The Differing Influence of the Stratosphere on Cold Air Outbreaks in the Great Plains of the United States

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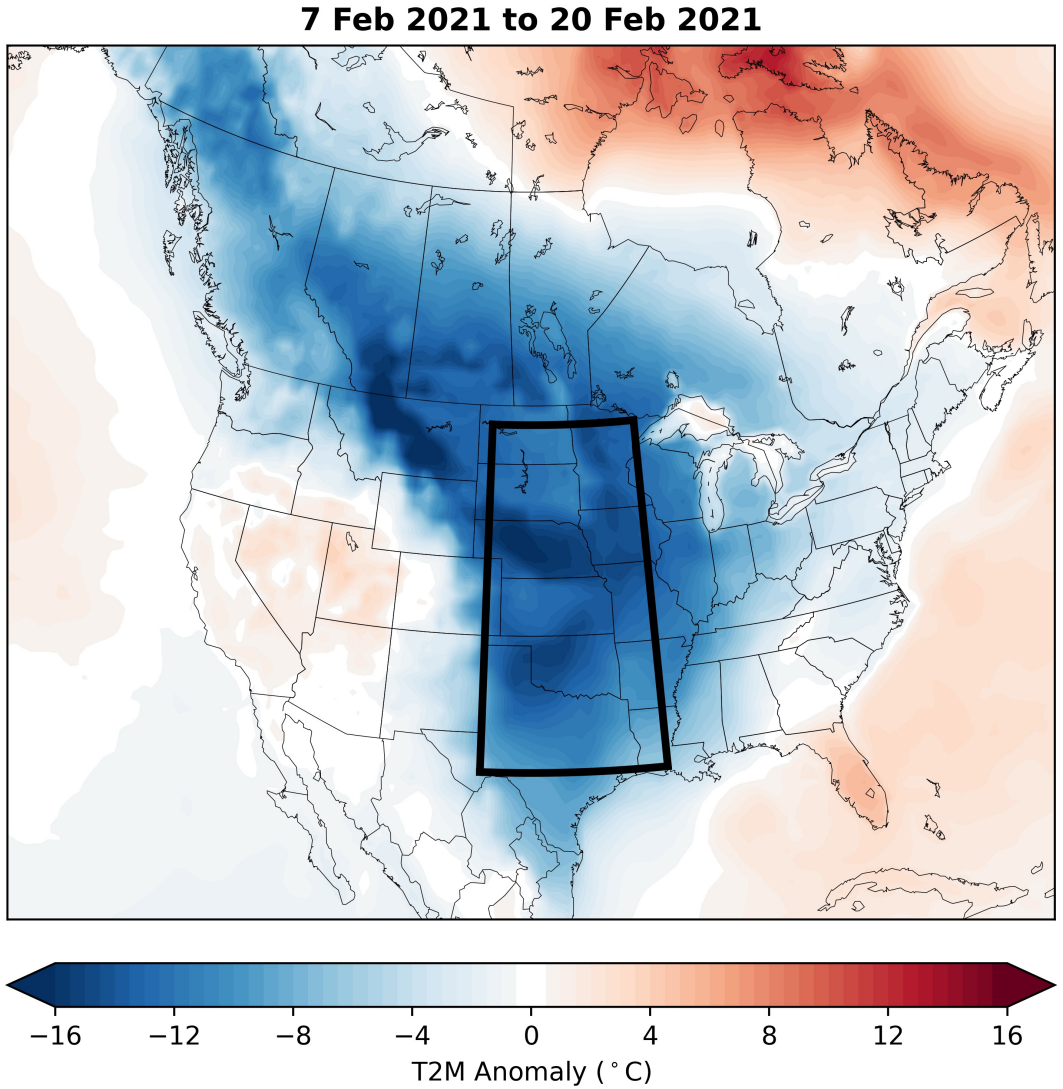
Motivation

- Wintertime cold air outbreaks (CAOs) are high-impact extreme events, involving the displacement of cold air from the polar regions into the midlatitudes.
- The **February 2021 CAO** in the Great Plains featured **very cold temperatures.**
- Widespread power outages occurred in Texas due to surging heating demand.

- **<u>What are the dynamics/characteristics of these events, and could this lead to predictability potential on the subseasonal to seasonal (S2S) timescale of two weeks to two months?</u>**



Data and defining Great Plains CAOs

Data

- ERA-5 reanalysis data 1950-2021; T2M, geopotential height (GPH), zonal wind (u), meridional wind (v), and air temperature (T).
- Derived quantities: wave activity flux (WAF, Plumb 1985) and 100 hPa meridional eddy heat flux (v'T').
- Daily climatological period: 1981-2010.
- Statistical significance at 95th percentile via 5000-iteration bootstrapping.

