Evaluating the Potential of a Blocking Predictor in a Hybridized Dynamical-Statistical Model for Improved Week 3-4 Temperature and Precipitation Outlooks

Cory Baggett

Laura Ciasto, Emerson LaJoie, Daniel Collins, Muthu Chelliah, Gregory Jennrich, Daniel Harnos, Kyle MacRitchie, Evan Oswald, Jon Gottschalck, and Michael Halpert

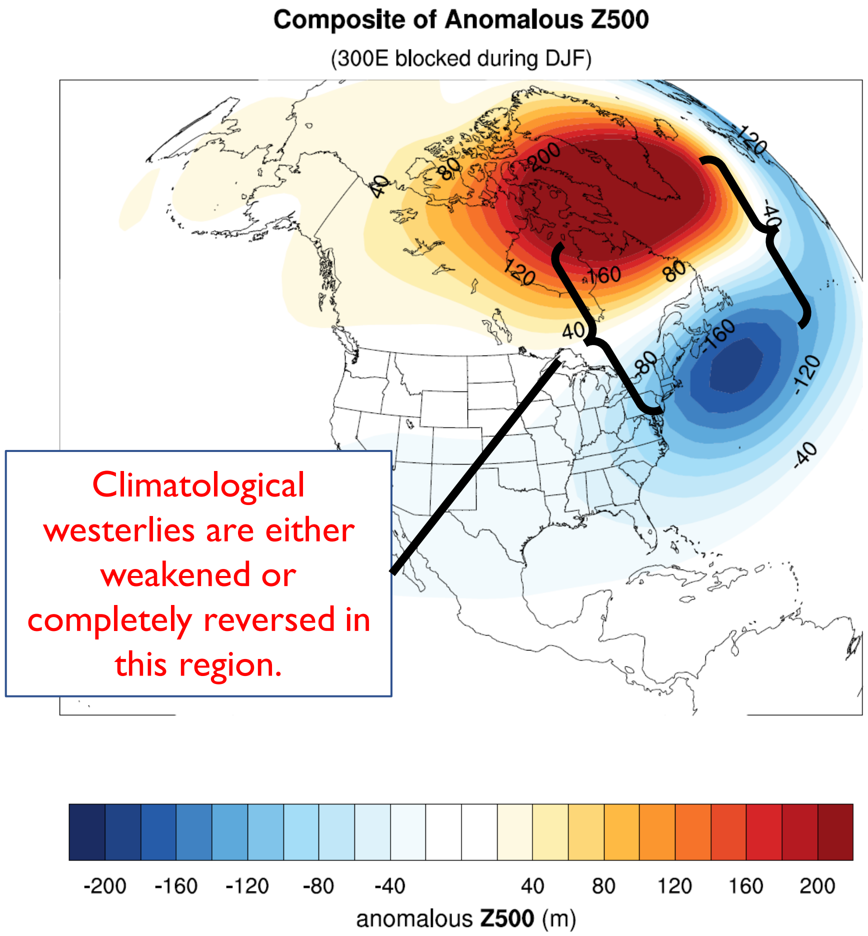
Innovim, LLC / NOAA / NWS / CPC

46th Climate Diagnostics and Prediction Workshop

October 26, 2021

Work funded by the **Modeling Program Division, Office of Science and Technology Integration, NWS**

Blocking Definition and Impacts



During blocking:

- An anomalous ridge exists to the north and an anomalous trough to its south.
- This results in a reversal of the climatological westerlies to easterlies.
- This reversal blocks the jet stream, forcing large-scale stationary waves and a diversion of the storm track.
- This pattern resembles the negative phase of the North Atlantic Oscillation (NAO).

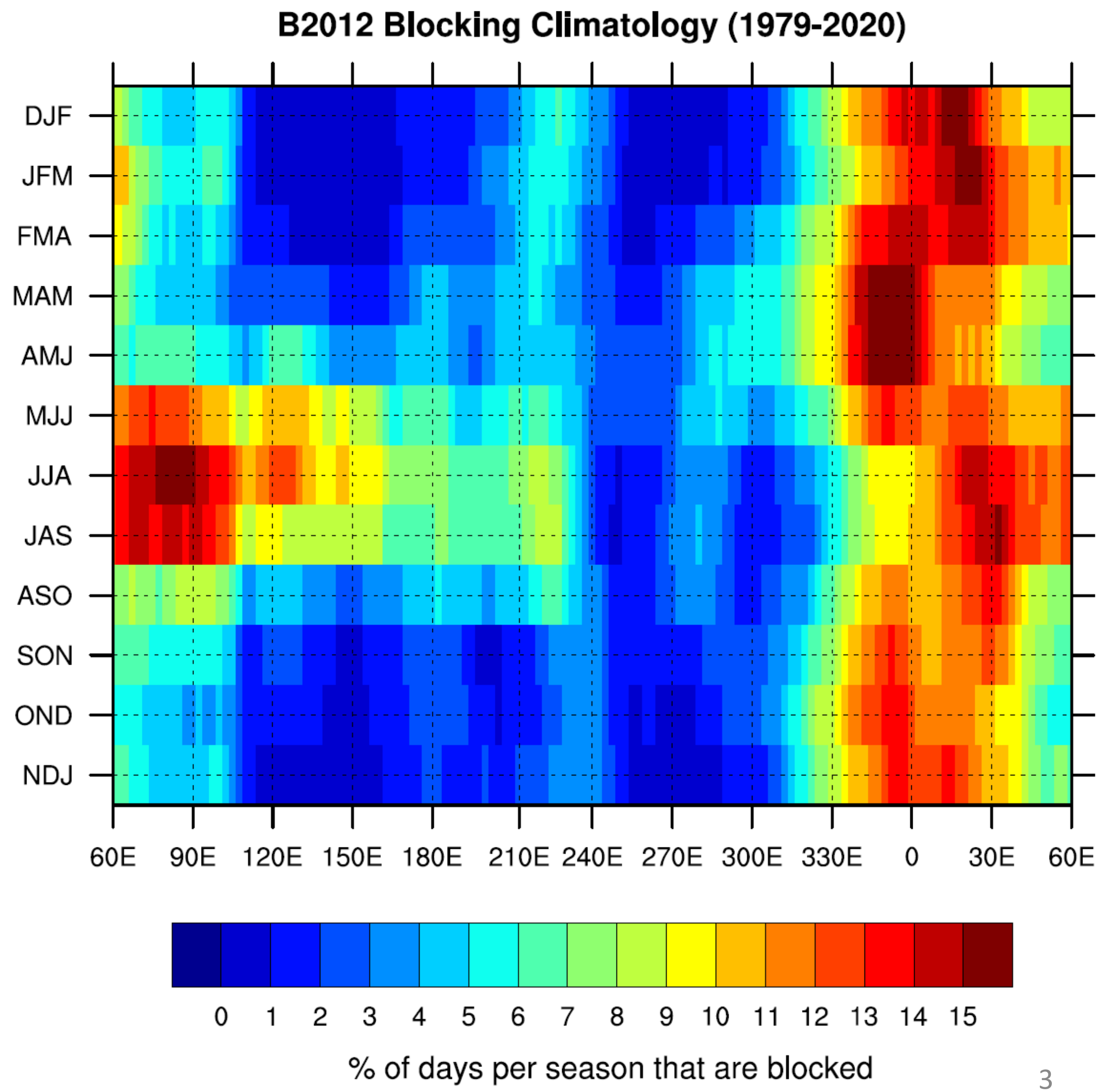
Examples of impacts:

- Extensive drought in the West (Wise 2016)
- Divert atmospheric rivers into Alaska (Baggett et al. 2015)
- **Extreme cold conditions** (Wang et al. 2010; Marinaro et al. 2015)
- Sudden stratospheric warmings (Martius et al. 2009; Butler et al. 2017)

Because blocks can persist for weeks, knowledge of blocking episodes and their surface impacts can perhaps lead to enhanced predictive skill of Week 3-4 temperature and precipitation across the United States.

