Project Title: **Variability and Predictability of the Atlantic Warm Pool and Its Impacts on Extreme Events in North America**

PIs: Sang-Ki Lee (Lead-PI)
Institutions: NOAA/AOML
Report Year: FY2016 (Final Report)

1. Changes in PIs:

1) Chunzai Wang, the lead PI, left NOAA/AOML in 2016. He is no longer serves as a PI. Sang-Ki Lee (NOAA/AOML) served as the lead PI during the remaining period of the project.
2) A co-PI, David Enfield retired in 2016. He is no longer serve as a co-PI.

2. Results and Accomplishments

Two specific areas of proposed work are (1) diagnosing the CMIP5 outputs to assess model biases near the AWP region and to understand their skill in simulating the mechanisms and climate impacts of AWP variability, and (2) performing coupled model experiments using CESM1 (also called CCSM4) and analyzing the Climate Forecast System version 2 (CFSv2) reforecasts to assess and improve predictability of the AWP and its impacts on climate and extreme events such as hurricanes, flood and drought in North America.

Here, we briefly describe the following 12 achievements:

1) Multidecadal ocean temperature and salinity variability in the tropical North Atlantic: linking with the AMO, AMOC, and subtropical cell
2) Multidecadal North Atlantic sea surface temperature and Atlantic meridional overturning circulation variability in CMIP5 historical simulations
3) Inhomogeneous influence of the Atlantic warm pool on United States precipitation
4) Response of freshwater and sea surface salinity to variability of the Atlantic warm pool
5) Atlantic warm pool variability in the CMIP5 simulations.
6) Remote effect of the model cold bias in the tropical North Atlantic on the warm bias in the tropical southeastern Pacific
7) A global perspective on CMIP5 climate model biases
8) A virtual workshop "*Observing & Modeling Climate Variability in the Intra-Americas Seas & Impacts on the Continental Americas & the Caribbean*"
9) Special iussue of CLIVAR Variations (winter 2016) "*The Intra-Americas Seas: Vital to regional climate & extreme events*"
10) The Intra-Americas Sea: Challenges and opportunities to understand North American climate variability and predictability (White paper)
11) Past and future climate variability in the Intra-Americas Sea
12) Contributions of the atmosphere–land and ocean–sea ice model components to the tropical Atlantic SST bias in CESM1

2.1 Multidecadal ocean temperature and salinity variability in the tropical North Atlantic: linking with the AMO, AMOC, and subtropical cell

Summary

The Atlantic multidecadal oscillation (AMO) is characterized by the sea surface warming (cooling) of the entire North Atlantic during its warm (cold) phase. Both observations and most of the phase 5 of the Coupled Model Intercomparison Project (CMIP5) models also show that the warm (cold) phase of the AMO is associated with a surface warming (cooling) and a subsurface cooling (warming) in the tropical North Atlantic (TNA). It is further shown that the warm phase of the AMO corresponds to a strengthening of the Atlantic meridional overturning circulation (AMOC) and a weakening of the Atlantic subtropical cell (STC), which both induce an anomalous northward current in the TNA subsurface ocean. Because the mean meridional temperature gradient of the subsurface ocean is positive because of the temperature dome around 9 degrees N, the advection by the anomalous northward current cools the TNA subsurface ocean during the warm phase of the AMO. The opposite is true during the cold phase of the AMO. It is concluded that the anticorrelated ocean temperature variation in the TNA associated with the AMO is caused by the meridional current variation induced by variability of the AMOC and STC, but the AMOC plays a more important role than the STC. Observations do not seem to show an obvious anticorrelated salinity relation between the TNA surface and subsurface oceans, but most of CMIP5 models simulate an out-of-phase salinity variation. Similar to the temperature variation, the mechanism is the salinity advection by the meridional current variation induced by the AMOC and STC associated with the AMO.

Wang, C., and L. Zhang (2013), Multidecadal ocean temperature and salinity variability in the tropical North Atlantic: Linking with the AMO, AMOC, and subtropical cell, *J. Climate*, *26*, 6137-6162.

