A Diagnosis of the Role of Anticyclonic Rossby Wave Breaking in Increasing Zonal Available Potential Energy

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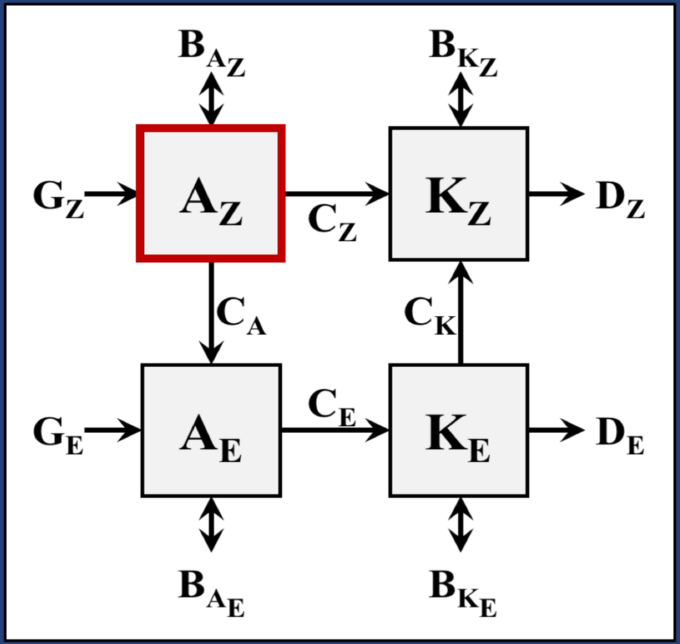
OBJECTIVES

1. Diagnose changes to Rossby wave break frequency in response to zonal available potential energy (A_Z) buildup periods

2. Examine the role of Anticyclonic Rossby wave breaking in modifying winter air mass properties for A_Z buildups to anomalously high A_Z

Introduction

- **Zonal available potential energy (A_Z)** is the largest energy storage term of the Lorenz energy cycle
  - **Metric to measure the relative strength of the hemispheric baroclinicity**, which in turn acts as an **approximation of the strength of the general circulation** in the atmosphere



$$\boldsymbol{A_Z = \frac{c_p}{2} \iiint \gamma [T]''^2 dm}$$

Static stability:

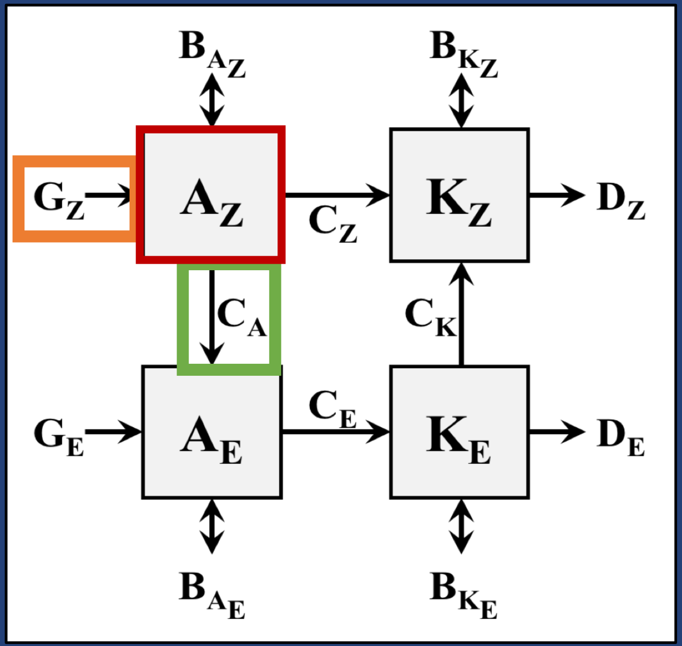
$$\gamma \propto \frac{1}{static\ stability}$$

Pole-to-equator (meridional) temperature gradient:

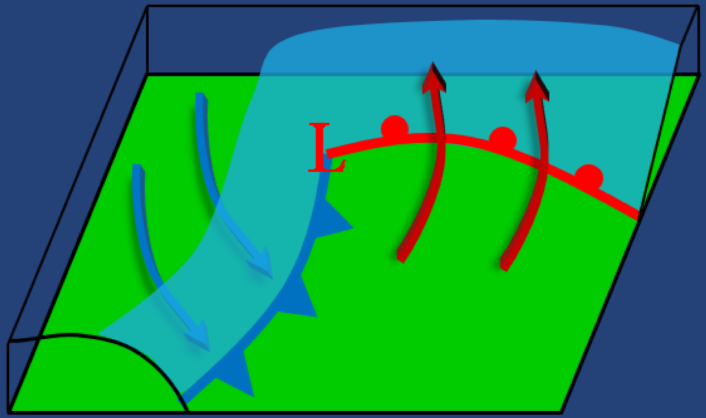
$$[T]'' = [T] - \left[\tilde{T}\right]$$

INTRODUCTION

- A_Z is predominantly modulated by changes in A_Z **generation** and **baroclinic conversion of A_Z to eddy kinetic energy (A_E)**.



A_Z generation is achieved by **diabatic processes** (e.g. Winston and Krueger 1961, Romanski and Rossow, 2013)



A_Z conversion (depletion) to K_E is achieved though **thermally-direct circulations** (e.g. Lorenz 1955, Winston and Krueger 1961)

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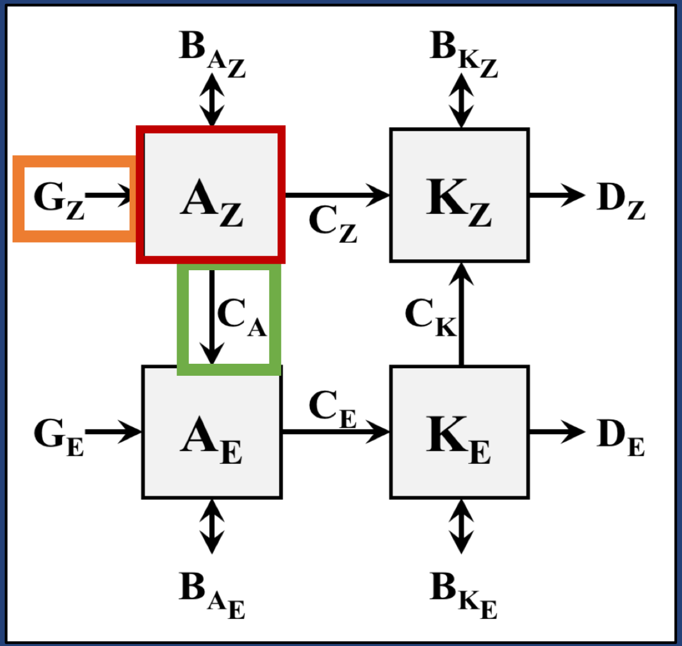
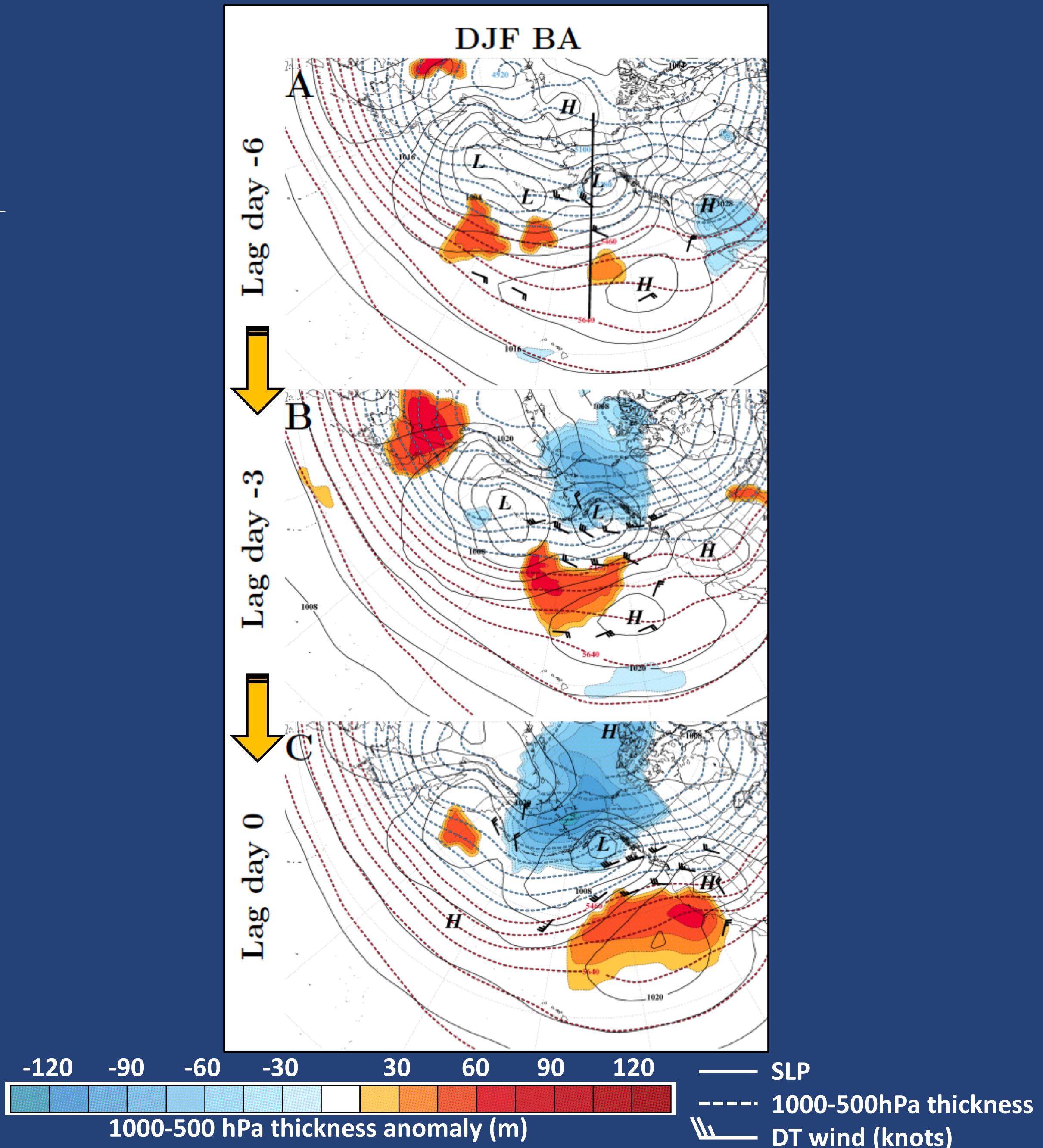


Bowley et al. (in press) found that for most seasons, robust increases in A_z on synoptic time scales were a function of both **anomalously high G_Z** and **anomalously low C_A**

Introduction

- Bowley et al. (in press) identified robust buildups in the standardized anomaly of Northern Hemisphere (20°-85° N) A_Z for all meteorological seasons
  - Found **winter periods that underwent *significant and sustained increases to anomalously high A_Z*** were subject to robust changes to eastern North Pacific basin air mass properties.



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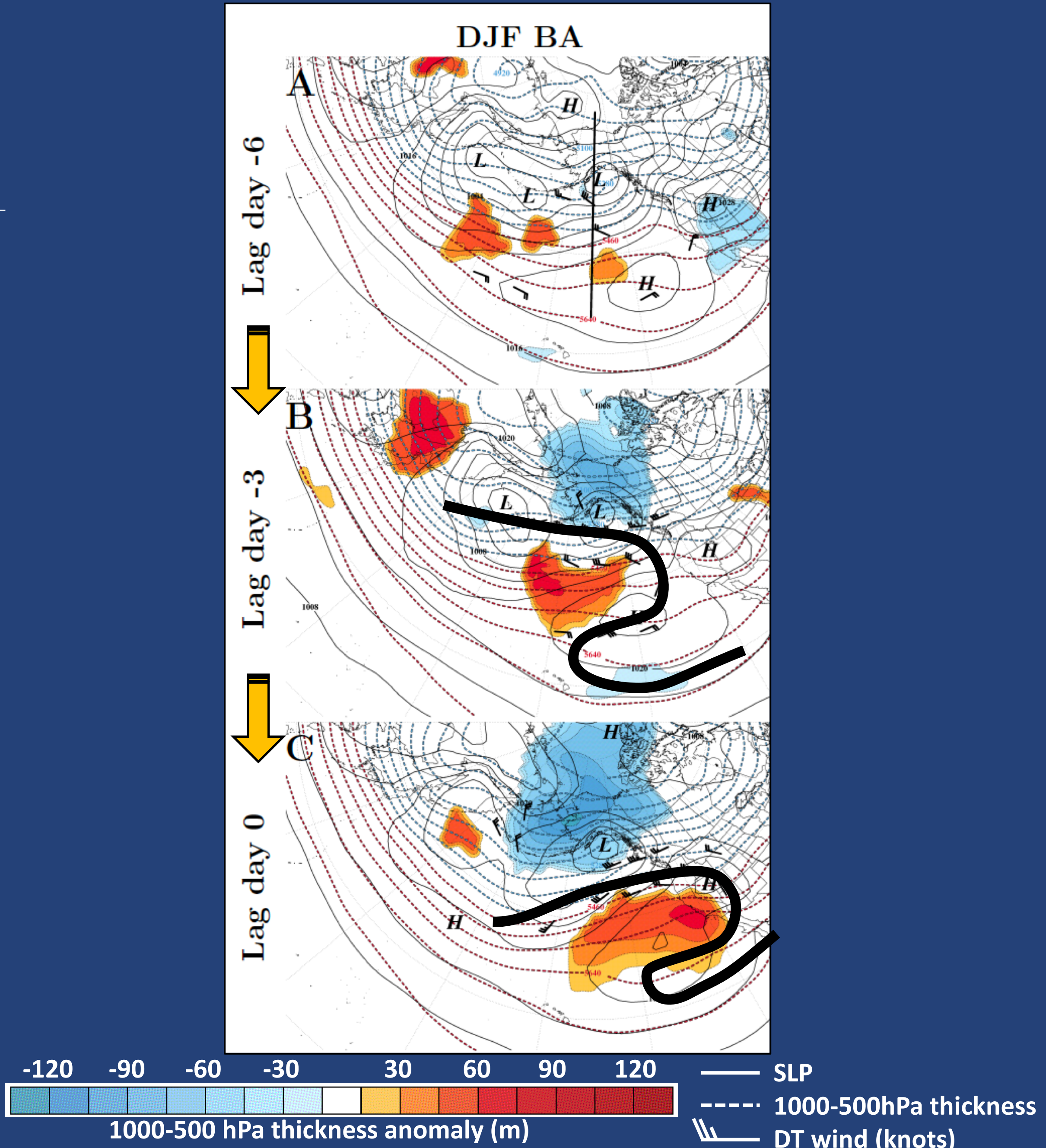
  - **Dynamic tropopause anticyclonic Rossby wave breaks** were subjectively identified in the eastern North Pacific basin for a majority (17 of 18) of these A_Z buildup periods.