Blocking Frequency & Indices

- Blocking occurs most frequently over the Atlantic sector.
- Which index should we use? Barnes et al. (2012)? Tibaldi and Molteni (1990)? Which blocking longitude?
- We tried many blocking-related indices, but we have found using the North Atlantic Oscillation (NAO) for the Atlantic and the Pacific-North American pattern (PNA) for the Pacific as "blocking" indices work well (Croci-Maspoli et al. 2007).
- Forthcoming results shown in this presentation use the NAO and PNA.



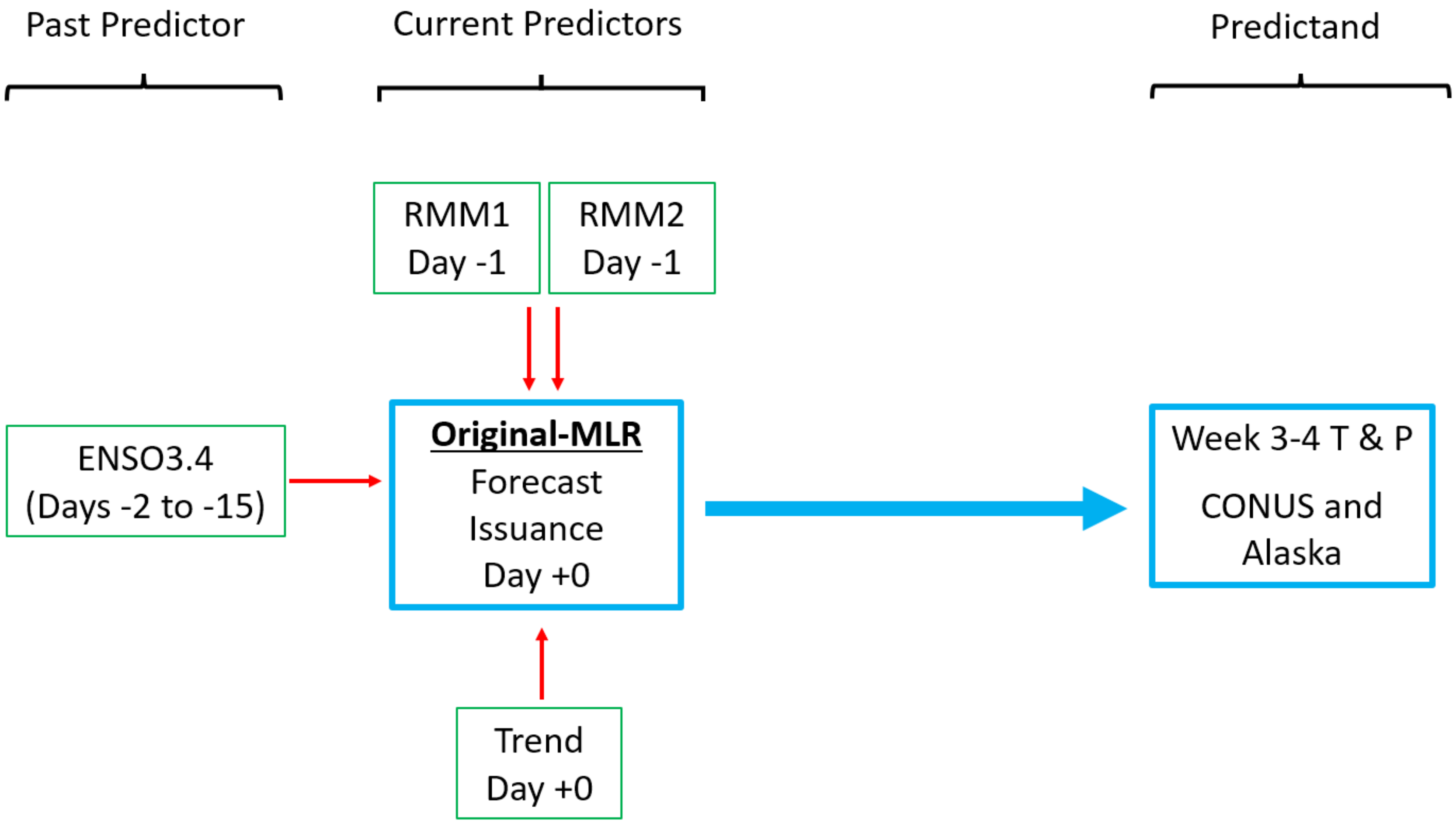
Schematic of the Week 3-4 Statistical Models

Original-Multiple Linear Regression Model (original-MLR)

versus

Merged-Multiple Linear Regression Model (merged-MLR)

Original-MLR Schematic



Harnos et al. 2020, in revision

Training Period: 1981-2010

Verification Period: 2011-2019

Region of Interest: CONUS/AK

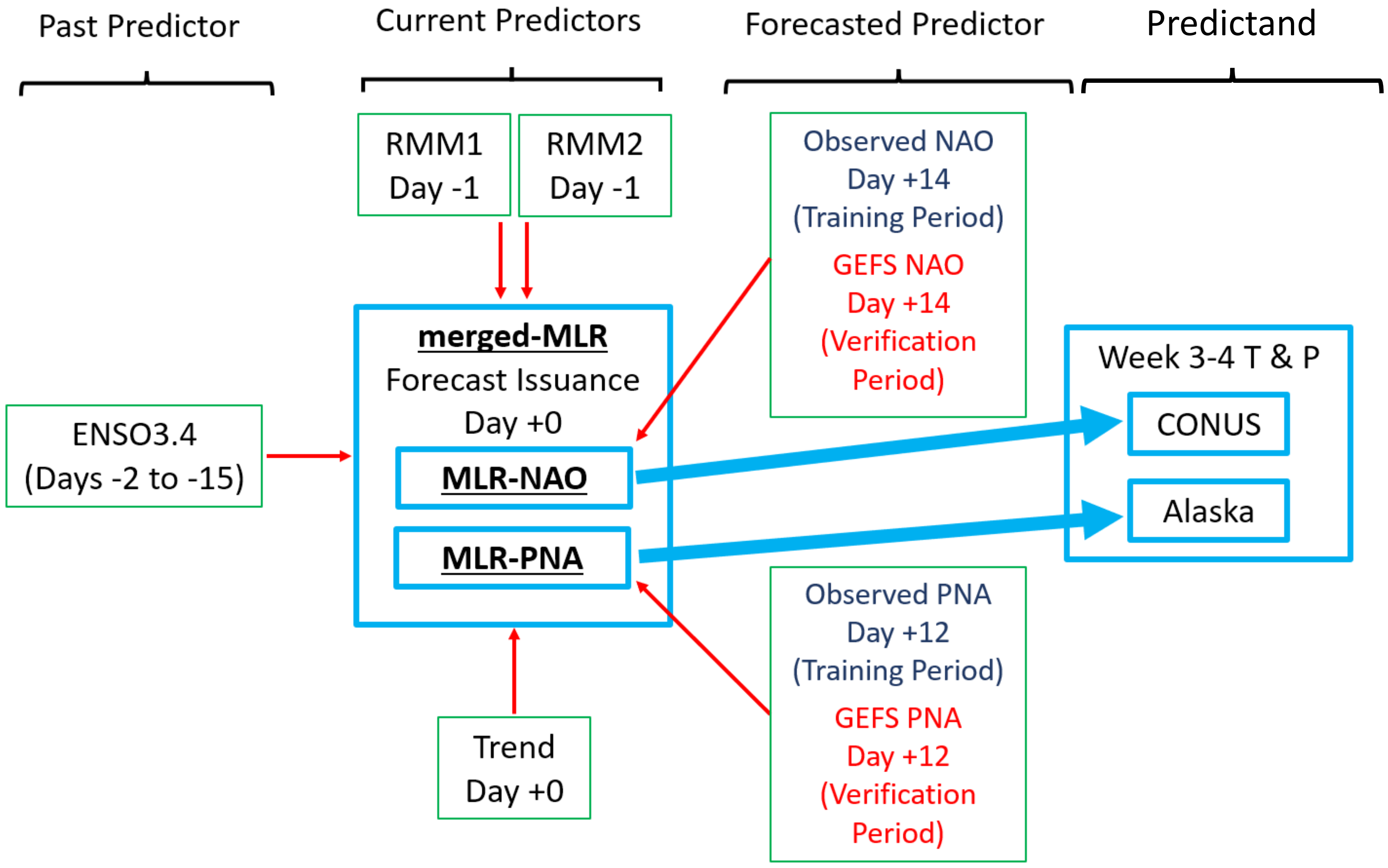
Predictand: categorical above or below normal temperature forecasts

