AR5. Fig. TS.21

- 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







IPCC-AR5. Fig. 6.30

- 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 version4 (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.

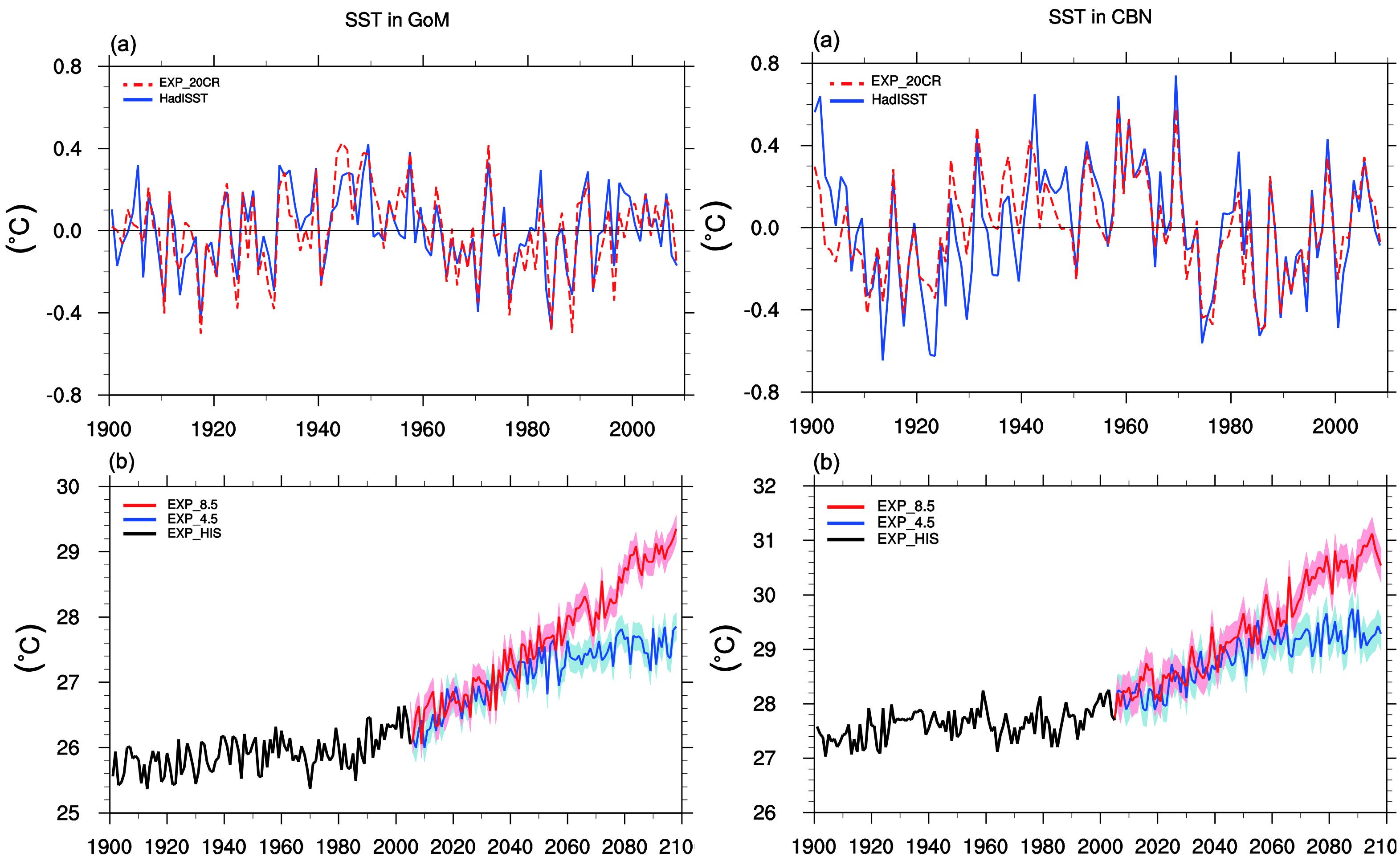
- **Surface and boundary conditions and initial conditions:**

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.

