# Impacts of Future Sea Ice Loss on Mid-Latitude Weather

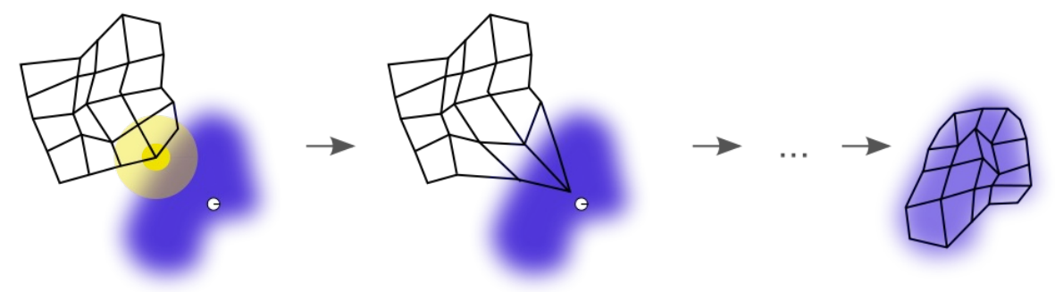
Melissa Gervais*[1], Lantao Sun[2], and Clara Deser[3]
The Pennsylvania State University and Institute for Computational and Data Science[1], Colorado State University[2], National Science Foundation National Center for Atmospheric Research[3]

## Introduction

- Arctic-midlatitude linkages have been the subject of considerable research and has been summarized in numerous review articles (Cohen et al. 2014; Vihma 2014; Barnes and Screen 2015; Screen et al. 2018)
- Historical changes in atmospheric variability owing to sea ice loss are unclear (Cohen et al. 2020)
- Future Arctic sea ice loss has been shown to impact atmospheric variability causing:
  1. Decreased variance over North America (Screen 2014; Screen et al. 2015; Collow et al. 2019; Dai and Deng 2021)
  2. Decreased intensity of cold air outbreaks (Ayarzagüena and Screen 2016)
- The methods used to study these impacts limits our ability to probe the mechanisms responsible

