Interannual Variability of the Circulation in the Indonesian Seas:

Impacts of Oceanic Waves from the Pacific

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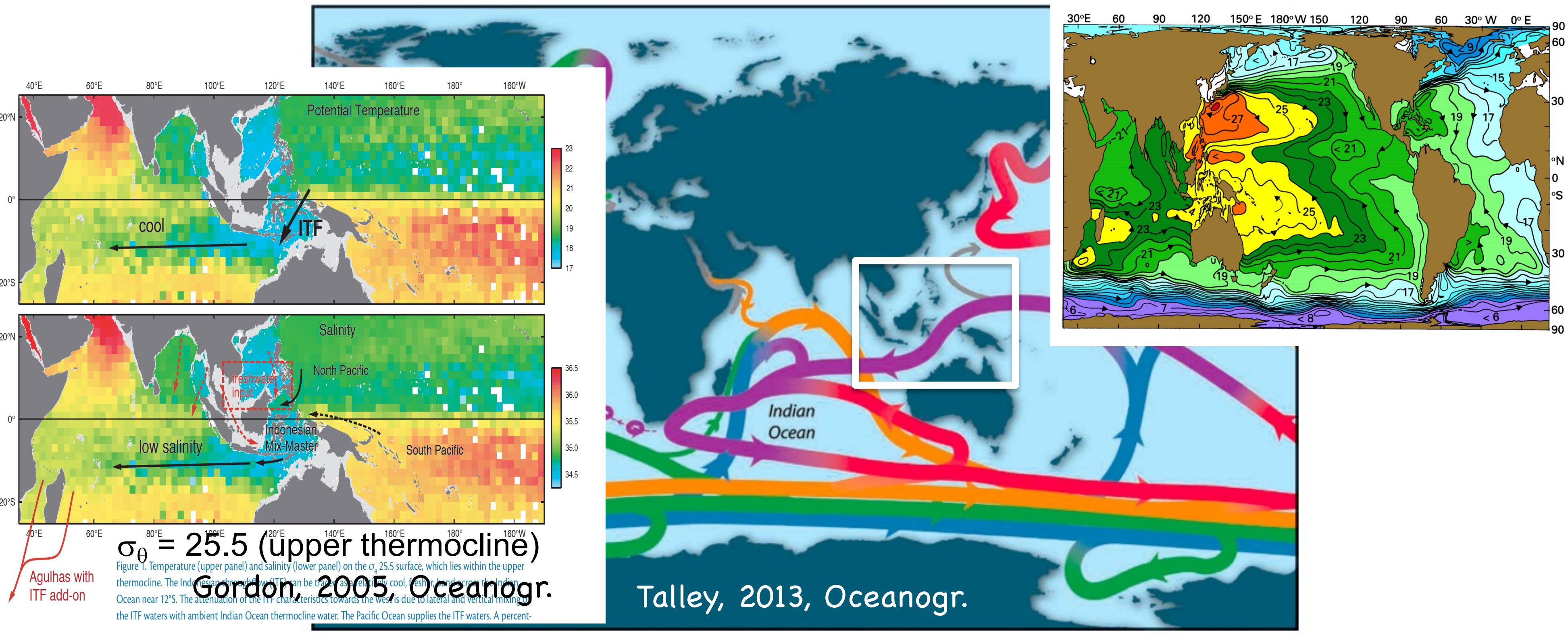
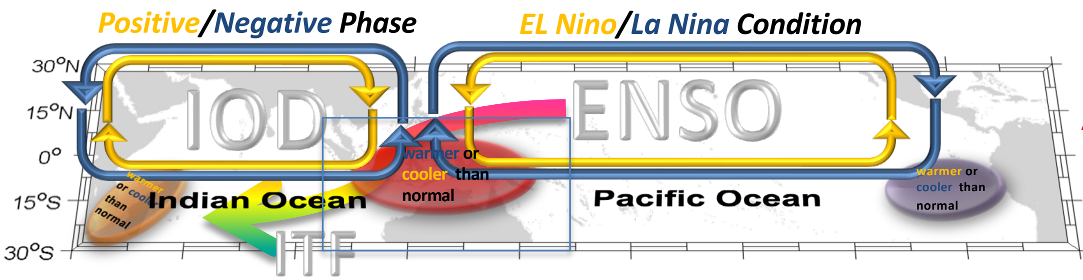
Indonesian Throughflow (ITF)



ITF, driven by the dynamic height difference between the W.P. and E.I., is a key element of the Global Overturing Circulation.

