Assessing the Dynamics of the Equatorial Indian Ocean Driven by the Indian Ocean Dipole Events with Satellite Ocean Color Observations

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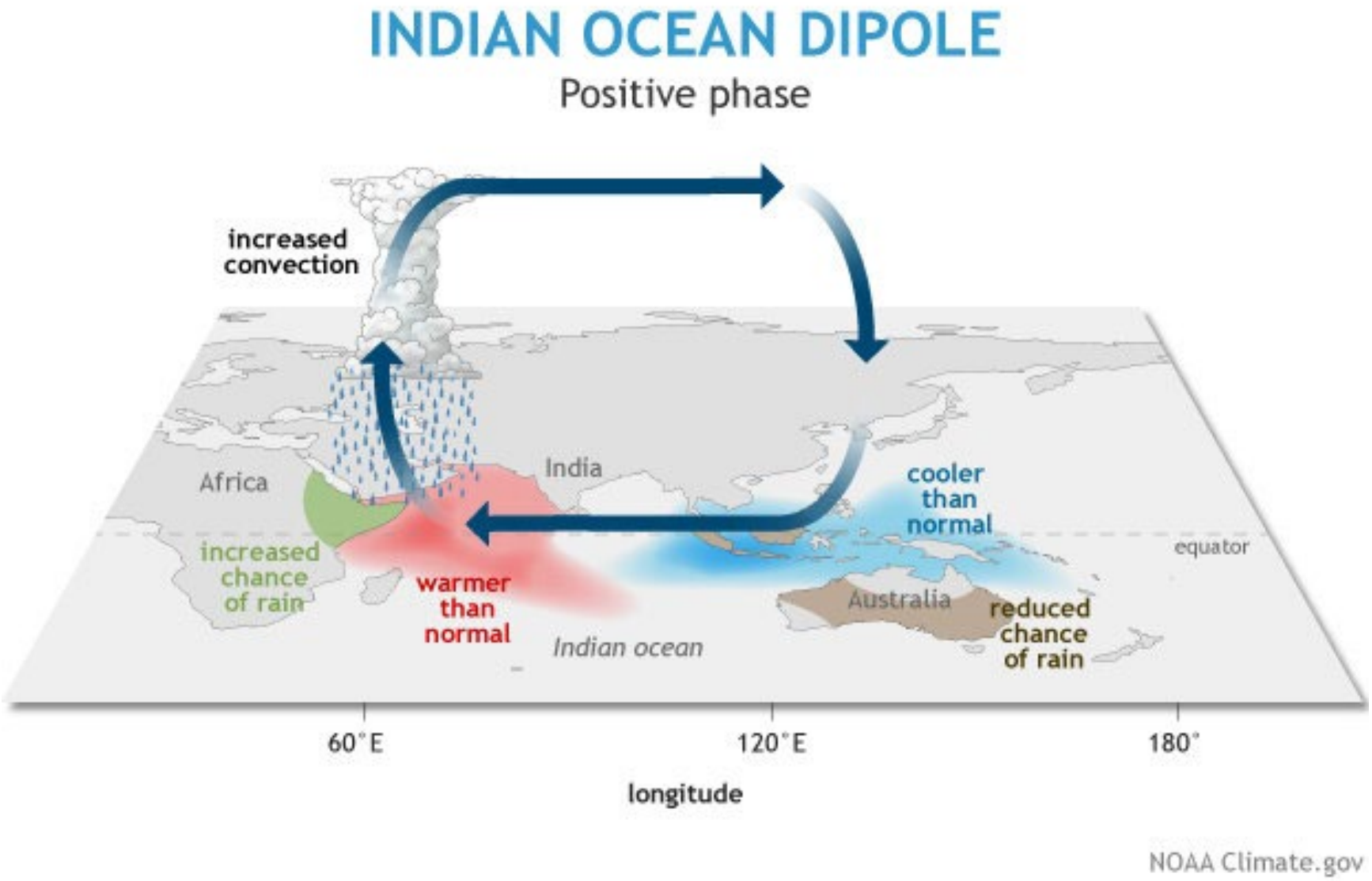
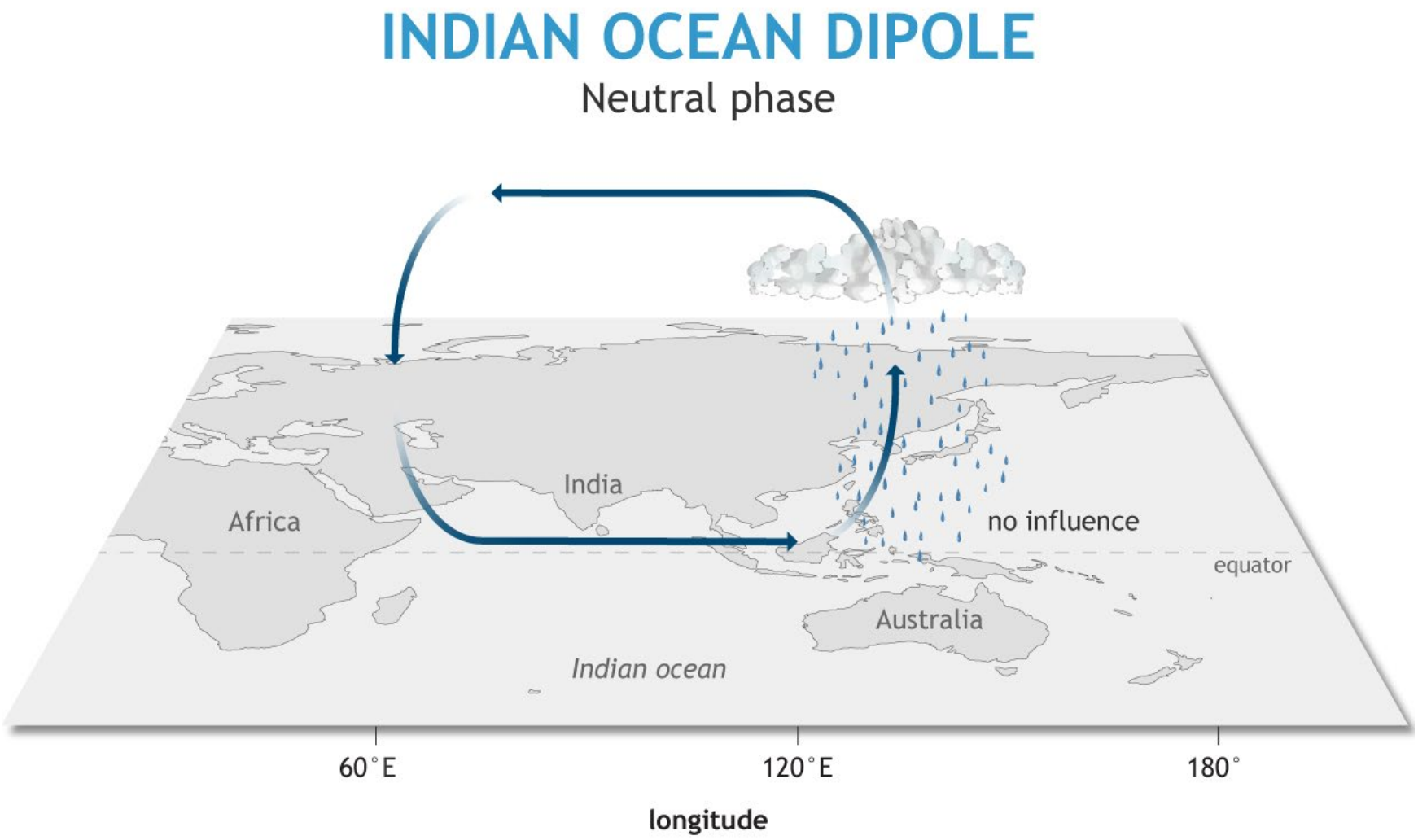
Indian Ocean Dipole (IOD) Event

- It was first identified and reported by Saji et al. (1999) with anomalously low sea surface temperature (SST) in the eastern Indian Ocean and high SST in the western Indian Ocean.
- Like ENSO, the impact of the IOD event on the global climate is significant. IOD event has a significant influence on the summer Indian Monsoon, anomalous rainfall in the East Africa, South America, and South Asia.
- Strong correlation is found climate anomalies over Europe, northeast Asia, North and South America and South Africa concurrent with IOD events. Over these regions, positive IOD events are associated with warm land surface anomalies and reduced rainfall.
- The most severe drought in a large part of the Australia and the southeast Australia bushfire, as well as the occurrence of the locust plague and the outbreaks of malaria in the Africa are all linked to the IOD events.
- In the ocean, IOD strongly modulated the upper ocean variability in the tropical Indian Ocean. It also contributed to the coral reef bleaching during the 1997 IOD event. The regional biological activities in the Indian Ocean has also been significantly impacted by the IOD events.

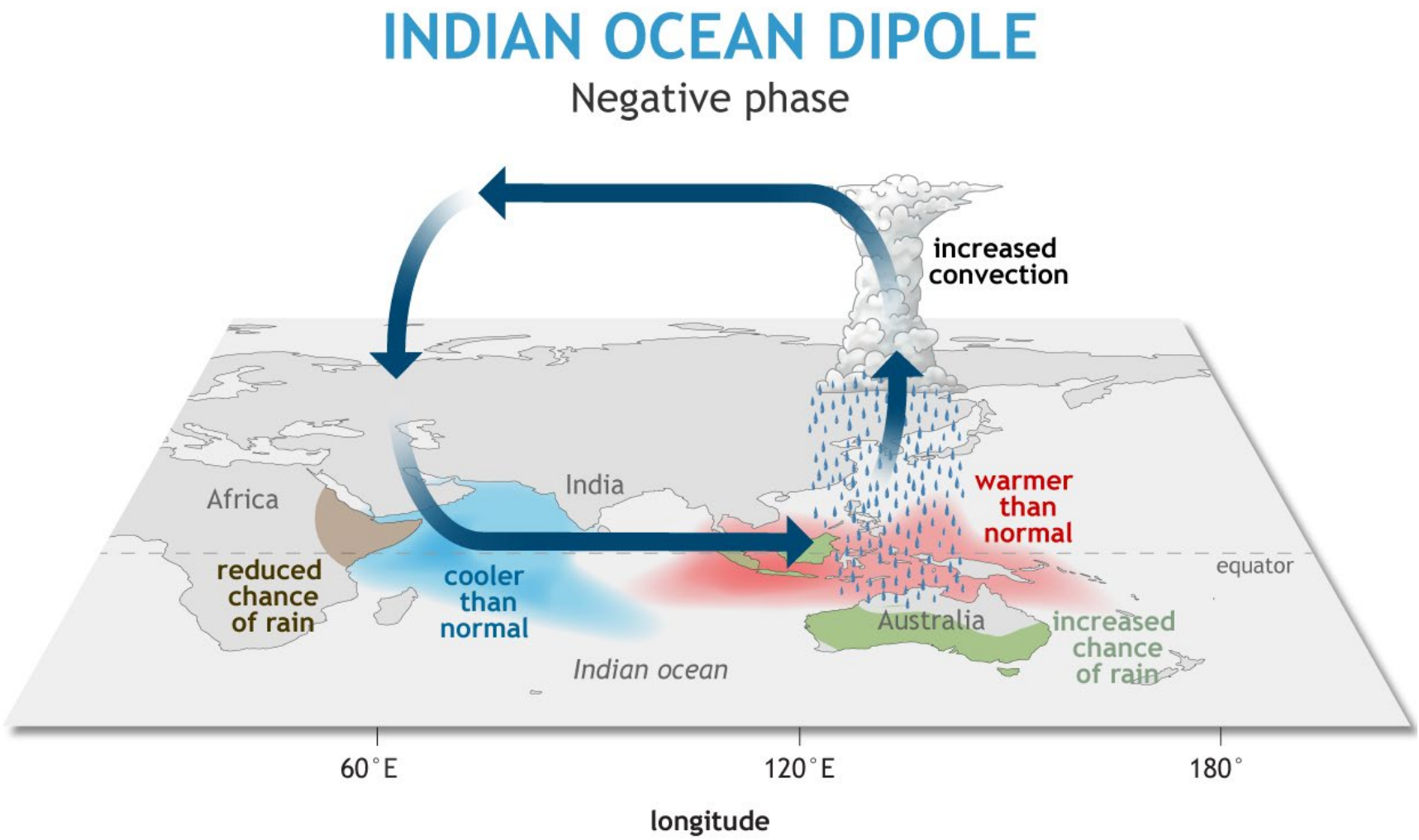
Indian Ocean Dipole Positive Phase



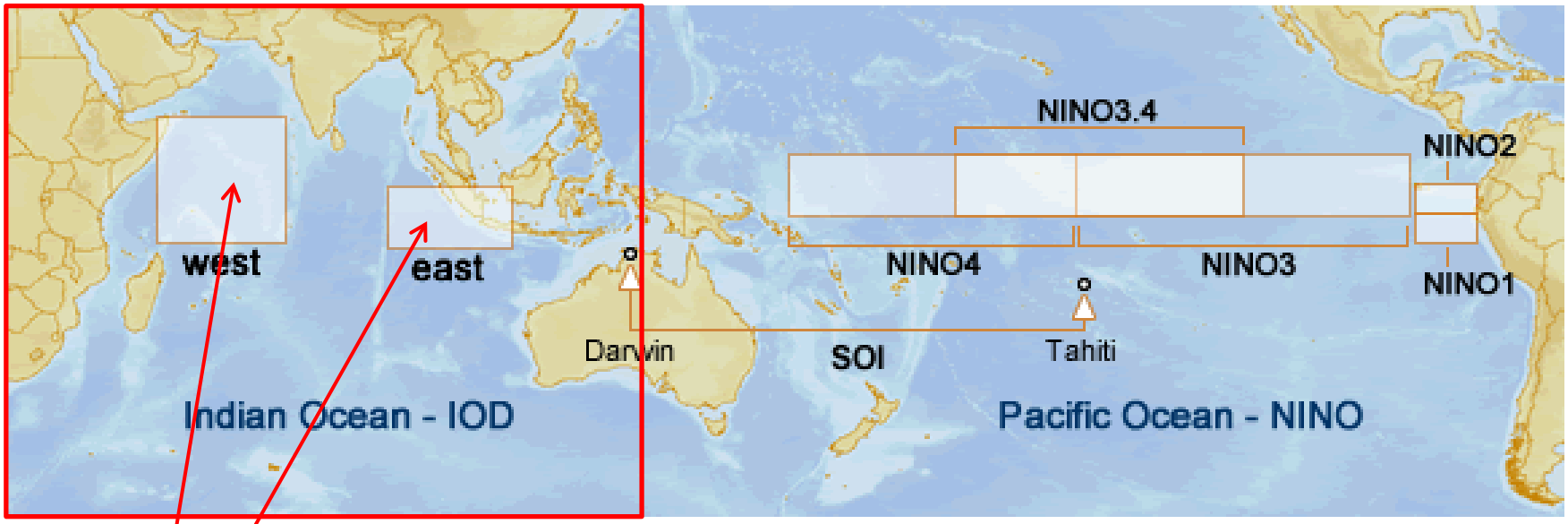
Indian Ocean Dipole Neutral Phase



Indian Ocean Dipole Negative Phase



Dipole Mode Index (DMI)



