Maritime Continent Water Cycle Regulates Low-latitude Chokepoint of Global Ocean Circulation

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Material based on Lee, Fournier, Gordon, and Sprintall (2018), in review

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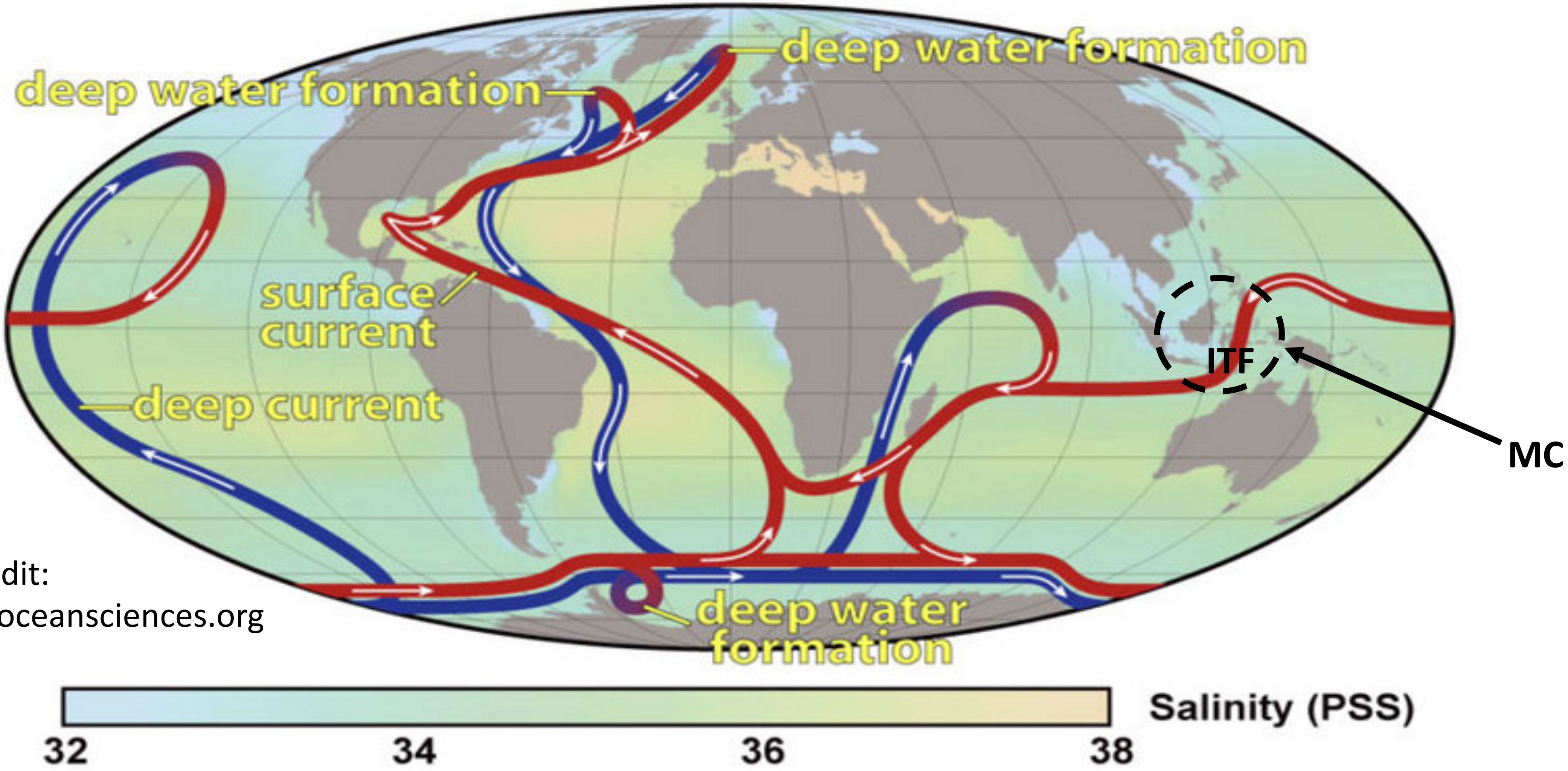
Motivation (1)

The Maritime Continent (MC) is a low-latitude chokepoint of global ocean circulation, with the Indonesian throughflow (ITF) going through the MC, affecting ocean, climate, & BGC *(e.g., Godfrey 1996, Lee et al. 2002, Gorgues et al. 2007, Sprintall et al. 2014)*



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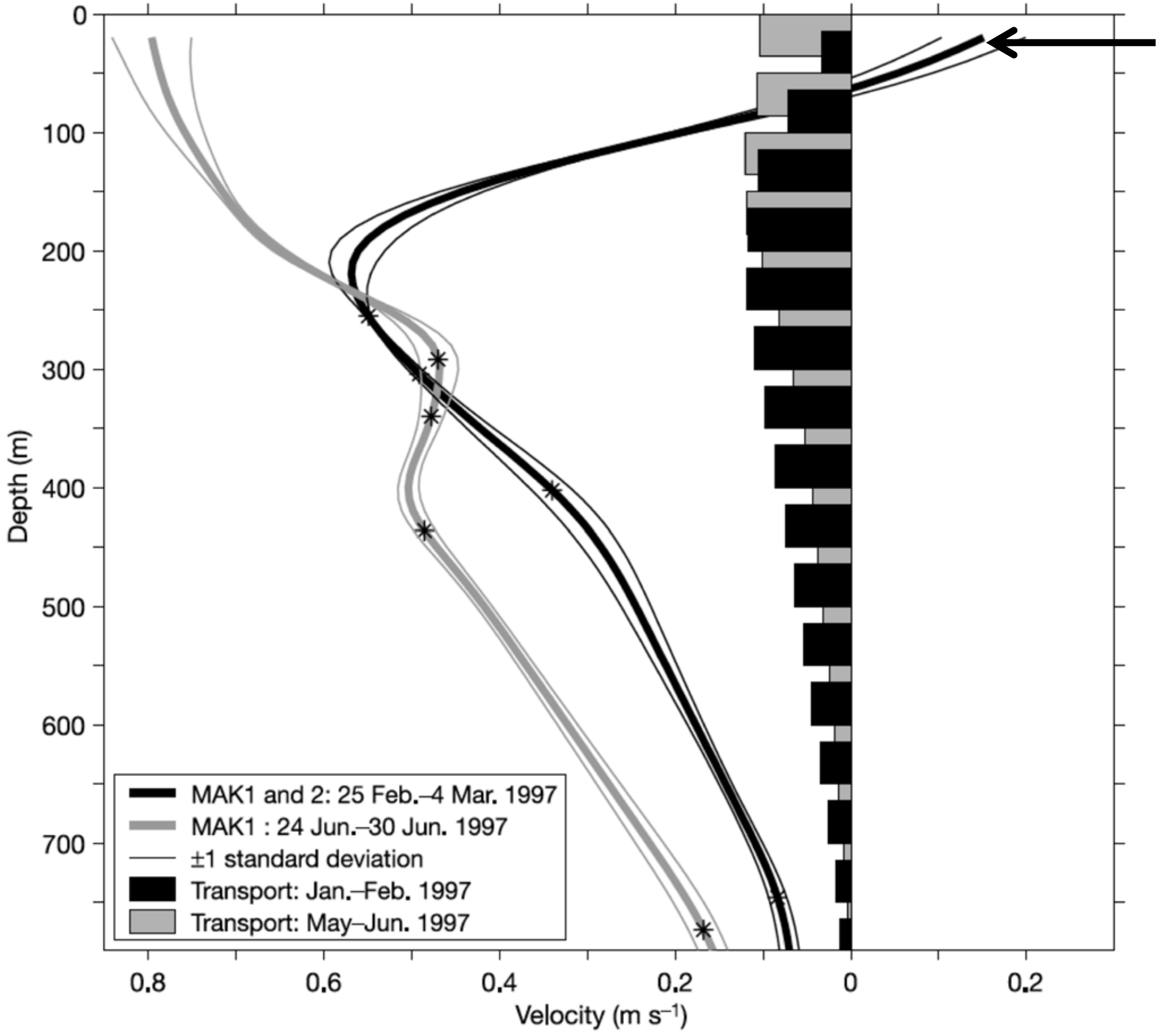
Motivation (2)

SSS in the MC affects vertical structure of the ITF, thereby influencing Indo-Pacific exchanges



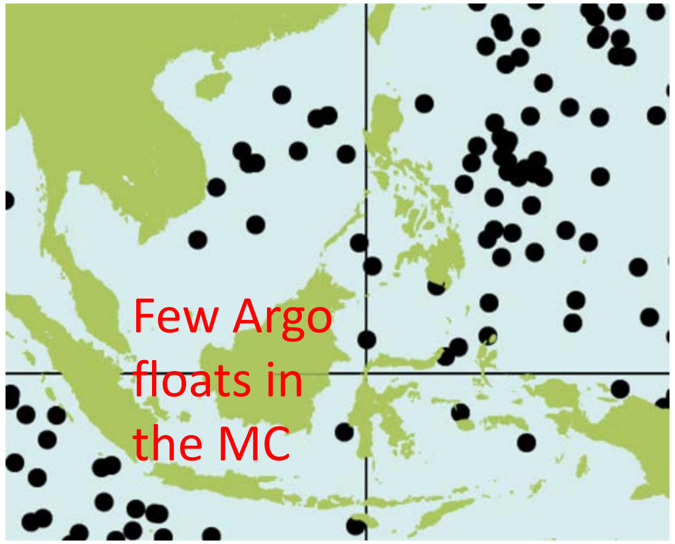
- Vertical profile of ITF velocity in the Makassar Strait (main ITF channel) show strong seasonality
- Much weaker upper-layer flow in boreal winter
- Caused by freshwater that increases the dynamic height, thereby reducing the N-to-S pressure gradient that drives the upper-layer flow

(Gordon et al. 2003, Nature)

Vertical structure of the ITF matters!

