The Role of Stratosphere-Troposphere Coupling in Subseasonal Forecasts of the North American 2017-2018 Cold Air Outbreak

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CESM Earth System Prediction

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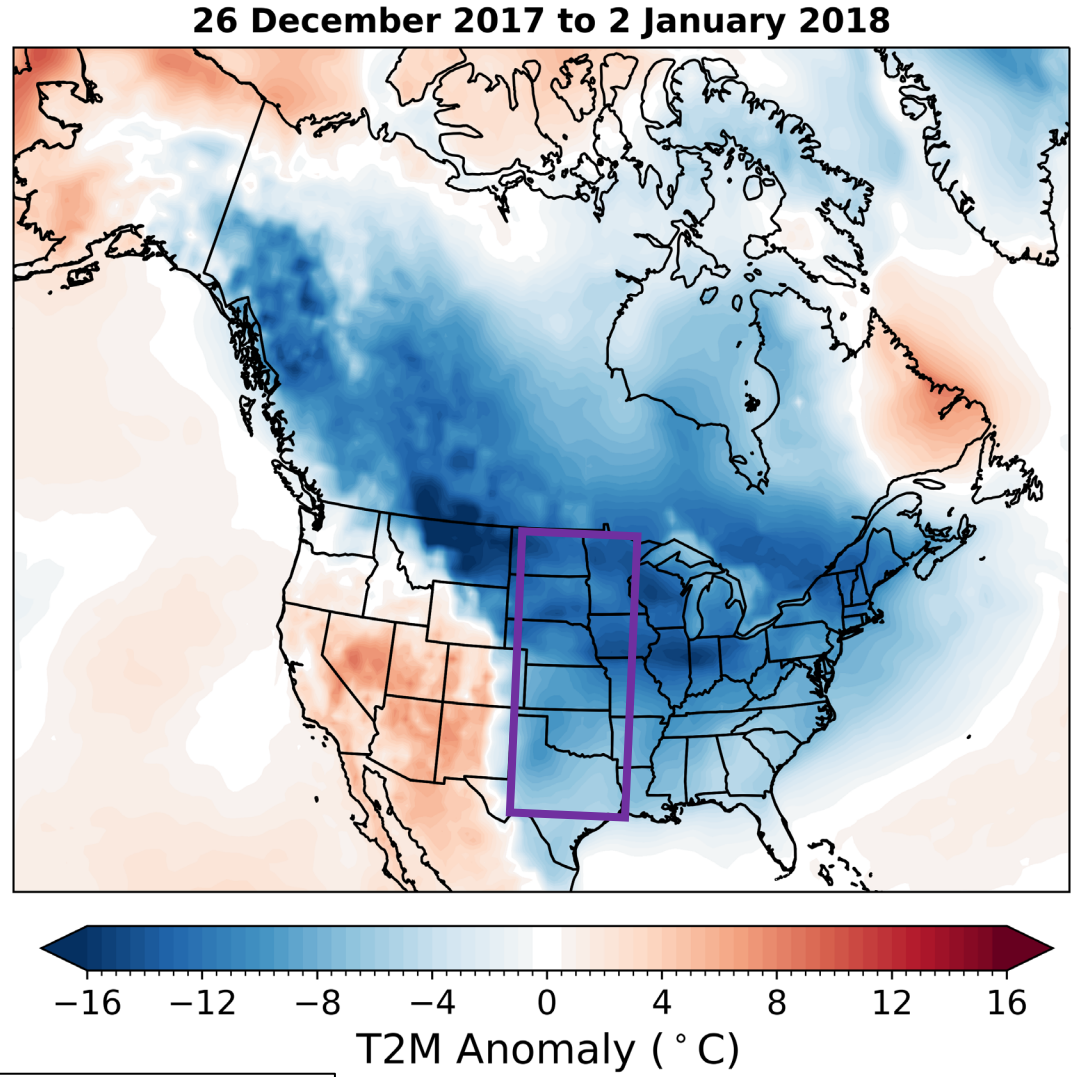
The December 2017/January 2018 CAO

- **Impactful** 8-day event in the Great Plains and Eastern US (26 Dec 2017 - 2 Jan 2018, Millin et al. 2022).

- Extreme cold across Central and Eastern North America.

- This event was strongly influenced by the stratosphere through **wave reflection**.



Data: *ERA-5 Reanalysis*
Shading: *Event average T2M Anomaly (°C)*
Box: *Great Plains Region*

