AGU100 ADVANCING EARTH AND SPACE SCIENCE

JGR Atmospheres

INTRODUCTION TO A SPECIAL SECTION
10.1029/2019JD031833

Special Section:
Bridging Weather and Climate: Subseasonal-to-Seasonal (S2S) Prediction

Key Points:
- This article acts as an introduction to the special collection on S2S prediction This article introduces the concept of the S2S prediction "gap"
- This article discusses organized efforts on S2S prediction

Correspondence to:
E. A. Barnes,
eabarnes@atmos.colostate.edu

Citation:
Lang, A. L., Pegion, K., & Barnes, E. A. (2020). Introduction to special collection: "Bridging weather and climate: Subseasonal-to-seasonal (S2S) prediction". *Journal of Geophysical Research: Atmospheres*, *125*, e2019JD031833. https://doi.org/10.1029/2019JD031833

Received 15 OCT 2019
Accepted 7 JAN 2020
Accepted article online 10 JAN 2020

Introduction to Special Collection: "Bridging Weather and Climate: Subseasonal-to-Seasonal (S2S) Prediction"

Andrea L. Lang[1], Kathleen Pegion[2], and Elizabeth A. Barnes[3]

[1]Department of Atmospheric and Environmental Sciences, University at Albany, State University of New York, Albany, NY, USA, [2]Department of Atmospheric, Oceanic and Earth Sciences, George Mason University, Fairfax, VA, USA, [3]Department of Atmospheric Science, Colorado State University, Fort Collins, CO, USA

Abstract This article acts as an introduction to the JGR-Atmospheres Special Section titled "Bridging Weather and Climate: Subseasonal-to-Seasonal (S2S) Prediction". It outlines the major findings of the articles published in the Special Section as well as discusses organized national and international efforts to advance subseasonal-to-seasonal prediction research.

1. Introduction

Meteorology, and atmospheric science more generally, is historically rooted in efforts to predict atmospheric conditions on time scales corresponding to weather (hours to days) or climate (a season or more). In recent years, diverse industries and enterprises have expressed renewed interest in the application of weather and climate forecasts on time scales between two weeks and three months. This subseasonal-to-seasonal (S2S) time scale is relevant to successful planning and preparation in a variety of sectors, including public health, disaster preparedness, water management, energy, and agriculture. Bridging this prediction "gap" between weather and climate forecasts, S2S prediction is an area of active research aimed at addressing the high public demand for skillful forecasts on these time scales.

In recent years, a number of organized efforts have contributed to the growing area of S2S prediction. In 2013, the World Weather Research Program and the World Climate Research Program together spanned this weather-to-climate gap by supporting the creation of the S2S Prediction Project. A key outcome of the first 5-year phase of this project was the creation of the S2S Prediction Project Database consisting of ensembles of subseasonal (up to 60 days) forecasts and supplemented with an extensive set of reforecasts from a suite of operational modeling centers (Vitart et al., 2017). Similarly, the National Oceanic and Atmospheric Administration and Modeling, Analysis, Predictions and Projections Program established the S2S Prediction Task Force, consisting of over 60 researchers working on addressing processes and approaches to improve S2S prediction. As part of the National Oceanic and Atmospheric Administration effort, the Subseasonal eXperiment (SubX) created an additional coordinated effort to provide experimental real-time forecasts for seven forecast systems in order to investigate S2S prediction, model set configuration, and skill (Pegion et al., 2019). These efforts provided a framework for the weather and climate research and operational communities to coordinate and investigate the S2S prediction gap.

This Special Collection presents contributions from across the S2S community, including research and data supported or generated by the programs above. The Collection features scientific research that increases understanding of the processes and approaches that lead to S2S predictability and prediction skill. Figure 1 is a conceptual representation of a sampling of the processes, pathways, and interactions explored in this Collection that lead to skillful forecasts at S2S lead times. A brief description of the Special Collection contributions represented schematically in Figure 1 follows in section 2.

