Tropospheric Response to Stratospheric Sudden Warmings in a Simple Global Circulation Model

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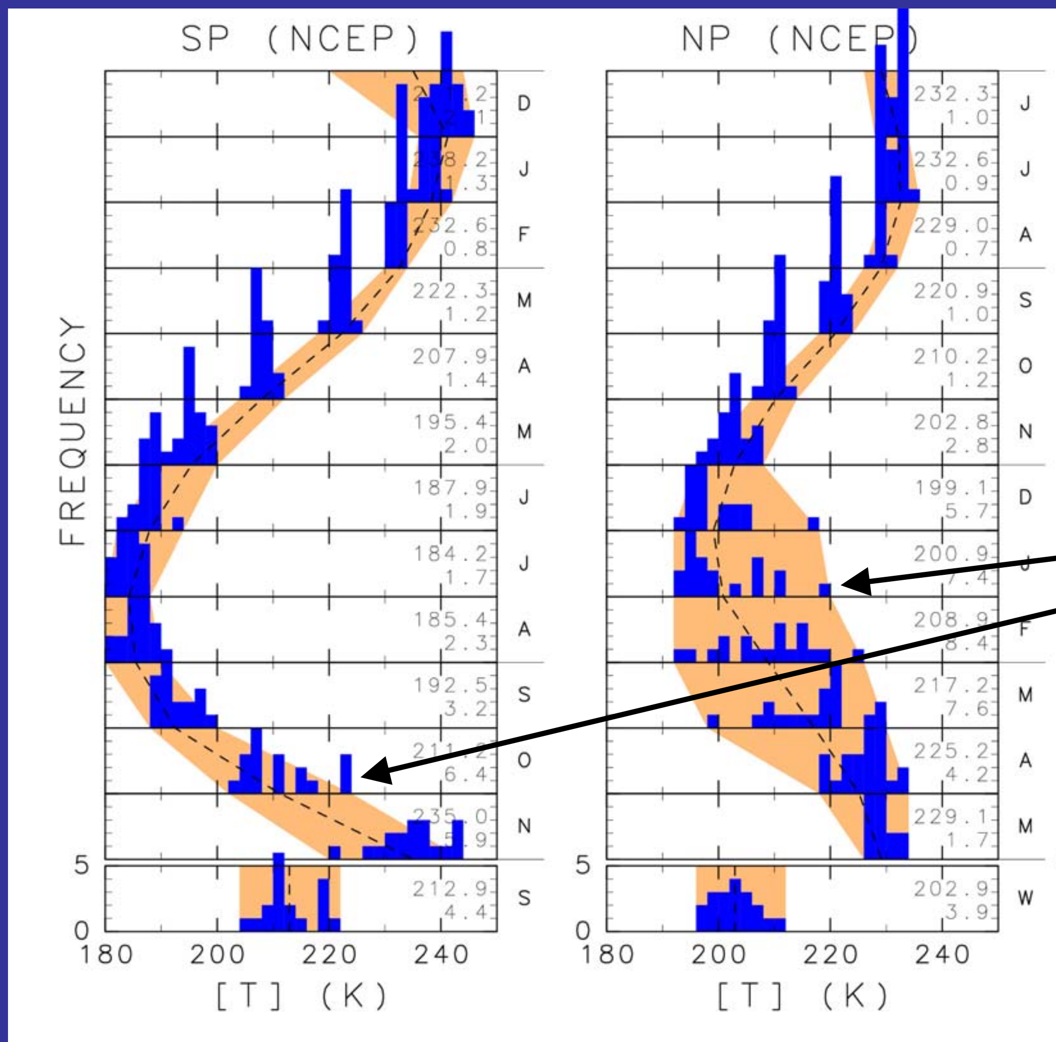
Importance of SSWs in S Variations

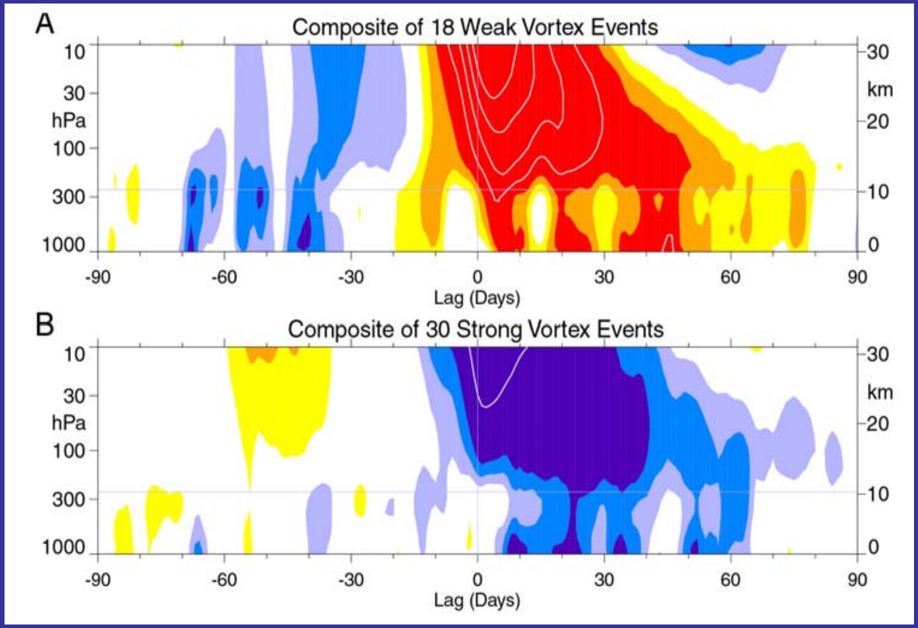
Frequency distributions of monthly-mean 30-hPa polar temperature

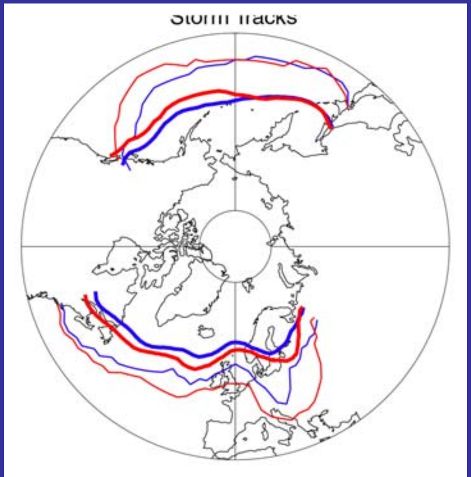


SSWs reflected in extreme temperatures

Importance of SSWs in T-S coupling

- SSWs may involve two-way T-S coupling.
  - Upward propagation of enhanced planetary waves
  - Downward propagation of S anomalies
  - S anomalies followed by anomalous T weather regimes





(Baldwin & Dunkerton 2001)

This study

- Use of mechanistic circulation models (MCMs) relative to obs. & GCMs
  - Obs. & GCMs

    Limited # of samples, coexisting various processes
  - MCMs

    Large # of samples, only dynamical processes
- This study

  Composite analysis of 132 SSWs in 10,000-day MCM run to understand nature of T-S coupling:
  - T circulation changes before & after SSWs
  - Interaction between planetary & synoptic waves
  - Relationship between SSWs & following T anomalies