Verification Frequency: forecast initializations every Thursday (to match extended-GEFSv12 reforecast frequency)

Original-MLR:

Predictors:
- Days -2 to -15 ENSO3.4
- Day -1 RMM1
- Day -1 RMM2, and
- Day +0 trend

Merged-MLR Schematic



Training Period: 1981-2010

Verification Period: 2011-2019

Region of Interest: CONUS/AK

Predictand: categorical above or below normal temperature forecasts

Verification Frequency: forecast initializations every Thursday (to match extended-GEFSv12 reforecast frequency)

Merged-MLR:

Predictors:

- same as Original-MLR, plus
- GEFS Day +14 NAO for CONUS (variance corrected)
- GEFS Day +12 PNA for AK (variance corrected)

Heidke Skill Scores of the MLRs

Heidke Skill Scores (HSSs)

original-MLR

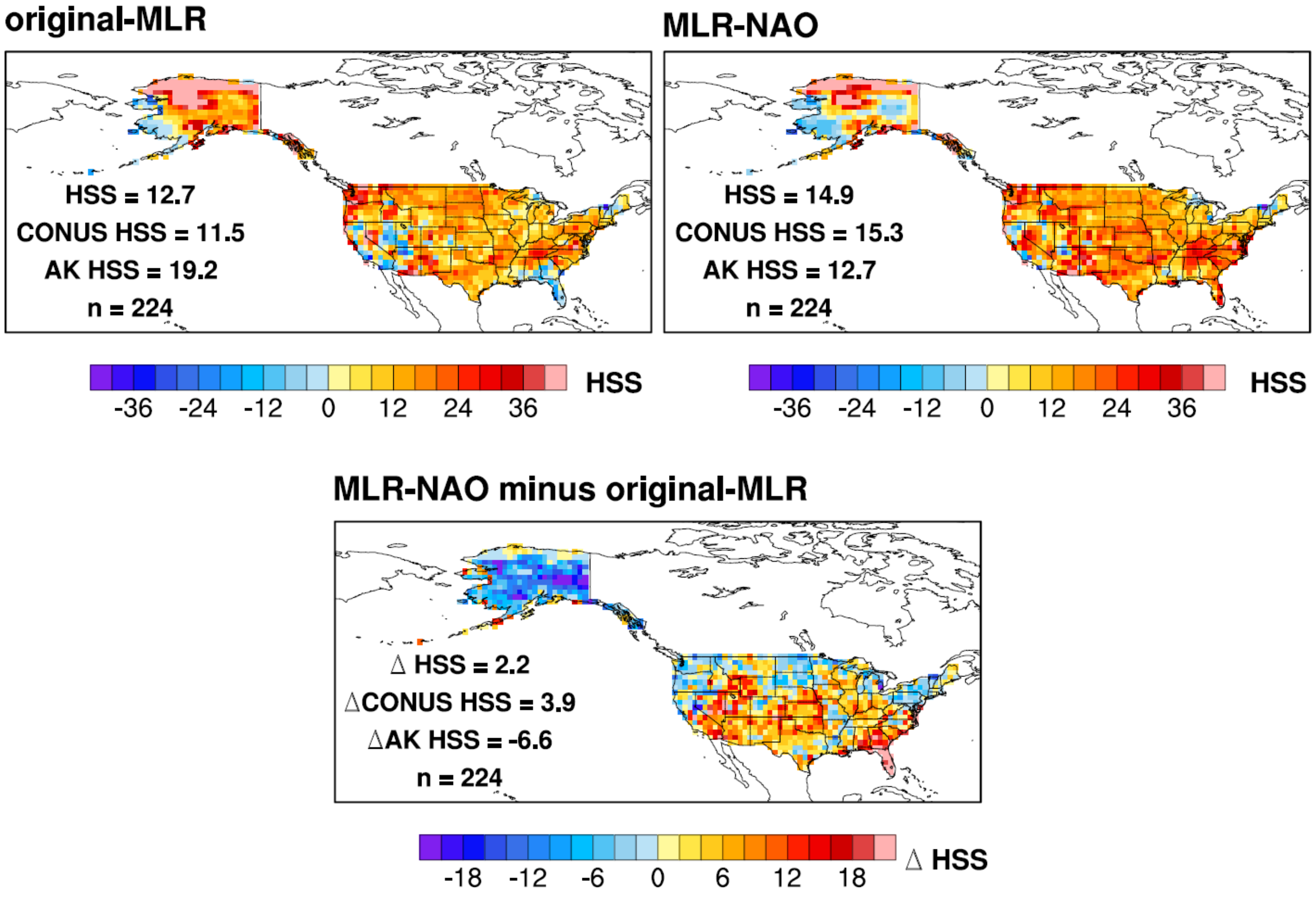
versus

MLR-NAO, MLR-PNA, and merged-MLR

Original-MLR versus MLR-NAO

Temperature

original-MLR versus MLR-NAO during NDJFMA (2011-2019)
during All Forecast Initializations

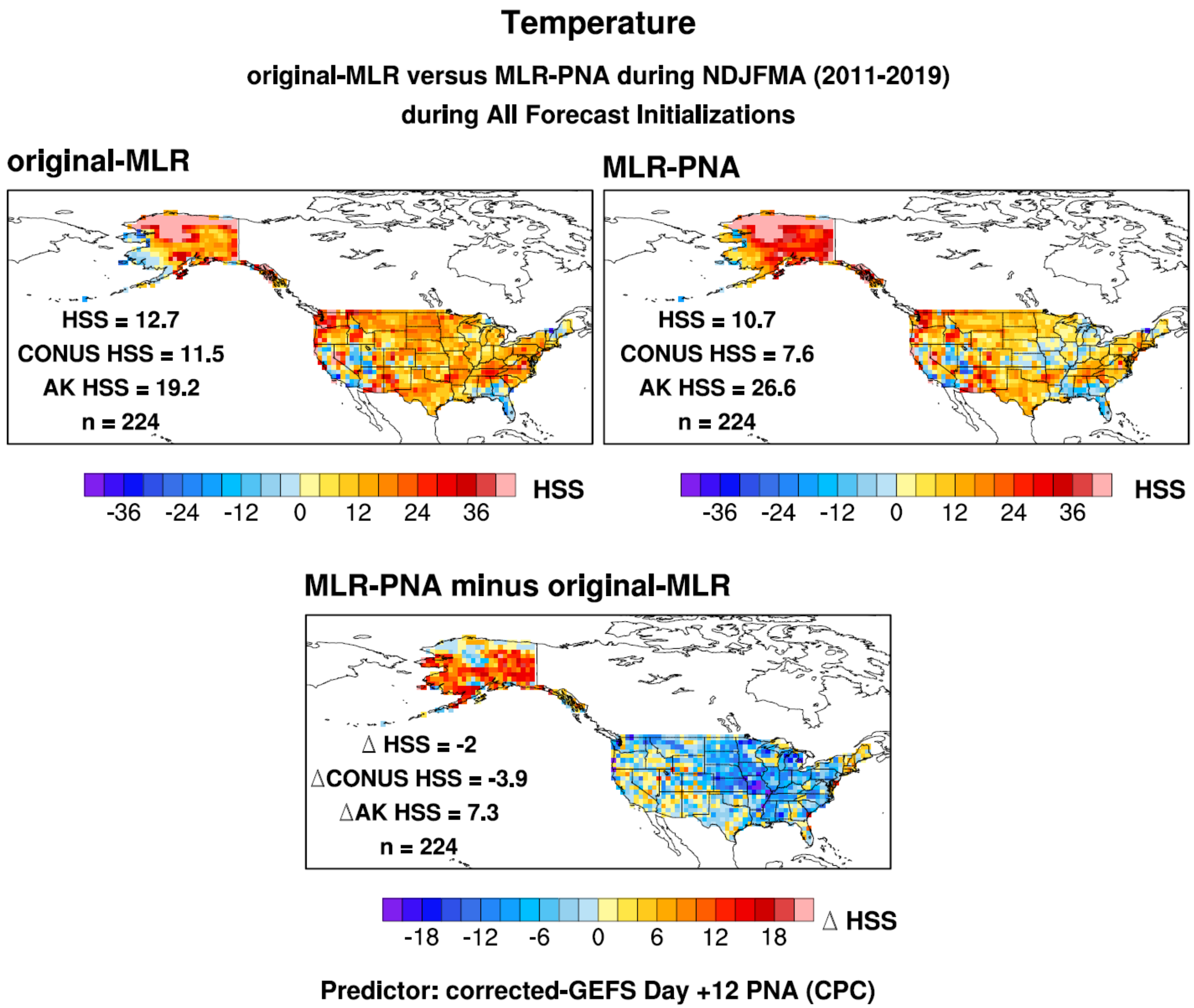


Predictor: corrected-GEFS Day +14 NAO (CPC)

