Captured MJO-QBO Connection in a Subseasonal Prediction System

Kai Huang[1], Jadwiga H Richter[2], and Kathleen V Pegion[3]

[1]AOES Department, George Mason University
[2]Climate and Global Dynamics Laboratory, National Center for Atmospheric Research
[3]School of Meteorology, University of Oklahoma

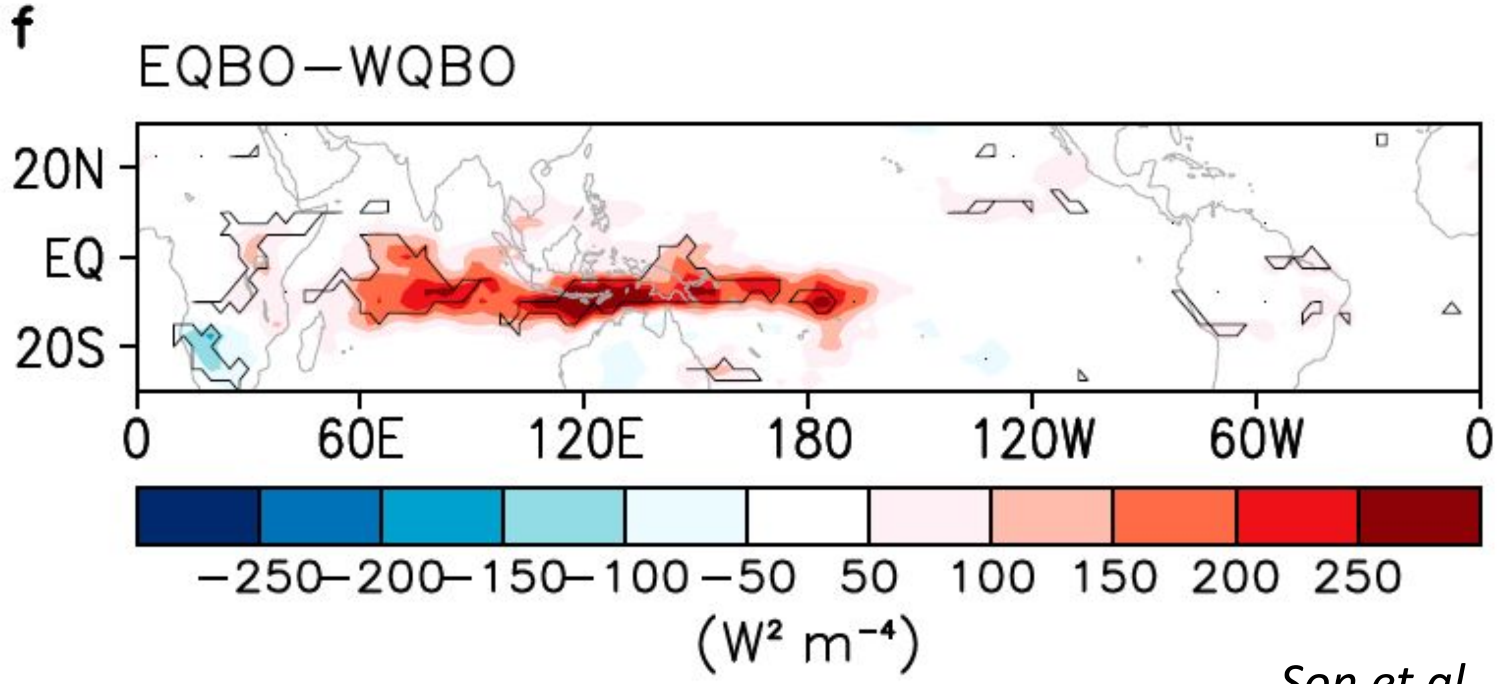
Discovery of QBO-MJO Connection (2016)

Yoo and Son 2016, Son et al., 2017.

MJO is stronger and more likely to cross the Maritime Continent (MC) in QBOE than QBOW.

Accounting for ~40% of the MJO interannual variation.

20-100-day-band-pass-filtered OLR Variance



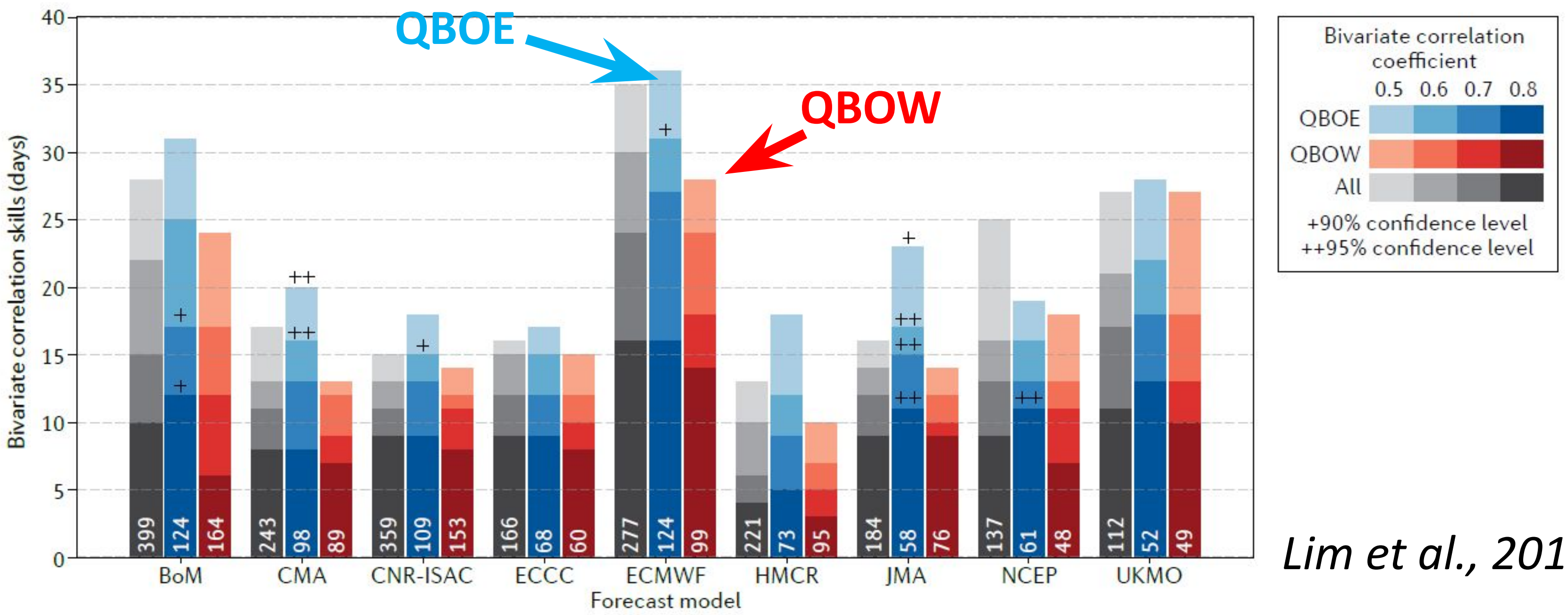
Son et al., 2017

Also Found in S2S Prediction Systems (2017-2020)

Marshall et al., 2017.
Higher MJO predictability in QBOE than QBOW years.

Wang et al., 2019, Lim et al., 2019, Abhik and Hendon, 2019, Kim et al., 2019, Martin et al., 2020.
Higher MJO prediction skill in QBOE than QBOW years.

MJO Prediction Skills (days) in Forecast Models



Lim et al., 2017

Struggling to find the Responsible Mechanism (2017-now)

Son et al., 2017, Zhang and Zhang, 2017, Sun et al., 2019, Sakaeda et al., 2020.

Increased **HIGH CLOUD** in QBOE over the MC.

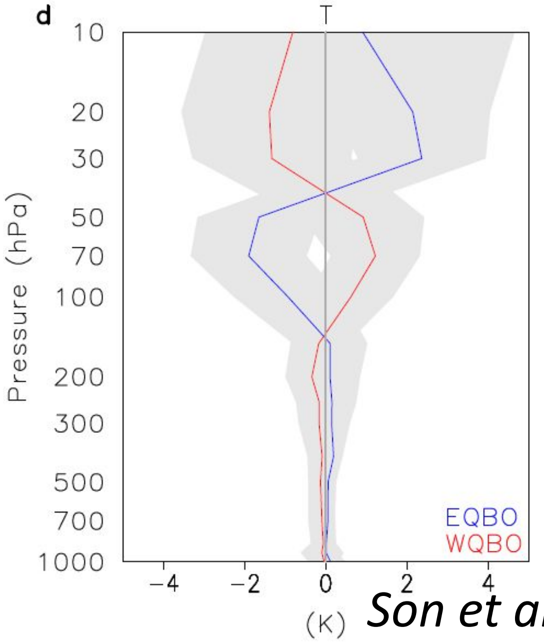
May influence the cloud-radiative feedback/local diurnal cycle precip.

Hendon and Abhik, 2018, Lee and Klingaman, 2018, Abhik and Hendon, 2019, Martin et al., 2019, Martin, et al., 2021 ***...***

Decreased **STATIC STABILITY** around the tropopause in QBOE.