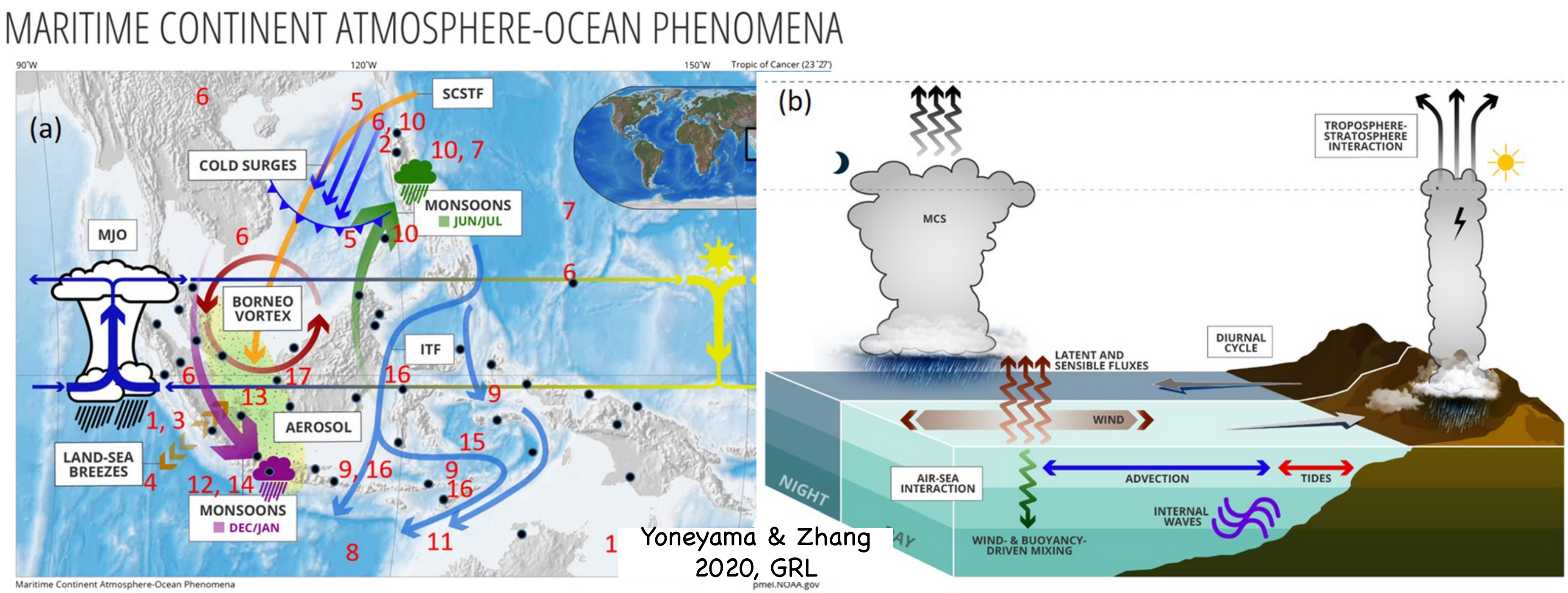
Waters are cooled and freshened as they pass through the IS.