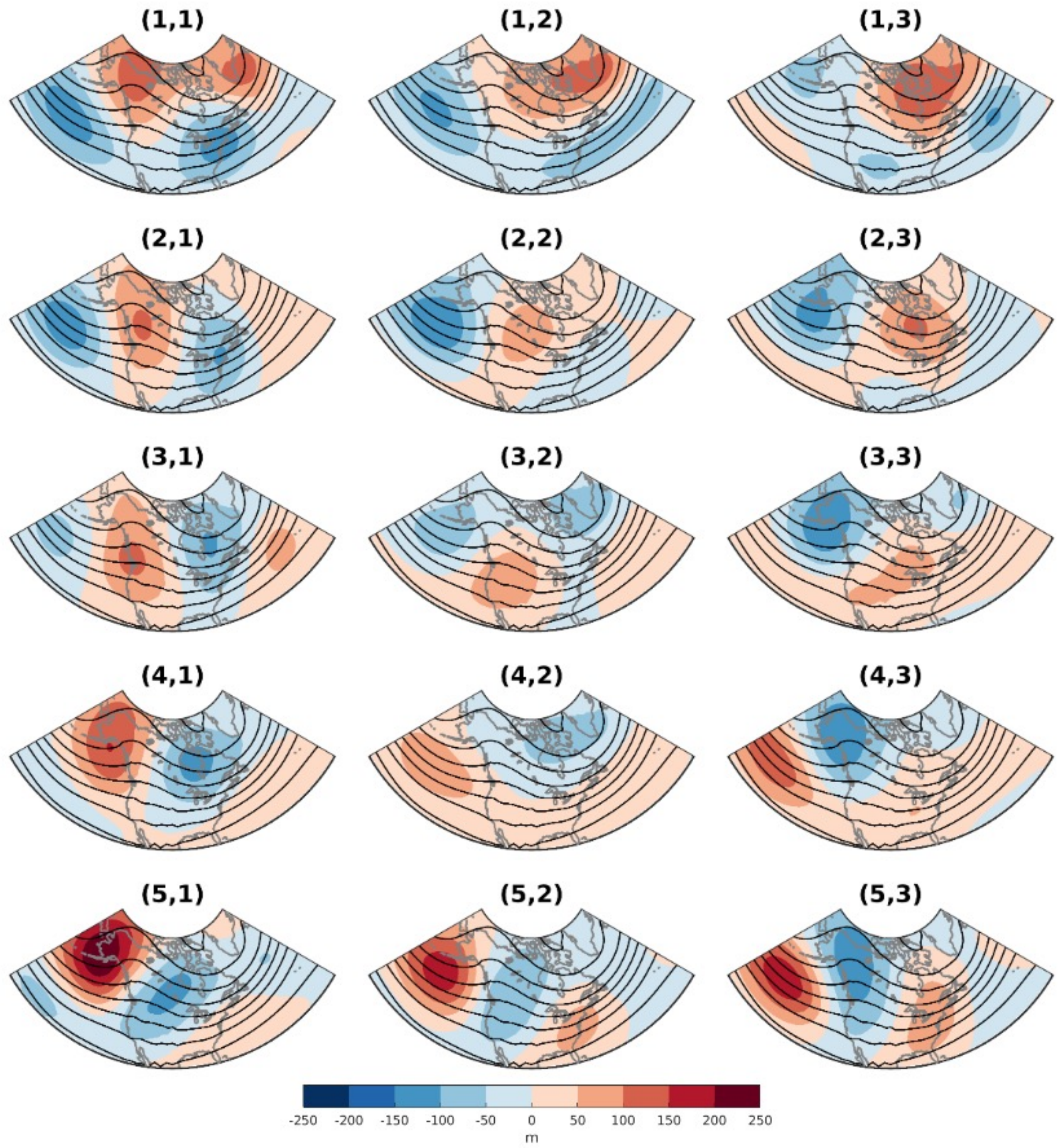
## Identifying Large-Scale Circulation Patterns

1. **Isolate the change in variability**: Compute daily 500hPa geopotential height anomalies ($Z'_{500}$) by removing the daily climatology separately for each simulations (CTL and EXP)
2. **Identify LSPs:** Using **self-organizing maps** to classify dominant patterns of atmospheric circulation.



3. **Analyze changes in variability:**
   - **Frequencies (f)** of the best match units provide information about how often each map occurs and **residency** is average the number of days in a row data is assigned to a given best match unit.
   - **Composites (S)** of days assigned to each map node are conducted to examine patterns associated with each node including additional meteorological fields. **ΔS is the difference in frequency between the EXP and CTL.**

## SOM of Z'500



SOM of DJF $Z'_{500}$ (color, m) over North America with DJF CTL mean $Z_{500}$ (black contours every 100 m).