Motivation (3)

- Paucity of synoptic in-situ SSS in the MC hinders understanding of the linkages of the ocean with the water cycle & climate



- Recent advance in salinity remote sensing such as NASA's SMAP & ESA's SMOS satellites provided a new capability to fill the knowledge gaps

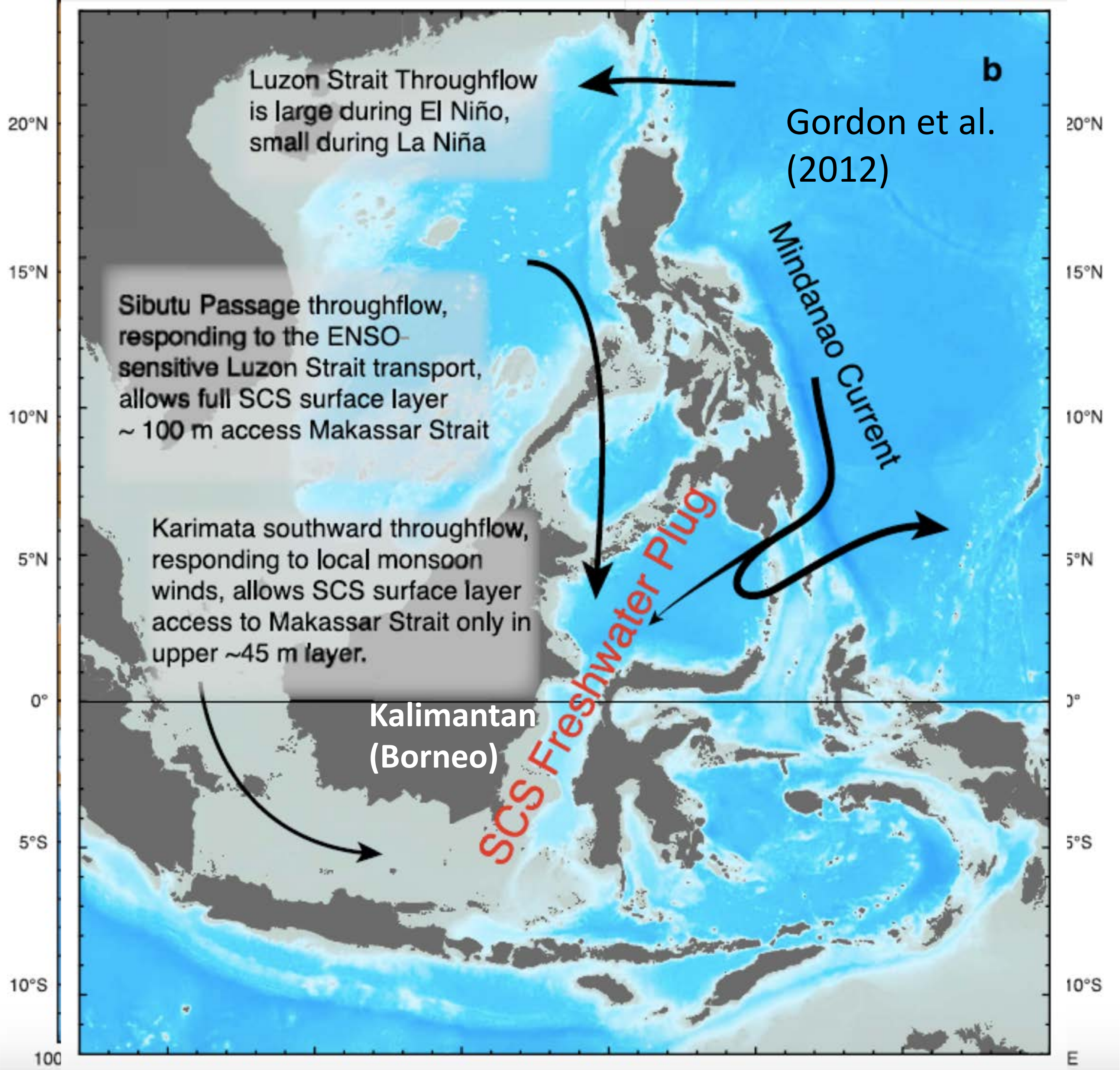
Background:

Schematic of circulation in the Southeast Asian Seas

- Indonesian throughflow (ITF) (solid)
- South China Sea throughflow (SCSTF) (dashed)

Previous studies suggested SCSTF & SCS freshwater modifying the ITF structure and transports

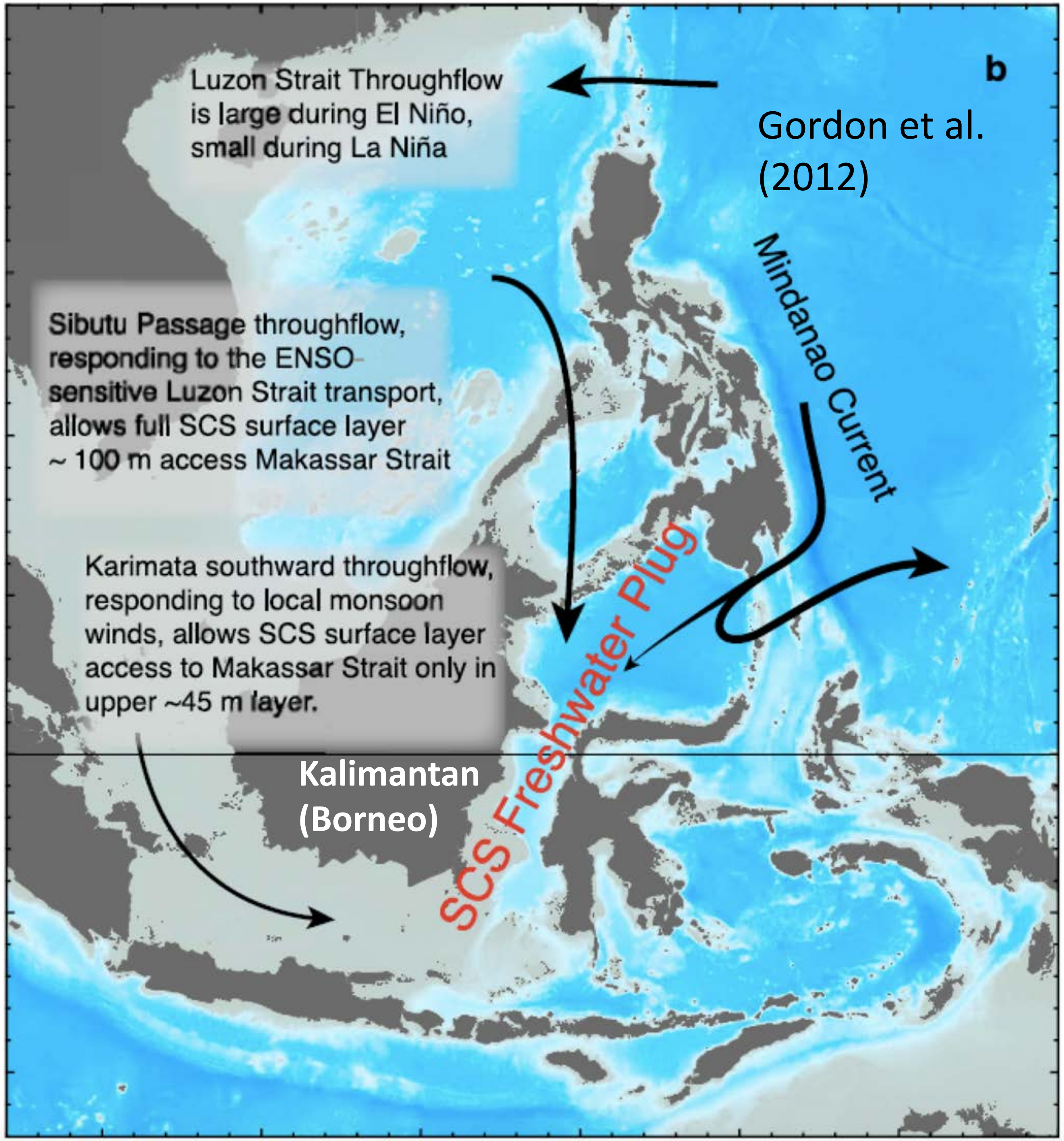
(e.g., Qu et al. 2005, Tozuka et al. 2007/2009, Fang et al. 2010, Gordon et al. 2012).



Knowledge gap

Although previous studies have discussed the effects of SCSTF and SCS freshwater on the ITF, the effects of MC **regional water cycle (local precipitation and runoff)** have not been investigated.

Here **we examined these effects** on the freshwater plug & the ITF



Ocean-atmosphere-land satellite observations

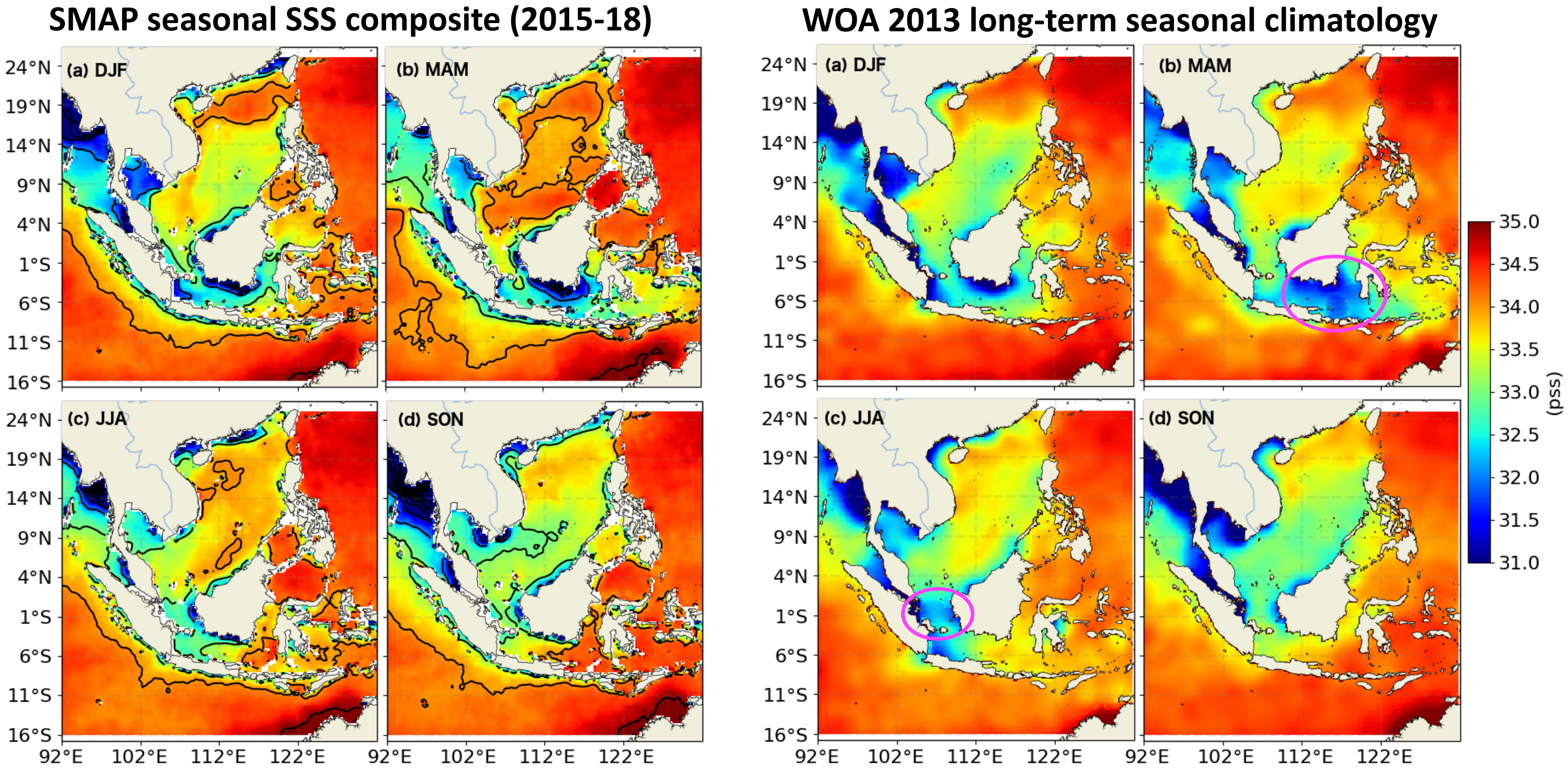
Parameter	Satellite	Resolution
SSS	SMAP V3 JPL	~50 km (0.25^o grid)
SSS	SMOS CATDS (only to Dec. 2017)	~55 km (0.25^o grid)
Precipitation	TRMM/GPM	10 km
Soil moisture	SMAP	~40 km (0.25^o grid)
Ocean color (Colored Dissolved Organic Matter – CDOM)	MODIS	1 km
Sea Level Anomaly (SLA)	Merged altimetry (AVISO)	0.25^o grid
SST	Reynolds OISSTv2	0.25^o grid

