

***Upwelling Wave Activity as Precursor to Extreme  
Stratospheric Events and Subsequent Anomalous  
Surface Weather Regimes***

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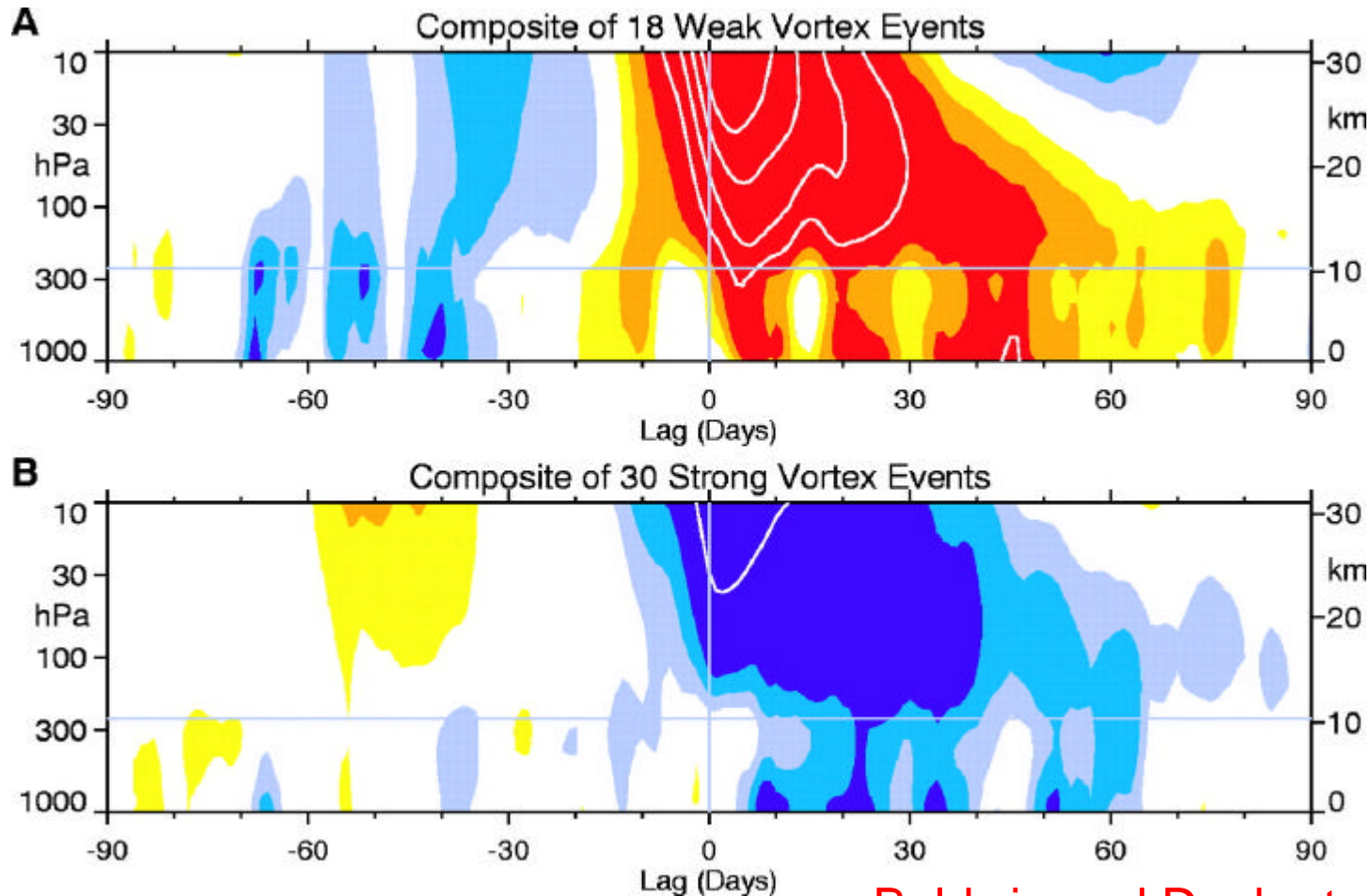
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# Stratospheric Harbingers of Anomalous Weather Regimes

Extreme Stratospheric Events (ESEs) are followed by anomalous weather regimes at the surface that persist for up to 2 months.



Baldwin and Dunkerton (2001)

# Issues

What dynamical mechanisms are responsible for the occurrence of Extreme Stratospheric Events (ESEs)?

Are these events intrinsically stratospheric or are they generated in the troposphere?

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Are these events intrinsically stratospheric or are they generated in the troposphere?

“Although stratospheric circulation anomalies are believed to be caused mainly by upward-propagating planetary-scale waves, other process within the stratosphere may affect the likelihood of extreme events” [Baldwin and Dunkerton, 2001]

“All stratospheric events are preceded by bursts of EP flux ”  
[Plumb, yesterday]

# Data and Analysis

Examine the relationship between ESEs and planetary wave activity emanating from the stratosphere.

Daily NCEP/NCAR Reanalyses from 1958 to 2001.

- ❑ Meridional eddy heat flux  $\overline{v'T'}$  at 100 hPa averaged between 45 and 75N.
- ❑ Northern Annular Mode (NAM) index from Baldwin and Dunkerton (2001).

Focus on heat flux averaged over  $N$  days prior to each day ( $N$  typically 40).

# Eddy Heat Flux – Polar Vortex Connection

Newman et al. (2001): Stratospheric polar temperature is related not to the instantaneous upward wave activity but to weighted integral over several weeks.

Polar cap  
averaged T  
at t=0

Radiative  
Equilibrium T

Radiative  
Damping

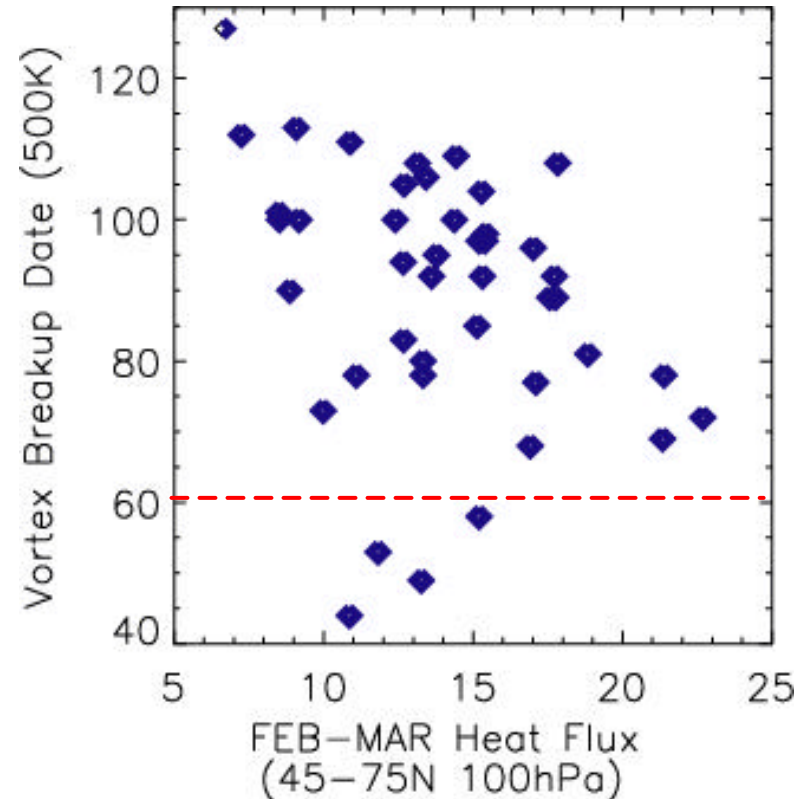
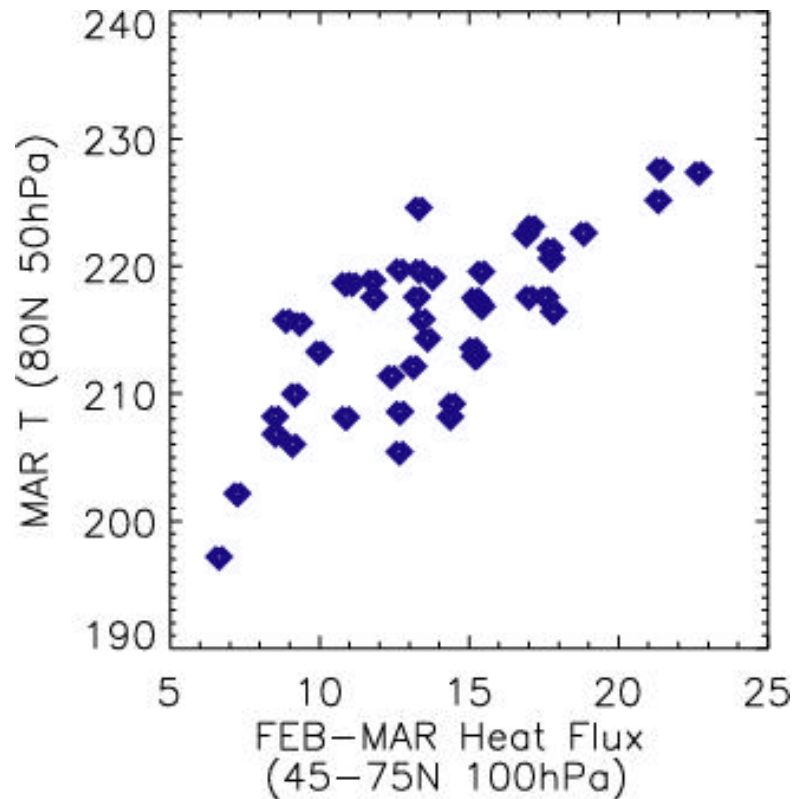
$$\begin{aligned} \langle T(0) \rangle_{\phi^*} = & \langle T_{RE} \rangle_{\phi^*} + e^{-\alpha t} [\langle T(-t) \rangle_{\phi^*} - \langle T_{RE} \rangle_{\phi^*}] \\ & + \frac{\cos \phi^*}{a(1 - \sin \phi^*)} \int_{-t}^0 e^{-\alpha \tau} \{ \overline{v' T'} \}_{\phi^*} d\tau \end{aligned}$$

