

PROJECT PROGRESS REPORT (FINAL)

1. Header

Project title

Collaborative Research: The American Midsummer Drought: Causal Mechanisms and Seasonal-to-Interannual Predictability

Principal investigators

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Program

National Oceanic and Atmospheric Administration (NOAA) / Climate Program Office (CPO) / Modeling, Analysis, Predictions and Projections (MAPP) *

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Award number

NA10OAR0110239 GC10-750a Woods Hole Oceanographic Institution

Related awards

NA10OAR4310253 GC10-750b University of Maryland (Busalacchi)
NA10OAR4310252 GC10-750c Columbia University (Giannini, Seager)

2. Results and Accomplishments

Preamble

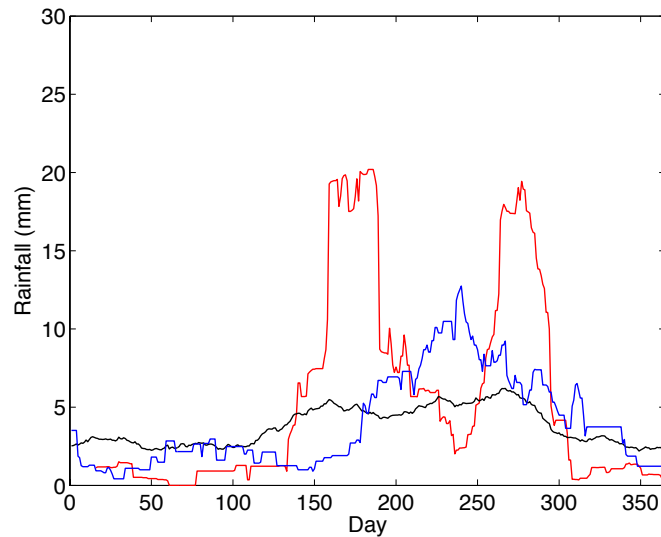
The overarching goal of our project was a better understanding of the seasonal cycle of rainfall in the Intra-Americas region, ultimately contributing to seasonal-to-interannual climate predictability for the region. In particular, we are interested in the basic causal mechanism for the break in the rainy season known as the midsummer drought (MSD), as well as its interannual variability.

The problem is well illustrated in the three plots of daily rainfall amounts from Cancun, Mexico shown to the right: one for the climatology (black line) and one for two different years within the same decade (red and blue lines). While Cancun exhibits a robust climatological midsummer drought, a given year may be marked by a particularly strong midsummer drought, while the next year may bring the extreme opposite. These results were presented in an invited talk at the 2013 AGU Meeting of the Americas (in Cancun), inspiring lively discussions of mechanisms and impacts.

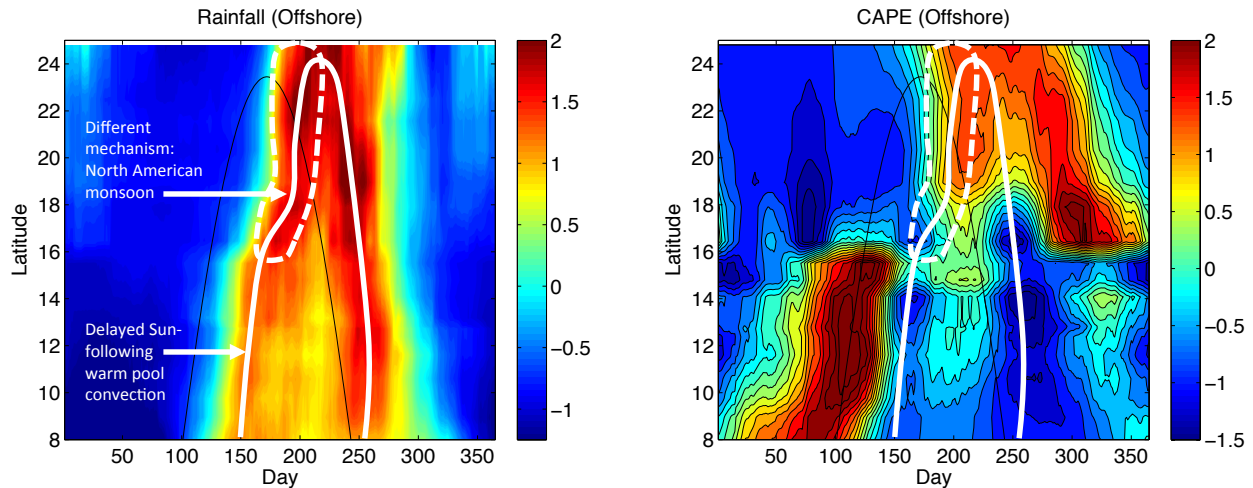
Our work over the course of the three-year project stayed true to the overarching goal, while pursuing interesting new areas and opportunities as they emerged. For example, following our initial paper on the underlying mechanism for the climatological midsummer drought (see 2a), the formation of the MAPP CMIP5 Task Force enabled us to allocate some of our time and attention toward understanding how well IPCC AR5/CMIP5 global coupled models represent the midsummer drought, and how they predict the midsummer drought will change in the future in response to anthropogenic forcing (see 2c). Related work by the PI on the Hadley circulation prompted connections between the global atmospheric circulation and its changes to be linked with the hydroclimate of this region including the midsummer drought (see 2d). Additionally, the Central American cordillera was brought into focus as a possible conduit linking high-latitude atmospheric variability with decadal variability in the tropical Pacific sector (see 2e). Finally, a NOAA Climate & Global Change Postdoctoral Fellow (Dr. Daniel Griffin) has recently joined our group at WHOI in August 2013 and is using many of these results as a springboard for developing and expanding his research program (see 2f).

