How Does the Atmosphere Respond to Extratropical SST Anomalies ?

- the Role of Transient Eddy Feedbacks

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OUTLINE

I. Recent studies on the atmospheric response to extratropical SST anomalies

II. Mechanisms for the NAO response to the North Atlantic SST tripole

I. Recent Studies on the Atmospheric Response to Extratropical SST Anomalies

(Kushnir et al. 2002)

. Motivations – seasonal-to-decadal variability

(eg. Latif and Barnett 1994; Marshall et al. 2001; Wu and Liu 2005)

. AGCM responses to extratropical SSTs

(eg. Palmer and Sun 1985; Kushnir and Held 1996; Peng et al. 1995; 1997)

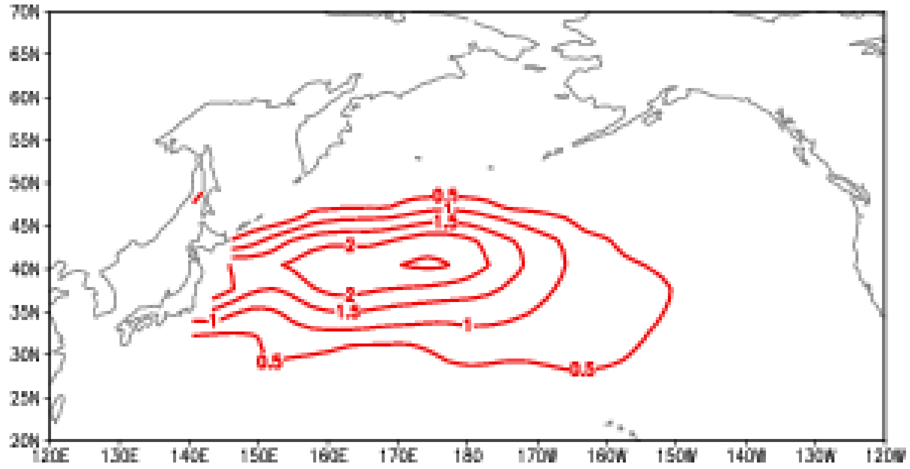
. Dependence on background intrinsic variability

- storm tracks
- LF variability

(eg. Branstator 1992; 1995; Whitaker and Sardeshmukh 1998)

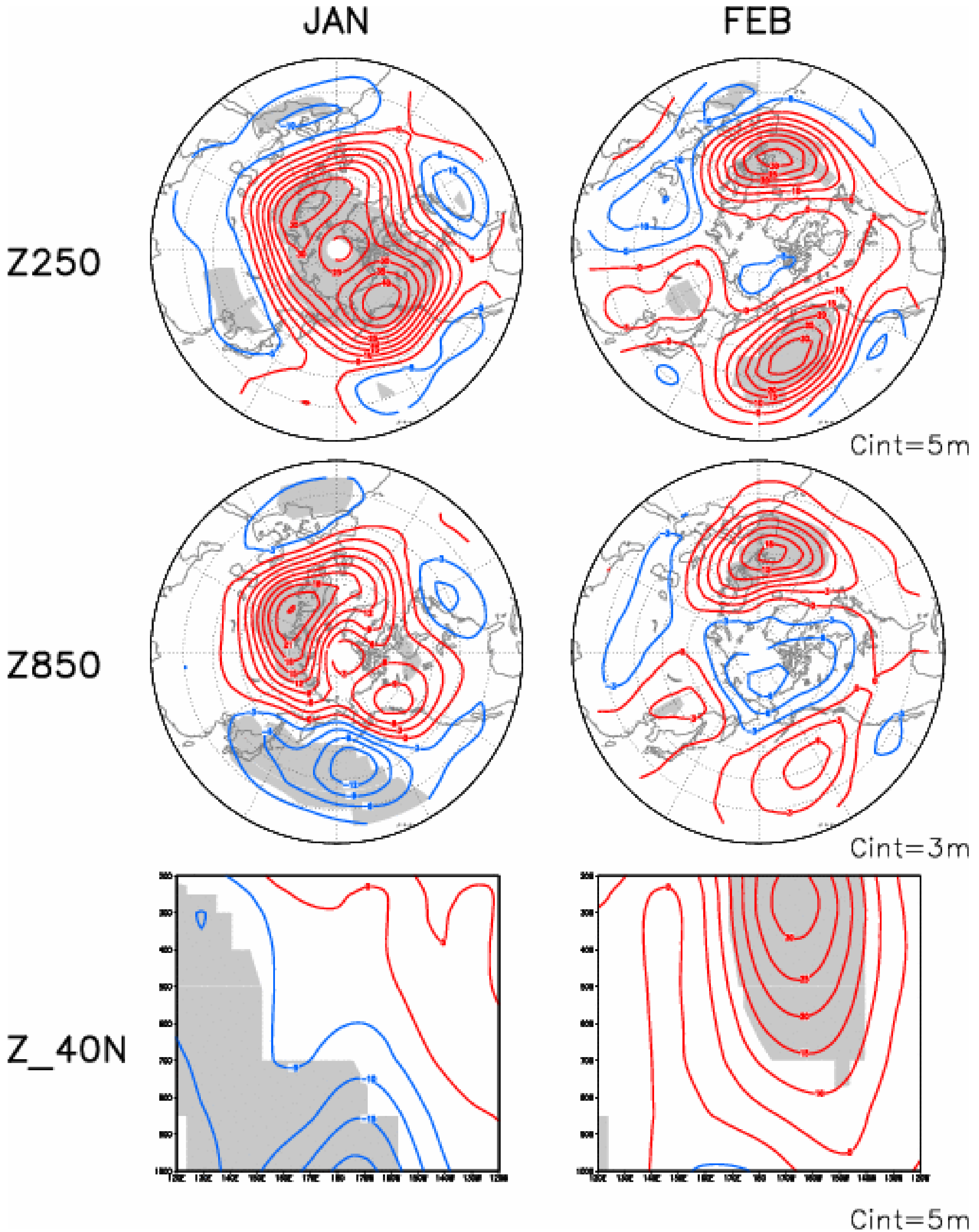
(eg. Ting and Peng 1995; Peng and Whitaker 1999; Peng and Robinson 2001; Deser et al. 2004)

SST ANOMALY



Cint=0.5K

AGCM Response:



Peng et al. (1997)

PW Eddy Feedback Mechanism

(*Peng and Whitaker 1999*)

SSTA => Q => Ψ_H => F_E => Ψ_E

(LBM) (STM) (LBM)

Q: Anomalous heating

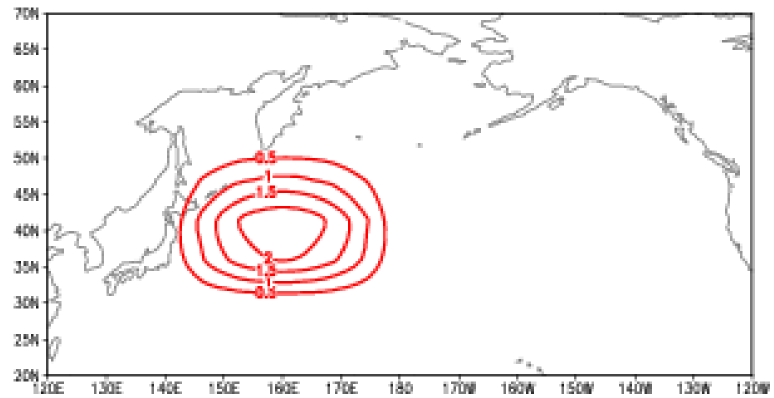
Ψ_H: Heating-forced anomalous flow

F_E: Anomalous eddy vorticity forcing

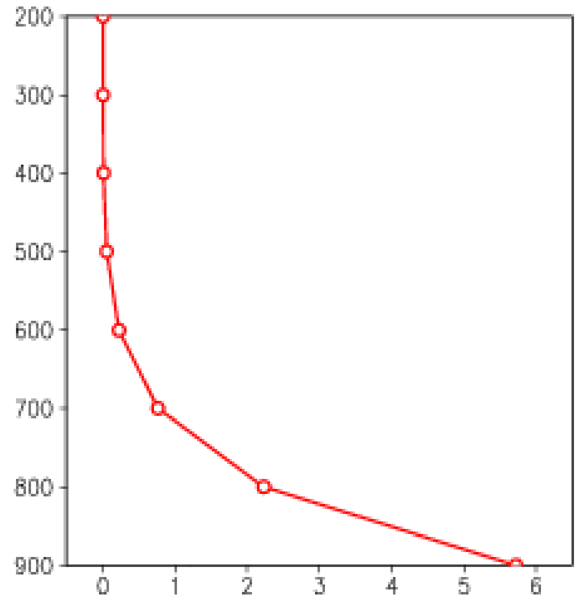
Ψ_E: Eddy-forced anomalous flow

(Schematic for the **initial** process !!)

Idealized Initial Heating (Q)



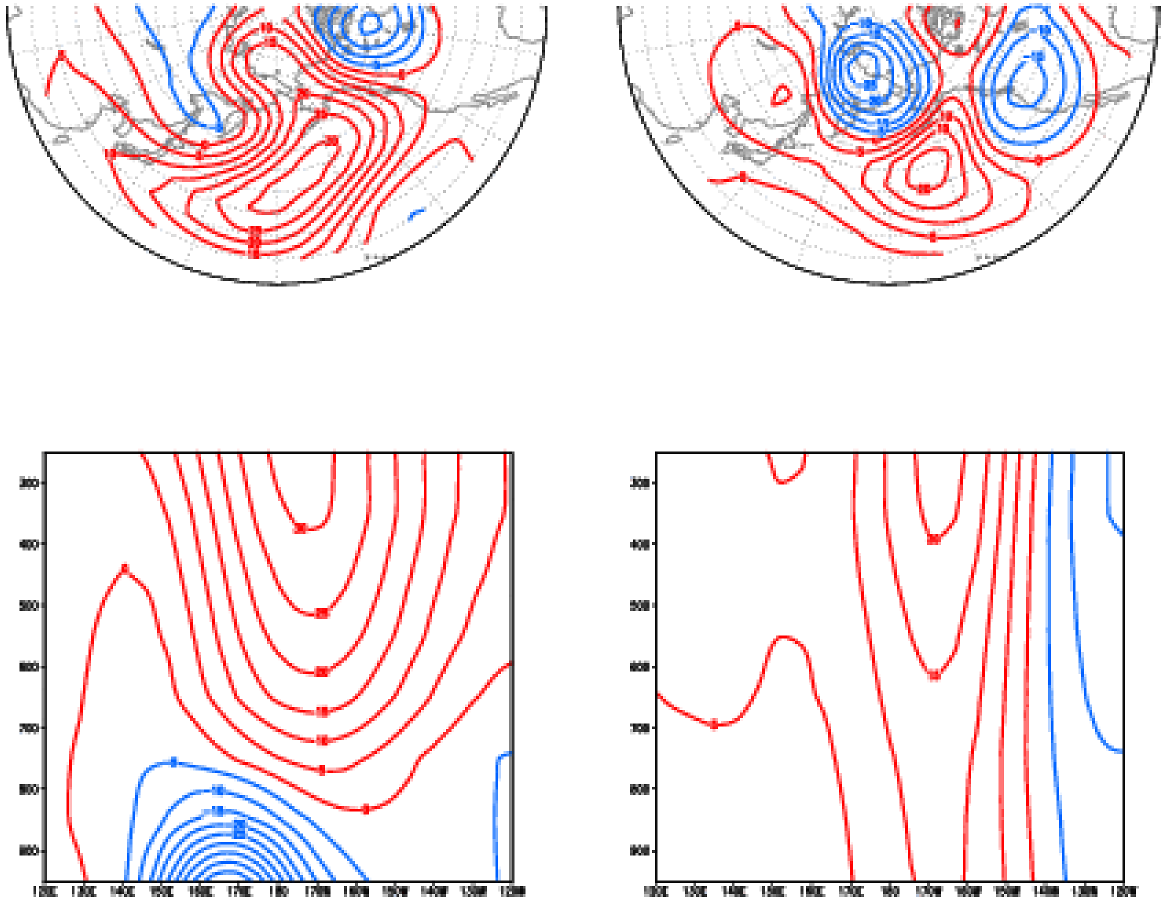
Cint=0.5 K/day



ψ_H ψ_E (<= highly variable !!)

