Integrated Multi-mission Satellite Altimetry data in Climatic Studies- Detection of the Madden-Julian Oscillations

Subramanyam Bulusu
Satellite Oceanography Laboratory
Marine Science Program &
Department of Earth and Ocean Sciences
University of South Carolina
sbulusu@geol.sc.edu

Gary Grunseich, University of Hawaii

This work is supported by the NASA Physical Oceanography Program

MJO Background

30-80 day oscillation

Reduced cloud-cover.

Enhanced convection.

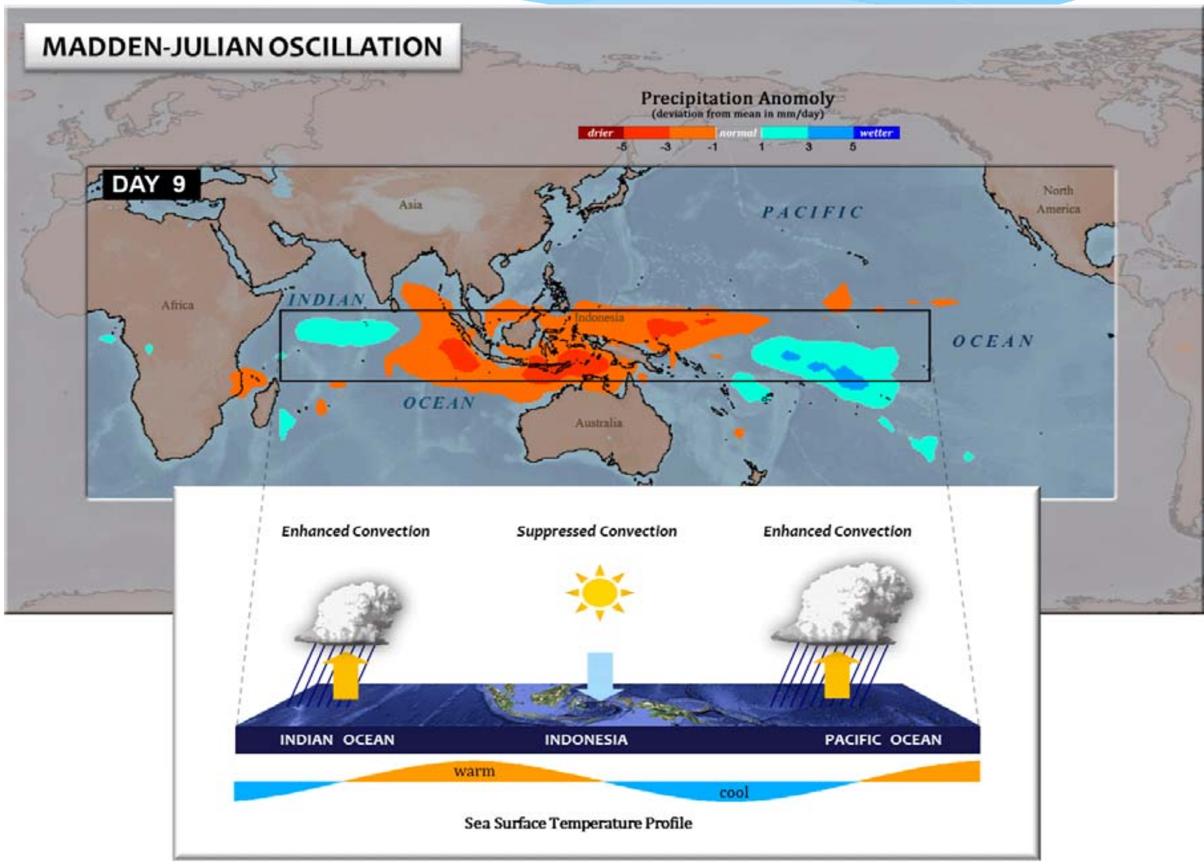
Equatorially trapped.

Travels eastward.

Strong air-sea coupling.

Propagates at a rate of 3-5 ms^{-1} and gradually weakens when it reaches the central Pacific.

Commonly defined using OLR(Outgoing Longwave Radiation) as a proxy for atmospheric conditions.



This illustration shows a moment in the evolution of the Madden-Julian Oscillation, a complex process involving sea surface temperatures and their influence on atmospheric processes. (©UCAR. Illustration by Lex Ivey, based on data from Adrian Matthews.)

MJO Background

Rossby Waves

Travel westward

c < 0.8 ms^{-1}

Upwelling: **shallow mixed layer**

Negative SSH anomaly

Downwelling: **deep mixed layer**

Positive SSH anomaly

Kelvin Waves

Travel eastward

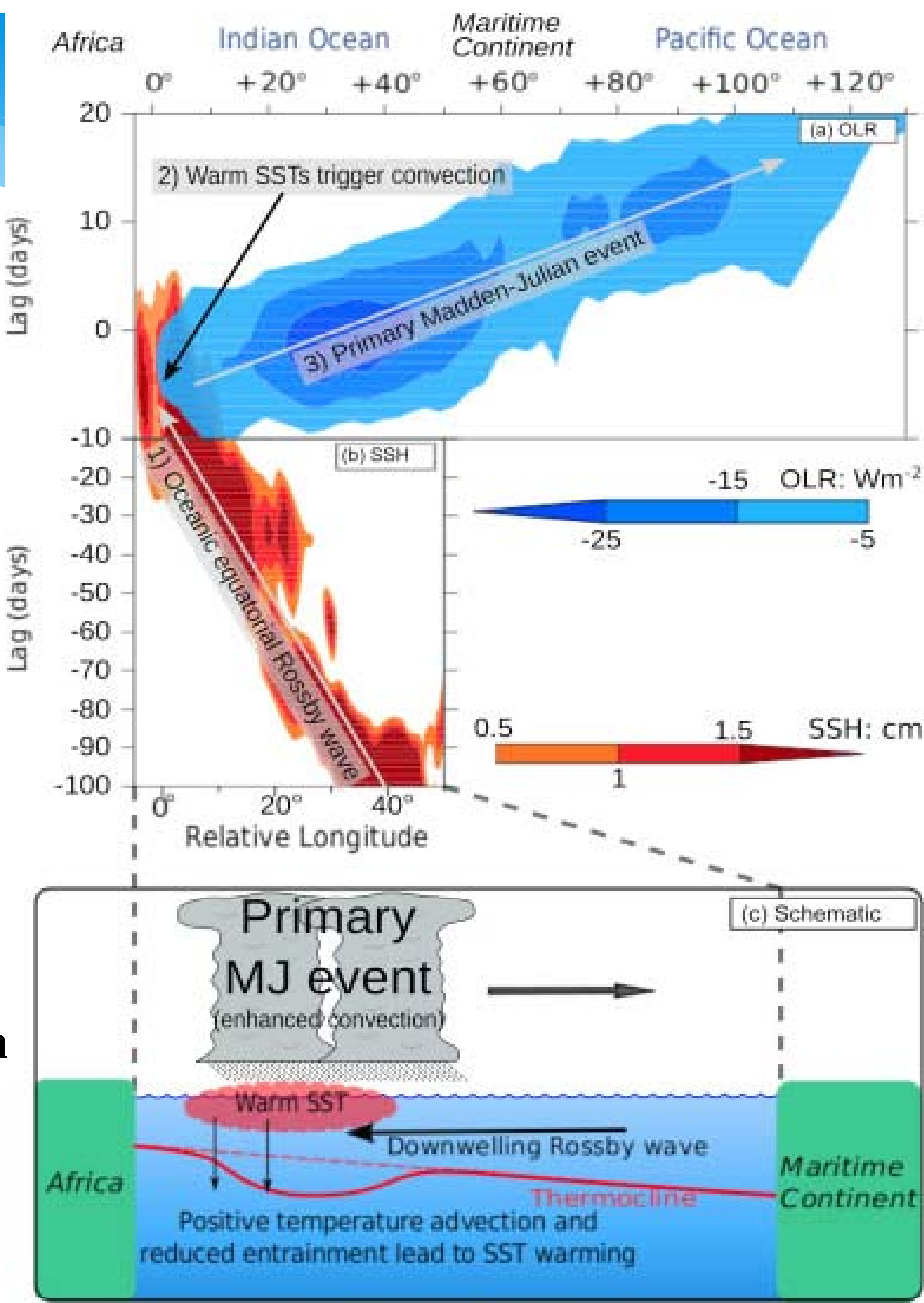
Equatorially trapped

Smaller SSH amplitudes

c ~ 3 ms^{-1}

Downwelling Rossby waves have been shown to initiate convection associated with the MJO.