a. Core mechanisms

The mechanism, summarized in the figure below, relates the latitudinal dependence of the two climatological precipitation maxima to the biannual crossing of the solar declination (SD), driving two peaks in convective instability and hence rainfall. The extent of the seasonal poleward excursion of the ITCZ at any longitude is likely influenced by the land surface, with Central America and Mexico having optimal characteristics for a large northward excursion during summer. Along the descending SD, the exaggerated ITCZ excursion returns equatorward

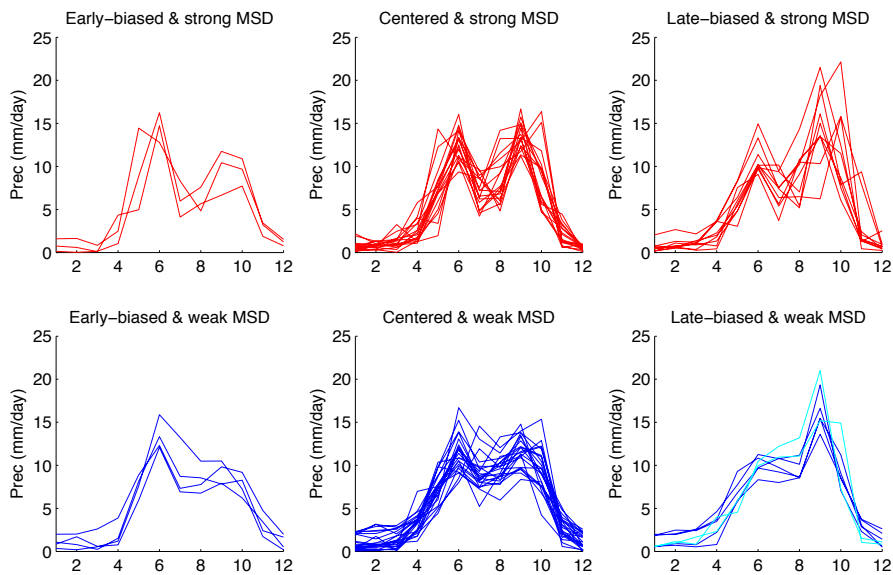


at the same pace and with appropriate lag to the solar declination. Meanwhile, the still-warm SSTs continue to supply enhanced moisture to the daytime thermal circulation and further enhance coastal rainfall by virtue of being on the periphery of widespread increased maritime convection and tropical storms.



