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Prediction of the Madden-Julian Oscillation
Current status and challenges

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- Kim, Vitart, Waliser: Prediction of the Madden Julian Oscillation: A Review (*submitted*)

Bridging the forecast gap

Weather forecast
~ 2weeks

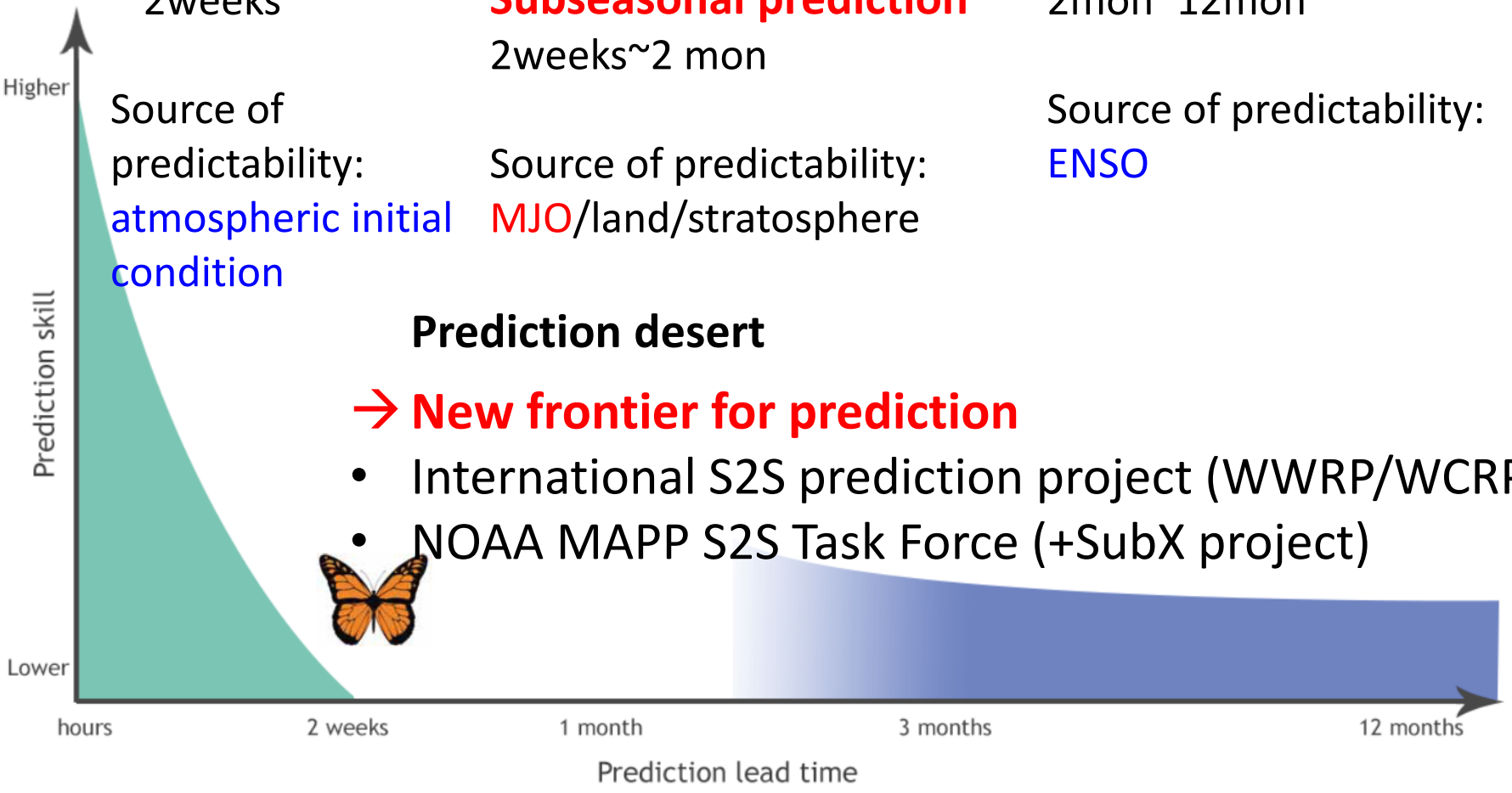
Source of predictability: atmospheric initial condition

Subseasonal prediction
2weeks~2 mon

Source of predictability: MJO/land/stratosphere

Seasonal prediction
2mon~12mon

Source of predictability: ENSO



Prediction desert

→ **New frontier for prediction**

- International S2S prediction project (WWRP/WCRP)
- NOAA MAPP S2S Task Force (+SubX project)

Adapted from: iri.columbia.edu/news/qa-subseasonal-prediction-project

16 Funded S2S Projects by NOAA (2017-2019)

MJO, a primary source of global subseasonal predictability

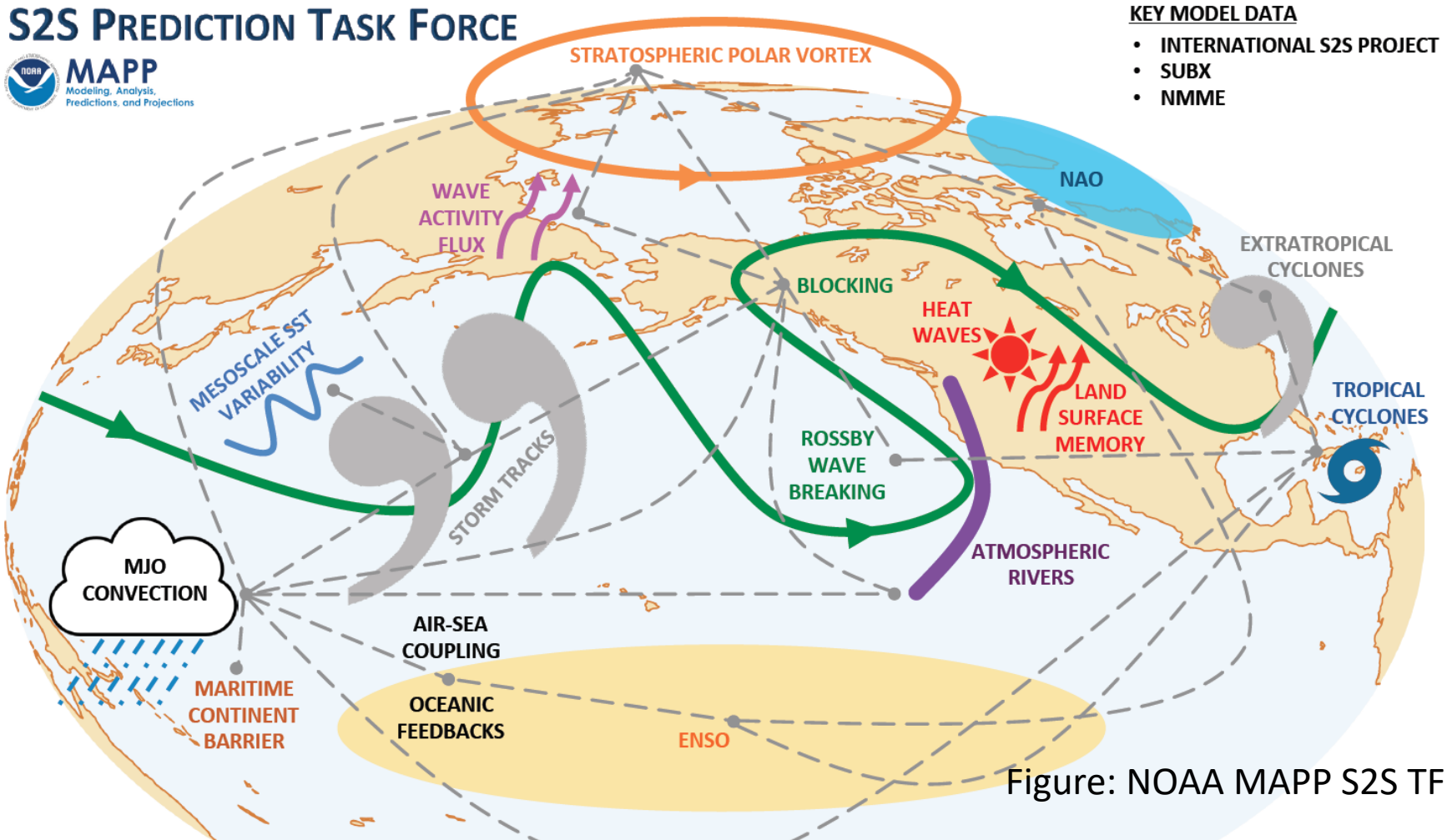
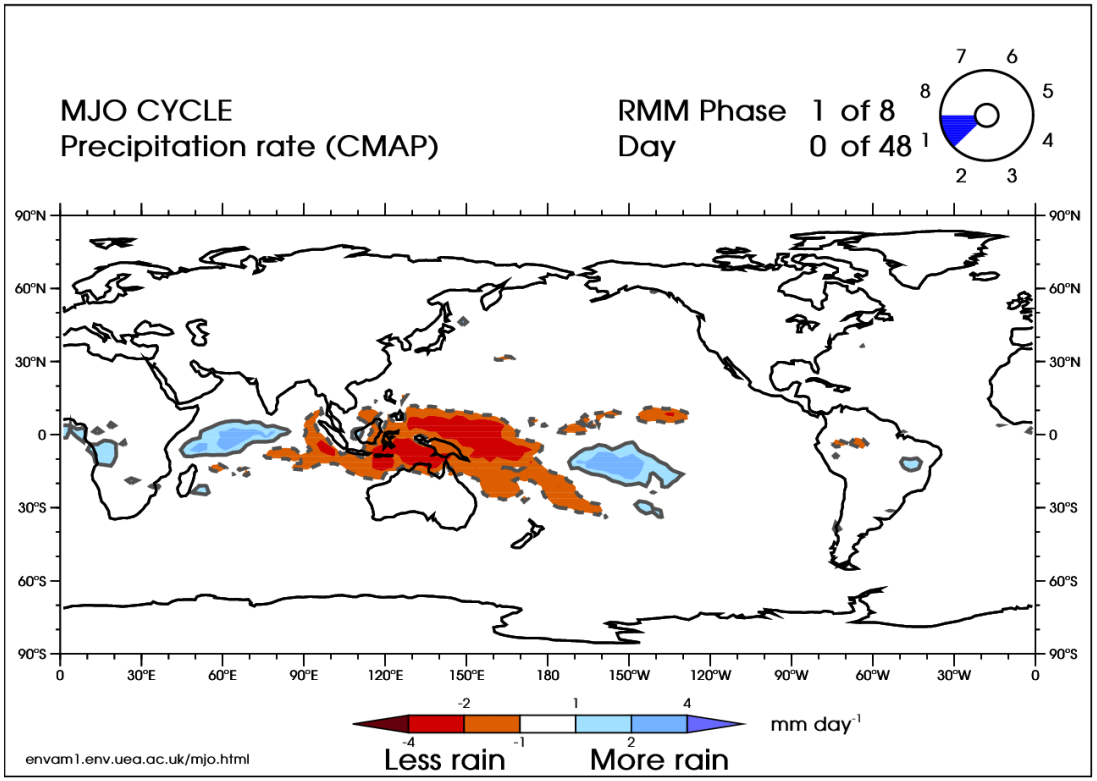


Figure: NOAA MAPP S2S TF

Madden Julian Oscillation (MJO)

- Discovered by Madden and Julian (1971).
- Dominant mode of intraseasonal variability in the tropics.
- Organized tropical convection varying within intraseasonal time scale (30-90 days).
- Vast horizontal scale (zonal wavenumber 1-3)
- Develops in the Indian Ocean and propagate eastward.

Precipitation anomaly

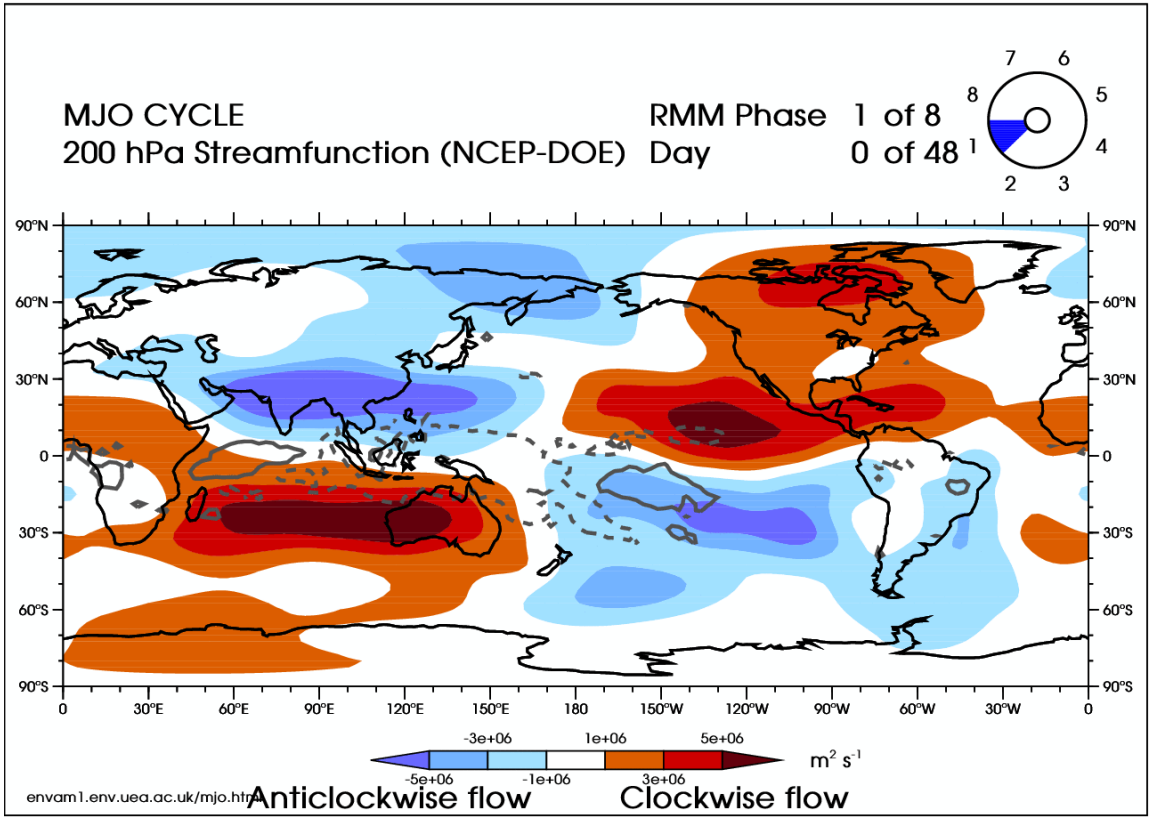


Source: http://envam1.env.uea.ac.uk/mjo.html

Madden Julian Oscillation (MJO)

- MJO convection is tightly coupled to tropical circulation.
- MJO affects global circulation anomalies.

Circulation anomaly

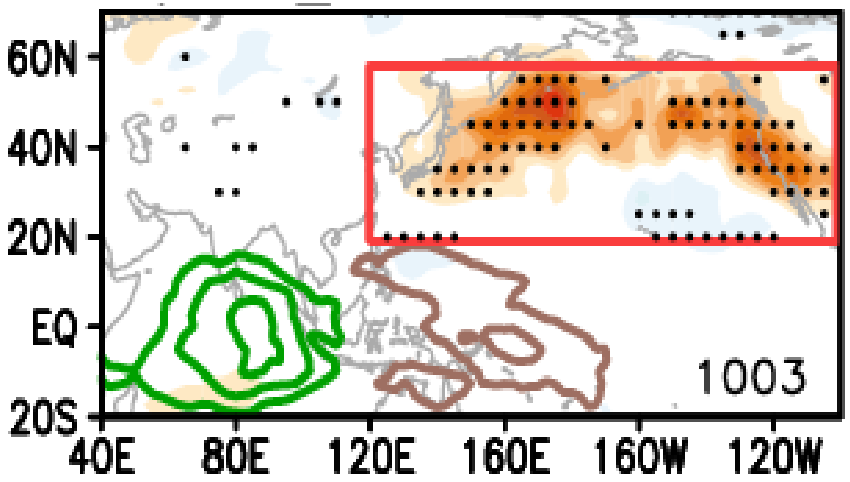


Source: http://envam1.env.uea.ac.uk/mjo.html

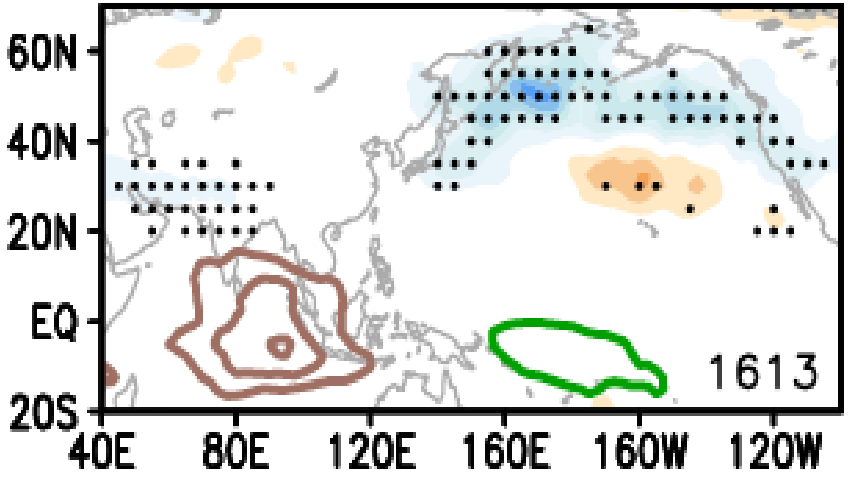
Global Impact

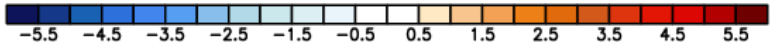
Storm Track activity (winter)