2. Advances in Understanding S2S Predictability and Skill

2.1. The Stratosphere

As represented in Figure 1, the stratospheric polar vortex has long been regarded as an important contributor to atmospheric predictability at multiweek leads. Several contributions to this Special Collection examine how anomalous stratospheric circulations can influence the tropospheric circulation, including shifting the frequency and durations of blocking, cold air outbreaks, and even tropical phenomena such as the

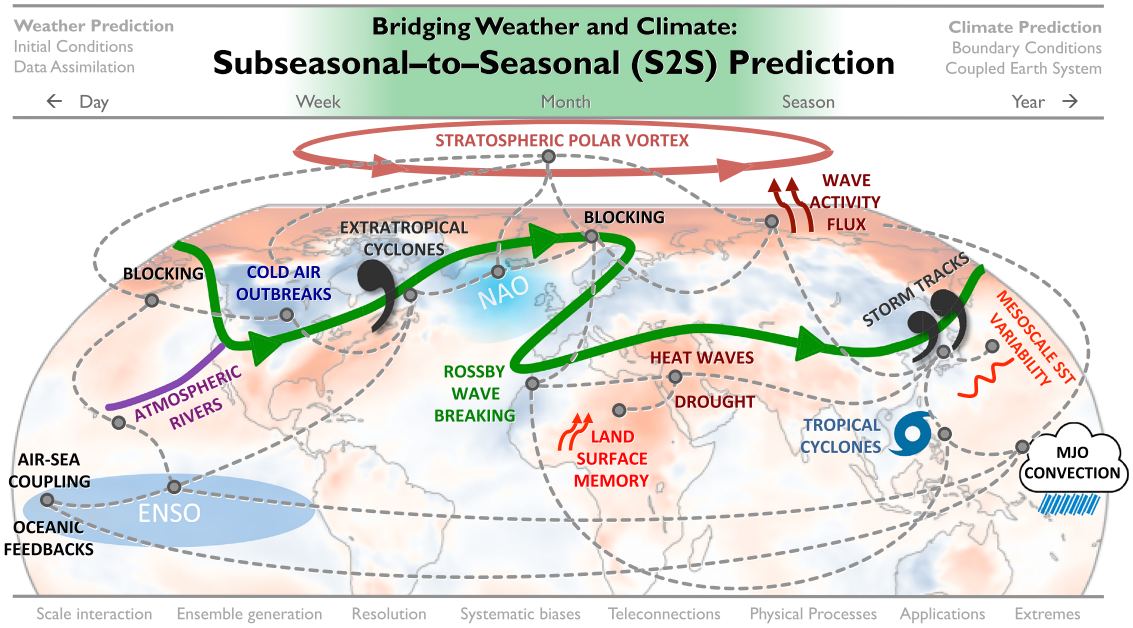

Figure 1. A schematic representation of many of the atmospheric phenomena and numerical modeling considerations needed to make accurate forecasts in the subseasonal-to-seasonal time scale.

Madden-Julian Oscillation (MJO). Several types of stratospheric variability are known to have impacts on surface weather and climate. These impactful types of stratospheric variability include anomalous states of the northern and southern hemispheric stratospheric polar vortices, extreme stratospheric ozone conditions, and the tropical stratospheric variability described by the quasi-biennial oscillation (QBO). The ability to capture the mechanisms and processes that facilitate the impactful troposphere-stratosphere coupling in S2S forecasts is relatively unknown.

The mechanisms for skillful S2S prediction associated with variability from the polar vortex in the form of sudden stratospheric warming events, strong vortex events, and final warming (FW) events are explored by several contributions to the special collection (Jucker & Reichler, 2018; Karpechko et al., 2018; Lee et al., 2019; Butler et al., 2019; Domeisen et al. 2020a, b). Several studies focus on the ability to resolve the key mechanisms involved in predicting stratospheric vortex variability require consideration of upward wave activity flux (e.g., Jucker & Reichler, 2018; Karpechko et al., 2018), the meridional potential vorticity gradient (Jucker & Reichler, 2018), accurate prediction of the Ural High (Karpechko et al., 2018; Lee et al., 2019), North Atlantic cyclones, and associated Rossby wave breaking (Lee et al., 2019). Studies also emphasize that the background climate patterns can extend the predictability horizon and the likelihood of these mechanisms to create a favorable environment for stratospheric variability (Rao et al., 2019).

A unique approach by Choi and Son (2019) explores the commonalities in initial conditions between high and low skill forecasts of extratropical sea level pressure anomalies. High and low skill sea level pressure forecasts are identified as having distinctly different initial conditions in the stratosphere. High skill forecasts are associated with damped vertically propagating waves and enhanced stratosphere-troposphere coupling, while low skill forecasts are associated with enhanced vertically propagating waves that propagate into the stratosphere and have less impact on the troposphere.

