Final Report

Project Title: Evaluation of the Large-Scale and Regional Climatic Response Across North Africa to Natural Variability in Oceanic Modes and Terrestrial Vegetation Among the CMIP5 Models (DE-SC0012534)

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Project Motivation: Hydrologic variability is a serious threat to the poverty-stricken regions of North Africa. Meanwhile, the scientific community continues to struggle to attribute these extreme climatic episodes to specific oceanic and terrestrial drivers. Prior modeling studies have not assessed simulated feedbacks over North Africa against an established observational benchmark, so their results are considered as untested, model-specific findings, not grounded in observations. The Coupled Model Intercomparison Project Phase Five (CMIP5) archive represents the state-of-the-art in climate projections for the study region, with most CMIP5 models now containing interactive vegetation phenology; however, there have been no studies to date of their simulated vegetation feedbacks. The capability of CMIP5 models at accurately simulating the forcing of both sea-surface temperature (SST) and regional leaf area index (LAI) anomalies on North African climate needs to be a key consideration in assessing the models' overall credibility and determining appropriate model weighting for developing climate projections. The Generalized Equilibrium Feedback Assessment (GEFA) is a promising multivariate statistical method, which can be applied to either model output or observations, for isolating the local and remote impacts of individual oceanic or terrestrial forcings on regional climate.

Project Methodology: We performed a combined observational and modeling assessment of land-ocean-atmosphere interactions across the distinct ecological and moisture gradients of North Africa. We evaluated and demonstrated the reliability of the GEFA statistical method over North Africa using the National Center for Atmospheric Research-Community Earth System Model (CESM), applied GEFA to observational data to quantify the observed forcing of ocean basin SST anomalies and regional LAI anomalies on North African climate, evaluated the CMIP5 models' performance in terms of representing these key observed feedbacks, and formulated CMIP5 feedback performance metrics for weighting North African climate projections. Our study represented the first attempt to separate the observed roles of oceanic and vegetation feedbacks across North Africa, the first systematic assessment and intercomparison of land-ocean-atmosphere feedbacks in CMIP5, and the first exploration of vegetation feedbacks among CMIP5 models.

Project Key Questions: Our study addressed three primary questions: (1) Is the multivariate statistical tool, GEFA, capable of accurately separating feedbacks induced by variability across individual oceanic basins and terrestrial ecoregions in North Africa? (2) What are the primary natural modes of oceanic and terrestrial variability which regulate the observed regional climate of North Africa? How important are vegetation biophysical feedbacks in modulating the observed seasonal climate of North Africa? (3) How well do CMIP5 models capture large-scale and regional-scale responses across North Africa to natural variability in oceanic modes and vegetation, compared to the observed GEFA benchmark?

Project Objectives: Our objectives were to (1) evaluate GEFA's reliability in diagnosing oceanic and terrestrial feedbacks to the atmosphere across North Africa through a comparison of statistical and dynamical methods within CESM; (2) apply GEFA to observational and remote sensing data to identify, and explore the mechanism behind, the primary natural modes of variability in global oceanic modes and regional LAI that regulate North African climate; (3) evaluate the CMIP5 models' ability to represent the atmospheric responses to dominant oceanic and terrestrial modes of variability for North Africa using GEFA, leading to the creation of performance metrics to aid in model intercomparison and development; and (4) apply GEFA in CMIP5 simulations for the 21st century to investigate potential future changes in the seasonality and intensity of land-ocean-atmosphere feedbacks.

Project Management: Michael Notaro directed the overall project's management; maintained the collaboration with Oak Ridge National Laboratory (ORNL); advised and mentored the associate researcher, Fuyao Wang, and the research assistant, Yan Yu; and aided in the application of GEFA to observational and CMIP5 data. Dr. Wang ran and analyzed the proposed CESM control run and ocean dynamic experiments. The University of Wisconsin-Madison research assistant, Dr. Yu, led the GEFA analysis, benefiting from the experience of Dr. Wang using the statistical method, and both ran and analyzed the land dynamic experiments. Within the Department of Energy (DOE) team, Jiafu Mao oversaw project activities and contributed to tasks related to the synthesis and analysis of global remote-sensing LAI and evapotranspiration (ET) products and their applications in assessing the CMIP5 models. Dr. Mao served as the lead collaborative contact at ORNL, directing their portion of the work. Xiaoying Shi assisted in CESM experiment design, running and analyzing CESM and Community Land Model (CLM) experiments, and exploring the mechanisms behind the identified differences between the Earth System Models and observations over North Africa. Dr. Shi also participated in the generation of the aforementioned LAI and ET products. Yaxing Wei led the effort to develop UV-CDAT-based visualizations of natural modes of variability, GEFA forcing and response fields, and CMIP5 feedback performance metrics to facilitate model intercomparison and development, while promoting result-sharing and reproducibility within the scientific community. All team members wrote scientific publications and presented research findings at conferences and workshops.

Key Results

Development and Validation of Stepwise GEFA

Wang et al. (2017) advanced the practicality and stability of GEFA for decomposing the key oceanic drivers of regional atmospheric variability by introducing an advanced stepwise GEFA (SGEFA) methodology, in which unimportant forcings were eliminated from the forcing matrix through stepwise selection. Validation of SGEFA was performed using CESM. First, a statistical assessment of the atmospheric response to each primary oceanic forcing was carried out by applying SGEFA to a fully coupled control run. Then, a dynamical assessment of the atmospheric response to individual oceanic forcings was performed through ensemble experiments by imposing SST anomalies over focal ocean basins. Finally, to quantify the reliability of SGEFA, the statistical assessment was evaluated against the dynamical assessment in terms of four metrics: the percentage of grid cells with consistent response sign, the spatial correlation of atmospheric response patterns, the area-averaged seasonal cycle of response magnitude, and consistency in associated mechanisms between assessments. In CESM, tropical modes, namely El Niño–Southern Oscillation (ENSO) and the tropical Indian Ocean Basin, tropical Indian Ocean dipole, and tropical Atlantic Niño modes, were the dominant oceanic controls of northern and tropical African climate (Fig. 1).