Exponentially  
weighted integral of  
preceding eddy heat  
flux

[  $\alpha^{-1}$  = damping time ]

# Eddy Heat Flux – Polar Vortex Connection

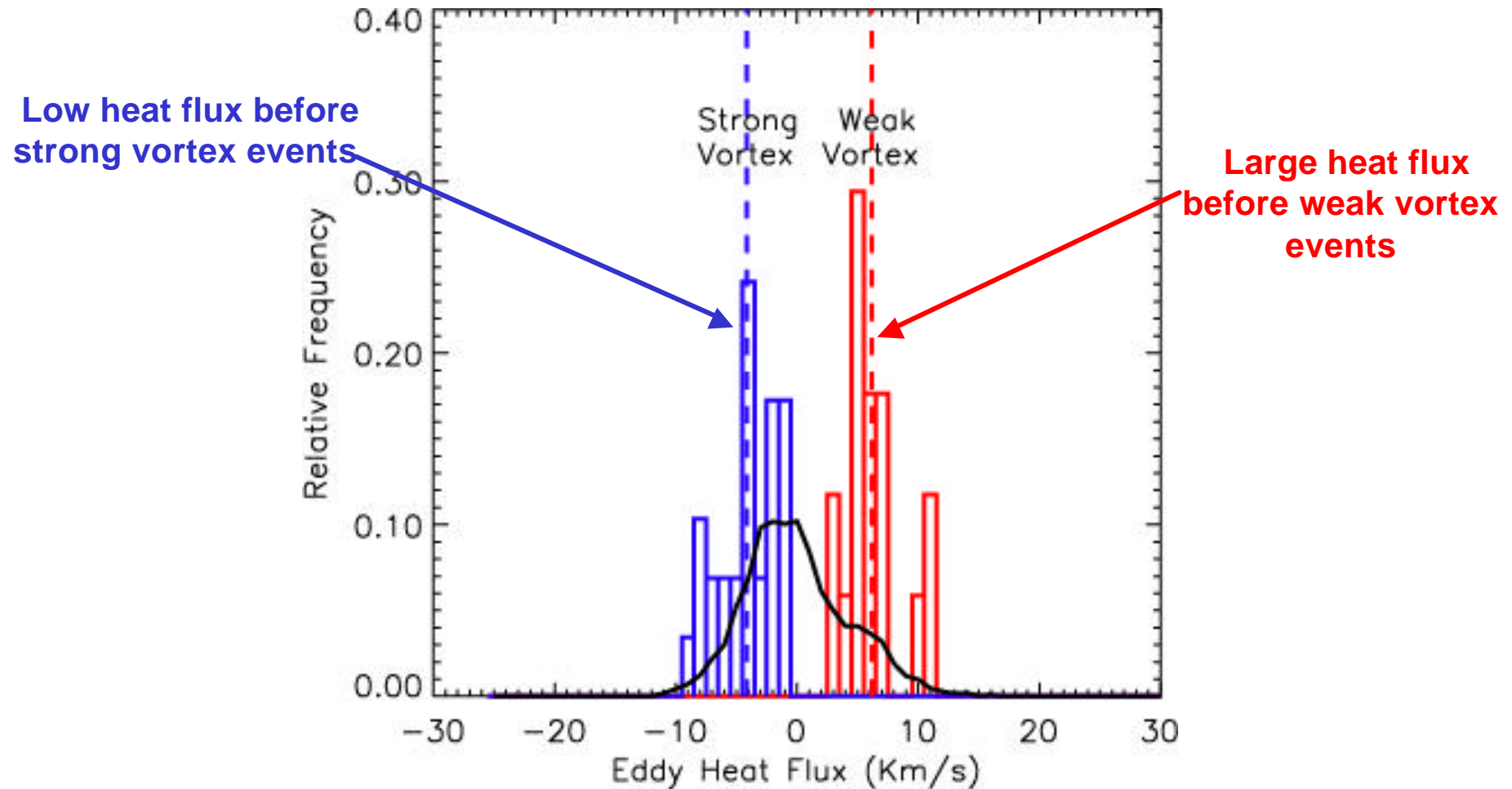
Studies have shown a strong relationship between vortex strength / breakup and eddy heat flux on interannual timescales.



Waugh et al. (1999).

# Heat Flux Preceding Extreme Vortex Events

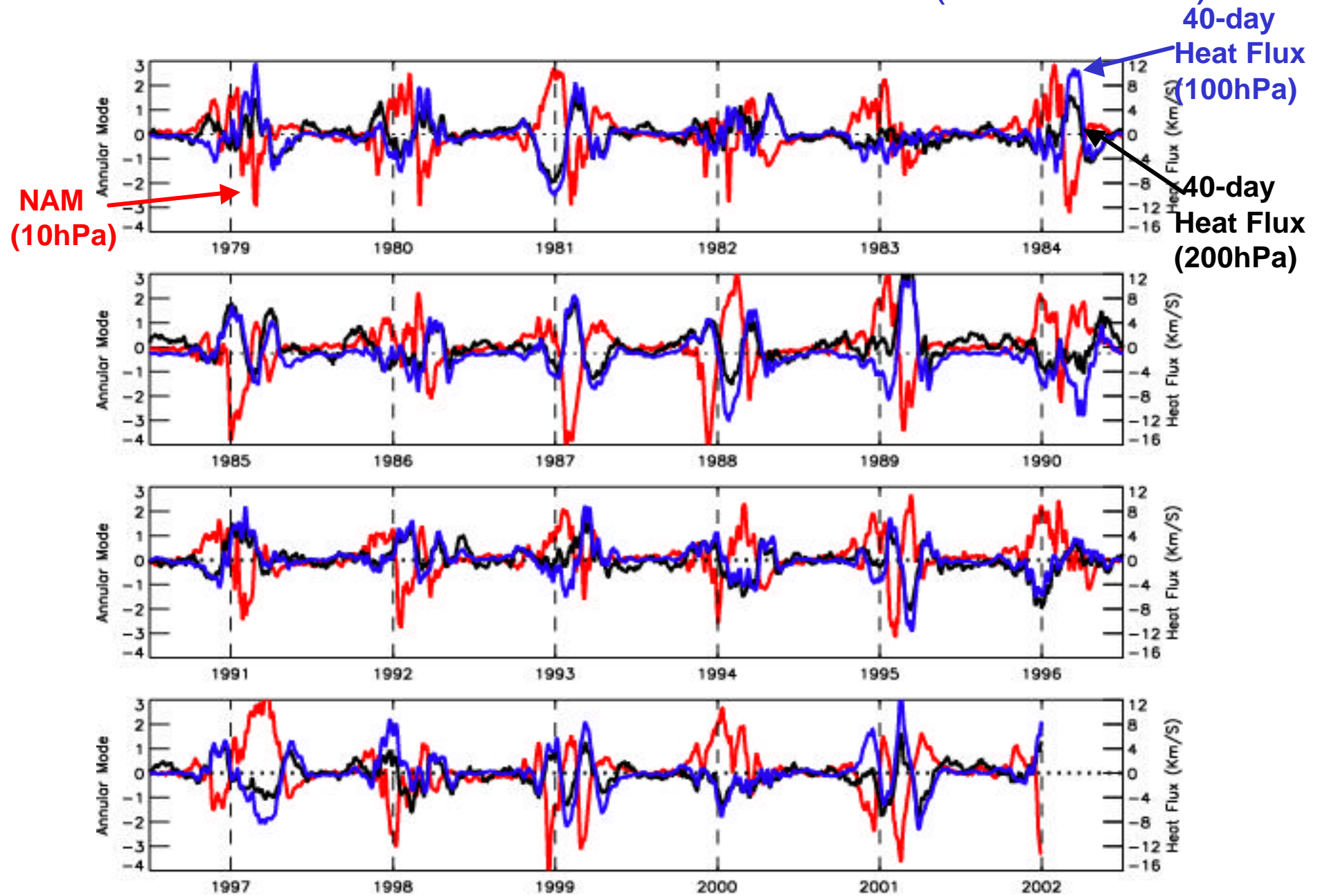
40-day average 100hPa Heat Flux before Strong/Weak Vortex Events (as defined by Baldwin and Dunkerton 2001).