While most of the focus on the high-latitude stratosphere from the S2S community focuses on midwinter predictability, consideration of the stratospheric variability in the early spring season can also inform the assessment of skill in S2S forecasts. The final reversal of the stratospheric polar vortex from its westerly winter state to easterly summer state are called FWs. FWs occur in early spring and their timing can vary by more than 2 months. The mechanisms that produce FWs also vary such that these phenomena can have surface temperature impacts different from sudden stratospheric warmings. Butler et al. (2019) investigate the predictability of the timing of FWs and find that early FWs are less predictable than late FWs and that

S2S prediction skill of 2-m temperature anomalies in the North Atlantic-Eurasian region is enhanced during early FWs. Large ozone variability is also a feature of the early spring period in the stratosphere. Stone et al. (2019) show that using extreme values of March stratospheric ozone as a predictor, skillful forecasts of April Northern Hemisphere surface temperatures are attainable.

The QBO is known to impact the stratospheric polar vortex through the Holtan-Tan effect in which the Arctic temperatures are warmer and heights are higher during easterly QBO compared to that of the westerly QBO (e.g., Anstey et al., 2010; Holton & Tan, 1980). As such, Garfinkel et al. (2018) explore the QBO as a source of S2S predictability and find that the QBO contributes to enhanced probabilistic skill in predicting Northern Hemisphere climate on S2S time scales when the models have a reasonable stratospheric resolution.

2.2. The MJO and BSISO

2.2.1. MJO and BSISO Predictability

The MJO and its boreal summer counterpart, the Boreal Summer Intraseasonal Oscillation (BSISO), are known to modulate extratropical weather both through tropospheric and stratospheric pathways. The MJO and BSISO have long been identified as sources of predictability for S2S time scales both locally and in the extratropics due to Rossby wave dispersion associated with the large-scale tropical heating anomalies in their convectively active regions. Ongoing efforts to understand and improve the ability of models to represent and predict MJO/BSISO events, as well as their impacts, are represented in this special collection. Further, papers in this collection advance our understanding of how these phenomena impact extratropical weather and climate.

Recent understanding of the MJO has identified the important role that moisture plays in its initiation, propagation and amplitude through preconditioning and moisture modes. Wei et al. (2019) introduce a new framework called “conditional nonlinear optimal perturbations,” which identifies precursors that lead to initiation of a primary MJO event—one that was not preceded by a circumnavigating MJO. Hagos et al. (2019) demonstrate that the zonal migration of Asian and Australian monsoon moisture to the moisture flux convergence is an important factor in determining the amplitude of the MJO. The ability of SubX and S2S models to represent the eastward propagation of the MJO is evaluated by Kim et al. (2019), which attributes errors in MJO propagation in a large collection of S2S models to a dry low troposphere, excess surface rainfall, and frequent occurrence of light rainfall which inhibit the mean moisture convergence process that is critical for eastward propagation of the MJO.

The BSISO is the boreal summer counterpart to the MJO. Due to differences in seasonality, the BSISO has a northward component to its propagation. While many metrics and diagnostics have been developed to quantify the characteristics of the MJO and BSISO, they differ in how well they represent the propagation characteristics for the BSISO (Wang et al., 2018).

2.2.2. MJO and BSISO Teleconnections

Previous studies have identified a relationship in which a Rossby wave train associated with MJO tropical heating impacts the phase and amplitude of the North Atlantic Oscillation (NAO). Feng and Lin (2019) identify differences in that teleconnection based on the phase of the QBO. They show that in observations, when the QBO is westerly, the MJO-NAO teleconnection is stronger and longer lasting than when the QBO is easterly. Further investigation of the dynamical mechanisms for these differences identify differences in the basic state of the atmospheric circulation under the different phases of the QBO. In addition to a tropospheric pathway connecting the MJO and NAO, there is also evidence of a stratospheric pathway linking the MJO and NAO. Barnes et al. (2019) explore this pathway using conditional probabilities and causal inference methods. They identify a pathway in which the MJO impacts the polar vortex, which impact the NAO and a second pathway in which the polar vortex conditions whether the NAO is likely to be influenced by MJO.

Given the periodic nature of the MJO, it is at times difficult to clearly identify its remote impacts. Jenney, Randall, et al. (2019) develop a metric, called STRIPES, for quantifying the predictive power of periodic events such as the MJO. The index combines both composite and lagged information relating a variable to the periodic event into a single number which quantifies the local response to the remote event. They apply this metric to daily observational circulation and sensible weather data to identify the locations where the MJO has the most impact in winter. Jenney, Nardi, et al. (2019) also apply the STRIPES metric in other

seasons and demonstrate the potential to use MJO information for skillful S2S prediction throughout the year.