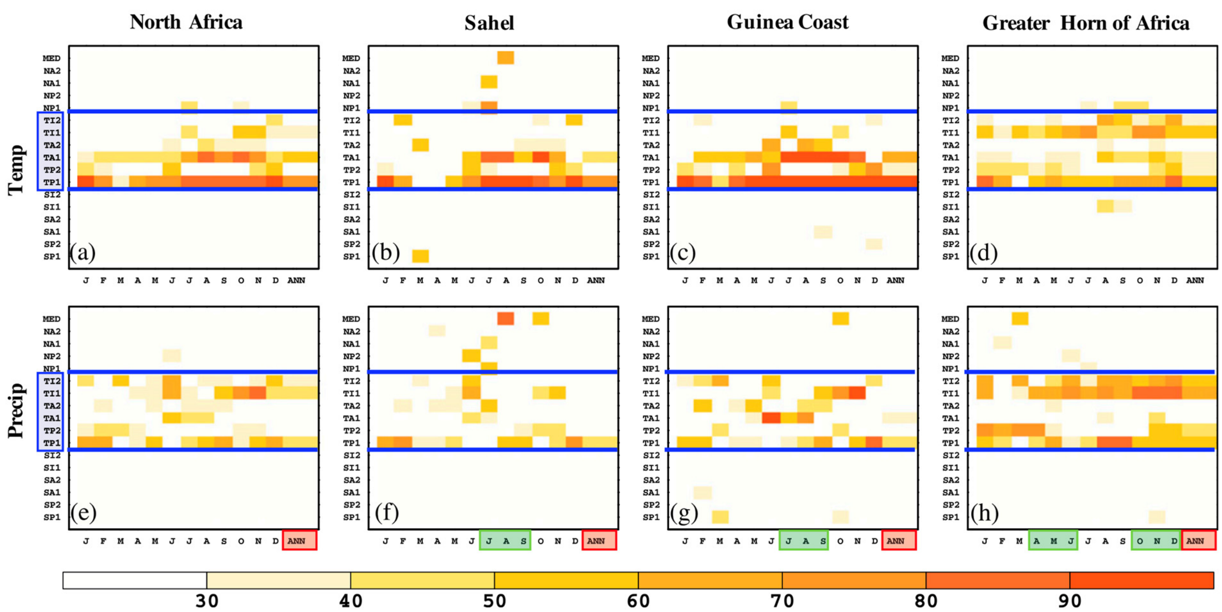

Figure 1. Percentage of area with significant responses (95%+ confidence level, based on the Monte Carlo bootstrapping) in (a-d) air temperature or (e–h) precipitation by month across the Sahel, Guinea Coast, Greater Horn of Africa, or entire area of northern and tropical Africa (10°S–20°N, 20°W–50°E) to 17 individual oceanic modes, based on the application of SGEFA to the CESM control run. The annual mean percentage of area with significant responses is shown as the last column of each panel figure (red boxes). The tropical oceanic modes are indicated within the blue lines. The green boxes denote the wet seasons per region.

The reliability of GEFA at capturing the terrestrial impacts on regional climate was demonstrated by Yu et al. (2018) using CESM, with focus on North Africa. The feedback was assessed statistically by applying GEFA to output from a fully coupled control run. Two ensembles of dynamical experiments were developed for the Sahel or West African monsoon region against which GEFA-based vegetation feedbacks were evaluated. In these dynamical experiments, regional LAI was modified either alone or in conjunction with soil moisture, with the latter runs motivated by strong regional soil moisture–LAI coupling. SGEFA boasted higher consistency between statistically and dynamically assessed atmospheric responses to land surface anomalies than full GEFA, especially with short data records. GEFA-based atmospheric responses were more consistent with the coupled soil moisture–LAI experiments, indicating that GEFA was assessing the combined impacts of coupled vegetation and soil moisture (Fig. 2). Both the statistical and dynamical assessments revealed a negative vegetation–rainfall feedback in the Sahel associated with an atmospheric stability mechanism in CESM versus a weaker positive feedback in the West African monsoon region associated with a moisture recycling mechanism in CESM.

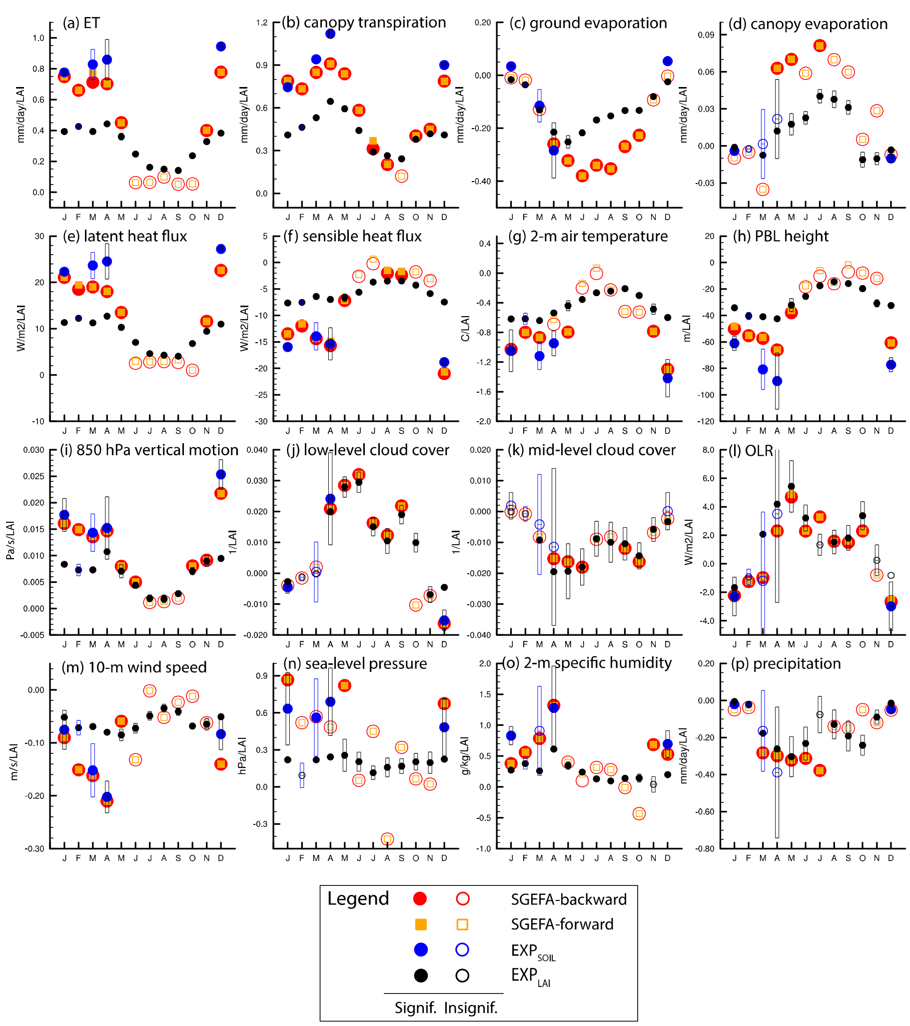

Figure 2. Seasonal cycle of local area-average responses to LAI anomalies across the Sahel in select variables assessed from EXP_{LAI} dynamic experiments with modified LAI (black circles), EXP_{SOIL} dynamic experiments with modified LAI and soil moisture (blue circles), and SGEFA (red circles: backward selection, orange square: forward selection) in CESM. Filled circles

indicate statistically significant ($p < 0.1$) responses. The boxes represent 90% confidence interval of the responses from EXP_{soil} (blue) and EXP_{LAI} (black).