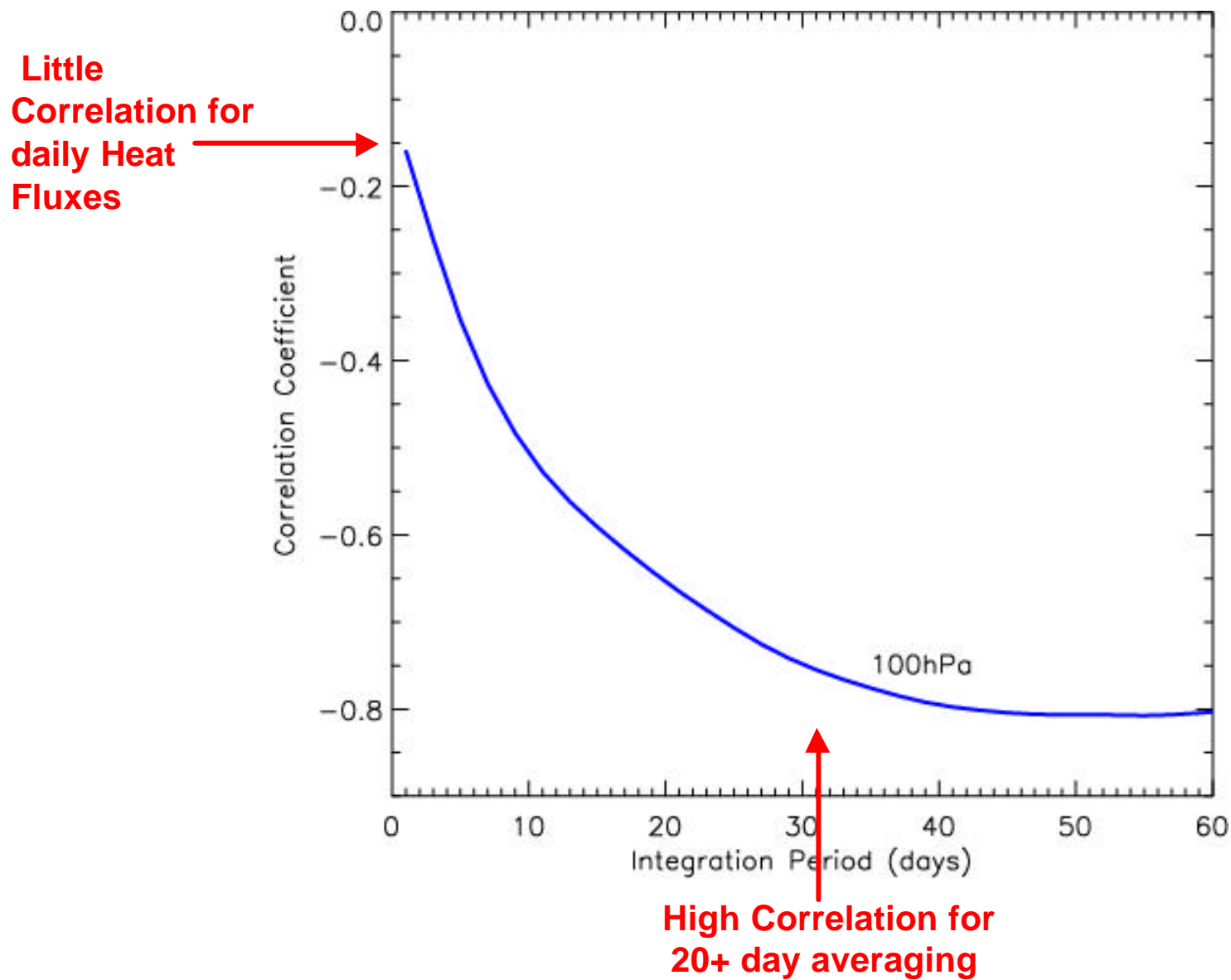
ESEs are preceded by anomalous wave activity entering the stratosphere.



