Response of the North Atlantic jet and its variability to increased greenhouse gasses in the CMIP5 models

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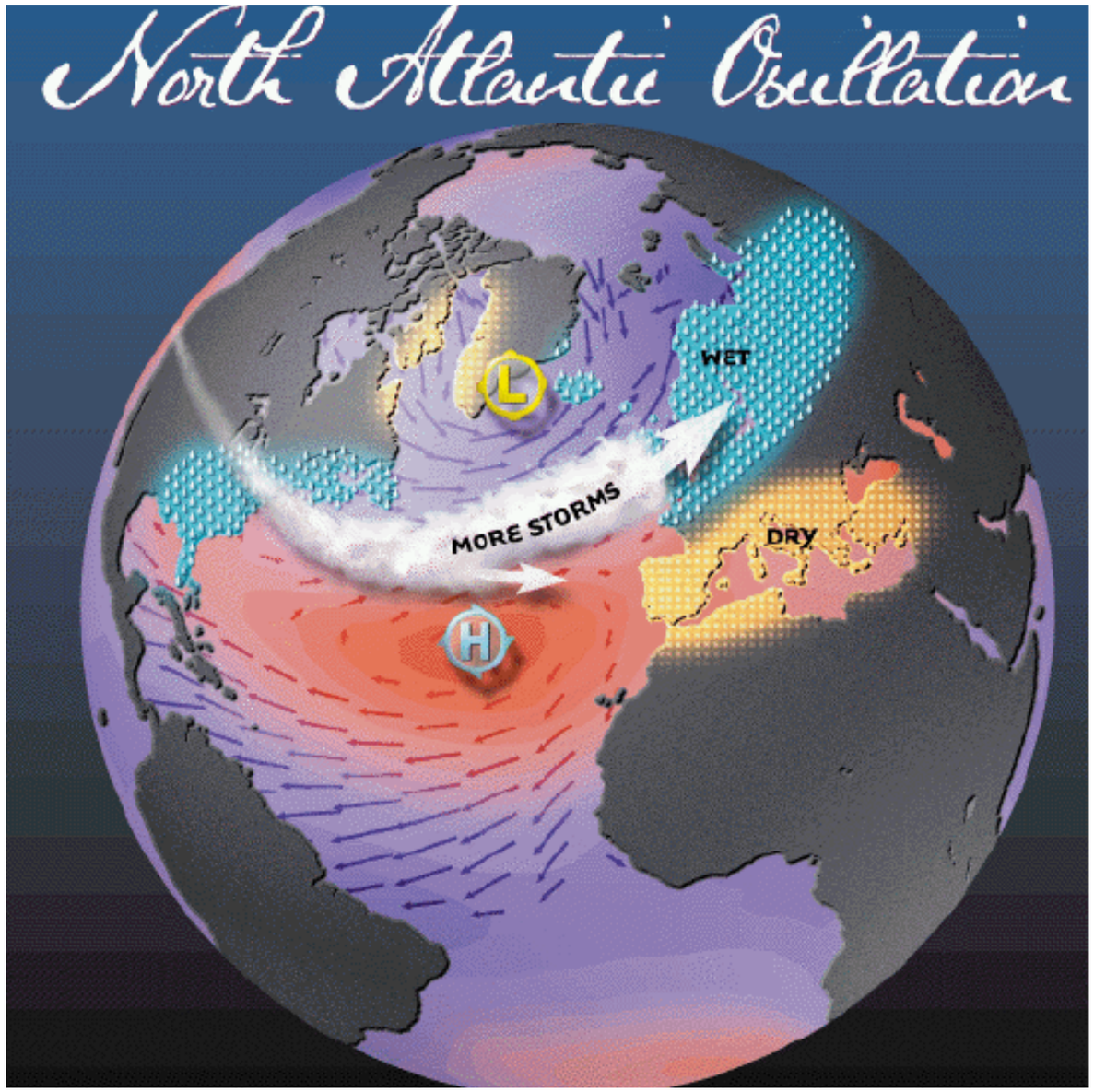
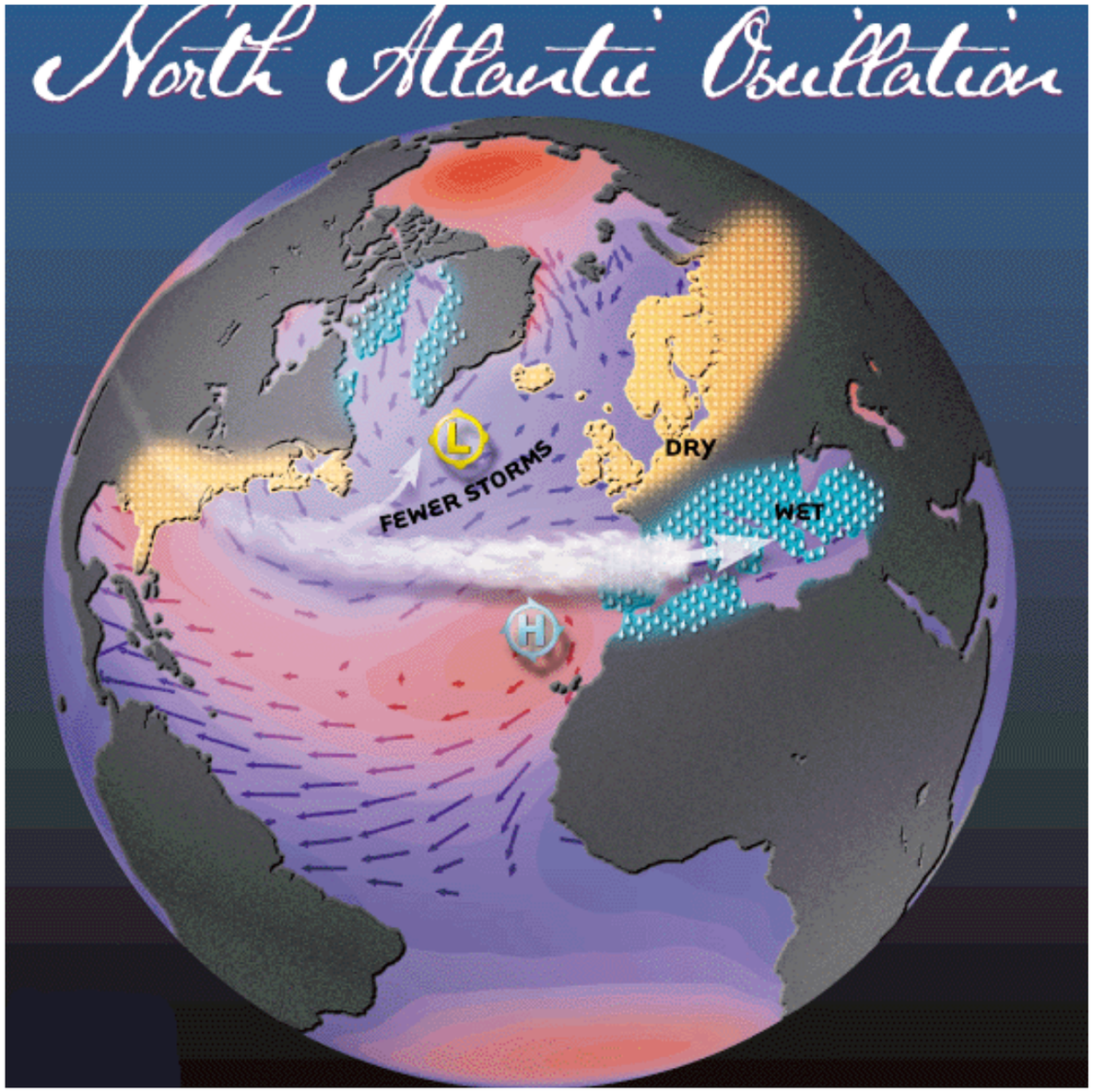
North Atlantic Oscillation: primary mode of variability

+NAO



-NAO



http://www.ldeo.columbia.edu/res/pi/NAO/

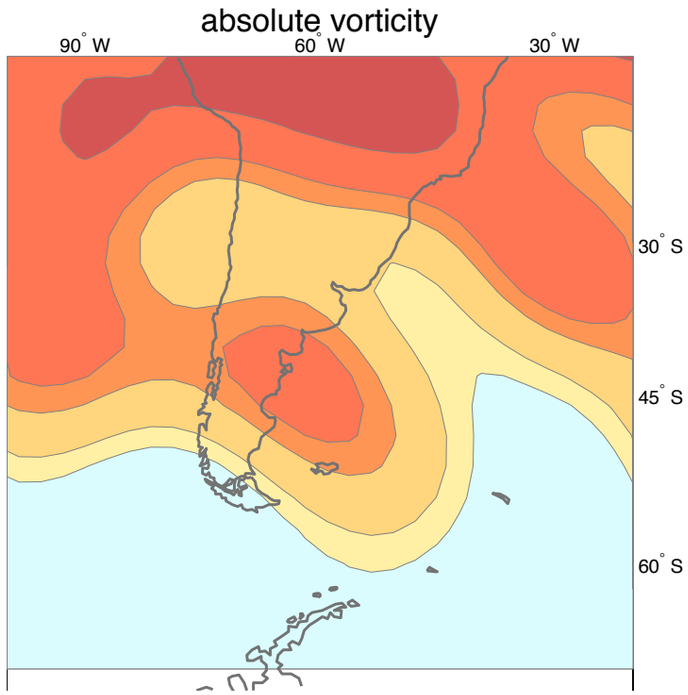
CMIP5 Results

How will eddy-driven jet **variability** respond to climate change?

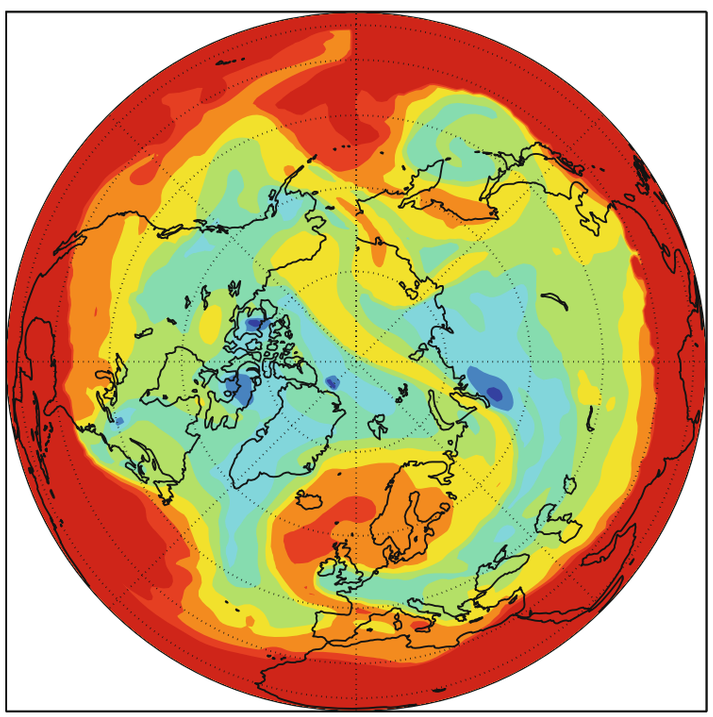
CMIP5 Results

How will eddy-driven jet **variability** respond to climate change?

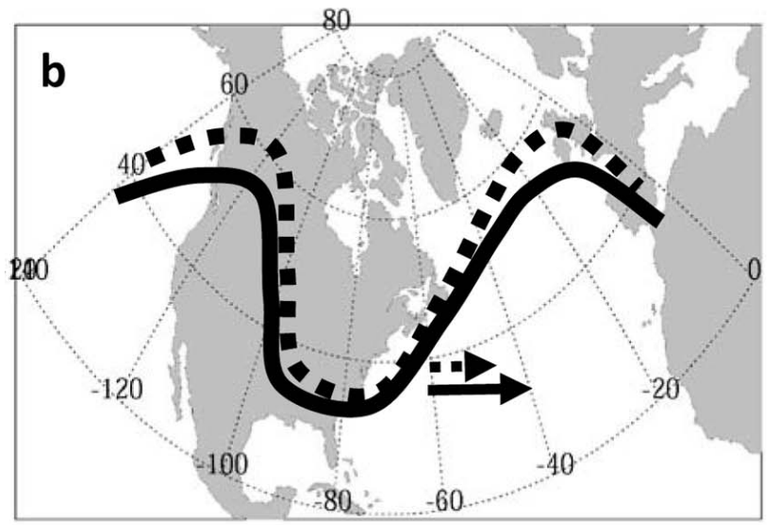
How do changes in the jet variability relate to **eddy/wave** activity?



wave breaking



blocking

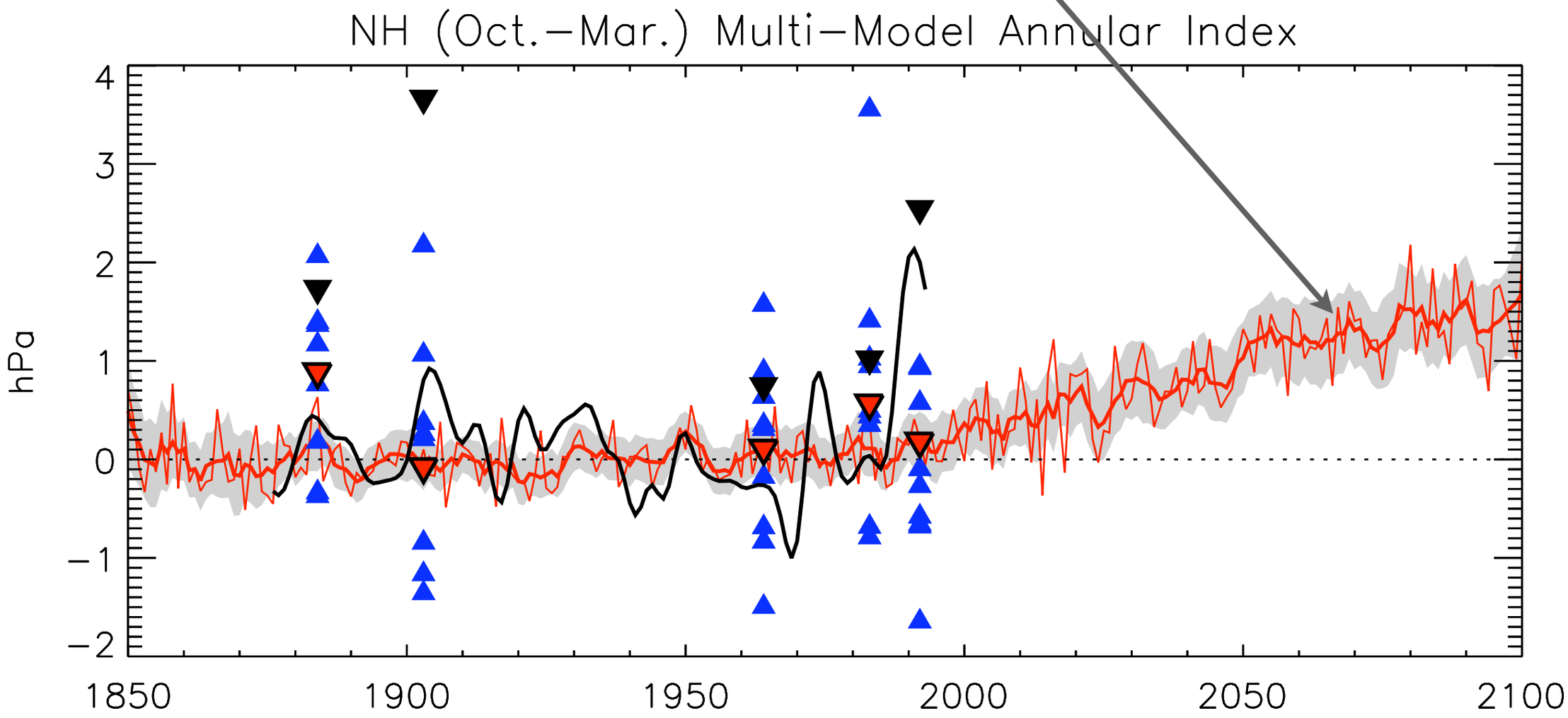


recent results on wave heights

Francis, & Vavrus (2012); GRL

What did IPCC AR4 say?

- focused on trends
- indicates poleward shift of the mean position



Miller, Schmidt et al. (2006); JGR

What did IPCC AR4 say?

- focused on trends
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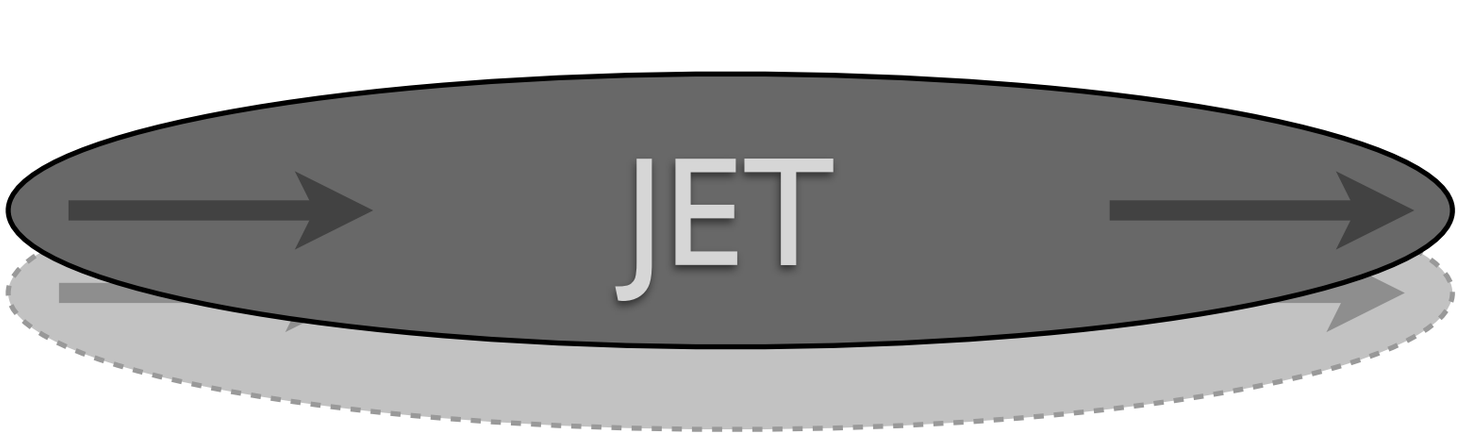
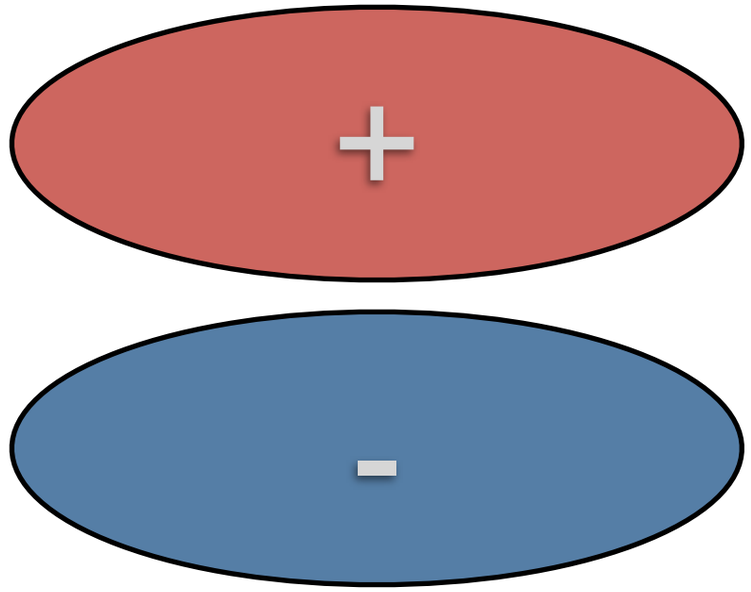
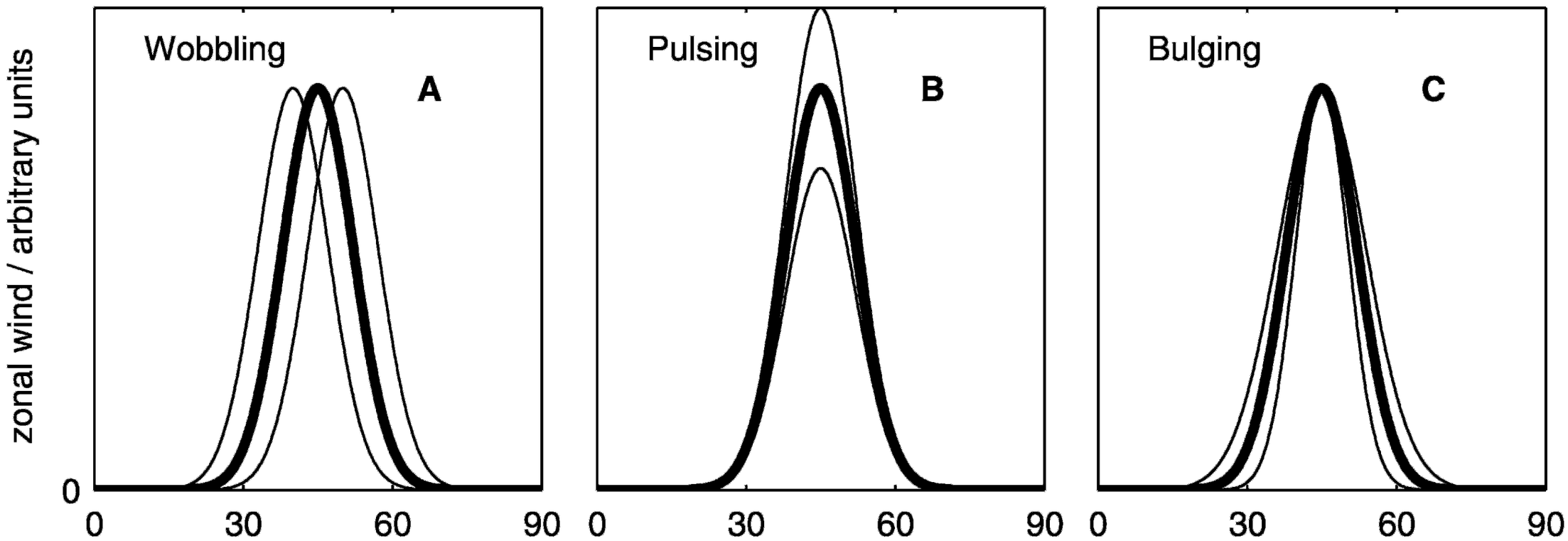
time-mean jet



