"Role of stratospheric processes in predicting ENSO-NAO connections on subseasonal time scale"

Final Report

1. General Information:

Project title: "Role of stratospheric processes in predicting ENSO-NAO connections on subseasonal time scale"
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Final Report: July 2017 - June 2019)
Grant #: N/A

2. Main goals of the project, as outlined in the funded proposal

- To improve our understanding of the role of the stratosphere on the predictability of the NAO and related extremes on subseasonal time scale in the context of ENSO-NAO connections
- To quantify changes in predictive skill of a model with and without a well-resolved stratosphere
- To provide the scientific community with a thoroughly tested and evaluated stratospheric resolving subseasonal to seasonal (S2S) forecast system and dataset based on the Community Earth System Model (CESM)

3. What was accomplished under these goals?

Modeling

1. A 10-member ensemble of AMIP simulations with the 46-level version of the Community Atmosphere Model (46LCAM5) was extended to year 2016.
2. The infrastructure for the Random Field (RF) perturbation initialization method in 46LCAM was developed that showed a superior generation of ensemble spread in S2S forecasting compared to other S2S forecasts systems used in SubX. This method was used to initialize the CESM1 reforecats.
3. 10-member S2S hindcasts with the 30L and 46L CESM1 were carried out that followed the SubX protocol for the time period 1999 – 2015. The output was made available to the community through the IRI/Subx website: https://iridl.ldeo.columbia.edu/SOURCES/.Models/.SubX/ The availability of this dataset has faciliated studies by other members of the S2S taskforce.

Diagnostic Studies

1. *Relationship between the QBO and the stratospheric polar vortex on multi-decadal time scales in 46LCAM5:*

Observations and model sensitivity studies suggest that the QBO provides predictive skill of the NAO through its impact on the strength of the stratospheric polar vortex. Our analysis of this relationship in a 10-member ensemble of AMIP simulations suggests that the observational relationship can be reproduced by CESM1, however it strongly varies between the individual ensembles, suggesting that the predictive skill of the QBO on the NAO is not robust feature on the S2S time scale (Figure 1). Results are summarized in publication [1].

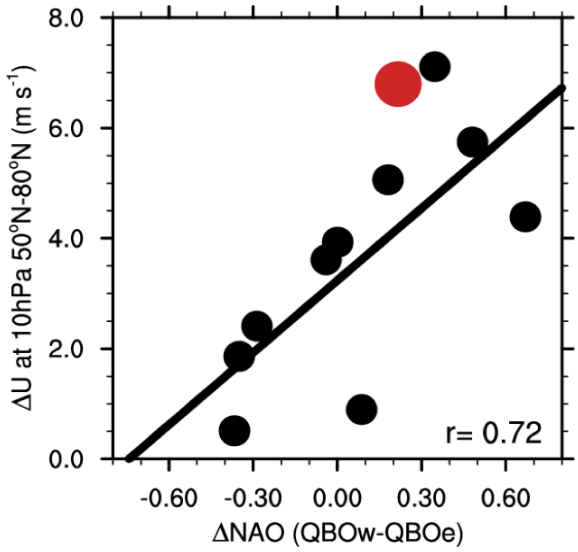

Figure 1: Scatter plot between QBOw-QBOe index values of the North Atlantic oscillation versus strength of the Holton-Tan relationship determined based on the 10 runs of the L46-CESM1 model ensemble together with the regression line. The red dot denotes the value for ERA-40/Interim merged dataset.

2. Feasibility of CESM1 as forecast tool on S2S time scales:

CESM1 has similar predictive skill of sea-level pressure and the NAO in the extratropical Northern Hemisphere to operational subseasonal forecasts, such ECMWF. CESM1 has better S2S predictive skill of sea surface temperature and precipitation as compared to the majority of SubX models and increases the skill of the multi-model mean (Figure 2). Results are summarized in publication [2].

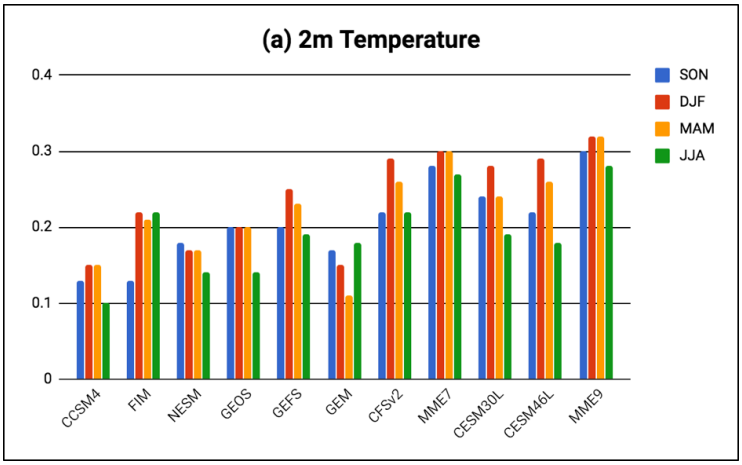

Figure 2: Week 3/4 2m North America Temperature anomaly correlation coefficient (ACC) for SubX models and CESM30L and CESM46L. MME7 represents the multi-model mean of the SubX models. MME9 represents the multi-model mean of the SubX models and CESM30L and CESM46L.

