The analysis of the interhemispheric coupling in the austral winter and its seasonal variation using WACCM6

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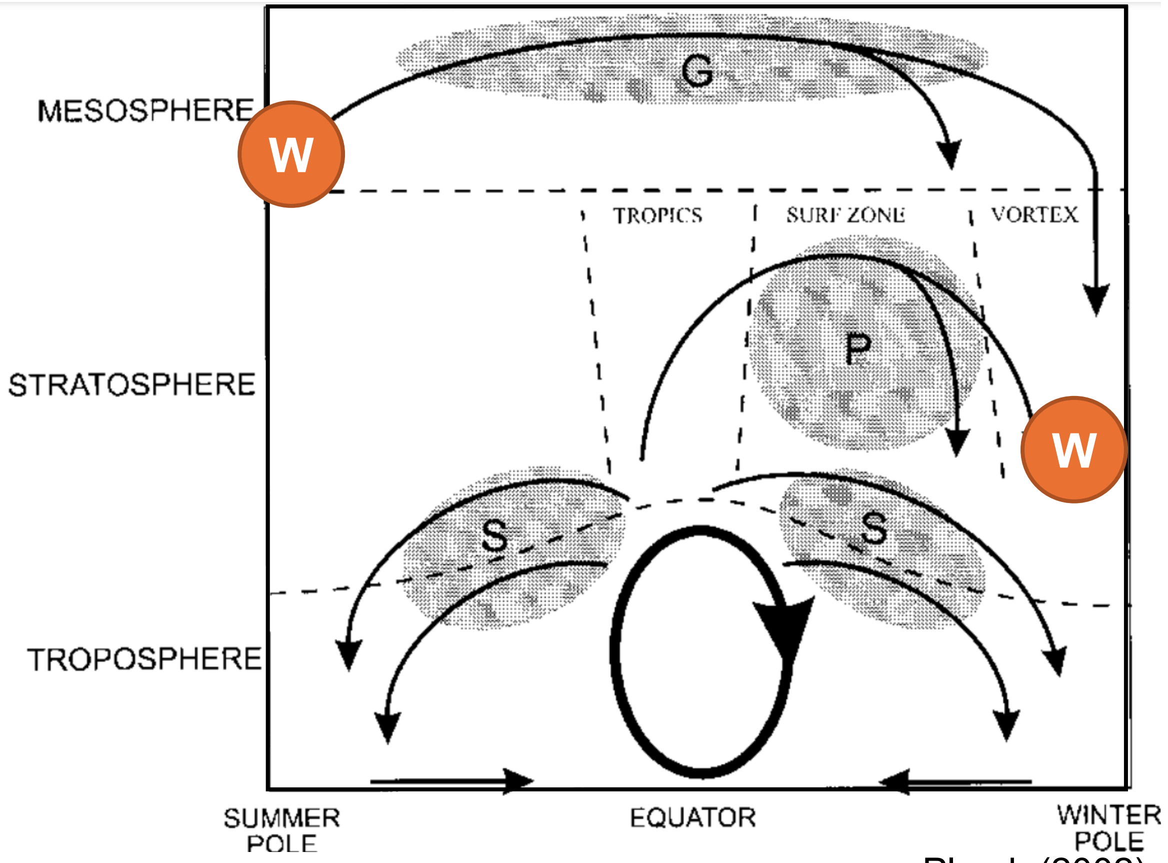
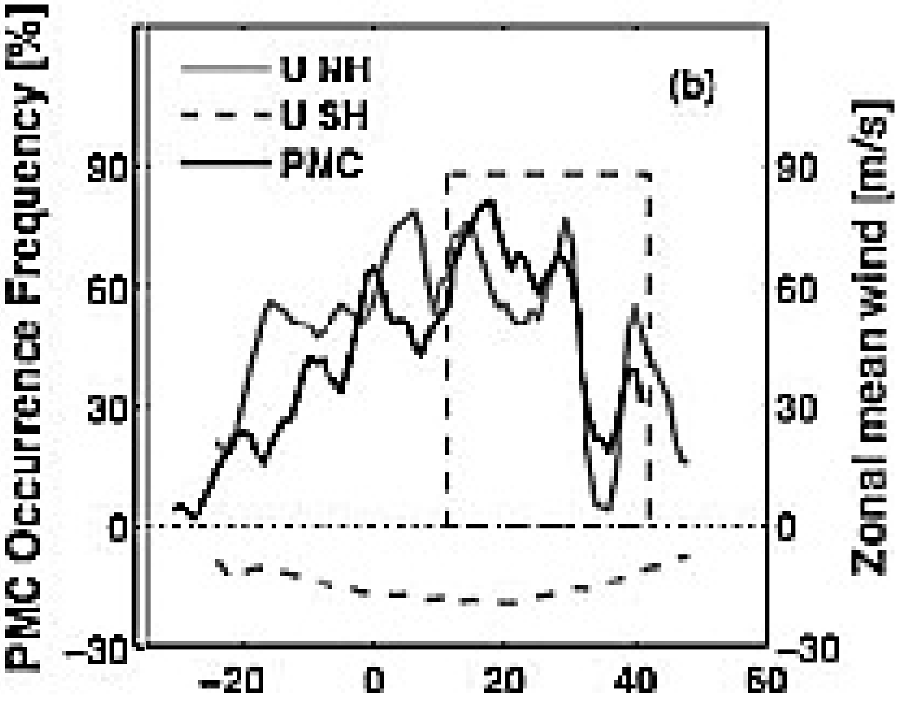
Introduction: Interhemispheric Coupling (IHC)



Plumb (2002)

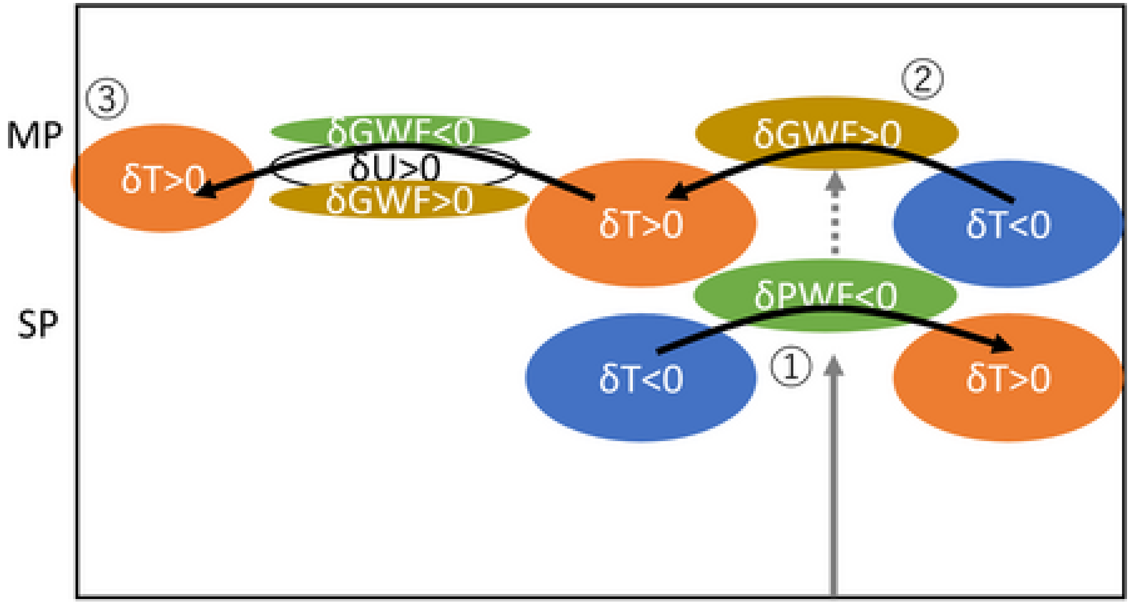


Karlsson et al. (2009a)
Gray and black curves: zonal wind (60N, 1000K) and PMC frequency (70S, shifted 7 days backward)
Day 0 = Dec 21, 2007

- After the warming in the winter polar stratosphere, the summer polar upper mesosphere also becomes warmer.