Observational Assessment of Ocean-Land-Atmosphere Interactions

Classic, model-based theory of land-atmosphere interactions across the Sahel promoted positive vegetation-rainfall feedbacks dominated by surface albedo mechanism. However, neither the proposed positive vegetation-rainfall feedback nor its underlying albedo mechanism was convincingly demonstrated using observational data. Yu et al. (2017) presented observational evidence for the region's proposed positive vegetation-rainfall feedback on the seasonal to interannual time scale, and found that it is associated with a moisture recycling mechanism, rather than the classic albedo-based mechanism (Fig. 3). Positive anomalies of remotely sensed vegetation greenness across the Sahel during the late and post-monsoon periods favored enhanced ET, precipitable water, convective activity and rainfall, indicative of amplified moisture recycling. The identified modest low-level cooling and anomalous atmospheric subsidence in response to positive vegetation greenness anomalies were counter to the responses expected through the classic vegetation-albedo feedback mechanism.

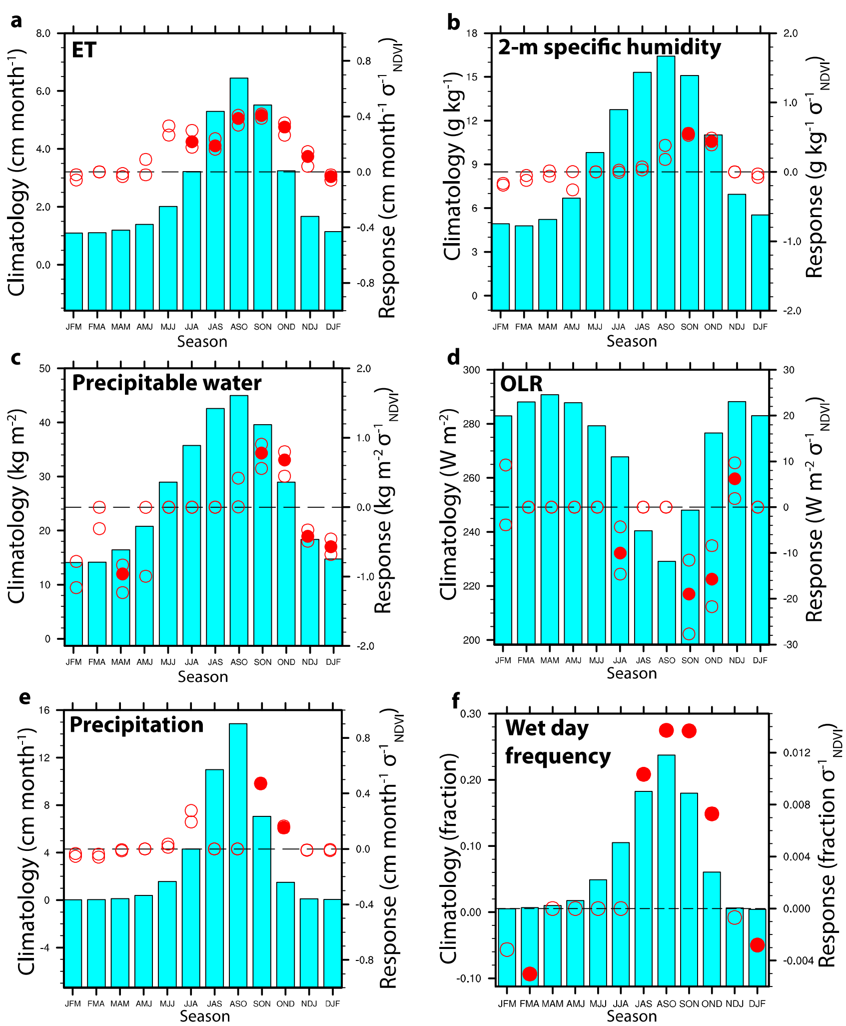

Figure 3. Multi-dataset observational responses to positive Normalized Difference Vegetation Index (NDVI) anomalies across the Sahel during 1982-2011 in (a) ET, (b) 2-m specific humidity,

(c) precipitable water, (d) outgoing longwave radiation, (e) precipitation, and (f) frequency of wet days. Bars indicate the climatology, while dots indicate the atmospheric response to NDVI anomalies.

Notaro et al. (2019) examined the role of terrestrial forcings on the regional climate of sub-Saharan Africa through the application of SGEFA to an array of observational, reanalysis, and remote sensing data products (Fig. 4). By applying multiple datasets, data uncertainty and the robustness of assessed land surface feedbacks were considered. The approach from Yu et al. (2017) was expanded to decompose the relative contribution of vegetation, soil moisture, and oceanic forcings; investigate the role of ET partitioning in terrestrial feedbacks; and compare land surface feedbacks among four key regions, namely the Sahel, Greater Horn of Africa, West African monsoon region, and Congo. ET partitioning differed notably among sub-Saharan regions and between available observational datasets. Across sub-Saharan Africa as a whole, oceanic and terrestrial forcings imposed a relatively comparable impact on year-round atmospheric conditions. The land surface feedbacks were most pronounced across the semi-arid Sahel and Greater Horn of Africa, although with unique seasonality of such feedbacks between regions. Moisture recycling was the dominant mechanism in these regions, with positive soil moisture–vegetation–rainfall feedbacks. The direct feedback of soil moisture anomalies on atmospheric conditions outweighed that of LAI anomalies.

