Detection of Intraseasonal Oscillations in the Indian Ocean using Satellite Altimetry

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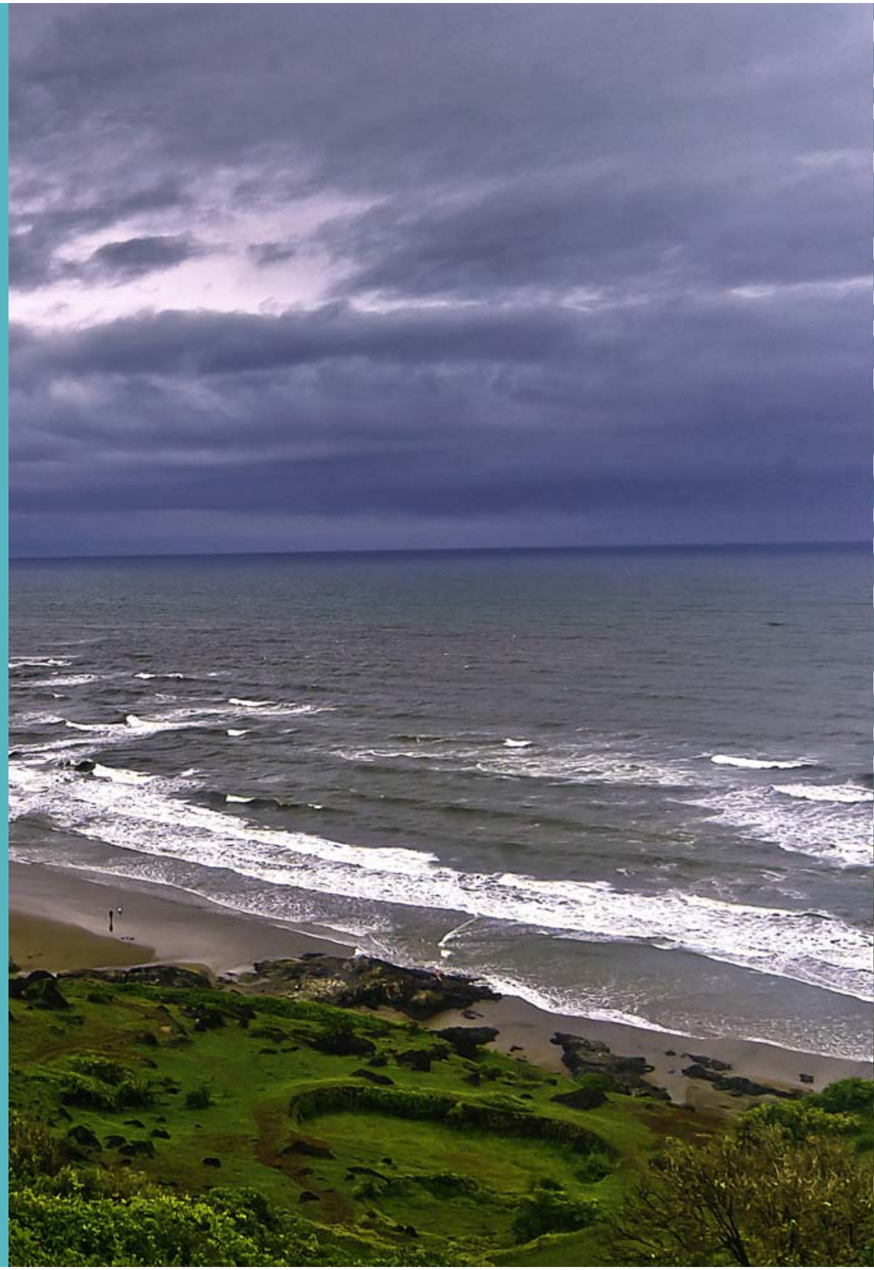
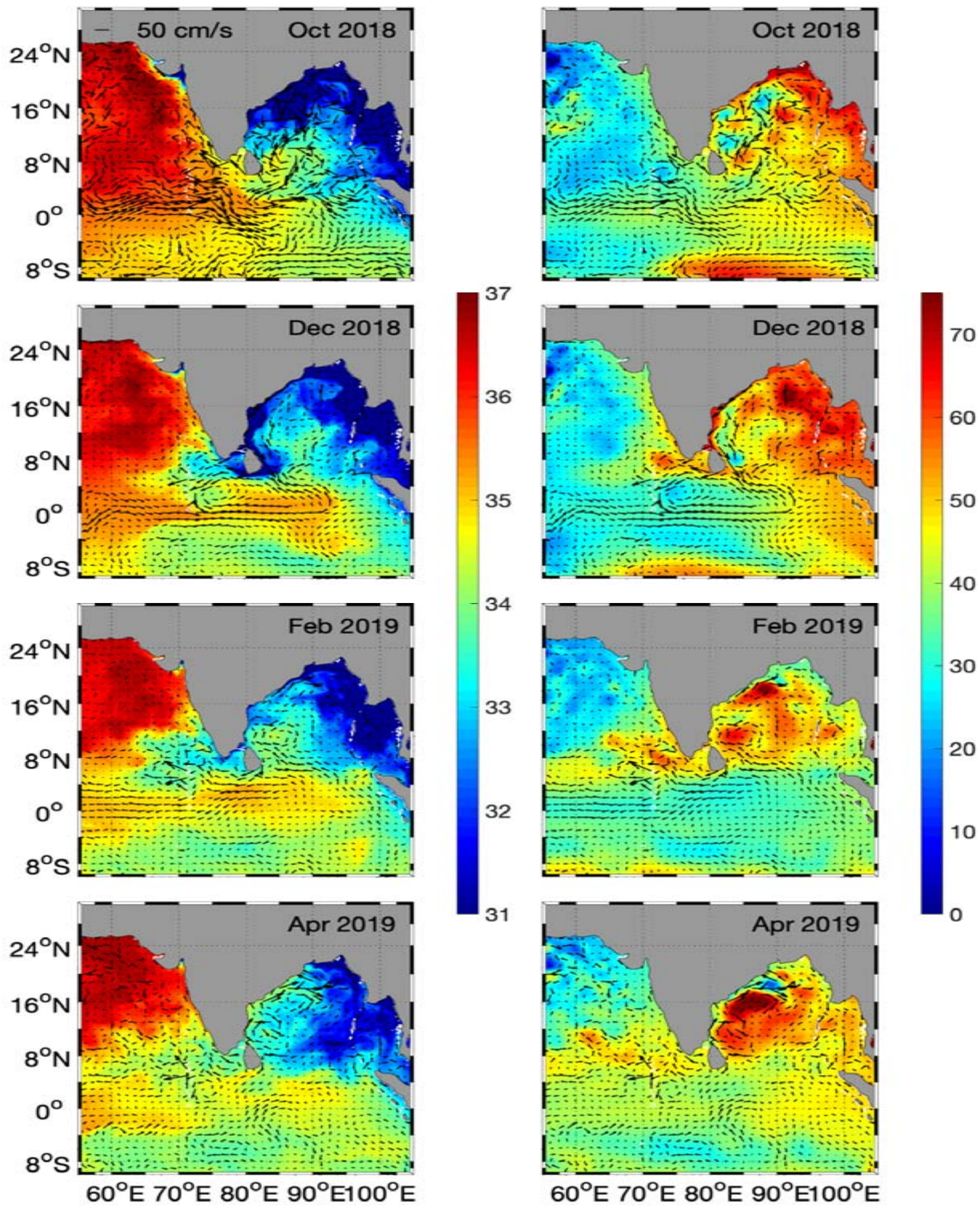


INTRODUCTION

- The atmospheric systems associated with monsoon ISOs that directly impact the strength and timing of active and break monsoon periods, which are respectively characterized by wet and dry conditions.
- Satellite altimetry-derived SLA allows us to observe longwave features such as Kelvin and Rossby waves.
- The atmospheric forcing (through anomalous wind and convective activity) at different stages of the MJO can force Kelvin waves in the equatorial regions of the Indian and Pacific Oceans. These Kelvin waves alter the SLA on the order of several centimeters.
- SLA, unlike SST and salinity, does not experience precipitative contamination due to the propagation of convective monsoon conditions or riverine input, but instead represents the dynamic response of the ocean to ISOs.

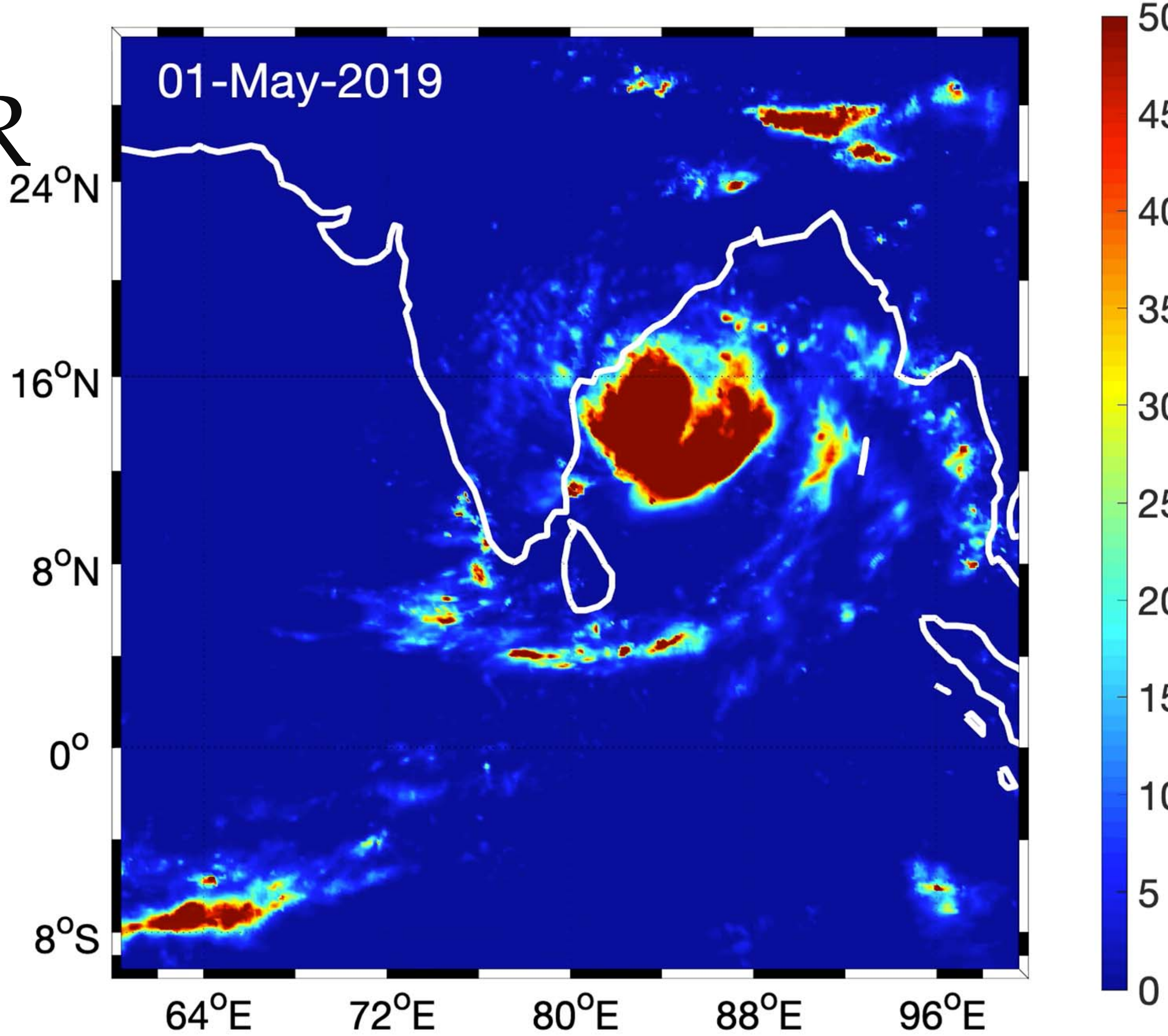
MONSOON ONSET

- Bimonthly NEMO SSS (left; psu) and SSH (right; cm) in the Northern Indian Ocean from October 2018 to April 2019
- Freshwater flux from BoB to SEAS in December-April