## Model Set-up

**Model**

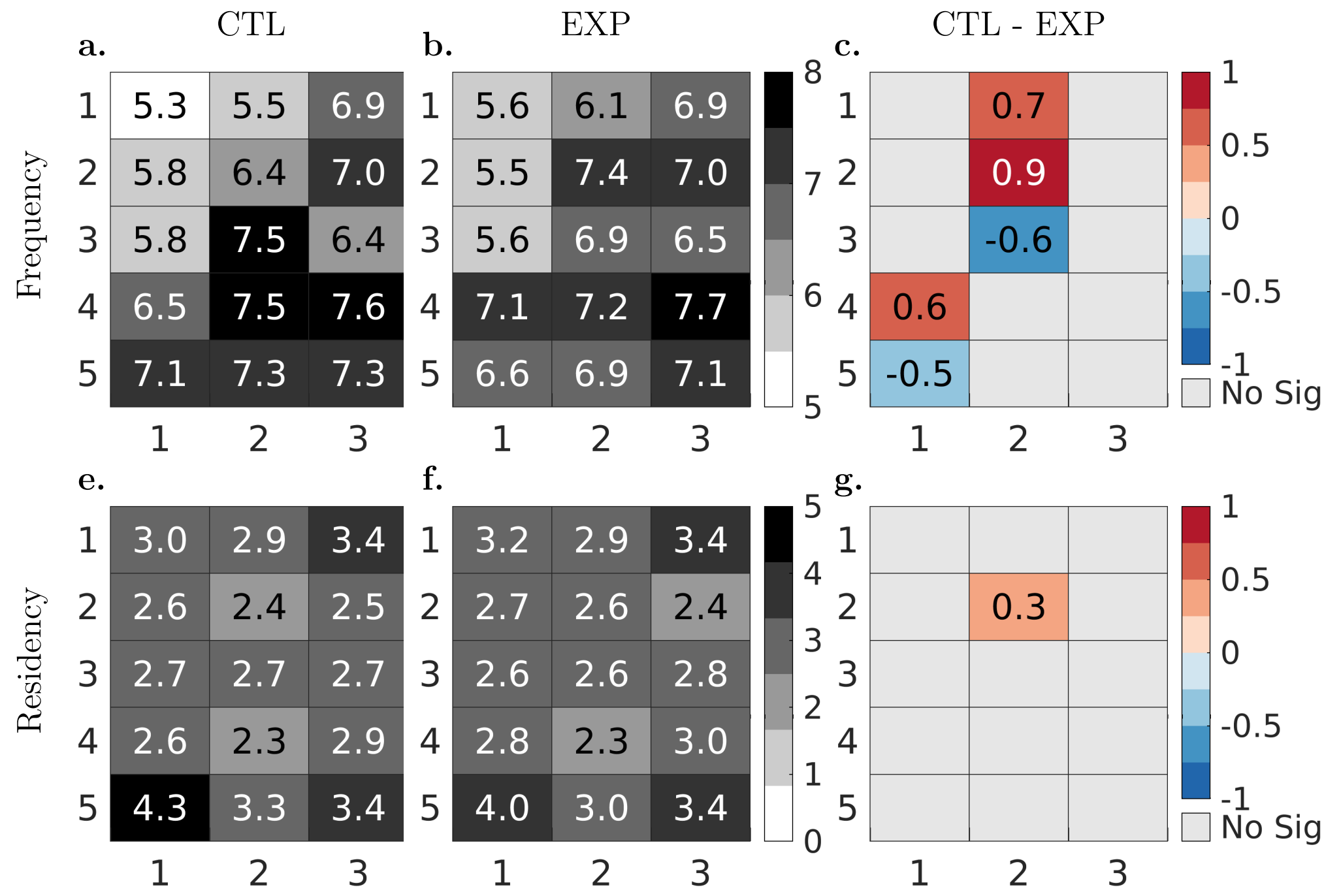
- Whole Atmosphere Community Climate Model (WACCM)
- Fully-coupled, 66 vertical pressure levels and 1.9 x 2.5 degrees
- Radiative forcing set to the year 2000
- 300-year simulations, first 100 years disregarded for spin-up time

**Experiments:**

1) Control (**CTL**): Sea ice nudged to ensemble mean of WACCM historical runs over 1980-1999 with seasonally varying conditions
2) Experiment (**EXP**): Sea ice nudged to ensemble mean of projected RCP 8.5 values over the period of 2080-2099

(method described in Deser et al. 2015)