Webber et al., 2011



MJO & OLR

OLR is a measure of the amount of radiation leaving earth's surface and can be used as a proxy for atmospheric conditions.

When the atmosphere has reduced cloud cover and clear skies, high amounts of radiation reach the satellite. However, when cloud cover is enhanced and there is convective activity, the OLR reaching the satellite is reduced.

During the active phase of the MJO propagation, enhanced convection reduces the amount of radiation reaching the satellite, while during the inactive phase (suppressed cloud-cover), the amount of radiation reaching the satellite is increased.

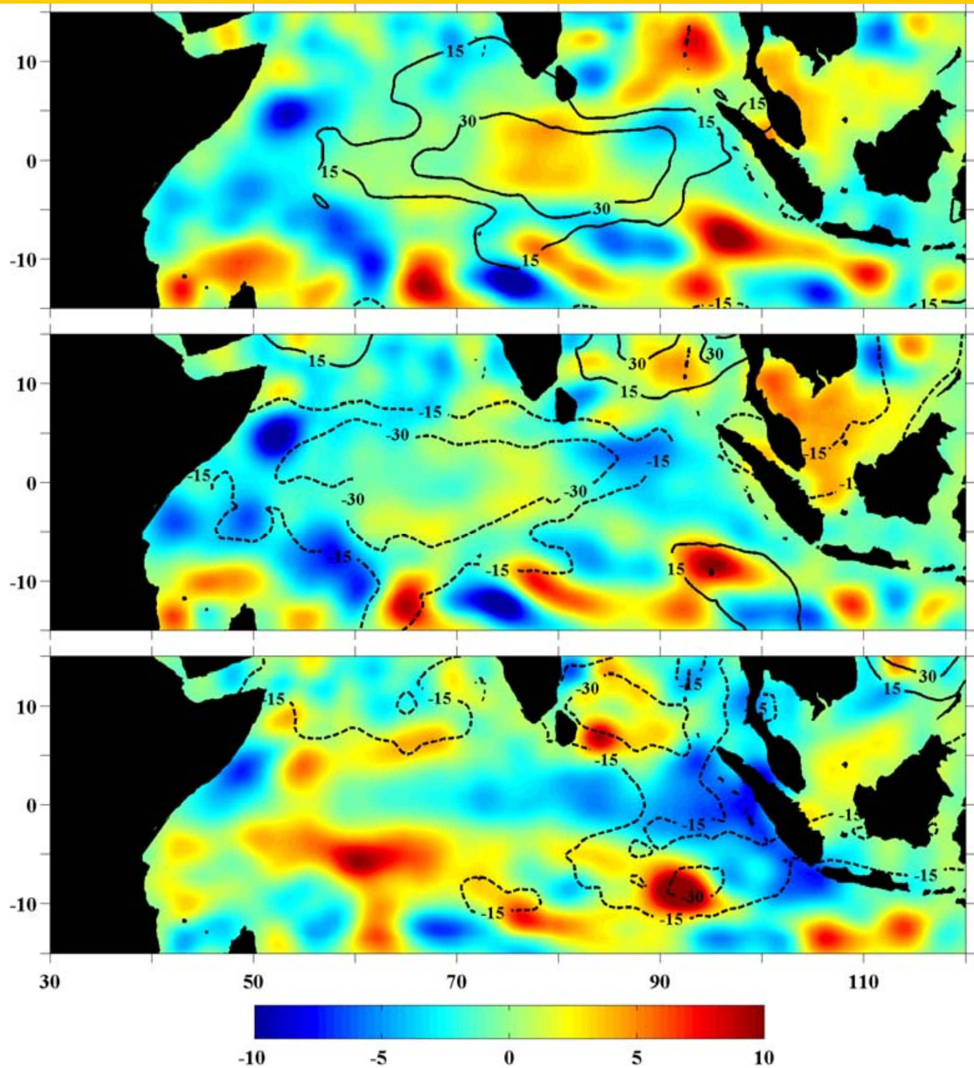
This relationship can be used to monitor which phase of the MJO is occurring at a particular location in the tropics.

MJO & SSH

Satellite altimetry derived Sea Surface Height (SSH) allows us to observe longwave features such as Kelvin and Rossby waves.

The atmospheric forcing (through anomalous wind and convective activity) different stages of the MJO can force Kelvin waves in the equatorial regions of the Indian and Pacific Oceans. These Kelvin waves alter the SSH on the order of several centimeters.

Different Stages of MJO



Different stages of a MJO propagation during April 20, 2002 (top), May 10, 2002 (middle), and May 25, 2002 (bottom) in the tropical Indian Ocean. The background color shows the satellite derived Sea Surface Height (SSH) in cm while the contours represent interpolated Outgoing Longwave Radiation (OLR) in W/m².

MJO-related activity is observed in both parameters in the tropical Indian Ocean indicating a unique interaction in this region. This figure represents the importance of altimetric SSH in understanding various scales of climate phenomena.

MJO and Equatorial Rossby Waves

Downwelling Rossby waves (red)

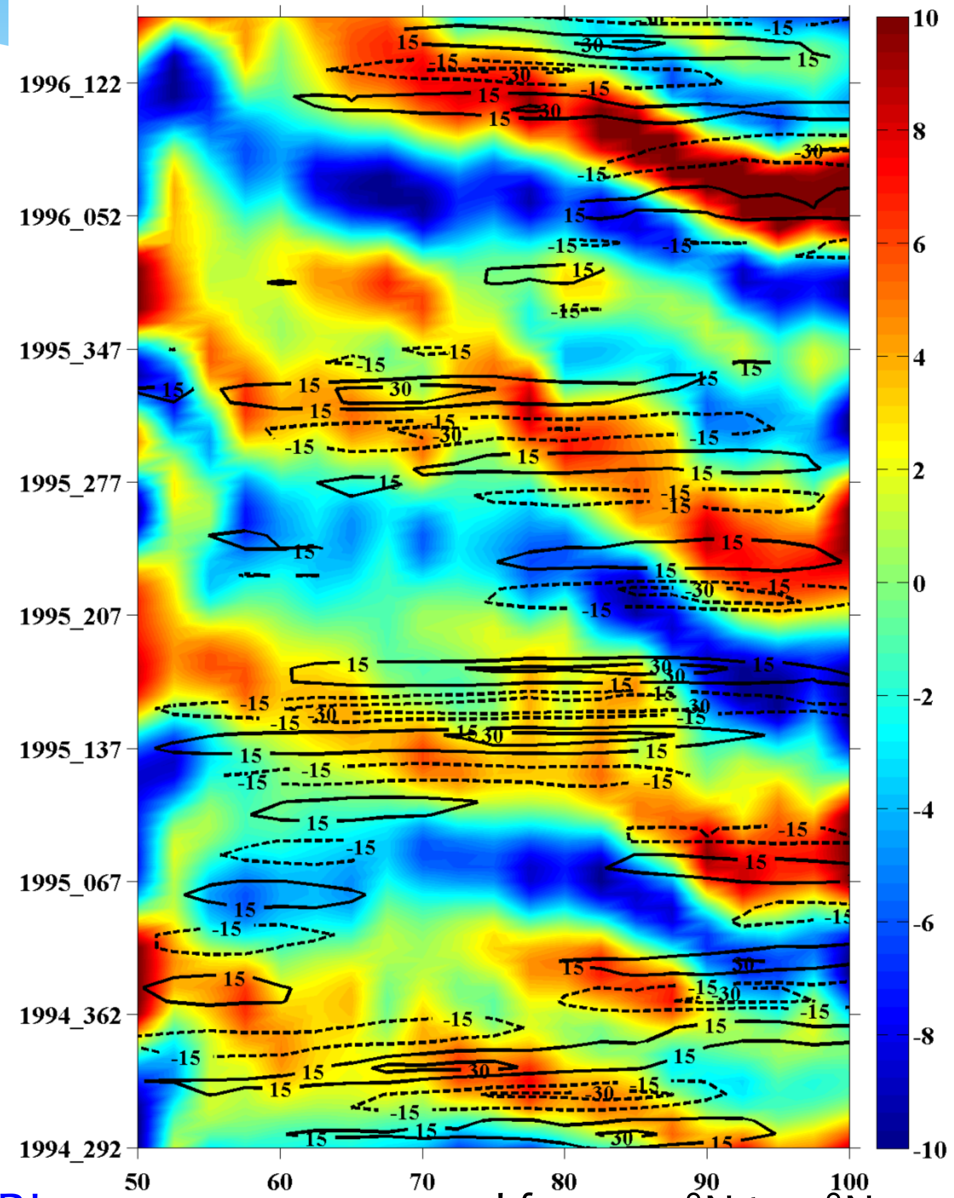
In central Indian Ocean correspond with strong OLR anomalies. OLR anomalies also propagate across entire basin.