INTRODUCTION

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Here, we further examine the role of Rossby wave breaking and their associated dynamical feedbacks for increasing A_Z on synoptic time scales

basin air mass properties.

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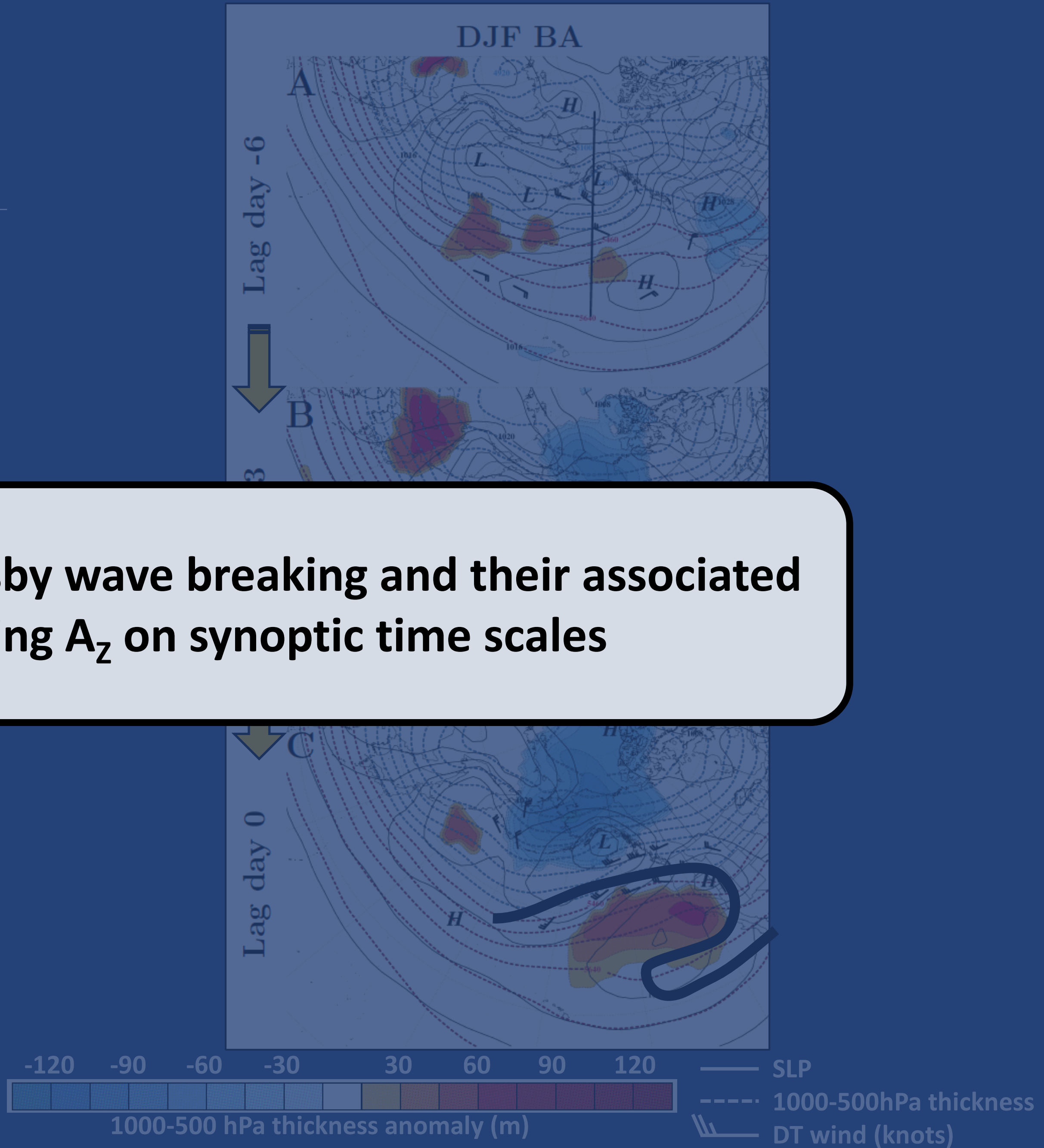
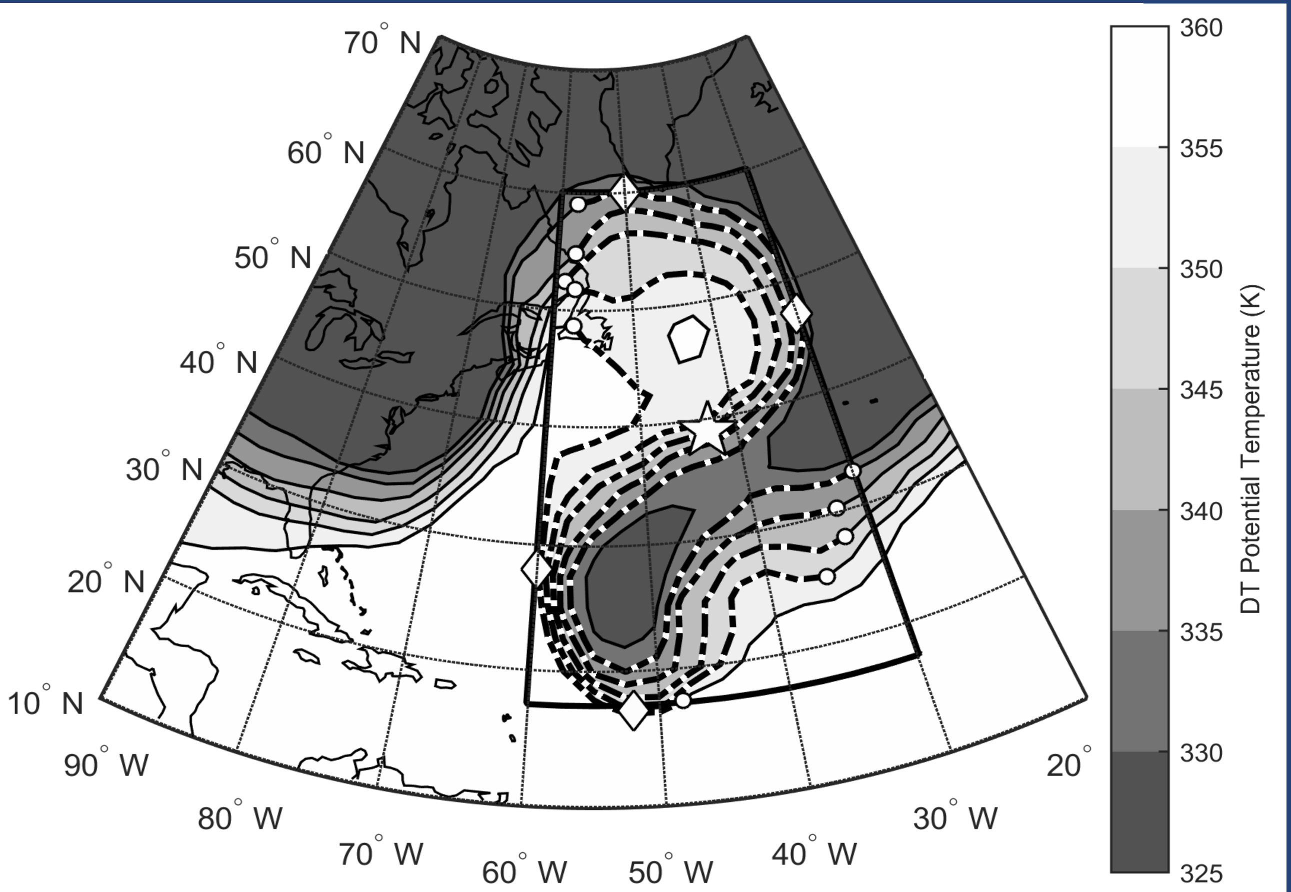


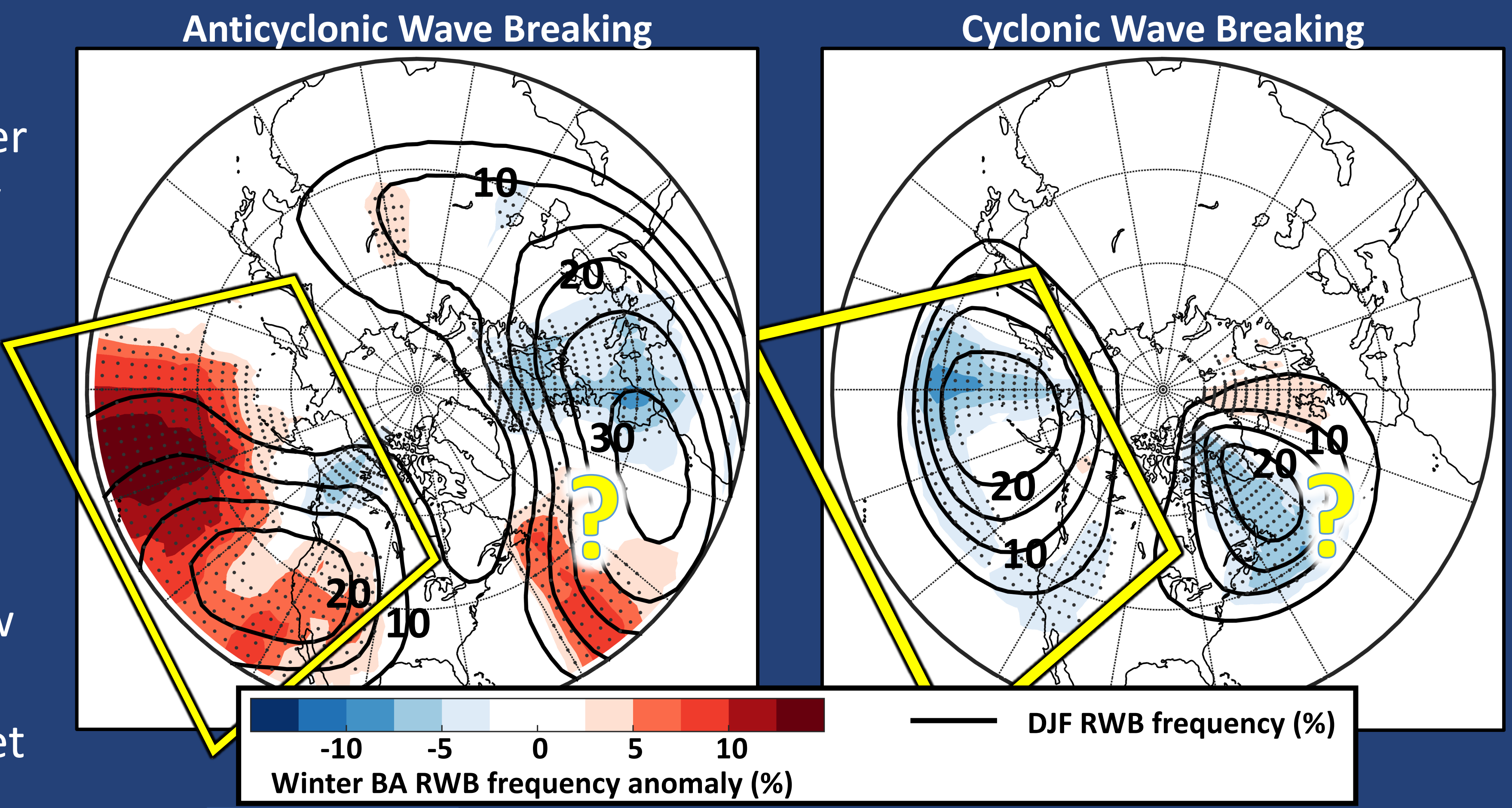
Rossby Wave Break Identification

- Identify instantaneous periods of overturning **isentropes** (Θ, dashed lines) on the **dynamic tropopause** (2.0 PVU)
- Wave breaking region is identified as the **area which fully encompasses the full wave length of overturning isentrope** (black box)
- Catalogues anticyclonic and cyclonic wave break events (black box)



WINTER A_Z BUILDUP ANOMALOUS (BA) EVENTS

- AWB frequencies in the eastern North Pacific basin for winter BA periods are nearly double the climatological mean
- Anomalously high AWB in the eastern North Pacific coupled with anomalously-low CWB suggests a poleward displaced jet



Winter A_Z BA events & anticyclonic wave breaking

- To examine the contributions associated specifically to anticyclonic wave breaking, we track and composite **35 long duration AWB events (>24 hour) found in the eastern North Pacific basin** (180°-100°W, 30°-50°N) for A_Z buildups to anomalously high A_Z

- Events are composited based upon the AWB life cycle to ascertain:
    - Sources of A_Z generation
    - Mechanisms for ascent

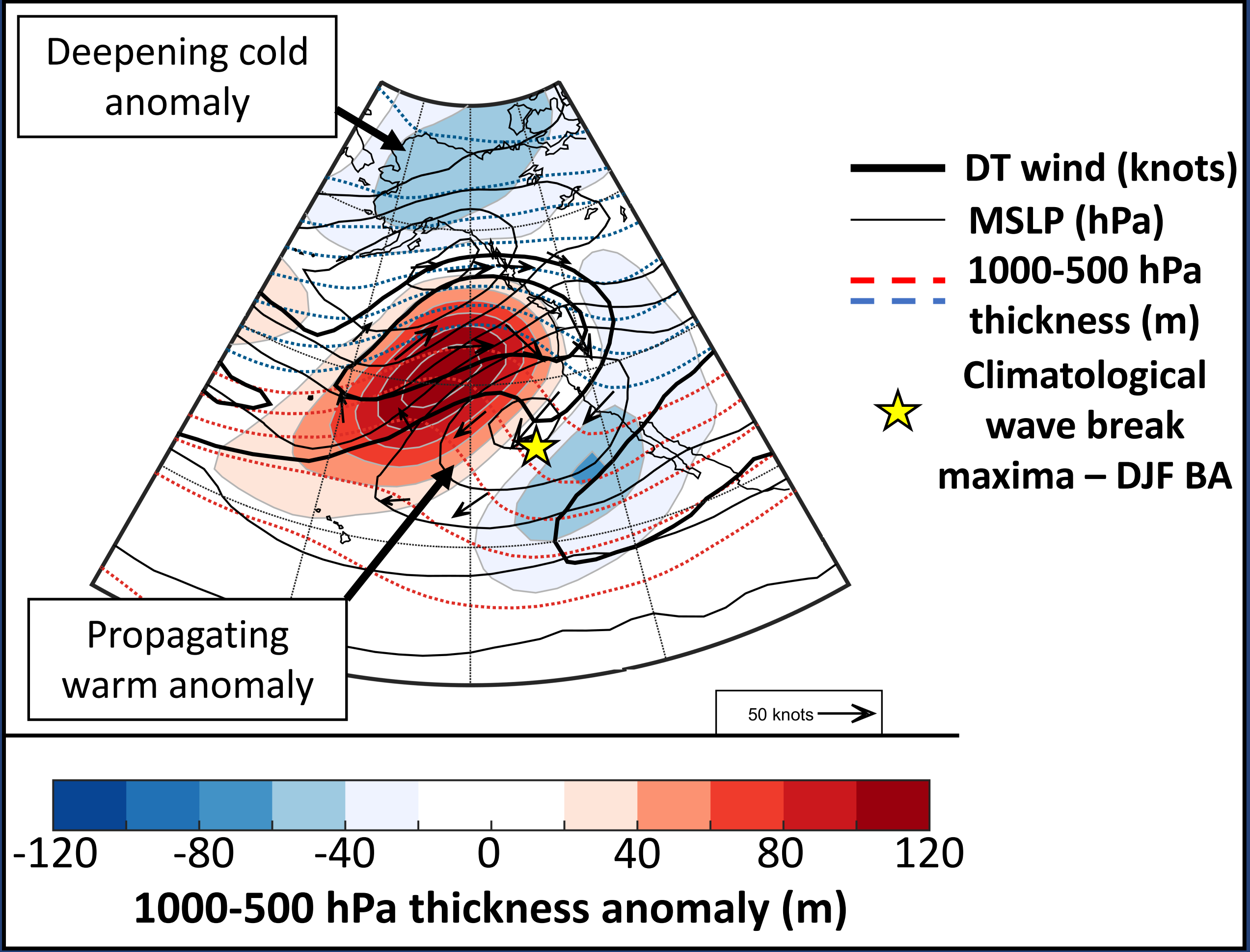
$$\left(\nabla_P{}^2 + \frac{f_o{}^2}{\sigma}\frac{\partial^2}{\partial P^2}\right)\omega = -\frac{f_o}{\sigma}\frac{\partial}{\partial P}\left(-\vec{v_g}\cdot\nabla_P(\zeta_g + f)\right) - \frac{1}{\sigma}\nabla_P{}^2\left(-\vec{v_g}\cdot\nabla_P\left(\frac{-\partial\Phi}{\partial P}\right)\right) - \frac{1}{\sigma}\nabla_P{}^2 Q - \cancelto{\sim 0}{\frac{f_o}{\sigma}\frac{\partial}{\partial P}\left(\hat{k}\cdot\nabla\times\vec{F}\right)}$$

