

What type of QBO-related variation induces polar vortex and surface changes?



Kohei Yoshida (MRI/JMA) kyoshida@mri-jma.go.jp

1. Introduction

The stratospheric quasi-biennial oscillation (QBO) is a downward propagation of alternating equatorial stratospheric easterly and westerly winds with a period of about two and a half years, and is considered important for long-term forecasts from one month to several years ahead because the QBO has highly predictable effects not only in the equatorial stratosphere but also in the global stratosphere and near the surface. However, stratospheric polar vortex (SPV) impact of QBO (so-called Holton-Tan phenomena) and the surface impact mechanism is not well understood, and global climate models cannot adequately reproduce the QBO SPV and surface impacts seen in observations. To clarify which process is important to reproduce the QBO impact and understand the mechanism, climate model simulations were performed with various nudging regions. Preliminary results are shown here.

2. Experimental design

The nudging experiment design is based on QBOi2 protocol.

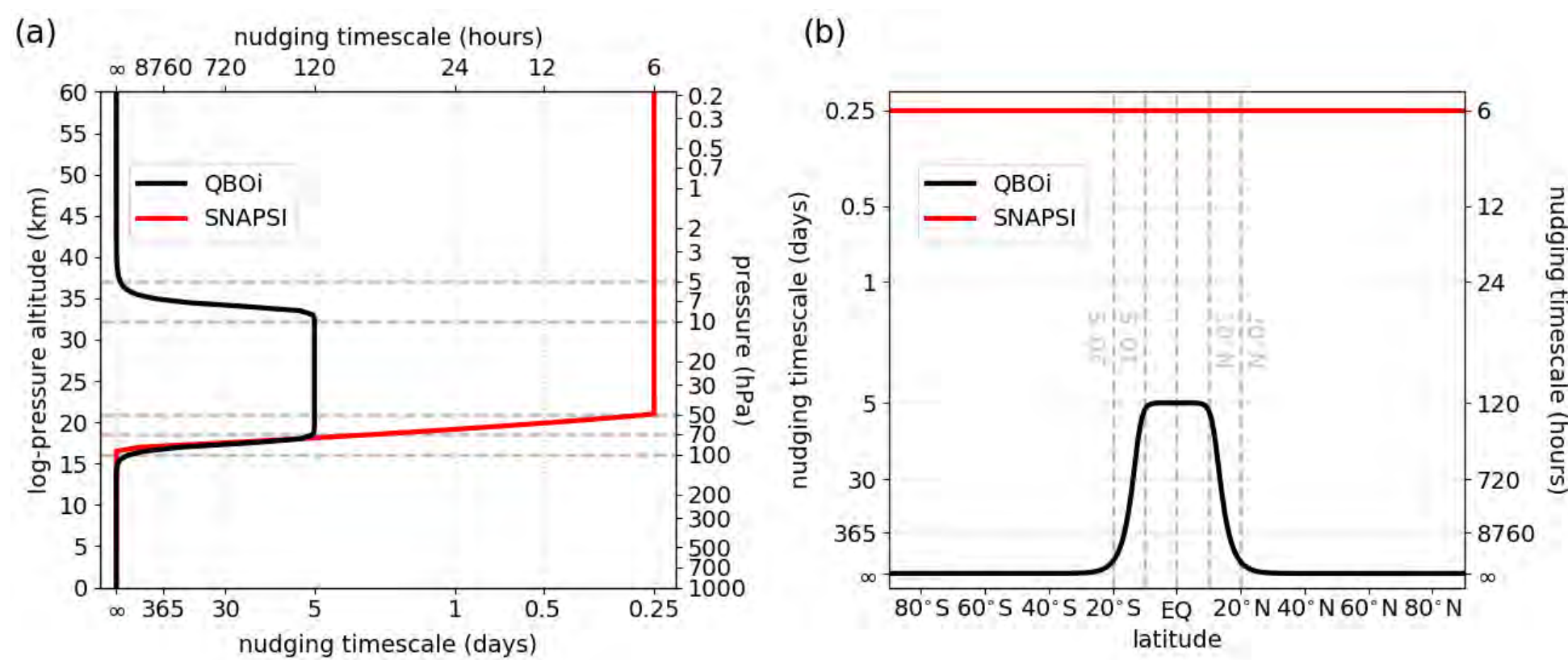


Figure 1: Spatial dependence of nudging timescale in the (a) vertical and (b) meridional directions. SNAPSI profiles are shown for comparison. From QBOi2 protocol description.