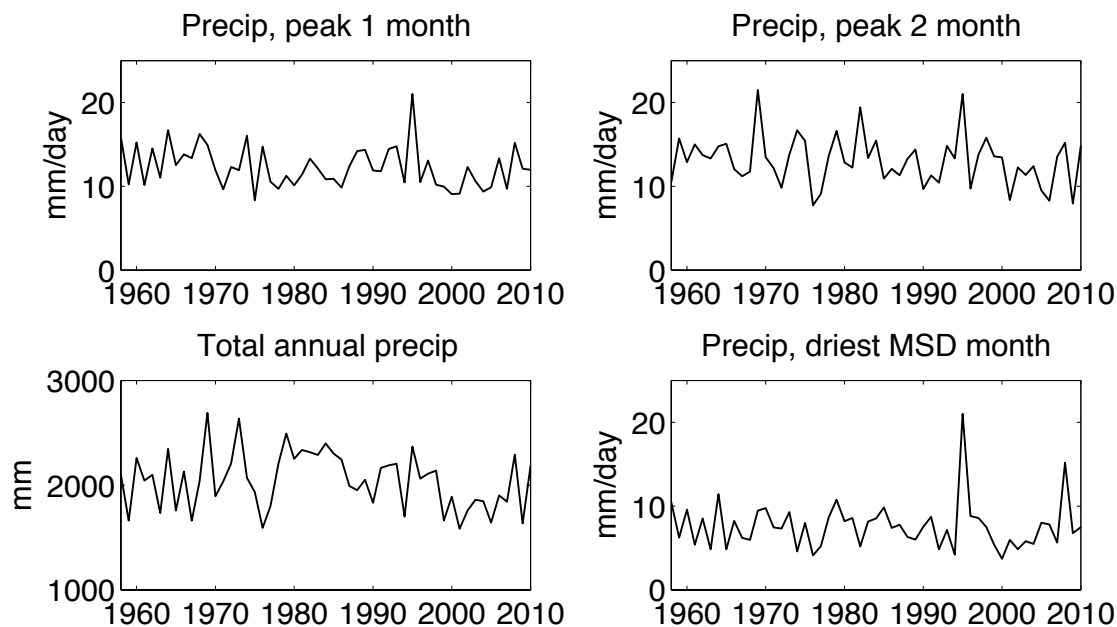
b. Interannual variability

Since FY12, we have continued to make progress in characterizing the observed interannual variability of the key features of the MSD by analyzing monthly gridded observations spanning 1948–2011 (NOAA PREC/L; Chen *et al.* 2002) and daily station data spanning 1979–1990 (GHCN v.1; Vose *et al.* 1992). While the MSD is a very robust feature of the hydroclimate of the region, in particular the Pacific coast of Central America and southern Mexico, there is clearly a significant amount of variability in both the annual total precipitation and the character of the MSD from year to year.



The character of the MSD in a given year can be objectively sorted according to whether the first peak was stronger, the second peak was stronger, or both peaks were roughly equivalent. When we sort the 64-year observed record in this way (see figure above), we find that the most frequent occurrence is a centered MSD (both peaks roughly equal), and that an early-biased MSD is quite rare. Furthermore, there is no apparent relationship between early vs. late-biased structure and whether the MSD was stronger vs. weaker than normal.

It is possible to explore whether there is inherent predictability in the MSD by evaluating interannual relationships between total annual precipitation, precipitation during the peak months, and precipitation during the height of the MSD (see figure below). For example, there is a significant correlation ($r=0.5$, 99%) between precipitation during the first peak in the seasonal cycle at 91°W , 14°N and that during the driest month during the MSD ($r=0.5$, 99%). Large-scale drivers of interannual climate variability (e.g., ENSO) likely play an important role in this apparent potential predictability.

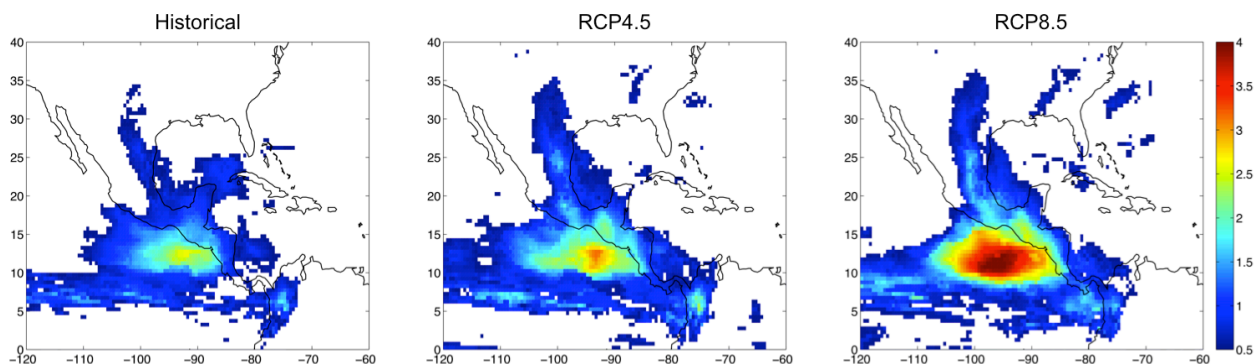


The spatiotemporal evolution of the MSD may also be leveraged to evaluate potential predictability on the seasonal-to-interannual time scale, as it was shown in Karnauskas *et al.* (2013) that the MSD is a robust climatological feature that propagates northward along the Pacific coast of Central America into southern Mexico at the Tropic of Cancer, then returns along the coast toward the equator.