Phase 2~3



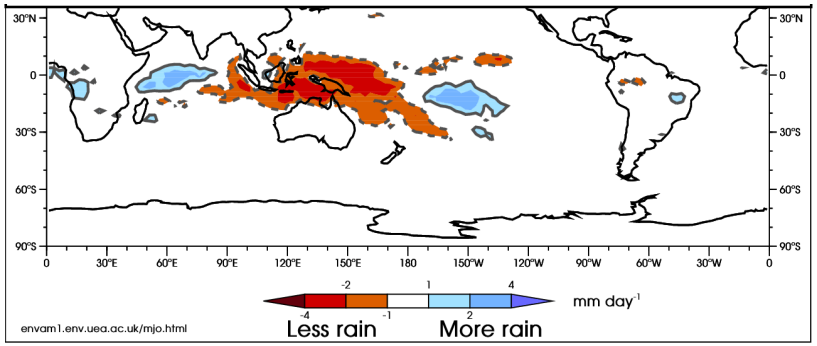
Phase 6~8





Shading: 2-8d filtered EKE

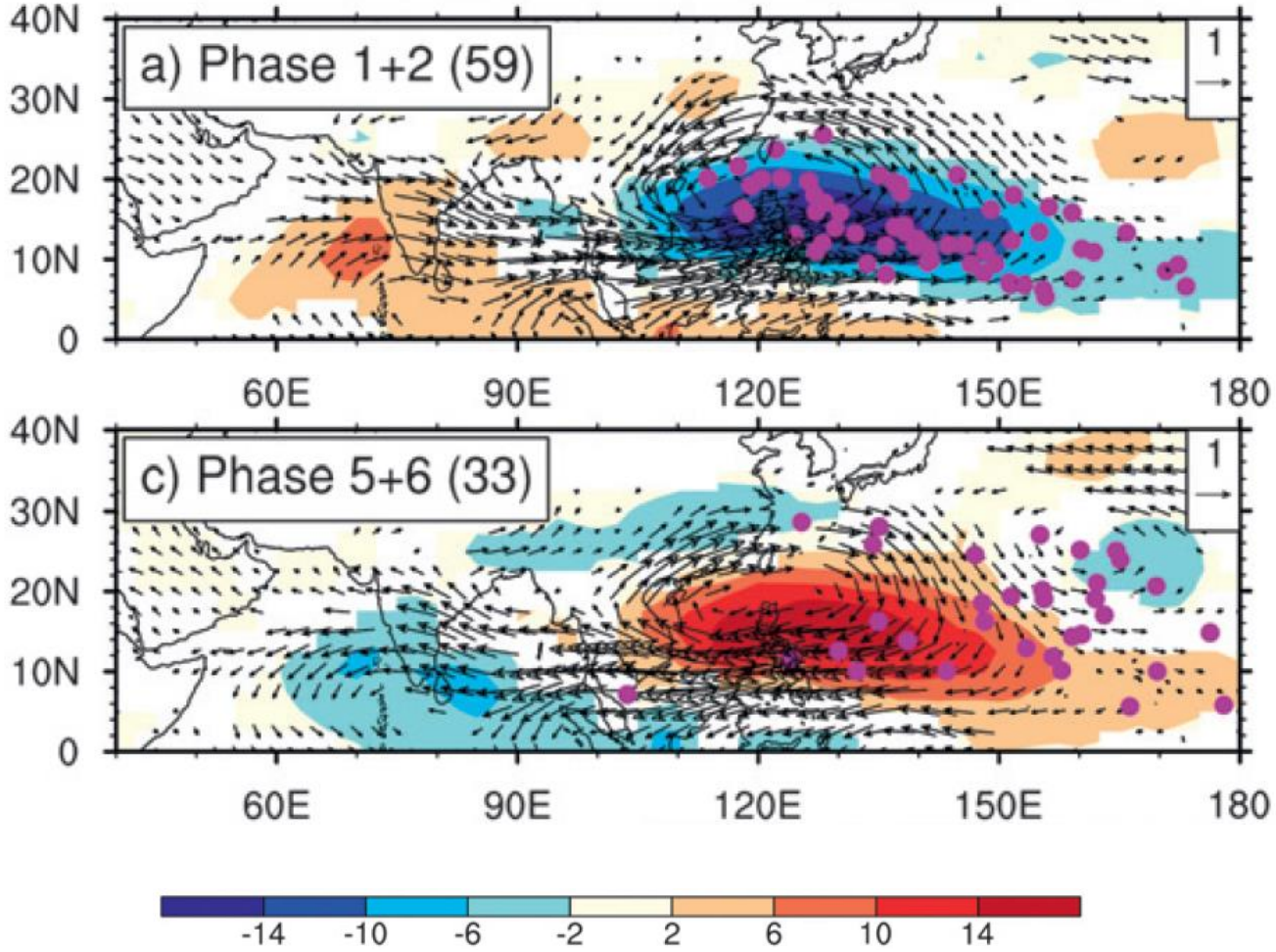
Contour: OLR (green: negative)



Wang, Kim, Chang, Son (2018)

Global Impact

Tropical Cyclone activity



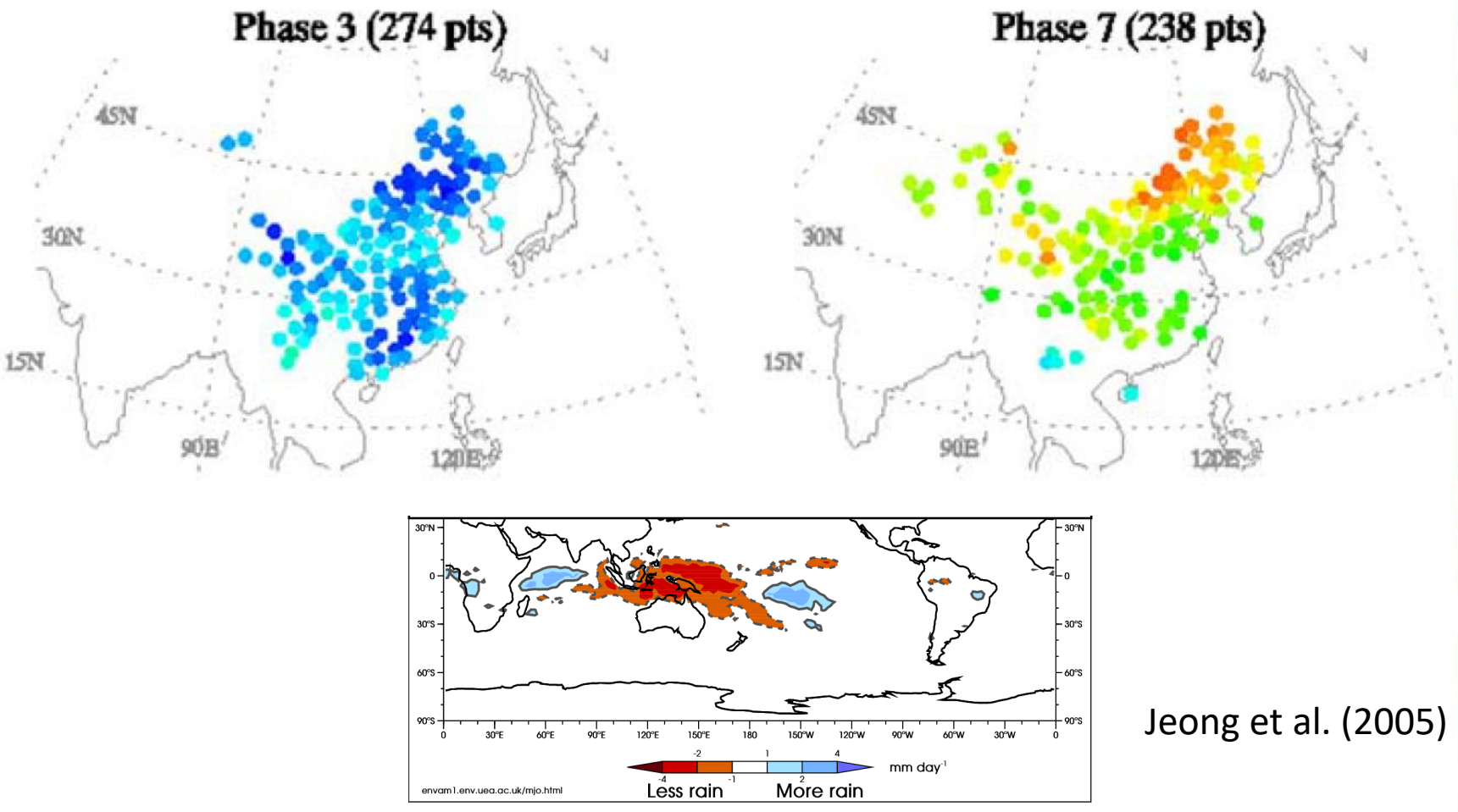
● Cyclogenesis
Parenthesis: # of TCs

OLR and 850-hPa wind anomalies

Li and Zhou (2013)

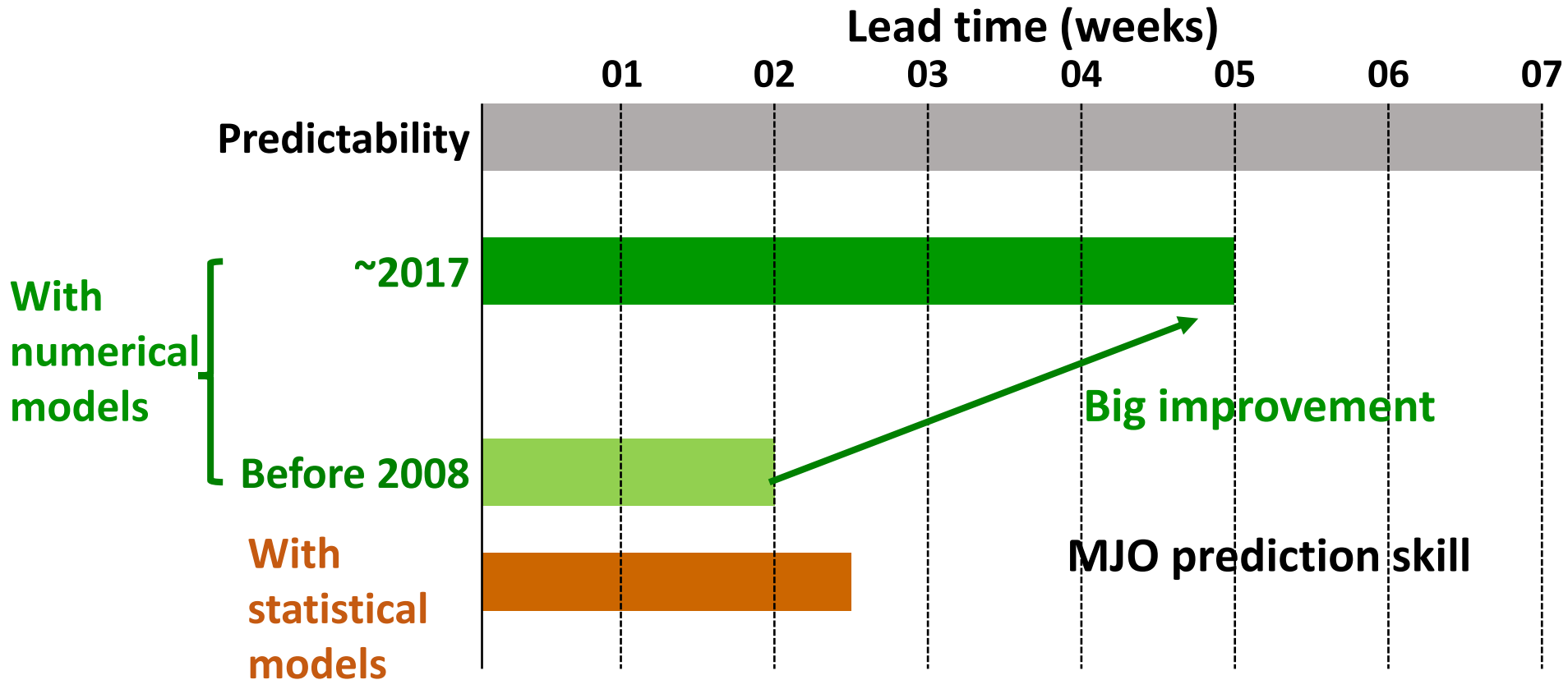
Global Impact

Surface temperature anomaly (winter)



Jeong et al. (2005)

MJO predictability and prediction



Outline

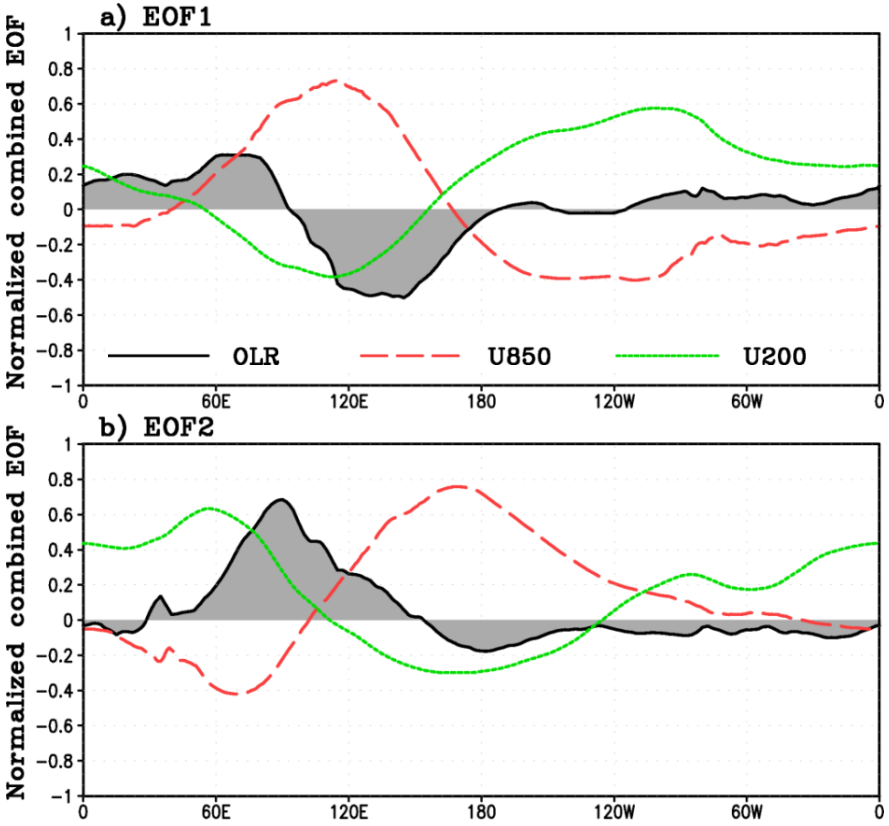
- Current status of MJO prediction ability
- General consensus
- Common issues
- Process-based hindcast evaluation

References (after 2008):
Jiang et al. 2008, Pegion and Kirtman 2008, Lin et al. 2008, Seo et al. 2009, Vitart and Molteni 2010, Arribas et al. 2011, Fu et al. 2011, 2013, Rashid et. al. 2011, Miyakawa et al. 2014, Neena et al. 2014, Wang et al. 2014, Xiang et al. 2015, Liu et al. 2016, Vitart 2014, 2017, Lim et al. 2018, Kim et al. 2008, 2010, 2014, 2016, 2017

MJO index

EOF 1st and 2nd mode

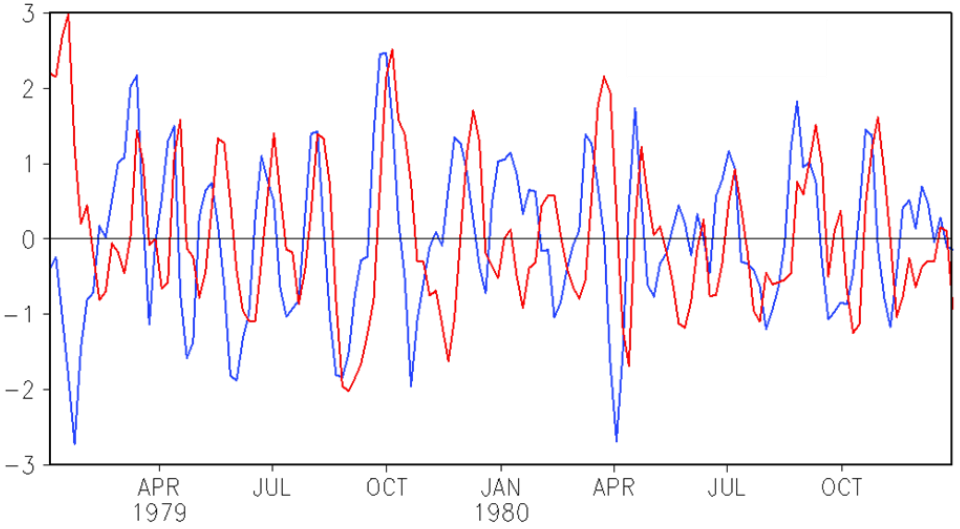
(OLR, U200, U850, 15S-15N averaged)



Real-time Multivariate MJO (RMM) index

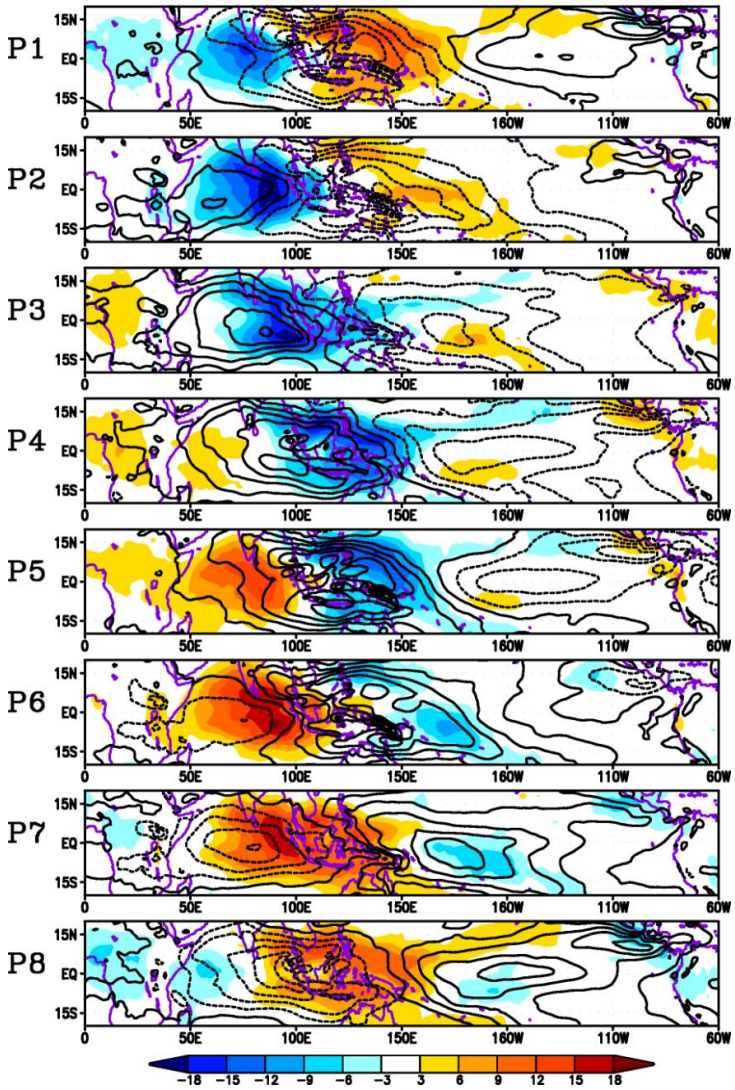
(Wheeler and Hendon 2004)

