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NOAA's MAPP-CTB Projects Update: Community R2O Contributions to the Improvement of Operational S2S Climate Prediction

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1. Introduction

NOAA's Modeling, Analysis, Predictions and Projections - Climate Test Bed (MAPP-CTB) projects support research to significantly increase the accuracy, reliability, and scope of NWS Climate Prediction Center operational seasonal-to-subseasonal (S2S) climate probabilistic forecast products. Out of twenty-six funded projects, twelve are on track to be completed by the end of fiscal year 2018, seven are in progress with an adjusted deliverable schedule, and seven are new development projects. This extended summary provides stakeholders an update on 1) completed projects leading to an improved operational prediction capability, 2) prominent progress of ongoing projects, and 3) challenging new developments supported by leveraging the research community. The CTB management solicits feedback on optimal project performance to accelerate the transition from research to operations for service improvement toward the NWS strategic goal of a "Weather-Ready-Nation".

2. Completed projects leading to an improved operational prediction capability

2.1 System implementations:

i) NCEP GEFS for monthly forecast (PI: Y. Zhu, EMC, NOAA/NWS/NCEP)

A real-time monthly GEFS version with the identical configuration as reforecast but larger ensemble size (21 members) is being conducted every Wednesday since July 2017. Finished a 17-yr reforecast with a high-resolution (34 km for 0-8 days and 52km for 8-35 day) model and 11 member ensemble. Eleven real-time priority variables are delivered to CPC. Other priority 2 and 3 variables are delivered to IRI. The weeks 3&4 forecast has been assessed. MJO forecast skill (from 12.5 days to 22 days) and NH 500hPa height ensemble mean AC scores (from 0.35 to 0.404) are improved after applying the new stochastic physics perturbation (SPs), updated SST (CFSBC) and new convective schemes (CNV). (Fig.1).

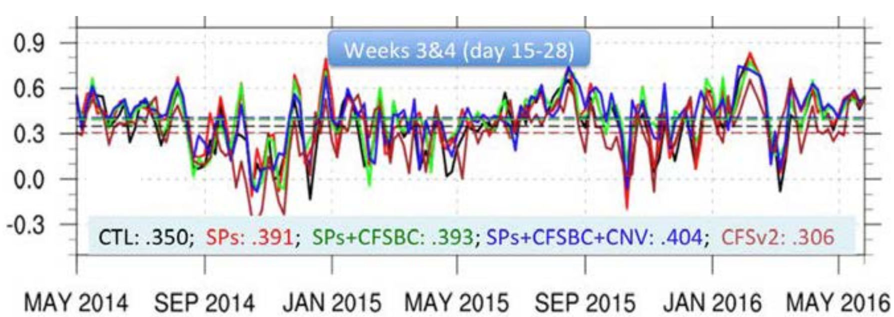

Fig. 1 Pattern Anomaly Correlation (PAC) for Northern Hemisphere 500 hPa geopotential height for lead weeks 3&4 during the period from May 2014 to May 2016. Control (CTL) is in black, SPs in red, SPs+CFSBC in green, SPs+CFSBC+CNV in blue and CFSv2 in brown with period average PAC scores for each configuration (numbers in the bottom of plot with corresponding color). (Courtesy of Y. Zhu)

ii) Improved turbulence and cloud processes (PI: S. K. Krueger, University of Utah)

The Simplified Higher-Order Closure (SHOC) and Chikira-Sugiyama-Arakawa-Wu (CSAW) unified cumulus parameterization have been implemented and tested in NEMS/GSM and GFS with FV3 dynamical core (FV3gfs). SHOC, CSAW along with Morrison-Gettelman double moment microphysics have been implemented in the Interoperable Physics Driver 4 of the NEMS/FV3 model.