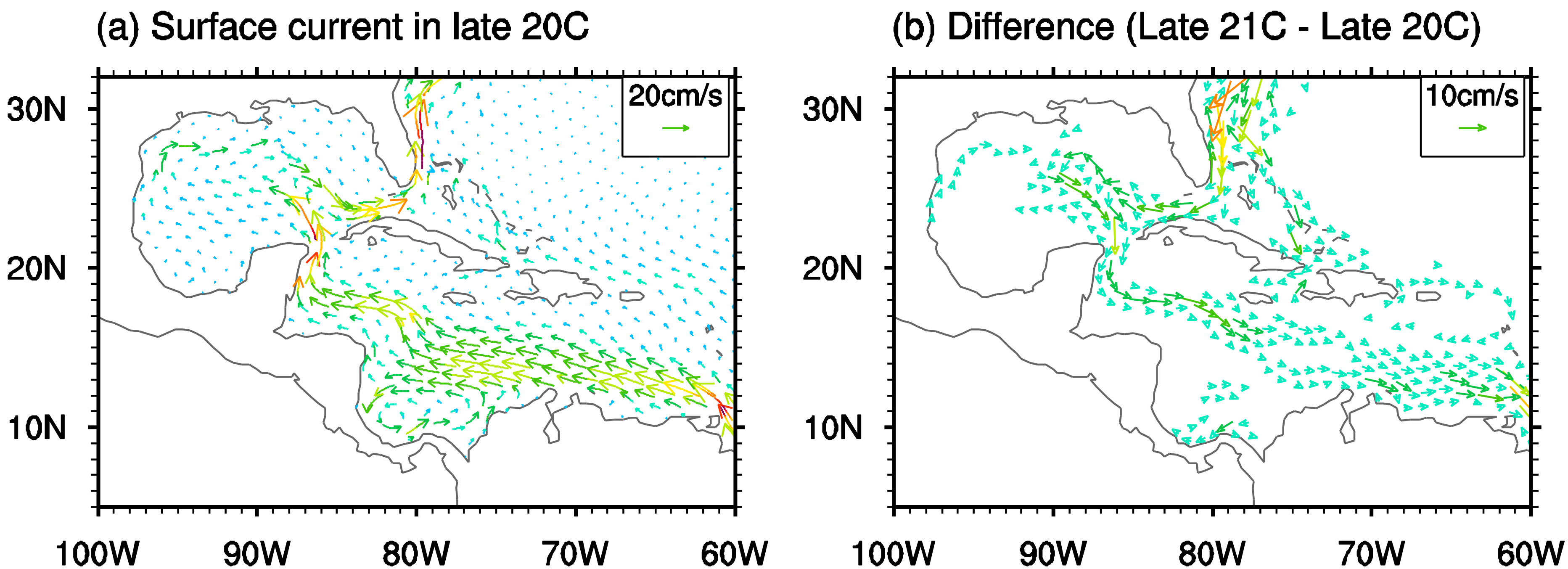
Dynamic Downscaling of IPCC-AR5 projections



- 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.

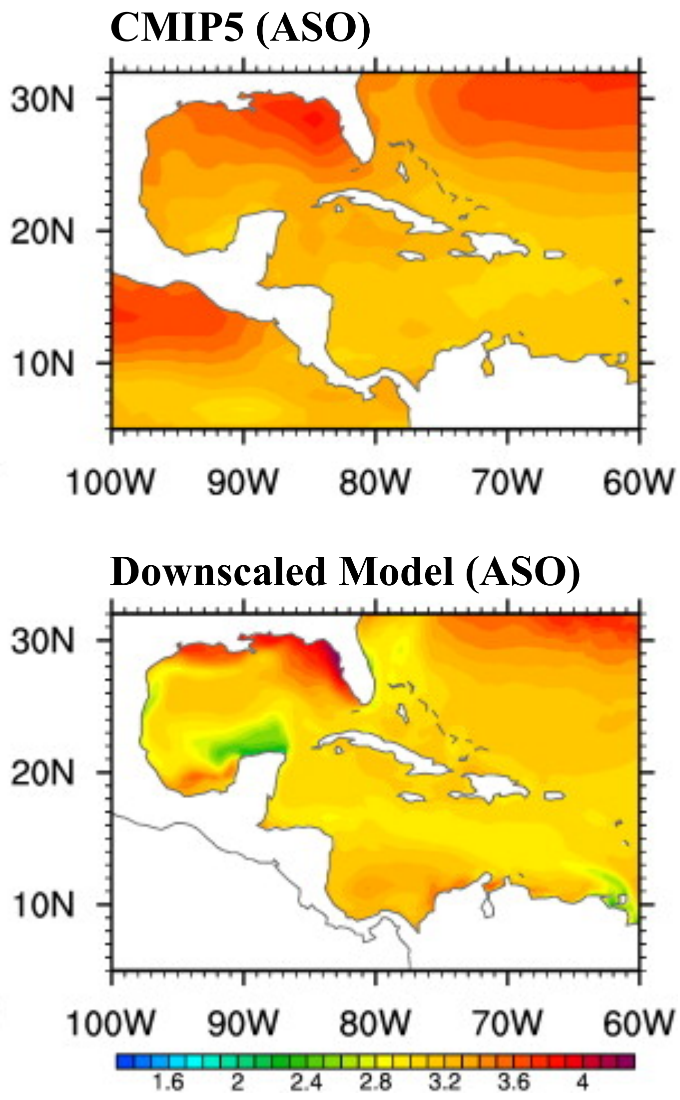
Dynamic Downscaling of IPCC-AR5 projections

MOM4: Surface Current



- 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).

Dynamic Downscaling of IPCC-AR5 projections



- 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.

IPCC-AR5: Summary (RCP8.5)

- Global-mean surface (ocean, land and sea-ice) temperature is projected to increase by **4°C** (RCP8.5) at 2100.
- Global ocean surface pH will decrease by **0.31** through to 2100.
- Surface Aragonite state (Ω) 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 Ω 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

Liu Y., S.-K. Lee, D. B. Enfield, B. A. Muhling, J. T. Lamkin, F. Muller-Karger, M. A. Roffer, 2015: Potential impact of climate change on the Intra-Americas Seas: Part-1. A dynamic downscaling of the CMIP5 model projections. *J. Mar. Syst*., 148, 56-69, doi:10.1016/j.jmarsys.2015.01.007.