Zonal mean nudging is applied in this study.

The altitude profile of the nudging is given by

$$\frac{\alpha}{4} \left(1 - \tanh\left(\frac{p - p_b}{\Delta p_b}\right) \right) \left(1 + \tanh\left(\frac{p - p_t}{\Delta p_t}\right) \right)$$

$$\alpha = 5, p_b = 80, \Delta p_b = 5, p_t = 8, \Delta p_t = 0.5.$$

The latitude profile of the nudging is given by

$$\frac{\alpha}{4} \left(1 + \tanh\left(\frac{\phi - \phi_s}{\Delta \phi}\right) \right) \left(1 - \tanh\left(\frac{\phi - \phi_N}{\Delta \phi}\right) \right)$$

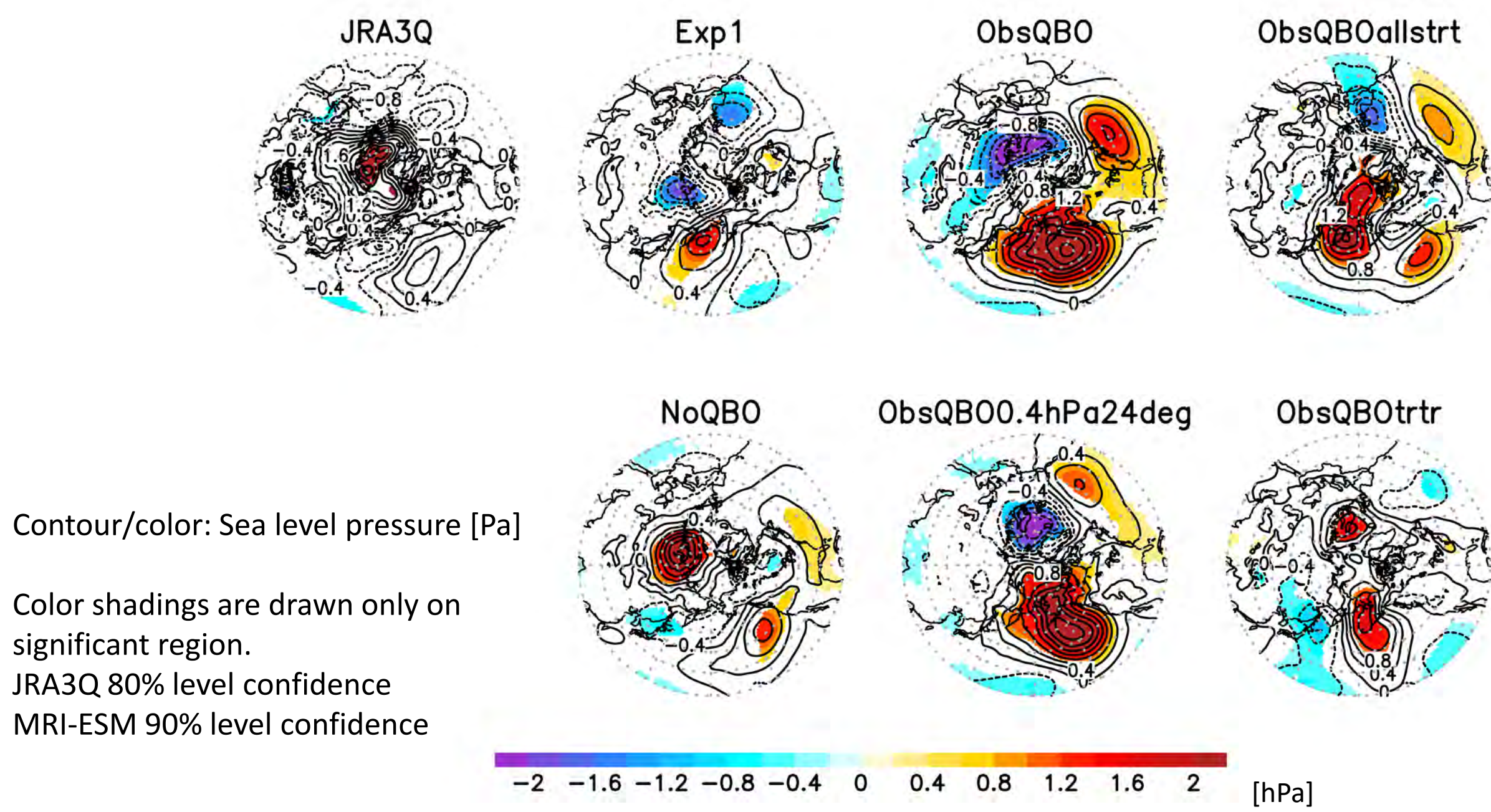
$$\phi_N = 12, \phi_s = -12, \Delta \phi = 2.$$