  ⇒ Insights to T-S coupling in real SSWs

Model

- 3D primitive-equation model for globe
- Resolution: T21, L42

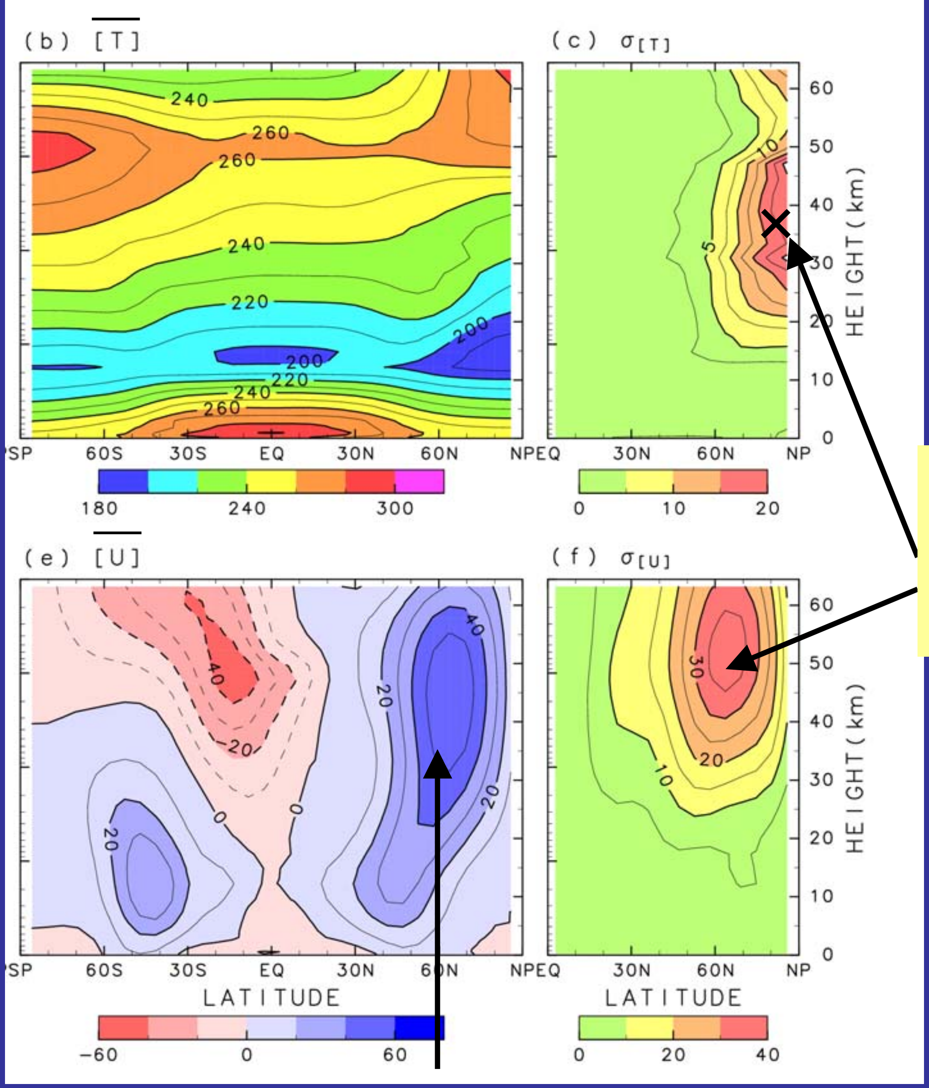
  (⇒ basic features of synoptic waves)
- Simplified physical processes
  - Newtonian thermal relaxation to perpetual winter condition
  - Rayleigh friction at surface
  - Dry atmosphere
- Sinusoidal surface topography
  - amplitude 1000 m
  - zonal wavenumber 1

Model climatology (for 1000 days)

[ ]: zonal mean

$\overline{\quad}$: time mean

Time mean | **Std dev**



Zonal mean temperature

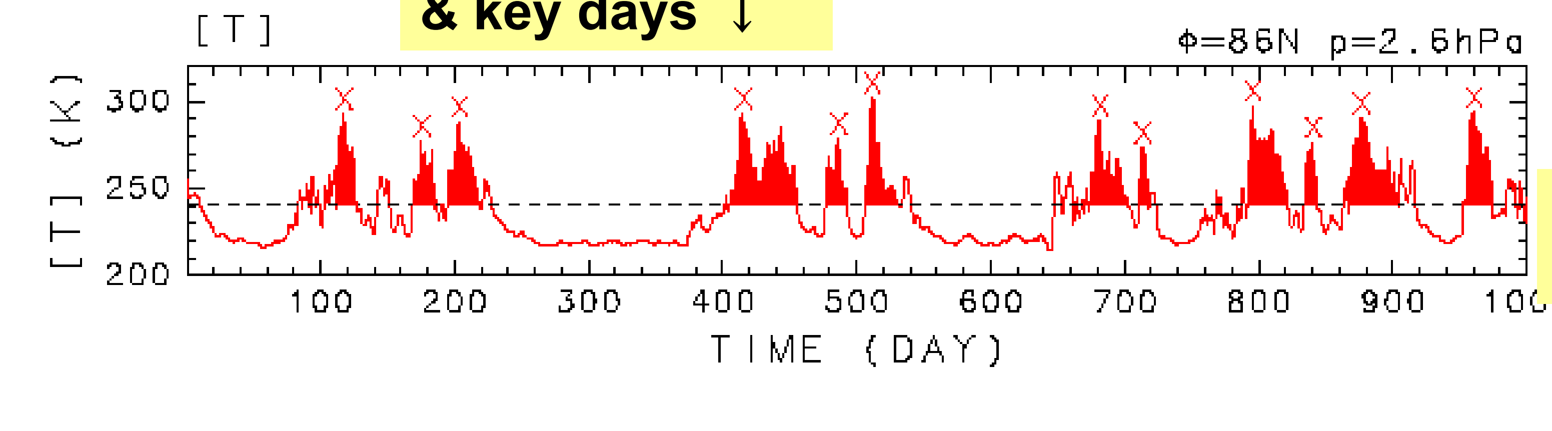
Zonal mean zonal wind

Large S variability ～ SSWs

Polar night jet

Stratospheric Variability

SSW periods
& key days ↓



←10000-day mean

⇒ **Intermittent occurrence of SSWs**

Define SSW events with the time series for composite analysis:

1. Search for periods when [T] is higher than time mean

2. Judge if maximum [T] in each period is higher than 270 K

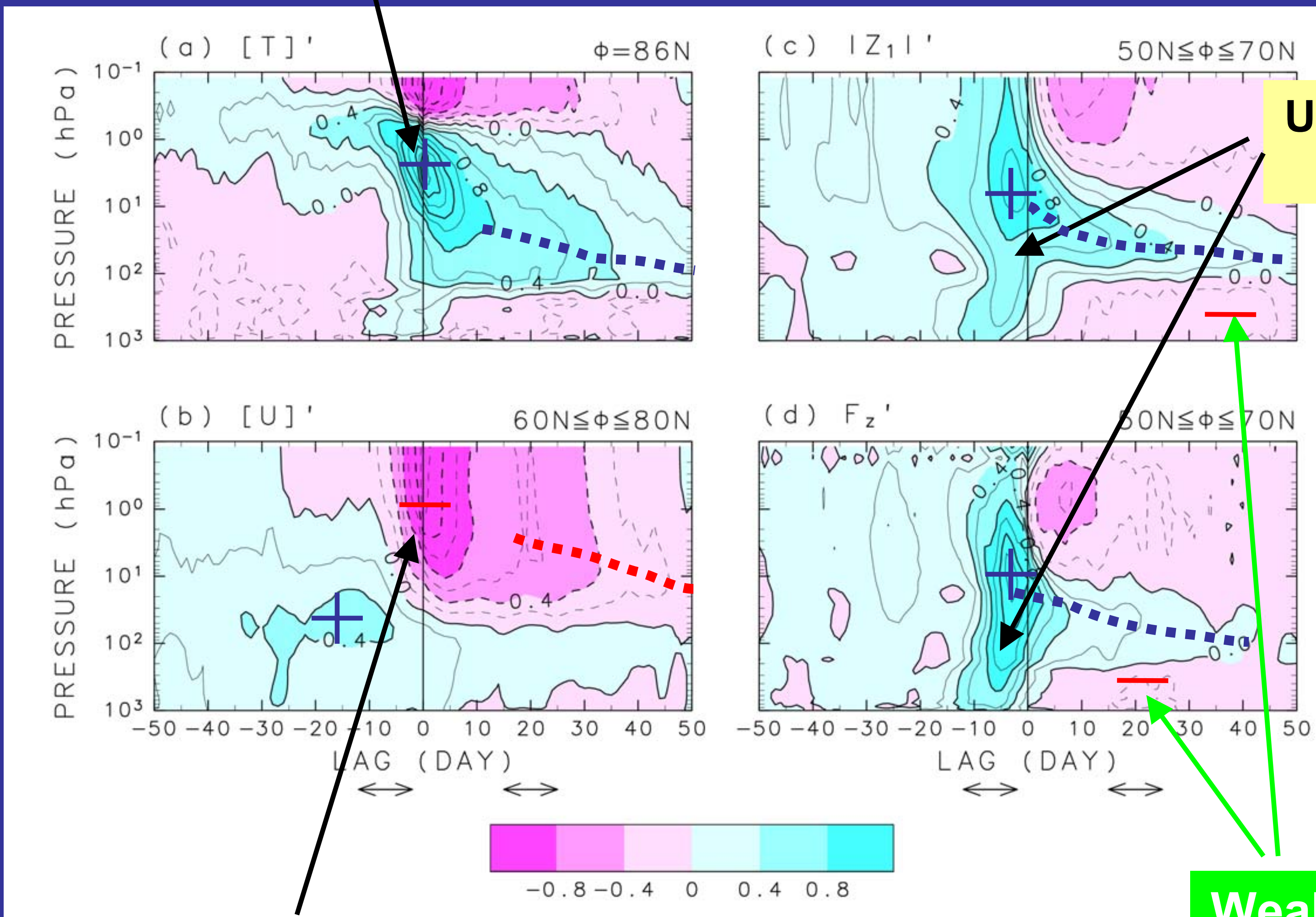
⇒ **132 SSWs in whole 10,000 days**

Results are robust, independent of subjective values

General Features of SSW Sequence

Composites shown in anomalies normalized with σ

Strong warming



Upward propagation of enhanced PW

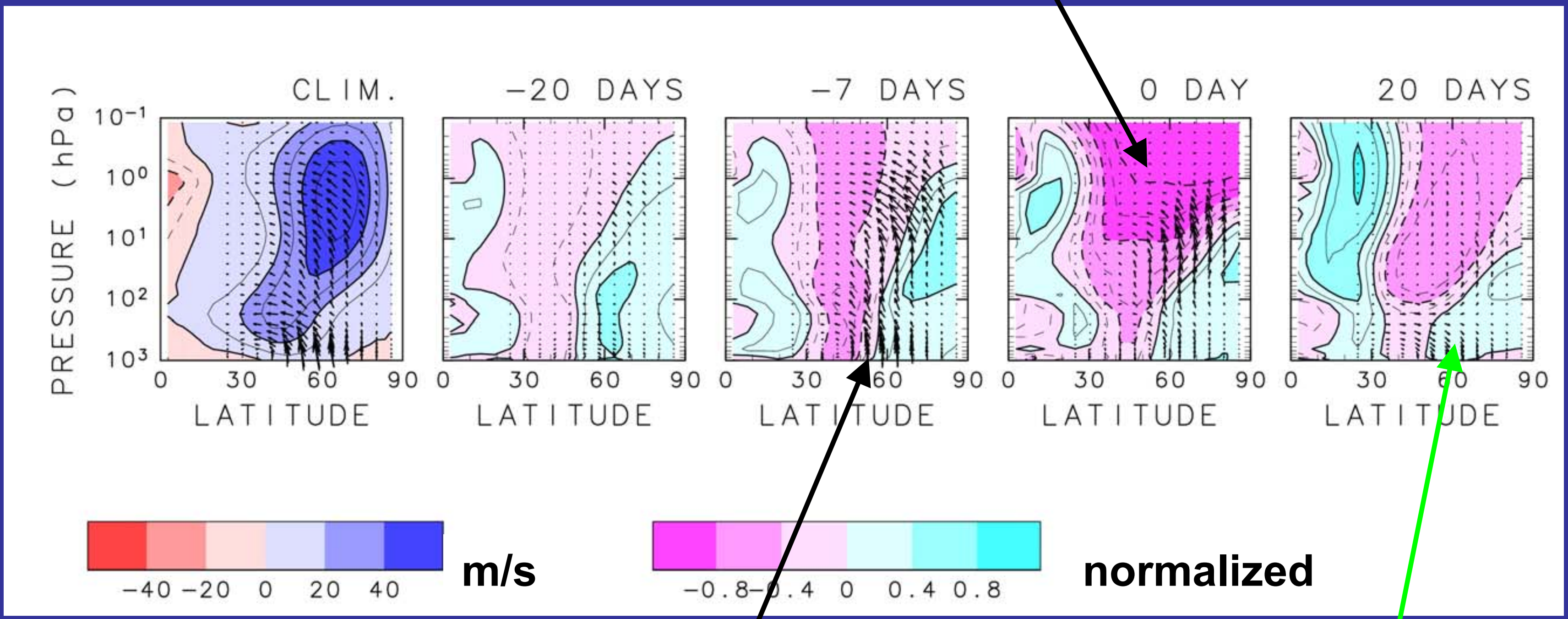
SSW signals propagate downward for a month or longer

PNJ deceleration

Weaker-than-normal PW activity

General Features of [U]’ & F’ (QG EP flux) for WN1

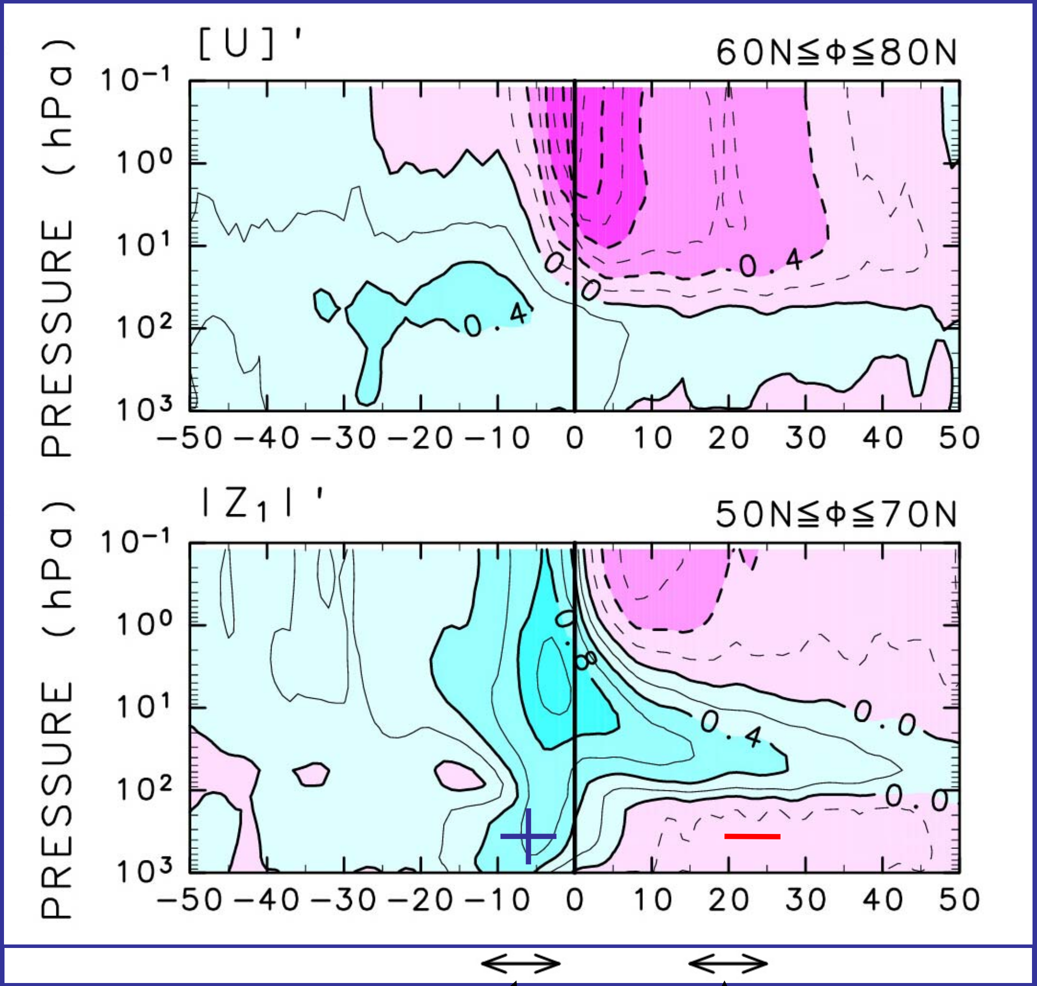
Poleward & downward propagation of [U]’ incl. SSW signal