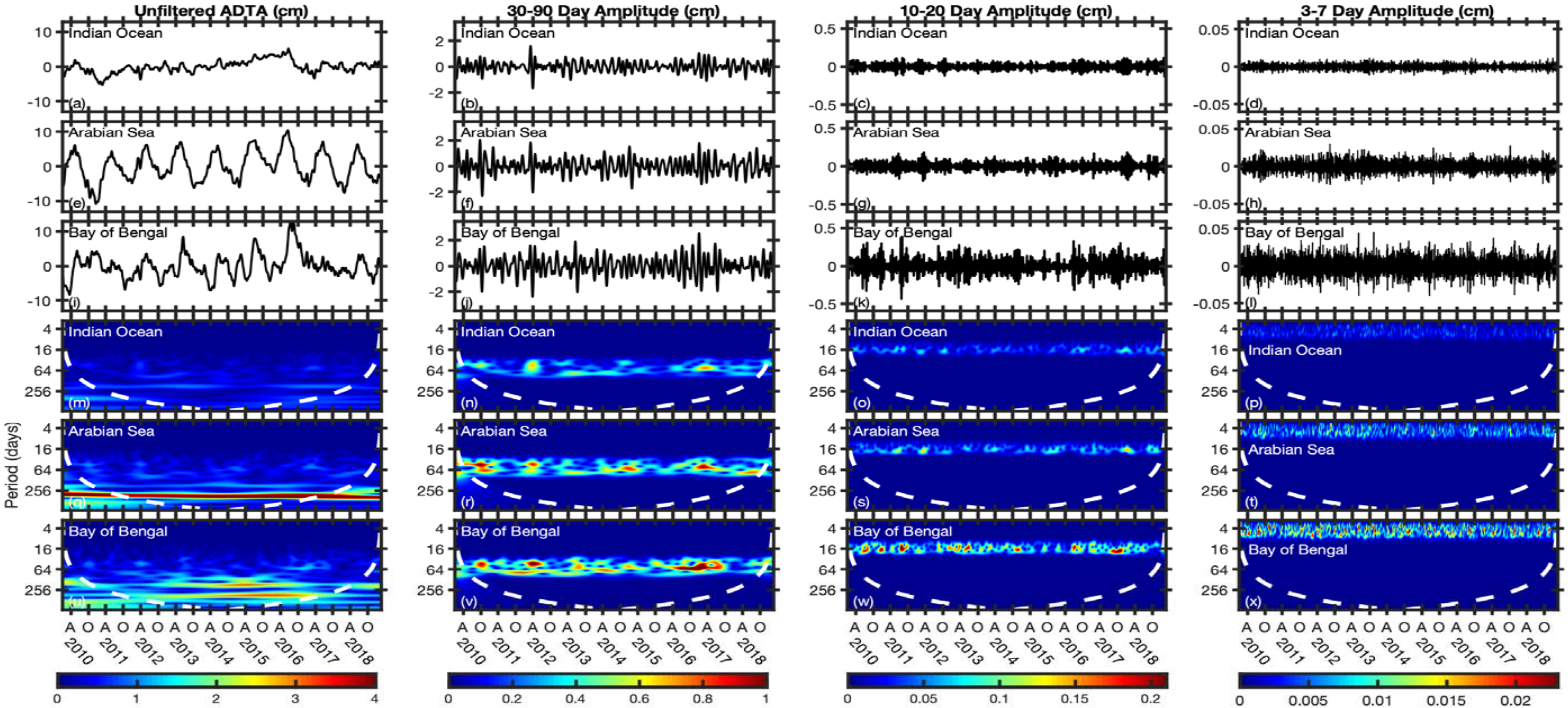
ISOs and ISMR

- ISMR: Indian Summer Monsoon Rainfall
- GPM Daily Precipitation (mm/day)
- Three ISOs:
  - 30-90-day
  - 10-20-day
  - 3-7-day
- Highly air-sea coupled phenomenon → need to understand ocean parameters
- Significantly contribute to monsoon rainfall
- Control active/break cycles
- Impact oceanic mixed layer



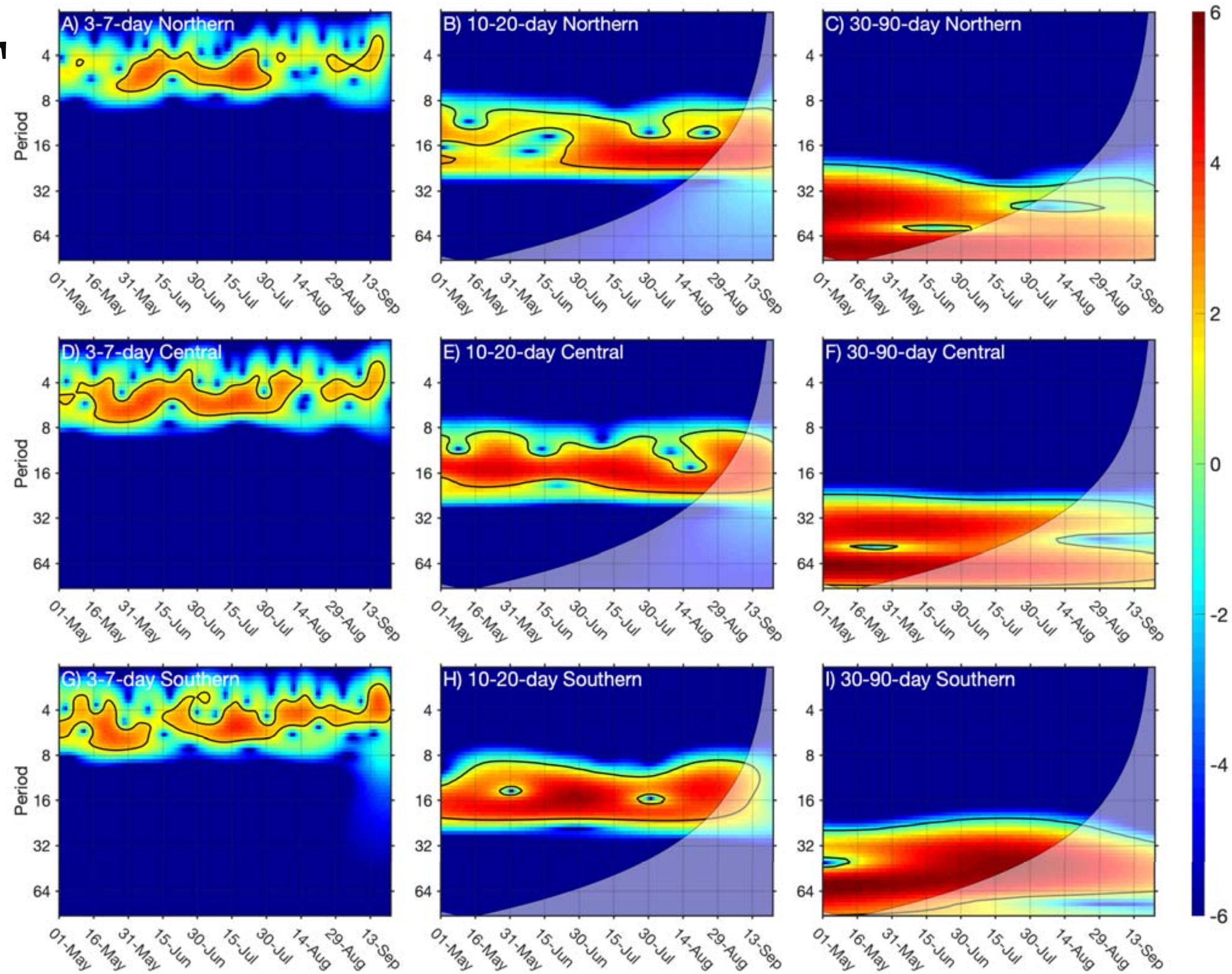
ISOs and ADT

Time series and wavelets of **CMEMS ADT** (cm) in the Indian Ocean, Arabian Sea, and Bay of Bengal from 2010 to 2018 that are unfiltered, 30-90-day filtered, 10-20-day filtered and 3-7-day filtered.



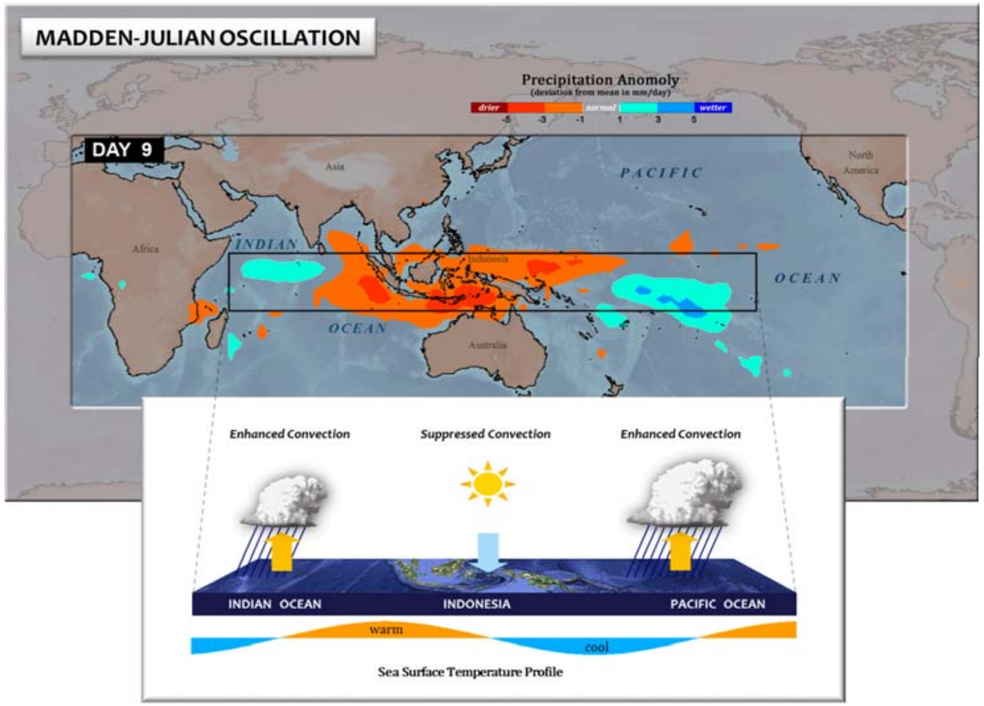
ISOs and ADT

CMEMS NRT ADT (cm) in the Northern (top), Central (middle), and Southern (bottom) Bay of Bengal from May-September 2019



Madden-Julian Oscillations (30-90 day)

- Commonly defined as 30-90 days, consistent with spectral peaks in precipitation and low-level winds
- Wavelength of 10,000 km
- Reduced cloud-cover vs. enhanced convection.
- Equatorially trapped.
- Travels eastward. And towards north over the BoB during SW monsoon
- Strong air-sea coupling.
- Propagates at a rate of 3-5 ms^{-1} and gradually weakens when it reaches the central Pacific.