Upwelling Rossby waves (blue)

Correspond with weak OLR anomalies. Propagation does not extend across entire basin.

Different phases of Rossby waves lead to conditions that could enhance or suppress MJO activity.

MJO activity is enhanced in western Indian Ocean during positive IOD due to downwelling.



averaged from 2.5°N to 5°N.

Grunseich & Subrahmanyam, 2013 IEEE GSRL

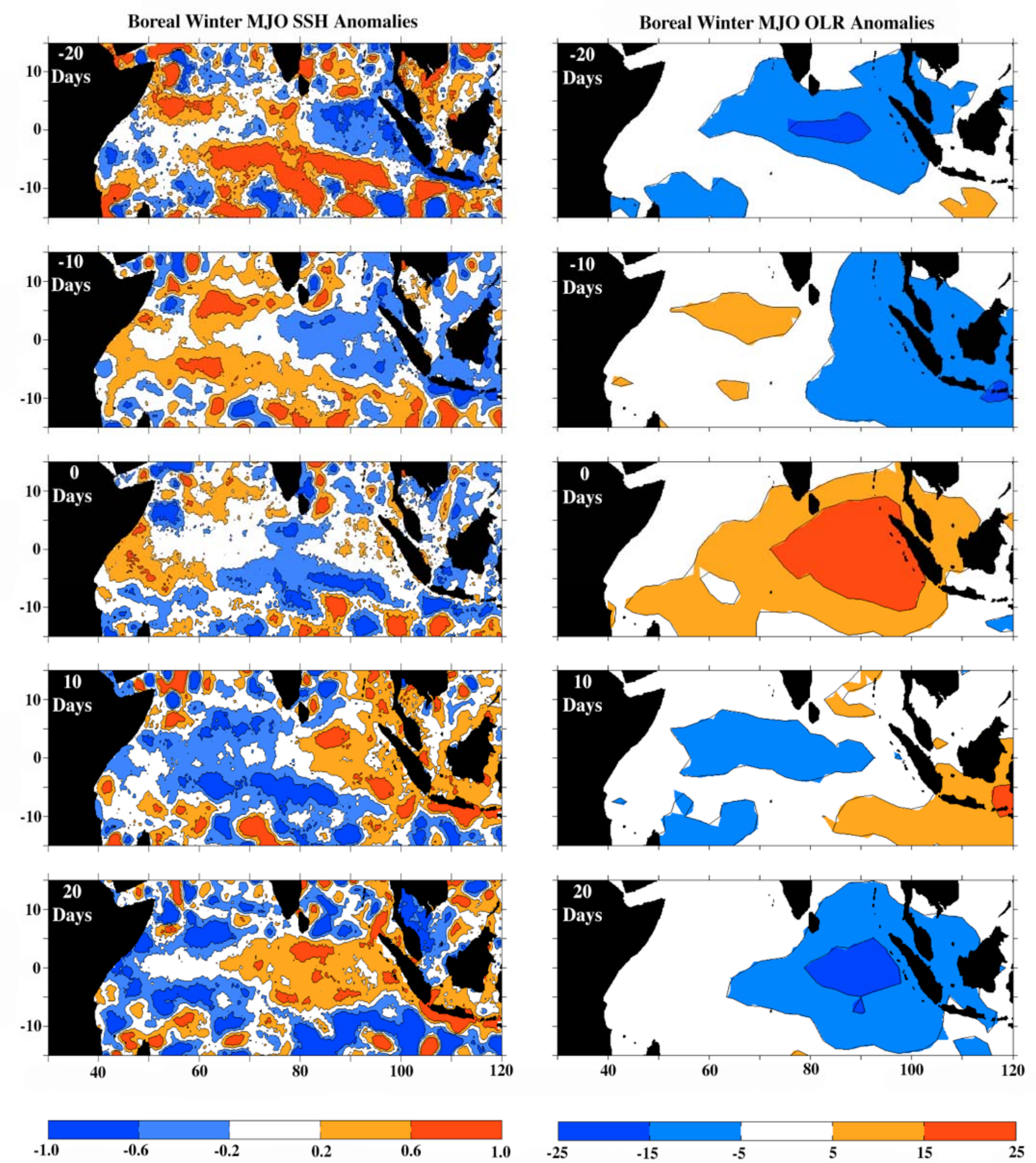
Boreal Winter MJO

Peaks in positive OLR anomalies at 0°, 90°E were used to define day 0.

Data 10 and 20 days before and after the peak in OLR were then isolated to exhibit an entire MJO propagation across the Indian Ocean during the boreal winter months when the atmospheric component of the MJO is strongest.

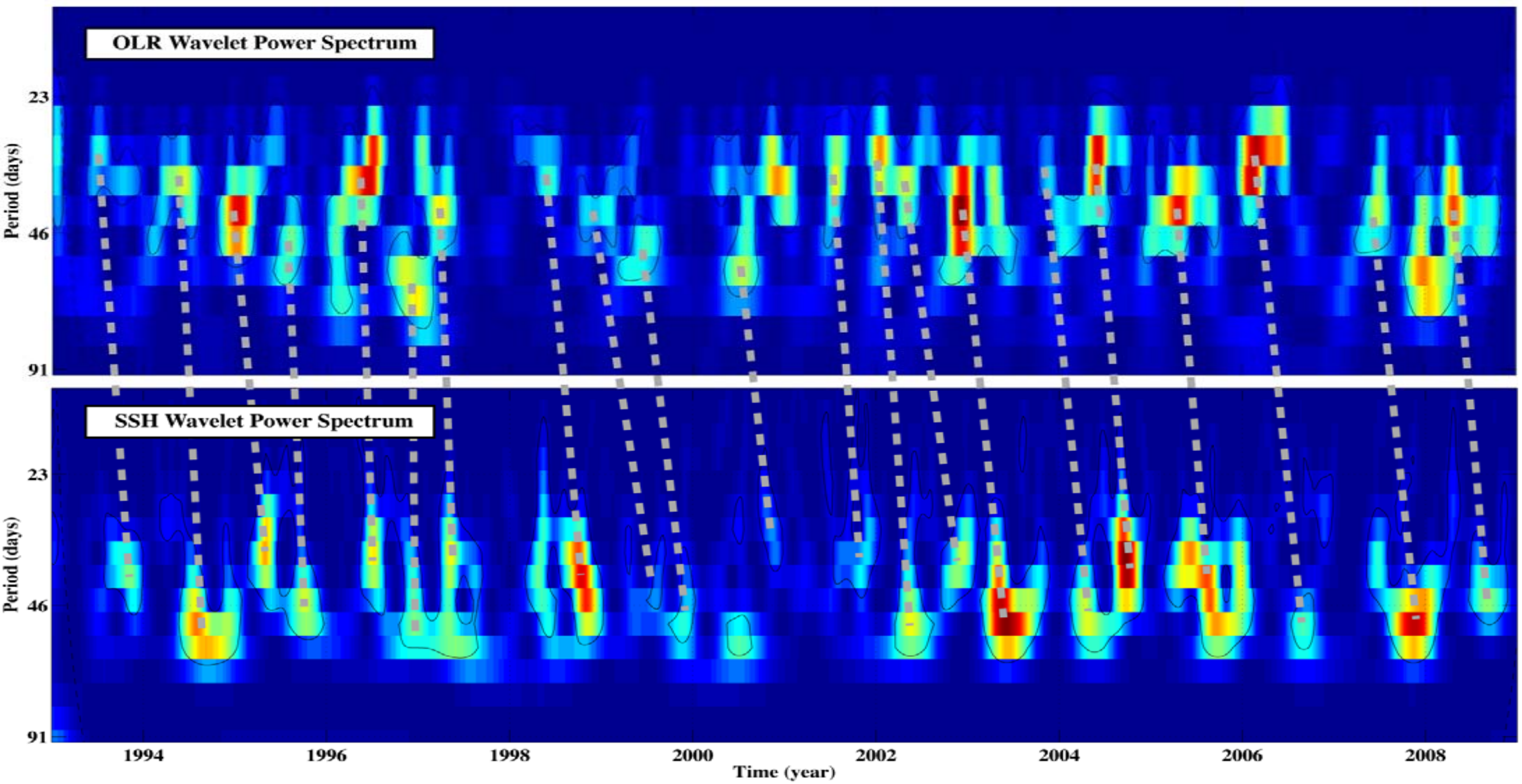
During lag -20 days, an upwelling Rossby wave forms off the coast of Indonesia (left) and propagates westward across the equatorial Indian Ocean reaching the African coast by lag 10 days.