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iii) NMME Phase 2 (PI: RSMAS, B. Kirtman, University of Miami)

NMME Partner Agreement was signed by all parties and the Community Earth System Model (CESM), and the retrospective forecast completed. NMME operational forecasts continue to be delivered on time. A new procedure for estimating forecast spread is developed.

iv) Real-time multi-model sub-seasonal predictive capability (SubX) (PI: B. Kirtman, RSMAS, University of Miami)

The SubX began making real-time predictions in July 2017. The data are provided to CPC as guidance to their week 3-4 forecast products and also to IRI for posting on the IRI Data Library. Completed re-forecast database. Comprehensive skill evaluation showed the benefit of the MME over any individual model.

v) U.S. monitoring and prediction system for flash droughts (PI: D. P. Lettenmaier, University of California)

An experimental real time flash drought monitor is on the CPC website. Experimental real time flash drought forecast in three categories based on the CFSv2 seasonal forecasts has been implemented.

vi) Ensemble-based sea ice analysis and forecasting (PI: J. Carton, University of Maryland)

Sea ice modeling and data assimilation (EnKF) capability has been implemented in CFS, and a full year sea ice analysis using the new ensemble-based system completed.

2.2 System new components

i) Lake-effect process (PI: J. Jin, Utah State University)

The 16-year retrospective forecasts with nine leads were performed with CFS and CFS-Flake. These forecasts for the Great Lakes region were quantitatively analyzed with different metrics, showing the predicted surface skin temperature, precipitation, and lake ice spatial distribution with the coupled CFS-Flake were significantly improved

ii) CCSM4 (SubX) (PI: B. Kirtman, RSMAS, University of Miami)

Real-time Community Climate System Model 4.0 (CCSM4) subseasonal forecasts began in July 2017. All priority 1 variables from all the hindcasts have been provided to IRI.

iii) Navy Earth System Model (NESM) (PI: N. Barton, Naval Research Laboratory)

Demonstrated that NESM forecasts can be supplied to NOAA in a timely manner for S2S operational products. Completed the re-forecasting effort from 1999 to start of the real-time experiment, and supplied these outputs to NOAA and IRI.

2.3 System analysis and optimization

i) Estimation of NASA GEOS-5 MJO forecast skill and land surface feedback (PI: D, Achuthavarier, Universities Space Research Association)

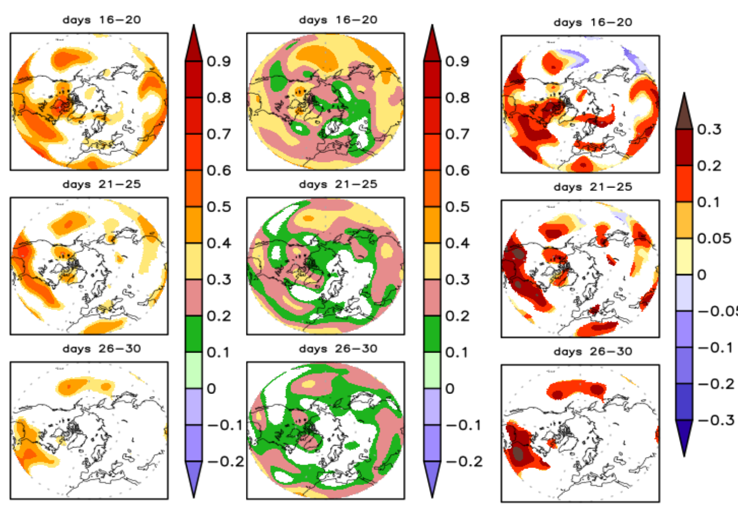

Fig. 2 Anomaly correlation coefficient for 5-day averaged H500 anomalies from GEOS-S2S hindcasts when (left column) forecast initialization contains MJO in phases 3 or 7, (middle column) for all forecasts irrespective of MJO signal in initial conditions, and (right column) difference between the two. The rows represent 5-day averaged fields as the forecast progresses from day-16 to day-30. Verification is performed against MERRA-2 data, and forecasts cover the period 1999-2015. All forecasts are initialized over an extended winter period (November through March). The results are promising in that increased skill (the red shading in the right column) is observed up to days 26-30, especially over the eastern US, suggesting a typical MJO-NAO teleconnection pattern. It indicates higher skill of H500 anomalies prediction when an MJO in phases 3 or 7 is present in the initial conditions. (Courtesy of D, Achuthavarier)

The near real-time production of sub-seasonal forecasts commenced at GMAO, NASA/GSFC on July 25, 2017, and since then, the forecasts (consisting of 10 Priority-1 variables) have been submitted to CPC every Wednesday. In addition, 39 output fields from the forecasts are being submitted to the IRI's SubX data repository. Figure 2 shows a promising result.

ii) NMME skill, predictability and optimum combination (PI: T. Delsole, George Mason University)

Developed a new method for determining the ensemble size and initialization frequency of the lagged ensemble that minimized the MSE. Identified the optimal lagged ensemble for monthly, subseasonal and seasonal forecasts in CFSv2. Developed new, rigorous methods (code available online) for comparing forecast skill.

iii) Assessment of CFS severe weather predictions (PI: M. Tippett, Columbia University)

The automated 00 UTC CFS ensemble mean severe weather guidance dashboard has been transitioned to application (www.spc.noaa.gov/exper/CFS_Dashboard/).