PC1 and PC2 → RMM1 and RMM2



MJO Life-cycle composite

OLR (shading) and U850 (contour) anomalies



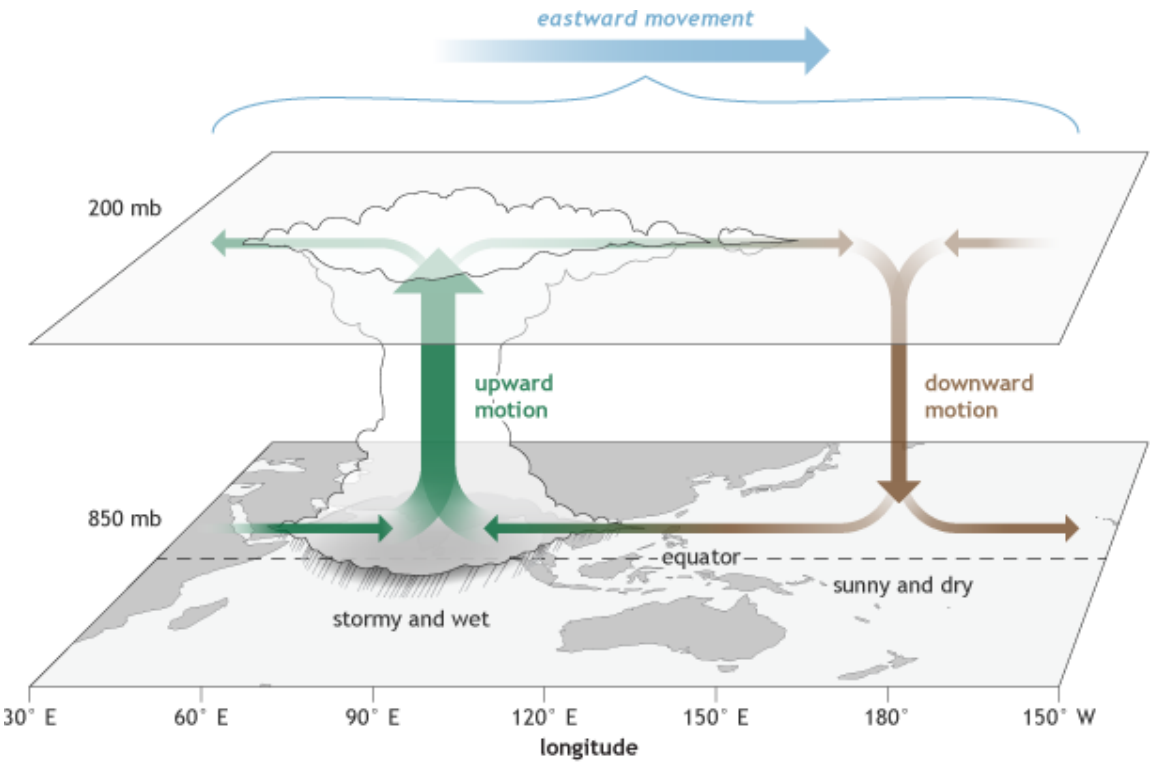
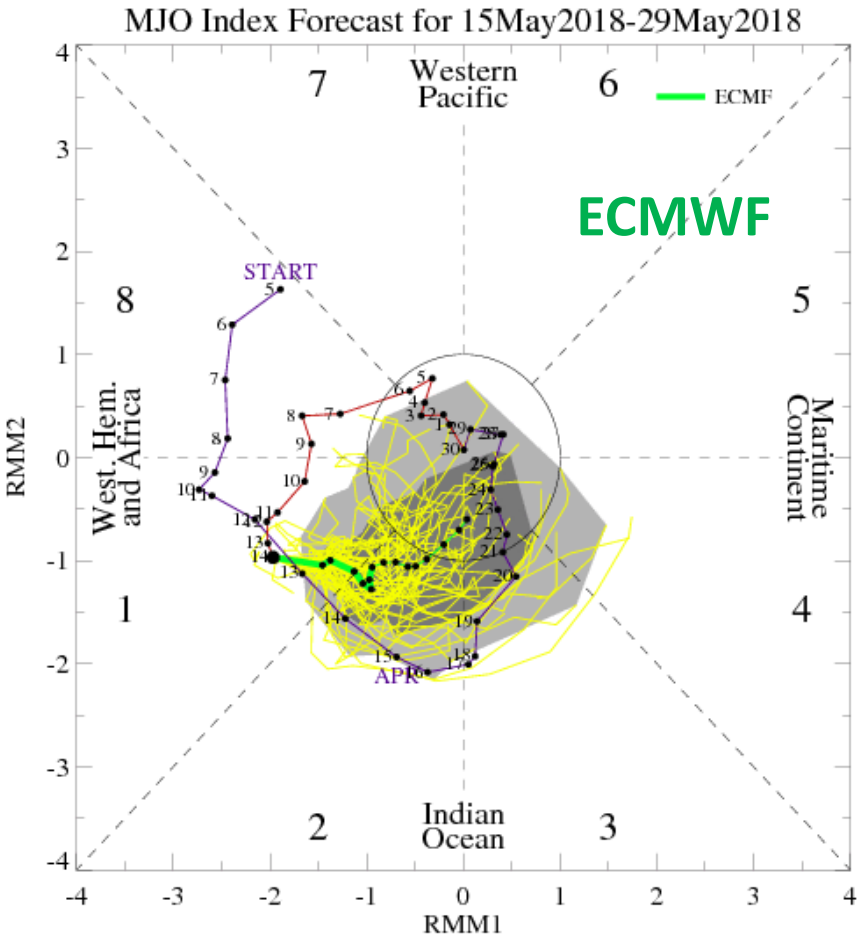
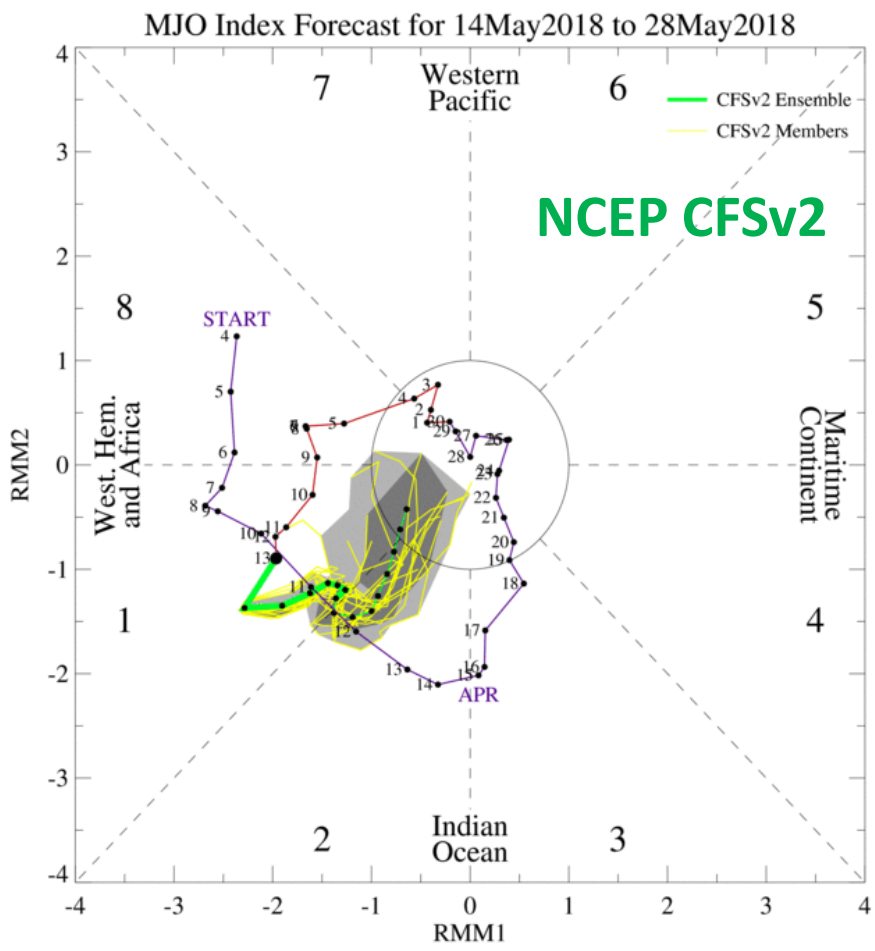


Figure source: https://www.climate.gov/

Real-time MJO monitoring/forecast

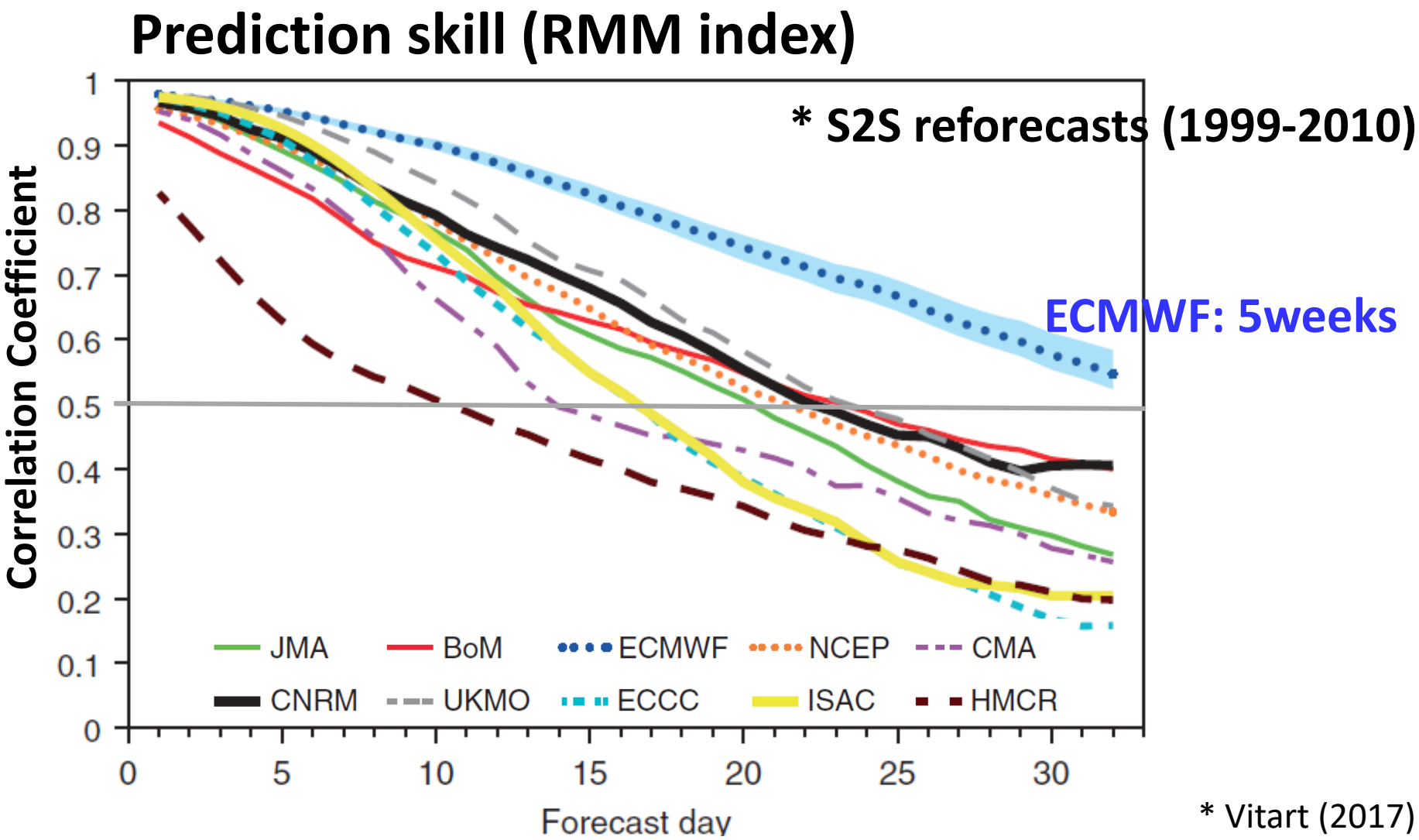
Forecast for the next two weeks





http://www.cpc.ncep.noaa.gov/products/precip/CWlink/MJO/mjo.shtml

MJO Prediction: S2S database

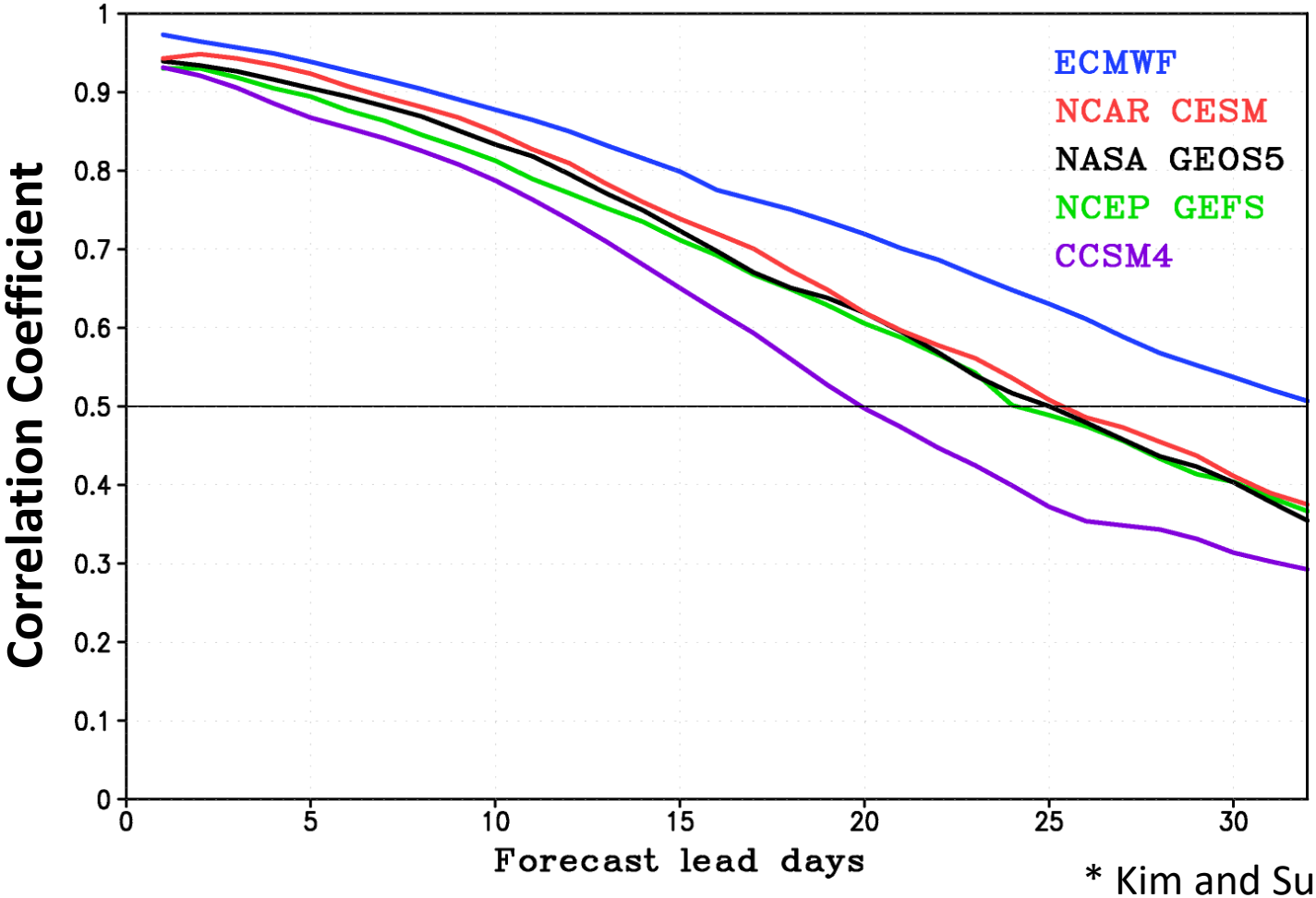


* Vitart (2017)

MJO Prediction: SubX database

SubX Models
(US & Canada), 1999-2016
http://cola.gmu.edu/kpegion/subx/

Prediction skill (RMM index)



* Kim and SubX team (in prep)

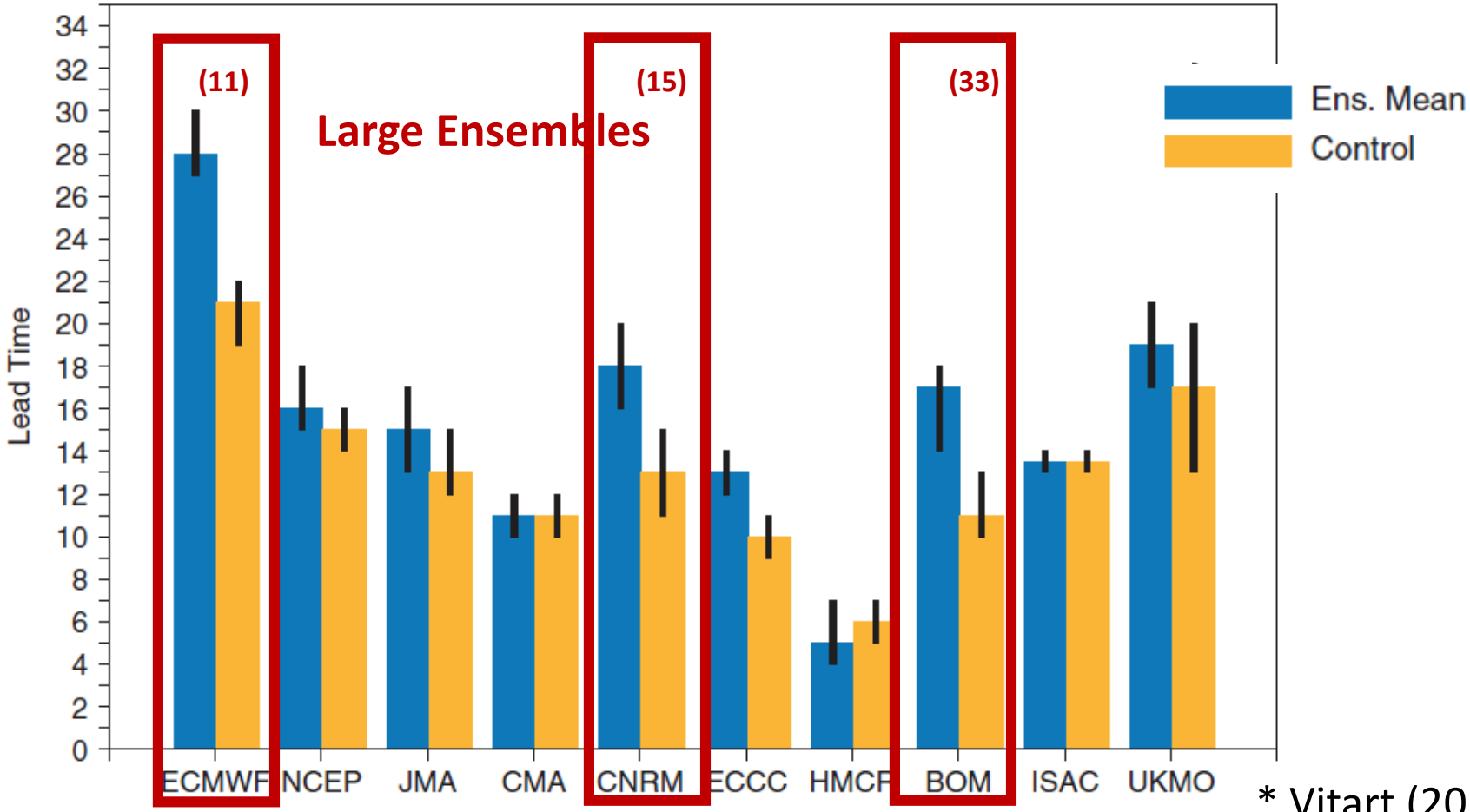
Outline

- Current status of MJO prediction ability: 3-5 weeks
- General consensus
- Common issues
- Process-based hindcast evaluation