# Time series of NAM and Heat Flux (1979-2001)

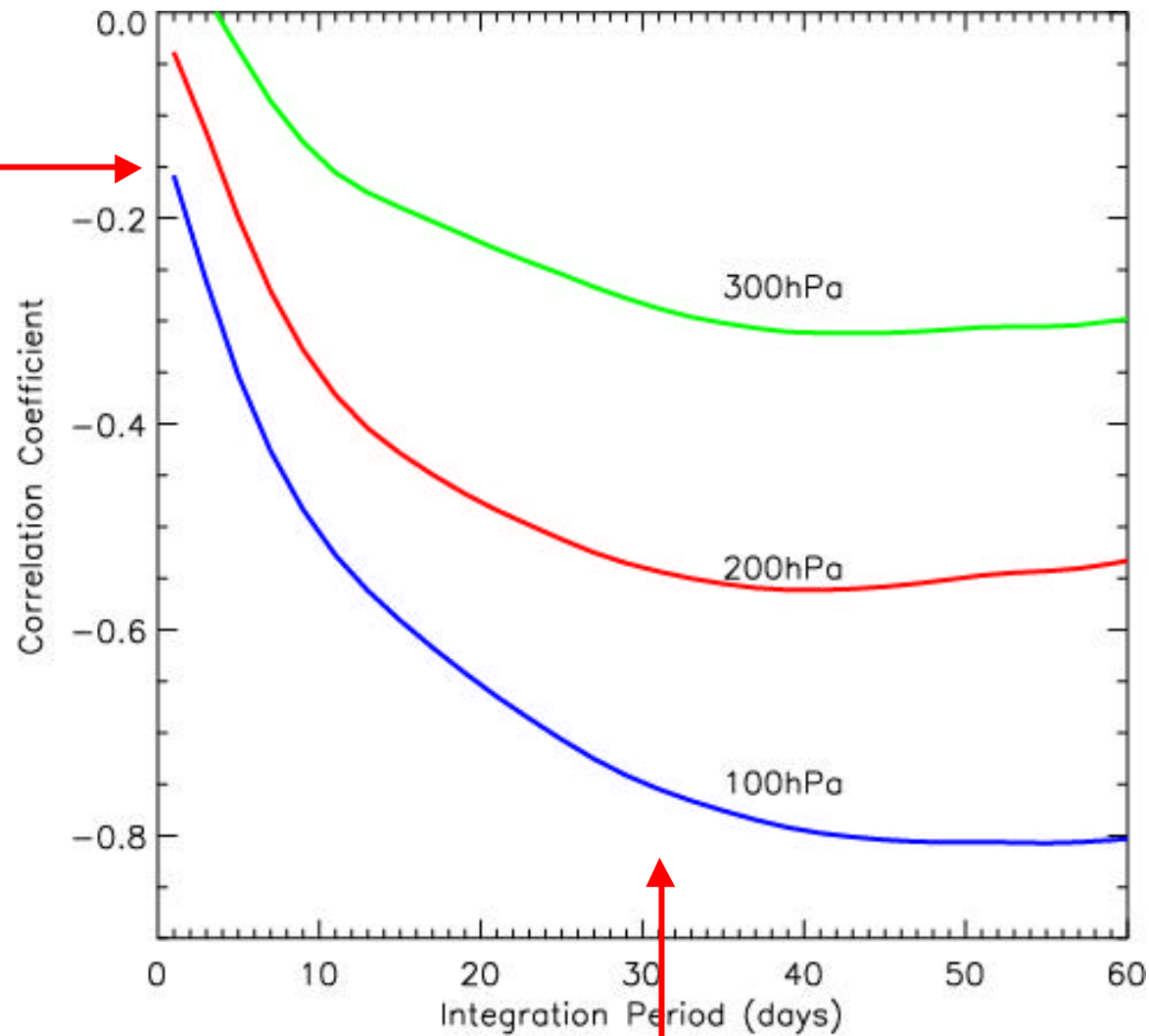


# Heat Flux – NAM Correlation



# Heat Flux – NAM Correlation

Little  
Correlation for  
daily Heat  
Fluxes



High Correlation for  
20+ day averaging

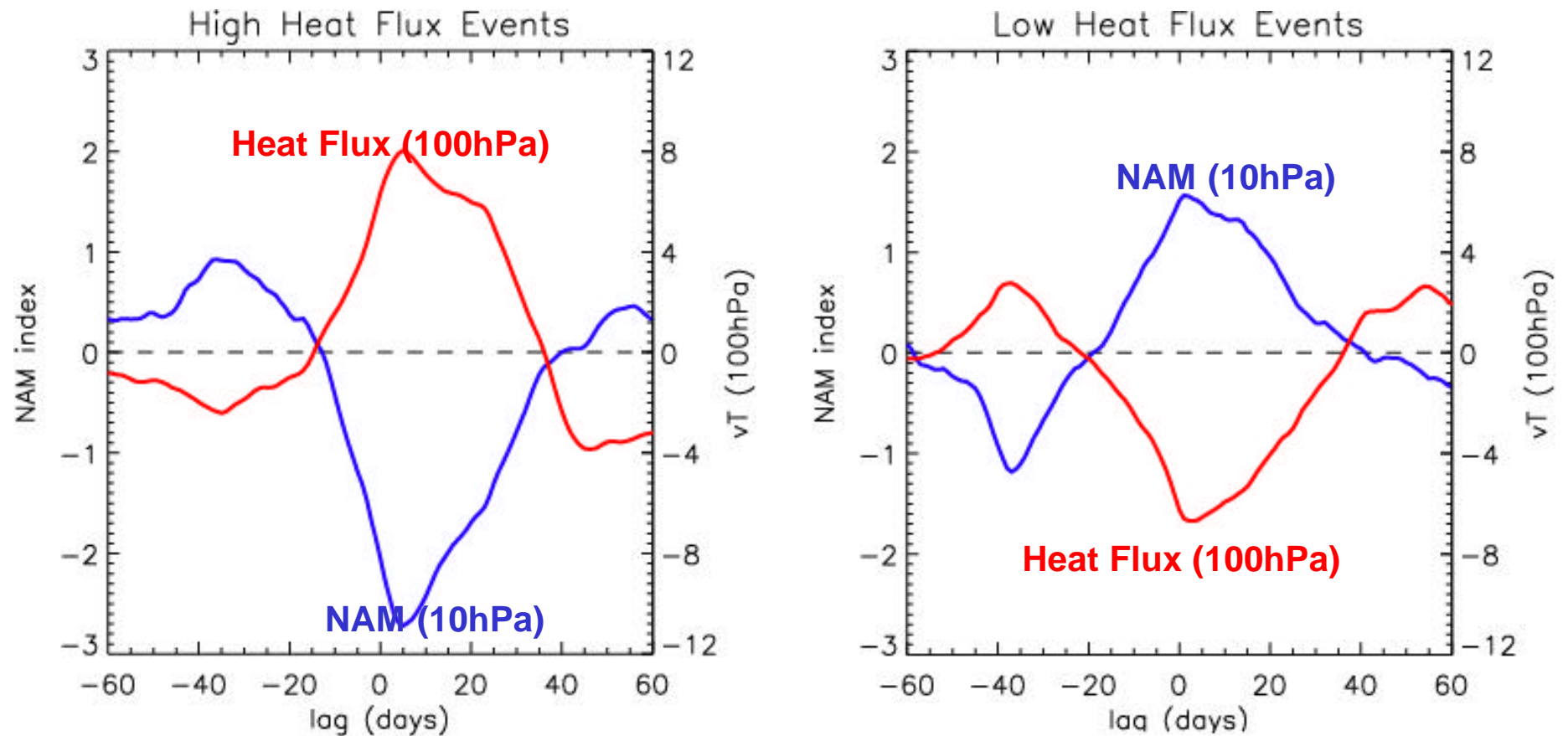
# Heat Flux Composites

What is the state of the atmosphere during/following periods with anomalous eddy heat fluxes?

Determine Heat Flux “events” when time integrated heat flux exceeds specified thresholds. (40-day HF exceeds  $\pm 5.5$  Km/s; 24/25 events).

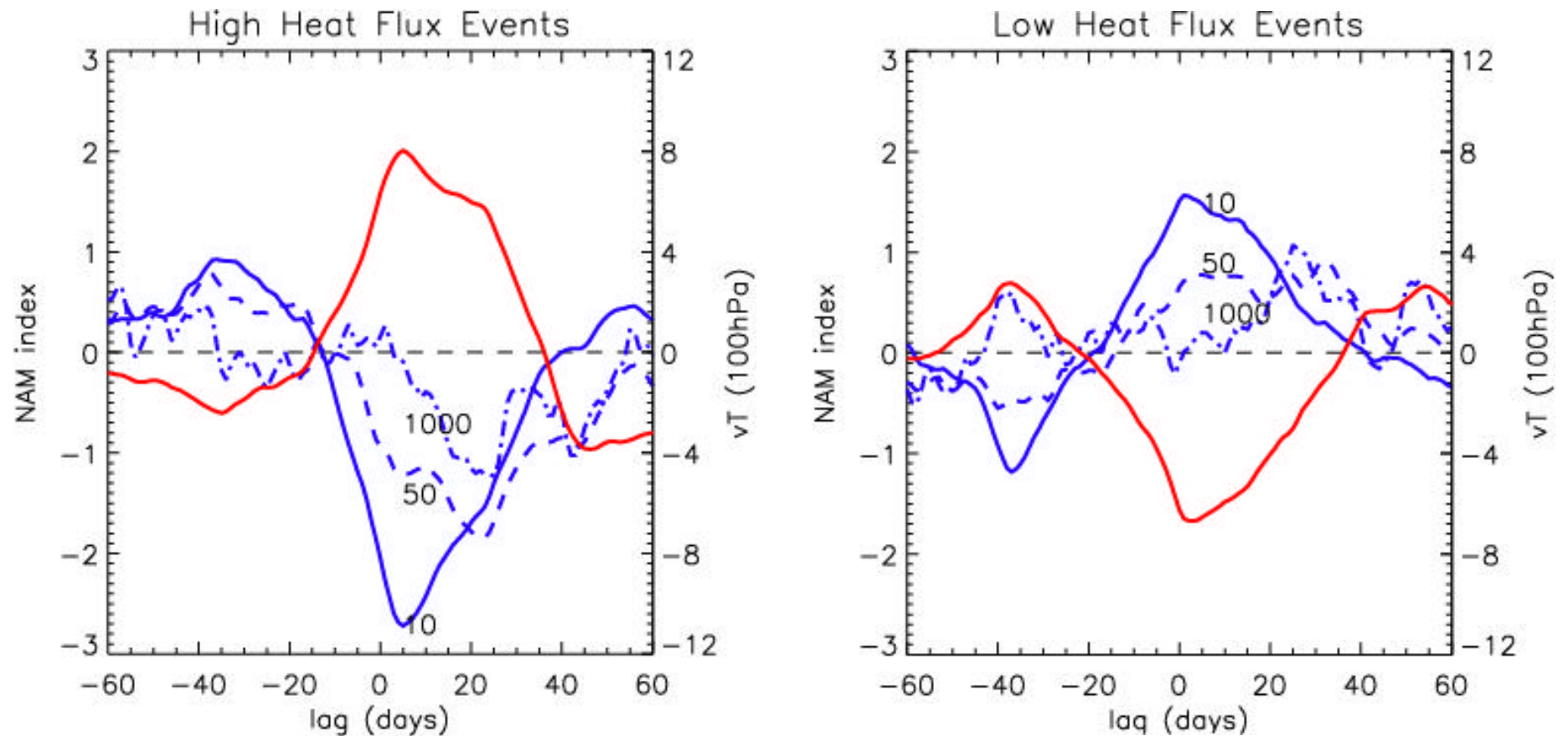
Examine composite (mean) of NAM index for heat flux events.

# Composites for Heat Flux Events



Very high anticorrelation, with onset of ESEs (high/low NAM) occurring at same time as anomalous heat flux events.