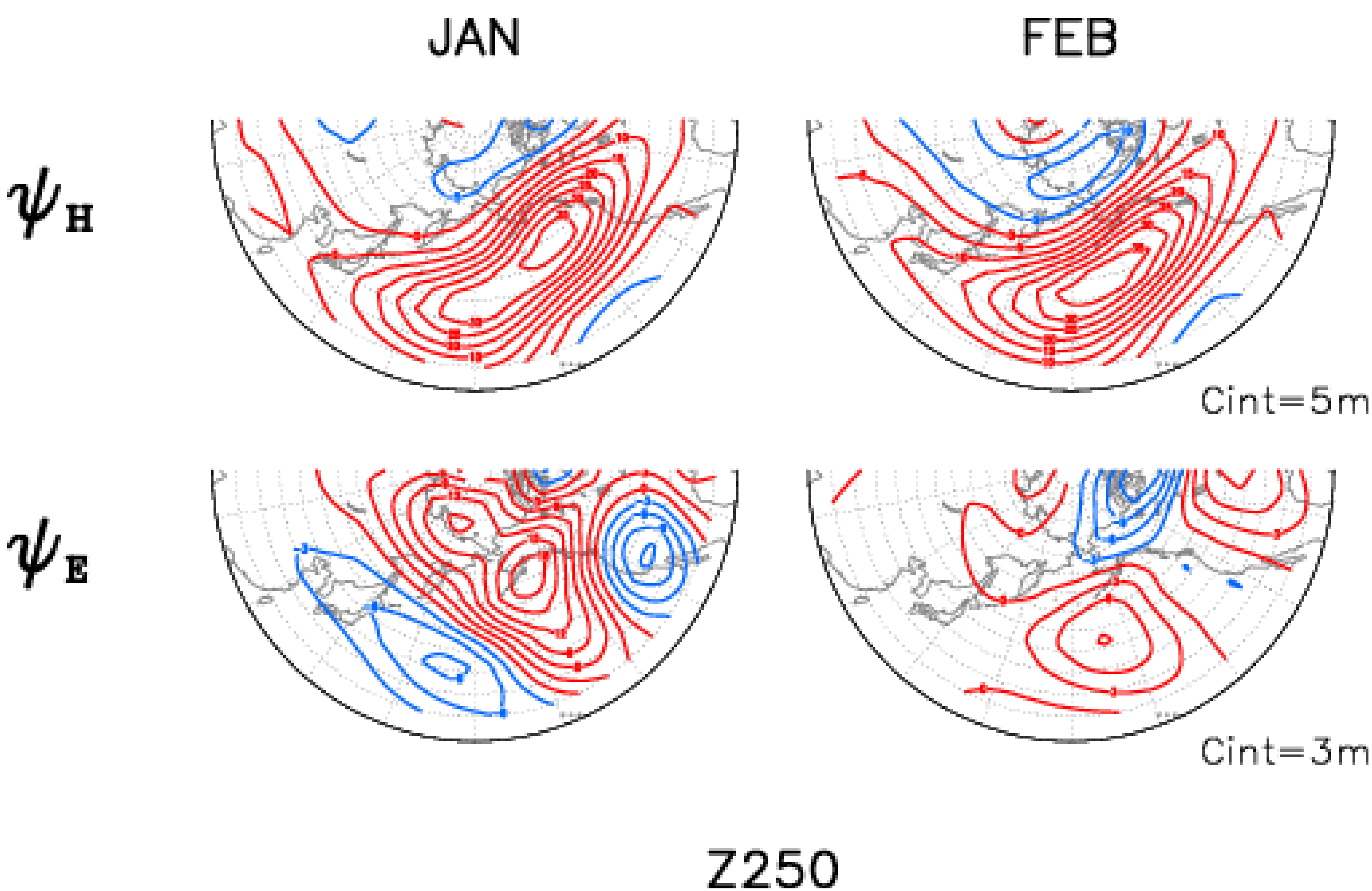
Z250

Z_40N



Cint=5m

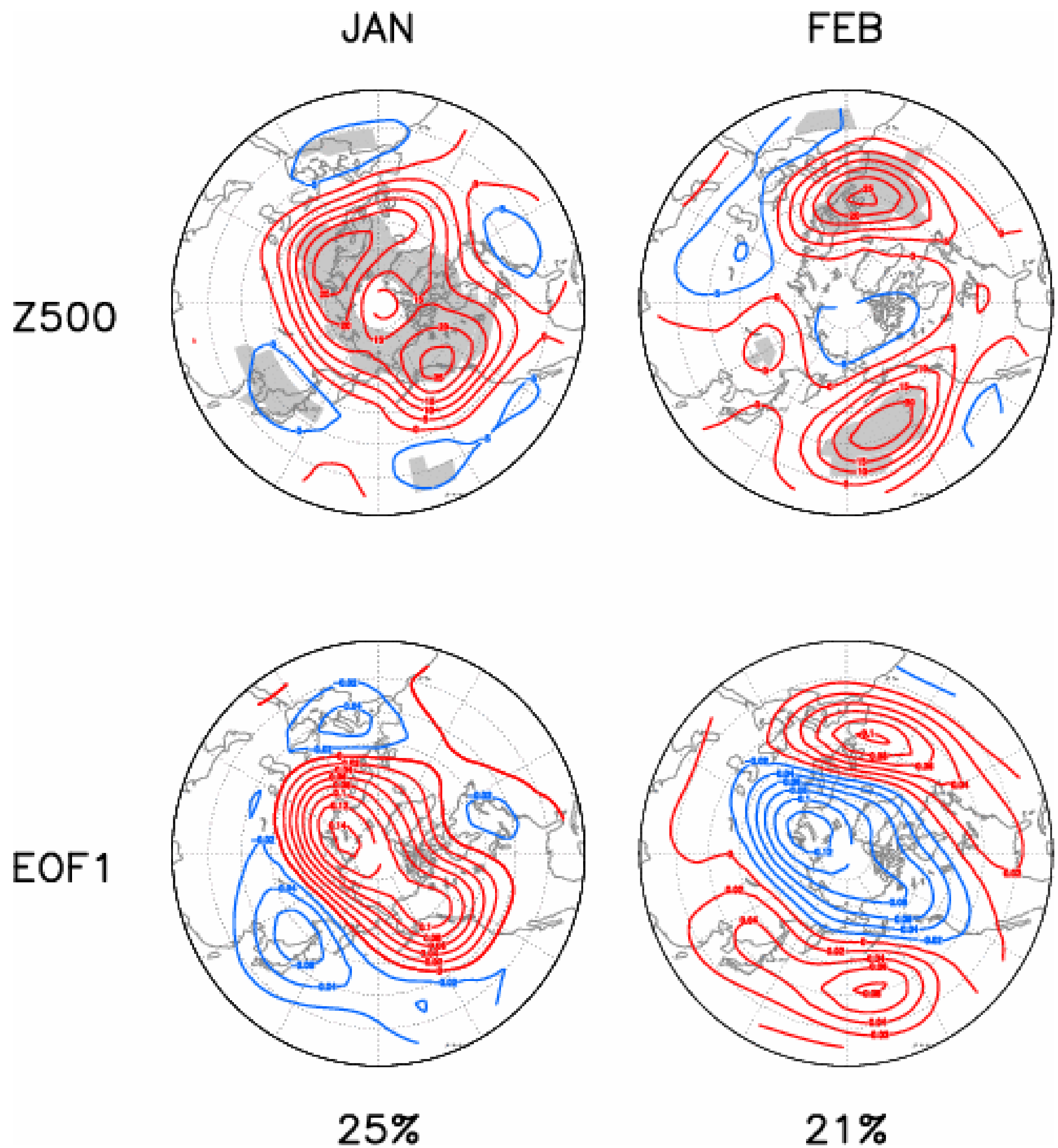
(Obs. DJF basic state; Q at 40N160E)



JAN
FEB
ψ_H
ψ_E
Cint=5m
Cint=3m
Z250

SST_forced

Ctrl Z500



Cint=5m

Peng and Robinson (2001)