2.2 Multidecadal North Atlantic sea surface temperature and Atlantic meridional overturning circulation variability in CMIP5 historical simulations

Summary

In this work, simulated variability of the Atlantic Multidecadal Oscillation (AMO) and the Atlantic Meridional Overturning Circulation (AMOC) and their relationship has been investigated. For the first time, climate models of the Coupled Model Intercomparison Project phase 5 (CMIP5) provided to the Intergovernmental Panel on Climate Change Fifth Assessment Report (IPCC-AR5) in historical simulations have been used for this purpose. The models show the most energetic variability on the multidecadal timescale band both with respect to the AMO and AMOC, but with a large model spread in both amplitude and frequency. The relationship between the AMO and AMOC in most of the models resembles the delayed advective oscillation proposed for the AMOC on multidecadal timescales. A speed up (slow down) of the AMOC is in favor of generating a warm (cold) phase of the AMO by the anomalous northward (southward) heat transport in the upper ocean, which reversely leads to a weakening (strengthening) of the AMOC through changes in the meridional density gradient after a delayed time of ocean adjustment. This suggests that on multidecadal timescales the AMO and AMOC are related and interact with each other.

Zhang, L., and C. Wang (2013), Multidecadal North Atlantic sea surface temperature and Atlantic meridional overturning circulation variability in CMIP5 historical simulations, *J. Geophys. Res.*, *118*, 5772-5791.

2.3 Inhomogeneous influence of the Atlantic Warm Pool on United States precipitation

Summary

On interannual time scales, the warming of the Atlantic warm pool (AWP) is associated with a tripole sea surface temperature (SST) pattern in the North Atlantic and leads to more rainfall in the central and eastern US. On decadal-to-multidecadal time scales, the AWP warming corresponds to a basin-wide warming pattern and results in less precipitation in the central and eastern US. The inhomogeneous relationship between the AWP warming and US rainfall on different time scales is largely due to the sign of mid-latitude SST anomaly. The negative mid-latitude SST anomaly associated with the tripole pattern may enhance the low sea level pressure over the northeastern North American continent and also enhance the barotropic response there of the AWP-induced barotropic Rossby wave. This strengthened low pressure system, which is not exhibited when the warming is basin-wide, results in a different moisture transport variation and thus the rainfall pattern over the United States.

Liu, H., C. Wang, S.-K. Lee, D. Enfield (2015), Inhomogeneous influence of the Atlantic warm pool on United States precipitation, *Atmos. Sci. Lett.*, *16*, 63-69.

2.4 Response of freshwater and sea surface salinity to variability of the Atlantic warm pool

Summary

The response of freshwater flux and sea surface salinity (SSS) to the Atlantic warm pool (AWP) variations from seasonal to multidecadal time scales is investigated by using various reanalysis products and observations. All of the datasets show a consistent response for all time scales: A large (small) AWP is associated with a local freshwater gain (loss) to the ocean, less (more) moisture transport across Central America, and a local low (high) SSS. The moisture budget analysis demonstrates that the freshwater change is dominated by the atmospheric mean circulation dynamics, while the effect of thermodynamics is of secondary importance. Further decomposition points out that the contribution of the mean circulation dynamics primarily arises from its divergent part, which mainly reflects the wind divergent change in the low level as a result of SST change. In association with a large (small) AWP, warmer (colder) than normal SST over the tropical North Atlantic can induce anomalous low-level convergence (divergence), which favors anomalous ascent (decent) and thus generates more (less) precipitation. On the other hand, a large (small) AWP weakens (strengthens) the trade wind and its associated westward moisture transport to the eastern North Pacific across Central America, which also favors more (less) moisture residing in the Atlantic and hence more (less) precipitation. The results imply that variability of freshwater flux and ocean salinity in the North Atlantic associated with the AWP may have the potential to affect the Atlantic meridional overturning circulation.

Wang, C., L. Zhang, S.-K. Lee (2013), Response of freshwater and sea surface salinity to variability of the Atlantic warm pool, *J. Climate*, *26*, 1249-1267, doi:10.1175/JCLI-D-12-00284.1.