CAO Definition/Criteria

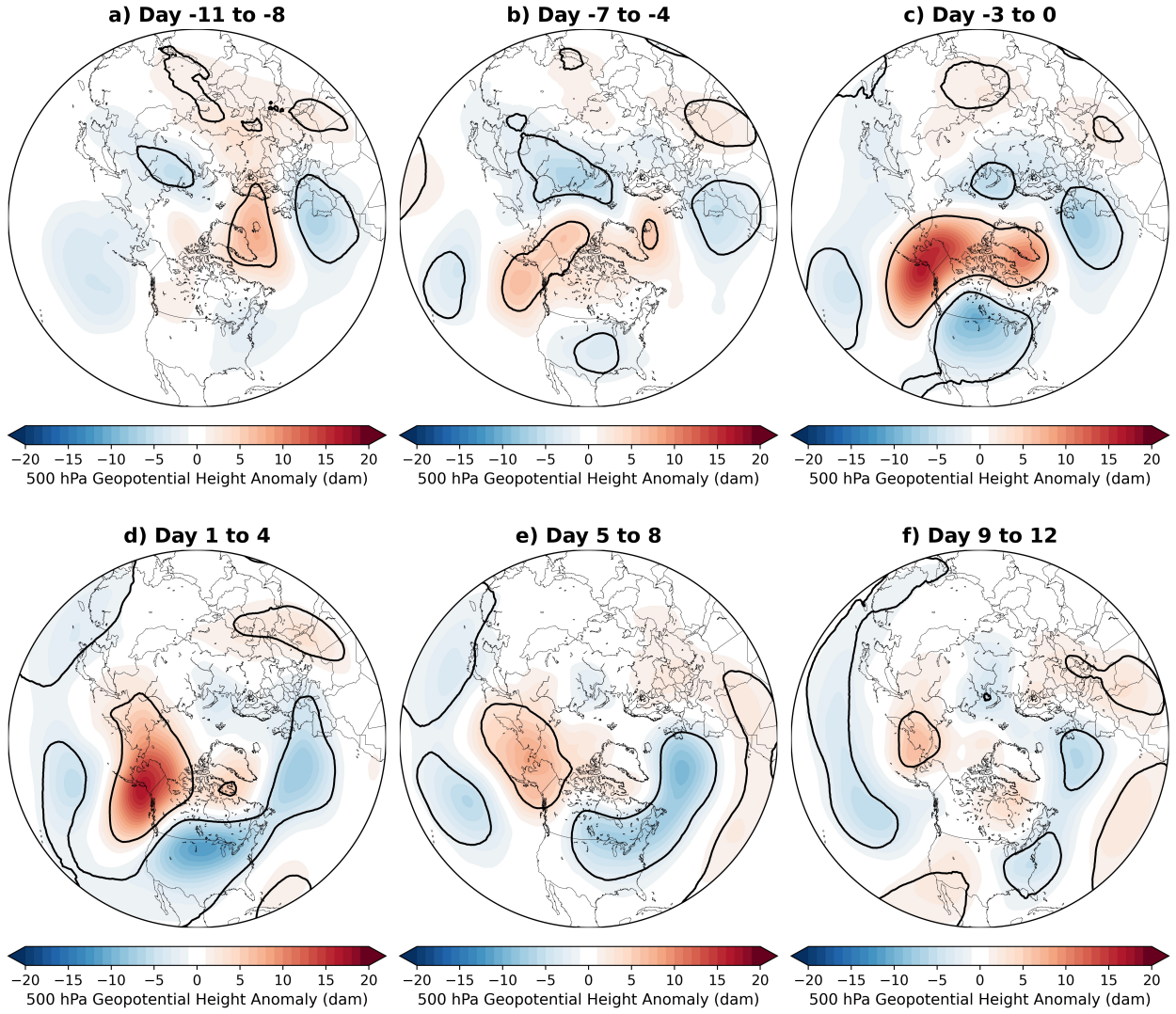
1. 5+ consecutive days below the 10th percentile of the DJF linearly-detrended and Great Plains area-averaged T2M anomalies.
2. Each CAO separated by 4+ days.
3. A maximum of one day per CAO can miss the magnitude threshold.

This definition yielded 37 events from 1950-2021.

500 hPa GPH CAO composites

- Two dominant areas of anomalous high-latitude ridging appear at CAO onset: **Alaska and Greenland/northern Canada.**

- Signals for these anomalous ridging areas appear prior to CAO onset and persist after CAO onset.



Millin et al. (2021), under review.