c. CMIP5 evaluations and projections

During FY13, a significant amount of our interest and attention has grown toward collaborations within the MAPP CMIP5 Task Force. Our specific contributions include evaluating the ability of state-of-the-art climate models to simulate the midsummer drought phenomenon and assessing their future projections thereof under various radiative forcing pathways (global warming). We have contributed to Papers II and III (see section 4 for complete

references). To summarize, despite biases in overall summertime rainfall amounts, CMIP5 models capture the essence of the MSD over much of the Inter-Americas. Furthermore, consistent with seasonal rainfall projections, the CMIP5 multi-model mean predicts a robust strengthening of the MSD where it exists today (see figure below). This is clearly related to seasonally dependent changes in mean precipitation rates. During each of the summertime months, the east Pacific ITCZ is projected to shift southward in concert with a drying over the east Pacific warm pool (EPWP), Central America/southern Mexico, and the Caribbean with enhanced drying over the major Caribbean islands of Cuba, Hispaniola, and Jamaica. The strongest drying is projected to occur during July and August, which are the months during which the MSD occurs in many regions throughout the Inter-Americas region. Western Mexico is projected to experience wetter conditions during the late summer (September).



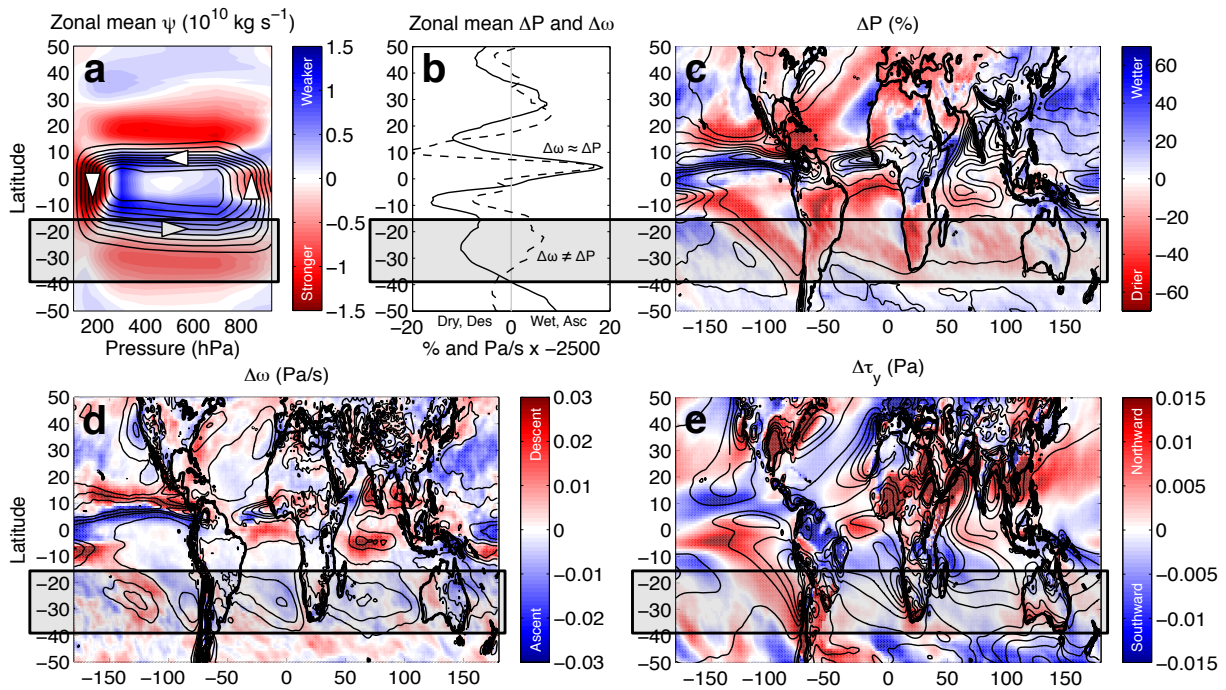
As a result of discussions at the 2013 AGU Meeting of the Americas, we are also now forming new collaborations with Yolande Serra, Eric Maloney, and Chunzai Wang to understand linkages between the strengthening amplitude of the midsummer drought and changes in east Pacific synoptic wave activity.