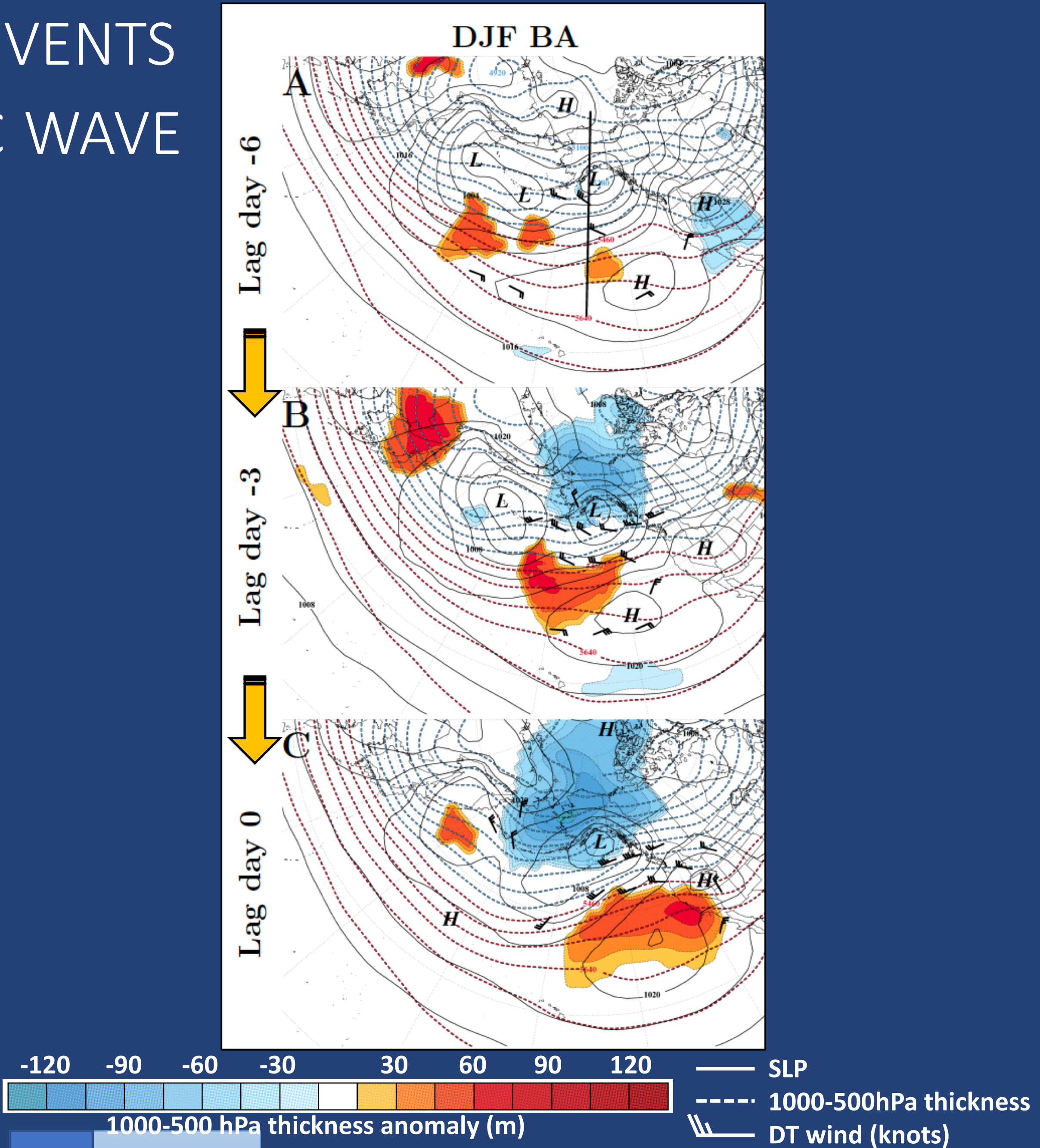
Rising Motion	~	**Differential CVA w/height**	+	**Warm Air Advection**	+	**Diabatic heating**
Sinking Motion		**Differential AVA w/height**		**Cold Air Advection**		**Diabatic cooling**

Mass field evolution

ONSET

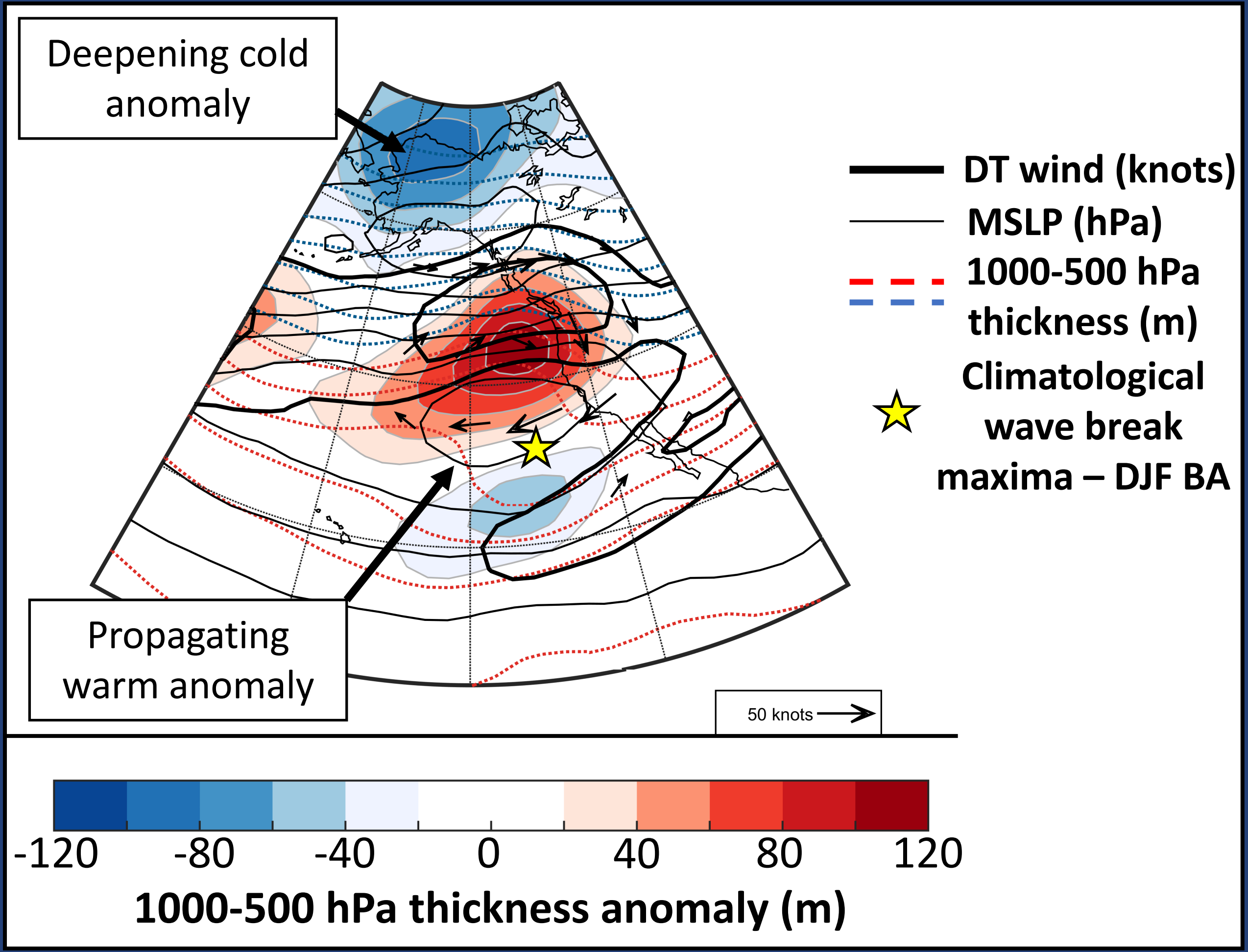
Winter A_Z BA events & anticyclonic wave breaking