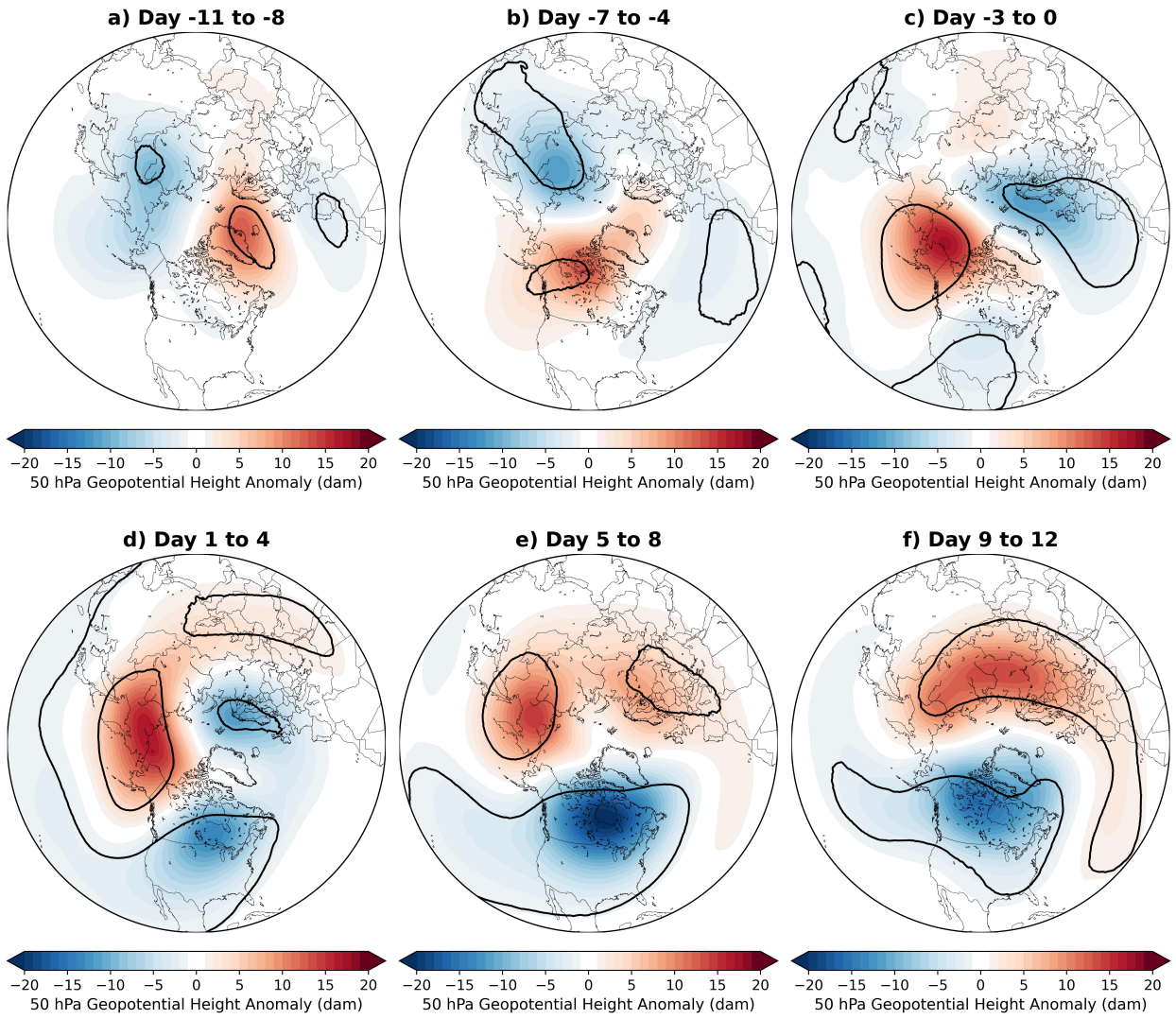
50 hPa GPH CAO composites

- Significant negative GPH anomalies persist over North America for longer than at 500 hPa.

- Positive GPH anomalies over Eurasia and North American anomalous troughing, **indicative of stretched/displaced stratospheric polar vortex (SPV).**

Key research questions:

1. Do Great Plains CAOs that start with Alaskan ridging have different dynamics to those that start with Arctic ridging?
2. Can the stratosphere enhance Great Plains CAO predictability potential?



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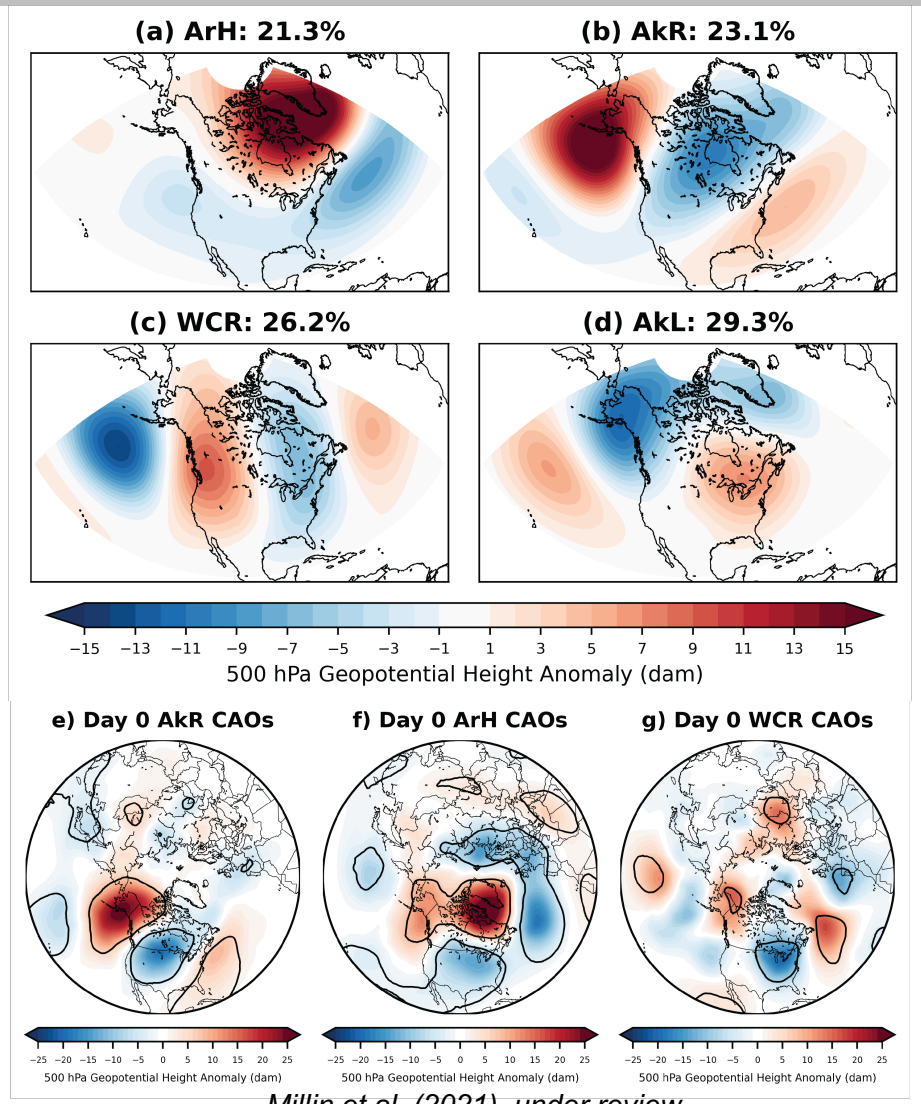
CAO weather regime categorizing