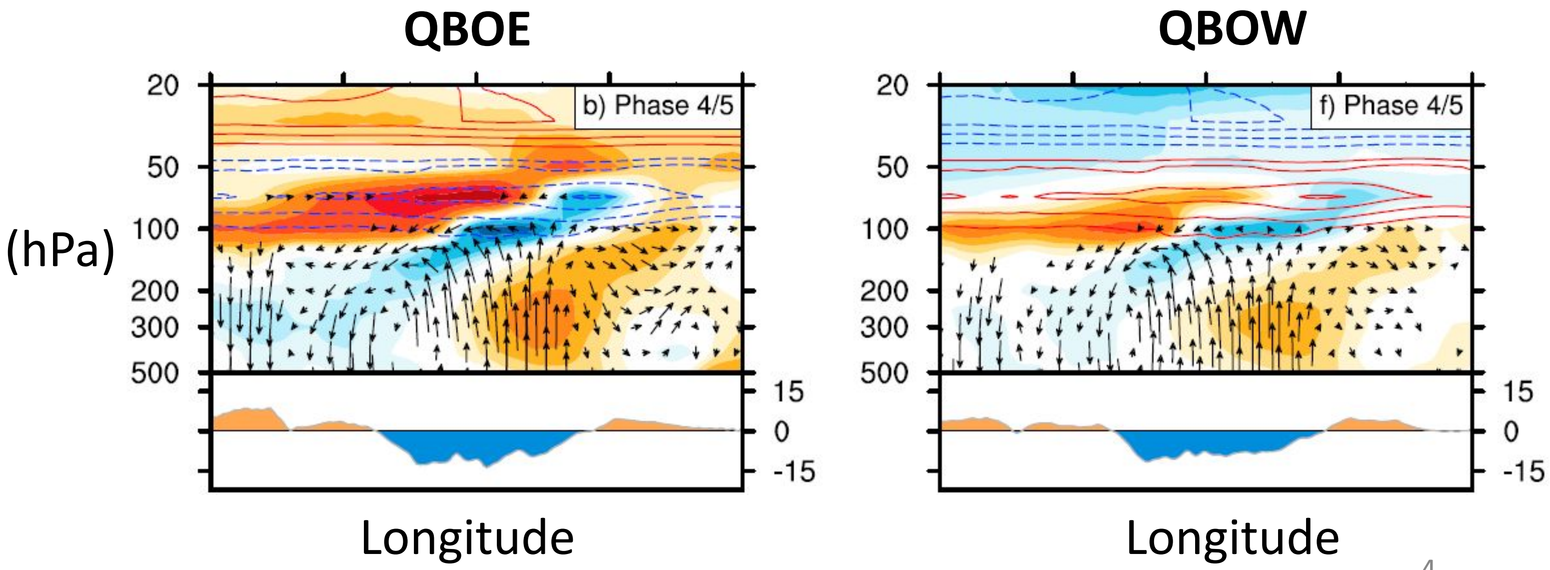
Destabilize the tropopause.

Equatorial Zonal Mean Temp Profile



Son et al., 2017

MJO Temp Anomalies

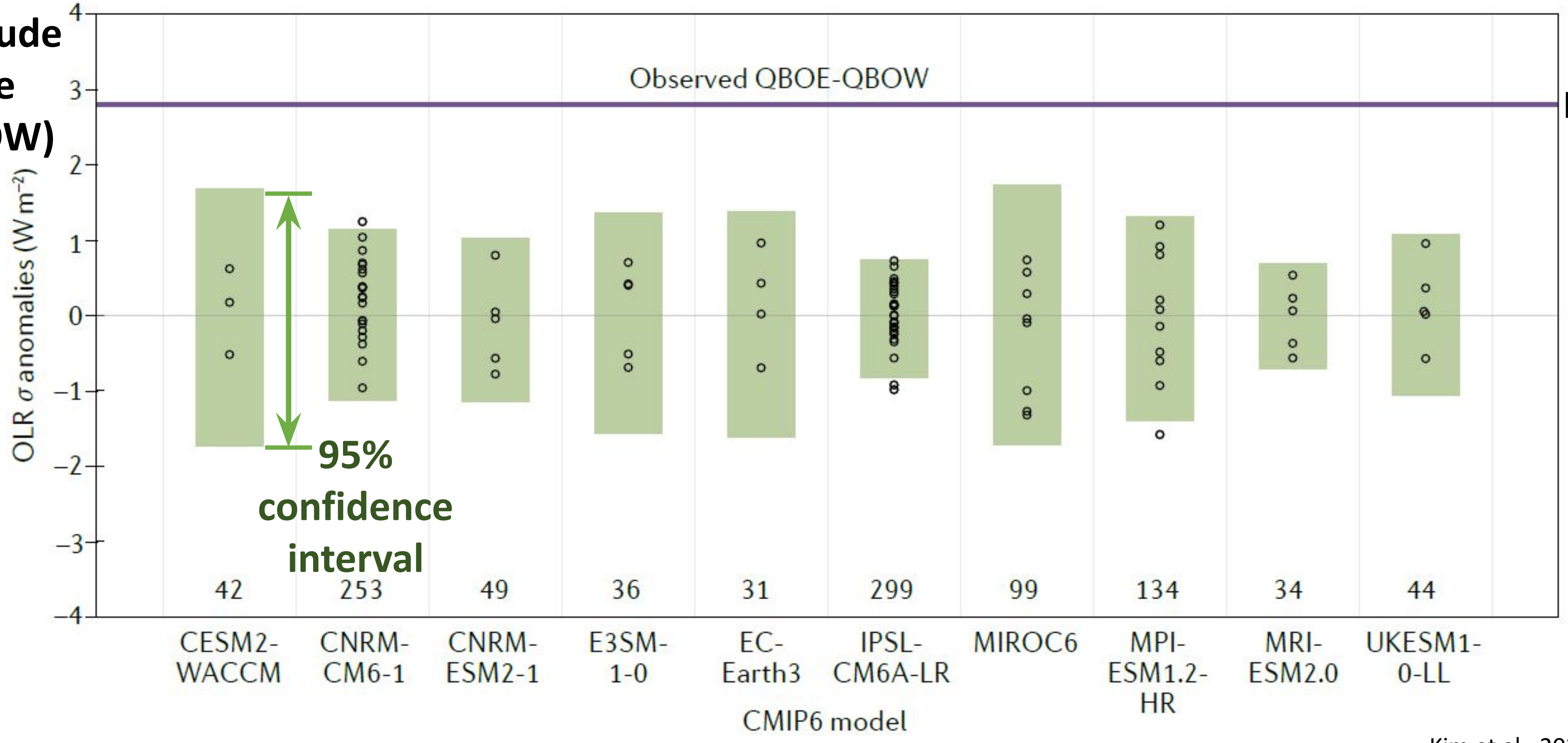


Hendon and Abhik, 2018

Missing in Climate Models (hopefully not forever)

Kim et al., 2020

MJO Amplitude Difference (QBOE-QBOW)



 observations

Ensemble members

Kim et al., 2020

Trying to Capture it in Models (2019-now)

Martin et al., 2019.

Two consecutive MJO cases by WRF.

Adding QBO temp/uwnd anomalies in the stratosphere.

Weak, but Captured, only by adding temp! (Supporting Tropopause Instability)

Martin et al., 2020.

S2S predictions by ECMWF.

Stratospheric initial conditions substituted by one arbitrarily selected QBOE/QBOW day, respectively.

Weak, but Captured!

Back et al., 2020.

One MJO Case in a QBOE winter by WRF.

Reversing the low-pass-filtered QBO variation in the stratosphere.

Weak, but Captured! (Supporting Tropopause Instability)

Trying to Capture it in Models (2019-now)

Martin et al., 2021.

Long-term Simulation by NASA GIS.

Nudged zonal-mean uwnd and vwnd in the stratosphere.

Realistic QBO temp but FAILED!

Several more GCMs are also tried, but all failed!

What might be wrong?

QBO by large-scale forcing data (**fixed**)

Regional Model (WRF)

Missing non-local effects. Fixed lateral boundary conditions.

QBO signals by the stratospheric initial conditions (**free**)

Forecast Model (ECMWF)

Non-local effects. Global model.

QBO signals by zonal-mean nudging (**fixed**)

Forecast Model ?

Non-local effects. Global model.

QBO signals by zonal-mean nudging (**fixed**)

Climate Models

Non-local effects. Global model.

Can We Answer More Questions?

Where comes the QBO-MJO connection in S2S Prediction Systems?