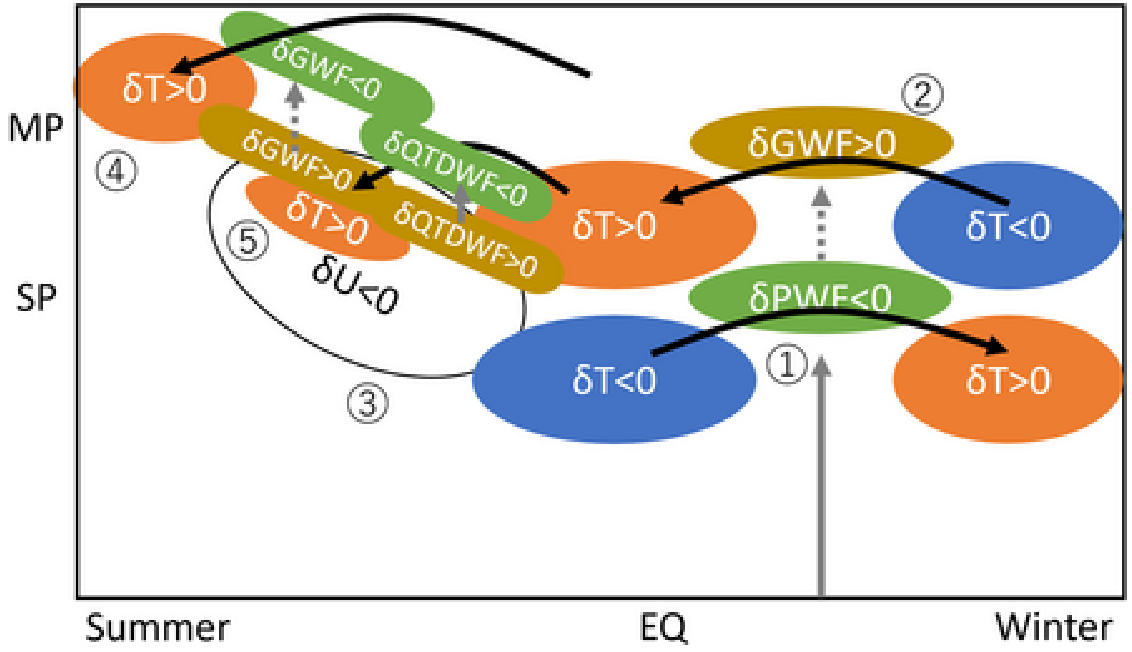
- The time lag of the response is explained by the mechanism of IHC.
- However, there are several mechanisms with different time lags (2–10 days).

Mechanisms of the IHC



GW modulation (Körnich and Becker, 2010)

1. Polar night jet is weakened in association with the SSW.
2. More eastward GW propagates, weakening the westward GW forcing and the poleward circulation.
3. The equatorial warming modulates the zonal wind in the summer hemisphere, which lowers the GW forcing and weakens the equatorward circulation.



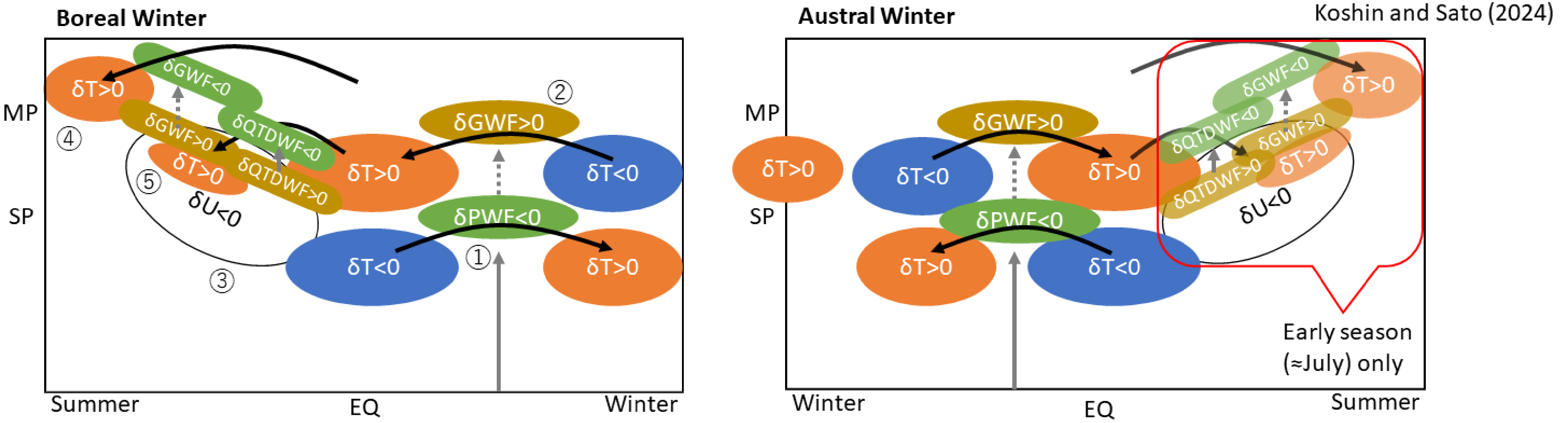
In-situ wave generation (Yasui et al., 2021)

1. Polar night jet is weakened in association with the SSW.
2. More eastward GW propagates, weakening the westward GW forcing and the poleward circulation.
3. Vertical shear of the zonal wind is enhanced.
4. GWs are generated by shear instability and deposit westward momentum.
5. QTDWs are generated by BT/BC instability and deposit westward momentum.

IHC during the austral winter

- Most previous studies have been analyzed for the IHC during the **boreal winter**, because SSW often occurs in the NH and rarely occurs in the SH.
- Even in the **austral winter**, a Cold Equatorial Stratosphere (CES) associated with the stratospheric warming occurs **once every two years.**
  - ✓The IHC in the austral winter was similar to that in the boreal winter.
  - ✓The characteristics are largely influenced by the seasonal variation.

Koshin and Sato (2024)



- The number of events used in the previous study is not large. (7 out of 15 years)

→ **WACCM6 simulation for ~200 years** is used to examine the IHC characteristics.

Methodology

WACCM6 Simulation (Gettelman et al., 2019)	
Horizontal resolution	1.25˚×0.95˚ (288×192)
Vertical resolution	~2 km (71 levels from 0 to ~140 km)
Time Period	65 years from 1950 to 2014 (daily)
Ensemble	3 (with different initial condition)

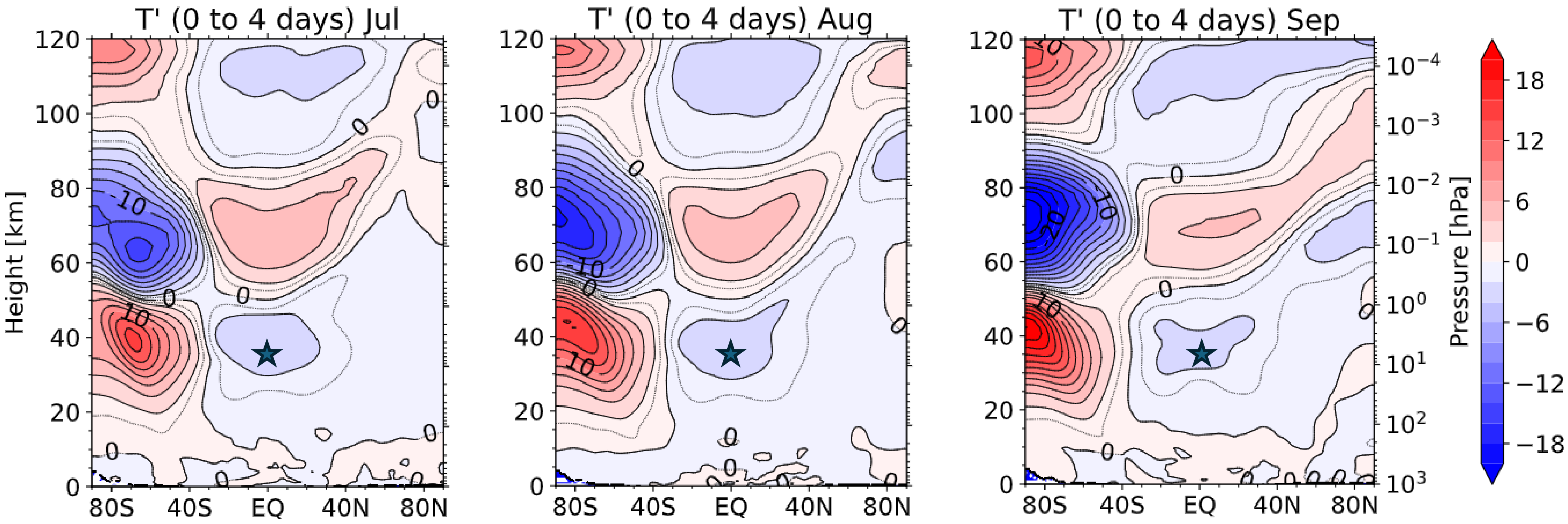
195 years in total (65×3)

