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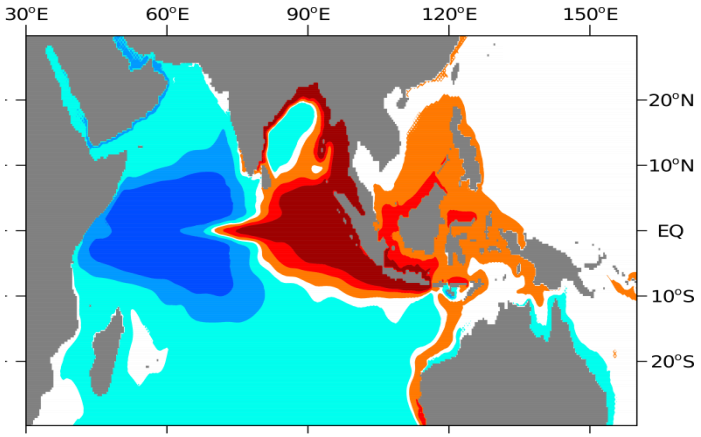
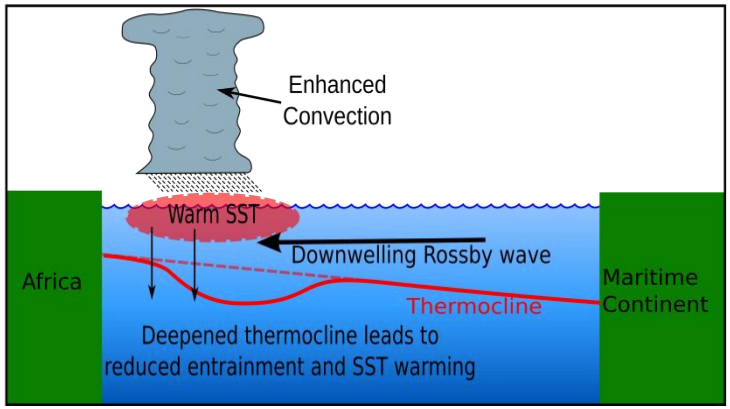
The Dynamic Ocean Component of the Madden-Julian Oscillation.

Benjamin G. M. Webber

Adrian J. Matthews, Karen J. Heywood and David P. Stevens





Webber BGM, Matthews AJ, Heywood KJ (2010) A dynamical ocean feedback mechanism for the Madden-Julian Oscillation. *Quart. J. Roy. Meteorol. Soc.* **136:** 740--754.

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Webber BGM, Stevens DP, Matthews AJ, Heywood KJ (2012) Dynamical ocean forcing of the Madden-Julian Oscillation at lead times of up to five months. *J. Climate.* In Press.

The Madden-Julian Oscillation

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- The Madden-Julian Oscillation (MJO) is the dominant mode of intraseasonal climate variability in the tropics.
- Propagating atmospheric anomalies: convection, rainfall, winds, surface fluxes
- Broadband spectral signature, primarily 40-60 day time scale.
- Affects rainfall throughout the tropics (and globally); the livelihoods of billions depend upon monsoon rainfall that is modulated by the MJO.
- Difficult to model numerically. Forecasting capability is currently limited to at most 20 days

The MJO: Convection

Phase 1

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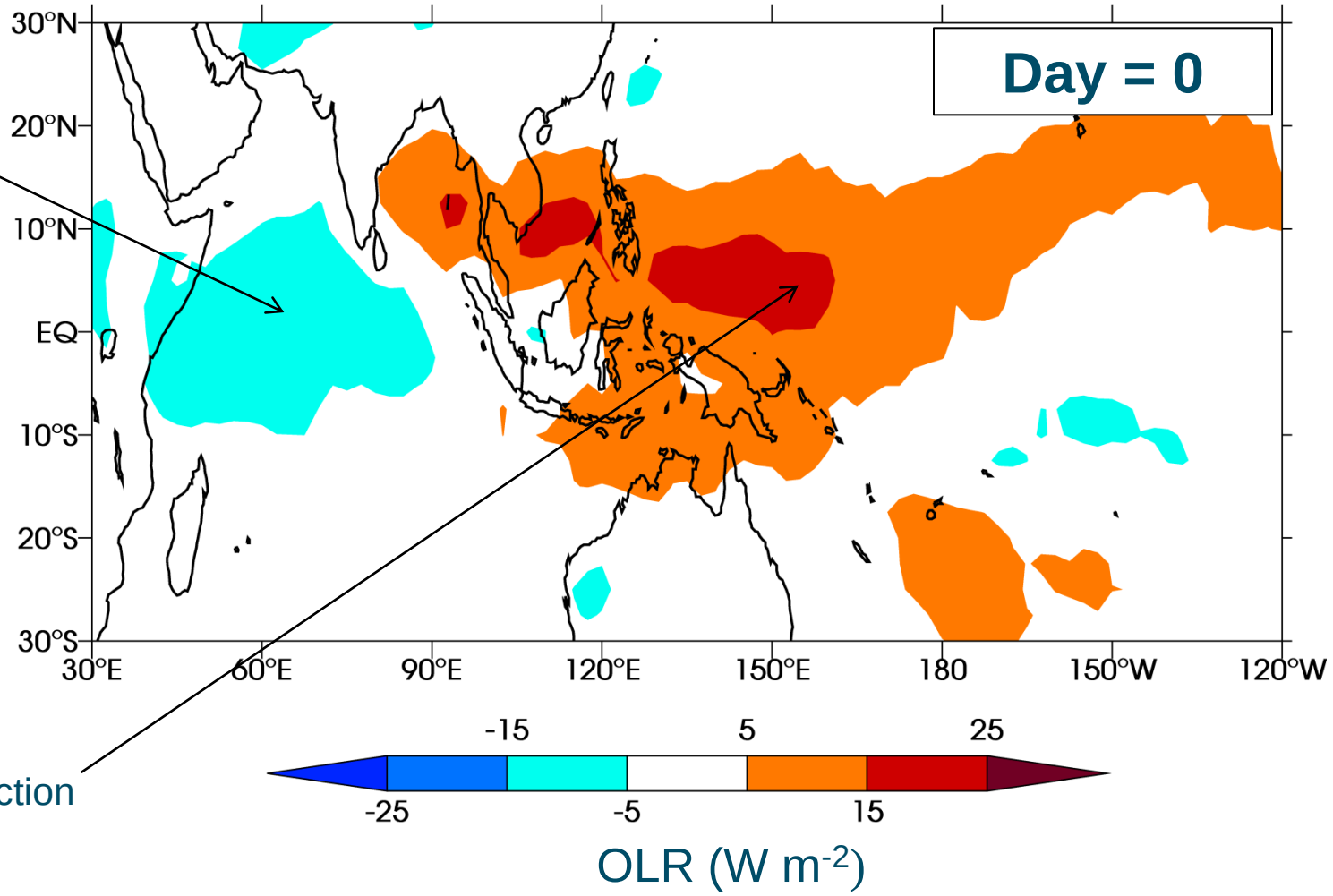
Initiation of enhanced convection in the western Indian Ocean

Suppressed convection



The MJO: Convection

Phase 2

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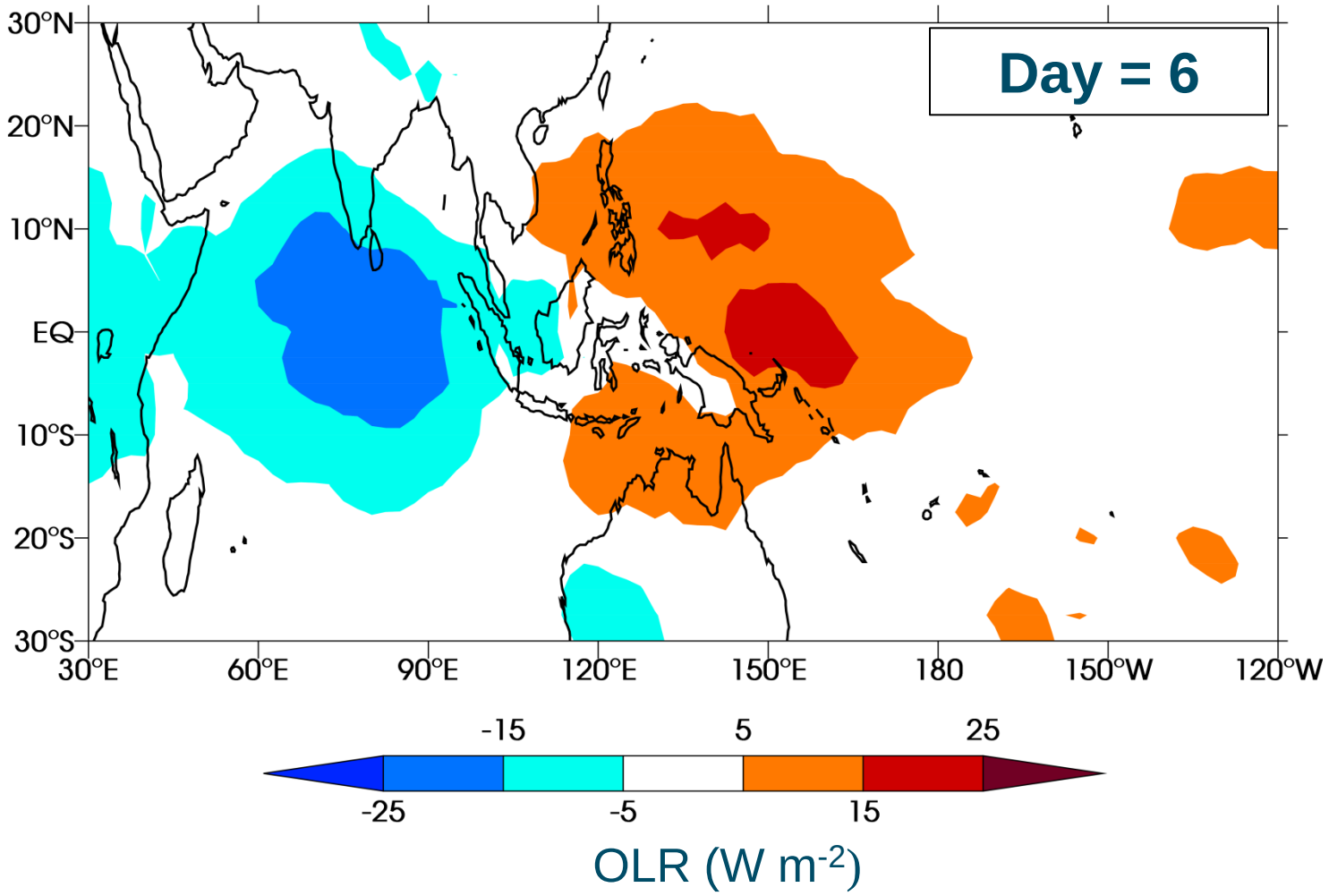