Climate change impact on the IAS

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

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

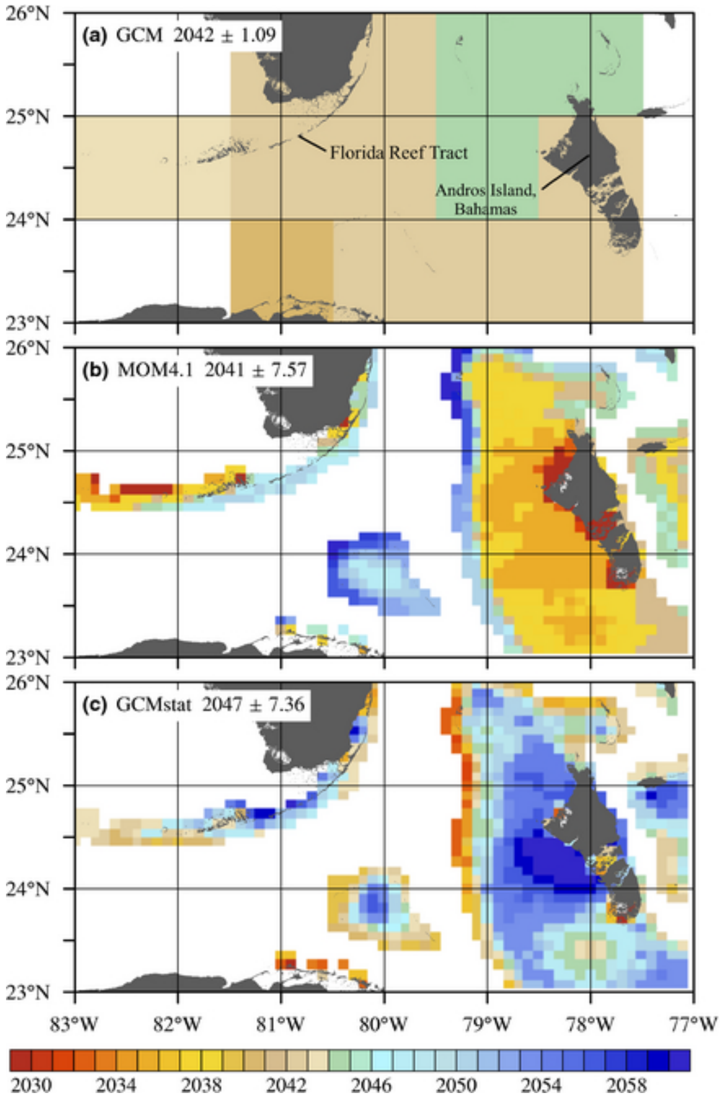
Muhling B. A., Y. Liu, S.-K. Lee, J. T. Lamkin, M. A. Roffer, F. Muller-Karger, 2015: Potential impact of climate change on the Intra-Americas Seas: Part 2. Implications for Atlantic bluefin tuna and skipjack tuna adult and larval habitats. *J. Mar. Syst*., 148, 1-13, doi:10.1016/j.jmarsys.2015.01.010.

Muhling, B. A., S.-K. Lee, J. T. Lamkin and Y. Liu, 2011: Predicting the effects of climate change on bluefin tuna (*Thunnus thynnus*) Spawning habitat in the Gulf of Mexico. *ICES J. Mar. Sci*., doi:10.1093/icesjms/fsr008.