NAO anomaly pattern



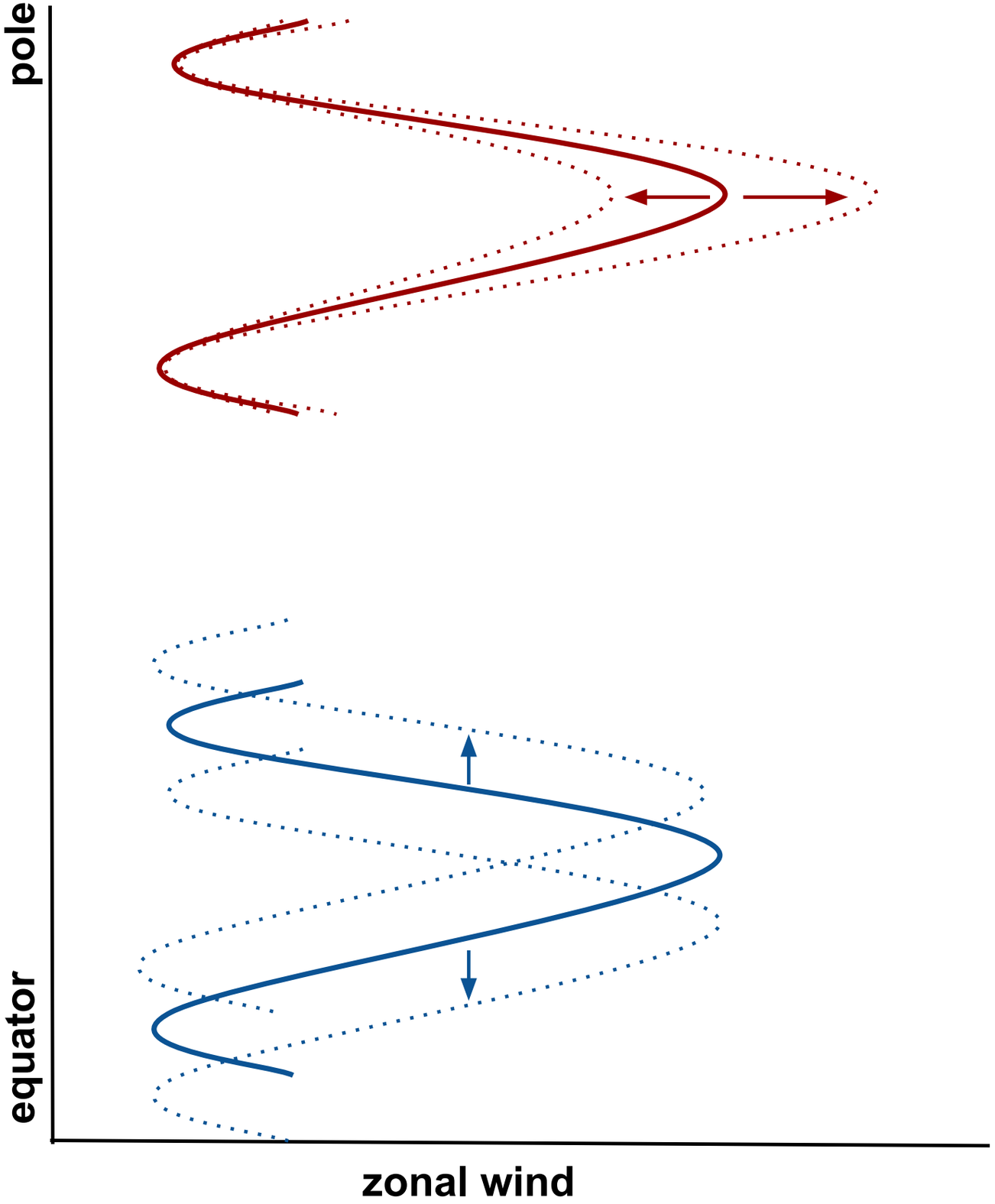
What do we mean by "variability"?



Wittman, Charlton et al. (2005); JCLI

Barotropic model: dependence of variability on latitude

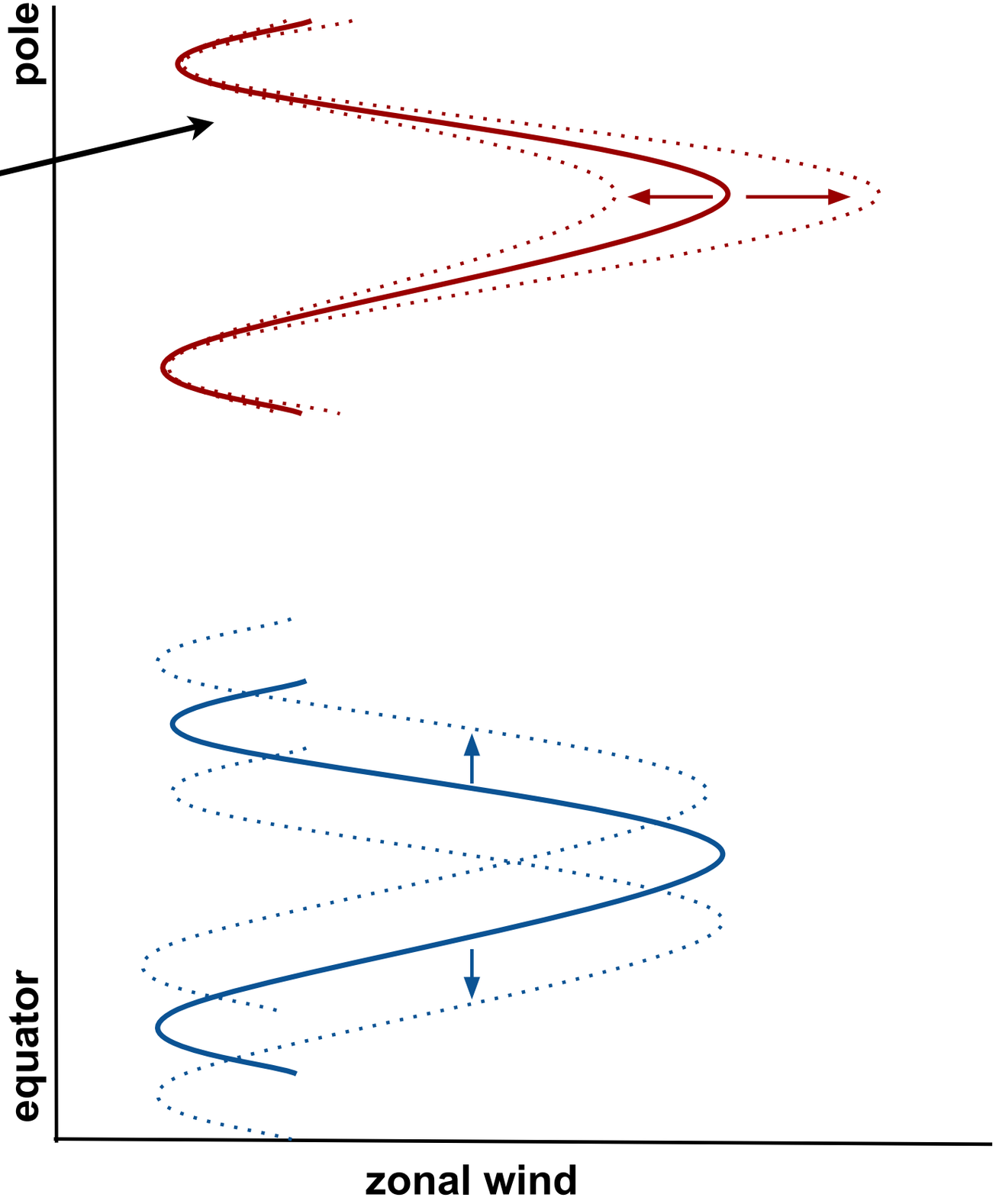
Variability of jet changes to <u>pulse</u> at high latitudes



Barotropic model: dependence of variability on latitude

MECHANISM: waves cannot propagate and break at high latitudes (beta is small), so no eddy-mean flow feedback to make jet wobble

Variability of jet changes to pulse at high latitudes



CMIP5 data

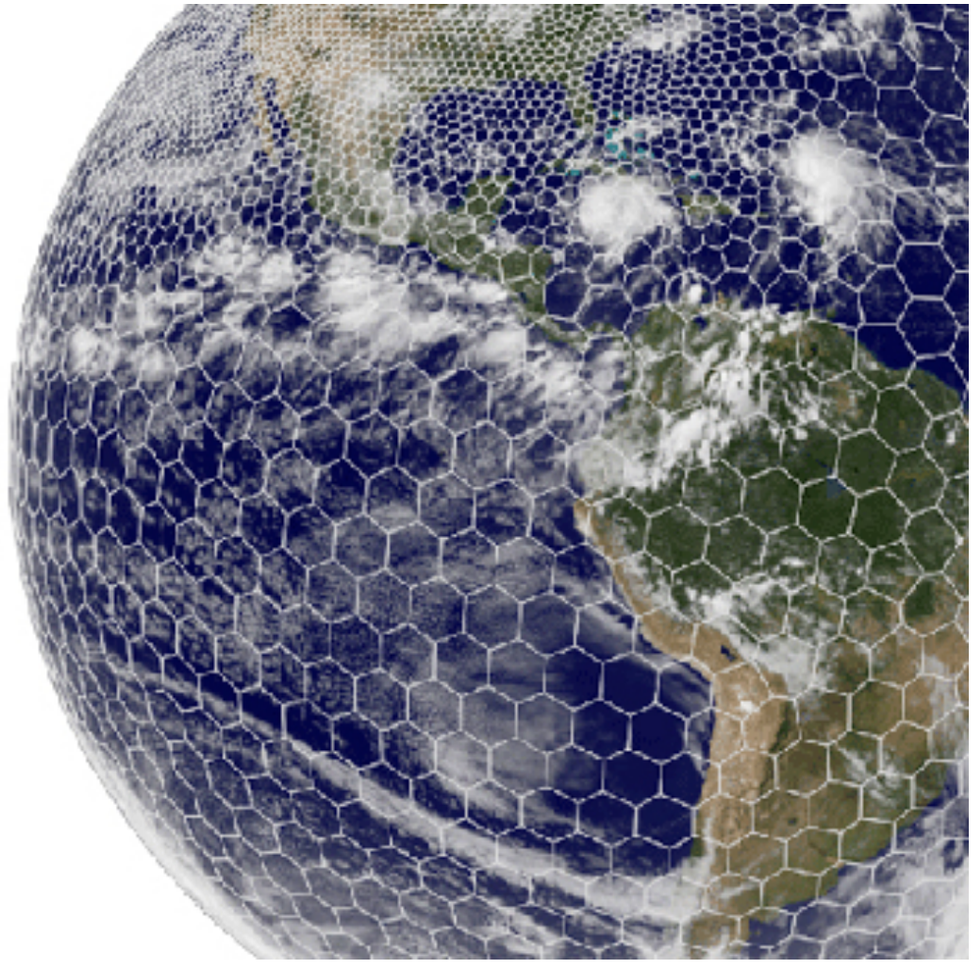
Preindustrial (25 years)

Historical (1980-2004)

RCP4.5 (2076-2099)

RCP8.5 (2076-2099)

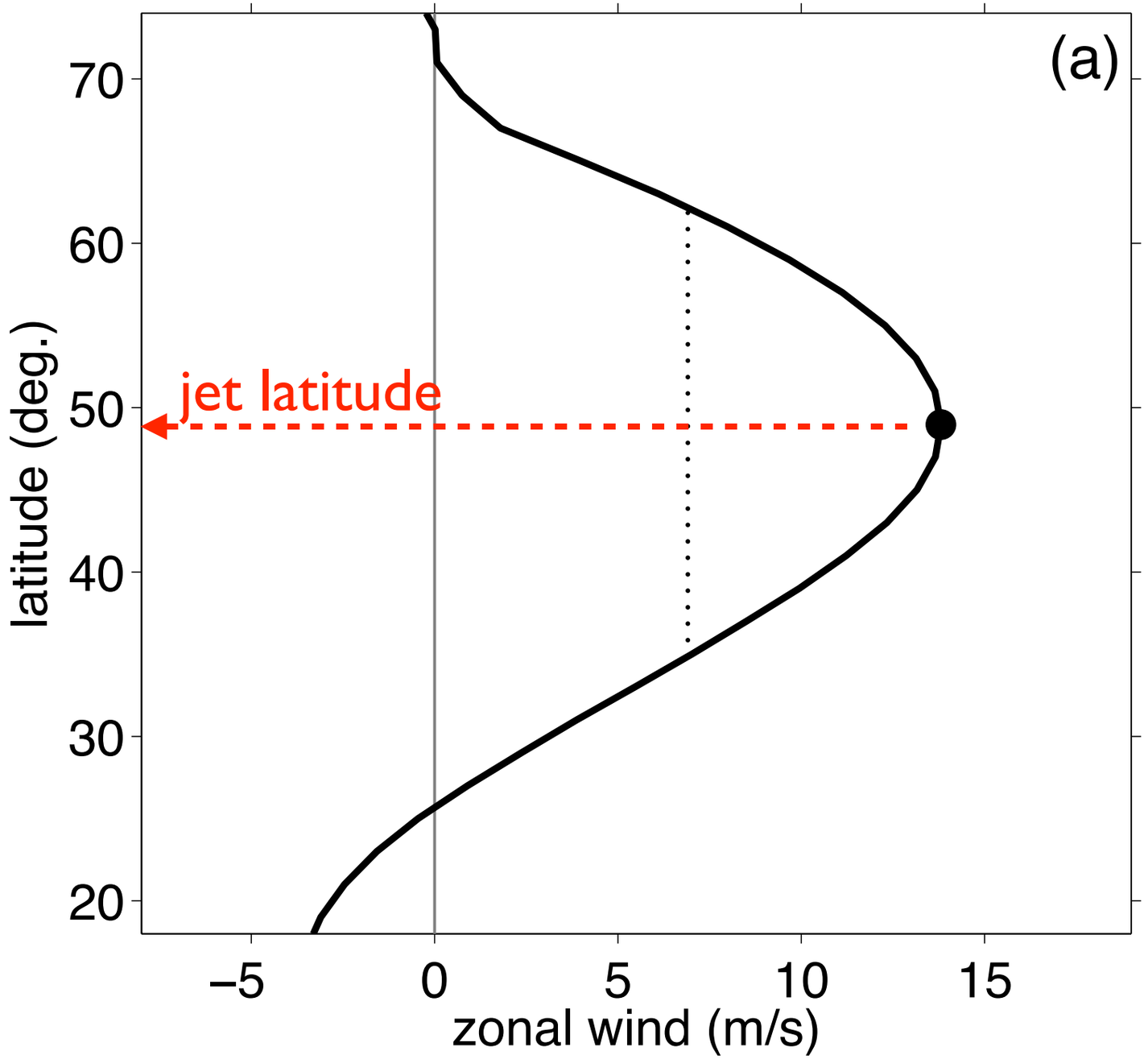
- bcc-csm1-1
- BNU-ESM
- CanESM2
- CNRM-CM5
- CSIRO-Mk3-6-0
- FGOALS-g2
- FGOALS-s2
- GFDL-CM3
- GFDL-ESM2G
- GFDL-ESM2M
- HadCM3
- HadGEM2-CC
- HadGEM2-ES
- inmcm4
- IPSL-CM5A-LR
- IPSL-CM5A-MR
- IPSL-CM5B-LR
- MIROC-ESM-CHEM
- MIROC5
- MPI-ESM-LR
- MPI-ESM-MR



Visualization by William Skamarock, NCAR.
http://www2.ucar.edu/sites/default/files/news/2010/pg51globe350.jpg