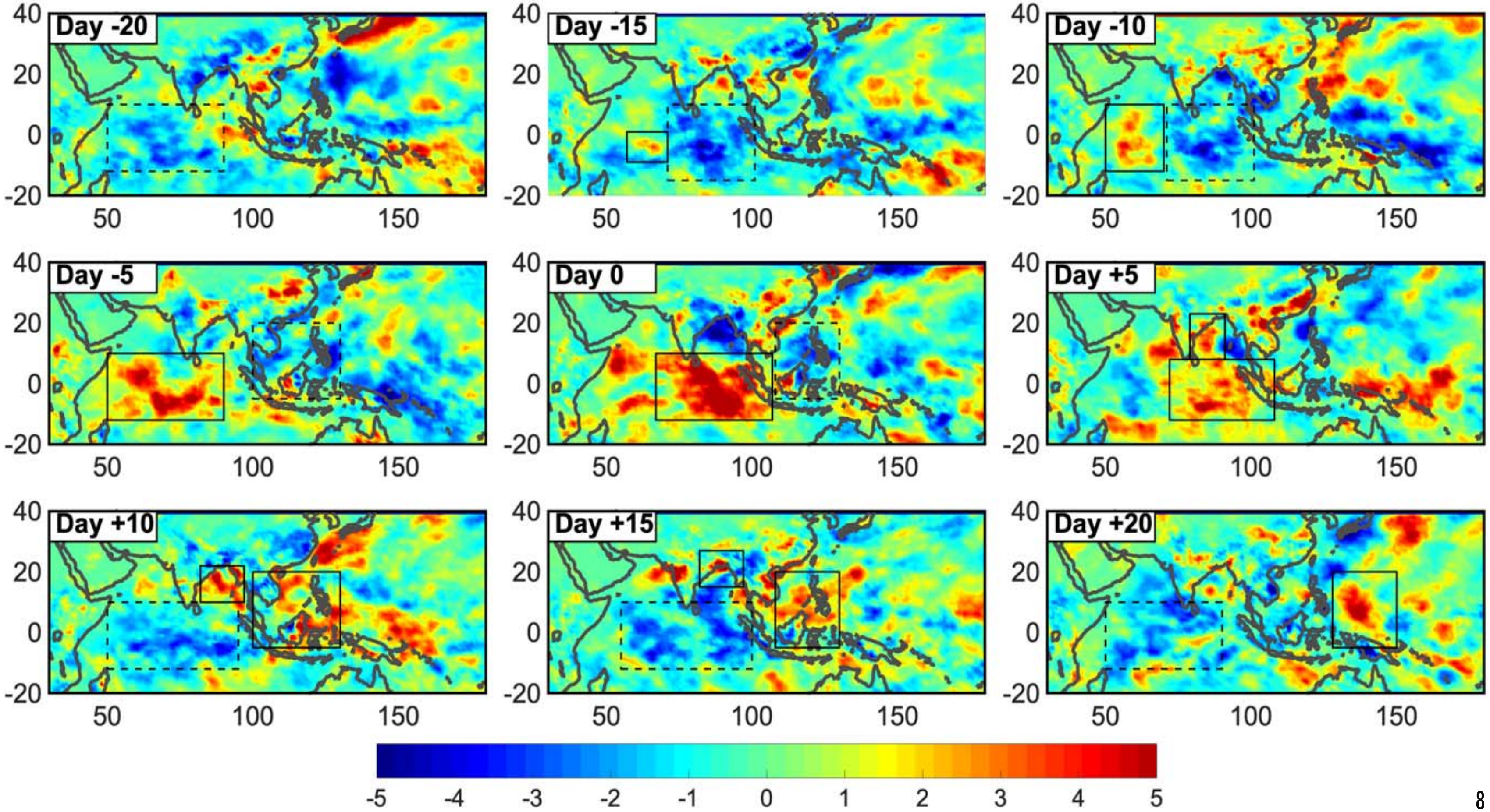
This illustration shows a moment in the evolution of the Madden-Julian Oscillation (MJO), a complex process involving sea surface temperatures and their influence on atmospheric processes. (©UCAR. Illustration by Lex Ivey, based on data from Adrian Matthews.)

30-90-day ISO

GPCP precipitation anomaly (mm/day) composite of the 30-90-day ISO in the Indian Ocean (20°S-20°N, 40°E-100°E) based a box averaged time series from 2015 to 2018 with the seasonal mean removed.