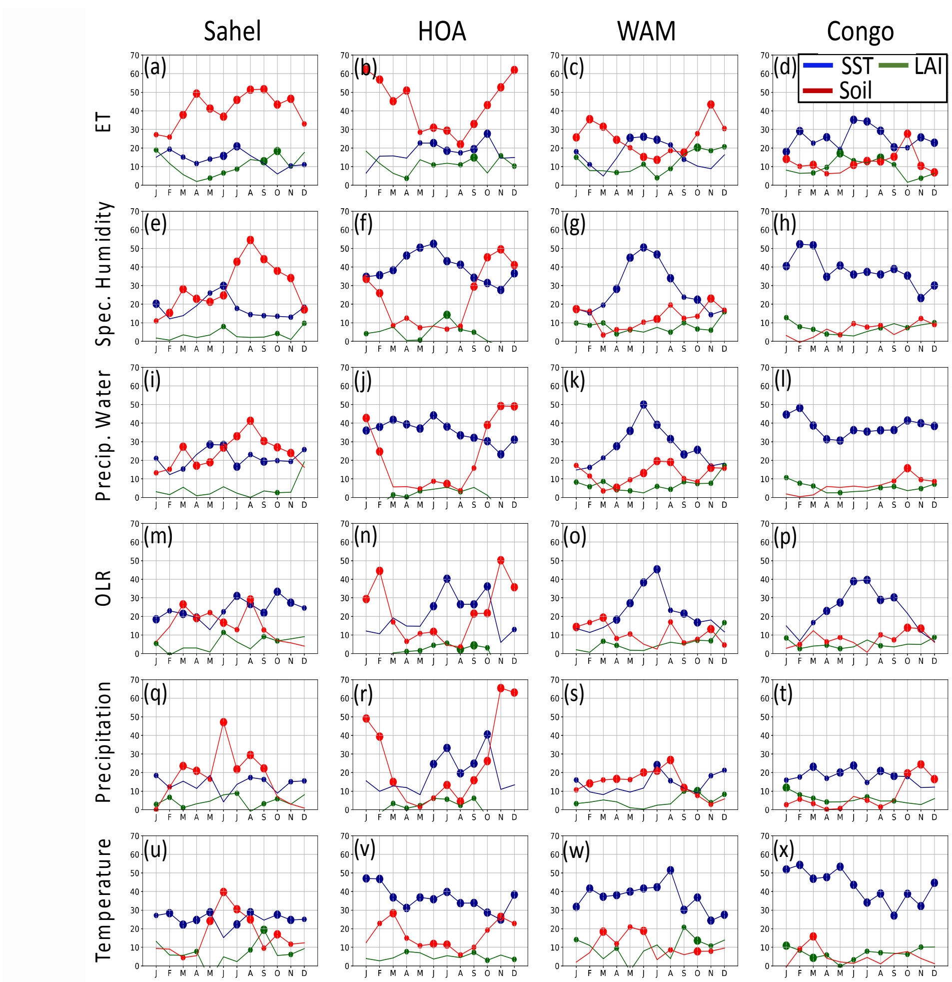

Figure 4. Seasonal cycle of percent explained variance of observed monthly ET, 2-m specific humidity, precipitable water, outgoing longwave radiation (OLR), precipitation, and 2-m air temperature across the Sahel, Horn of Africa (HOA), West African Monsoon (WAM) region, and Congo attributed to oceanic (blue), vegetation (green), and soil moisture (brown) forcings, according to SGEFA.

The predictability of tropical vegetation greenness based on SSTs has not been well explored. Yan et al. (2019) employed fine spatial resolution remotely-sensed Enhanced Vegetation Index (EVI) and SST indices from tropical ocean basins to investigate the predictability of tropical vegetation greenness in response to SSTs and established empirical models with optimal parameters for hindcast predictions. Pan-tropical EVI was found to be tightly connected to tropical ocean SSTs (Fig. 5). The strongest impacts of SSTs on EVI were identified mainly over the arid or semi-arid tropical regions. Vegetated areas across South America, Africa, and Southeast Asia exhibited notably significant SST-EVI correlations. In general, statistical models correctly predicted the sign of EVI anomalies. These results provided a basis for the prediction of changes in greenness of tropical terrestrial ecosystems at seasonal to intra-seasonal scales. The statistics-based observational relationships have the potential to facilitate the benchmarking of Earth System Models regarding their ability to capture the responses of tropical vegetation growth to long-term signals of oceanic forcings.

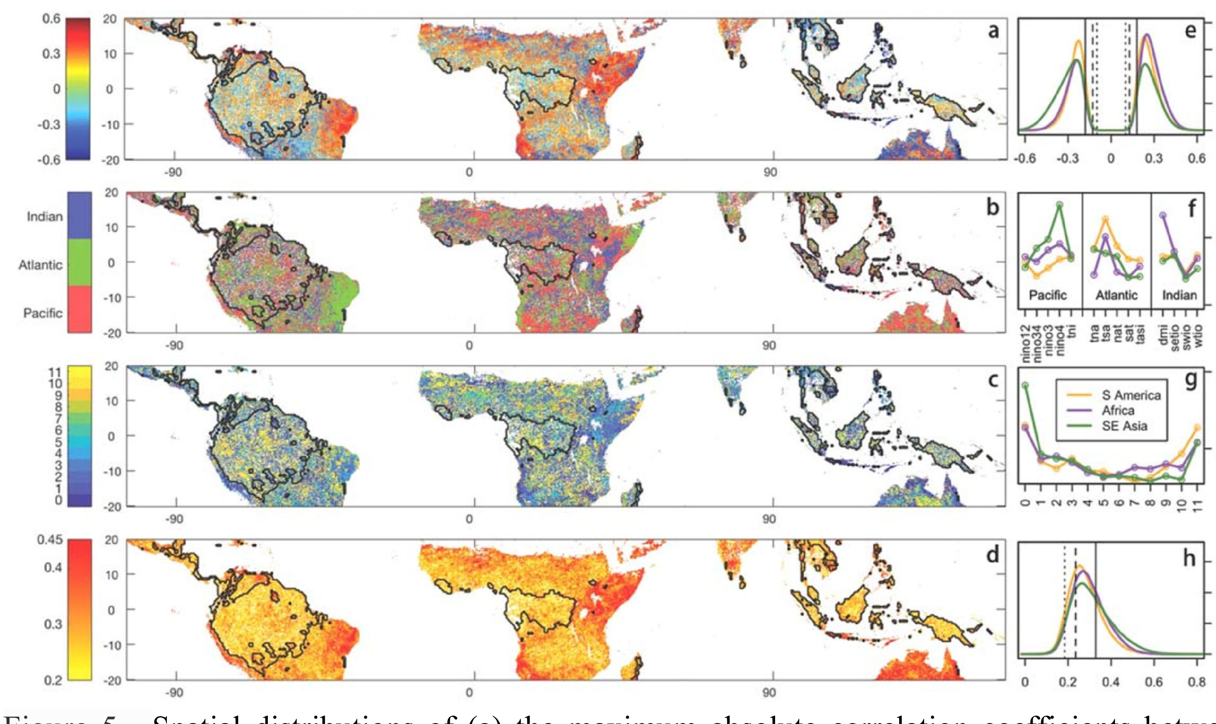

Figure 5. Spatial distributions of (a) the maximum absolute correlation coefficients between EVI and the controlling SST index, (b) the controlling SST index, (c) the number of months with the controlling SST leading EVI responses, and (d) the anomaly predictability with $p < 0.05$. Only those grid cells with significant ($p<0.01$) correlations between SST index and EVI are shown. The right column shows the density distributions of (e) correlation coefficients for each region, (f) the same, but for each SST, (g) the number of leading months for all three tropical continents, and (h) anomaly predictability. The line colors denote different continents as

indicated in (g). The vertical black lines in (e) and (h) indicate the thresholds beyond which values are significant with $p < 0.01$ (solid line), 0.05 (dashed line), and 0.1 (dotted line).