Southeast Asia Archipelago



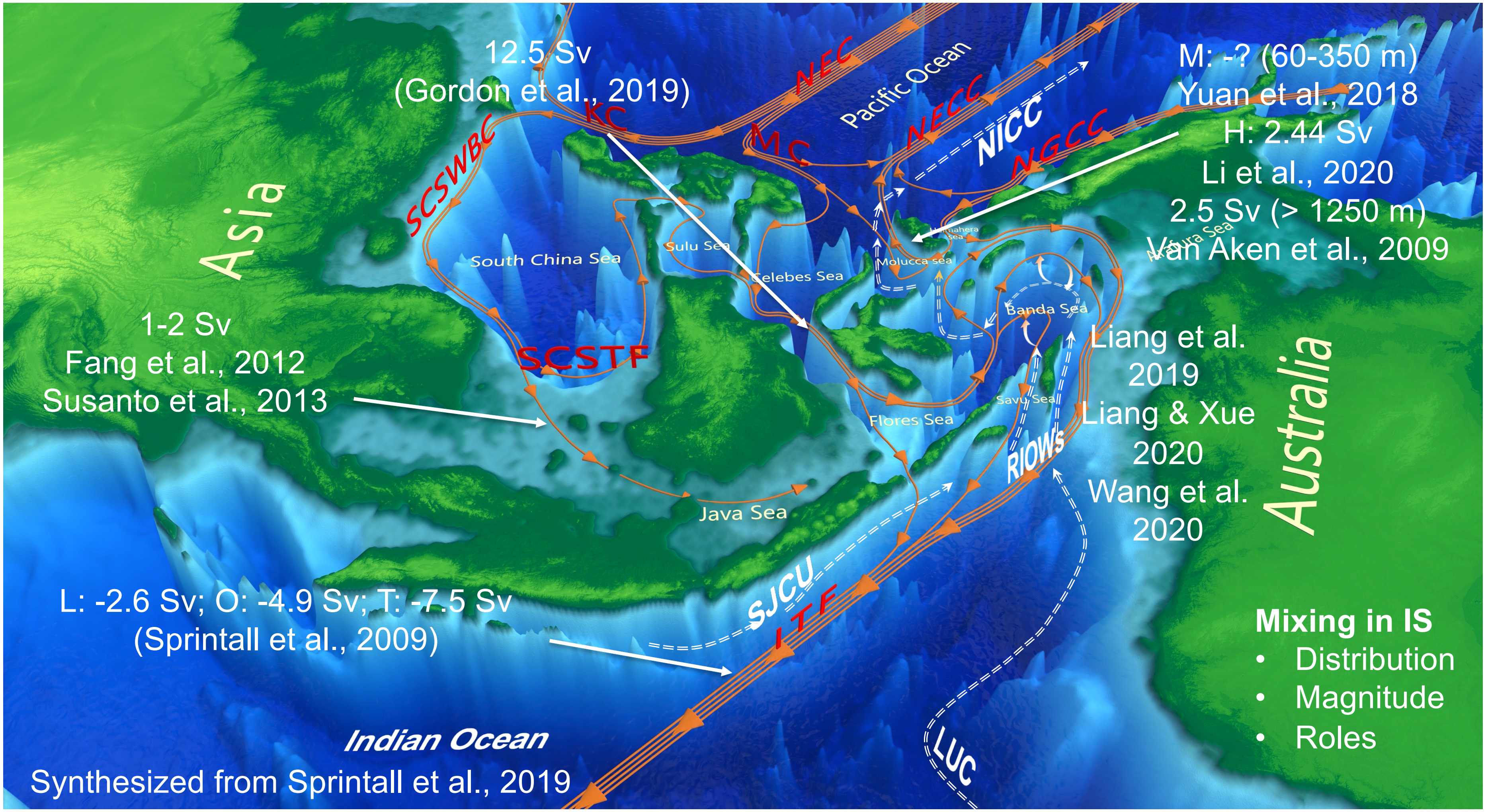
Warmest water
Ascending branch of Walker circulation