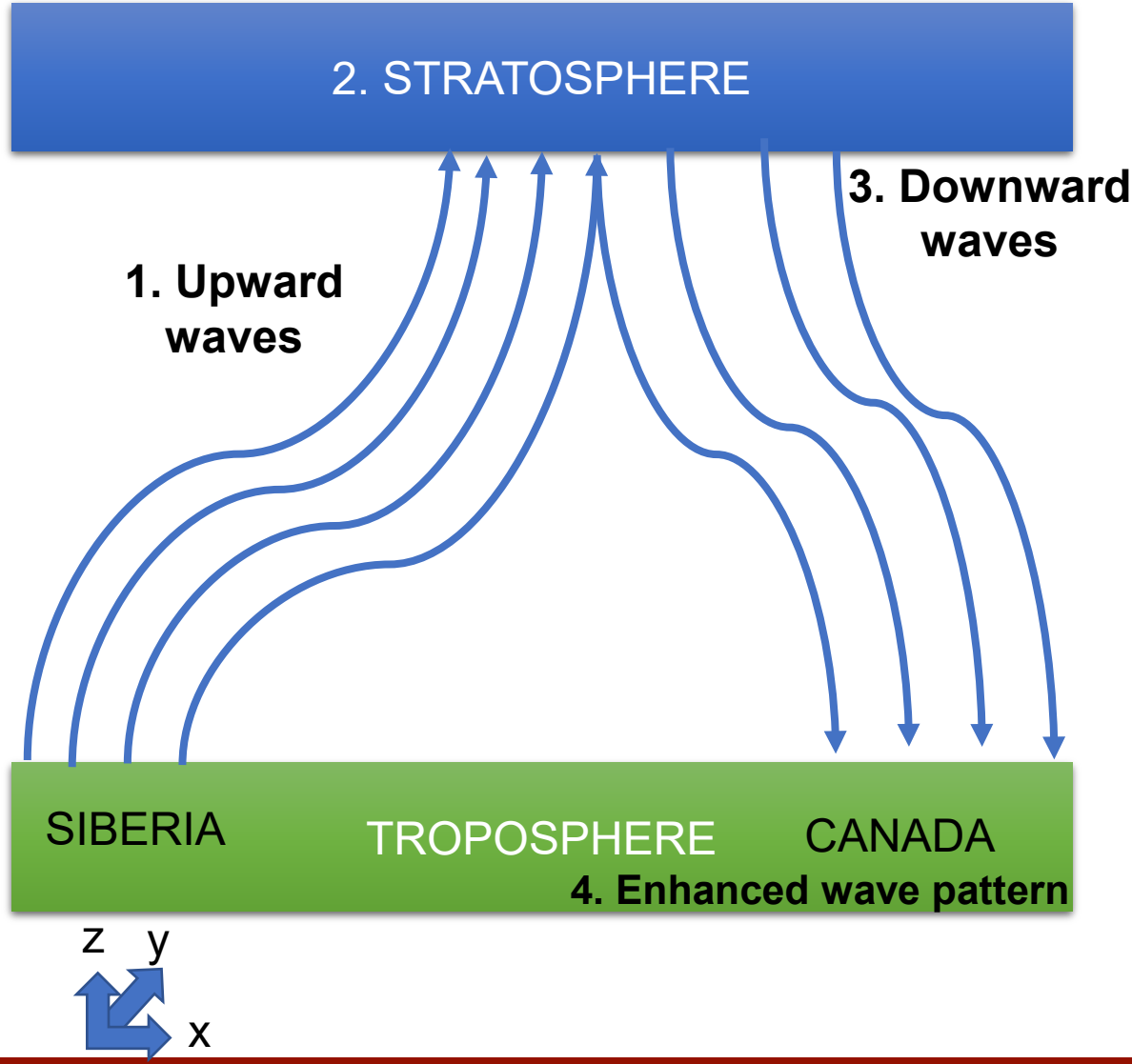
Stratospheric Wave Reflection

1. Upward wave activity from the troposphere over Siberia.

2. Wave activity reflects off the stratosphere due to a reflecting surface - like a mirror.

3. Downward wave activity from the stratosphere over Canada.

4. **Wave pattern amplifies**, enhancing CAO pattern.