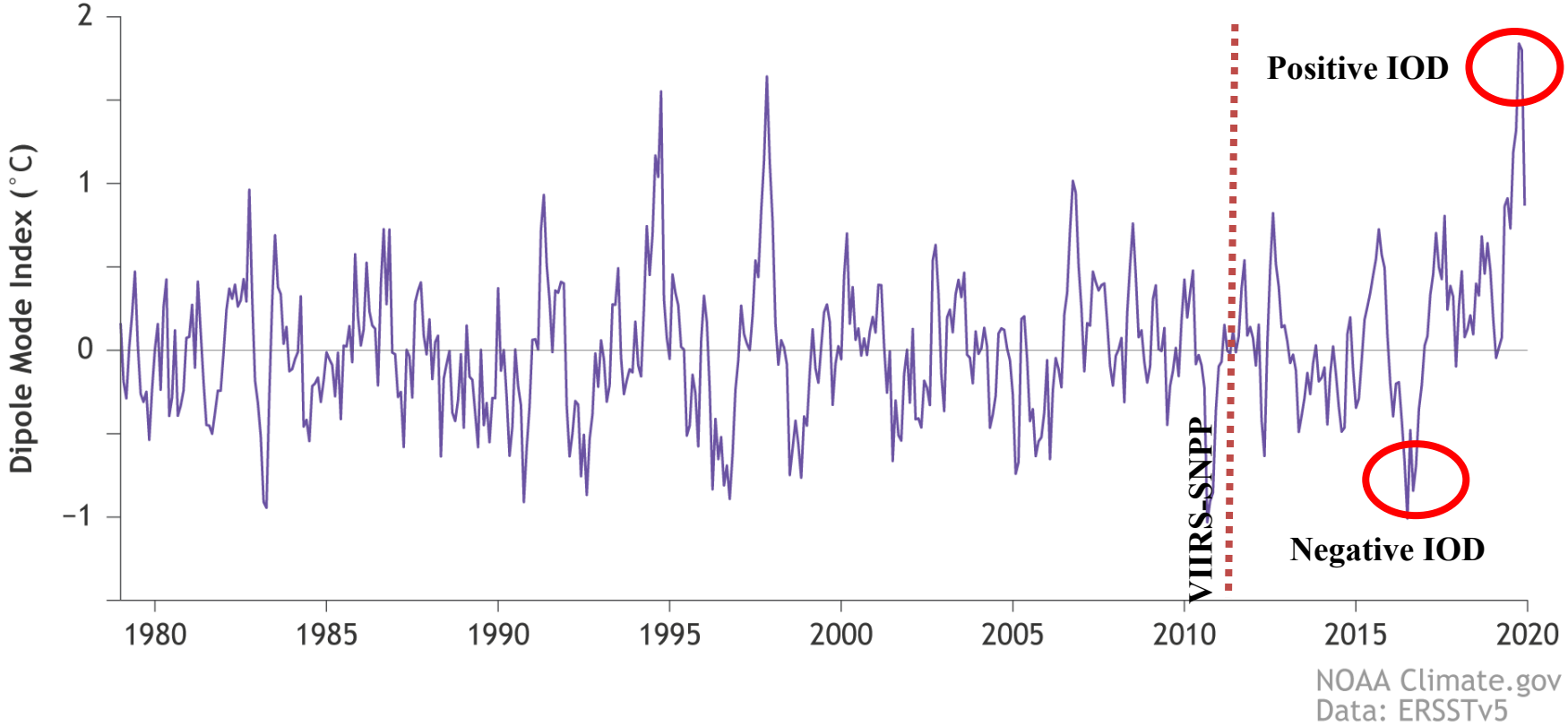
$$\textbf{DMI-E} = \textit{Mean}\ [SST^{(E)}_{mon}(x,y) - SST^{(E)}_{clim}(x,y)], \qquad (1)$$

$$\textbf{DMI-W} = \textit{Mean}\ [SST^{(w)}_{mon}(x,y) - SST^{(w)}_{clim}(x,y)], \qquad (2)$$

$$\textbf{DMI} = \textbf{DMI-W} - \textbf{DMI-E} \qquad (3)$$

Dipole Mode Index (DMI)

Monthly Dipole Mode Index (DMI) from January 1979 to December 2019



Ocean Color Work with Recent IOD Events

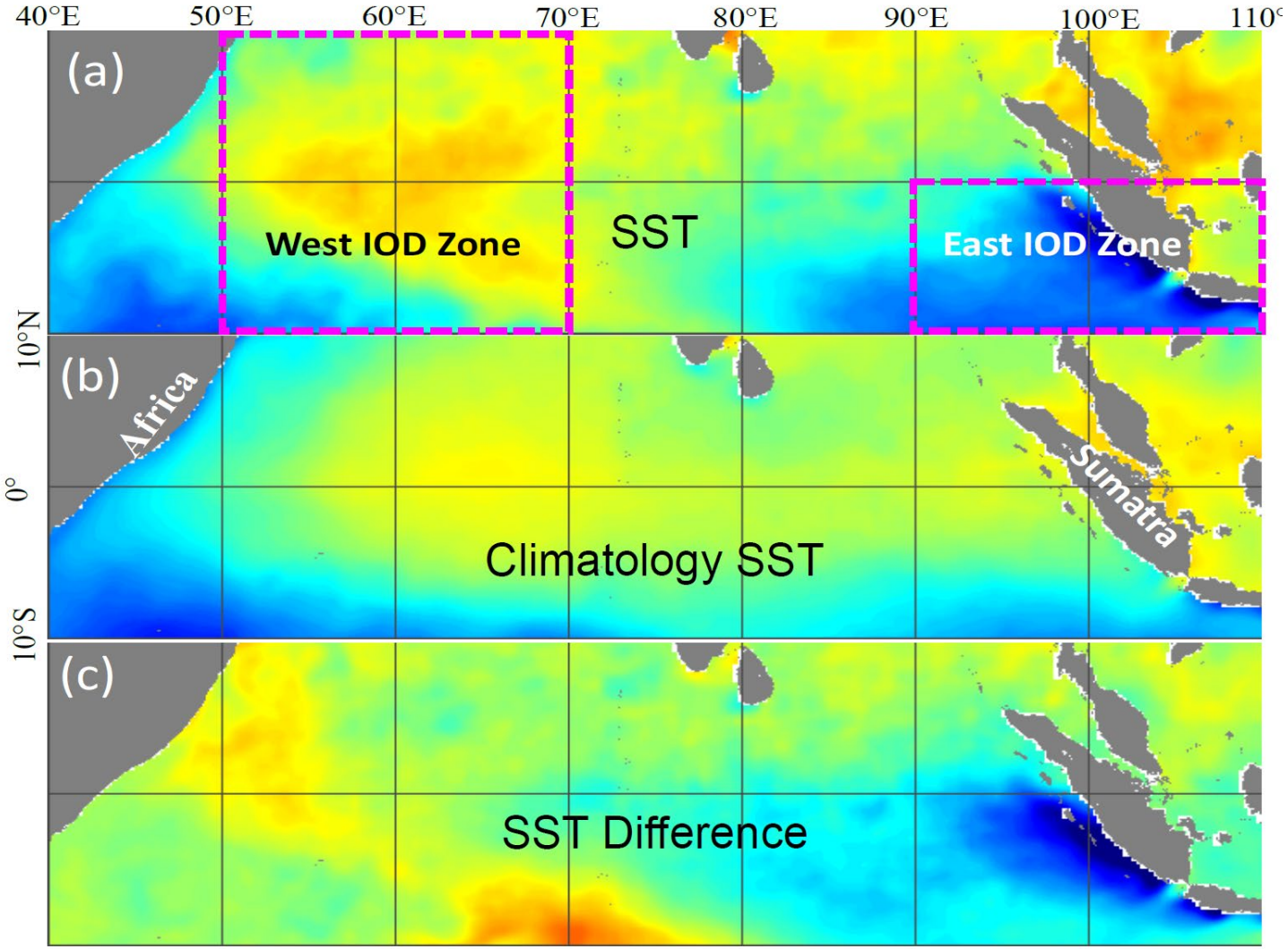
- Using observations of VIIRS onboard SNPP between 2012 and 2020, we study the significant biological dipole response that occurred in the Equatorial Indian Ocean following the 2019 positive IOD event. For the first time, we propose, identify, characterize, and quantify the biological IOD using observations of VIIRS between 2012 and 2020.
- We propose biological dipole mode indices (BDMIs) based on the dipolar observations of chlorophyll-a (Chl-a) anomalies in the east and west IOD zones. In comparison to traditional DMI, the two BDMIs not only represent the dipolar biological activities in the Equatorial Indian Ocean, but also reflect the thermocline dynamics in the Equatorial Indian Ocean.

(1) Ocean Color Work with Recent IOD Events

Shi, W. and M. Wang, "A biological Indian Ocean Dipole event in 2019," *Sci. Reps*, **11**, 2452 (2021). doi:10.1038/s41598-021-81410-5

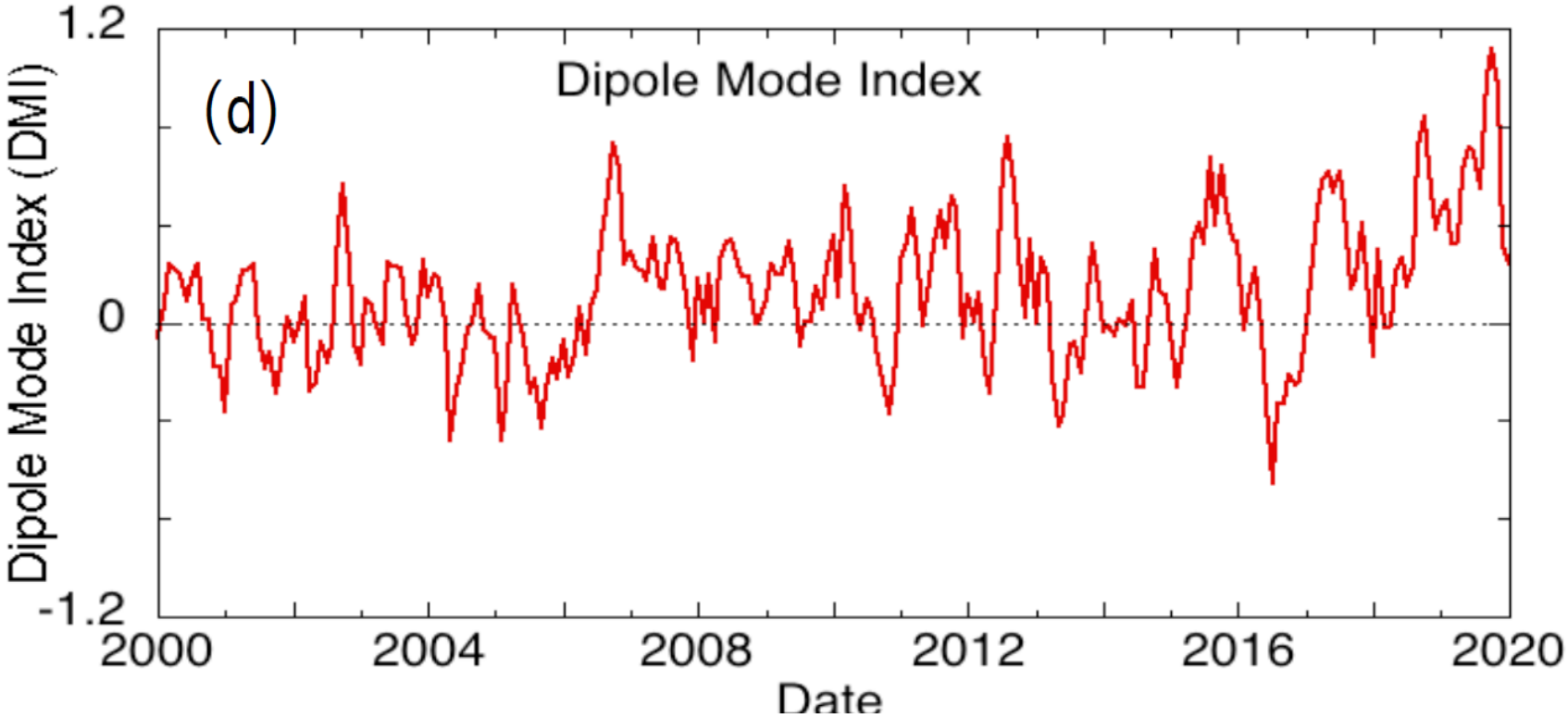
(1) A biological Indian Ocean Dipole event in 2019