Maintaining the stronger MJO from the I.Cs in QBOE than in QBOW

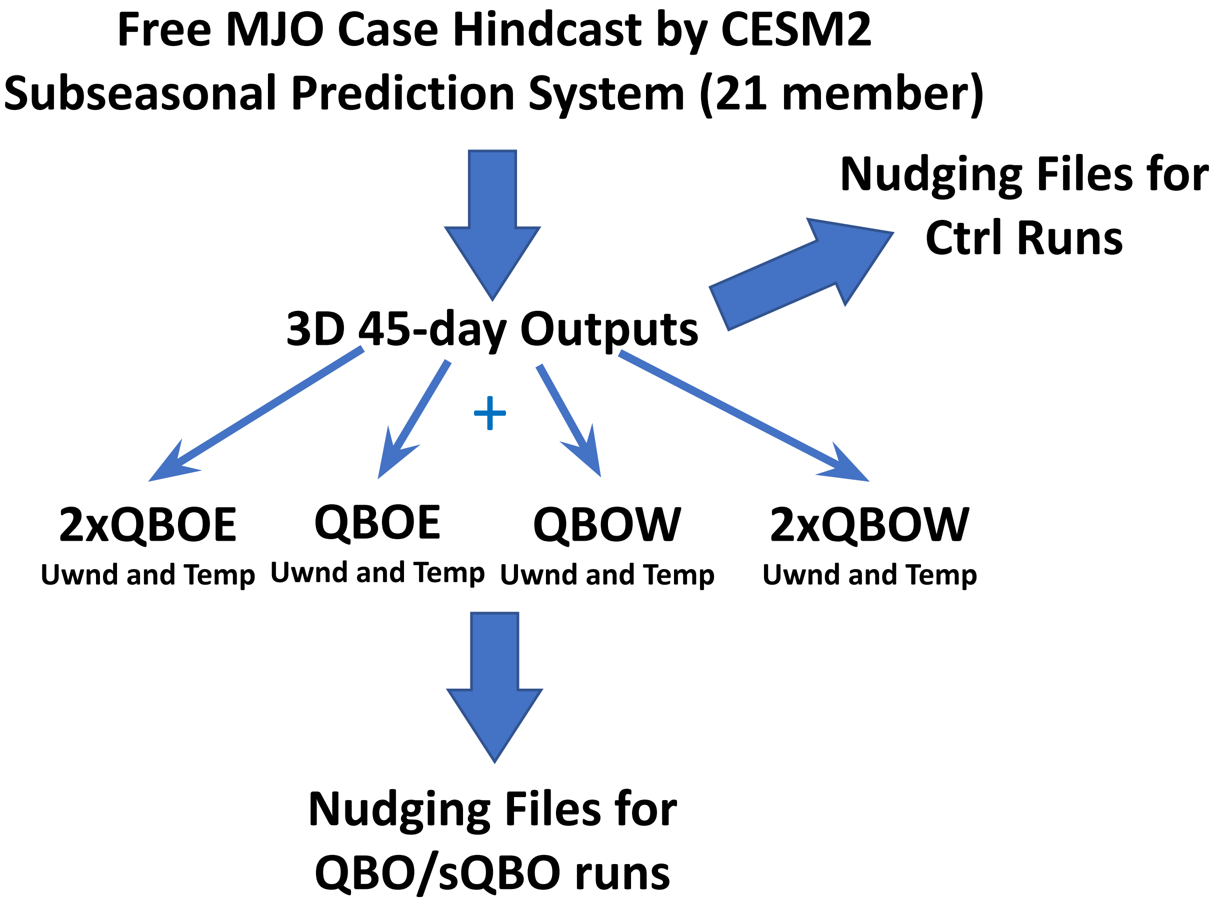
The correct model physics

- *Design: Two MJO case hindcasts in QBO-neutral winters*
  - ✔ *NO QBO influence on MJO in the I.Cs.*

Which is crucial, the QBO wind shear, or the QBO temperature profile?

Revisit the tropopause instability theory.

- *Design: Adding zonal mean QBO temperature and uwnd respectively.*

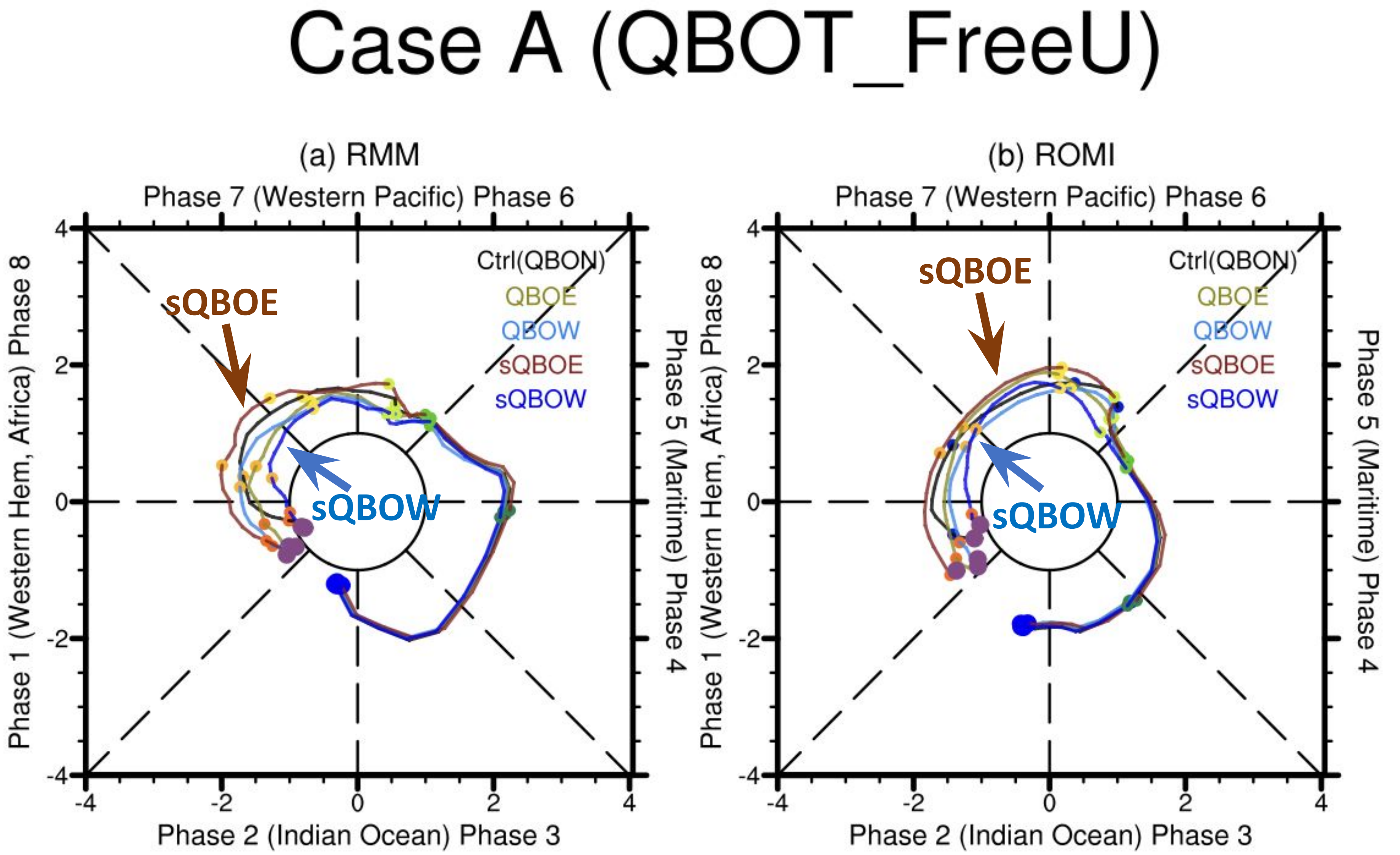


Stratospheric Nudging

- Zonal mean nudging
- 12 hourly
- Complete nudging above 100hPa
- No nudging below 150hPa
- Linear transition in between