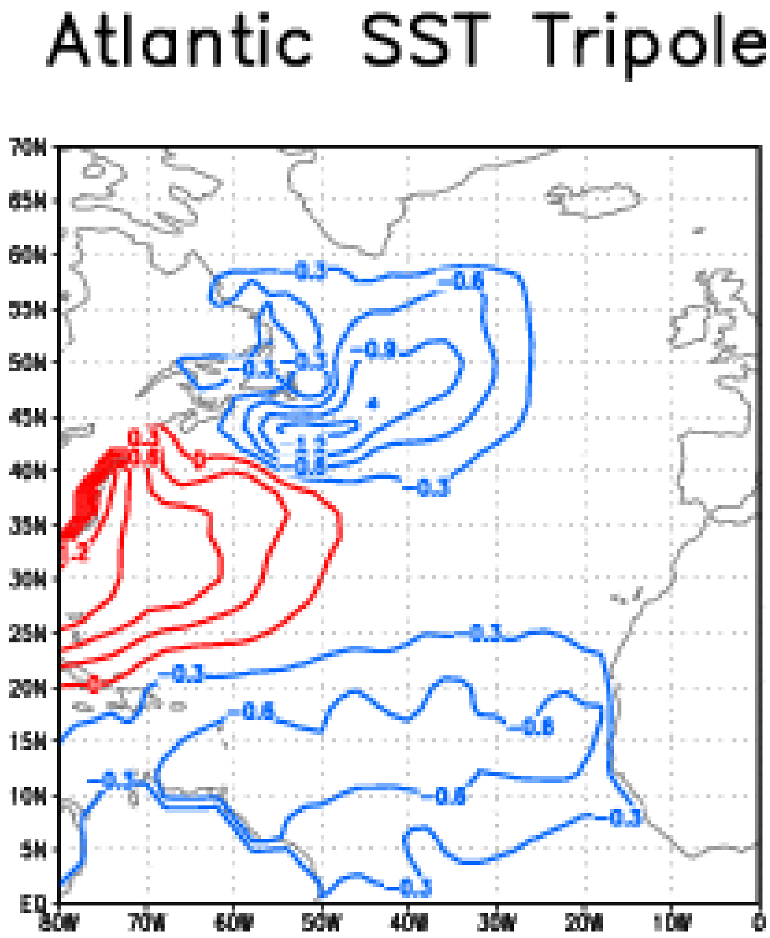
II. Mechanisms for the NAO Response to the North Atlantic SST Tripole

(*Peng et al. 2002; 2003*)

. AGCM responses

. Mechanisms

- symmetric response
- asymmetric response


Atlantic SST Tripole
70N
65N
60N
55N
50N
45N
40N
35N
30N
25N
20N
15N
10N
5N
EQ
80W
70W
60W
50W
40W
30W
20W
10W
0

Cint=0.3K

AGCM Experiments

Model:

AGCM - NCEP Seasonal Forecast Model (T42L28)

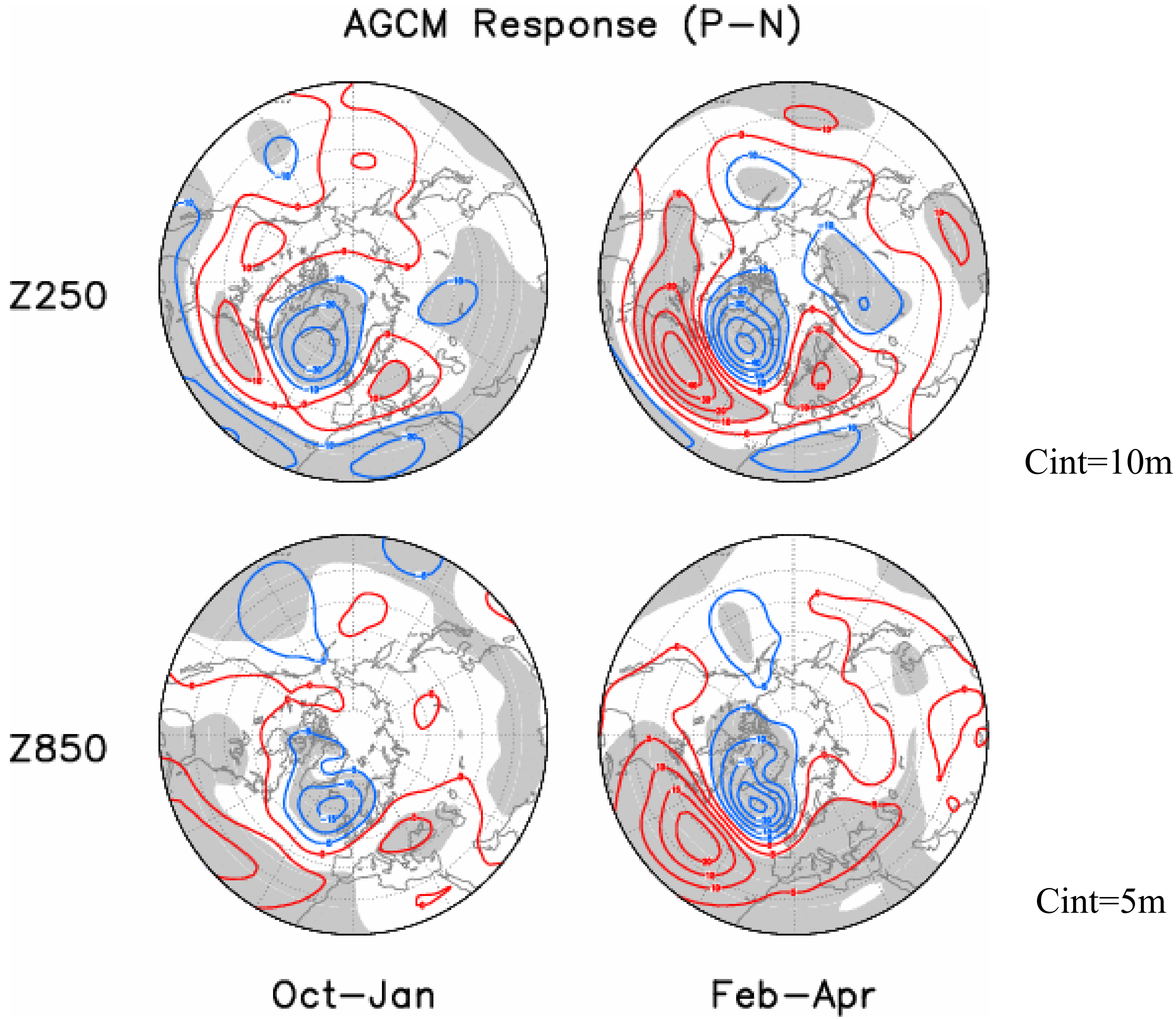
Experiments:

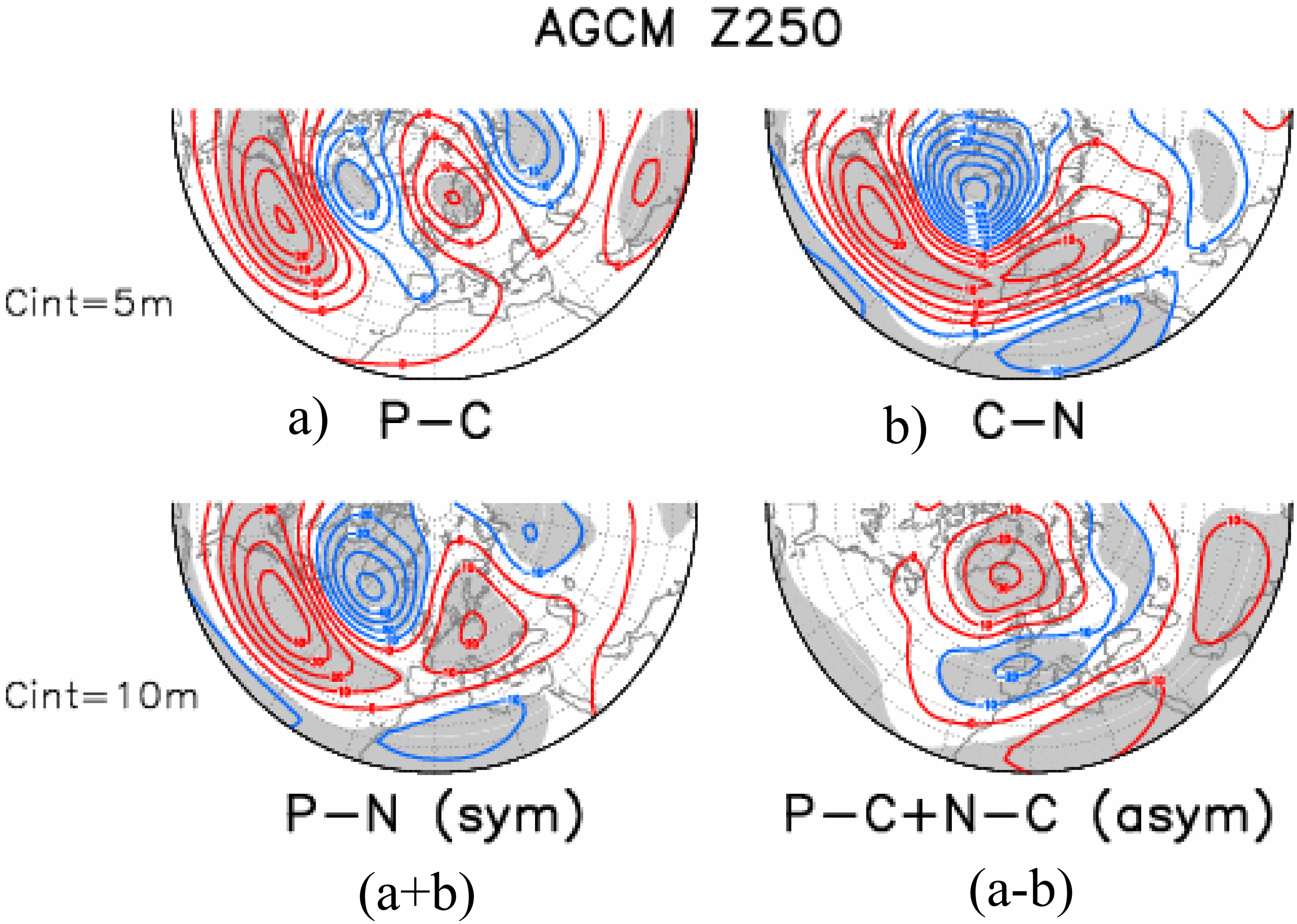
=> 8-month integration from Sept - Apr

=> INCs: Sept 1-5, 80-99

=> 100-member ensembles for:

a) Climo SST	(C)
b) Climo SST + SSTA	(P)
c) Climo SST - SSTA	(N)


AGCM Response (P–N)
Z250
Z850
Oct–Jan
Feb–Apr
Cint=10m
Cint=5m


AGCM Z250
Cint=5m
a) P−C
b) C−N
Cint=10m
P−N (sym)
P−C+N−C (asym)
(a+b)
(a-b)

Mechanisms ??