Implications for Caribbean coral bleaching

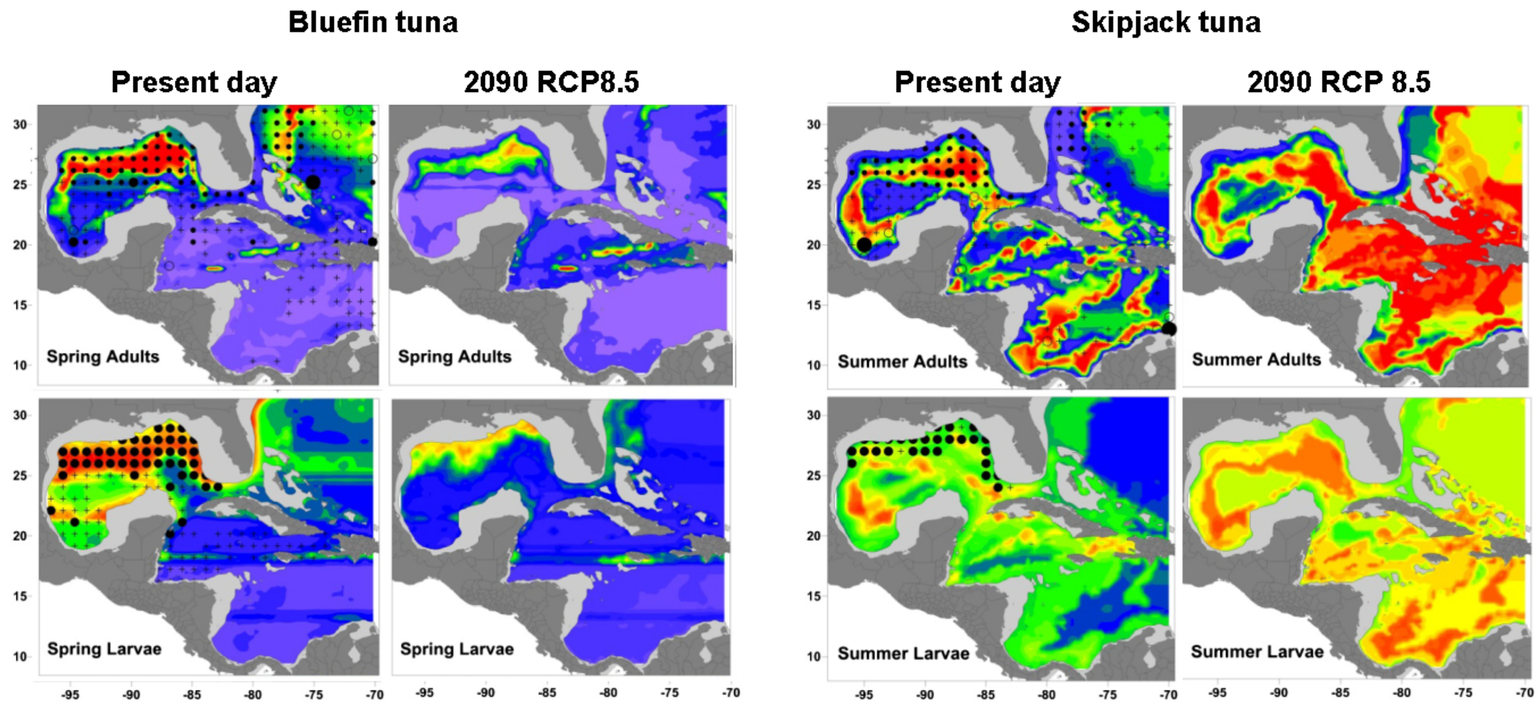
van Hooidonk, R., J. A. Maynard, Y. Liu and S.-K. Lee, 2015: Downscaled projections of Caribbean coral bleaching that can inform conservation planning. *Glob. Change Biol*., doi: 10.1111/gcb.12901.

Dynamic Downscaling of IPCC-AR5 projections



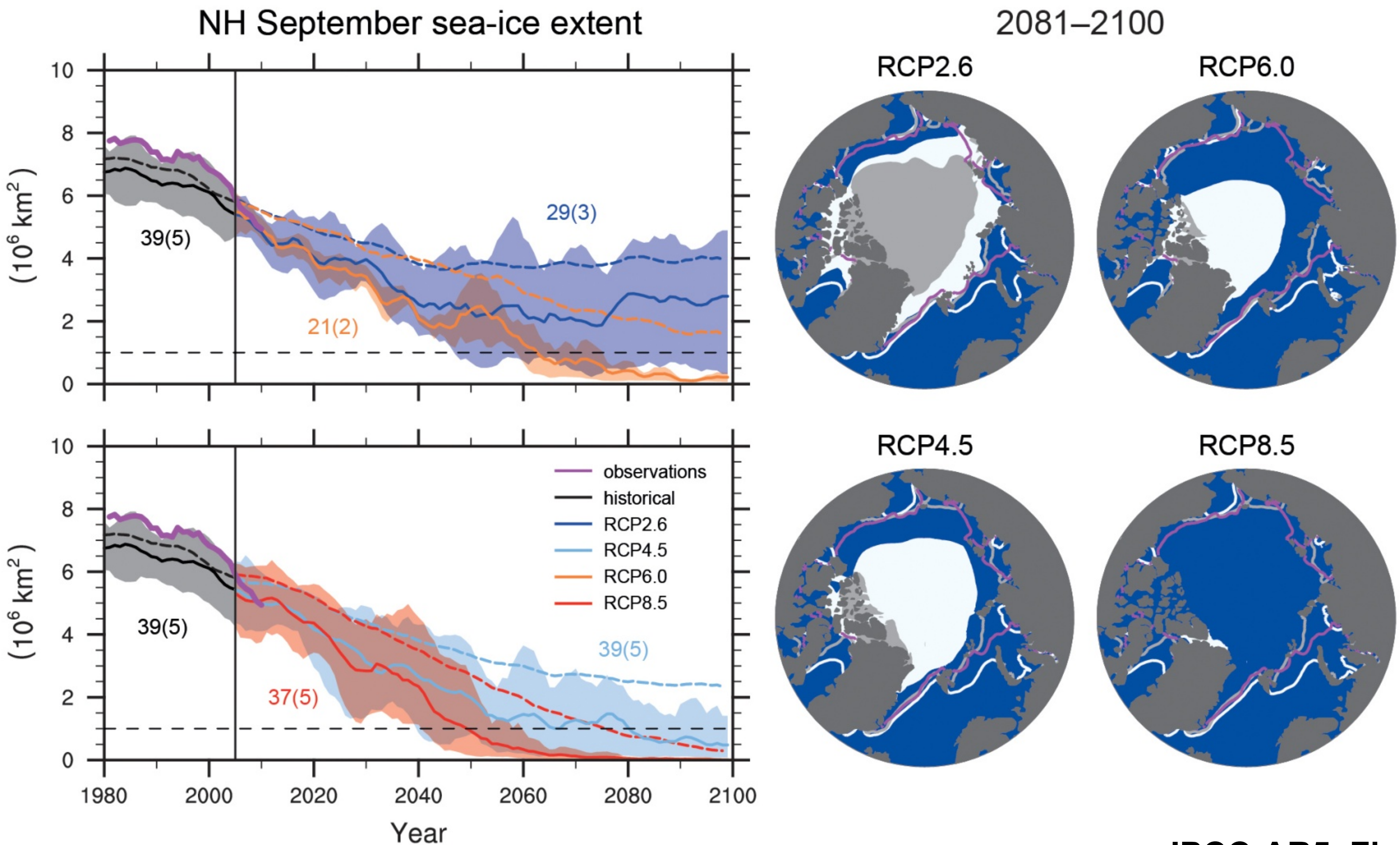
- Used IPCC-AR5 models, a dynamical downscaled model and a statistical downscaling to project the onset of annual coral bleaching conditions in the Caribbean.
- The average year for the onset of annual severe bleaching is 2040–2047 for all three projections.
- However, the dynamically downscaled projections 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.