## Difference in Frequency and Residence time



a. CTL (Frequency)

| | 1 | 2 | 3 |
|---|---|---|---|
| 1 | 5.3 | 5.5 | 6.9 |
| 2 | 5.8 | 6.4 | 7.0 |
| 3 | 5.8 | 7.5 | 6.4 |
| 4 | 6.5 | 7.5 | 7.6 |
| 5 | 7.1 | 7.3 | 7.3 |

b. EXP (Frequency)

| | 1 | 2 | 3 |
|---|---|---|---|
| 1 | 5.6 | 6.1 | 6.9 |
| 2 | 5.5 | 7.4 | 7.0 |
| 3 | 5.6 | 6.9 | 6.5 |
| 4 | 7.1 | 7.2 | 7.7 |
| 5 | 6.6 | 6.9 | 7.1 |

c. CTL - EXP (Frequency)

| | 1 | 2 | 3 |
|---|---|---|---|
| 1 | | 0.7 | |
| 2 | | 0.9 | |
| 3 | | -0.6 | |
| 4 | 0.6 | | |
| 5 | -0.5 | | |

e. (Residency, CTL)

| | 1 | 2 | 3 |
|---|---|---|---|
| 1 | 3.0 | 2.9 | 3.4 |
| 2 | 2.6 | 2.4 | 2.5 |
| 3 | 2.7 | 2.7 | 2.7 |
| 4 | 2.6 | 2.3 | 2.9 |
| 5 | 4.3 | 3.3 | 3.4 |

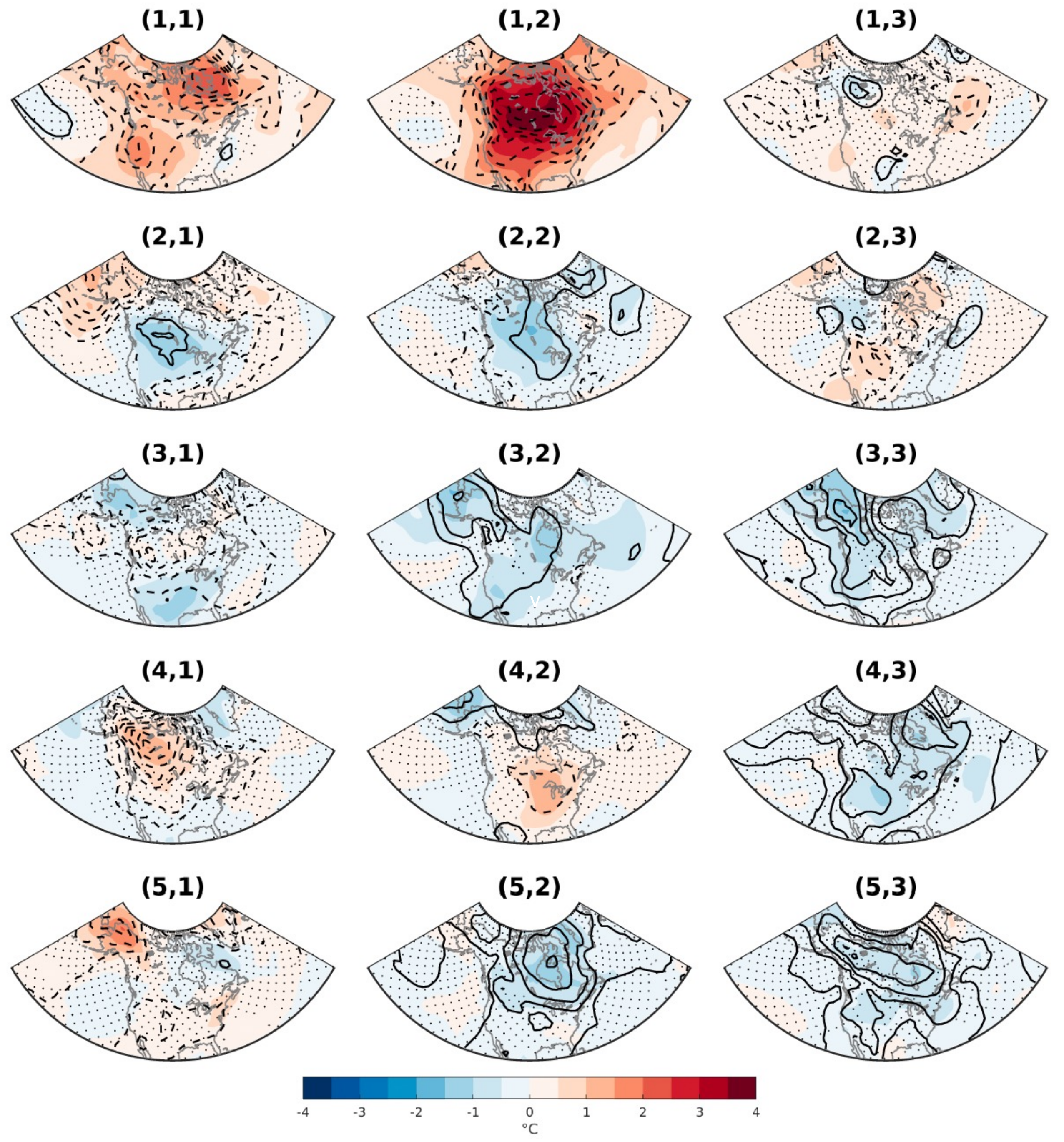
f. (Residency, EXP)