Since every MJO event is different, its impact on the extratropics also vary. The skill of tropical short-range forecasts (e.g., tropical convection) and Northern Hemisphere S2S forecasts is positively correlated (Dias & Kiladis, 2019). Zheng and Chang (2019), identify differences in the extratropical response to MJO heating depending on the propagation, lifetime, and intensity of the MJO. Their model experiments demonstrate that the extratropical response to an MJO event depends strongly on its initiation and decay, with a strong response occurring only when the MJO propagates through specific phases.

2.3. Ocean and Land

The land and ocean (including sea ice) surface are also sources of S2S prediction given their multiweek memory. It has long been conjectured that the contribution of the land surface to atmospheric predictability peaks on the subseasonal time scale. Dirmeyer et al. (2018) perform a series of hindcast experiments, which, for the first time, quantify and confirm this conjecture relating land surface and S2S prediction skill. They further demonstrate that the signal from the land surface is clearly identifiable at the land atmosphere interface and boundary layer but disappears when analyzing precipitation due to errors in convective parameterizations. Mesoscale sea surface temperature variability—the ocean's weather—can impact the atmospheric circulation on S2S time scales. Jia et al. (2019) perform experiments using a high-resolution atmosphere and a slab ocean model and show that ocean mesoscale variability impacts large scale atmospheric circulation, including the jet streams and midlatitude storm tracks, which has direct implications for S2S prediction in midlatitudes.

2.4. Sea Ice Prediction

Predicting sea ice in the Arctic and Antarctic is a new area being explored on S2S time scales. Due to increasing human activities in the polar regions, there is a growing need for skillful predictions across a range of time scales in these regions (Jung et al., 2016). Zampieri et al. (2018, 2019) provide the first evaluation of the skill of operational prediction systems for Arctic and Antarctic sea ice prediction on S2S time scales. They find a wide range of skill across models with the best model having skill up to 1.5-month lead times in the Arctic and 30 days in the Antarctic. In both the Arctic and Antarctic model biases and initial condition errors play a significant role in contributing to forecast errors. The rapidly changing high-latitude climate has made statistical modeling of the high latitudes more complicated. Cox et al. (2019) propose a climate index that includes metrics sensitive to linkages to midlatitude variability that addresses some of these issues.

2.5. Midlatitude Atmospheric Variability

The variability in the midlatitude regions on S2S time scales is largely tied to the characteristics of the dispersion, amplification, and breaking of synoptic-scale waves associated with Rossby wave packets. Quinting and Vitart (2019) examine the representation of synoptic-scale Rossby wave packets and blocking in the S2S Prediction Project Database. They show that most models tend to underestimate the Rossby wave packets decay frequency in the Atlantic-European sector and that this underestimation is most obvious in models with coarse resolution. The under resolved decay of Rossby wave packets was linked to an underestimation of atmospheric blocking frequency at S2S time scales.

Midlatitude variability at S2S time scales is largely assessed by teleconnections and other climate modes of variability. Using a Geophysical Fluid Dynamics Laboratory coupled model system, the three of the most predictable modes (e.g., El Niño–Southern Oscillation [ENSO], NAO, and the Eurasian Meridional Dipole) have skill at up to 5-week leads and provide significant sill for Week 3–5 wintertime surface air temperature prediction (Xiang et al., 2019). A statistical analysis by Miller and Wang (2019) revealed that Atlantic sea surface temperature, the stratospheric state, and sea ice are skillful predictors for atmospheric blocking frequency over the Eurasia region and the regional temperature impacts associated with blocking regimes. A similar result was found using the Norwegian Climate Prediction Model. Skillful surface temperature forecasts were obtained at lead times longer than 30 days by resolving a land surface-stratosphere teleconnection initiated by well-resolved anomalous Eurasian snow cover Li et al. (2019).

In the Southern Hemisphere, S2S predictability of midlatitude variability in the eddy-driven jet in spring and summer is shown to be linked to the stratospheric polar vortex Byrne et al. (2019). The observed subseasonal

influence of the ENSO on the Southern Hemisphere midlatitude jet occur via a stratospheric dynamical pathway. Garfinkel et al. (2019) assess the weakening of the teleconnection from ENSO to the Arctic stratosphere over the last several decades using S2S ensemble forecasts and find that natural variability in the anomalies in the eastern European sector were at the center of the weakening ENSO-stratosphere relationship.