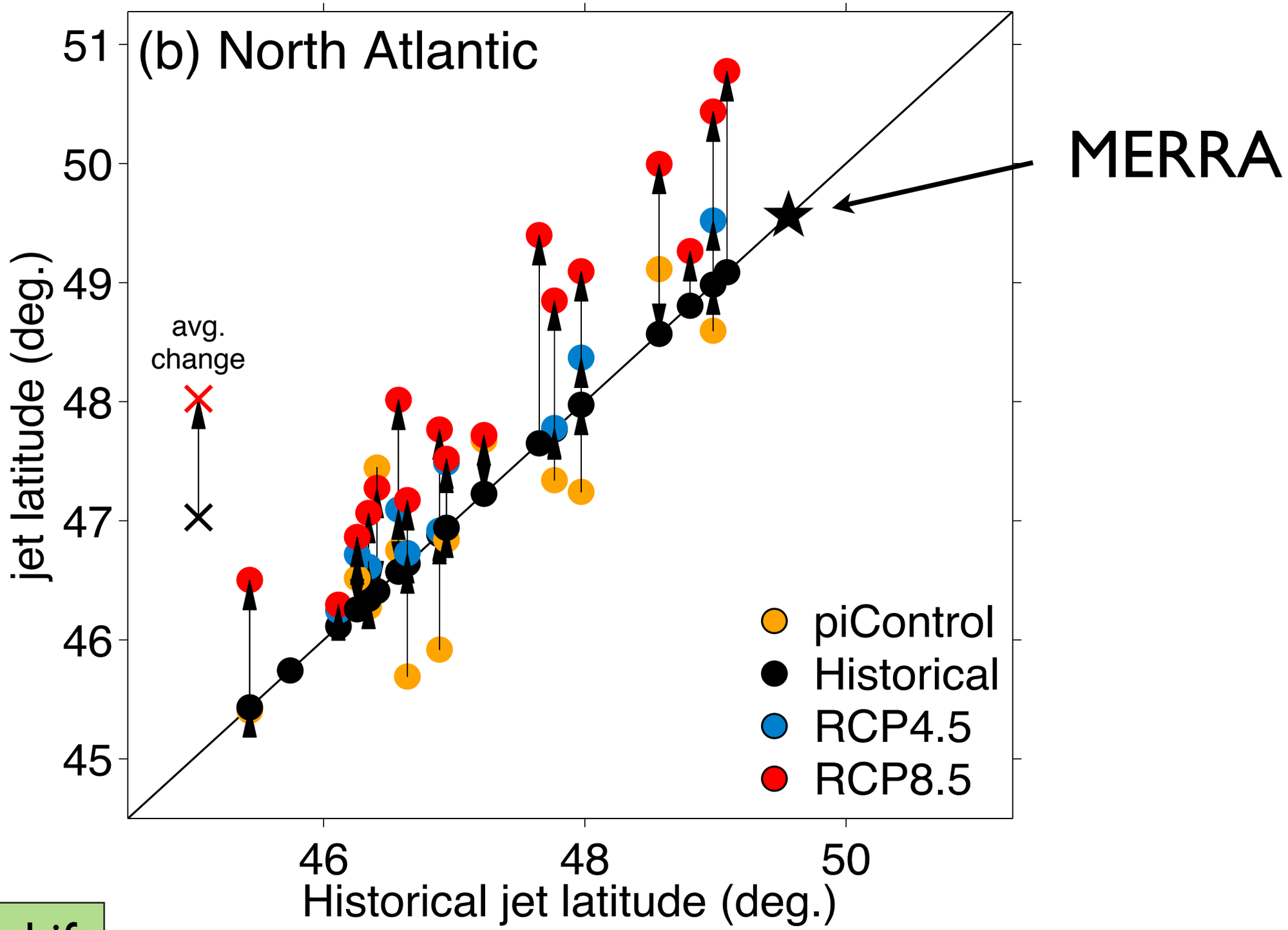
Jet definitions

- 850-700 hPa winds
- 10-day lowpass filtered
- jet latitude time series



Barnes & Polvani (2012); submitted

Mean jet position

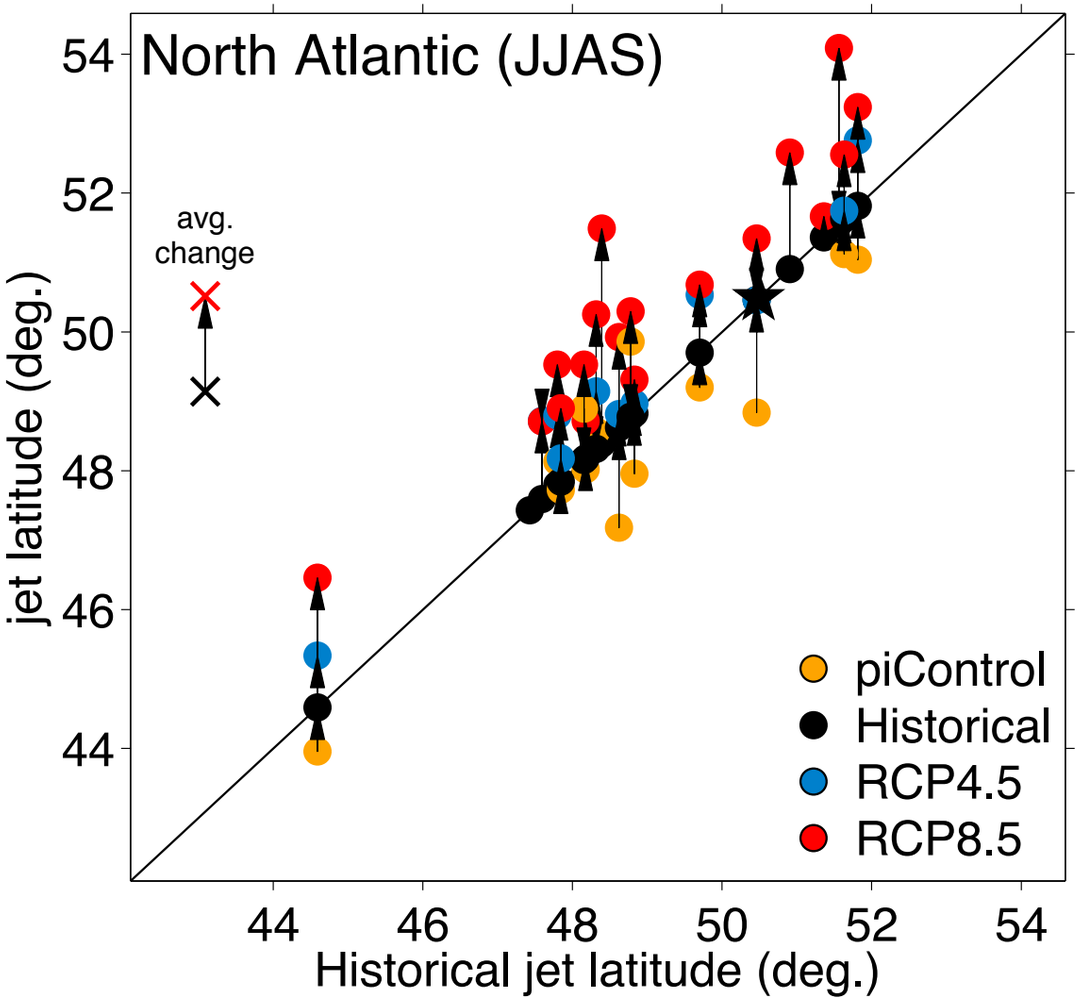


- poleward jet shift

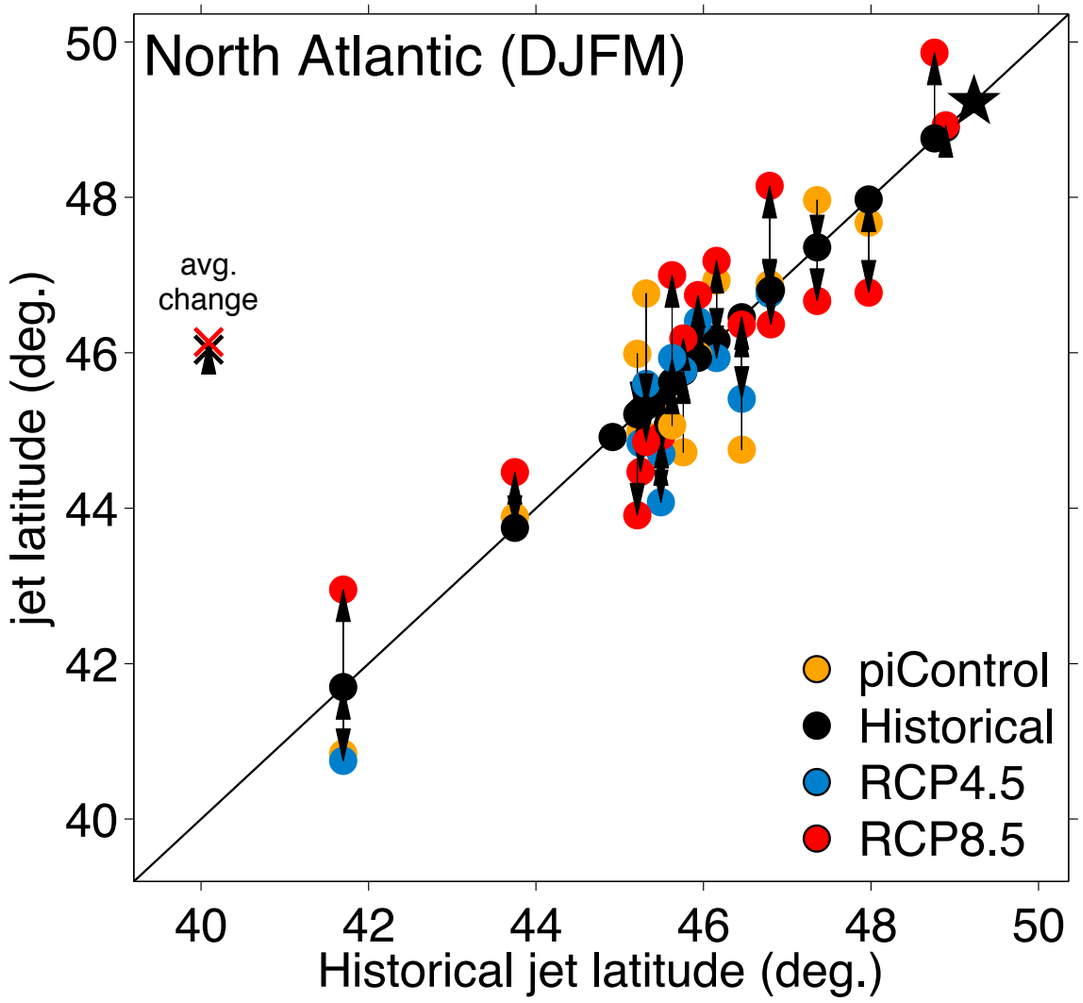
Barnes & Polvani (2012); submitted

Mean jet position (seasonal shifts)

June-Sept.



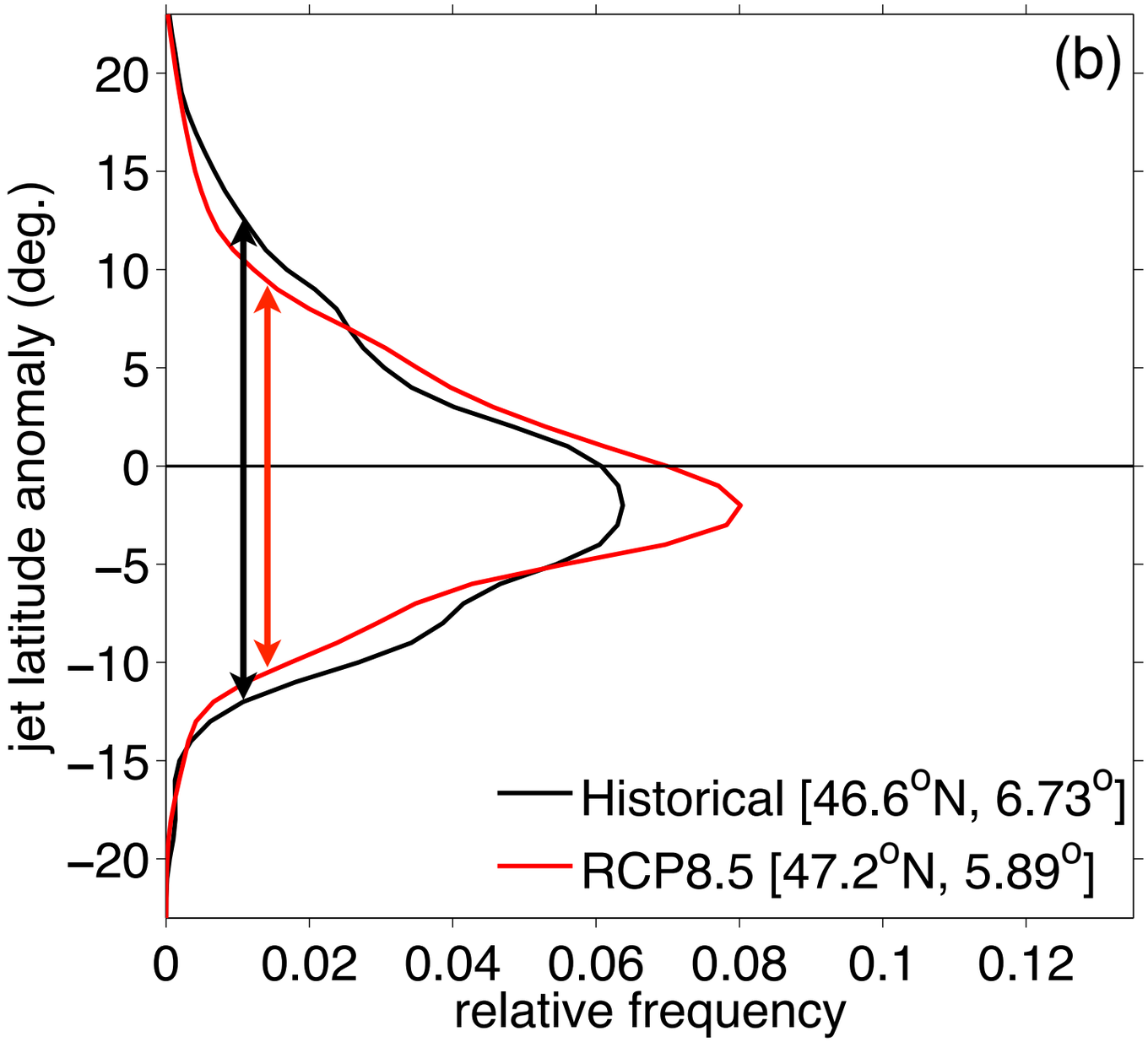
Dec.-Mar.



- shift depends on season

Daily jet latitude histograms

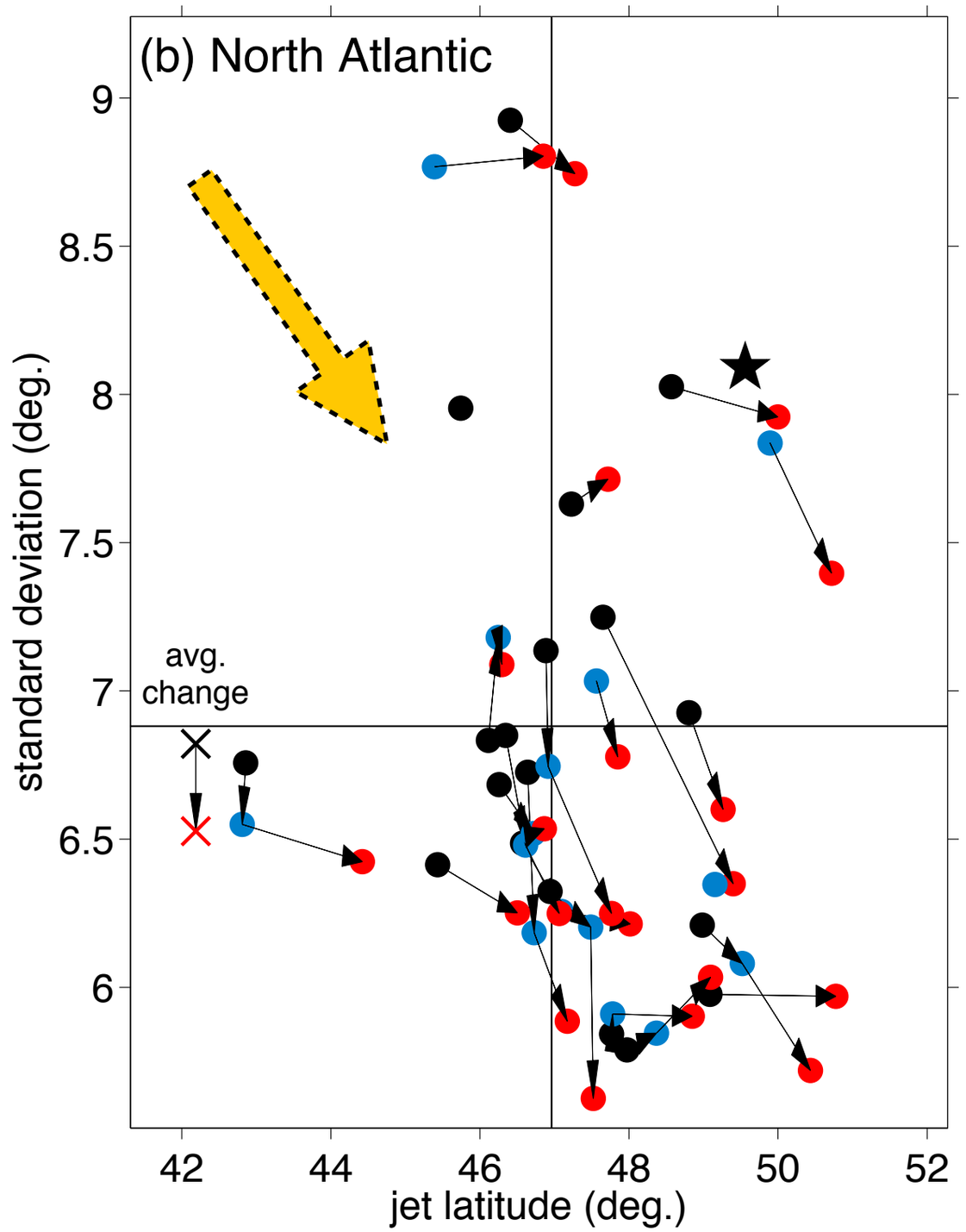
- standard deviation of daily jet latitude decreases