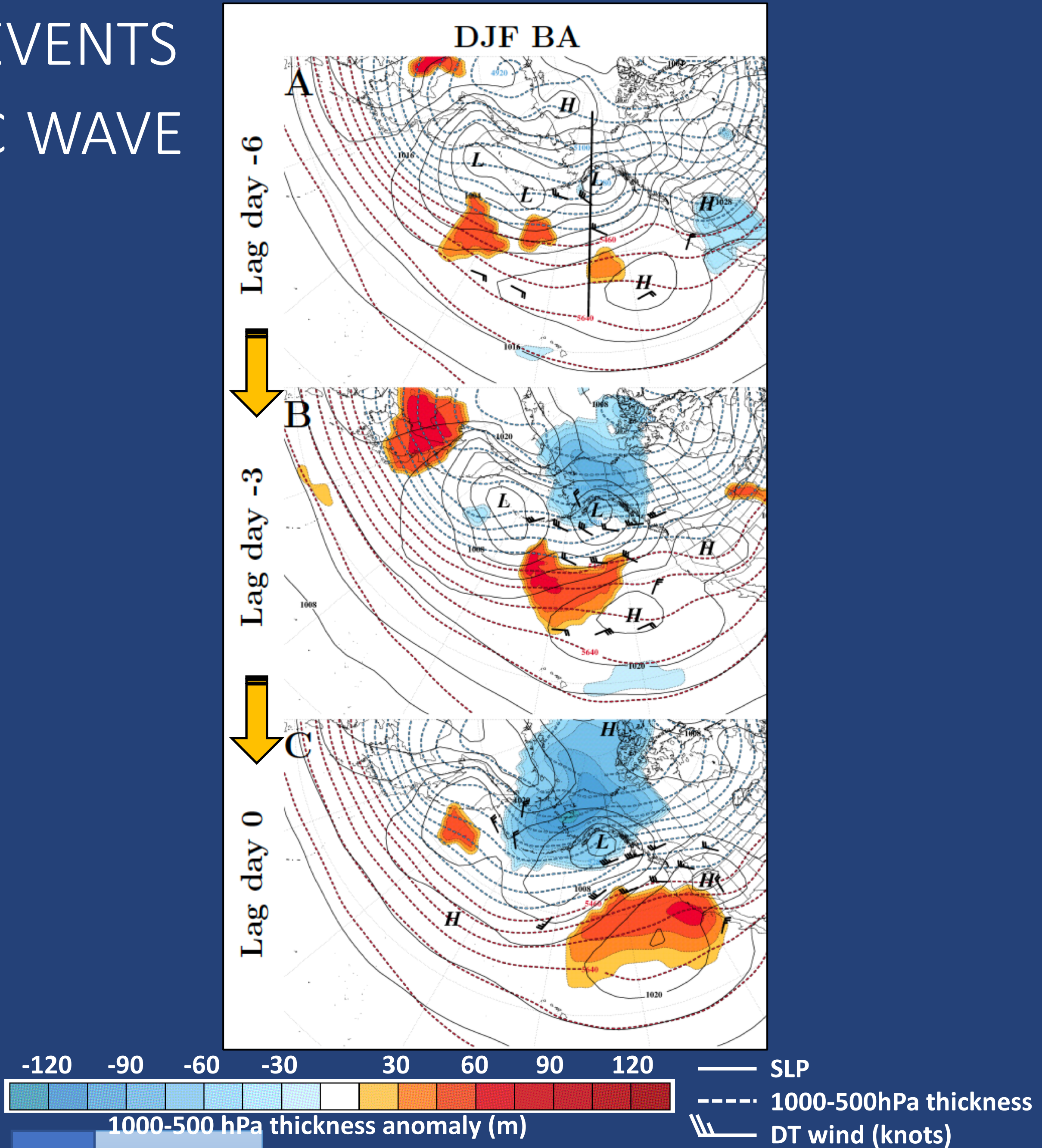




Mass field evolution **COMPLETION**

Winter A_Z BA events & anticyclonic wave breaking

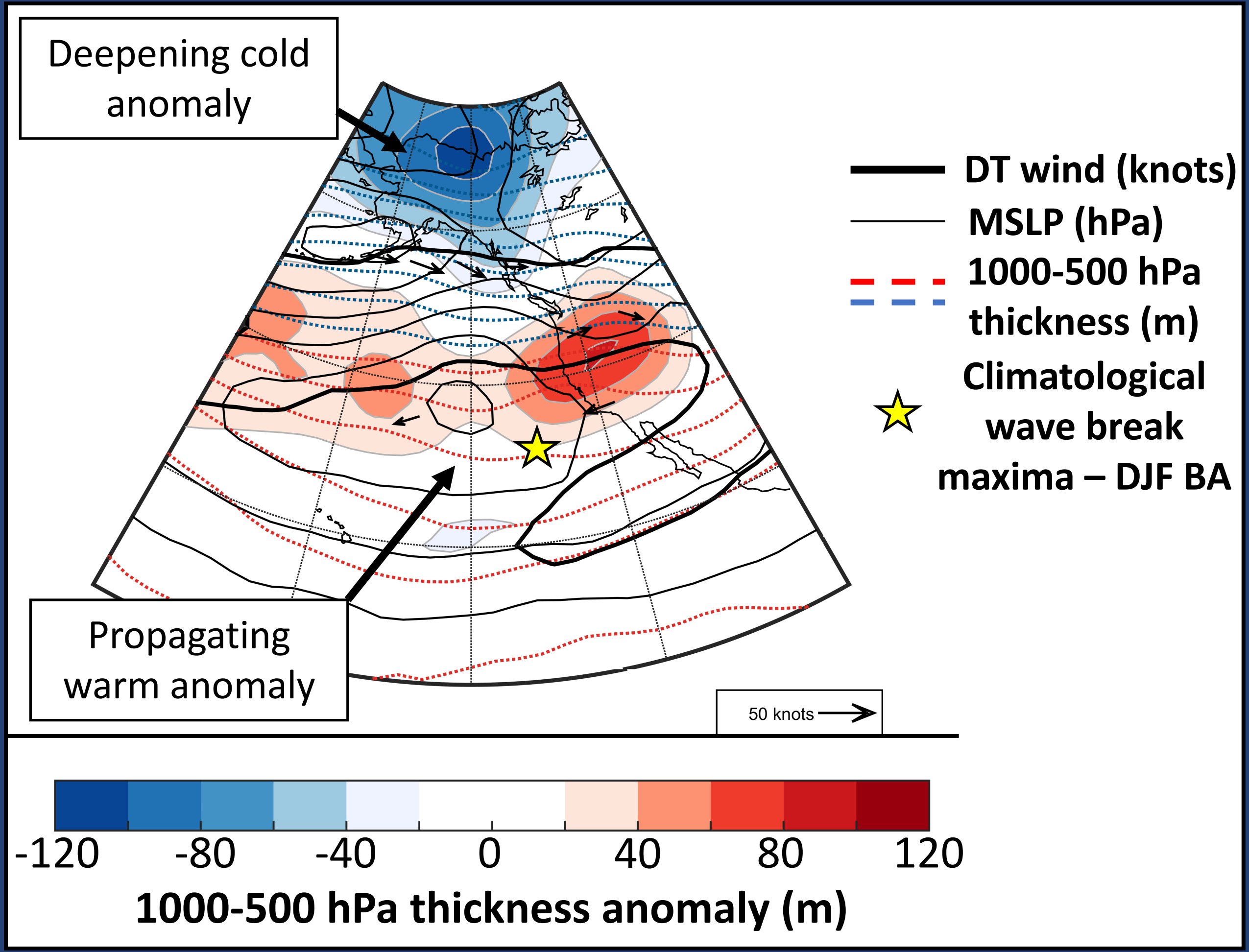


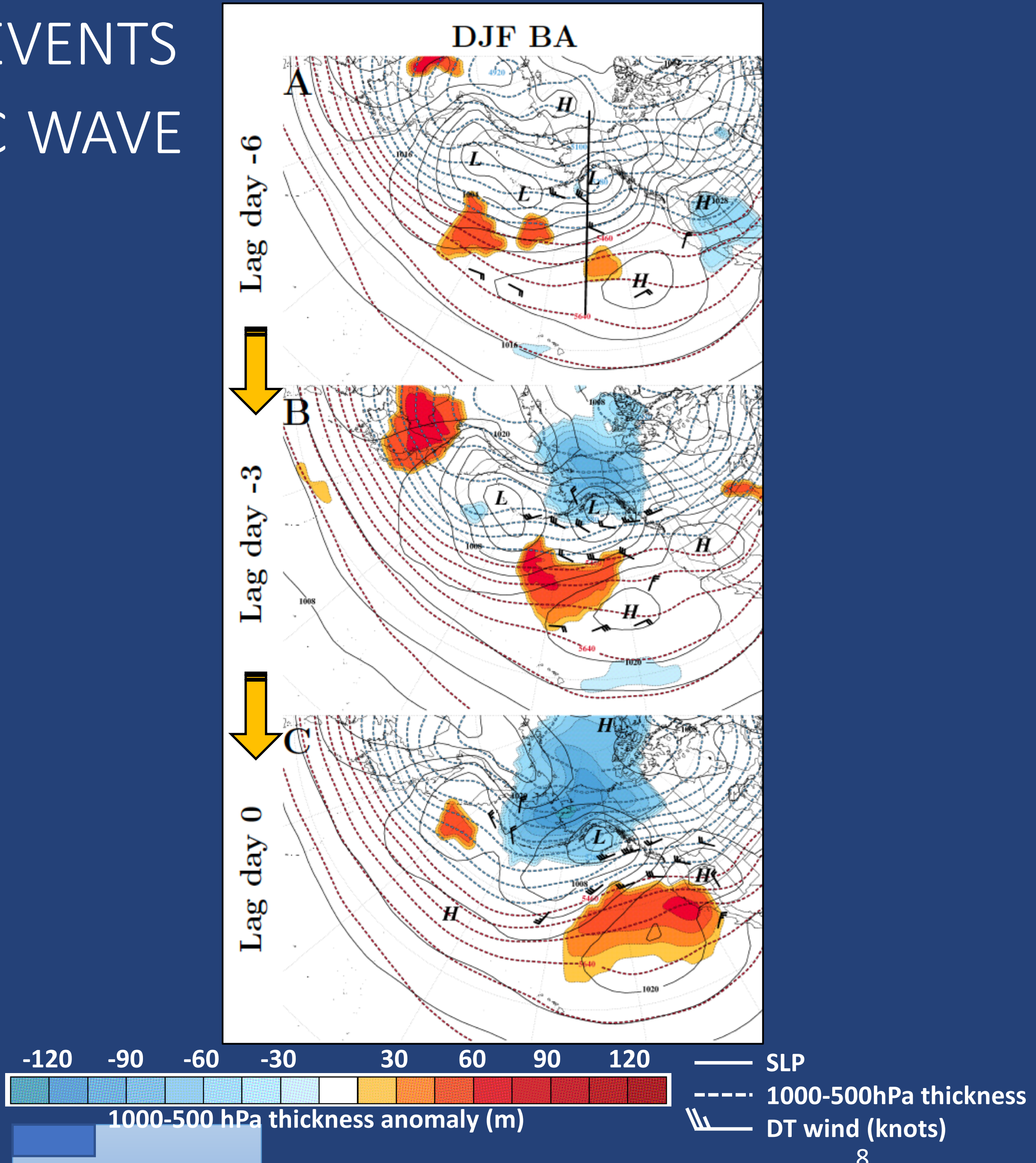


Mass field evolution

+24 hours

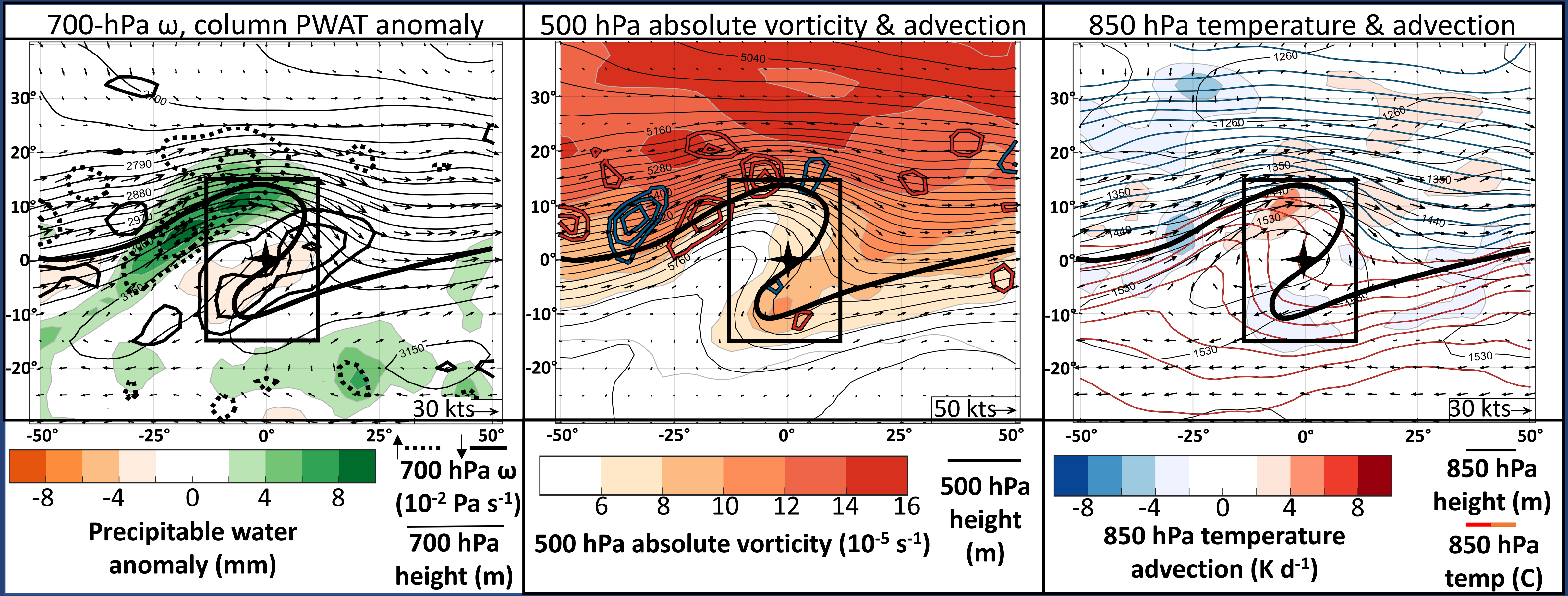
Winter A_Z BA events & anticyclonic wave breaking



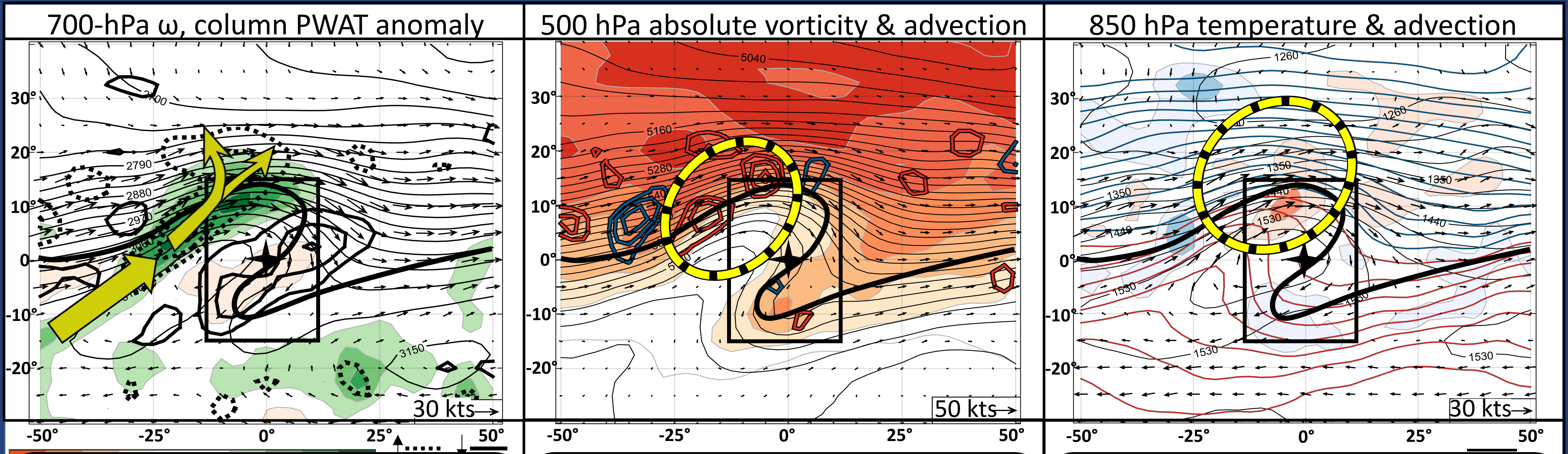


Air mass modification

Winter A_Z BA events & anticyclonic wave breaking



Winter A_Z BA events & anticyclonic wave breaking



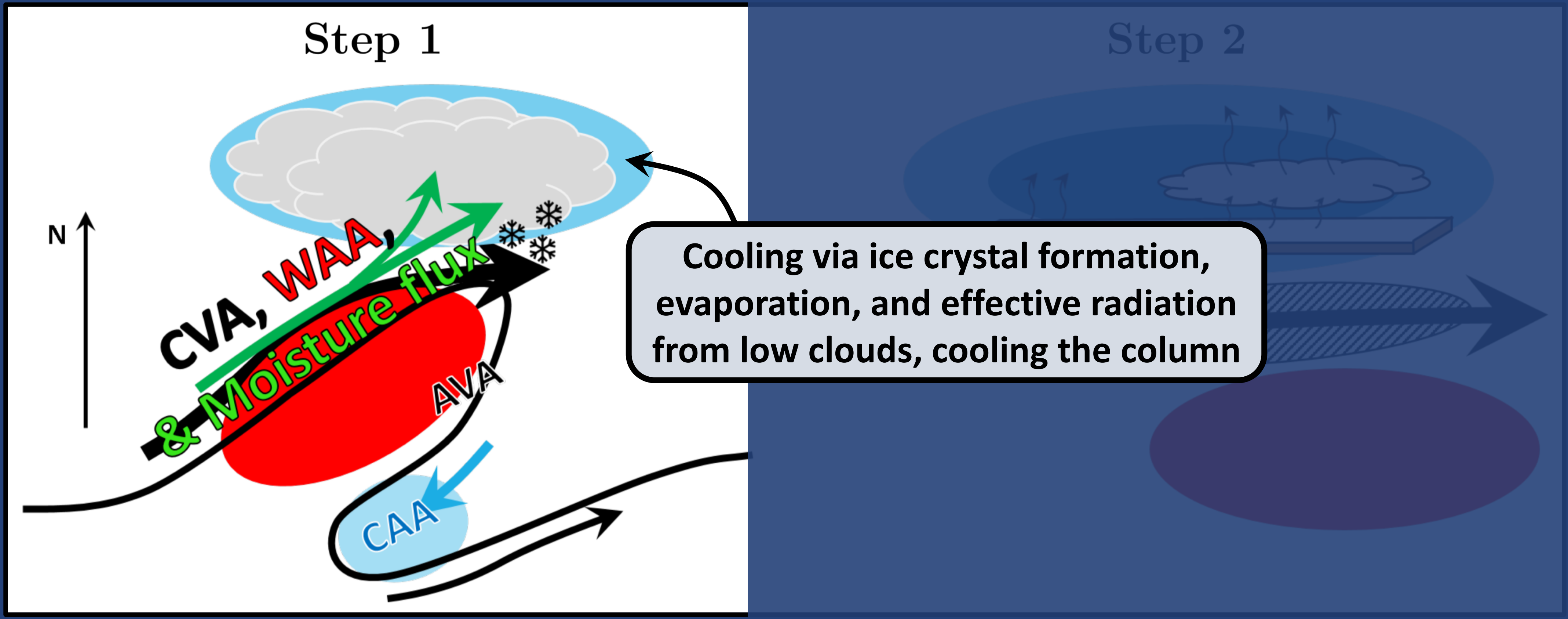
Ascent along NW/N'erly flank of AWB – collocated with poleward plume of high precipitable water air