CMIP5 SGEFA Applications

Wang et al. (2019) investigated how realistic land surface feedbacks were represented across sub-Saharan Africa in CMIP5 models compared to observations. SGEFA was applied to multiple observational, remote sensing, and reanalysis datasets to quantify the observed impact of terrestrial forcings, namely variability in LAI and root-depth soil moisture, on Sahel regional climate. Subsequent application of SGEFA to historical output from 23 CMIP5 Earth System Models facilitated model evaluations compared to the observed feedback benchmark. The forcing matrix was comprised of the principal component time series from the leading two empirical orthogonal functions of global SSTs from eight non-overlapping ocean basins, time series of area-average Mediterranean SSTs, time series of area-average vegetation indices across the four sub-regions, and time series of area-average root depth soil moisture from the four sub-regions. According to observational data, moisture recycling was the dominant mechanism of land surface feedbacks in the Sahel, with positive soil moisture-vegetation-rainfall feedbacks, and the direct feedback of soil moisture anomalies on atmospheric conditions outweighed that of LAI anomalies. The CMIP5 ESMs largely underestimated the importance of terrestrial feedbacks across the Sahel, especially related to the impacts of soil moisture on ET, atmospheric moisture, and rainfall (Fig. 6).

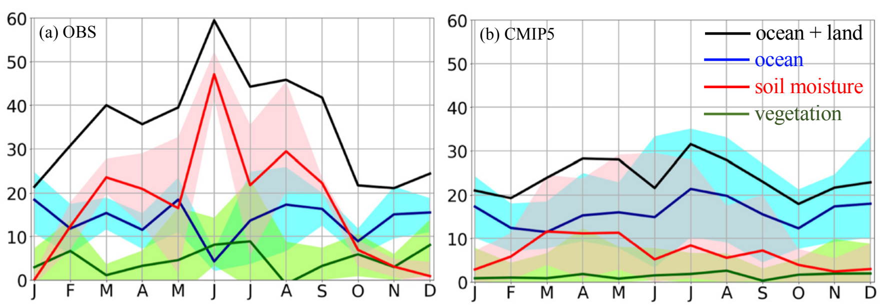

Figure 6. Seasonal cycle of percent explained variance of monthly precipitation anomalies across the Sahel attributed to oceanic (blue), vegetation (green), soil moisture (red), and total (black) forcings in (a) observations and (b) CMIP5 models during 1960-2000. The shading indicates the 10^{th} and 90^{th} percentiles across either multi-observational datasets or multi-CMIP5 models.

Future changes in the sign and intensity of land-atmosphere interactions have been insufficiently studied, despite implications for regional climate change projections, extreme event statistics, and total climate predictability. In response to this deficiency, Notaro et al. (2019) focused on projected responses to the enhanced greenhouse effect in the mean state of the atmosphere and land surface, oceanic and terrestrial drivers of sub-Saharan climate variability, and total climate predictability of sub-Saharan Africa, a known land-atmosphere coupling hotspot. SGEFA was applied to output over sub-Saharan Africa from 23 Earth system models for the late 20^{th} and 21^{st} centuries. The models indicate that the study region's climate variability was dominated by oceanic drivers, with secondary contributions from soil moisture and very modest impacts from vegetation. Overall, the general consensus among the models indicated a concerning diminished seasonal predictability of sub-Saharan African regional climate based on key oceanic and terrestrial predictors and an elevated role of the land surface (associated with soil moisture anomalies) compared to oceanic drivers in regulating regional climate variability (Fig. 7).