Also during the 20 day lag, a downwelling Rossby wave can be observed in the central tropical Indian Ocean lasting through the day 0 lag.



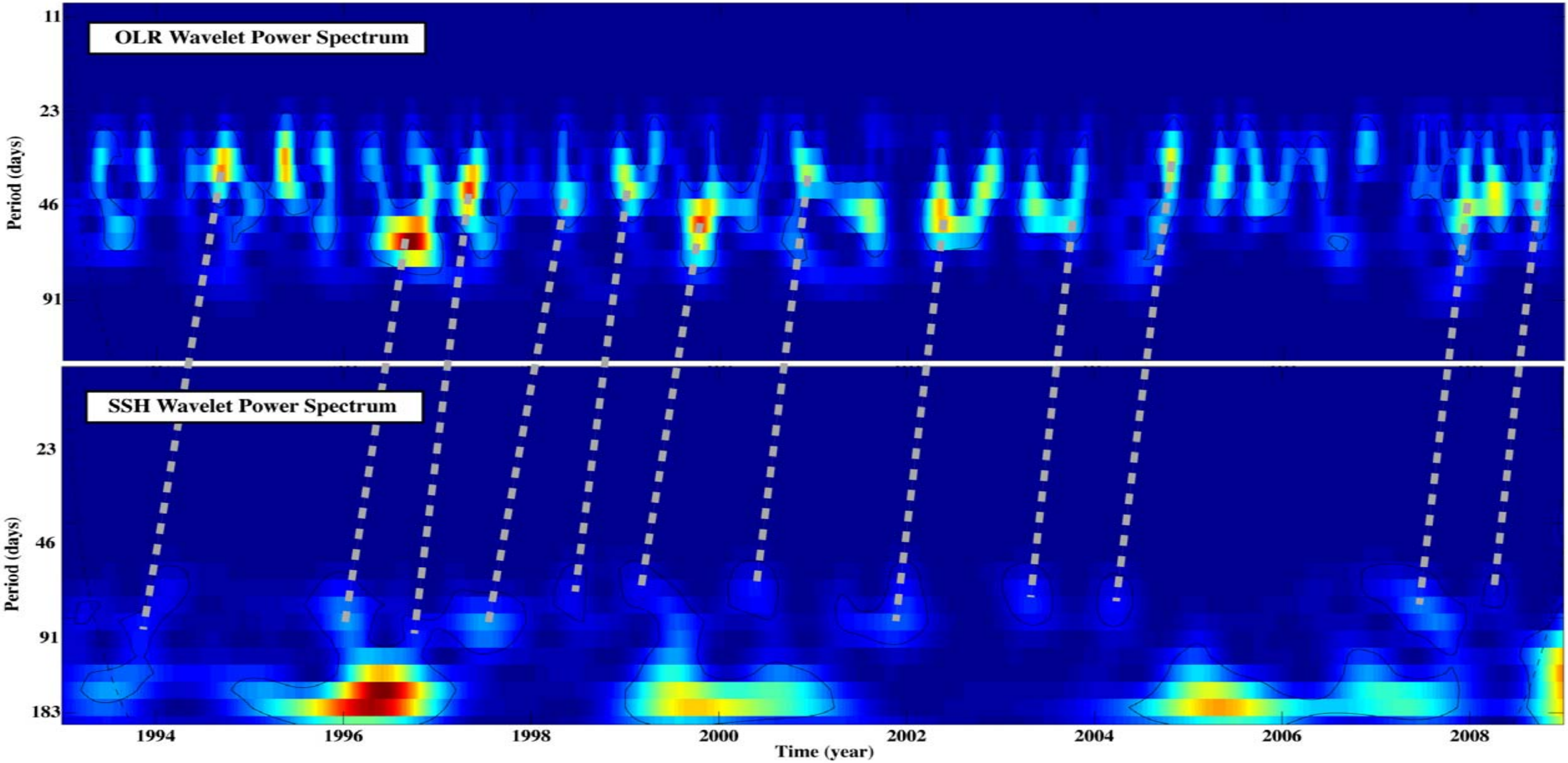
MJO and Equatorial Kelvin Waves

Analysis performed at 0°, 90°E
21 strong MJO related peaks in OLR.
Each peak corresponds to lagged Kelvin wave activity.



The average lag of 51 days correspond to roughly one complete MJO propagation indicating that **one MJO propagation may be necessary to create the oceanic conditions that invoke a Kelvin wave response in sea surface height.**

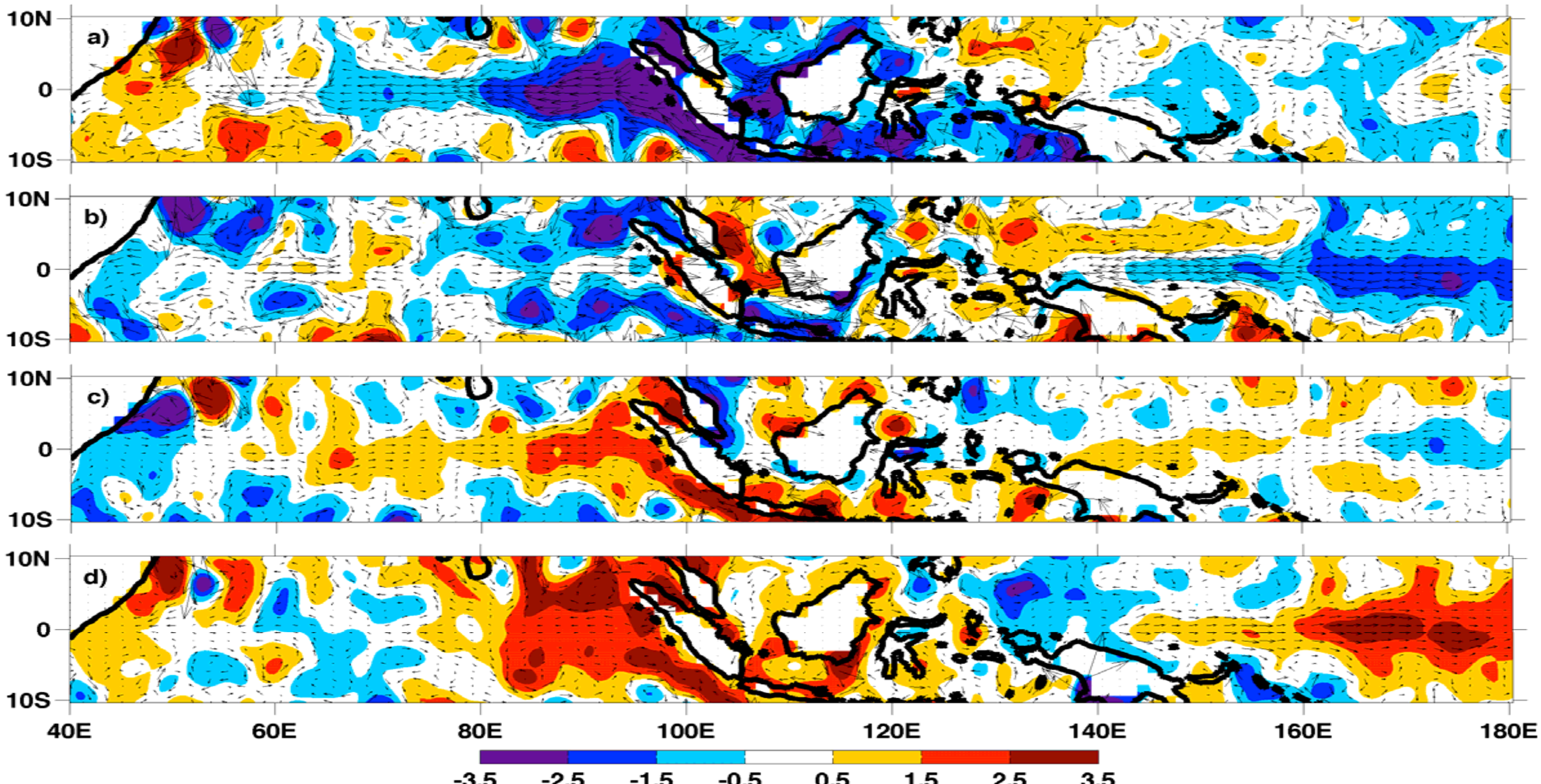
The time between SSH and OLR peaks in spectral activity shows that when SSH lags peaks in OLR, there is on average a lag time of 51 days between the peaks compared to 86 days when OLR lags SSH peaks.