SST in October 2019, October Climatology SST and SST Anomaly

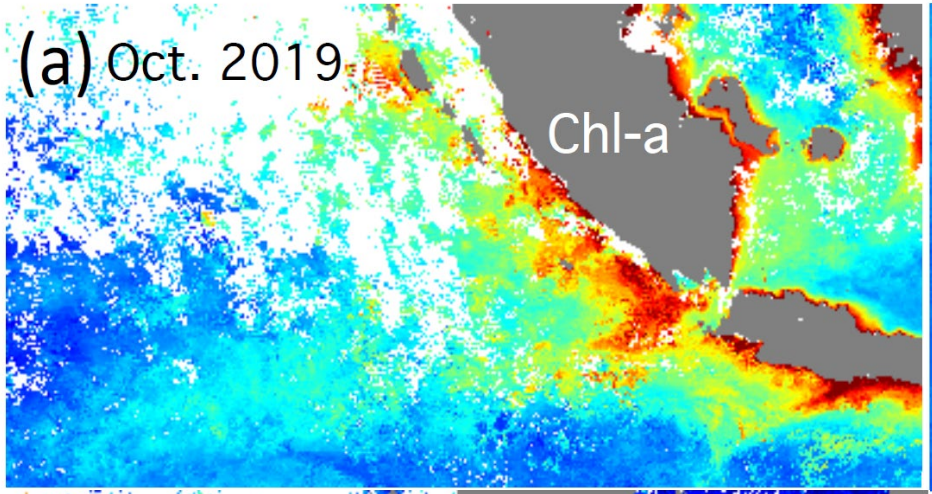


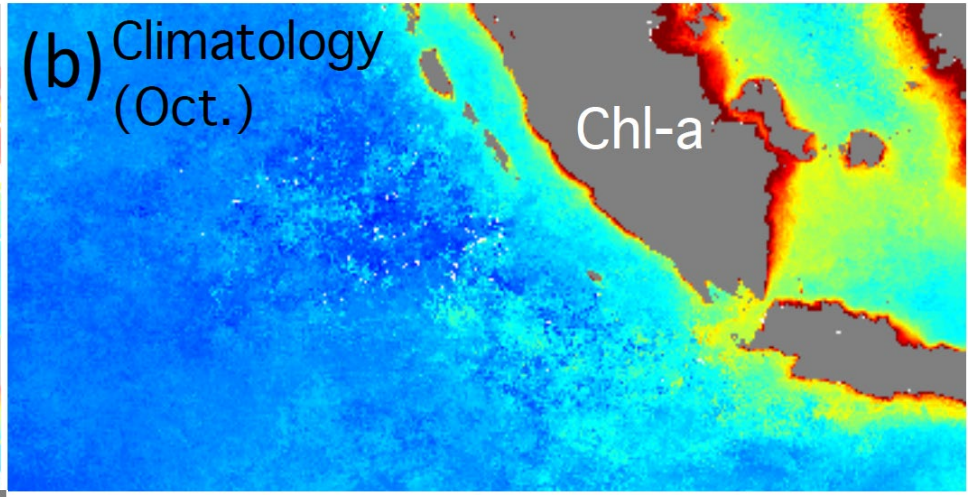
(1) A biological Indian Ocean Dipole event in 2019

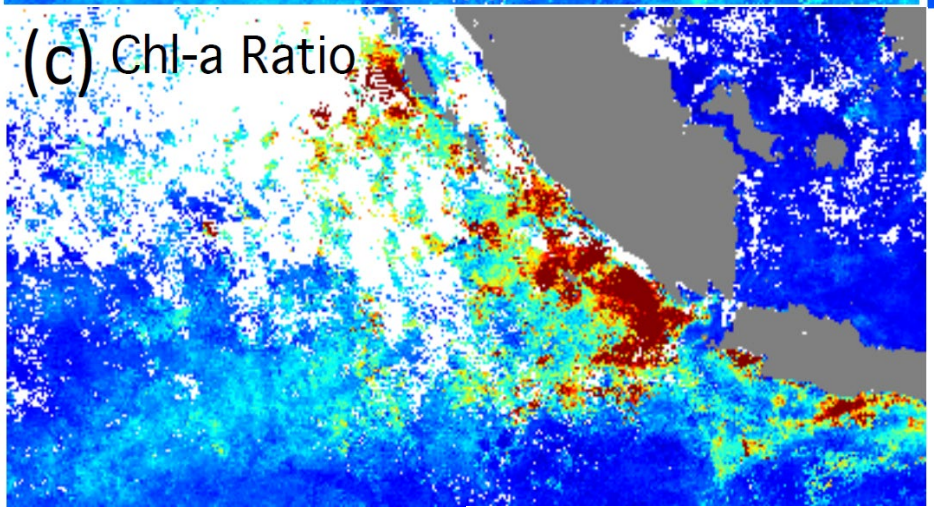
Temporal Variation of the DMI since 2000



(1) A biological Indian Ocean Dipole event in 2019



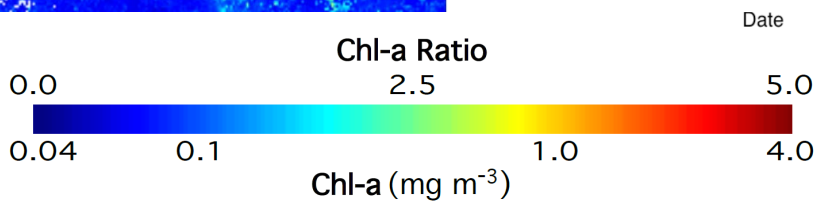




(a) Chl-a in October 2019

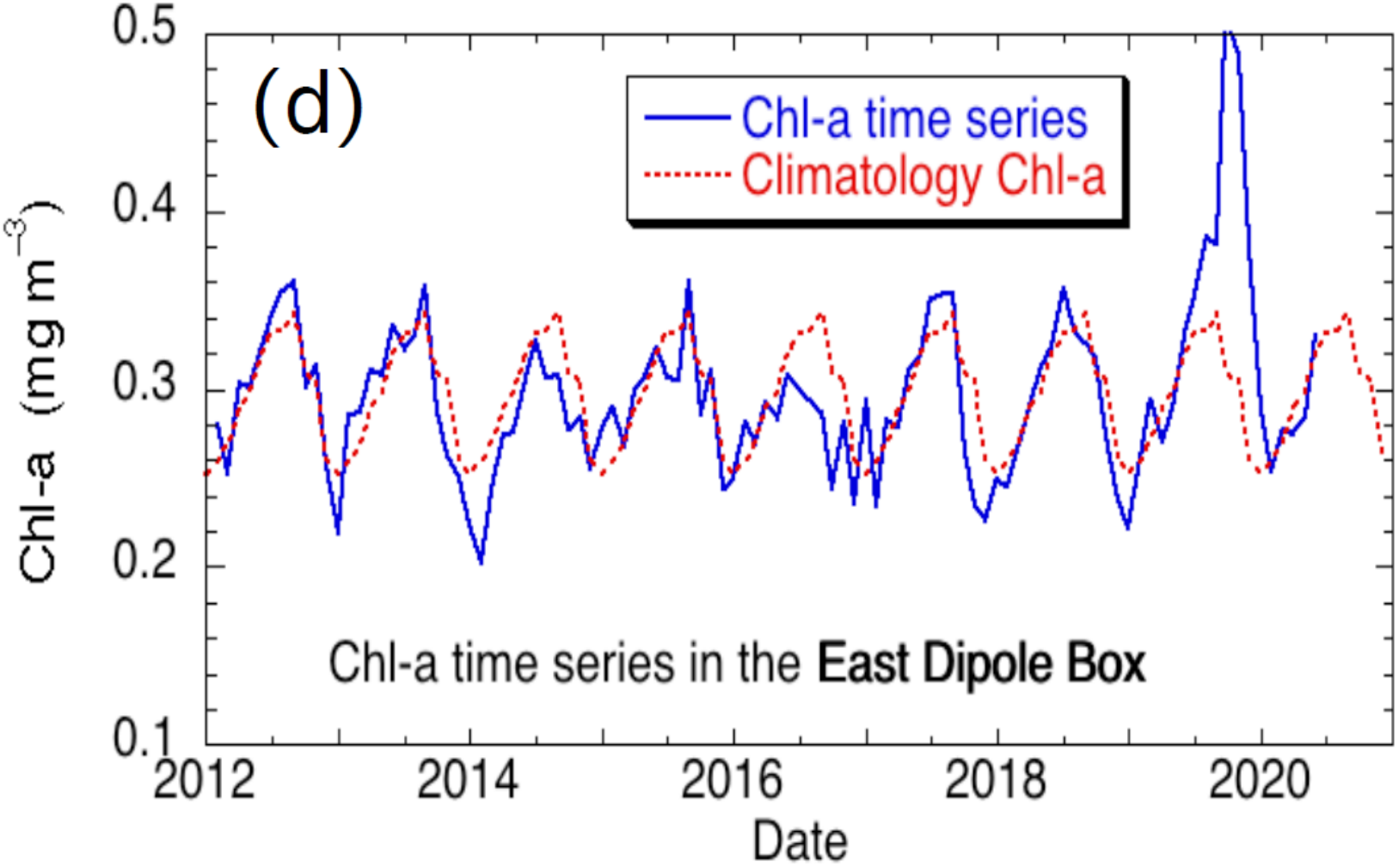
(b) Chl-a climatology in October

(c) Ratio of Chl-a in October 2019 from (a) and (b)



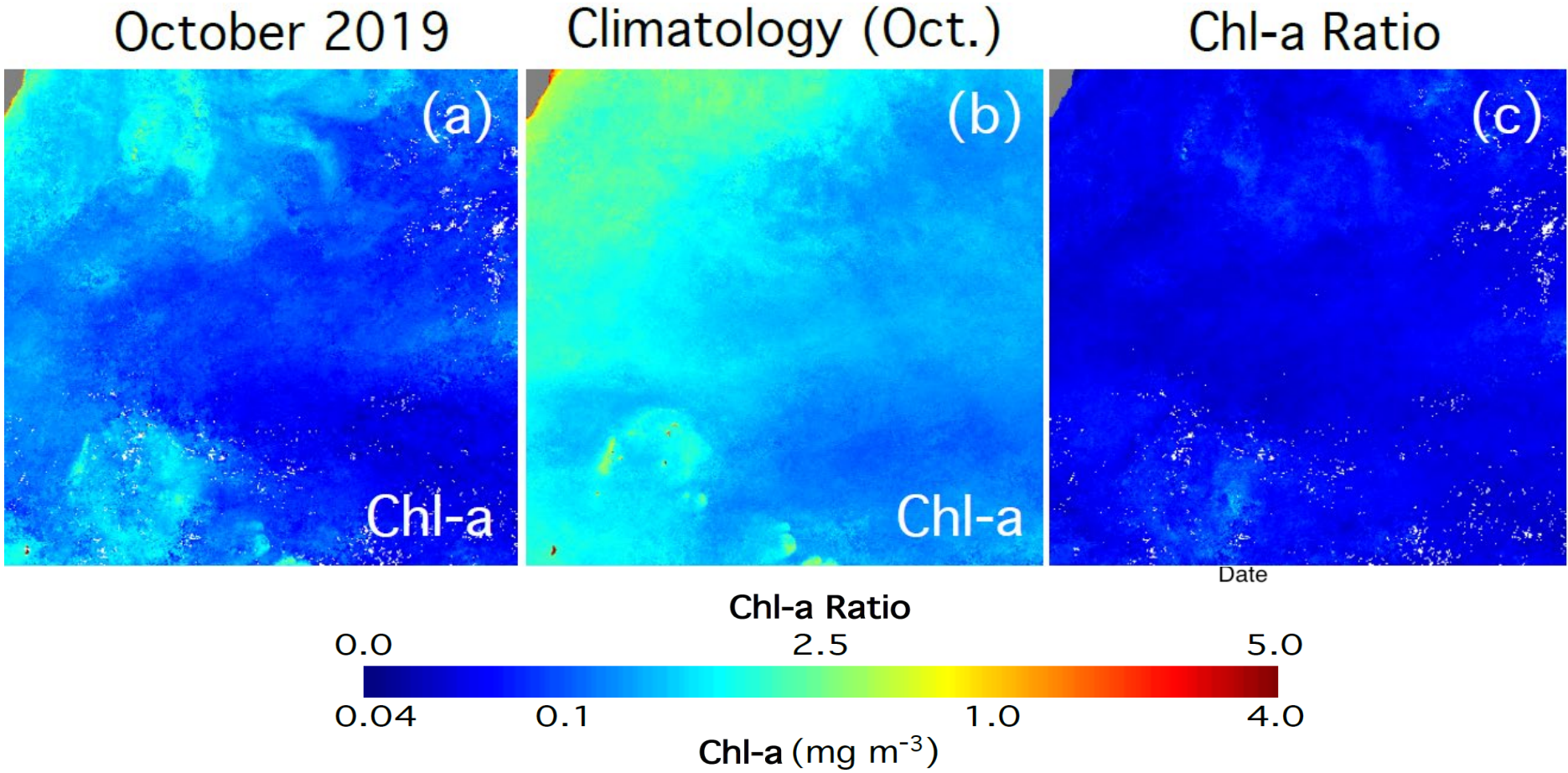
(1) A biological Indian Ocean Dipole event in 2019