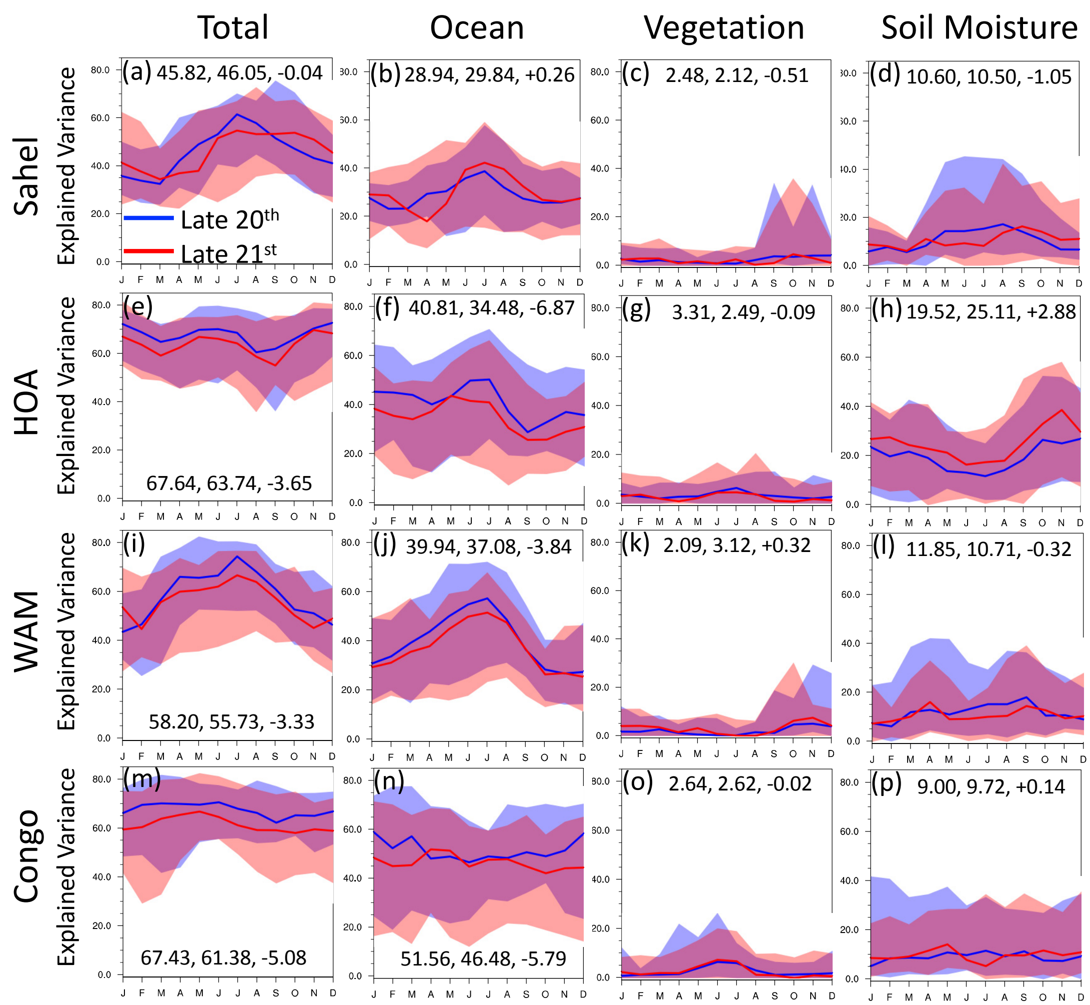

Figure 7. Percent explained variance of CMIP5-simulated monthly anomalies in 2-m air temperature across the (a-d) Sahel, (e-h) HOA, (i-l) WAM region, and (m-p) Congo during the (blue) late 20th and (red) late 21st centuries, attributed to (a,e,i,m) combined oceanic and terrestrial forcings, (b,f,j,n) oceanic forcings, (c,g,k,o) vegetation forcings, and (d,h,l,p) soil moisture forcings. The red and blue lines indicate the median result across models, while the red and blue shaded areas represent the extent of the 10th to 90th percentiles of the explained variance across models (with the overlap of the semi-transparent shaded areas shown as purple). Upward and downward green arrows indicate months in which the explained variance increases or decreases, respectively, while achieving statistical significant (hollow: $p<0.1$, filled: $p<0.05$) according to the Wilcoxon signed-rank test. In each panel, three numbers are provided: (1) annual average of the across-model median by month for the late 20th century, (2) annual average of the across-model median by month for the late 21st century, and (3) annual average of the across-model median of differences (late 21st-late 20th) by month.

Regulators of African Fire and Dust Variability

Tropical and sub-tropical Africa is highly vulnerable to wildfires. Successful prediction of the wildfire activity over these fire-prone regions remains a challenge and relies heavily on the deep understanding of various driving mechanisms that underlie the wildfire evolution. Yu et al. (2019) assessed the seasonal environmental drivers and predictability of wildfire variability in Africa using the analytical framework of SGEFA and Machine Learning Techniques (MLTs). By comparing previously identified climatic and socio-economical predictors, greater contribution to the seasonal predictability of African wildfire variability was quantified from the slowly-evolving SSTs, soil moisture, and leaf area index (Fig. 8). Land-ocean-atmosphere interactions were demonstrated to be key contributors to the seasonal predictability of wildfire activity. The combined SGEFA-MLT tool can be generalized for seasonal prediction of regional and global wildfire risk.

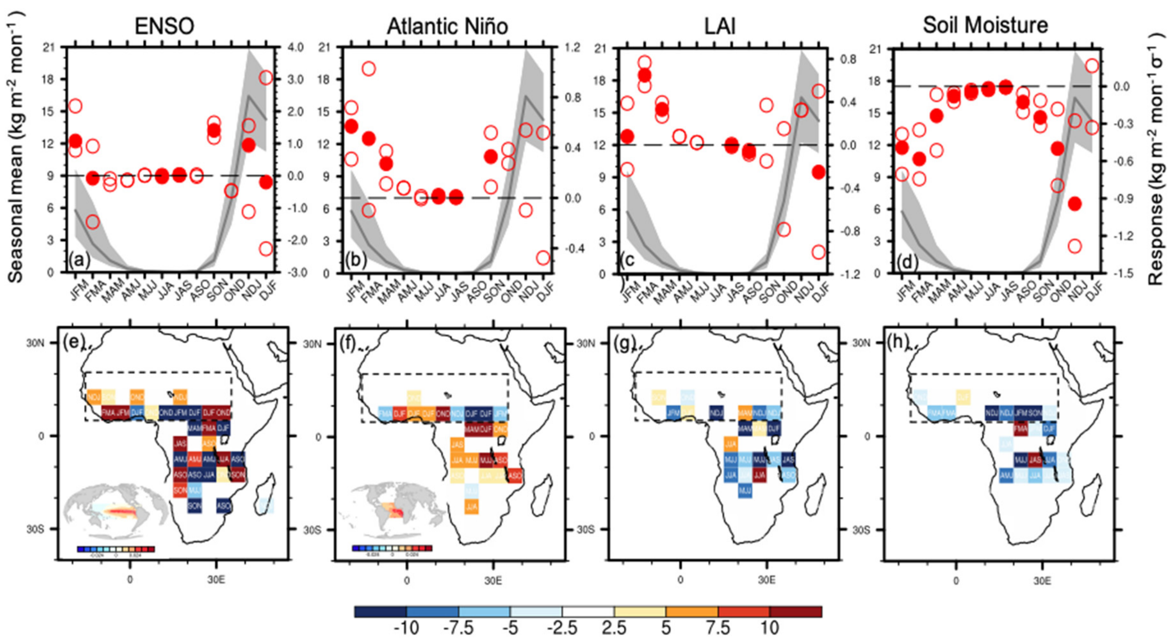

Figure 8. Observed response of African wildfire carbon emissions to select environmental forcings according to SGEFA. These forcings include (a, e) ENSO, (b, f) Atlantic Niño mode, (c, g) LAI, and (d, h) soil moisture. (a-d) Seasonal cycle of the northern African regional average climatology, with line and shading represents mean and interannual standard deviation, referring to the left *Y*-axis (unit: gC m^{-2} $month^{-1}$), and response to the corresponding forcing, with the filled and open circles indicate the multi-dataset average and 10^{th} and 90^{th} percentiles, referring to the right *Y*-axis (unit: gC m^{-2} $month^{-1}$ $\sigma_{forcing}{}^{-1}$). (e-h) Spatial distribution of the season (letter) and sign and magnitude (color) of the maximum absolute response, among 12 seasonal responses, to the corresponding forcing. The spatial pattern of the ENSO and Atlantic Niño forcing is demonstrated in the inserted global map in (e) and (f), respectively. The box in (e-h) indicates the geographic location of the currently assessed northern African ecoregion.

Motivated by the ongoing debates about the relative contribution of specific North African dust sources to the trans-Atlantic dust transport to the Americas, Yu et al. (2019) integrated a suite of satellite observations into a novel trajectory analysis framework to investigate dust transport from the leading two North African dust sources, namely the Bodélé depression and El Djouf. This approach provided observation-based quantification of the dust's dry and wet deposition along its transport pathways and validated against multiple satellite observations. The current large ensemble trajectory simulations identified favorable transport pathways from the El Djouf across the Atlantic Ocean with respect to seasonal rain belts. The limited potential for long-range transport of dust from the Bodélé depression was confirmed by the observed evolution of dust vertical structures and attributed to the currently identified extensive near-source dust removal primarily by dry and wet deposition during boreal winter and summer, respectively (Fig. 9).