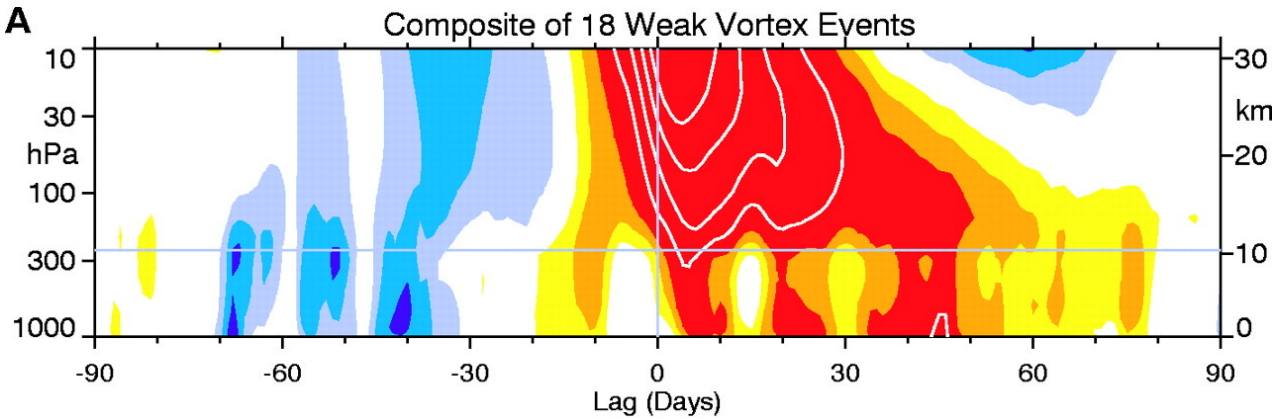
- **EOF analysis and *k*-means clustering** is performed to define **four North American weather regimes**.
- Each CAO is categorized by its weather regime on onset day; **16 ArH-CAOs, 16 AkR-CAOs, and 5 WCR-CAOs.**
- **<u>We focus on the dynamics and stratospheric impact on the dominant AkR- and ArH-CAOs.</u>**



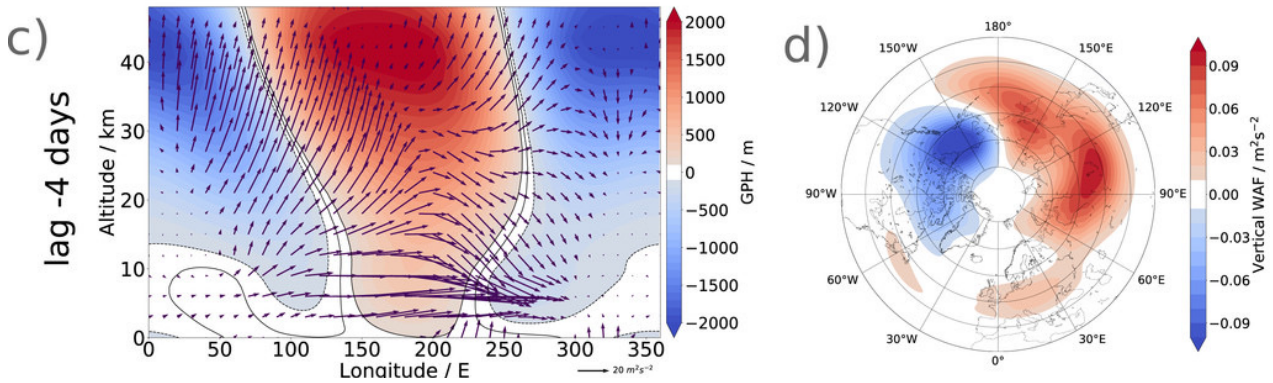
Millin et al. (2021), under review.

The stratosphere – a tool for CAO predictability?