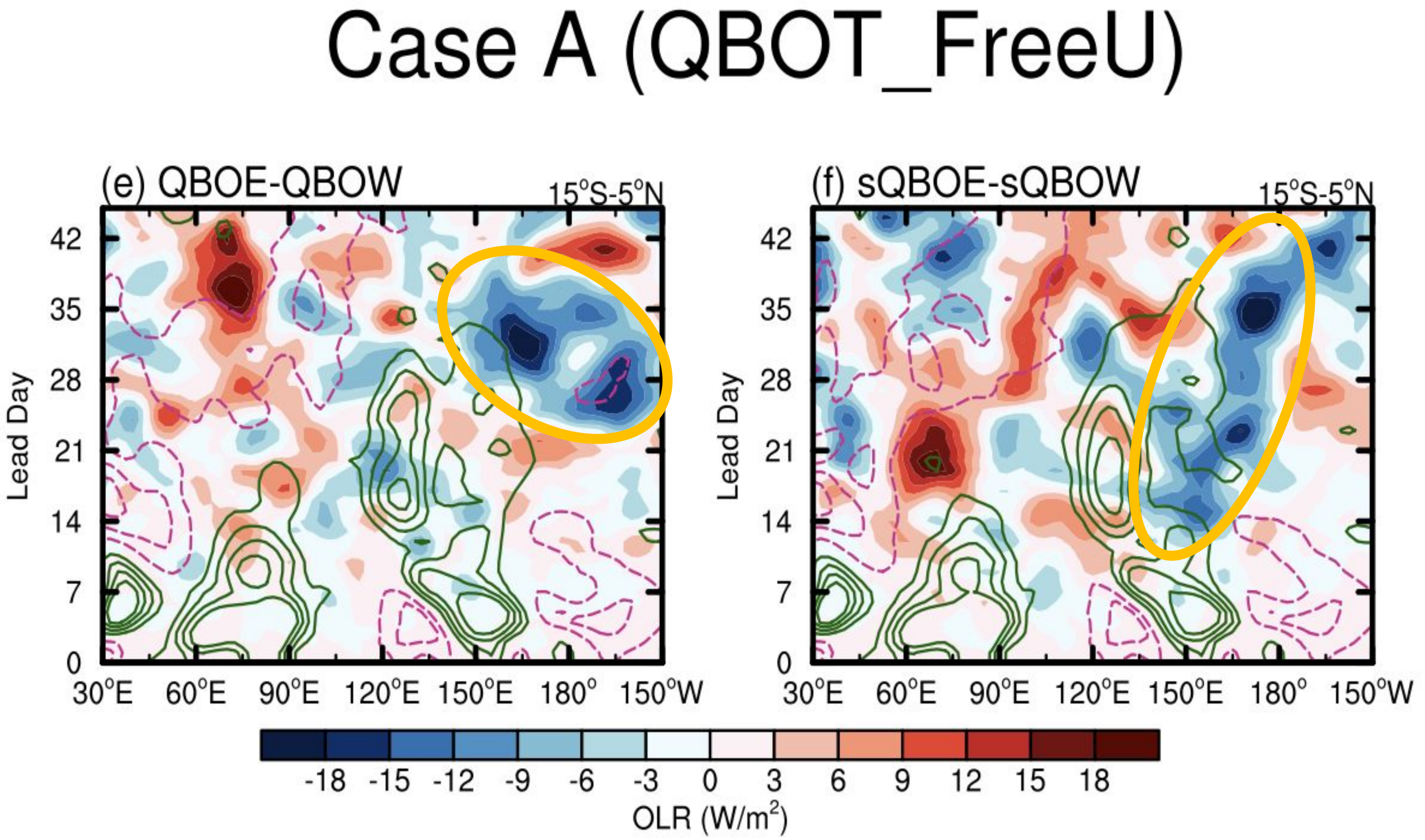
Experiment	Run	Nudged Variable U	Nudged Variable T
PreCtrl	N/A	No	No
QBOT_FreeU	Ctrl	No	PreCtrl
	QBOE	No	PreCtrl+QBOE
	QBOW	No	PreCtrl+QBOW
	sQBOE	No	PreCtrl+2×QBOE
	sQBOW	No	PreCtrl+2×QBOW
QBOU_FreeT	Ctrl	PreCtrl	No
	QBOE	PreCtrl+QBOE	No
	QBOW	PreCtrl+QBOW	No
	sQBOE	PreCtrl+2×QBOE	No
	sQBOW	PreCtrl+2×QBOW	No
QBOUT	Ctrl	PreCtrl	PreCtrl
	QBOE	PreCtrl+QBOE	PreCtrl+QBOE
	QBOW	PreCtrl+QBOW	PreCtrl+QBOW
	sQBOE	PreCtrl+2×QBOE	PreCtrl+2×QBOE
	sQBOW	PreCtrl+2×QBOW	PreCtrl+2×QBOW

QBO-MJO Connection is Captured!

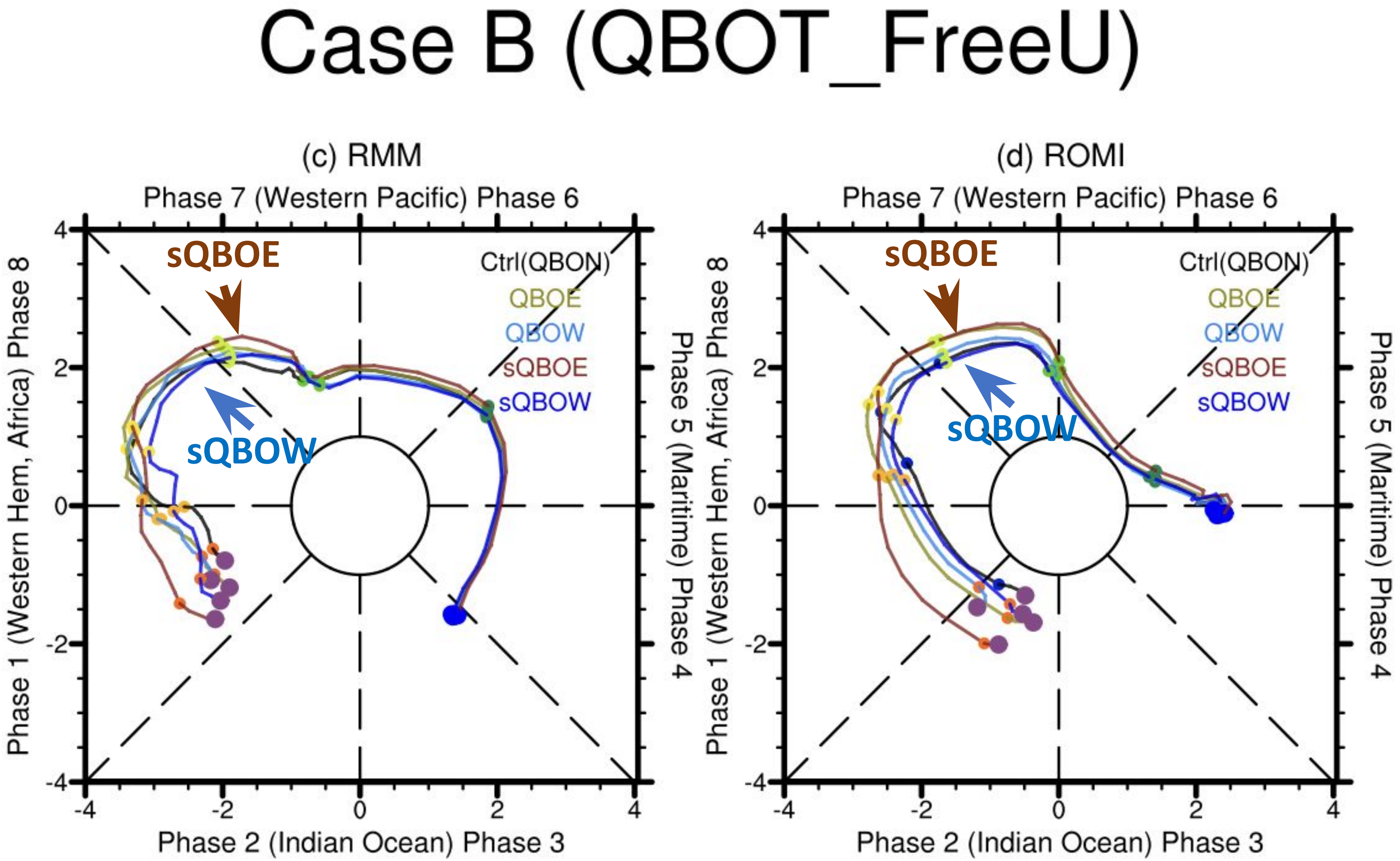


QBO-MJO Connection is Captured!

Predicted Ensemble-Mean OLR Anomaly Hovmoller Diagram



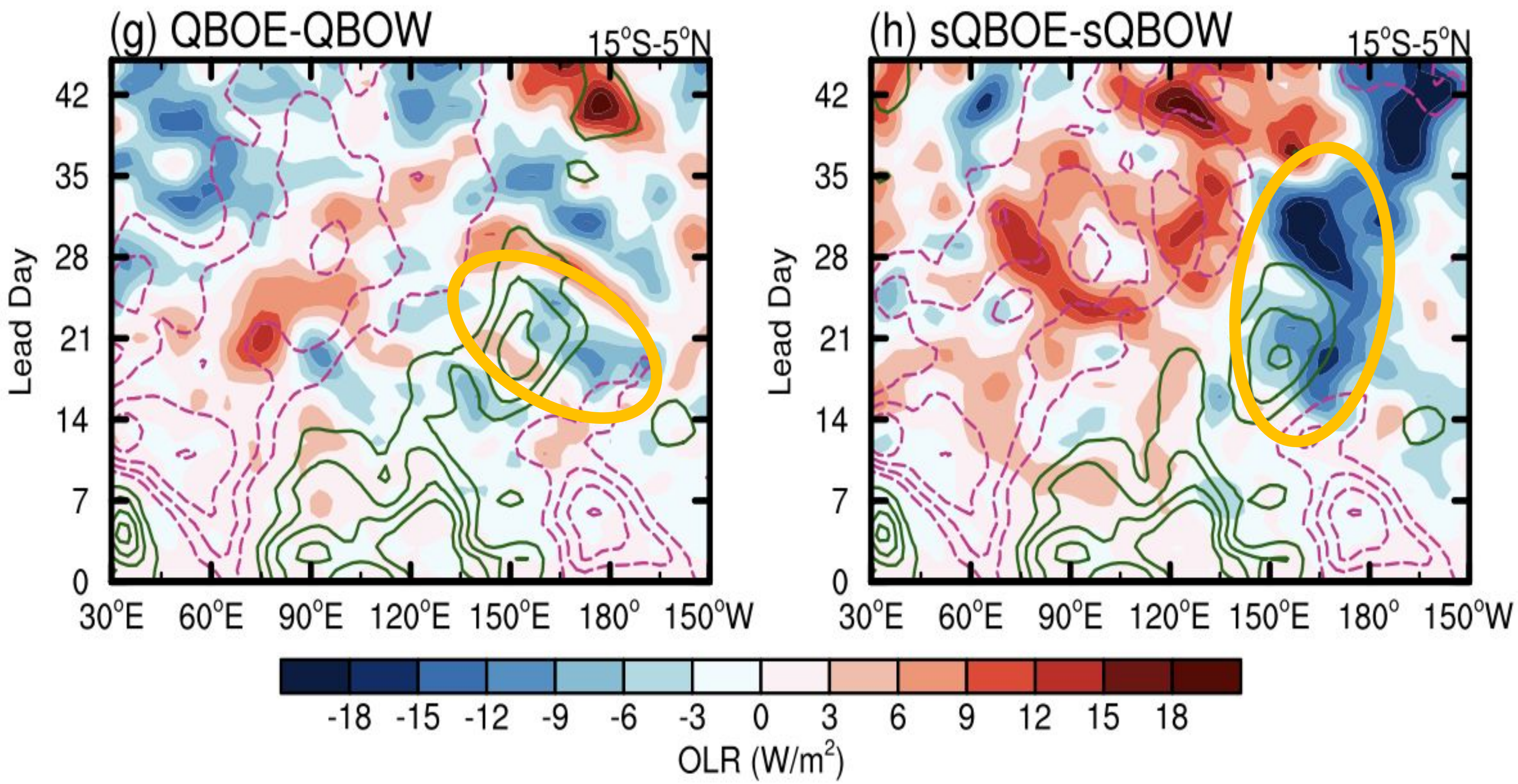
QBO-MJO Connection is Captured!