GFDL-ESM2M

Standard deviation of jet latitude

- decrease in standard deviation when jet shifts poleward

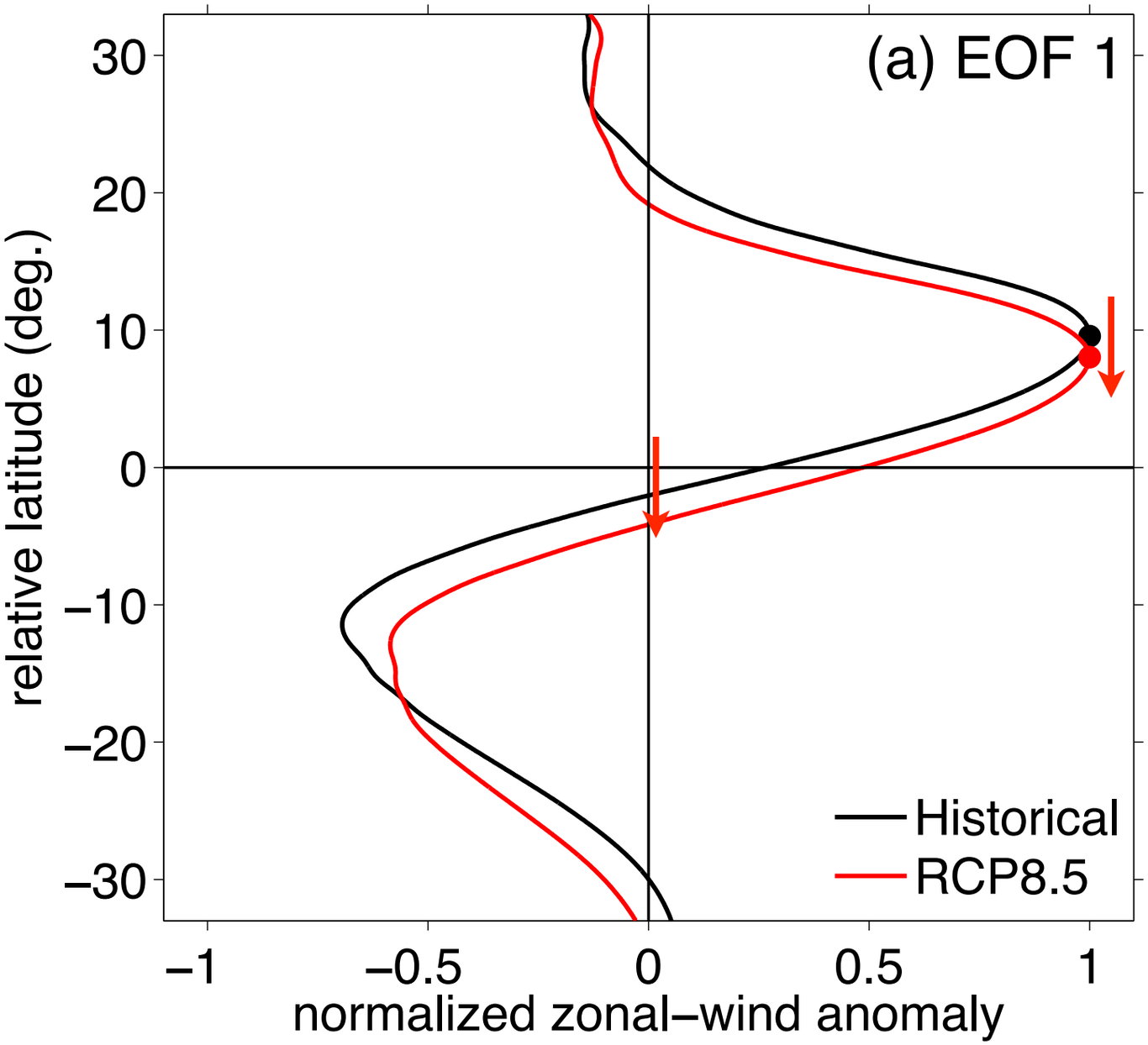


Barnes & Polvani (2012); submitted

EOF Analysis

calculate EOF 1 of sector-averaged low-level winds

EOF 1 pattern

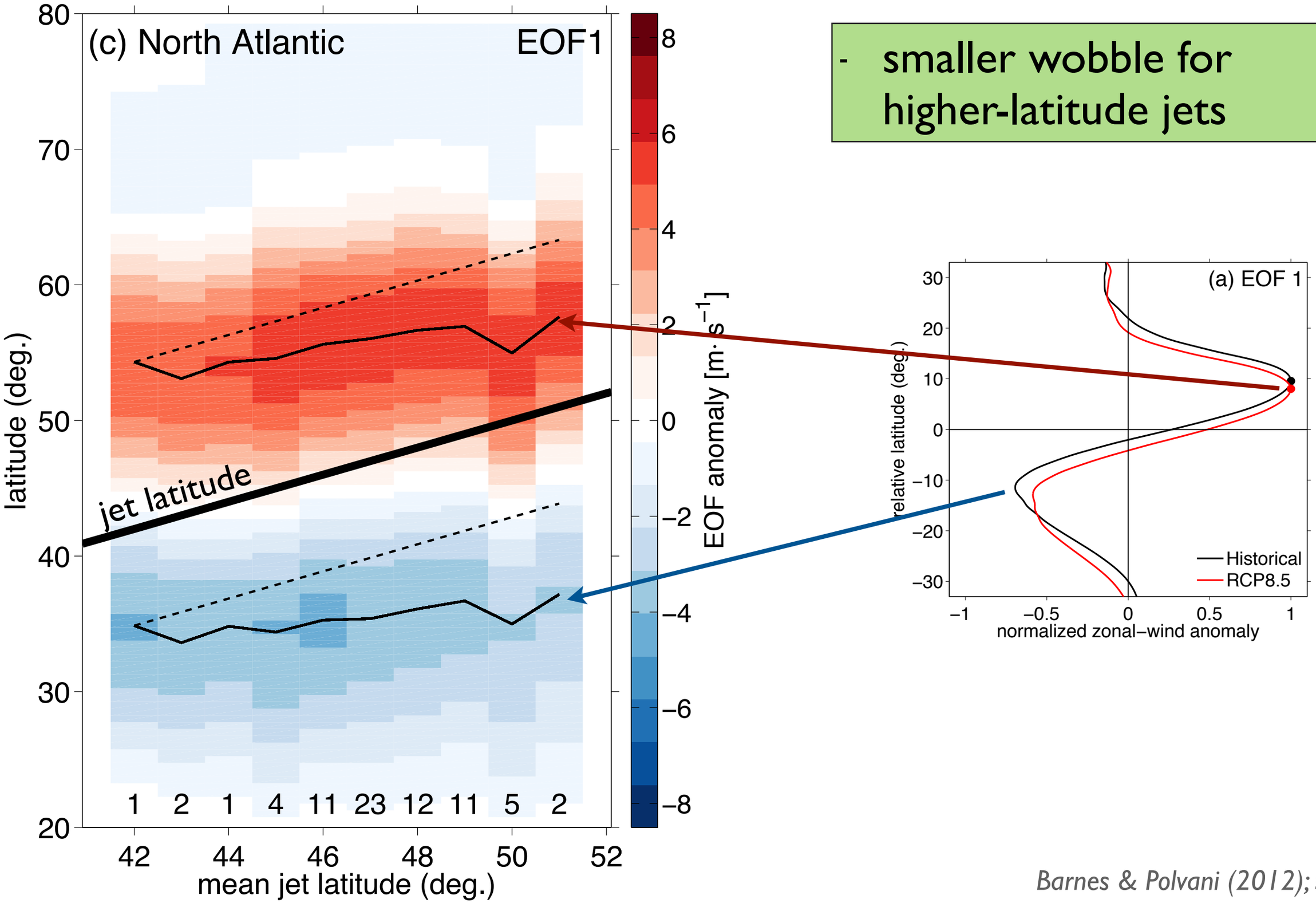


- less wobble, more pulse

IPSL-CM5A-MR

EOF 1 pattern versus jet latitude

- smaller wobble for higher-latitude jets

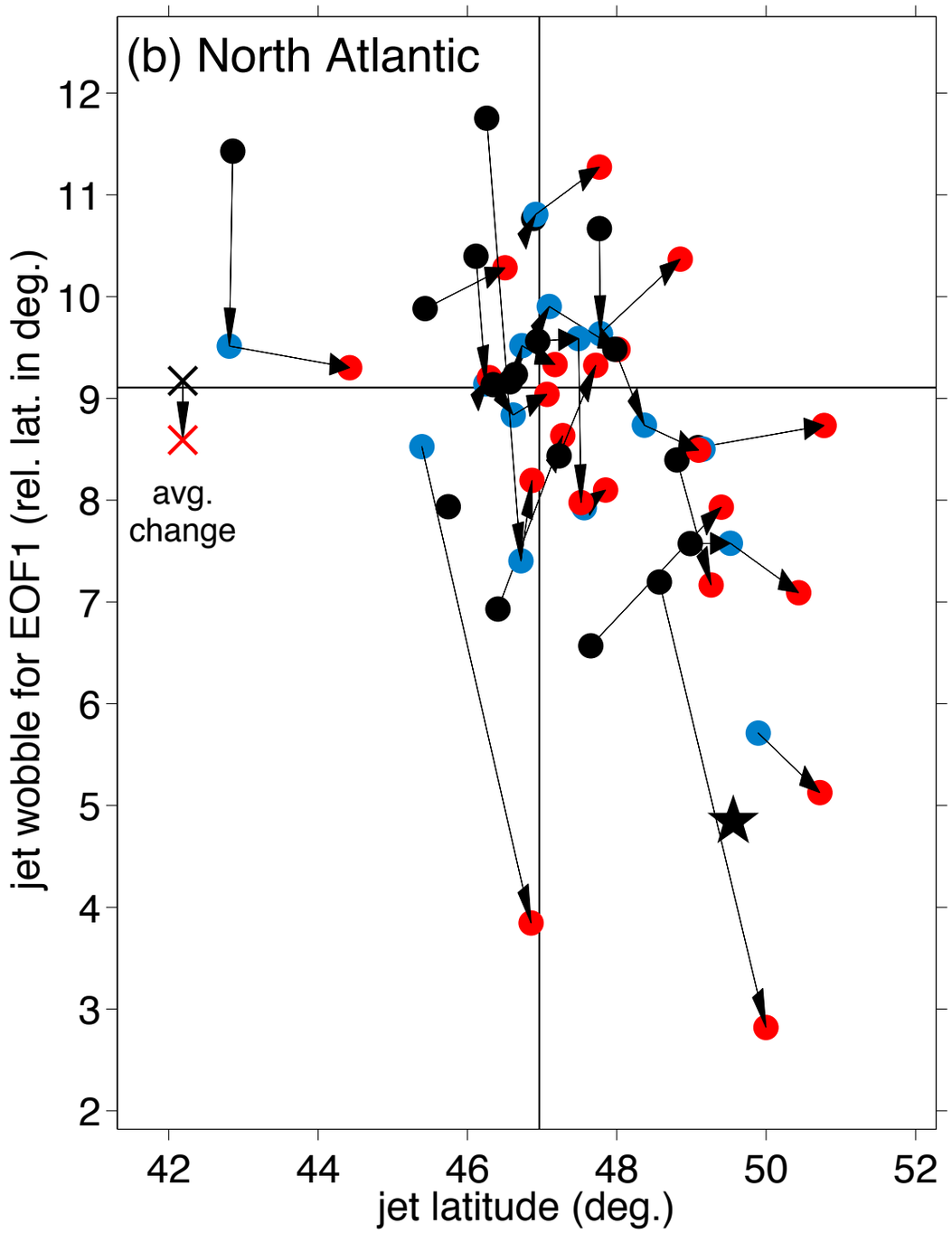


Barnes & Polvani (2012); submitted

EOF 1 wobble with climate change

- decrease in jet wobble with climate change predicted by models

- signal is less clear than when plotted against latitude alone (so other important processes are at play here)



Barnes & Polvani (2012); submitted

Eddy activity in the future

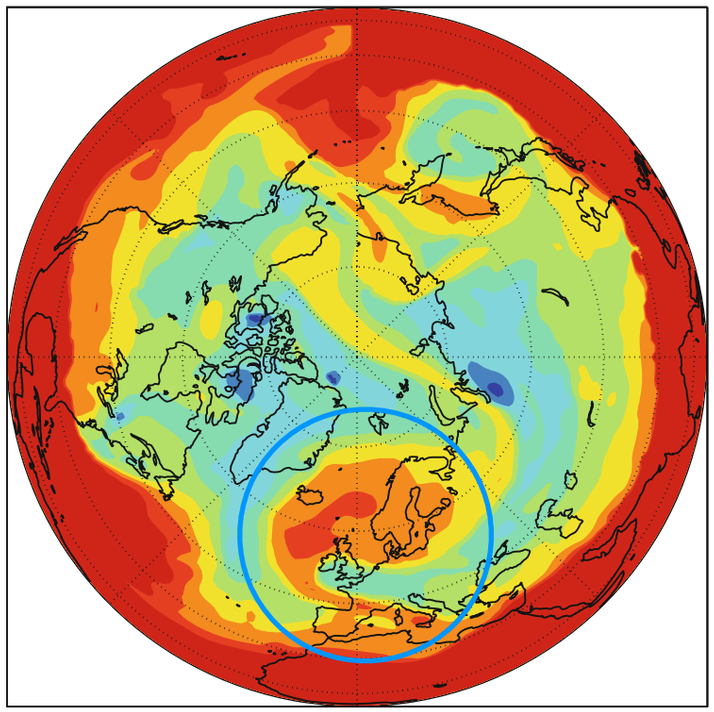
Large-scale Rossby wave breaking is linked to jet variability

Previous results suggest that wave breaking will decrease over the Atlantic as the jet shifts poleward...

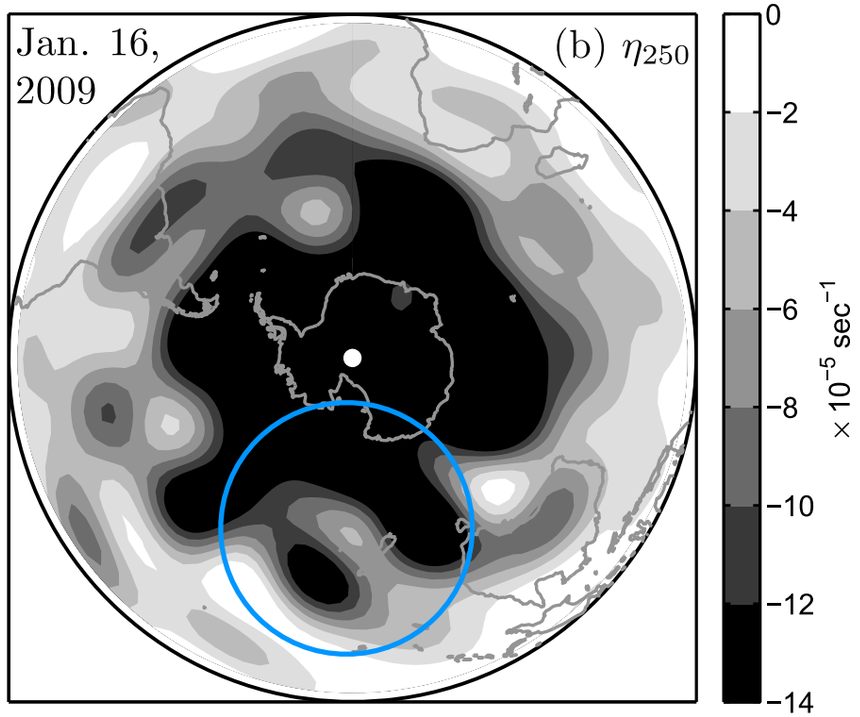
(Barnes & Hartmann (2010, 2011, 2012))

Does it?

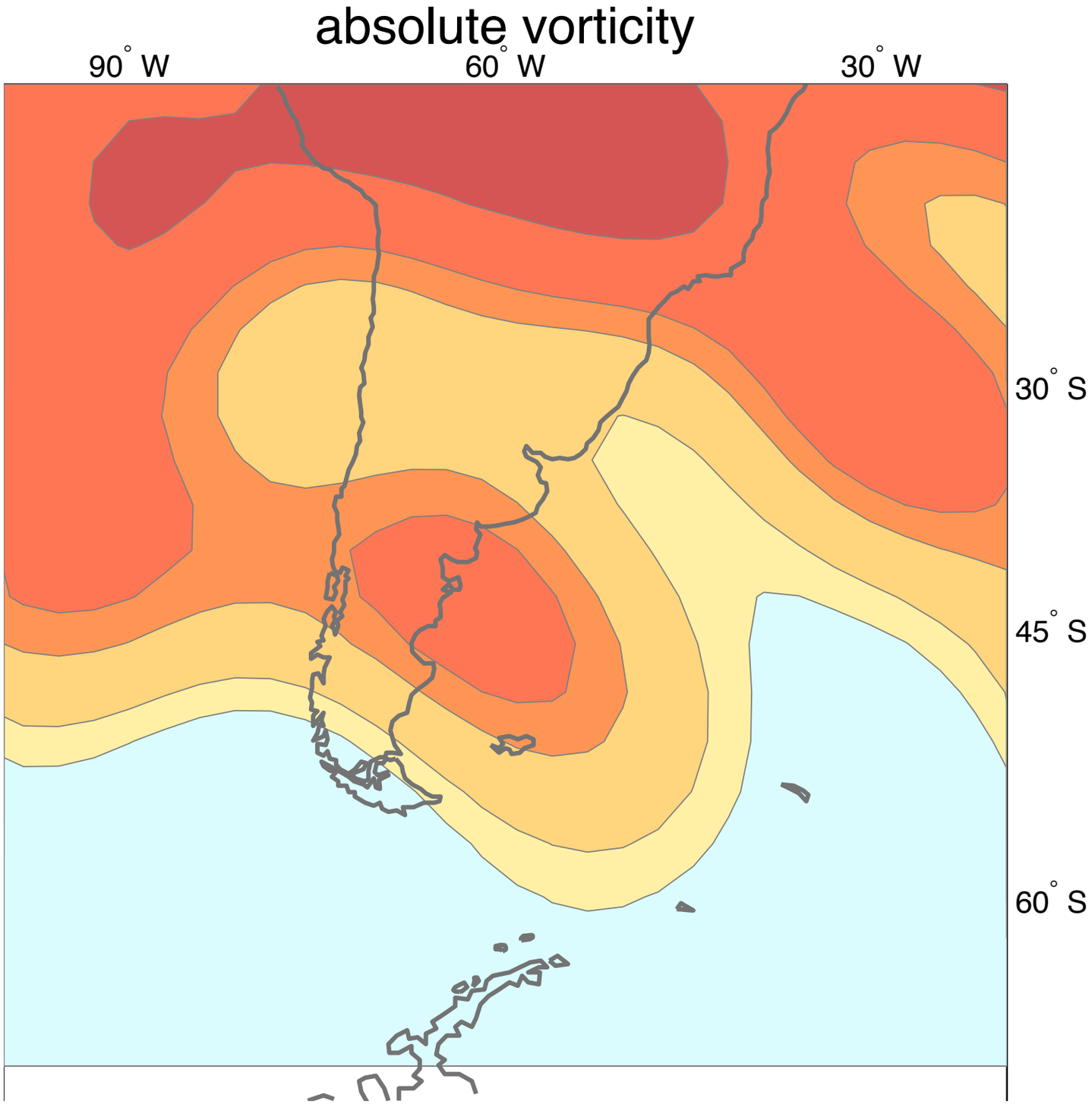
θ_2: Feb 14, 1994



examples of wave breaking



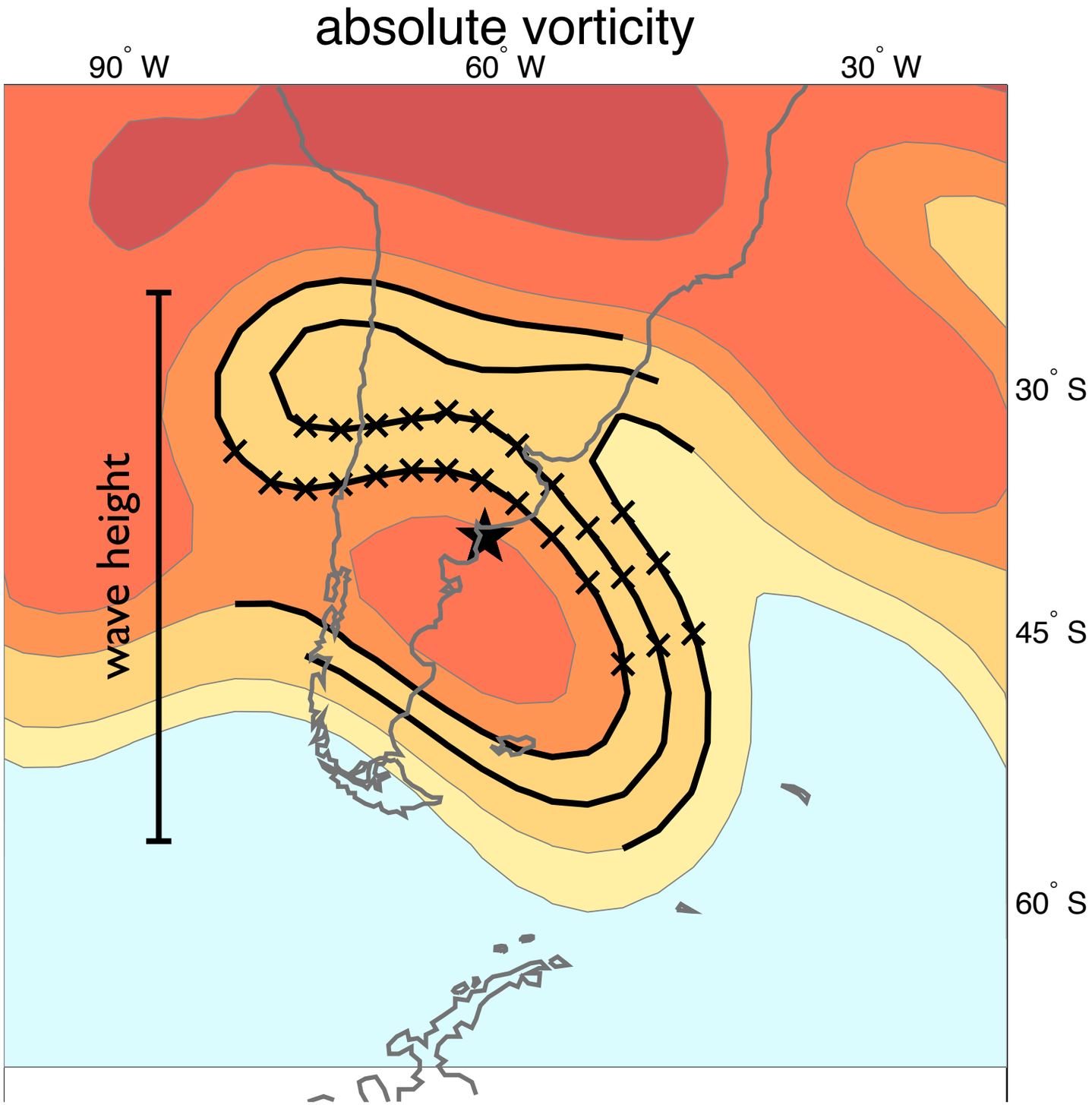
Detecting wave breaking at 250 hPa



1. find breaking contours of vorticity
2. group contours in wave breaking events
3. look at tilt to determine orientation of breaking

Barnes & Hartmann (2012b); JGR

Detecting wave breaking at 250 hPa



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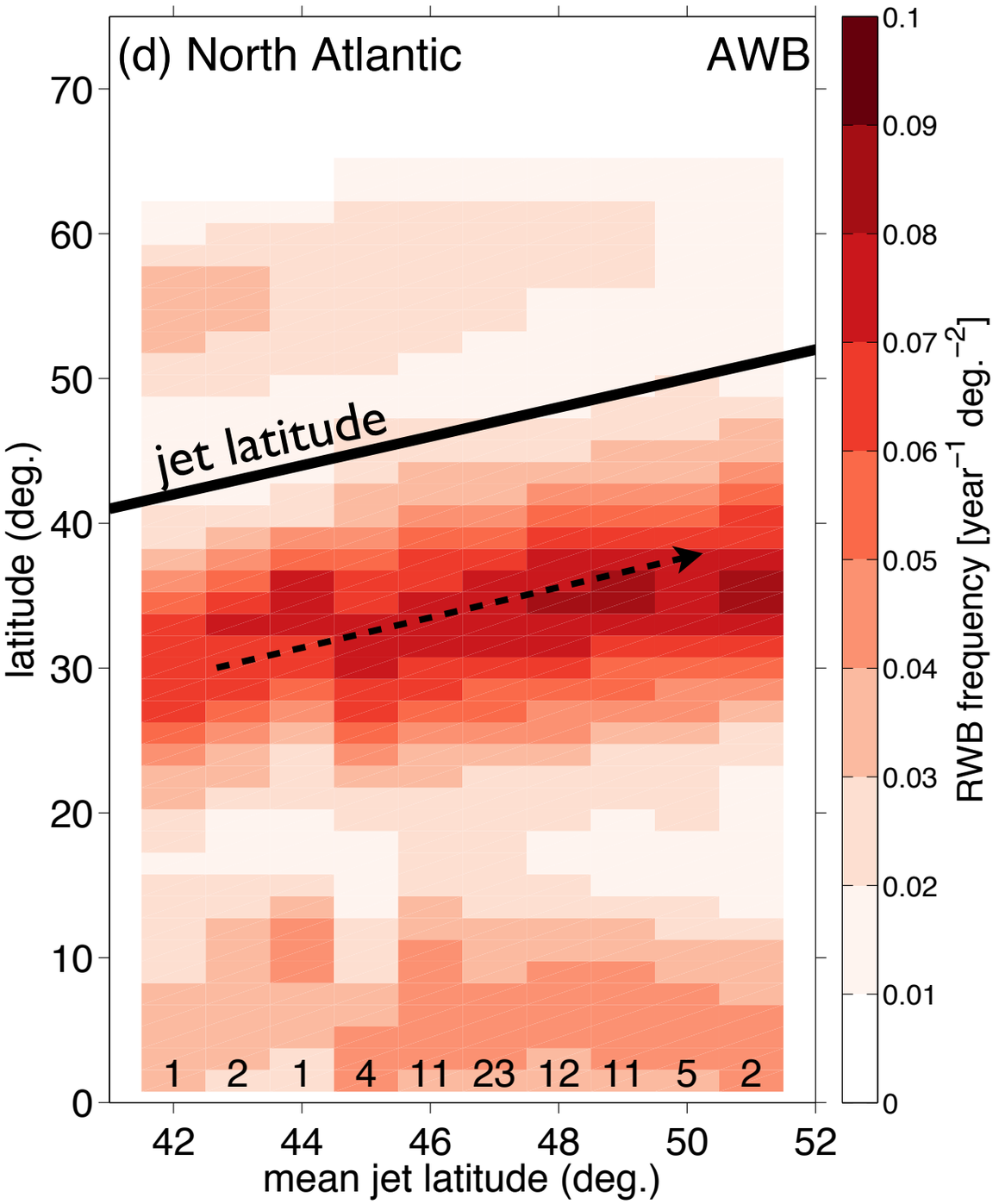
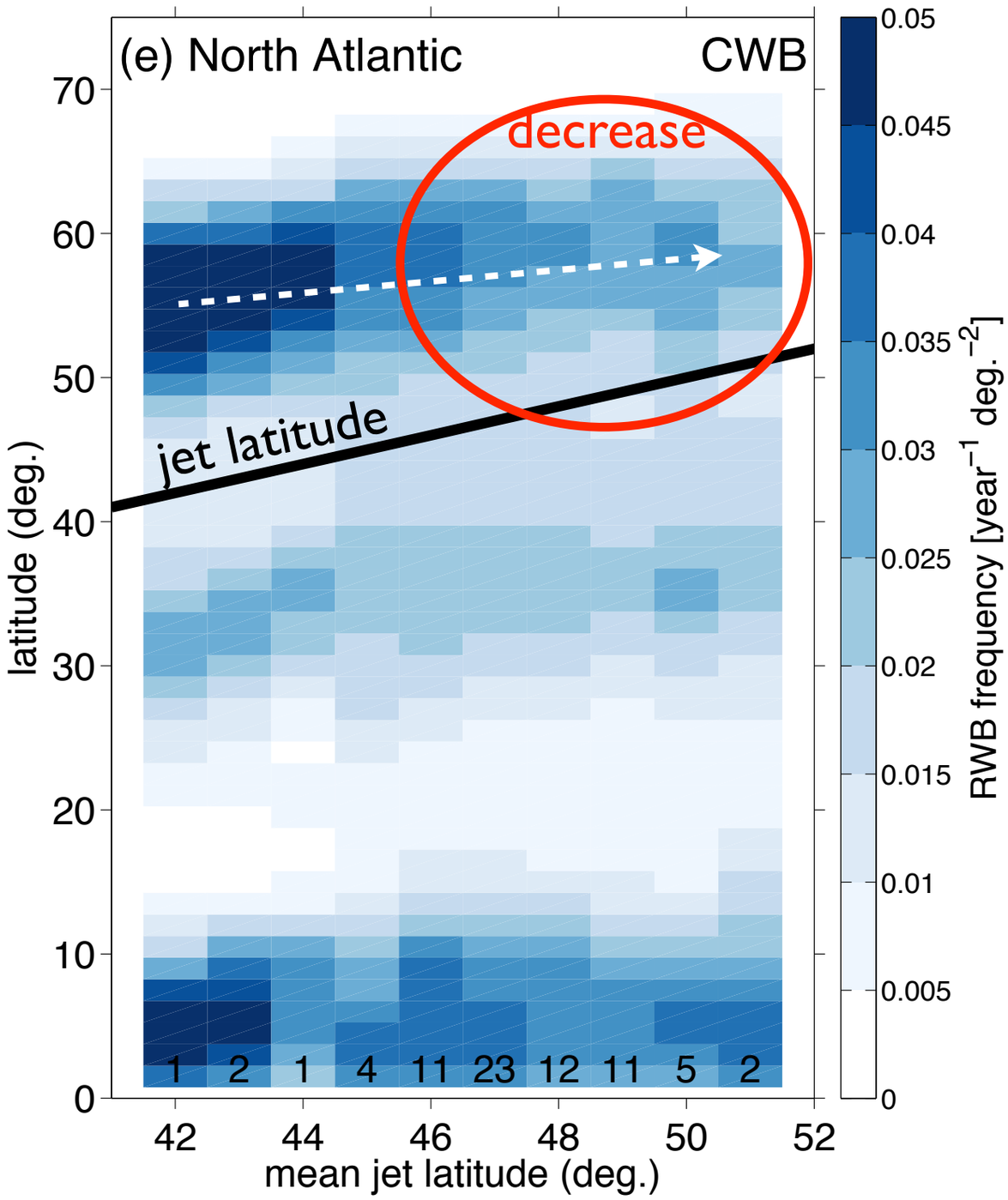
Wave breaking vs. jet latitude