Wavelet analysis of OLR and SSH averaged for 2.5°N-5°N, 65°E-70°E. Corresponding pulses in peak MJO related activity in OLR and Rossby wave activity in SSH are shown using grey dashed lines.

peaks in MJO related activity in OLR and Rossby wave activity in SSH indicate that during and shortly after 12 strong periods of Rossby wave activity a strong atmospheric MJO response is induced. This could be due to different phases of Rossby wave propagations in this region reinforcing the conditions necessary to trigger enhanced convection or suppressed cloud cover during MJO propagations.

MJO using altimetry data during Aquarius period (Sep 2011-Dec 2012)



Altimetry derived Sea Surface Height anomalies during different stages of the MJO propagation in (Sep 2011-April 2013). Composite dates are based on peak negative OLR anomalies arriving at a) 60°E and b) 90°E. Dates of subsequent peak positive SSH anomalies at c) 60°E and d) 90°E are composited to complete an entire convective propagation. Altimetry current vectors are overlaid.

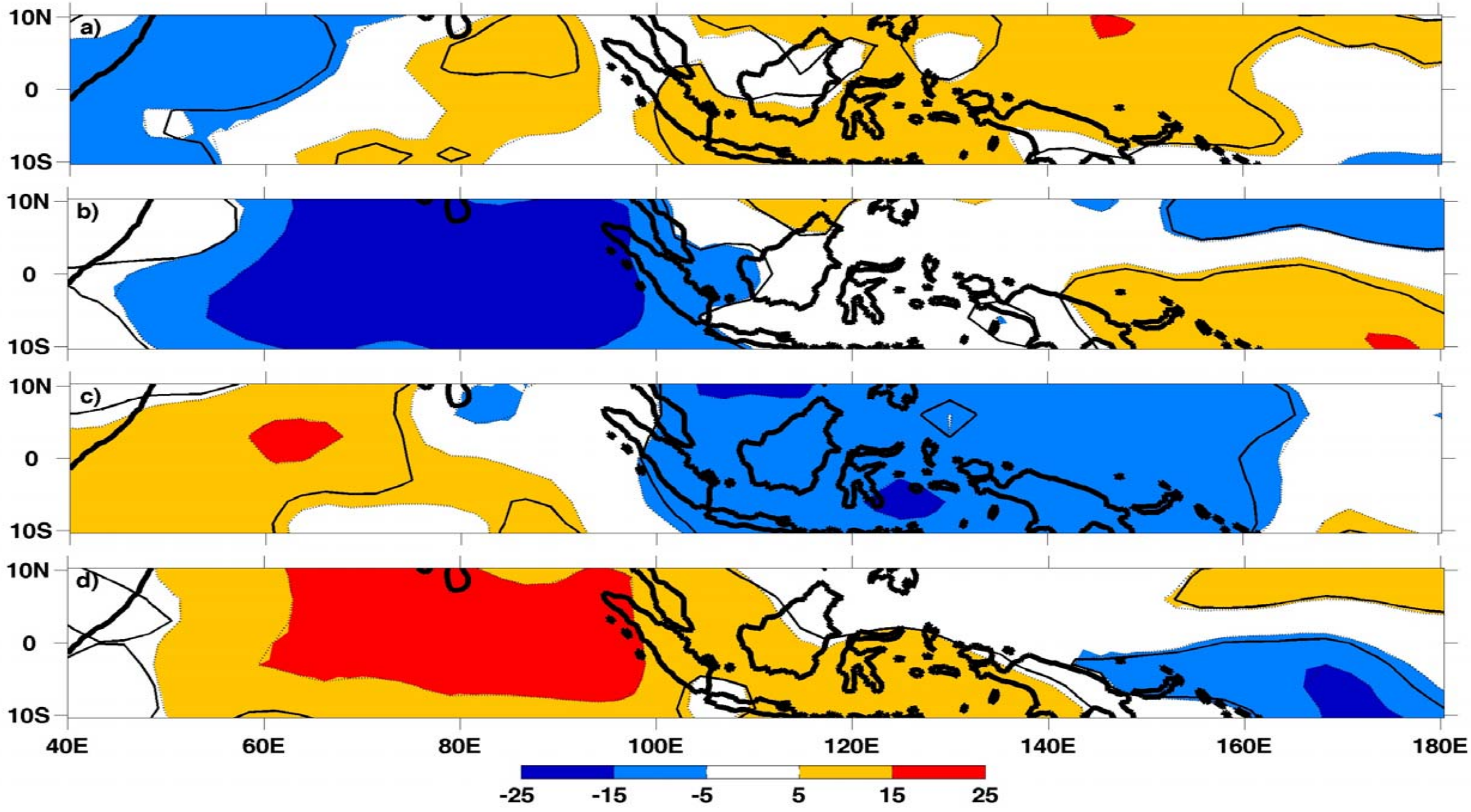
MJO & Sea Surface Salinity

Sea Surface Salinity (SSS) is affected by the different stages of the MJO through anomalous atmospheric and oceanic conditions depending upon the season.

During the **boreal winter** the atmospheric component of the **MJO is stronger and therefore SSS responds mainly to enhanced evaporation and precipitation** during the different stages of the MJO.

