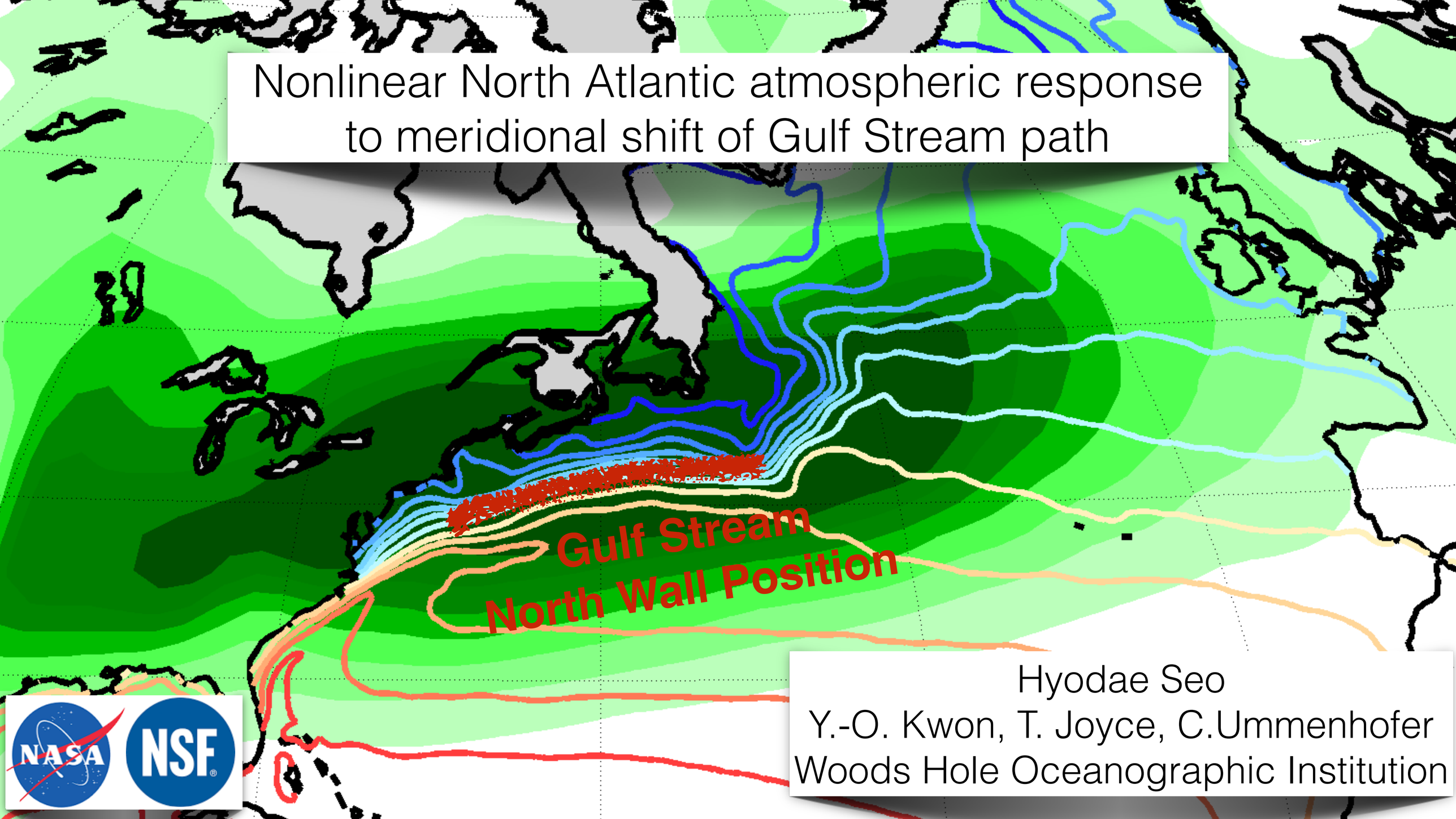
Nonlinear North Atlantic atmospheric response to meridional shift of Gulf Stream path

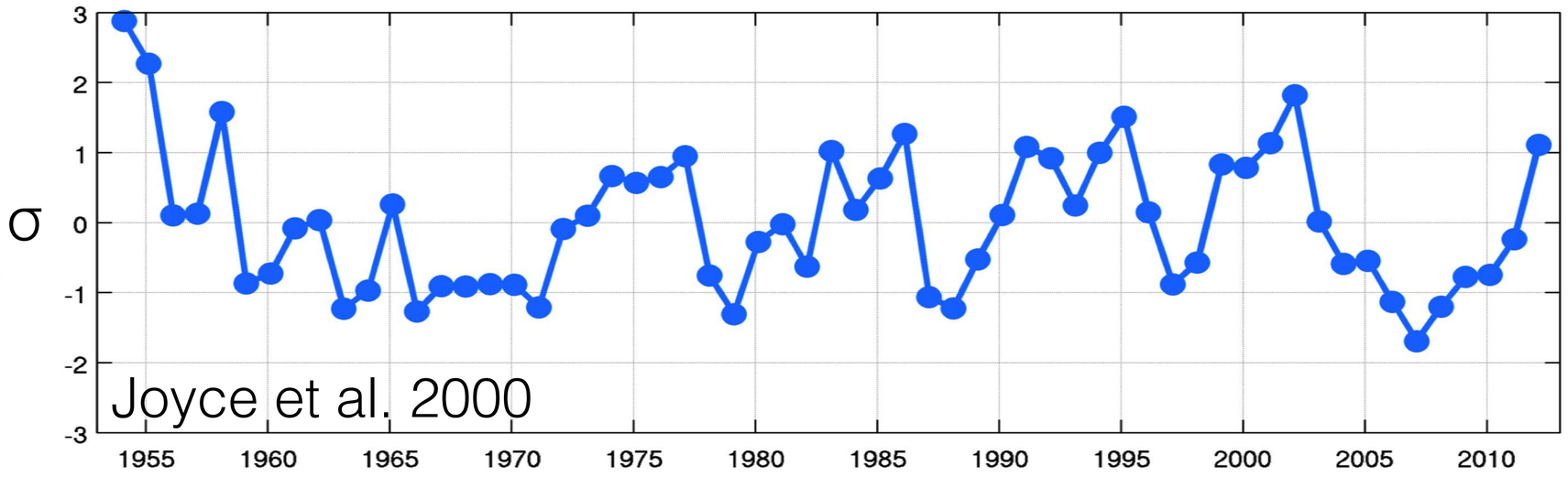


Hyodae Seo
Y.-O. Kwon, T. Joyce, C.Ummenhofer
Woods Hole Oceanographic Institution

Winter Gulf Stream position and linear circulation responses

JFM GSI
(1954-2013)

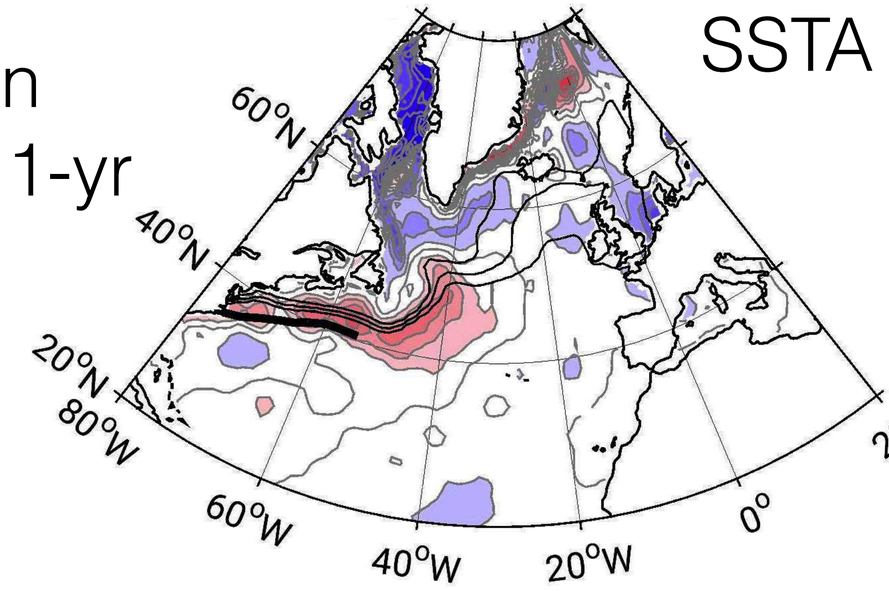
based on subsurface temperature data



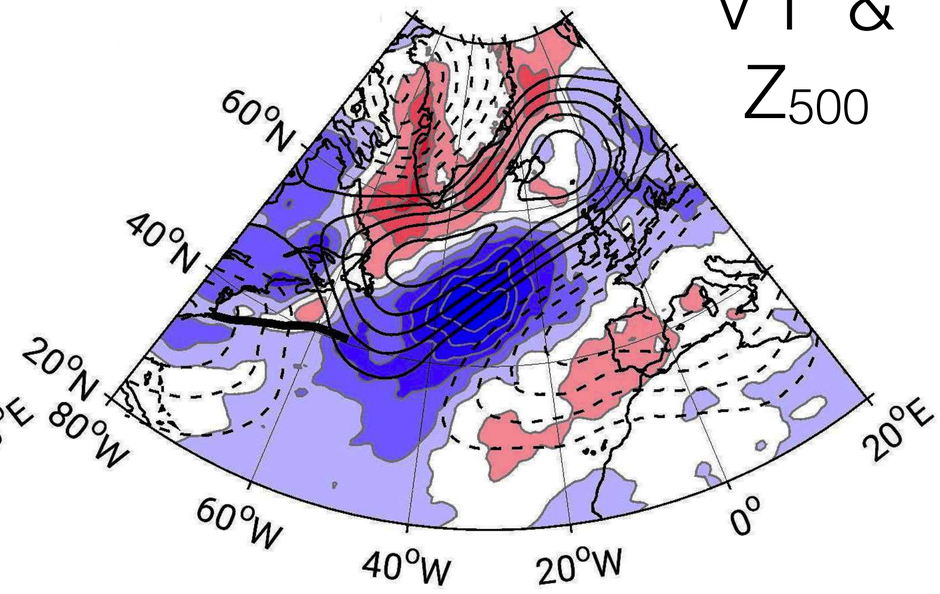
Linear regression
when GSI leads by 1-yr