= + phase

= - phase

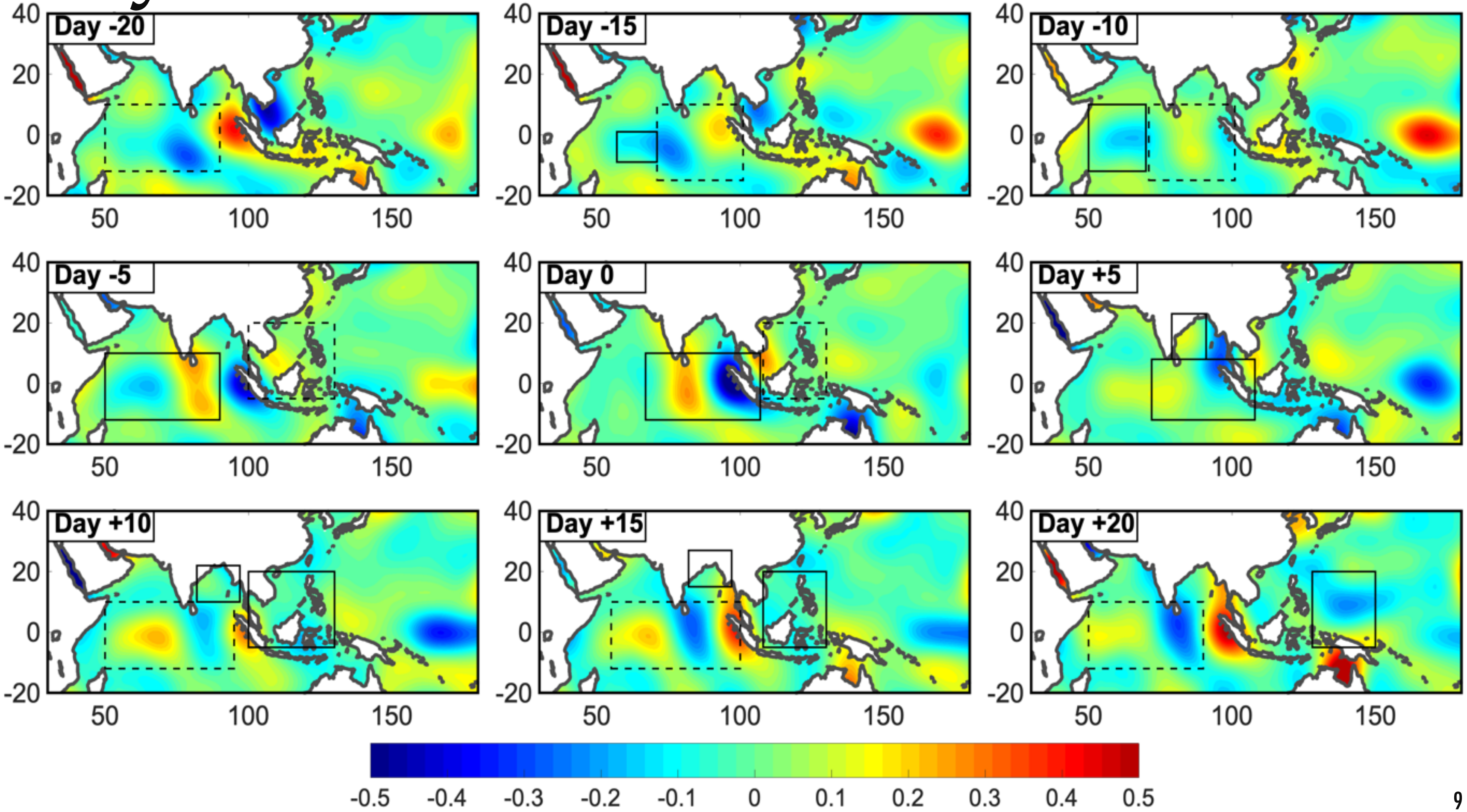


30-90-day ISO

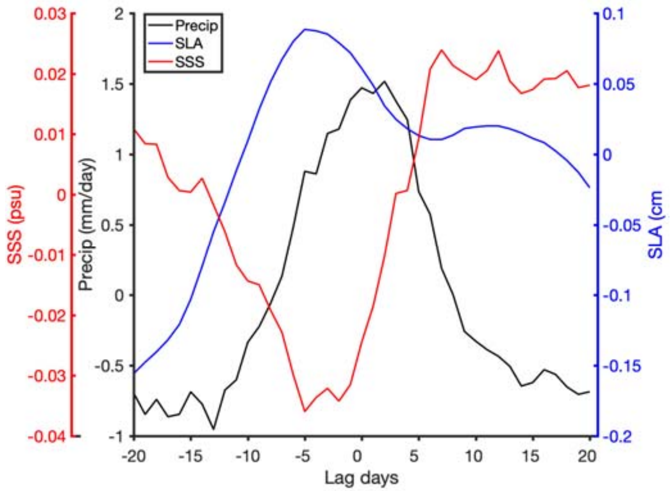
= + phase

= - phase

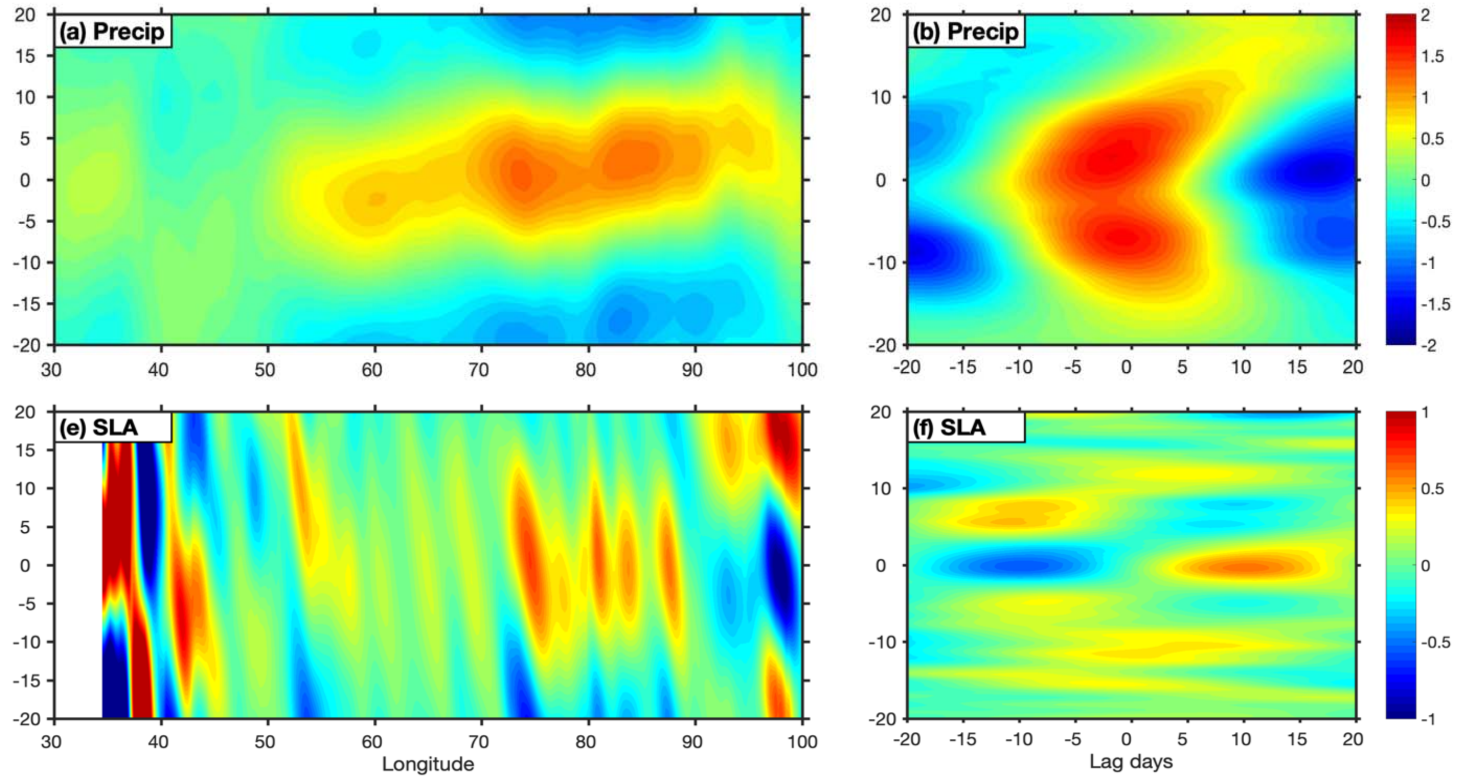
Deseasonalized **CMEMS ADT** anomaly (cm) composite of the 30-90-day ISO in the Indian Ocean (20°S-20°N,40°E-100°E) based a box averaged time series of GPCP precipitation from 2015 to 2018 and spatially filtered to the MJO wavelength in the Indian Ocean.



30-90-day ISO



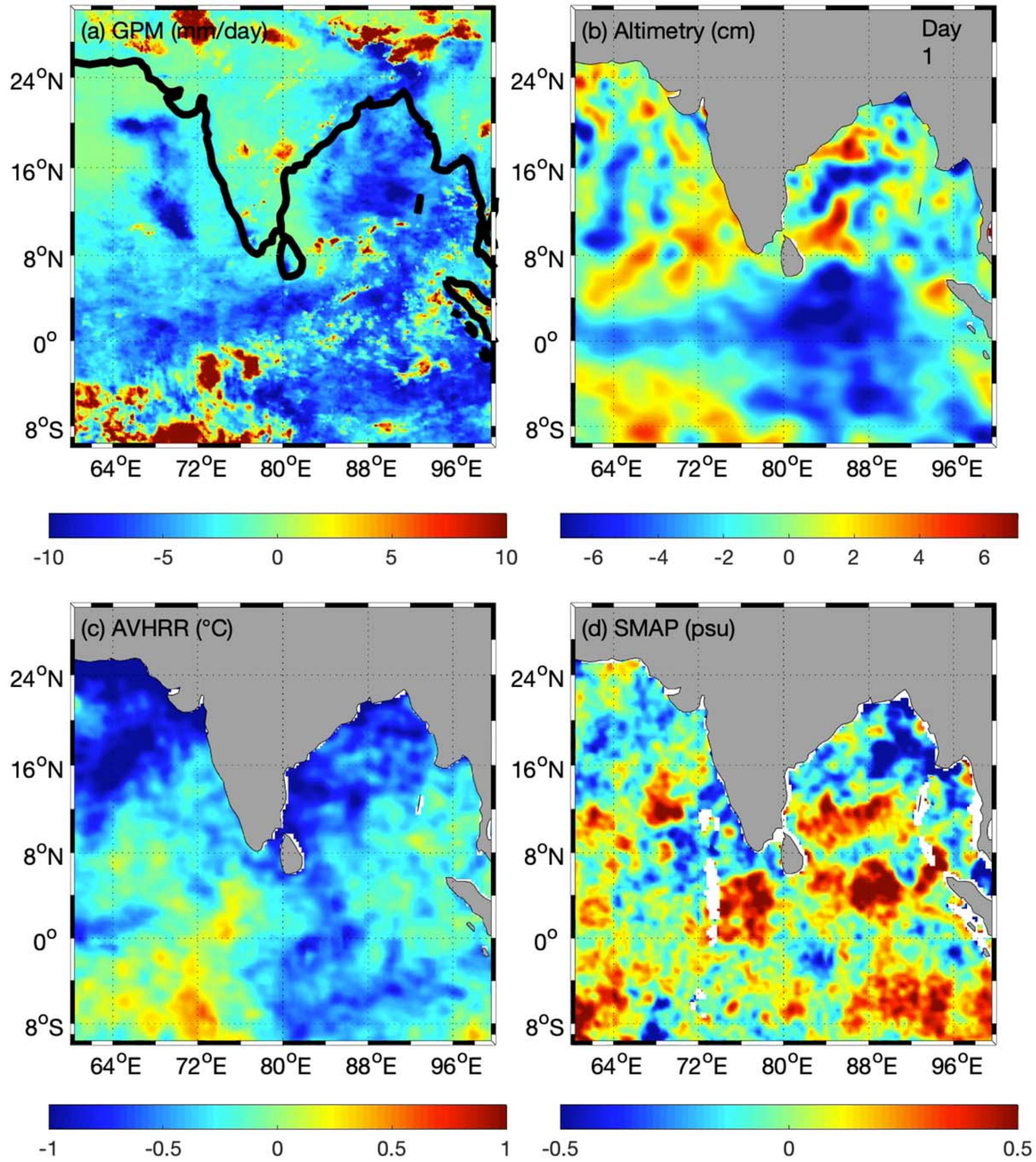
Lag composite of times series of **GPCP precipitation** (black; mm/day, **CMEMS ADT** (blue; cm), and SMAP SSS (red; psu) in the Indian Ocean (20°S-20°N, 40°E-100°E)



30-90-day bandpass filtered composite time/lag-longitude plots (left) and time/lag-latitude (right) of **GPCP precipitation** (top; mm/day) and CMEMS SLA (bottom; cm) in the Indian Ocean (20°S-20°N, 40°E-100°E)

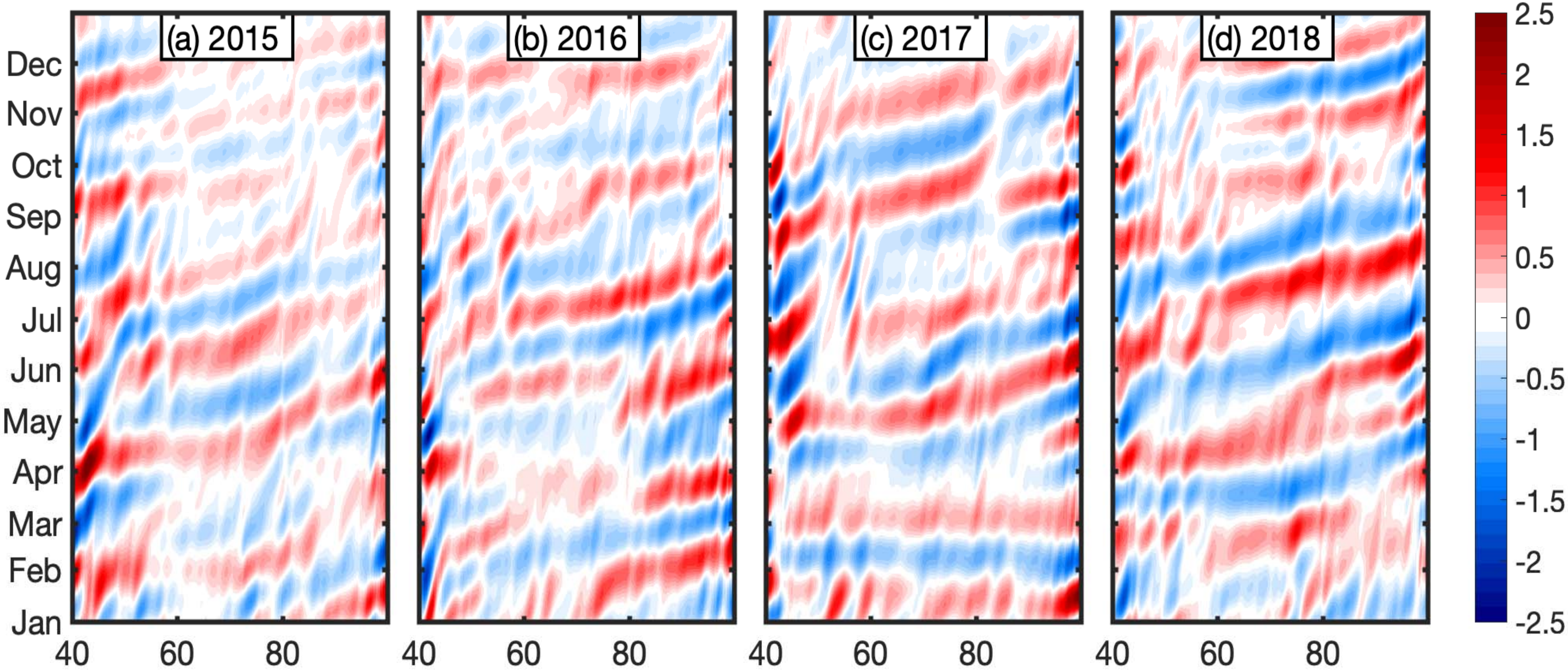
30-90-day ISO

- 30-90-day composite based on Indian Ocean precipitation (GPM)
- 51 day lag composite
- Day 1 = lag day -25
- Day 26 = the peak in precipitation (lag day 0)
- Day 51 = lag day +25
- See Northward propagation of BSISO around day 24-36