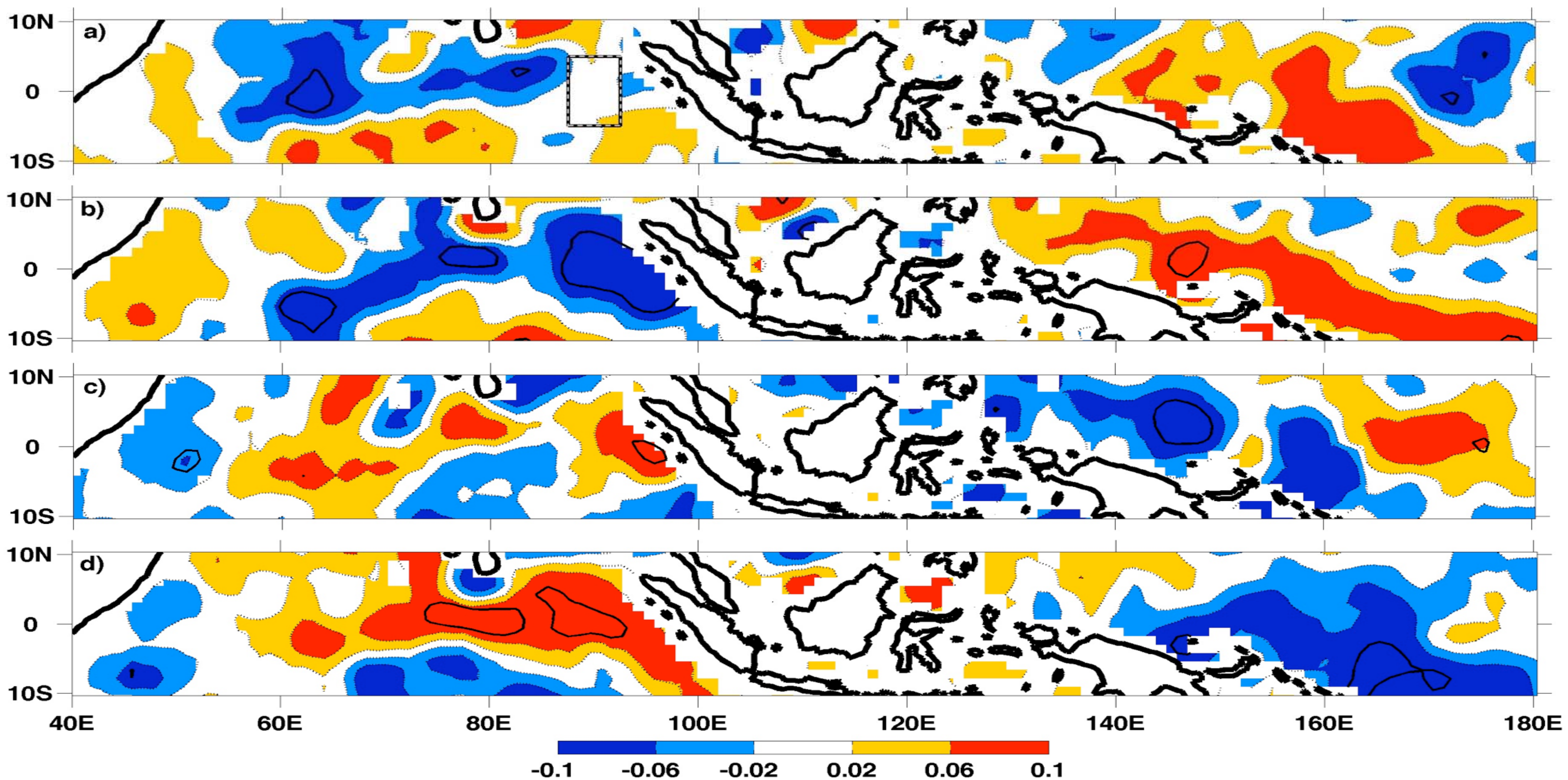
During the **boreal summer not only does SSS respond to evaporation and precipitation during the different stages of the MJO, it is also influenced by changes in surface currents** invoked by the winds during each phase. (e.g These currents advect low salinity waters out of the Bay of Bengal and also invoke equatorial upwelling of high salinity waters, thus changing the SSS patterns).

OLR anomalies

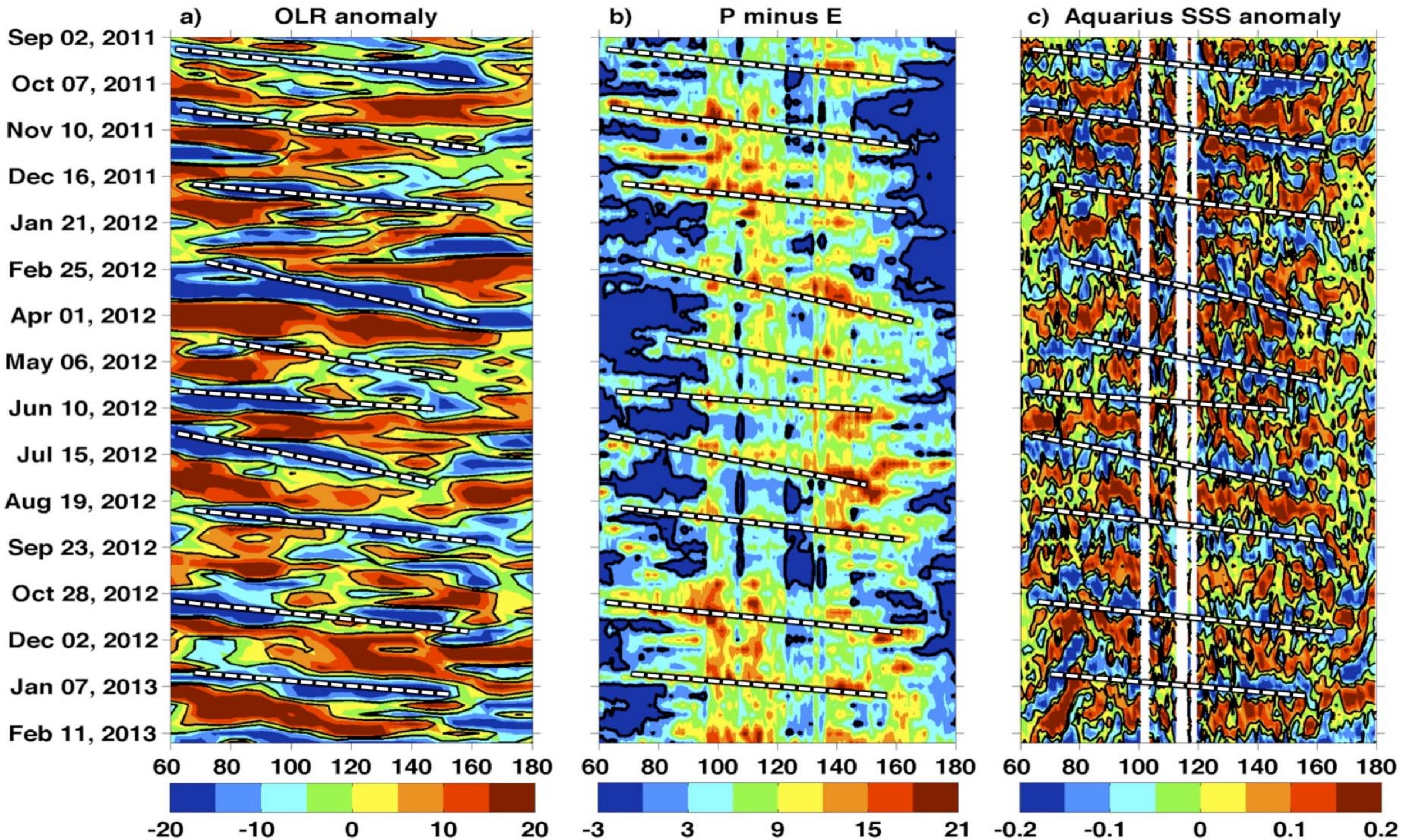


Composites of OLR anomalies (W/m²) during different stages of the MJO propagation. Composite dates are based on peak negative OLR anomalies arriving at a) 60°E and b) 90°E. Dates of subsequent peak positive OLR anomalies at c) 60°E and d) 90°E are composited to complete an entire convective propagation. Statistically significant anomalies at the 90% level are indicated with solid contours.