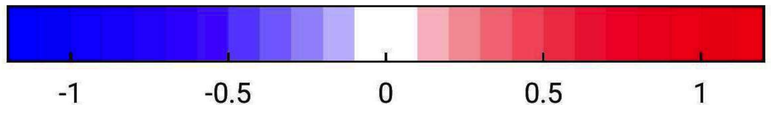
±0.3°C

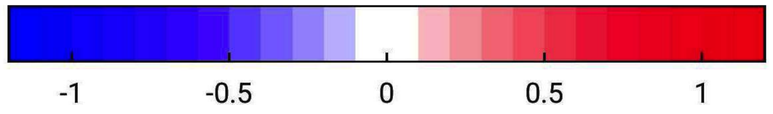
SSTA



v'T' &
Z_{500}



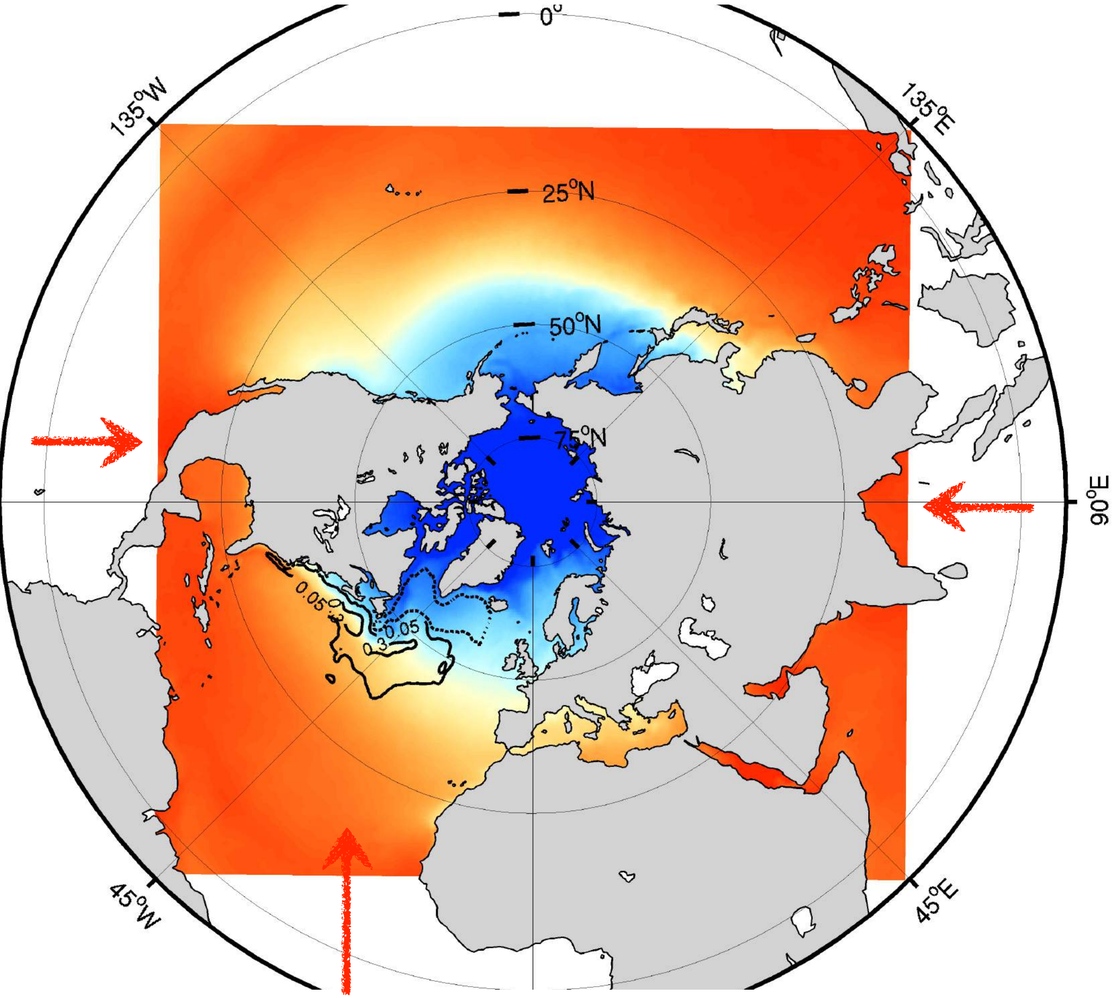




Kwon and Joyce 2013

Modeling atmospheric response to GS shift

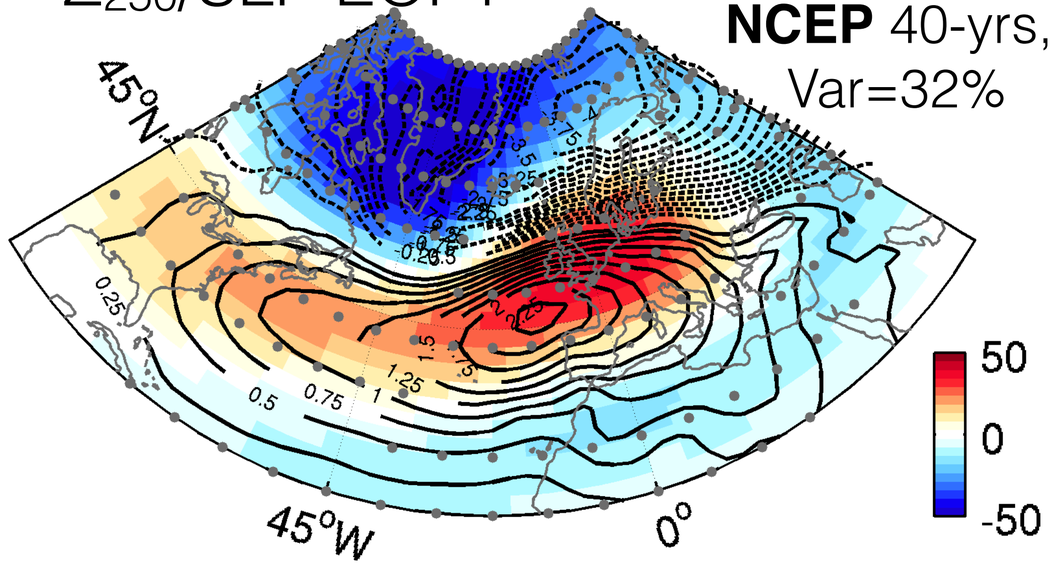
40km Hemispheric WRF
40 ens, NDJFMA

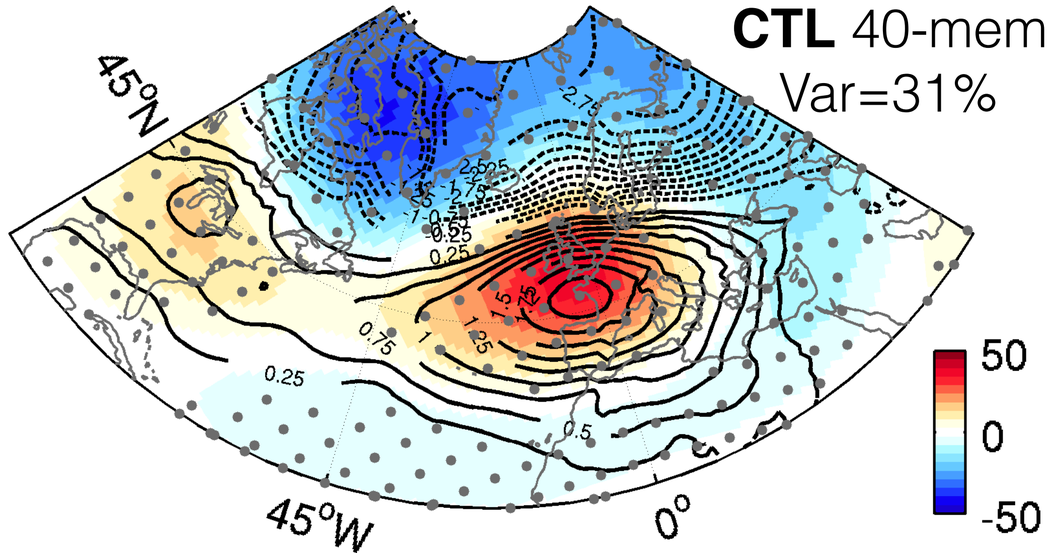


LBC: NCEP climatology

CTL: forced with SST climatology

Z_{250}/SLP EOF1



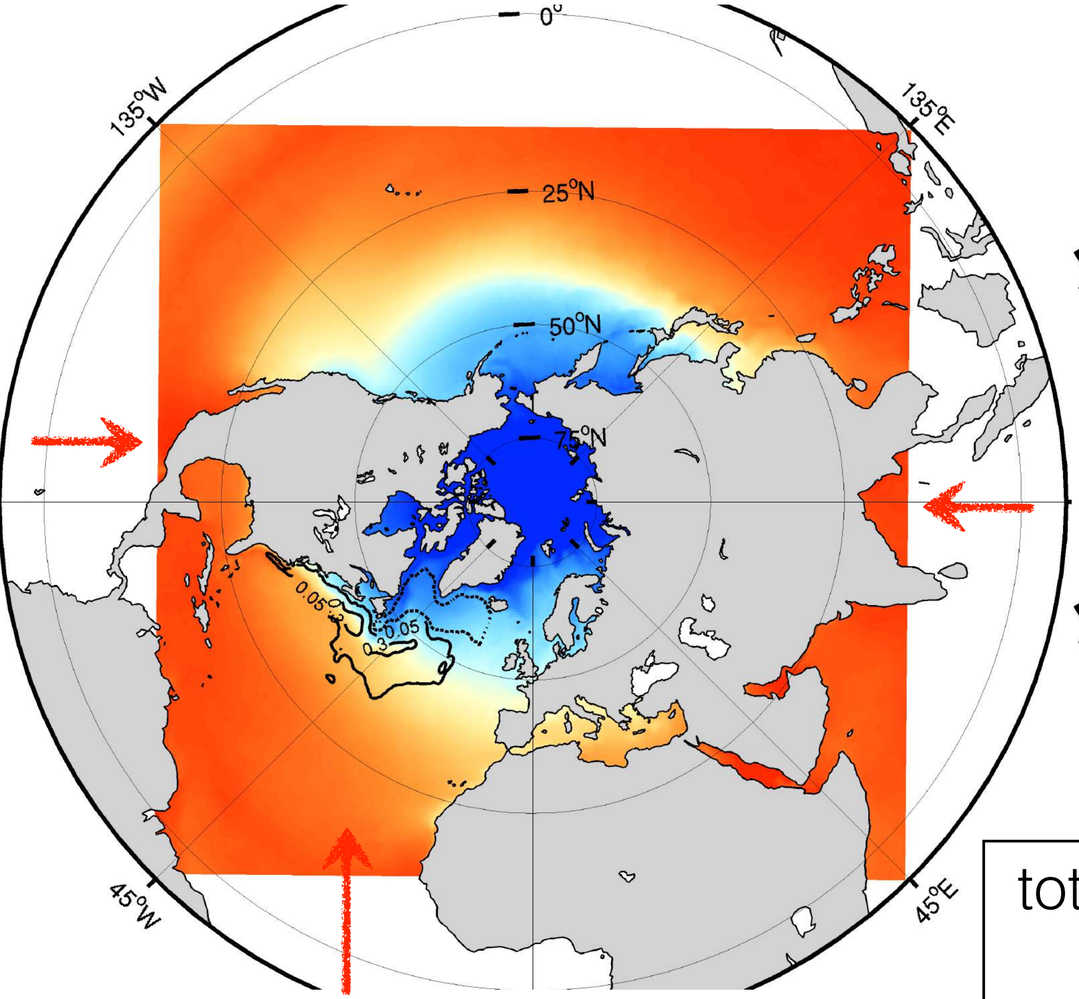


Modeling atmospheric response to GS shift

40km Hemispheric WRF
40 ens, NDJFMA