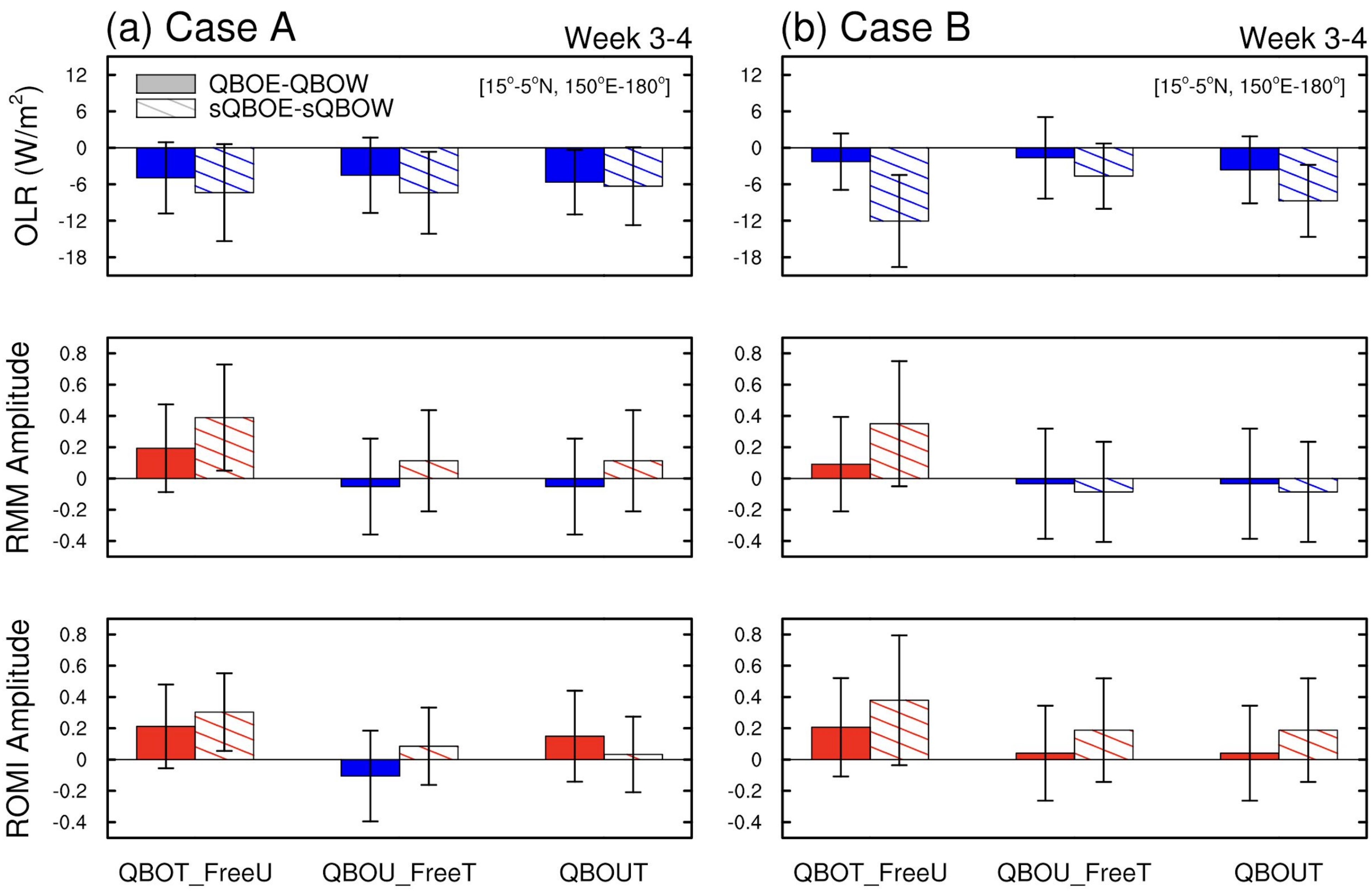
QBO-MJO Connection is Captured!

Predicted Ensemble-Mean OLR Anomaly Hovmoller Diagram

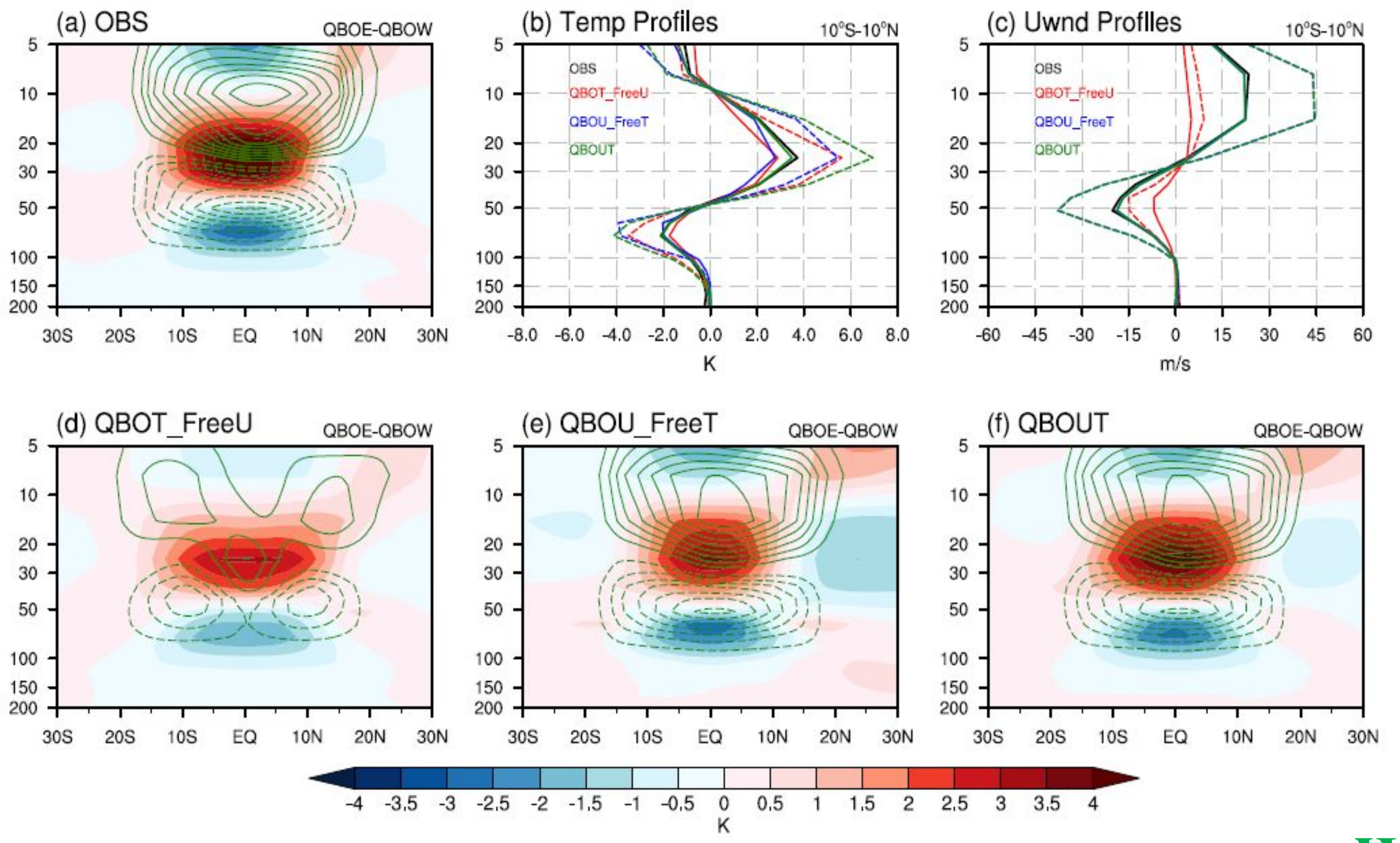
Case B (QBOT_FreeU)



Captured Only in QBOT_FreeU!