30-90-day ISO

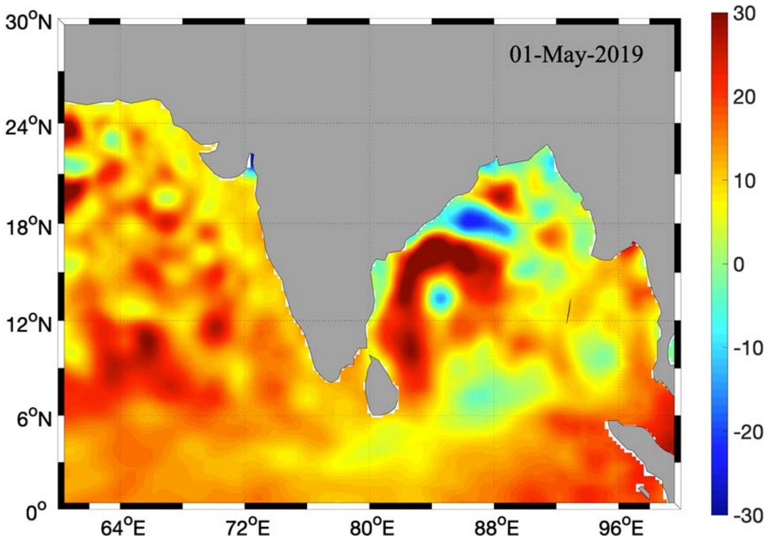
30-90-day bandpass filtered time-longitude plot of **CMEMS ADT** (cm) from 2015 (a) to 2018 (d) in the Indian Ocean (20°S-20°N,40°E-100°E), filtered for eastward propagation



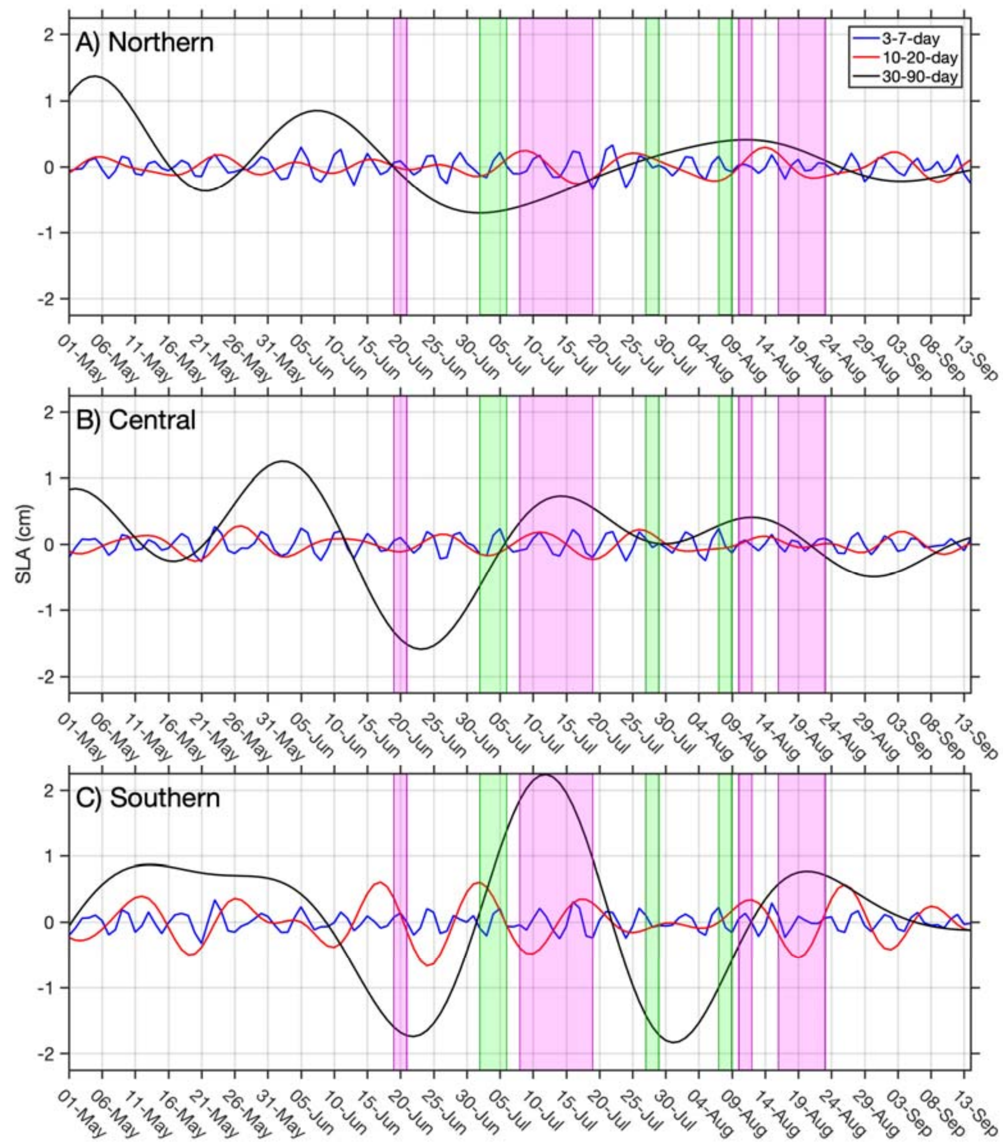
30-90-day ISO

CMEMS NRT SLA for the 2019 monsoon by region of the BoB

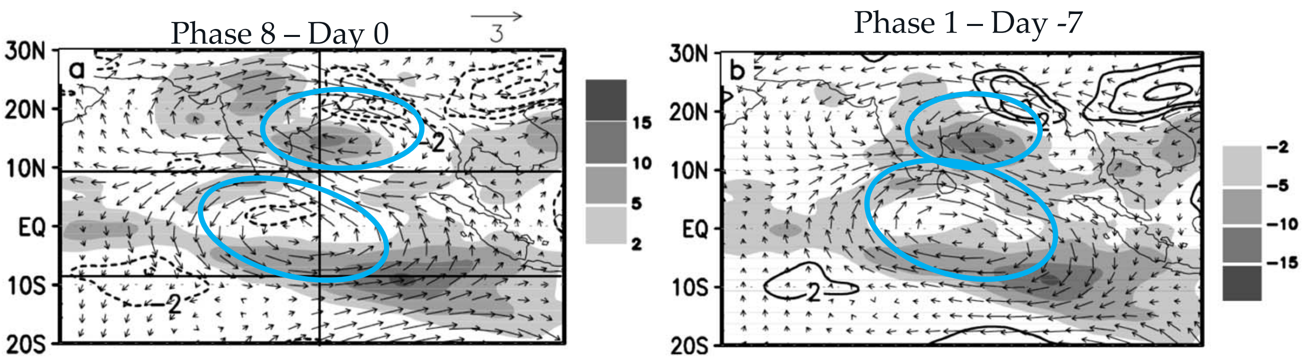
- Active phases = 3+ days above 0.5 standard deviations
- Break phases = 3+ days below 0.5 standard deviations



CMEMS NRT SLA for the 2019 monsoon in the Northern Indian Ocean



Quasi-biweekly oscillations (10-20-day)



Double cell structure of the 10-20-day ISO during Phase 1 (Day -7) and Phase 8 (Day 0), where Day 0 is the day of maximum precipitation in the Bay of Bengal. Shading indicates TRMM precipitation, vectors are 850 mb winds, (Chatterjee and Goswami, (2004)

Overview:

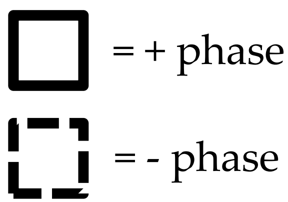
- One of the main controls on active/break cycles of monsoon rainfall
- Propagation speed: 4.5-6 ms^{-1} (NW or W)
- Dominant wavelength: 6,000 km

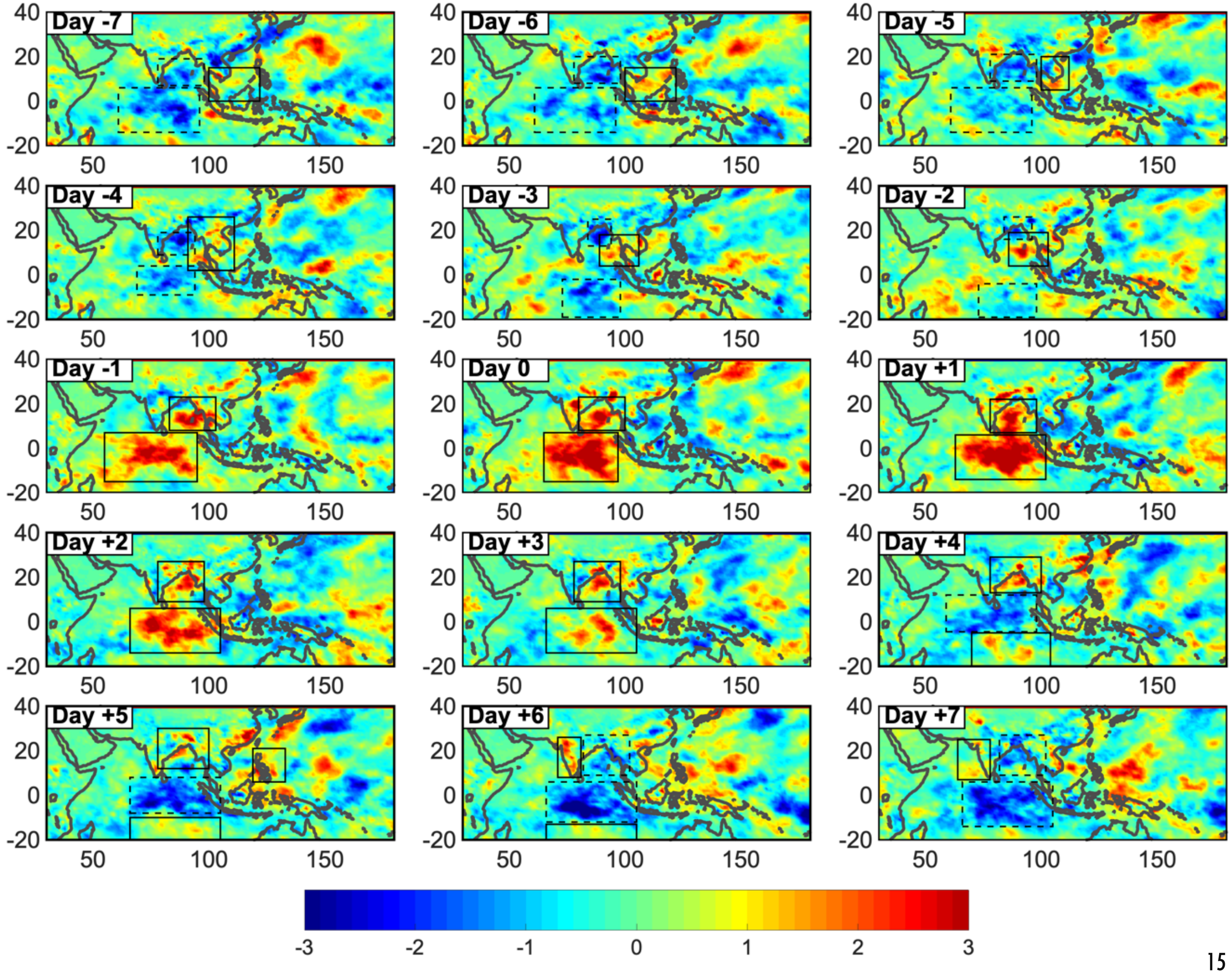
Structure and dynamics:

- **Double-cell structure** of either lows or highs around the equator and 15-20°N
- Structure propagates west, where the northernmost cell propagates along the monsoon trough → Mixed Rossby Gravity Waves translated north in the atmosphere
- Triggered by breaking Rossby Waves in upper atmosphere over Northern Pacific Ocean into the South China Sea/Western Pacific (Ortega et al., 2017)

10-20-day ISO

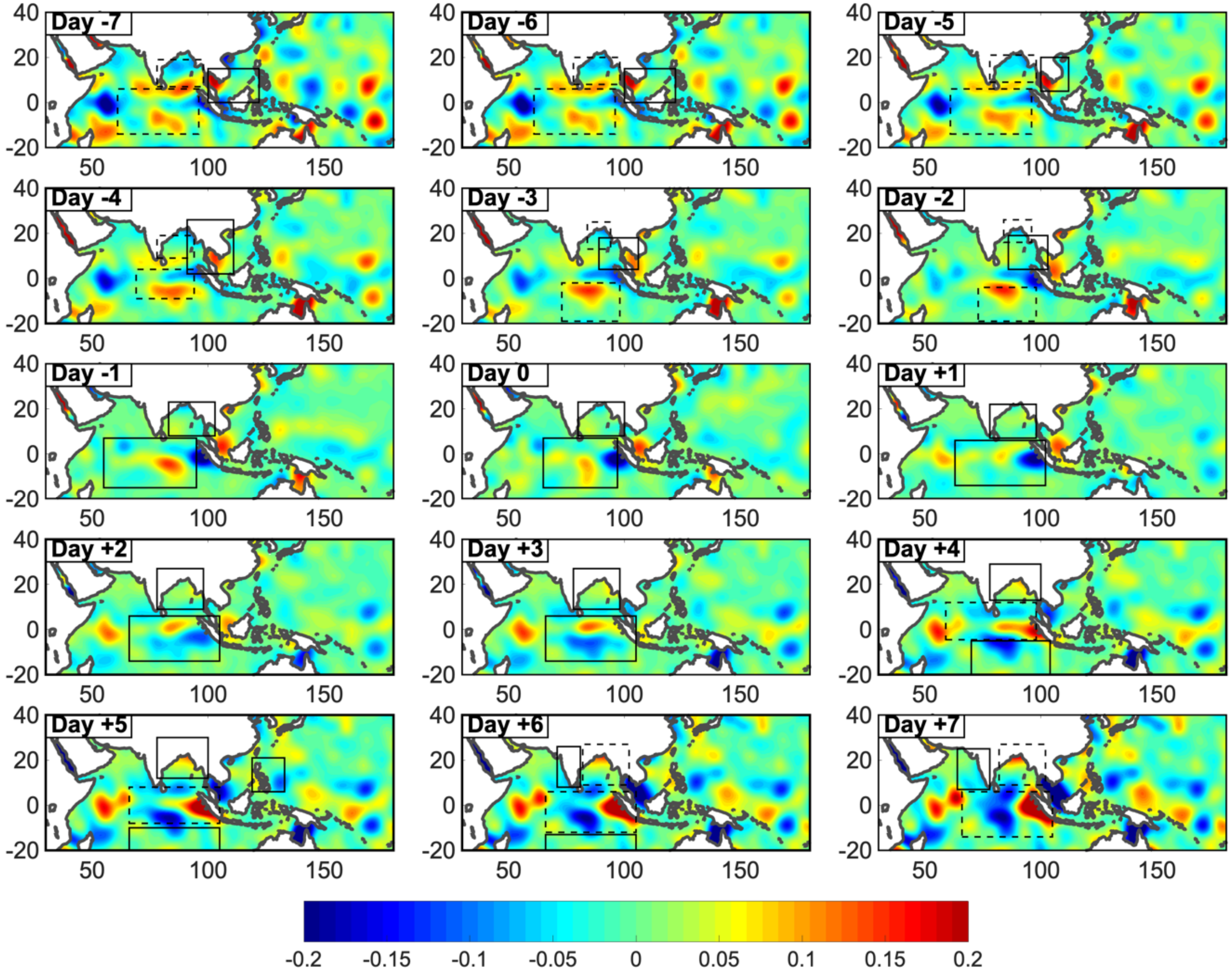
Deseasonalized **GPCP precipitation** anomaly (mm/day) composite of the 10-20-day ISO in the Indian Ocean (20°S-20°N, 40°E-100°E) based a box averaged time series from 2015 to 2018 with the seasonal mean removed.





10-20-day ISO

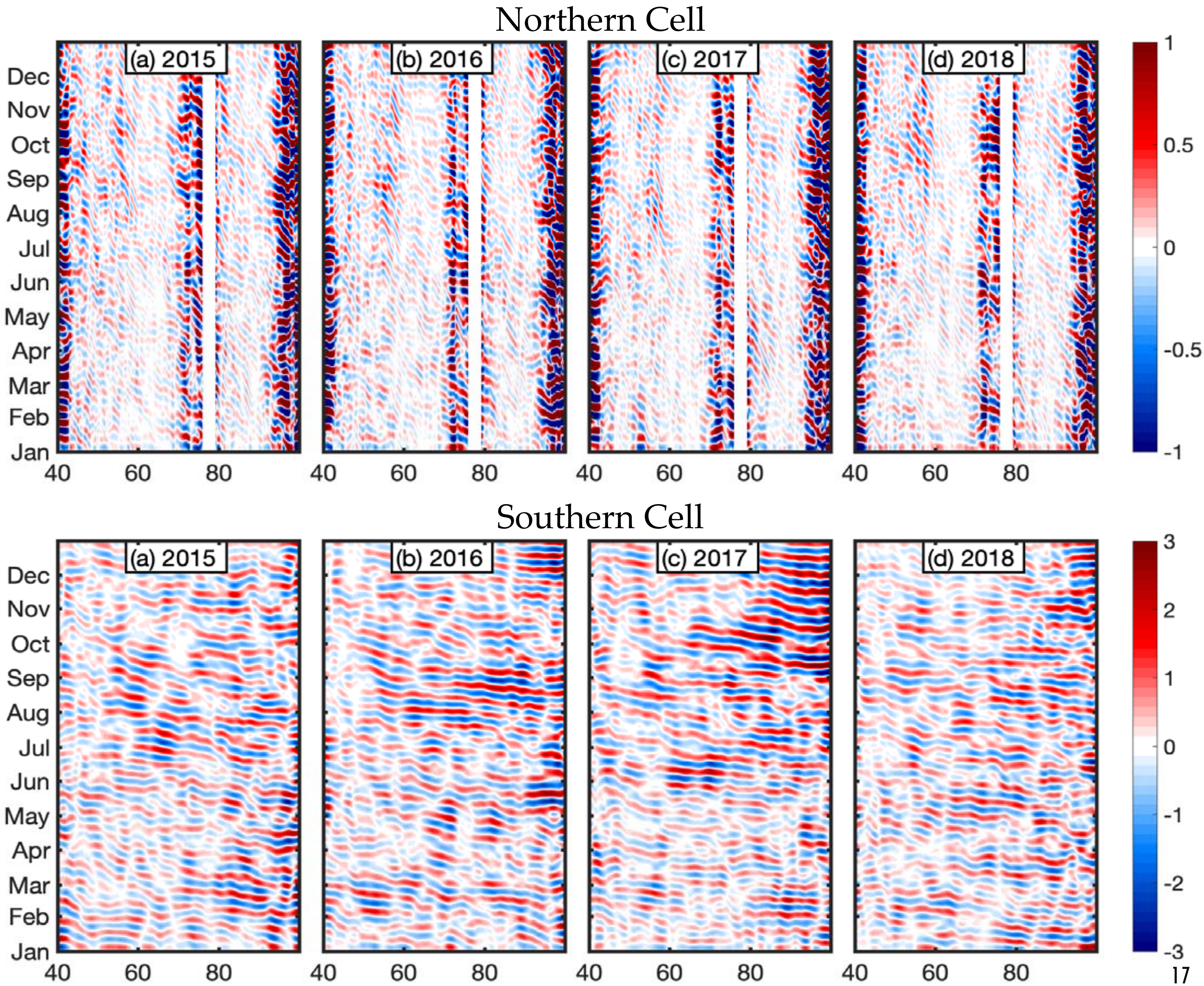
Deseasonalized **CMEMS ADT** anomaly (cm) composite of the 10-20-day ISO in the Indian Ocean (20°S-20°N,40°E-100°E) based on a box averaged time series of GPCP precipitation from 2015 to 2018 and spatially filtered to the quasi-biweekly wavelength in the Indian Ocean.