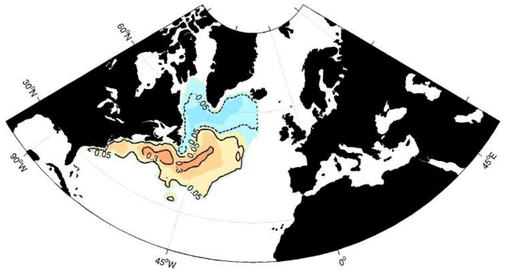
CTL: forced with SST climatology

SST perturbation experiments

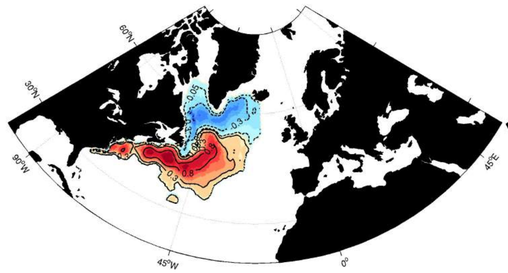


LBC: NCEP climatology

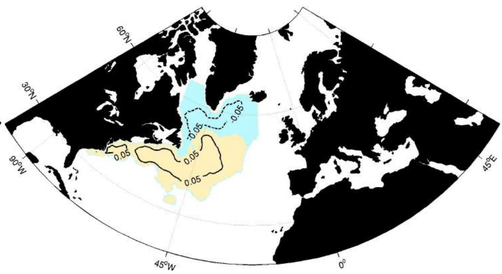
1σ+



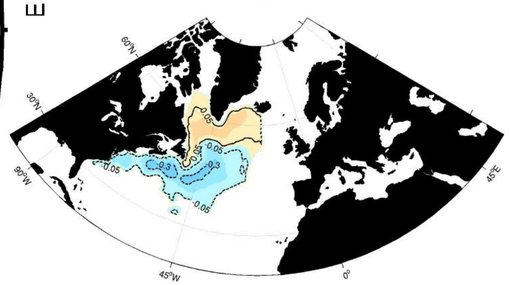
3σ+



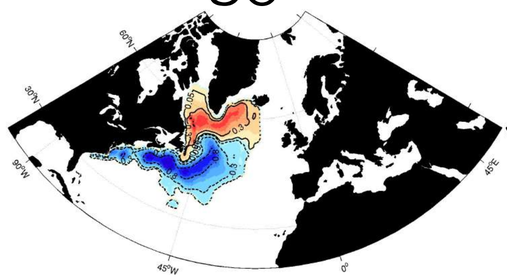
1/3σ+



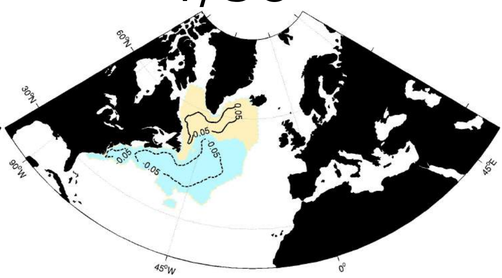
1σ-



3σ-



1/3σ-

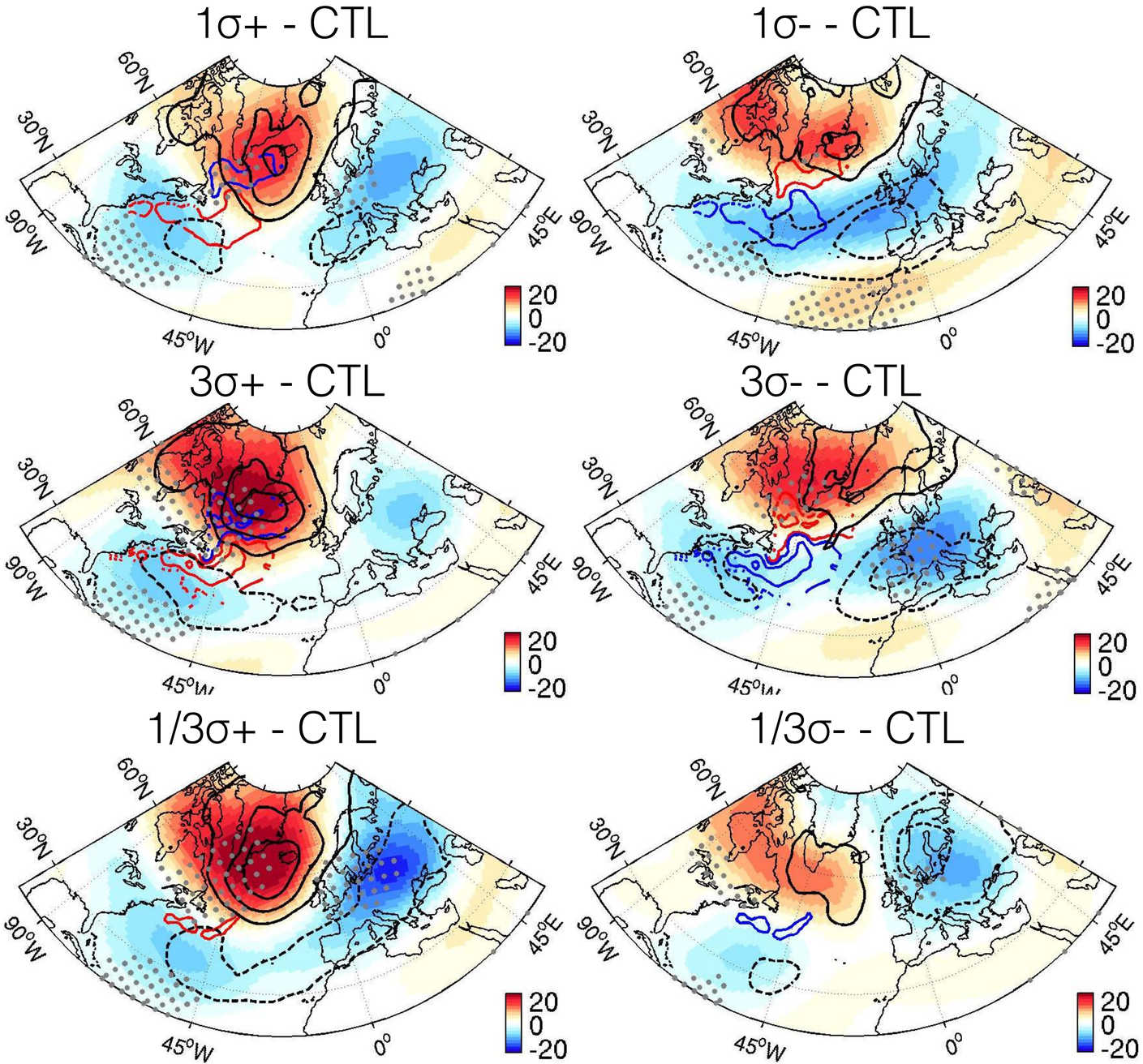


±0.3°C **±0.9°C** **±0.1°C**

total response = 1σ+ - CTL 1σ- - CTL	linear (symmetric) = ½ × (1σ+ - 1σ-) nonlinear (asymmetric) = ½ × [(1σ+ - CTL) + (1σ- - CTL)]