***Schematic**: Stratospheric wave reflection*

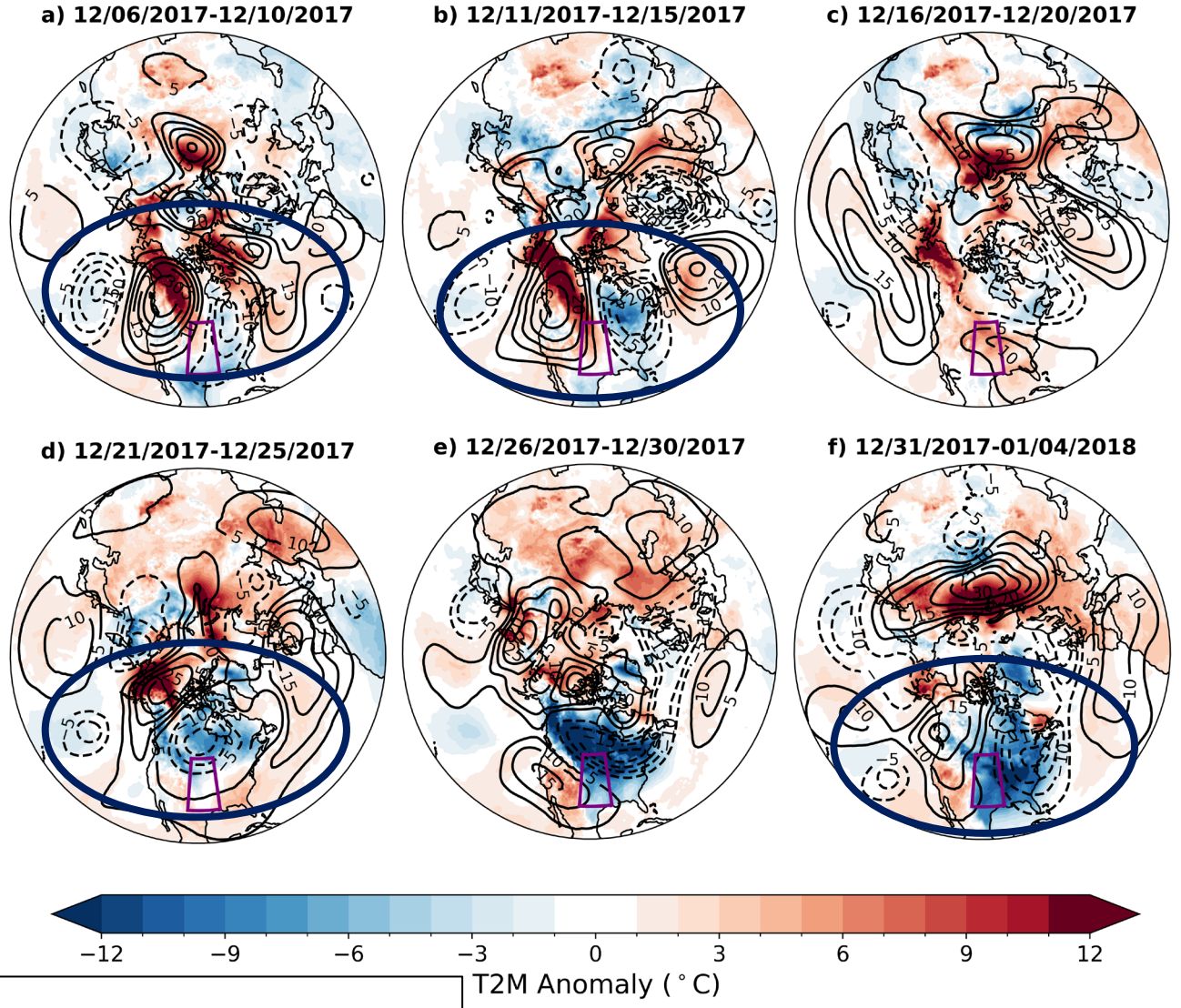
Objectives

1. Evaluate the meteorological evolution prior to and during the December 2017/January 2018 CAO.

2. Investigate the role of stratosphere-troposphere coupling through wave reflection in subseasonal forecast nudging experiments.

Event Evolution

- Rossby wave train across North America and into the Atlantic in early-mid December.
- Amplification of Alaskan ridging between 21-25 December.
- Alaskan and West Coast ridging regimes dominate the flow pattern during the CAO.
- How does this tropospheric evolution influence the stratospheric evolution?



***Data**: ERA-5 Reanalysis*
***Shading**: T2M Anomaly (°C)*
***Contours:** 500 hPa Geopotential Height Anomaly (dam)*
***Purple Box:** Great Plains Region*

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Stratospheric Influence - Wave Reflection

Reflective index (RI, Messori et al. 2022):

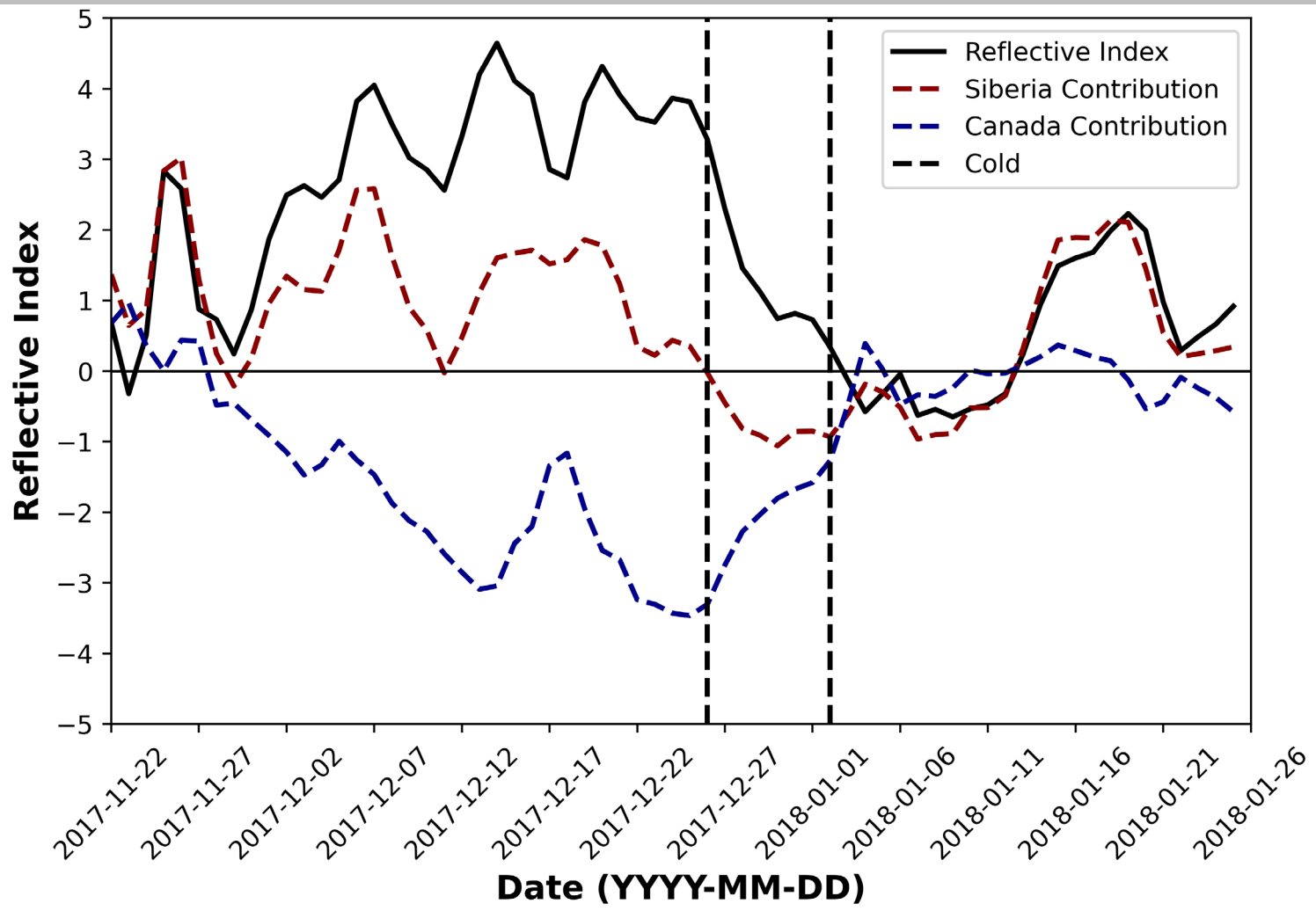
- Difference between standardized 100 hPa meridional eddy heat flux over Siberia and Canada:

$$RI = (v'T')^*_{Sib} - (v'T')^*_{Can}$$

- **+ve RI with +ve Siberian and -ve Canadian component indicates reflection.**

- **Highly reflective** conditions from early December with multiple upward/downward pulses.

How is the reflection and its impacts represented in subseasonal forecasts?



Data: *ERA-5 Reanalysis*
Lines: *Unsmoothed reflective index (black line), Siberia contribution (red dashed line), Canada contribution (blue dashed line), and CAO dates (black dashed line)*

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Model Experiments and Setup

Model Information

- Community Earth System Model Version 2 (**CESM2**) subseasonal prediction system (Richter et al. 2022).
- 21-member ensemble weekly forecast using the Community Atmosphere Model Version 6 (**CAM6**) atmospheric component.
- Horizonal resolution ~ 1°.
- 32 vertical levels up to ~ 40 km.

Stratospheric Nudging Experiments

Nudging Strategy:

- **Zonal mean nudging** on zonal wind and temperature with **6-hourly timescale.**
- **Full strength at and above 100 hPa** with no nudging below 150 hPa - linear taper between 150-100 hPa.

Nudging Experiments:

1. **FREE** – free evolution.
2. **NUDGE-ERA5** – nudged to ERA5.
3. **NUDGE-CLIMO** – nudged to ERA5 climatological conditions (1991-2020).

Following **SNAPSI** experimental outline.

- Can be applied to other events.

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SNAPSI: Stratospheric Nudging and Predictable Surface Impacts (Hitchcock et al. 2022)

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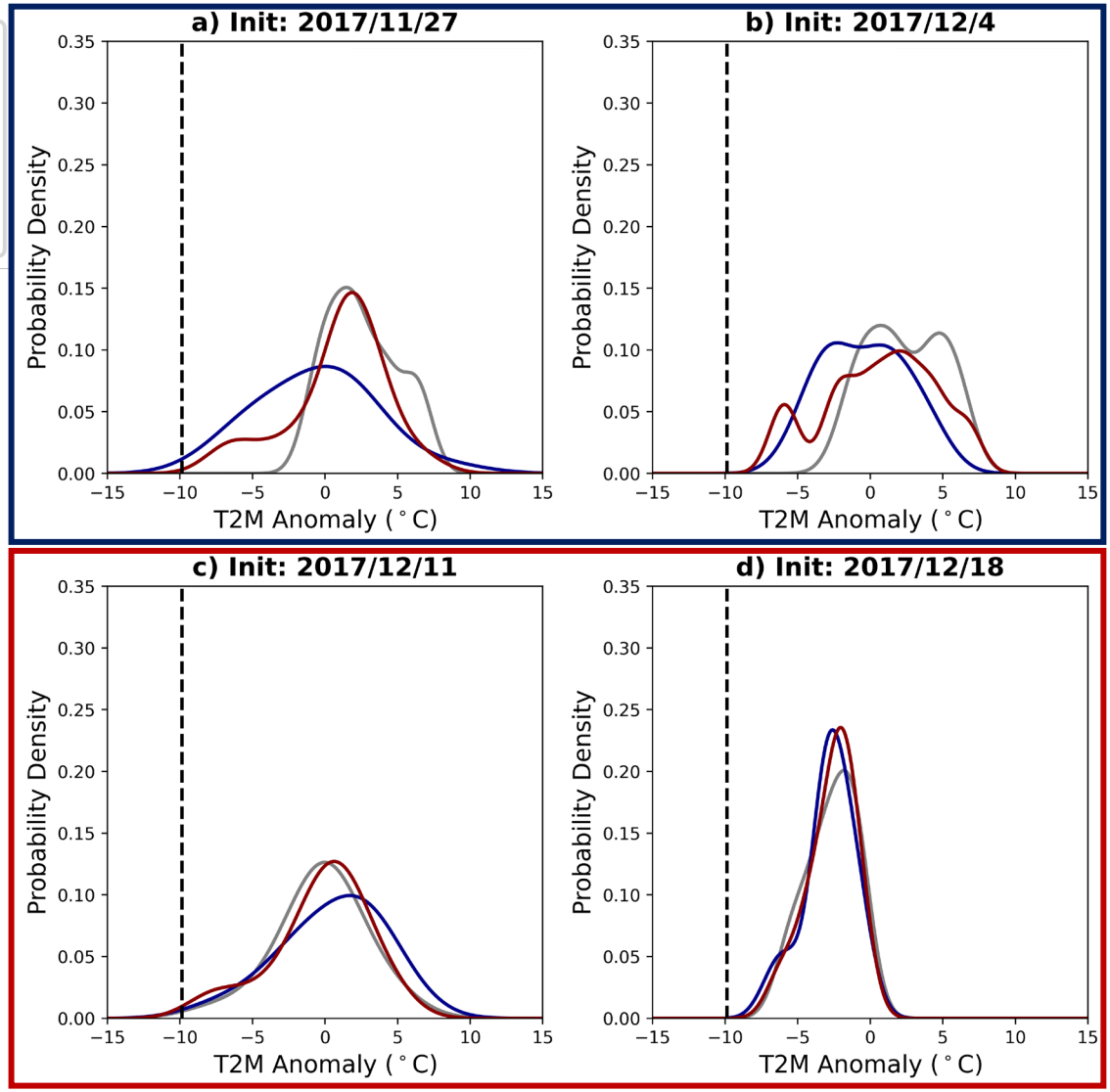
Great Plains T2M Anomaly Subseasonal Forecasts