| | 1 | 2 | 3 |
|---|---|---|---|
| 1 | 3.2 | 2.9 | 3.4 |
| 2 | 2.7 | 2.6 | 2.4 |
| 3 | 2.6 | 2.6 | 2.8 |
| 4 | 2.8 | 2.3 | 3.0 |
| 5 | 4.0 | 3.0 | 3.4 |

g. (Residency, CTL - EXP)

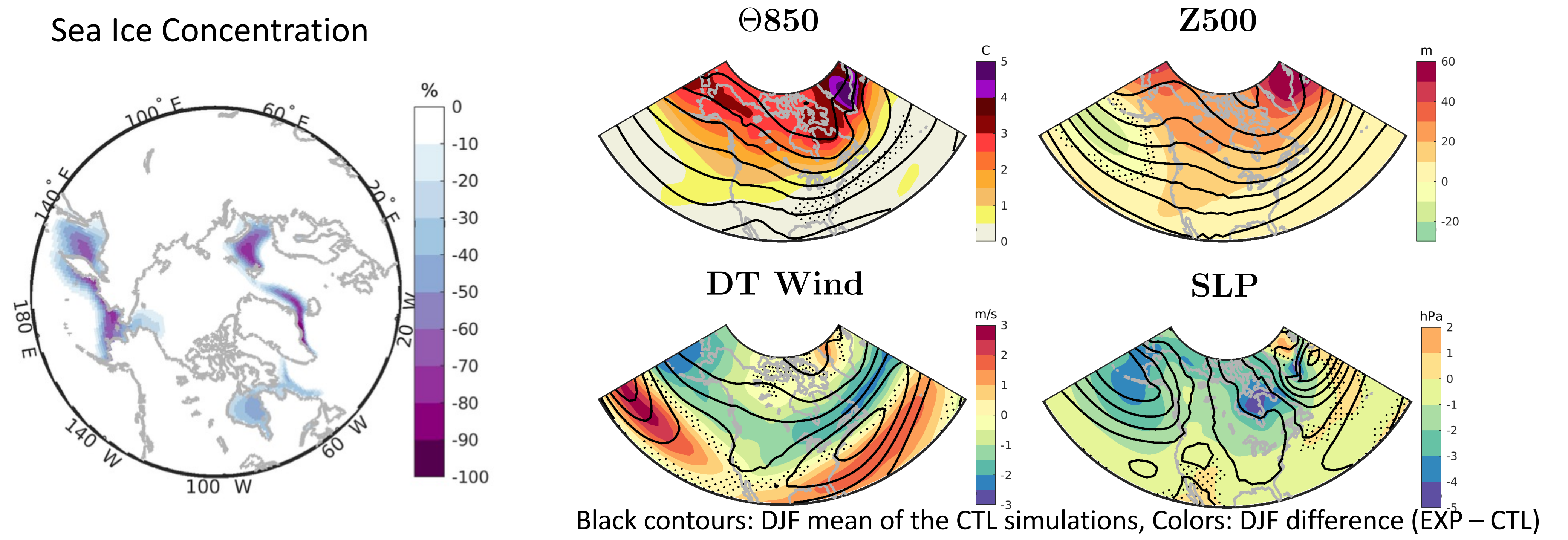
| | 1 | 2 | 3 |
|---|---|---|---|
| 1 | | | |
| 2 | | 0.3 | |
| 3 | | | |
| 4 | | | |
| 5 | | | |