- **Weakening and warming of the SPV** with downward propagation of the negative Northern Annular Mode **can aid CAO development**.
- **Stratospheric wave reflection** has links with North American CAOs; upward wave activity from Siberia is reflected over Canada, changing the tropospheric flow.
- **<u>Could the stratosphere be a key tool for S2S predictability of Great Plains CAOs?</u>**



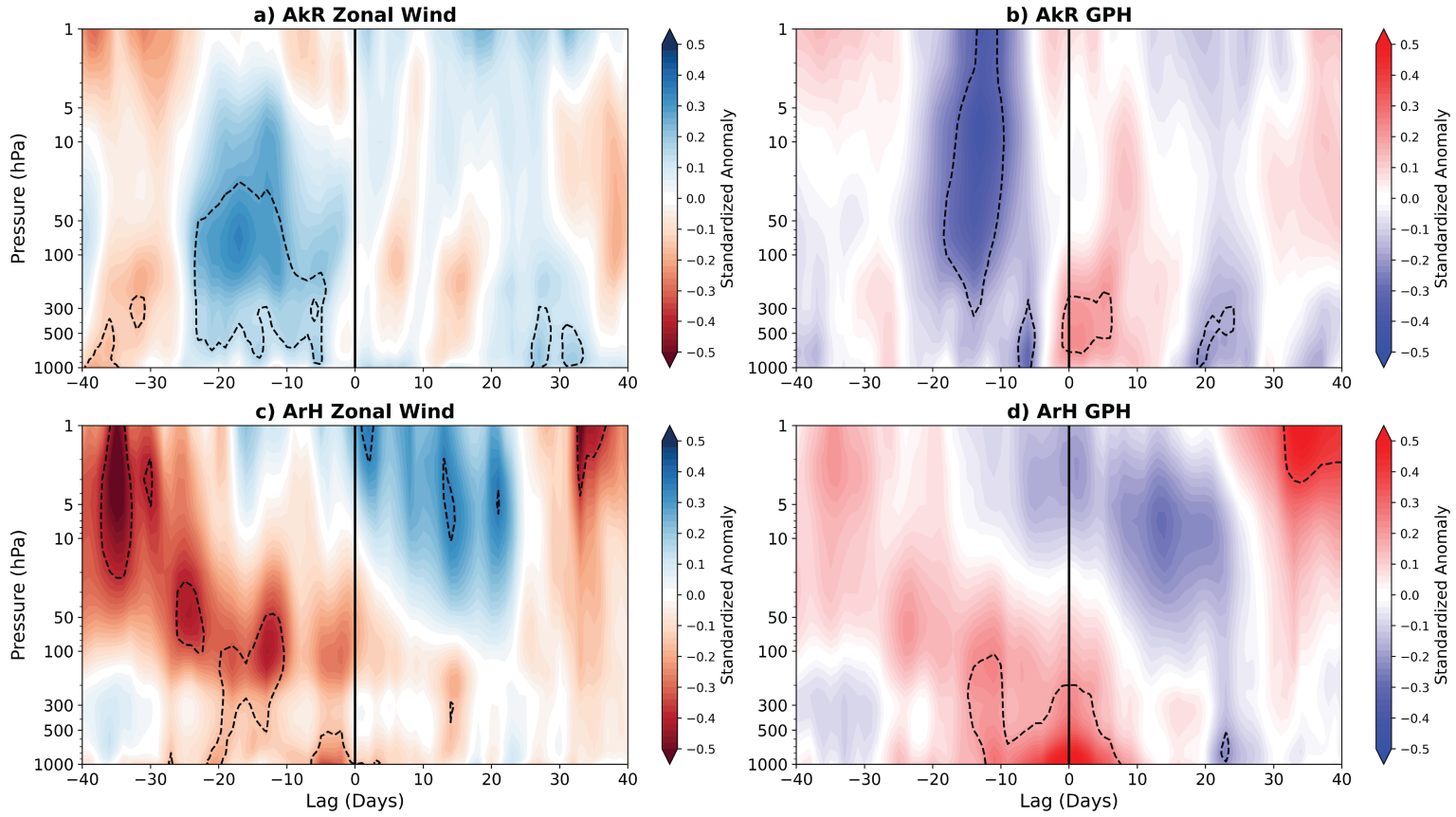
From Baldwin and Dunkerton (2001).



From Matthias and Kretschmer (2020).

SPV Variability

- **AkR-CAOs** feature anomalously **strong SPV** conditions.
- **ArH-CAOs feature anomalously weak SPV** conditions with downward propagation into the troposphere.
- Two opposing signals suggest that **different forcing dynamics** may be occurring, with different S2S predictability potential.