d. Linkages with the Hadley circulation

In recognition of the potentially important and interesting linkages between the regional mechanisms giving rise to the midsummer drought (and future changes thereof) and the larger-scale atmospheric general circulation, we have also begun to relate the midsummer drought and, especially, mechanisms for its future projected strengthening, to the Northern Hemisphere summertime Hadley circulation (HC) and subtropical drying in general. The Hadley cell is one of the most basic aspects of the Earth's atmospheric circulation, and is of global importance because its strength and structure dictate the climatological wet and dry zones of the world. Understandably, a great deal of attention is now being paid to how the Hadley circulation may respond to global warming and what this means for hydroclimate and impacts on subsistence farming across the tropics, including Central America and Mexico.

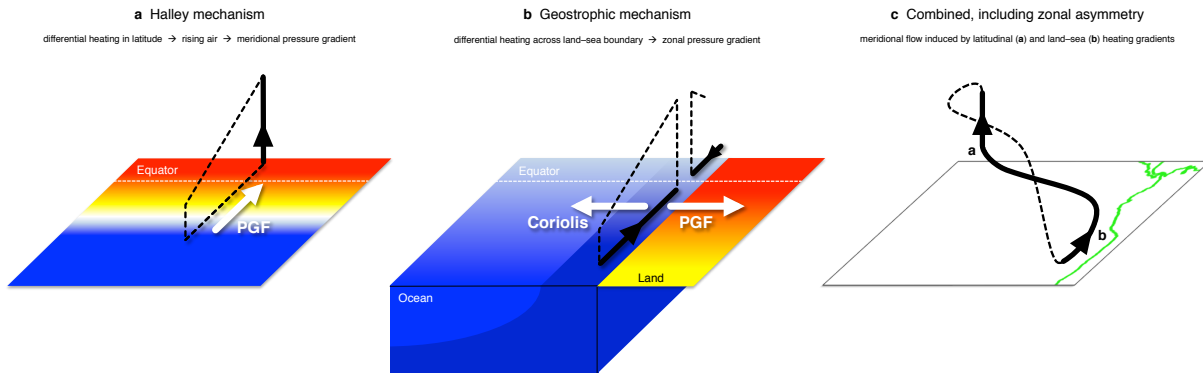
To illustrate the link between HC changes and regional precipitation trends, using an ensemble of six simulations by one such model, the Community Climate System Model version 4 (CCSM4), we show the mean ensemble changes over the 21st Century in climatic fields in response to 8.5 W m⁻² radiative forcing by long-lived greenhouse gases. Panel a of the figure below depicts the climatological austral wintertime HC in terms of mean meridional overturning streamfunction (ψ) along with its projected change. While the descending branch of the cell expands poleward (red shading along the outermost mean contours), it also spreads inward (blue

shading along the innermost mean contours). Since vertical velocity (ω) is proportional to the meridional gradient of streamfunction ($\partial\psi/\partial y$), the broadening of the descending branch implies weaker $\partial\psi/\partial y$ and thus dictates weaker descent by continuity (panel b). North of $\sim 15^\circ\text{S}$, the change in vertical velocity ($\Delta\omega$) and change in precipitation (ΔP) covary: i.e., where ω is trending toward ascent (descent), precipitation trends toward wetter (drier) conditions. However, in the latitude band surrounding the poleward limit of the descending branch of the HC (15–40 $^\circ\text{S}$), substantial drying ensues despite a weakening of the large-scale descent (panel b). The drying in this latitude band is far from zonally uniform; much of the drying extends in a northwestward band from 35 $^\circ\text{S}$ at the eastern coastline of the ocean basins towards the equator and includes the oceanic dry zones typically characterized by large-scale descent (panel e), despite ω trends that would support the opposite (panel d).