Time Series of Average Chl-a between 2012 and mid-2020 in the East IOD Zone



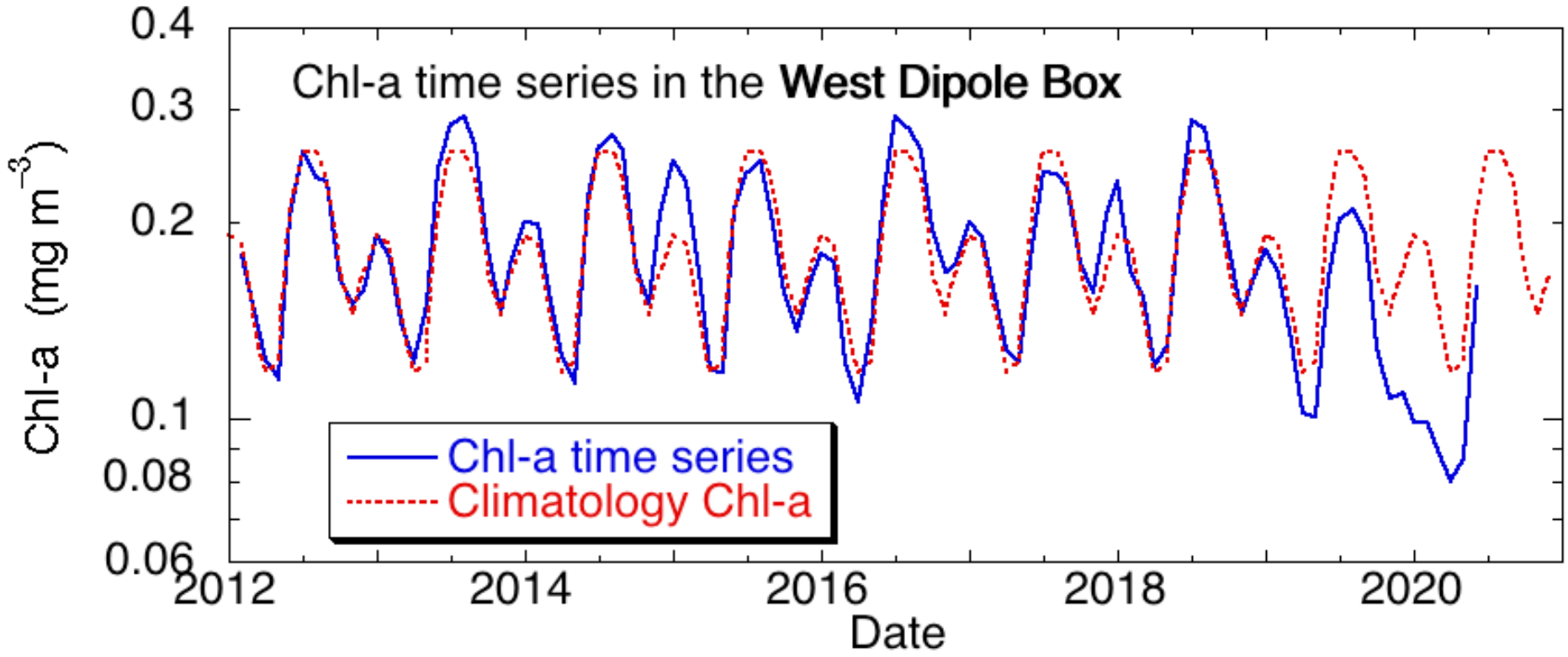
(1) A biological Indian Ocean Dipole event in 2019

Chl-a in the West IOD Zone



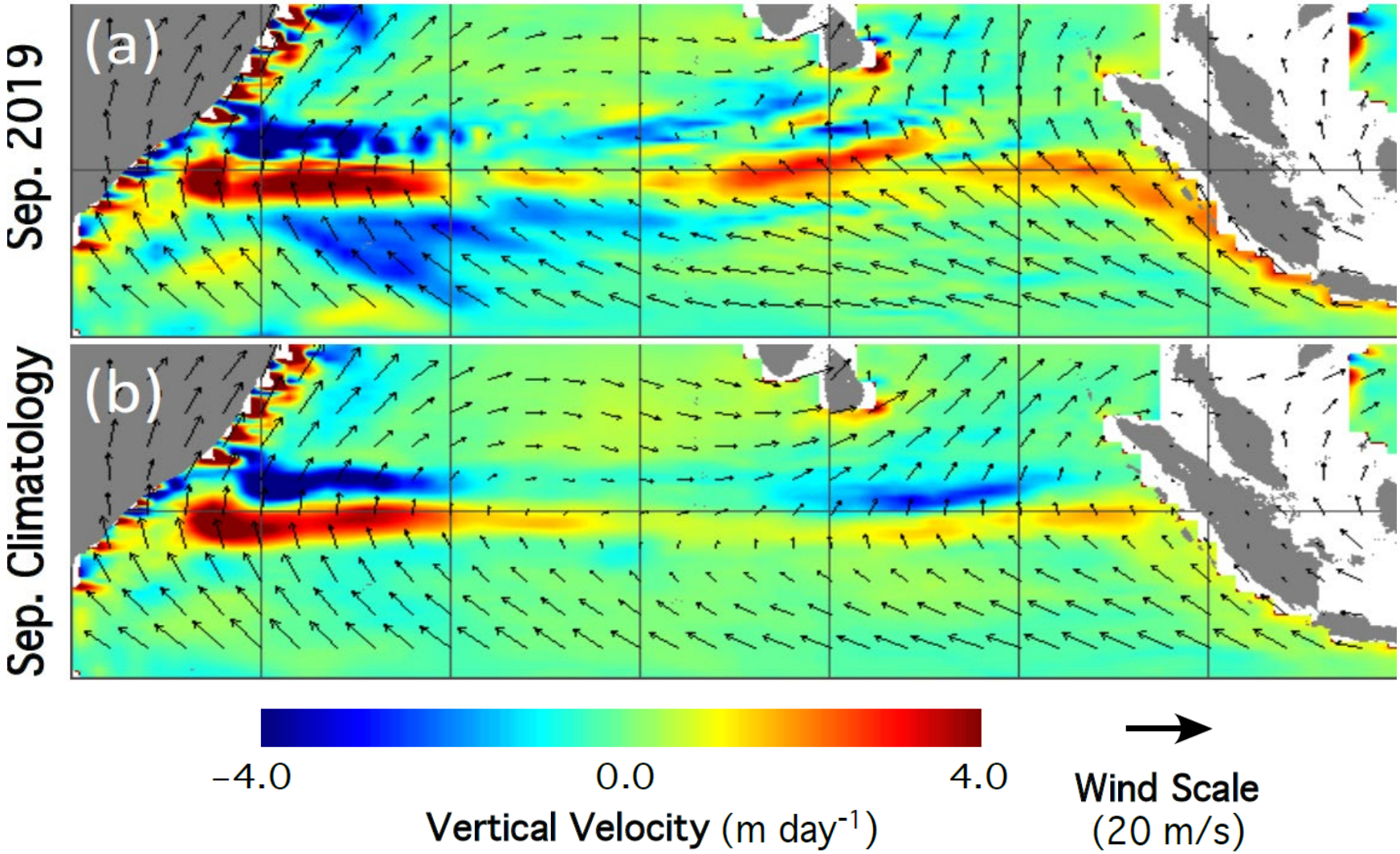
(1) A biological Indian Ocean Dipole event in 2019

Time Series of Average Chl-a between 2012 and mid-2020 in the West IOD Zone



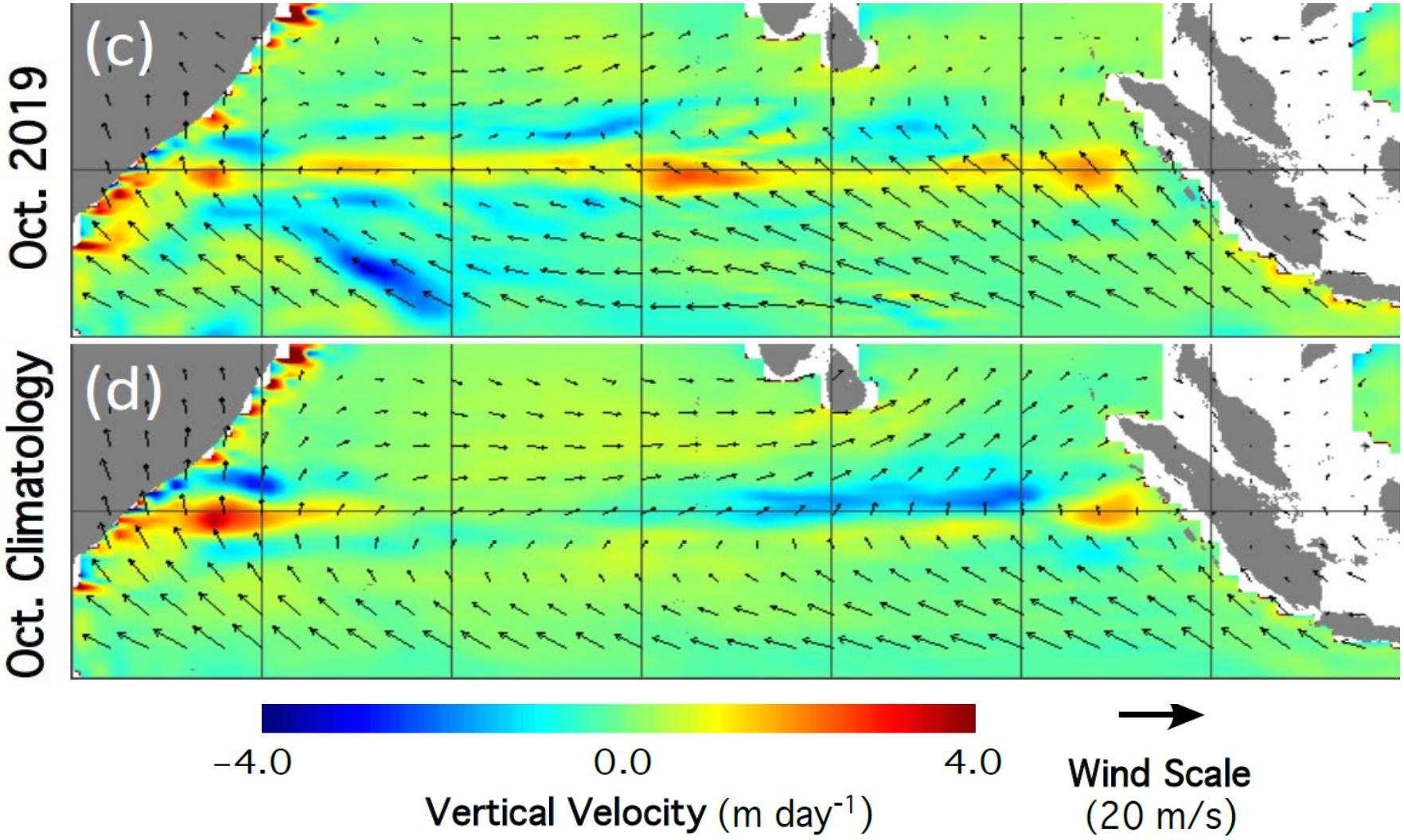
(1) A biological Indian Ocean Dipole event in 2019