Most robust regions of CVA and AVA are associated with the trough along northwest flank of the wave break

Couplet of WAA & CAA along Northwestern and Northern flank of AWB; CAA into low θ streamer

Step 1

Winter A_Z BA events & anticyclonic wave breaking

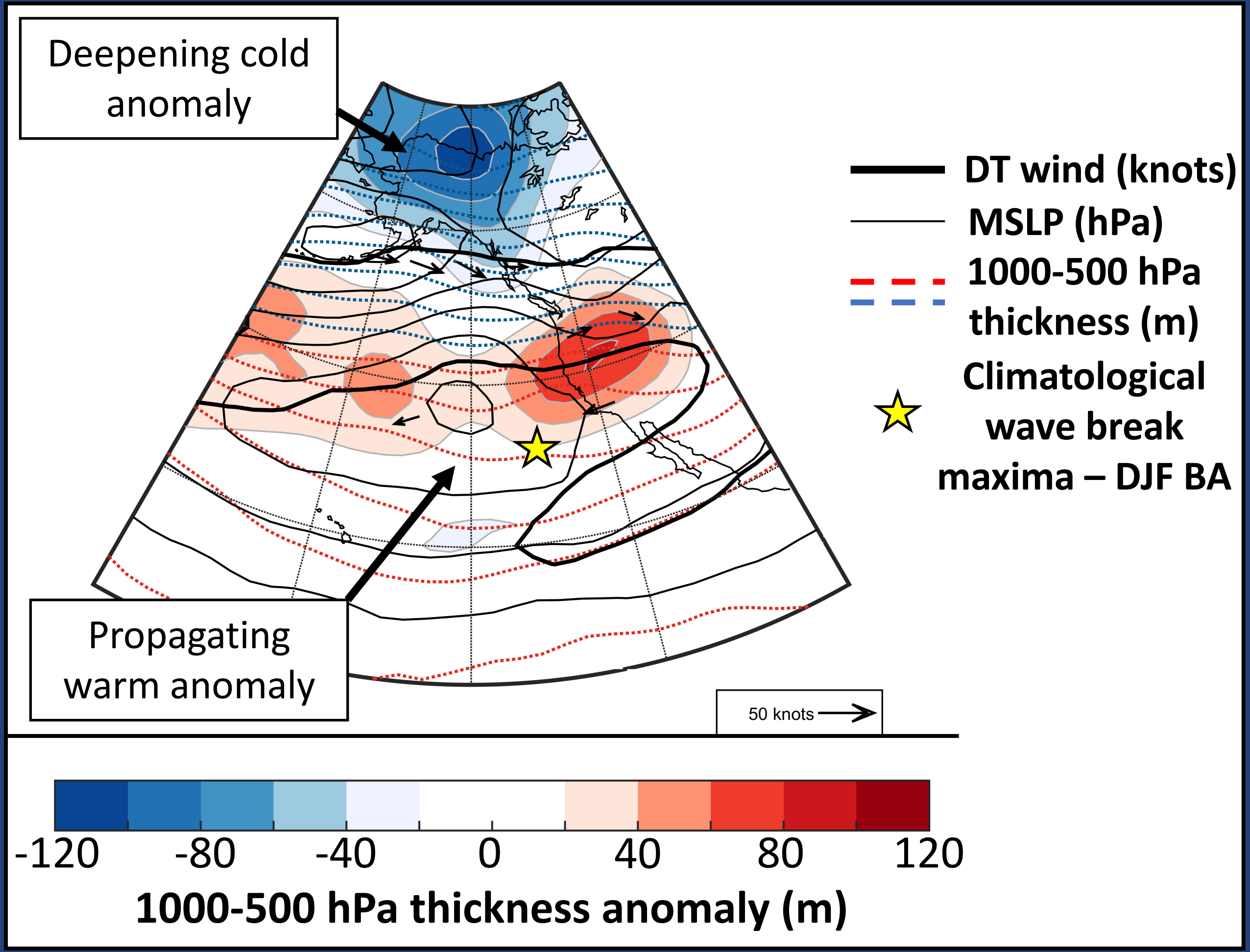


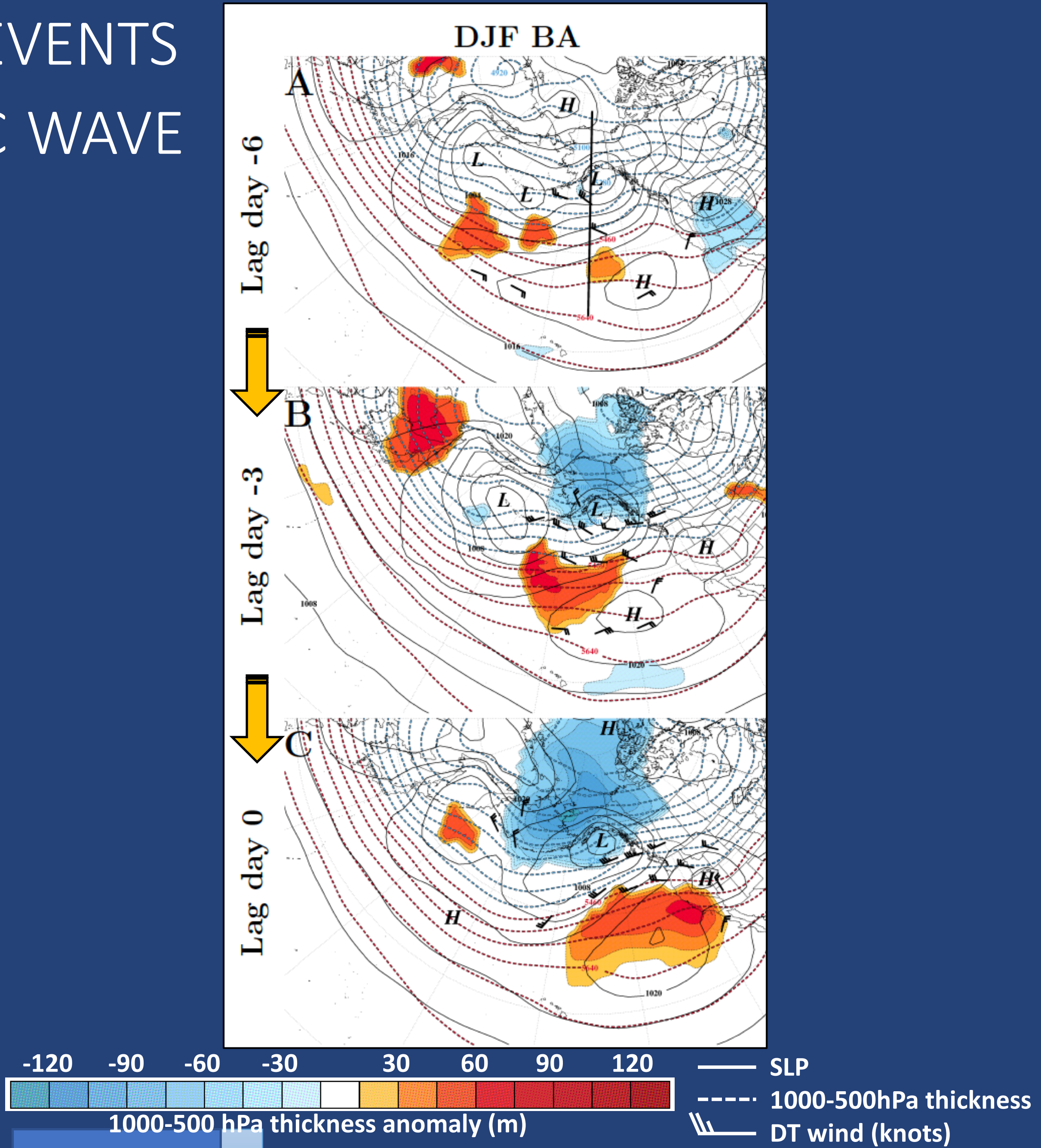
Cooling via ice crystal formation, evaporation, and effective radiation from low clouds, cooling the column

Mass field evolution

+24 hours

Winter A_Z BA events & anticyclonic wave breaking





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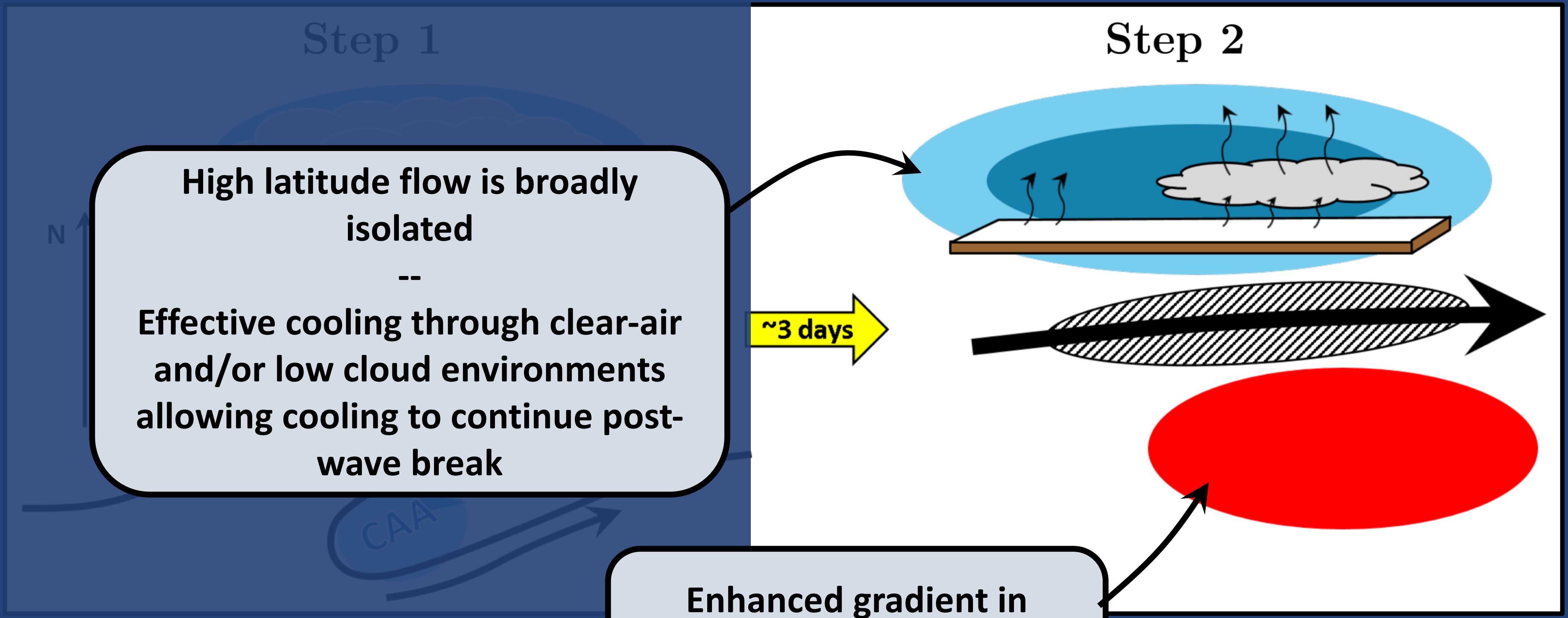

High latitude flow is broadly isolated

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Effective cooling through clear-air and/or low cloud environments allowing cooling to continue post-wave break

Enhanced gradient in isentropes results in eastward elongation of NPJ

Conclusions

1. Diagnose changes to Rossby wave break frequency in response to A_Z buildup periods

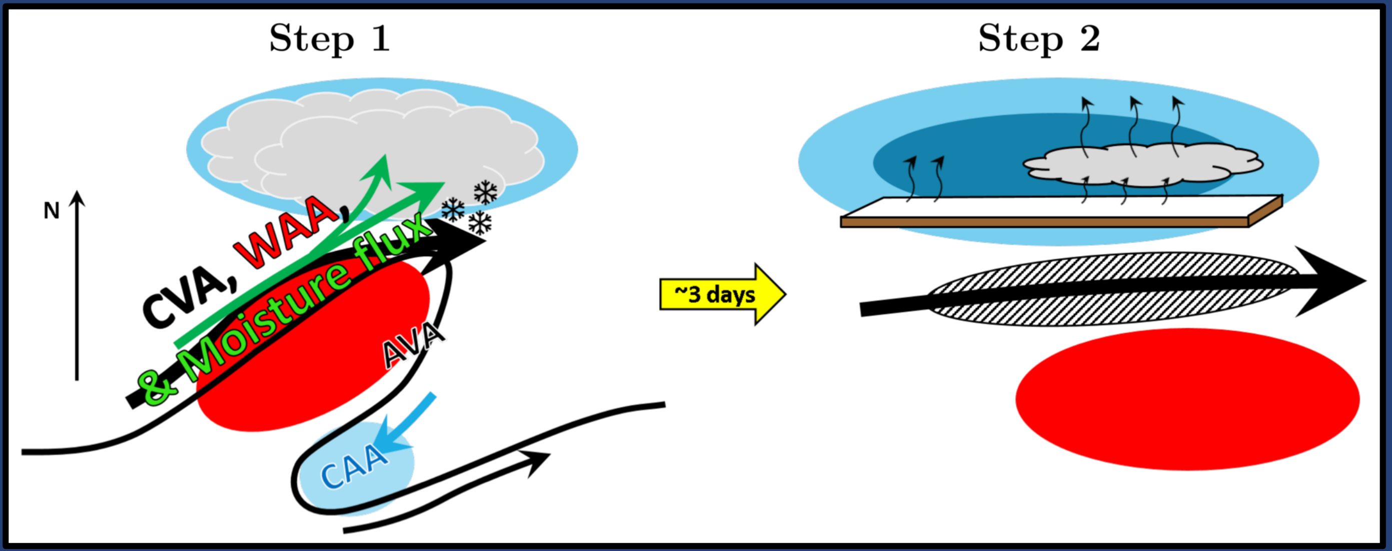
   - Changes to the structure of the Northern Hemisphere circulation can be ascertained from anomalies in Rossby wave break frequencies during A_Z buildup periods

   - North Pacific basin above average AWB and below average CWB for winter buildup anomalous suggest a poleward shifted North Pacific jet

CONCLUSIONS

2. Examine the role of Anticyclonic Rossby wave breaking in modifying winter air mass properties for A_Z buildups to anomalously high A_Z

   - The poleward surging warm air mass associated with the AWB has several key roles:
     1. Enhancing the eastern North Pacific troposphere-deep temperature gradient results in elongation of the North Pacific jet into western North America
     2. Mechanism for QG ascent on the northwestern/northern flank of the AWB
     3. Focuses a poleward surge of subtropical moisture into high latitude regions poleward of the AWB



THANK YOU FOR YOUR TIME!