=> Symmetric response

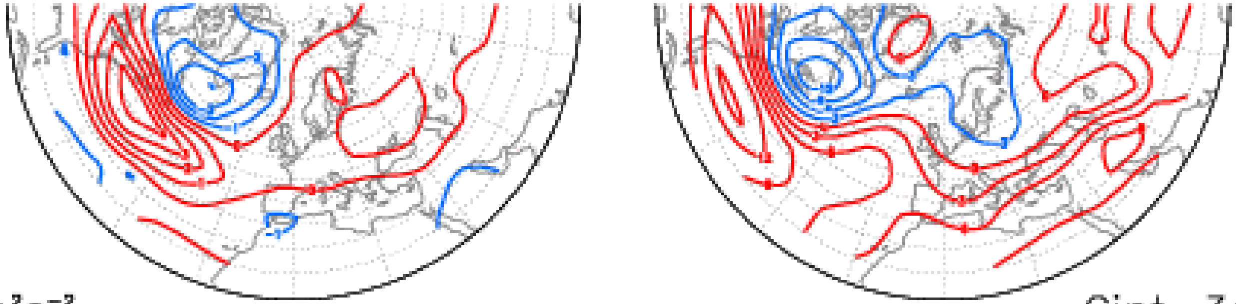
Linear Model Experiments

=> *Maintenance of the AGCM response*

LBM – Linear baroclinic model (J. Whitaker)
(PE; T21L10)

AGCM forcing => LBM => response

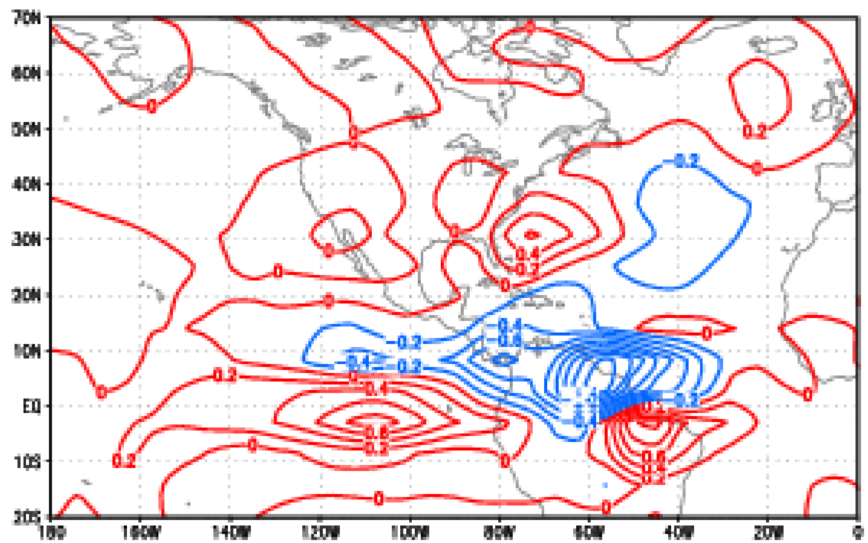
Eddy Vorticity Forcing (950−250mb)



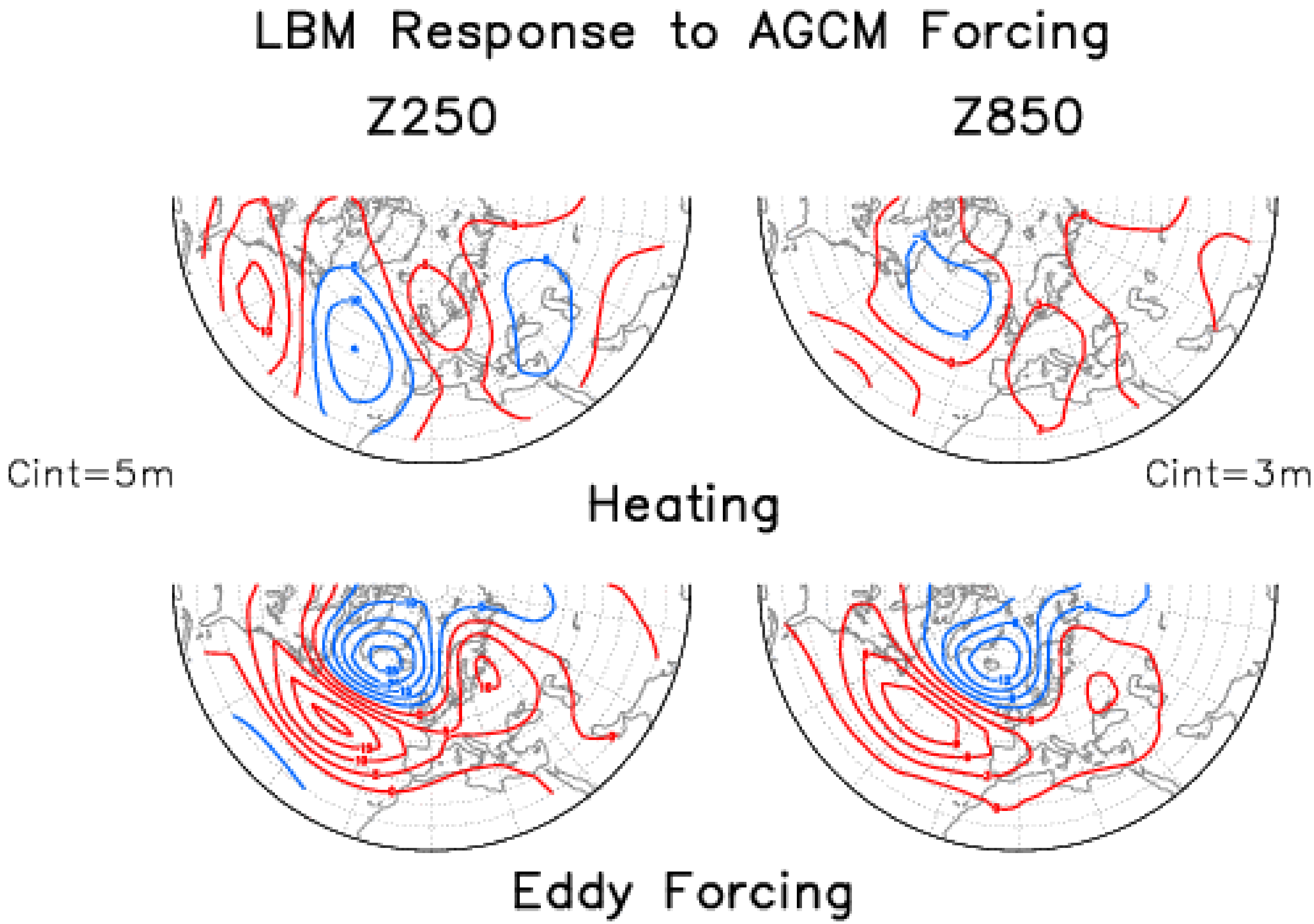
Cint=1 m²s⁻² Cint=3 m²s⁻²

P−N Ctl

Diabatic Heating (950−250mb)



Cint=0.2 k/day


LBM Response to AGCM Forcing
Z250
Z850
Cint=5m
Heating
Cint=3m
Eddy Forcing

PW Eddy Feedback Mechanism

(*Peng and Whitaker 1999*)

SSTA => Q => Ψ_H => F_E => Ψ_E

(LBM) (STM) (LBM)

Q: Anomalous heating

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Ψ_E: Eddy-forced anomalous flow

(Schematic for the **initial** process !!)

Linear Model Experiments

=> *Mechanisms for developing the response*

LBM - Linear baroclinic model (J. Whitaker)
(PE; T21L10)

STM - Statistical storm track model
(in EOF space; T21L10)

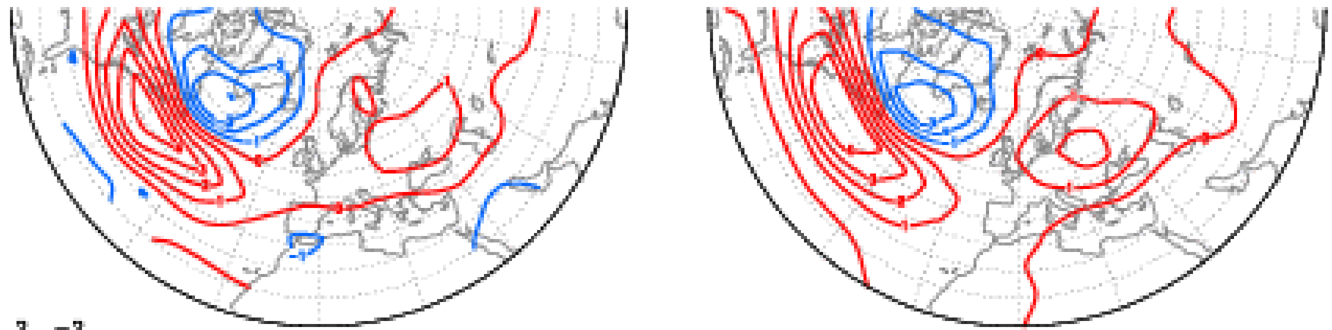
$$\mathbf{Y = C_{yx} \bullet X}$$

X - predictor vector - geopotential height

Y - predictand vector - eddy vorticity forcing

C_{yx} - Covariance matrix based on AGCM intrinsic variability

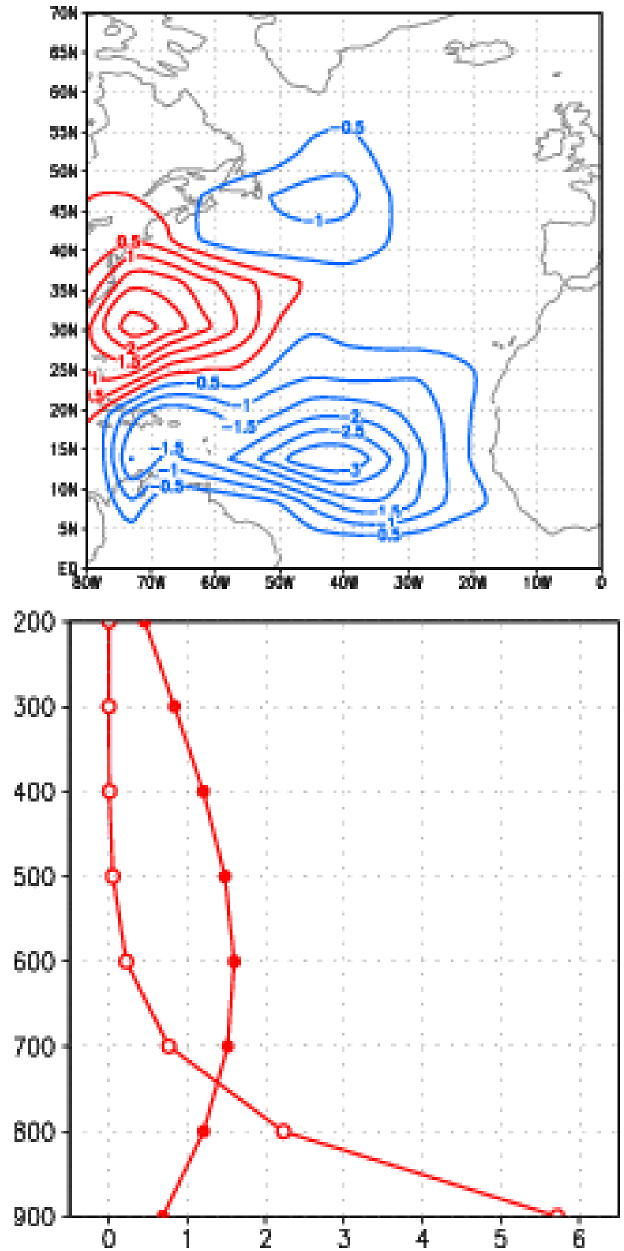
Eddy Vorticity Forcing (950−250mb)