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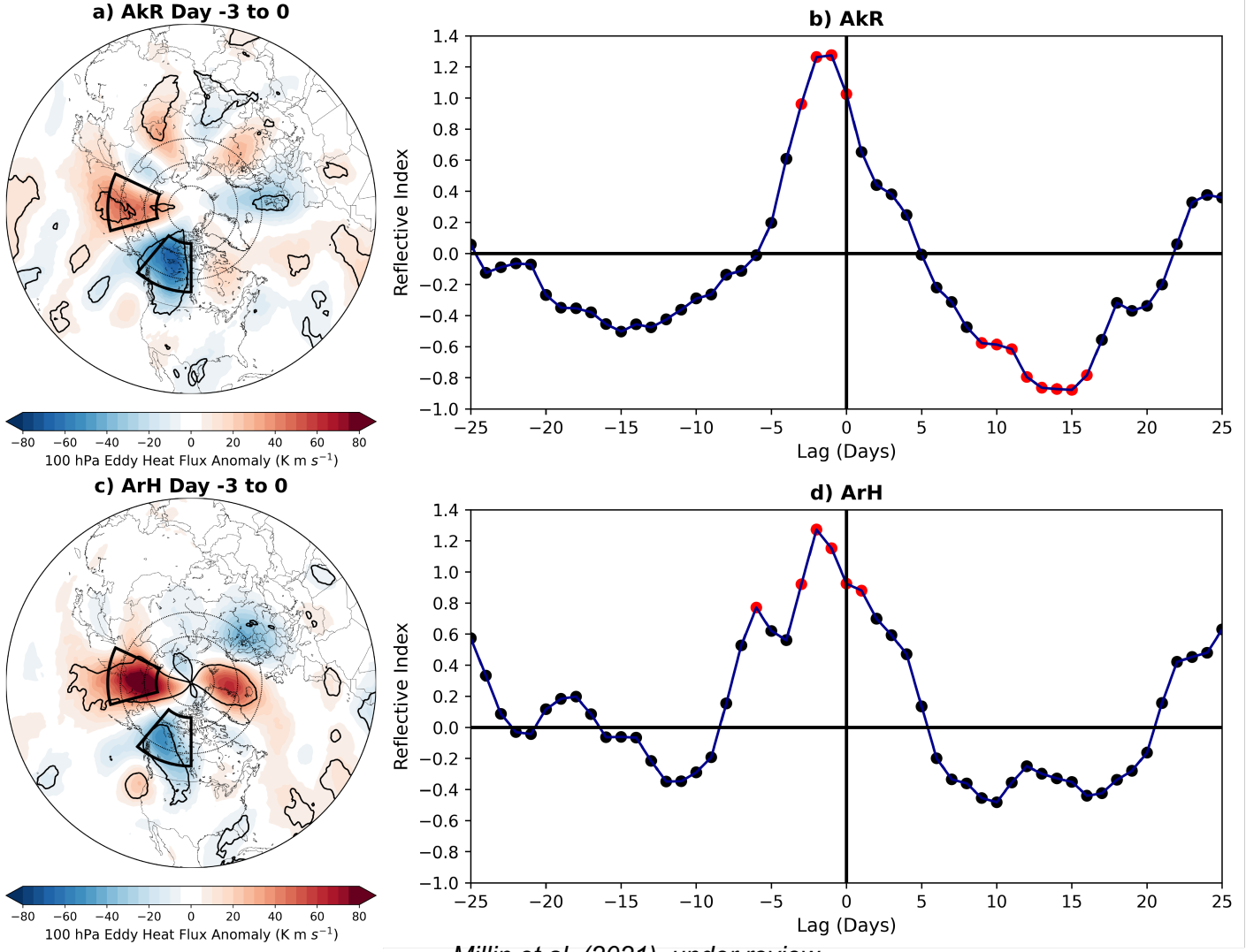
Stratospheric Wave Reflection Index

- An edited **stratospheric wave reflection index** from Matthias and Kretschmer (2020):

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

- <u>A sharp peak before AkR-CAOs:</u>
- Positive v'T' anomalies over Siberia (upward wave propagation).
- Negative v'T' anomalies over Canada (downward wave propagation).
- **Could wave reflection be happening?**

- A similar peak for ArH-CAOs, but with stronger positive anomalies in Siberia.



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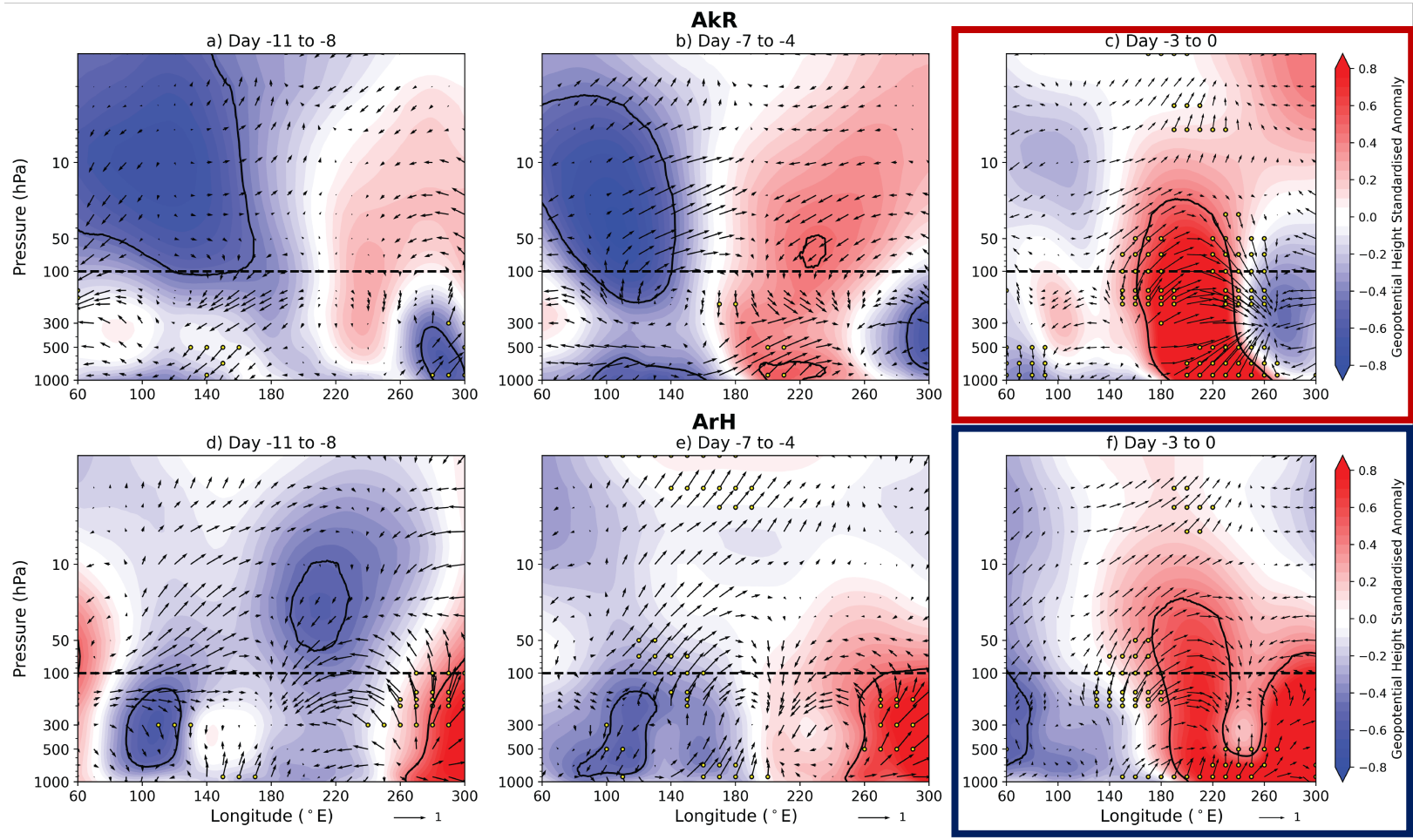
Stratospheric Wave Reflection