T2M anomaly target: **26 Dec 2017 – 2 Jan 2018** in the Great Plains (92-103°W, 30-48°N).

FREE
NUDGE-ERA5
NUDGE-CLIMO
ERA5

- The longest lead subseasonal NUDGE-ERA5 experiments exhibit a notable **cold shift** compared to NUDGE-CLIMO and FREE.
- Ensemble forecasts in mid-to-late December have comparable output between experiments but shift colder.

- Could the subseasonal representation of the stratosphere have an impact on the reflection forecast which impacts the T2M forecast?



Data: *CESM2 CAM6 Output*
Coloured Lines: *Probability density for Great Plains T2M anomalies from the 3 different experiments*
Black Dashed Line: *ERA5 value*

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Subseasonal Reflection Forecast

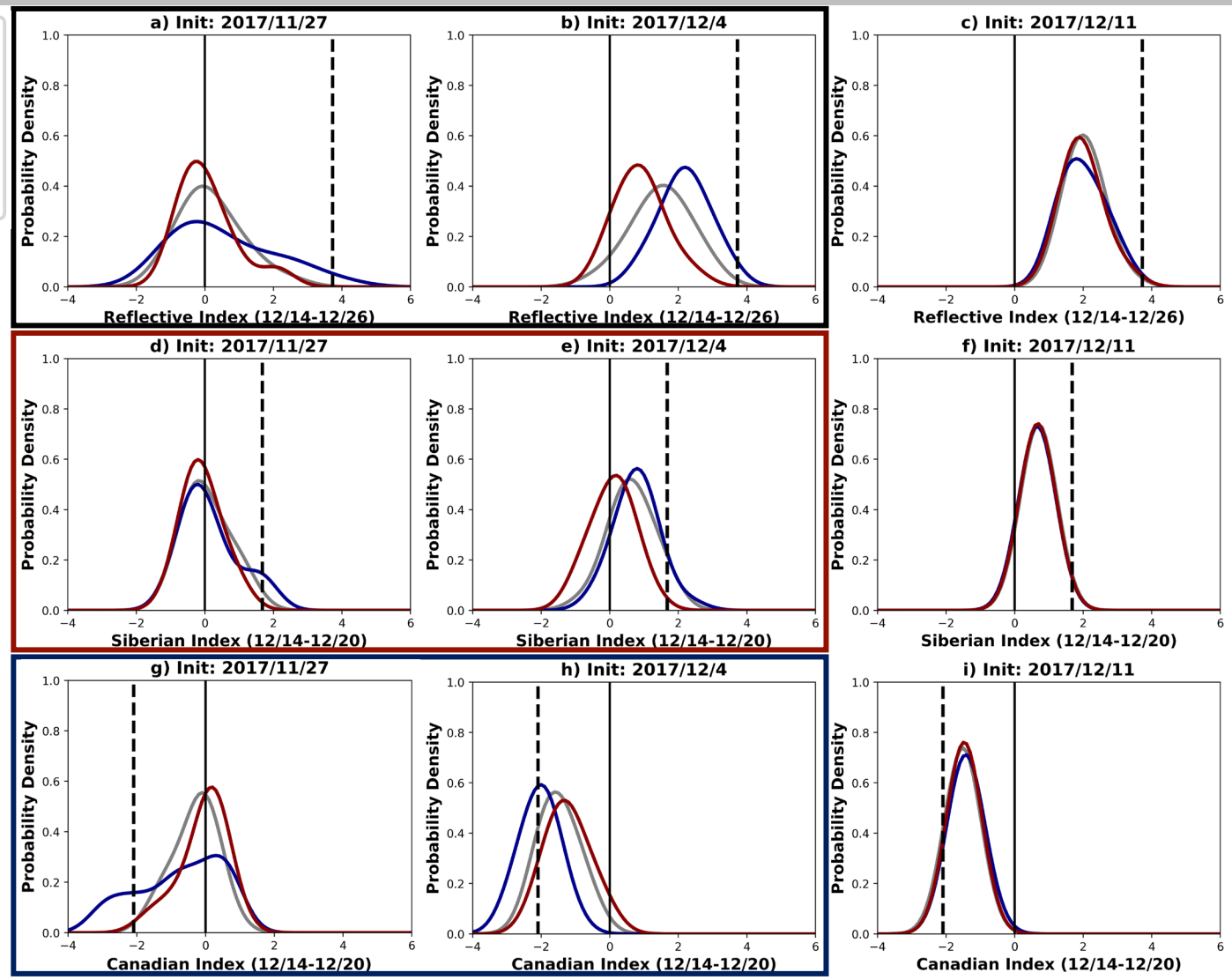
- RI components during **key wave activity periods**:

1. **RI** – 14-26 December
2. **Siberia and Canada** – 14-20 December (upward/downward wave periods)

- NUDGE-ERA5 subseasonal reflection forecasts produce:

1. Larger positive RI tail/shift
2. Modest shift to larger Siberian flux
3. Notable shift to downward Canadian flux

- More accurate stratospheric representation may result in better subseasonal forecasts of **downward waves** that enhance CAOs.



***Data**: CESM2 CAM6 Output*
***Colored Lines**: Probability density for RI components from the 3 different experiments*
***Black Dashed Line:** ERA5 value*

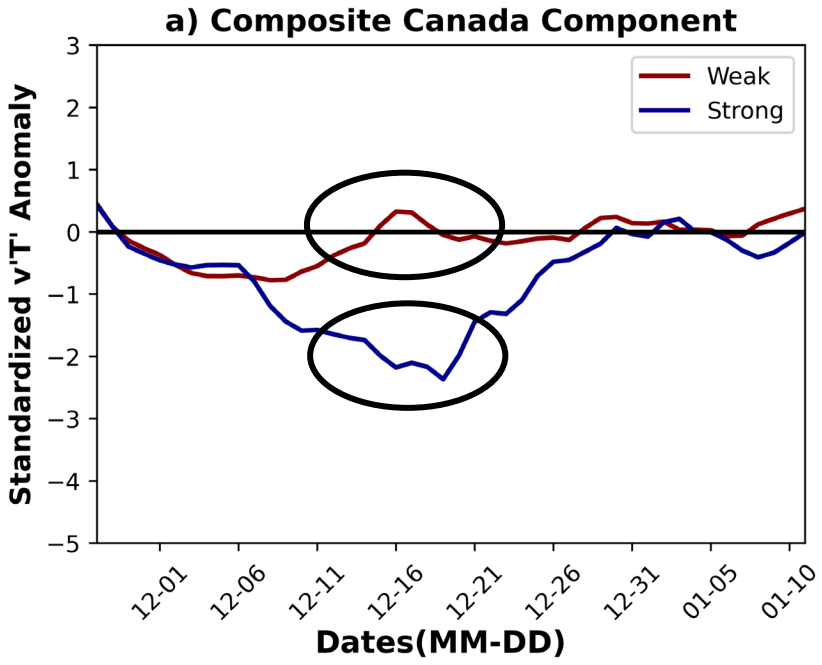
Representation of Downward Reflection – 11/27 NUDGE-ERA5

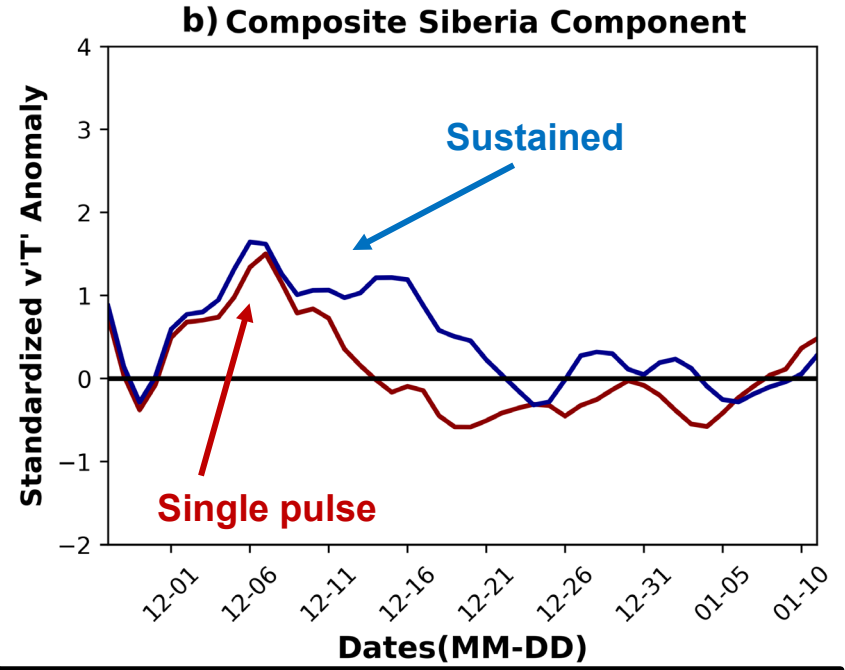
Downward Pulse Experiment

- Target period: **14-20 December**
- Chosen Init: **27 November**
- Chosen Exp: **NUDGE-ERA5**

- Separate ensemble members with >-1 (weak) and <-1 (strong) downward area-averaged Canadian 100 hPa v'T' standardized anomalies.