3 Progress from projects on finalization

One-year no-cost extensions are granted to seven projects in final stage for completion. Here are some prominent achievements shown in project reports.

i) Improved cloud and boundary layer processes (PI: C. S. Bretherton, University of Washington)

The new scheme has neutral results in the short and medium range forecast skill metrics used by NCEP, but has the benefit of increasing forecast global low cloud cover by 5%, in better agreement with satellite observations as shown in Fig. 3.

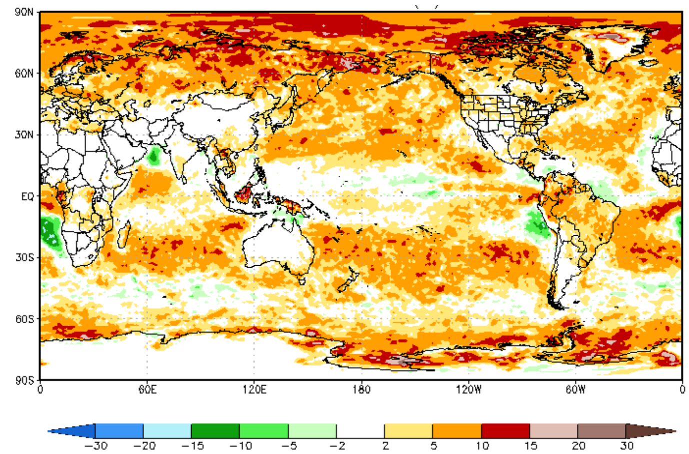

Fig. 3 Mean difference of low (<680 hPa) cloud fraction (%) for the forecasts with the new scheme (EDMF-TKE) with respect to the control forecasts (EDMF-CTL). The forecast period for the mean difference calculation is from 1 Dec 2016 to 6 Dec 2017, and the low cloud fraction is the average of 102, 108, 114, and 120 forecast hours. (Courtesy of C. S. Bretherton)

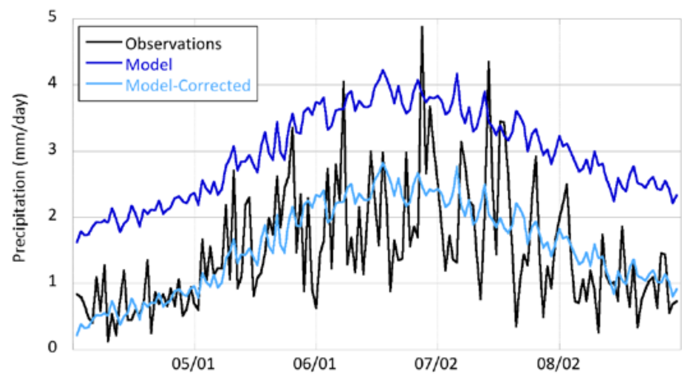

Fig. 4 Tanana Valley-West climatological seasonal cycle of daily precipitation from observations (black), raw model forecast (dark blue) and corrected model forecast using quantile mapping (light blue). The plot shows a seasonal cycle averaged over 1994-2010. (Courtesy of U. Bhatt)

ii) Seasonal forecast application for AK wildland fire management (PI: U. Bhatt, University of Alaska)

The key index, Buildup Index (BUI), from the Canadian Forest Fire Weather Index System (CFFWIS) represents potential fuel availability and flammability. It is based on cumulative scoring of daily temperature, relative humidity, and precipitation. The biases in temperature and precipitation result in systematic biases in BUI for Interior Alaska. The quantile mapping method is used, which shifts the cumulative distribution of the model forecast to match the observed distribution to reduce biases as seen in Fig. 4.