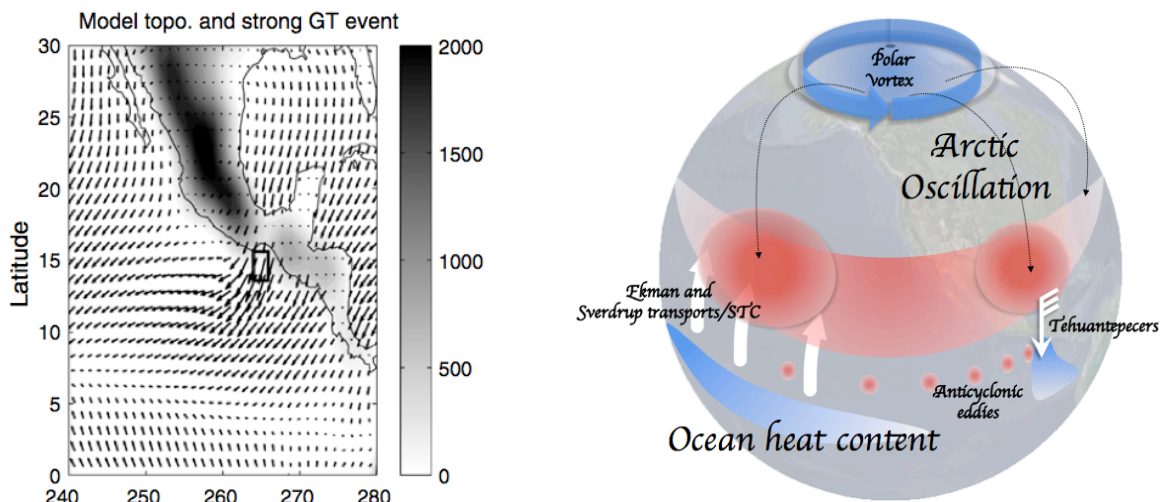
Upon deeper investigation, we found that the geostrophic contribution to the meridional flow near the poleward limit of the descending branch of the HC highlights the role of zonal pressure gradients in driving the Earth’s atmospheric meridional overturning. We demonstrated that a substantial part of the Earth’s HC is driven by zonal pressure gradients that only exist due to continental heating and air-sea interaction. The interplay of different mechanisms – from those envisioned by Edmund Halley in 1686 to that proposed here – is portrayed schematically in the figure below. The Halley view of the HC mechanism fundamentally relies on the meridional pressure gradient arising from differential heating in latitude and rising air in the deep tropics (panel a). This mechanism likely dominates within 5–10 $^\circ$ of the equator and in the open ocean sufficiently far from continental coastlines. It must also explain the cross-equatorial component of the HC, as well as its seasonal reversal. Poleward of 5–10 $^\circ$ and near continental coastlines, strong equatorward geostrophic flow dominates the meridional velocity field (panel b). This mechanism cannot explain the HC crossing into the summer hemisphere as the implied geostrophic flow immediately reverses direction across the equator, but does explain the

matching cell of opposite sign in the summer hemisphere. In the Pacific sector, this mechanism and its seasonal evolution are surprisingly well aligned with the seasonal migration of regional atmospheric circulation described in Karnauskas *et al.* (2013, *Atmósfera*).