- A **rapid development of stratospheric wave reflection** occurs between Days -3 to 0 for AkR-CAOs.
- Upward anomalous WAF from the Siberian troposphere into the stratosphere.
- Downward anomalous WAF into the Canadian troposphere from the stratosphere.
- A **horizontal wave train from the Pacific** leads to the possibility of remote tropical forcing.

- Such wave reflection is not seen for ArH-CAOs.



Millin et al. (2021), under review.

Summary

1. The dominant onset day regimes for Great Plains CAOs were the Alaskan Ridge and the Arctic High.
2. AkR-CAOs involve stratospheric wave reflection and a strong SPV, whereas ArH-CAOs feature a longer timescale downward propagation of weak SPV conditions.
3. Both types of Great Plains CAO have potential for S2S predictability through stratospheric connections.

Future Work

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- Investigate the predictability of the February 2021 CAO in S2S models.
- Extend the S2S model analysis to predictability of AkR- vs ArH-CAOs.
- Do tropical modes of variability (i.e., Madden-Julian Oscillation and El Nino Southern Oscillation) have an impact on the development of AkR-CAOs through remote forcing on the S2S timescale?

Thanks to Jason Furtado, Jeff Basara, Simon Lee, and Ty Dickinson.

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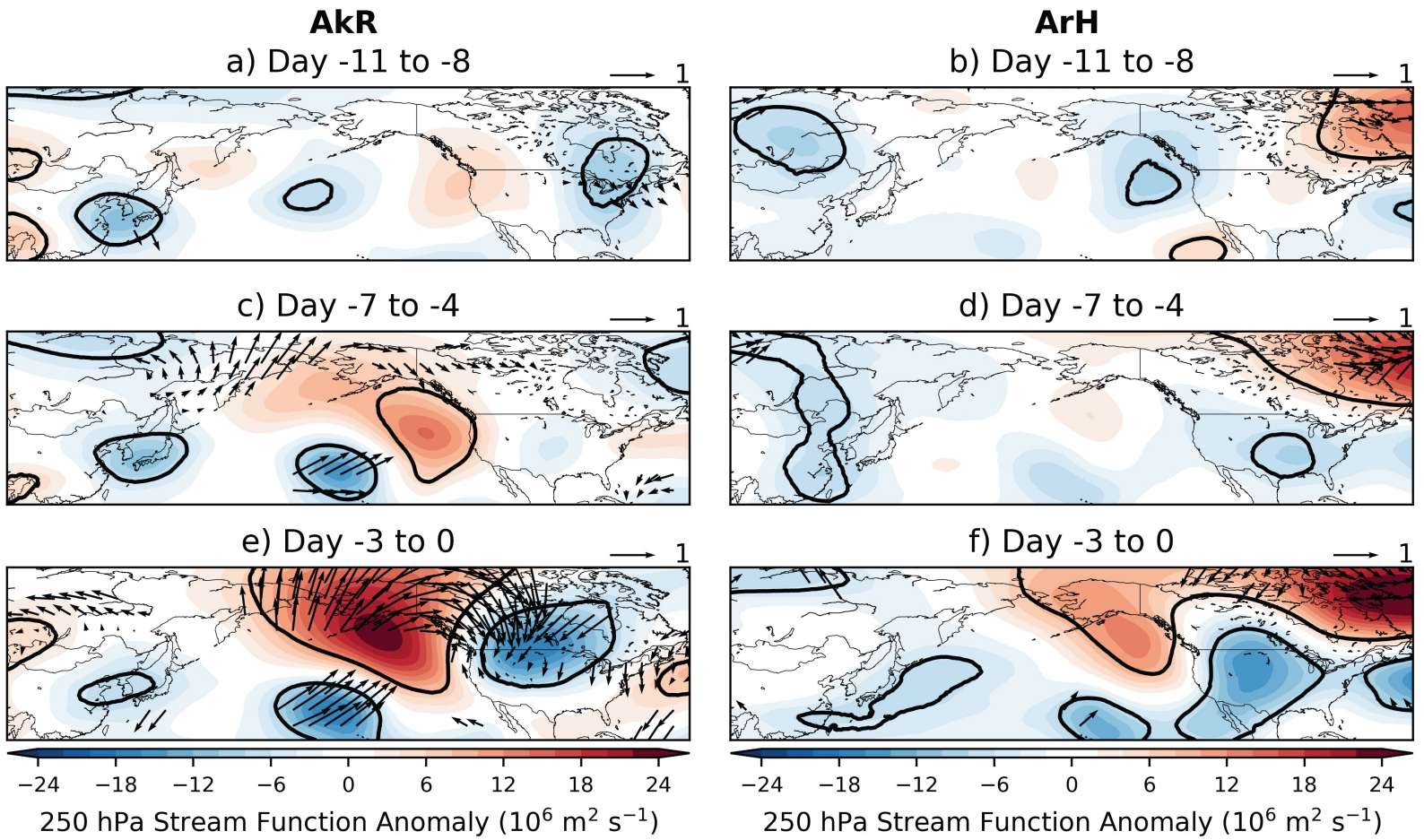
Extra Slide: Horizontal WAF and Streamfunction