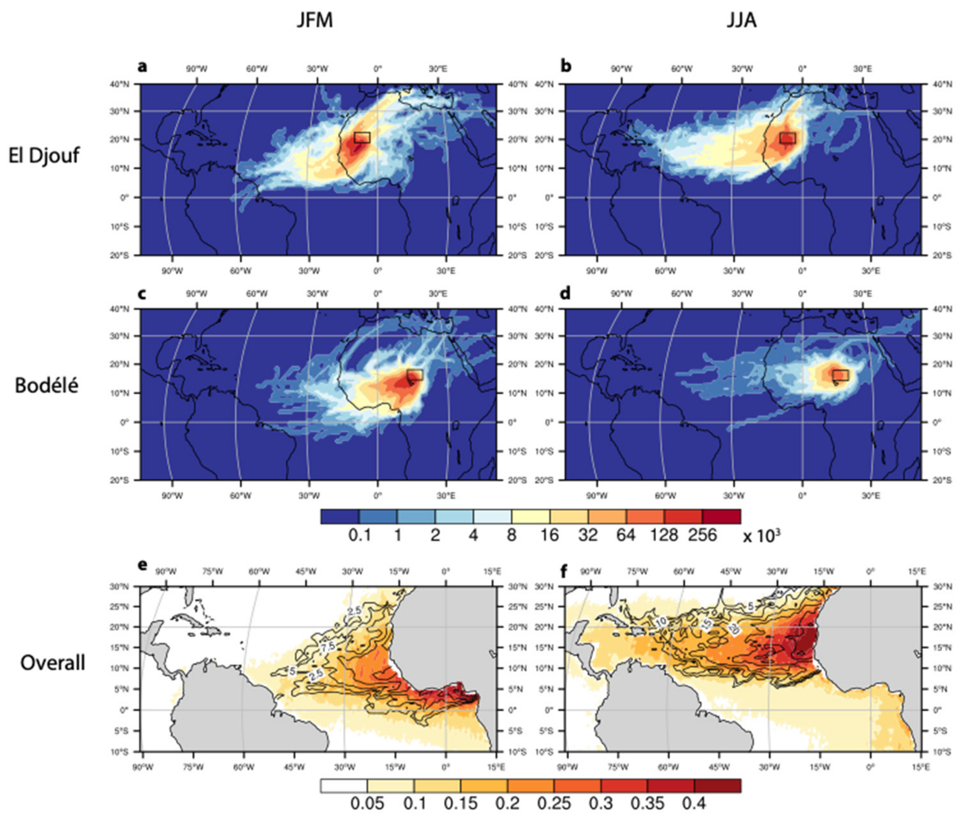

Figure 9. Spatial distribution of dust particles from the El Djouf and Bodélé depression, compared with Multiangle Imaging SpectroRadiometer (MISR) dust aerosol optical depth (AOD). (**a**-**d**) Trajectory passage frequency, represented by the climatological total number of dust particles passing each 1˚x1˚ pixel, from the (**a**, **b**) El Djouf and (**c**, **d**) Bodélé depression during (**a**, **c**) JFM and (**b**, **d**) JJA in 2005-2017. The source regions are indicated in (**a**-**d**). In (**e**, **f**), the seasonal average dust AOD (color) over the tropical Atlantic Ocean from the MISR aerosol product during 2005-2017 is compared with overall trajectory passage from both North African sources (total number of passing particles from both North African sources, $x10^3$, contour) during (**e**) JFM and (**f**) JJA.

List of Publications and Presentations

Publications

Wang, F., M. Notaro, Y. Yu, and J. Mao, 2019: Deficient precipitation sensitivity to Sahel land surface forcings among CMIP5 models. Climate Dynamics, in preparation.

Yu, Y., J. Mao, M. Notaro, et al., 2019b: Quantifying the drivers and predictability of the wildfire variability in Africa. Nature Climate Change – Letters, in preparation.
Ma, D., J. Mao, F. Wang, Y. Yu, and M. Notaro, 2019: Oceanic and land drivers on seasonal changes of European temperatures. Environmental Research Letters, in preparation.
Notaro, M., F. Wang, Y. Yu, and J. Mao, 2019b: Projected changes in the terrestrial and oceanic regulators of climate variability across sub-Saharan Africa. Climate Dynamics, in revision.
Yu, Y., O.V. Kalashnikova, M.J. Garay, H. Lee, M. Notaro, J.R. Campbell, J. Marquis, and G.S. Okin, 2019a: Disproving the Bodélé depression as the primary source of dust fertilizing the Amazon Rainforest. Geophysical Research Letters, in revision.
Notaro, M., F. Wang, and Y. Yu, 2019a: Elucidating observed land surface feedbacks across sub-Saharan Africa. Climate Dynamics, 53, 1741-1763.
Yan, B., J. Mao, X. Shi, F.M. Hoffman, M. Notaro, et al., 2019: Predictability of tropical vegetation greenness using sea surface temperatures. Environmental Research Communications, https://doi.org/10.1088/2515-7620/ab178a.
Yu, Y., and M. Notaro, 2019: Observed land surface feedbacks on the Australian monsoon system. Climate Dynamics, in revision.
Yu, Y., M. Notaro, F. Wang, J. Mao, X. Shi, and Y. Wei, 2018a: Validation of a statistical methodology for extracting vegetation feedbacks: Focus on North African ecosystems in the Community Earth System Model. Journal of Climate, 31, 1565-1586.
Yu, Y., O.V. Kalashnikova, M. Garay, H. Lee, and M. Notaro, 2018b: Identification and characterization of dust source regions across North Africa and the Middle East using MISR satellite observations. Geophysical Research Letters, doi.org/10.1029/2018GL078324.
Yu, Y., M. Notaro, F. Wang, J. Mao, X. Shi, and Y. Wei, 2017: Observed vegetation-climate feedbacks in the Sahel: Is the classic albedo feedback mechanism truly dominant? Nature Communications, 8, doi:10.1038/s41467-017-02021-1.
Wang, F., Y. Yu, M. Notaro, J. Mao, X. Shi, and Y. Wei, 2017: Advancing a model-validated statistical method for decomposing the key oceanic drivers of regional climate: Focus on northern and tropical African climate variability in the Community Earth System Model (CESM). Journal of Climate, 30, 8517-8537.
Notaro, M., 2017: Does climate affect the world's vegetation – or is it the other way around? Scientia.
Mao, J., W. Fu, X. Shi, D.M. Ricciuto, J.B. Fisher, R.E. Dickinson, Y. Wei, W. Shem, S. Piao, K. Wang, C.R. Schwalm, H. Tian, M. Mu, A. Arain, P. Ciais, R. Cook, Y. Dai, D. Hayes, F.M. Hoffman, M. Huang, S. Huang, D.N. Huntzinger, A. Ito, A. Jain, A.W. King, H. Lei, C. Lu, A.M. Michalak, N. Parazoo, C. Peng, S. Peng, B. Poulter, K. Schaefer, E. Jafarov, P.E. Thornton, W. Wang, N. Zeng, Z. Zeng, F. Zhao, Q. Zhu, and Z. Zhu., 2015: Disentangling climatic and anthropogenic controls on global terrestrial evapotranspiration trends. Environmental Research Letters, 10, 094008.