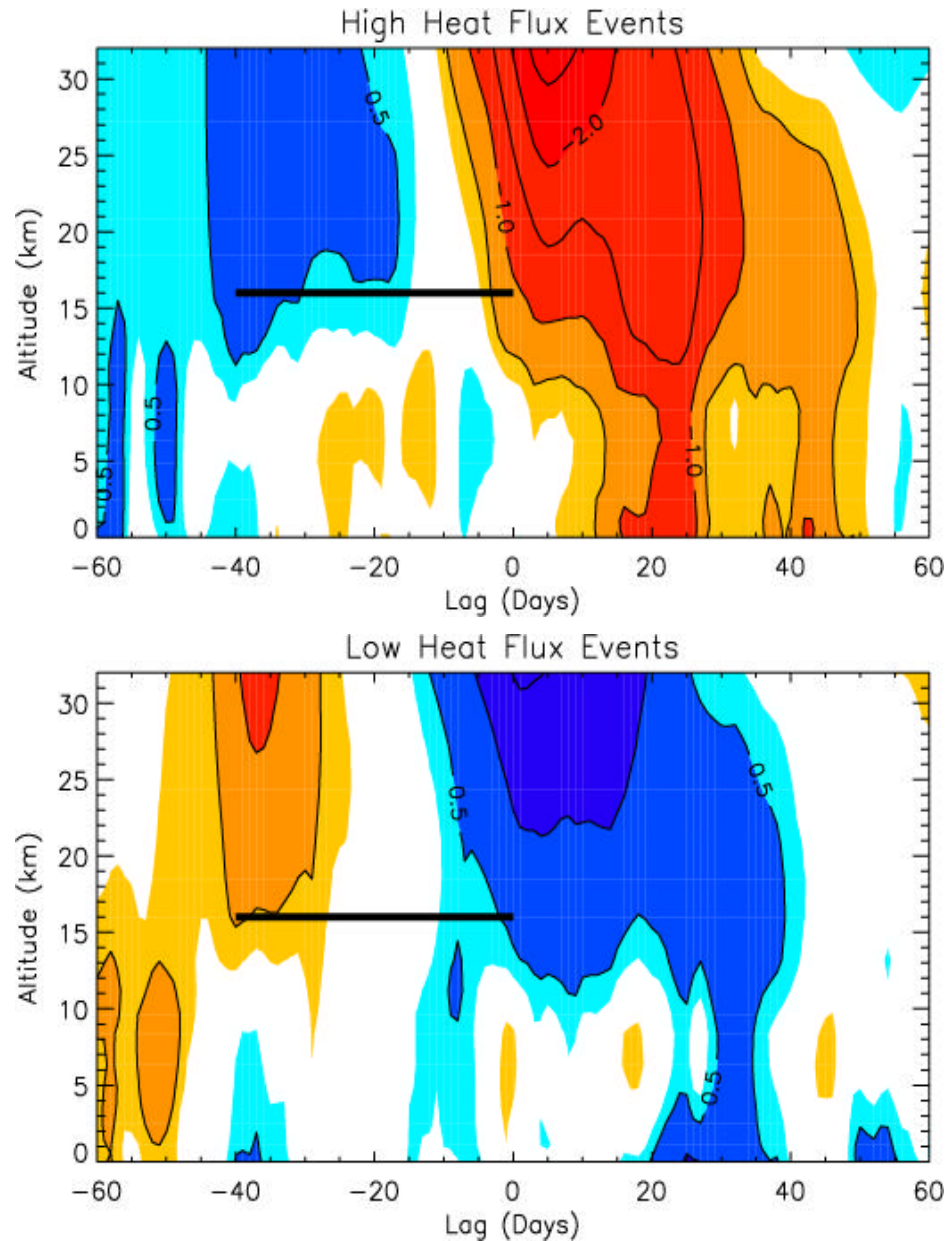
## NAM Composites at 10, 50, 1000hPa



Difference in NAM at 50 and 1000 hPa following heat flux events.



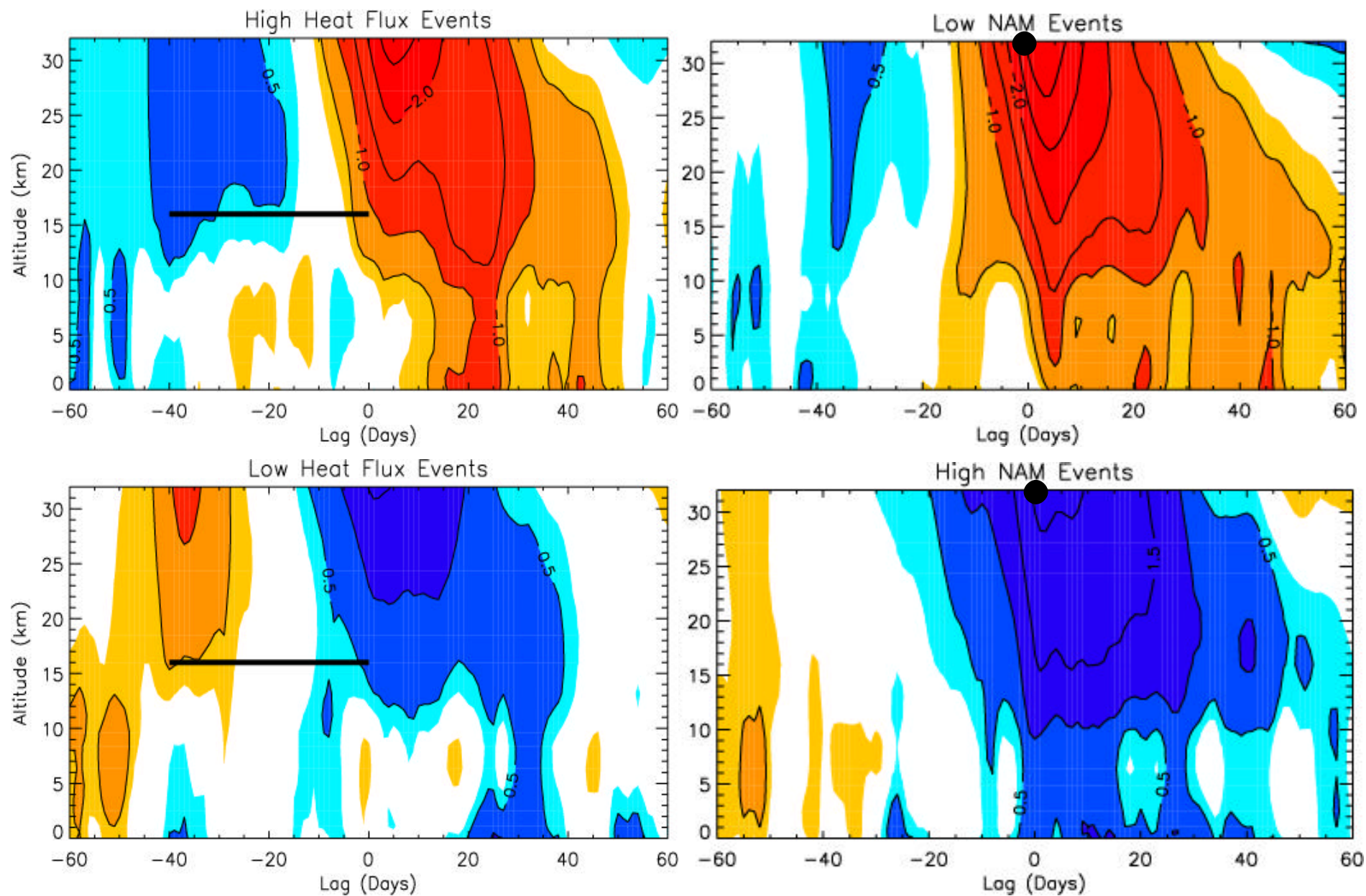
# NAM Composites for Heat Flux Events



Evolution of NAM index following heat flux events is very similar to that following ESEs (Baldwin and Dunkerton 2001),

e.g., NAM anomalies appear first in middle stratosphere and migrate down to surface, where “persist” for 60 days.