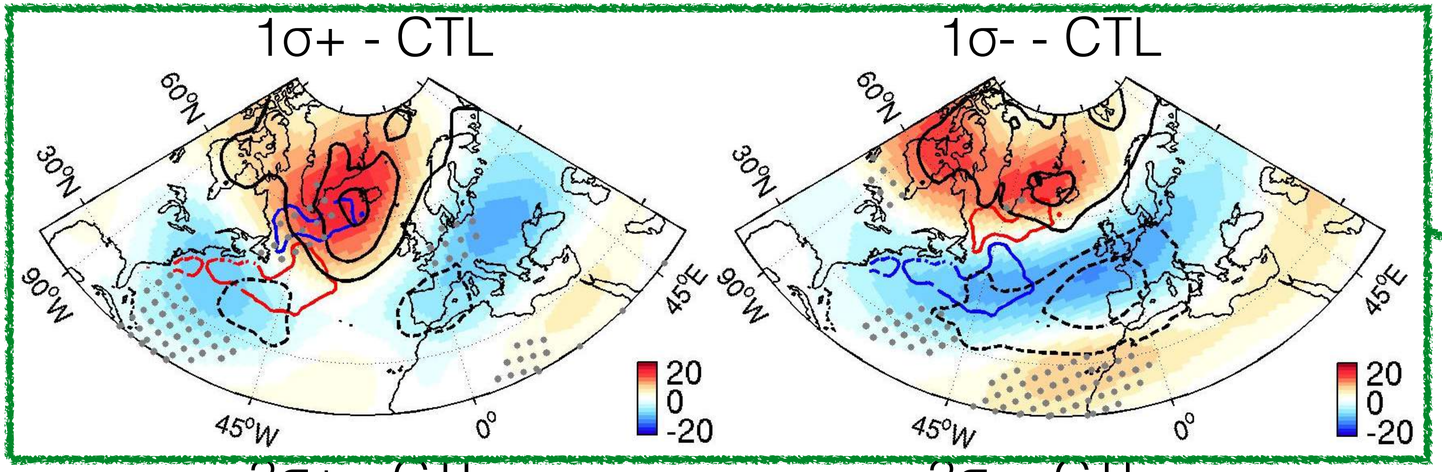
Z_{250}/SLP NDJFMA

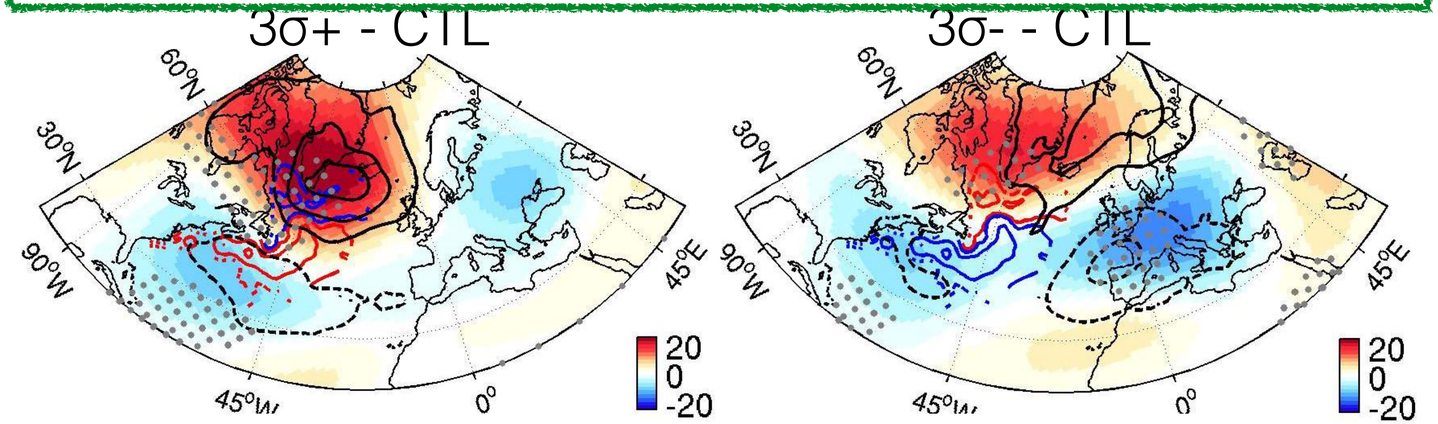
Strongly nonlinear equilibrium response

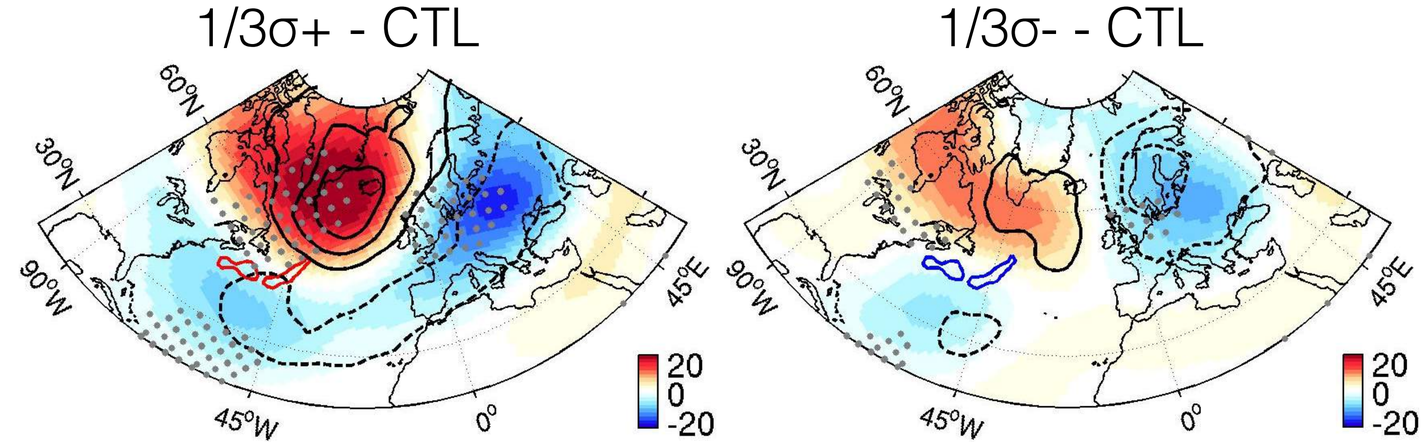


Z_{250}/SLP NDJFMA

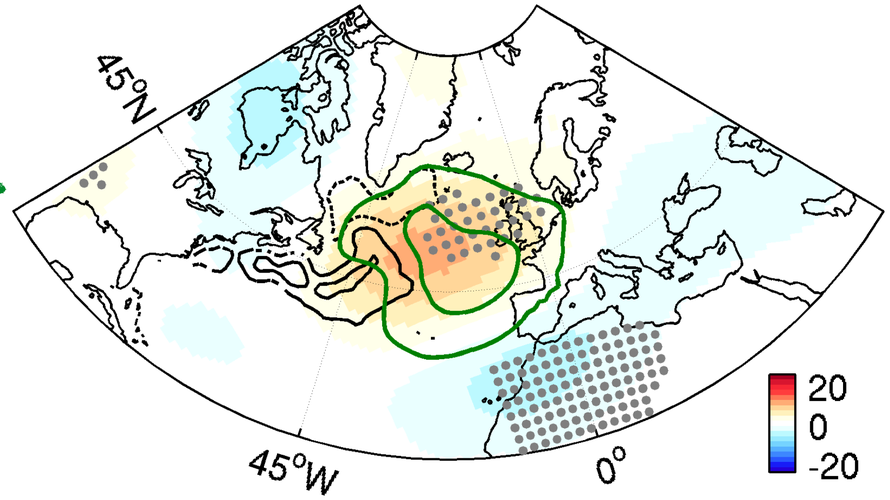
Strongly nonlinear equilibrium response



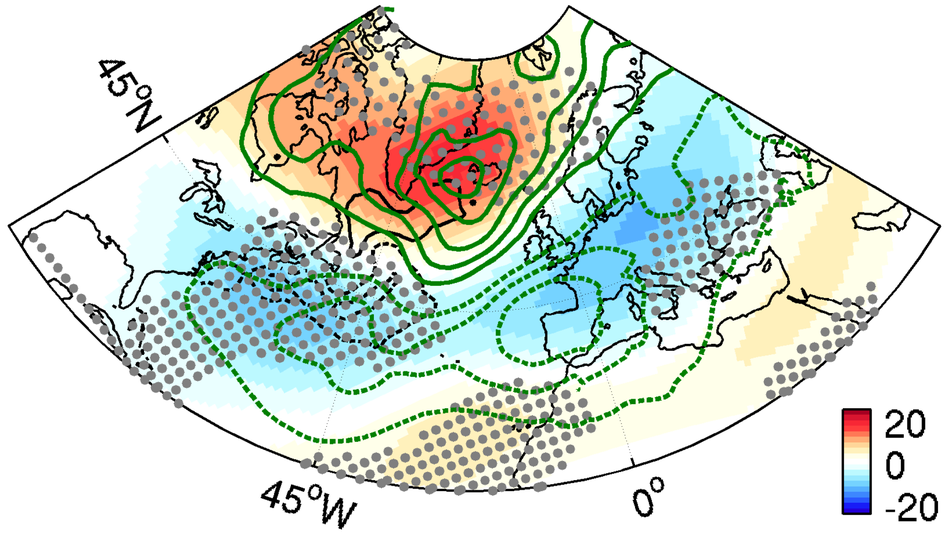