## Difference in Pattern or Composite (ΔS)



CTL Composites (contours, every 0.25°C from ±0.25°C, dashed negative) and difference in composites (EXP-CTL) of $\Theta'_{850}$ (color, stippled insignificant).

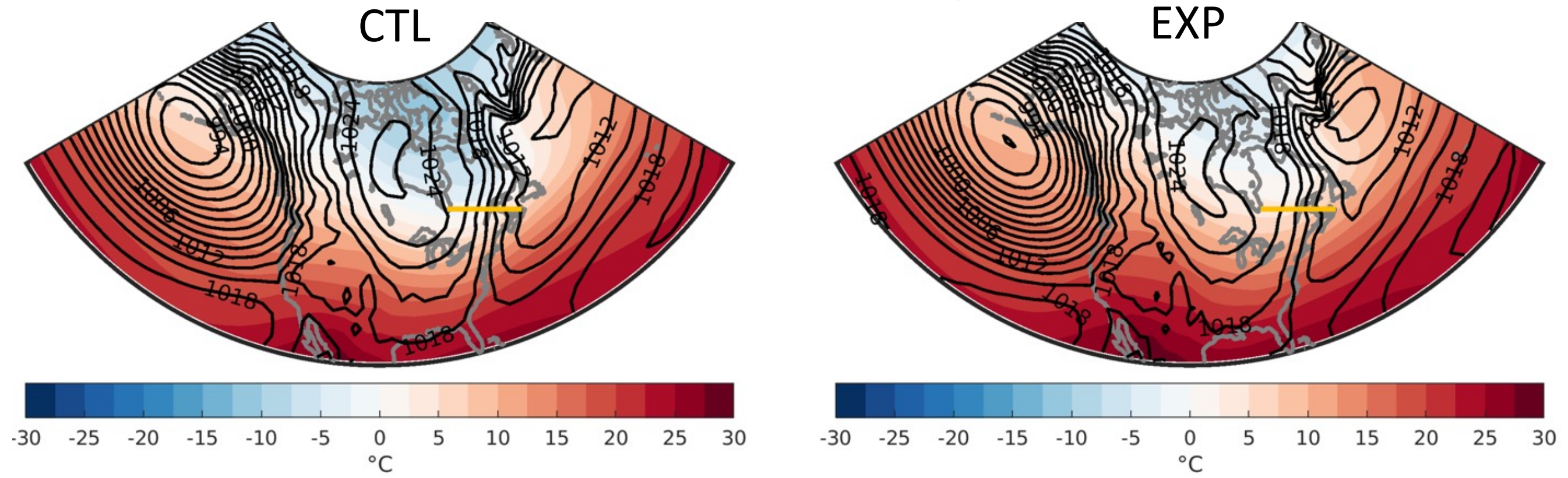
## DJF Mean Difference (EXP-CTL)



Black contours: DJF mean of the CTL simulations, Colors: DJF difference (EXP – CTL)