General Consensus

- **Averaging multi-ensembles extends the skill**

Forecast lead time when correlation coeff reaches 0.6



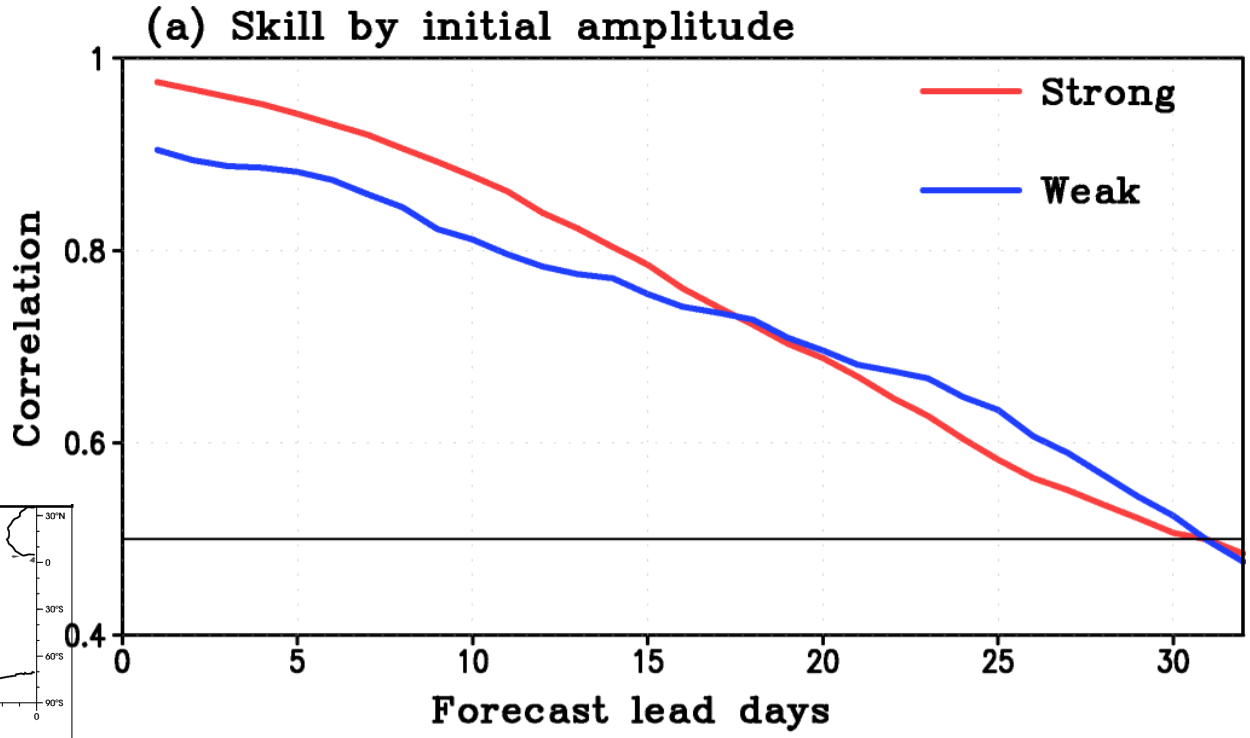
* Vitart (2017)

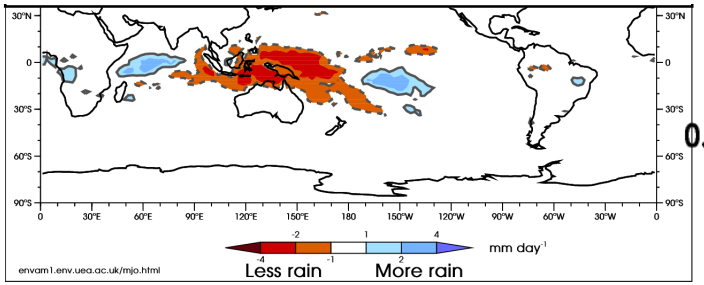
General Consensus

MJO skill depends on…

- **Initial amplitude: Higher with stronger MJO signal**
- **Season: Higher in boreal winter**
- **OA coupling**

RMM skill (ECMWF)





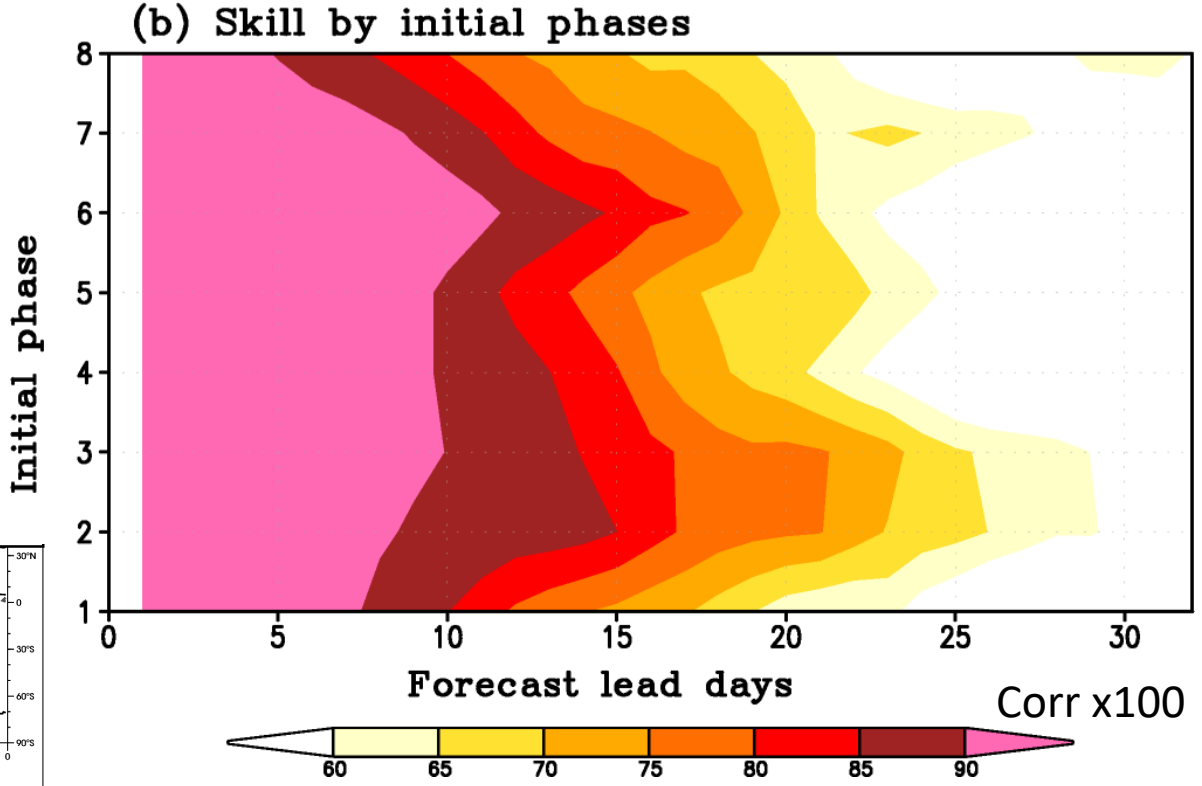
* Kim (2017)

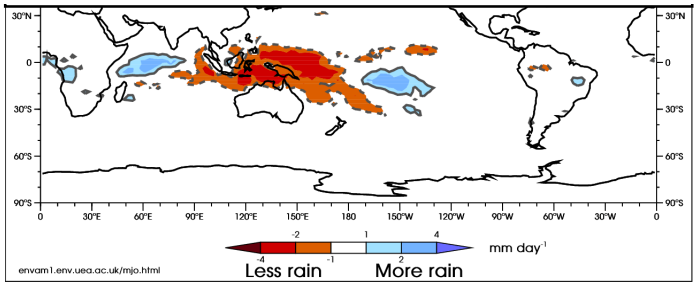
General Consensus

MJO skill depends on…

- **Initial amplitude: Higher with stronger MJO signal**
- **Season: Higher in boreal winter**
- **OA coupling**
- **MJO Phase**

RMM skill (ECMWF)

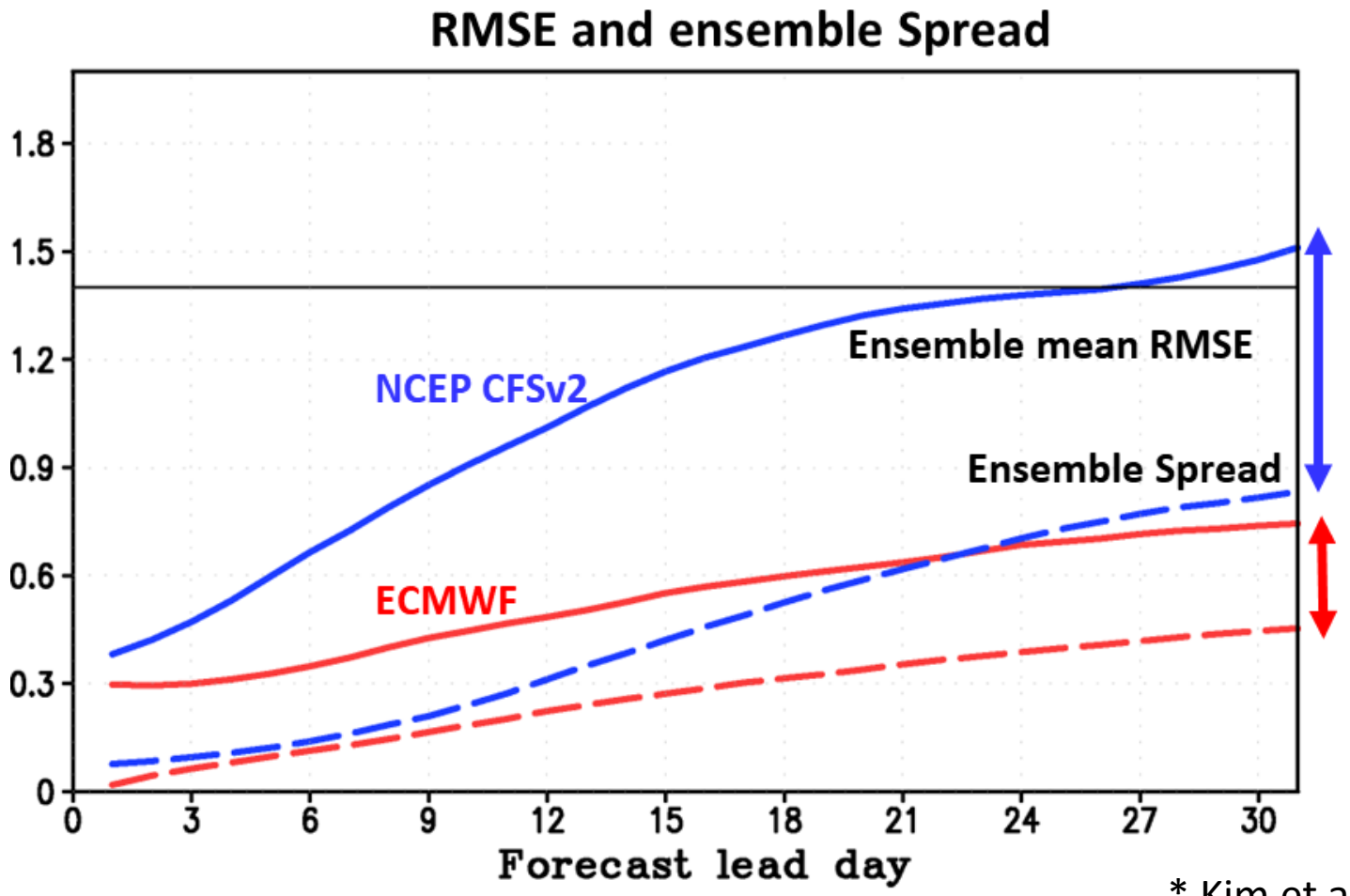




* Kim (2017)

Common Issues

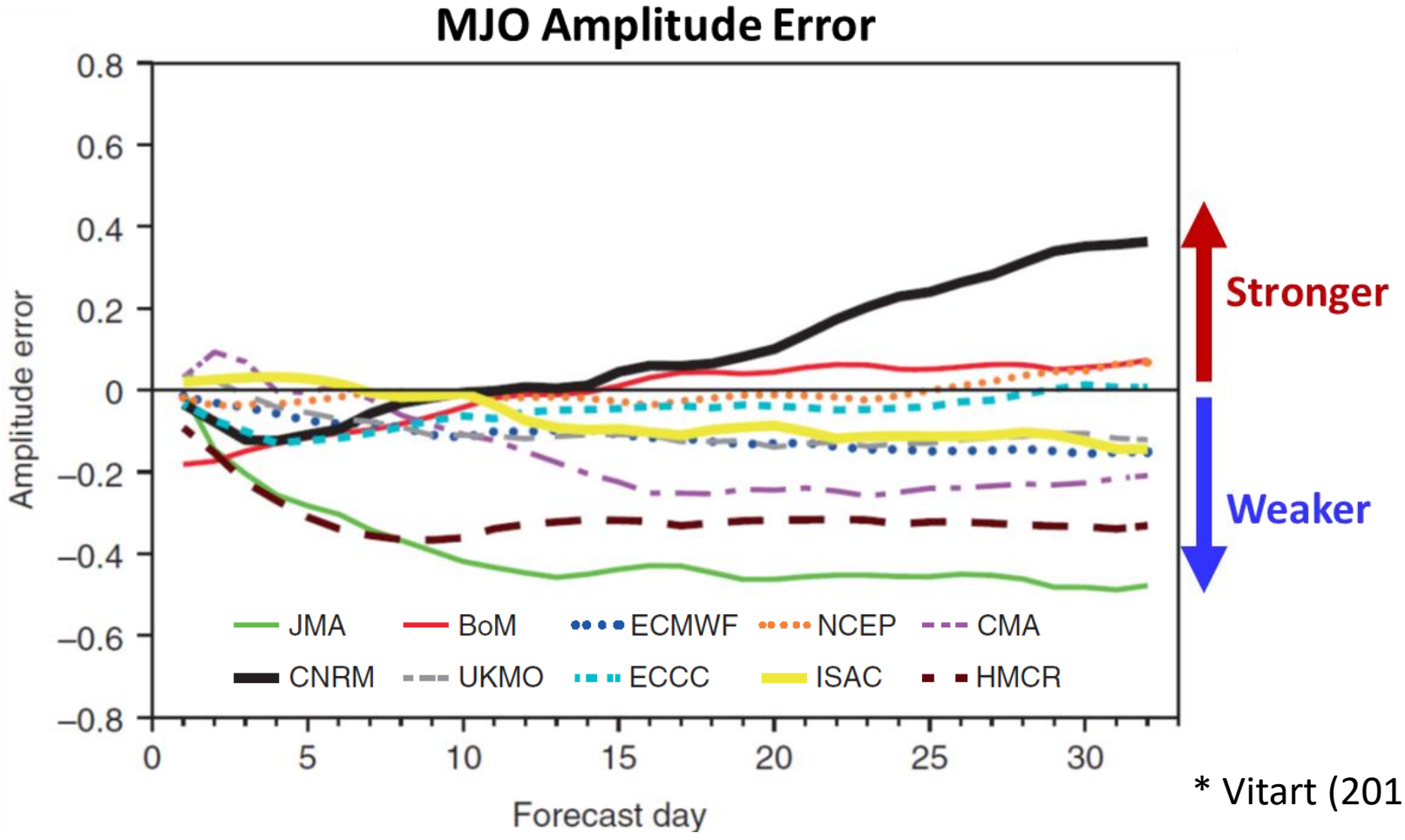
- Lack of ensemble spread
- Models are under-dispersive (overconfident)



* Kim et al. (2014)

Common Issues

- **Weaker amplitude**
- **Quick decay of MJO signal**



* Vitart (2017)

ECMWF Reforecast (S2S database)