3. Impact of stratospheric processes on predictive skill on S2S time scales:

The impact of improved stratospheric representation on predictive skill can be assessed by comparing the skill of 46LCESM1 (medium-high top, self-generated tropical QBO) to 30LCESM (low top). The subseasonal forecast skill of stratospheric circulation (tropical QBO, polar vortex) is enhanced in 46LCESM1as compared to 30LCESM1 (Figure 3), however no significant changes to seasonally/annually averaged skill between the two versions of the model is noted. These results are included in publication [2].

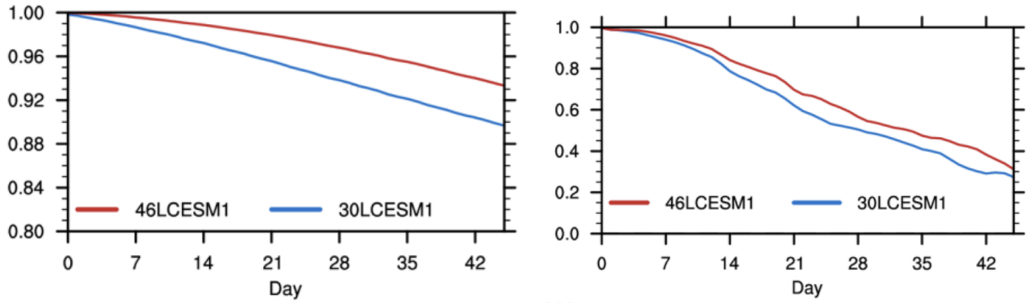

Figure 3: Annually averaged ACC for QBO (50 hPa zonal-mean zonal wind between 5S to 5N) (left) and polar vortex (10 hPa 60N zonal-mean zonal wind) (right) for 30LCESM1(blue) and 46LCESM1(red).

4. Attribution of week 3-6 NAO predictive skill:

CESM1 hindcasts show that forecasts initiated during anomalously strong and weak stratospheric polar vortex conditions show enhanced tropospheric NAM skill up to week 6 compared to stratospheric conditions initialized close to climatology. The higher NAO predictive skill persists longer (up to week 6) for weak as compared to strong stratospheric vortex events (only up to week 4) (Figure 4). Forecast skill of tropospheric Northern Annular Mode averaged during week 3 to 6 after occurrence of weak vortex events is enhanced in 46LCESM1 compared to 30LCESM1. The combination of initialized reforecasts and uninitialized AMIP style experiments reveal that the enhanced NAO predictive skill for weak vortex events is related to stratospheric downward coupling, while in the case of strong vortex events the skill is partly related to lower boundary forcing (e.g., ENSO). The results of this work are summarized in publication [3].

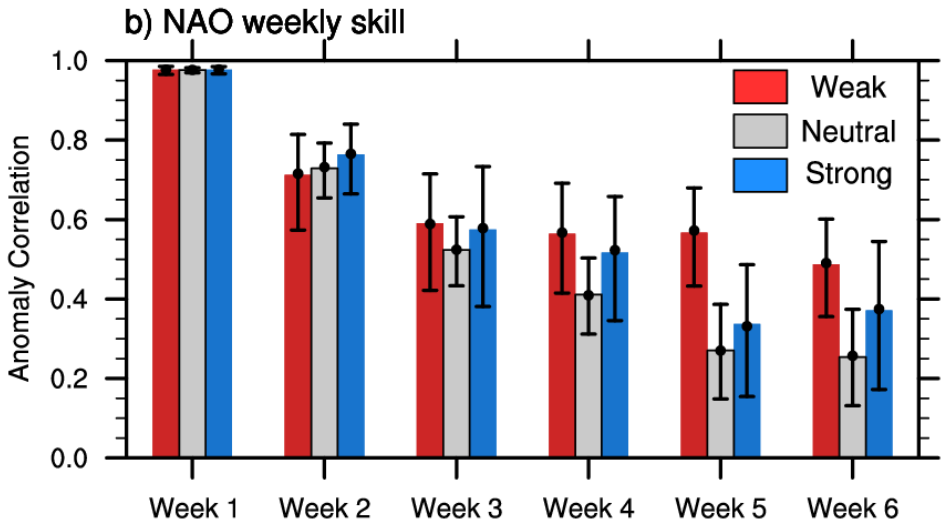

Figure 4: Weekly NAO skill following these three stratospheric states for CESM1 hindcasts (30L and 46L together).