Aquarius Salinity anomalies

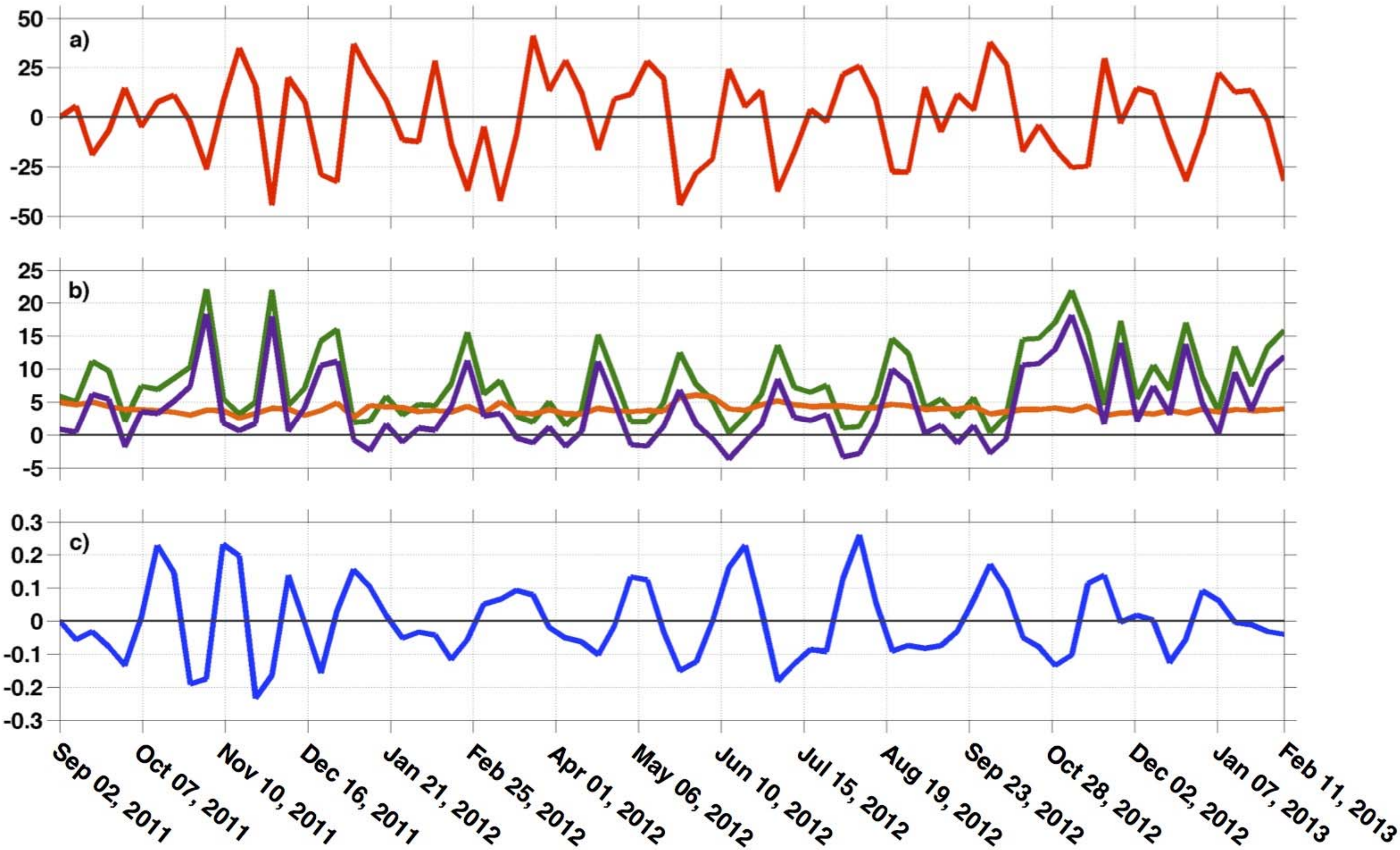


Composites of SSS anomalies during different stages of the MJO propagation. Composite dates are based on peak negative OLR anomalies arriving at a) 60°E and b) 90°E. Dates of subsequent peak positive OLR anomalies at c) 60°E and d) 90°E are composited to complete an entire convective propagation. Statistically significant anomalies at the 90% level are indicated with solid contours. The box in a) represents the region where spatial averages are taken (5°S to 5°N, 87.5°E to 92.5°E).



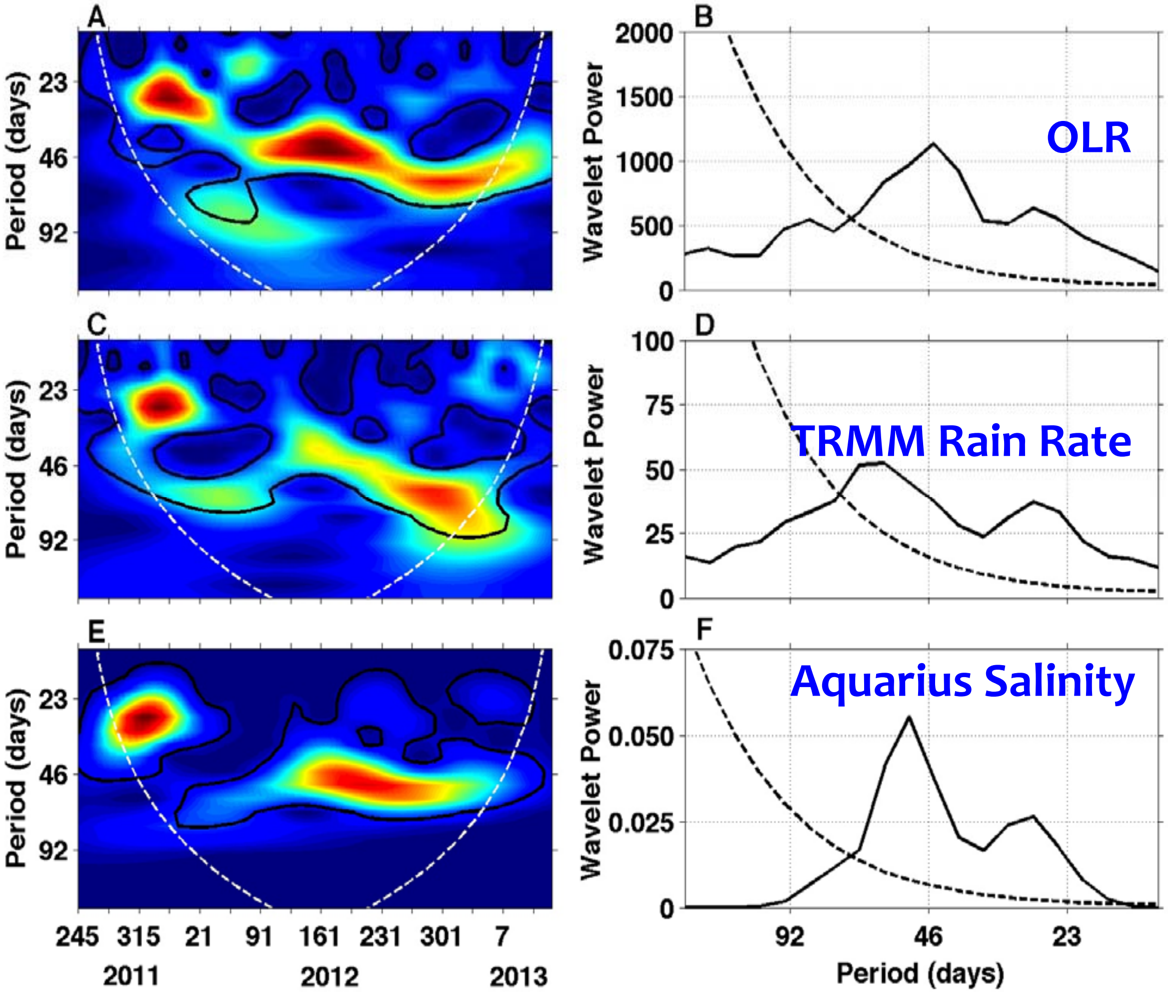
Hovmoller diagrams of a) filtered OLR (W/m²), b) TRMM rain rate (mm/day) and c) filtered Aquarius SSS. Data are averaged over 5°S to 5°N for each longitudinal point. White dashed lines mark the 10 convective phases of the MJO that were identified during this time period.

Grunseich, Subrahmanyam, and Wang 2013 GRL



Time series of a) filtered OLR (W/m²), b) precipitation (green), evaporation (orange), and precipitation minus evaporation (purple) (mm/day), and c) filtered Aquarius SSS averaged over 5°S to 5°N, 87.5°E to 92.5°E.