Vertical Velocity at 50 m and Wind Fields in September 2019



(1) A biological Indian Ocean Dipole event in 2019

Vertical Velocity at 50 m and Wind Fields in October 2019



(1) A biological Indian Ocean Dipole event in 2019

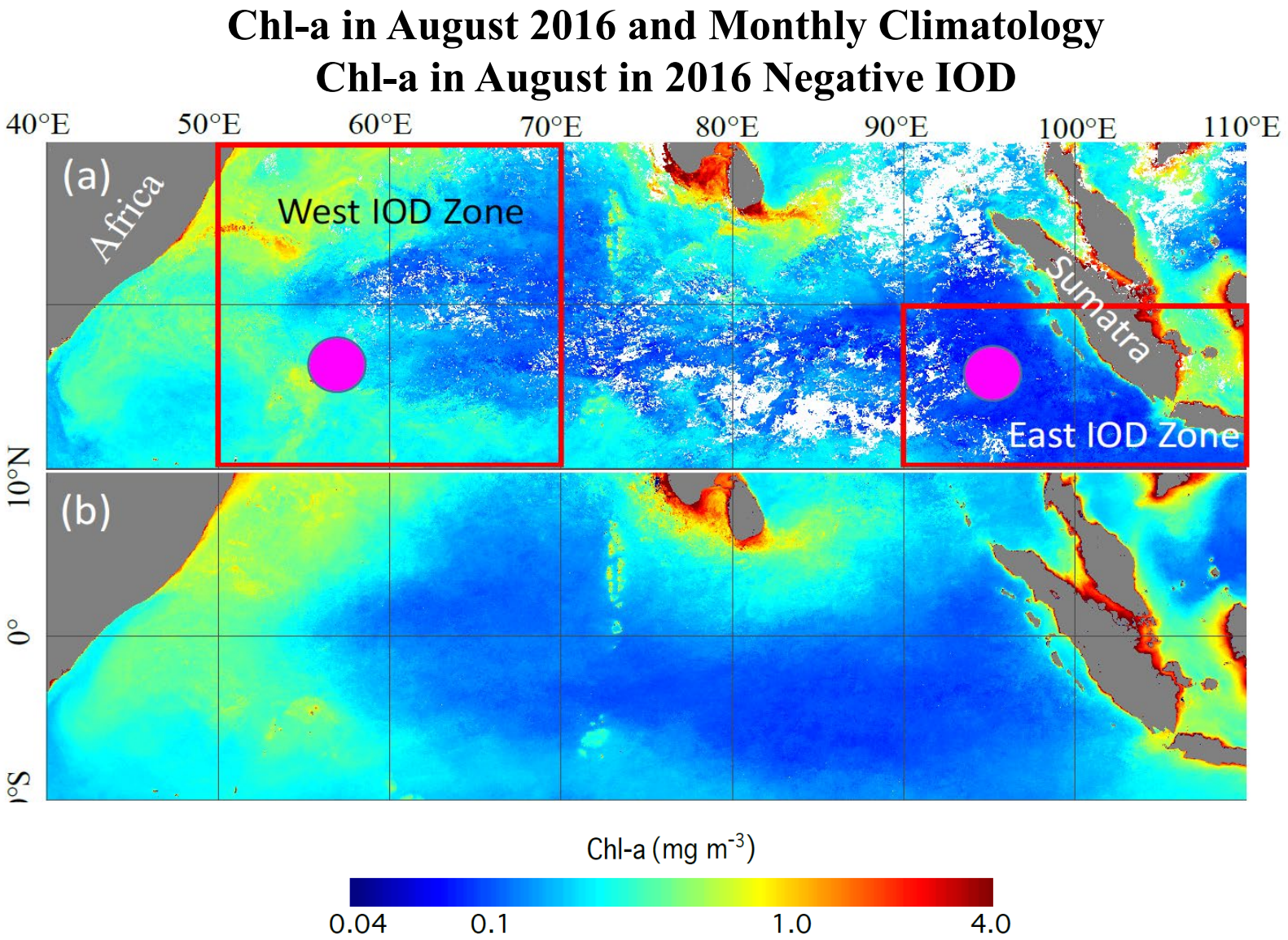
Conclusion Remarks (1)

- VIIR-SNPP observations show significant dipolar biological changes in the equatorial Indian Ocean following the 2019 IOD event
- Chl-a in the east IOD zone increased to over ~0.5 mg m^3 in October 2019 from the climatology (normal) Chl-a of ~0.3 mg m^3.
- In the west IOD zone, Chl-a dropped more than 30% in the 2019 IOD event in comparison to the climatology Chl-a, and the depressed Chl-a in the west IOD zone lasted until May 2020.
- Phytoplankton bloom during the 2019 IOD event is attributed to higher nutrient supplies in the east IOD zone following the advection of the high-nutrient upwelling water in the region.
- Weaker Chl-a in the west IOD zone is attributed to the nutrient deficiency due to the convergence of the surface water and the thermocline deepening in the west equatorial Indian Ocean.

(2) **Biological Dipole Mode Indices (BDMIs)**

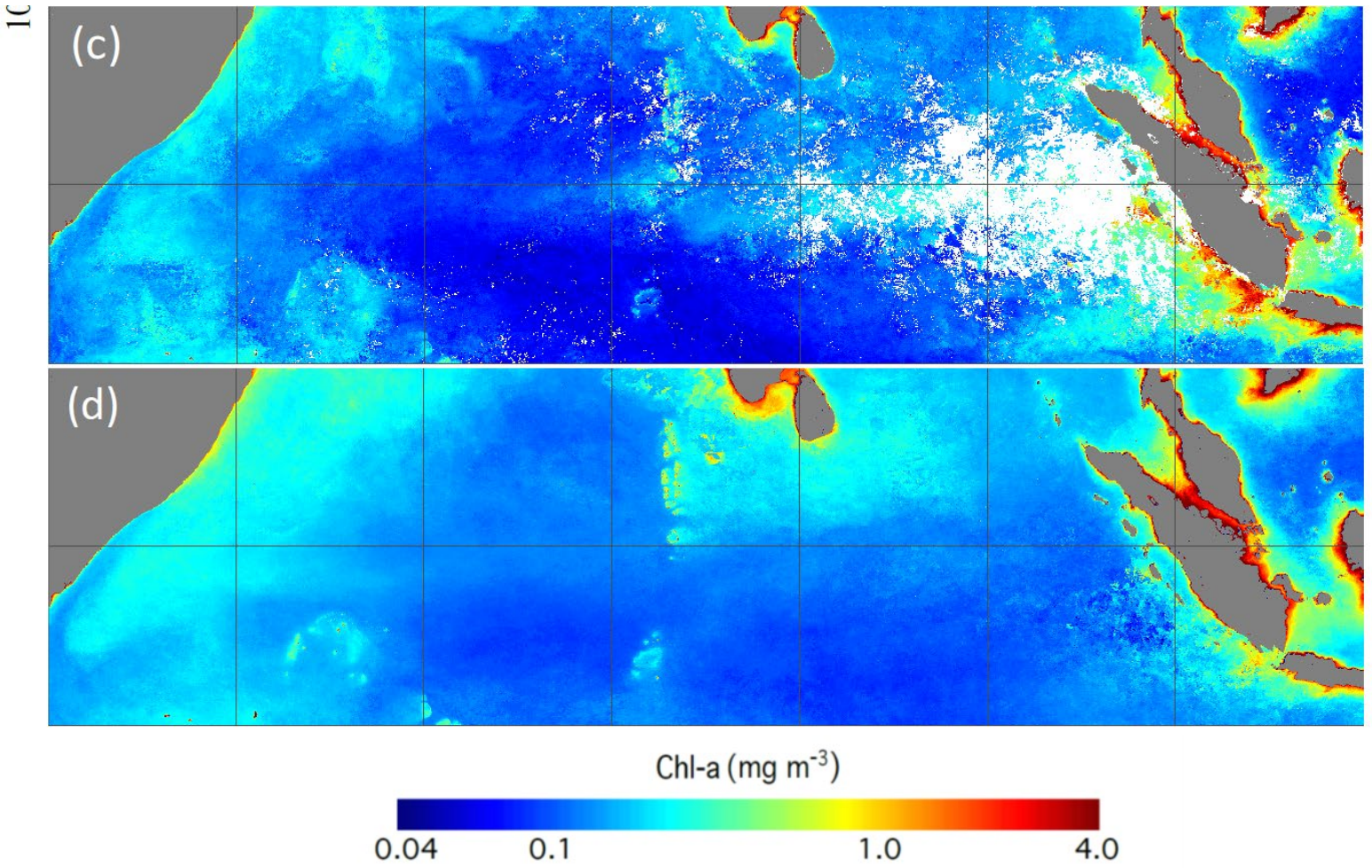
Shi, W. and M. Wang, "Biological dipole mode indices: New parameters to characterize the physical and biological processes of the Indian Ocean Dipole event," *Prog. Oceanogr.*, **206**, 102847 (2022). doi:10.1016/j.pocean.2022.102847

(2) Biological Dipole Mode Indices (BDMIs)



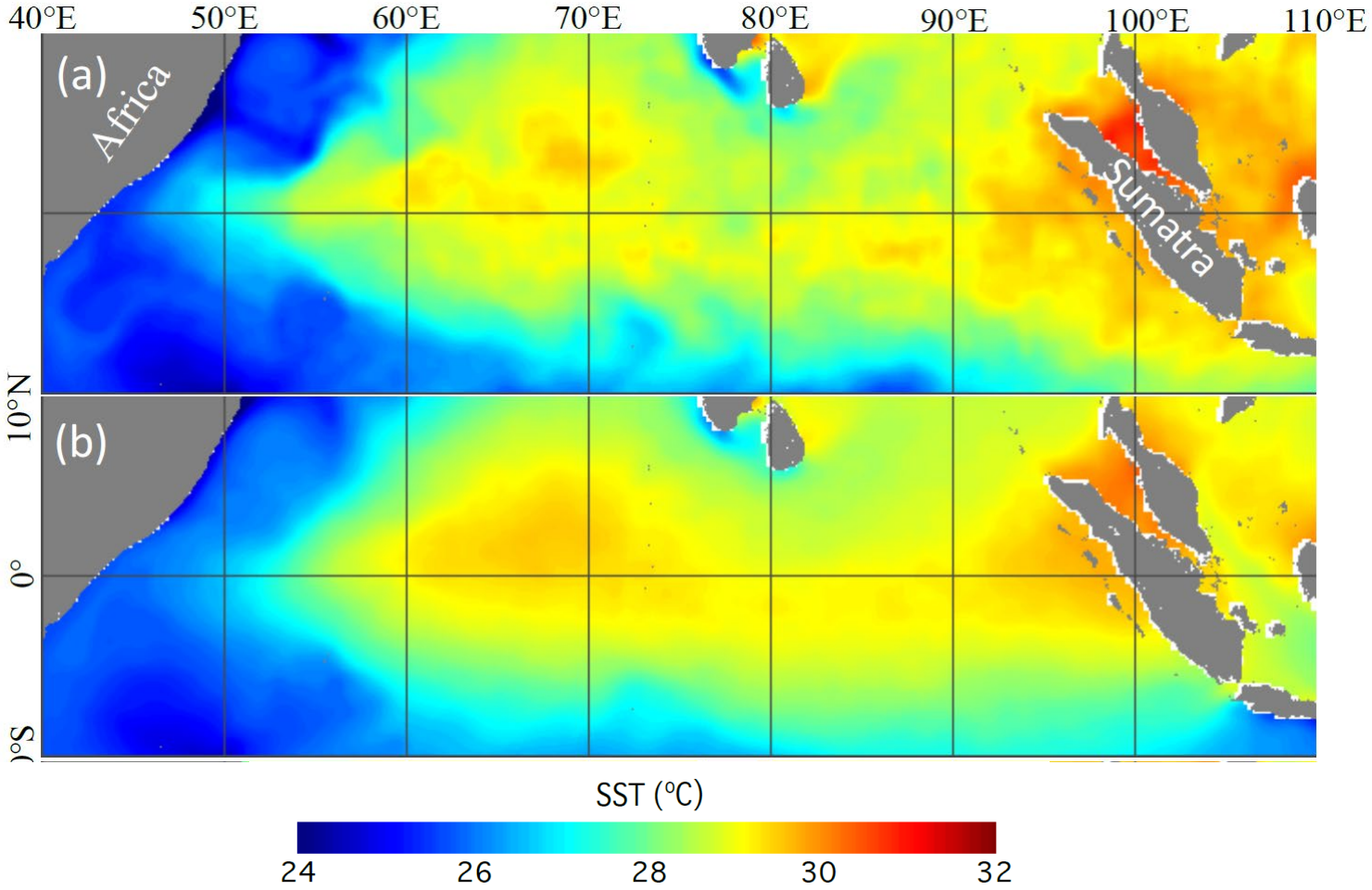
(2) Biological Dipole Mode Indices (BDMIs)

Chl-a in October 2019 and Monthly Climatology Chl-a in October in the 2016 Positive IOD