5. Predictability of the Madden-Julian Oscillation (MJO):

The CESM1 hindcasts set is being utilized by the community to study the predictability of the MJO. CESM1 shows very good MJO prediction skill (Figure 5). CESM1, as well as eight other models show an insignificant relationship between the QBO and the MJO. (Figure 6). The relationship is however sensitive to the choice of QBO events and its significance might be limited by the relatively small number of available hindcast years. The results of this work as summarized in publication [4] and publication [5].

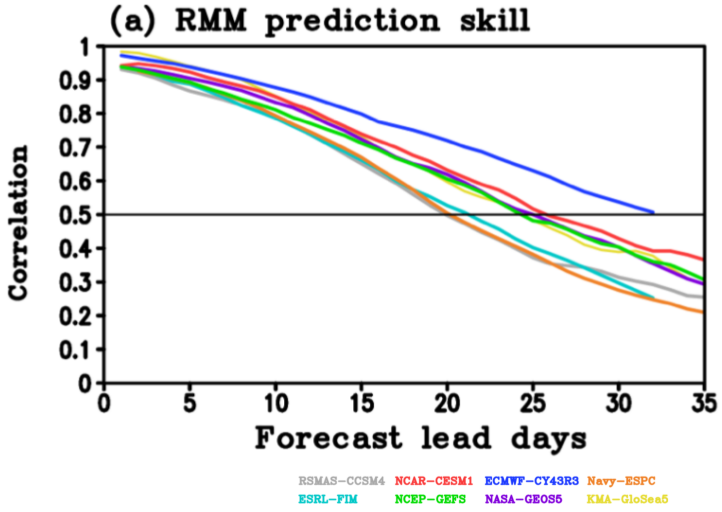

Figure 5: Real-time multivariate MJO index (RMM) between the model ensemble means and observation for SubX models (RSMAS-CCM4, ESRL-FIM, NCEP-GEFS, NASA-GEOS5, Navy-ESPC, and KMA-GloSea5), ECMWF-CY43R3, and NCAR-CESM1 (30L and 46L combined).

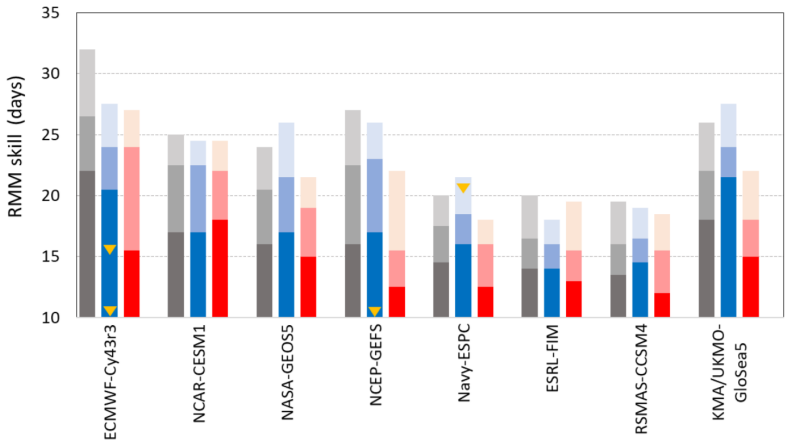

Figure 6: Forecast lead days when RMM skill reaches 0.7 (dark), 0.6 (medium), and 0.5 (light) in all (gray), EQBO (blue), and WQBO (red) winters. Yellow triangles indicate when RMM skill difference between EQBO and WQBO is statistically significant at 95% confidence level at the forecast lead days 10, 15, 20, 25, and 30.

Learning about and carrying out real-time subseasonal forecasts contributed to the professional development of the NCAR scientists J. Richter

4. What opportunities for training and professional development has the project provided?

The project provided opportunity for professional growth of the early career scientist Lantao Sun at CIRES/University of Colorado. Learning about how to run subseasonal forecasts contributed to the professional development of the NCAR scientists J. Richter.

5. How were the results disseminated to communities of interest?

The results were presented at Monthly S2S Task Force Web Meeting and International Conferences

6. Publications, conference papers, and presentations

Publications:

[1] Perlwitz, J., L. Sun, J. Richter and J. Albers, 2017: “What determines the strength of the QBO-Stratospheric Polar Vortex connection”, Geophys. Res. Lett. *In revision*

[2] Richter, J. H., K. Pegion, L. Sun, H. Kim, J. Caron, S. Yeager, W. Kim, A. Tawfik: "Subseasonal prediction skill of 30L and 46L CESM1", Weather and Forecasting, In preparation

[3] Sun, L., J. Perlwitz, J. Richter and M. Hoerling: Attribution of NAO Predictability beyond two Weeks, Geophys. Res. Lett., *In preparation*