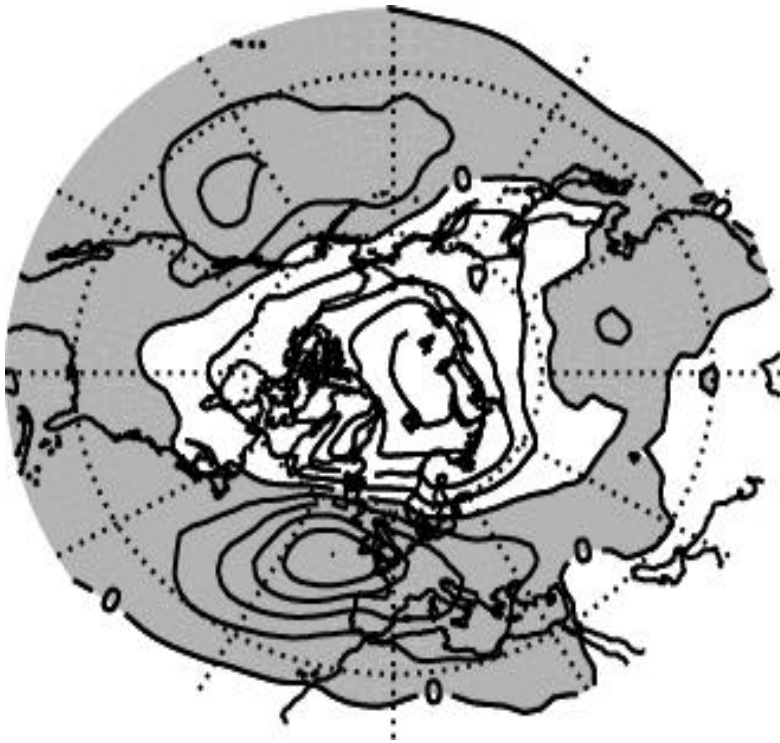
# NAM Composites for Heat Flux Events



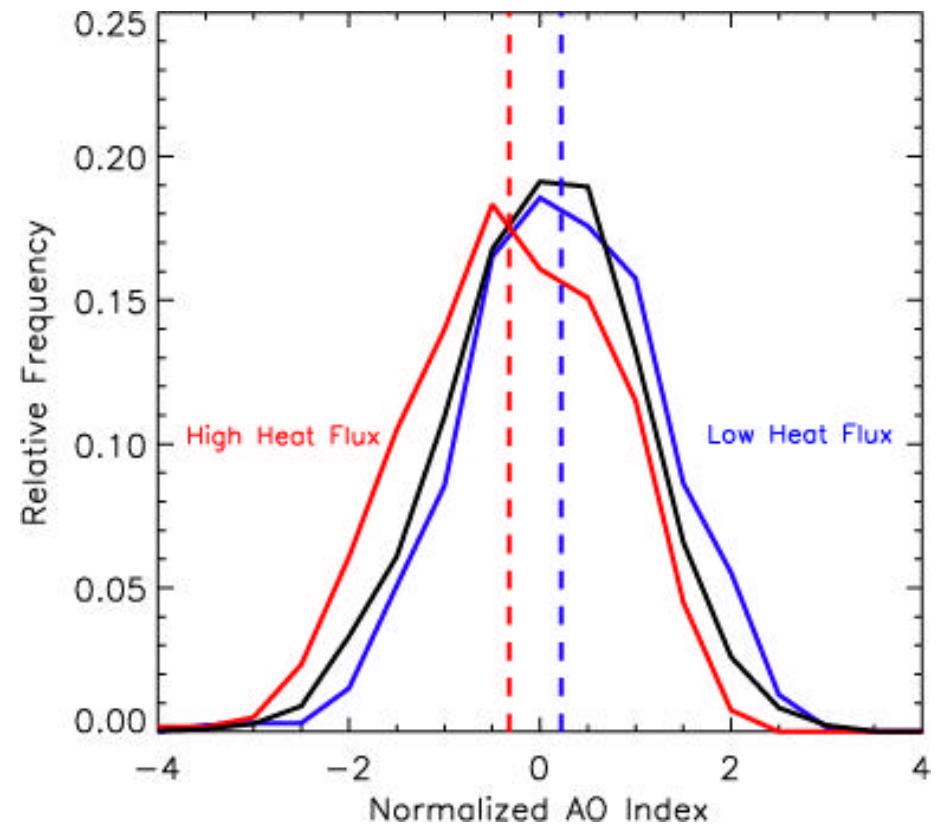


# Surface Signal

As with NAM events there is a different in surface for 60 days following heat flux events.



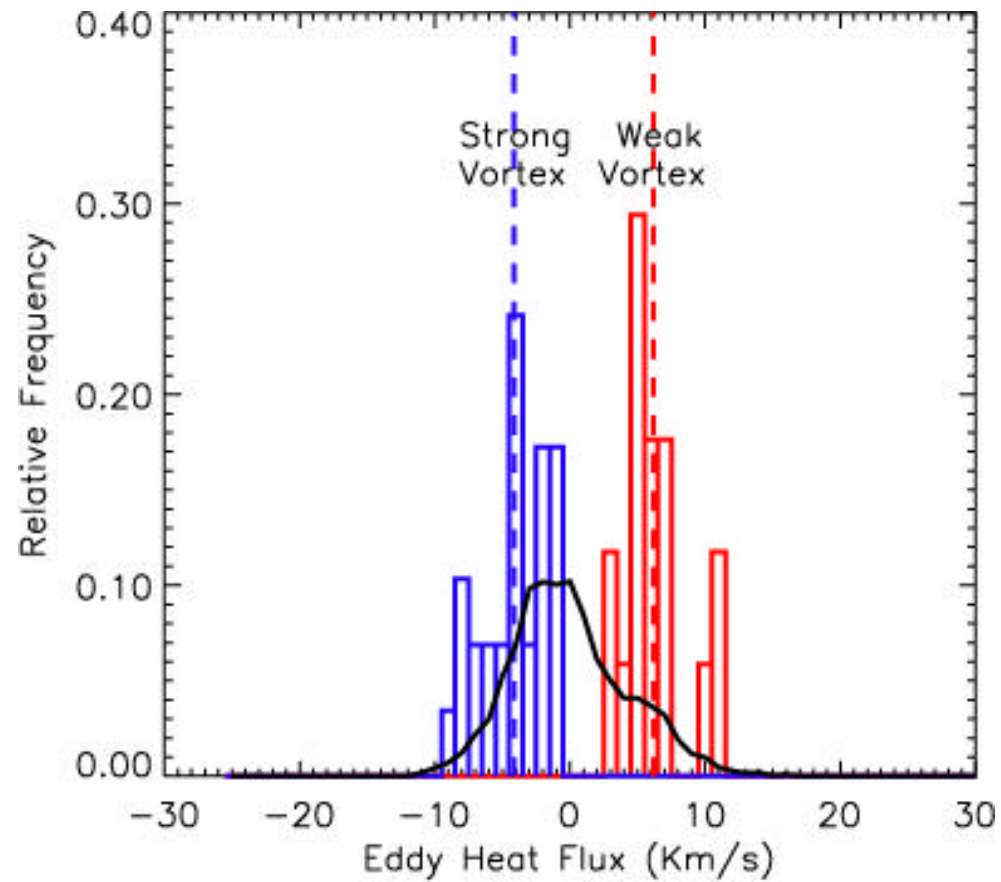
Difference in sea-level pressure between high and low HF events.



PDFs of surface NAM index for high and low HF events.

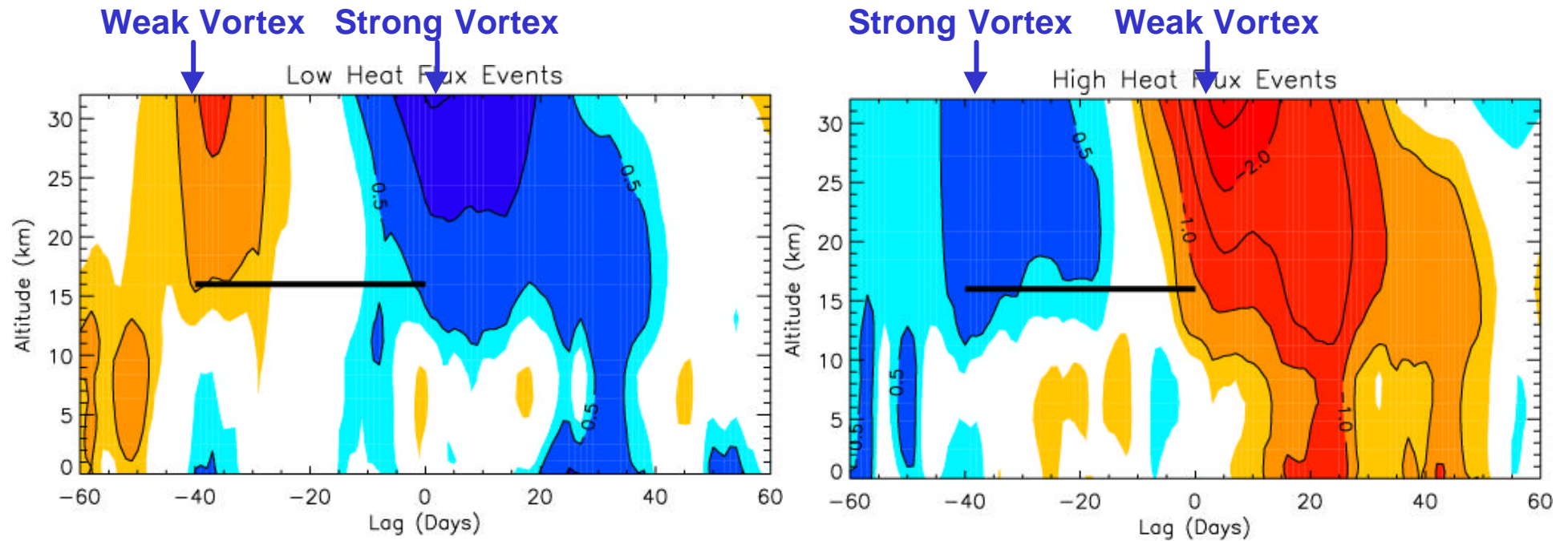
What is the cause of the anomalous periods of wave activity entering the stratosphere?