Cold Equatorial Stratosphere events (CES: following Koshin and Sato, 2024)		
Criteria		Temperature anomaly (T’) < 2σ
Definition	Anomaly	Difference from the background
	Background	Long-term trend (2^{nd}-order polynomial) + seasonal variation (climatology + 90-day running mean)
	Region	10˚S–10˚N, 4–10 hPa
Onset date		The day with the minimum T’

~100 CES events in Jul, Aug, and Sep

Number of CES event	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
Koshin and Sato (2024)							4	2	1	0		
Yasui et al. (2021)	8+6	2+2										8+6
WACCM6 (this study)	37	27	18	1	0	18	**30**	**32**	**28**	14	10	24

Result: IHC in WACCM6



T anomaly during CES events:

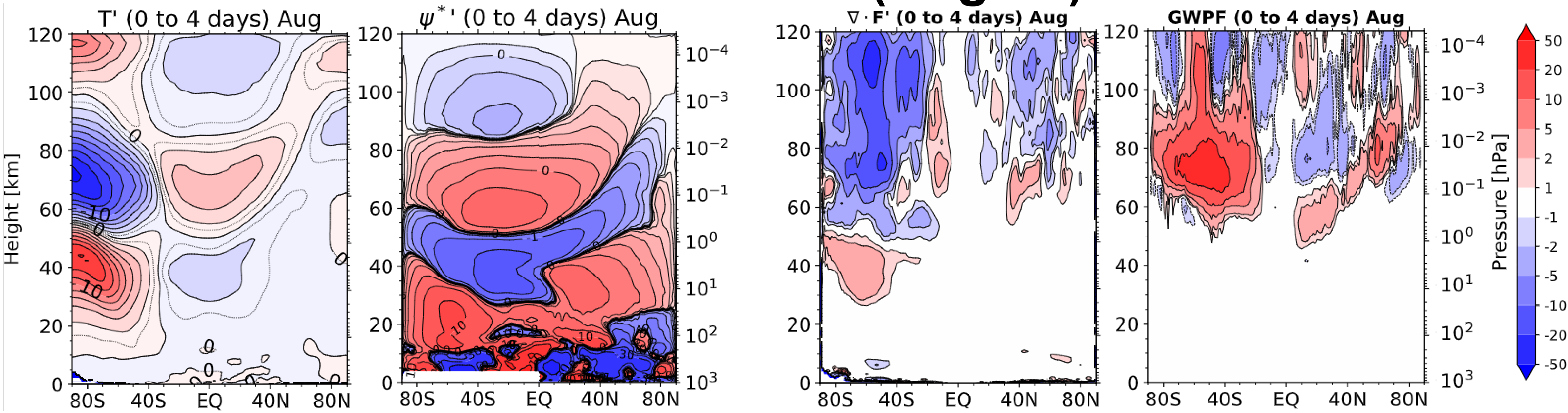
✓Warming in the northern polar upper mesosphere is observed in all months: IHC

✓The pattern in the southern hemisphere and equatorial region is similar among the months.

In the following,

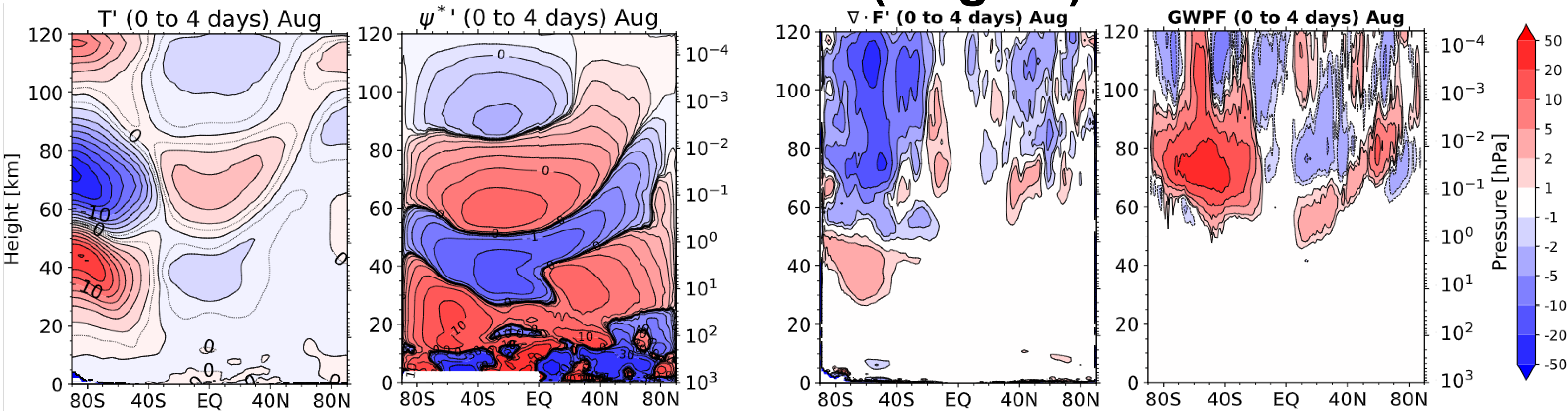
1. Examine the IHC mechanism
2. Compare the seasonal difference

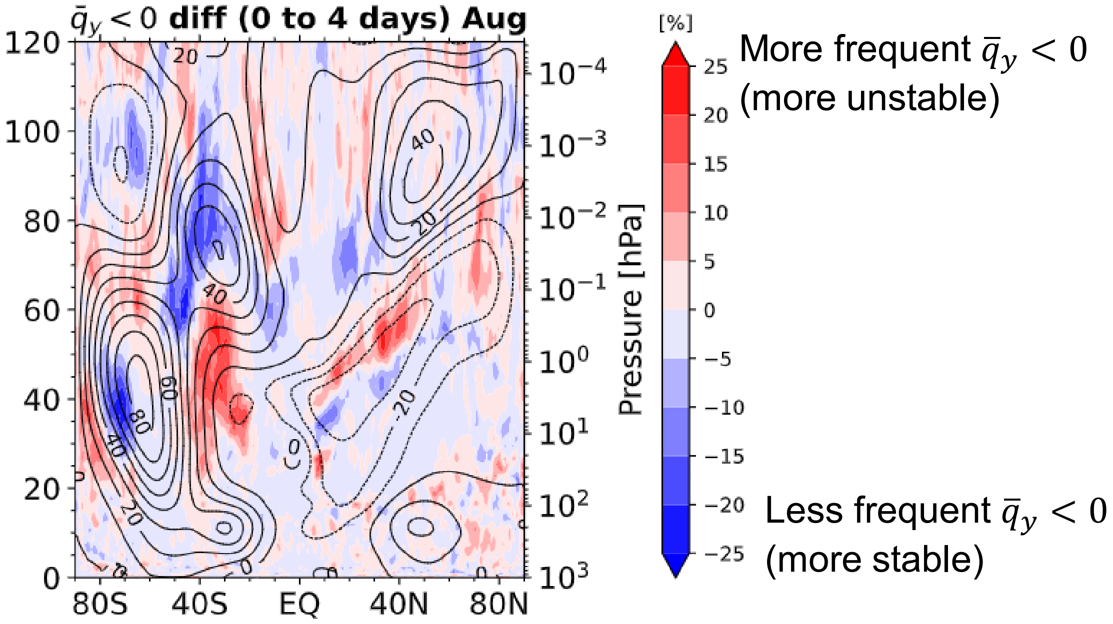
1. Mechanism of IHC in WACCM6 (August)



- The distribution of T anomalies can be explained by the change of the residual mean circulation.
- In the northern MLT region, a positive anomaly is observed, corresponding to the weakening of the poleward circulation.
- This anomaly seems to be induced by negative (resolved) **PW** and (parameterized) **GW** forcing anomalies.