Linear response



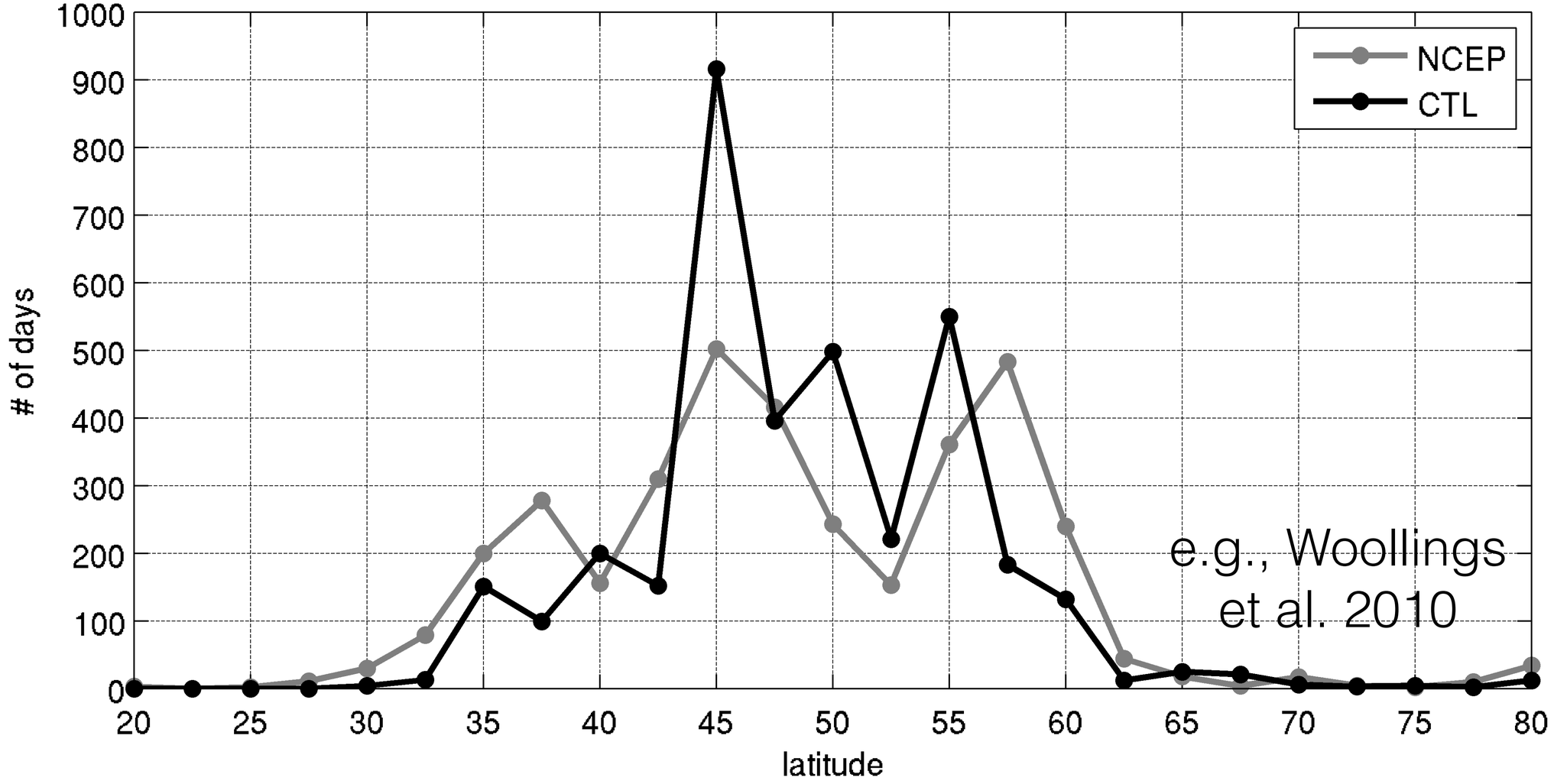
Nonlinear response



Dynamical adjustment processes responsible for the NAO-like nonlinear quasi-steady response?

North Atlantic eddy-driven jet stream: Increased occurrence in the south

Jet latitude PDFs (60W°-0°E averaged $U_{850,}$ DJF)