= + phase   = - phase

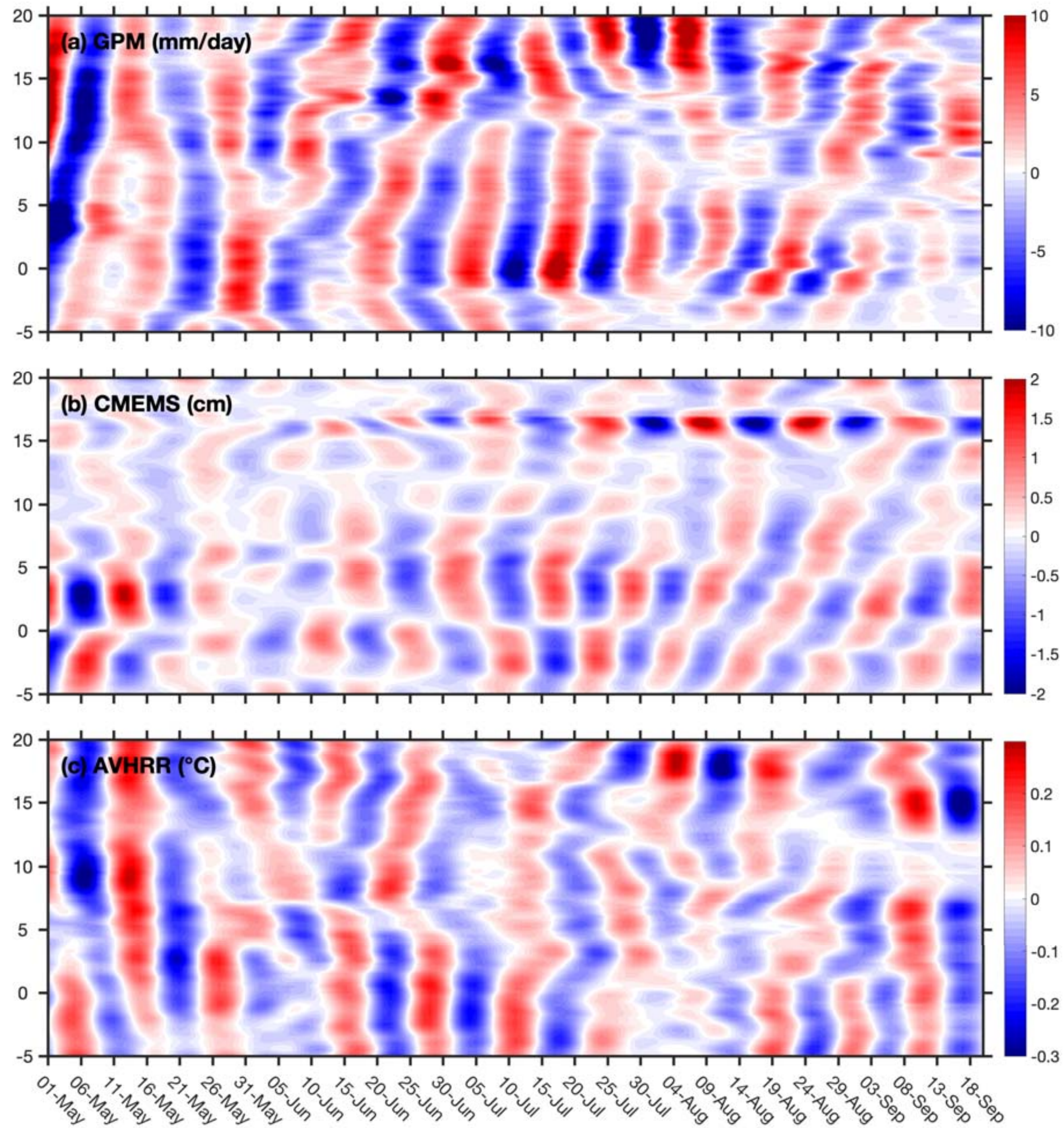
10-20-day ISO

10-20-day bandpass filtered time-longitude plot of **CMEMS ADT** (cm) from 2015 (a) to 2018 (d) in the Indian Ocean (20°S-20°N,40°E-100°E) for the northern cell (top; 10°N-20°N) and the southern cell (bottom; 5°S-0°S)



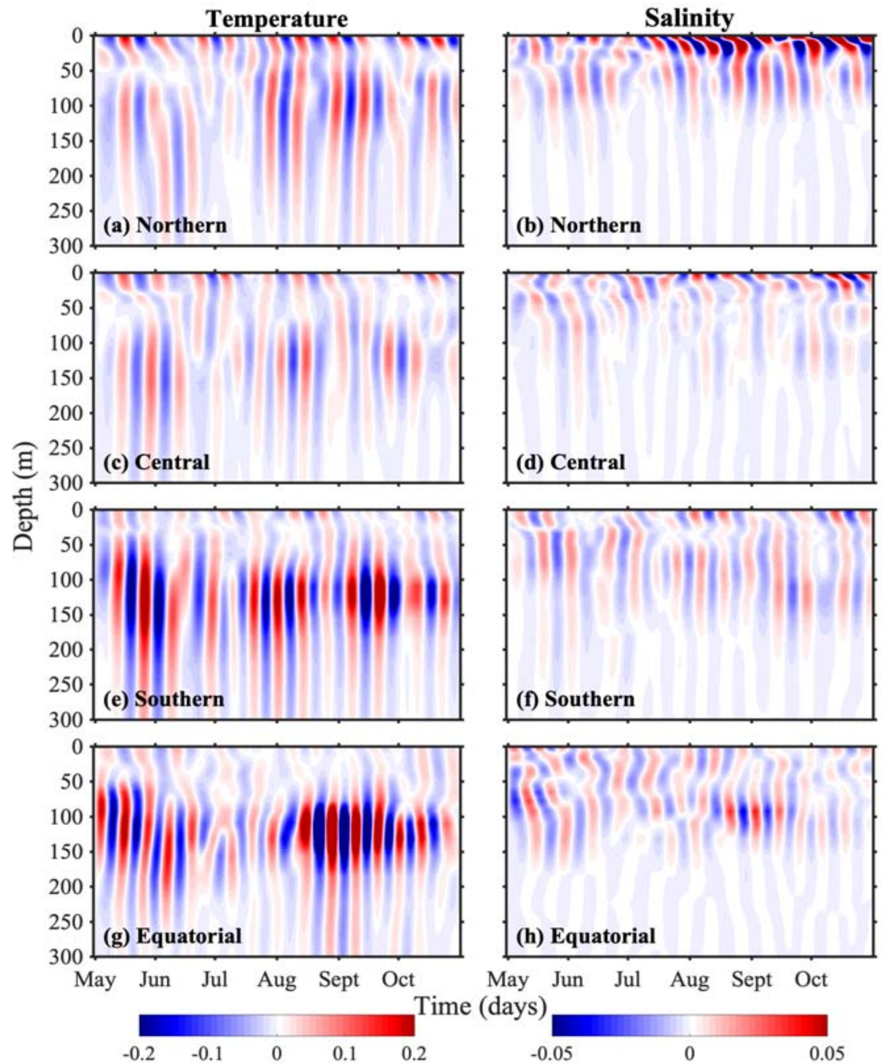
10-20-DAY ISO

- 2019 Monsoon in the BoB
- Strong precipitation signal in northern Bay of Bengal
- Slight northward propagation in precipitation, ADT



10-20-DAY ISO IN SUBSURFACE BOB

- 10-20-day bandpass filtered NEMO temperature and salinity with depth for May-October 2016
- Temperature signal strongest in Southern, Equatorial BoB below MLD to 250 m
- Salinity signal weaker than temperature, strongest at surface in Northern BoB above MLD, penetrates down to ~100 m
  - Indonesian Throughflow
  - Thermocline variability



10-20-day bandpass filtered depth-time diagrams for NEMO temperature (left; °C) and salinity (right; shaded; psu) anomalies, box-averaged in the (a-b) Northern (85-100°E, 15-20°N), (c-d), Central (85-100°E, 10-15°N), (e-f) Southern (85-100°E, 5-10°N), and (g-h) Equatorial (85-100°E, 0-5°N) Bay of Bengal for May-October 2016.

Roman-Stork et al., (2019) Deep-Sea Res.

Synoptic scale (3-7 day)

Associated with weather systems (lows and highs)

- Tropical Convergence Zone (TCZ) over continent in active spells, over equatorial Indian Ocean in break spells

Wavelength of 2,000 km

TCZ = ascending branch of local Hadley circulation of monsoon

- During NH summer located around 25°N over India

TCZ and 3-7 day mode both likely modulated by other ISOs and interannual variability

- Spatial/temporal structure of TCZ consistent with 30-60 day mode
- Variations in monsoon trough → variations in rainfall

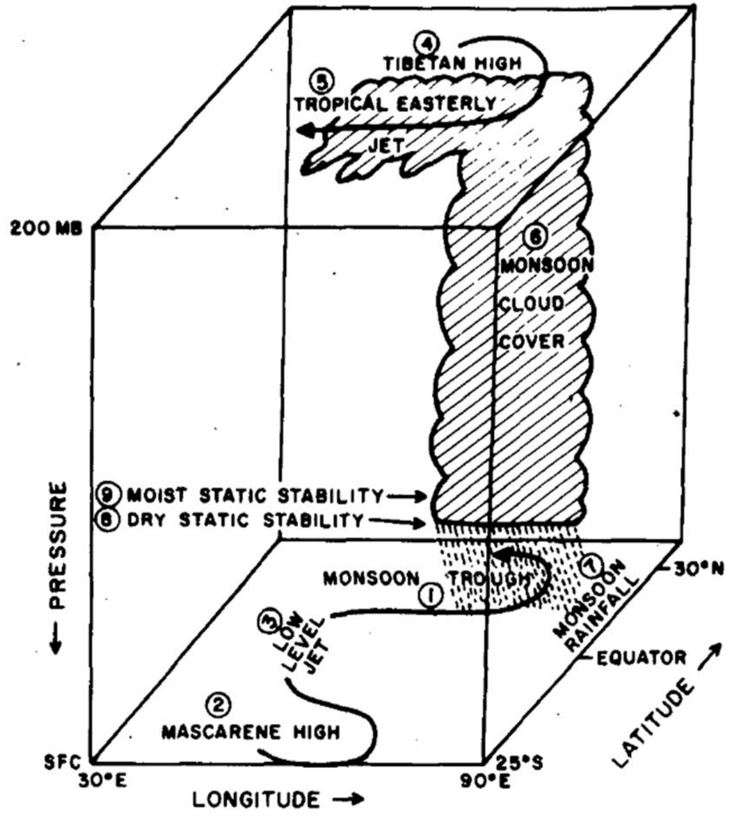
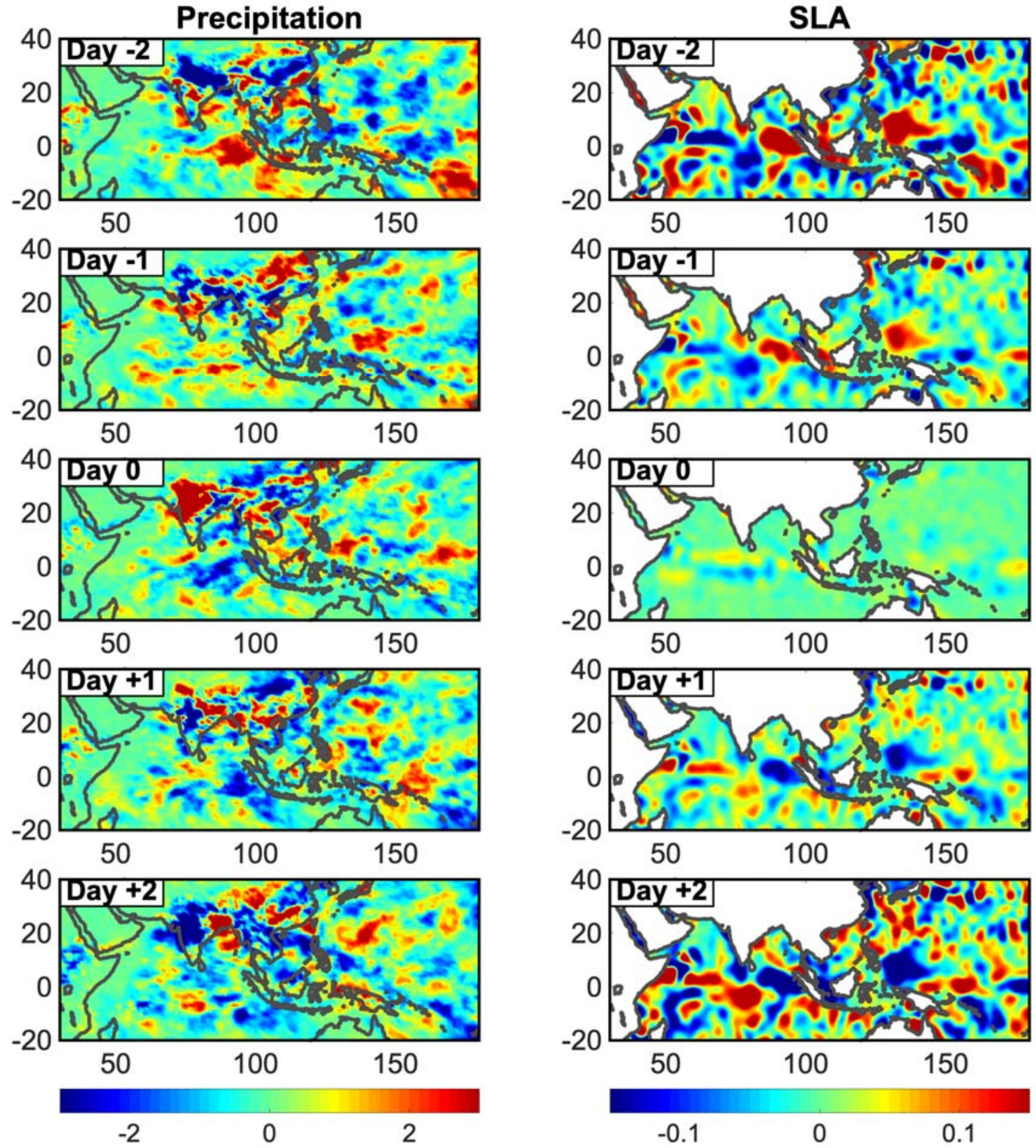