<u>Difference in Week 3-4 TEMPERATURE skill scores</u>

- **original-MLR versus MLR-NAO**
- **Predictor:** GEFS Day +14 NAO
- **Verification Period:** 2011-2019, Thursdays
- **Additional Conditions:** during November-April only
- **Key Points:**
  - Overall, skill scores improve by ~17%.
  - Generally, the MLR-NAO offers improvements over CONUS and makes things worse over AK.
  - Skill scores over CONUS improve by ~33%.

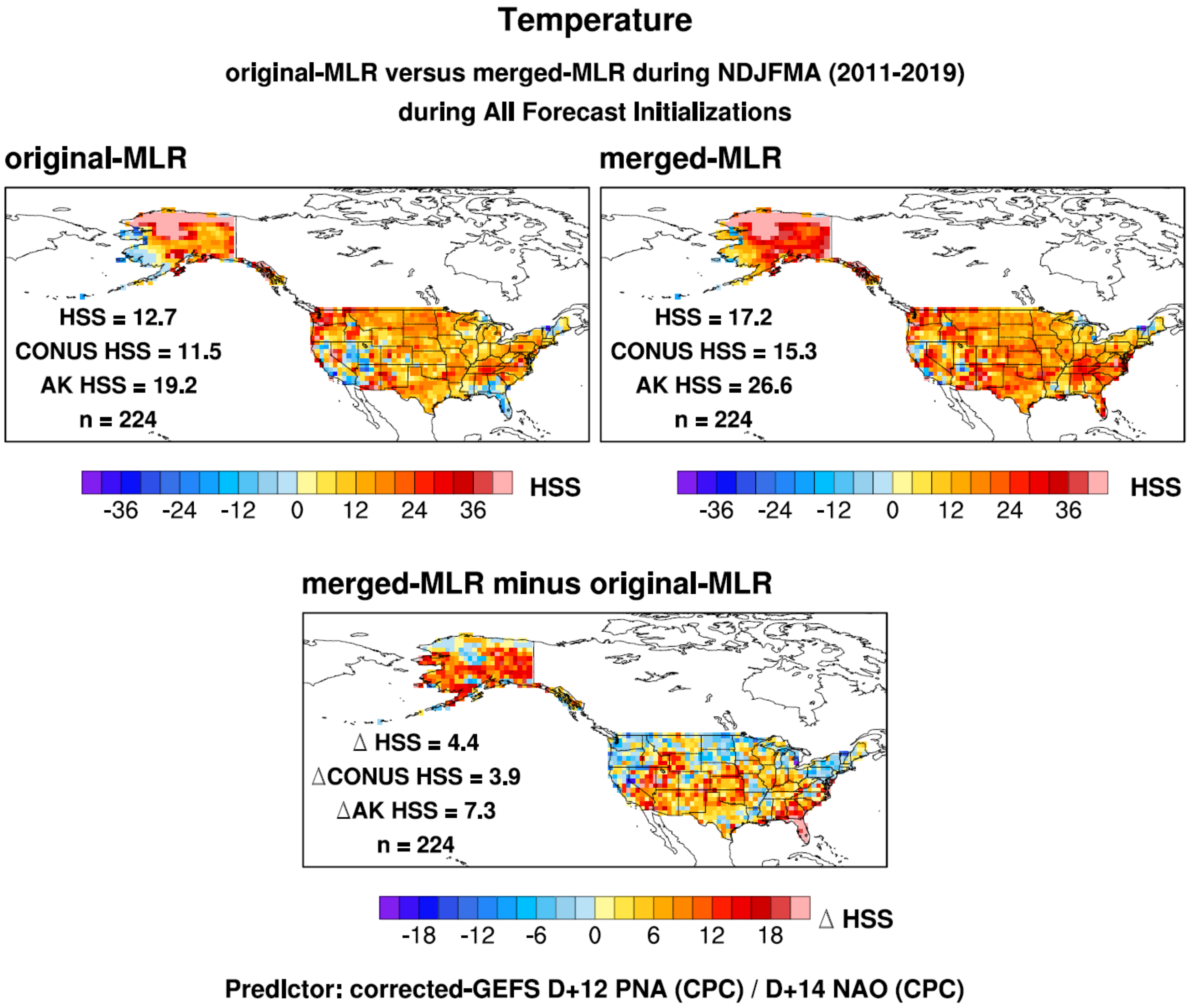
Original-MLR versus MLR-PNA



Difference in Week 3-4 TEMPERATURE skill scores

- **original-MLR versus MLR-PNA**
- **Predictor:** GEFS Day +12 PNA
- **Verification Period:** 2011-2019, Thursdays
- **Additional Conditions:** during November-April only
- **Key Points:**
  - Overall skill scores decrease by ~16%.
  - However, the MLR-PNA offers improvements over Alaska where skill scores increase by 38%.

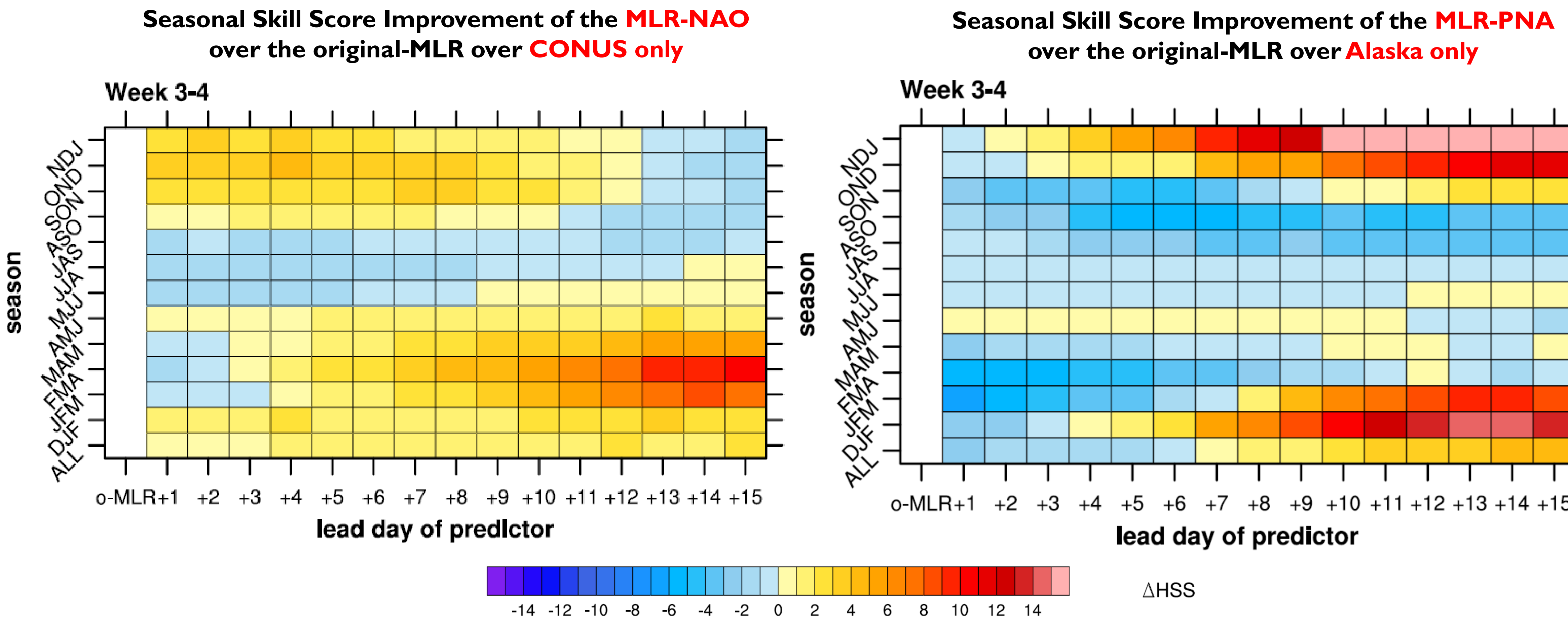
Original-MLR versus merged-MLR



Difference in Week 3-4 TEMPERATURE skill scores

- **original-MLR versus merged-MLR**
- **Predictor:** GEFS Day +14 NAO & GEFS Day +12 PNA
- **Verification Period:** 2011-2019, Thursdays
- **Additional Conditions:** during November-April only
- **Key Points:**
    - Overall skill scores improve by ~35% over CONUS/AK