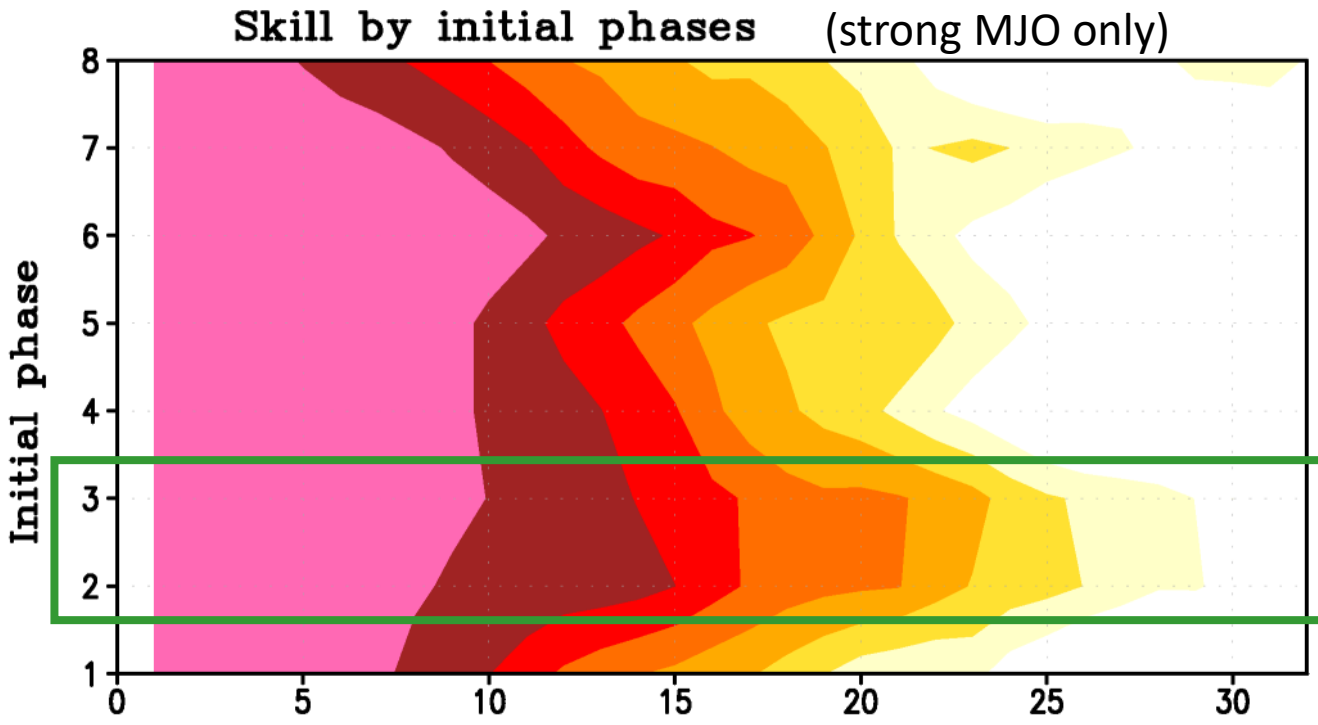
ECMWF Reforecast (CY40R1)	
Period, lead time	• 1994~2013 (20yr) • 32-day forecast lead
Initialization	• Once/week (Jan-Dec)
Ensembles	• 5 ensemble members
Resolution	• 32 km (64 km after day 10) • 91 levels (0.01 hPa)
Variables	• u, v, w, T, q, z (1000~100 hPa, 8 vertical levels)

→ 5,200 sets of 32-day forecasts

- ERA Interim

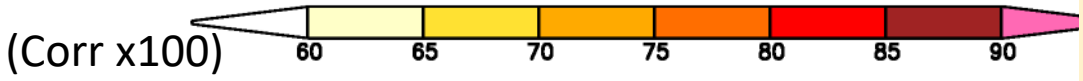
Details: https://software.ecmwf.int/wiki/display/S2S/ECMWF+Model+Description+CY40R1

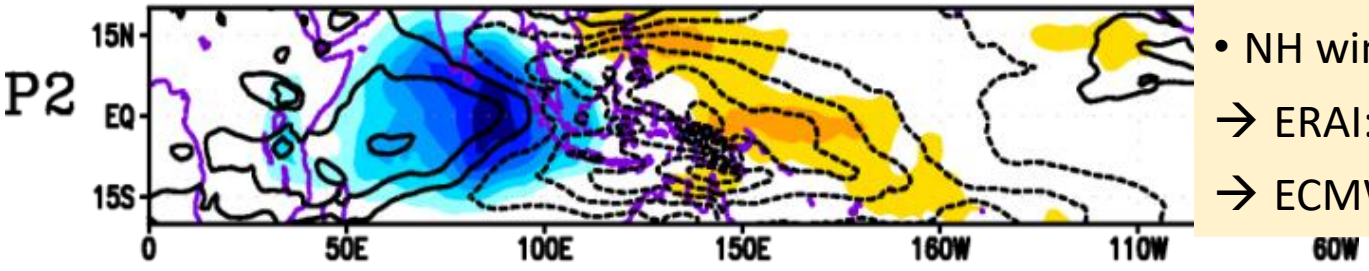
MJO event selection



* Kim (2017)

High skill when forecasts start @P2&P3





MJO events selection

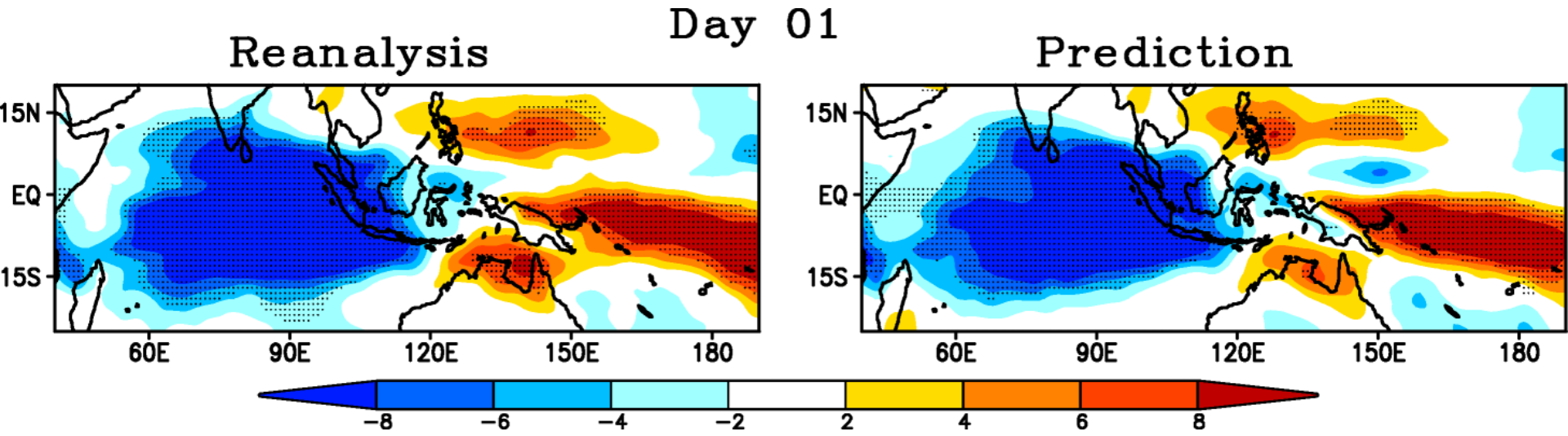
- Initial P2&3, strong (>1.0)
- NH winter (Oct-Mar, 1994-2013)

→ ERAI: 89 events

→ ECMWF: 445 events (5ens)