Enhancement of upward propagation of PW

Weakening of upward propagation

Define pre- & post-SSW periods



pre-SSW

post-SSW

T circulation is quite different before and after SSWs.

- **pre-SSW : lag = –7±5 days**

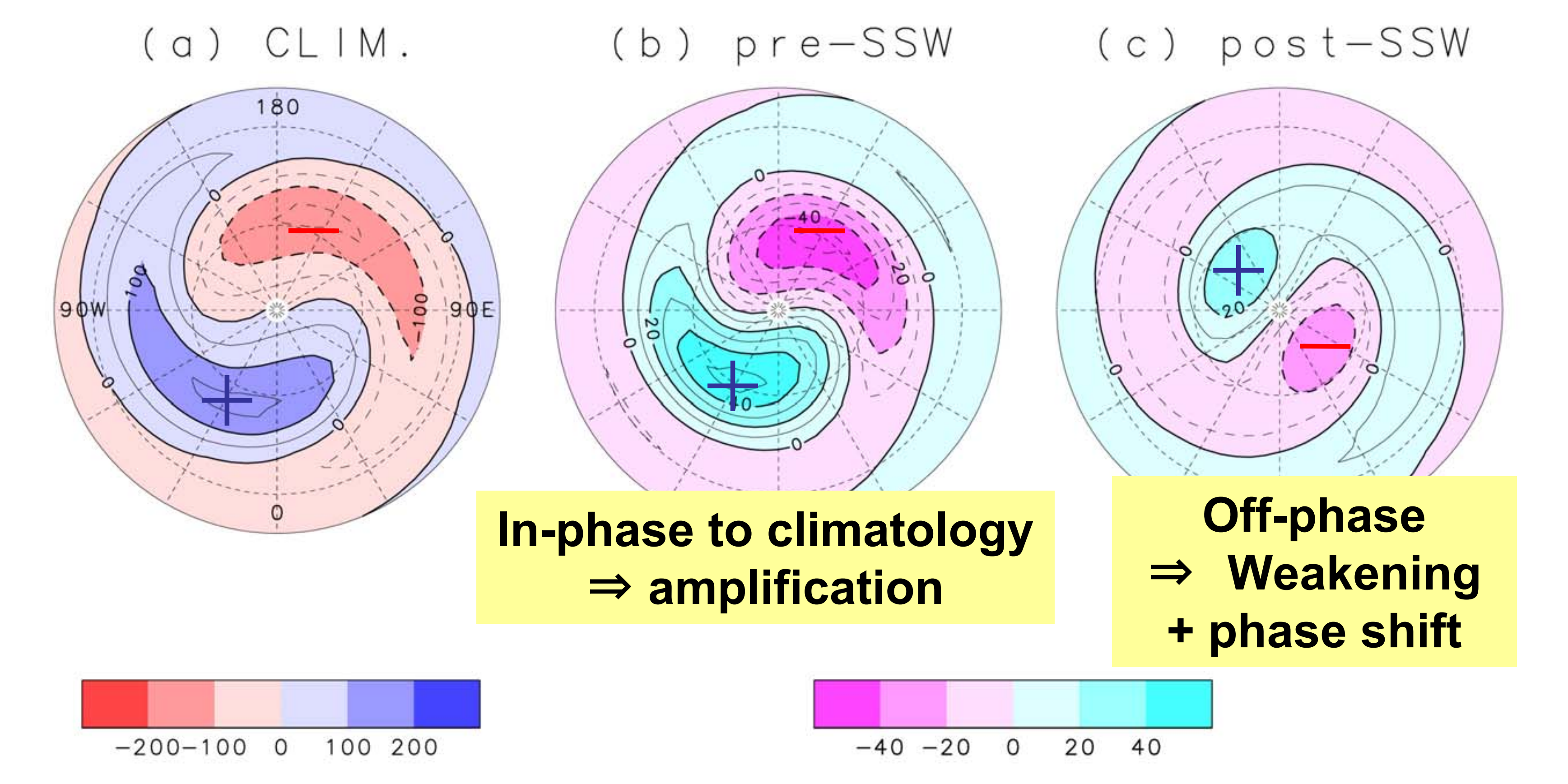
  PW stronger than normal

- **post-SSW : lag = –20±5 days**

  PW weaker than normal

Z^*_1 (WN1) @ 254 hPa

(Composites shown in anomalies)