- equatorward wave breaking moves with the jet

Barnes & Polvani (2012); submitted

Wave breaking vs. jet latitude

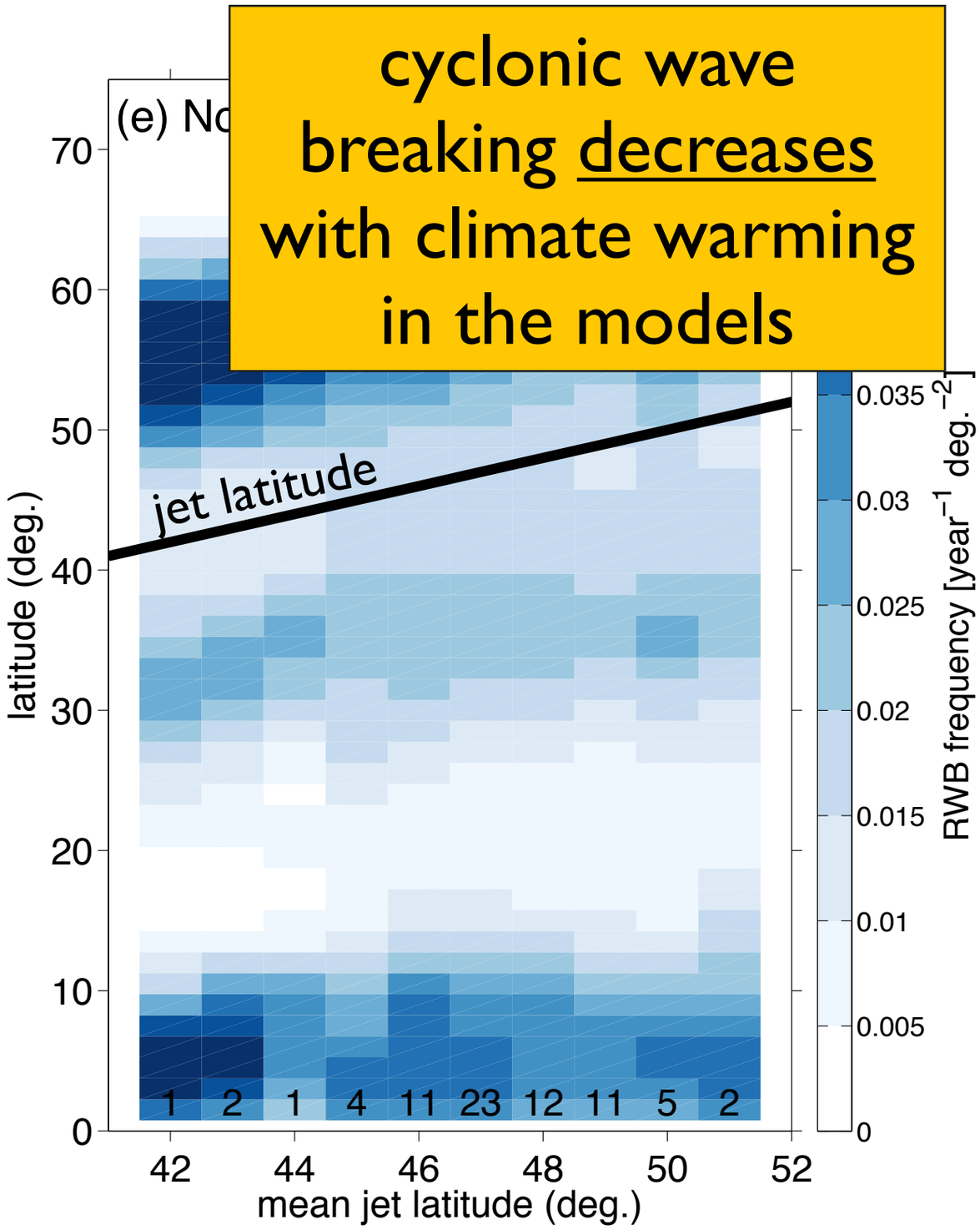


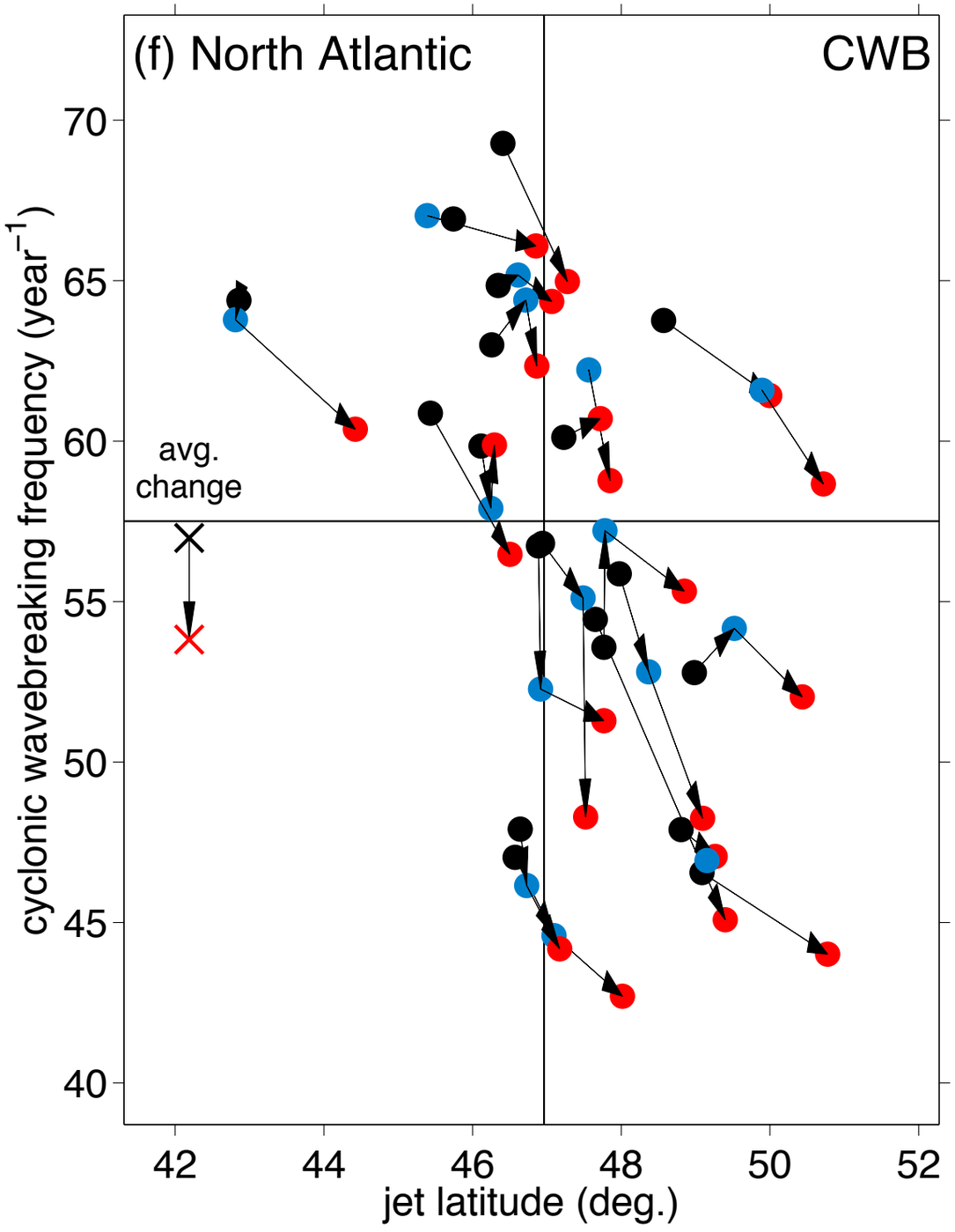
- cyclonic wave breaking decreases on poleward jet flank
- wave breaking appears to have a meridional "ceiling"

Barnes & Polvani (2012); submitted

Wave breaking vs. jet latitude

cyclonic wave breaking decreases with climate warming in the models





Barnes & Polvani (2012); submitted

What does this say about blocking in the future?

Quarterly Journal of the Royal Meteorological Society *Q. J. R. Meteorol. Soc.* 138: 1285–1296, July 2012 A

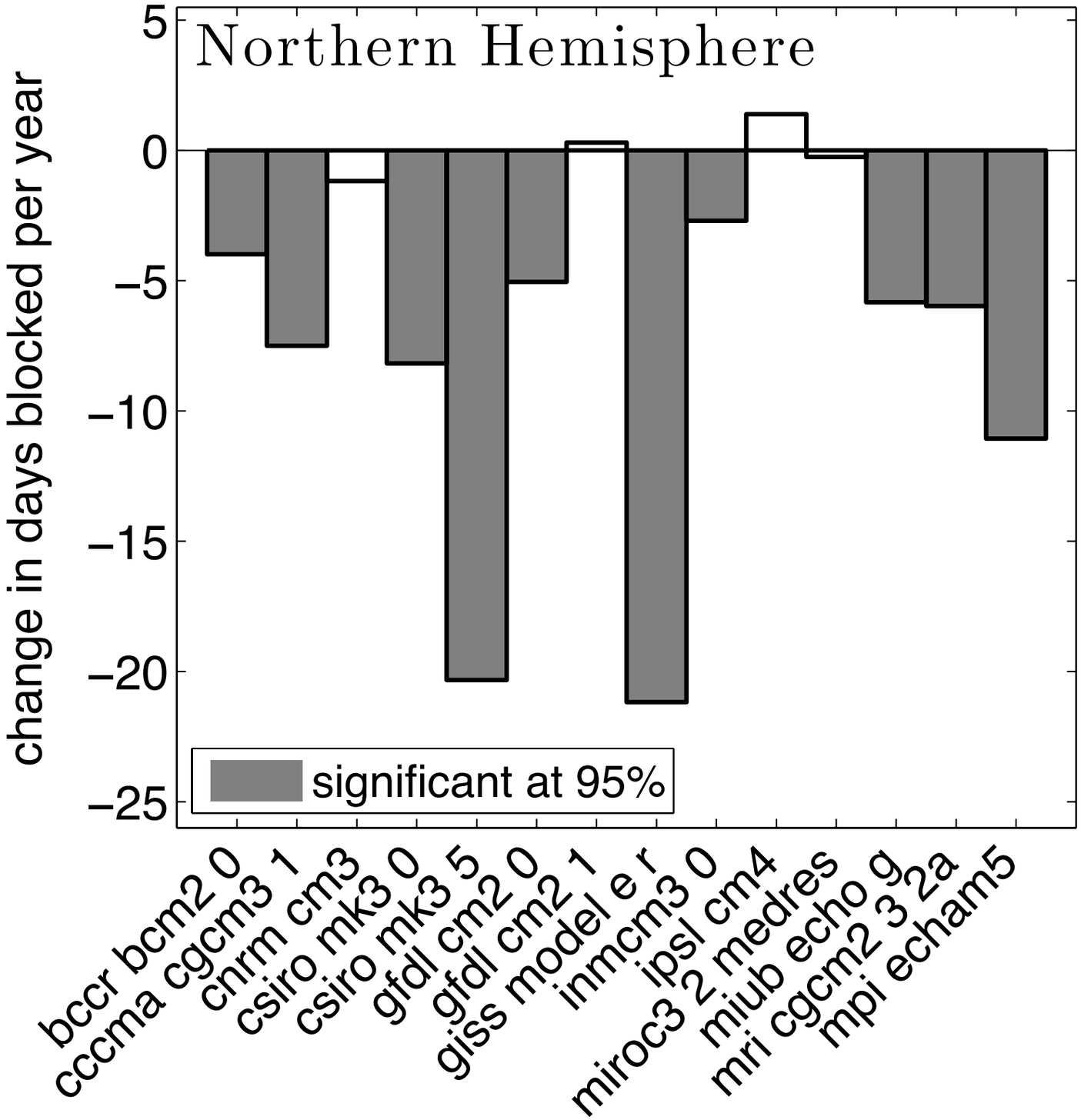
RMetS
Royal Meteorological Society

Wave-breaking characteristics of midlatitude blocking

G. Masato,[a]* B. J. Hoskins[b] and T. J. Woollings[a]
[a]*Department of Meteorology, University of Reading, UK*
[b]*Grantham Institute, Imperial College, London, UK*

"Rossby wave breaking is identified as a key process in blocking occurrence, as it provides the mechanism for the meridional reversal pattern typical of blocking."

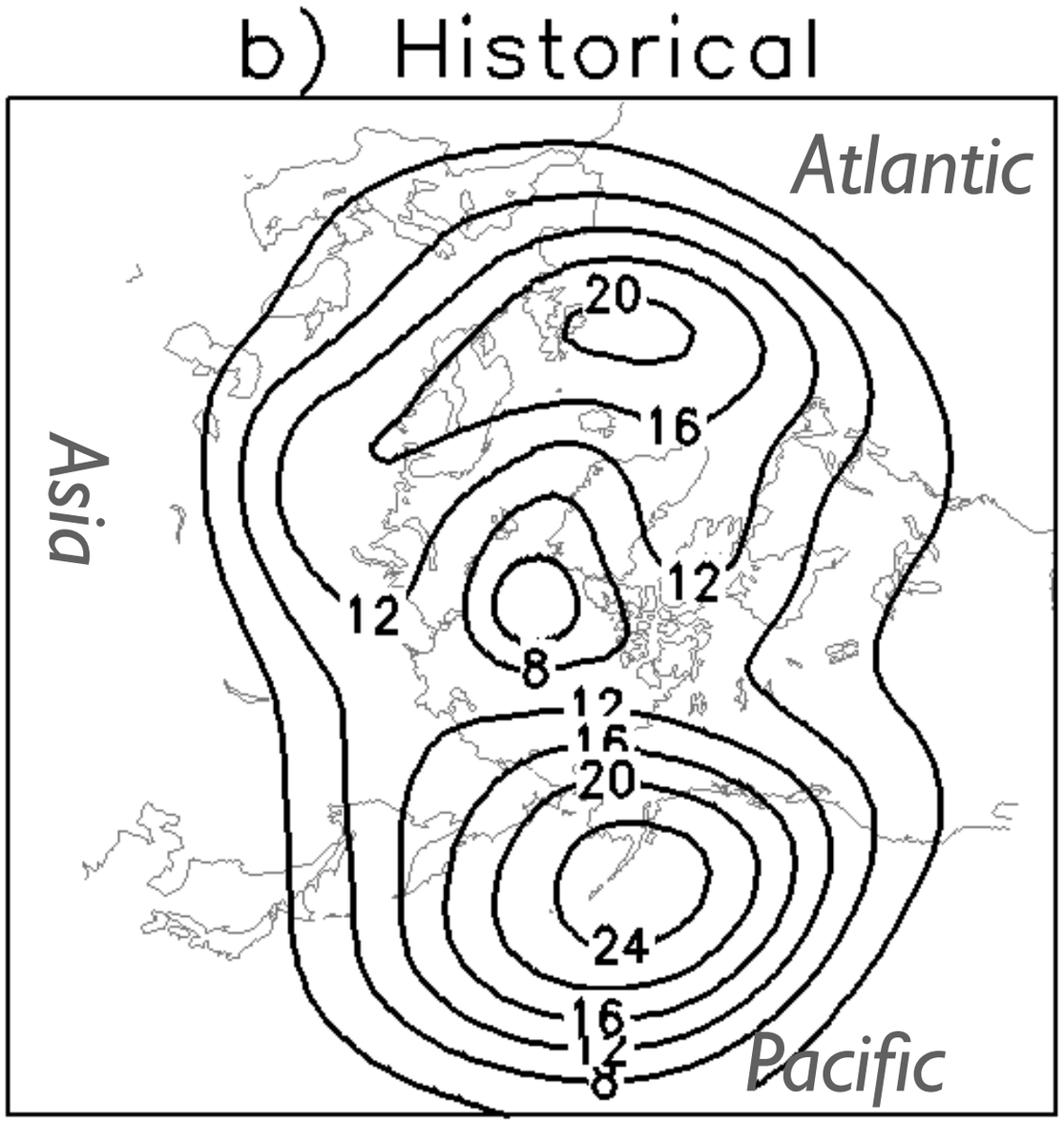
CMIP3 Atlantic blocking frequency

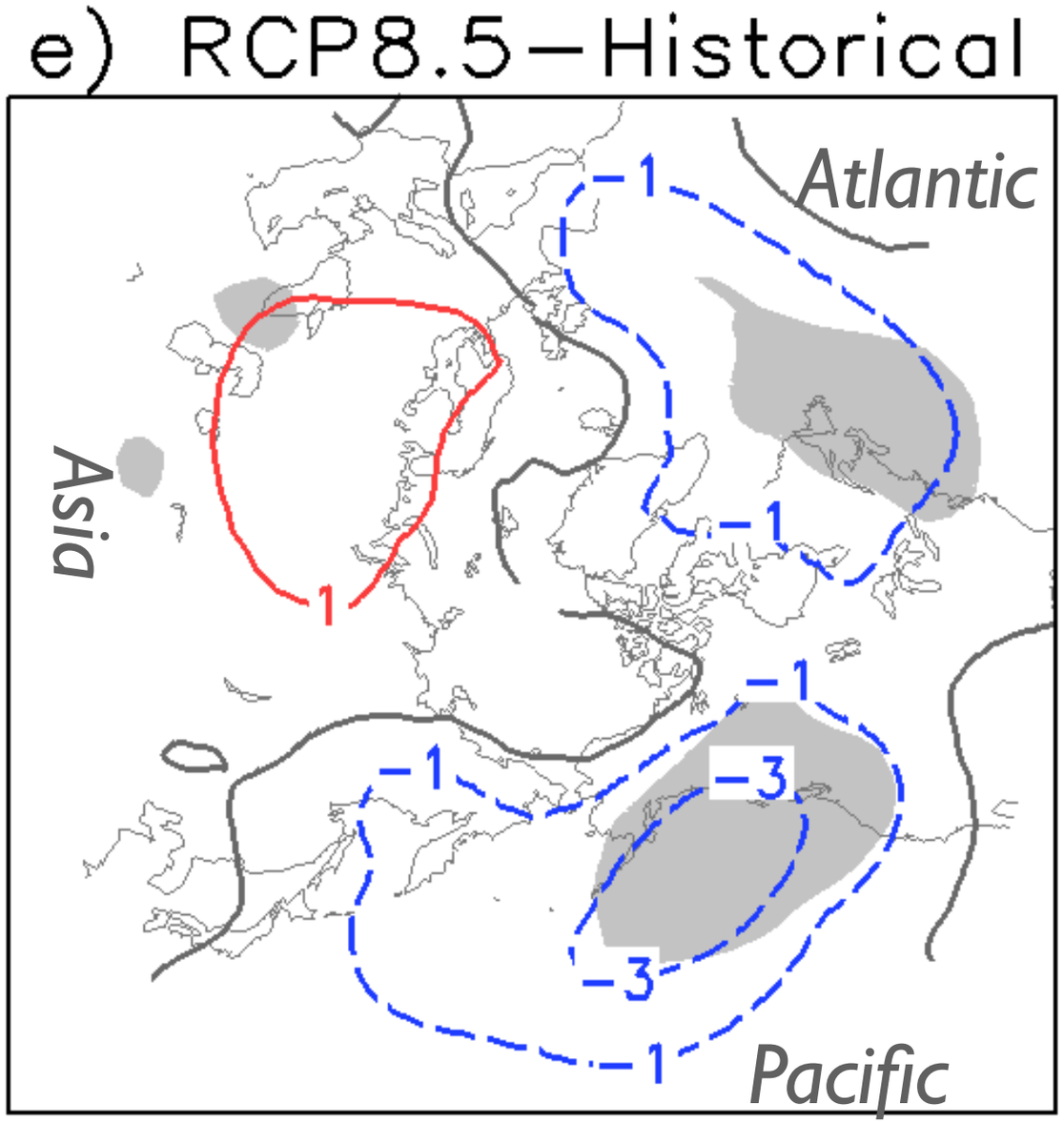


blocking frequency <u>decreases</u> with warming in CMIP3

Barnes, Slingo, Woollings (2012); CDYN

CMIP5 blocking frequency from *Dunn-Siouin & Son (2012)*





blocking frequency <u>decreases</u> with warming in CMIP5

Dunn-Sigouin & Son (2012); submitted, Fig. 1
units are days/year gridpoint is "blocked"

What about blocking duration?