Other products

Ocean surface currents	HYCOM operational data assimilation OSCAR satellite-derived currents	1/12^o 1/4^o
Evaporation	OAFLUX (only to Dec. 2017)	1^o
In-situ SSS climatology	WOA2013	0.25^o

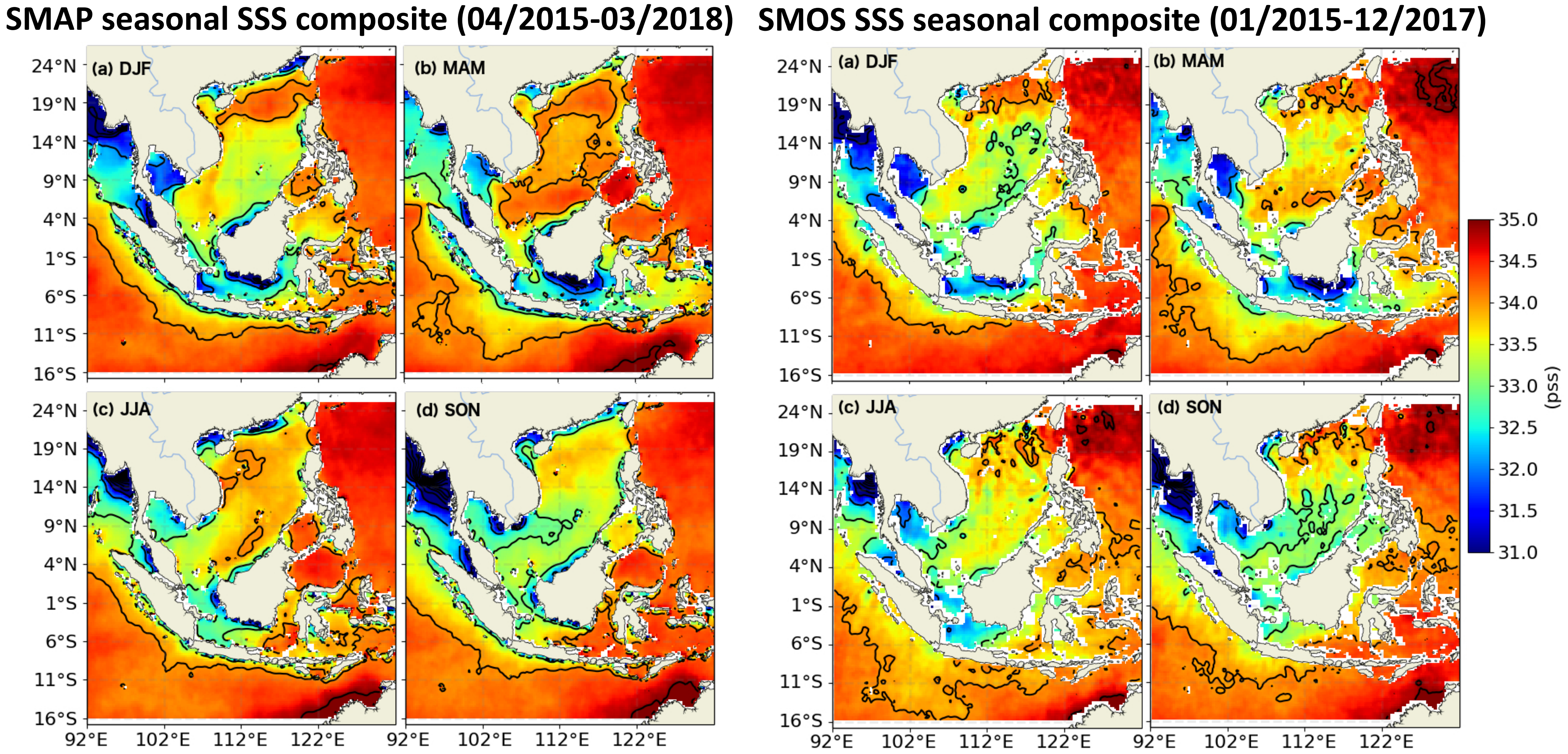
Analysis period: focused on April 2015-March 2018 (SMAP period)

Comparison of SMAP SSS & WOA13 climatology



- Similar pattern of seasonal variations; some possible artifacts in WOA13
- Higher SSS in SMAP consistent with influence of El Nino & IOD during 2015-2016 (ongoing work)
- SCS waters not fresh enough to explain the seasonal freshwater plug

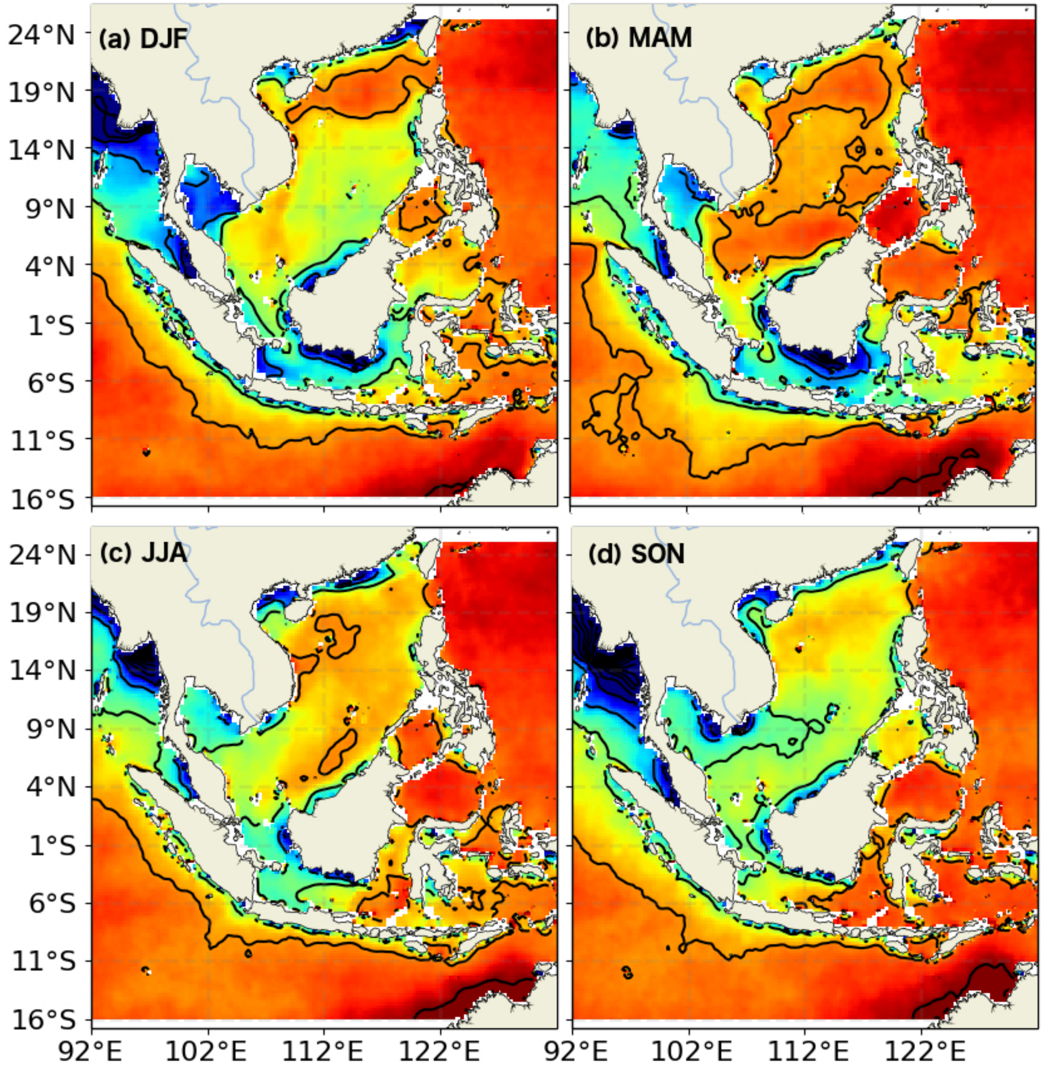
Comparison of SMAP & SMOS SSS for the SMAP period



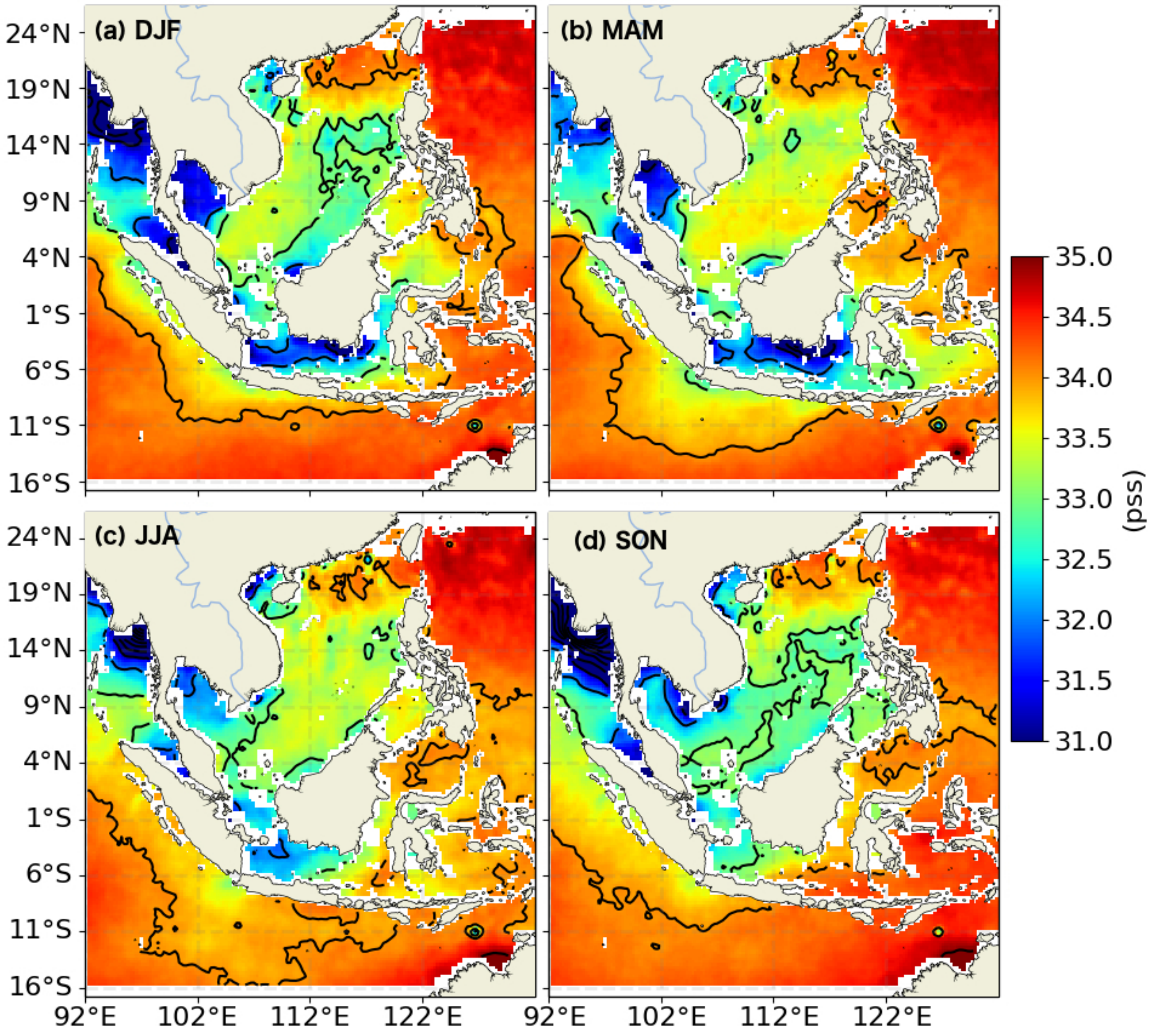
- Similar pattern of seasonal variations, some relative biases
- SMAP SSS less noisy, helpful for budget analysis