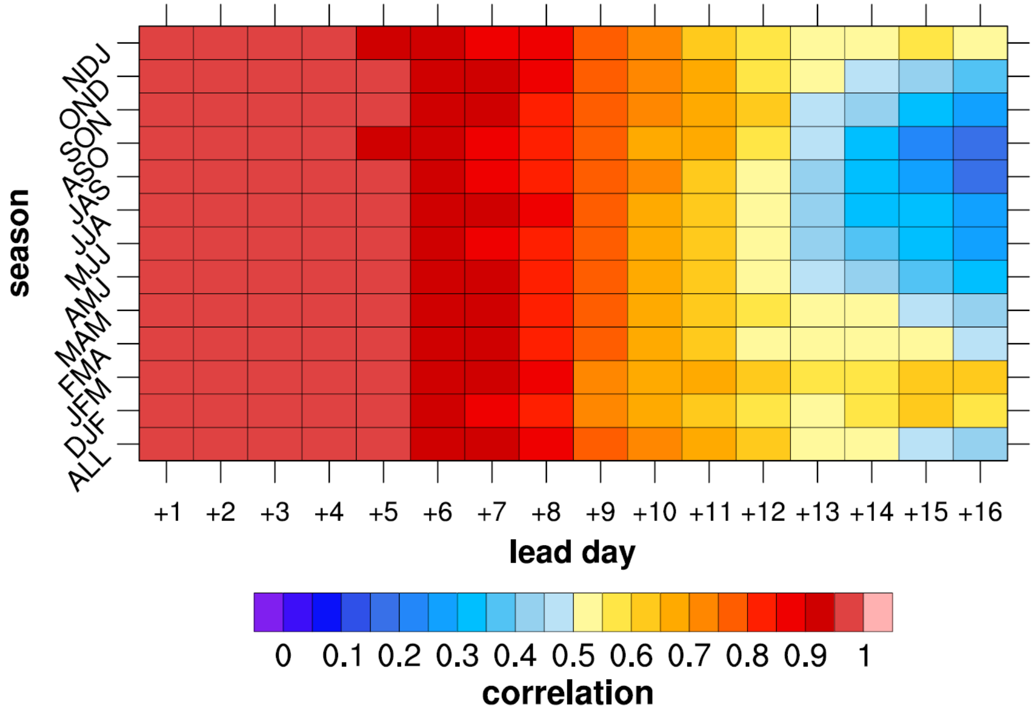
Why Day +14 NAO and Day +12 PNA?



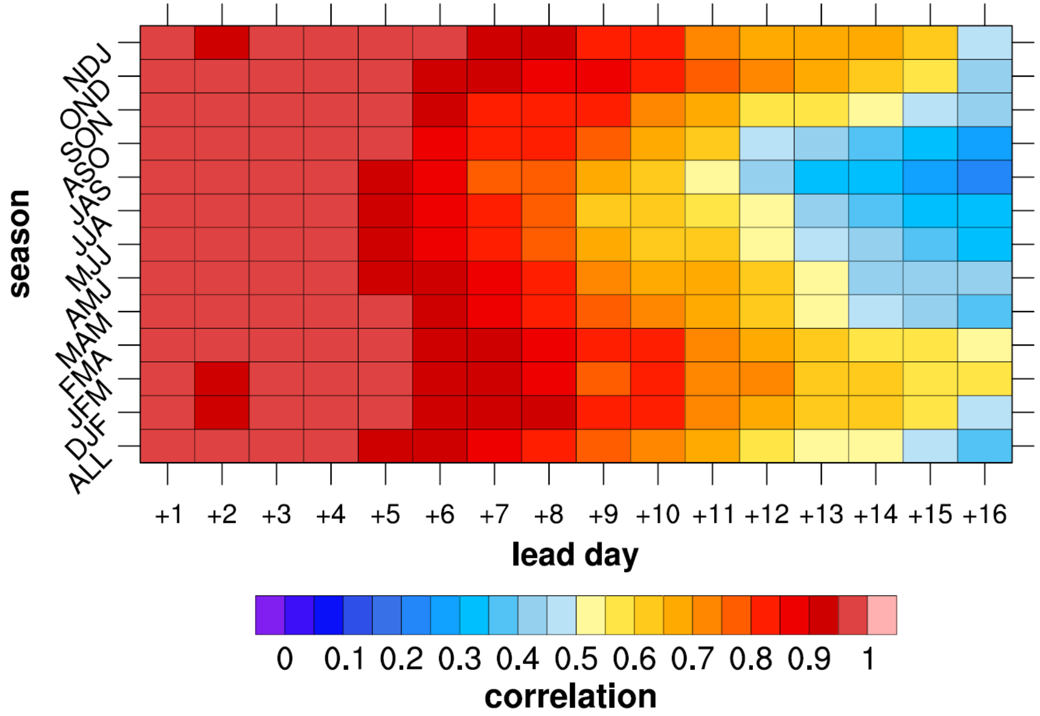
- A large suite of MLR-NAO and MLR-PNA models were tested to determine the lead time at which a predictor from the GEFS adds the most value over the original-MLR.
- One could justify using ~Day +12 to +15 values for either predictor, but perhaps the lead day should be a function of season.

Why Day +14 NAO and Day +12 PNA?

<u>Observed NAO versus GEFS NAO</u>



<u>Observed PNA versus GEFS PNA</u>



- Both the NAO and PNA are predicted well by the GEFS (correlations exceeding 0.5) out to ~Day +14
- The skill is seasonal, with the highest correlations seen during winter.
- This partly explains why the merged-MLR does not do as well during summer as it does during winter.