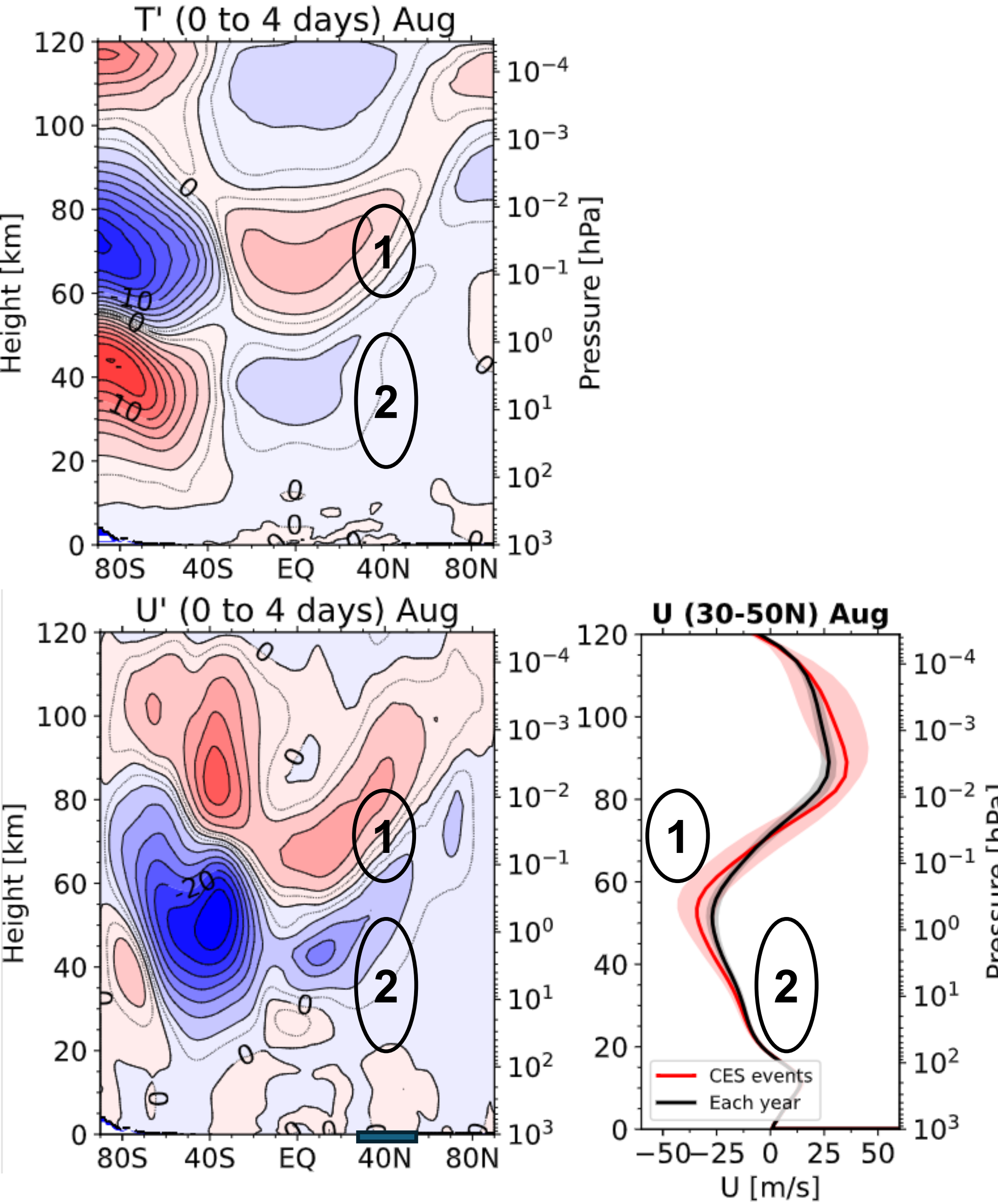
1. Mechanism of IHC in WACCM6 (August)

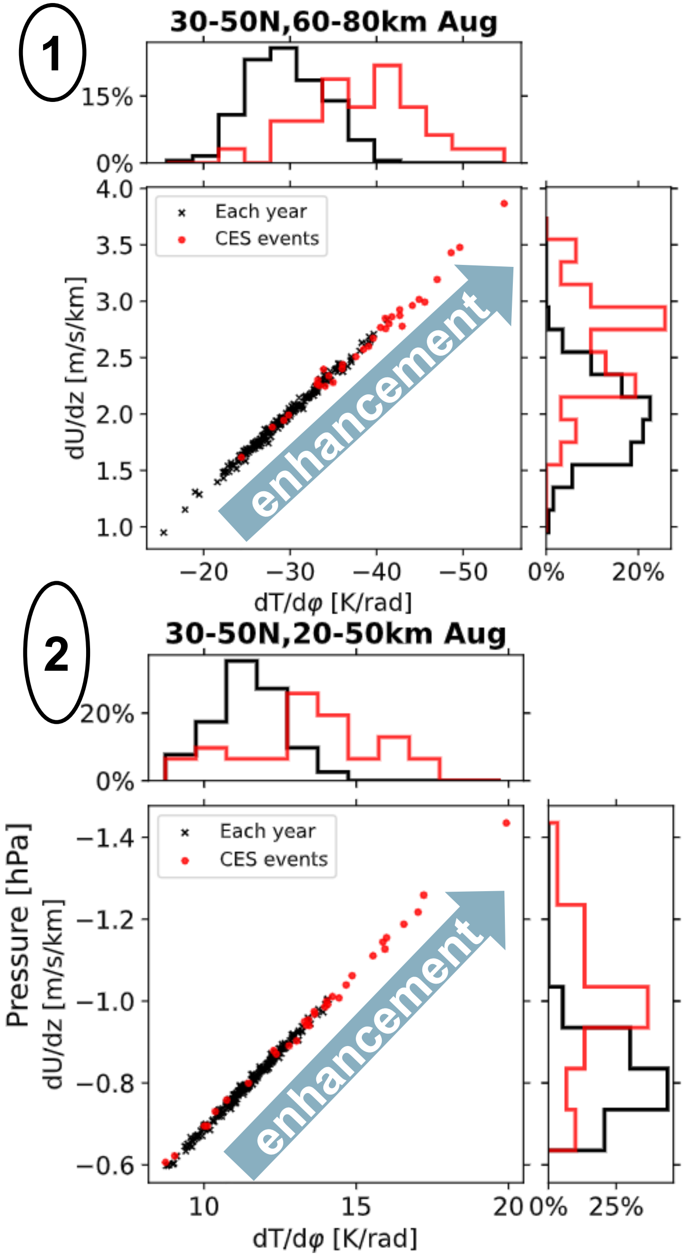




- $\bar{q}_y < 0$ is more frequent in the northern mesosphere, which is a climatologically unstable region (i.e., frequent $\bar{q}_y < 0$).
  - ✓This is consistent with the enhancement of BT/BC instability and QTDWs.
- Both PW and GW modulations are related to the **change in the zonal wind**.

Relation between T and U variation





The meridional T gradient $\left(\frac{dT}{d\varphi}\right)$ and vertical U gradient $\left(\frac{du}{dz}\right)$ are compared.

✓ $\frac{dT}{d\varphi}$ and $\frac{du}{dz}$ are almost in a thermal wind balance.