The MJO: Convection

Phase 3

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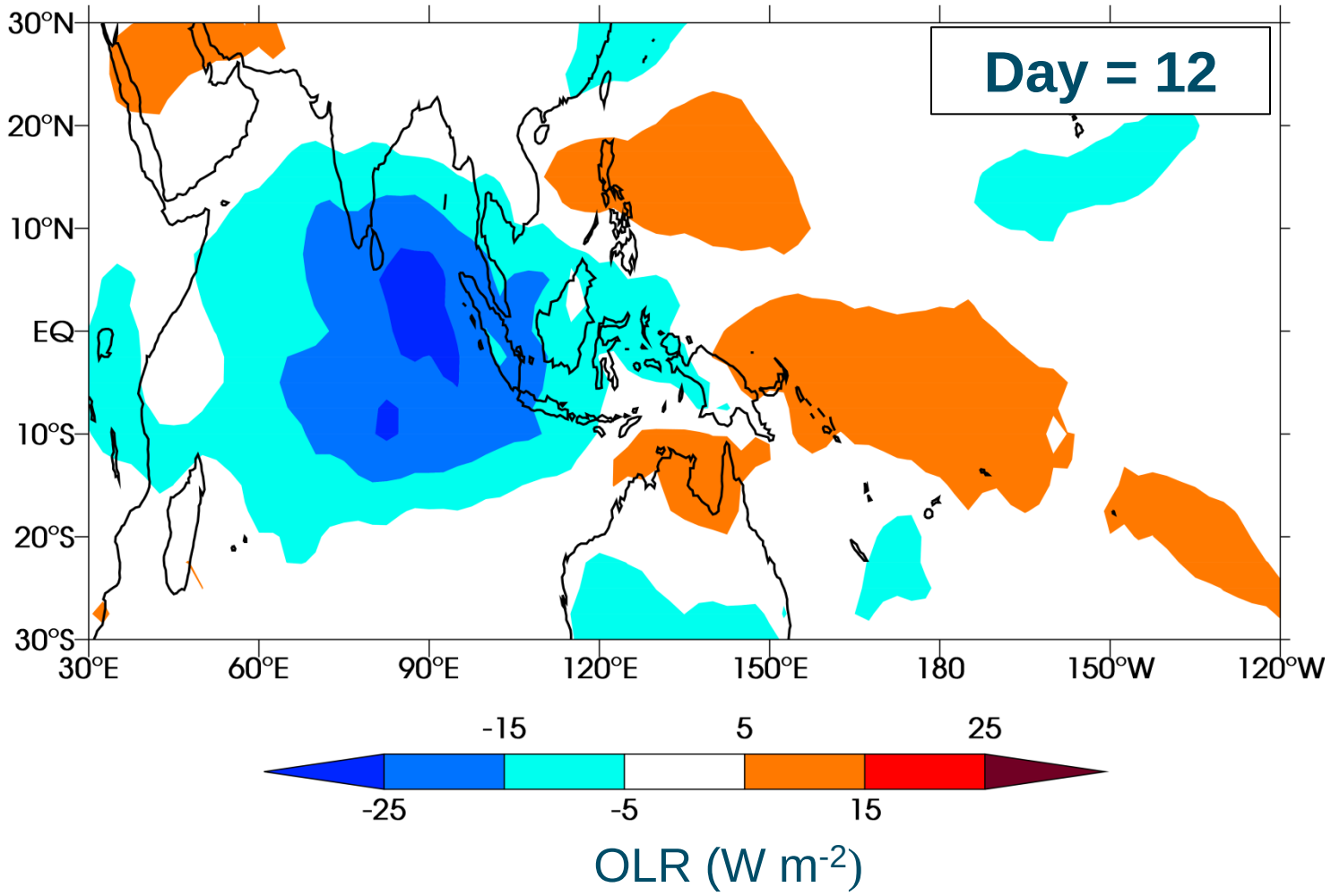

The MJO: Convection

Phase 4

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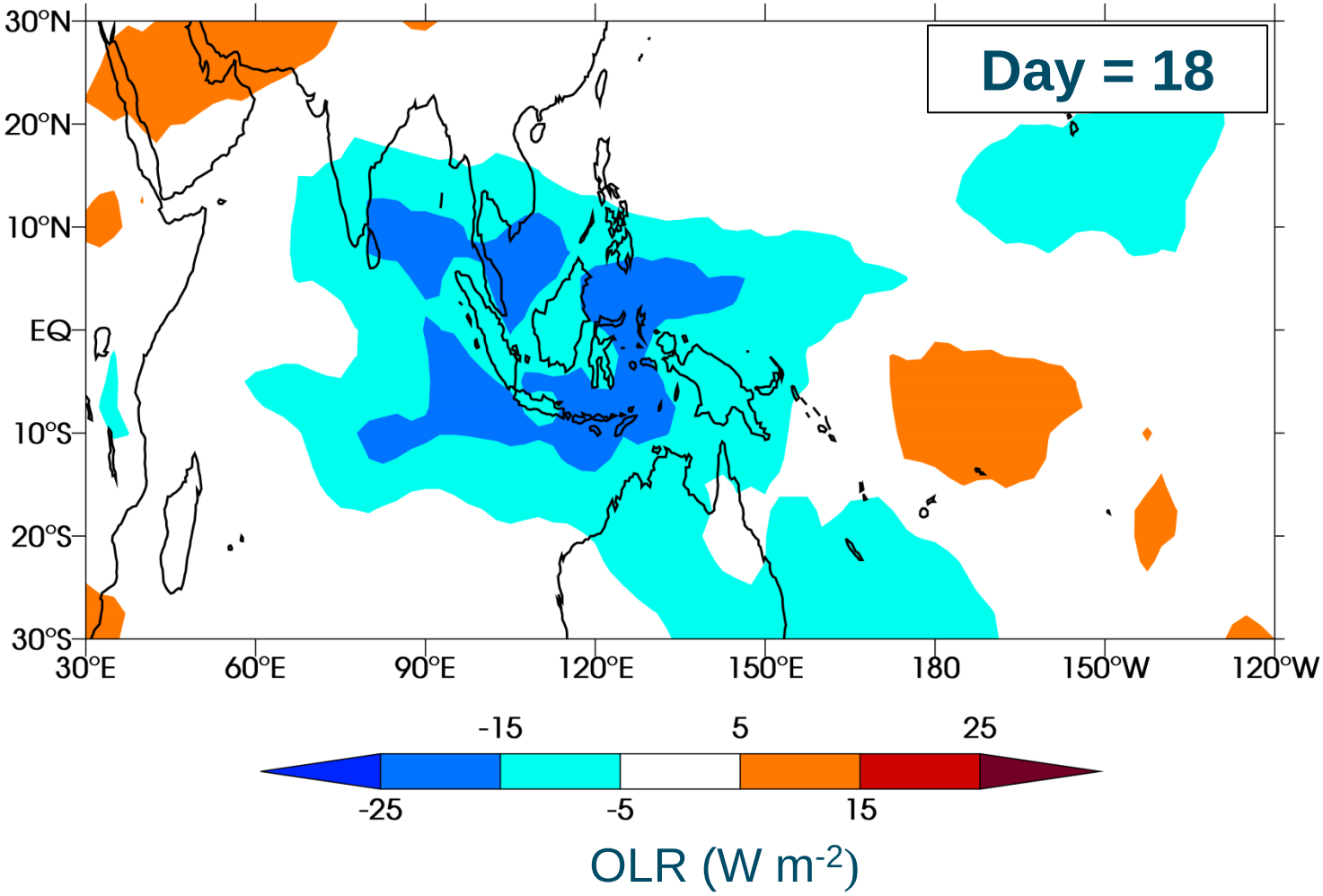

The MJO: Convection

Phase 5

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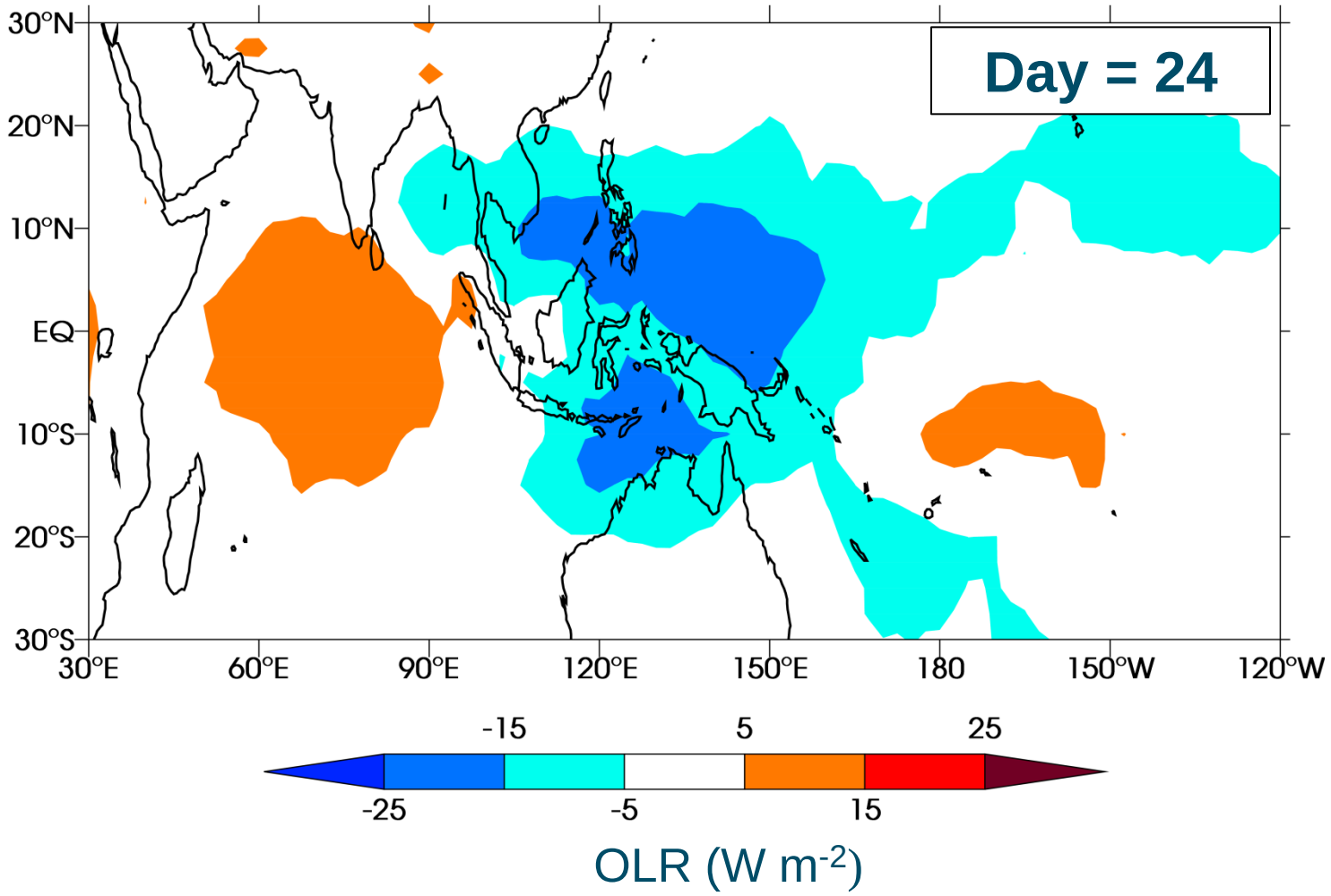

The MJO: Convection

Phase 6

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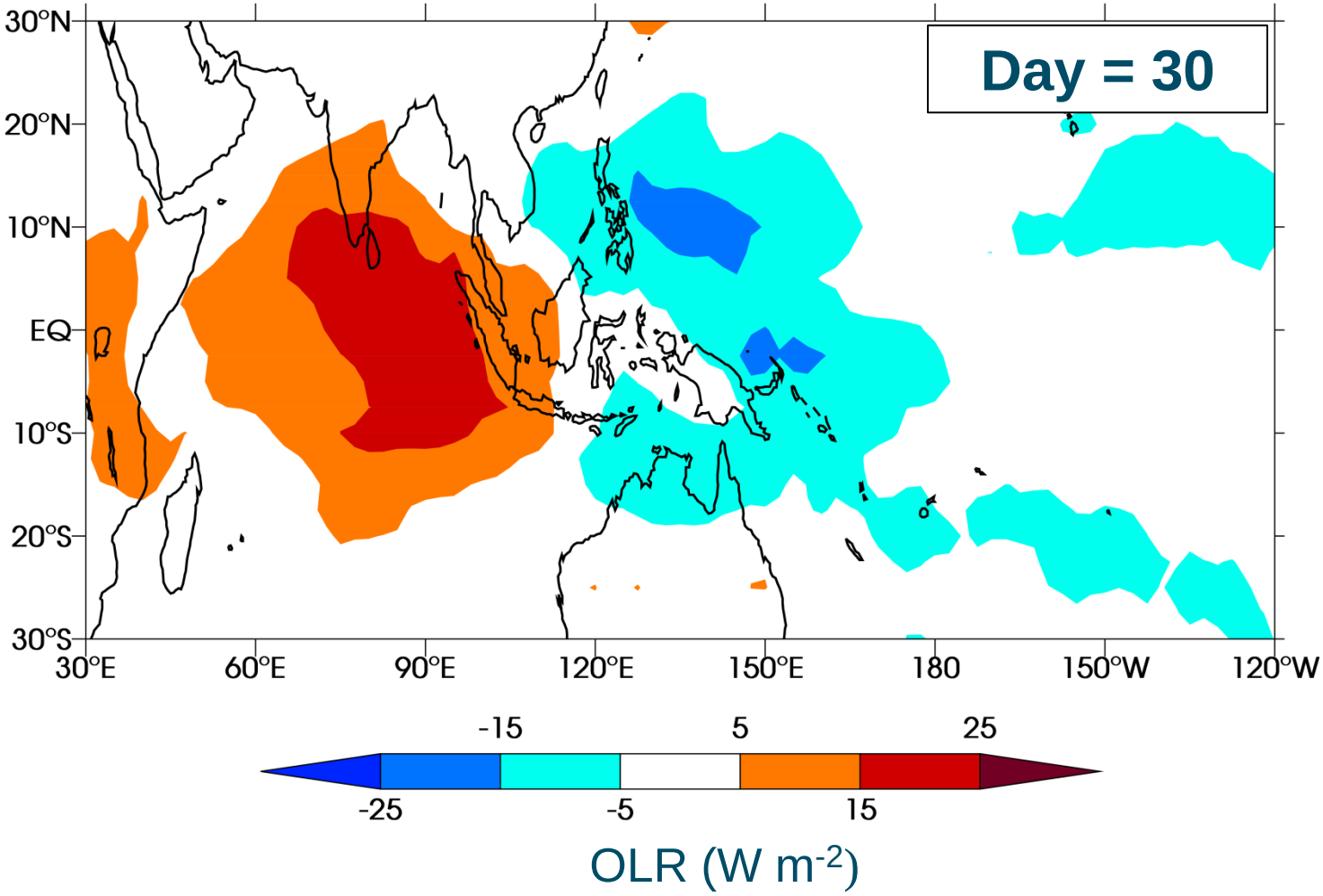