Cint=1 m^2s^{-2}

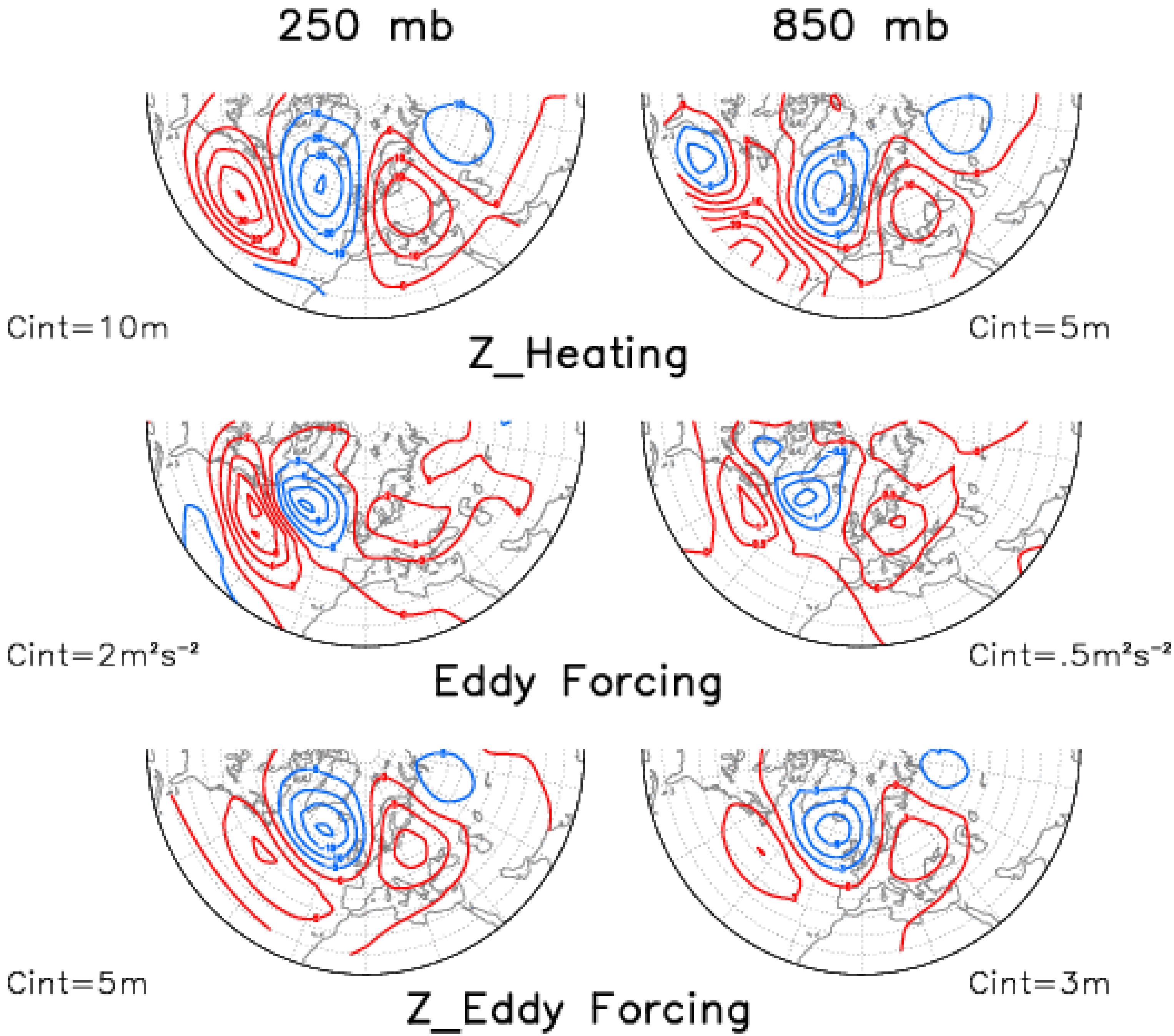
AGCM STM

Idealized Initial Q



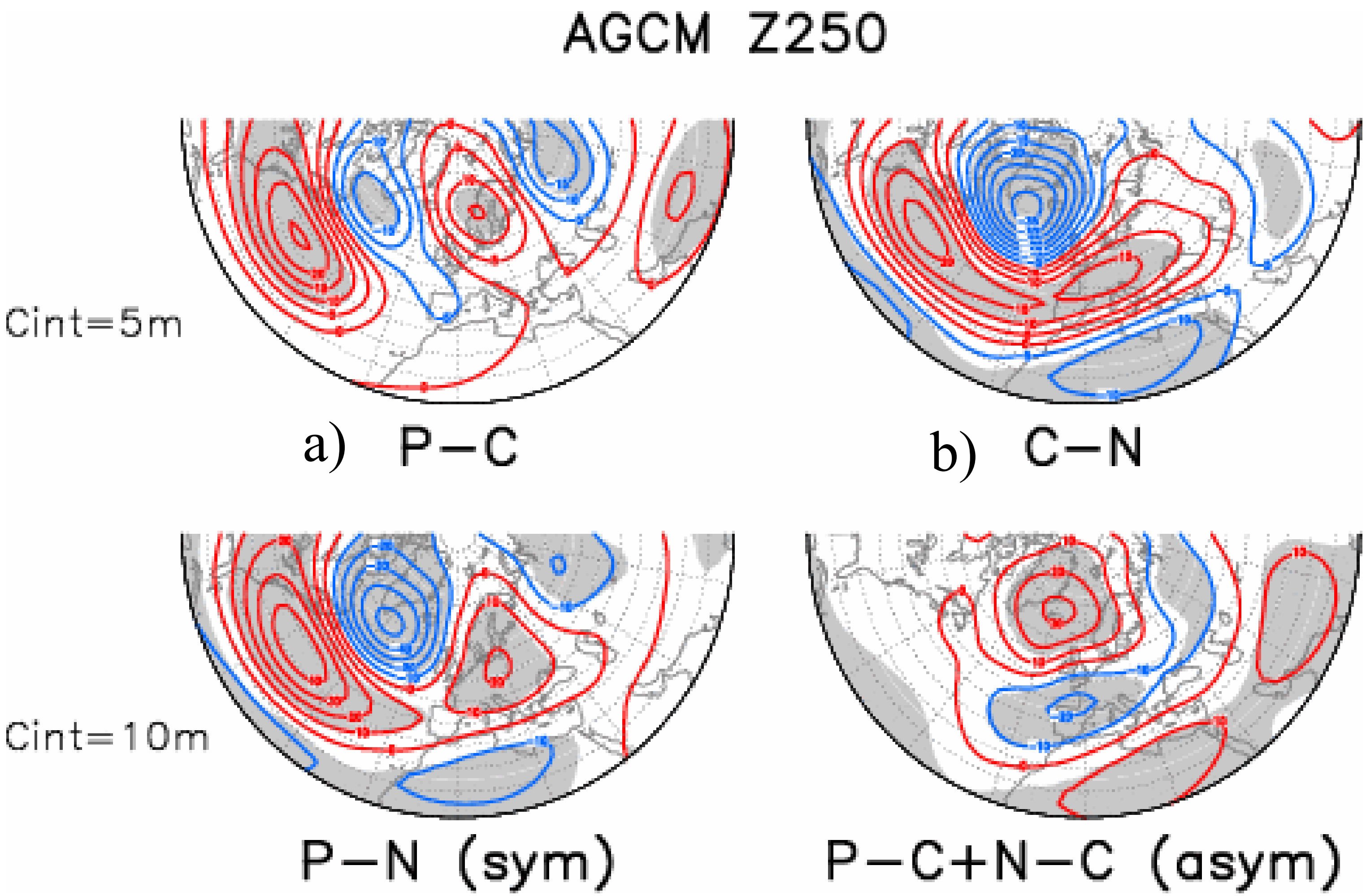
Cint=0.5 K/day

PW Mechanism for Symmetric Response



Mechanisms ??

=> Asymmetric response



(a+b)

(a-b)

PW Eddy Feedback Mechanism

(*Peng and Whitaker 1999*)

SSTA => Q => Ψ_H => F_E => Ψ_E

(LBM) (STM) (LBM)

Q: Anomalous heating

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(Schematic for the **initial** process !!)

Heating-Induced Asymmetric Response:

$$\Psi_{+Q} = \Psi_{H} + \Psi_{NL}$$

$$\Psi_{-Q} = -\Psi_{H} + \Psi_{NL}$$

(or $-\Psi_{-Q} = \Psi_{H} - \Psi_{NL}$ **)**

Ψ_{H}: Heating-forced linear anomalous flow

Ψ_{NL}: **Nonlinearity due to** Ψ_{H} **self-interaction**

Under the control basic state, Ψ_C , the linearized vorticity fluxes may be expressed as:

$$\partial \zeta_H / \partial t = ... - (V_H \bullet \nabla\zeta_C + V_C \bullet \nabla\zeta_H)$$