- Weak = 13 members
- Strong = 8 members





- Strong downward flux members exhibit negative Canadian heat flux **anomalies of ~ -2σ.**
- Weak downward flux members **trend toward 0 (i.e., no anomalous wave response)**.

- Strong downward flux members also show **sustained anomalous Siberian upward 100 hPa flux**.
- Weak downward flux members show just an early single pulse from Siberia; **less sustained.**

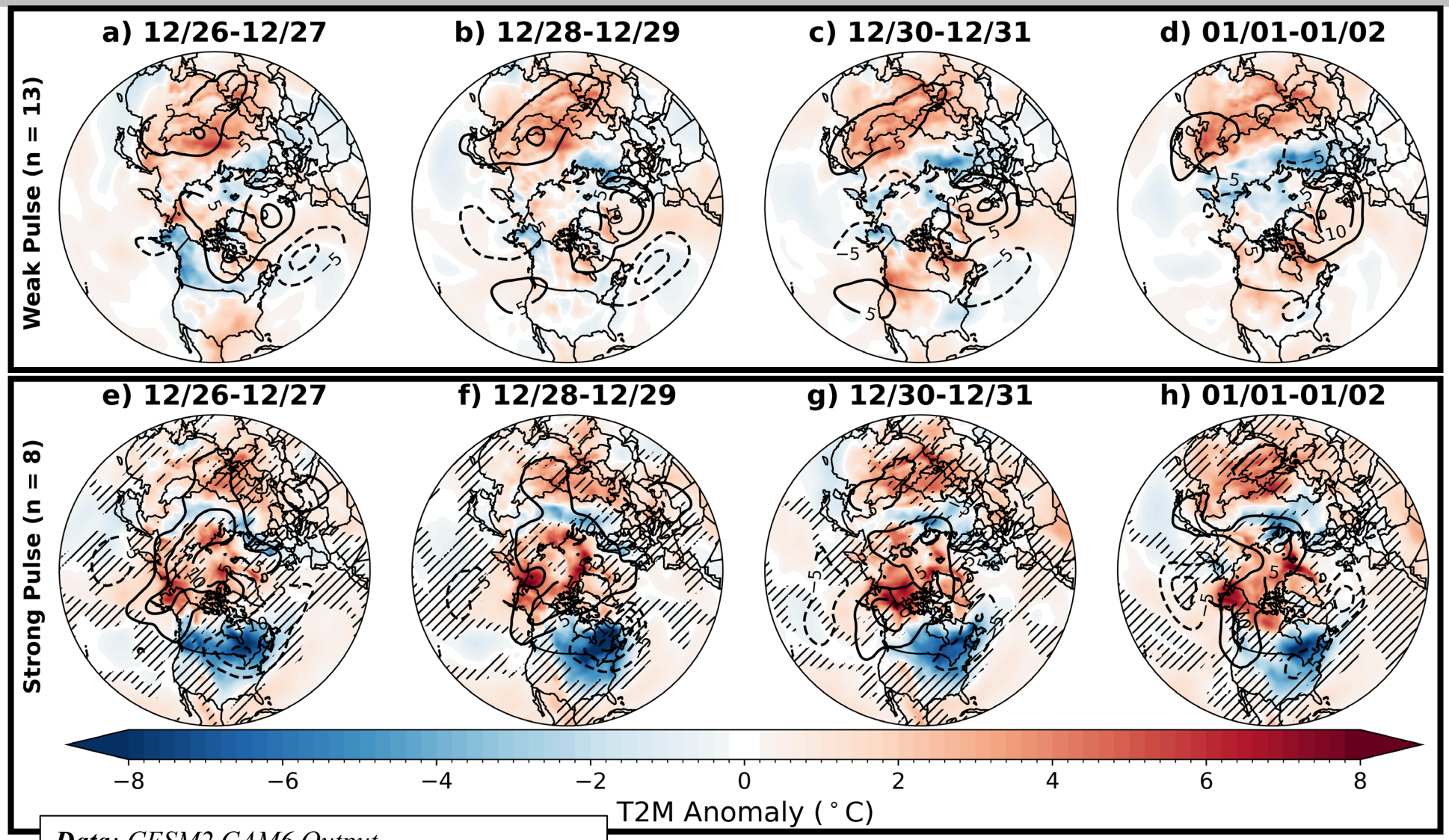
Data: *CESM2 CAM6 Output*
Colored Lines: *Composite weak (red lines) and strong (blue lines) members of Canada 100 hPa v'T' standardized anomaly component*

Strong vs Weak Downward Flux Response – 11/27 NUDGE-ERA5

Effect on T2M/GPH

- Weak flux members produce **anomalous warmth across much of US** during the CAO period.
- Strong downward flux members show **colder US temperatures and similar evolution** to the CAO.