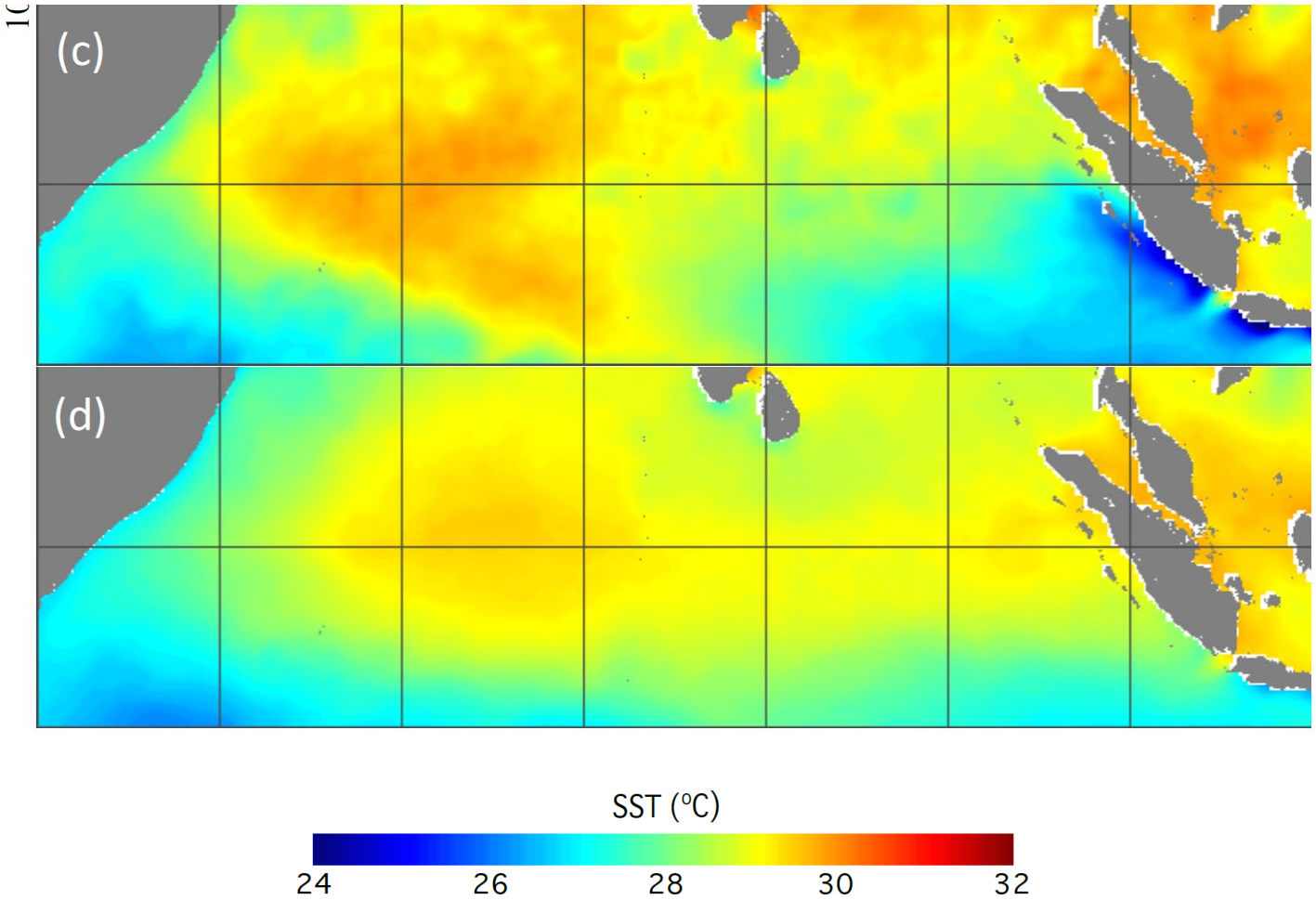
(2) Biological Dipole Mode Indices (BDMIs)

SST in August 2016 and Monthly Climatology SST in August in the 2016 negative IOD

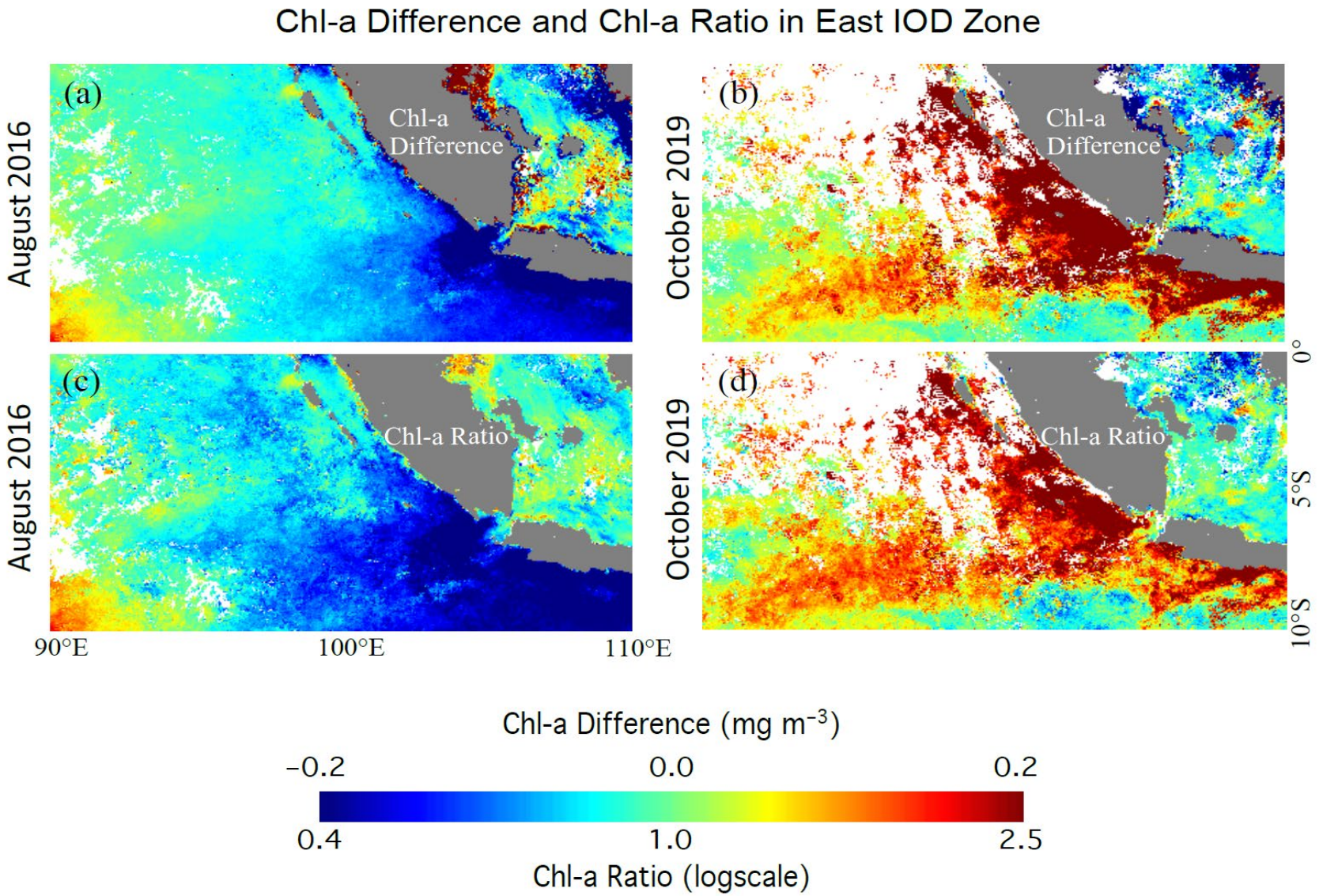


(2) Biological Dipole Mode Indices (BDMIs)

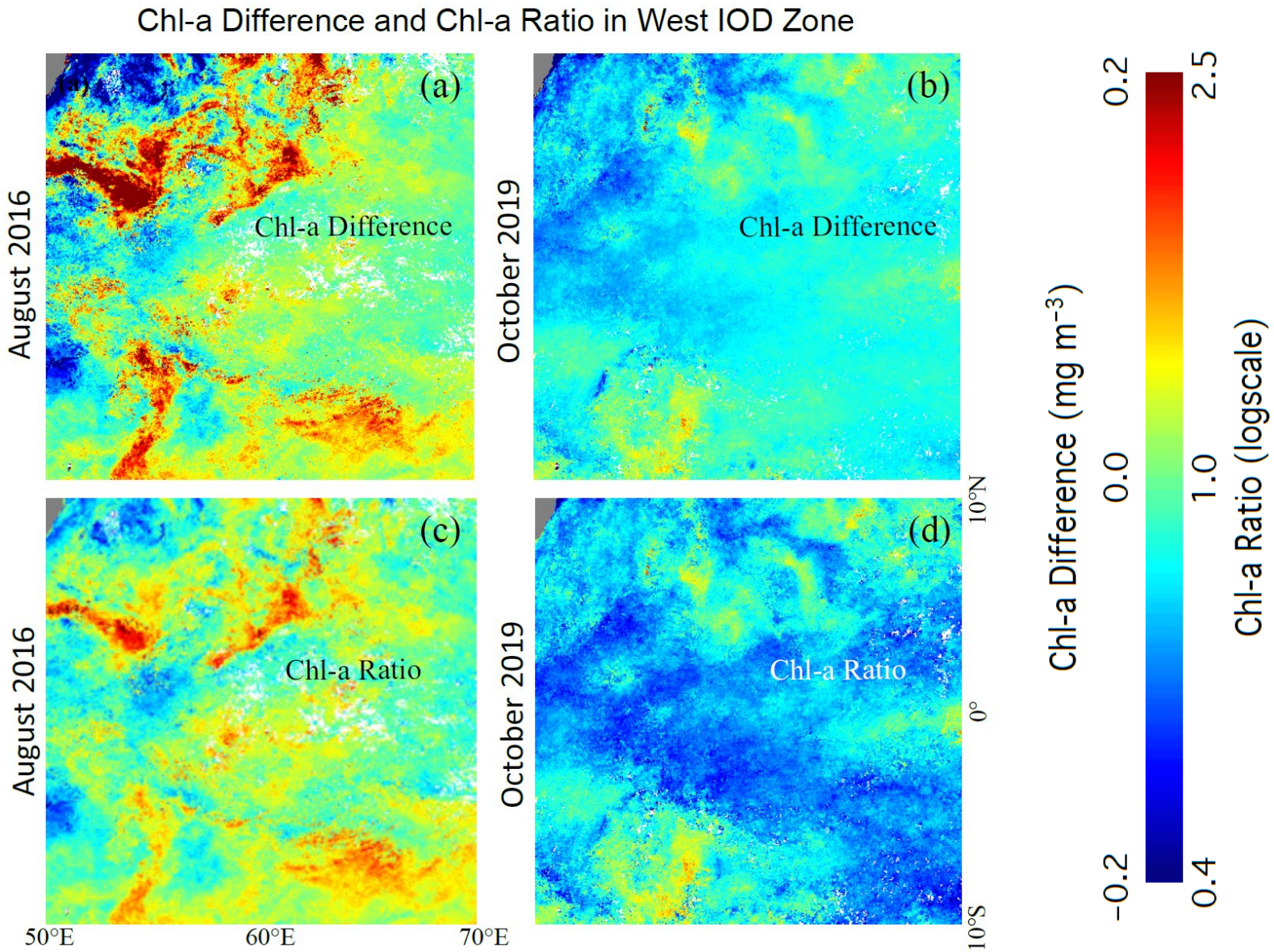
SST in October 2019 and Monthly Climatology SST in October in the 2019 positive IOD



(2) Biological Dipole Mode Indices (BDMIs)



(2) Biological Dipole Mode Indices (BDMIs)



(2) Biological Dipole Mode Indices (BDMIs)

Development of Biological Dipole Mode Indices (BDMIs)

$$\mathrm{BDMI}^{(\mathrm{Diff})}\text{-E} = Mean\ [Chl\text{-}a^{(E)}_{mon}(x,y) - Chl\text{-}a^{(E)}_{clim}(x,y)\ ], \quad (1)$$

$$\mathrm{BDMI}^{(\mathrm{Diff})}\text{-W} = Mean\ [Chl\text{-}a^{(w)}_{mon}(x,y) - Chl\text{-}a^{(w)}_{clim}(x,y)], \quad (2)$$

$$\mathrm{BDMI}^{(\mathrm{Diff})} = \mathrm{BDMI}^{(\mathrm{Diff})}\text{-E} - \mathrm{BDMI}^{(\mathrm{Diff})}\text{-W}, \quad (3)$$

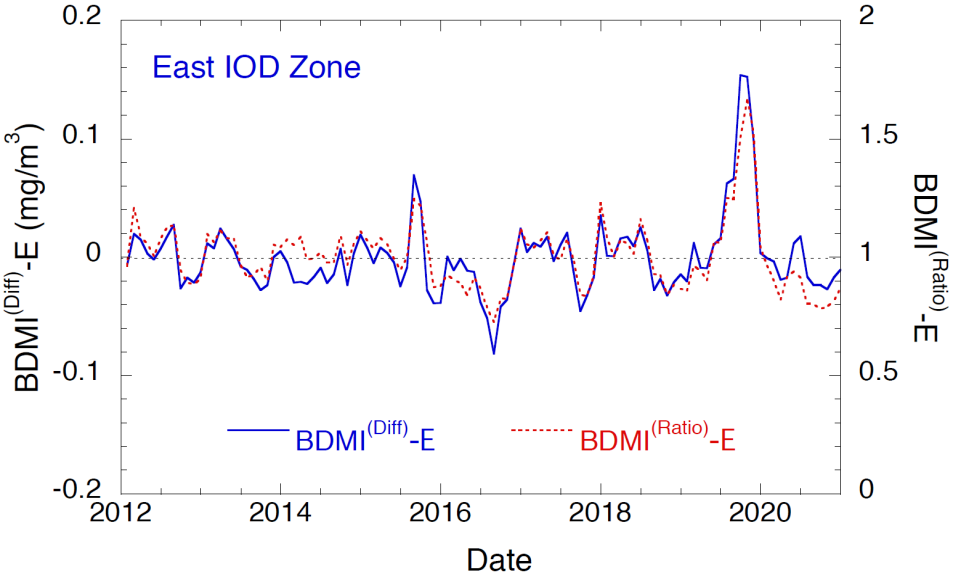
$$\mathrm{BDMI}^{(\mathrm{Ratio})}\text{-E} = Mean\ [Chl\text{-}a^{(E)}_{mon}(x,y) / Chl\text{-}a^{(E)}_{clim}(x,y)], \quad (4)$$