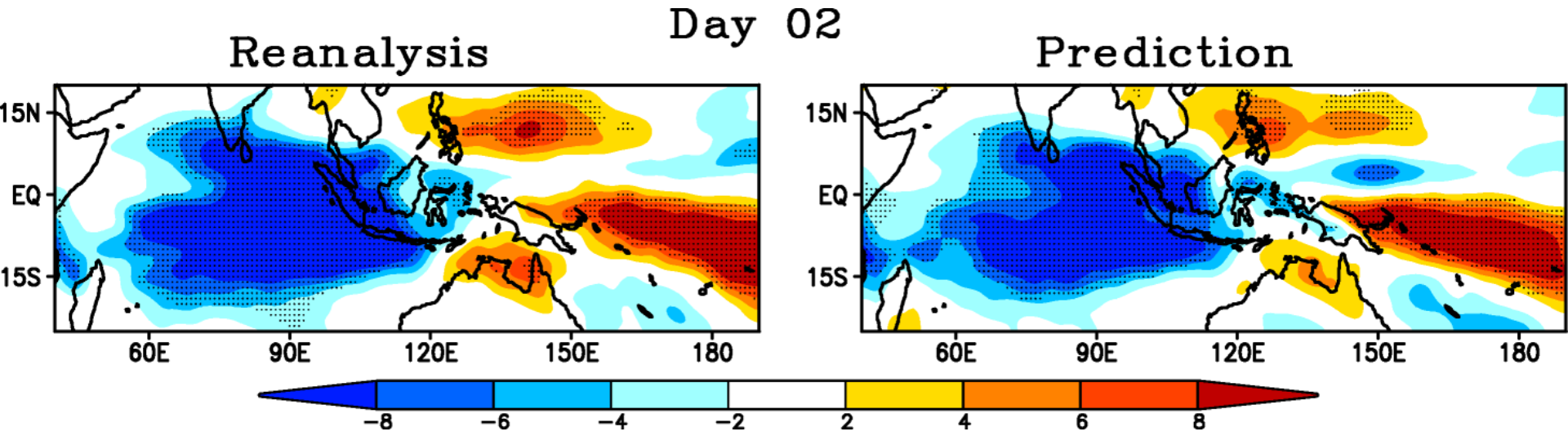
MJO eastward propagation

OLR anomaly



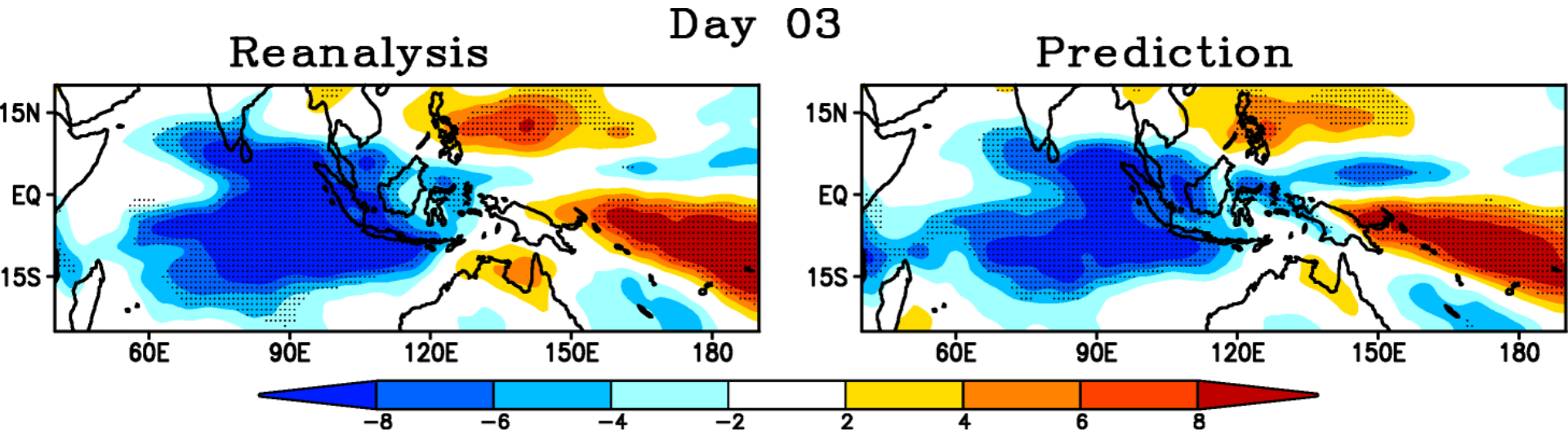
MJO eastward propagation

OLR anomaly



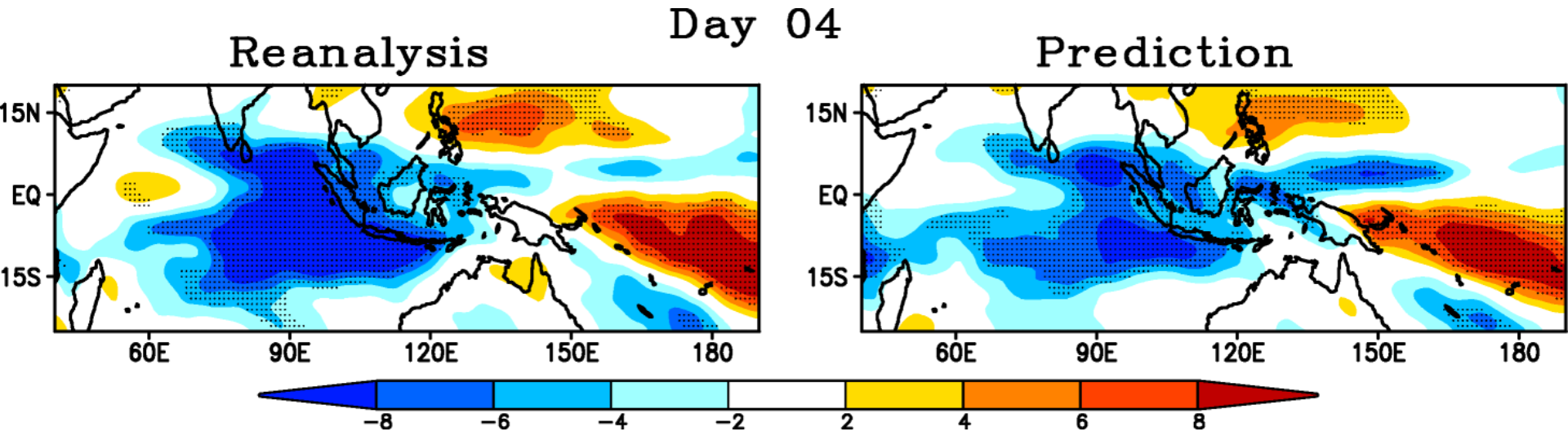
MJO eastward propagation

OLR anomaly



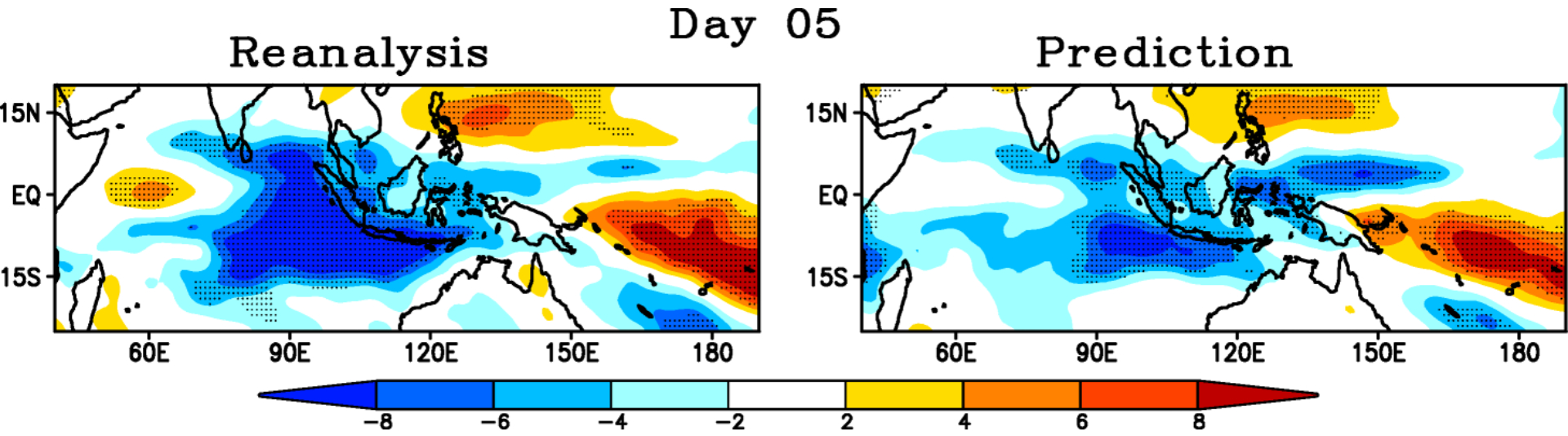
MJO eastward propagation

OLR anomaly



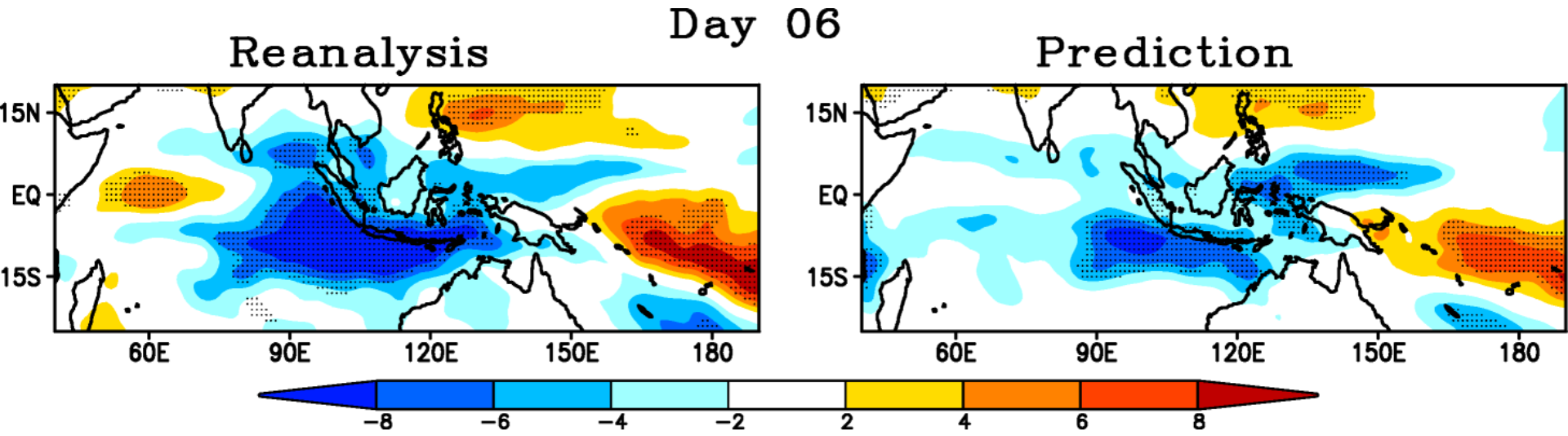
MJO eastward propagation

OLR anomaly



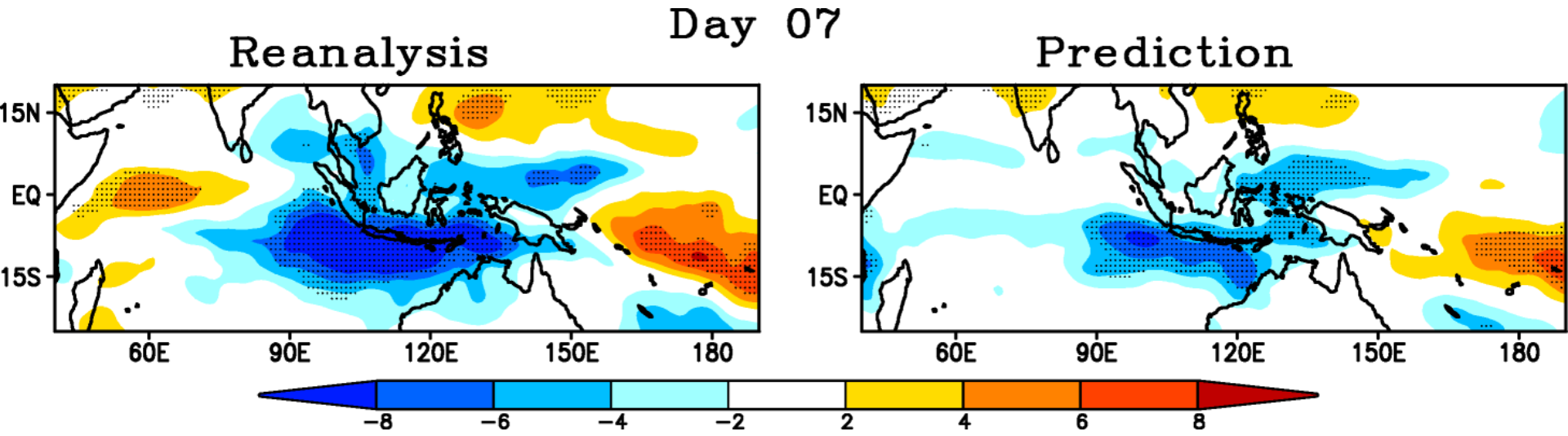
MJO eastward propagation

OLR anomaly



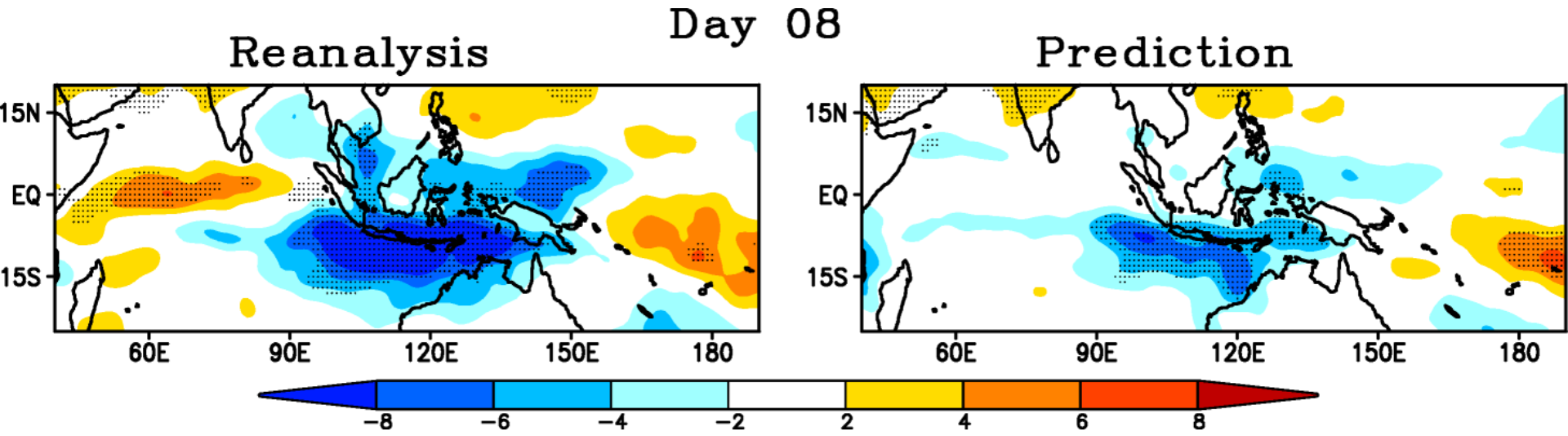
MJO eastward propagation

OLR anomaly



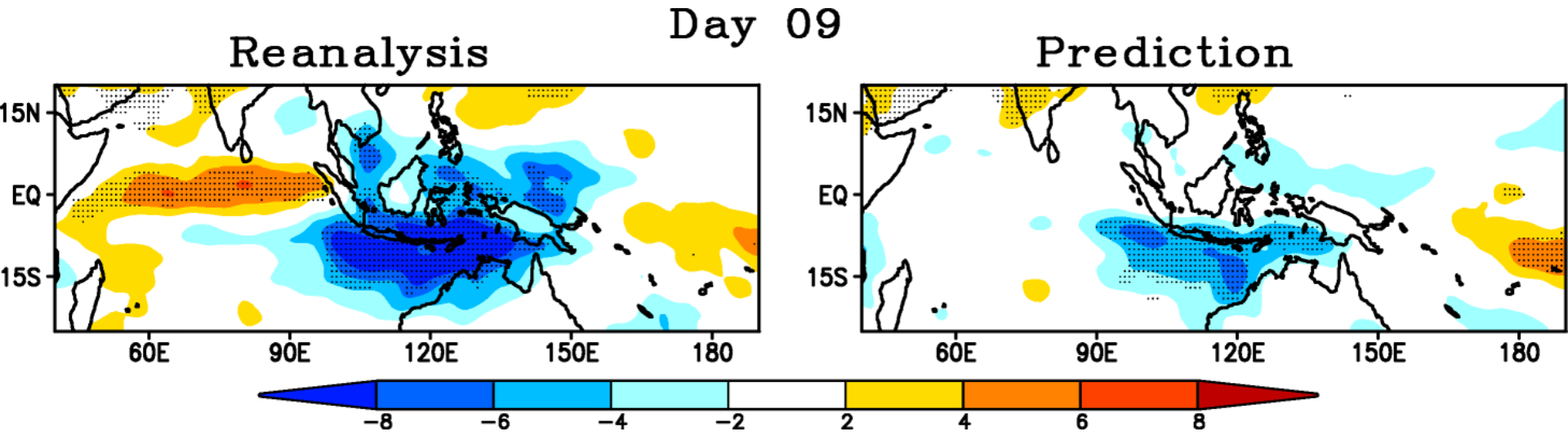
MJO eastward propagation

OLR anomaly



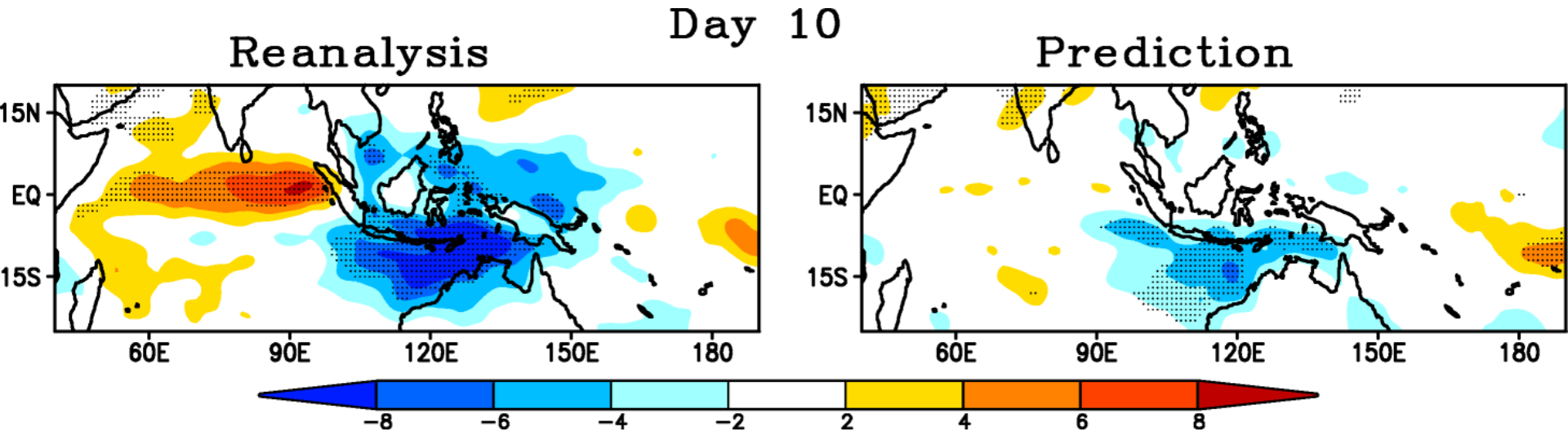
MJO eastward propagation

OLR anomaly



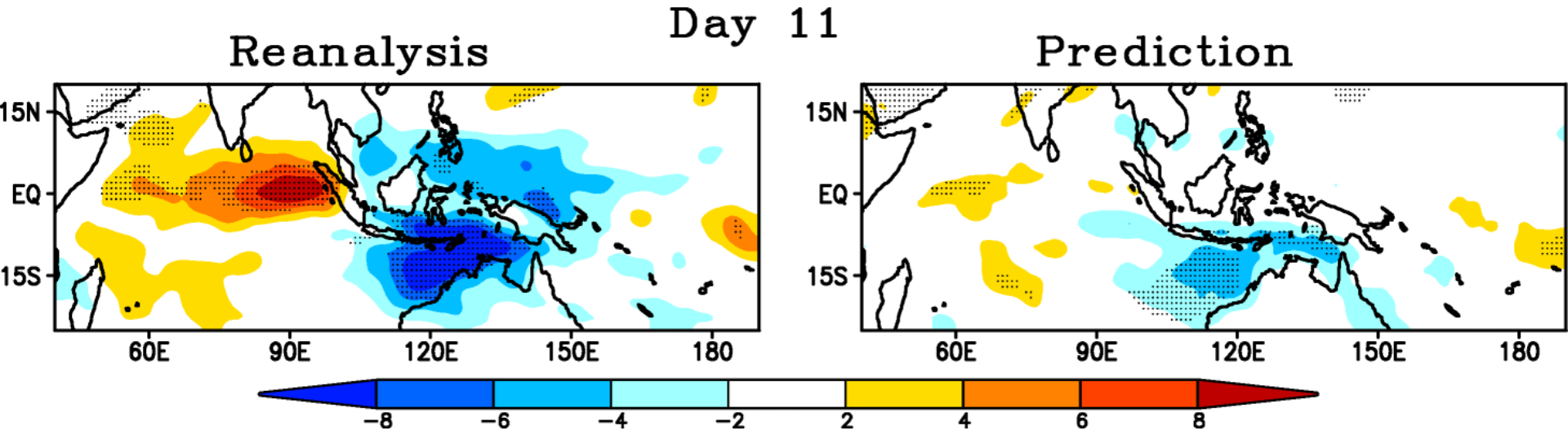
MJO eastward propagation

OLR anomaly



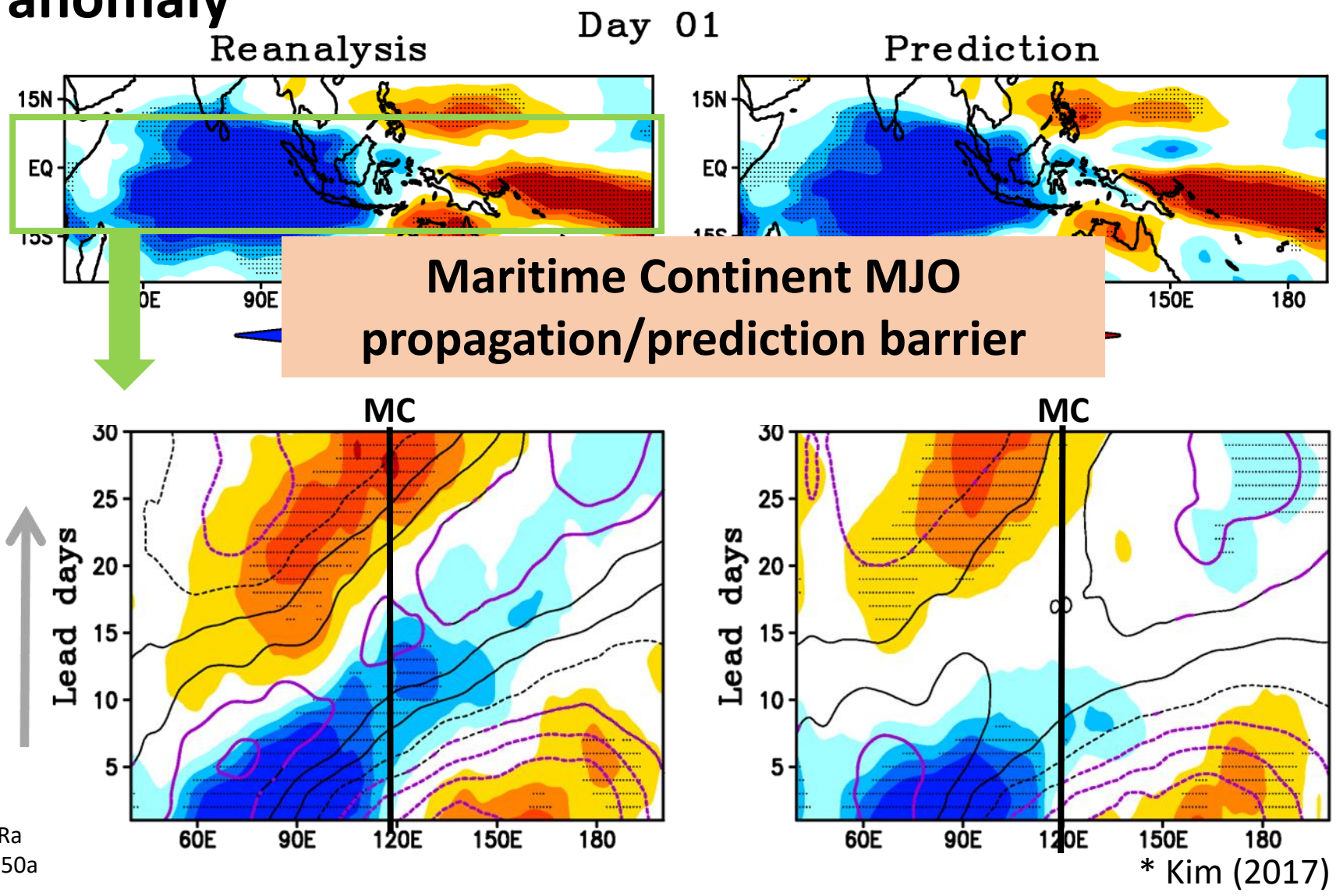
MJO eastward propagation

OLR anomaly



MJO eastward propagation

OLR anomaly



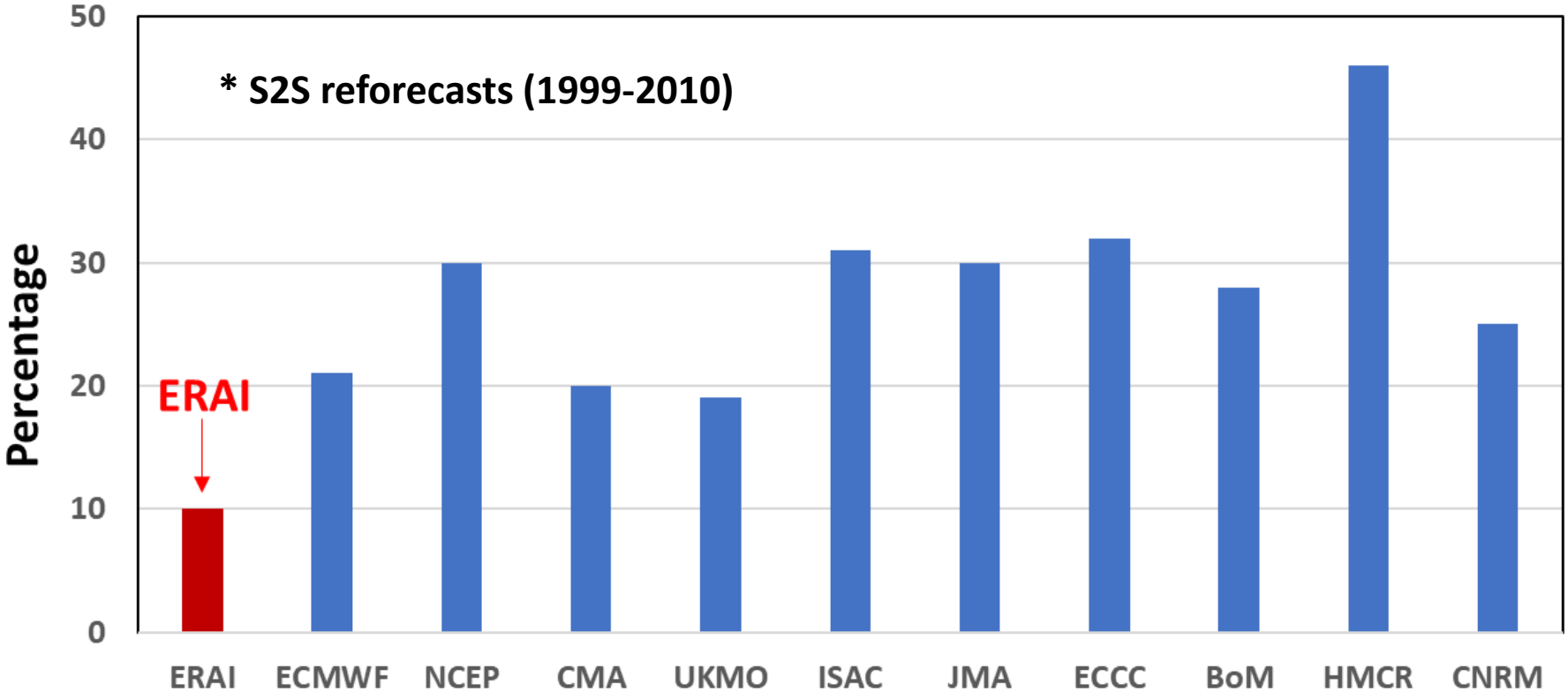
Shading: OLRa
Contour: U850a

* Kim (2017)

MC Propagation Barrier

% of MJO events **NOT crossing the MC**

(starting from Phase 2&3)