EXP Name	Explanation
EXP1	No nudging (AMIP experiment)
NoQBO	Climatology of JRA3Q is nudged.
ObsQBO	JRA3Q is nudged.
ObsQBO0.4hPa24deg	$\phi_N = 24, \phi_s = -24, p_t = 0.4$
ObsQBOallstr	$\phi_N = 90, \phi_s = -90, p_t = 0.4$
ObsQBOtrtr	ObsQBO + longitudinally varying u, v nudging in the tropical troposphere ($\phi_N = 30, \phi_s = -30, p_b = 850, p_t = 200$)

Climate model **MRI-ESM2.0** (Yukimoto et al., 2019) is used for the simulations. The calculation period is for 1978-2020 (1979-2020 for analysis) and each experiment has 6 ensemble members. JRA3Q (Kosaka et al., 2024.) is used for validation.

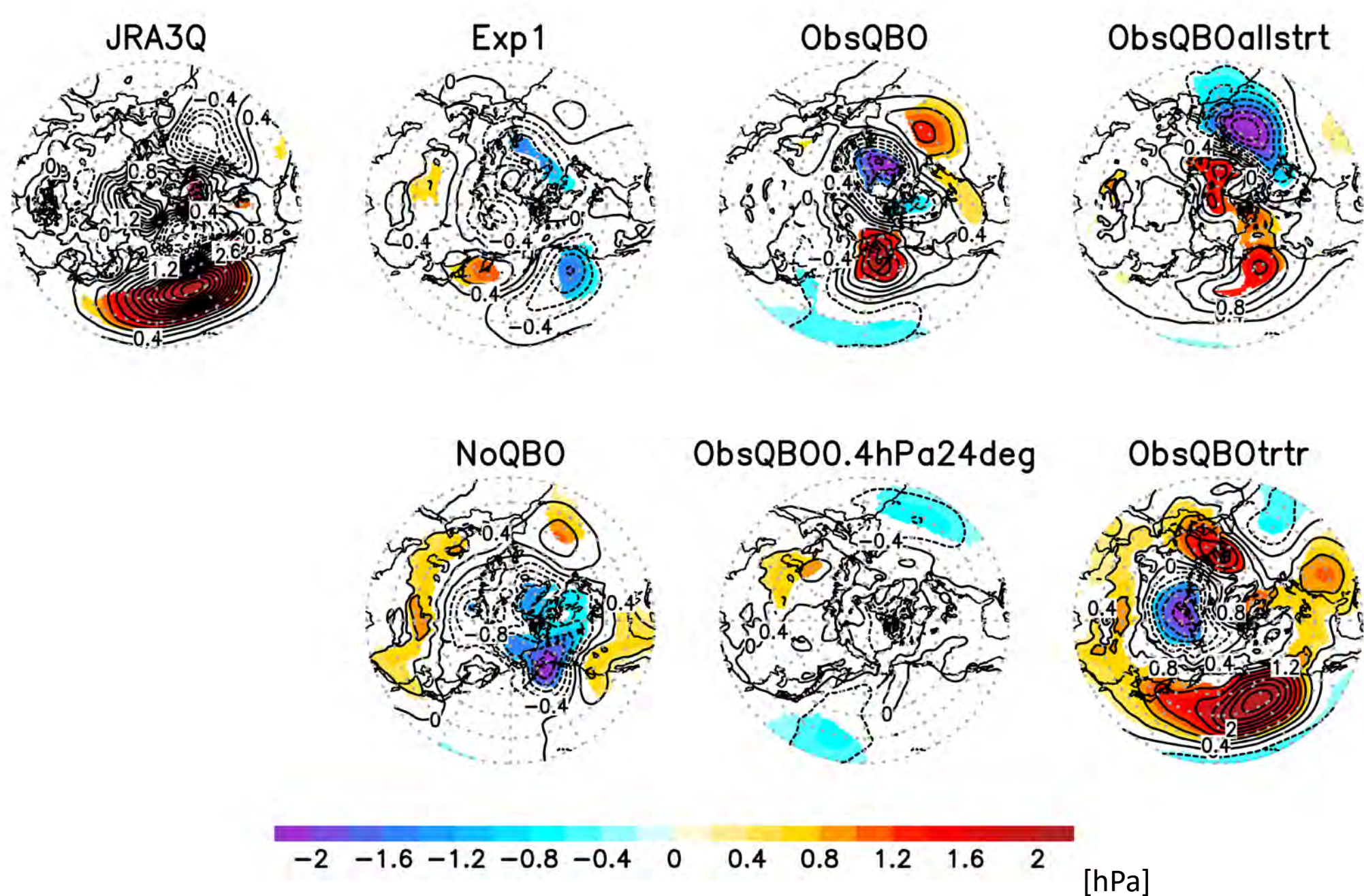
4. Surface response

QBOE-QBOW (u=0 criterion) composite in DEC-JAN



- Negative NAO-like pattern: JRA3Q, ObsQBOallstr and ObsQBOtrtr
- QBO nudging is not enough to simulate -NAO-like pattern in this model?