Dynamic Downscaling of IPCC-AR5 projections



- 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.

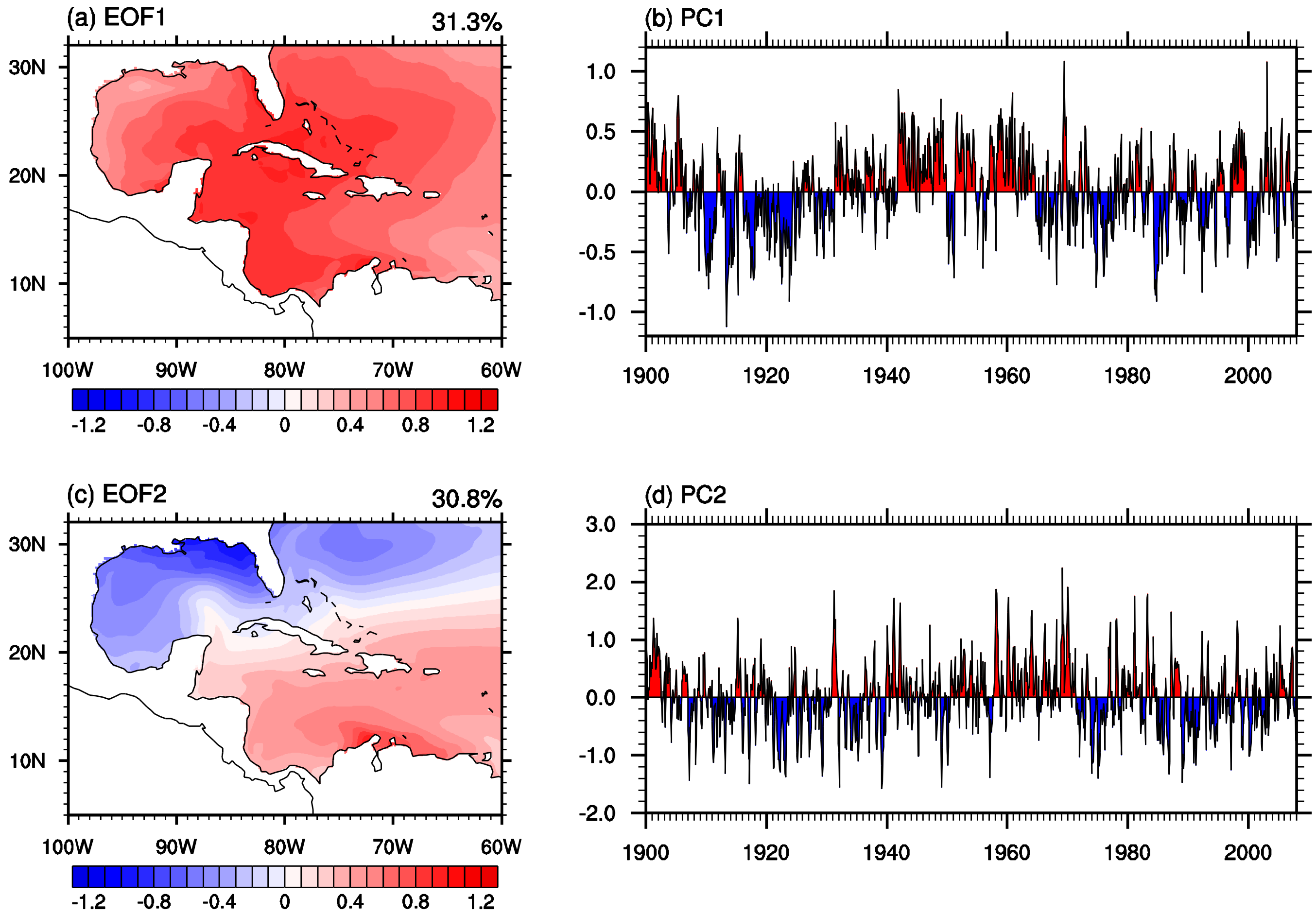
IPCC-AR5: Sea-Ice Melting



IPCC-AR5. Fig. TS.17

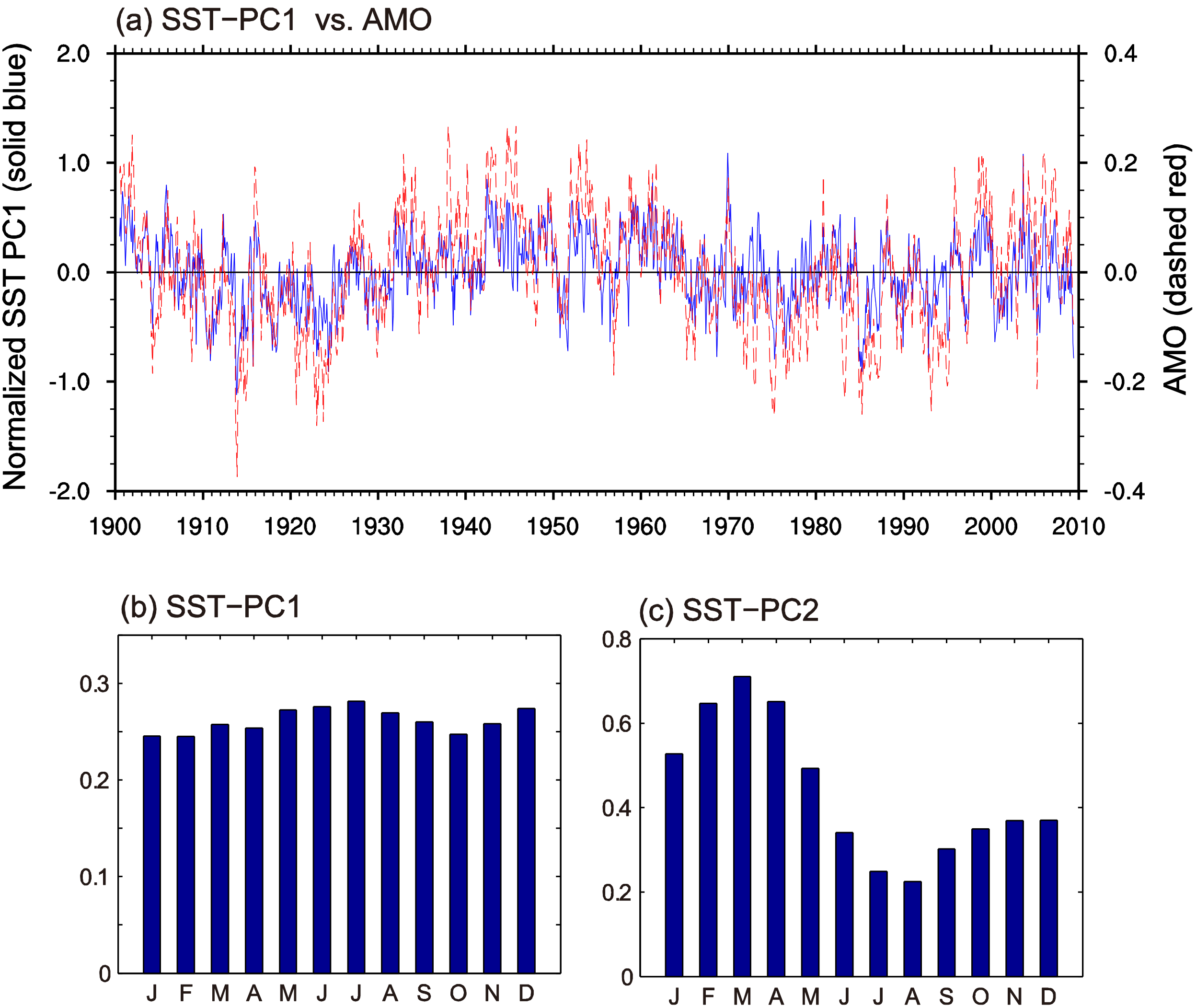
- Under RCP8.5, the Arctic Sea in summer will be completely ice-free around 2050.
- This will lead to (1) sea water freshening, (2) sea level rise & (3) slowdown of Atlantic Meridional Overturning Circulation (AMOC), which will affect the Atlantic Ocean circulations.