- No measurable change in blocking duration in CMIP3 by Barnes, Slingo & Woollings (2012)

- Difficult to determine if any change in blocking duration in CMIP5 by Dunn-Sigouin & Son (2012)

NO CHANGE IN BLOCKING DURATION

suggests that physics of blocking doesn't change, just the number of events

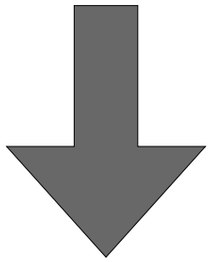
How does this relate to recent work?

GEOPHYSICAL RESEARCH LETTERS, VOL. 39, L06801, doi:10.1029/2012GL051000, 2012

Evidence linking Arctic amplification to extreme weather in mid-latitudes

Jennifer A. Francis[1] and Stephen J. Vavrus[2]

Polar Amplification leads to:
- weakened zonal winds
- increased wave amplitude



- increased blocking frequency
- increased blocking duration
  (from slower wave progression)

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X

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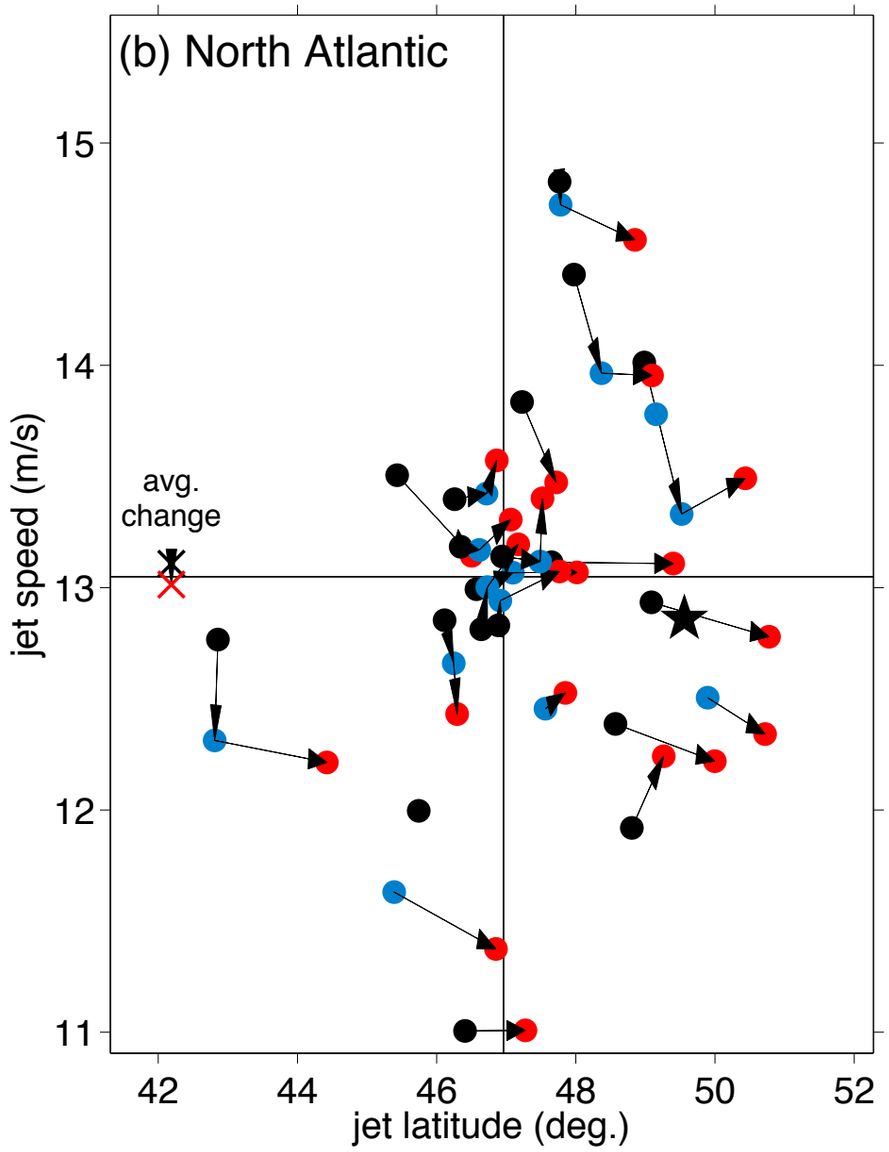

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- weakened zonal winds ✗
- increased wave amplitude ✗

↓

- increased blocking frequency
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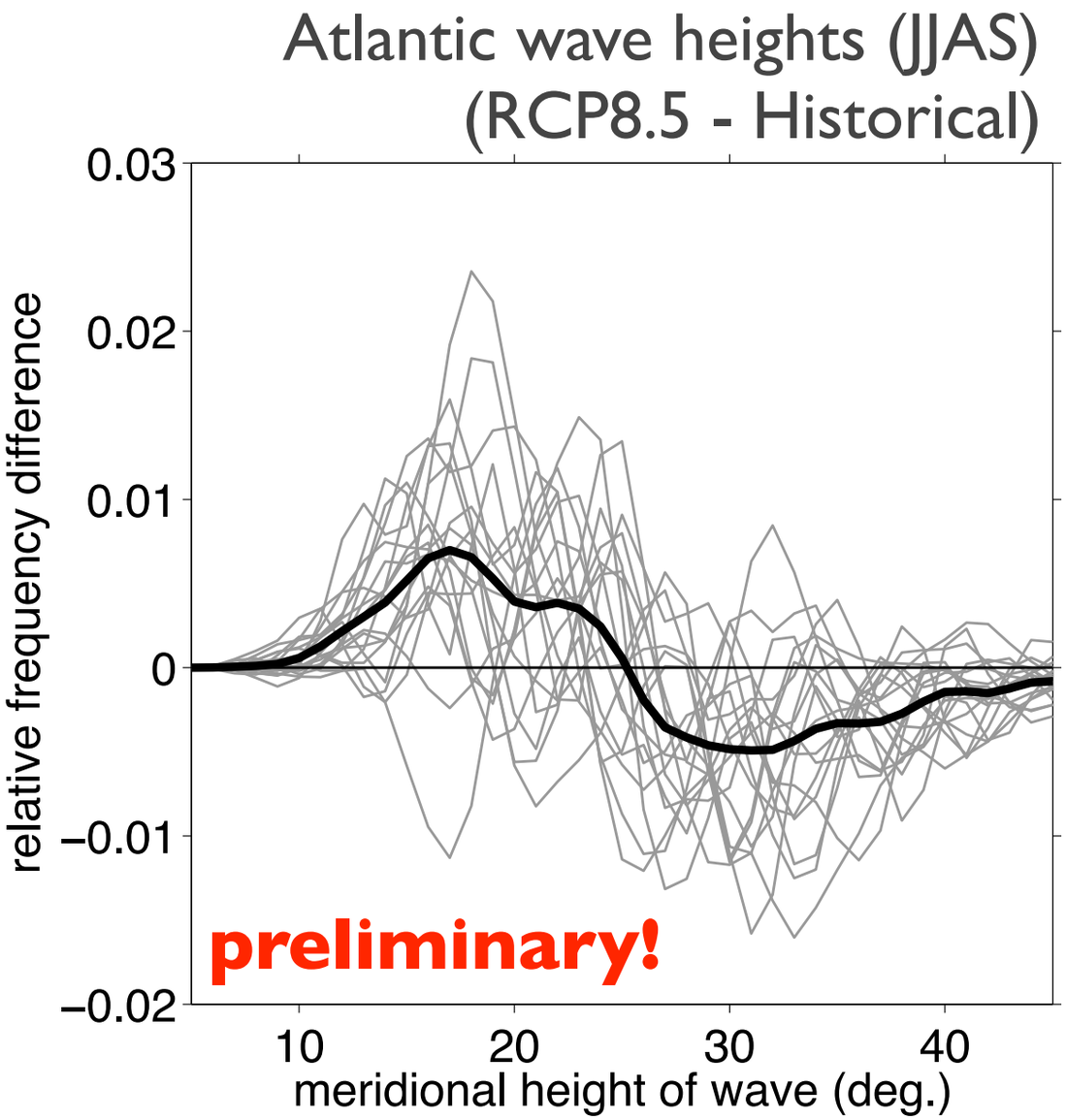

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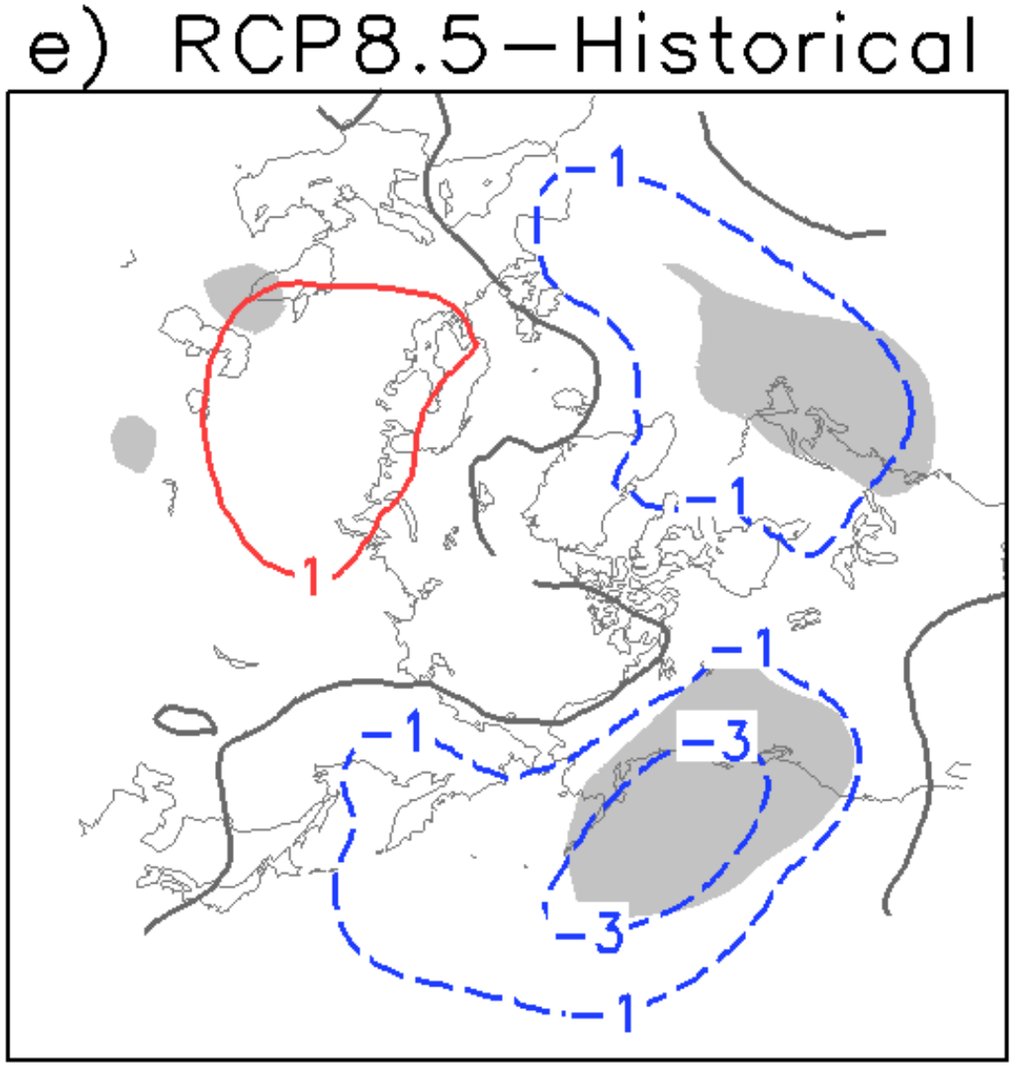
Polar Amplification leads to:
- weakened zonal winds X
- increased wave amplitude X

- increased blocking frequency X
- increased blocking duration X
  (from slower wave progression)



Conclusions

- models still struggle to get correct jet position

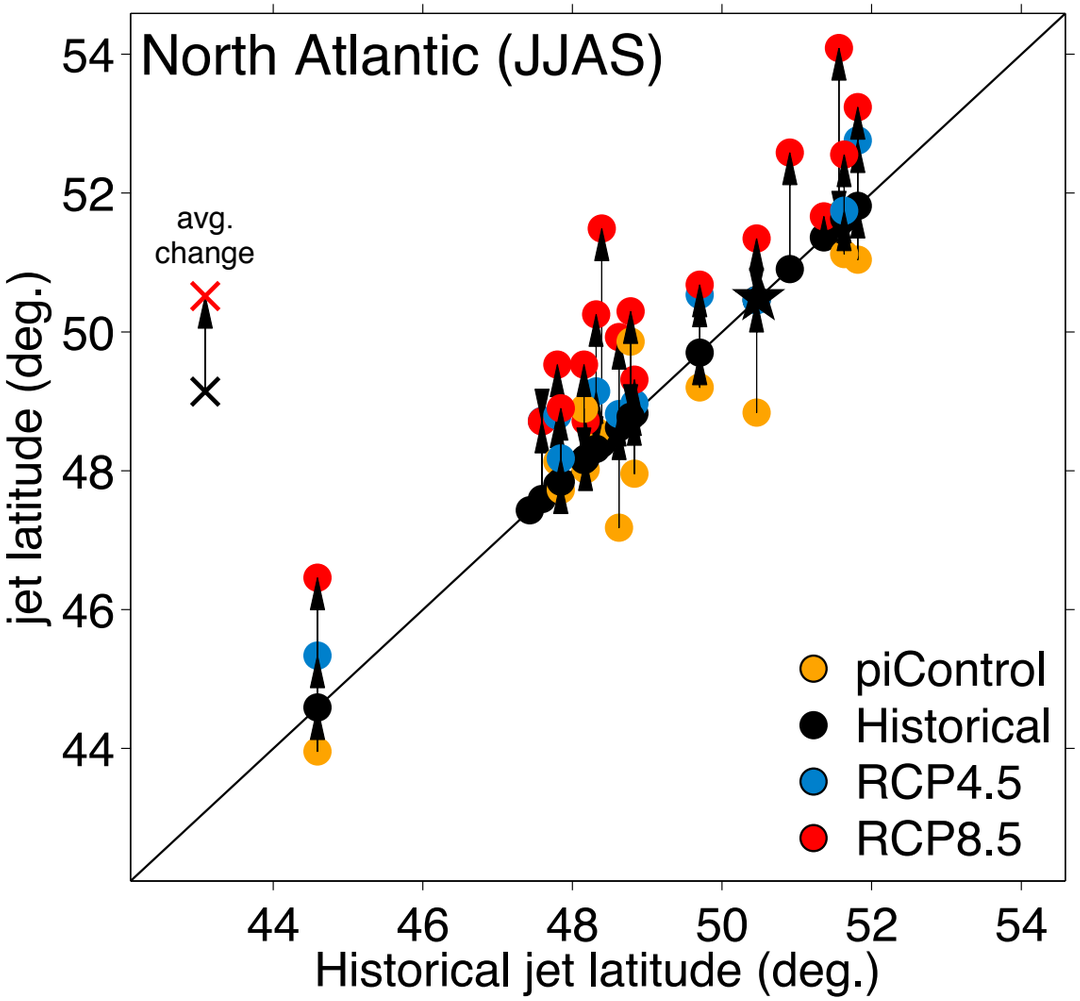
with climate warming, CMIP5 models show ...

- a poleward shift of the jet (although seasonally dependent)
- amount of "wobble" of NAO decreases (especially if grouped w.r.t. to jet latitude)
- wave breaking and blocking frequency decreases

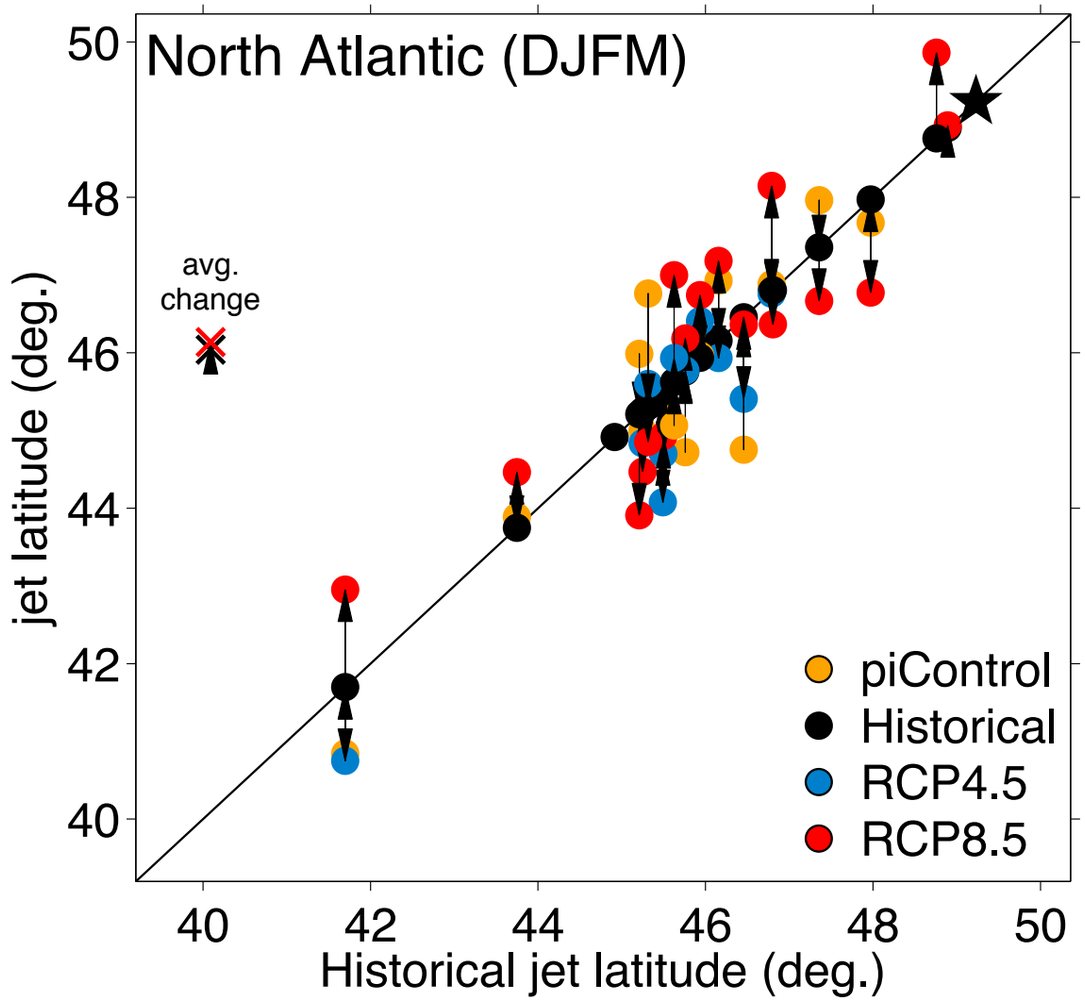
EXTRA SLIDES

Mean jet position (seasonal shifts)

June-Sept.



Dec.-Mar.