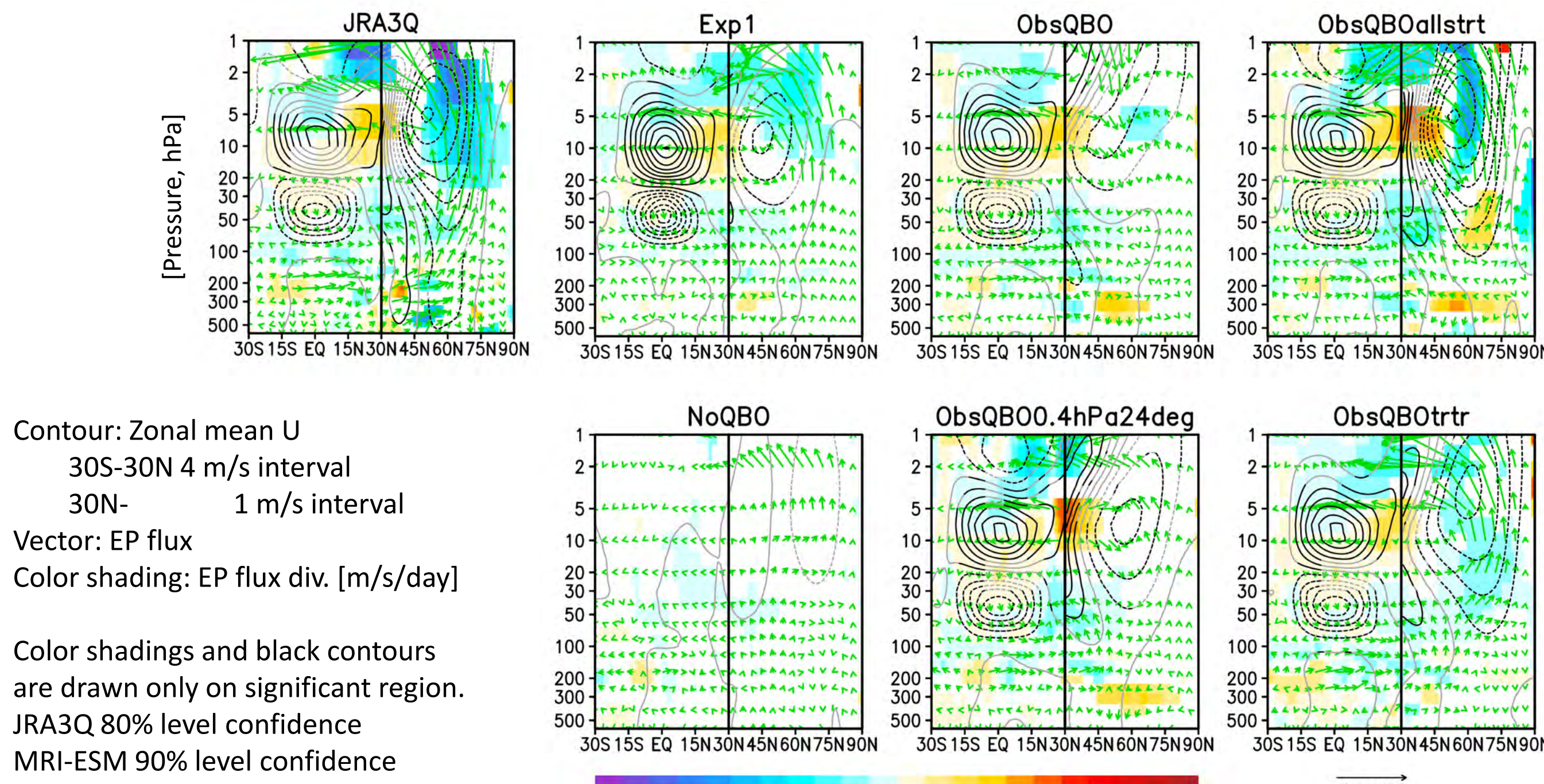
QBOE-QBOW (u=0 criterion) composite in FEB-MAR



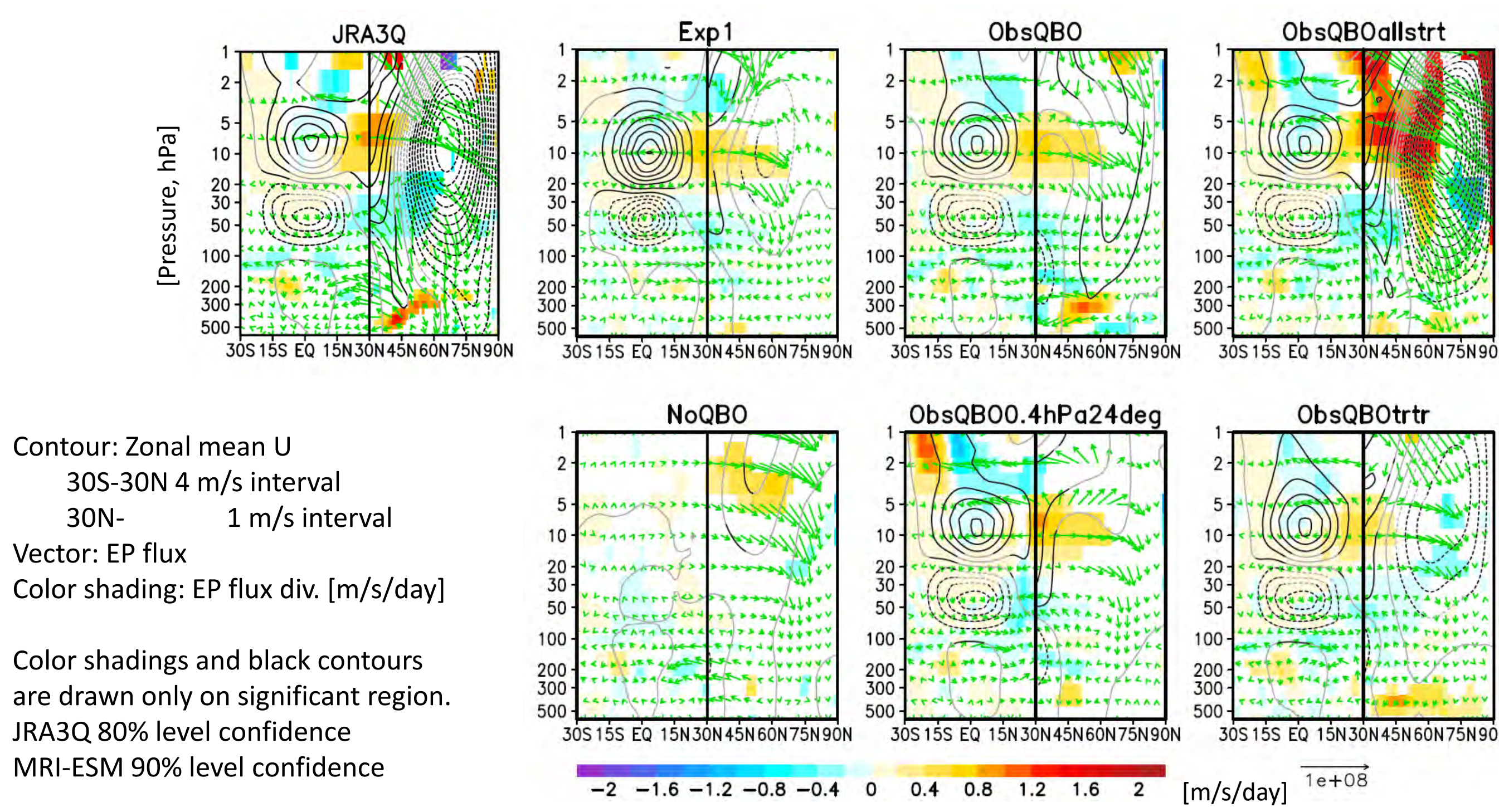
- Negative NAO: JRA3Q (insignificant), ObsQBOallstr
- Strong positive around Aleutian isls. is reproduced in ObsQBOtrtr.