Impact of Natural Climate Variability on the IAS



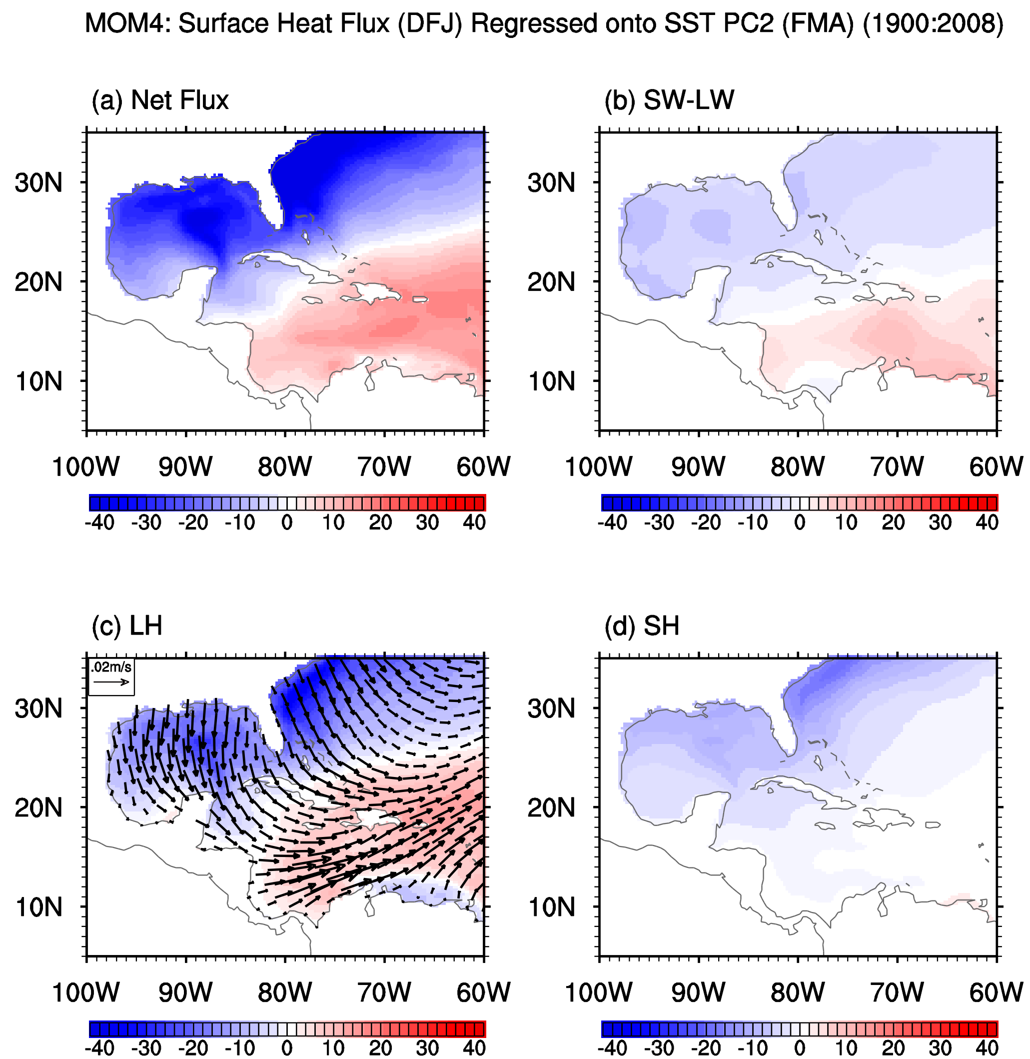
- First two EOF modes explain more than 60% of the total SST variance in the IAS during 1901-2010.
- The first mode describes a multi-decadal oscillation of the SST in the entire IAS.
- The second mode describe a interannual dipole oscillation between GoM and CBN.

Impact of Natural Climate Variability on the IAS



- 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).

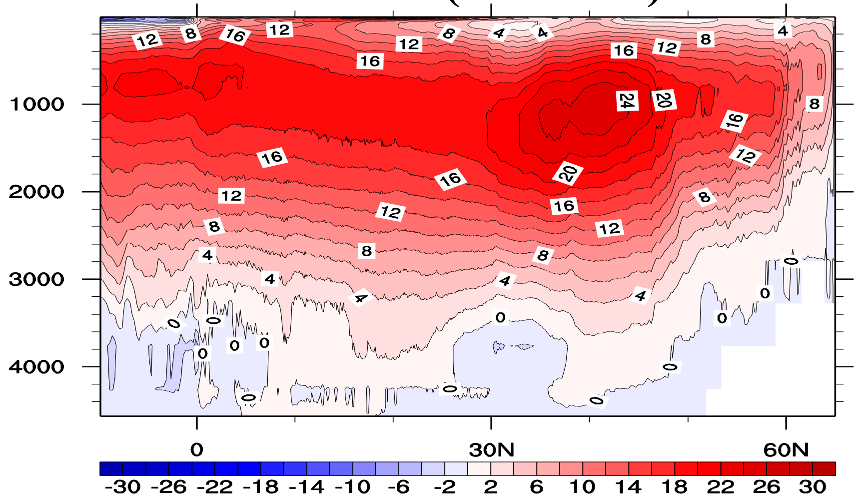
Impact of Natural Climate Variability on the IAS