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Extra Slides

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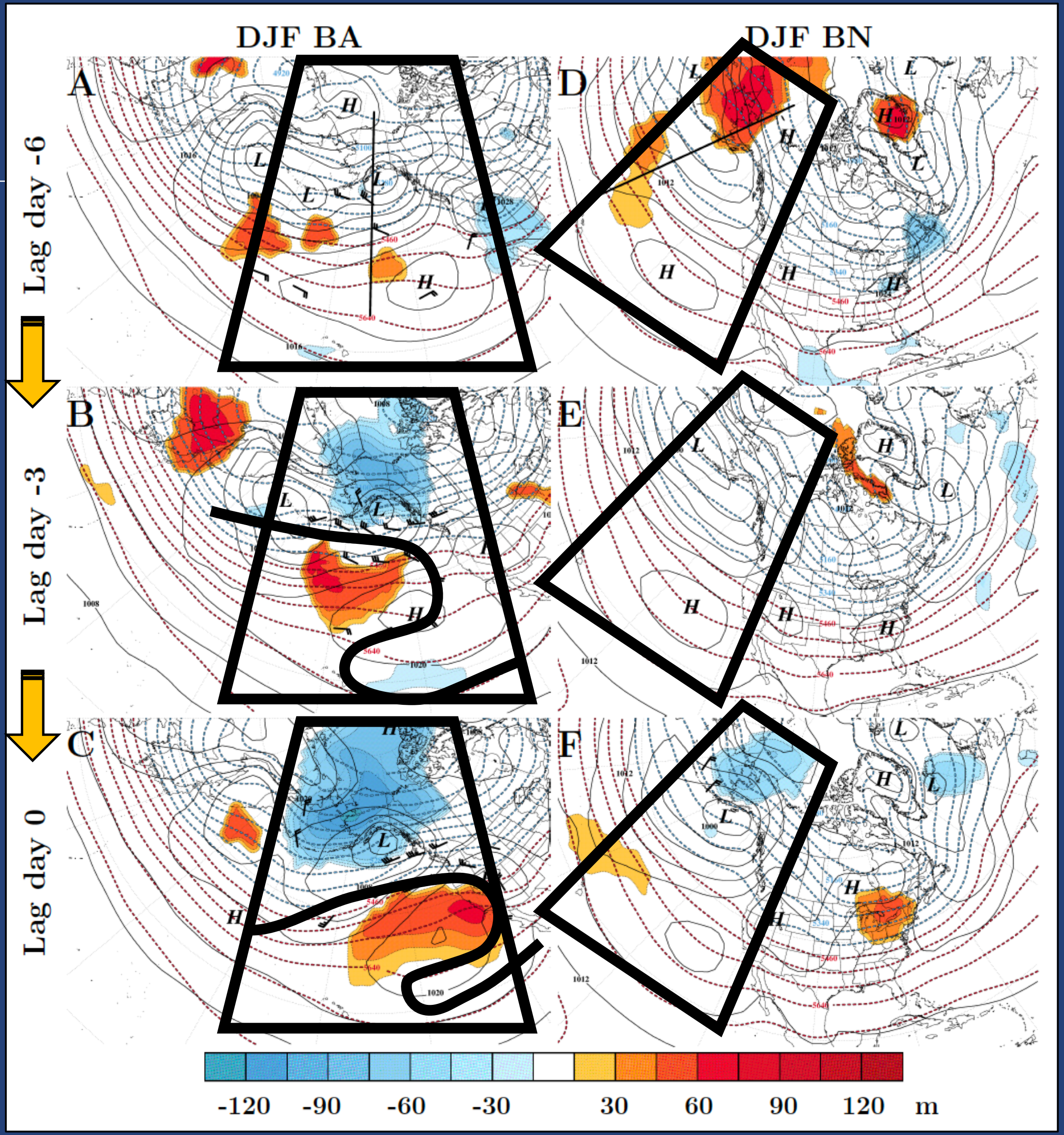
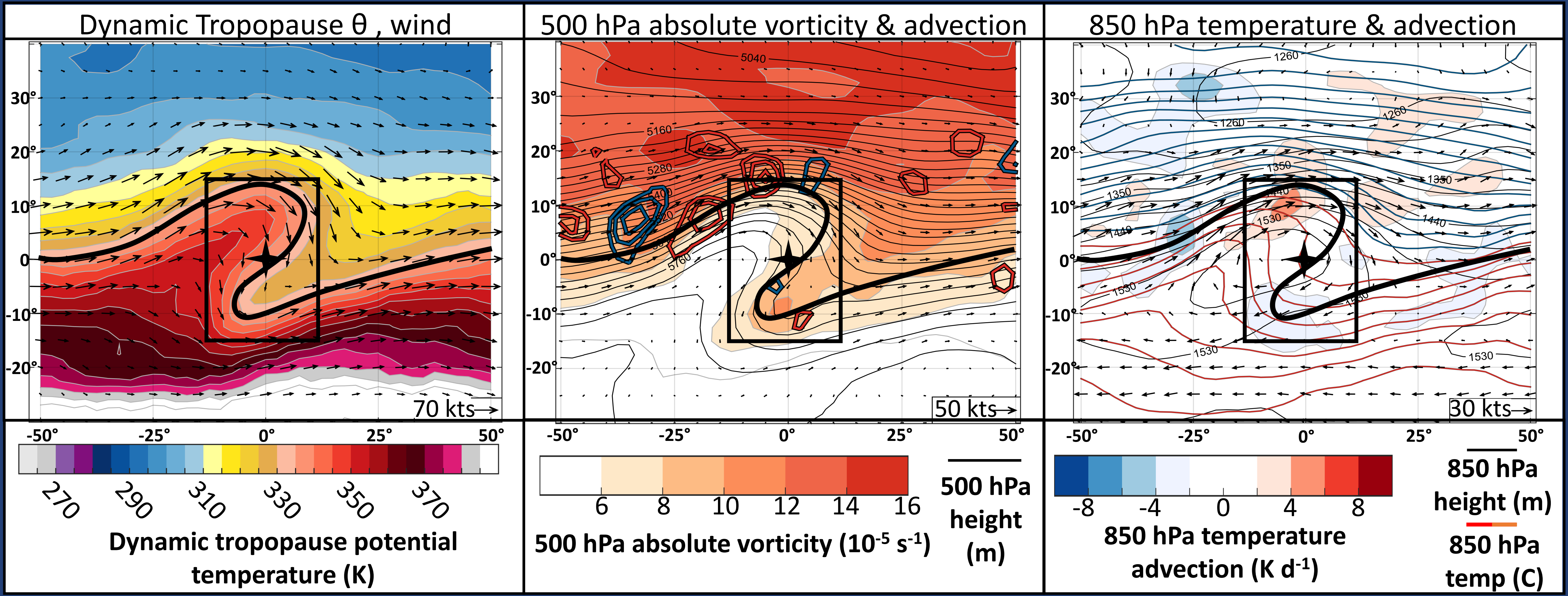


Vort. and temp. advections | Winter A_Z BA events & anticyclonic wave breaking



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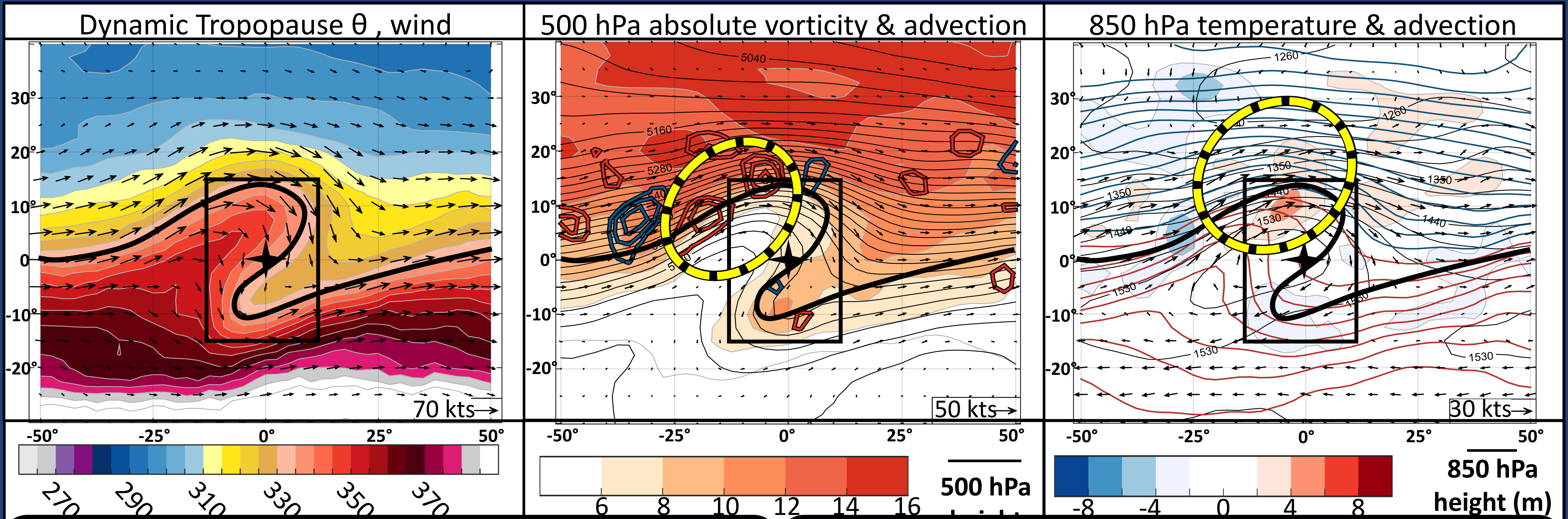
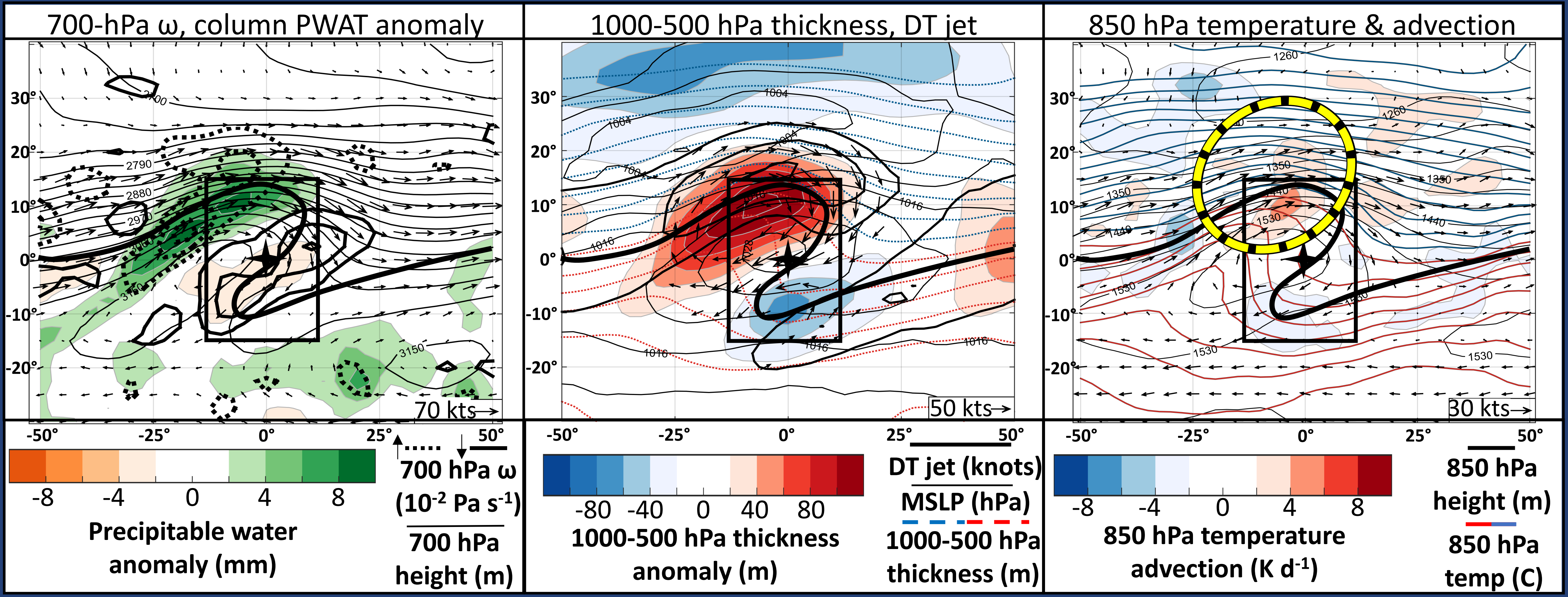


Most robust regions of CVA and AVA are associated with the trough along northwest flank of the wave break

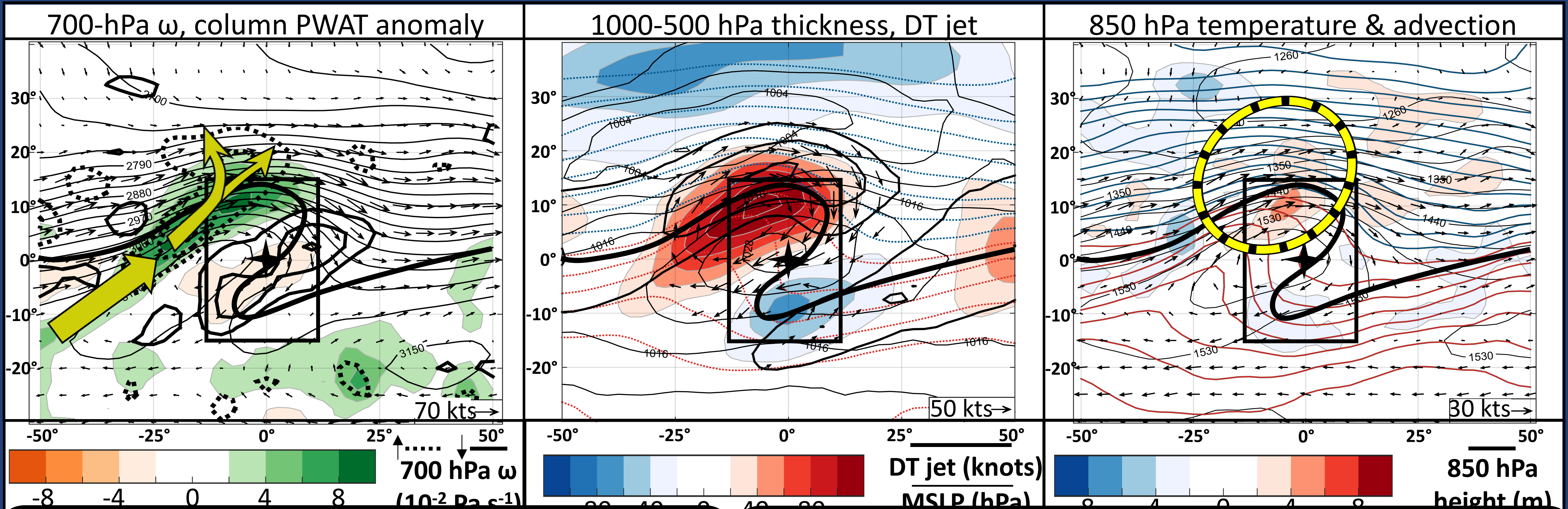
Couplet of WAA & CAA along Northwestern and Northern flank of AWB; CAA into low θ streamer