- The three separate locations of the jet stream position

North Atlantic eddy-driven jet stream: Increased occurrence in the south

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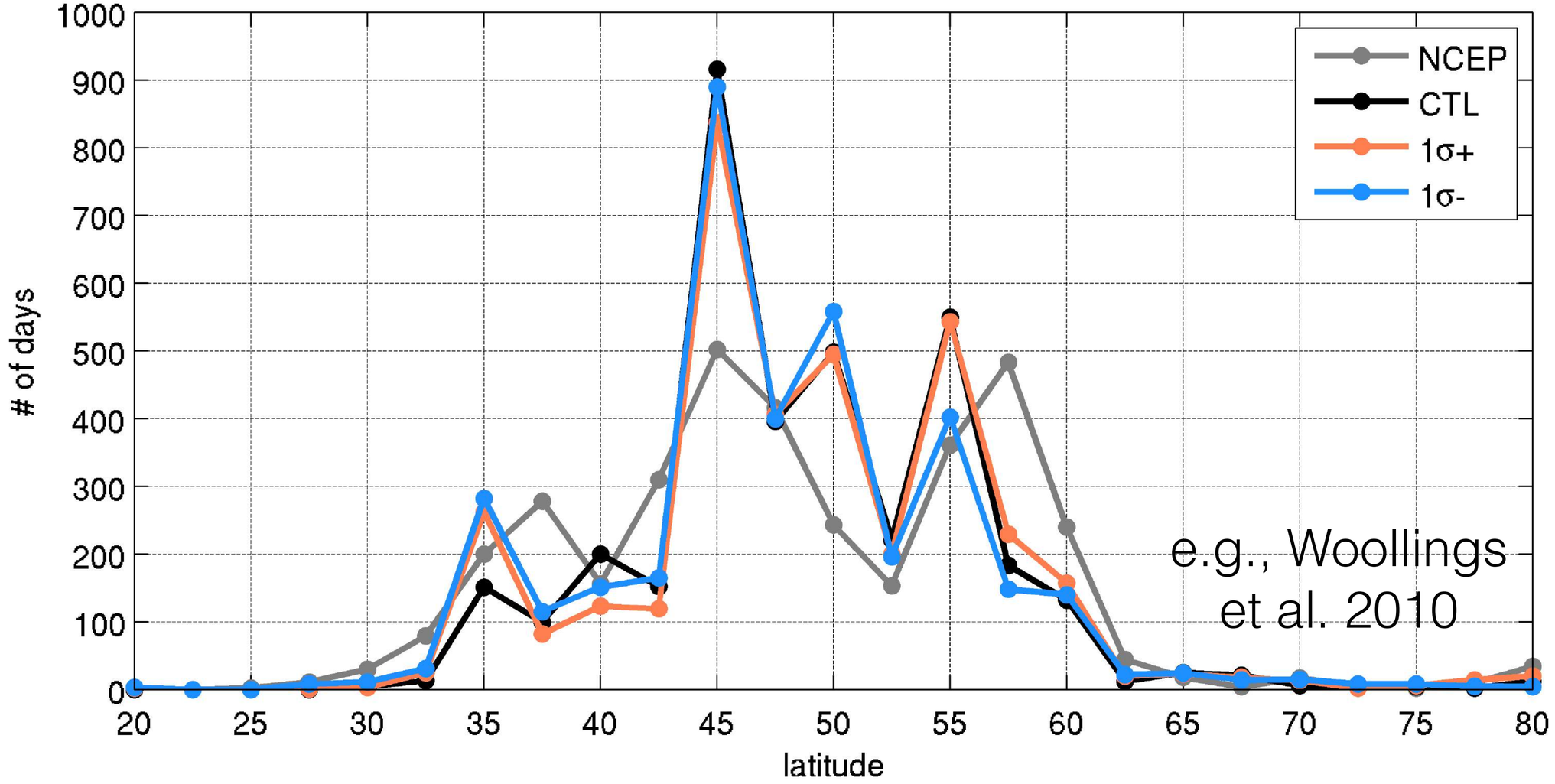
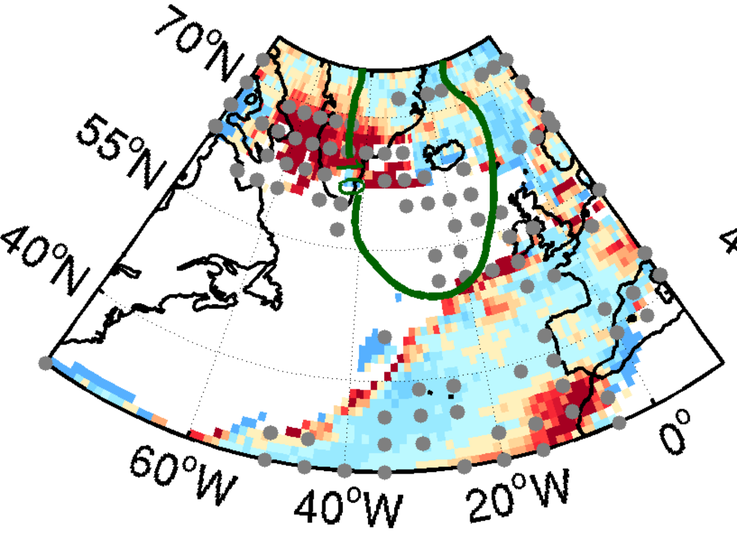


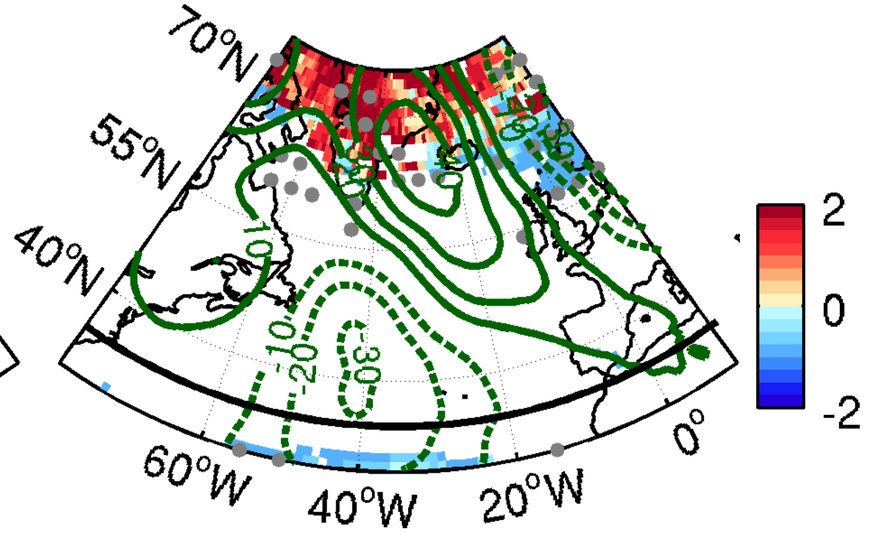
- The three separate locations of the jet stream position
- 74% (87%) more occurrence in the southern peak with the GS SSTA

High-latitude blocking and the jet latitude

Ratio: 1σ+/CTL

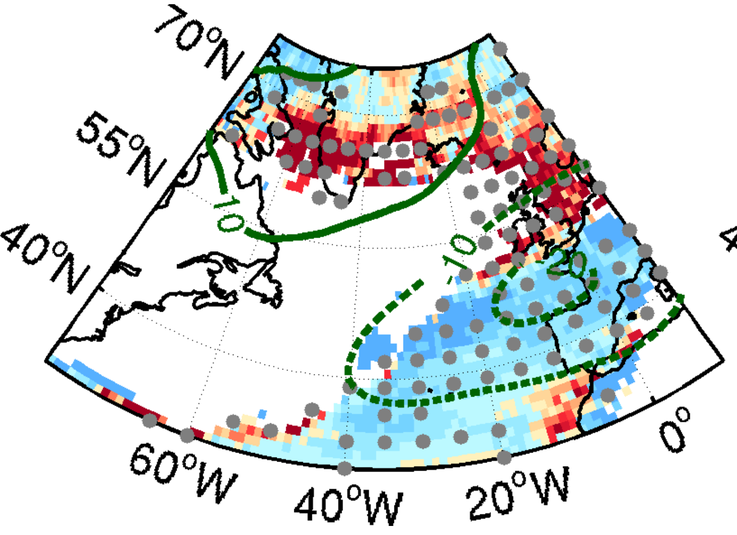


Ratio: 1σ+/CTL when jet is @ 35N

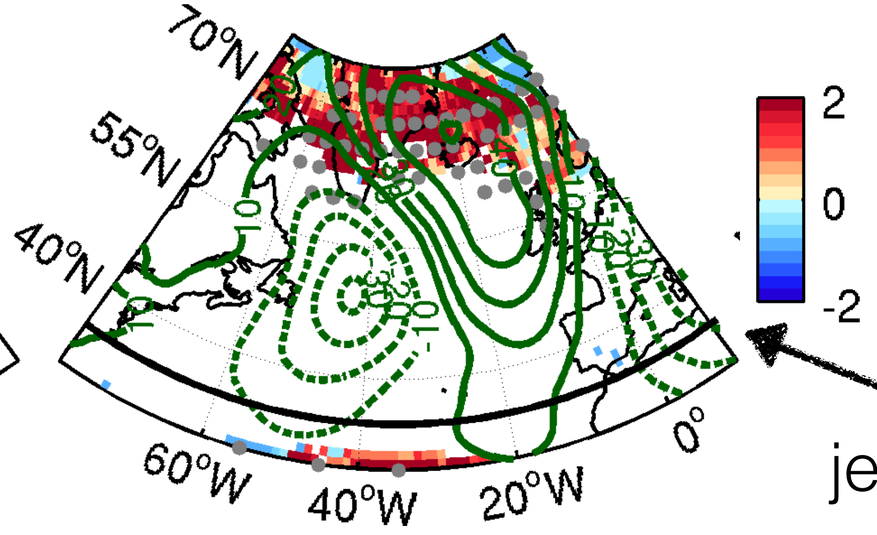


twice as many blocking occurrences in the high latitudes (cyclonic wave breaking events)

Ratio: 1σ-/CTL



Ratio: 1σ-/CTL when jet is @ 35N



The increase is more apparent when jet is pushed to the south

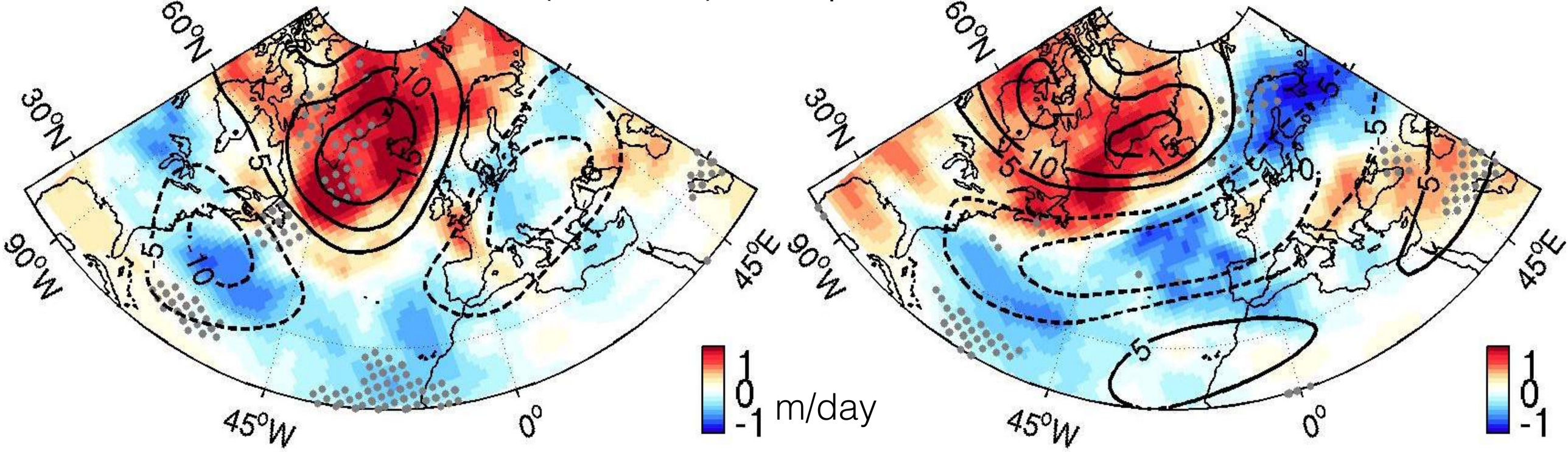
jet stream location

How is the high-latitude blocking ridge maintained?