Comparison of SMAP SSS (2015-2018) & SMOS SSS (2010-2017)

SMAP seasonal SSS composite (04/2015-03/2018)

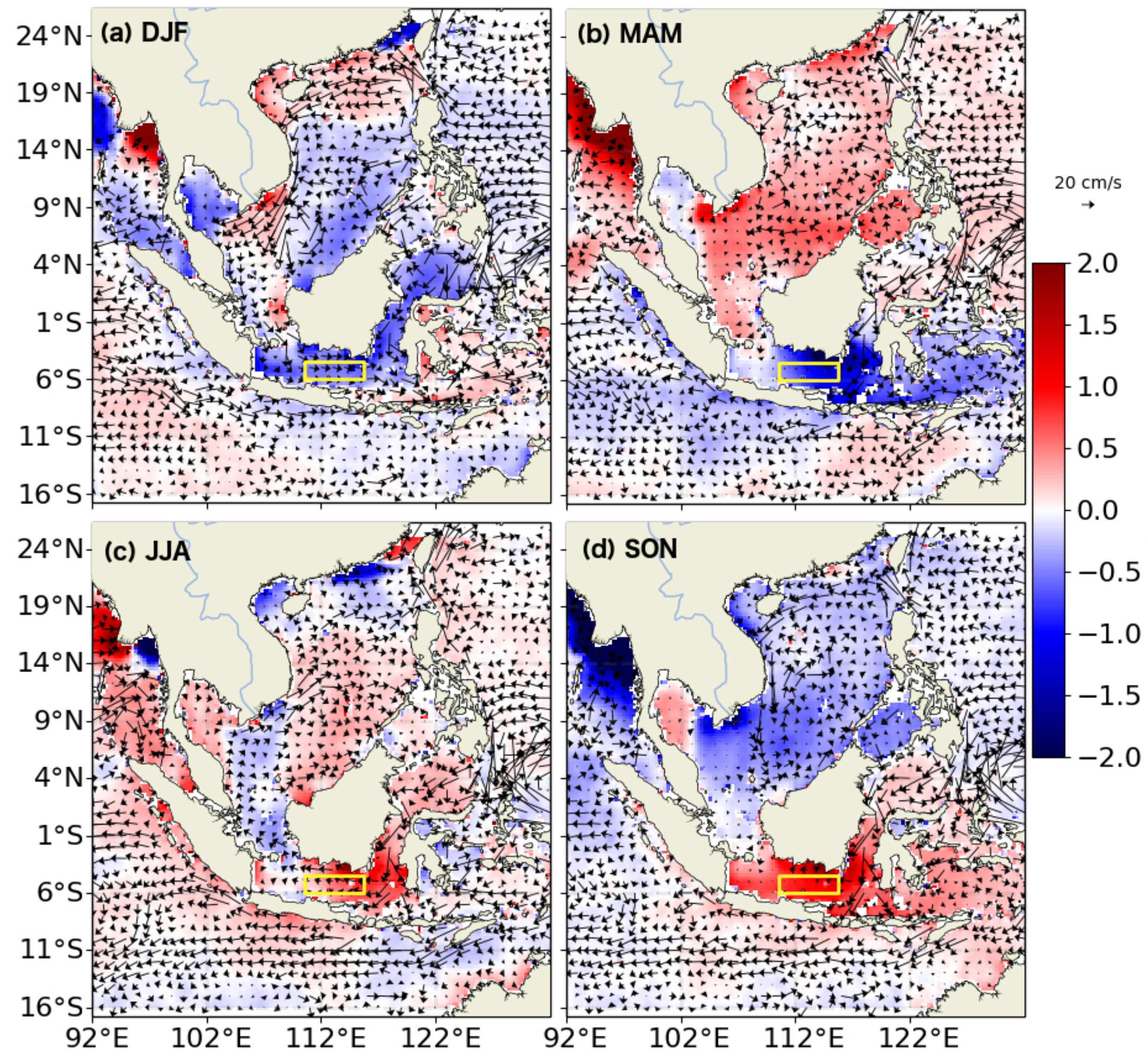


SMOS SSS seasonal composite (2010-2017)