2.5 Atlantic warm pool variability in the CMIP5 simulations

Summary

This study investigates Atlantic warm pool (AWP) variability in the historical run of 19 coupled general circulation models (CGCMs) submitted to phase 5 of the Coupled Model Intercomparison Project (CMIP5). As with the CGCMs in phase 3 (CMIP3), most models suffer from the cold SST bias in the AWP region and also show very weak AWP variability as represented by the AWP area index. However, for the seasonal cycle the AWP SST bias of model ensemble and model sensitivities are decreased compared with CMIP3, indicating that the CGCMs are improved. The origin of the cold SST bias in the AWP region remains unknown, but among the CGCMs in CMIP5 excess (insufficient) high-level cloud simulation decreases (enhances) the cold SST bias in the AWP region through the warming effect of the high-level cloud radiative forcing. Thus, the AWP SST bias in CMIP5 is more modulated by an erroneous radiation balance due to misrepresentation of high-level clouds rather than lowlevel clouds as in CMIP3. AWP variability is assessed as in the authors' previous study in the aspects of spectral analysis, interannual variability, multidecadal variability, and comparison of the remote connections with ENSO and the North Atlantic Oscillation (NAO) against observations. In observations the maximum influences of the NAO and ENSO on the AWP take place in boreal spring. For some CGCMs these influences erroneously last to late summer. The effect of this overestimated remote forcing can be seen in the variability statistics as shown in the rotated EOF patterns from the models. It is concluded that the NCAR Community Climate System Model, version 4 (CCSM4), the Goddard Institute for Space Studies (GISS) Model E, version 2, coupled with the Hybrid Coordinate Ocean Model (HYCOM) ocean model (GISS-E2H), and the GISS Model E, version 2, coupled with the Russell ocean model (GISS-E2R) are the best three models of CMIP5 in simulating AWP variability.

Liu, H., C. Wang, S.-K. Lee and D. B. Enfield (2013), Atlantic warm pool variability in the CMIP5 simulations, *J. Climate*, *26*, 5315-5336, doi: http://dx.doi.org/10.1175/JCLI-D-12-00556.1.

2.6 Remote effect of the model cold bias in the tropical North Atlantic on the warm bias in the tropical southeastern Pacific

Summary

Most state-of-the-art climate models show significant systematic biases in the tropical southeastern Pacific (SEP) and tropical North Atlantic (TNA). These biases manifest themselves as the sea surface temperature (SST) in the SEP being too warm and the SST in the TNA being too cold. That is, as the cold SST biases appear in the TNA, the warm SST biases also occur in the SEP. This indicates that if climate models cannot succeed in simulating the TNA variability, they will also fail at least partially in the SEP. Our coupled model experiments show that the cold SST bias in the TNA results in a weakening of the Hadley-type circulation from the TNA to the SEP. This meridional circulation reduces the South Pacific subtropical anticyclone and the associated subsidence, which in turn leads to a reduction of low clouds, a weakening of the easterly trade wind, and thus an increase of the warm SST bias in the SEP.

Zhang, L. C. Wang, Z. Song, S.-K. Lee (2014), Remote effect of the model cold bias in the tropical North Atlantic on the warm bias in the tropical southeastern Pacific. *J. Adv. Model. Earth Syst*., *6*, 1016-1026, doi:10.1002/2014MS000338.

2.7 A global perspective on CMIP5 climate model biases

Summary

The Intergovernmental Panel on Climate Change's Fifth Assessment Report largely depends on simulations, predictions and projections by climate models1. Most models, however, have deficiencies and biases that raise large uncertainties in their products. Over the past several decades, a tremendous effort has been made to improve model performance in the simulation of special regions and aspects of the climate system2, 3, 4. Here we show that biases or errors in special regions can be linked with others at far away locations. We find in 22 climate models that regional sea surface temperature (SST) biases are commonly linked with the Atlantic meridional overturning circulation (AMOC), which is characterized by the northward flow in the upper ocean and returning southward flow in the deep ocean. A simulated weak AMOC is associated with cold biases in the entire Northern Hemisphere with an atmospheric pattern that resembles the Northern Hemisphere annular mode. The AMOC weakening is also associated with a strengthening of Antarctic Bottom Water formation and warm SST biases in the Southern Ocean. It is also shown that cold biases in the tropical North Atlantic and West African/Indian monsoon regions during the warm season in the Northern Hemisphere have interhemispheric links with warm SST biases in the tropical southeastern Pacific and Atlantic, respectively. The results suggest that improving the simulation of regional processes may not suffice for overall better model performance, as the effects of remote biases may override them.