$$\left(\frac{\partial Z_{250}}{\partial t}\right)_{\mathrm{HFT}} = \frac{f_0}{g}\nabla^{-2}[-\boldsymbol{\nabla}\cdot(\overline{v'\zeta'} + \overline{\bar{v}\zeta'} + \overline{v'\bar{\zeta}})]$$

Nakamura et al. 1997

1σ+ - CTL $(\partial Z_{250}/\partial t)_{HF}$ response 1σ- - CTL



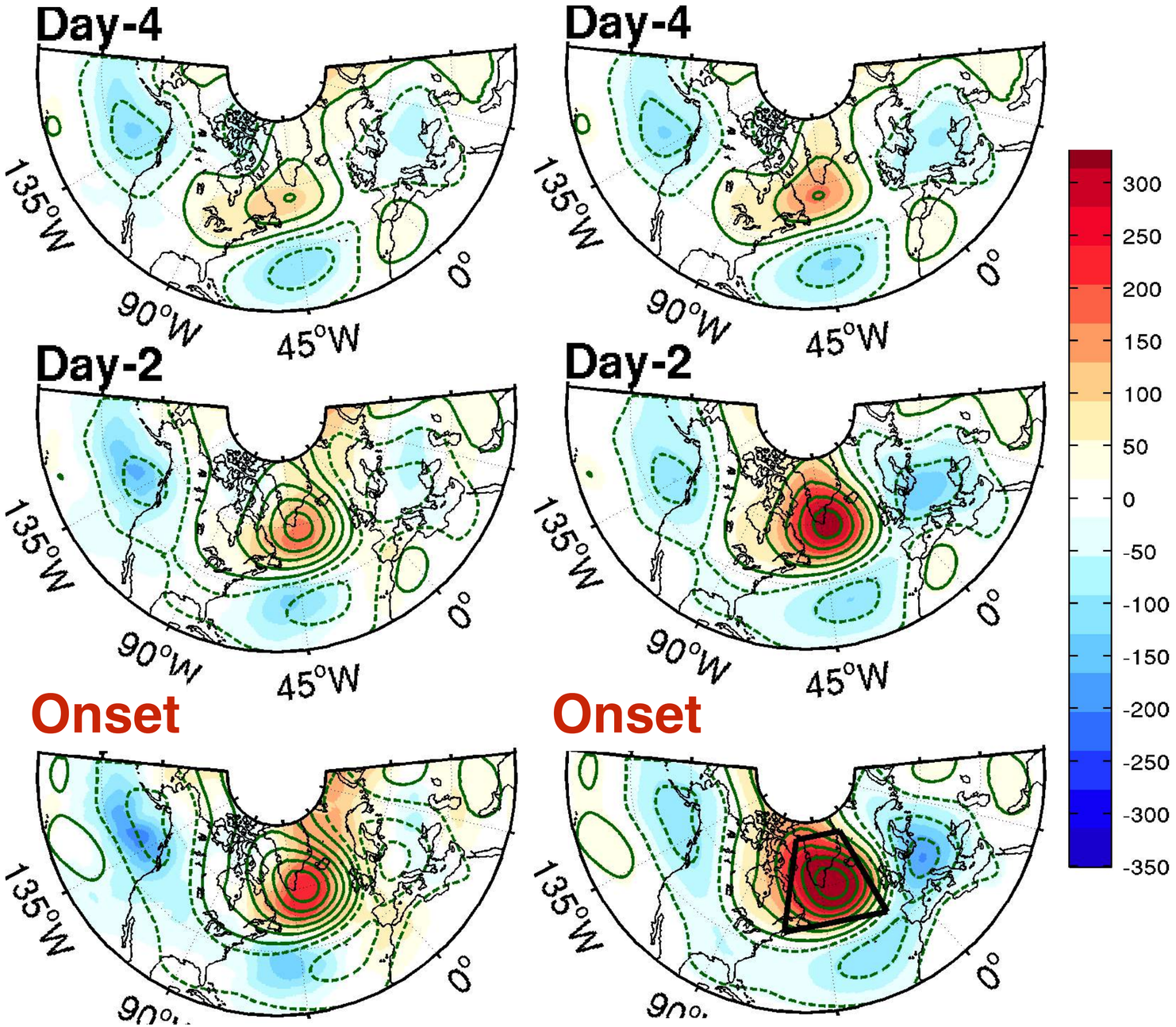
Quantifying the role of high-frequency transient eddy feedback: **1σ+ - CTL case**

Composite evolutions of time-accumulated $\partial Z_{250}/\partial t$ against *the life cycle of the Greenland blocking*

At onset, ~50% of the blocking ridge formation is attributed to by the high-frequency transient eddy feedback

Nakamura et al. 1997

$(\partial Z_{250}/\partial t)_{HF}\Delta t$ $(\partial \tilde{Z}_{250}/\partial t)_{TOT}\Delta t$←total Z_{250}

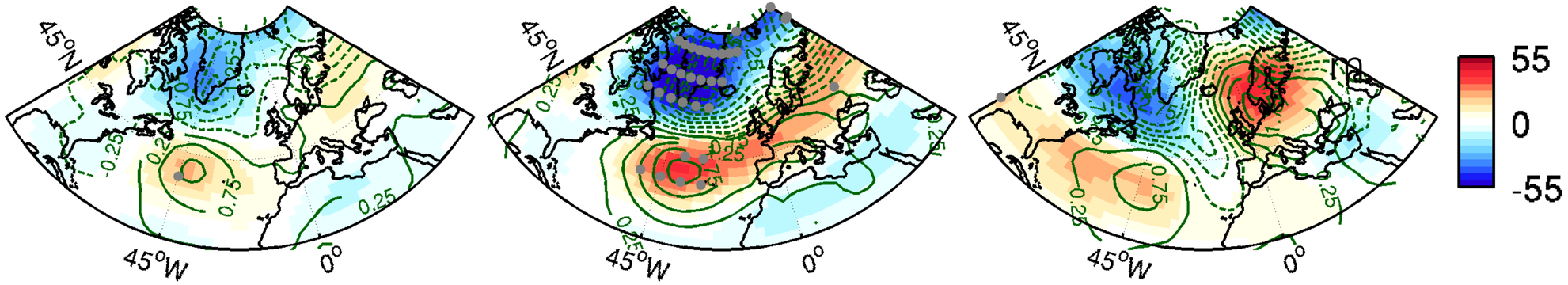


Nonlinearity of the JFM circulation anomalies in NCEP?

— Composite NCEP (1954-2012) Z_{250}/SLP when GSI leads by 1-yr

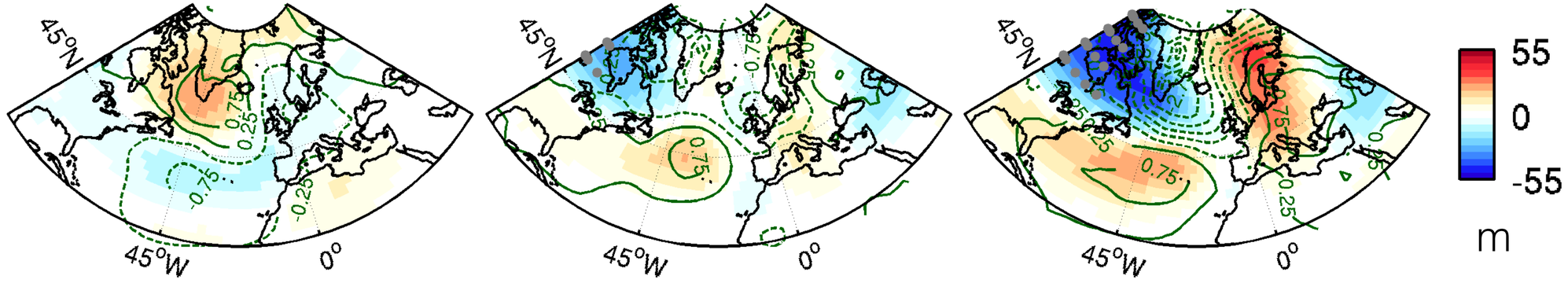
GSI>+1/3σ N=16 | GSI>+1.0σ N=10 | GSI>+5/4σ N=5