The MJO: Convection

Phase 7

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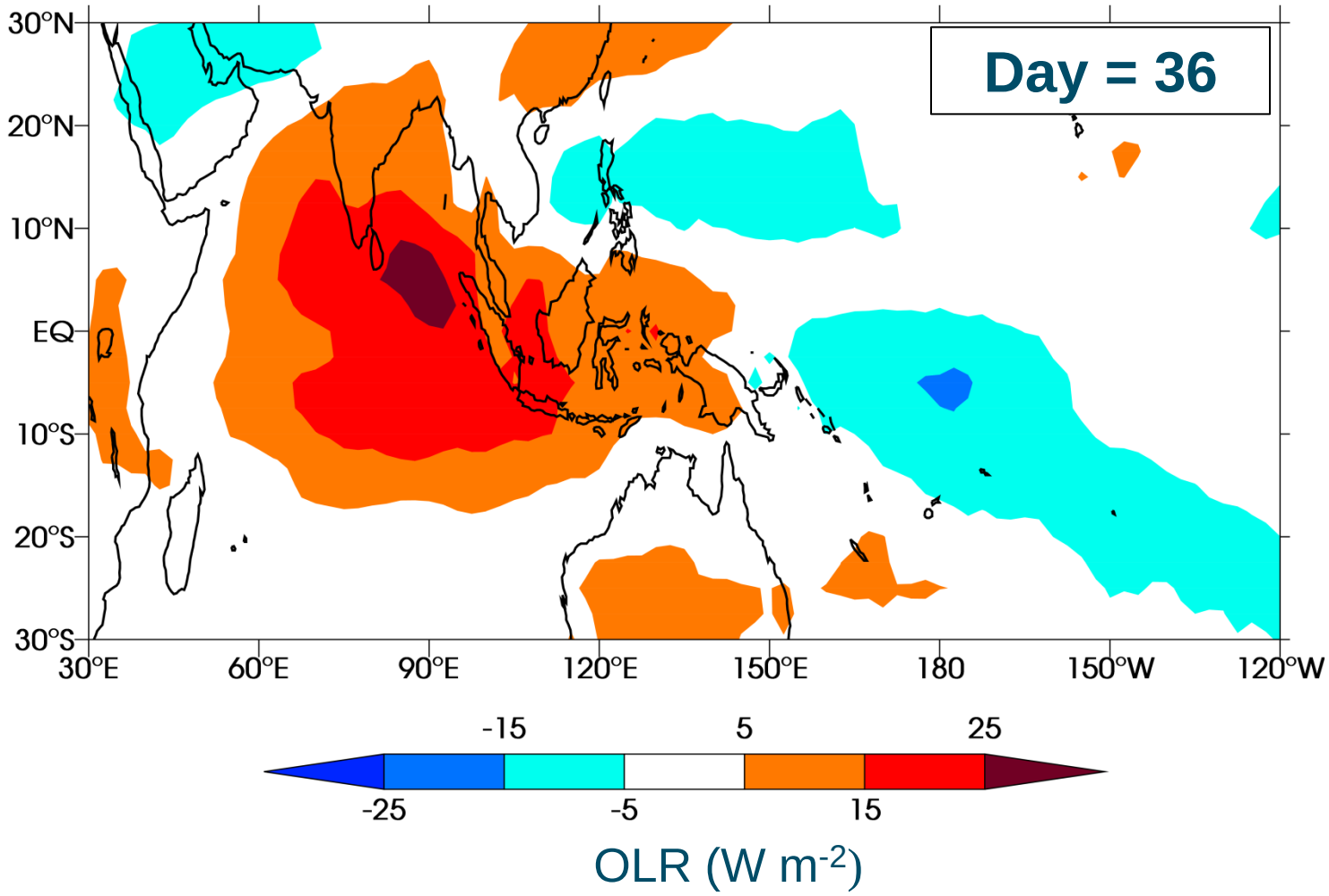

The MJO: Convection

Phase 8

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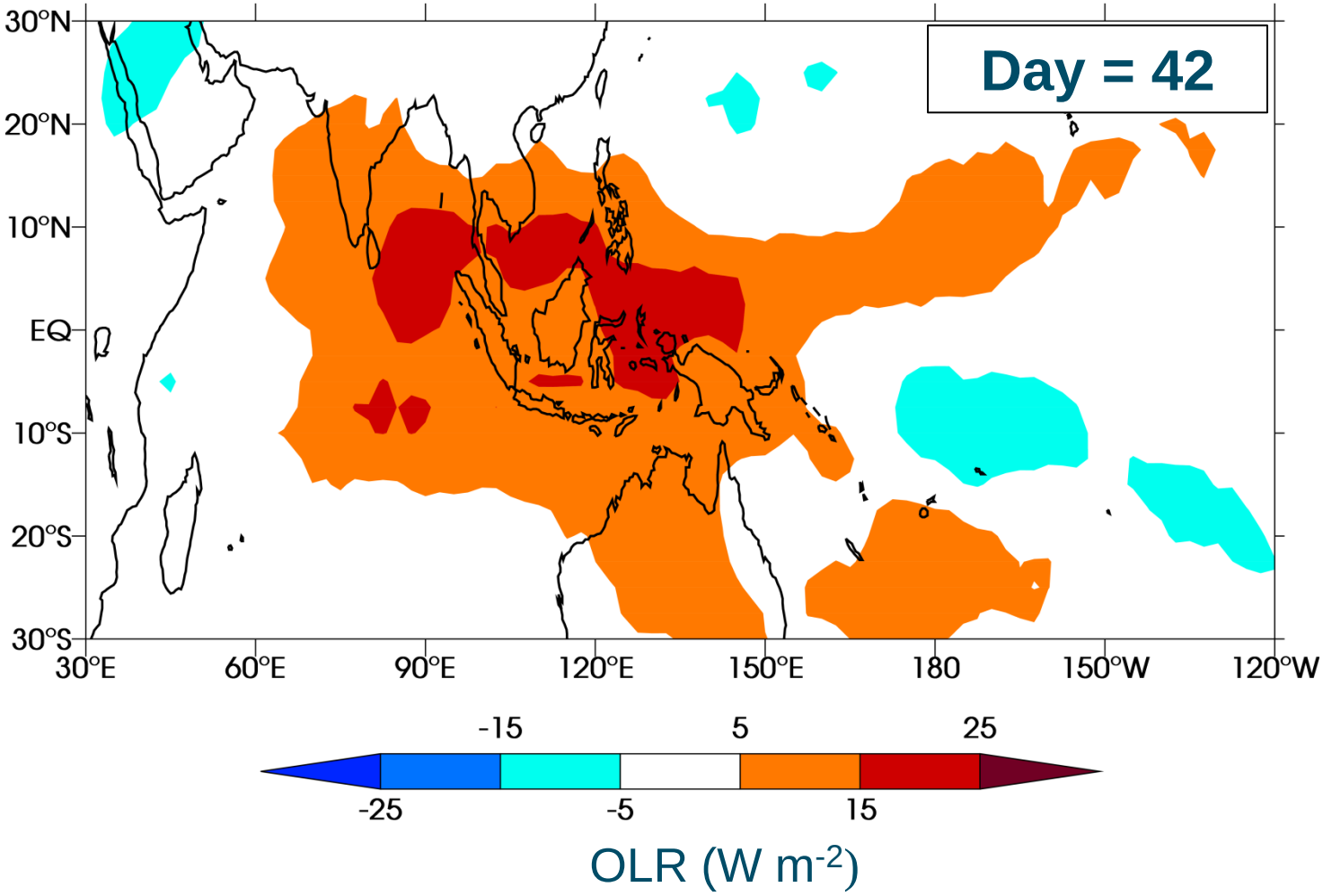

The MJO: Convection

Phase 1

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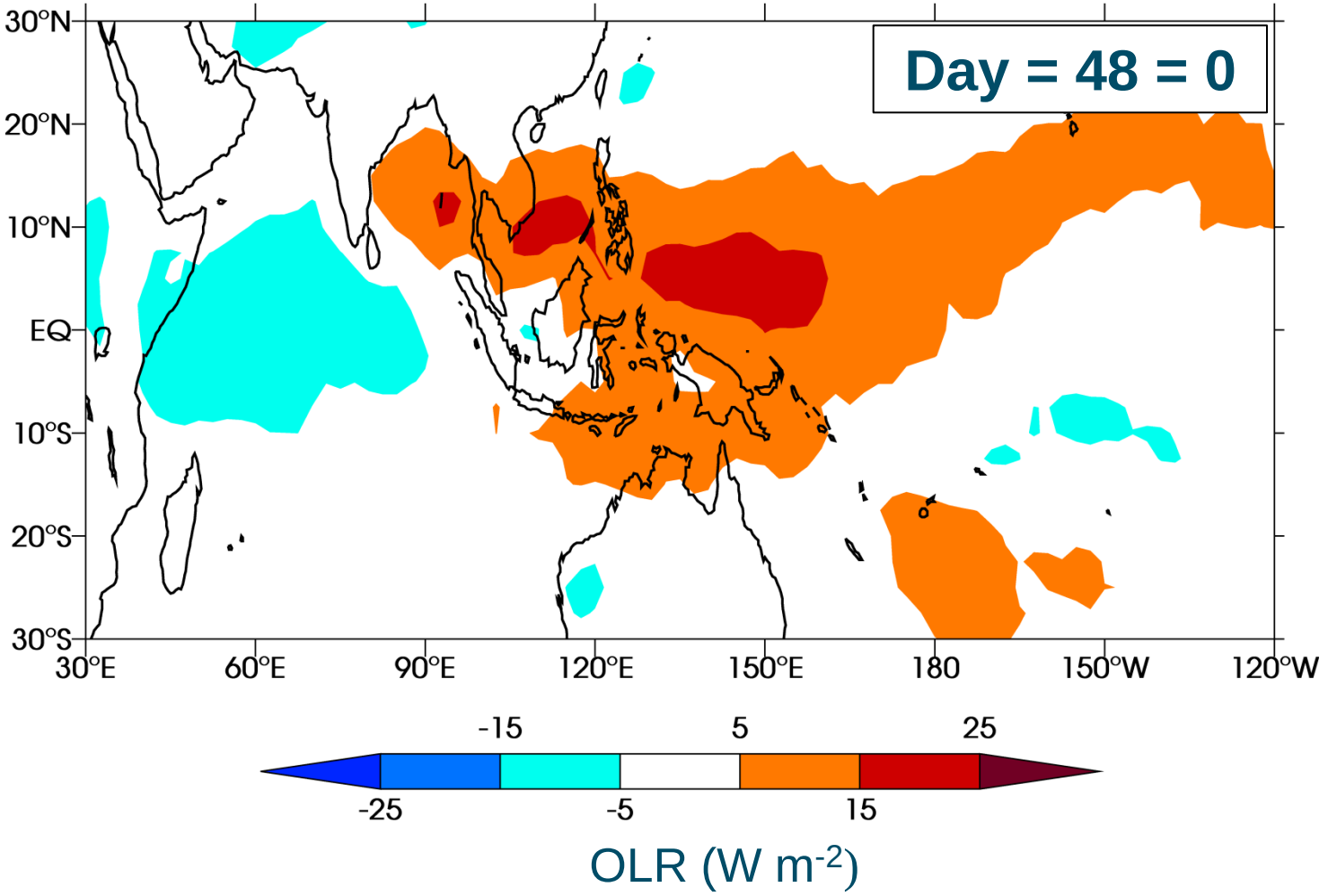
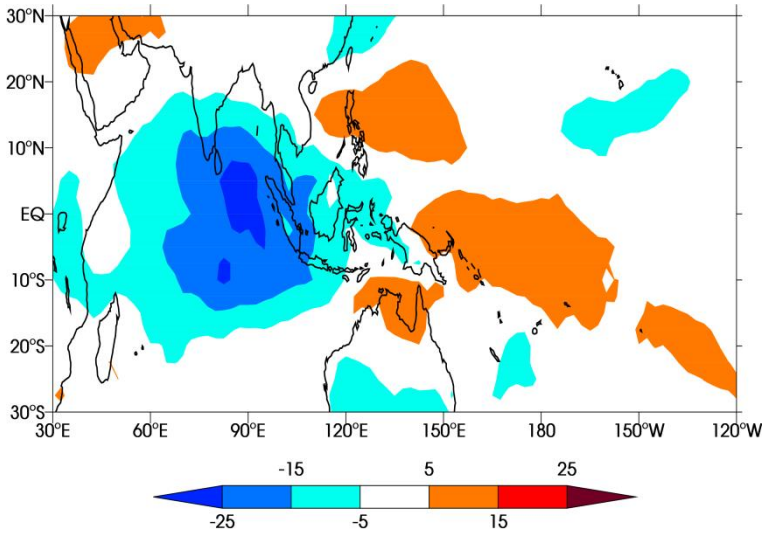