iii) Subseasonal excessive heat outlook system (PI: A. Vintzileos, ESSIC, University of Maryland)

The global heat-impact oriented subseasonal excessive heat system runs experimentally on real time at the University of Maryland since May 2018 and provides probabilistic forecasts of the wet and dry Excess Heat Factor (EHF). Preliminary results are presented in Fig. 5. Further exploring the margins provided by acclimatization and the geographical modulation of the danger level is going to proceed.

iv) Eddy-permitting hybrid global ocean data assimilation system (PI: S. G. Penny, University of Maryland)

The bulk of the software engineering for Hybrid-GODAS has been recently completed, allowing for initial performance tests on the whole system to begin on the Gaea supercomputer. The code has been made publically available online while development and tuning continues. Figure 6 shows the Hybrid-DA improvement, especially in the tropical Atlantic, a region that the existing GODAS often has trouble with. (https://github.com/UMD-AOSC/hybrid-godas).

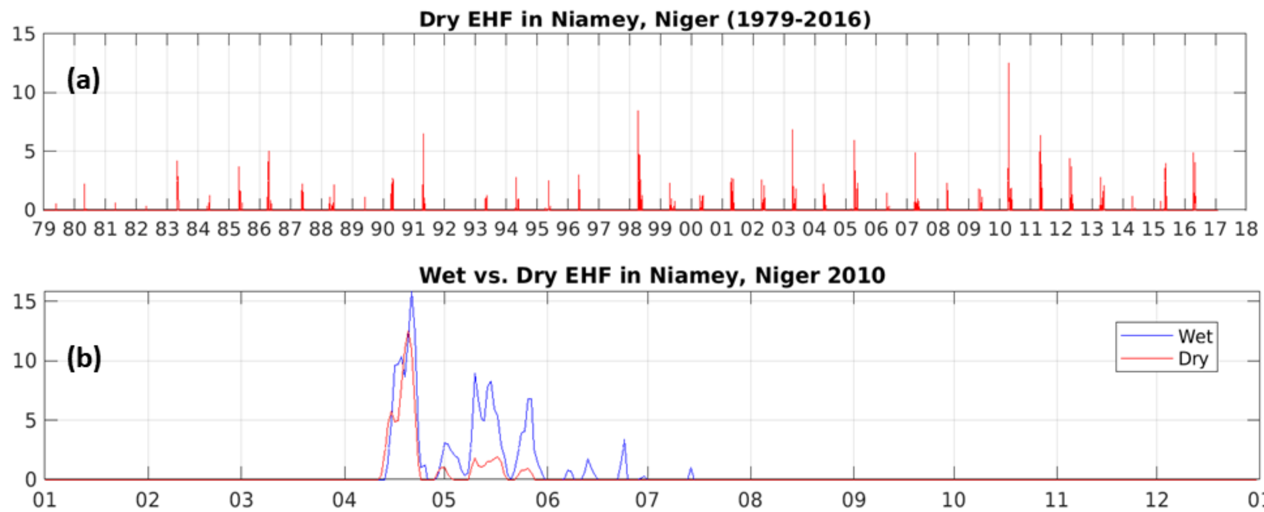

Fig. 5 (a) The dry EHF as calculated using ERA-Interim data from 1979-2016 at the closest grid point to Niamey airport, Niger. The reported excessive heat wave, which occurred in April 2010 is well captured. (b) Both dry and wet EHF are successful in capturing the April 2010 event, however, during May as the monsoon season approaches the wet EHF shows higher sensitivity. The wind induced skin evaporation and lower solar incoming radiation provide relief from excessive heat. (Courtesy of A. Vintzileos)