The troposphere itself also exhibits variability on S2S time scales, which suggests that certain periods may be more predictable than average. Several papers in this Special Collection explore these potentially more predicable periods and windows of opportunity for prediction. For example, Albers and Newman (2019) identify a priori 10–30% of Week 3–6 forecasts for the extratropics constitute such forecasts of opportunity.

2.6. Extremes

The ability to provide extended range predictions of severe weather, tropical cyclones, drought, heat waves, extreme precipitation, and flooding at the S2S time scales is beneficial from an emergency preparedness, planning, and mitigation perspective (e.g., White et al., 2017). Multiple studies in this Special Collection demonstrate that severe weather activity has the potential to be predicted weeks in advance. For example, the occurrence and frequency of tornado and hail activity in the central United States can be skillfully predicted weeks in advance using the MJO (Baggett et al., 2018). Similarly, a case study of the May 2019 tornado outbreak over the central United States shows that the favorable supercell conditions were probabilistically predicted nearly 4 weeks in advance (Gensini et al., 2019). Beyond severe weather, the occurrence of increased periods of cloud-to-ground lightning strikes was shown to show skill for lead times of up to 15 days (Tippett and Koshak, 2018).

Subseasonal prediction of tropical cyclone activity is also demonstrated in this Special Collection, although the relative contribution of the direct (e.g., storm damages) and indirect (e.g., interaction with the midlatitude flow) impacts of tropical cyclones can differ by region (Chang and Wang, 2018). The occurrence of the most extreme North Atlantic hurricanes (e.g., major hurricanes) is more skillfully predicted in dynamical models with higher-resolution nests (Gao et al., 2019).

The poleward transport of tropical moisture can occur in concentrated regions that organize into atmospheric rivers. The landfall of atmospheric rivers is known to be associated with periods of persistent precipitation that can lead to devastating flooding (e.g., Mundhenk et al., 2016). In the western United States skill is modulated by the phase of ENSO and the MJO (DeFlorio et al., 2019), while over the North Atlantic, established European weather regimes are important for assessing potential atmospheric river impacts at S2S lead times (Pasquier et al., 2019).

With amplified warming over land in recent decades, summer temperatures are increasingly characterized by persistent extreme heat and on S2S time scales; summer warm extremes are more predictable at weekly lead times than average and cold events (Wulff & Domeisen, 2019). The enhanced warm extreme skill is suggested to be related to persistent flow patterns and land-atmosphere interactions during the summer season. Over eastern China, prediction of maximum temperatures associated with heat waves is limited by a late-July barrier due to variability of the western North Pacific subtropical high (Yang et al., 2018).

This Special Collection represents our current understanding of the myriad of phenomena, relationships, and modeled representation important to resolving the evolution of the weather and climate at S2S time scales.

Acknowledgments
No data were used for this article. This introduction was conducted as part of the NOAA MAPP S2S Prediction Task Force and supported by NOAA Grants NA16OAR4310068 (A. L. L.), NA16OAR4310146 (K. P.), and NA16OAR4310064 (E. A. B.).

References

Albers, J. R., & Newman, M. (2019). A priori identification of skillful extratropical subseasonal forecasts. *Geophysical Research Letters*, *46*, 12,527–12,536. https://doi.org/10.1029/2019GL085270

Anstey, J. A., Shepherd, T. G., & Scinocca, J. F. (2010). Influence of the quasi-biennial oscillation on the extratropical winter stratosphere in an atmospheric general circulation model and in reanalysis data. *Journal of the Atmospheric Sciences*, *67*, 1402–1419.

Baggett, C. F., Nardi, K. M., Childs, S. J., Zito, S. N., Barnes, E. A., & Maloney, E. D. (2018). Skillful subseasonal forecasts of weekly tornado and hail activity using the Madden-Julian Oscillation. *Journal of Geophysical Research: Atmospheres*, *123*, 12,661–12,675. https://doi.org/10.1029/2018JD029059

Barnes, E. A., Samarasinghe, S. M., Ebert-Uphoff, I., & Furtado, J. C. (2019). Tropospheric and stratospheric causal pathways between the MJO and NAO. *Journal of Geophysical Research: Atmospheres*, *124*, 9356–9371. https://doi.org/10.1029/2019JD031024

Butler, A. H., Charlton Perez, A., Domeisen, D. I. V., Simpson, I. R., & Sjoberg, J. (2019). Predictability of Northern Hemisphere final stratospheric warmings and their surface impacts. *Geophysical Research Letters*, *46*, 10,578–10,588. https://doi.org/10.1029/2019GL083346