The MJO: Motivation for this study

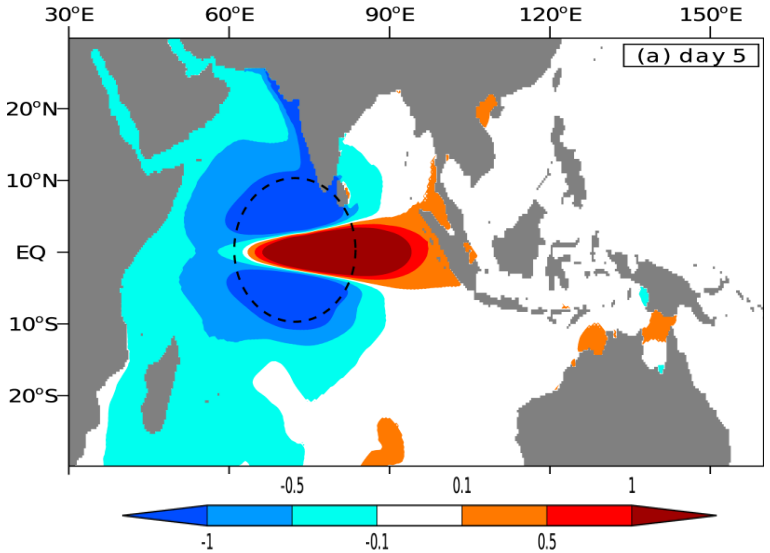
Motivation: to investigate the dynamical ocean component of the MJO

Key questions for the MJO:

- What causes its sporadic, intermittent nature?
- How can we predict and model it better?
- Can we predict “primary” Madden-Julian (MJ) events that do not have a consistent atmospheric or thermodynamic trigger?



OLR (Wm^{-2})



Sea surface height (SSH; cm)

Dynamic ocean response to the MJO

Global response

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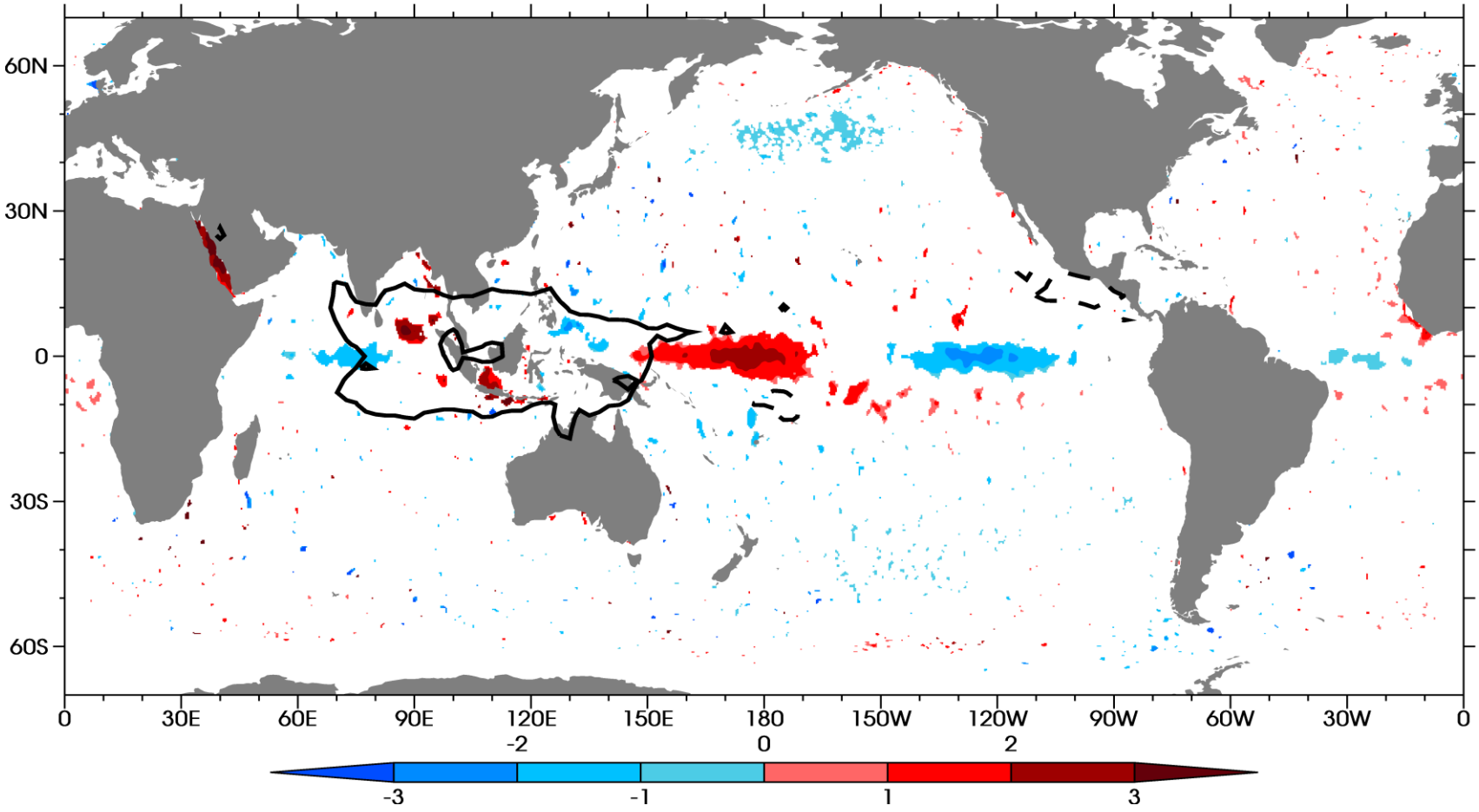

Sea surface height (SSH; cm)

Webber BGM, Matthews AJ, Heywood KJ, Stevens DP (2011) A dynamical ocean feedback mechanism for the Madden-Julian Oscillation. *Quart. J. Roy. Meteorol. Soc.* **136:** 740--754.

Dynamic ocean response to the MJO

Global wave propagation

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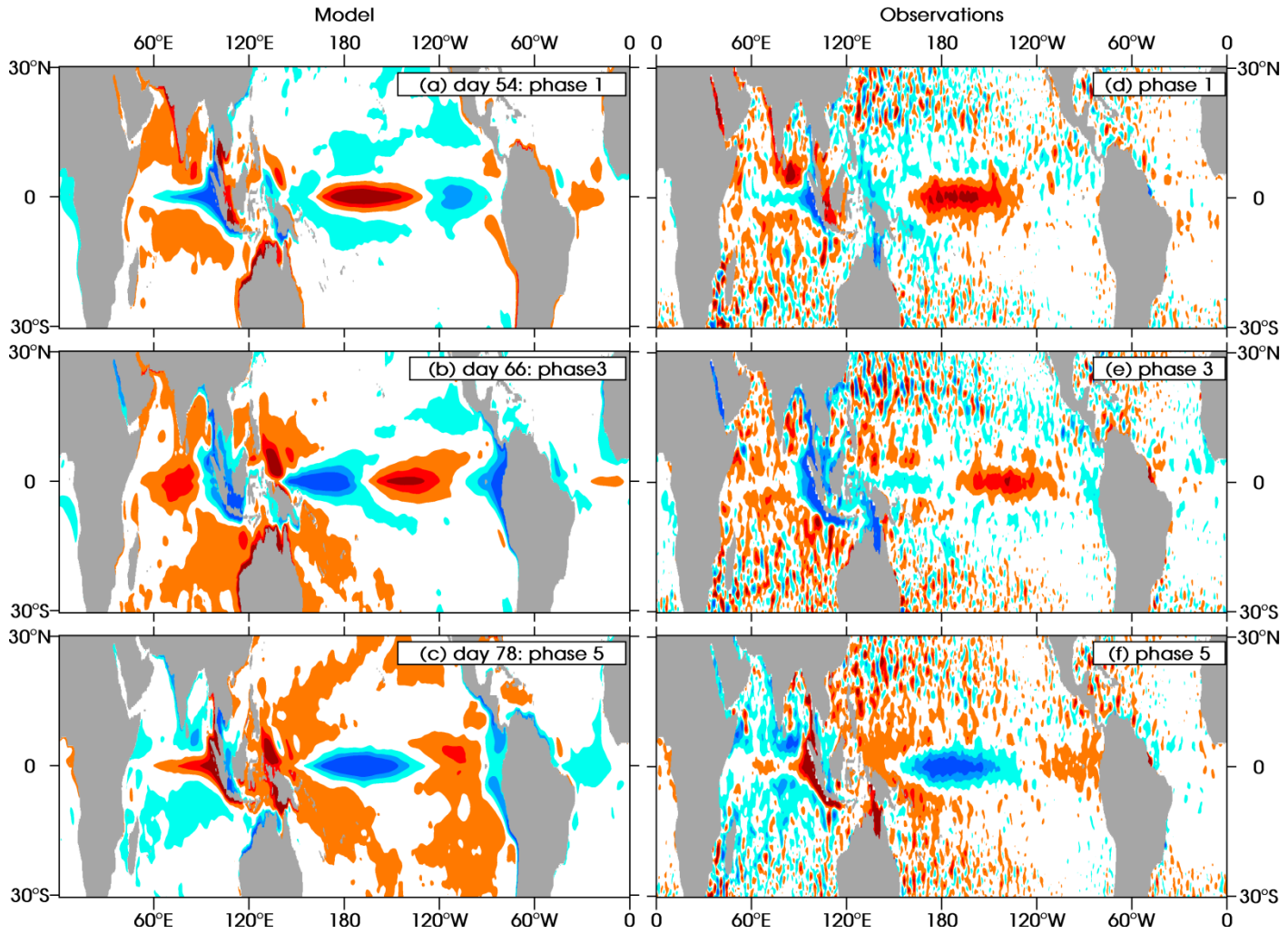

Sea surface height (SSH; cm)