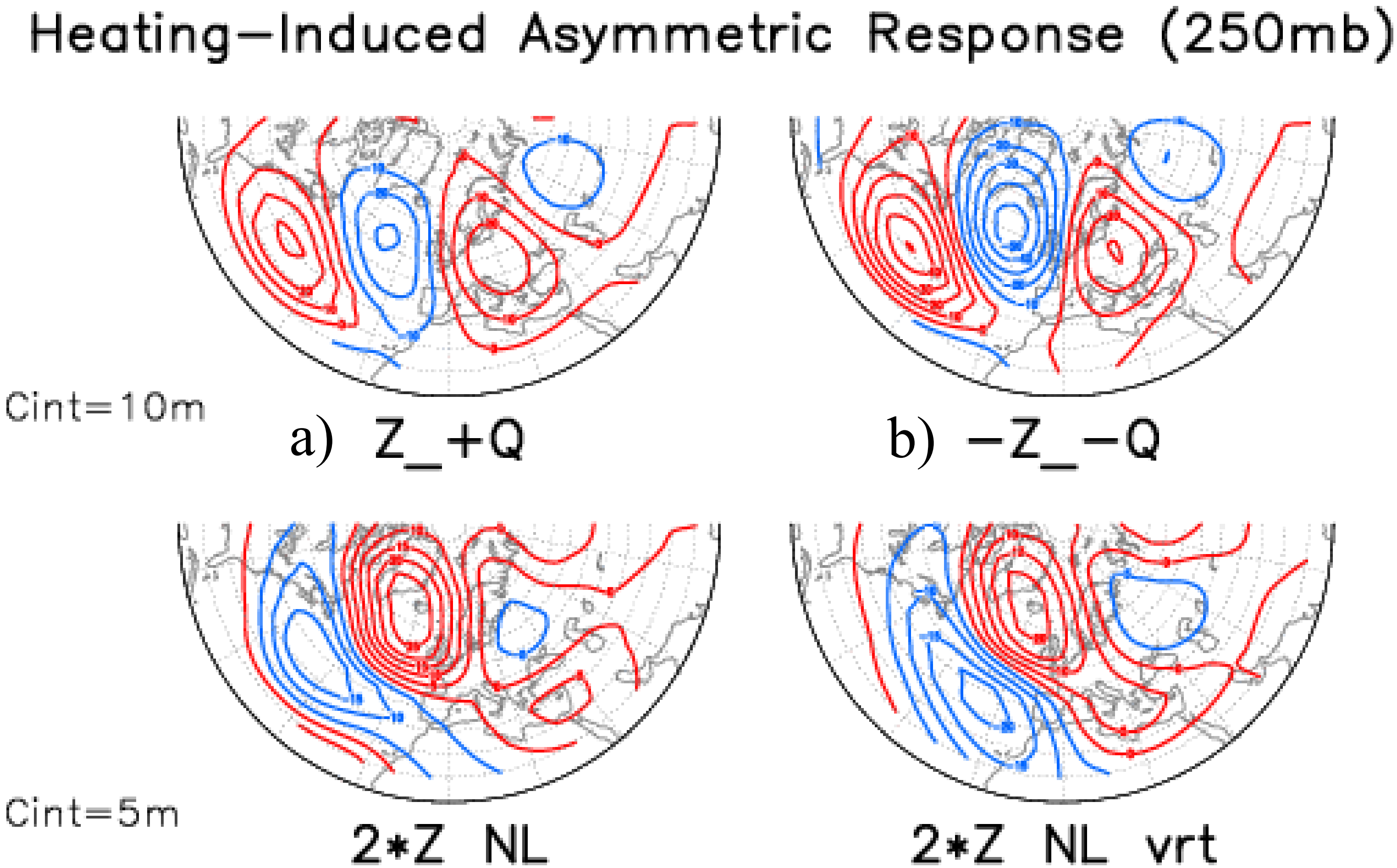
Here, the response (V_H , ζ_H) corresponds to Ψ_H .

Under the modified basic state, $\Psi_C + \Psi_H / 2$, the linearized vorticity fluxes become:

$$\partial \zeta_{+Q} / \partial t = ... - (V_{+Q} \bullet \nabla\zeta_C + V_C \bullet \nabla\zeta_{+Q} + V_H \bullet \nabla\zeta_H$$

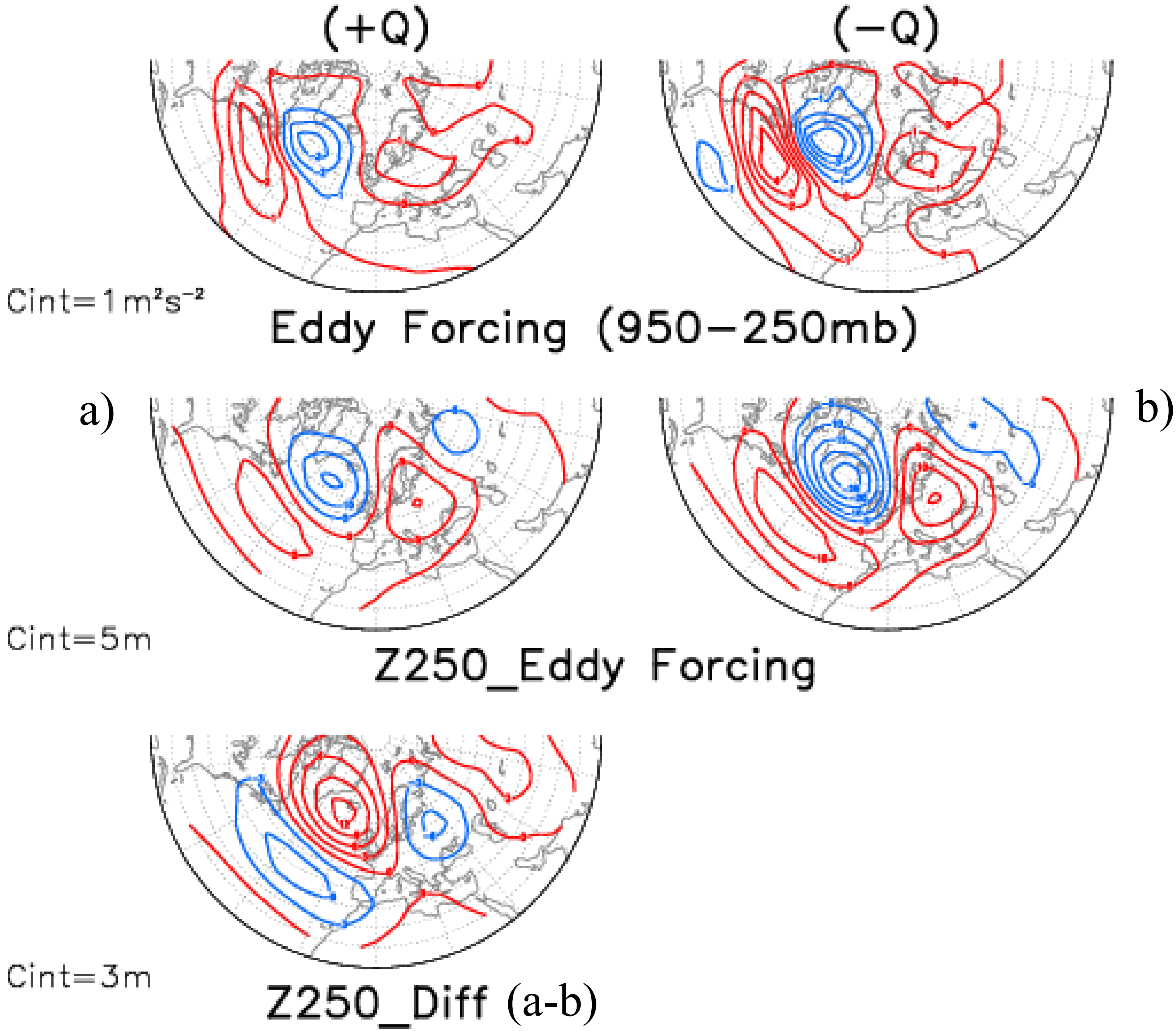
$$+ \text{higher order nonlinearity})$$

Now, the response (V_{+Q} , ζ_{+Q}) corresponds to the asymmetric response Ψ_{+Q} .

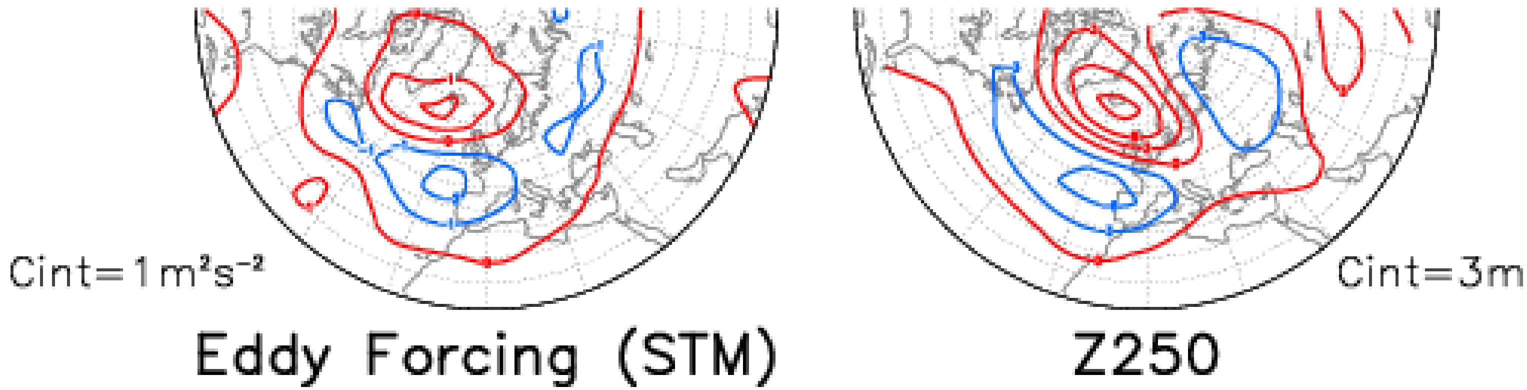

Heating-Induced Asymmetric Response (250mb)
Cint=10m
a) Z_+Q
b) -Z_-Q
Cint=5m
2*Z_NL
2*Z_NL_vrt

(a-b)

Eddy–Feedback on the Asymmetric Response



Estimated AGCM Eddy-Forced Asymmetric Component



Nonlinear Eddy Feedback Mechanism

$\Rightarrow \Psi_{+Q} \Rightarrow F_{+E} \Rightarrow \Psi_{+E}$

SSTA => Q

$\Rightarrow \Psi_{-Q} \Rightarrow F_{-E} \Rightarrow \Psi_{-E}$

$\Psi_{\pm Q}$: Heating-forced asymmetric anomalous flows
(due to nonlinear self-interaction !!)

$F_{\pm E}$: Asymmetric eddy vorticity forcings

$\Psi_{\pm E}$: Eddy-forced asymmetric anomalous flows

(Schematic for the **initial** process !!)