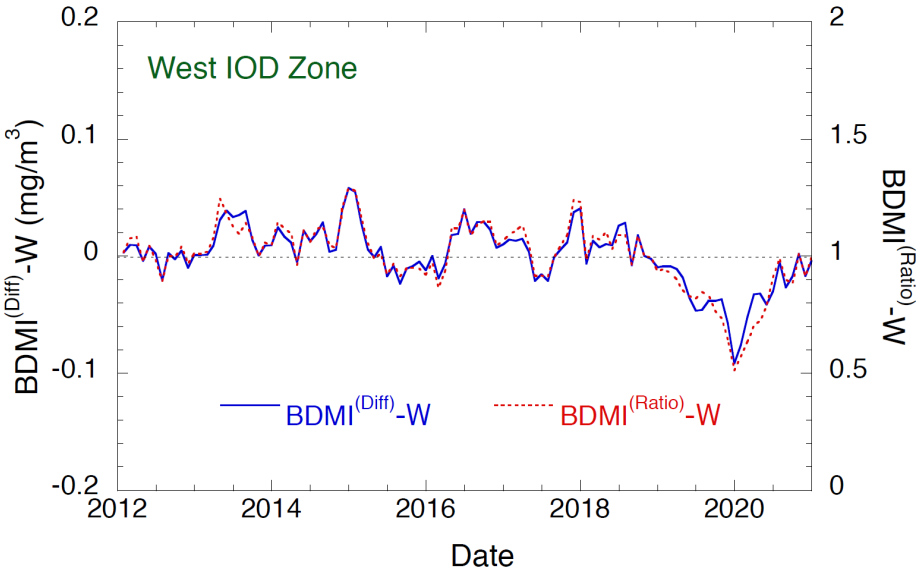
$$\mathrm{BDMI}^{(\mathrm{Ratio})}\text{-W} = Mean\ [Chl\text{-}a^{(w)}_{mon}(x,y) / Chl\text{-}a^{(w)}_{clim}(x,y)], \text{ and} \quad (5)$$

$$\mathrm{BDMI}^{(\mathrm{Ratio})} = \mathrm{BDMI}^{(\mathrm{Ratio})}\text{-E} - \mathrm{BDMI}^{(\mathrm{Ratio})}\text{-W}, \quad (6)$$

(2) Biological Dipole Mode Indices (BDMIs)

Time Series of BDMI-E and BDMI-W (2012–2020)

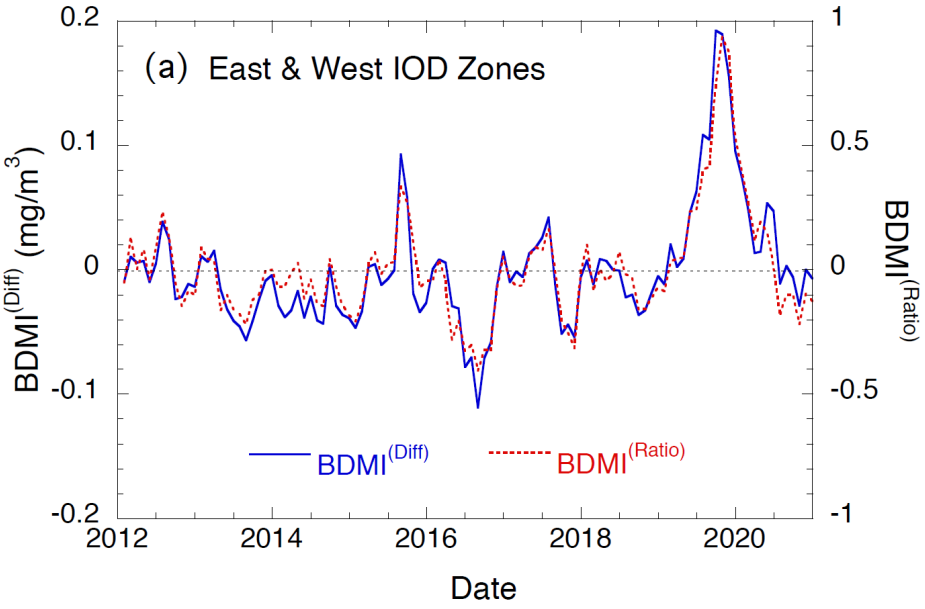


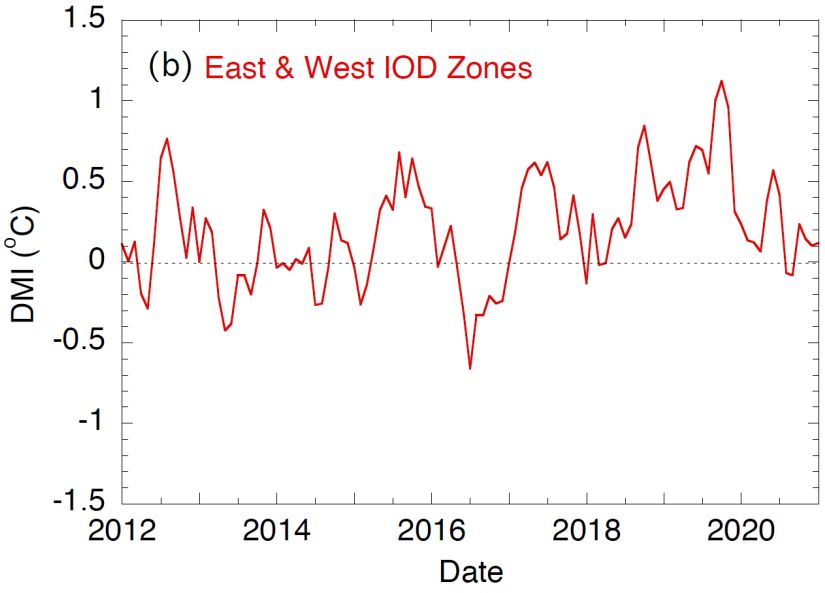


- $BDMI^{(Diff)}$-E was ~ –0.08 mg/m^3, and $BDMI^{(Ratio)}$-E was close to 0.7 in the late summer of 2016 during the negative IOD event. $BDMI^{(Ratio)}$-E rose from 1.09 in July to 1.51 in October, and further 1.67 in November 2019.
- In August 2016, the $BDMI^{(Ratio)}$-W was moderately high with values of ~1.25, while $BDMI^{(Diff)}$-W was ~0.05 mg/m^3. During the positive IOD event, $BDMI^{(Diff)}$-W was close to –0.10 mg/m^3, and the $BDMI^{(Ratio)}$-W dropped to ~0.5 in late 2019 and early 2020.

(2) Biological Dipole Mode Indices (BDMIs)

Comparison of BDMIs and Traditional DMI (2012–2020)

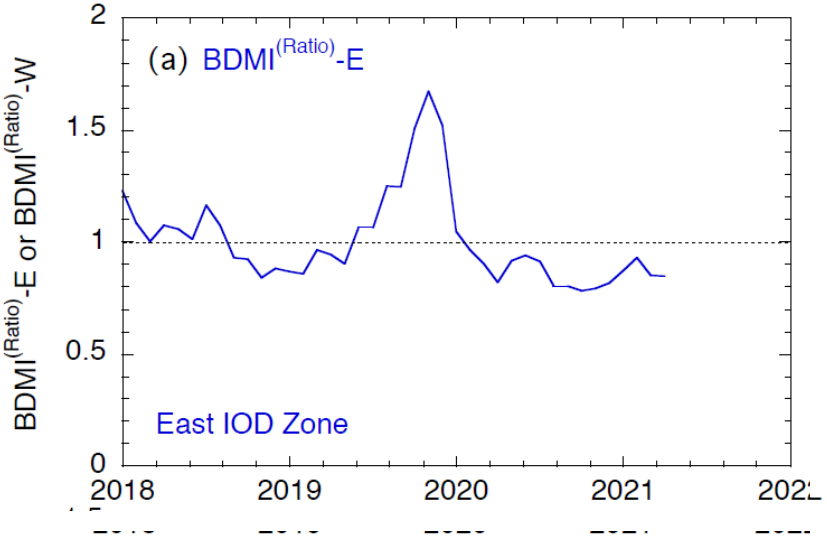


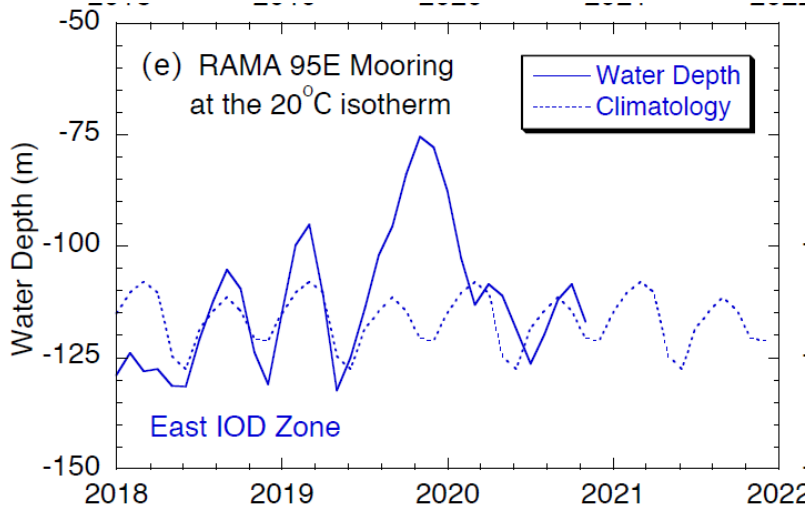


- Time series of the BDMI$^{(Diff)}$, BDMI$^{(Ratio)}$, and DMI can all represent the IOD variability in the Equatorial Indian Ocean.
- BDMI$^{(Diff)}$, BDMI$^{(Ratio)}$, are more sensitive than the DMI In detecting the IOD variability in the Equatorial Indian Ocean.

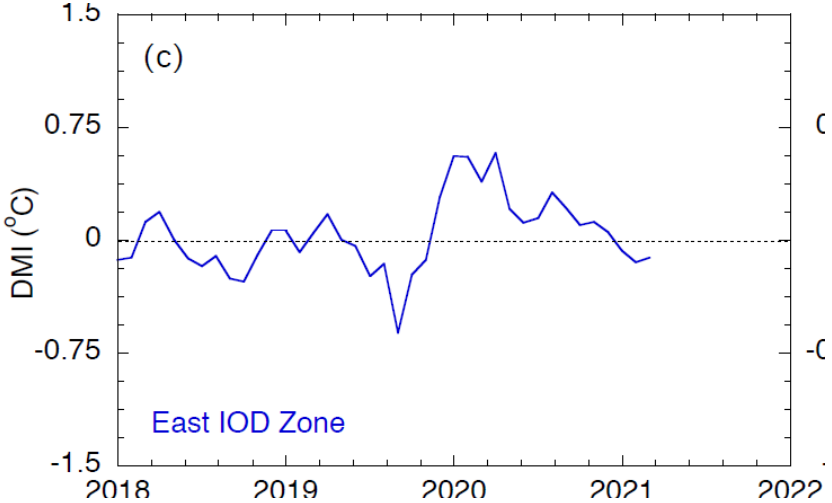
(2) Biological Dipole Mode Indices (BDMIs)

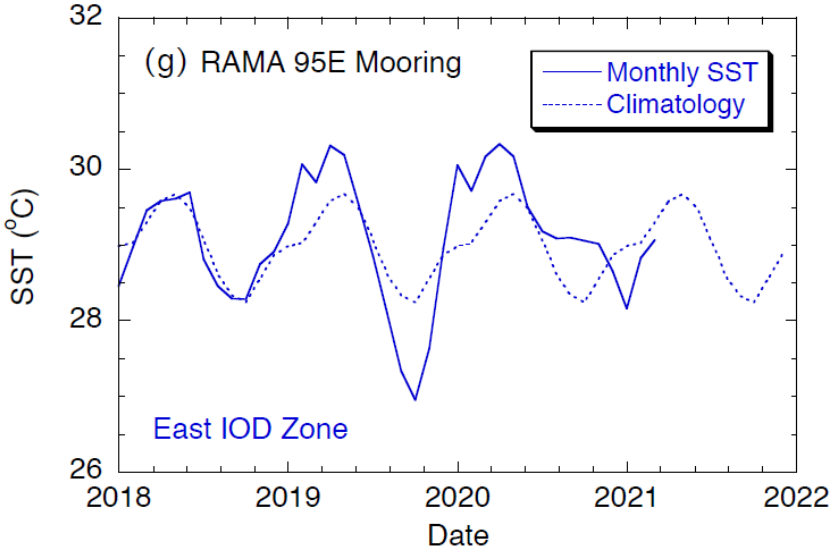
BDMI$^{(Ratio)}$-E *vs.* ISO20





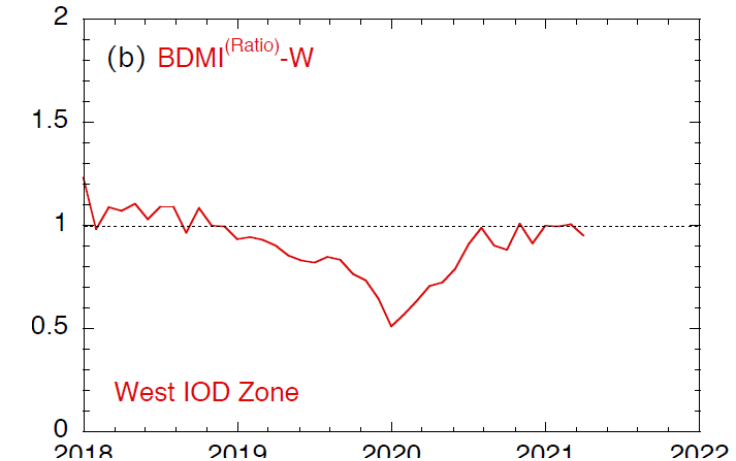
DMI-E *vs.* SST (RAMA_95E)