Comparison to the GEFSv12

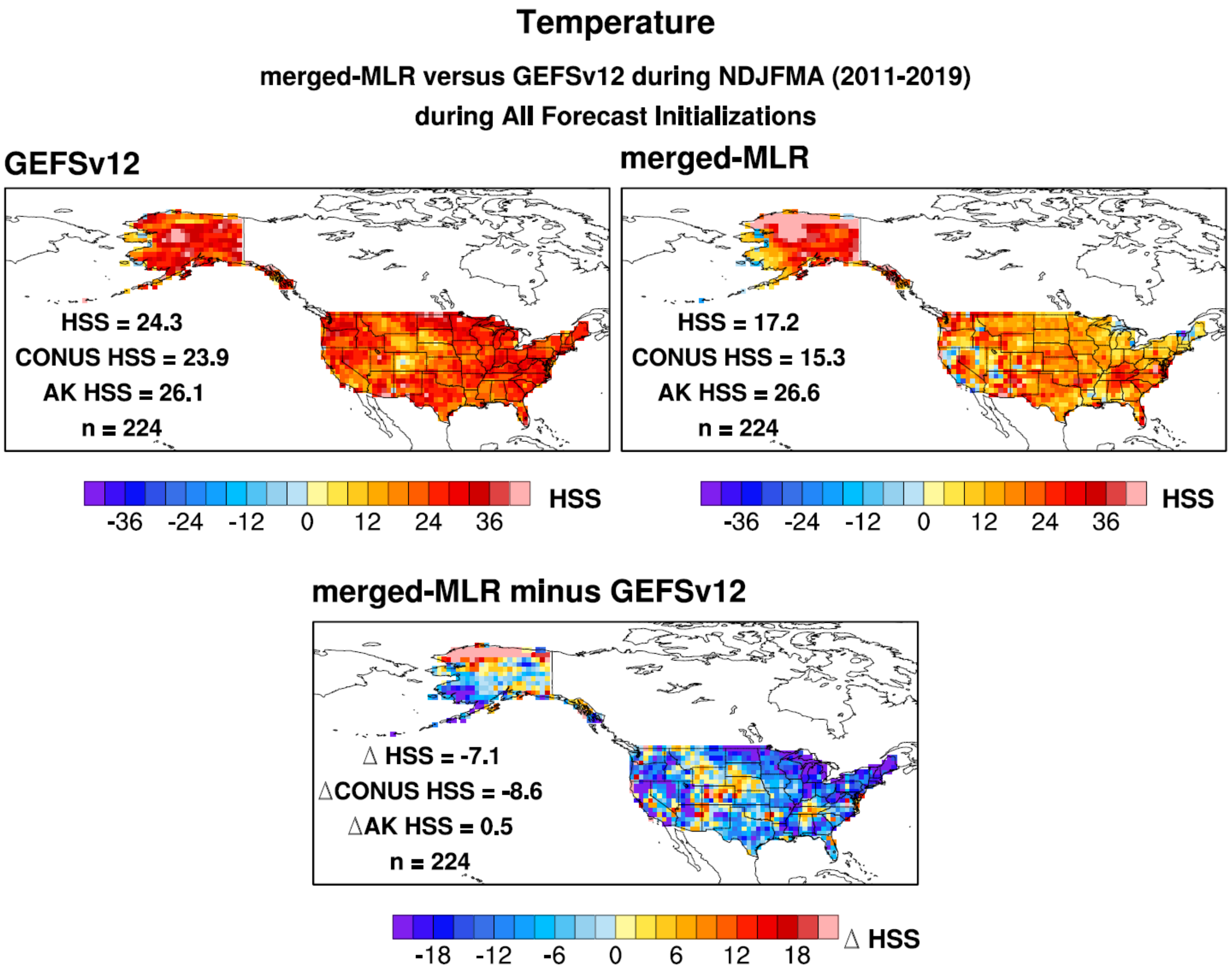
HSSs compared to the GEFSv12

All Initializations

versus

Amplified NAO Initializations

Merged-MLR versus GEFSv12



<u>Difference in Week 3-4 TEMPERATURE skill scores</u>

- **merged-MLR versus GEFSv12**
- **Predictor:** GEFS Day +14 NAO & GEFS Day +12 PNA
- **Verification Period:** 2011-2019, Thursdays
- **Additional Conditions:** during November-April only
- **Key Points:**
  - The GEFSv12 outperforms the merged-MLR by 59%.

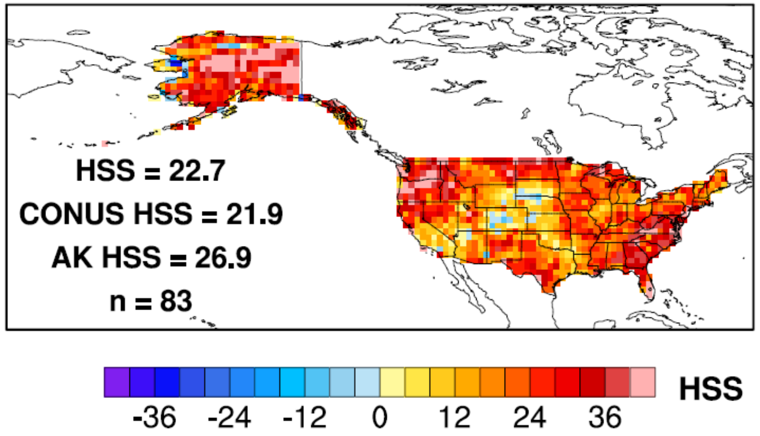
Merged-MLR versus GEFSv12 during Amplified NAO Conditions

Temperature

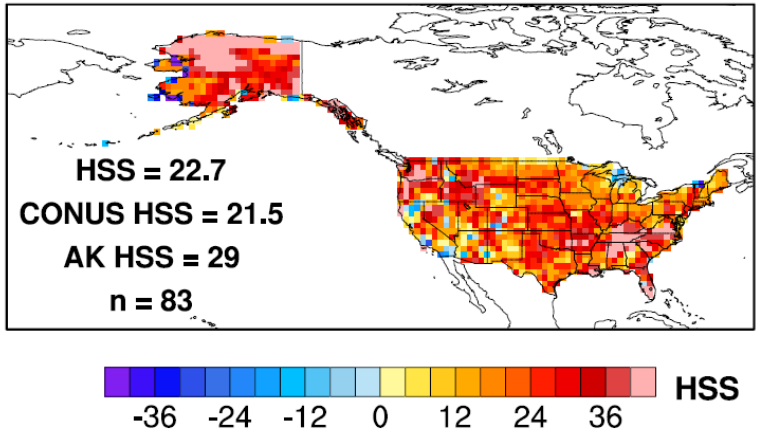
merged-MLR versus GEFSv12 during NDJFMA (2011-2019)

During Forecast Initializations when |Day +0 NAO| ≥ 0.85

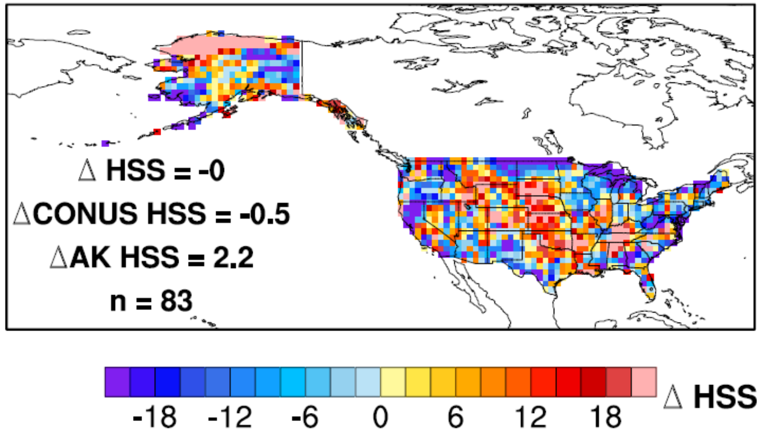
GEFSv12



merged-MLR



merged-MLR minus GEFSv12



Difference in Week 3-4 TEMPERATURE skill scores

- **merged-MLR versus GEFSv12**
- **Predictor:** GEFS Day +14 NAO & GEFS Day +12 PNA
- **Verification Period:** 2011-2019, Thursdays
- **Additional Conditions:** during November-April only, when the NAO is amplified on Day 0
- **Key Points:**
  - The merged-MLR performs as well as the GEFSv12 during these **Forecasts of Opportunity** (Mariotti et al. 2020)
  - The statistical model outperforms the GEFS over northern AK and central CONUS.
  - The merged-MLR scores ~32% higher when the NAO is amplified on Day 0 compared to all forecast initializations.