- NUDGE-ERA5 more readily produces a **stronger downward wave response** on subseasonal timescales.



***Data**: CESM2 CAM6 Output*
***Shading**: T2M Anomaly (°C)*
***Contours:** 500 hPa Geopotential Height (dam)*
***Hatching:** 95th percentile significance*

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Conclusions

- The December 2017/January 2018 CAO featured **stratospheric wave reflection** and the development of Alaskan/West Coast ridging.

- Subseasonal forecasts for nudged simulations show that the most accurate representation of the zonal-mean stratospheric circulation produces a **more robust coupling** at the longest lead times.

- The stratospheric circulation representation could be **important for long-lead S2S prediction** of CAOs resulting from wave reflection. How much does the tropical troposphere matter for these types of events? → **Ongoing work**

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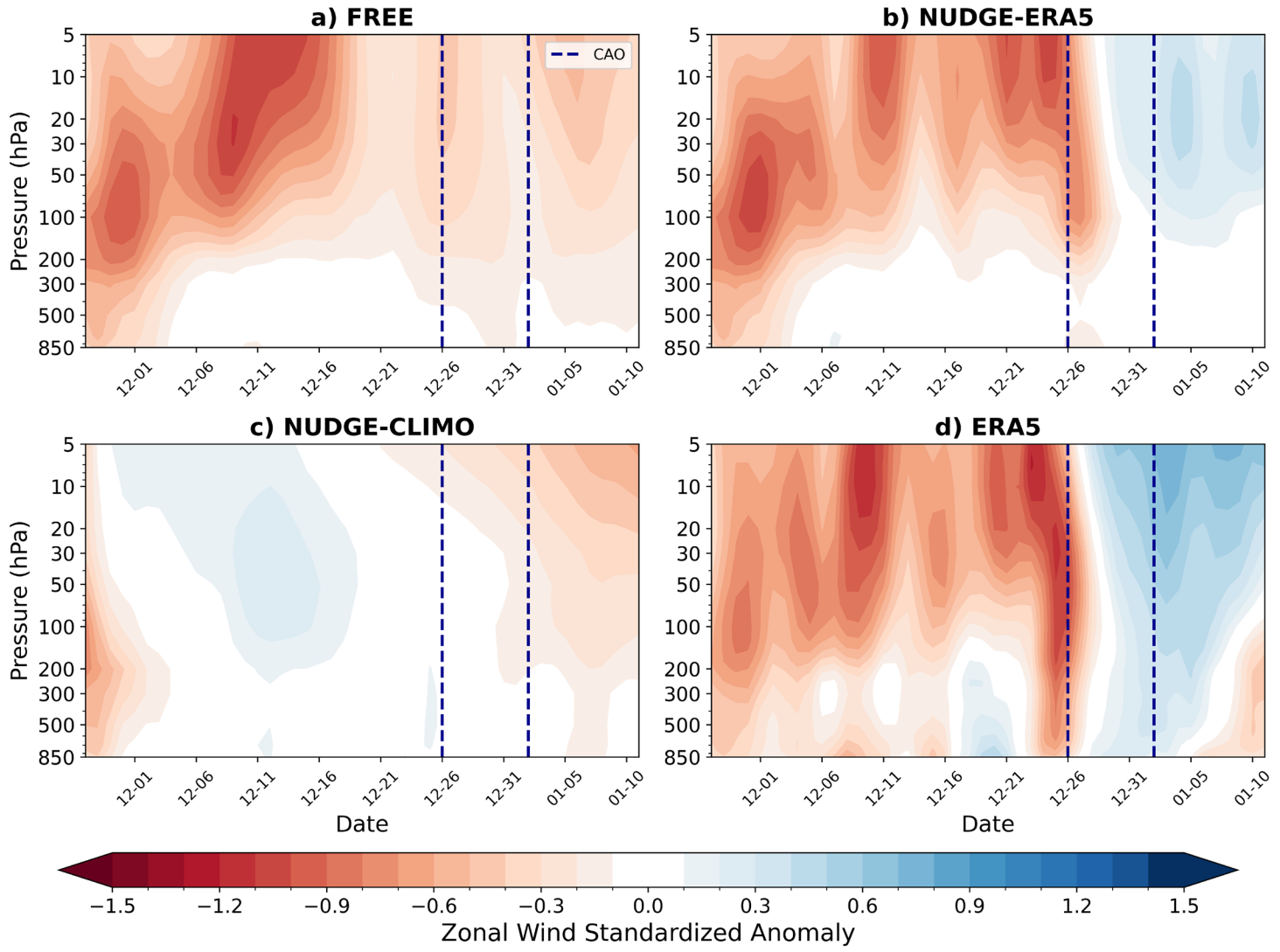
Extra Slide: Nudging Performance on Circulation

- NUDGE-ERA5 and ERA5 very similar in evolution in the stratosphere.
- NUDGE-CLIMO damped to near-zero anomaly in the stratosphere respective to model climo.
- FREE run starts like ERA5 but evolves on its own.



Data: *CESM2 CAM6 Output*
Shading: *Polar Cap (60-90°N) Zonal Wind Standardized Anomaly*