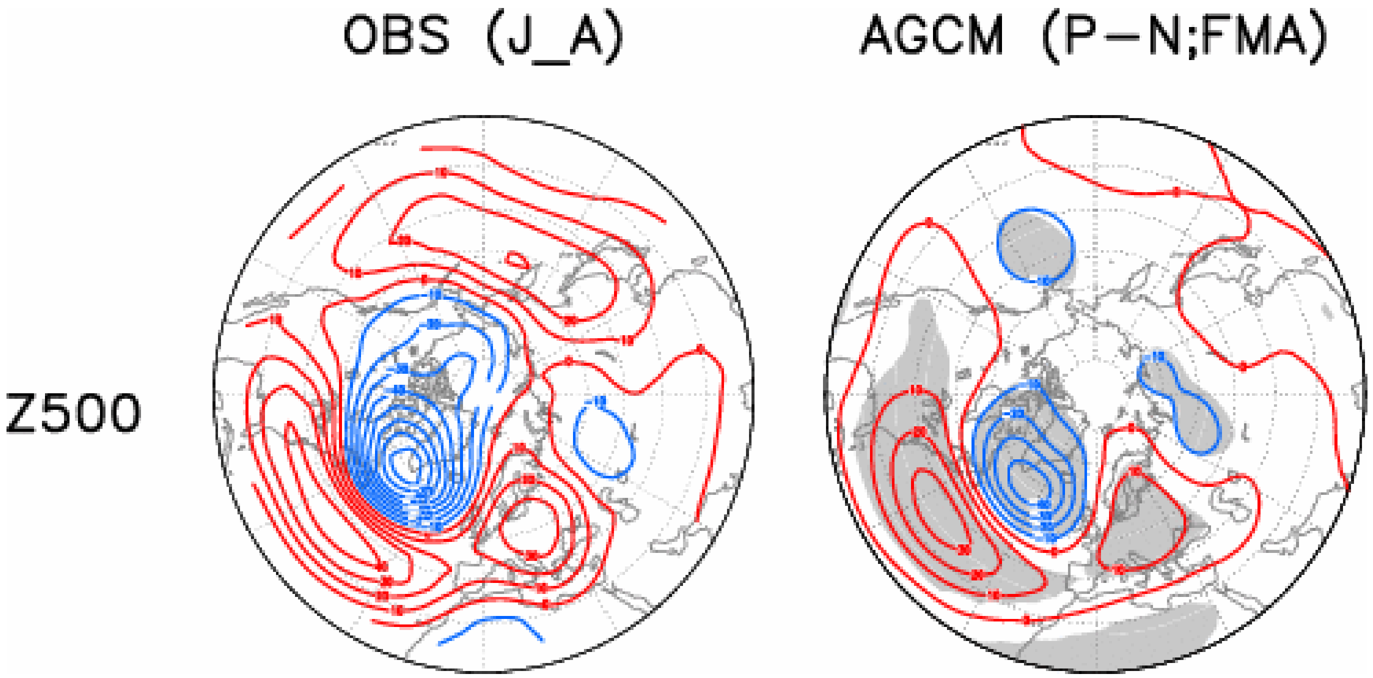
SUMMARY

1. The SST tripole induces a NAO-like response in late-winter in the AGCM (~ 15-30 m /K in Z500) that indicates a positive feedback between the NAO and the tripole.

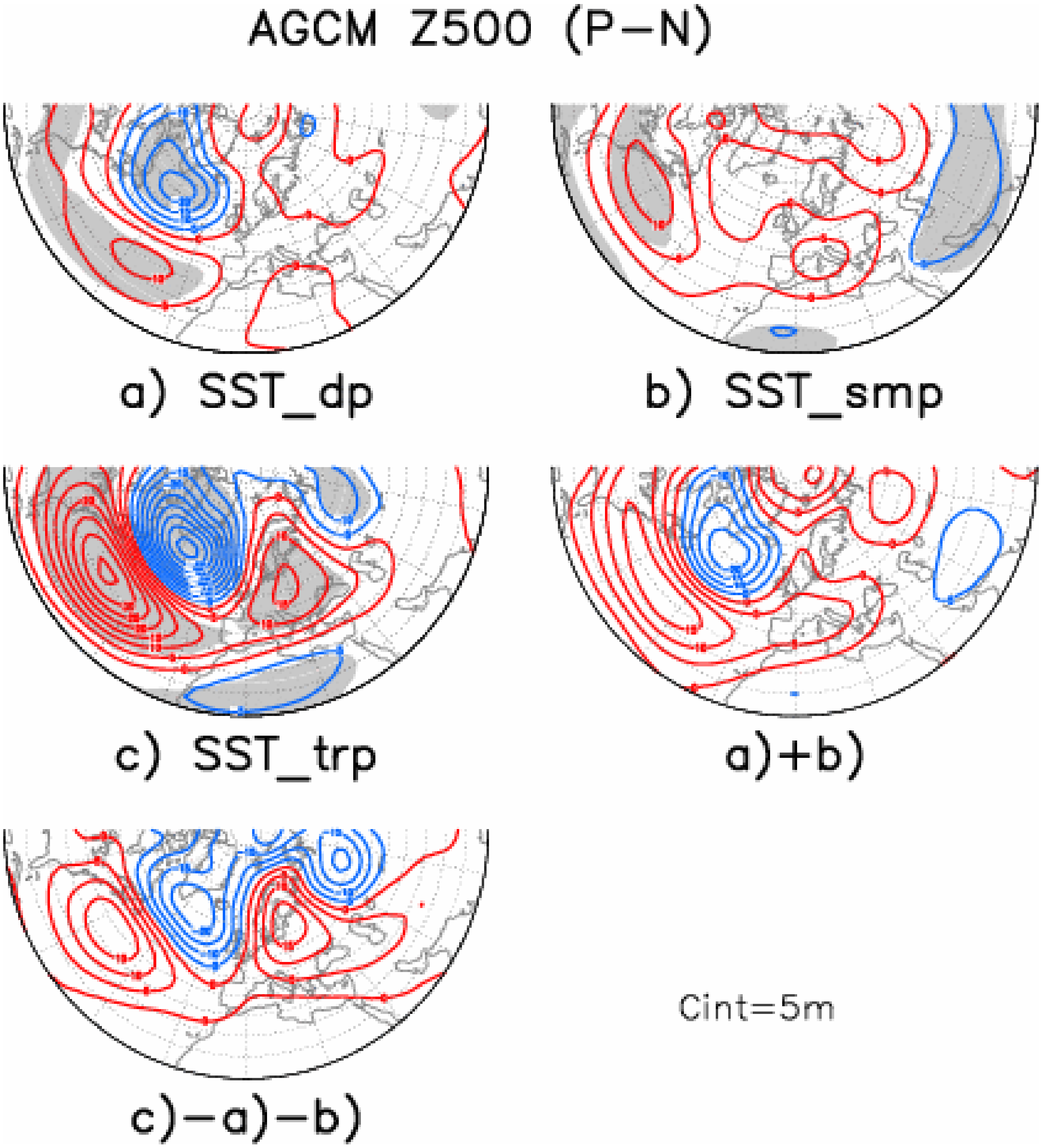
2. The NAO response is mainly sustained by anomalous eddy forcing, developed through the eddy feedback mechanisms:

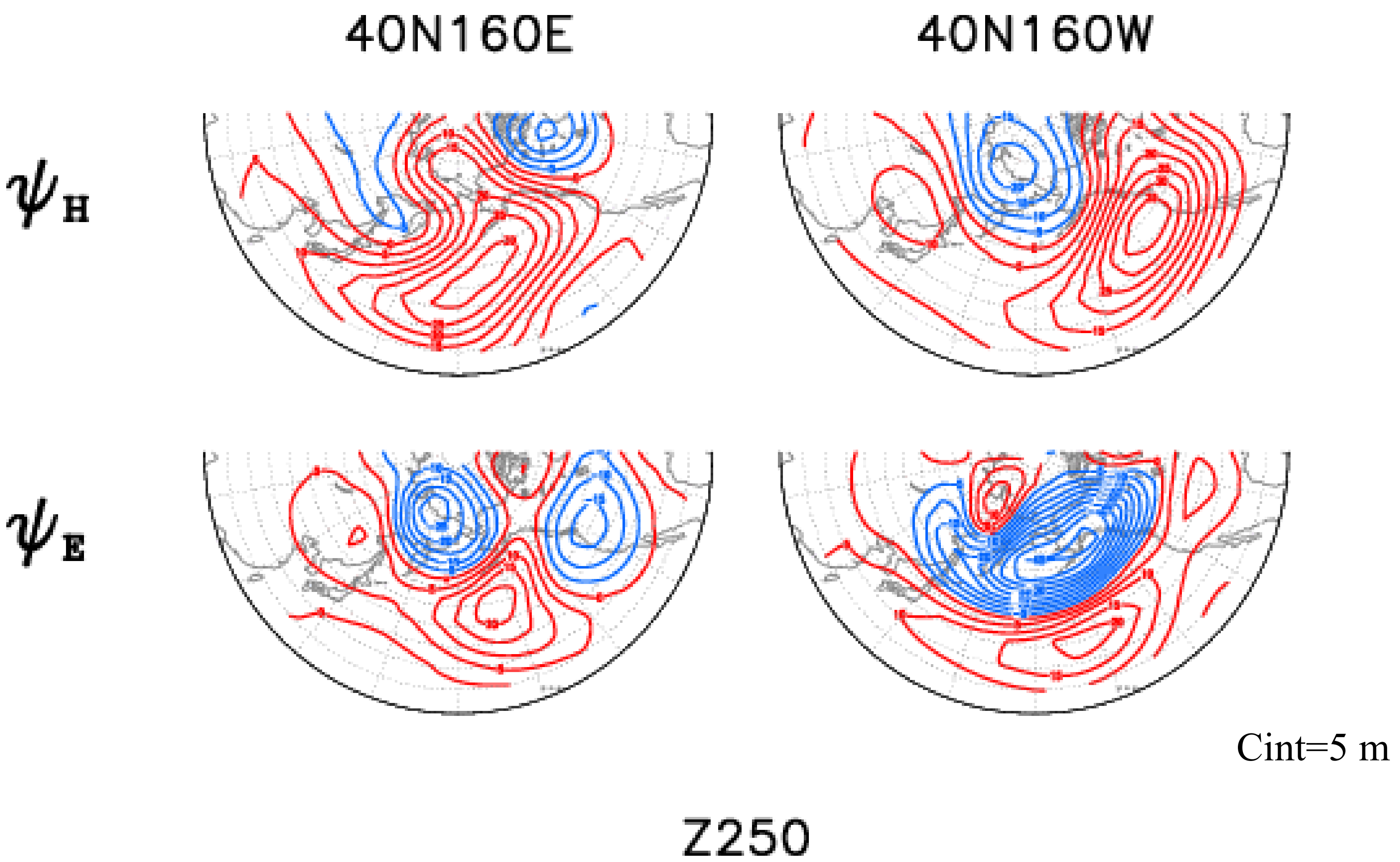
=> Symmetric component - PW eddy feedback mechanism