Zonal-Mean Temp (shading) and Uwnd (Lines), QBOE-QBOW



Freely-Evoving QBO Uwnd shear might be Crucial.

Zonal-Mean Tropopause Instability can NOT fully explain it!!!

- Nudging temp/uwnd will generate the other.
- Bias in the center for uwnd shear by nudging temp.

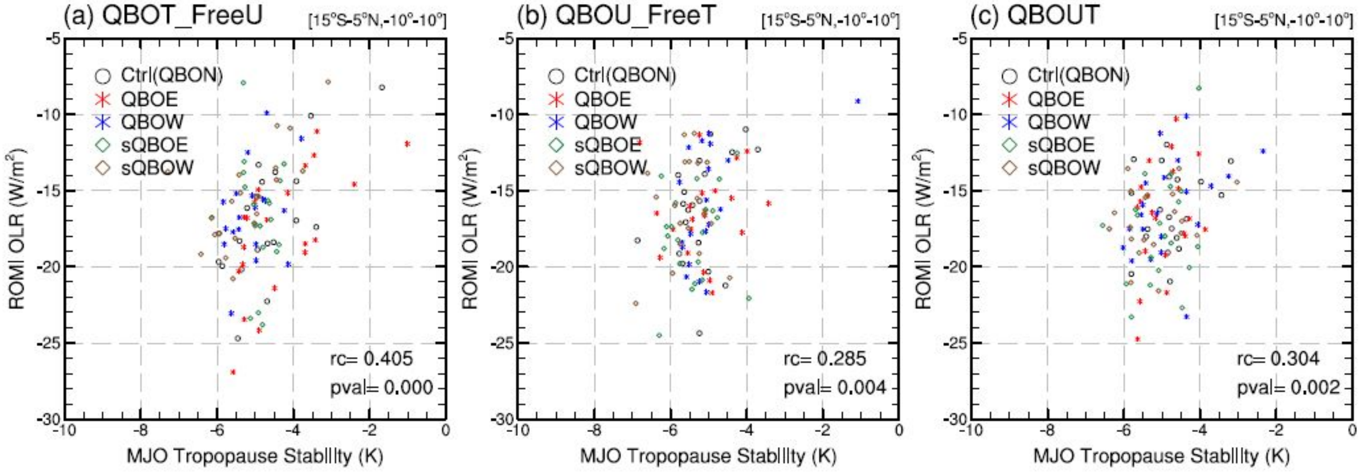
What about MJO-scale tropopause instability?

MJO Amplitude (ROMI OLR) Against MJO-Scale Tropopause Stability (T’100-T’200)

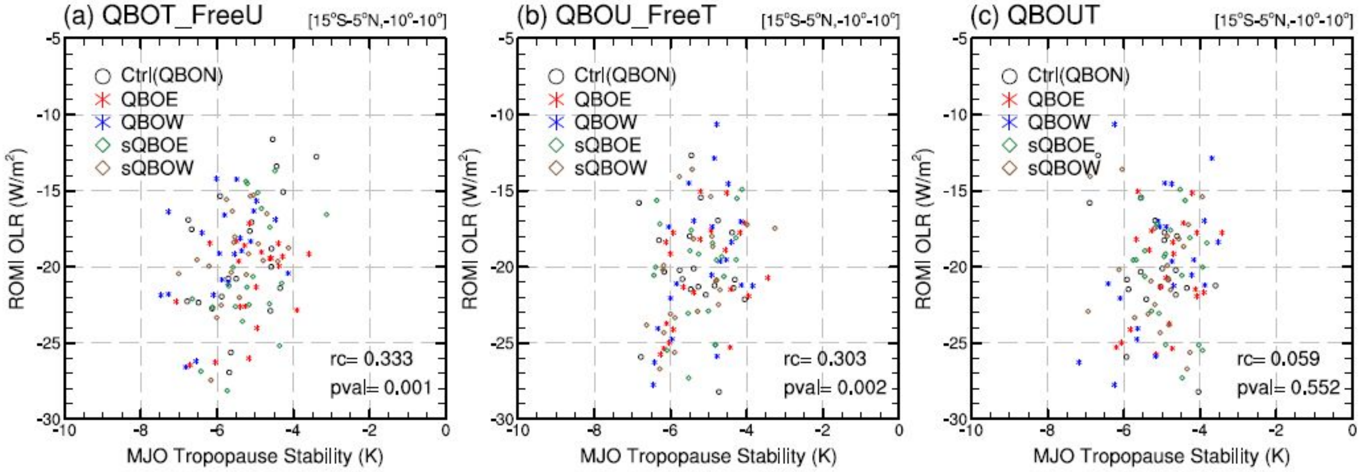
- Significant correlation between MJO amplitude and MJO tropopause stability in all experiments.
- But only QBOT_FreeU captures QBO-MJO connection.

MJO-Scale Tropopause Instability is also NOT enough to explain it!!!

ROMI Phase 6/7 Case A



ROMI Phase 6/7 Case B



Summary

- Zonal-mean QBO uwnd/temp nudged into two MJO case hindcasts in QBO-neutral winters.

- Only QBOT_FreeU can capture the QBO-MJO connection.

- Prediction system has the potential to capture QBO-MJO connection even without the help from the I.Cs.

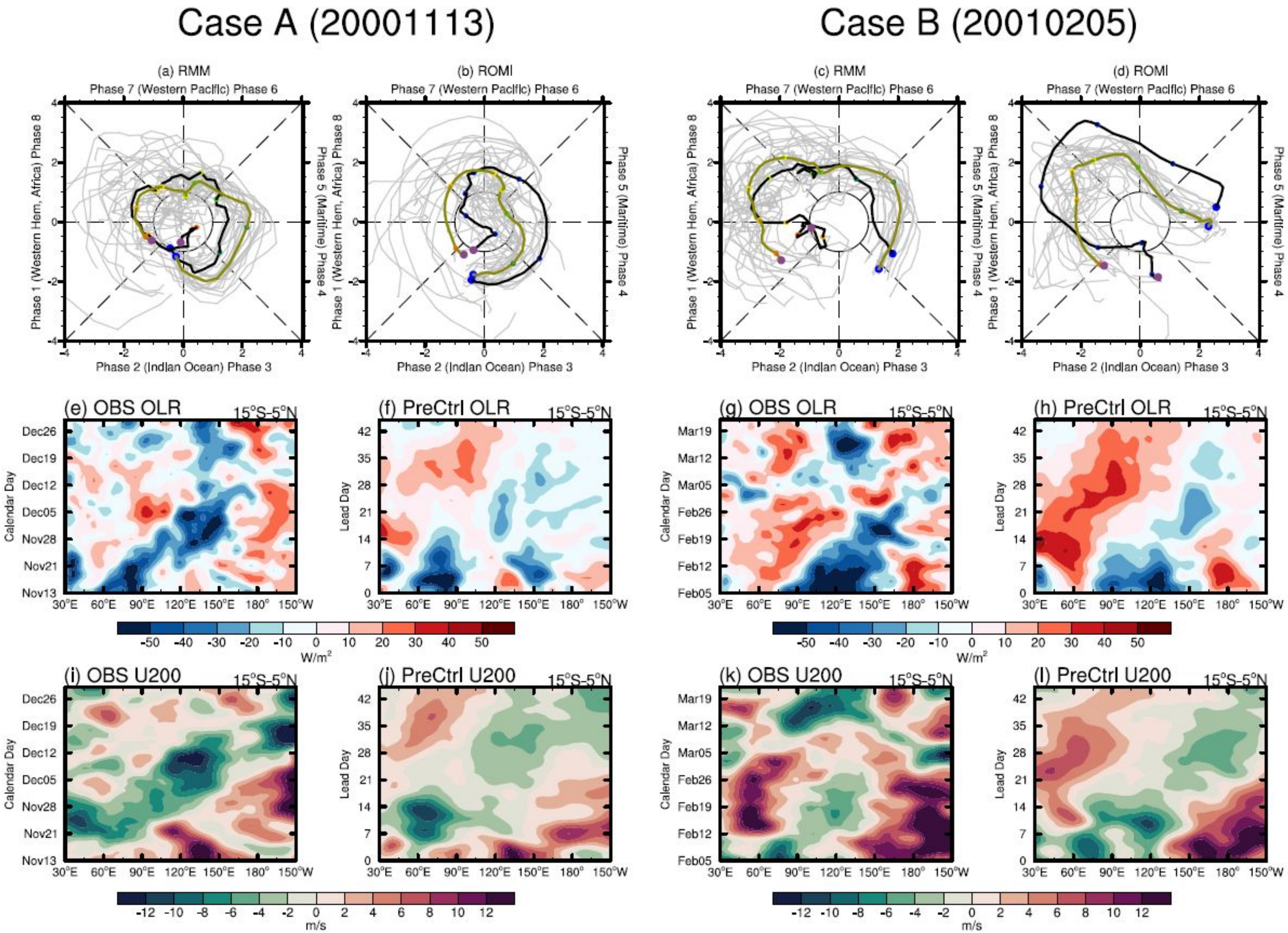
- Tropopause instability theory alone can not fully explain the capture connection.