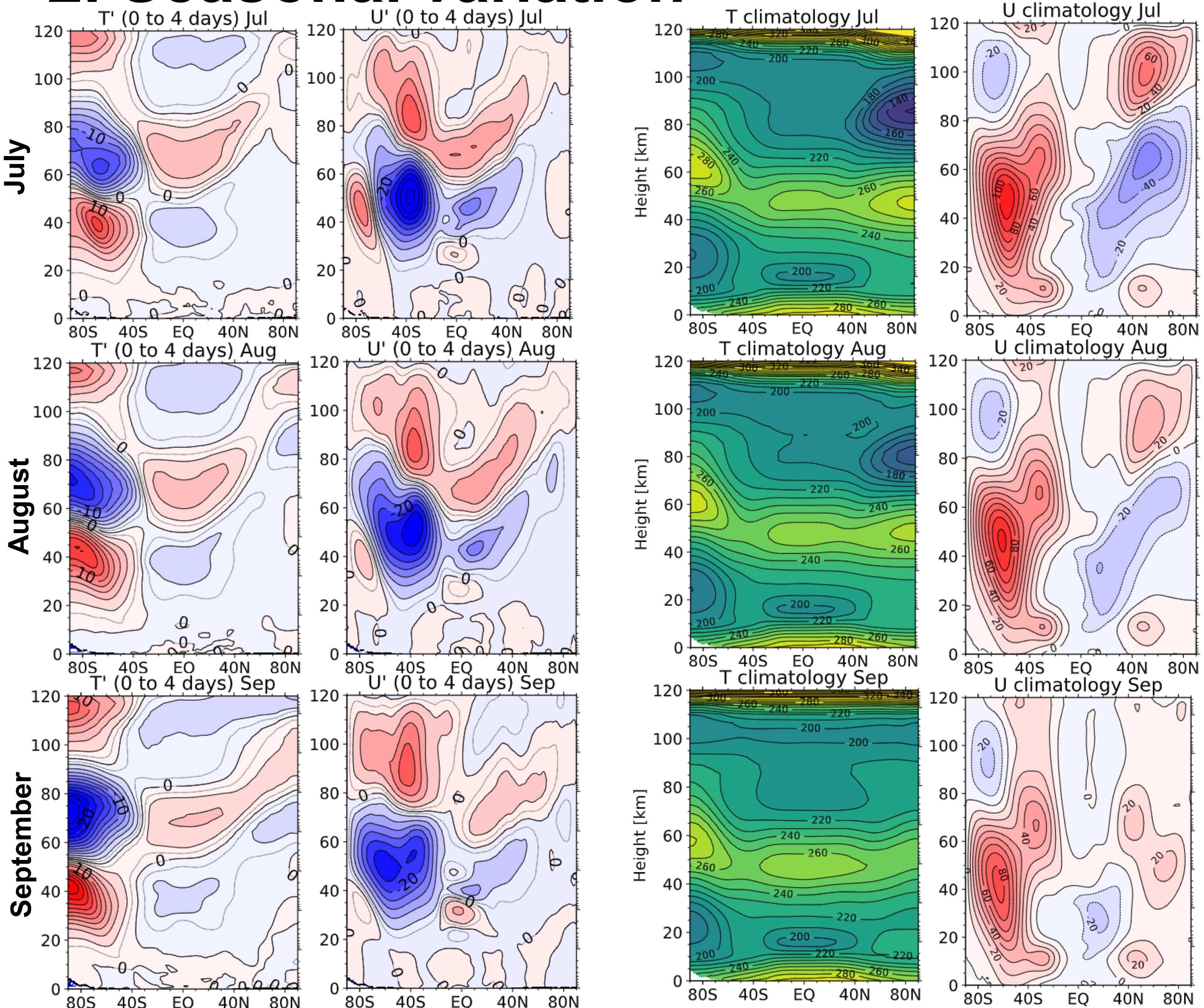
① In the upper mesosphere, they are enhanced during IHC.

② In the upper stratosphere, they are enhanced in most cases.

However,

- There is a large deviation due to interannual variability. (→ Discussion)
- Not enhanced for some cases.

2. Seasonal variation

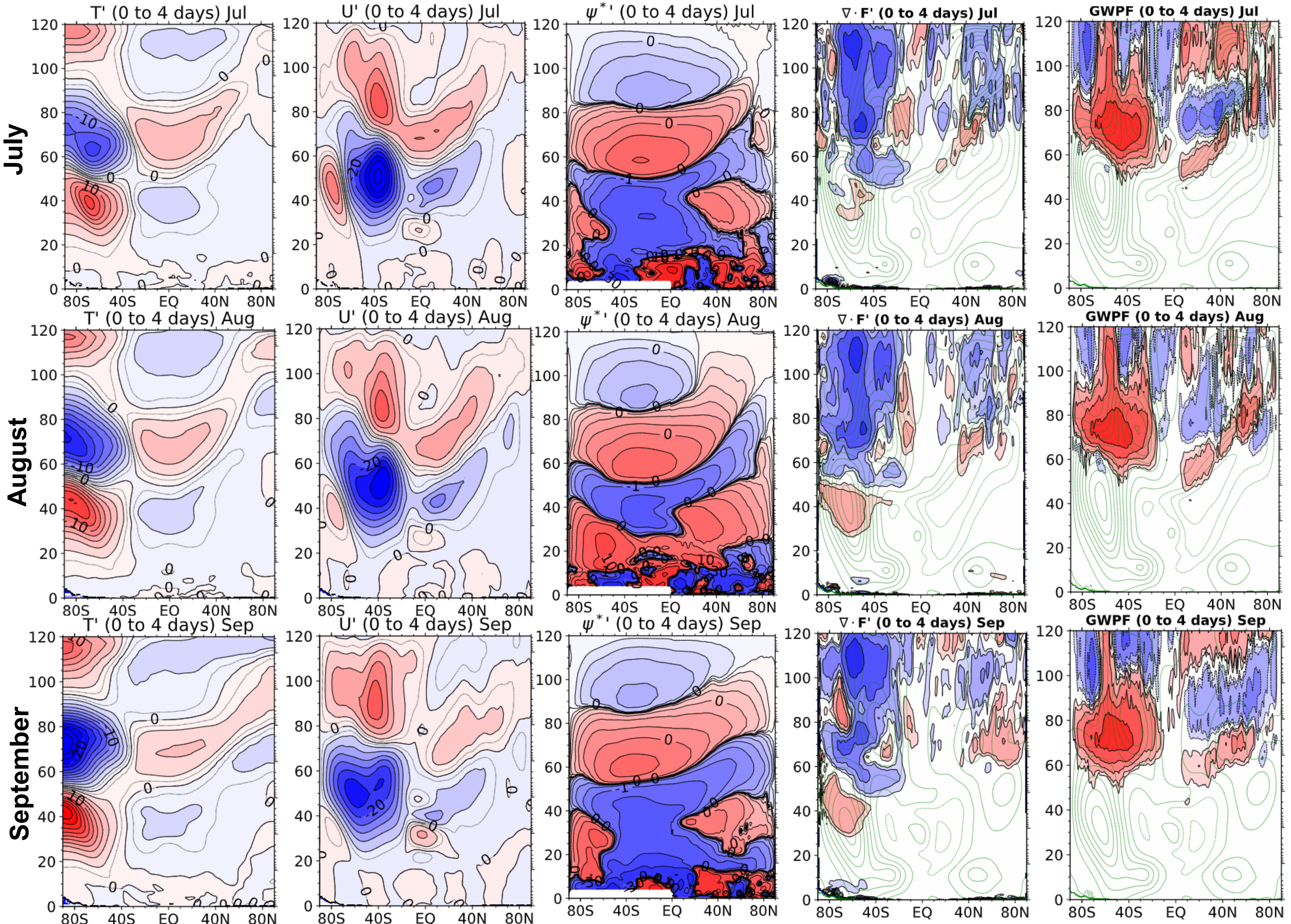


The structure of the T and U anomalies is similar. However, the **background** field is different among the months.

- ✓T minimum in the northern polar upper mesosphere is not observed in September.
- ✓The zonal wind in the northern high latitudes is eastward in September.

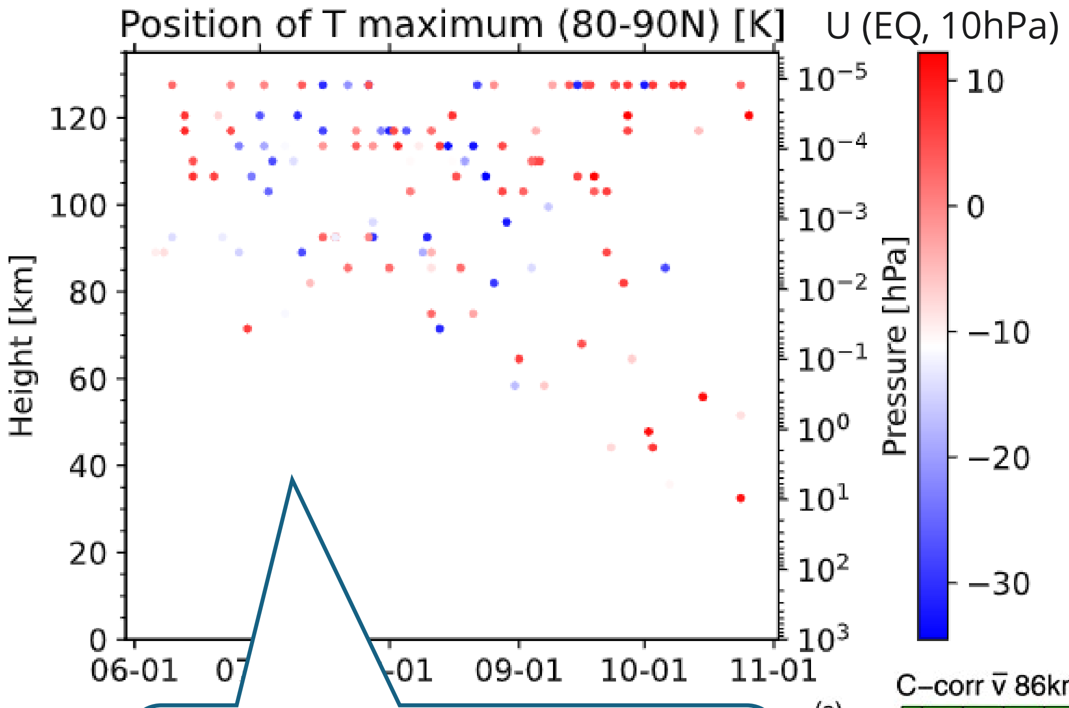
Are the roles of the waves different between these months?