Ocean dynamics

Propagation in the Indian Ocean

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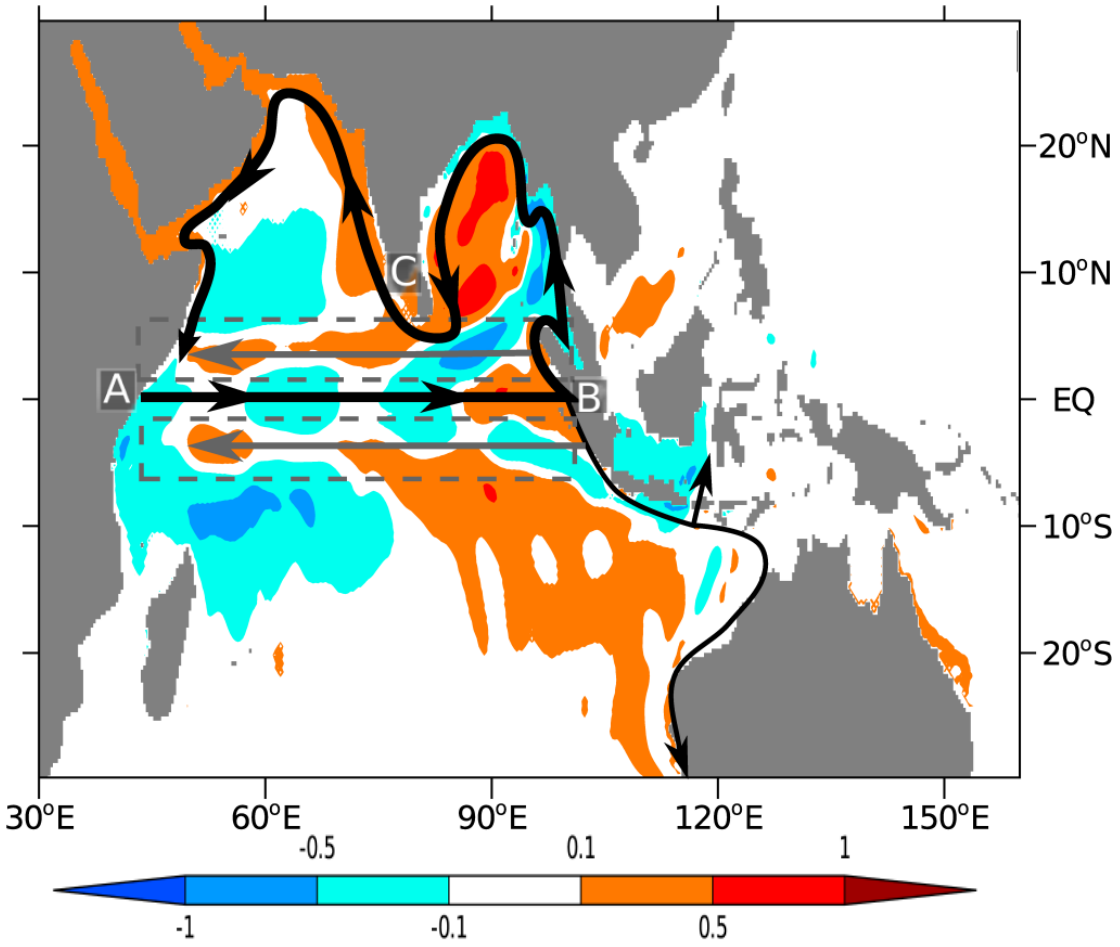
The MJO triggers equatorial waves that slosh back and forth in the Indian Ocean.

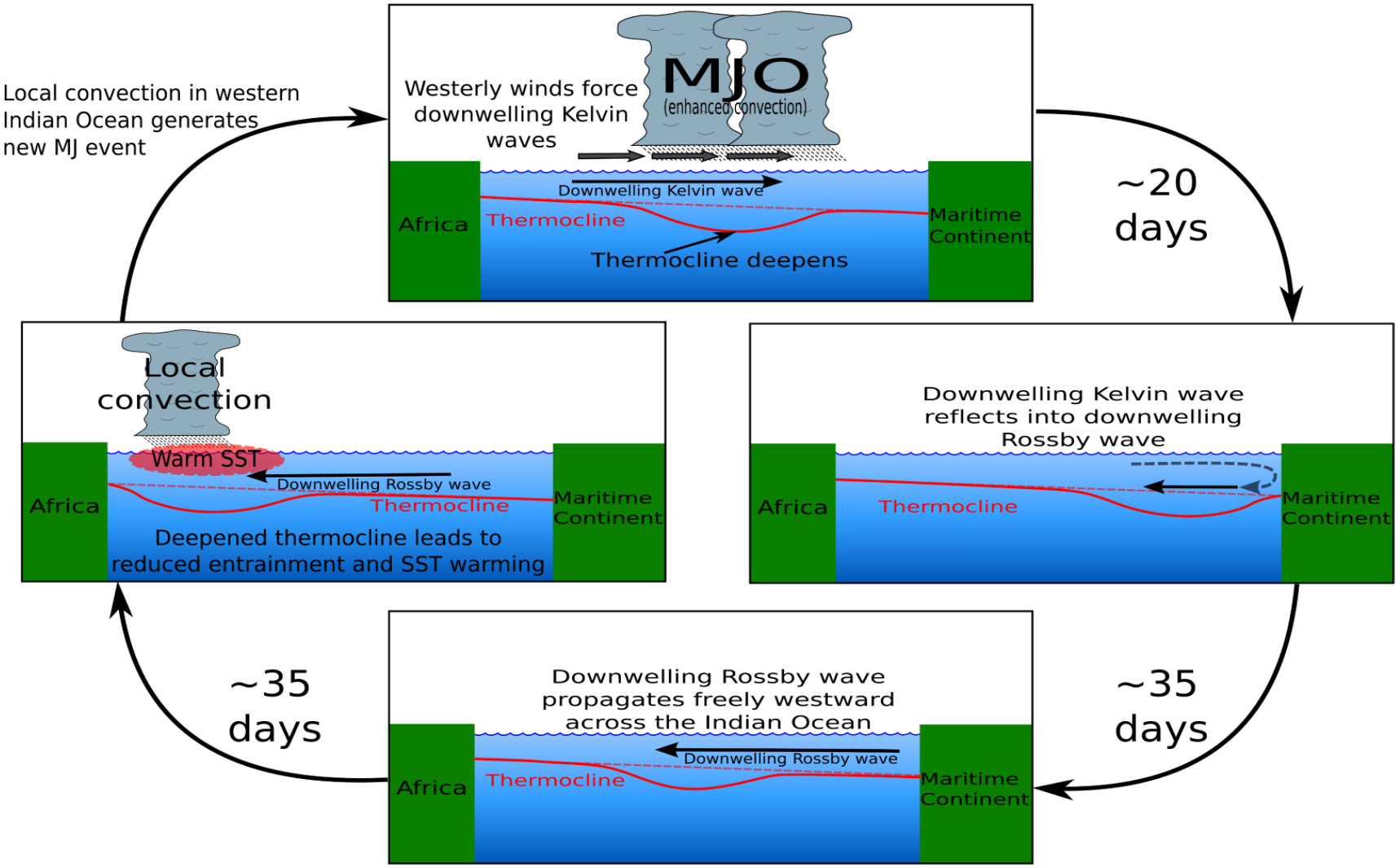
Downwelling Rossby waves reach the western Indian Ocean ~90 days after initial forcing.

These waves can feed back onto the next-but-one MJO event!



Sea surface height (SSH; cm)

Ocean dynamics
Feedback mechanism for the MJO



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Primary Madden-Julian (MJ) events

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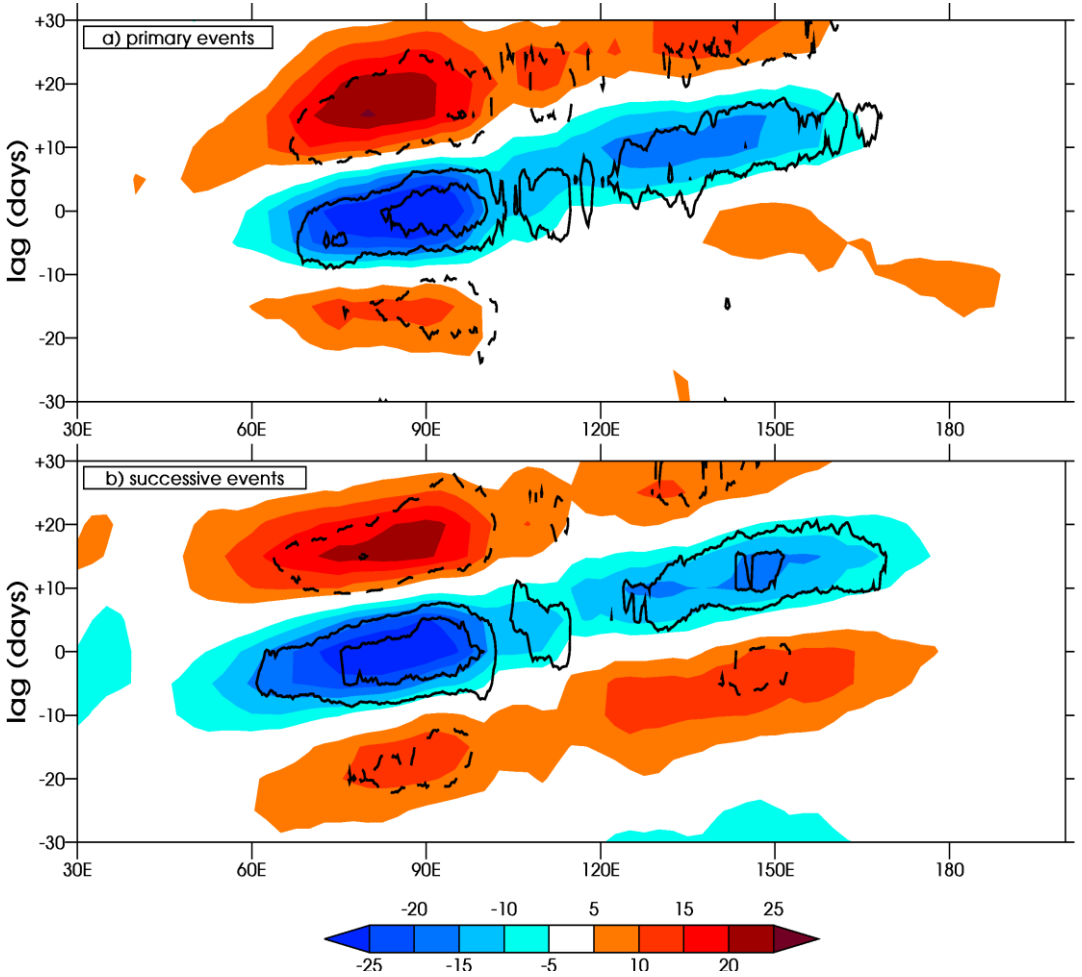
Primary MJ events follow period of MJO inactivity.

No coherent triggers found for such events (Matthews 2008).

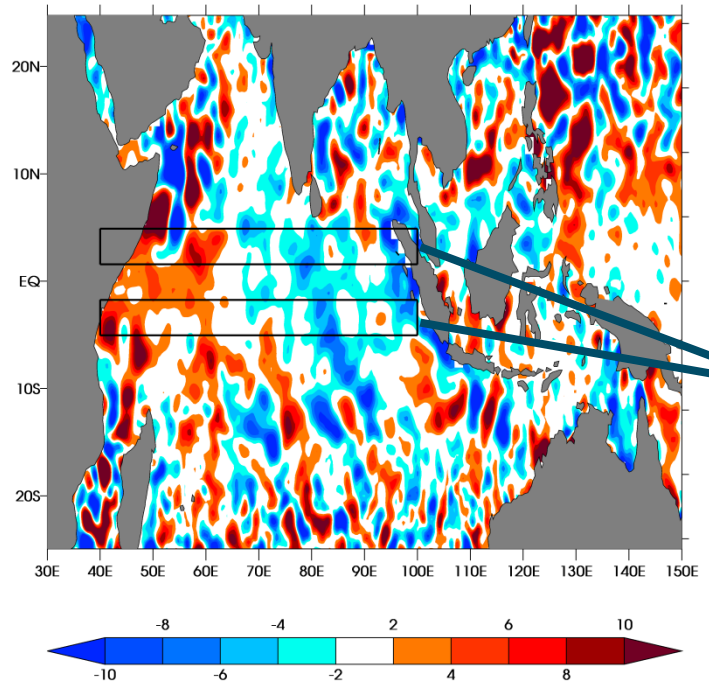
So what causes them?