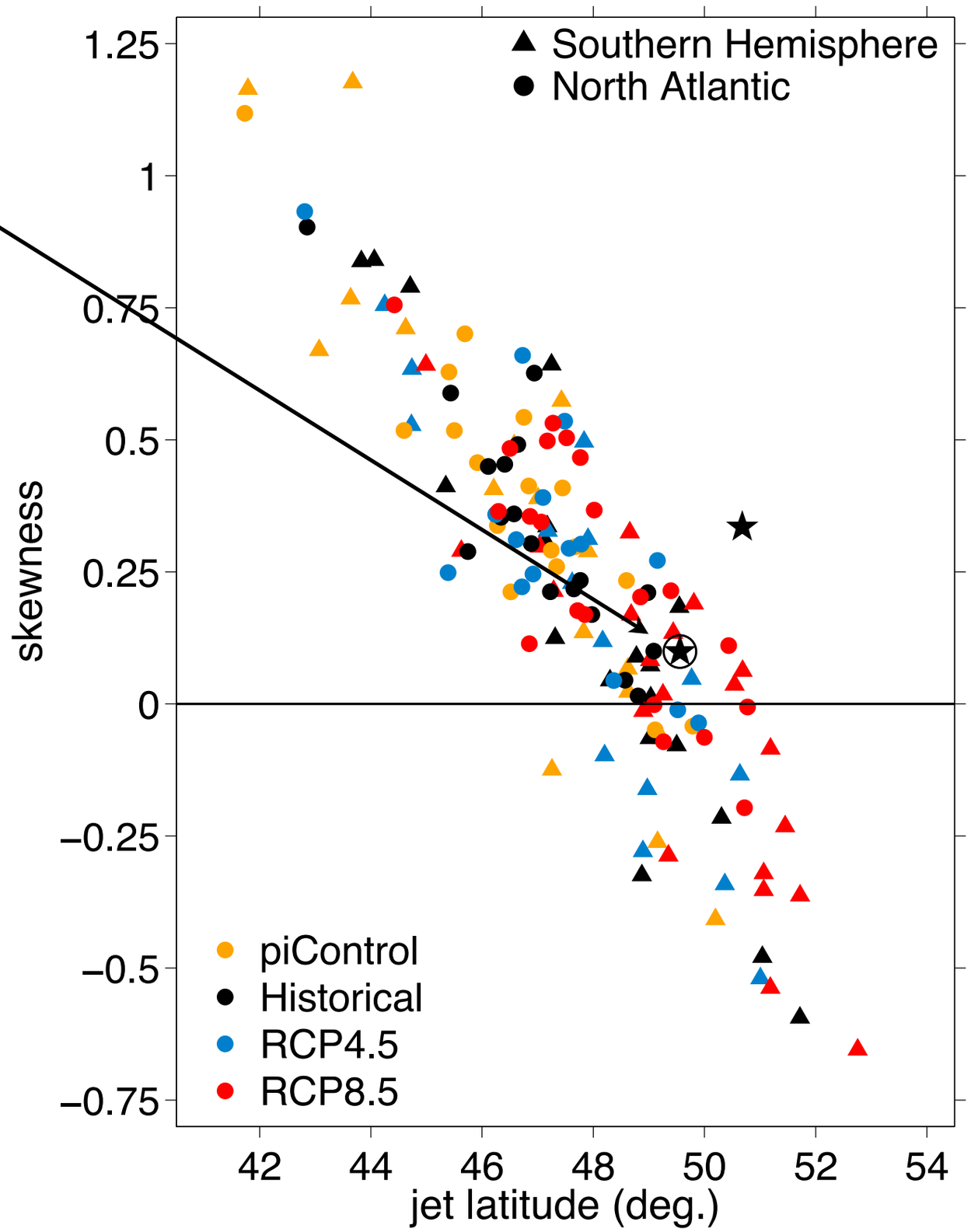


- shift is dependent on season

Skewness of jet latitude

MERRA
North Atlantic

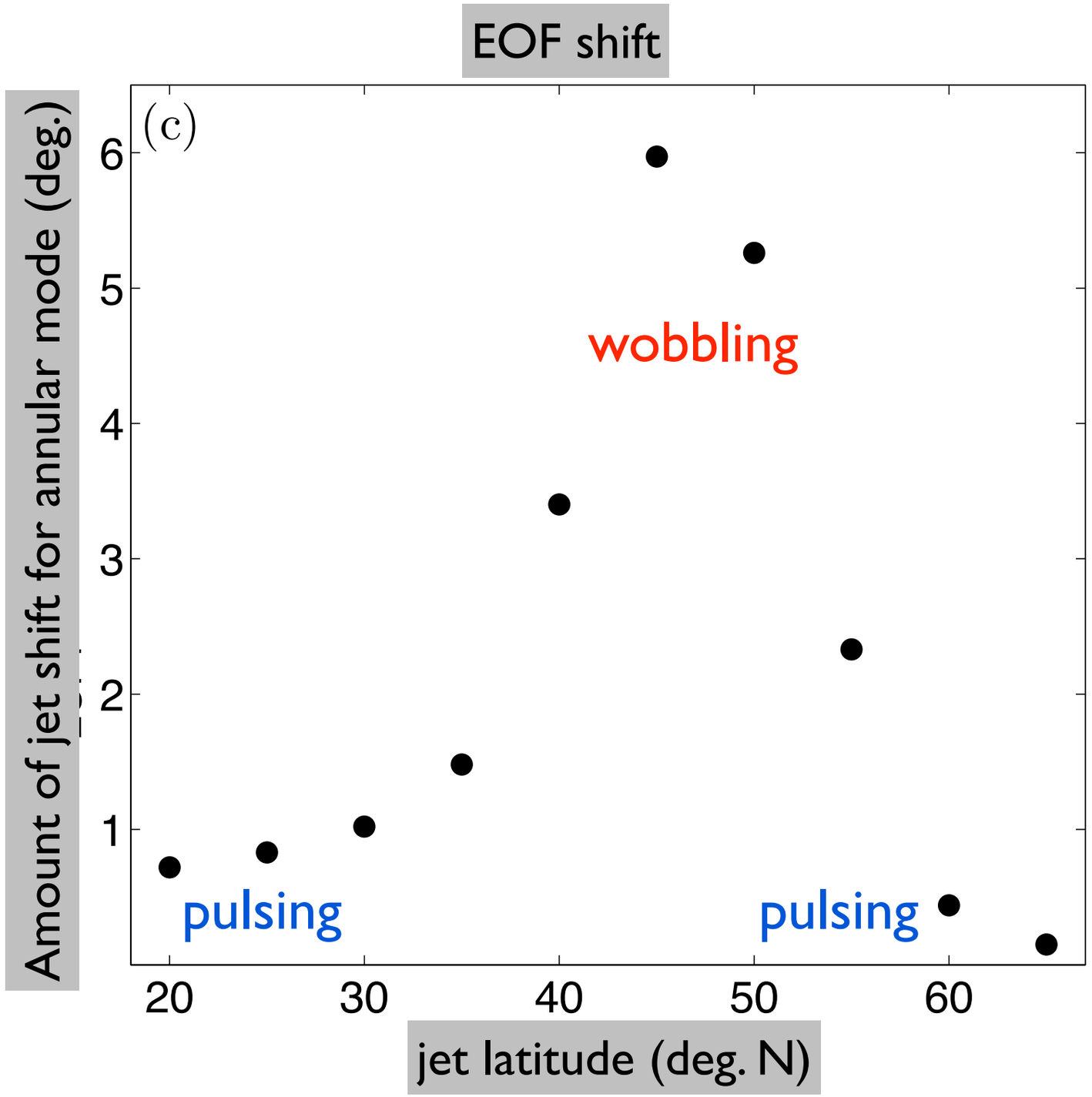
- skewness decreases with jet latitude



Barnes & Polvani (2012); submitted

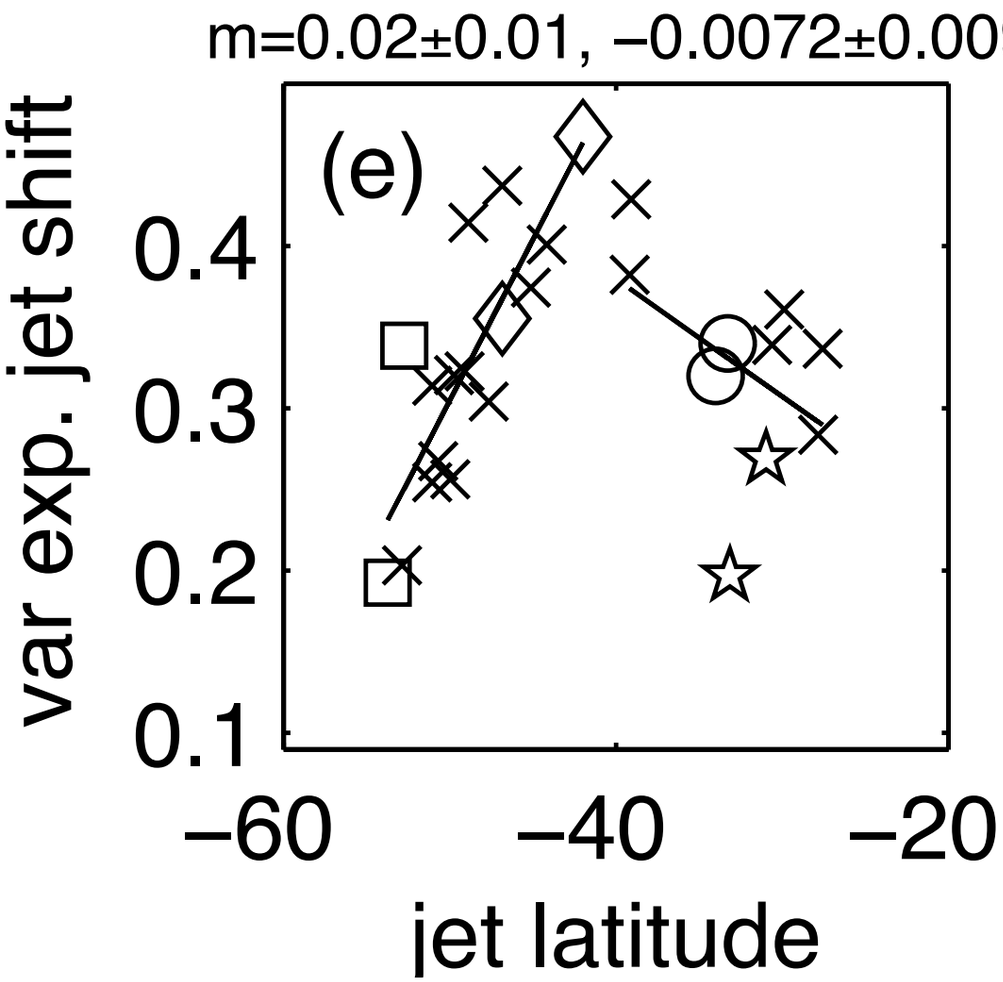
Barotropic model results

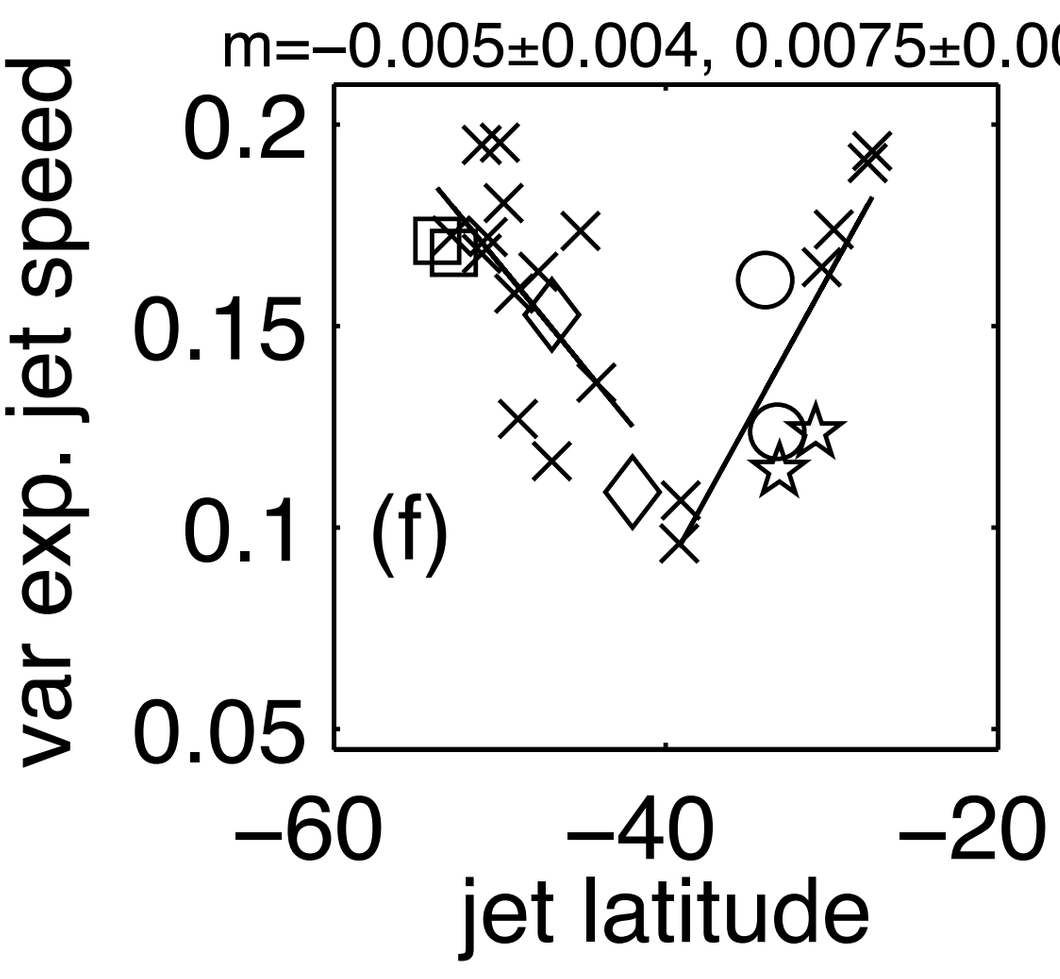
leading EOF describes less of a shift at high and low latitudes



Barnes & Hartmann (2011); JAS

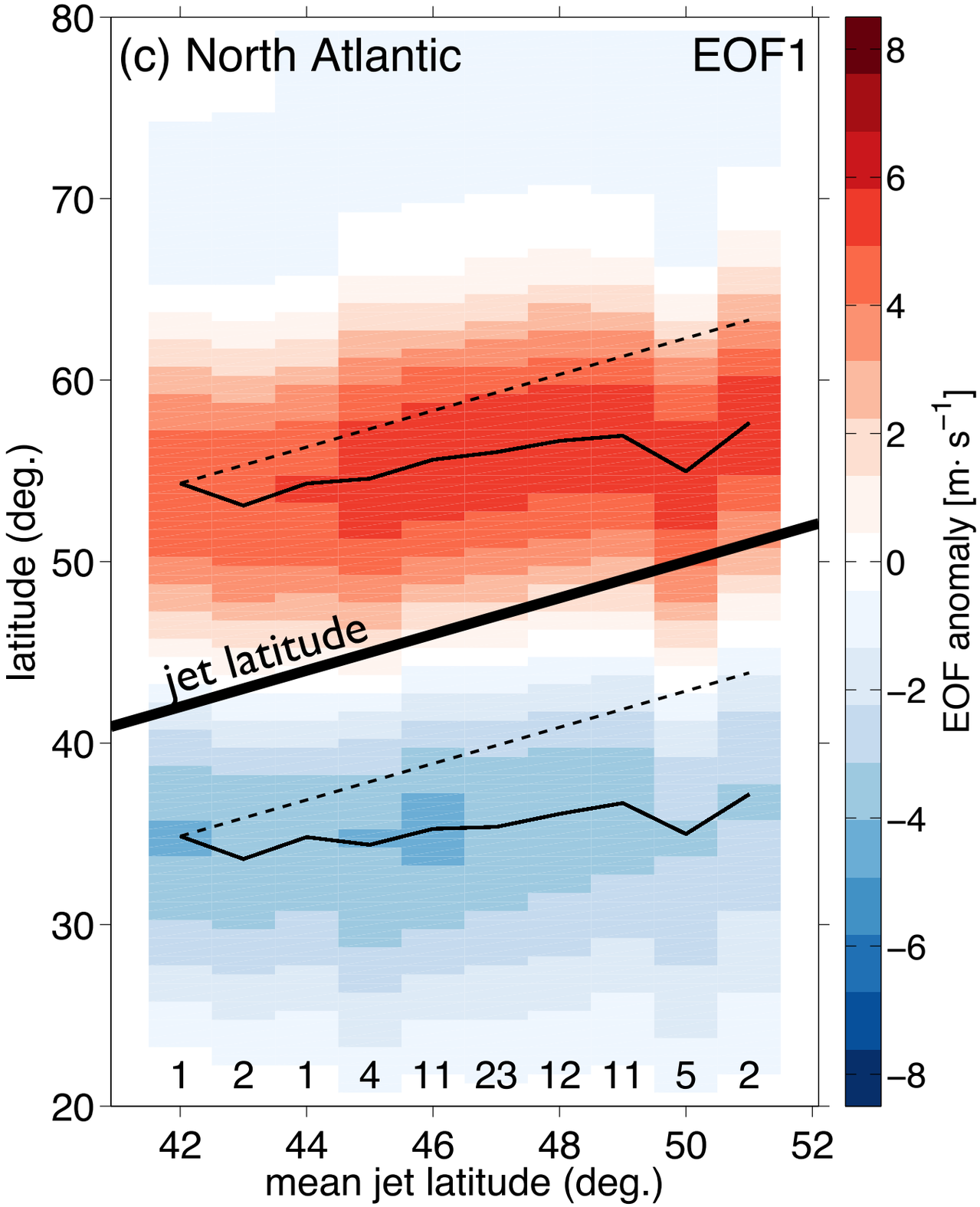
Idealized model results from Garfinkel et al. (2012)