GS northward



GSI<-1/3σ N=25 | GSI<-1.0σ N=12 | GSI<-5/4σ N=8

GS southward



Linear response with a moderate shift of GS

But, the response ceases to be linear as the shift becomes large

Summary

Prevailing nonlinear response to a wide range of GS shifts
— resembles the NAO pattern, the leading mode of internal variability

- This nonlinear response pattern is associated with
  - increased occurrence of jet stream at 35N
  - increased blocking in the high latitudes

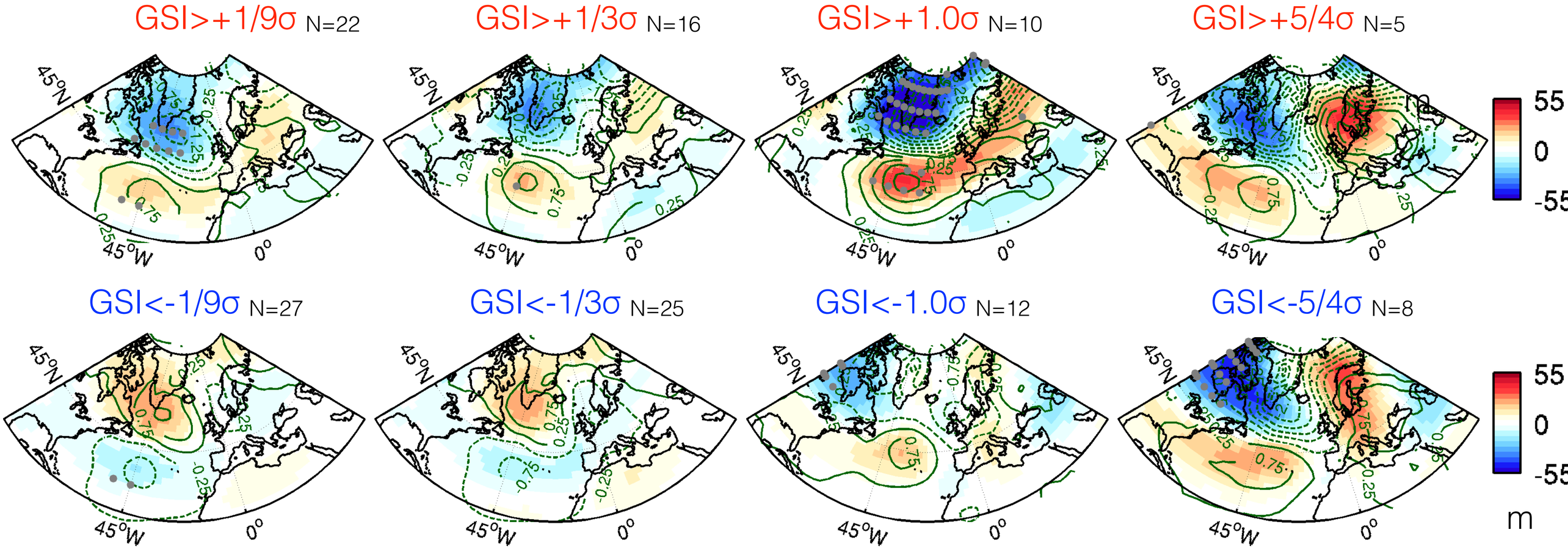
- The nonlinear ridge maintained by barotropic transient eddy feedback

- Observational analysis also suggests some asymmetry in the circulation

Thanks!

Nonlinearity of the JFM circulation anomalies in NCEP?

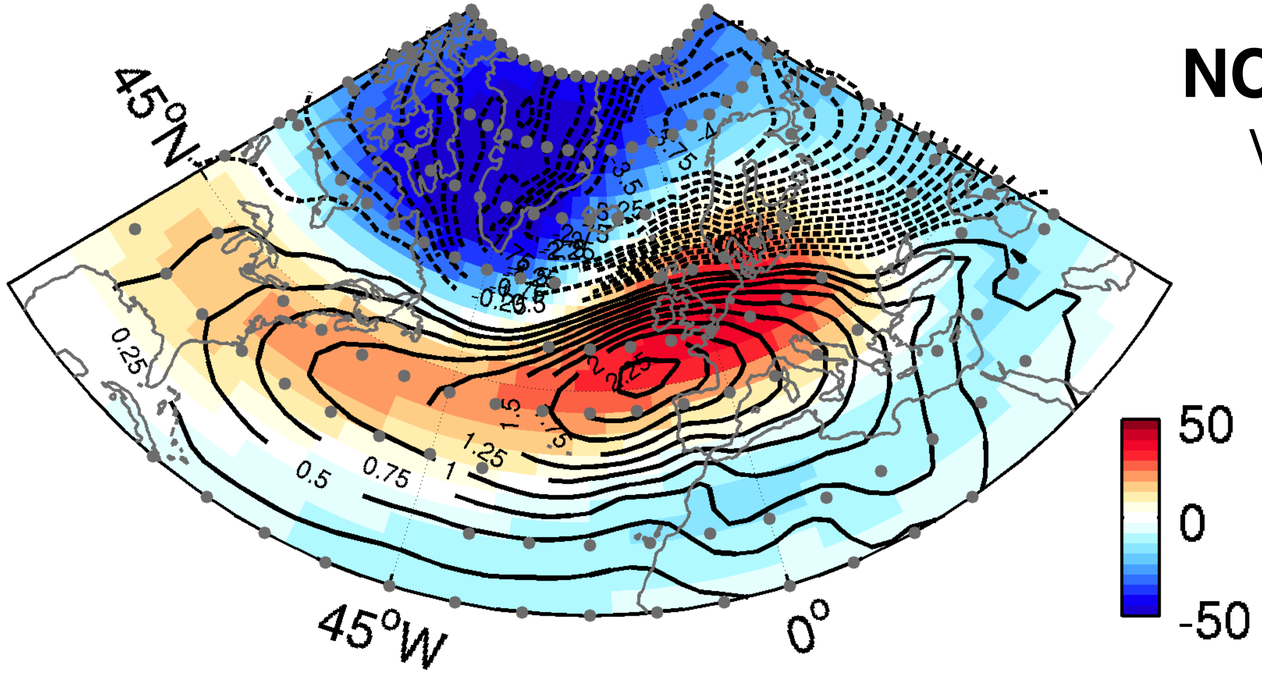
— Composite NCEP (1954-2012) Z_{250}/SLP when GSI leads by 1-yr



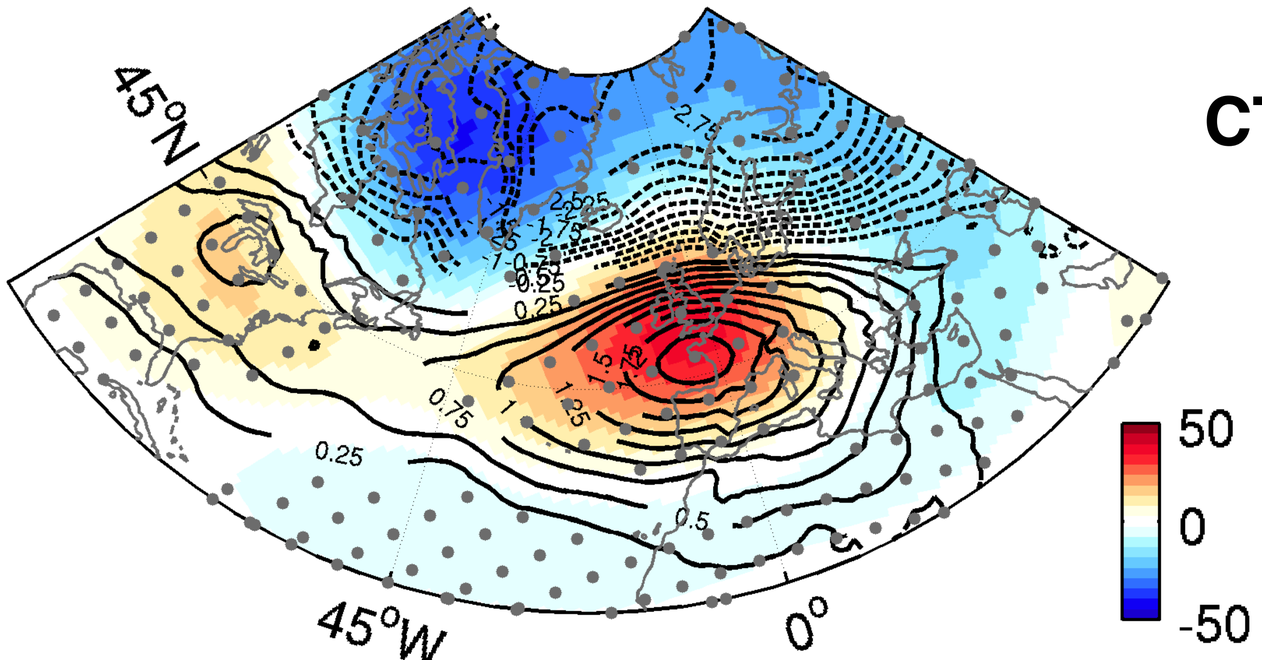
Linear circulation anomaly with a moderate shift in GS

But, the response is highly nonlinear when the shift is large

Z_{250}/SLP EOF1



NCEP 40-yrs,
Var=32%



CTL 40-mem,
Var=31%