Wang, C., L. Zhang, S.-K. Lee, L. Wu and C. R. Mechoso (2014), A global perspective on CMIP5 climate model biases, *Nature Clim. Change*, *4*, 201-205, doi:10.1038/nclimate2118.

2.8. A virtual workshop on "*Observing & Modeling Climate Variability in the Intra-Americas Seas & Impacts on the Continental Americas & the Caribbean*"

Summary

Chunzai Wang (the former Lead-PI), Vasu Misra (FSU), German Poveda (National University of Colombia), Erick Rivera Fernandez (University of Costa Rica) and Yolande Serra (University of Washington) co-hosted a virtual workshop on "Observing & Modeling Climate Variability in the Intra-Americas Seas & Impacts on the Continental Americas & the Caribbean", which was held during September 9-11, 2016 (https://usclivar.org/meetings/2015-iasclip-virtual-workshop). Both oral and poster presentations were solicited in this unique online format, which allowed participants from different regions to join remotely and interact in meaningful ways. The purpose of the virtual workshop is to provide a platform to facilitate discussions to understand local and remote atmospheric and oceanic processes that lead to variations in the warm pool in the Intra-Americas Seas (IAS), the dynamics and physics of the teleconnections of the IAS with the continental monsoons of the Americas and weather extremes spanning across time scales, and the opportunities for translating understanding to improved monitoring and prediction of the variations and change in the IAS and their associated impacts. The virtual workshop also address model biases in the region and identify new technology or platforms to improve the rapidly deteriorating observational network of the atmosphere, to bolster ocean observations, and to enhance capacity building in the region.

The virtual workshop was organized around six sessions that cover observational and modeling studies of the IAS spanning intra-seasonal to secular time scales including extremes. The aim of

these sessions is to assess the current limitations of both the observational networks and model performance for the region, report on the current state of our understanding of the important physical processes in both the atmosphere and ocean across weather and climate time scales, and promote new ideas for a regional observing system and modeling studies aimed at improving understanding and predictive skill on intra-seasonal to secular time scales. During the three-day meeting, 20 talks and 23 posters were presented, followed by four pannel discusisons.

The IASCLiP virtual workshop agenda, the titles and abstracts of the presentations can be found in the link below. Each poster presentation (located below the agenda) has an abstract and PDF of the poster. Please view the posters and comments (or questions) for the author in the comment box:
https://usclivar.org/meetings/2015-iasclip-virtual-workshop-agenda-page

2.9 Special iussue of CLIVAR Variations (winter 2016) "*The Intra-Americas Seas: Vital to regional climate & extreme events*"

Summary

Chunzai Wang (former lead PI) and Vasu Misra (FSU) served as the Guest editor of the special issue of CLIVAR Variations (winter 2016 issue). Five articles from the IASLip virtual workship were included in this issue, which clearly attest to the vital role of the Intra-Americas Sea (IAS) in climate variations of the surrounding North American continental region stretching from the Caribbean to the Mesoamerica and across the Midwest Plains to the northeast US.

The special issue of CLIVAR Variations can be found here:
https://usclivar.org/sites/default/files/documents/2016/Variations2016Winter_0.pdf

2.10 Intra-Americas Sea: Challenges and opportunities to understand North American climate variability and predictability (White paper)

Summary

Chunzai Wang (former lead-PI) and Sang-Ki Lee (lead-PI) participated in a whitepaper "Intra-Americas Sea: Challenges and opportunities to understand North American climate variability and predictability"

Misra, V, C. Wang , Y. Serra, K. Karnauskas , E. M. Ellinor, J. Sheinbaum, P. Chang, S.-K. Lee, B. Rosenheim, B. Kirtman, D. Enfield, E. D. Maloney, A. Kumar, G. Poveda, R. Fu, J. Jouanno, S. Berthet, A. Mishra, M. Bourassa, J. Candela, and J. Ochoa, 2016 The Intra-Americas Sea: Challenges and Opportunities to Understand North American Climate Variability and Predictability.
ftp.aoml.noaa.gov/phod/pub/sklee/projects/cpo_awp/bams_ias_final.pdf

2.11 Past and future climate variability in the Intra-Americas Sea

Summary

This study examines the potential impact of anthropogenic greenhouse warming 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.