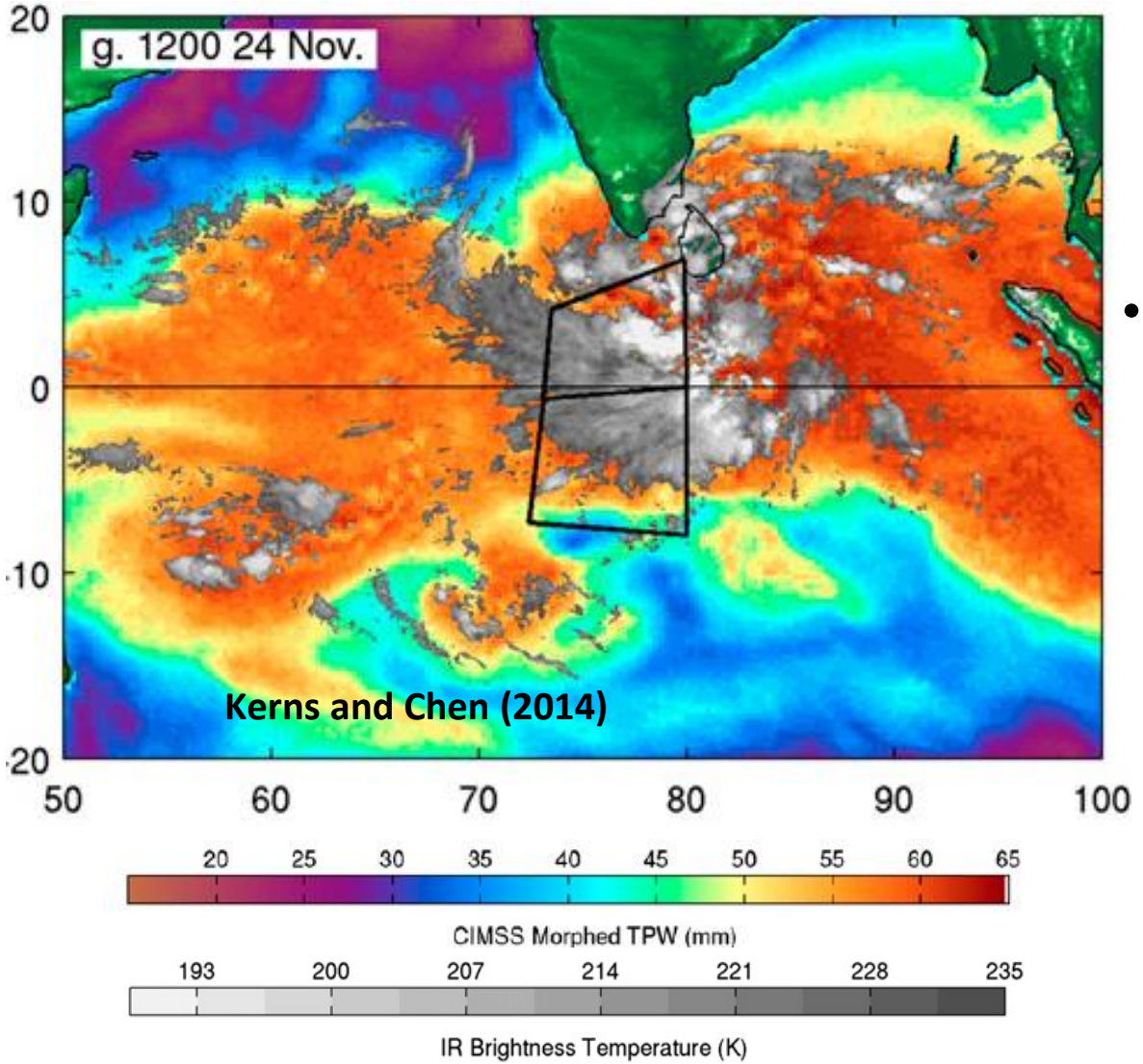
Q: What process impacts the faster decay of the MJO propagation during prediction?

* Vitart (2017)

- Current status of MJO prediction ability: 3-5 weeks
- General consensus
- Common issues
- **Process-based hindcast evaluation**

Moisture-convection coupling

Strong MJO event (24-Nov, 2011)



- MJO is distinguished from other waves by the strong **coupling between moisture and convection** anomalies.

e.g., Bretherton et al. (2004), Yasunaga and Mapes (2013)

“Moisture mode” theory

- Growth, decay, and propagation of MJO convection are explained by those of anomalous moisture.
- MSE as a proxy for MJO convection.

Moist static energy (MSE): $\boldsymbol{m} = c_p T + gz + \boldsymbol{Lq}$

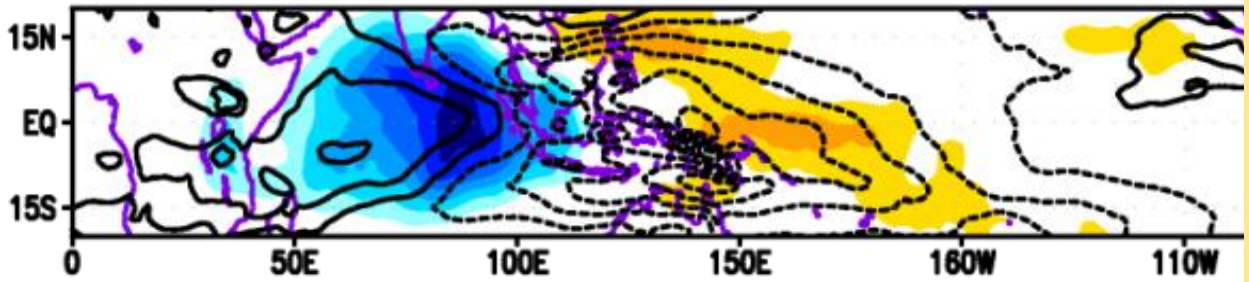
Colum-integrated MSE budget:

$$\frac{\partial \langle m \rangle}{\partial t} = -\langle \boldsymbol{V} \cdot \boldsymbol{\nabla} m \rangle - \left\langle \omega \frac{\partial m}{\partial p} \right\rangle + Fsfc + \langle Qr \rangle$$

Tendency = **Horizontal advection** + Vertical advection + Surface Fluxes + Radiative Fluxes

* Yu and Neelin (1994), Sobel et al. (2001), Raymond and Fuchs (2008), Raymond et al. (2009), Maloney (2009), Sobel and Maloney (2012, 2013), Jiang et al. (2015), Adames and Kim (2016)

MJO Propagation



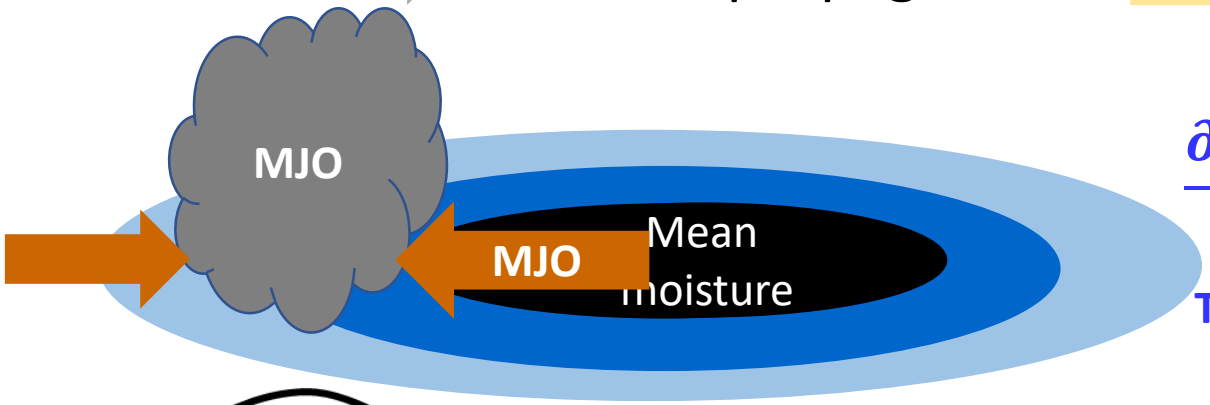
Eastward propagation

MJO propagation

↑

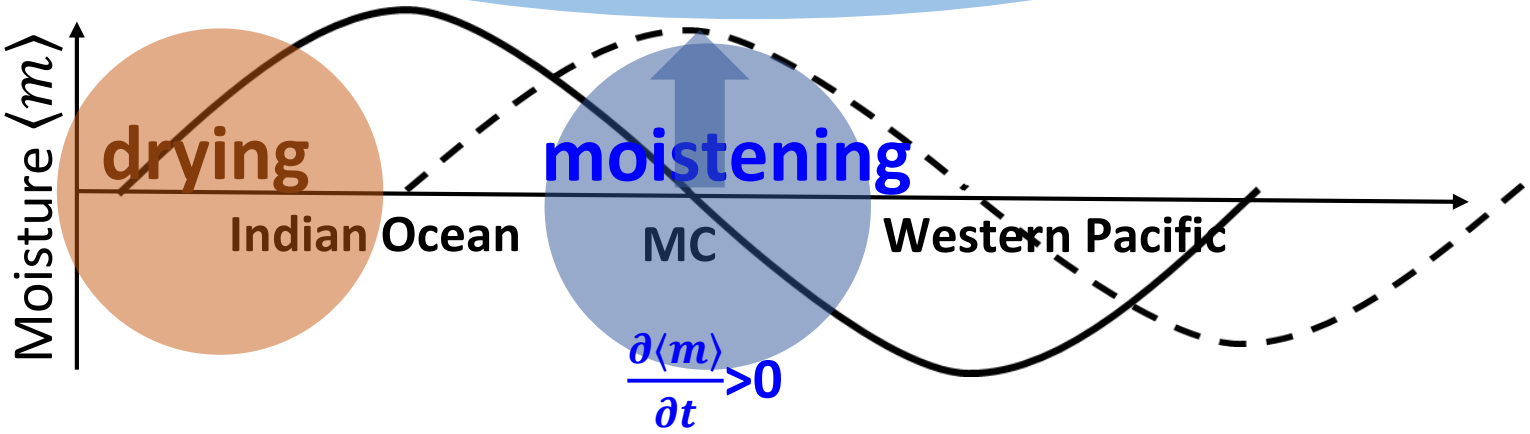
Horizontal moisture advection

$-\langle V \cdot \nabla m \rangle$



$$\frac{\partial \langle m \rangle}{\partial t} = -\langle V \cdot \nabla m \rangle + \cdots$$

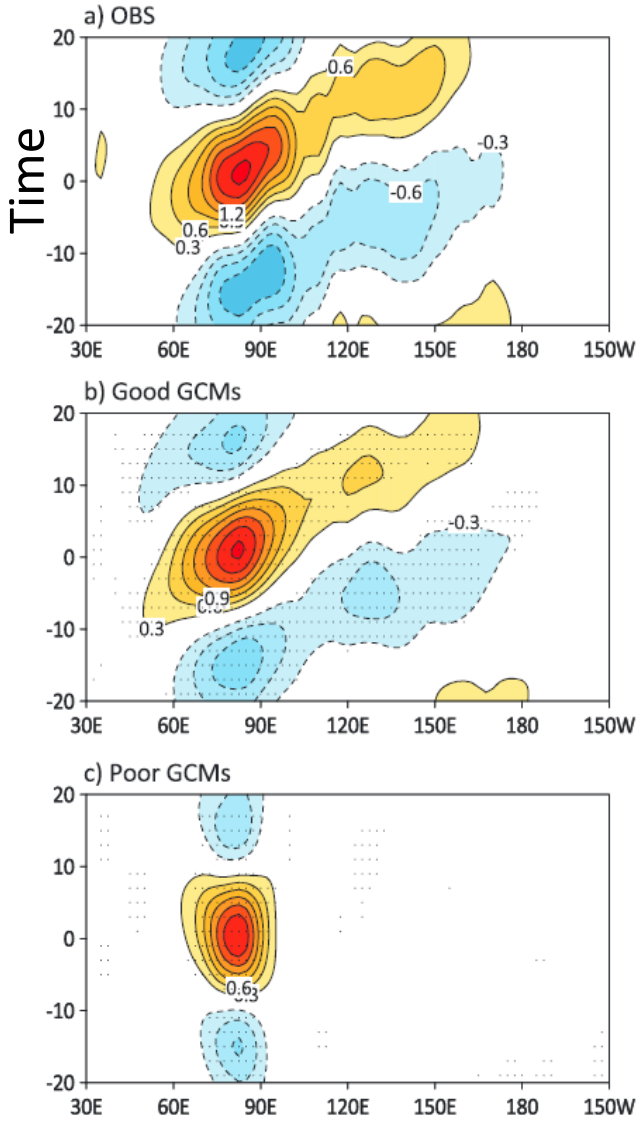
Tendency — Horizontal advection

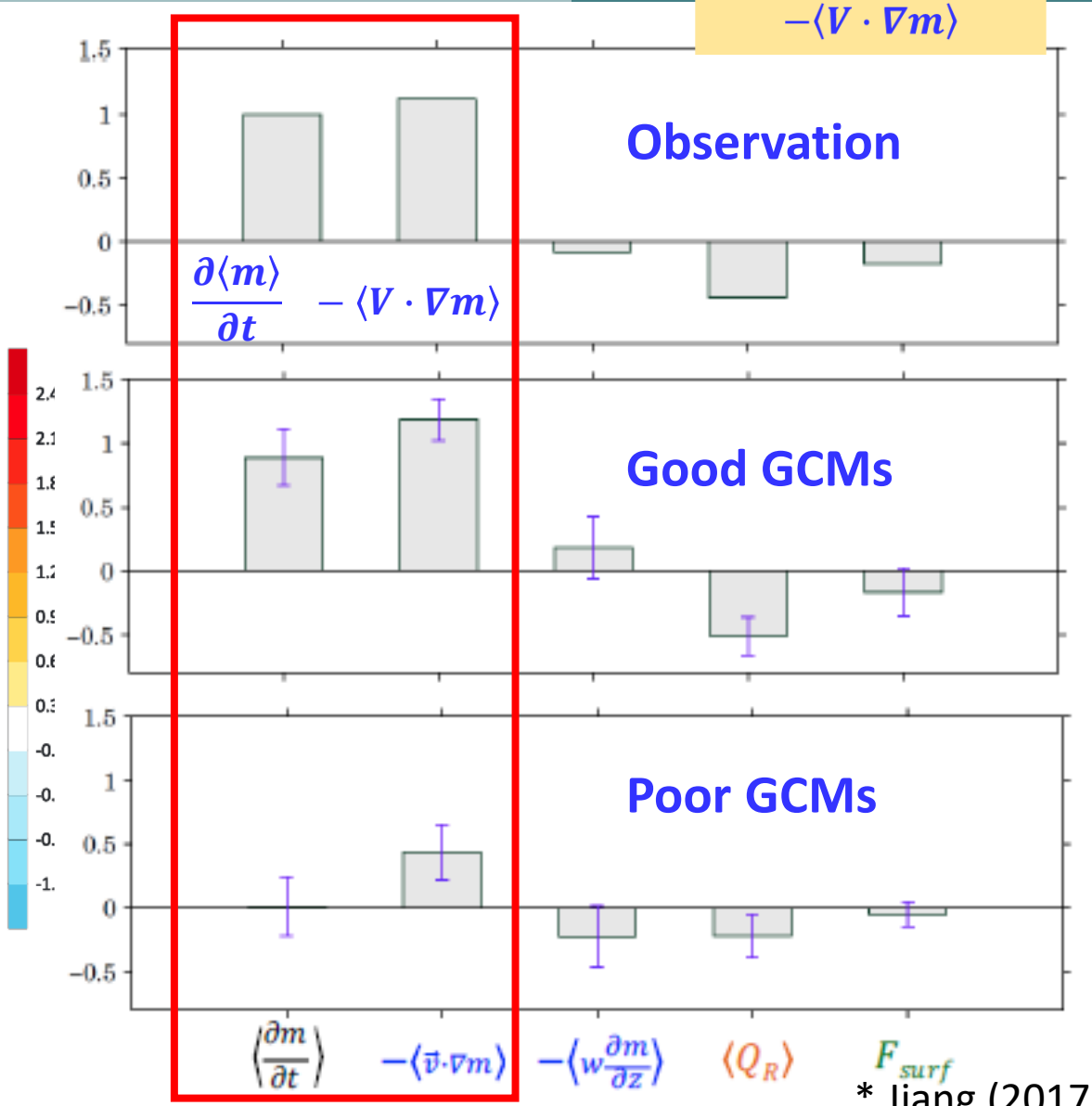


MSE budget in multi-models

MJO propagation ↑ Horizontal moisture advection $-\langle V \cdot \nabla m \rangle$

Precip. anomalies





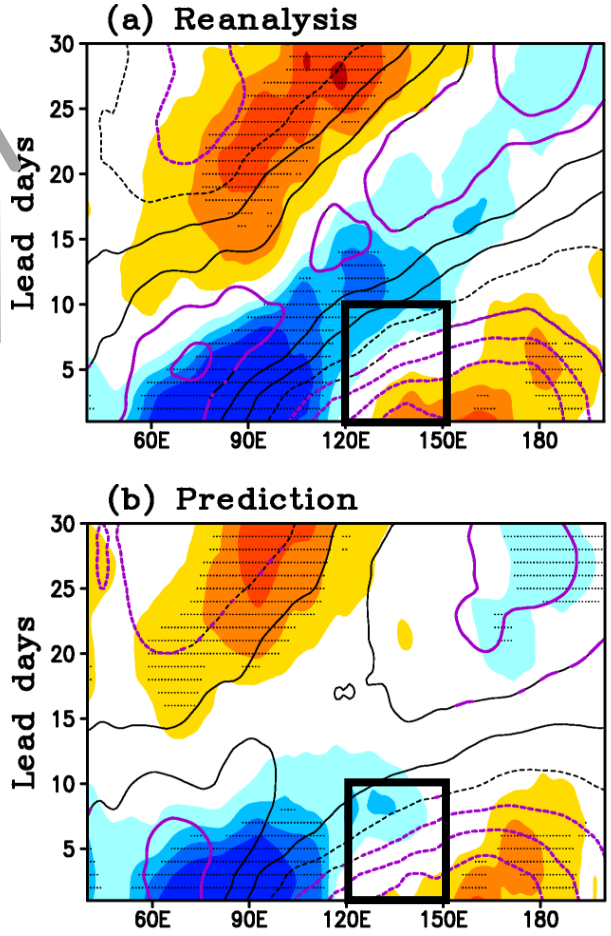
* Jiang (2017)