## Random Events?



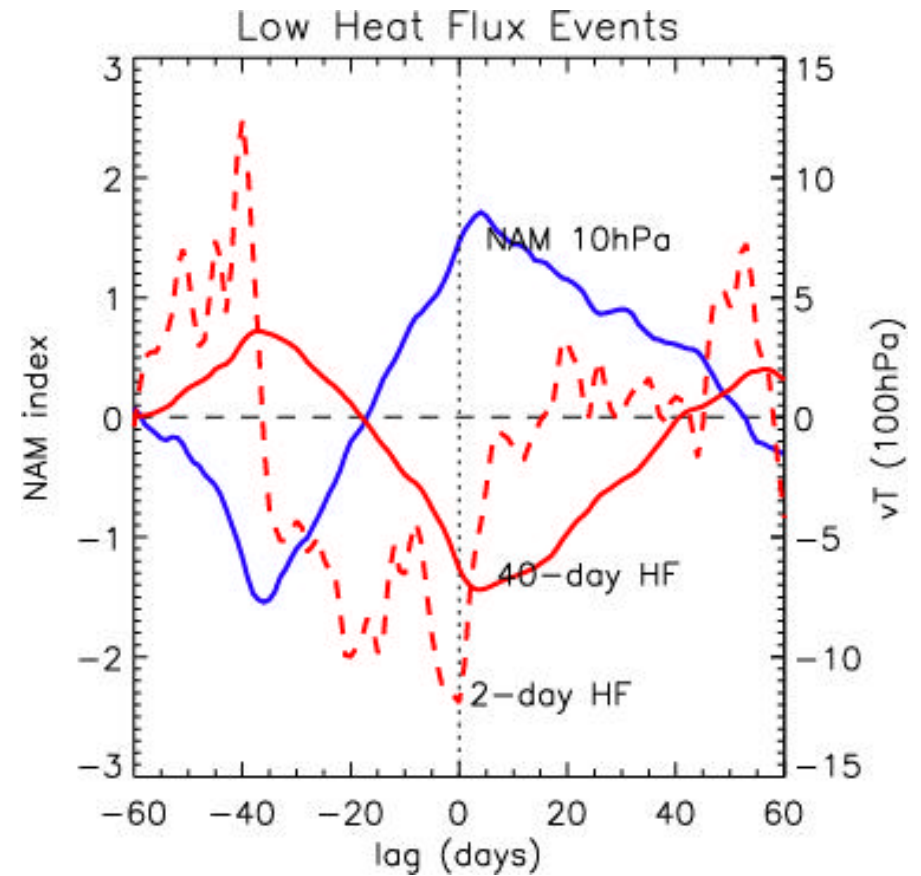
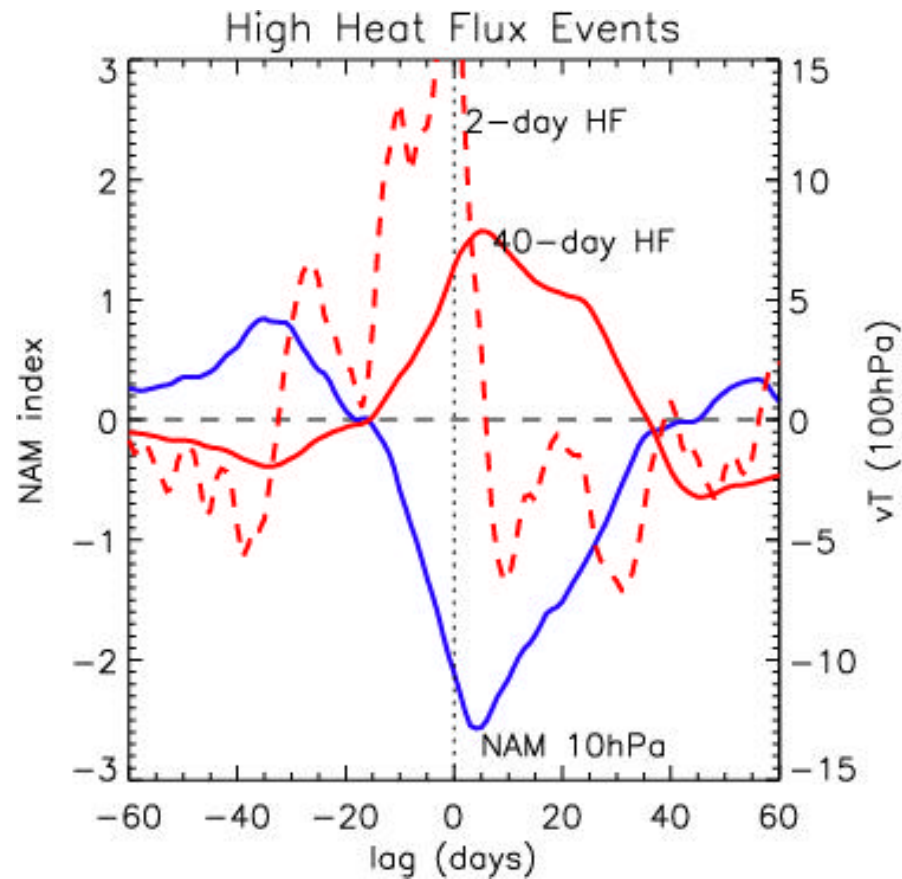
Heat flux events could be interpreted as tails of a Gaussian PDFs -> Random Events?

# Stratospheric Preconditioning?

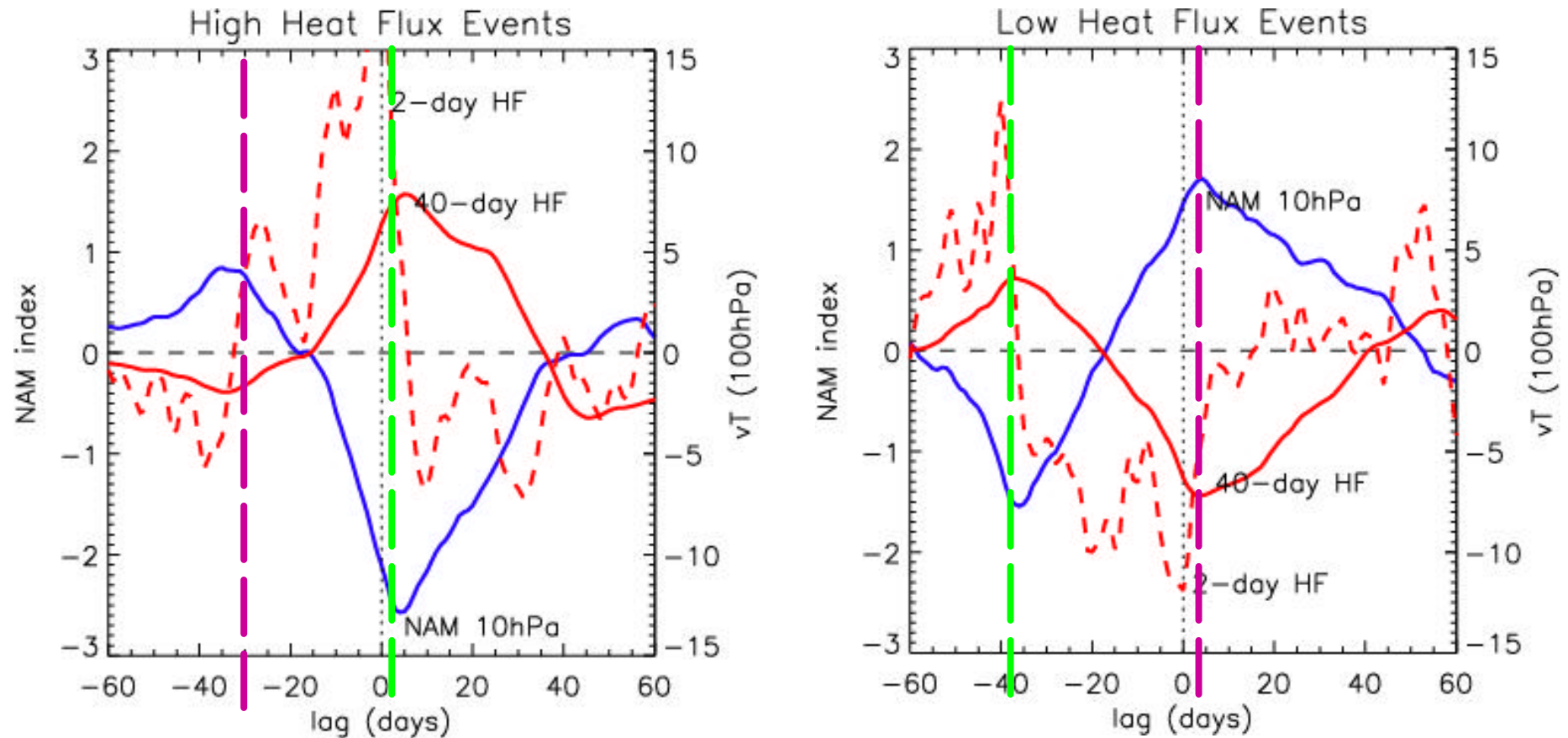


Strong (Weak) vortex preceding periods of High (Low) heat flux suggests the stratosphere may play a role.