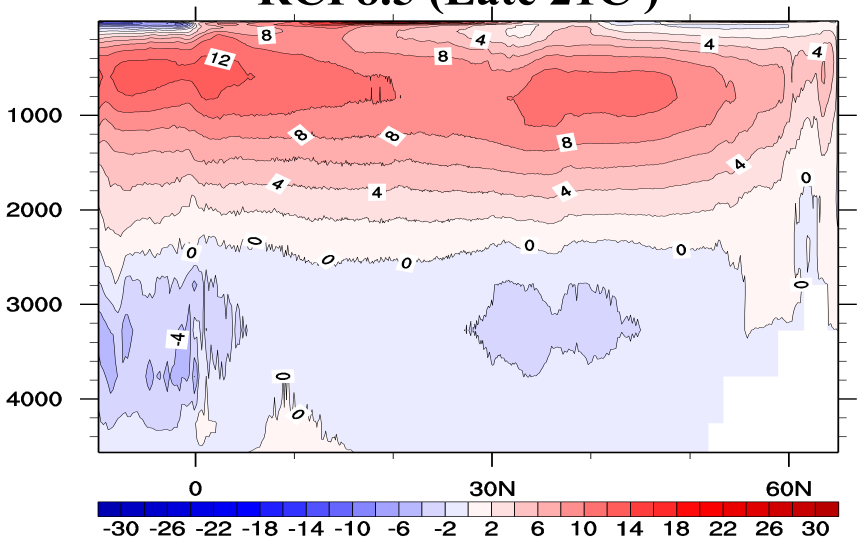
- Net surface heat flux in winter very well explains the SST dipole variability between GoM and CBN.
- The IAS dipole mode is largely forced by surface latent heat flux associated with changes in surface winds.
- After the peak of El Nino in winter, cold SST anomalies usually develop in GoM and warm 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.

Dynamic Downscaling of IPCC-AR5 projections

Historical (Late 20C)

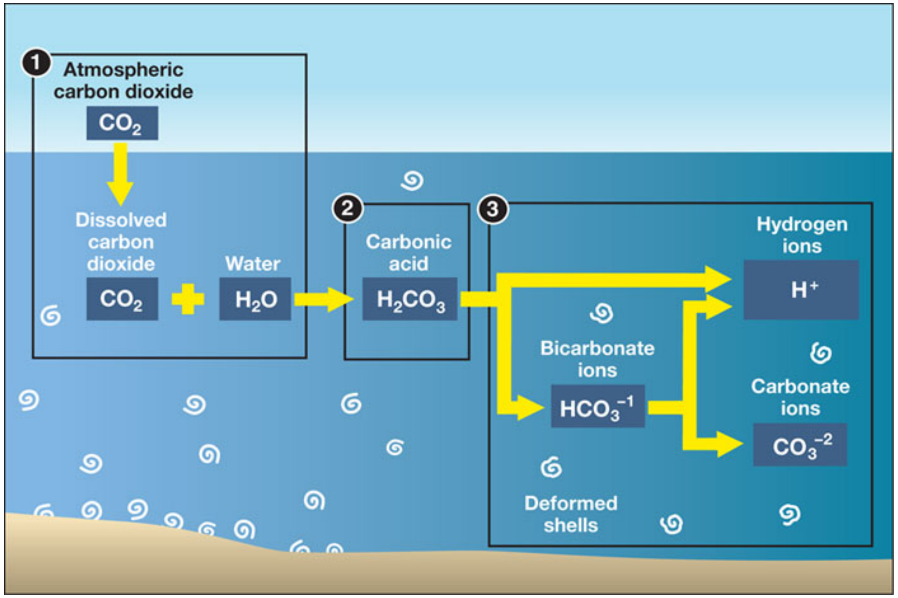


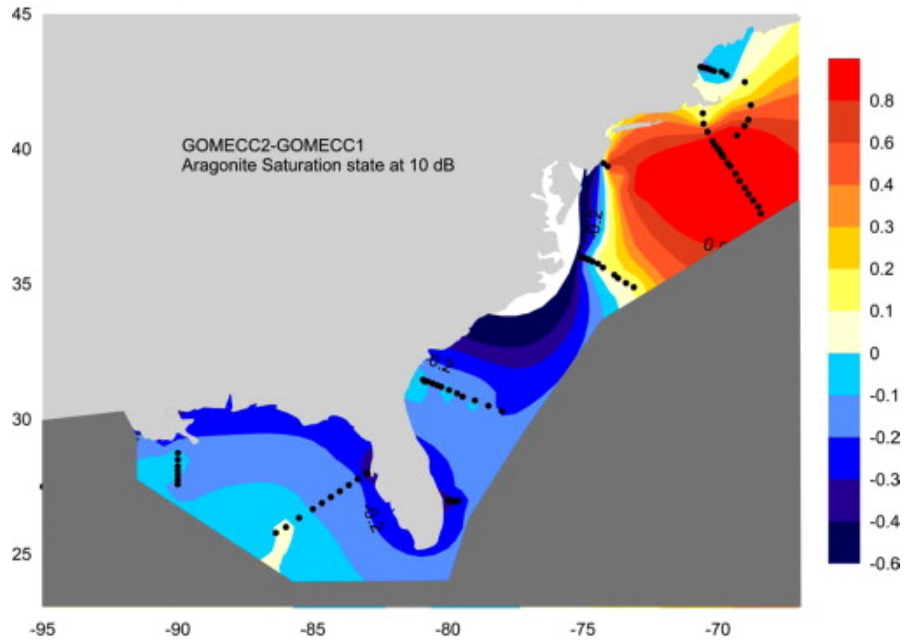
RCP8.5 (Late 21C)



- 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.

Dynamic Downscaling of IPCC-AR5 projections





- The first (2007) and the second (2012) GOMECC cruises showed measurable temporal pH and aragonite saturation state (Ω_{ar}) changes in the East and Gulf coast of the U.S
- The expected 2% average decrease in Ω_{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