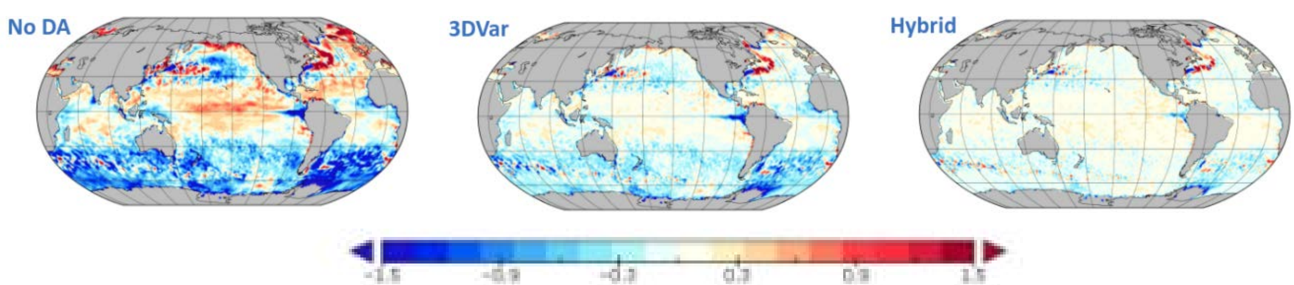

Fig. 6 Comparison of SST bias over a three month test period using no data assimilation (left), 3DVar only (middle) and hybrid LETKF/3DVar (right). (Courtesy of S. G. Penny)

Also projects at the final stage are 1) modeling and data infrastructure (PI: C. Deluca, CIRES, University of Colorado), 2) S2S climate products for hydrology and water management (PI: A. Wood, NCAR), and 3) operational transition of soil moisture and snow data assimilation in NLDAS (PI: Christa Peters-Lidard, NASA/GSFC).

4 Challenging new developments supported by leveraging the research community

In FY 2018, seven projects are newly supported, focusing on testing and demonstrating experimental prediction methodologies or systems developed in the broader community for operational purposes, and improving multi-model ensemble prediction systems by utilizing new or higher-resolution models, improved forecast initialization practices, and upgrades to other aspects of the system.

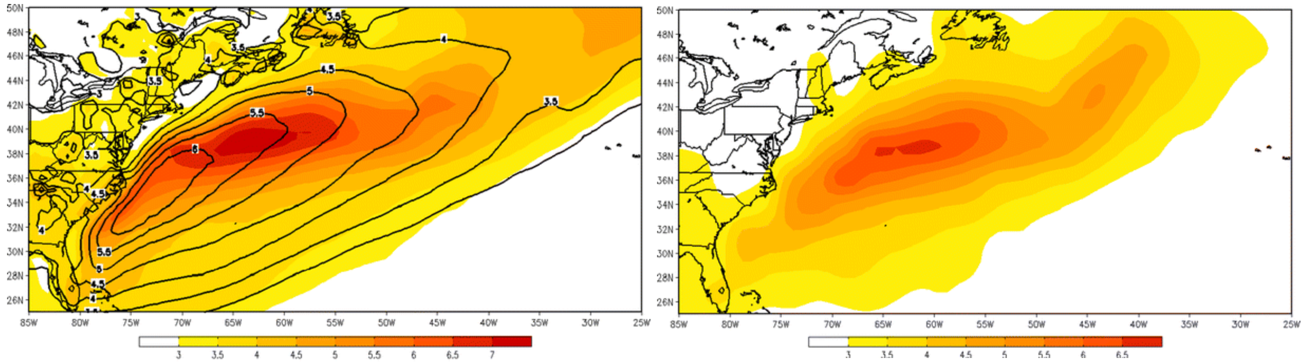

Fig. 7 Time mean precipitation simulations in mm day-1 with low (contours) and high (shaded) model resolutions (left panel), and the climatological precipitation of CPC Merged Analysis of Precipitation (right panel). It demonstrates the presence of resolved ocean eddies modified the mean climate. (Courtesy of B. Kirtman)