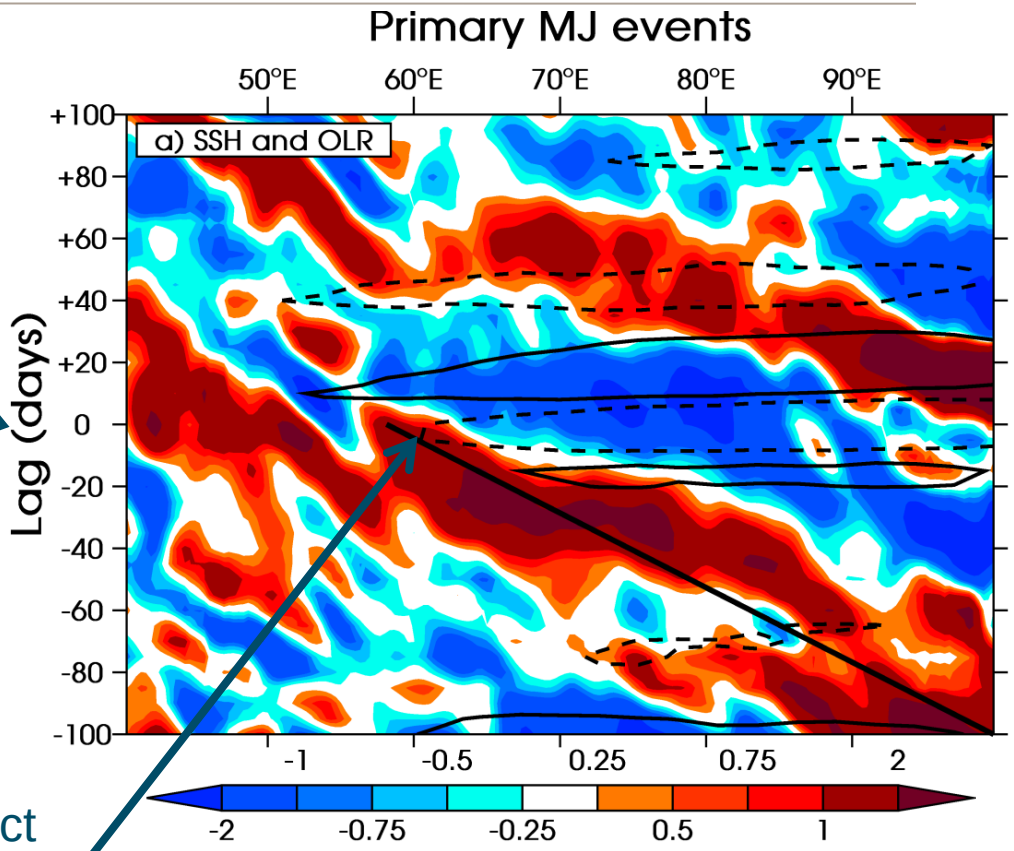
Could it be that the ocean dynamics act as a trigger for such events?



Webber et al. (2011)

Triggering primary events
Composites





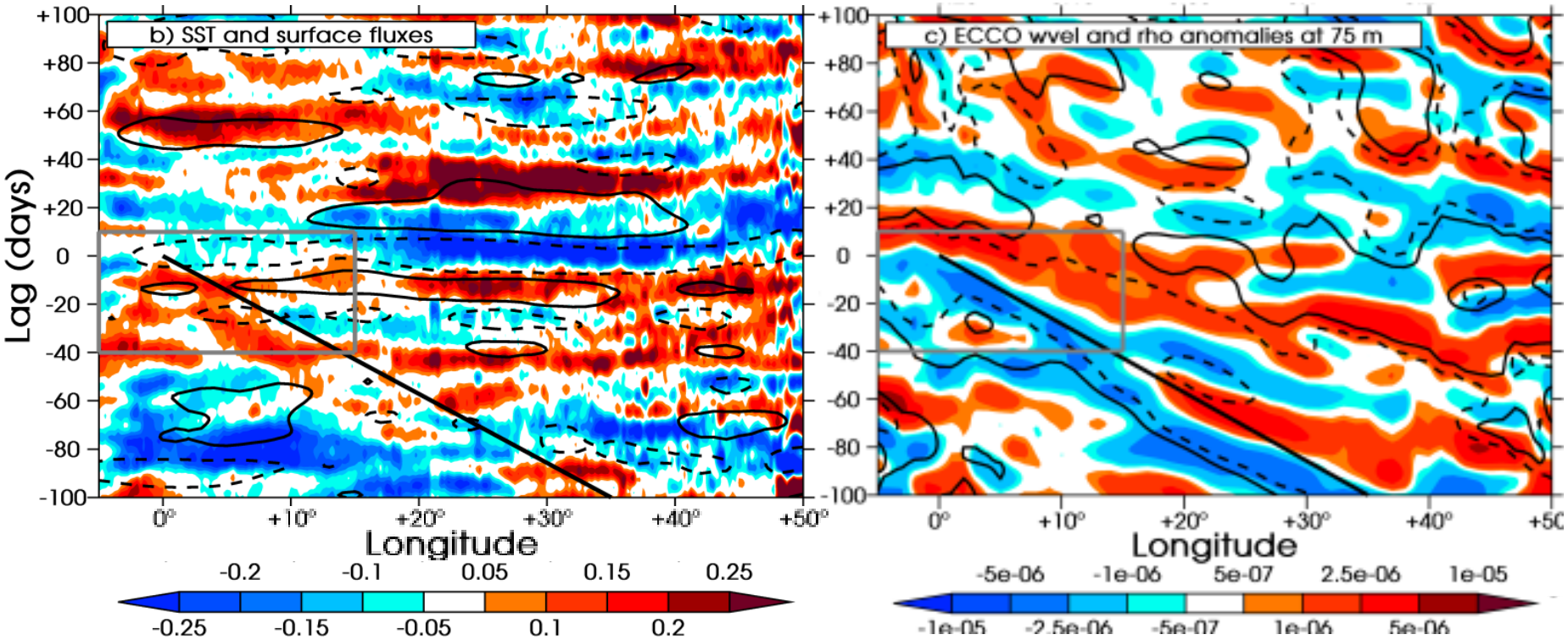
Could it be that the ocean dynamics act as a trigger for such events?

The timing agrees for SSH and OLR...

Shading: SSH anomalies (cm)
Contours: OLR anomalies (W m^{-2})

Composites of primary MJ events

SST and density anomalies



Clear link between Rossby wave and convection

Downwelling Rossby wave is associated with positive SST anomalies.

SST anomalies caused by positive temperature advection and mixed layer deepening

Rossby waves trigger primary events

Temperature advection

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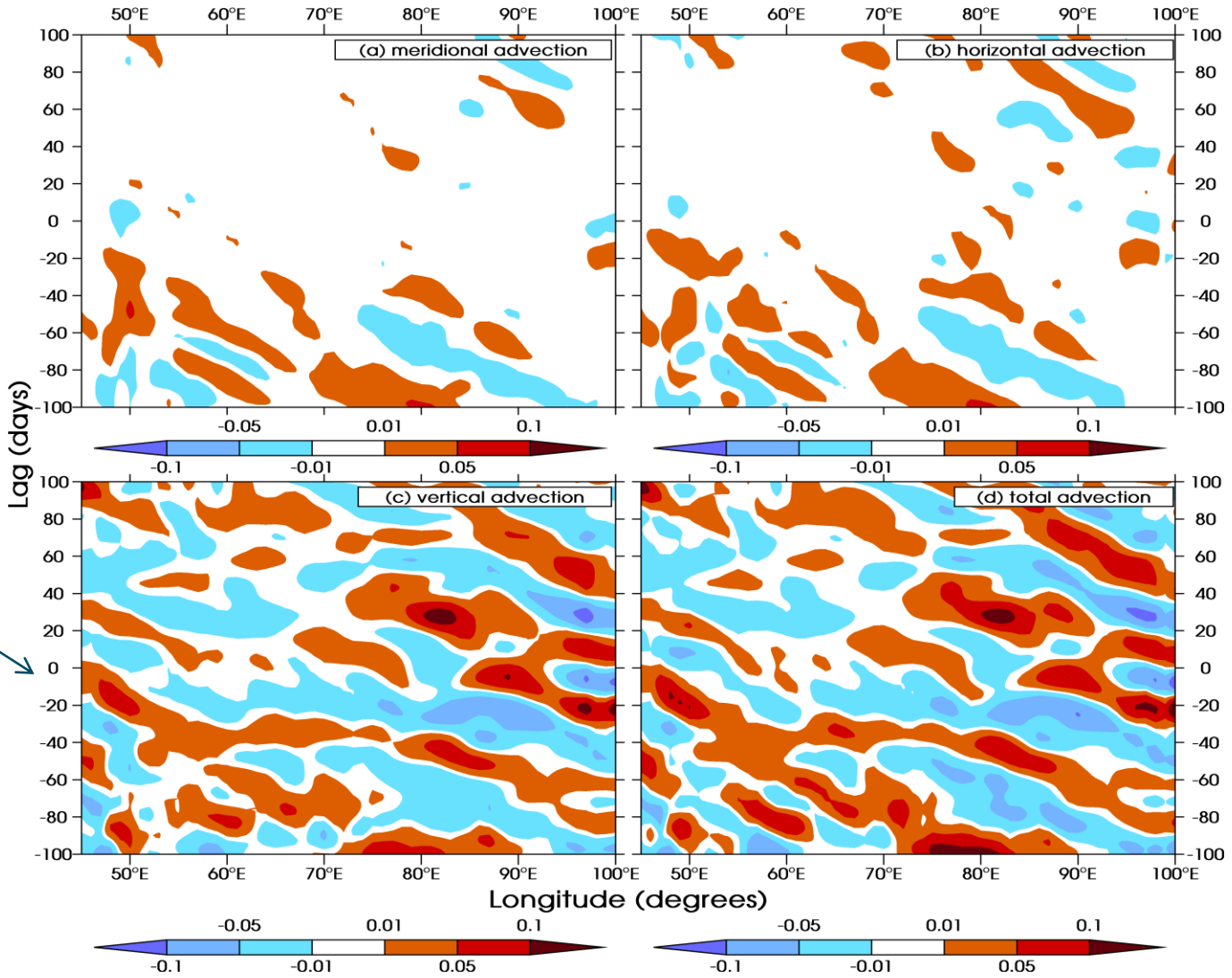
Temperature tendencies per day.