2 .Seasonal variation for the roles of the waves



- In the northern MLT region, the modulation of the meridional circulation is consistent with T.
  - ✓ Altitude: **High** in Jul and Aug, **low** in Sep.
  - ✓ **Negative** circulation is large in Aug and Sep.
- These differences seem to be related to the different PW forcing.
  - ✓ **Higher** negative anomaly in July
  - ✓ **Positive** anomaly in September
- GW forcing is similar in the northern midlatitudes, and some difference is observed in the higher latitudes: likely related to the zona wind.

Discussion: Possible cause of the large interannual variability



However, significant relation to the QBO have not yet been obtained.

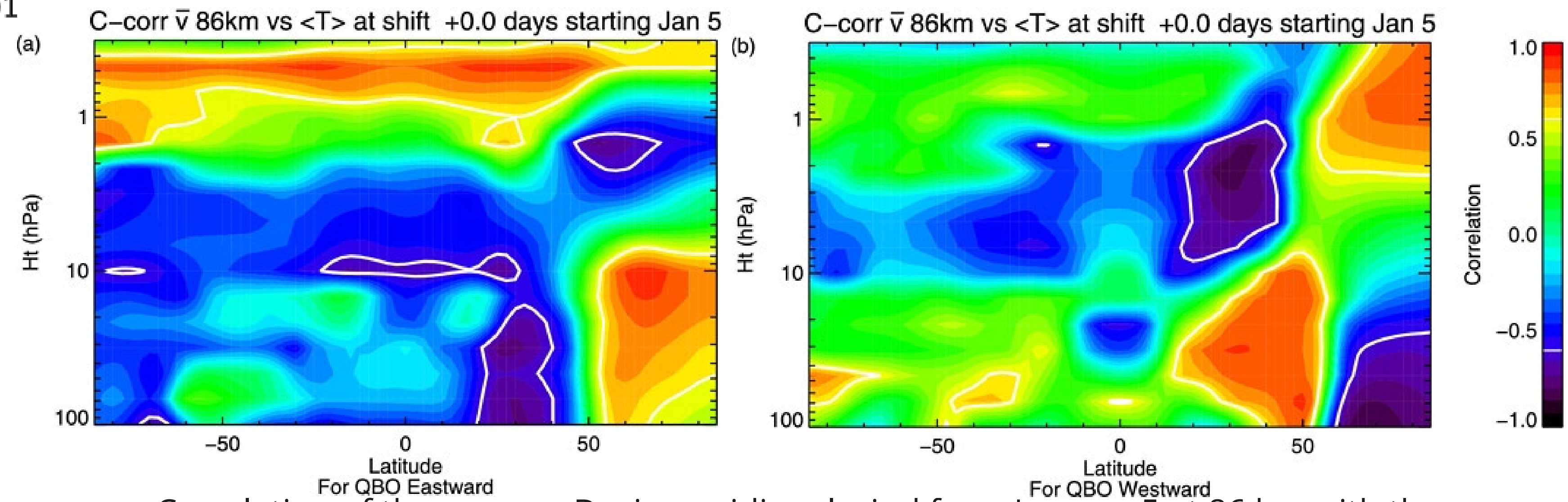
IHC response is sometimes high, and sometimes low.

→ What determines the altitude?

Murphy et al. (2012) calculated the correlation between V (southern polar mesopause) and T (northern polar stratosphere). The results is:

- **Positive** during the QBO eastward: IHC
- **Negative** during the QBO westward: Opposite to IHC

Hypothesis: Another correlation at another altitude?



Correlation of the average Davis meridional wind from January 5 at 86 km with the zonal-mean temperature from 100–0.3 hPa for (a) QBO eastward and (b) westward.

Summary

The IHC during the austral winter is examined, using the WACCM6 simulation.

✓Both the **modulation of PWs and GWs**, which contribute to the polar summer upper mesospheric warming, are observed.

✓The **variation of U**, which modulates these wave activities, can be explained by the modulation of T and its meridional gradient, qualitatively.

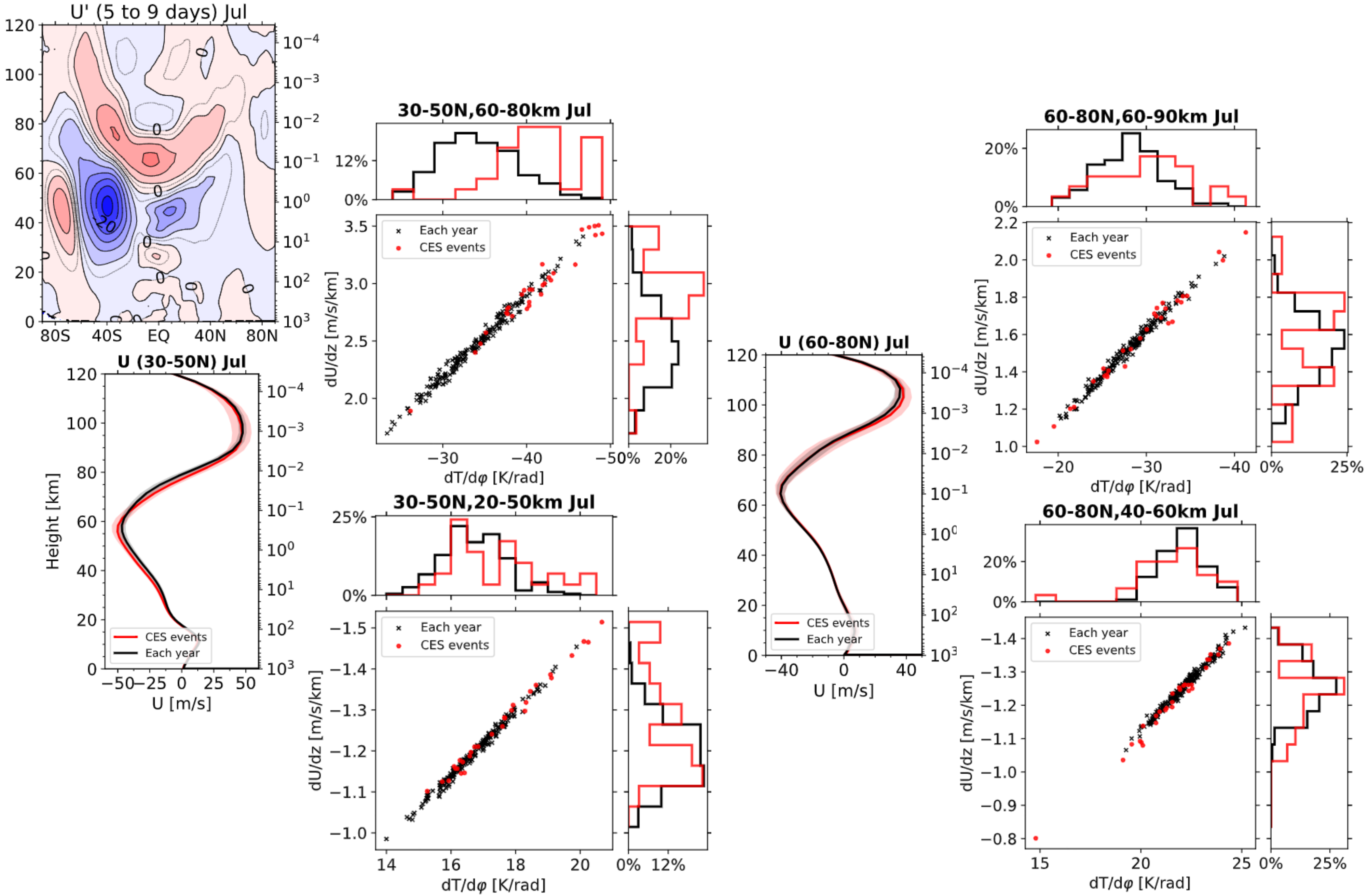
✓The seasonal variation of the IHC characteristics is consistent with the difference in wave activities explained by the **background field**.