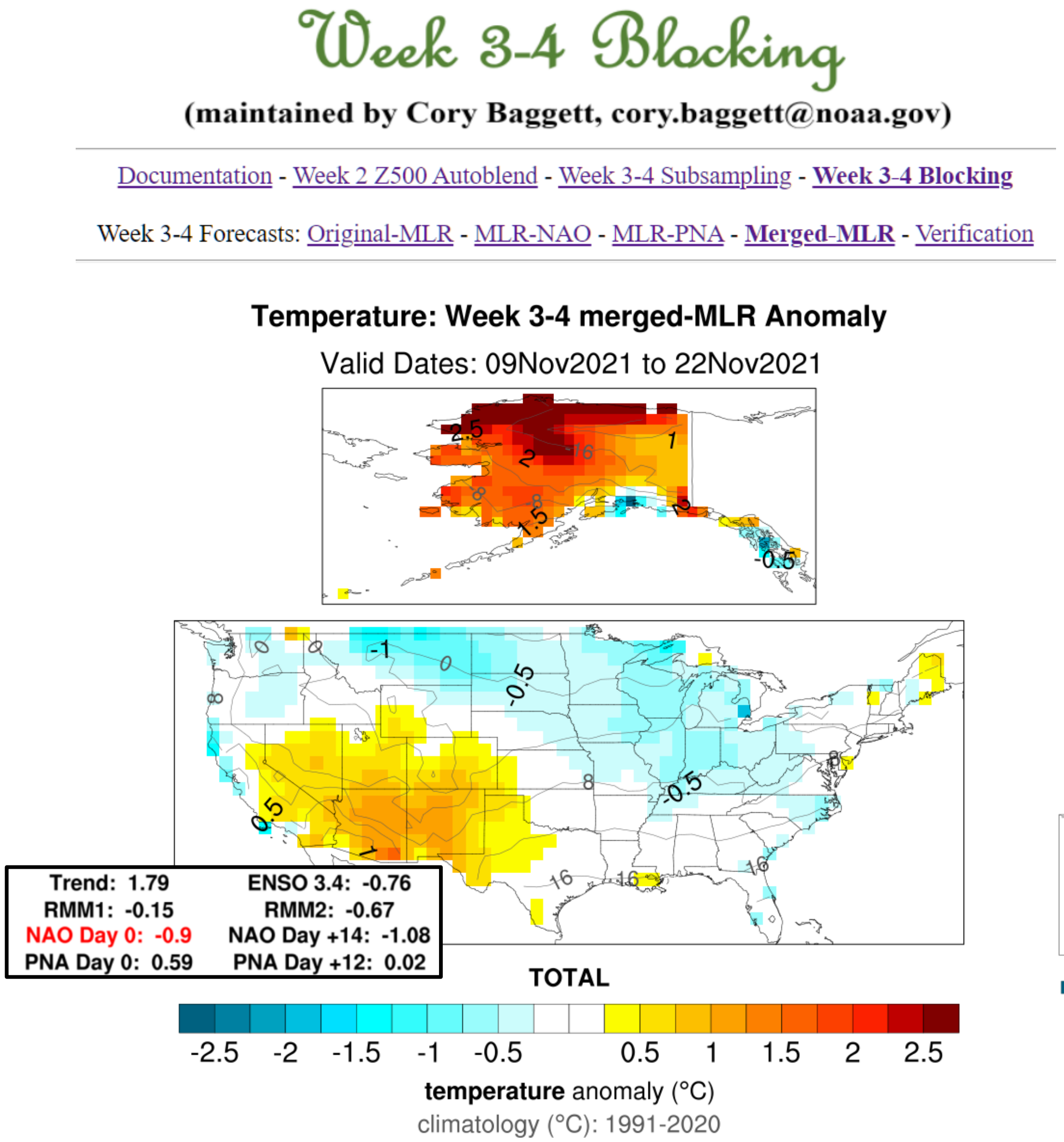
Moving forward…

Experimental Real-Time Merged-MLR,

and

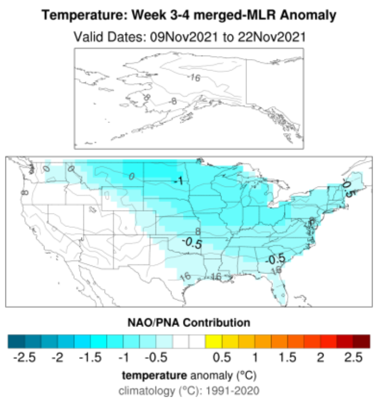
Conclusions

Experimental Real-Time Merged-MLR

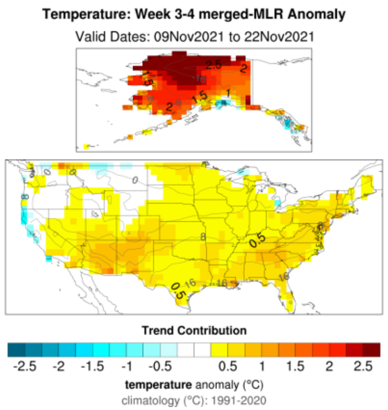


- Currently, the NAO is negative and is forecasted to stay negative at Day +14 by the GEFSv12.
- This is considered a "forecast of opportunity" because the NAO is relatively strong right now.
- The PNA is forecasted to be neutral.
- The trend contribution damps the cold signal in the East considerably.
- ENSO is damping the very warm trend contribution in Alaska.
- The MJO contribution (not shown) is weak.
- Time will tell.

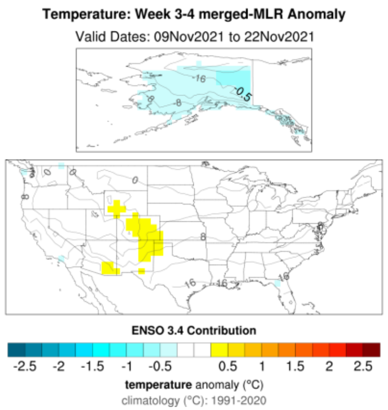
NAO Contribution



Trend Contribution



ENSO3.4 Contribution



Conclusions

- By using blocking-related predictors, such as the NAO and PNA, we can improve our Week 3-4 statistical models.
- Further, by hybridizing the statistical models with indices forecasted by the dynamical models, we gain the most improvement.
- Finally, this improvement largely occurs during so-called "forecasts of opportunity" when the relative indices are amplified. In such instances, the statistical model performs on-par with the GEFSv12.
- Unfortunately, positive results for precipitation have been elusive, but a few more tests are ongoing.
- Moving forward, we will be experimentally monitoring the merged-MLR's performance in real-time, with the particular hope that it can provide insight into upcoming episodes of cold during winter.

Thank you! Questions?

References

Baggett, C., S. Lee, and S. Feldstein, 2016: An Investigation of the Presence of Atmospheric Rivers over the North Pacific during Planetary-Scale Wave Life Cycles and Their Role in Arctic Warming. *J. Atmos. Sci.*, **73**, 4329–4347, https://doi.org/10.1175/JAS-D-16-0033.1.

Barnes, E. A., J. Slingo, and T. Woollings, 2012: A methodology for the comparison of blocking climatologies across indices, models and climate scenarios. *Clim Dyn*, **38**, 2467–2481, https://doi.org/10.1007/s00382-011-1243-6.

Barnston, A. G., and R. E. Livezey, 1987: Classification, seasonality and persistence of low-frequency atmospheric circulation patterns. *Monthly Weather Review*, **115**, 1083-1126.

Butler, A. H., J. P. Sjoberg, D. J. Seidel, and K. H. Rosenlof, 2017: A sudden stratospheric warming compendium. *Earth System Science Data*, **9**, 63–76, https://doi.org/10.5194/essd-9-63-2017.

Croci-Maspoli, M., C. Schwierz, H. Davies, 2007: Atmospheric blocking: space-time links to the NAO and PNA. *Climate Dynamics*, **29**, 703-725.

Domeisen, D. I. V., and Coauthors, 2020: The Role of the Stratosphere in Subseasonal to Seasonal Prediction: 1. Predictability of the Stratosphere. *Journal of Geophysical Research: Atmospheres*, **125**, e2019JD030920, https://doi.org/10.1029/2019JD030920.

Domeisen, D. I. V., and Coauthors, 2020: The Role of the Stratosphere in Subseasonal to Seasonal Prediction: 2. Predictability Arising From Stratosphere-Troposphere Coupling. *Journal of Geophysical Research: Atmospheres*, **125**, e2019JD030923, https://doi.org/10.1029/2019JD030923.

Feng, P.-N., H. Lin, J. Derome, T. Merlis, 2021: Forecast skill of the NAO in Subseasonal-to-Seasonal Prediction Models. *Journal of Climate*, **34**, 4757-4769, https://doi.org/10.1175/JCLI-D-20-0430.1.

Harnos, D. and Coauthors, 2021: Differences in the application of large-scale modes of tropical variability for subseasonal prediction of North American temperature and precipitation. *Weather & Forecasting*, in prep.

Kim, M., C. Yoo, and J. Choi, 2021: Enhancing Subseasonal Temperature Prediction by Bridging a Statistical Model with Dynamical Arctic Oscillation Forecasting. *Geophysical Research Letters*, **48**, https://doi.org/10.1029/2021GL093447.