Vertical advection dominates



Primary vs Successive
Comparison of composites

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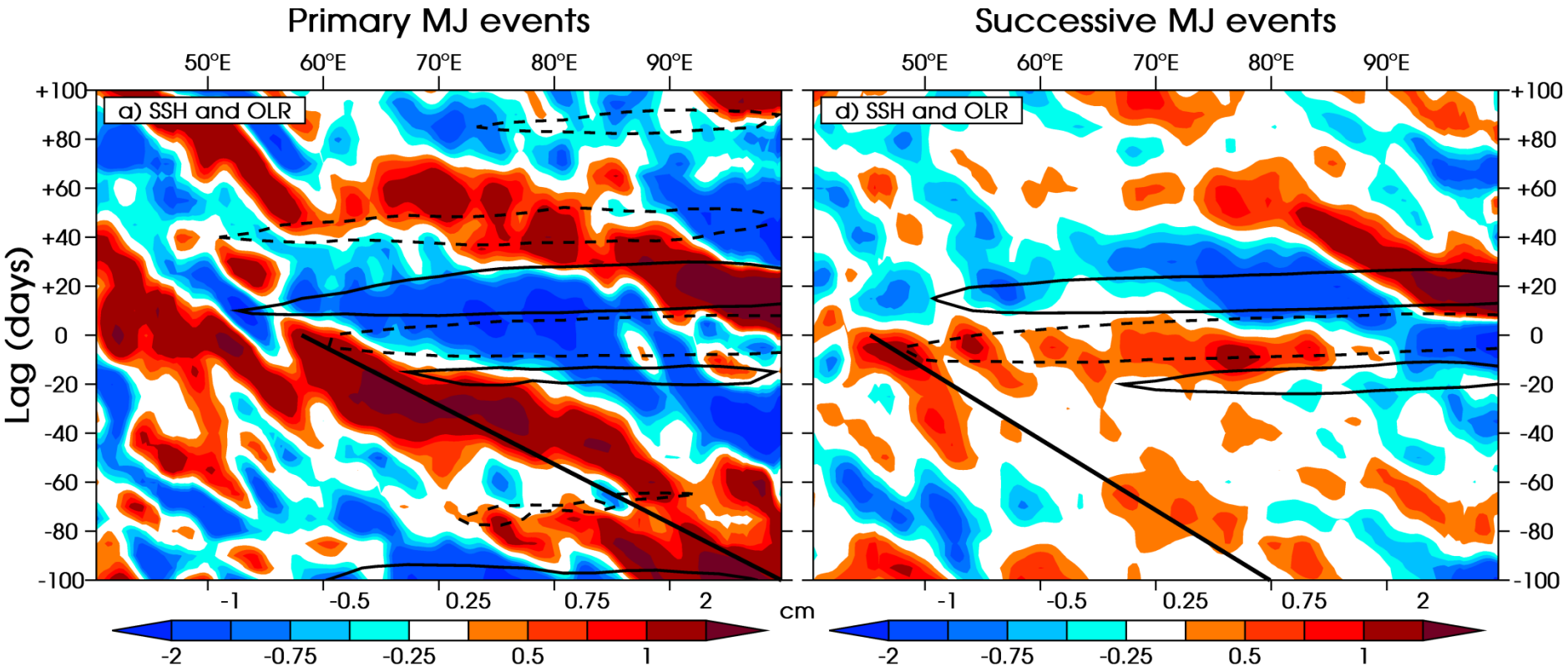
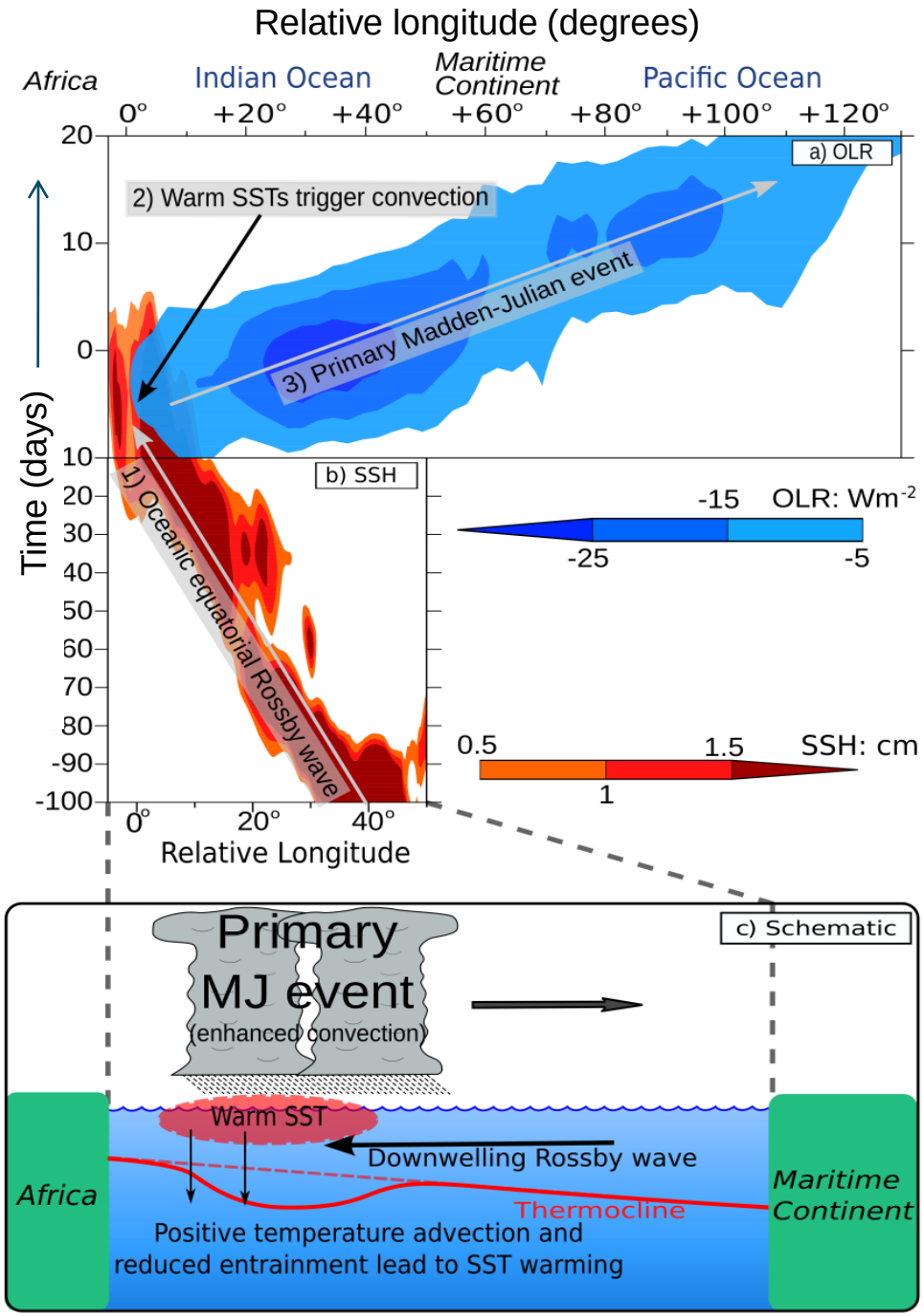


Shading: SSH anomalies (cm) ; Contours: OLR anomalies (W m^{-2})

Primary events are triggered by Rossby waves – Successive events are not



Can primary MJ events be triggered by ocean dynamics?

Yes.

But what triggers the ocean dynamics?

Webber BGM, Matthews AJ, Heywood KJ, Stevens DP (2011) Ocean Rossby waves as a triggering mechanism for primary Madden-Julian events. *Quart. J. Roy. Meteorol. Soc.* Accepted, subject to minor revisions.

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Conclusions

Downwelling **Rossby waves** act as a **trigger** for primary **MJ events**.

These waves are a consistent trigger in both case studies and composites.

The downwelling Rossby waves lead to a **deepening of the mixed layer,** associated with positive horizontal and vertical **temperature advection**.

In addition, the deeper mixed layer will **suppress entrainment** of cold water to the surface

The Rossby waves are therefore associated with **warm SST** anomalies of 0.5-1^{o}C that lead to **convection** and thus trigger primary MJ events.

But what triggers the Rossby waves themselves?

See my J Climate paper..

Webber BGM, Matthews AJ, Heywood KJ, Stevens DP (2011) Dynamical ocean forcing of the Madden-Julian Oscillation at lead times of up to five months. *J. Climate.* In Press.

What triggers the ocean dynamics? Turn to modelling studies to find out

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The model equations:

Zonal (x) momentum:
$$\frac{\partial u}{\partial t} - fv = -\frac{1}{\rho_0 a \cos\phi}\frac{\partial p}{\partial \lambda} + A_h \nabla^2 u + K_m \frac{\partial^2 u}{\partial z^2},$$

Meridional (y) momentum:
$$\frac{\partial v}{\partial t} + fu = -\frac{1}{\rho_0 a}\frac{\partial p}{\partial \phi} + A_h \nabla^2 v + K_m \frac{\partial^2 v}{\partial z^2},$$

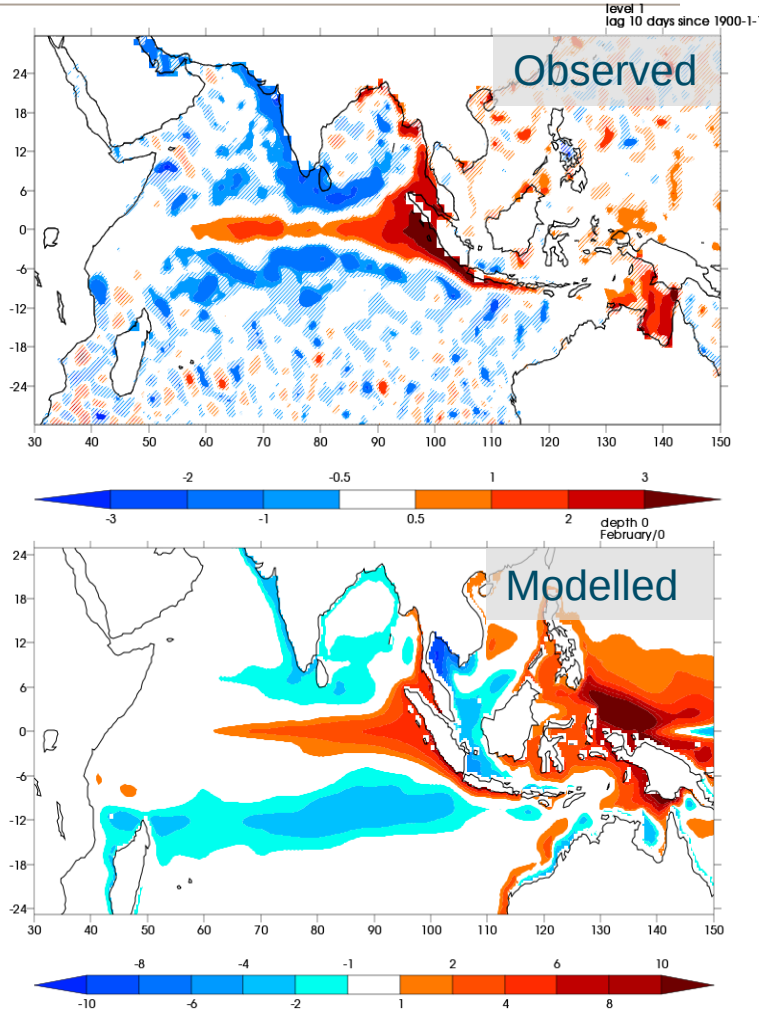
Hydrostatic balance:
$$\frac{\partial p}{\partial z} = -\rho g,$$

Mass conservation:
$$\frac{1}{a\cos\phi}\frac{\partial u}{\partial \lambda} + \frac{1}{a\cos\phi}\frac{\partial}{\partial \phi}(v\cos\phi) + \frac{\partial w}{\partial z} = 0,$$

Thermodynamic equation: (for density)
$$\frac{\partial \rho}{\partial t} + w\frac{\partial \overline{\rho}}{\partial z} = K_h \frac{\partial^2 \rho}{\partial z^2},$$

The model is linearised about a resting basic state. There are no currents or surface fluxes (apart from wind stress).

It simulates Kelvin and Rossby waves (rather well).



Sea surface height (SSH; cm)