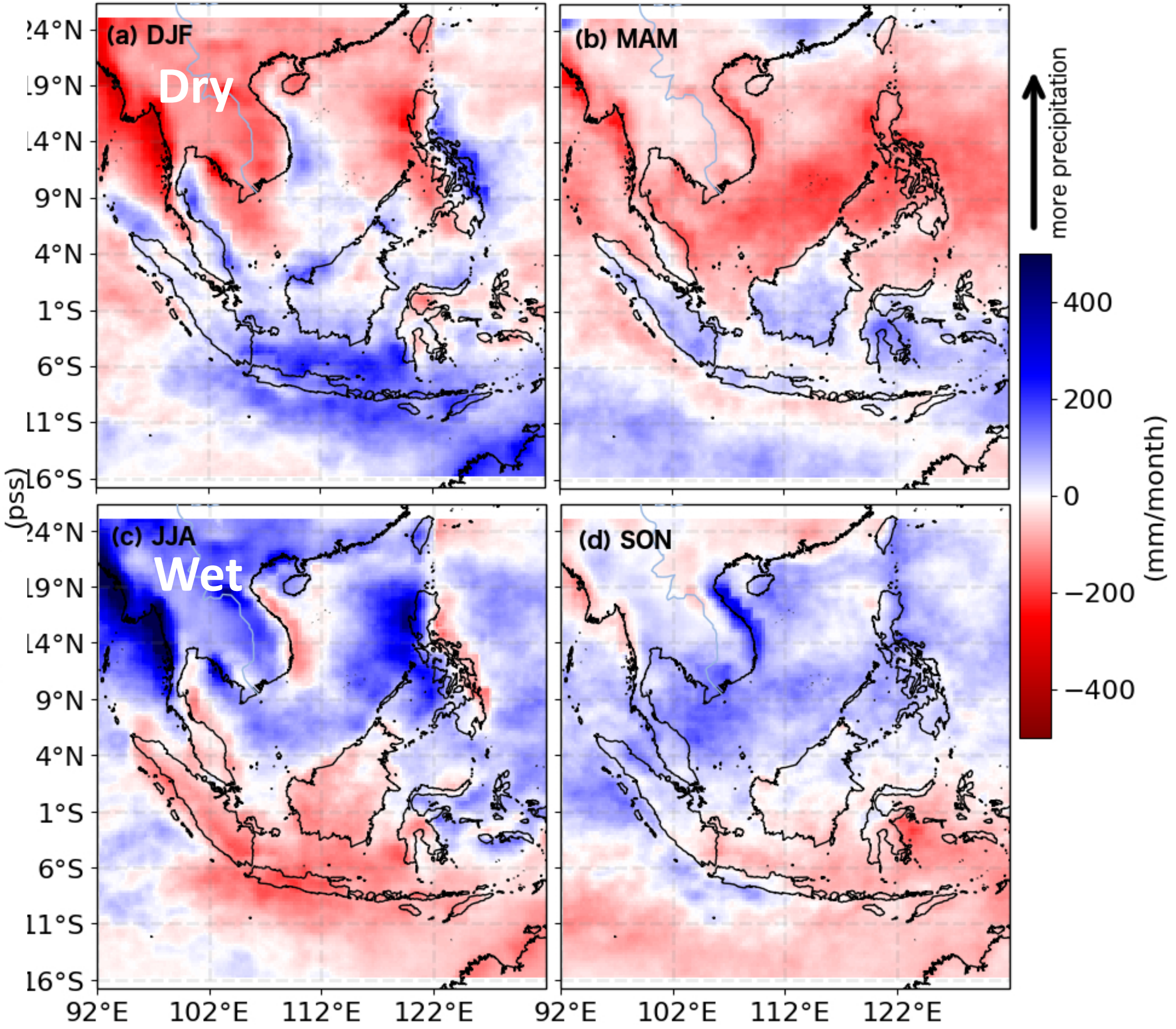


- Pattern of seasonal variations remain similar

Seasonal SSS anomalies & total surface Current

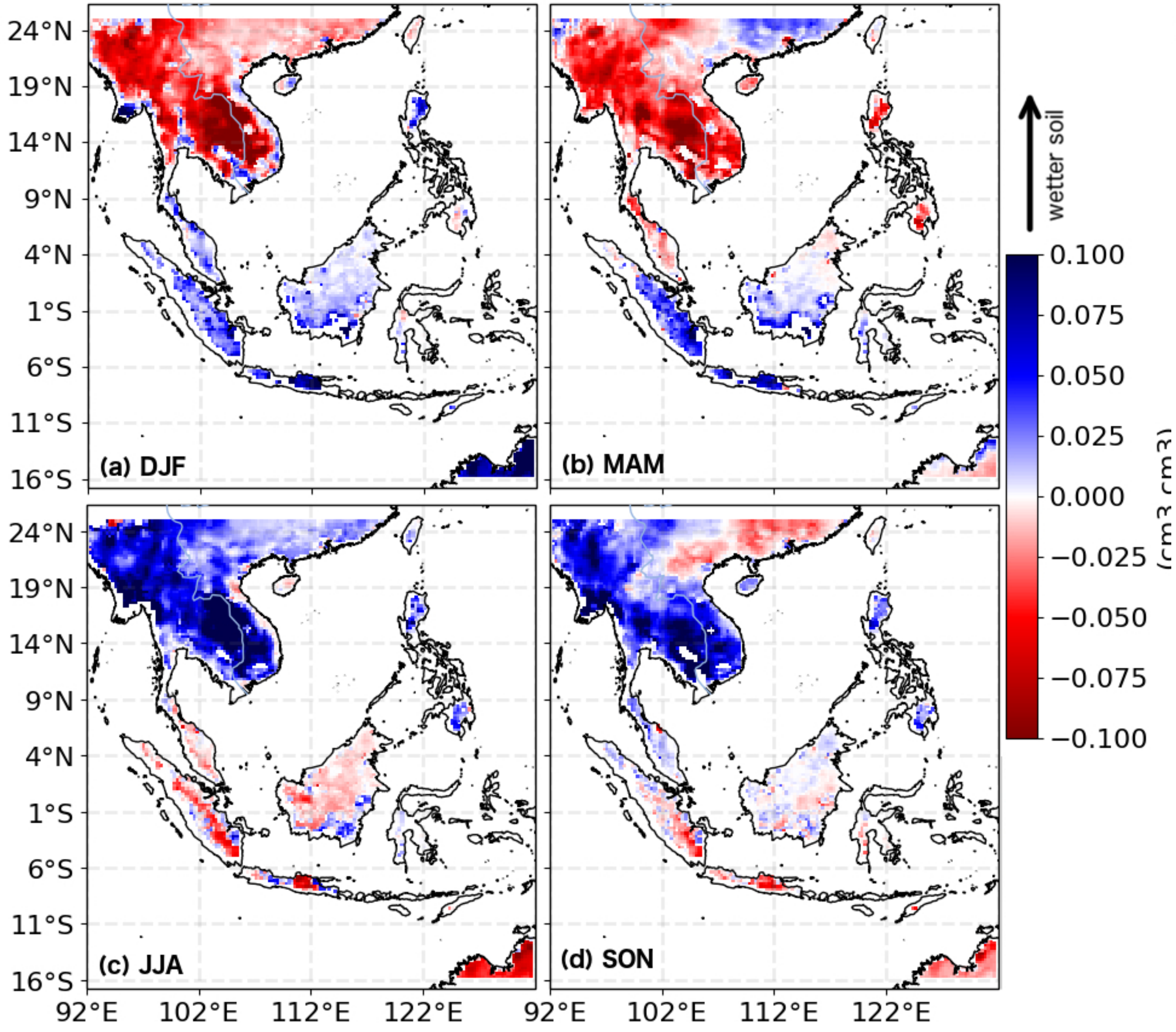


Seasonal precipitation anomalies

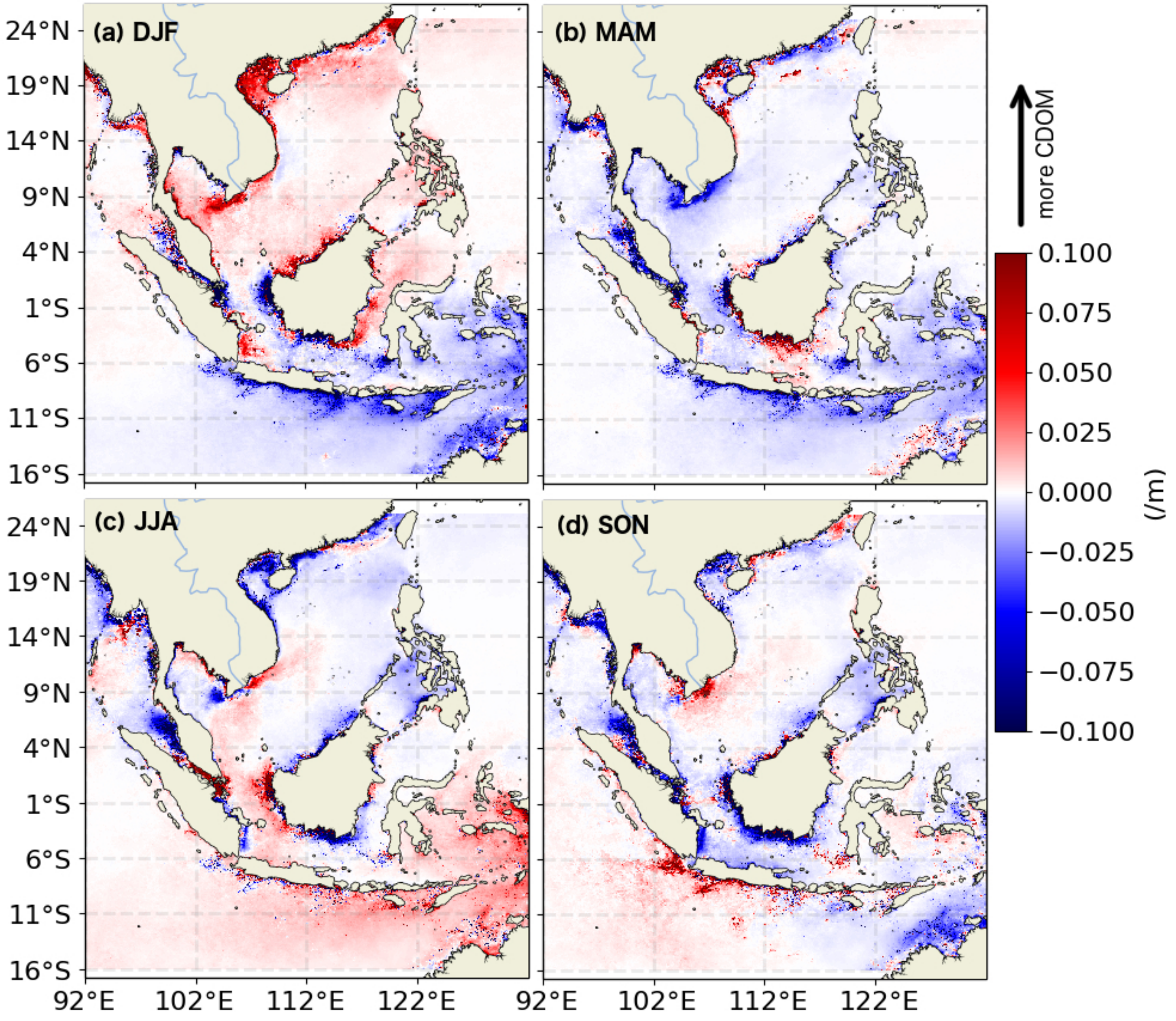


Strong boreal-winter precipitation over the Java Sea expected to have a major contribution to the “freshwater plug” (see quantitative budget analysis later for the yellow box)

Seasonal anomalies of soil moisture



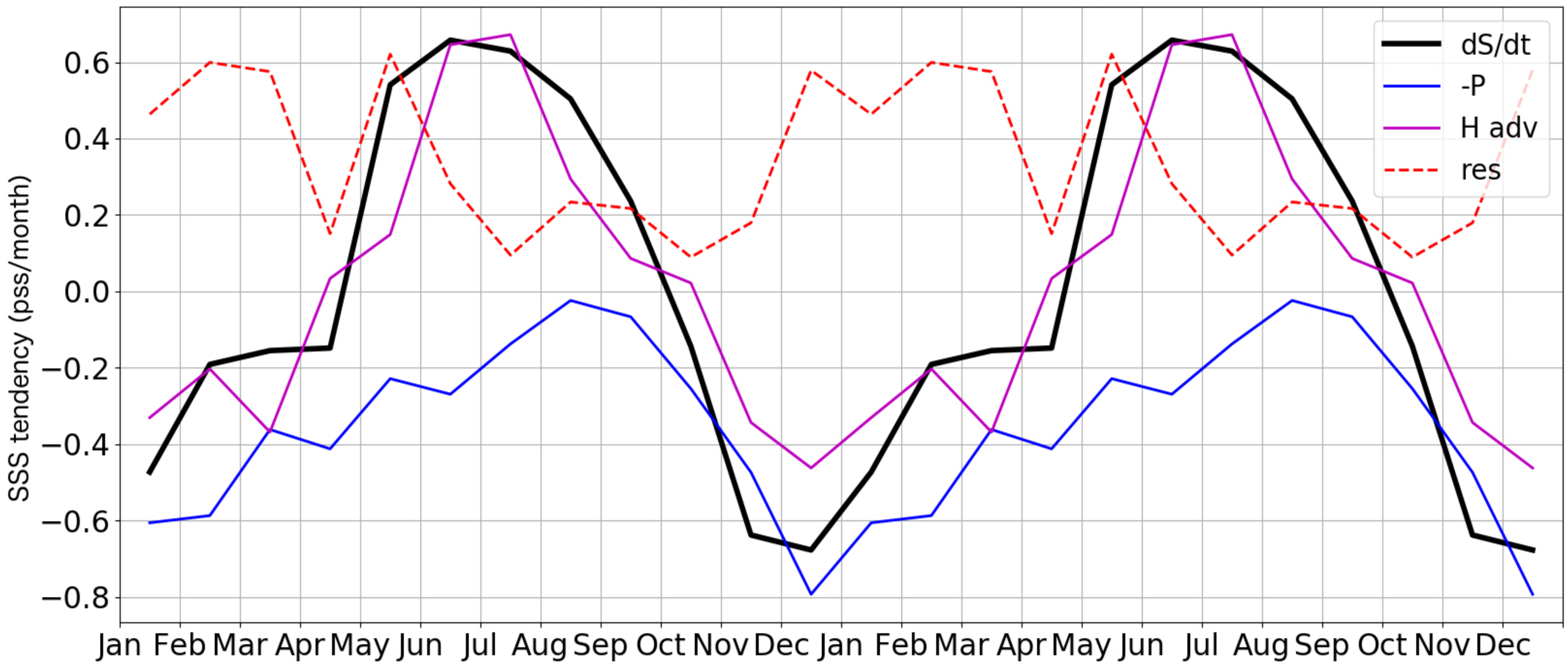
Seasonal anomalies of ocean color (CDOM)



Monsoon-rain-induced runoff from Kalimantan (Borneo) into Java Sea & Makassar Strait re-enforce freshwater plug & prolong it into boreal spring, as evident from anti-correlation of SSS anomaly & CDOM