In-phase to climatology
⇒ amplification

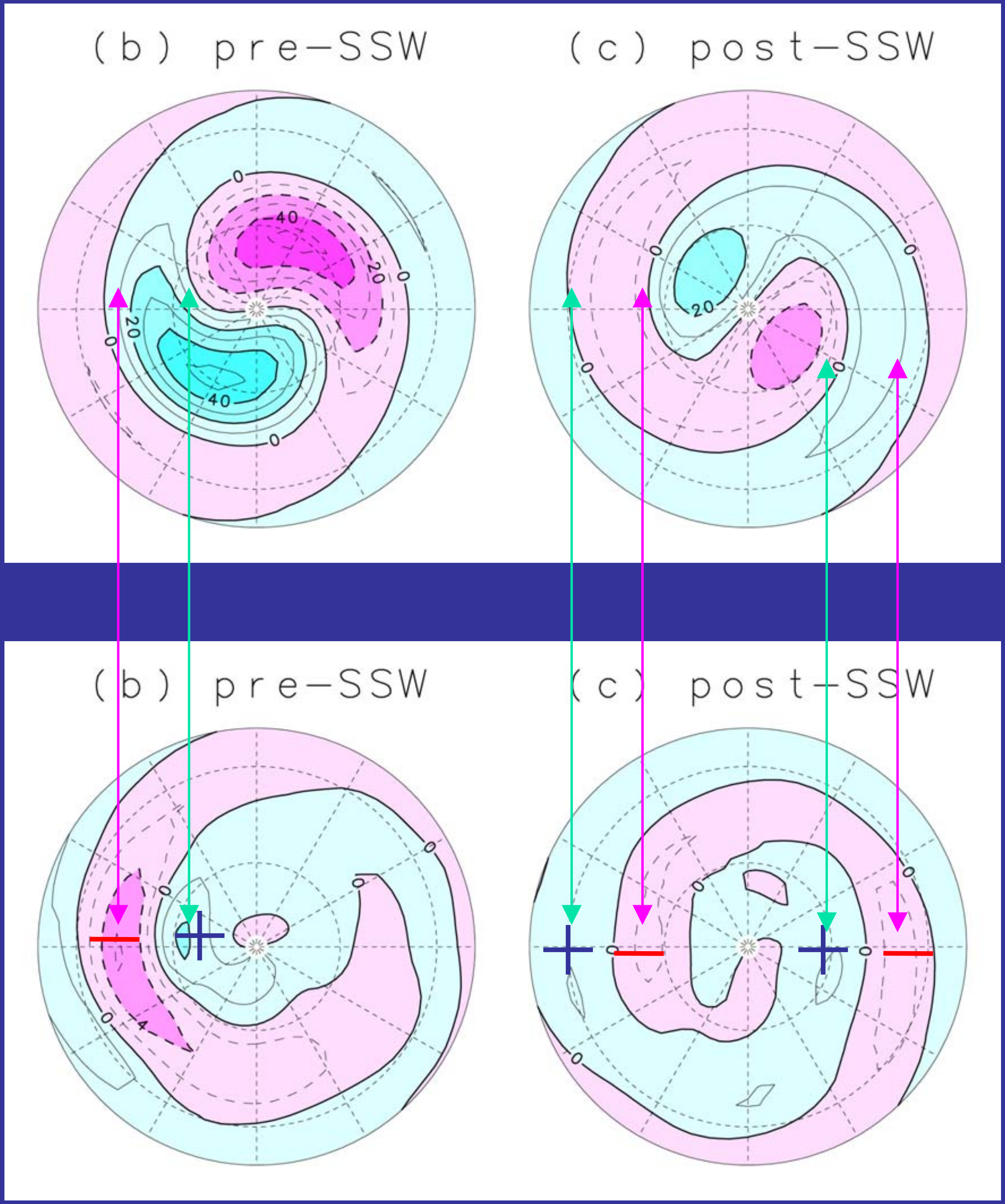
Off-phase
⇒ Weakening
+ phase shift

254 hPa

Z*$_1$ (WN1)

Geostrophic wind relationship:
U* reflect wave-1 Z*

U*
(zonal mean+
all WNs)

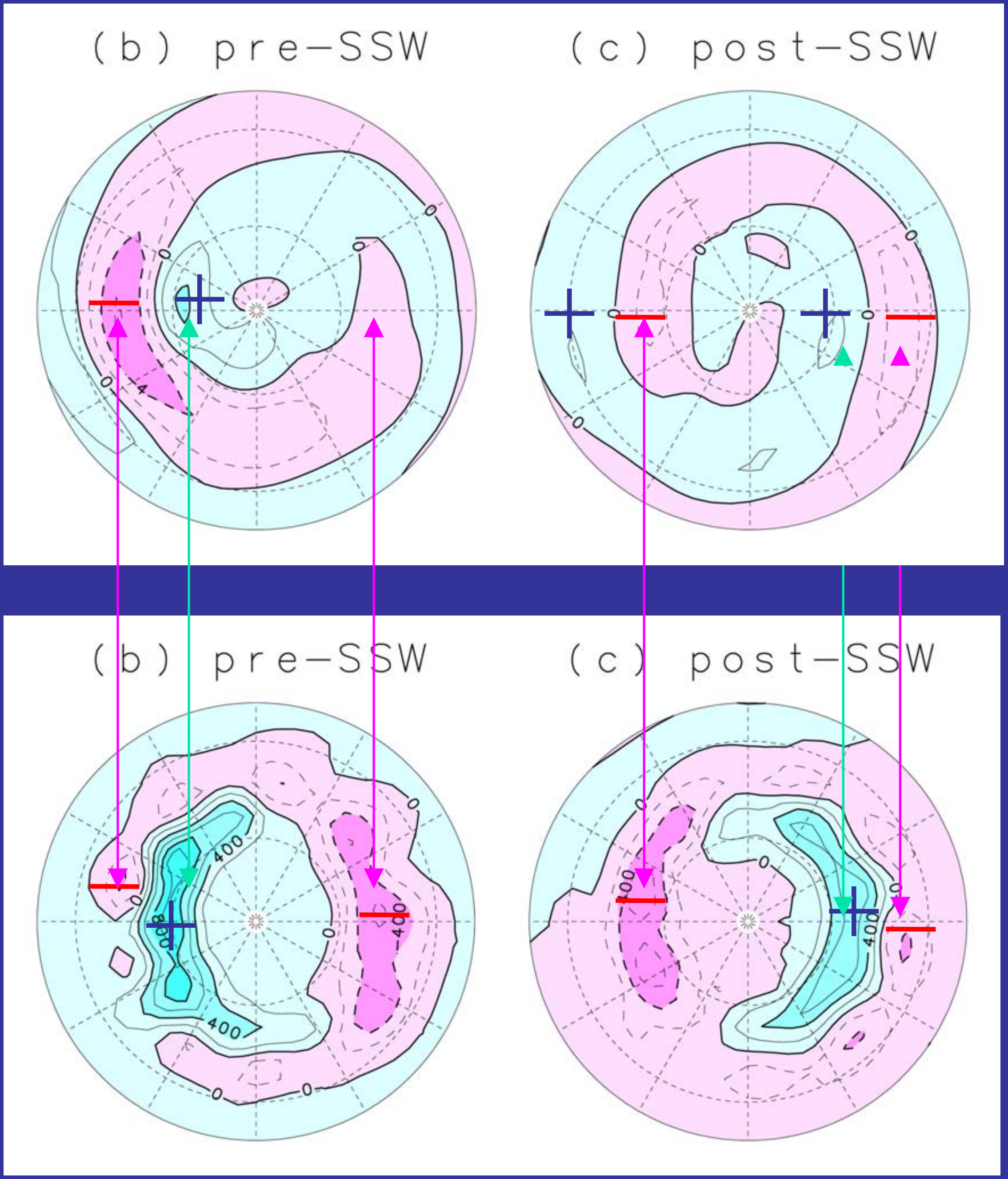


254 hPa

U*
(zonal mean + all WNs)

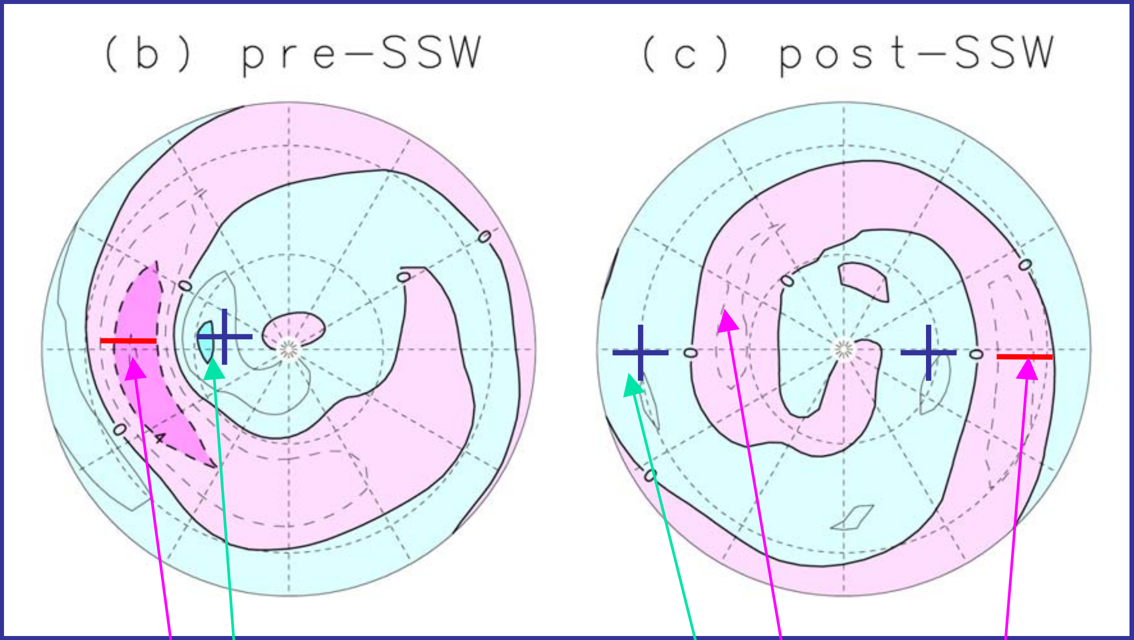
Zonal wind regulates spatial distribution of SW activity