✓However, the **interannual variation** is large, as is the interseasonal variation.

Future work

- Investigate the cause of the interannual variability.
- Explain both the interannual and interseasonal variations of the IHC.

Thermal wind balance (July)



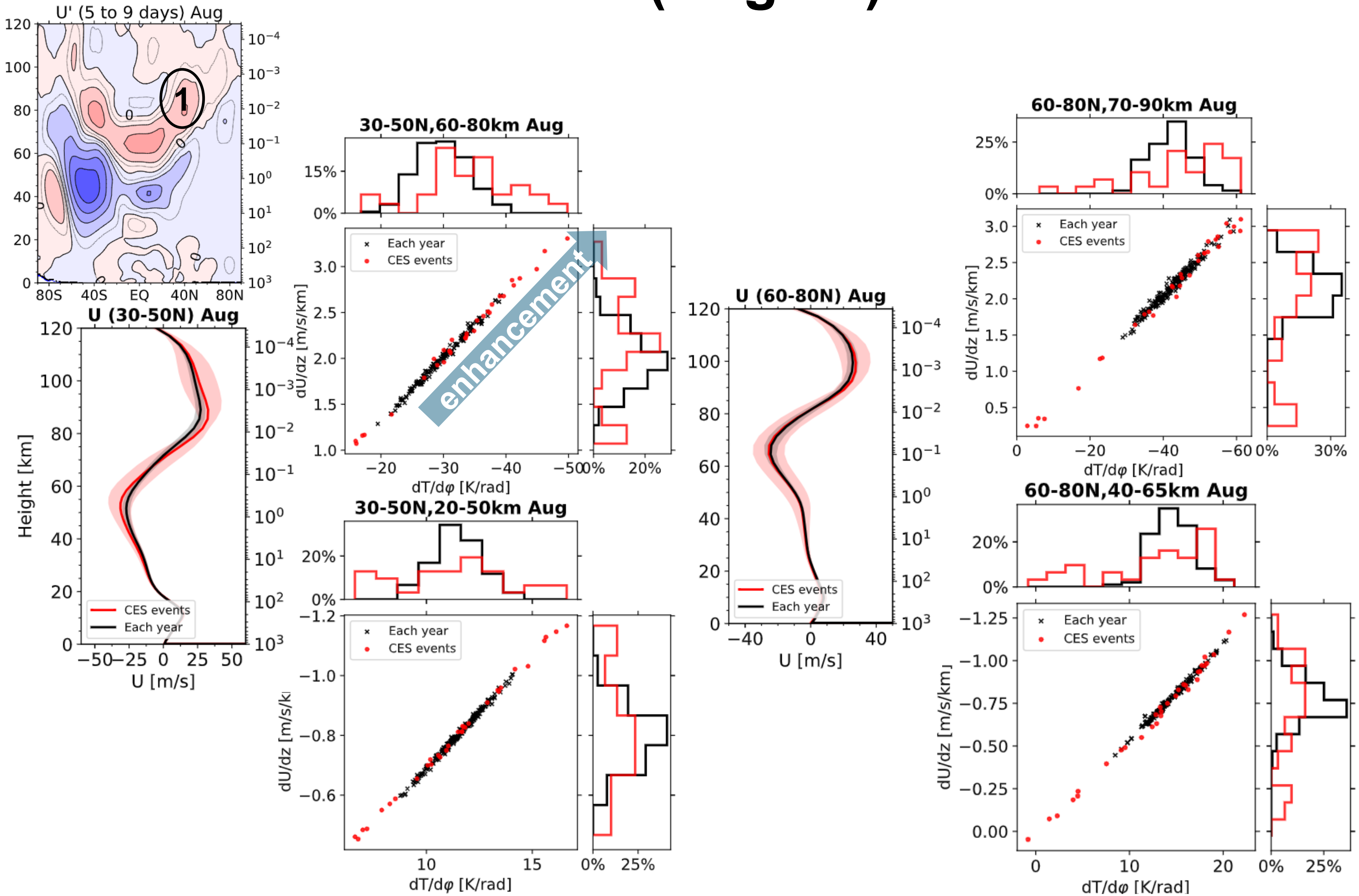
Midlatitude mesosphere: enhancement

Midlatitude stratosphere: a little enhanced?

Polar mesosphere: a little enhanced?

Polar stratosphere: not significant

Thermal wind balance (August)



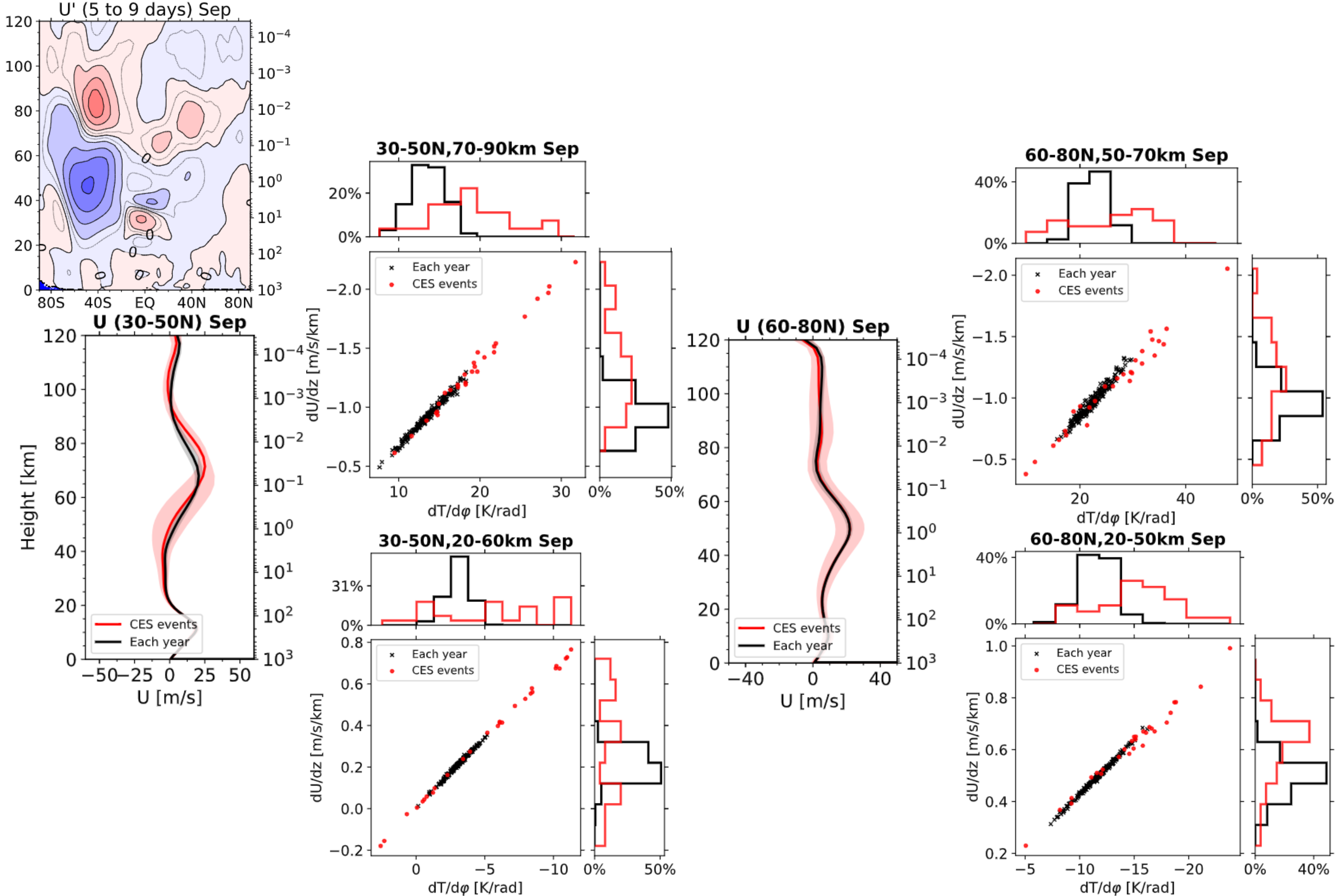
Midlatitude mesosphere: enhancement

Midlatitude stratosphere: a little enhanced?