Byrne, N. J., Shepherd, T. G., & Polichtchouk, I. (2019). Subseasonal-to-seasonal predictability of the Southern Hemisphere eddy-driven jet during austral spring and early summer. *Journal of Geophysical Research: Atmospheres*, *124*, 6841–6855. https://doi.org/10.1029/2018JD030173

Chang, C.-C., & Wang, Z. (2018). Relative impacts of local and remote forcing on tropical cyclone frequency in numerical model simulations. *Geophysical Research Letters*, *45*, 7843–7850. https://doi.org/10.1029/2018GL078606

Choi, J., & Son, S.-W. (2019). Stratospheric initial condition for skillful surface prediction in the ECMWF model. *Geophysical Research Letters*, *46*, 12,556–12,564. https://doi.org/10.1029/2019GL083519

Cox, C. J., Stone, R. S., Douglas, D. C., Stanitski, D. M., & Gallagher, M. R. (2019). The Aleutian Low-Beaufort Sea Anticyclone: A climate index correlated with the timing of springtime melt in the Pacific Arctic cryosphere. *Geophysical Research Letters*, *46*, 7464–7473. https://doi.org/10.1029/2019GL083306

DeFlorio, M. J., Waliser, D. E., Ralph, F. M., Guan, B., Goodman, A., Gibson, P. B., et al. (2019). Experimental subseasonal-to-seasonal (S2S) forecasting of atmospheric rivers over the western United States. *Journal of Geophysical Research: Atmospheres*, *124*(21), 11,242–11,265. https://doi.org/10.1029/2019JD031200

Dias, J., & Kiladis, G. N. (2019). The influence of tropical forecast errors on higher latitude predictions. *Geophysical Research Letters*, *46*, 4450–4459. https://doi.org/10.1029/2019GL082812

Dirmeyer, P. A., Halder, S., & Bombardi, R. (2018). On the harvest of predictability from land states in a global forecast model. *Journal of Geophysical Research: Atmospheres*, *123*, 145–117. https://doi.org/10.1029/2018JD029103

Domeisen, D. I. V., Butler, A. H., Charlton-Perez, A. J., Ayarzagüena, B., Baldwin, M. P., Dunn-Sigouin, E., et al. (2020a). The role of the stratosphere in subseasonal to seasonal prediction, Part I: Predictability of the stratosphere. *Journal of Geophysical Research*, *125*. https://doi.org/10.1029/2019JD030920

Domeisen, D. I. V., Butler, A. H., Charlton-Perez, A. J., Ayarzagüena, B., Baldwin, M. P., Dunn-Sigouin, E., et al. (2020b). The role of the stratosphere in subseasonal to seasonal prediction Part II: Predictability arising from stratosphere–troposphere coupling. *Journal of Geophysical Research*, *125*. https://doi.org/10.1029/2019JD030923

Feng, P.-N., & Lin, H. (2019). Modulation of the MJO-related teleconnections by the QBO. *Journal of Geophysical Research: Atmospheres*, *124*, 12,022–12,033. https://doi.org/10.1029/2019JD030878

Gao, K., Chen, J.-H., Harris, L., Sun, Y., & Lin, S.-J. (2019). Skillful prediction of monthly major hurricane activity in the North Atlantic with two-way nesting. *Geophysical Research Letters*, *46*(15), 9222–9230. https://doi.org/10.1029/2019GL083526

Garfinkel, C. I., Schwartz, C., Butler, A. H., Domeisen, D. I., Son, S.-W., & White, I. P. (2019). Weakening of the teleconnection from El Niño–Southern Oscillation to the Arctic stratosphere over the past few decades: What can be learned from subseasonal forecast models? *Journal of Geophysical Research: Atmospheres*, *124*, 7683–7696. https://doi.org/10.1029/2018JD029961

Garfinkel, C. I., Schwartz, C., Domeisen, D. I. V., Son, S.-W., Butler, A. H., & White, I. P. (2018). Extratropical atmospheric predictability from the quasi-biennial oscillation in subseasonal forecast models. *Journal of Geophysical Research: Atmospheres*, *140*, 1–12. https://doi.org/10.1029/2018JD028724

Gensini, V. A., Gold, D., Allen, J. T., & Barrett, B. S. (2019). Extended U.S. tornado outbreak during late May 2019: A forecast of opportunity. *Geophysical Research Letters*, *46*, 10,150–10,158. https://doi.org/10.1029/2019GL084470