Seasonal budget of SSS for the Java Sea box

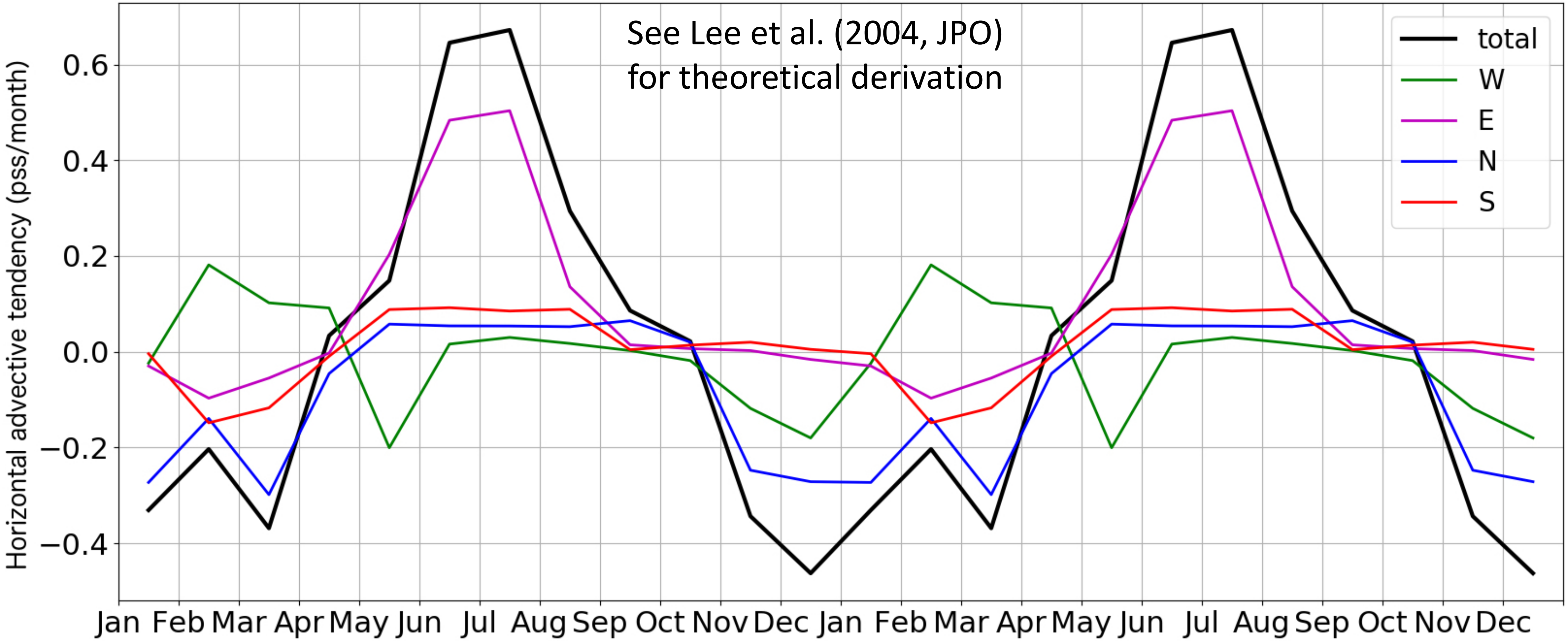
$$\frac{H}{Vol}\iint \frac{dS}{dt}\,dxdy = \frac{S_0}{Vol}\iint(-P)\,dxdy + Hadv + RES$$



- During boreal winter, precipitation is sufficient to cause the observed freshening
- Horizontal advection re-enforces boreal-winter freshening, and prolongs it to boreal spring
- Counteracting effect of the residual term indicates dissipative effects (vertical mixing & evaporation)

Decomposition of horizontal advective tendencies into contributions from the W, E, N, and S interfaces

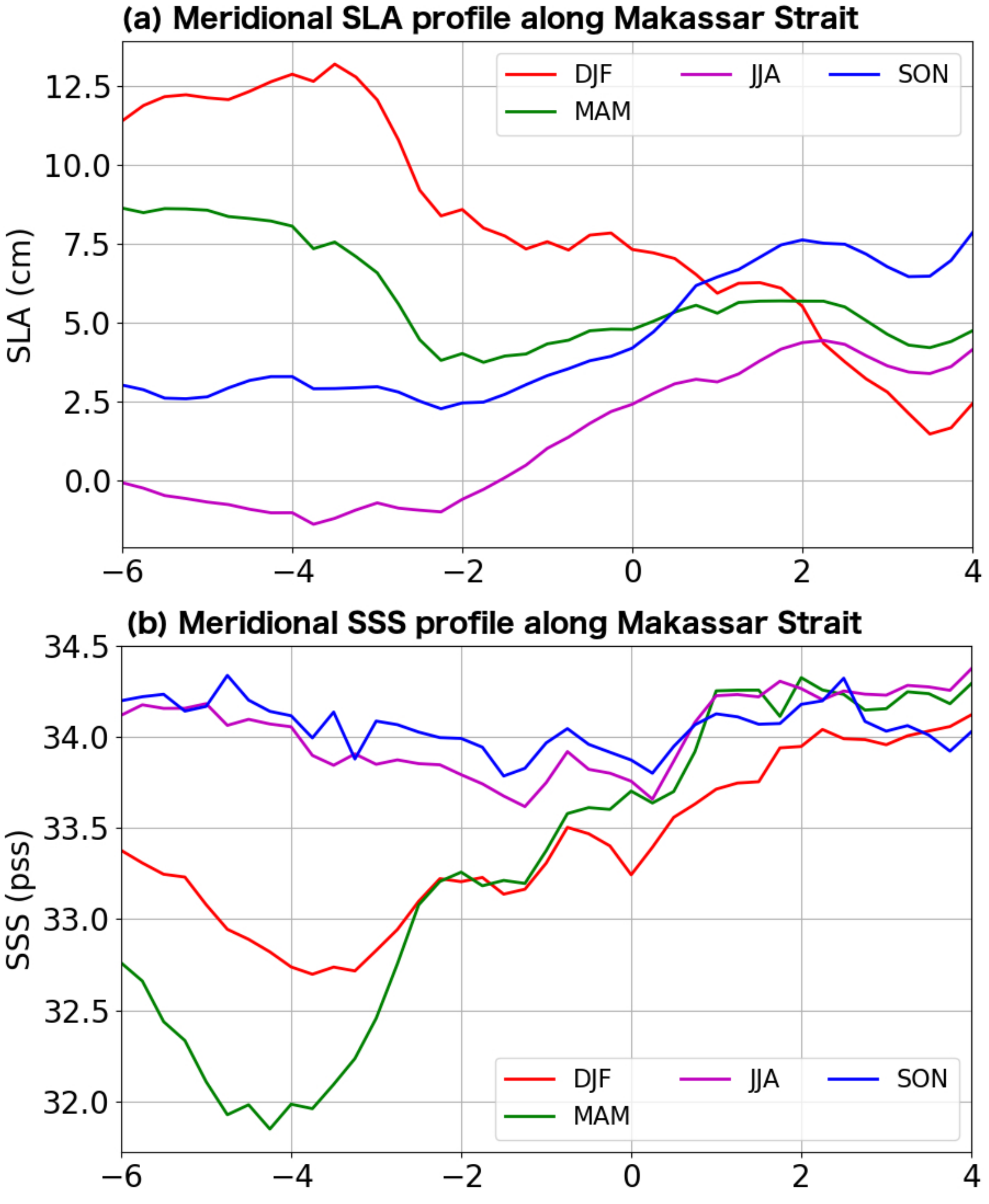
$$Hadv = \frac{H}{Vol}\left[\int u_W(S_W - S_{Ref})\,dy - \int u_E(S_E - S_{Ref})\,dy + \int v_S(S_S - S_{Ref})\,dx - \int v_N(S_N - S_{Ref})\,dx \right]$$



- The horizontal advection during boreal winter-spring is primarily contributed by the N-interface
- Reflect the southward intrusion of freshwater runoff from Kalimantan

Meridional profiles of SLA & SSS along the Makassar Strait

- Southward increase of SLA correspond to decrease of SSS
- Exemplifies the effect of seasonal freshening on N-to-S pressure gradient that drives the ITF

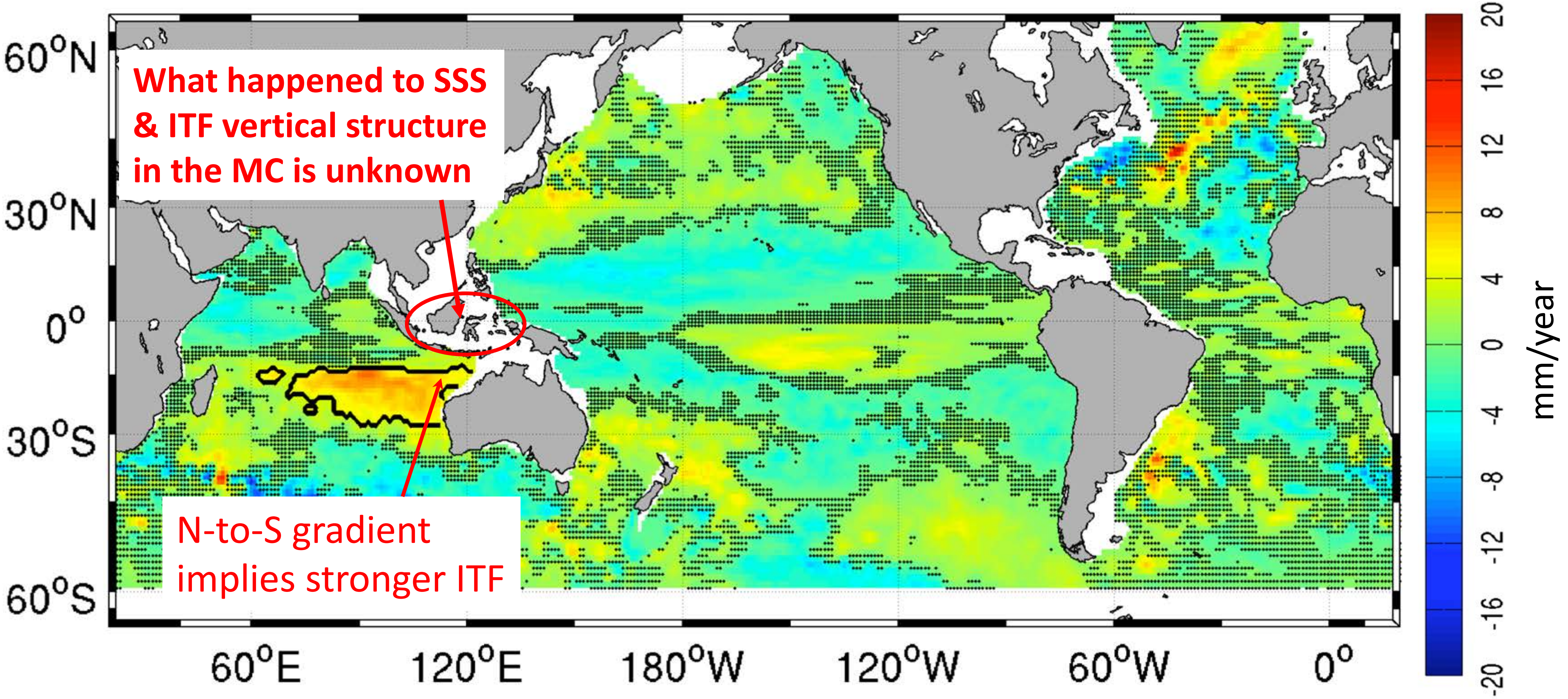


Summary

- SMAP satellite provided an unprecedented capability to monitor synoptic SSS in the MC region.
- Seasonal freshwater plug in the MC not only exists in boreal winter, but in boreal spring as well.
- The major sources of the freshwater plug are MC monsoonal precipitation over the Java Sea & runoff from Kalimantan – different from the previously suggested dominant role of the SCS freshwaters.
- MC water cycle regulates low-latitude chokepoint of global ocean circulation
    - Affecting seasonality and influencing annual mean

Implications for longer time scales (1)