=> Asymmetric component - Nonlinear eddy feedback mechanism

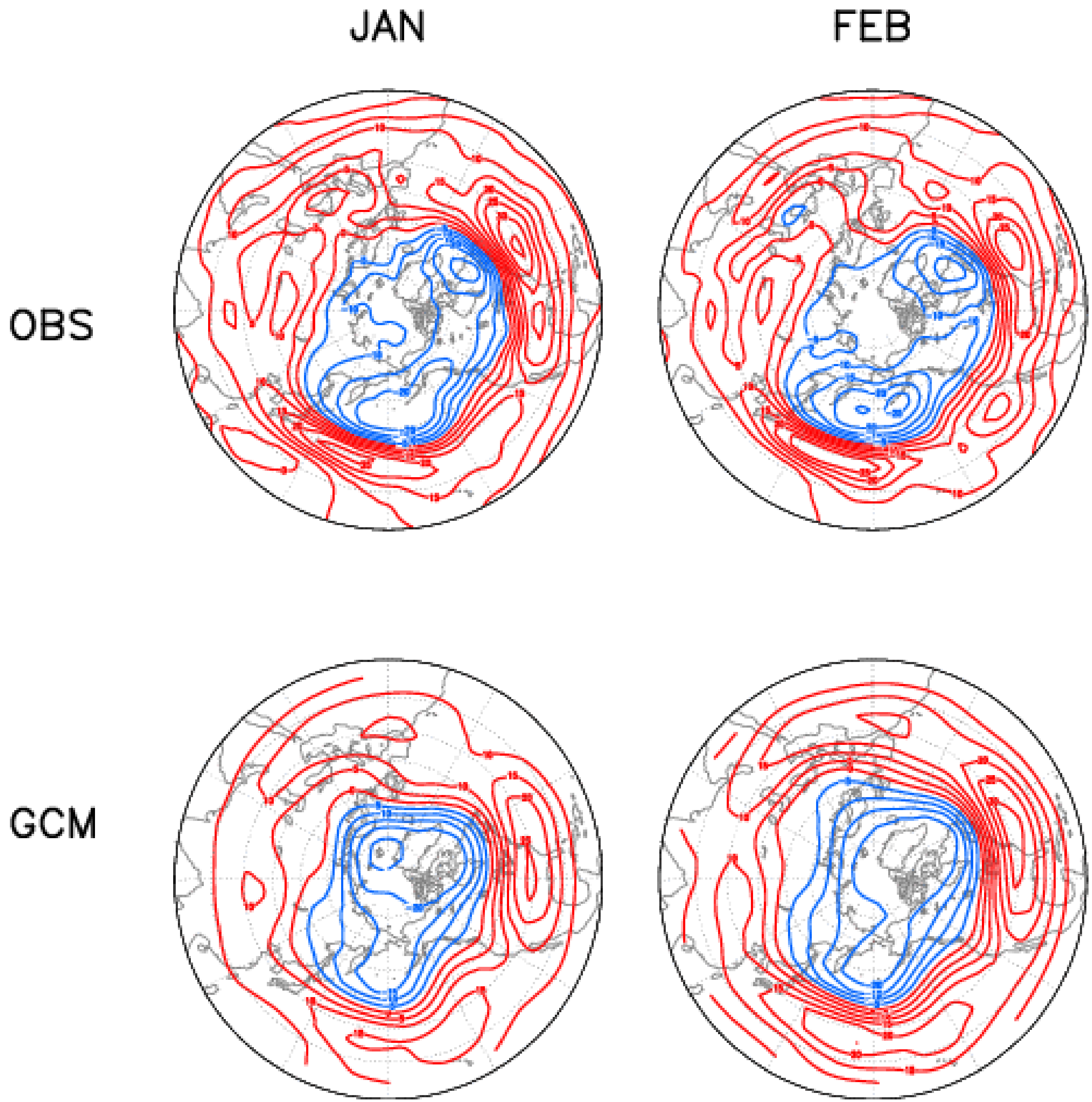


Cint=10m


AGCM Z500 (P-N)
a) SST_dp
b) SST_smp
c) SST_trp
a)+b)
c)-a)-b)
Cint=5m


40N160E
40N160W
ψH
ψE
Cint=5 m
Z250

250mb ψ_t (3−10d) (eddy vorticity forcing)

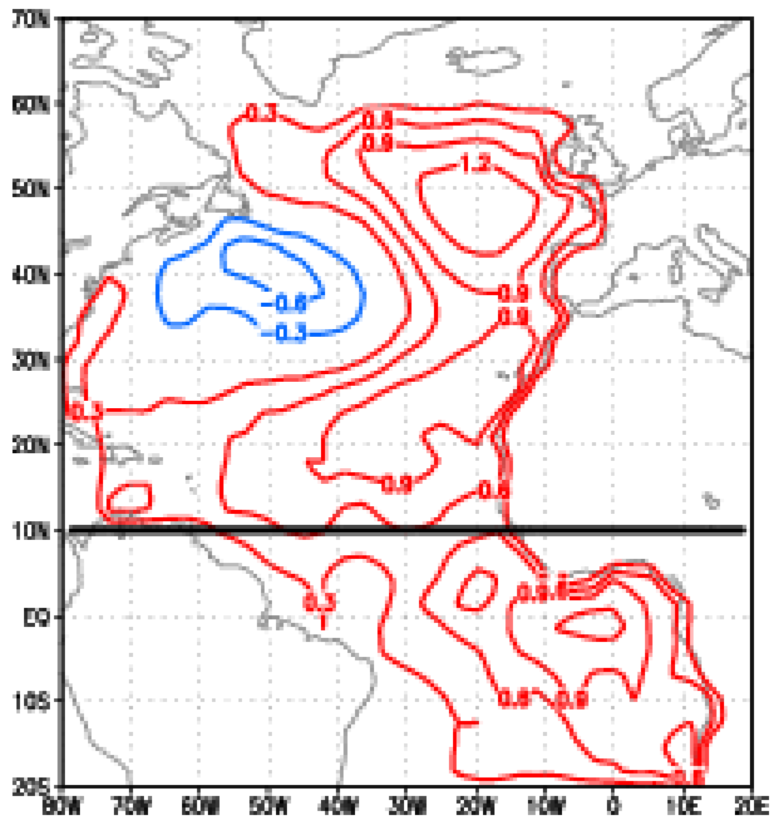


Cint=5 m^2s^{-2}

Fall Pan-Atlantic SST Anomaly

North Atlantic horseshoe (NAH) anomaly →

Tropical anomaly →

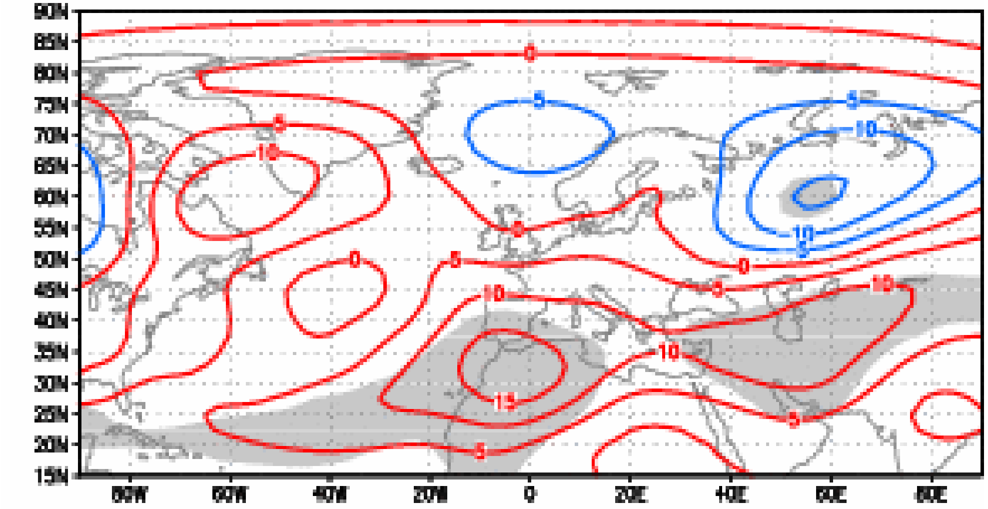


10N

Cint=0.3 K

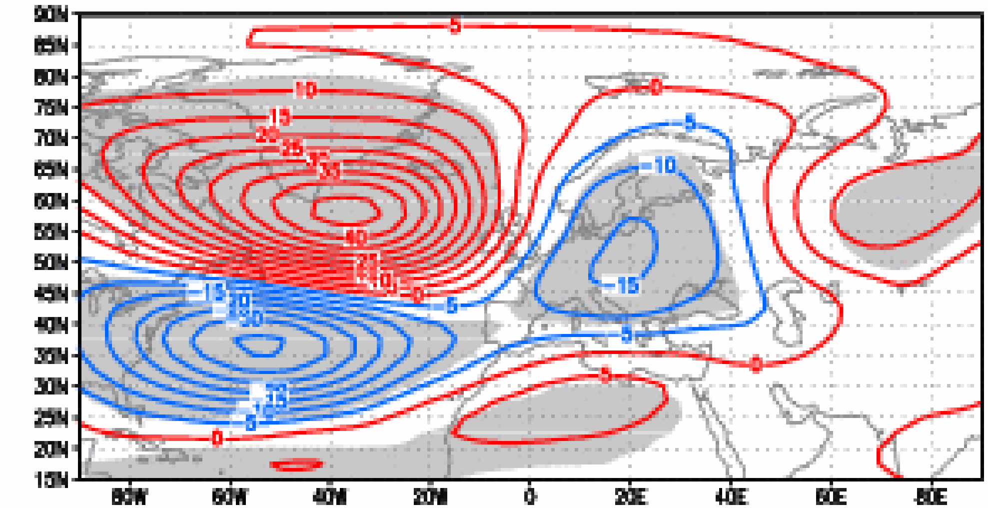
AGCM Response (P-N)

a) Feb–Apr Z500 (NAH)

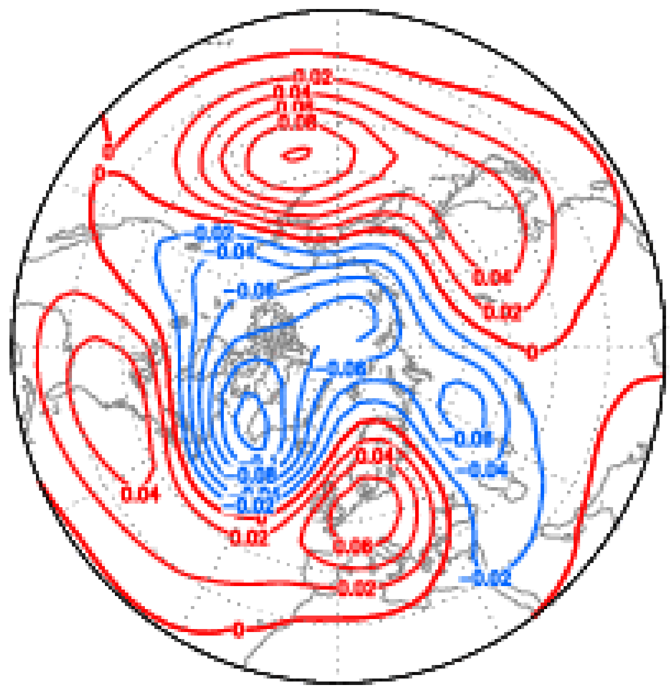


Cint=5 m

b) Z500 (tripole)



OBS Z500 EOF1 (16%;O_A)



An estimation of the ensemble size based on the t - test:

$$N = 2 * t^2 / S^2$$

N - ensemble size

t - student t value

S - signal-to-noise ratio

Given: $S^2 = 10 - 20\%$; $t = 2$

=> $N = 40 - 80$