Variance of GPH of SWs (waves 4-10)

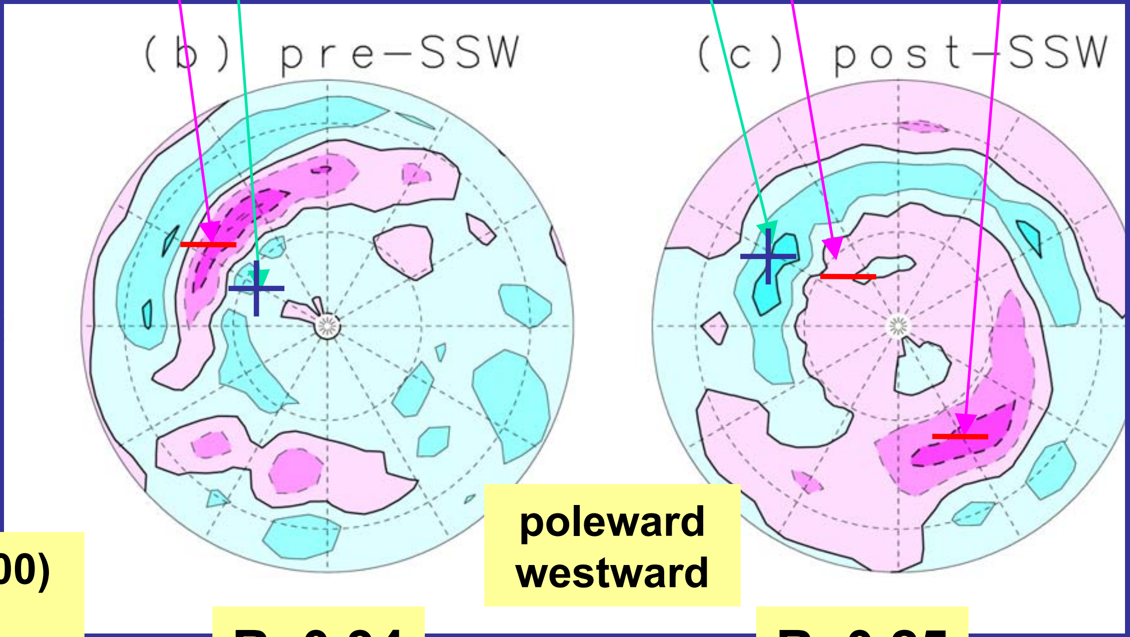


254 hPa

U*
(zonal mean
+ all WNs)



SWs act to maintain wave 1 zonal wind



poleward westward

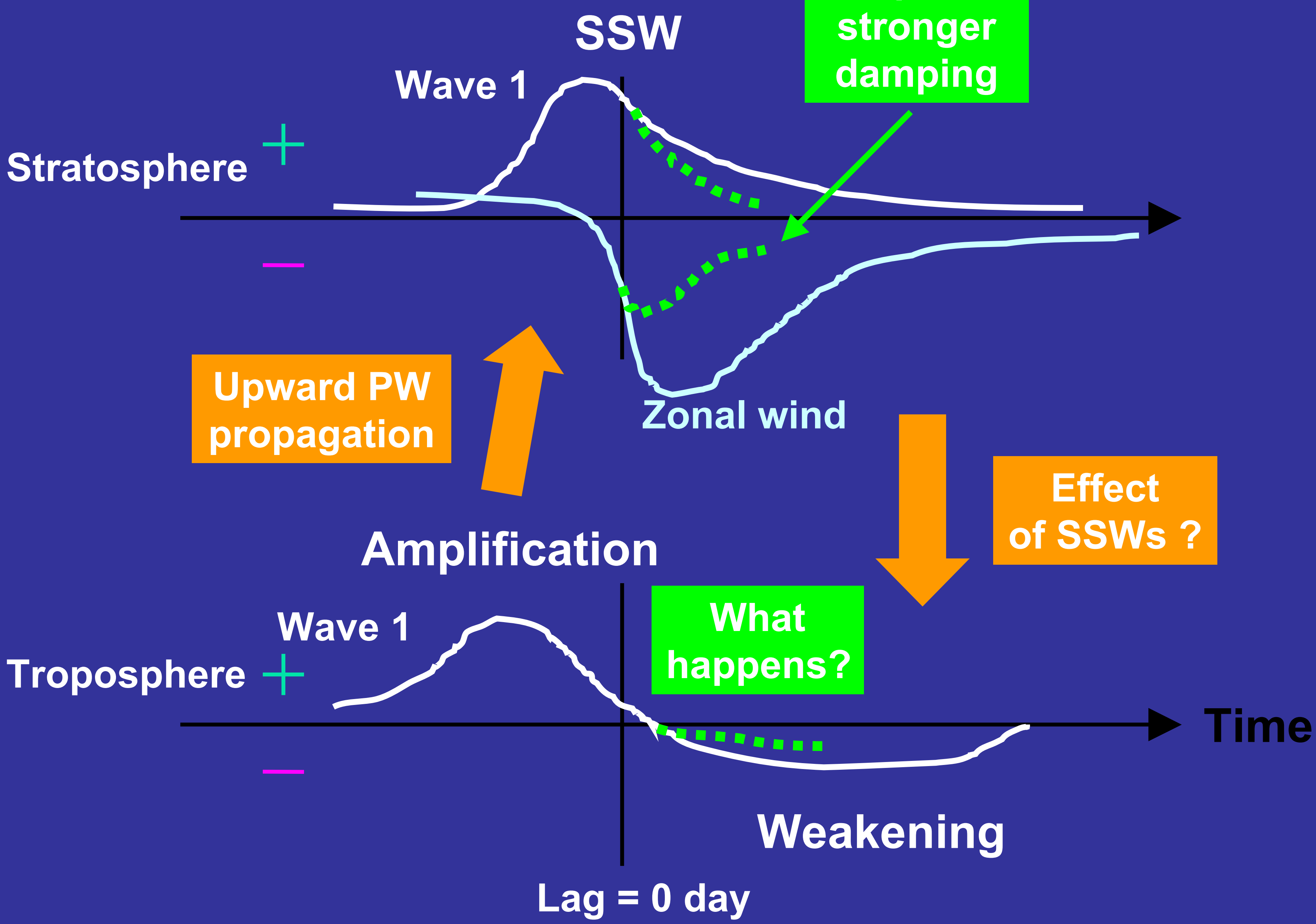
Zonal wind accel. by SWs: Div. of 3D EP flux

Region >20° for U* (N>600)
(Div. shifted by 5.6°)