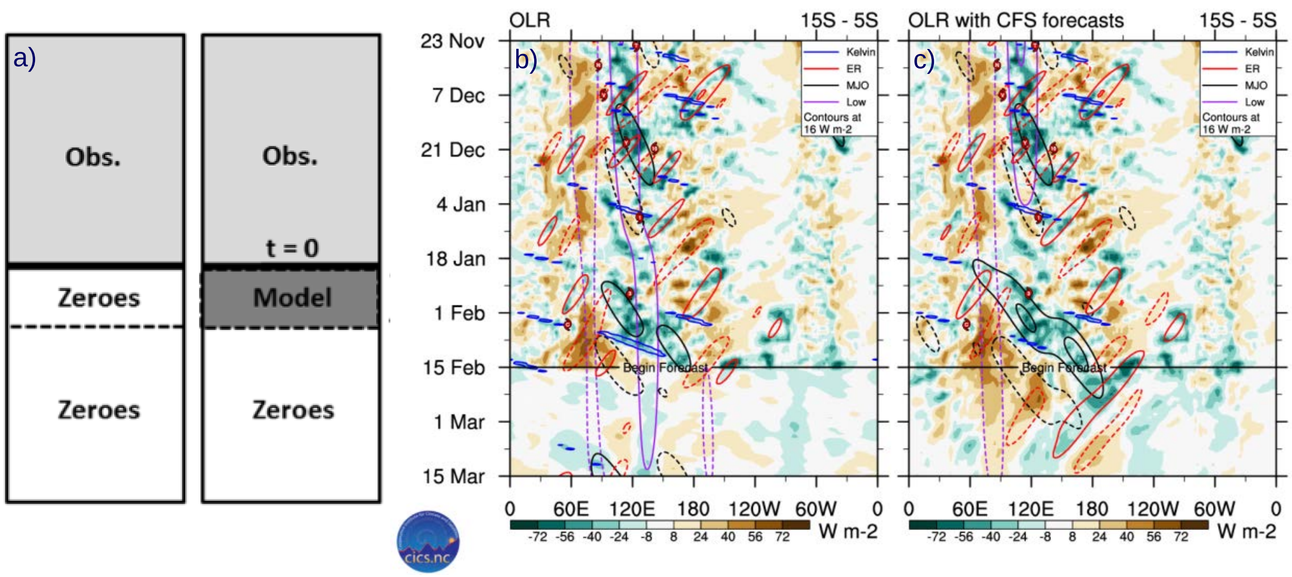

Fig. 8 (a) Schematic comparison between original Wheeler–Weickmann method (left) and the new methodology (right). Latter pads additionally with 45-day CFSv2 forecasts, which are more accurate than the zeros used in former. The new methodology combines recent observations with CFSv2 forecasts for Fourier filtering of the MJO, the low-frequency interannual variability, and convectively coupled equatorial waves, honing the most predictable aspects of the tropical S2S variability while removing less predictable small-scale noise. (b) and (c) compare the two methods using examples from 16 February 2017. The filtered OLR anomalies (contours) are broadly similar in the past, diagnostic data. However, the CFSv2-padded anomalies (see in panel c) maintain higher amplitudes since the CFSv2 is able to simulate these modes to a degree. (Courtesy of C. J. Schreck III)

i) Sensitivity analysis of NMME seasonal predictions to ocean eddy resolving coupled models (PI: B. Kirtman, RSMAS, University of Miami)

Develop ocean eddy resolving global coupled prediction system to test the hypothesis of that the presence of oceanic mesoscale features, i.e. fronts and eddies, significantly modifies local air-sea coupling, which in turn affects the local representation of the predictable large scale climatic features (Fig. 7). Predictions will be made remotely but data given to CPC.

ii) Novel statistical-dynamical forecasts for tropical S2S drivers (PI: C. J. Schreck III, NCICS, North Carolina State University)

Transition tropical S2S diagnostics from the demonstration platform at NCICS.org/mjo (Fig. 8) into the operational environment at CPC.

iii) Predicting atmospheric rivers (AR) and their impacts in weeks 2-5 based on the state of the MJO and QBO (PI: E. A. Barnes, Colorado State University)

Transition to operations the anomalous atmospheric river (AR) frequency forecast tool based on the observed state of the Madden-Julian Oscillation (MJO) and Quasi Biennial Oscillation (QBO). It is demonstrated that robust AR frequency anomalies can be seen more than 4 weeks ahead due to the propagation of the MJO, and the sign of the anomalous frequencies are a strong function of QBO phase as shown in Fig. 9.