Polar mesosphere: a little enhanced?

Polar stratosphere: weakening?

Thermal wind balance (September)



Midlatitude mesosphere: enhancement

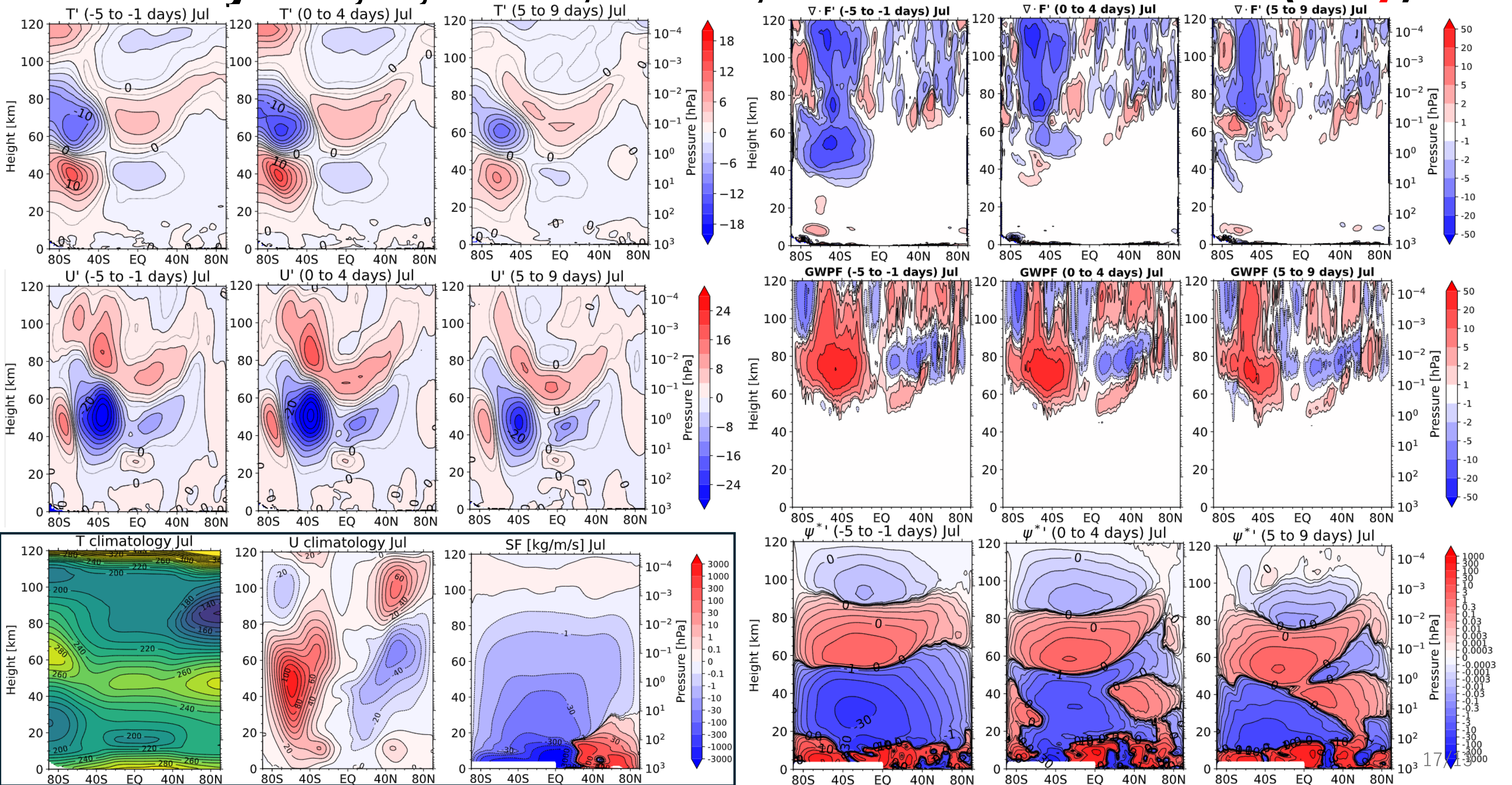
Midlatitude stratosphere: enhancement

Polar mesosphere: enhancement

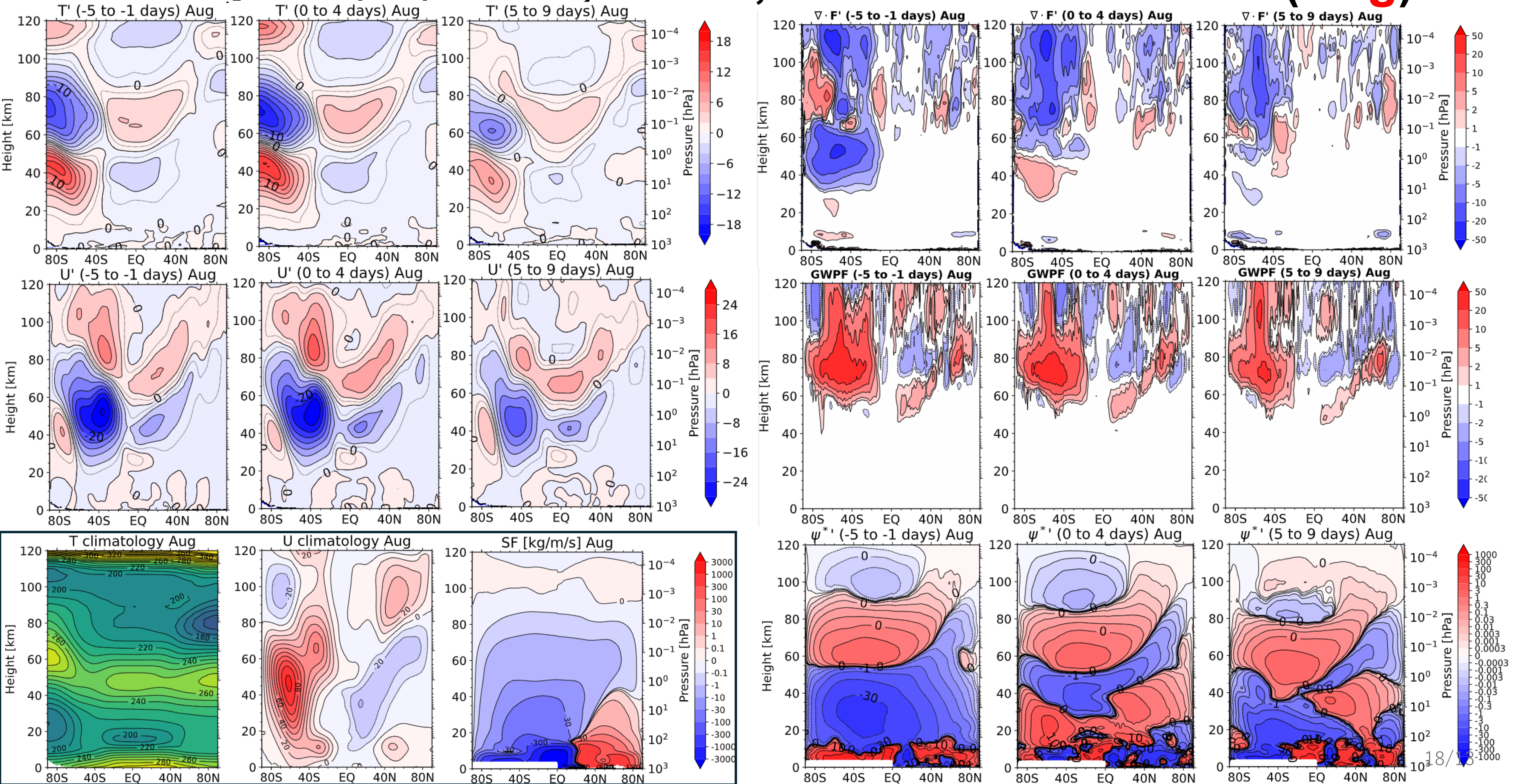
Polar stratosphere: enhancement

(the direction of the zonal wind and its gradient is different from Jul and Aug)

Anomaly of T, U, EPFD, GWPF, and Stream function (July)



Anomaly of T, U, EPFD, GWPF, and Stream function (Aug)



Anomaly of T, U, EPFD, GWPF, and Stream function (Sep)