Presentations

Notaro, "Elucidating observed land surface feedbacks across sub-Saharan Africa," American Geophysical Union Fall Meeting, December 2018, Washington, D.C.
Mao, "Predictability of tropical vegetation greenness using sea surface temperatures," NGEE-Tropics Annual Meeting, December 2018, Washington D.C.
Notaro, "Elucidating observed land surface feedbacks across sub-Saharan Africa," Department of Energy Primary Investigators Meeting, November 2018, Bethesda, MD.

Notaro, “Evaluation of the representation of terrestrial feedbacks across sub-Saharan Africa in the CMIP5 Earth System Models,” Department of Energy Primary Investigators Meeting, November 2018, Bethesda, MD.

Yu, "Disproving the Bodélé depression as the primary source of dust fertilizing the Amazon Rainforest," 18th Aerosol Comparisons between Observations and Models (AeroCom) workshop, September 2019, Barcelona, Spain.

Mao, “Predictability of tropical vegetation greenness using sea surface temperatures,” Ecological Society of America Annual Meeting, August 2018, New Orleans, Louisiana.

Yu, "Interactions between vegetation, dust, and climate in North Africa assessed from observation and modeling," Invited seminar at NOAA Geophysical Fluid Dynamics Laboratory, May 2019, Princeton, New Jersey.

Yu, "Is Bodélé depression the dominant source of North African dust transported to the Americas?" EGU General Assembly, April 2019, Vienna, Austria.

Notaro, “Extracting the oceanic and terrestrial drivers of North African hydrological variability,” State University of New York at Albany, Atmospheric Sciences Research Center / Department of Atmospheric and Earth Sciences Joint Seminar, April 2018, Albany, NY.

Notaro, “Do state-of-the-art CMIP5 Earth System Models accurately represent observed vegetation-rainfall feedbacks? Focus on the Sahel”, American Meteorological Society Annual Meeting, January 2018, Austin, TX.

Yu, "Identification of dust source regions and dust emission trends across North Africa and the Middle East using MISR satellite observations," Invited seminar at University of California Los Angeles, May 2018, Los Angeles, CA.

Wang, “Advancing a model-validated statistical method for decomposing the key oceanic drivers of observed regional climate variability and evaluating model performance: Focus on North African rainfall in CESM,” American Geophysical Union Fall Meeting, December 2016, San Francisco, California.

Notaro, “Observed vegetation feedbacks in the Sahel: Is the classic albedo feedback mechanism truly dominant?,” Department of Energy RGCM Primary Investigator Meeting, November 2016, Washington D.C.

Notaro, “Validation of a statistical methodology for extracting vegetation feedbacks: Focus on North African ecosystems in the Community Earth System Model,” Department of Energy RGCM Primary Investigator Meeting, November 2016, Washington D.C.

Wang, “Advancing a model-validated statistical method for decomposing the key oceanic drivers of observed regional climate variability and evaluating model performance: Focus on North African rainfall in CESM,” DOE PI Meeting, November 2016, Washington D.C.

McDowell and coauthors, including Jiafu Mao, “NGEE-Tropics El Niño and drought impacts research,” Environmental System Science (ESS) PI Meeting, April 2016, Potomac, Maryland.

Yu, “Observed vegetation-climate feedbacks across the Sahel,” University of Wisconsin-Madison Reid Bryson Scholarship Poster Competition, Climate Change Symposium, April 2016, Madison, Wisconsin.

Yu, “Observed oceanic and terrestrial drivers of North African climate,” University of Wisconsin-Madison Climate, People, and Environment Program (CPEP) seminar, April 2016, Madison, Wisconsin.

Mao, “Disentangling natural and anthropogenic controls on terrestrial evapotranspiration and vegetation growth trends,” Yale School of Forestry and Environmental Studies seminar, March 2016, Yale University, New Haven, Connecticut.

Wang, "Evaluating CMIP5 models' representation of oceanic drivers of North African climate," American Meteorological Society Annual Meeting, January 2016, New Orleans, Louisiana.
Yu, "Observed oceanic and terrestrial drivers of North African climate," American Meteorological Society Annual Meeting, January 2016, New Orleans, Louisiana.
Yu, "Observed oceanic and terrestrial drivers of North African climate," American Geophysical Union Fall Meeting, December 2015, San Francisco, California.
Mao, "Disentangling climatic and anthropogenic controls on global terrestrial evapotranspiration trends," American Geophysical Union Fall Meeting, December 2015, San Francisco, California.
Notaro, "Evaluating CMIP5 models' representation of oceanic drivers of North African climate," American Geophysical Union Fall Meeting, December 2015, San Francisco, California.
Notaro, "Evaluation of the large-scale and regional climatic response across North Africa to natural variability in oceanic modes and terrestrial vegetation," Department of Energy Biogeochemistry Feedbacks webinar, October 2015, Madison, Wisconsin.
Mao, "Impacts of natural and human forcings on the global land evapotranspiration and vegetation growth," International workshop on Quantifying Uncertainties in Land Surface Models, Beijing Normal University, Beijing, China.
Mao, "Disentangling climatic and anthropogenic controls on global terrestrial evapotranspiration trends," Climate Change Science Institute (CCSI) Scientific Advisory Board (SAB) meeting, April 2015, Oak Ridge, Tennessee.
Yu, "Literature review on oceanic and land surface drivers of Sahel drought," Atmospheric and Oceanic Sciences (AOS) 900 presentation, April 2015, Madison, Wisconsin.
Yu, "Statistical and dynamical analysis of land-ocean-atmosphere interactions across North Africa," PhD preliminary exam, April 2015, Madison, Wisconsin.
Mao, "How the anthropogenic effects modulate the climate-dominated land evapotranspiration trends," American Geophysical Union Fall Meeting, December 2014, San Francisco, California.