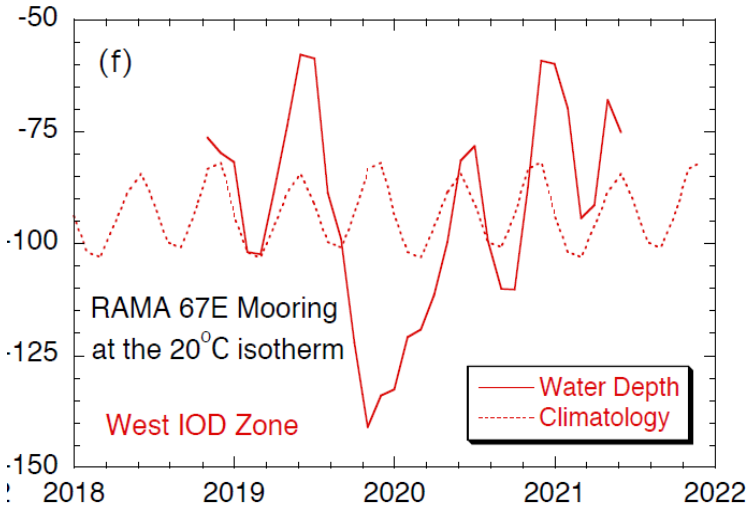




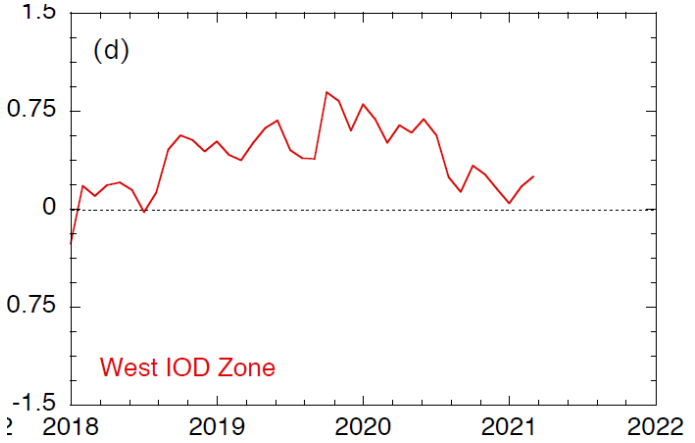
(2) Biological Dipole Mode Indices (BDMIs)

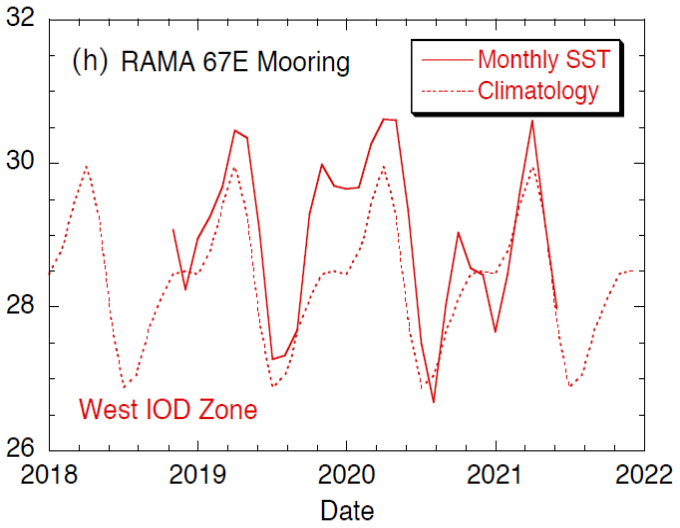
BDMI$^{(Ratio)}$-W *vs.* ISO20 (RAMA_67E)





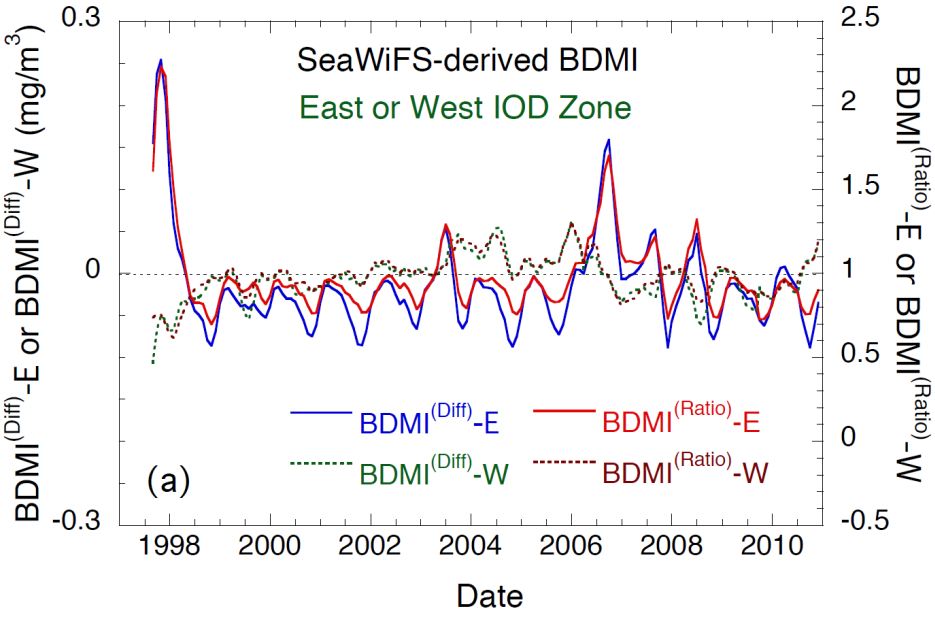
DMI-W *vs.* SST (RAMA_67E)

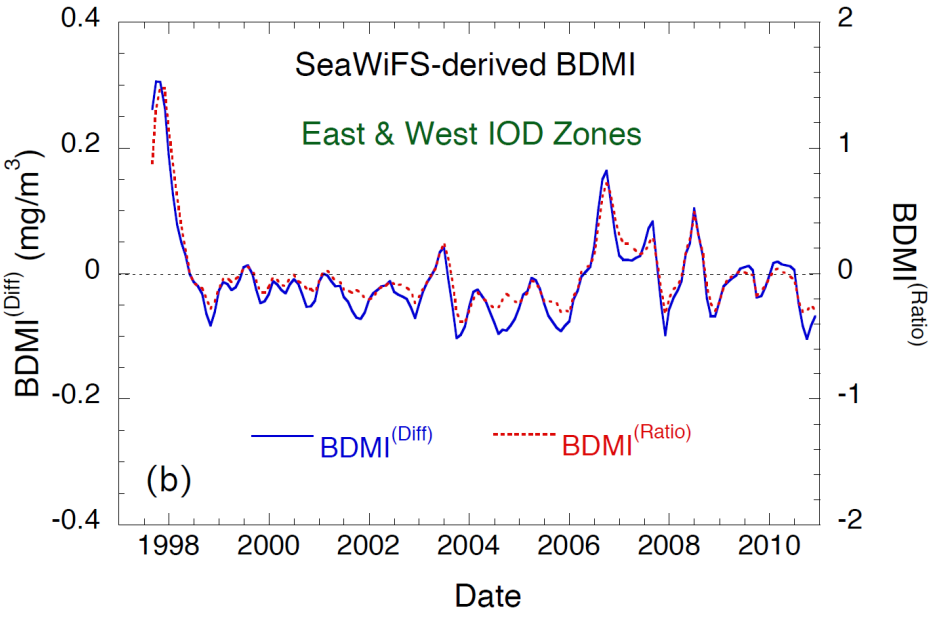




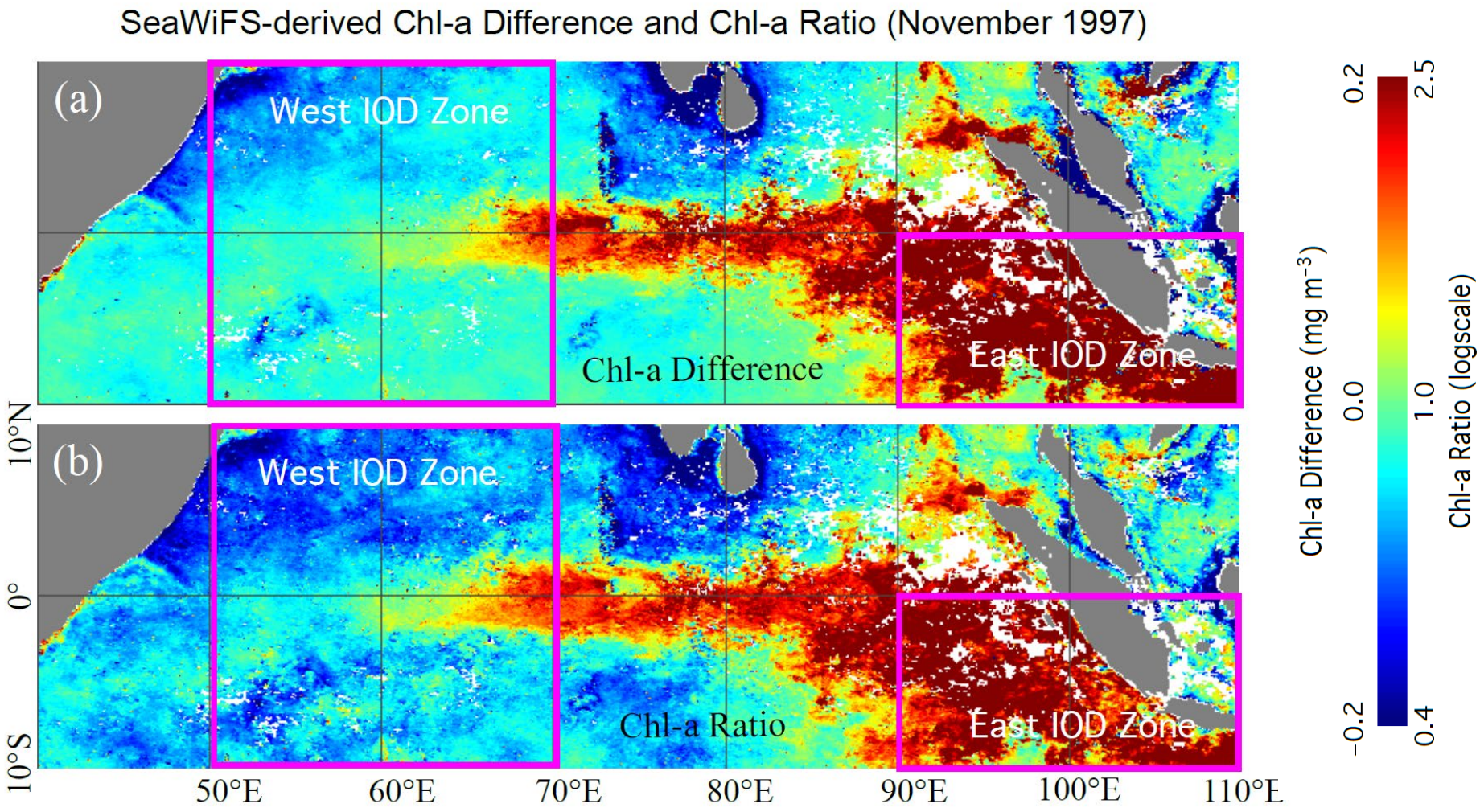
(2) Biological Dipole Mode Indices (BDMIs)

BDMIs in SeaWiFS Era (1997–2010)





(2) Biological Dipole Mode Indices (BDMIs)



(2) Biological Dipole Mode Indices (BDMIs)

(2) Conclusion Remarks

- Biological dipole mode indices BDMIs ($BDMI^{(Diff)}$ and $BDMI^{(Ratio)}$) are proposed.
- $BDMI^{(Diff)}$ and $BDMI^{(Ratio)}$ can characterize the physical and biological processes of the Indian Ocean Dipole event.
- The performance comparison between the two BDMIs and DMI also shows that the BDMIs and traditional DMI can effectively detect IOD signal for the major IOD events
- $BDMI^{(Diff)}$ and $BDMI^{(Ratio)}$ are demonstrated to be more sensitive than the traditional DMI. RAMA in situ measurements show BDMI reflects the subsurface ocean dynamics in the Equatorial Indian Ocean.
- Combination of BDMIs and DMI can provide a better understanding of the atmosphere and ocean processes for both surface and subsurface, as well as biological processes in the Equatorial Indian Ocean.