Outlook

- How about the long-term uninitialized simulations in climate models?

- What is also responsible other than the tropopause instability?
    - Interactions between the waves and zonal-mean flow?

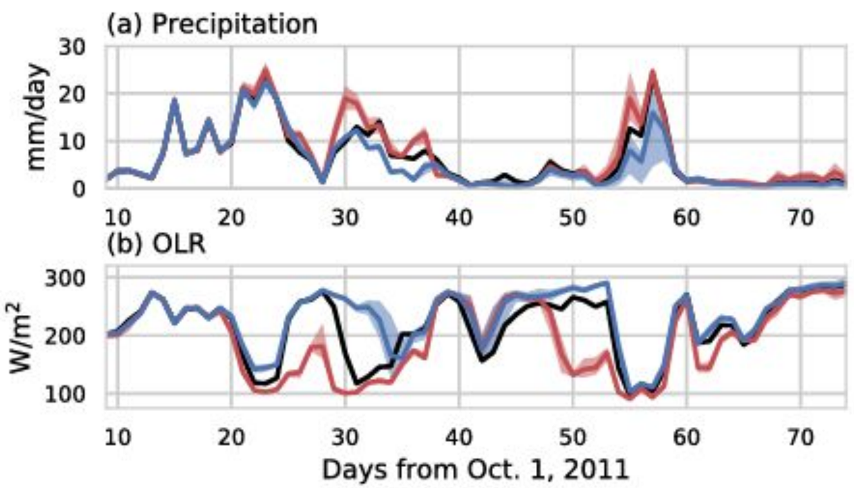
Case A&B in OBS and PreCtrl (no nudging)

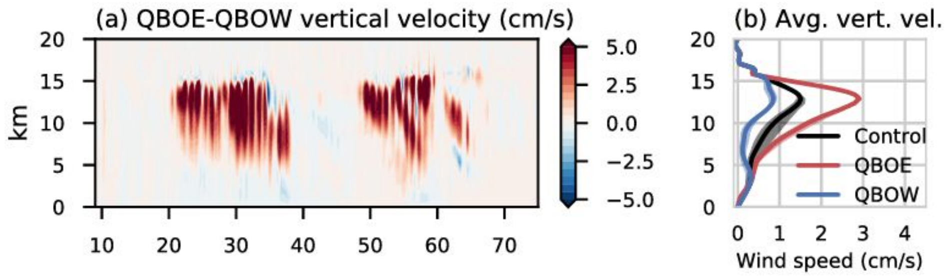


Why these Conclusions are Different from that in Martin et al., 2019?

One possible reason:
How to Measure MJO Amplitude

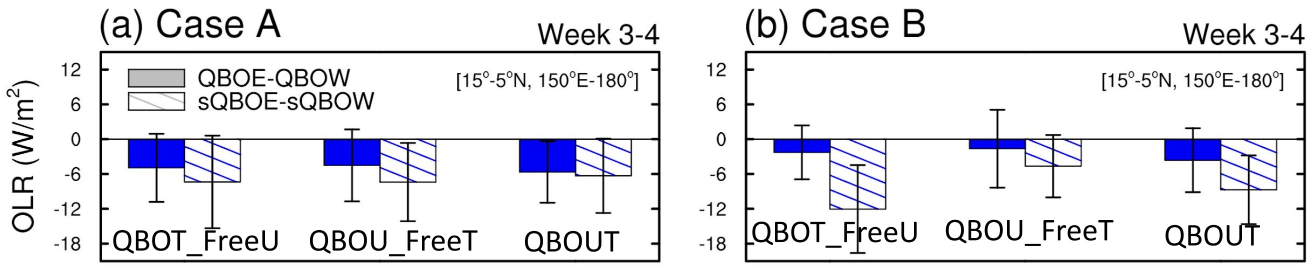
In WRF (Regional Model)



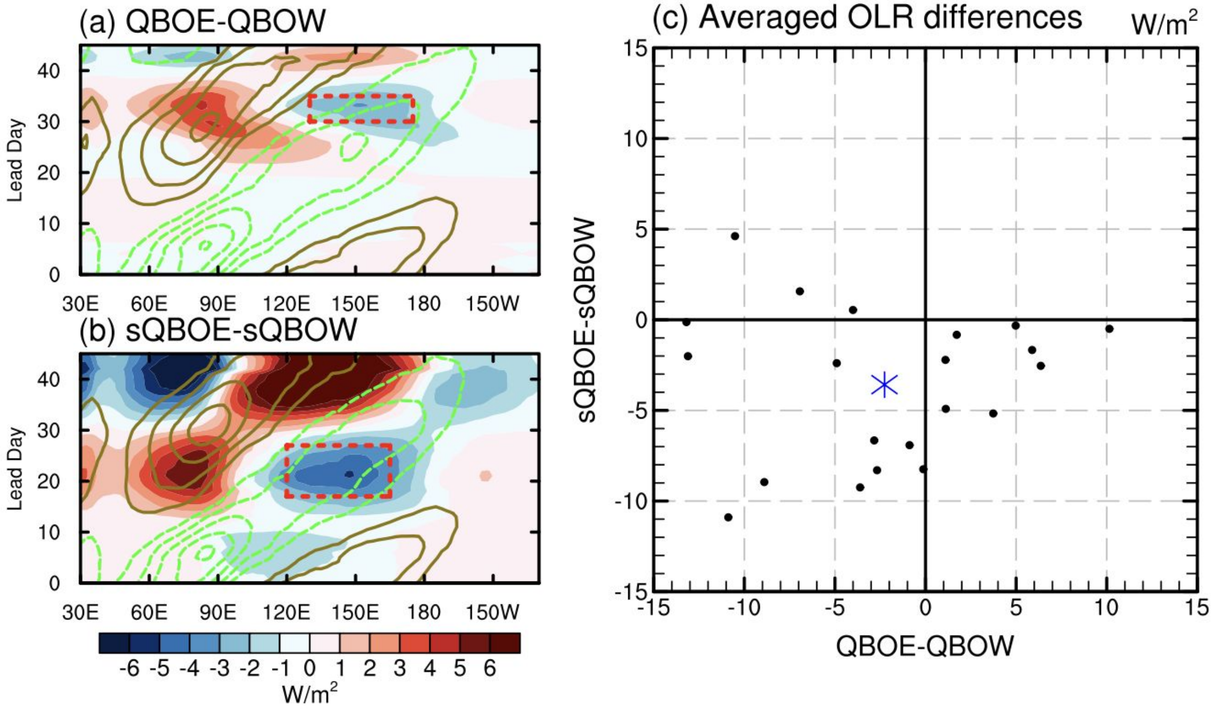


Martin et al., 2019

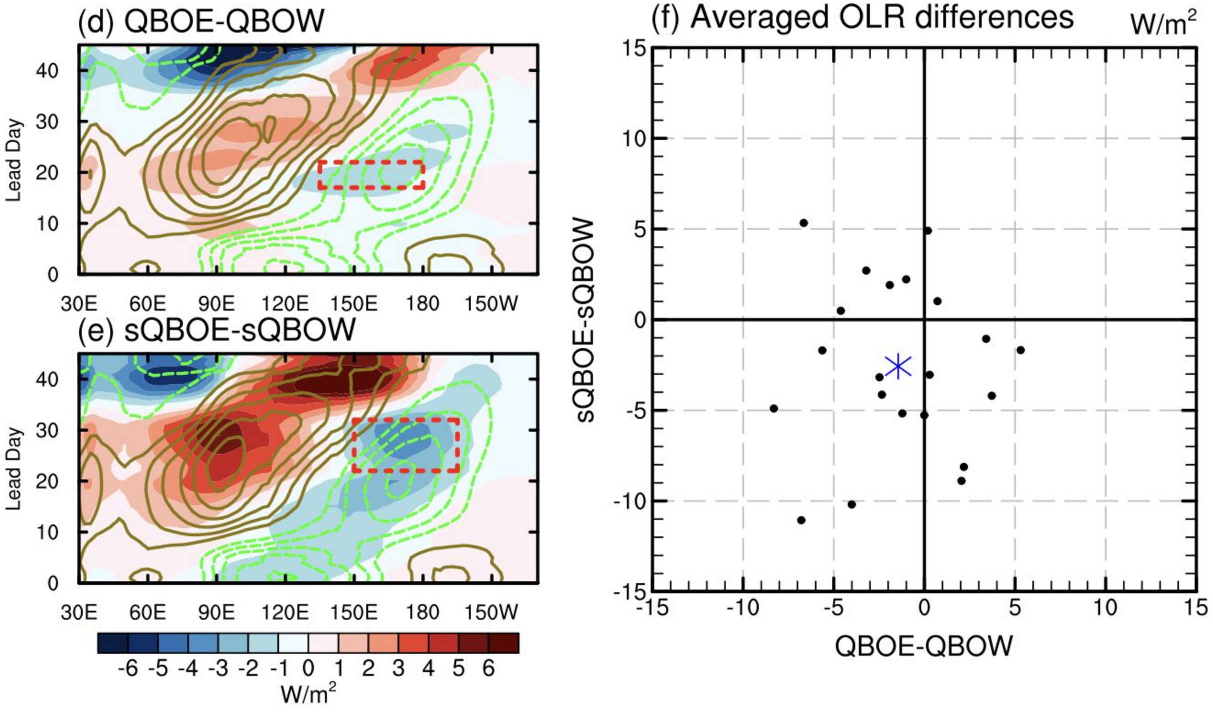
In CESM2 (Global Model)