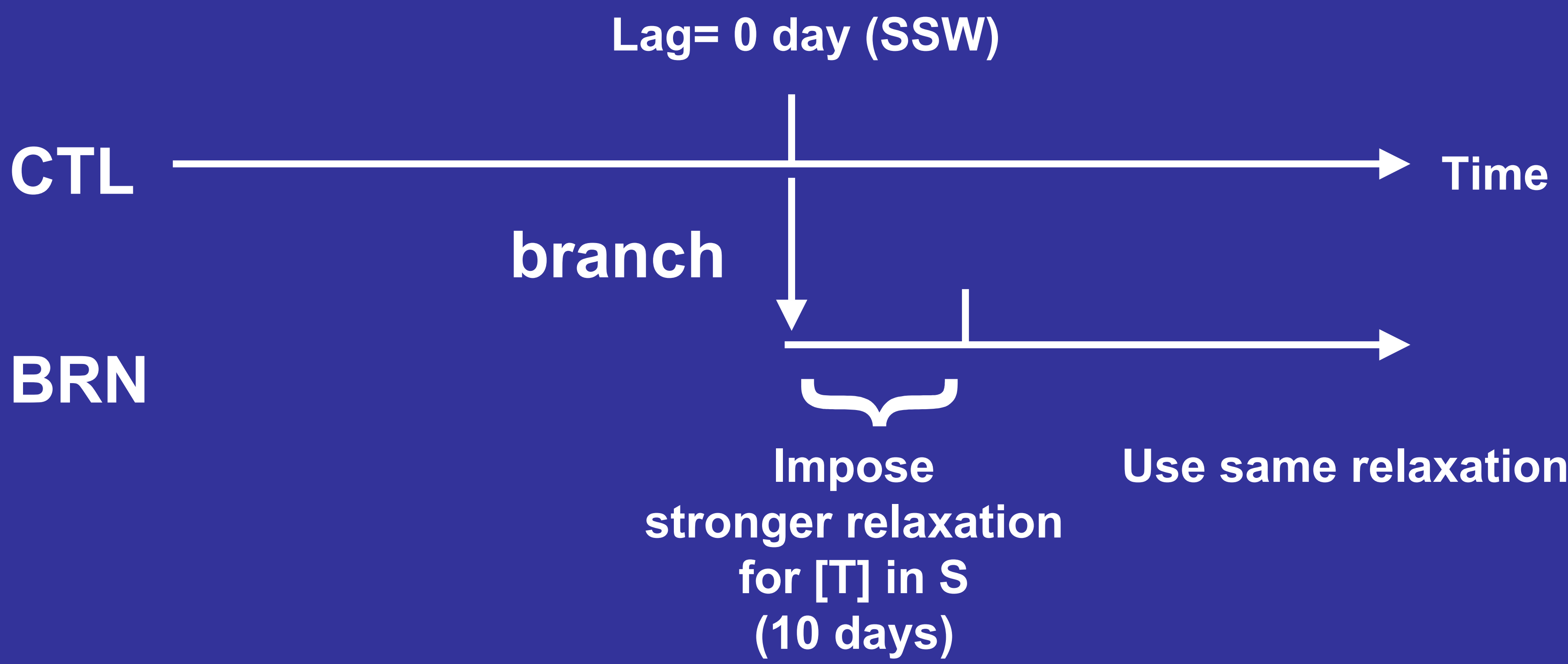
R=0.34

R=0.25

Obtained SSW sequence

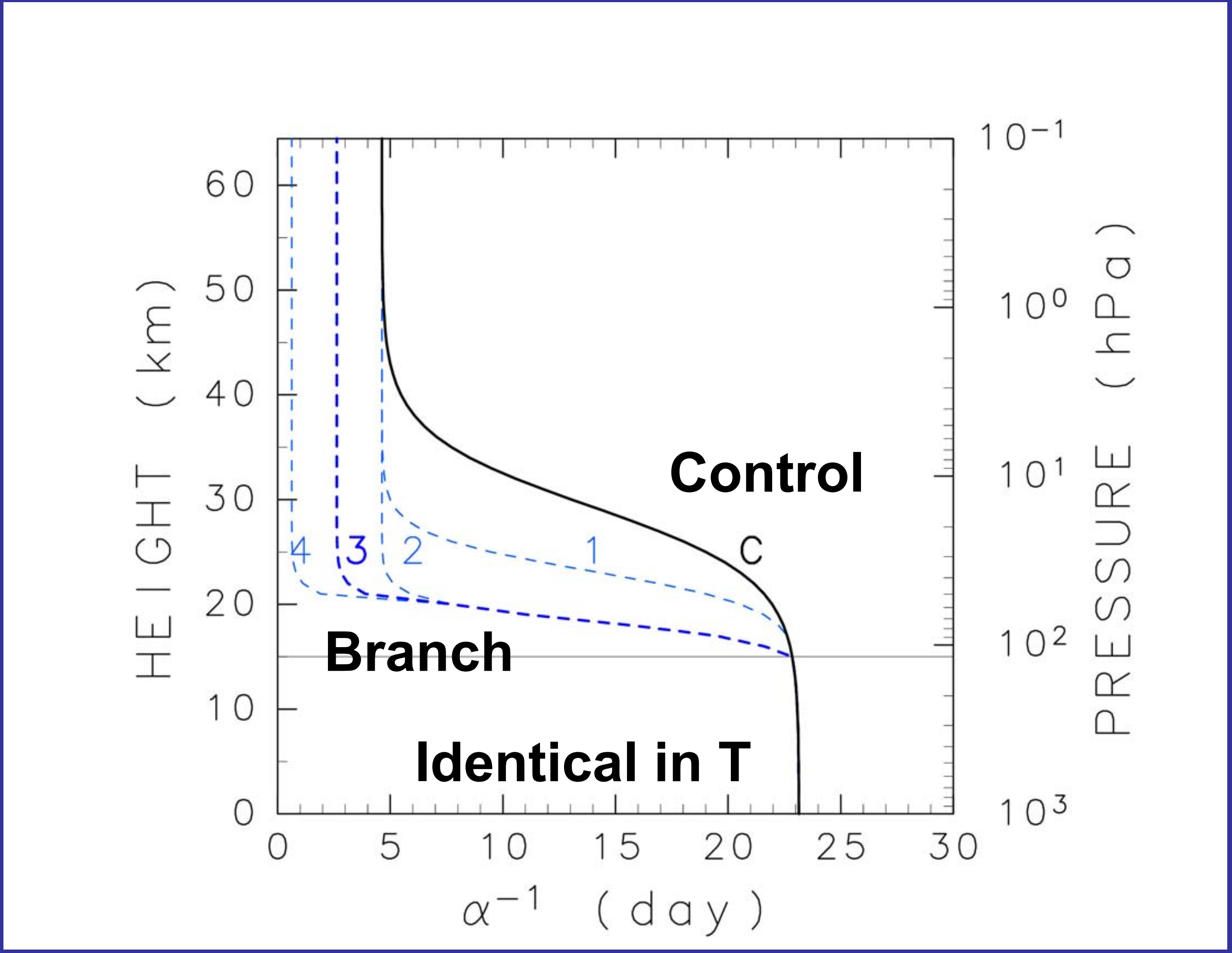


Procedures for Branch Runs

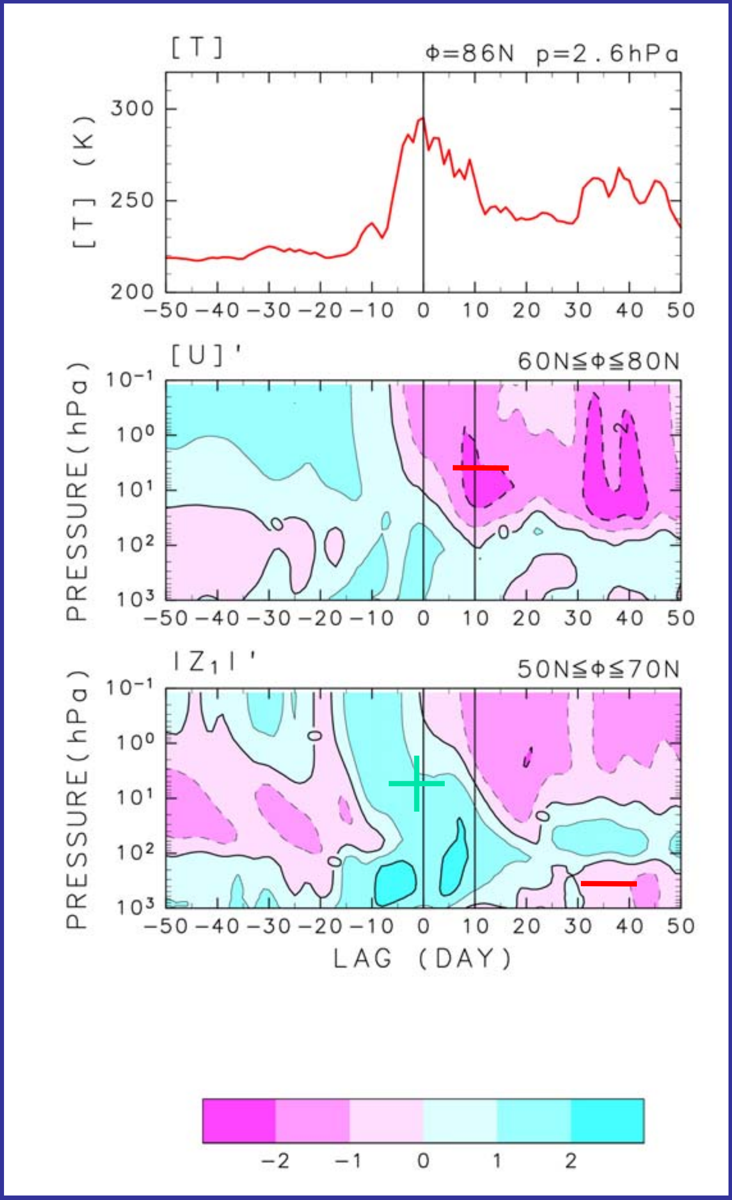


In branch runs, we can look at how T changes after we damp SSW signals for 10 days.

Thermal Relaxation Time for Branch Runs

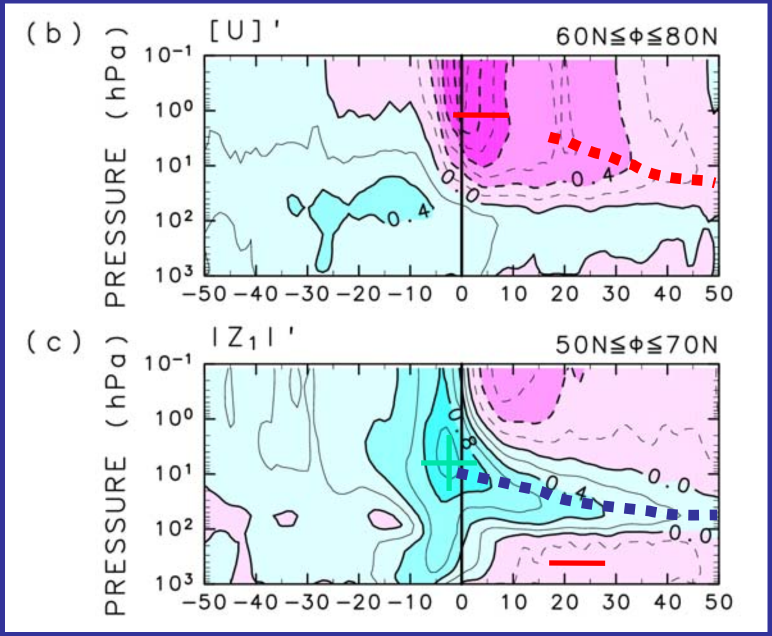


Choose one particular SSW event



Broadly similar ⇔

Composites of 132 events

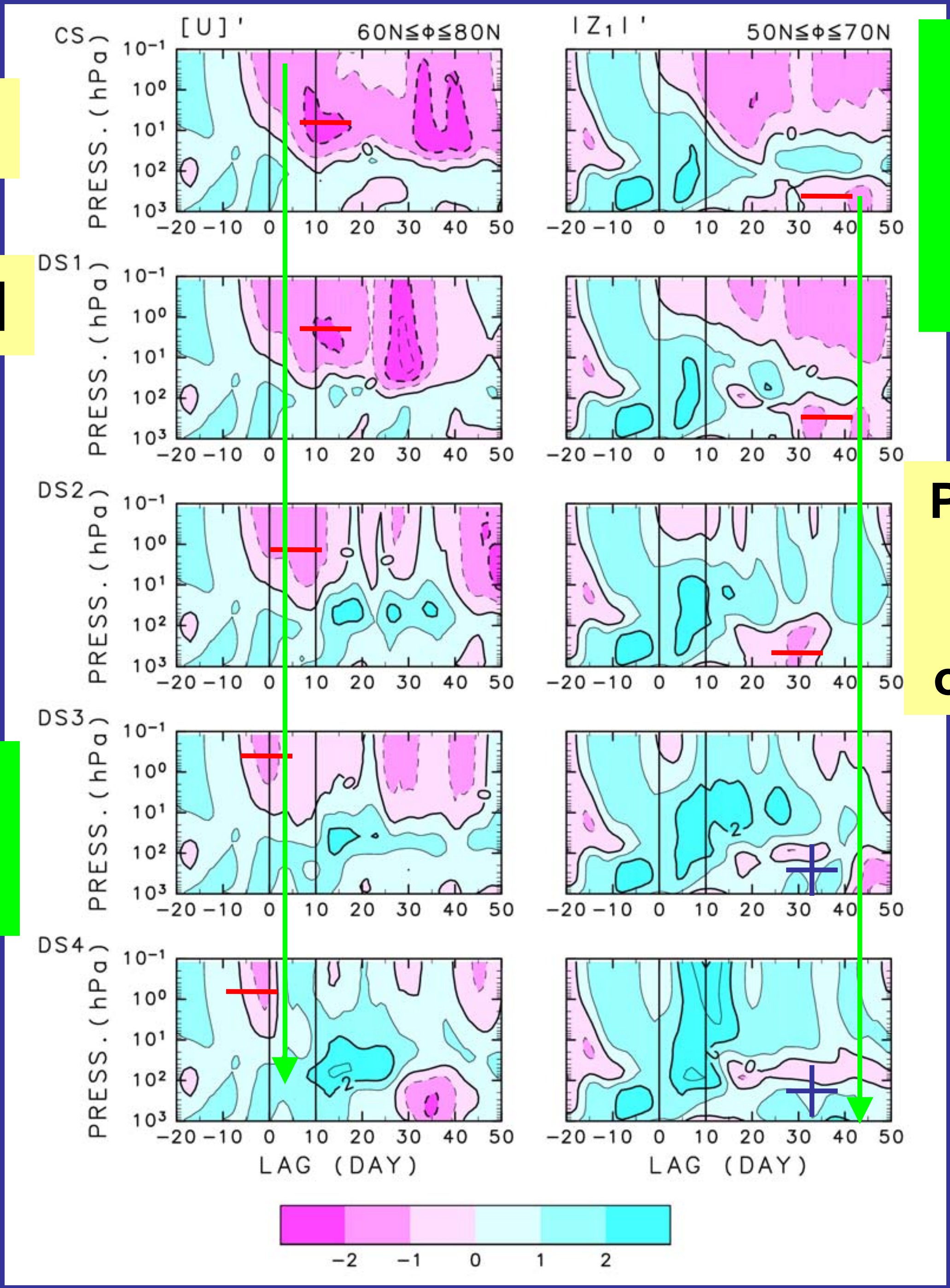


(color bars different)

Control vs Branch Runs

CTL

BRN



PW Weakening appears only following long-lasting SSW signals

PW signals in T change with damping of SSW signals

SSW signals damped

Shorter relaxation time

Conclusion

Nature of dynamical T-S coupling associated with SSWs

Composite analysis of 132 SSWs in 10,000-day MCM run

- Basically Similar Features to obs. & GCM results
- Diagnosis of T Circulation before and after SSWs

  Interaction between PW & SWs

  ⇒ “positive feedback”
- PW Signal in T after SSWs

  Appears only following long-lasting SSW signals

  ⇒ tropospheric response to SSWs

To summarize T-S coupling in this model,
PW in T, interacting with SWs (and also mean flow),
responds to SSWs which the wave itself induces.