Modelling: case study primary MJ event

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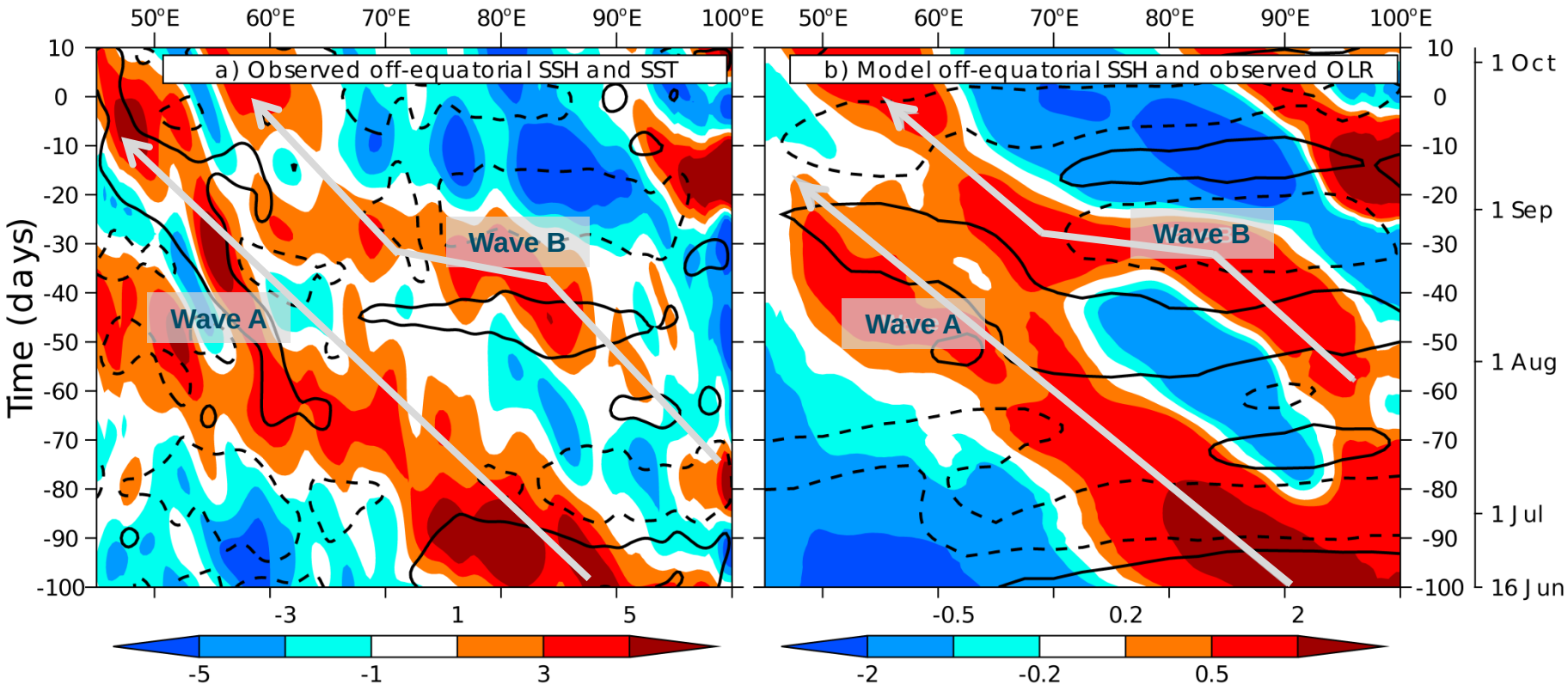
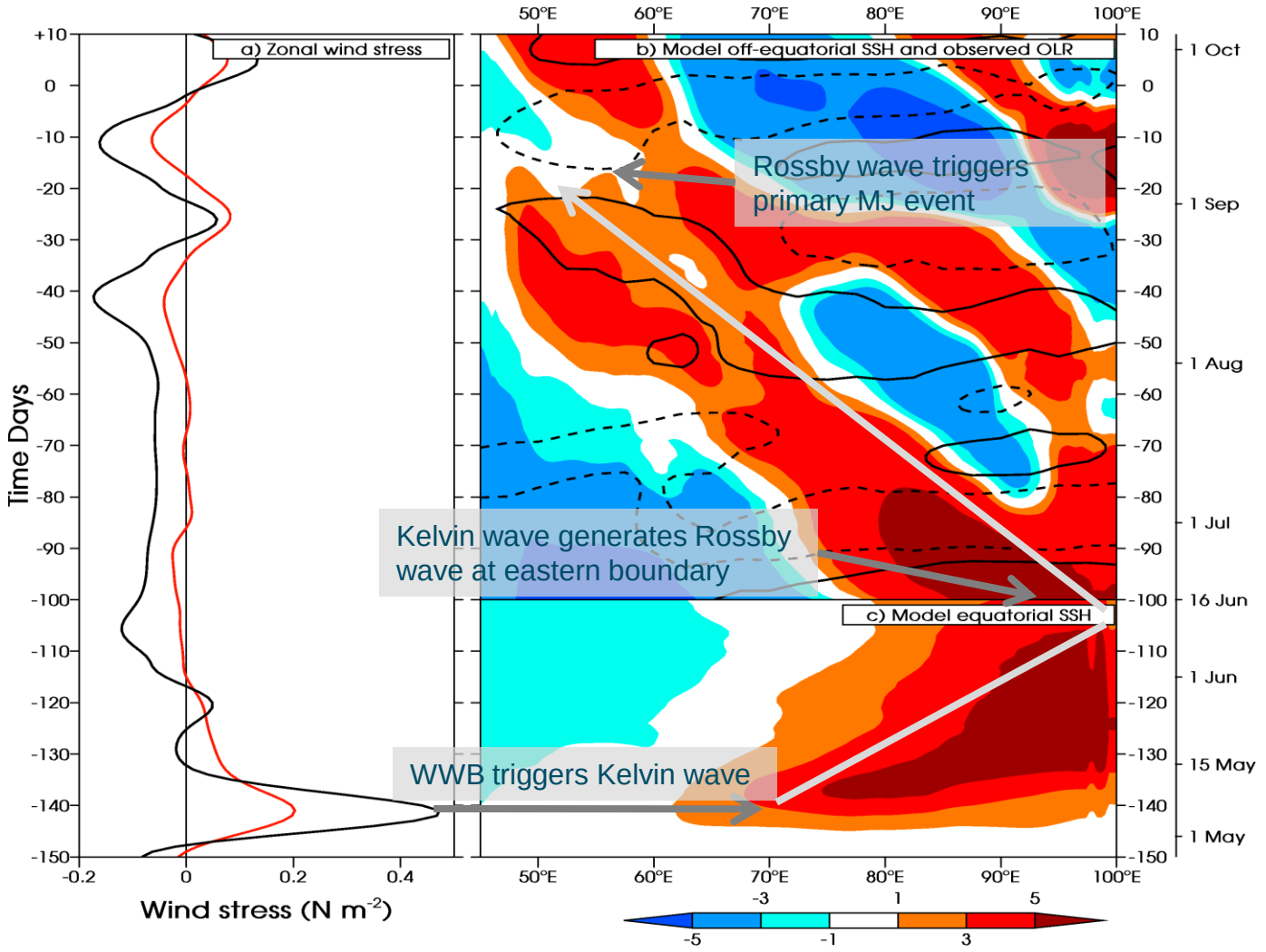


Model forced by observed winds over the 150 days leading up to the primary event of 24 September 2004. Model SSH closely matches observations.

Modelling: case study primary MJ event

Therefore, the westerly wind burst in May forces a response in the ocean dynamics that triggers MJO activity 140 days (almost 5 months) later.

But how important is the more recent wind forcing?



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Modelling: sensitivity to length of wind forcing

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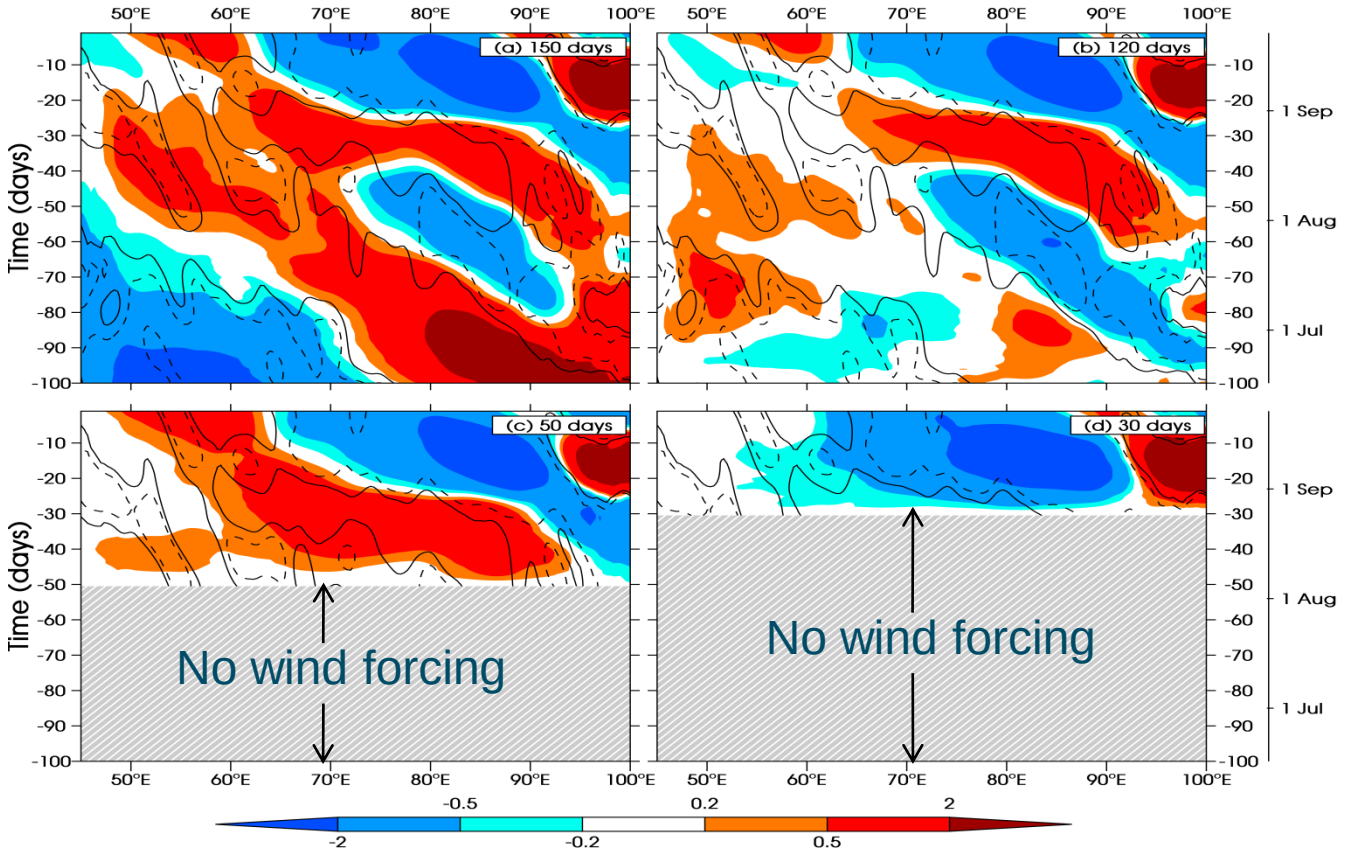

Shorter periods of wind forcing do not reproduce the observed ocean dynamics. Thus we can conclude that the integration of wind forcing events over the preceding 150 days **is** important.

Re-emergence of ocean dynamics

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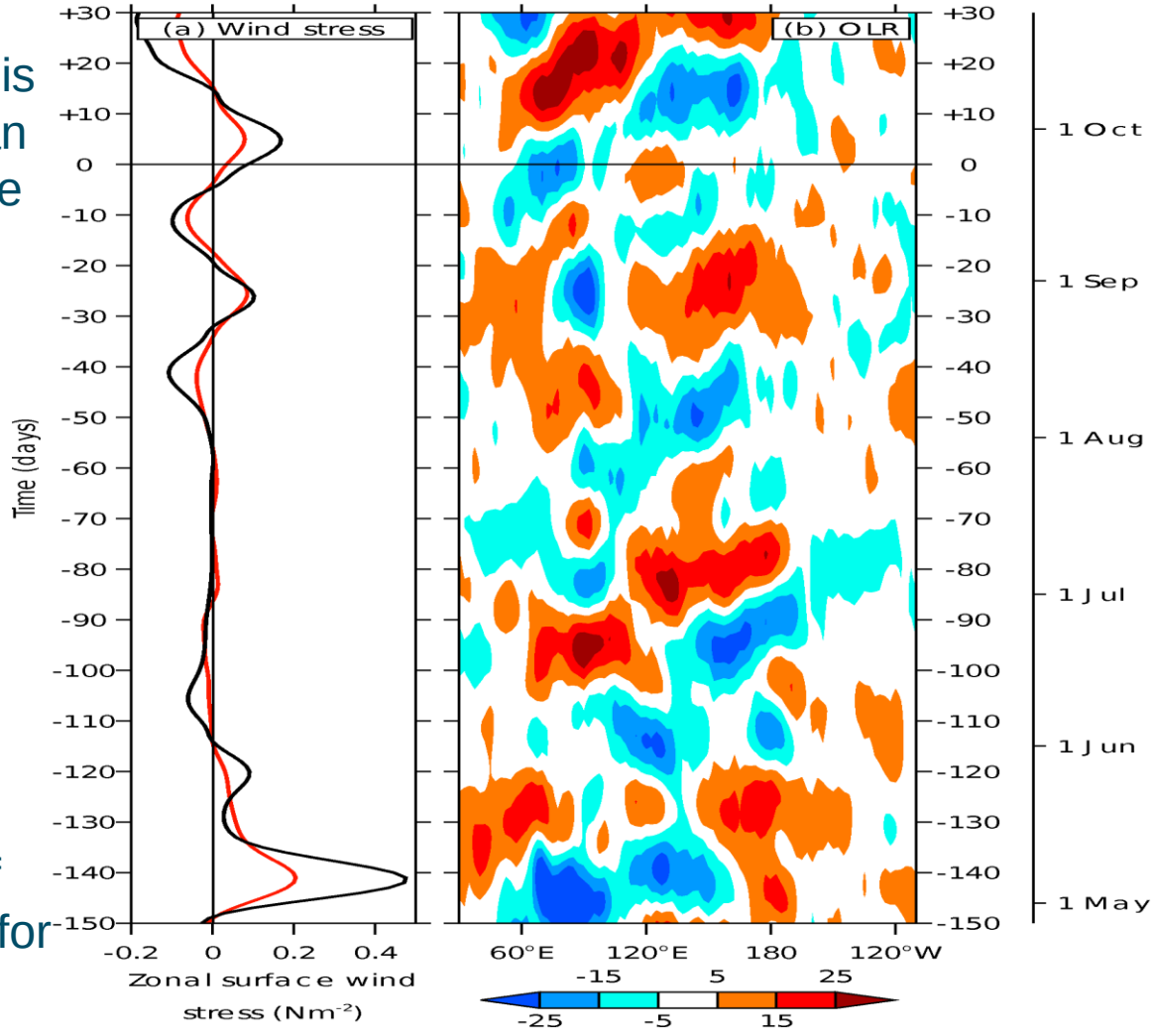
The **westerly wind burst** that is the original trigger for the ocean dynamics is associated with the **last strong MJ event before the summer** (when the MJO moves north off the equator).

Thus, one MJ event can influence another almost 5 months later, after **re-emergence** of the dynamical ocean signal in the western Indian Ocean.

This suggests the possibility of unprecedented **predictability** for the MJO



Conclusions

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- Downwelling Rossby waves can **trigger primary MJ events.**
- These waves are associated with large **warm SST** anomalies
- The waves appear to originate through reflection at the eastern boundary.
- The ocean dynamics integrate the **surface wind stress** forcing over periods of up to **five months**.
- This suggests the potential for **unprecedented predictability** of the MJO.