# Variations in Daily Heat Flux



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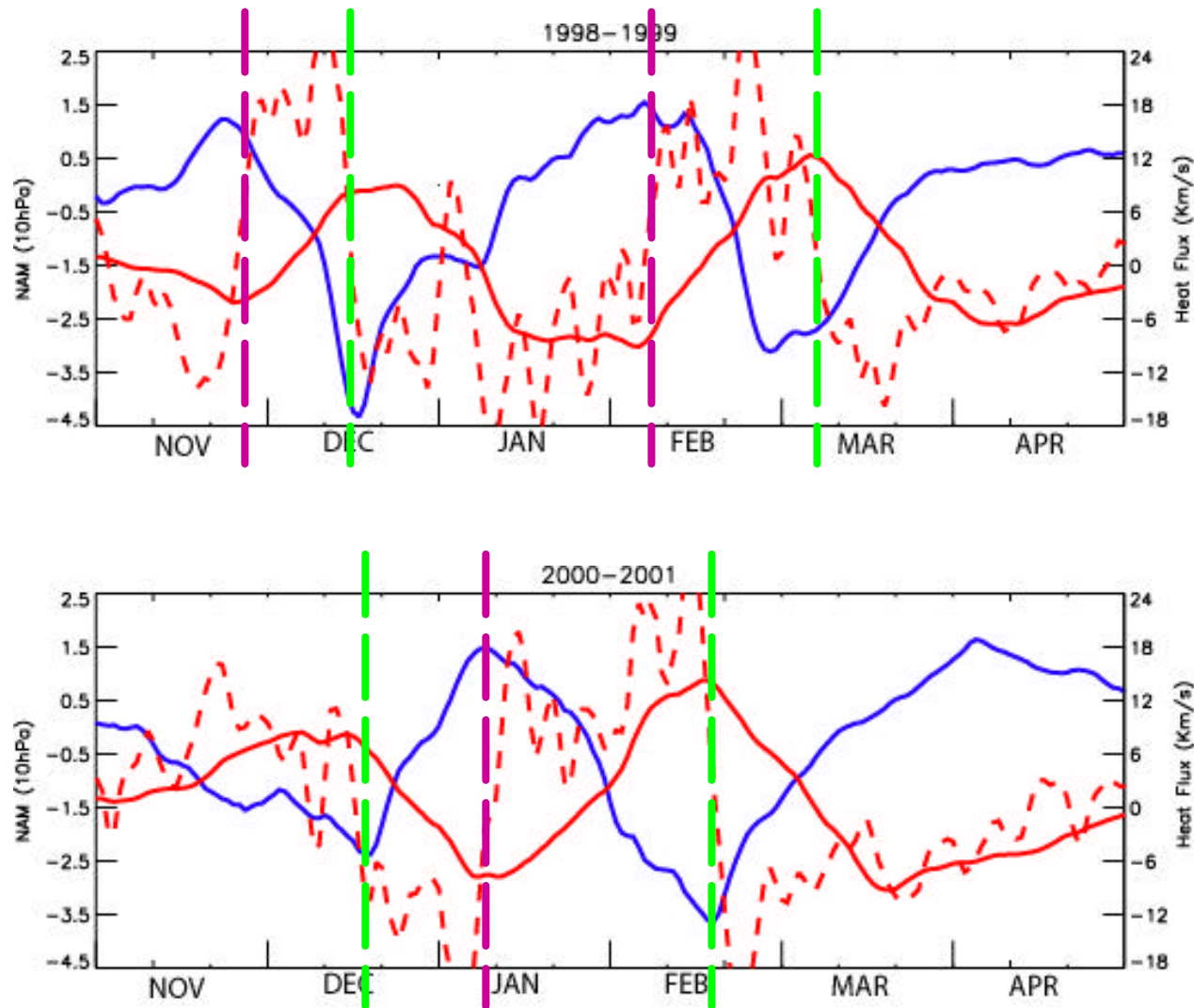


Rapid changes in daily heat flux at time of ESEs.

Periods with NAM in high or low phase generally include both days with high and low upward wave activity



## 1998-1999 and 2000-2001 winters



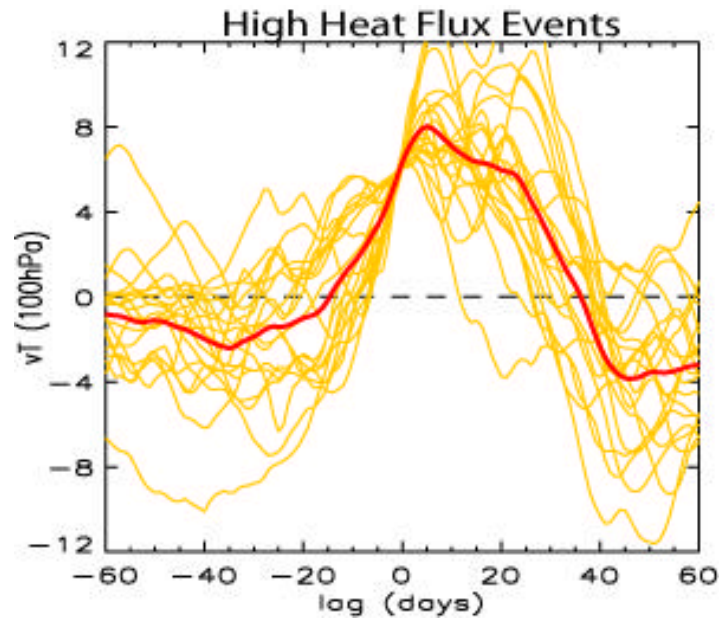
## Concluding Remarks

- ❑ State of middle stratosphere vortex is high correlated with time-integrated wave activity entering the stratosphere.
- ❑ The time-integrated wave activity is nearly always anomalous prior to Extreme Stratospheric Events.
- ❑ Key outstanding issue is what determines anomalies in the upwelling flux. Some suggestion that stratosphere plays a role.

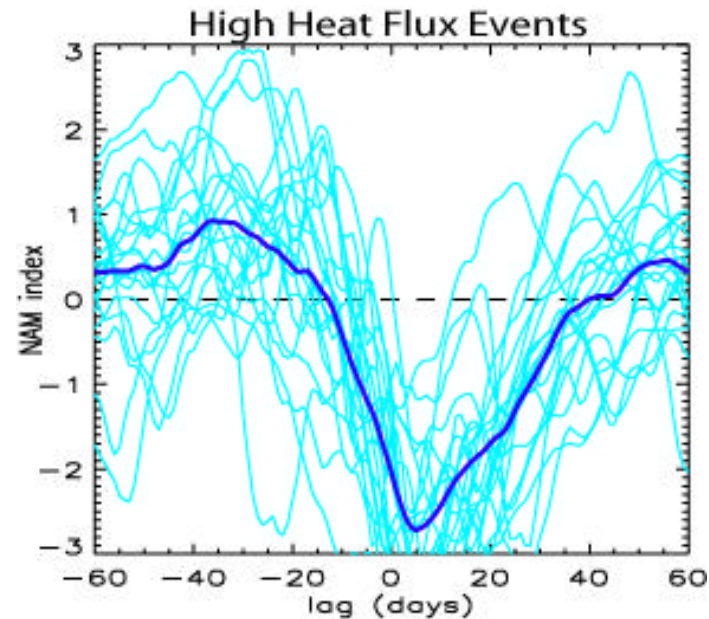


# Variability between Events

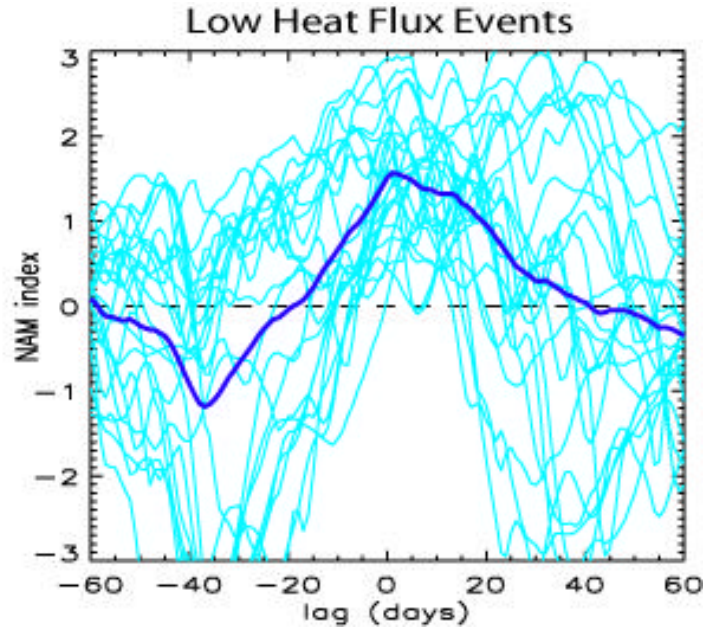
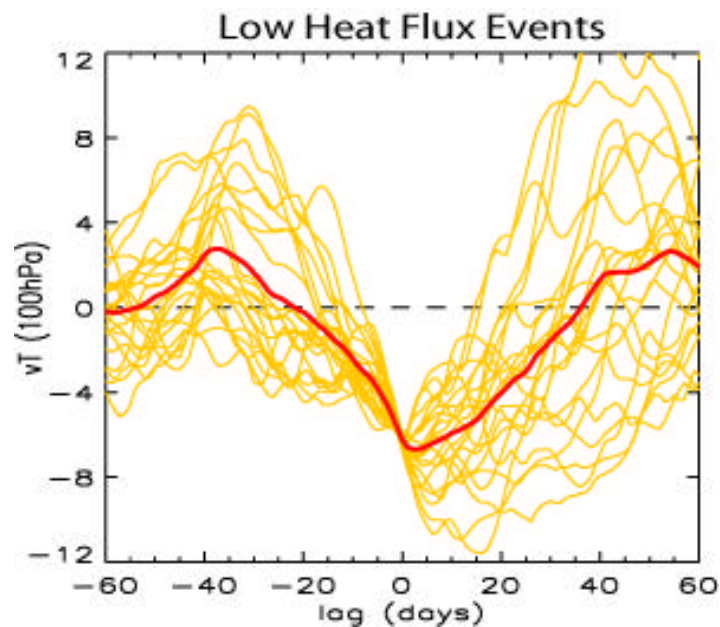
Heat Flux (100hPa)



NAM (10hPa)



High Heat Flux  
Events



Low Heat Flux  
Events