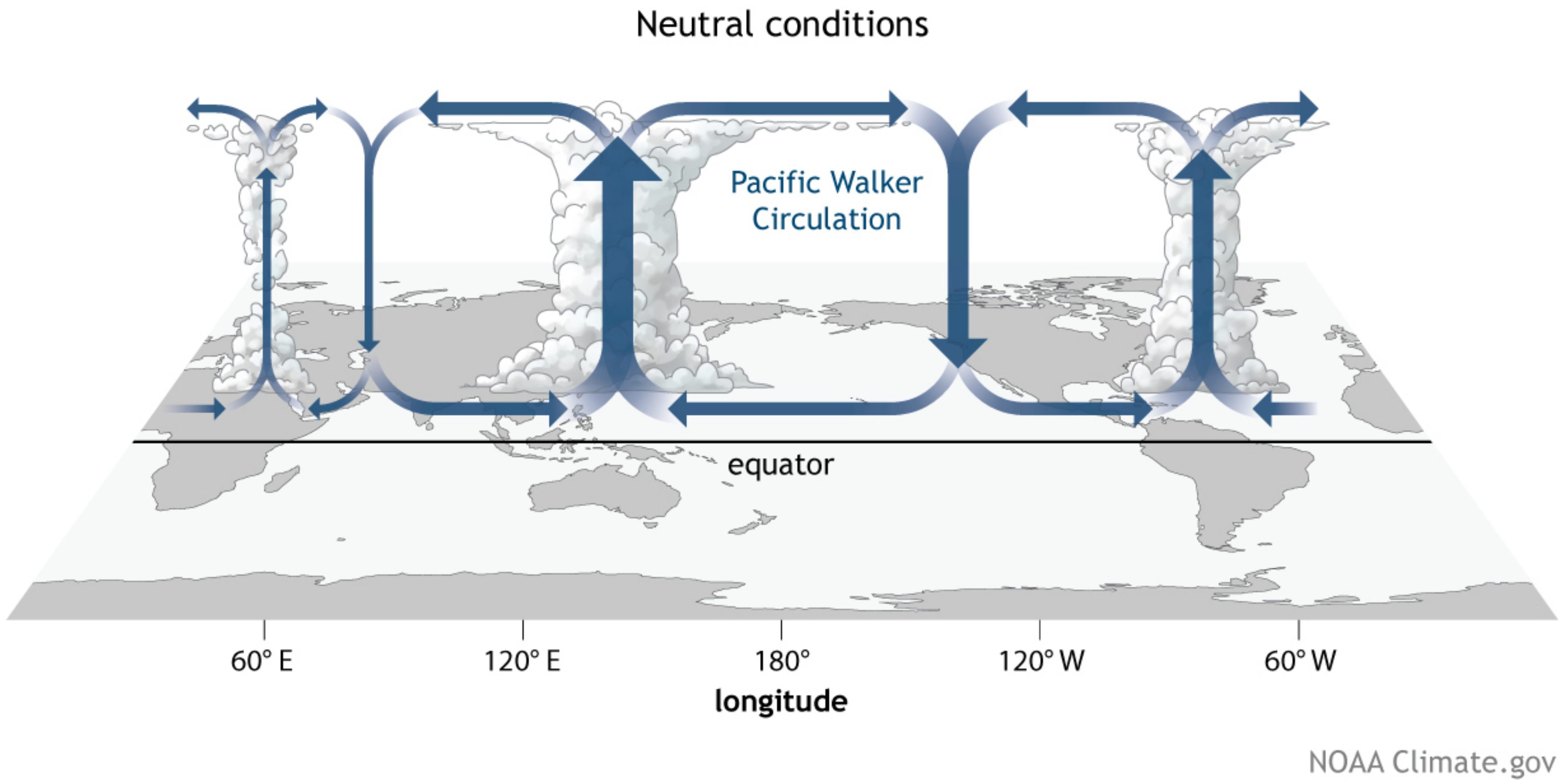
Freshening of the southeast Indian Ocean during the Argo period, accounted for 2/3 of regional SL rise; associated with enhanced precip in the SE Asian Seas *(Llovel & Lee 2015)*



See related presentation next by Hu and Sprintall

Implications for longer time scales (2)

- The Walker Circulation is projected to weaken with increasing CO_2 *(e.g., Vecchi & Soden 2007)*
- May impact the monsoonal water cycle in the MC and thus the ITF
- Relative contributions of the Pacific trade winds and MC water cycle need to be investigated



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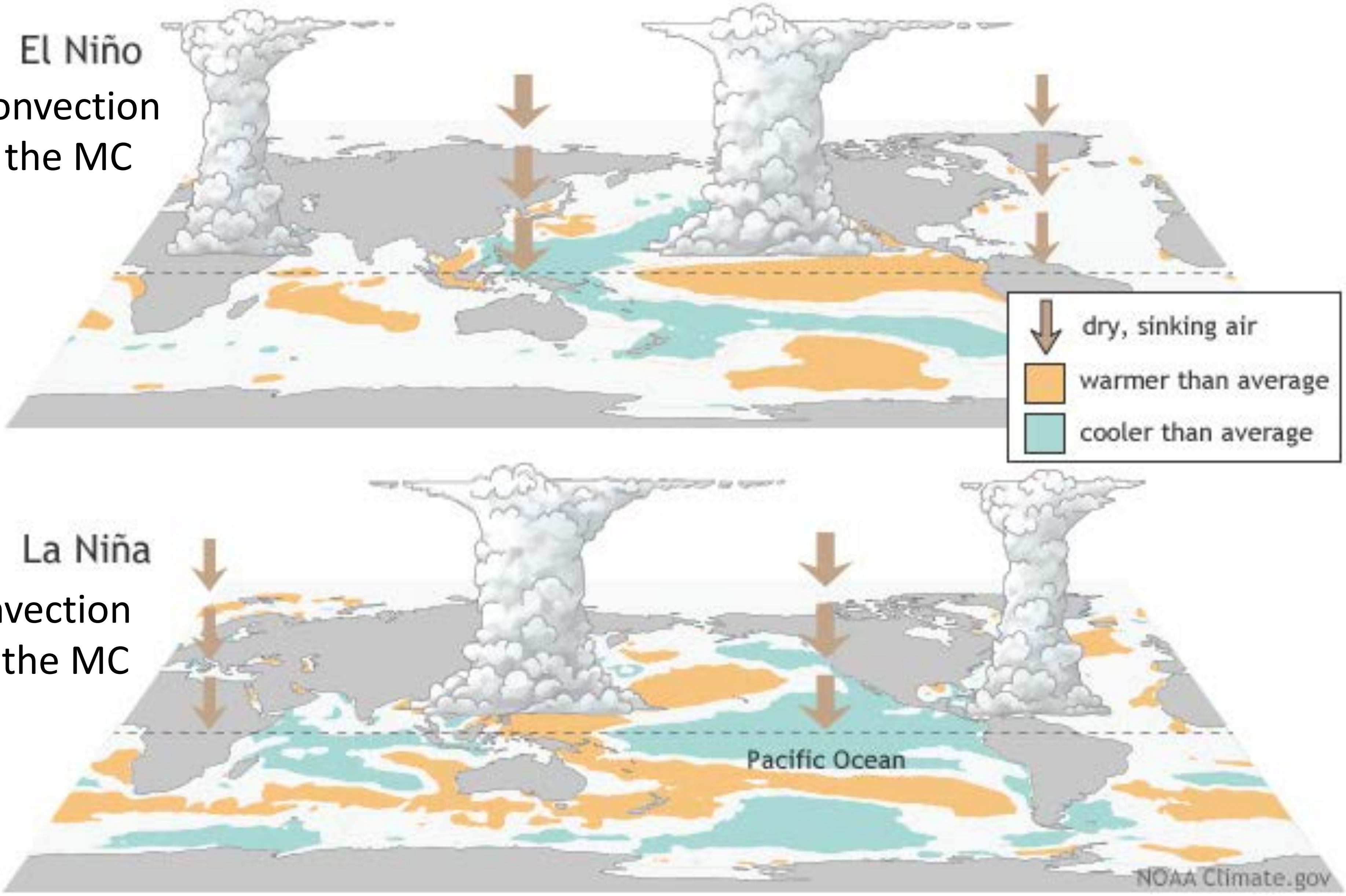
- The major sources of the freshwater plug are MC monsoonal precipitation over the Java Sea & runoff from Kalimantan – different from the previously suggested dominant role of the SCS freshwaters.
- MC water cycle regulates low-latitude chokepoint of global ocean circulation
- How longer-term climate variability & change in the Indo-Pacific sector influence the MC water cycle and the ITF (esp. vertical structure) needs to be investigated
- Sustained satellite SSS such as those from SMAP and SMOS are essential for such studies