Marinaro, A., S. Hilberg, D. Changnon, and J. Angel, 2015: The North Pacific-driven Severe Midwest Winter of 2013/14. *Journal of Applied Meteorology and Climatology*, **54**, 2141-2151.

Mariotti, A., and Coauthors, 2020: Windows of Opportunity for Skillful Forecasts Subseasonal to Seasonal and Beyond. *Bull. Amer. Meteor. Soc.*, **101**, E608–E625, https://doi.org/10.1175/BAMS-D-18-0326.1.

Martius, O., L. M. Polvani, and H. C. Davies, 2009: Blocking precursors to stratospheric sudden warming events. *Geophysical Research Letters*, **36**, https://doi.org/10.1029/2009GL038776.

Quinting, J. F., and F. Vitart, 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.

Tibaldi, S., F. Molteni, 1990: On the operational predictability of blocking. *Tellus*, **42A**, 343-365.

Wang, C., H. Liu, and S.-K. Lee, 2010: The record-breaking cold temperatures during the winter of 2009/2010 in the Northern Hemisphere. *Atmospheric Science Letters*, **11**, 161–168, https://doi.org/10.1002/asl.278.

Wise, E. K., 2016: Five centuries of U.S. West Coast drought: Occurrence, spatial distribution, and associated atmospheric circulation patterns. *Geophysical Research Letters*, **43**, 4539–4546, https://doi.org/10.1002/2016GL068487.

MLR-NAO Regression Coefficients

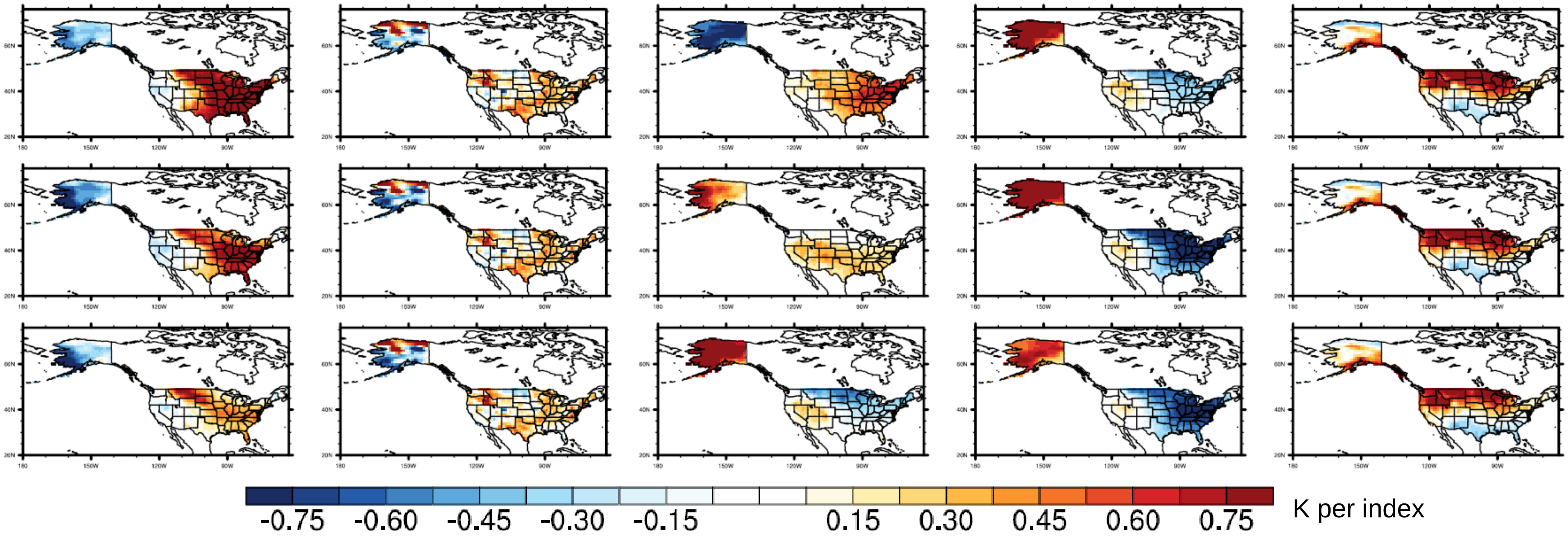
Temperature (DJF; 1981-2010)

NAO (Day 0) | Trend (Day 0) | RMM 1 (Day -1) | RMM 2 (Day -1) | ENSO 3.4 (Days -2 to -15)

Week 1-2

Week 2-3

Week 3-4



- Trend remains constant with lead-time.
- MJO and ENSO signals are large across all leads ands persist out to Week 3-4.
- The large NAO signal over CONUS fades significantly by Week 3-4.

Precipitation HSSs

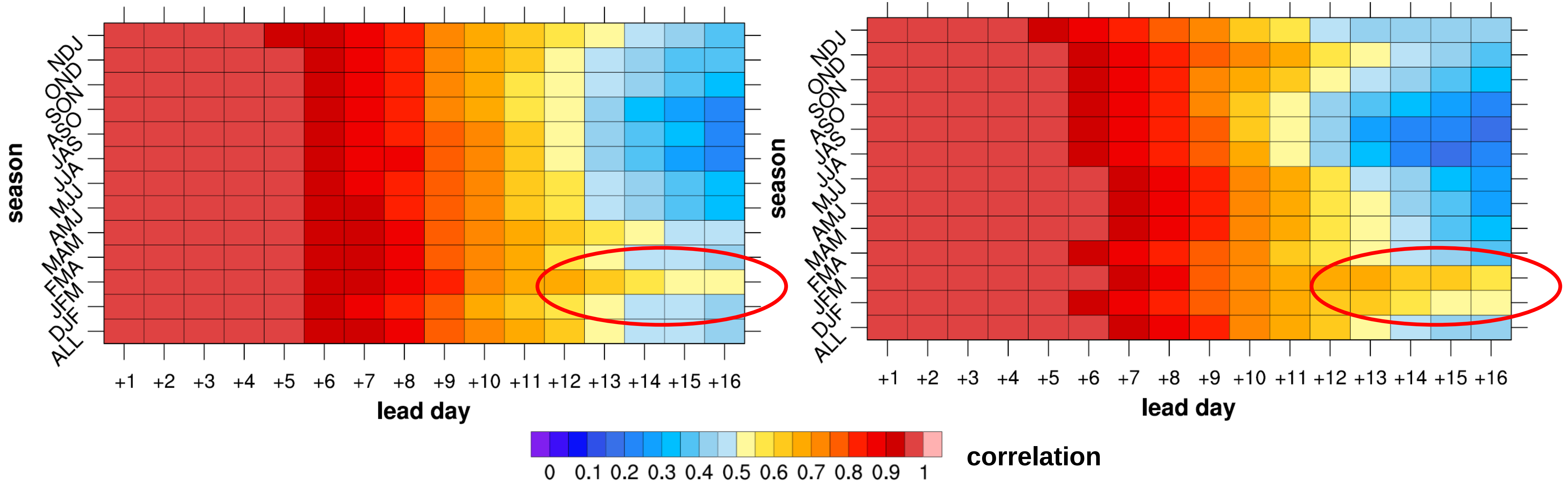
Precipitation HSS (All Initializations)					
Region	**GEFSv12**	**original-MLR**	**MLR-NAO**	**MLR-PNA**	**merged-MLR**
CONUS & AK	6.9	3.6	2.6	2.6	2.4
CONUS	6.5	2.4	1.4	1.6	1.4
AK	9.1	10.2	9.2	8.0	8.0

- Unfortunately, precipitation skill scores are still low.
- Generally, the GEFSv12 outperforms the statistical models, but scores are close in Alaska.
- Further ideas are being tested.

GEFSv12 Prediction Skill of the NAO during Amplified NAO Conditions

GEFS NAO vs Observed NAO (All Initializations)

GEFS NAO vs Observed NAO (Amplified Day +0 NAO Initializations)



- During winter, the GEFSv12 forecasts the NAO at extended leads better when the Day +0 NAO is amplified.
- This is not the case during summer.
- This can at least partly explain why the merged-MLR performs well during November-April when the Day +0 NAO is amplified.
- Feng et al. (2021) found that most dynamical models predict the NAO better at extended leads when the NAO is amplified at model initialization.