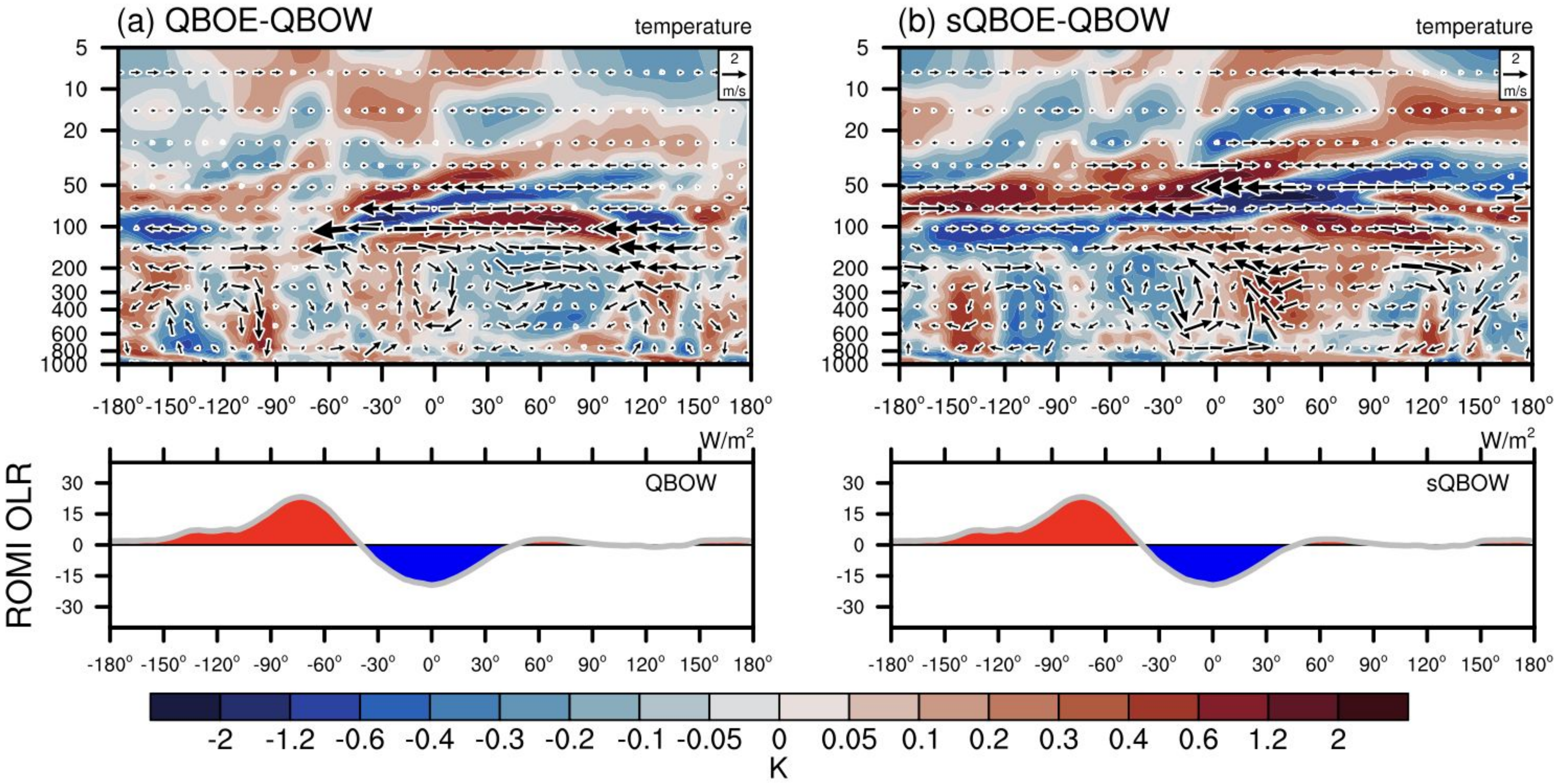
ROMI OLR Case A (QBOT_FreeU)



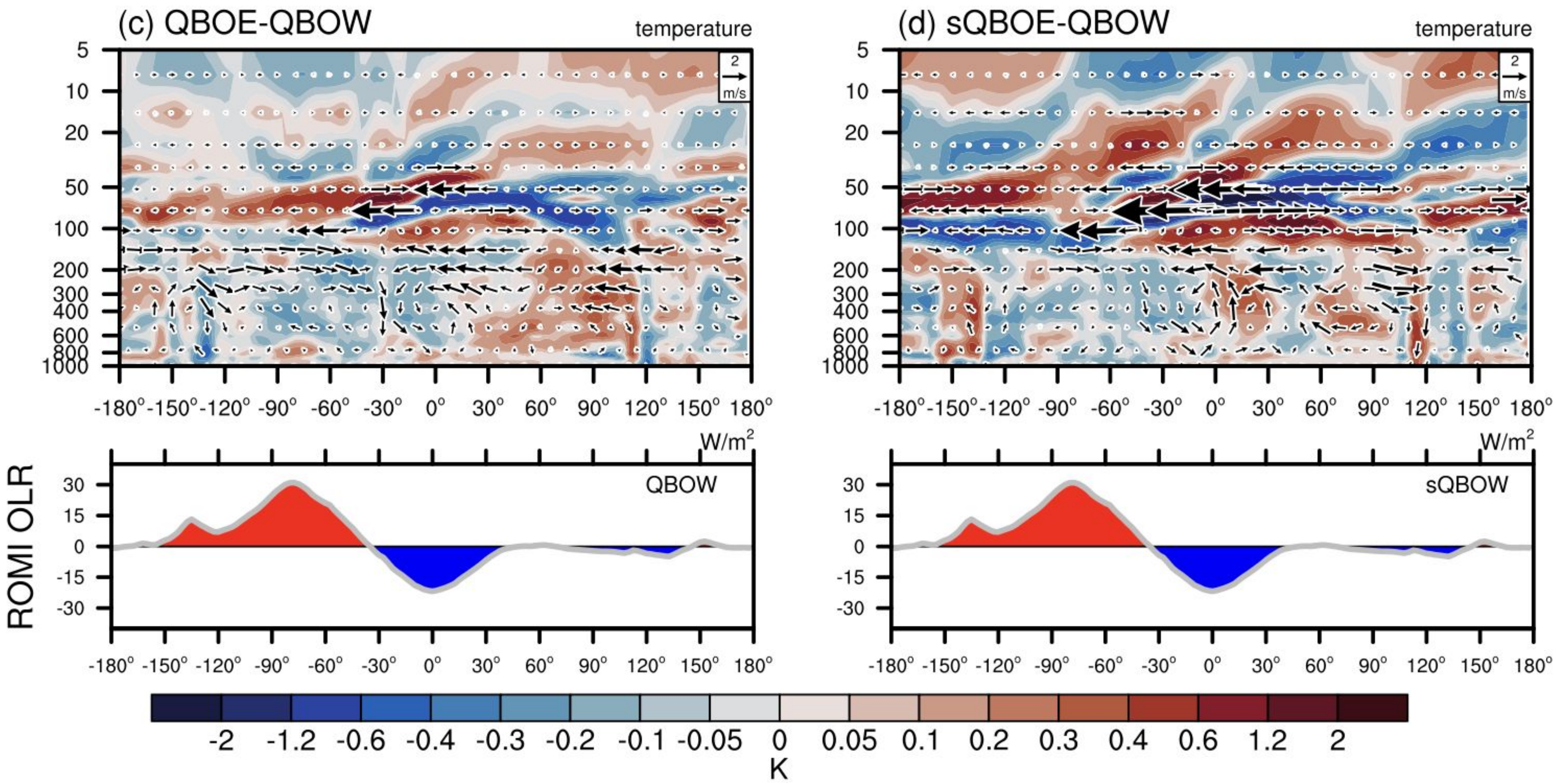
ROMI OLR Case B (QBOT_FreeU)



ROMI Phase 6/7 Case A (QBOT_FreeU)



ROMI Phase 6/7 Case B (QBOT_FreeU)



Linear Correlation Coefficients of High-Freq U100 Variance against Phase 6/7 ROMI Amplitude among Ensemble Members