- Rapid development of Pacific wave train for AkR-CAOs with strong, significant wave propagation.
- No significant WAF signal in Pacific for ArH-CAOs, only in the North Atlantic due to the ArH.
- These results suggest that the development of AkR-CAOs could be related to remote forcing from the tropics, i.e., MJO and ENSO.



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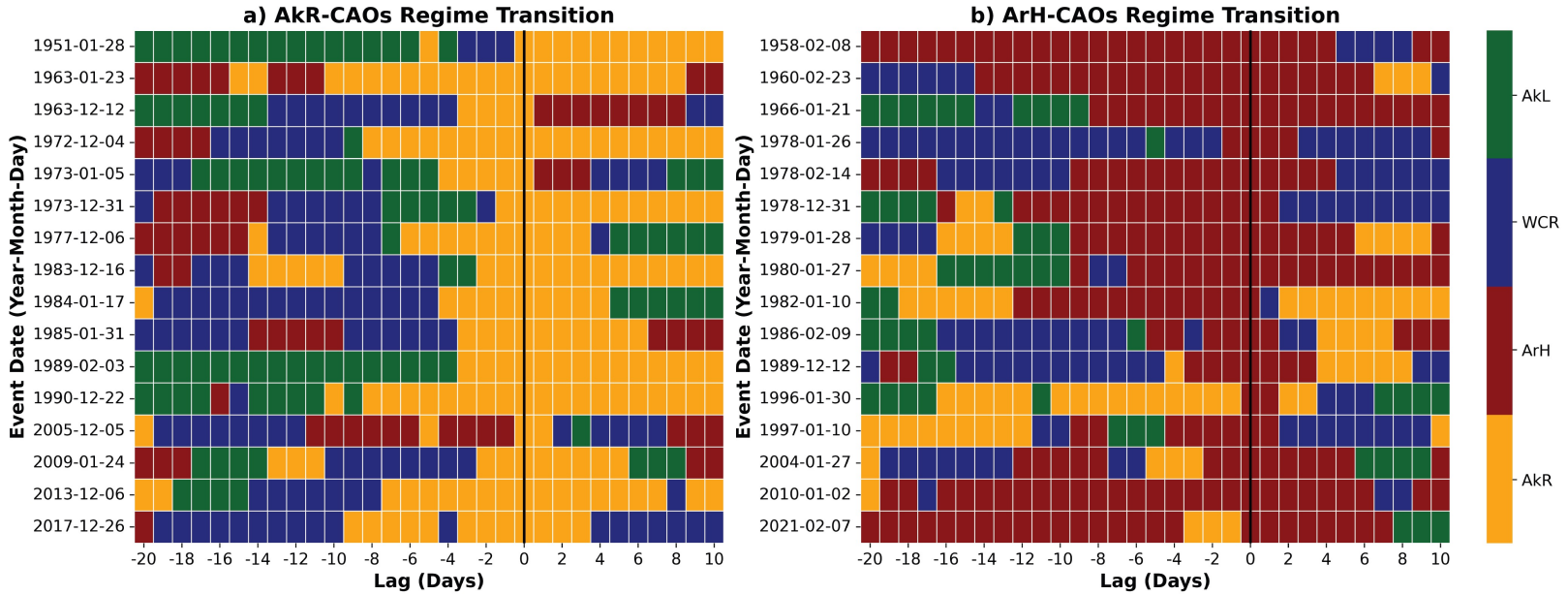
Extra Slide: Weather Regime Transitions

- AkR-CAOs are often preceded by weather regime associated with stronger SPV conditions.
- ArH-CAOs are preceded by persistent ArH regimes associated with a weaker SPV.



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