Precip. water and thickness | Winter A_Z BA events & anticyclonic wave breaking



PRECIP. WATER AND THICKNESS

WINTER A_Z BA EVENTS & ANTICYCLONIC WAVE BREAKING

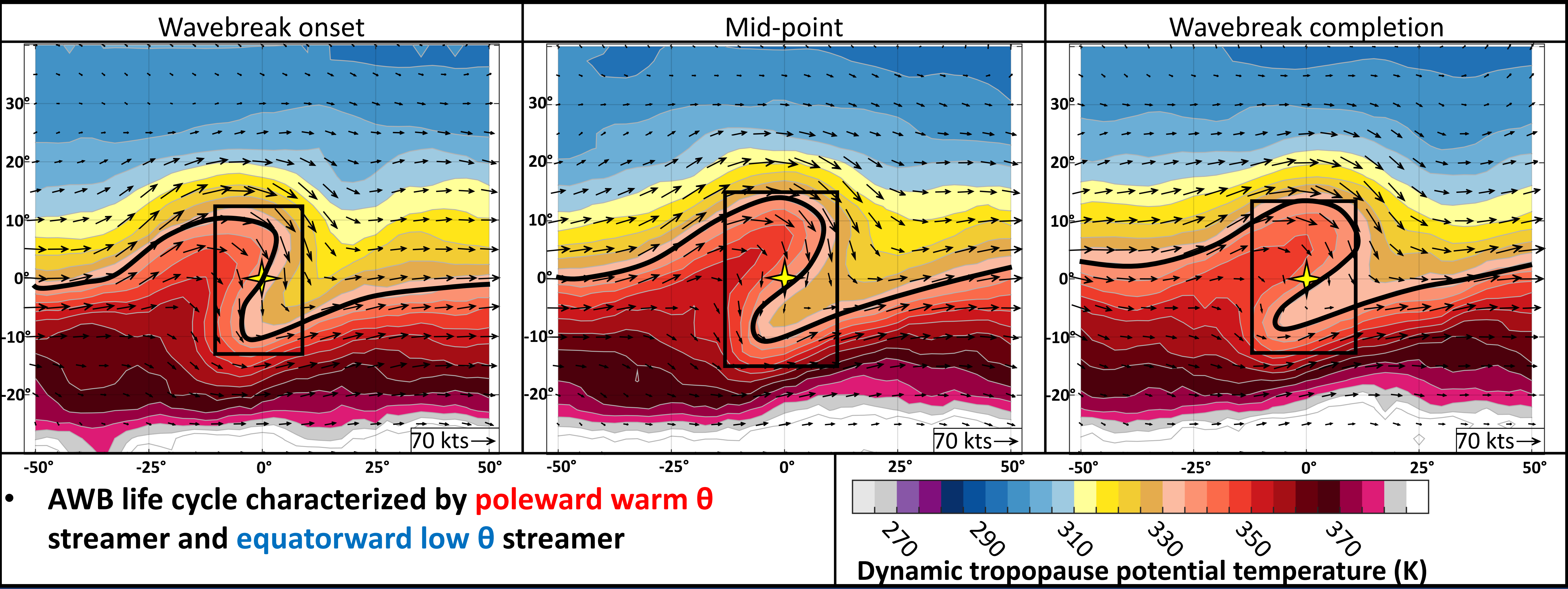


Ascent along NW/N'erly flank of AWB – collocated with poleward plume of high precipitable water air

- **Warm thickness anomaly predominantly confined to equatorward side of jet streak (region of WAA, CVA, diabatic heating)**
- **Cold thickness anomaly offset to north remains stationary and deepens**

Dynamic Tropopause

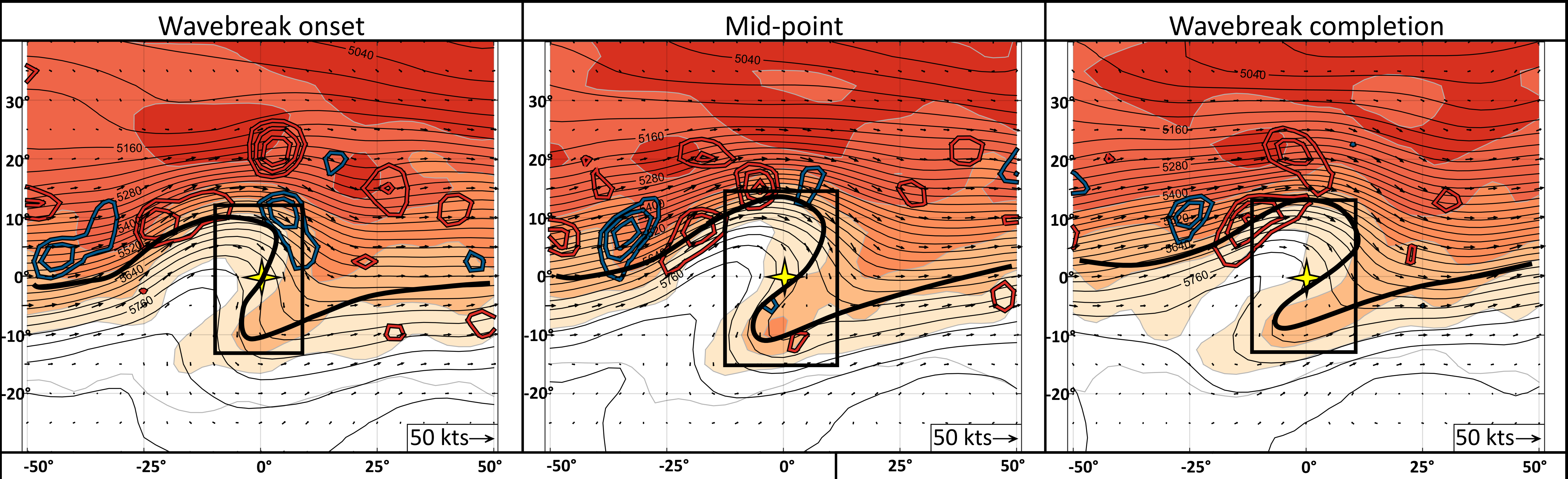
Winter A_Z BA events & anticyclonic wave breaking



- **AWB life cycle characterized by poleward warm θ streamer and equatorward low θ streamer**

Vorticity advection

Winter A_Z BA events & anticyclonic wave breaking



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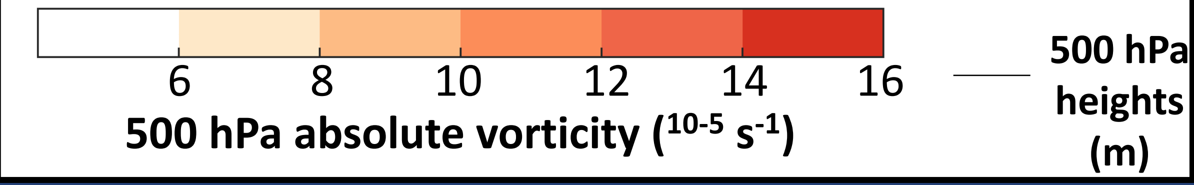

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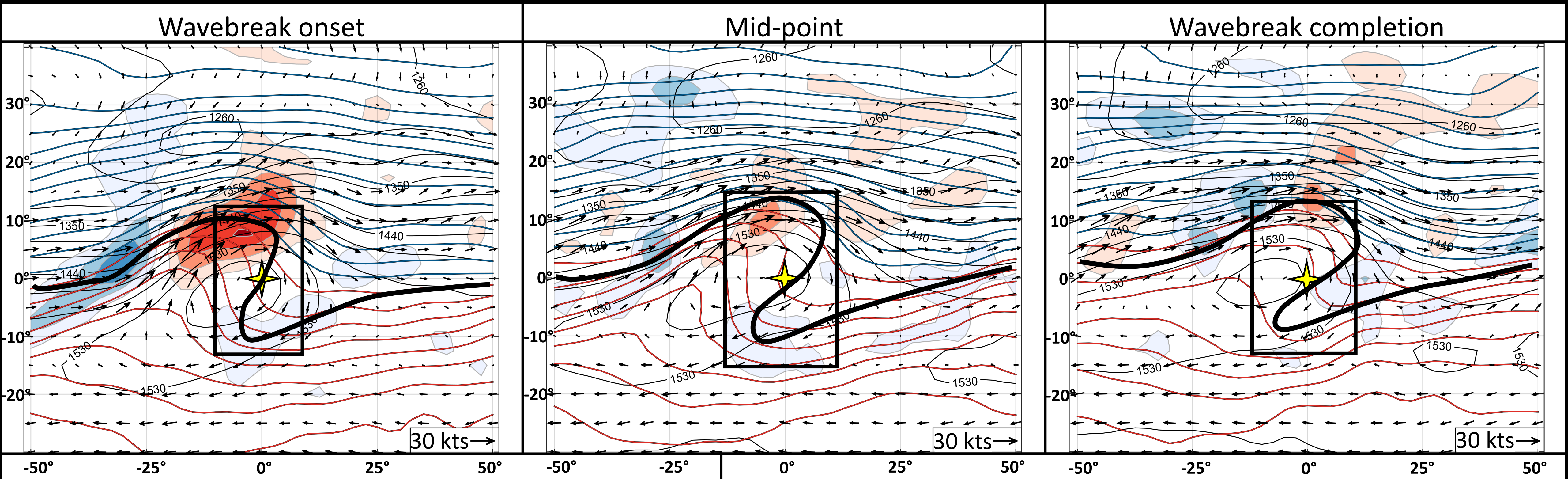

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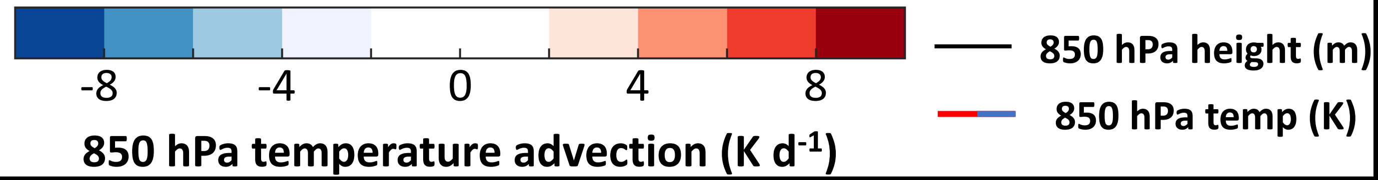
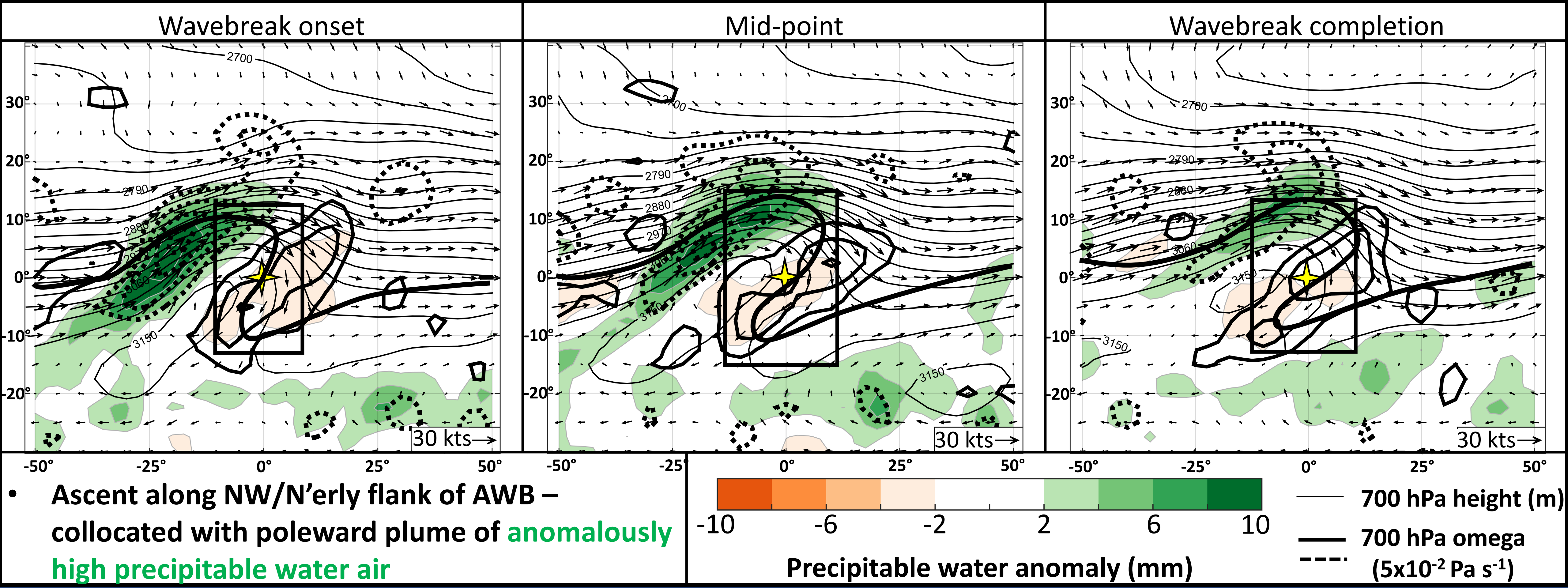