This work was published in the Journal of Marine Systems in August 2015 and the winter 2016 issue of CLIVAR Variations, and also presented as a poster during the 2015 IASLip virtual workshop:

Liu, Y., S.-K. Lee, D. B. Enfield, B. A. Muhling, J. T. Lamkin, F. Muller-Karger and 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. Marine Syst., 148, 56-69, doi:10.1016/j.jmarsys.2015.01.007. http://www.aoml.noaa.gov/phod/Liu_et_al_2015_JMS.pdf

Liu, Y., S.-K. Lee, D. B. Enfield, B. A. Muhling, J. T. Lamkin, F. E. Muller-Karger, and M. A. Roffer, 2016: Past and future climate variability in the Intra-Americas Sea and its impact on the marine ecosystem and fisheries, US CLIVAR Variations, Vol. 14, No. 1, 27-32.

2.12 Contributions of the atmosphere–land and ocean–sea ice model components to the tropical Atlantic SST bias in CESM1

Summary

In order to identify and quantify intrinsic errors in the atmosphere–land and ocean–sea ice model components of the Community Earth System Model version 1 (CESM1) and their contributions to the tropical Atlantic sea surface temperature (SST) bias in CESM1, we propose a new method of diagnosis and apply it to a set of CESM1 simulations. Our analyses of the model simulations indicate that both the atmosphere–land and ocean–sea ice model components of CESM1 contain large errors in the tropical Atlantic. When the two model components are fully coupled, the intrinsic errors in the two components emerge quickly within a year with strong seasonality in their growth rates. In particular, the ocean–sea ice model contributes significantly in forcing the eastern equatorial Atlantic warm SST bias in early boreal summer. Further analysis shows that the upper thermocline water underneath the eastern equatorial Atlantic surface mixed layer is too warm in a stand-alone ocean–sea ice simulation of CESM1 forced with observed surface flux fields, suggesting that the mixed layer cooling associated with the entrainment of upper

thermocline water is too weak in early boreal summer. Therefore, although we acknowledge the potential importance of the westerly wind bias in the western equatorial Atlantic and the low-level stratus cloud bias in the southeastern tropical Atlantic, both of which originate from the atmosphere–land model, we emphasize here that solving those problems in the atmosphere–land model alone does not resolve the equatorial Atlantic warm bias in CESM1.

Song, Z. S.-K. Lee, C. Wang, B. Kirtman and F. Qiao (2015), Contributions of the atmosphere-land and ocean-sea ice model components to the tropical Atlantic SST bias in CESM1, *Ocean Modelling*, 96, 280-290, doi:10.1016/j.ocemod.2015.09.008.

3. Highlights of Accomplishments

1) Identified the physical mechanisms that link the tropical Atlantic Ocean temperature and Salinity with the AMO, AMOC, and subtropical cell (Wang and Zhang, 2013);
2) Showed that the relationship between the AMO and AMOC in most of the CMIP5 models can be explained by using the delayed advective oscillation (Zhang and Wang, 2013);
3) Showed that, in CMIP5 models, the cold SST bias in the tropical North Atlantic and the warm SST bias in the Southeast Pacfic are dynamically connected through Hadley-type circulation (Zhang et al., 2014);
4) Showed that regional sea surface temperature (SST) biases in CMIP5 models are commonly linked to the AMOC bias (Wang et al,, 2014)
5) Showed that the western boundary current system in the Intra Americas Seas, including the Caribbean Current, Yucatan Current and Loop Current, are likely to be reduced by 20-25% during the 21st century, due to the similar rate of reduction in the AMOC (Liu et al., 2015).
6) Organized and hosted a virtual workshop on "*Observing & Modeling Climate Variability in the Intra-Americas Seas & Impacts on the Continental Americas & the Caribbean*"
7) Co-edited a special iussue of CLIVAR Variations (winter 2016) "*The Intra-Americas Seas: Vital to regional climate & extreme events*"