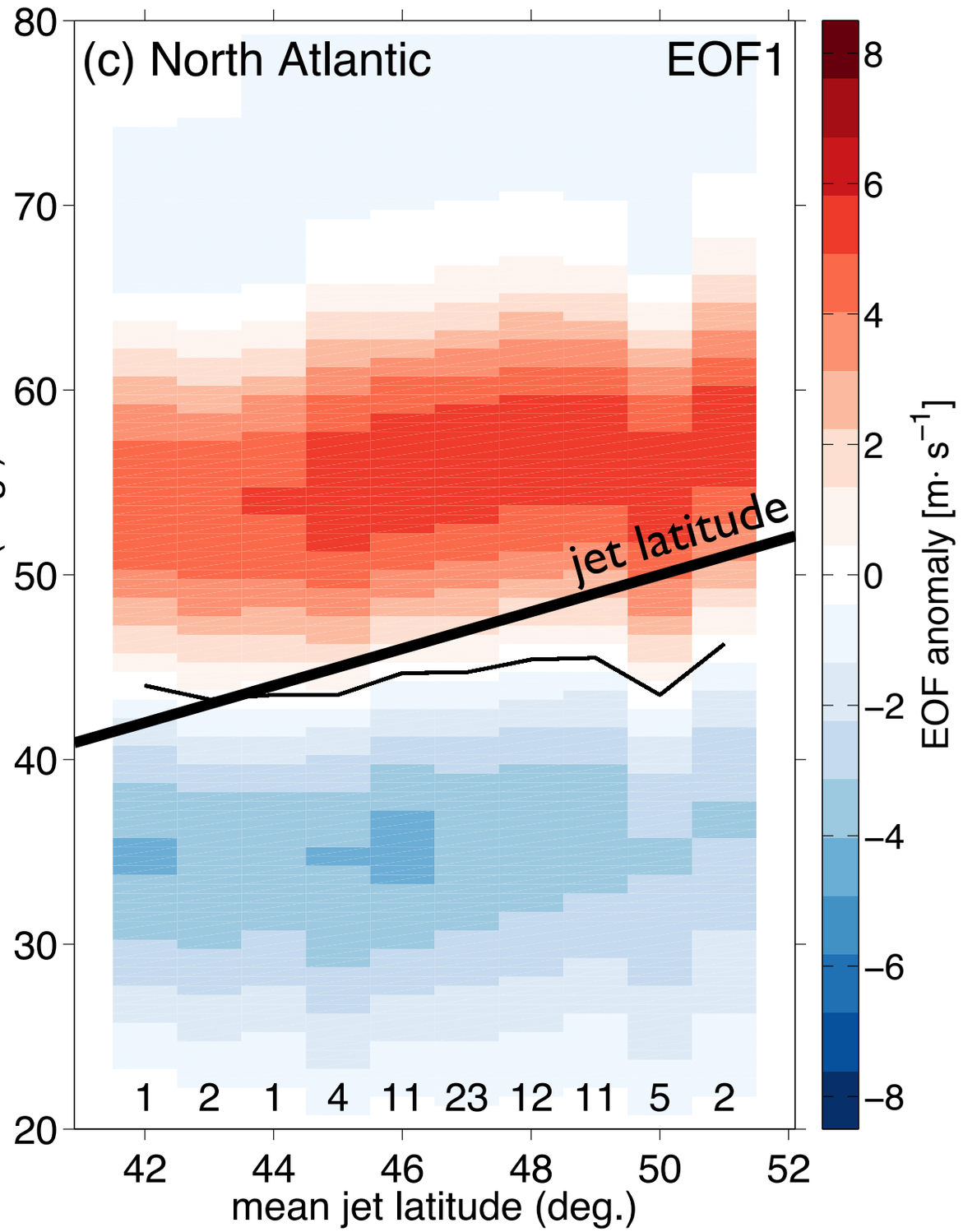




Garfinkel, Waugh & Gerber (2012); submitted

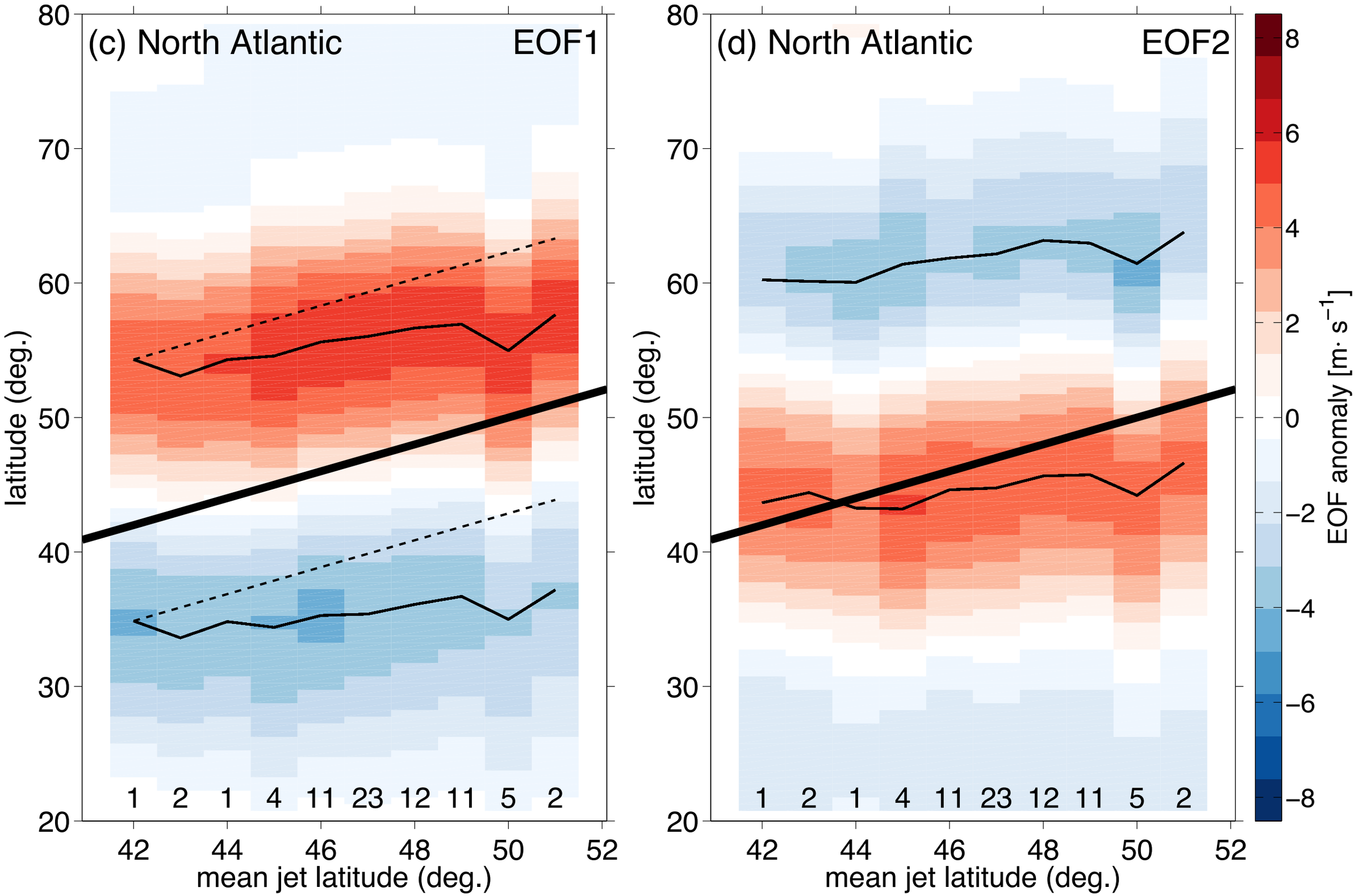
EOF 1 pattern versus jet latitude





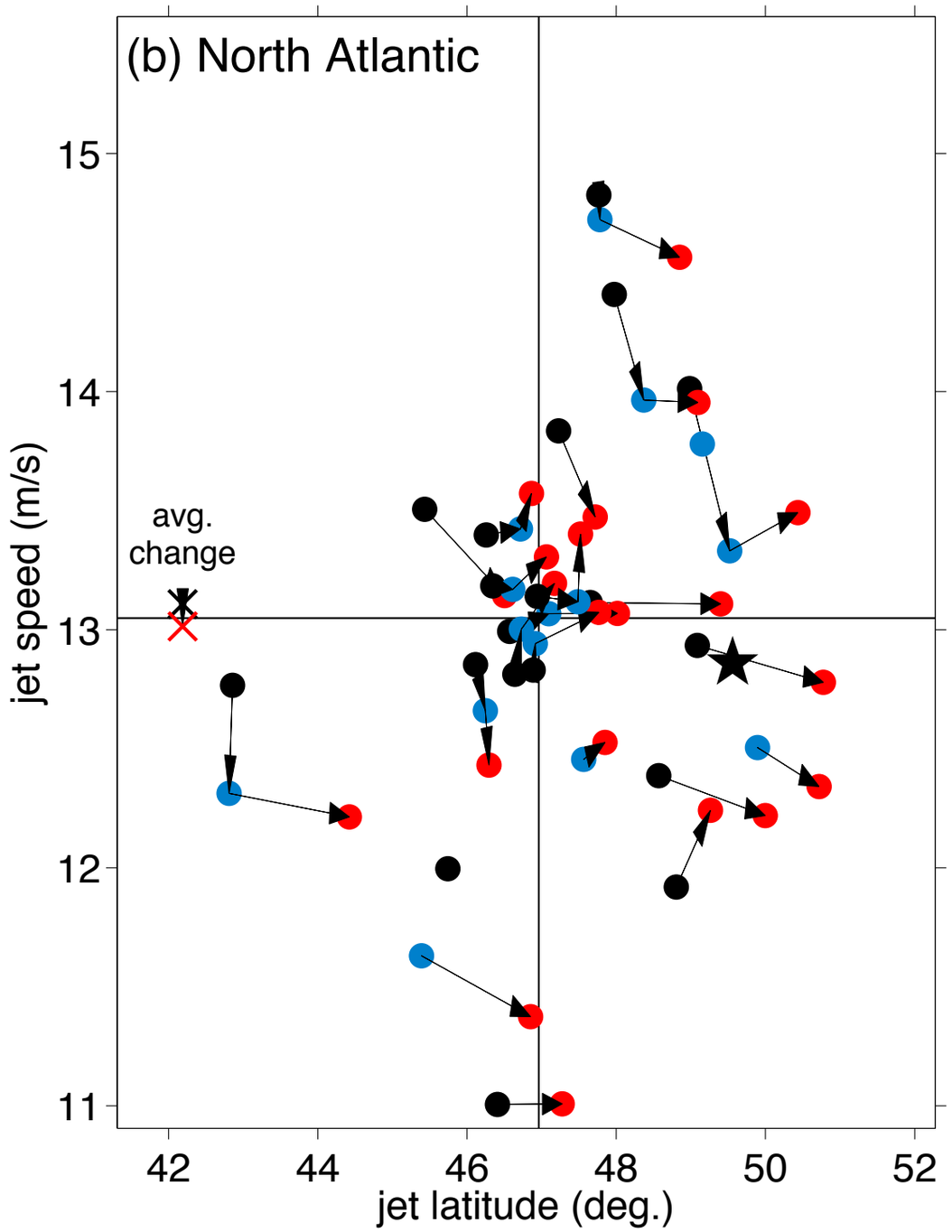
Barnes & Polvani (2012); submitted

EOF 1 & 2


(c) North Atlantic
EOF1
(d) North Atlantic
EOF2
latitude (deg.)
mean jet latitude (deg.)
80
70
60
50
40
30
20
42
44
46
48
50
52
1 2 1 4 11 23 12 11 5 2
8
6
4
2
0
−2
−4
−6
−8
EOF anomaly [m· s^{-1}]

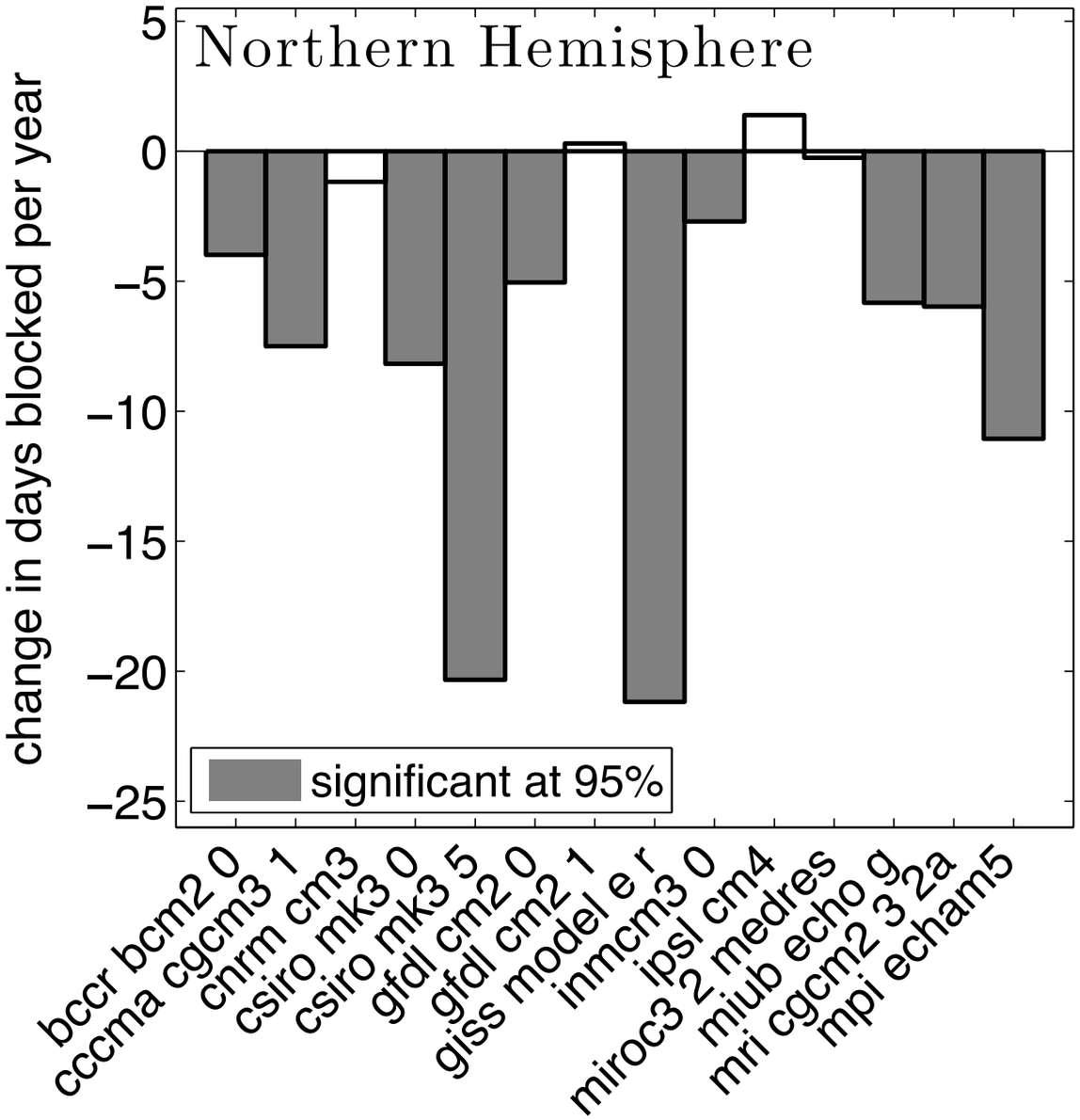
Mean jet speed in CMIP5

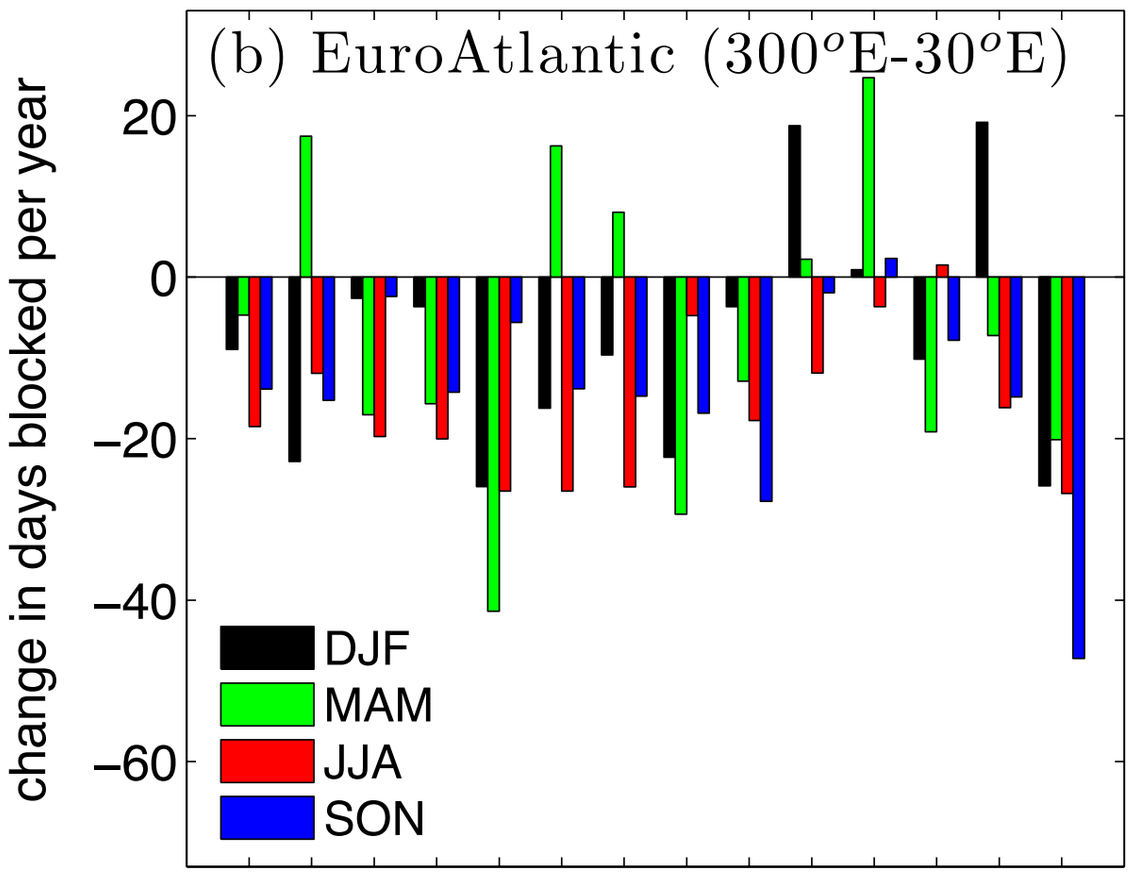
- no obvious changes in jet speed



Barnes & Polvani (2012); submitted

CMIP3 Atlantic blocking frequency

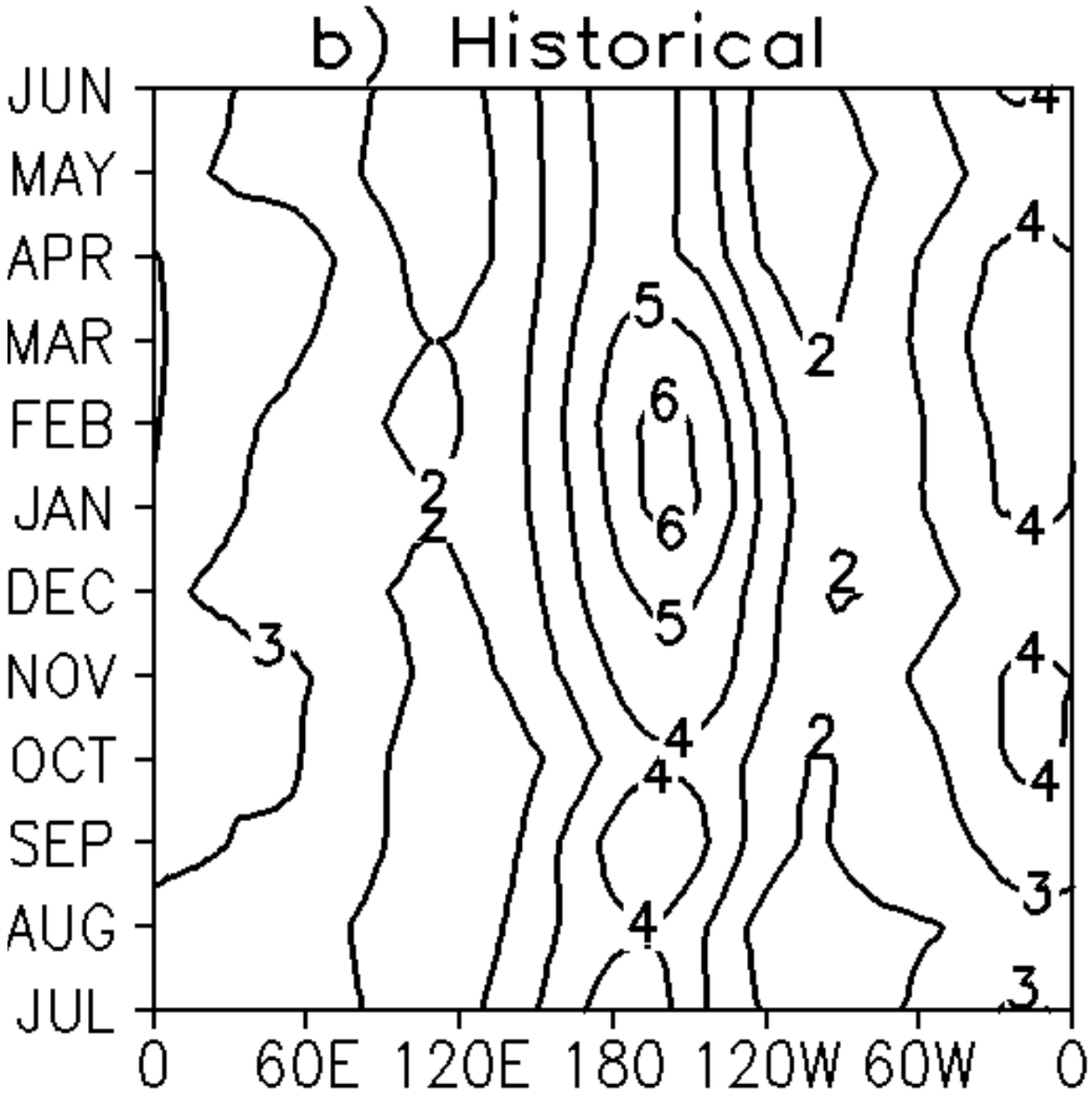


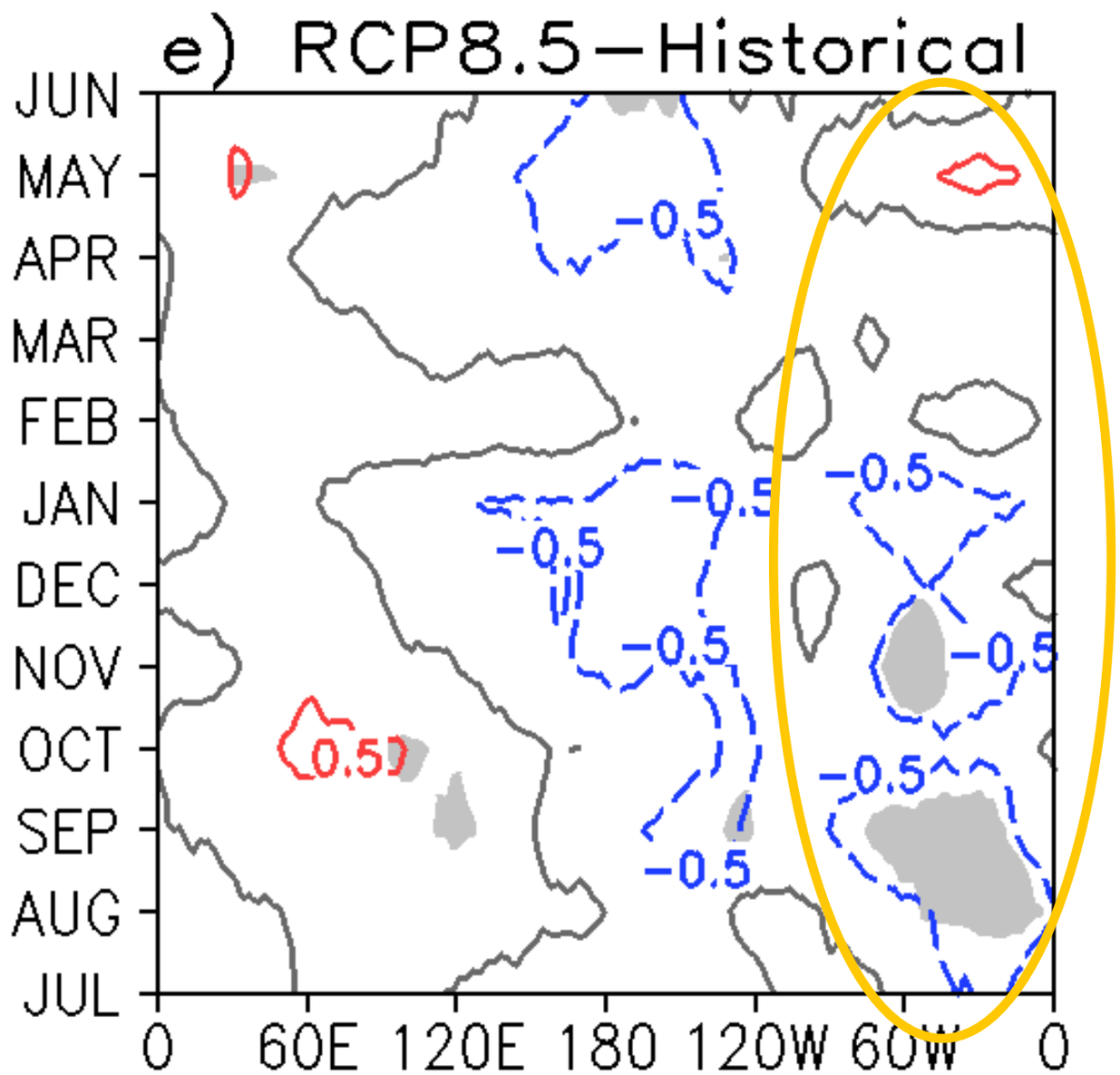


blocking frequency <u>decreases</u> in the future

Barnes, Slingo, Woollings (2012); CDYN

Seasonality from *Dunn-Siouin & Son (2012)*





blocking frequency <u>decreases</u> July-Jan.

Dunn-Sigouin & Son (2012); submitted, Fig. 2