Hagos, S., Zhang, C., Leung, L. R., Burleyson, C. D., & Balaguru, K. (2019). A zonal migration of monsoon moisture flux convergence and the strength of Madden-Julian Oscillation events. *Geophysical Research Letters*, *46*(14), 8554–8562. https://doi.org/10.1029/2019GL083468

Holton, J. R., & Tan, H. (1980). The influence of the equatorial quasi-biennial oscillation on the global circulation at 50 mb. *Journal of the Atmospheric Sciences*, *37*, 2200–2208. https://doi.org/10.1175/1520-0469(1980)037<2200:TIOTEQ>2.0.CO;2

Jenney, A. M., Randall, D. A., & Barnes, E. A. (2019). Quantifying regional sensitivities to periodic events: Application to the MJO. *Journal of Geophysical Research: Atmospheres*, *124*, 3671–3683. https://doi.org/10.1029/2018JD029457

Jenney, A. M., Nardi, K. M., Barnes, E. A., & Randall, D. A. (2019). The seasonality and regionality of MJO impacts on North American temperature. *Geophysical Research Letters*, *46*, 9193–9202. https://doi.org/10.1029/2019GL083950

Jia, Y., Chang, P., Szunyogh, I., Saravanan, R., & Bacmeister, J. T. (2019). A modeling strategy for the investigation of the effect of mesoscale SST variability on atmospheric dynamics. *Geophysical Research Letters*, *46*, 3982–3989. https://doi.org/10.1029/2019GL081960

Jucker, M., & Reichler, T. (2018). Dynamical precursors for statistical prediction of stratospheric sudden warming events. *Geophysical Research Letters*, *45*, 13,124–13,132. https://doi.org/10.1029/2018GL080691

Jung, T., Gordon, N. D., Bauer, P., Bromwich, D. H., Chevallier, M., Day, J. J., et al. (2016). Advancing polar prediction capabilities on daily to seasonal time scales. *Bulletin of the American Meteorological Society*, *97*, 1631–1647. https://doi.org/10.1175/BAMS-D-14-00246.1

Karmakar, N., & Misra, V. (2019). The relation of intraseasonal variations with local onset and demise of the Indian summer monsoon. *Journal of Geophysical Research: Atmospheres*, *124*, 2483–2506. https://doi.org/10.1029/2018JD029642

Karpechko, A. Y., Charlton Perez, A., Balmaseda, M., Tyrrell, N., & Vitart, F. (2018). Predicting sudden stratospheric warming 2018 and its climate impacts with a multimodel ensemble. *Geophysical Research Letters*, *45*, 13,538–13,546. https://doi.org/10.1029/2018GL081091

Kim, H., Janiga, M. A., & Pegion, K. (2019). MJO propagation processes and mean biases in the SubX and S2S reforecasts. *Journal of Geophysical Research: Atmospheres*, *124*, 9314–9331. https://doi.org/10.1029/2019JD031139

Lee, S. H., Charlton Perez, A. J., Furtado, J. C., & Woolnough, S. J. (2019). Abrupt stratospheric vortex weakening associated with North Atlantic anticyclonic wave breaking. *Journal of Geophysical Research: Atmospheres*, *124*, 8563–8575. https://doi.org/10.1029/2019JD030940

Li, F., Orsolini, Y. J., Keenlyside, N., Shen, M.-L., Counillon, F., & Wang, Y. G. (2019). Impact of snow initialization in subseasonal-to-seasonal winter forecasts with the Norwegian Climate Prediction Model. *Journal of Geophysical Research: Atmospheres*, *124*, 10,033–10,048. https://doi.org/10.1029/2019JD030903

Miller, D. E., & Wang, Z. (2019). Skillful seasonal prediction of Eurasian winter blocking and extreme temperature frequency. *Geophysical Research Letters*, *46*, 11,530–11,538. https://doi.org/10.1029/2019GL085035

Mundhenk, B. D., Barnes, E. A., & Maloney, E. D. (2016). All-season climatology and variability of atmospheric river frequencies over the north pacific. *Journal of Climate*, *29*, 4885–4903. https://doi.org/10.1175/JCLI-D-15-0655.1

Pasquier, J. T., Pfahl, S., & Grams, C. M. (2019). Modulation of atmospheric river occurrence and associated precipitation extremes in the North Atlantic Region by European weather regimes. *Geophysical Research Letters*, *46*, 1014–1023. https://doi.org/10.1029/2018GL081194