4. Publications and Presentations

Domingues, R., G. Goni, F. Bringas, **S.-K. Lee**, H.-S. Kim, G. Halliwell, J. Dong, J. Morell and L. Pomales, 2015: Upper-ocean response to Hurricane Gonzalo (2014): salinity effects revealed by sustained and targeted observations from underwater gliders. *Geophys. Res. Lett.*, *42*, 7131-7138, doi:10.1002/2015GL065378.

Liang, Y.-C., J.-Y. Yu, M.-H. Lo, and **C. Wang**, 2015: The changing influence of El Niño on the Great Plains low-level jet. *Atmo.Sci.Lett*., 16(4):512-517, (doi: 10.1002/asl.590).

Liu, H., **C. Wang**, **S.-K. Lee** and **D. B. Enfield** (2013), Atlantic warm pool variability in the CMIP5 simulations, *J. Climate*, *26*, 5315-5336, doi: http://dx.doi.org/10.1175/JCLI-D-12-00556.1.

Liu, H., **C. Wang**, **S.-K. Lee**, **D. Enfield** (2015), Inhomogeneous influence of the Atlantic warm pool on United States precipitation, *Atmos. Sci. Lett*., *16*, 63-69.

Liu, Y., S**.-K. Lee**, **D. B. Enfield**, B. A. Muhling, J. T. Lamkin, F. Muller-Karger and 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. Marine Syst., 148, 56-69, doi:10.1016/j.jmarsys.2015.01.007.

Liu, Y., **S.-K. Lee**, **D. B. Enfield**, B. A. Muhling, J. T. Lamkin, F. E. Muller-Karger, and M. A. Roffer, 2016: Past and future climate variability in the Intra-Americas Sea and its impact on the marine ecosystem and fisheries, US CLIVAR Variations, Vol. 14, No. 1, 27-32.

Moon, I.-J., S.-H. Kim, and **C. Wang**, 2015: Reply: El Niño and intense tropical cyclones. Nature, 526(7575):E4-E5 (doi:10.1038/nature15546)

Song, Z. **S.-K. Lee**, **C. Wang**, B. Kirtman and F. Qiao, 2015: Contributions of the atmosphere-land and ocean-sea ice model components to the tropical Atlantic SST bias in CESM1. Ocean Modelling, 96, 280-290, doi:10.1016/j.ocemod.2015.09.008.

Wang, C., L. Zhang, and **S.-K. Lee** (2013), Response of freshwater and sea surface salinity to variability of the Atlantic warm pool, *J. Climate*, *26*, 1249-1267, doi:10.1175/JCLI-D-12-00284.1.

Wang, C., and L. Zhang (2013), Multidecadal ocean temperature and salinity variability in the tropical North Atlantic: Linking with the AMO, AMOC, and subtropical cell, *J. Climate*, *26*, 6137-6162.

Wang, C., L. Zhang, **S.-K. Lee**, L. Wu and C. R. Mechoso (2014), A global perspective on CMIP5 climate model biases, *Nature Clim. Change*, *4*, 201-205, doi:10.1038/nclimate2118.

Zhang, L., and **C. Wang** (2013), Multidecadal North Atlantic sea surface temperature and Atlantic meridional overturning circulation variability in CMIP5 historical simulations, *J. Geophys. Res*., *118*, 5772-5791.

Zhang, L. **C. Wang**, Z. Song, and **S.-K. Lee** (2014), Remote effect of the model cold bias in the tropical North Atlantic on the warm bias in the tropical southeastern Pacific. *J. Adv. Model. Earth Syst*., *6*, 1016-1026, doi:10.1002/2014MS000338.

5. PI Contact Information

Dr. Sang-Ki Lee (Lead-PI)
NOAA AOML
4301 Rickenbacker Causeway
Miami, FL 33149
Email) sang-ki.lee@noaa.gov
Phone) 305-361-4521

6. Budget for Coming Year

N/A