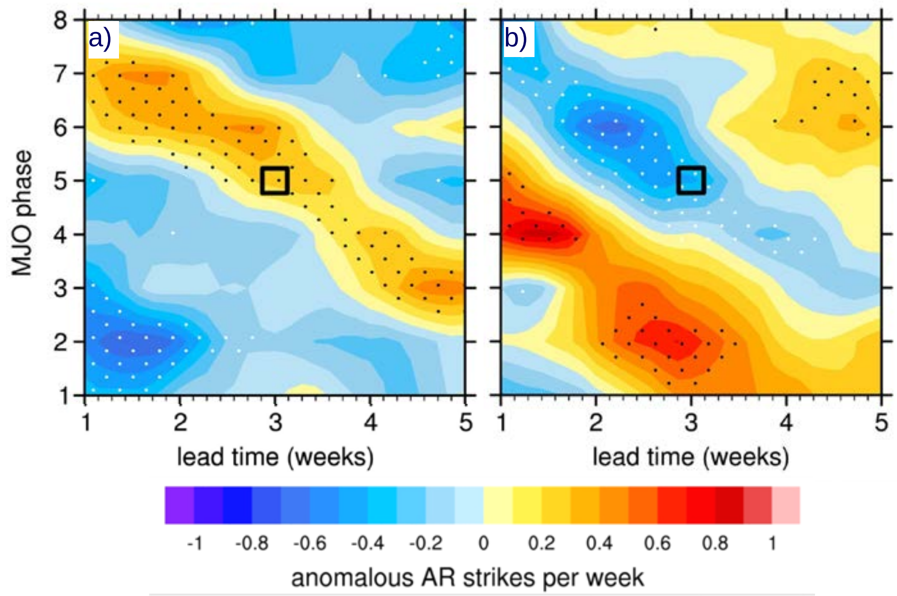

Fig. 9 ERA-Interim composites of anomalous AR strikes-per-week for the Pacific Northwest following days when the MJO was in a particular phase during (a) easterly and (b) westerly QBO periods. (Courtesy of E. A. Barnes)

FY18 new projects will also make following contributions: 1) a new technique for improved MJO prediction (PI: C. Zhang, PMEL, NOAA), 2) probabilistic multimodel, calibrated subseasonal global forecast products (P.I: A. W. Robertson, IRI, Columbia University), 3) S2S prediction improvement with NCAR's CESM2-WACCM (PI: J. H. Richter, NCAR - CGD), and 4) a hybrid statistical-dynamical system for the seamless prediction of daily extremes and S2S climate variability (PI: D. Collins, CPC, NOAA/NWS/NCEP).

5. Remarks

Recent comprehensive skill metric based on all CPC extended to long range outlooks revealed continuous improvement of CPC products, which was inseparable with progresses of ongoing R2O activities. The improvements were reflected in newly implemented systems, tools and products. In view of future challenges, on which researches present to raise prediction skill and hence boost credibility of seasonal-to-subseasonal climate service, we placed hopes on our research partners and people in field with considerable effort, and sufficient and sustained investment to work together on trying to make a break through.

Project new publications

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DelSole, T., L. Trenary, and M. K. Tippett, 2018: The weighted-average lagged ensemble. *J. Adv. Model. Earth Syst*, **9**, 2739-2752, doi:10.1002/2017MS001128.

Lima, L.N., L.P. Pezzi, S.G. Penny, and C. A. S. Tanajura, 2019: An investigation of ocean model uncertainties through ensemble forecast experiments in the Southwest Atlantic Ocean. Journal of Geophysical Research: Oceans, 124, 432-452, https://doi.org/10.1029/2018JC013919

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Tippett, M. K., L. Trenary, T. DelSole, K. Pegion, and M. L'Heureux, 2018: Sources of bias in the monthly CFSv2 forecast climatology. *J. Appl. Meteor. Climatol.*, **57**, 1111-1121, doi:10.1175/JAMC-D-17-0299.1.

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Zhu, Y., X. Zhou, W. Li, D. Hou, C. Melhauser, E. Sinsky, M. Pena, B. Fu, H. Guan, W. Kolczynski, R. Wobus, and V. Tallapragada, 2018: Towards the improvement of sub-seasonal prediction in the NCEP Global Ensemble Forecast System (GEFS), *Journal of Geophysical Research*, 6732-6745, doi:10.1029/2018JD028506

Zhu, Y., W. Li, E. Sinsky, H. Guan, X. Zhou, and D. Hou, 2018: An Assessment of subseasonal forecast using extended Global Ensemble Forecast System (GEFS), [in 42nd NOAA Climate Diagnostics and Prediction Workshop Special Issue, Climate Prediction S&T Digest], NWS Science & Technology Infusion Climate Bulletin Supplement, 150-153, https://doi.org/10.7289/V5/CDPW-NWS-42nd-2018.