Moisture flux | Winter A_Z BA events & anticyclonic wave breaking



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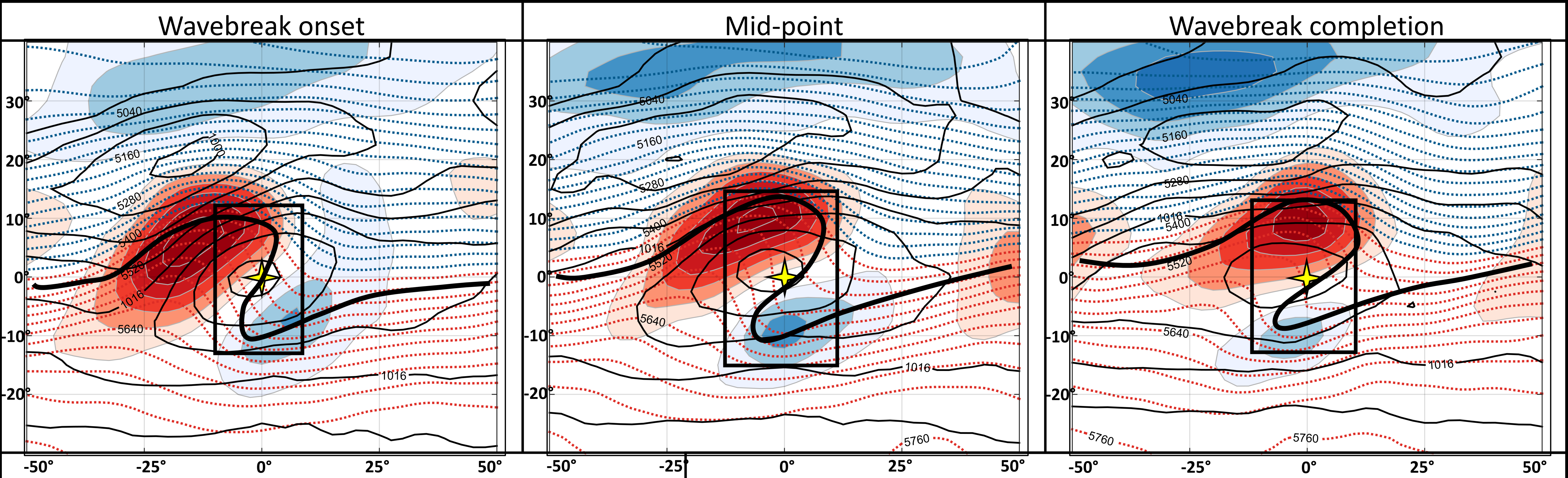
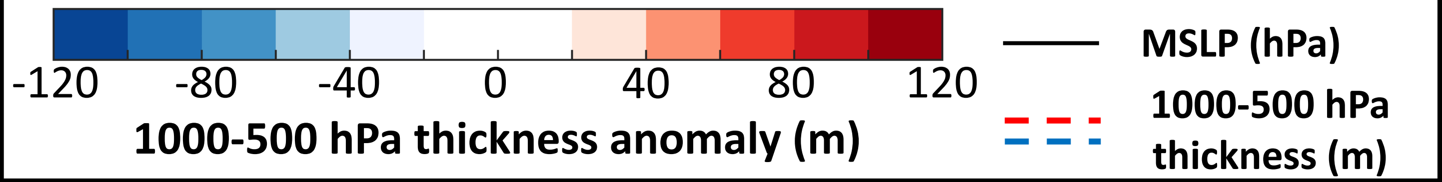
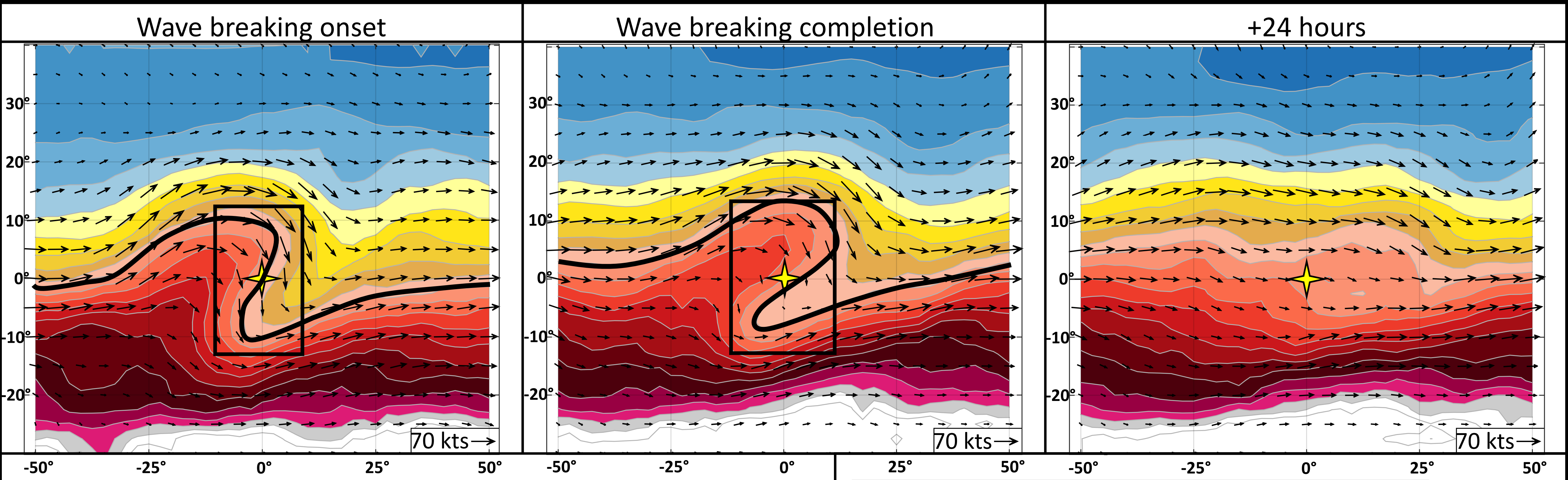
Lower tropo. thickness | Winter A_Z BA events & anticyclonic wave breaking





- **Warm anomaly propagates with along crest of AWB**
- **Poleward cold anomaly is relatively stationary**

Winter A_Z BA events & anticyclonic wave breaking



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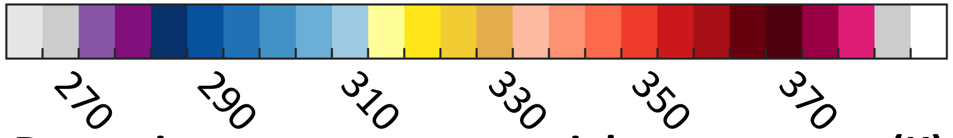
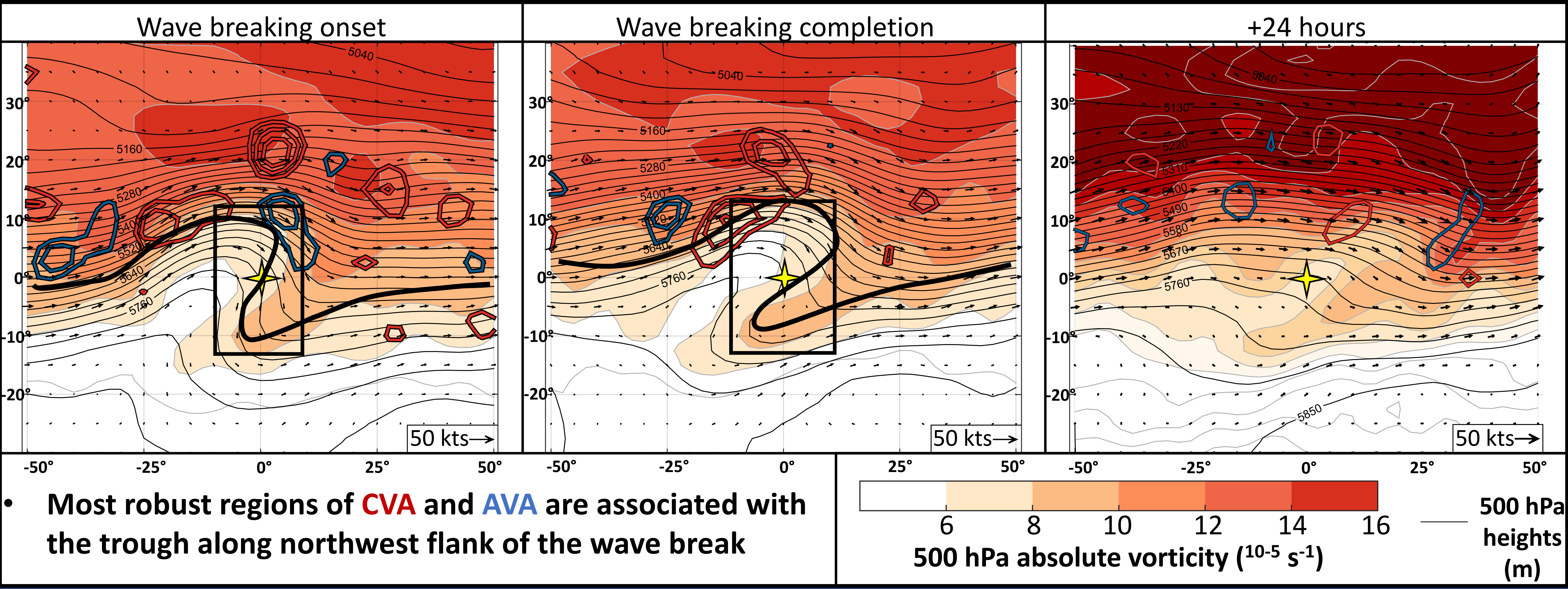


Dynamic tropopause potential temperature (K)

Winter A_Z BA events & anticyclonic wave breaking



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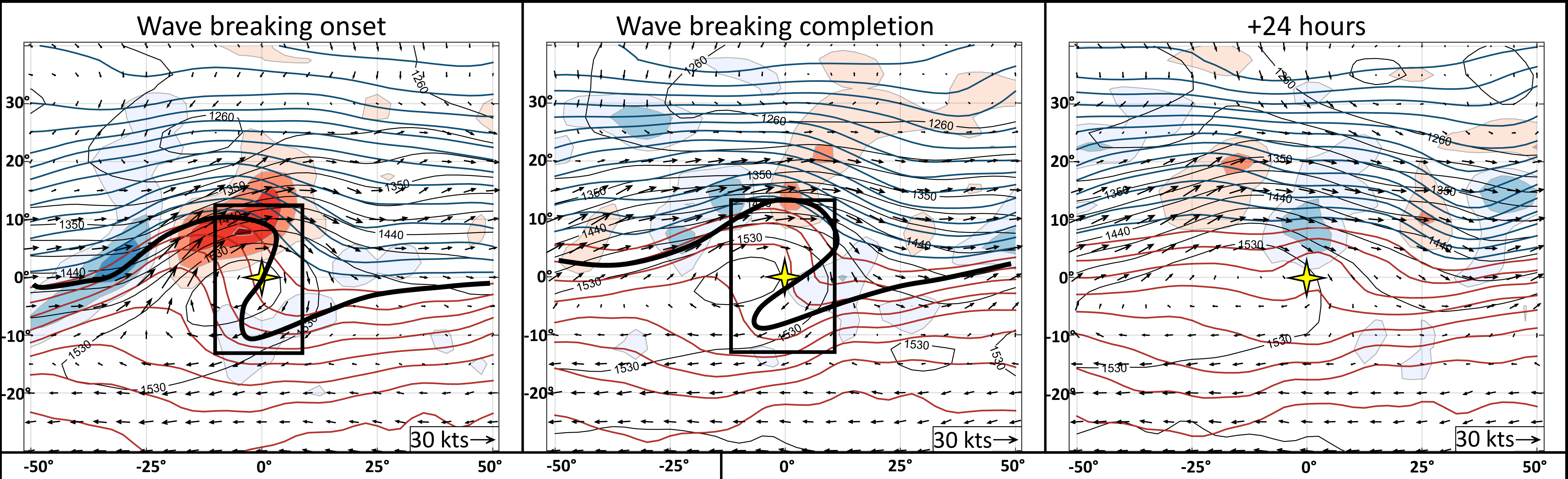
Winter A_Z BA events & anticyclonic wave breaking



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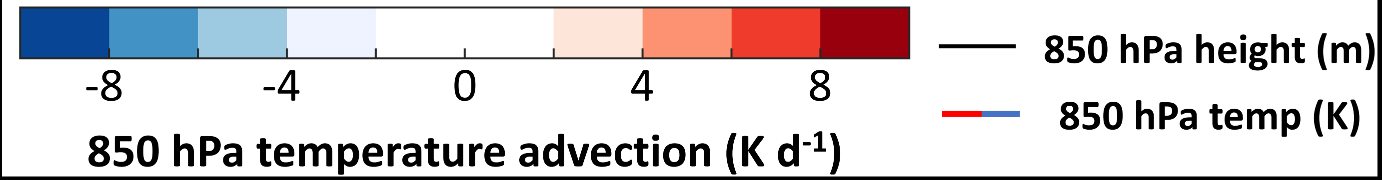
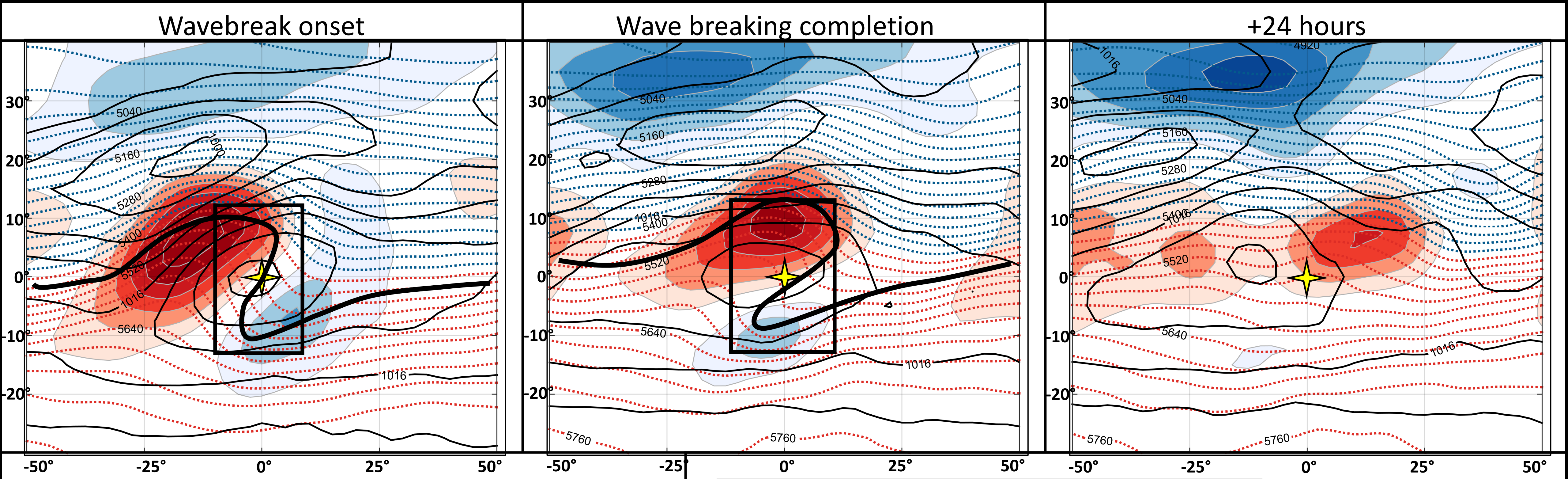


Lower tropo. thickness

Winter A_Z BA events & anticyclonic wave breaking



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