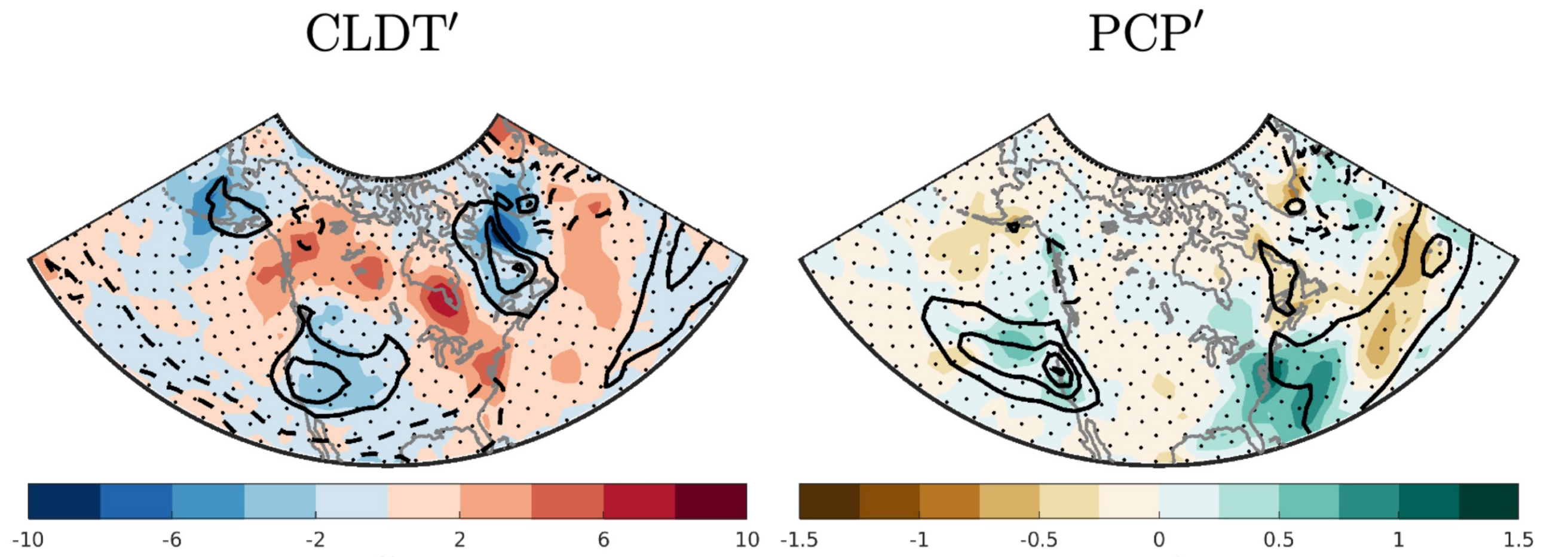
## Mechanisms Governing $\Theta'_{850}$ Differences in LSP [1,2]

**Full Field Composites of $\Theta_{850}$ and SLP**



Node [1,2] composites of $\Theta_{850}$ (color) and SLP (black contours every 4hPa)

**Anomaly Control Composites and Differences (EXP-CTL)**



Node [1,2] Composite $S'_{CNT}$ (contours) and $\Delta S'$ (color). (left) total cloud cover anomalies (CLDT′, contours every 5% from ±5%, dashed negative). (Right) precipitation anomalies (PCP′, contours every 1mm d$^{-1}$ from ±1mm d$^{-1}$, dashed negative)

$$\frac{dT}{dt} = \vec{v} \cdot \nabla T$$

1. Arctic Amplification → ↓ $\nabla T$ → less cold air advection (Thermodynamic Effect)
2. Weaker high → ↓ $\overrightarrow{v_g}$ by ~30%! → less cold air advection (Dynamic Effect)
3. ↑ Clouds and precipitation → ↑ diabatic heating → warming (Diabatic Effect)

## Conclusion

1. There is **no stagnation** of the flow with sea ice loss but some patterns become more common
2. Sea ice loss acts to **de-amplify and/or shift** the ridges and troughs that characterize these large-scale meteorological patterns and the associated anomalies in potential temperature at 850hPa.
3. This framework we provide **new mechanistic insights**, demonstrating a role for **thermodynamic**, **dynamic** and **diabatic** processes in sea ice impacts on atmospheric variability.
4. Understanding these processes from a synoptic perspective is critical as **some patterns play an outsized role** in producing the mean response to Arctic sea ice loss.