3. SPV and wave responses

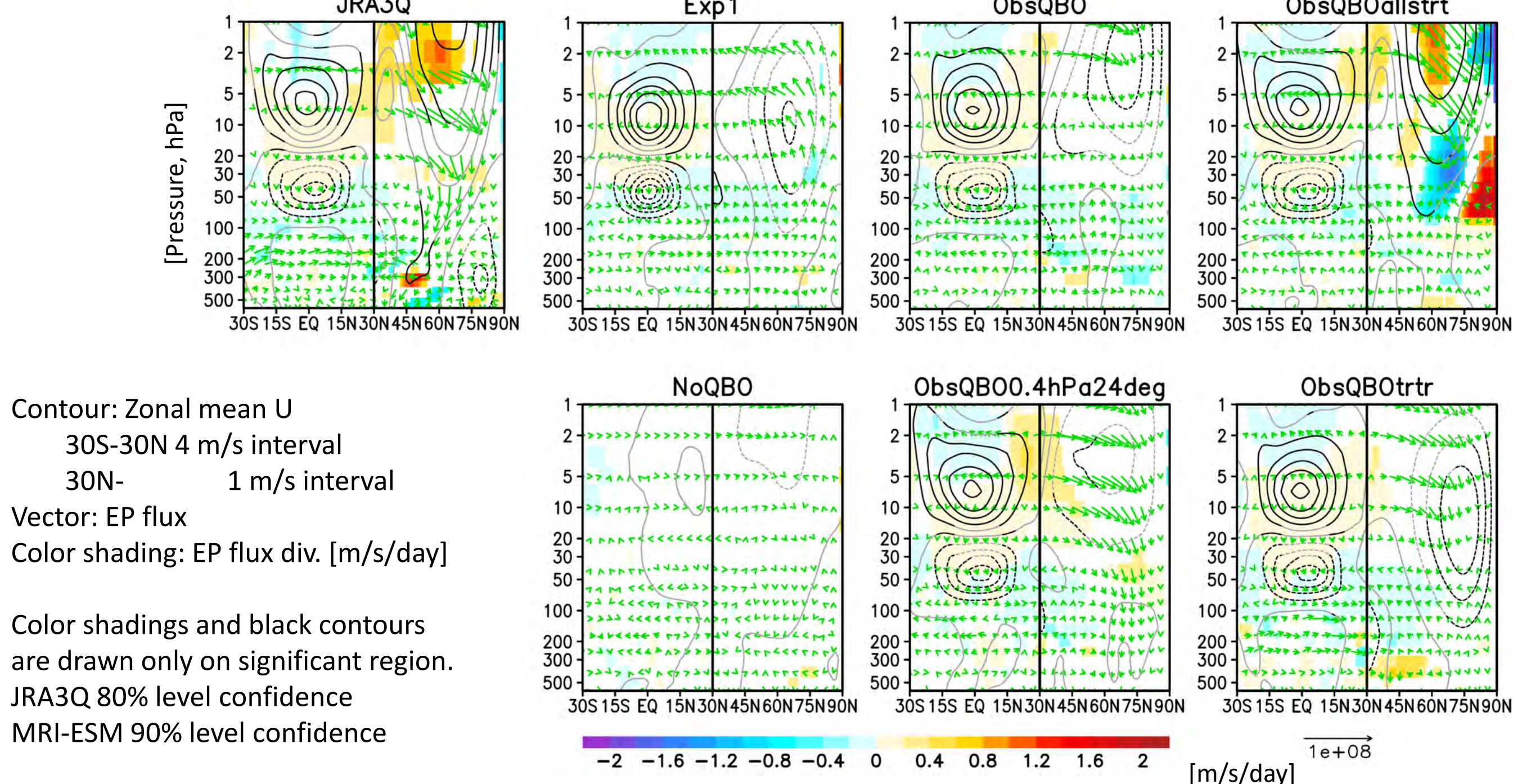
QBOE-QBOW (u=0 criterion) composite in NOV-DEC