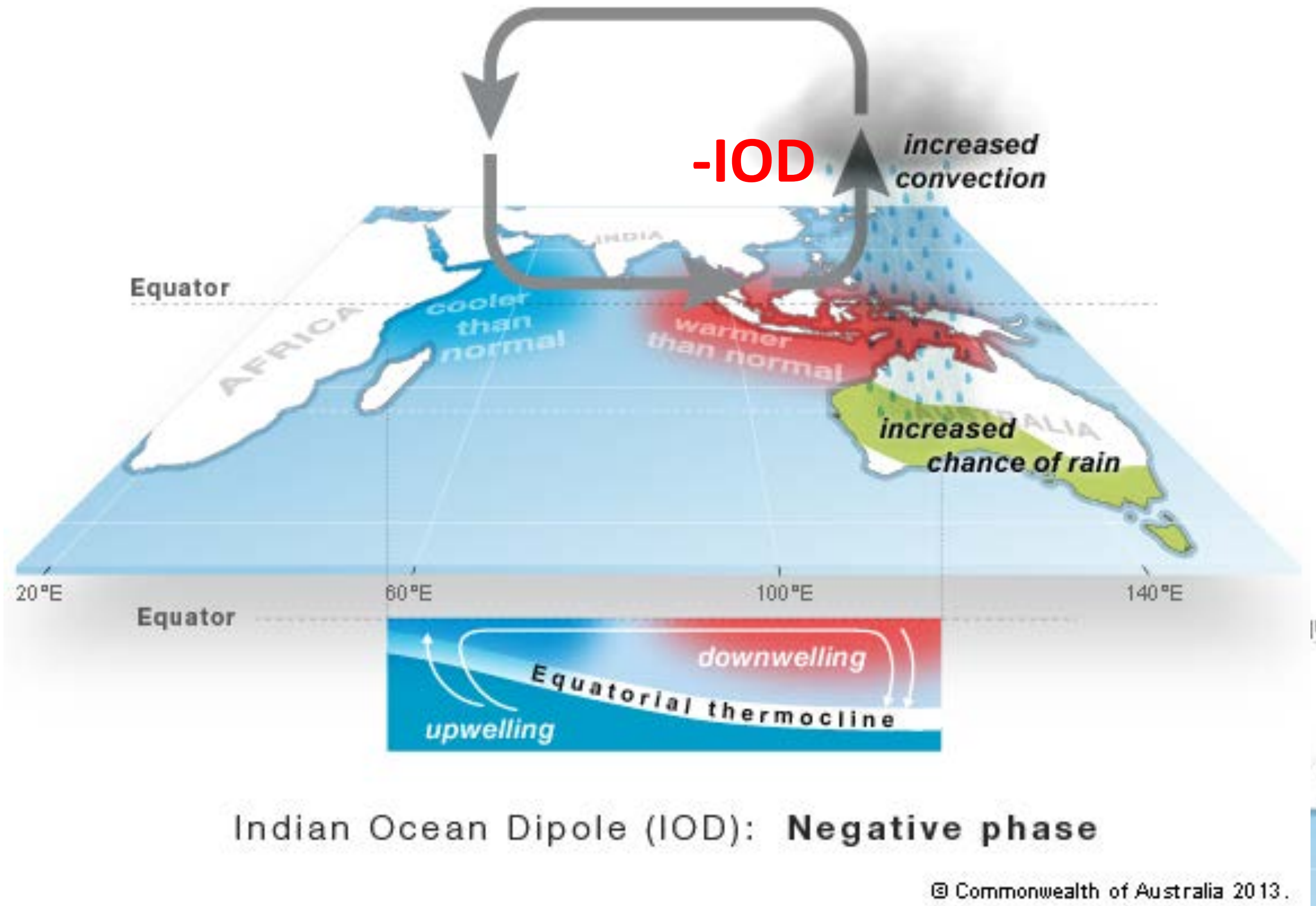
ENSO effect on MC precipitation

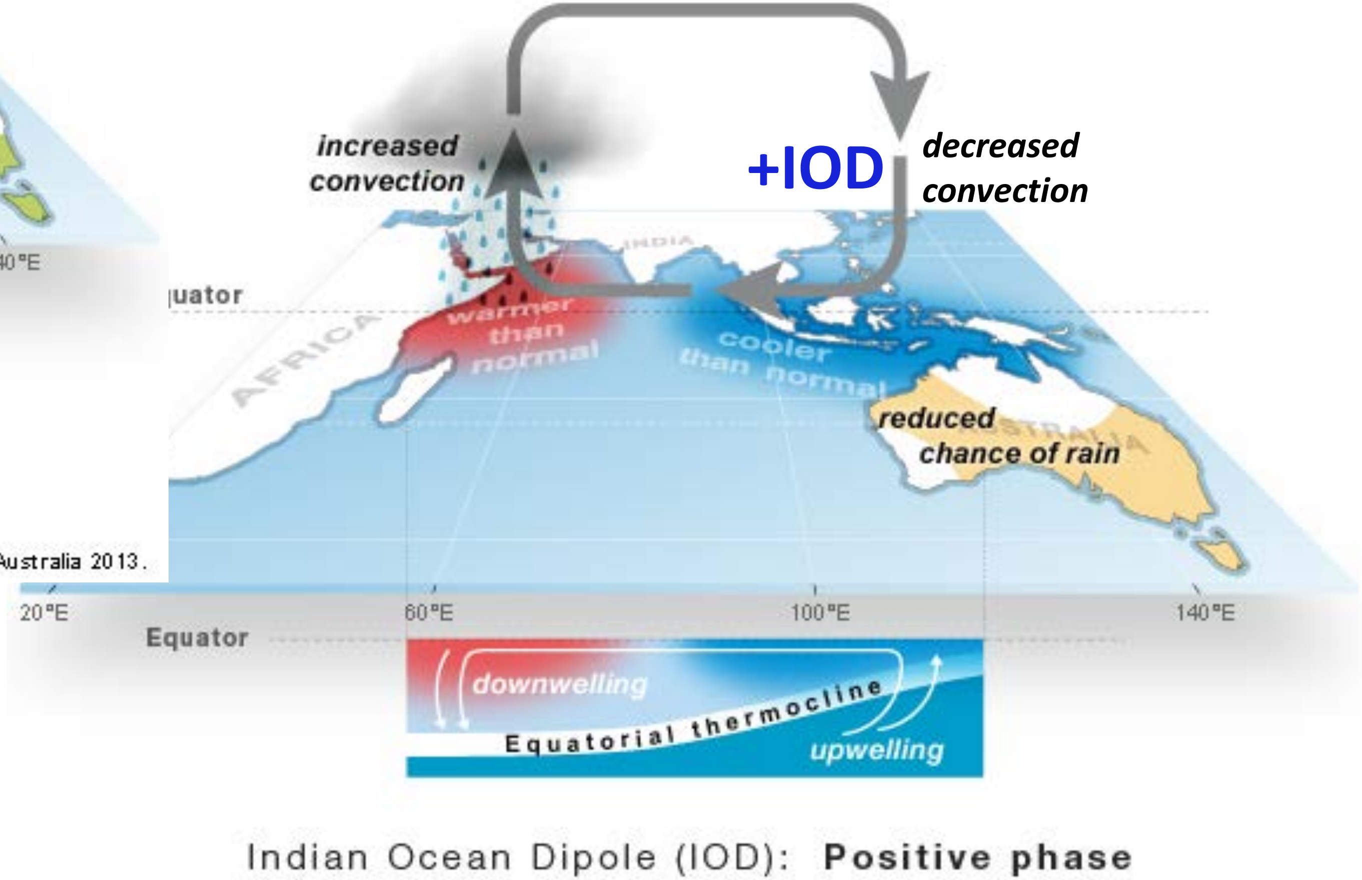


El Niño suppresses convection & precp over the MC

La Niña enhances convection & precp over the MC

Indian Ocean Dipole (IOD) effect on MC precipitation





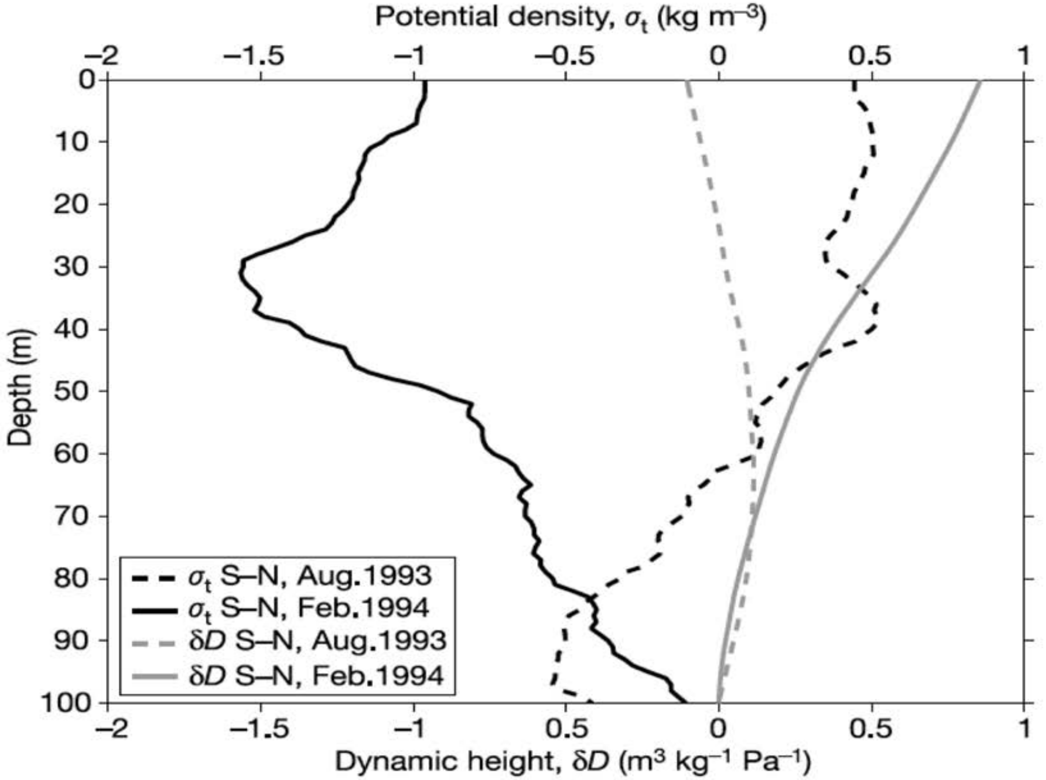
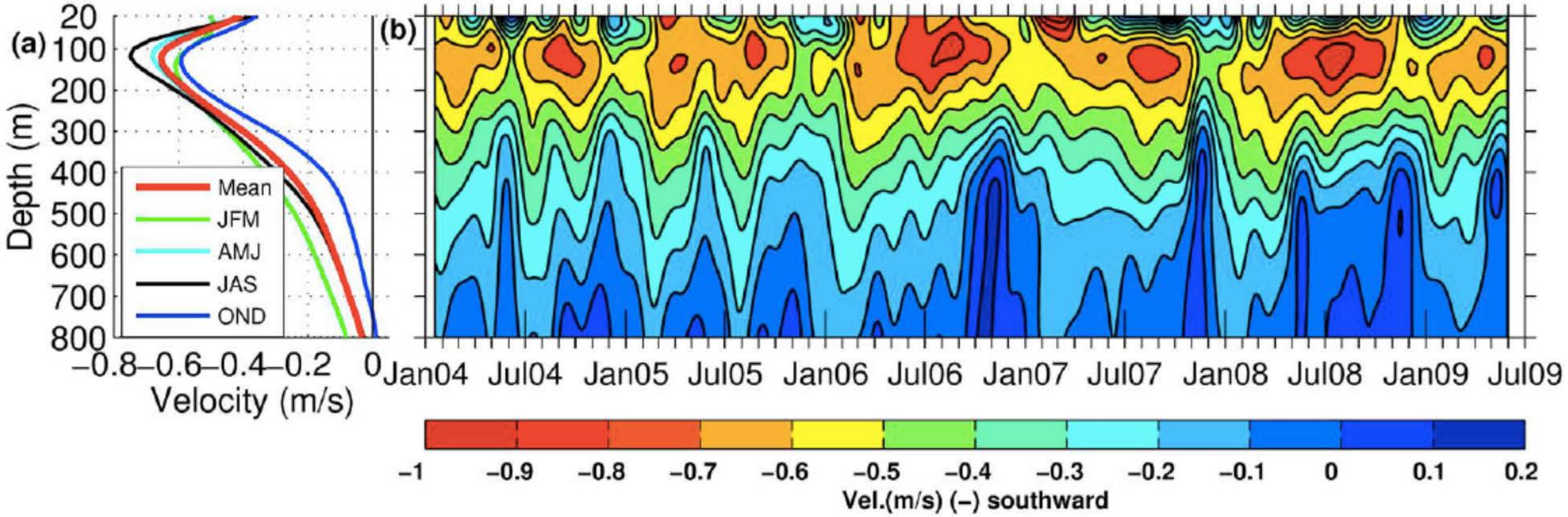


Figure 3 Differences in density and dynamic height within the upper 100 m between the northern and southern Makassar Strait (northern subtracted from southern) for two monsoon phases. In February 1994, (solid black line) representing the northwest monsoon, the density difference from the sea surface to a depth of 100 m is negative, meaning that the southern density profile is less dense or more buoyant than the northern profile. During August 1993 (solid grey line), representing the southeast monsoon, the density difference along the Makassar Strait is relatively small but positive in the upper 60 m. The dynamic height anomalies of the isobaric surfaces from 0 to 100 decibars (1 db is approximately equivalent to 1 m) relative to 100 db are shown as dashed lines. During the northwest monsoon (dashed black line), the surface layer isobaric surfaces in the southern Makassar Strait are higher than they are in the north, signifying a northward pressure gradient within the surface layer. During the southeast monsoon (dashed grey line), the meridional pressure gradient within the surface layer is essentially zero.

Gordon et al. (2003) Northward pressure gradient during boreal winter in the upper Makassar Strait inhibits Pacific inflow

Vertical profile of velocity of the ITF in in the Makassar Strait from INSTANT mooring measurements (Susanto et al. 2012)



SCS freshwater was suggested to cause the weaker flow in the upper 100 m of the ITF velocity profile, esp. in boreal winter