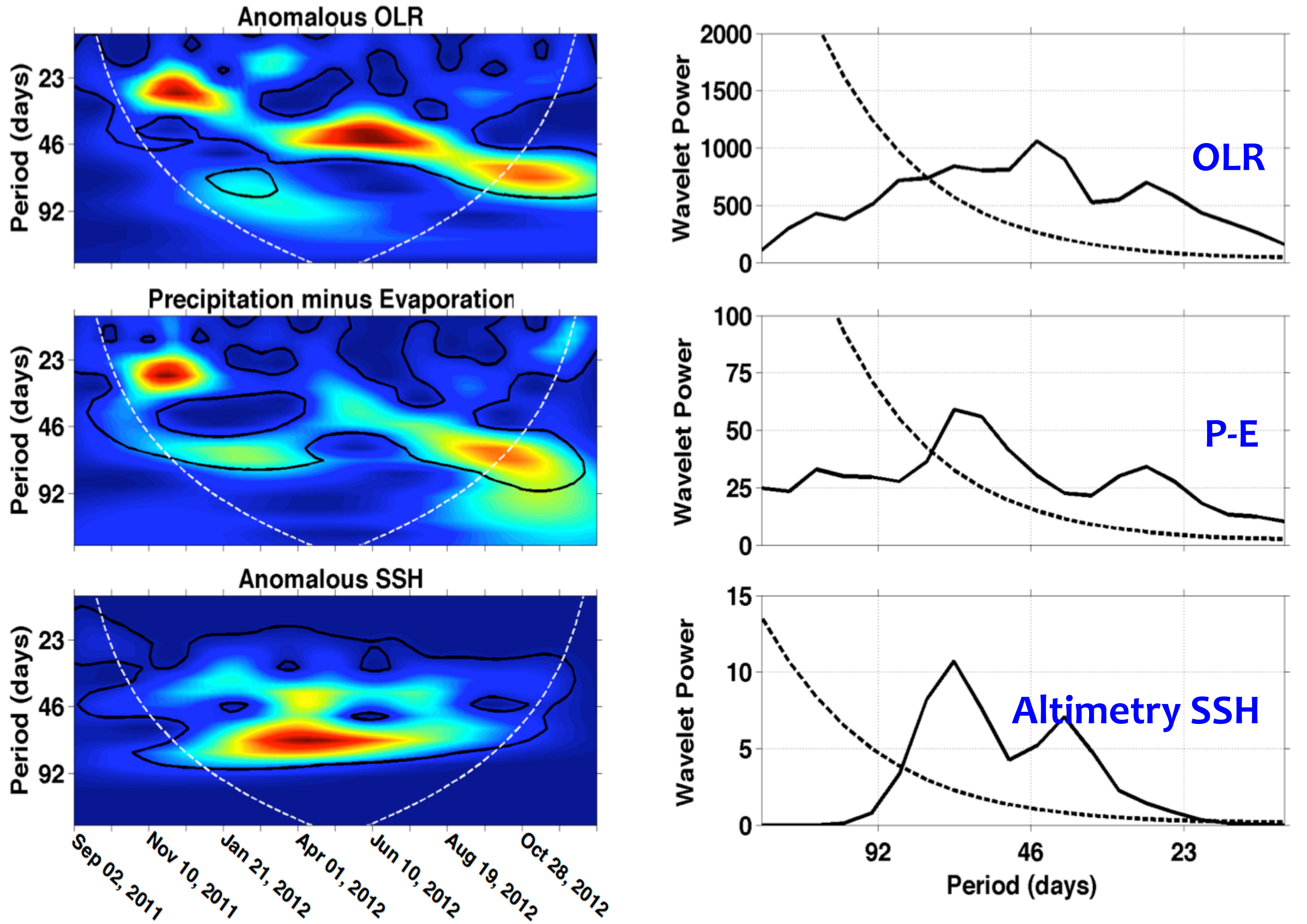
Wavelet Transforms OLR, P and Aquarius Salinity



Averaged over 5°S to 5°N, 87.5°E to 93.5°E

1. Weak MJO activity occurring 2011 and early 2012. The remainder of 2012 shows strong MJO.
2. Wavelet analysis of OLR shows strong activity at 44.5 days in the middle of 2012 and lengthens to 57 days.
3. A similar trend is observed in the rain rate time series with MJO activity in the middle of 2012 focused on a 39-day period and shifting to a strong 57-day period in late 2012.
4. The strengthening of the rain rate signal in the latter half of 2012, could likely be due to the seasonal shift in propagation direction of the MJO.
5. The filtered SSS time series shows consistently strong activity centered on a 50-day period with a slight seasonal shift .

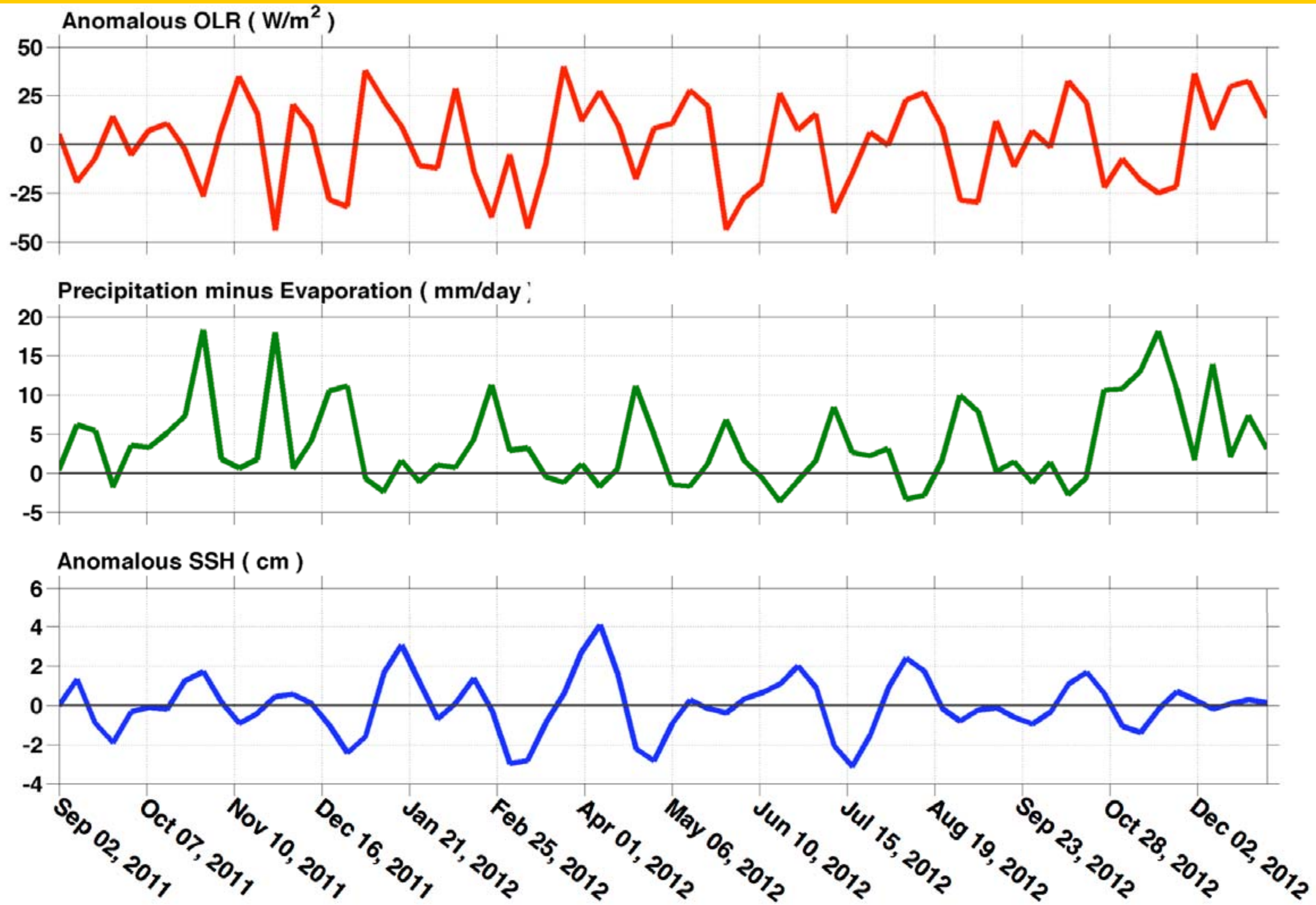
Wavelet Transforms OLR, P-E and SSH



Summary

- In this study, the connection between long waves and MJO propagations is explored by examining the impact of both downwelling and upwelling Rossby waves on MJO activity across the Indian Ocean.
- **The downwelling phase of equatorial Rossby waves corresponds to a strengthening of OLR anomalies** in extent and magnitude across the equatorial Indian Ocean while the **upwelling phase appears to weaken atmospheric MJO activity.**
- Our study reveals that the **MJO is influenced by Rossby waves on long time scales and across the equatorial Indian Ocean** rather than just focusing on MJO initiation the western Indian Ocean as shown in previous studies.
- SSH measurements serve as an important resource to understand the sea surface conditions that may be responsible for triggering a MJO event. They are also an indicator of the possible impacts atmospheric conditions associated with each phase of the MJO may have on oceanic features.
- Aquarius salinity to study the MJO is important because it allows for atmospheric conditions to be inferred from the **freshwater flux** (precipitation minus evaporation) on which Sea Surface Salinity is highly dependent.

OLR vs SSH



Time series of a) filtered OLR (red) (W/m^2), b) precipitation minus evoparation (green) (mm/day), and c) filtered SSH averaged over 5°S to 5°N, 87.5°E to 92.5°E.