QBOE-QBOW (u=0 criterion) composite in JAN-FEB



QBOE-QBOW (u=0 criterion) composite in MAR-APR



- In Nov-Dec, QBO and tropical stratosphere nudging enhances Holton-Tan like SPV and wave responses, and wider nudging simulate more realistic responses.
- However, EPF conv. anom. is weak in SPV in ObsQBO, ObsQBO0.4hPa24deg, ObsQBOtrtr.
- ObsQBOallstr has strong EPF conv. anom. in high latitude stratosphere, but EPF div. anom. at around 100 hPa may reduce surface response.
- All nudged simulations show EPF div. anom. at around 50N and 300 hPa, which may come from deformed subtropical route response. This anom. also causes surface response reduction.
- In Jan-Feb, tropical stratosphere nudging simulations do not cause Holton-Tan like responses, and show westerly or weak easterly anomaly contradicting to JRA3Q.
- ObsQBOallstr and ObsQBOtrtr simulate EPF convergence anom., which may cause weaker polar vortex responses in the model.
- In Mar-Apr, ObsQBO, ObsQBO0.4hPa24deg, ObsQBOtrtr and Exp1 show easterly anom. in SPV, which contradict to JRA3Q.
- ObsQBOallstr in spite of same zonal mean SPV to JRA3Q show EPF conv. anom., which induces easterly anom.

5. Summary and Discussions

- Nudging simulations using MRI-ESM2.0 show realistic Holton-Tan like SPV response only in late autumn and early winter (Nov-Dec)
- Contradicting to JRA3Q, the model simulations show different SPV anomaly from mid winter to early spring (Jan-Apr).
- Even in whole stratosphere zonal wind nudging, wave activity partly does not match with JRA3Q, which may work to violate observed QBO response.
- ObsQBOtrtr (+ tropical troposphere nudging simulation) is not enough to reproduce SPV response to QBO.
- Reproducibility of waves (in both stratosphere and troposphere) and SPV (e.g., seasonal march) may be important.
- Does gravity wave parameterization work reasonably?
- ObsQBOallstr simulations with modified physics and additional nudging region may reveal source of the difference.

Acknowledgements

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