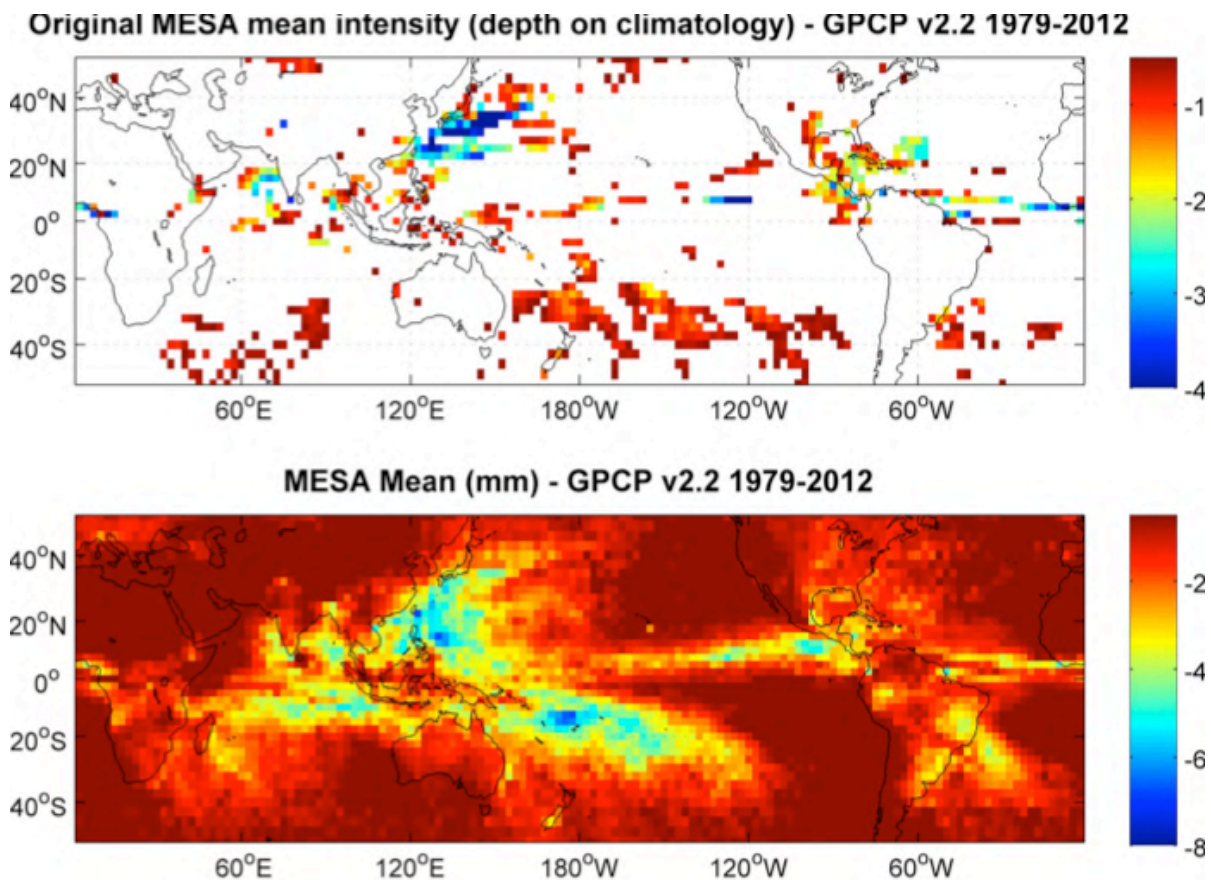
e. Role as a conduit for decadal variability

Based on previous observations of decadal-like variations of GT winds with origins in the higher latitudes, it was hypothesized that the Gulf of Tehuantepec would provide a conduit linking the high latitudes with the tropical Pacific with possible rectification effects at the decadal time scale. To this end, a century-long control integration of a fully coupled global GCM was analyzed to consider possible mechanisms for decadal variability in the tropical Pacific Ocean. The coupled model was shown to do a remarkably good job simulating the spatial and temporal aspects of the GT winds (figure below/left), and the decadal variations of the GT winds are indeed forced by the high-latitude atmospheric variability akin to the AO. The hypothesis that decadal variability in the GT winds would generate decadal variability in the tropical Pacific Ocean by way of modulating the mesoscale ocean eddy field is certainly supported by the analyses, but with the confounding factor that the large-scale decadal atmospheric forcing for the GT winds is also of the kind that would force similar variability in the tropical Pacific Ocean directly, specifically by modulating the strength of the northern STC. This duality of pathways for Arctic forcing of tropical Pacific decadal variability is illustrated in the figure below/right.



f. Postdoctoral Fellow Griffin

As mentioned in the preamble, NOAA Climate & Global Change Postdoctoral Fellow Dr. Daniel Griffin joined WHOI in August 2013, bring co-mentored by PI Karnauskas and colleague Dr. Kevin Anchukaitis. Griffin plans to combine his expertise in dendrochronology with instrumental records and model simulations capturing the midsummer drought. Limited observational data are available from the region, prohibiting the characterization of basic climatology and the detection of global change impacts on regional climate variability. Griffin's project will utilize a network of novel, precisely dated, tropical tree-ring data to explore climate variability across Mesoamerica at seasonal to inter-centennial timescales. It will employ a state-of-the-art analytical and statistical approach to produce sub-annual tree-ring chronologies and an ensemble of gridded, seasonally resolved precipitation reconstructions covering the past 300-500 years. Griffin has begun refining the MESA algorithm developed in Karnauskas *et al.* (2013) and analyzing a range of gridded precipitation data sets to better understand the regional variability and context, and prospects for utilizing sub-annual tree ring chronologies. One recent example of Griffin's work is shown below; Griffin has already uncovered that it makes a substantial difference whether the MESA algorithm is applied to the climatology of precipitation to define the climatological strength of the midsummer drought, or the MESA algorithm is applied to each year's distinct precipitation and then taking the average of the MESA from each year. Griffin will continue exploring these questions over the next year or so and combine approaches with tree ring samples from the Inter-Americas region.