Pegion, K., Kirtman, B. P., Becker, E., Collins, D. C., LaJoie, E., Burgman, R., et al. (2019). The Subseasonal Experiment (SubX): A multimodel subseasonal prediction experiment. *Bulletin of the American Meteorological Society*, *100*, 2043–2060. https://doi.org/10.1175/BAMS-D-18-0270.1

Quinting, J. F., & Vitart, F. (2019). Representation of synoptic-scale Rossby wave packets and blocking in the S2S Prediction Project Database. *Geophysical Research Letters*, *46*, 1070–1078. https://doi.org/10.1029/2018GL081381

Rao, J., Garfinkel, C. I., Chen, H., & White, I. P. (2019). The 2019 New Year stratospheric sudden warming and its real-time predictions in multiple S2S models. *Journal of Geophysical Research: Atmospheres*, *124*, 11,155–11,174. https://doi.org/10.1029/2019JD030826

Stone, K. A., Solomon, S., Kinnison, D. E., Baggett, C. F., & Barnes, E. A. (2019). Prediction of Northern Hemisphere regional surface temperatures using stratospheric ozone information. *Journal of Geophysical Research: Atmospheres*, *124*, 5922–5933. https://doi.org/10.1029/2018JD029626

Tippett, M. K., & Koshak, W. J. (2018). A baseline for the predictability of U.S. cloud-to-ground lightning. *Geophysical Research Letters*, *45*, 10,719–10,728. https://doi.org/10.1029/2018GL079750

Vitart, F., Ardilouze, C., Bonet, A., Brookshaw, A., Chen, M., Codorean, C., et al. (2017). The subseasonal to seasonal (S2S) Prediction Project Database. *Bulletin of the American Meteorological Society*, *98*, 163–173. https://doi.org/10.1175/BAMS-D-16-0017.1

Wang, S., Ma, D., Sobel, A. H., & Tippett, M. K. (2018). Propagation characteristics of BSISO indices. *Geophysical Research Letters*, *45*(18), 9934–9943. https://doi.org/10.1029/2018GL078321

Wei, Y., Mu, M., Ren, H.-L., & Fu, J. X. (2019). Conditional nonlinear optimal perturbations of moisture triggering primary MJO initiation. *Geophysical Research Letters*, *46*, 3492–3501. https://doi.org/10.1029/2018GL081755

White, C. J., Carlsen, H., Robertson, A. W., Klein, R. J., Lazo, J. K., Kumar, A., et al. (2017). Potential applications of subseasonal-to-seasonal (S2S) predictions. *Meteorological Applications*, *24*, 315–325. https://doi.org/10.1002/met.1654

Wulff, C. O., & Domeisen, D. I. V. (2019). Higher subseasonal predictability of extreme hot European summer temperatures as compared to average summers. *Geophysical Research Letters*, *46*, 11,520–11,529. https://doi.org/10.1029/2019GL084314

Xiang, B., Lin, S.-J., Zhao, M., Johnson, N. C., Yang, X., & Jiang, X. (2019). Subseasonal week 3–5 surface air temperature prediction during boreal wintertime in a GFDL model. *Geophysical Research Letters*, *46*, 416–425. https://doi.org/10.1029/2018GL081314

Yang, J., Zhu, T., Gao, M., Lin, H., Wang, B., & Bao, Q. (2018). Late-July barrier for subseasonal forecast of summer daily maximum temperature over Yangtze River Basin. *Geophysical Research Letters*, *45*, 12,610–12,615. https://doi.org/10.1029/2018GL080963

Zampieri, L., Goessling, H. F., & Jung, T. (2018). Bright prospects for Arctic sea ice prediction on subseasonal time scales. *Geophysical Research Letters*, *45*, 9731–9738. https://doi.org/10.1029/2018GL079394

Zampieri, L., Goessling, H. F., & Jung, T. (2019). Predictability of Antarctic sea ice edge on subseasonal time scales. *Geophysical Research Letters*, *46*, 9719–9727. https://doi.org/10.1029/2019GL084096

Zheng, C., & Chang, E. K. M. (2019). The role of MJO propagation, lifetime, and intensity on modulating the temporal evolution of the MJO extratropical response. *Journal of Geophysical Research: Atmospheres*, *124*, 5352–5378. https://doi.org/10.1029/2019JD030258

Zheng, C., Chang, E. K.-M., Kim, H., Zhang, M., & Wang, W. (2019). Subseasonal to seasonal prediction of wintertime northern hemisphere extratropical cyclone activity by S2S and NMME models. *Journal of Geophysical Research: Atmospheres*, *124*, 12,057–12,077. https://doi.org/10.1029/2019JD031252