FIG. 1. Schematic diagram of the nine elements of the monsoon system considered in this study.

From Krishnamurti and Bhalme (1976)

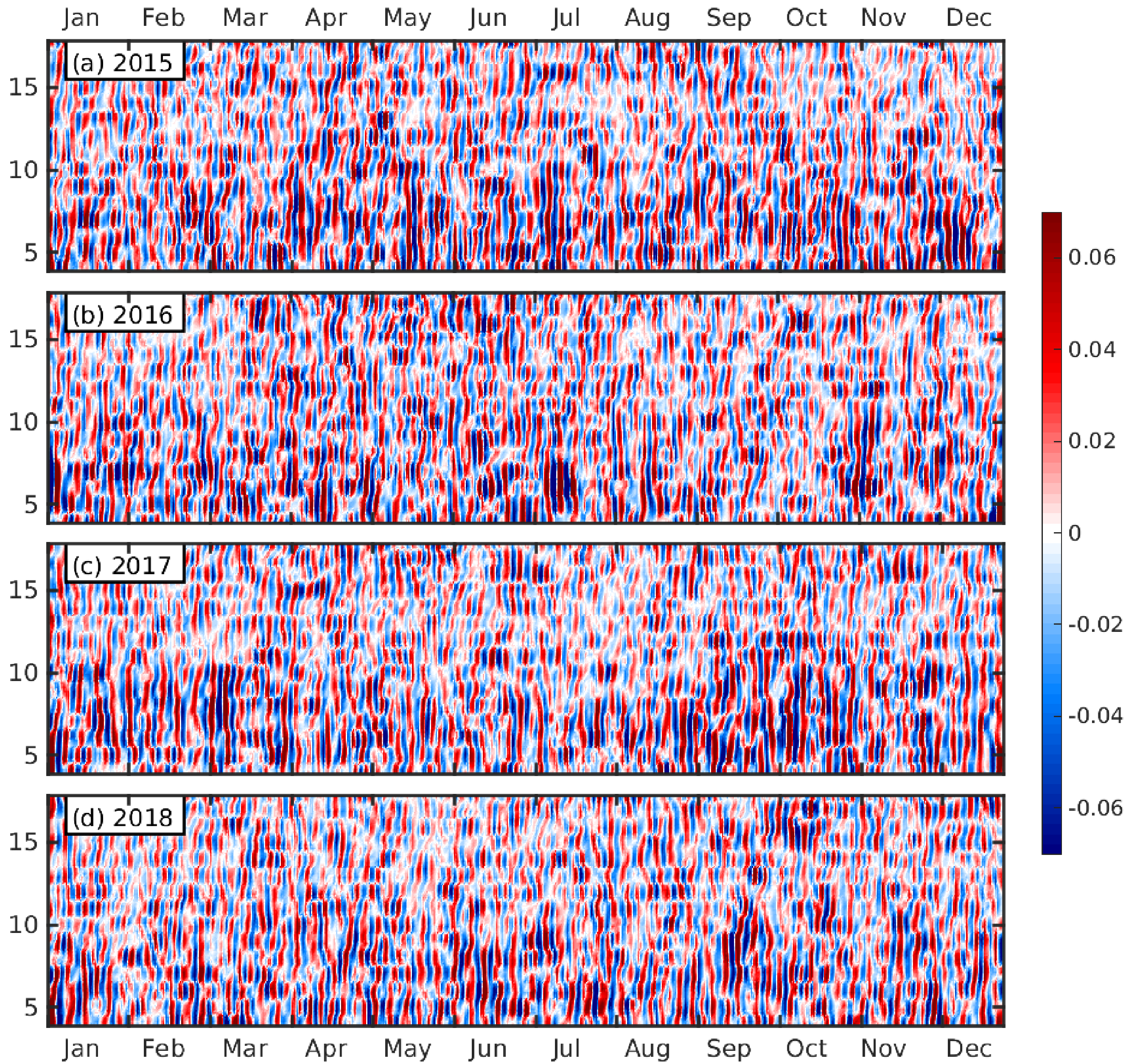
3-7-day ISO

Deseasonalized **GPCP precipitation** anomaly (left; mm/day) and **CMEMS blended altimetry ADT** (right; cm) composites of the 3-7-day ISO in the Indian Ocean (20°S-20°N, 40°E-100°E) based a box averaged time series from 2015 to 2018.



3-7-DAY ISO

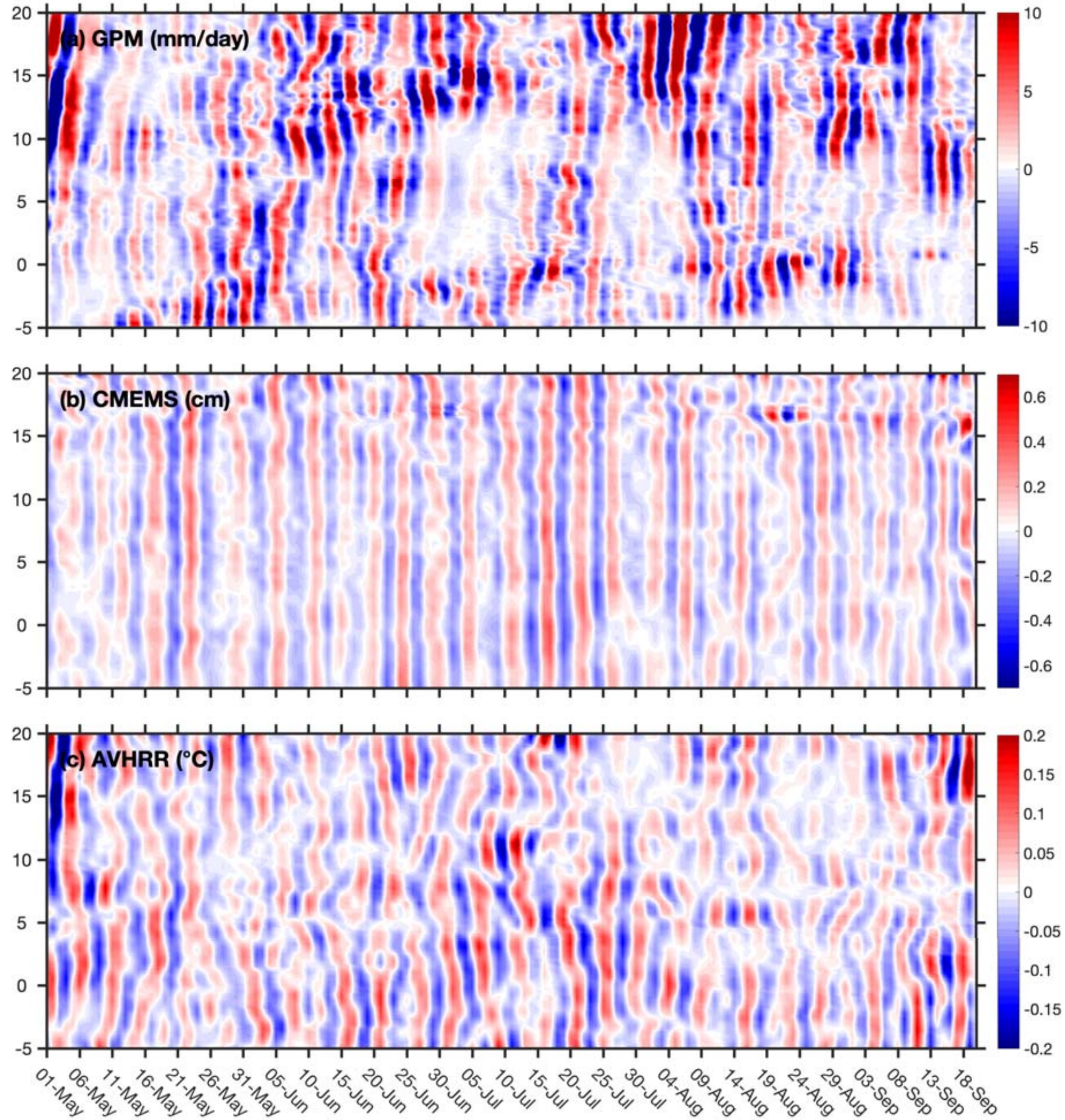
- 2019 Monsoon in the BoB
- Strong precipitation signal in northern Bay Bengal
- Weak propagation



Trott and Subrahmanyam (2019) Atmospheric Science Letters

3-7-DAY ISO

- 2019 Monsoon in the BoB
- Strong precipitation signal in northern Bay of Bengal
- Weak propagation in ADT



Summary

- ISOs in the Indian Ocean strongly contribute to Southwest Monsoon rainfall
- We find that satellite altimetry can be used to monitor ISOs in the Indian Ocean, especially the 30-90-day (MJO & BSISO) and 10-20-day (QBW) oscillations, which is important for monsoonal rainfall prediction
- Longitudinal propagation of the 30-90-day ISO and the southern cell of the 10-20-day ISO are clear in altimetry
- Though ISOs are present in all years, ISOs in SLA tend to be higher-amplitude during strong monsoon seasons due to the enhanced wind forcing.
- Structure of 3-7 day ISO features apparent, but the amplitude is too low → need more high resolution observations
- Addition of SWOT altimetry is necessary for future monitoring and forecasting of ISOs, particularly in the 3-7-day signal