3. Highlights of Accomplishments – Condensed, updated, and sorted by FY.

FY11

- Characterization of the global geographic distribution of rainfall climatology associated with a midsummer drought;
- Analysis of the spatio-temporal evolution of the midsummer drought along the Pacific coast of Central America as a testbed for mechanisms;
- Identification of a basic mechanism for the midsummer drought.

FY12

- Extension of observations–based approach to a detailed reanalysis–based diagnostic study of the seasonal thermodynamic energy budget for the Pacific coast of Central America and southern Mexico;
- Submission and revision of a paper in the *Atmósfera* special issue on the climate of the greater Caribbean region encompassing most of the FY11 observational results as well as the above point;
- Characterization of the observed interannual variability of the midsummer drought in gridded (1948–2011) and station data (1979–1990);
- Contributing global coupled GCM analyses for MAPP CMIP5 Task Force papers I and II for the *J. Climate* special issue on CMIP5;
- Preparing abstract on all of the above points for the 2012 AGU Fall Meeting, session: “The North American Monsoon: Past, Present, and Future.”

FY13

- Contribution to MAPP webinar series on CMIP5 Evaluations/Projections, Nov. 2012.
- Oral presentation of multi-model evaluation and projections of the midsummer drought in CMIP5 models at the AGU Fall Meeting session on “North American Climate in CMIP5 Experiments,” Dec. 2012.
- Publication of “A simple mechanism for the climatological midsummer drought along the Pacific coast of Central America (Edited by H. Diaz)” in the 25th anniversary issue of *Atmósfera*, Feb. 2012.
- Invited oral presentation of core mechanism and future projections of the midsummer drought in CMIP5 models at the AGU Meeting of the Americas session on “Intraseasonal to Decadal Variability of the Tropical Americas,” May 2013.

- Linkage of mechanisms for– and projected changes in– the midsummer drought with those of the summertime Hadley circulation.
- Publication of paper on the role of Central America as a conduit for high-latitude forcing of decadal variability in the tropical Pacific (*Climate Dynamics*).
- Invited oral presentation of the Hadley circulation results at the Columbia University/Lamont-Doherty Earth Observatory symposium on “Climate Change: Recent Discoveries and Future Challenges,” May 2013.
- Contributed evaluation of the CMIP5-simulated midsummer drought to the MAPP CMIP5 Task Force paper “North American climate in CMIP5 experiments. Part II: Evaluation of historical simulations of intra–seasonal to decadal variability,” currently accepted.
- Contributed CMIP5 multi-model projections of the midsummer drought to the MAPP CMIP5 Task Force paper “North American climate in CMIP5 experiments. Part III: Assessment of 21st century projections,” currently in minor revisions.

4. Publications from the Project

Relevant papers and manuscripts

- Karlsruhkas, K.B., A. Giannini, R. Seager, and A.J. Busalacchi, 2013: A simple mechanism for the climatological midsummer drought along the Pacific coast of Central America. *Atmósfera*, **26**(2), 261–281.
- Karlsruhkas, K.B., 2013: Arctic forcing of decadal variability in the tropical Pacific Ocean in a high–resolution global coupled GCM. *Climate Dynamics*, doi:10.1007/s00382–013–1836–3.
- Sheffield, J., et al., 2013: North American climate in CMIP5 experiments. Part II: Evaluation of historical simulations of intra–seasonal to decadal variability. *Journal of Climate*, doi:10.1175/JCLI–D–12–00593.1.
- Maloney, E., et al. (2013) North American climate in CMIP5 experiments. Part III: Assessment of 21st century projections. *Journal of Climate*, in minor revision.
- Karlsruhkas, K.B. and C.C. Ummenhofer (2013) On the dynamics of the Hadley circulation and subtropical drying. Revising for resubmission.

Relevant talks and conference proceedings

- The American Midsummer Drought in CMIP5: Multi–Model Evaluation and Projections. *NOAA Climate Program Office MAPP Webinar*. Nov. 13, 2012.

- The American Midsummer Drought in CMIP5: Multi-Model Evaluation and Projections. *AGU Fall Meeting*, San Francisco, CA. Dec. 3–7, 2012.
- La canícula (midsummer drought): Underlying mechanisms, interannual variability, and forced response. *AGU Meeting of the Americas*, Cancun, Mexico. May 14–17, 2013 (invited).
- The Hadley circulation: Dynamics, asymmetry, and CMIP5 projections. *Symposium on Climate Change: Recent Discoveries and Future Challenges*, Columbia University, Palisades, NY. May 21–23, 2013.

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