## References and Acknowledgements

Ayarzaguena, B., and J. A. Screen, 2016: Future Arctic sea ice loss reduces severity of cold air outbreaks in midlatitudes. Geophysical Research Letters, 43 (6), 2801–2809, https://doi.org/10.1002/2016GL068092.
Barnes, E. A., and J. A. Screen, 2015: The impact of Arctic warming on the midlatitude jet-stream: Can it? Has it? Will it? Wiley Interdisciplinary Reviews: Climate Change, 6 (3), 277–286, https://doi.org/10.1002/wcc.337.
Cohen, J., Zhang, X., Francis, J., Jung, T., Kwok, R., Overland, J., Ballinger, T. J., Bhatt, U. S., Chen, H. W., Coumou, D., Feldstein, S., Gu, H., Handorf, D., Henderson, G., Ionita, M., Kretschmer, M., Laliberte, F., Lee, S., Linderholm, H. W., … Yoon, J. (2020). Divergent consensuses on Arctic amplification influence on midlatitude severe winter weather. *Nature Climate Change*, *10*(1), 20–31. https://doi.org/10.1038/s41558-019-0662-y
Cohen, J., and Coauthors, 2014: Recent Arctic amplification and extreme mid-latitude weather. Nature Geoscience, 7 (9), https://doi.org/10.1038/ngeo2234.
Collow, T.W.,W.Wang, and A.Kumar, 2019: Reduction inNorthern Midlatitude 2-m Temperature Variability due to Arctic Sea Ice Loss. Journal of Climate, 32 (16), 5021–5035, https://doi.org/10.1175/JCLI-D-18-0692.1.
Dai, A., and J. Deng, 2021: Arctic amplification weakens the variability of daily temperatures over northern middle-high latitudes. Journal of Climate, 34 (7), 2591–2609, https://doi.org/10.1175/JCLI-D-20-0514.1.
Gervais, M. (Primary Author, 90%), Sun, L., & Deser, C. Impacts of projected Arctic sea ice loss on daily weather patterns over North America. *Journal of Climate*. DOI: 10.1175/JCLI-D-23-0389.1
Screen, J. A., and Coauthors, 2018: Consistency and discrepancy in the atmospheric response to Arctic sea-ice loss across climate models. Nature Geoscience, 11 (3), 155–163, https://doi.org/ 10.1038/s41561-018-0059-y
Screen, J. A., C. Deser, and L. Sun, 2015: Reduced Risk of North American Cold Extremes due to Continued Arctic Sea Ice Loss. Bulletin of the American Meteorological Society, 96 (9), 1489–1503, https://doi.org/10.1175/BAMS-D-14-00185.1.
Screen, J., 2014: Arctic amplification decreases temperature variance in northern mid- to high-latitudes. Nature Climate Change, 4, 577–582, https://doi.org/10.1038/NCLIMATE2268.
Vihma, T., 2014: Effects of Arctic Sea Ice Decline on Weather and Climate : A Review. Surveys in Geophysics, 35, 1175–1214, https://doi.org/10.1007/s10712-014-9284-0.

This research was supported by NSF Grant AGS-2236771. NCAR is sponsored by the National Science Foundation under Cooperative Agreement 1852977. We would like to acknowledge high-performance computing support from Cheyenne (doi:10.5065/D6RX99HX) provided by NCAR's Computational and Information Systems Laboratory, sponsored by the National Science Foundation. Additional computations for this research were performed on the Pennsylvania State University's Institute for Computational and Data Sciences' Roar supercomputer.