[4] H. Kim, M. Janiga, and K. Pegion: "MJO Propagation Processes and Mean Biases in the SubX and S2S Reforecasts", J. of Geophys. Res. , 124, https://doi.org/10.1029/2019JD031139

[5] H. Kim, J. H. Richter, and Z. Martin: "Insignificant QBO-MJO prediction skill relationship in the SubX and S2S subseasonal reforecasts", Geophys. Res. Lett., *In revision*

Presentations:

[A] Perlwitz, J., L. Sun, J. Richter, J. Bacmeister, 2016: Towards Understanding the Role of Stratospheric Processes in Predicting ENSO-NAO Connections on Subseasonal to Seasonal Timescale. Workshop on Sub-Seasonal to Seasonal Predictability of Extreme Weather and Climate, Palisades, NY, USA

[B] Sun, L., J. Richter, J. Bacmeister, 2016: Towards Understanding the Role of Stratospheric Processes in Predicting ENSO-NAO Connections on Subseasonal to Seasonal Timescale. AGU Fall meeting, San Francisco, CA, USA

[C] Perlwitz J., 2016 (Invited): The Role of Stratospheric Processes in Large-Scale Teleconnections. ECMWF Annual Seminar, Reading, United Kingdom.

[D] Perlwitz, J., L. Sun, J. Richter and J. Albers, 2017:' What determines the strength of the QBO-Stratospheric Polar Vortex connection" NOAA MAPP S2S Taskforce

[E] J. H. Richter, J. Perlwitz, L. Sun, J. Bacmeister, and J. Tribbia: "Role of stratospheric processes in predicting the ENSO-NAO connections on subseasonal time scale", CESM Annual Meeting, Boulder, CO, June 2017

[F] Perlwitz, J., L. Sun, J. Richter and J. Albers, 2017:' What determines the strength of the QBO-Stratospheric Polar Vortex connection", Regional SPARC Workshop, Incheon, South Korea

[G] Perlwitz J., for NOAA S2S TaskForce, 2017: US/NOAA-S2S Capability Development and Research Projects, SPARC Scientific Steering Group Meeting, Incheon, South Korea.

[H] Richter, J., L. Sun and J. Perlwitz, '*S2S Simulations with 30-level and 46-level CESM1*', NOAA MAPP S2S Taskforce, Feb 2018

[I] Perlwitz, J., L. Sun, J. Richter and J. Albers, 2018: What determines the strength of the QBO-Stratospheric Polar Vortex connection, International *Workshop* on Subseasonal to Seasonal Prediction, Boulder

[J] Sun, L., J. Perlwitz, J. Richter and M. Hoerling, 2018: Attribution of NAO Predictability beyond two Weeks, International *Workshop* on Subseasonal to Seasonal Prediction, Boulder

[K] Sun L., J. Perlwitz, J. H. Richter, M. Hoerling (2019): "Attribution of NAO predictability beyond two weeks", AMS Conference on the Middle Atmosphere, Phoenix, AZ, Jan 2019

7. What individuals have worked on this project?

Jadwiga Richter and Jim Edwards (NCAR), Judith Perlwitz and Lantao Sun, CIRES/Univeristy of Colorado and NOAA/ESRL/PSD; Collaborators: J. Caron, S. Yeager, W. Kim, A. Tawfik (NCAR); K. Pegion (George Mason U.), H. Kim (Stony Brook University)

8. What was the impact on the development of the principal discipline(s) of the project?

This project has an impact on dynamical modeling and subseasonal forecasting by expanding the capacity for modeling forecasting at this timescale through and providing new knowledge on the generation of initial conditions for these forecast.

9. What was the impact on physical, institutional, and information resources that form infrastructure?

The project involved close collaborations among NCAR scientists and CIRES/CU scientists that are working at NOAA/ESRL/PSD and extensive use of NCAR computing systems.

10. What was the impact on technology transfer?

Nothing to report

11. What was the impact on society beyond science and technology?

The project provided tools to better assess the role of stratosphere on the predictive skill of the North Atlantic Oscillation. Enhanced subseasonal forecasts skill provides early warning of extreme weather events.

12. What were the outcomes of the award?

- A S2S reforecast data set with two versions of NCAR's CESM1 were carried out that differ in the representation of stratospheric processes. These data set are available to the scientific community through NOAA funded SUBX data distribution.
- The project strengthened evidence for the importance of the proper representation of stratospheric processes to enhance the tropospheric S2S forecast skill.

- The project provided new knowledge on the relative contribution of stratospheric processes and lower boundary conditions related to El Nino Southern Oscillation on the prediction of the North Altantic Oscillation. This knowledge has important implications on the approach used to evaluate subseasonal forecasts model skill with respect to proper representation of stratospheric processes.