MSE budget in ECMWF hindcast

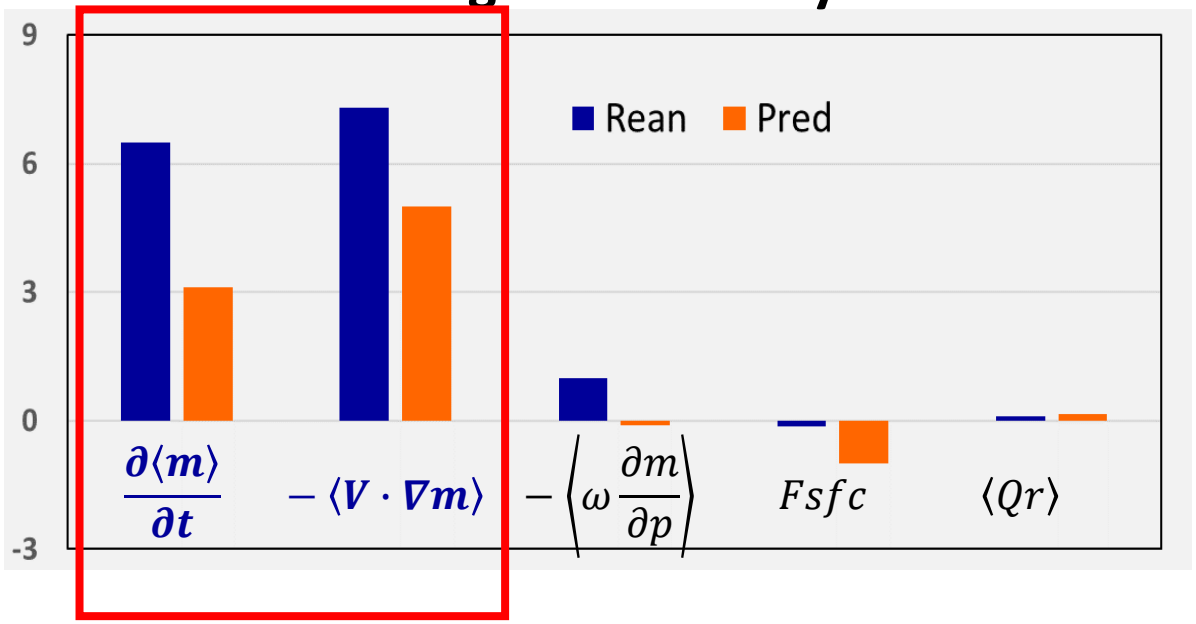
MJO propagation

Weaker **Horizontal moisture advection** $-\langle V \cdot \nabla m \rangle$

OLR and U850



MSE budget terms: Day 1~10

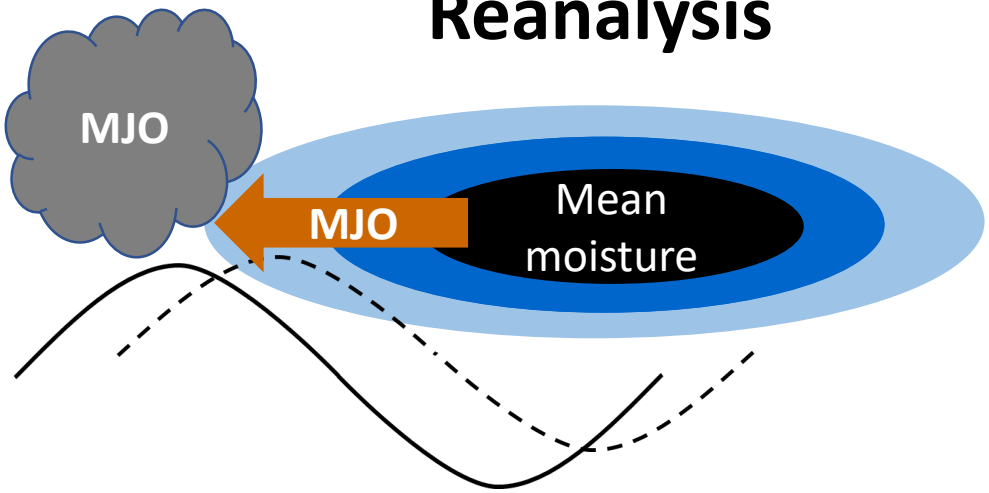


* Area: 20°S-5°S, 120°-150°E

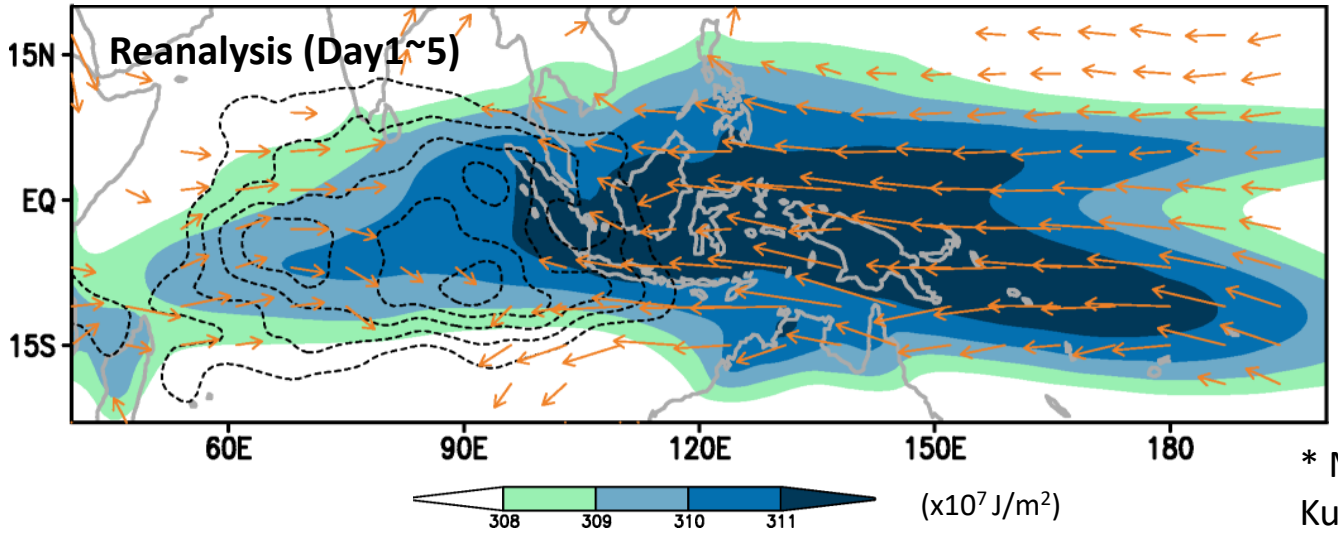
* Kim (2017)

Horizontal moisture advection

Reanalysis



Contour: OLR' **Vector: V' (850hPa)** **Shading: $\overline{m}$**



MJO eastward propagation

↑

Horizontal moisture advection

$-\langle V \cdot \nabla m \rangle$

↑

$-\langle V' \cdot \nabla \overline{m} \rangle$

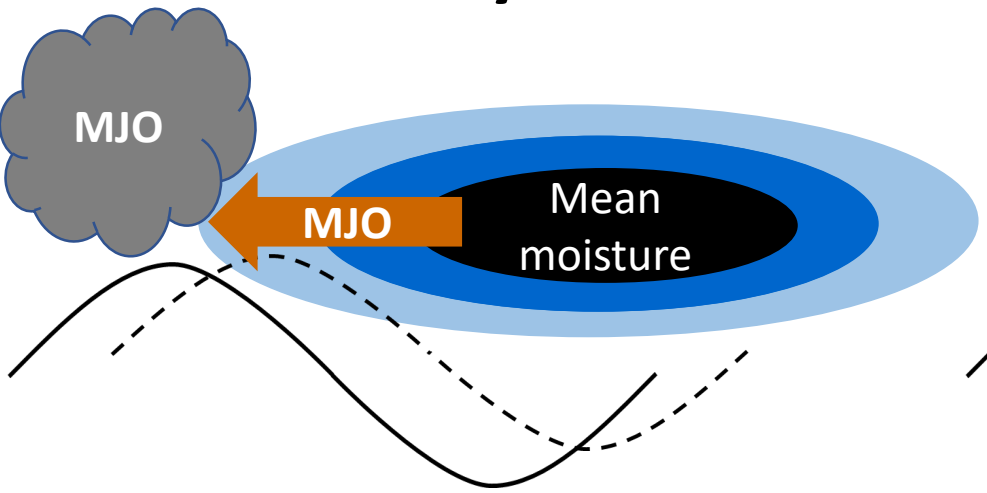
MJO wind **Mean MSE**

* Maloney (2009), Andersen and Kuang (2012), D.Kim et al. (2014), Adames and Kim (2016), Jiang (2017)

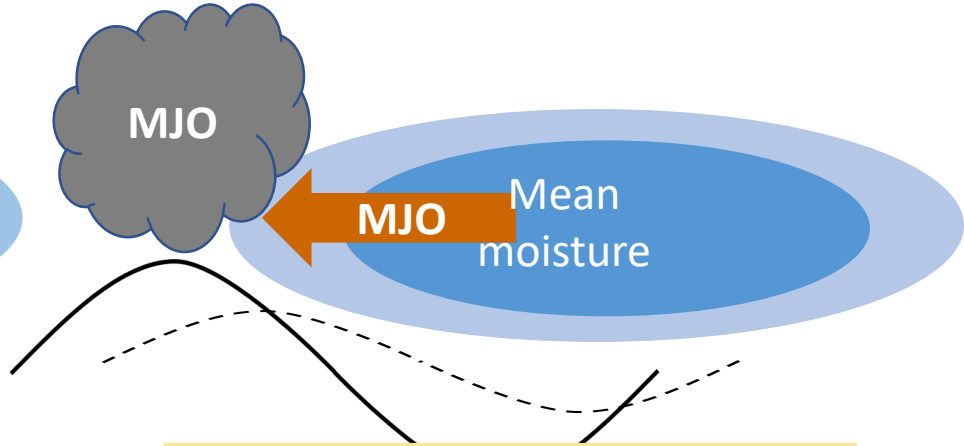
Horizontal moisture advection

Day 1~5

Reanalysis

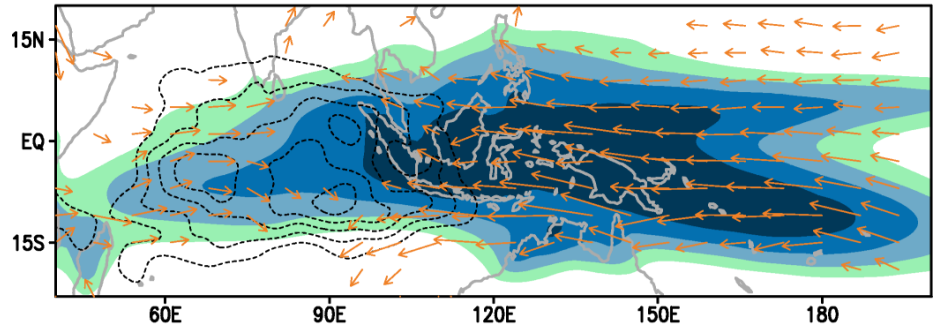


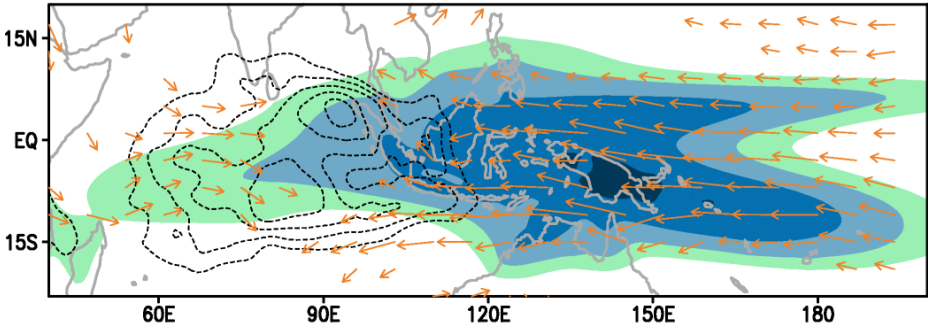
Prediction



Similar OLR' and V'
but drier mean state

Contour: OLR' **Vector: V' (850hPa)** **Shading: $\overline{m}$**





Dry mean bias

MJO eastward propagation

↑

Horizontal moisture advection

$-\langle V \cdot \nabla m \rangle$

↑

$-\langle V' \cdot \nabla \bar{m} \rangle$

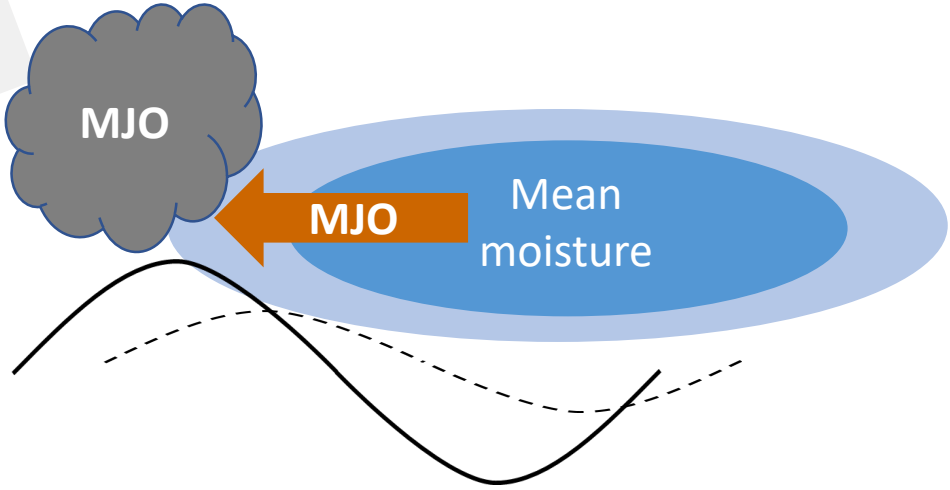
MJO wind **Mean MSE**

Faster decay

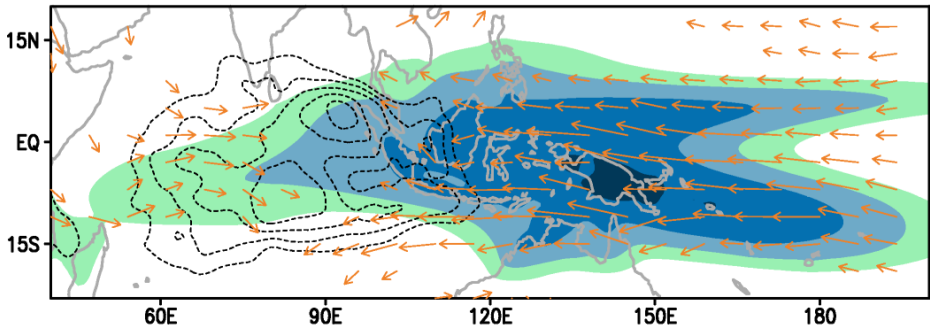
Weaker

Drier

Prediction



Similar OLR' and V' but drier mean state

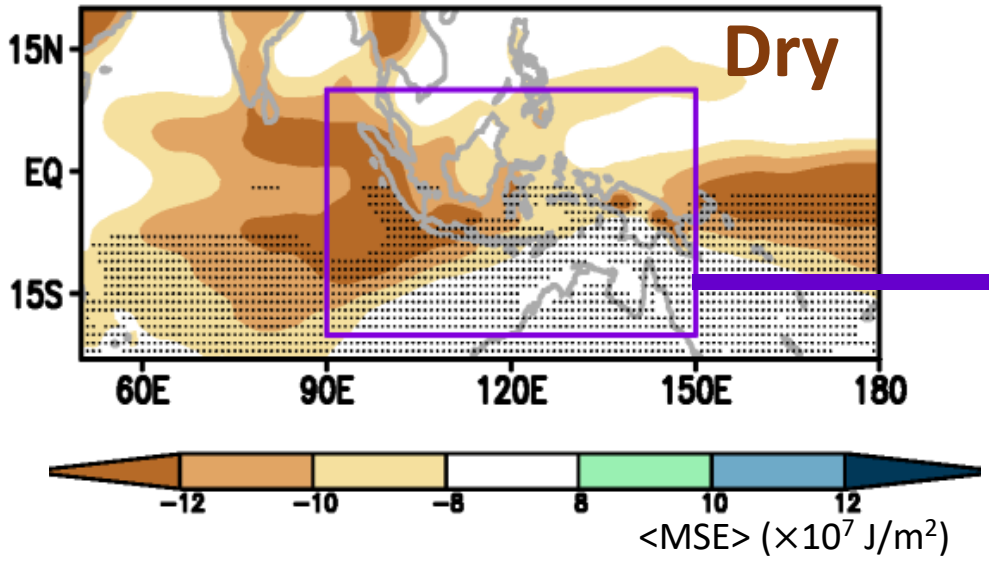


* Kim (2017)

Dry mean bias

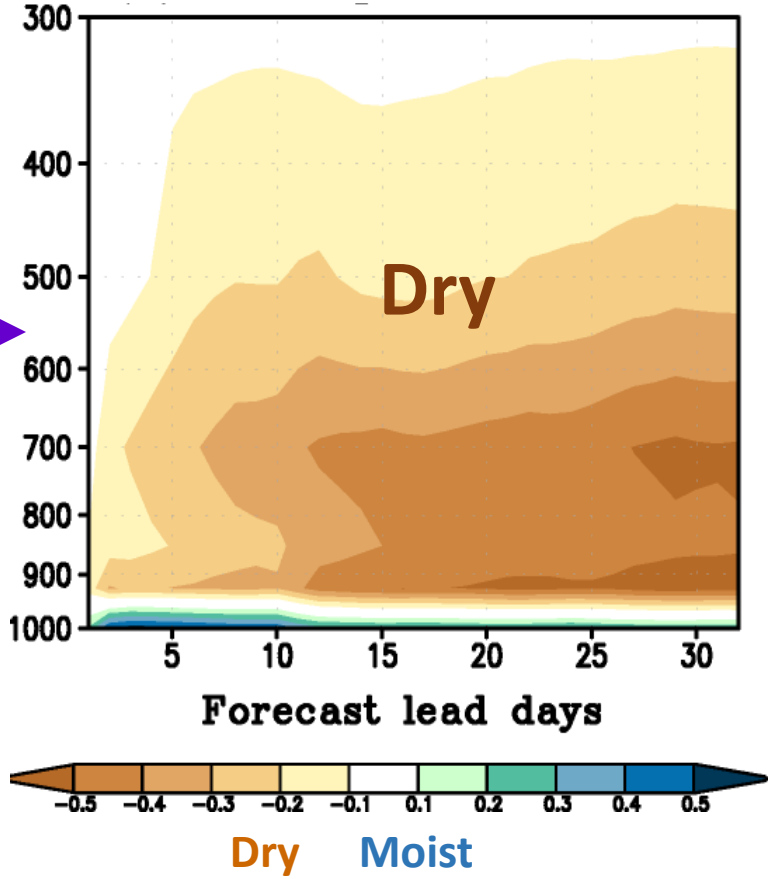
Bias (Prediction-Reanalysis)

MSE bias (32day avg)



Stippling: Reduced MSE y-gradient

Specific humidity bias



Need of improved mean state.

* Kim (2017)

Summary

- Current models successfully predict the **MJO up to 4-5 weeks**.
- Forecasts are under-dispersive, show quick decay of MJO signal and **Maritime Continent MJO propagation barrier**.
- The **biases in seasonal mean tropospheric moisture field** is a key factor that weakens the horizontal moisture advection, and propagation.