Hot spot of
Air-Sea Interactions

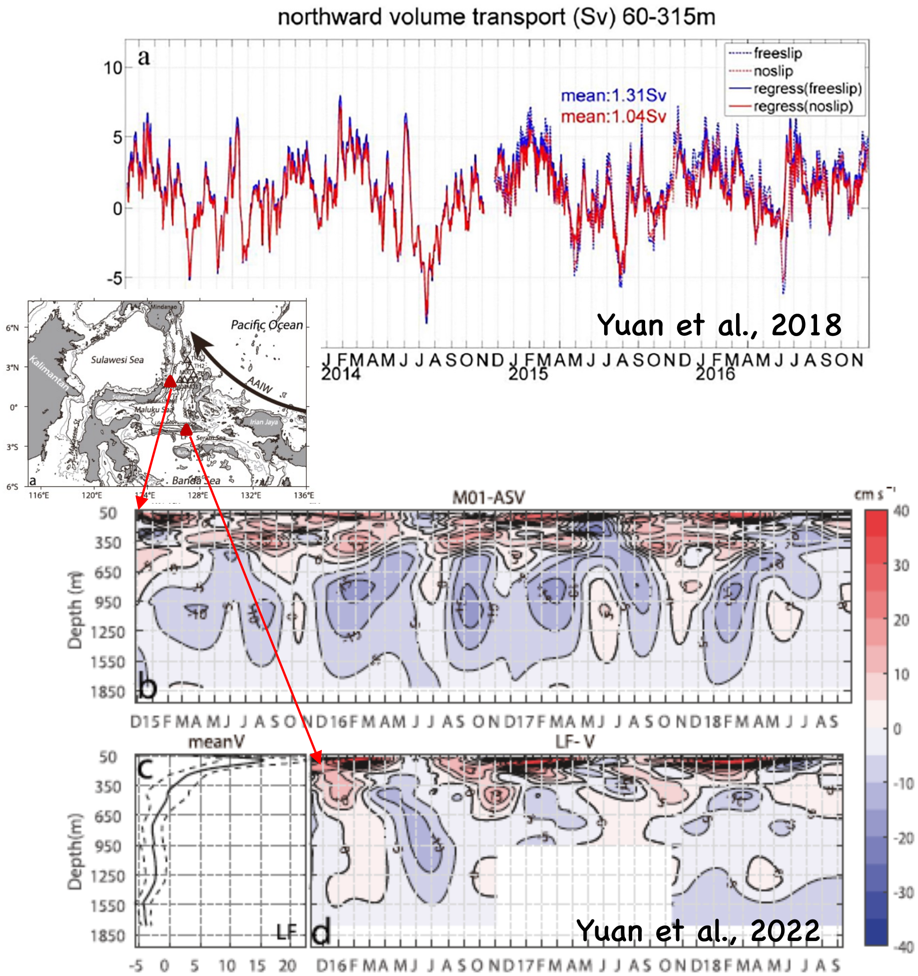


Yoneyama & Zhang 2020, GRL

Prior Understanding of Regional Oceanography

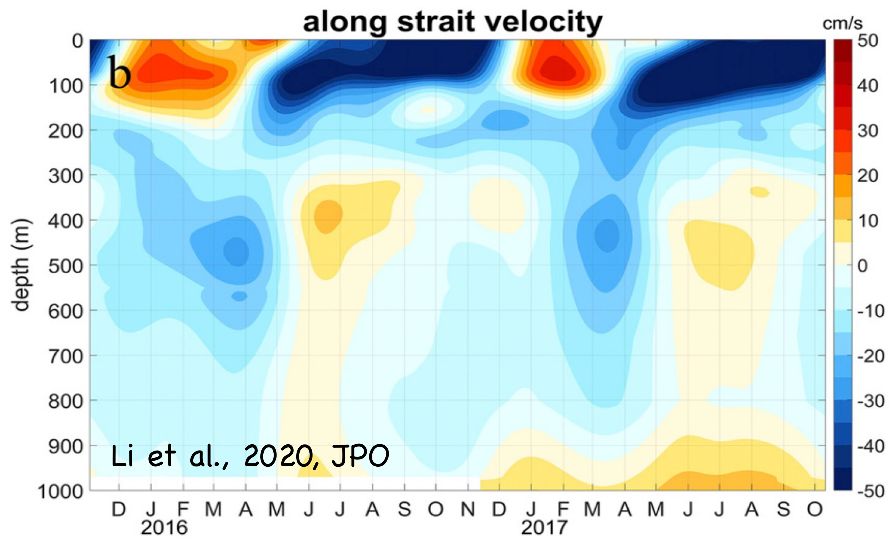


Variability in the Eastern Passages



The Maluku Channel (Yuan et al., 2018, 2022):

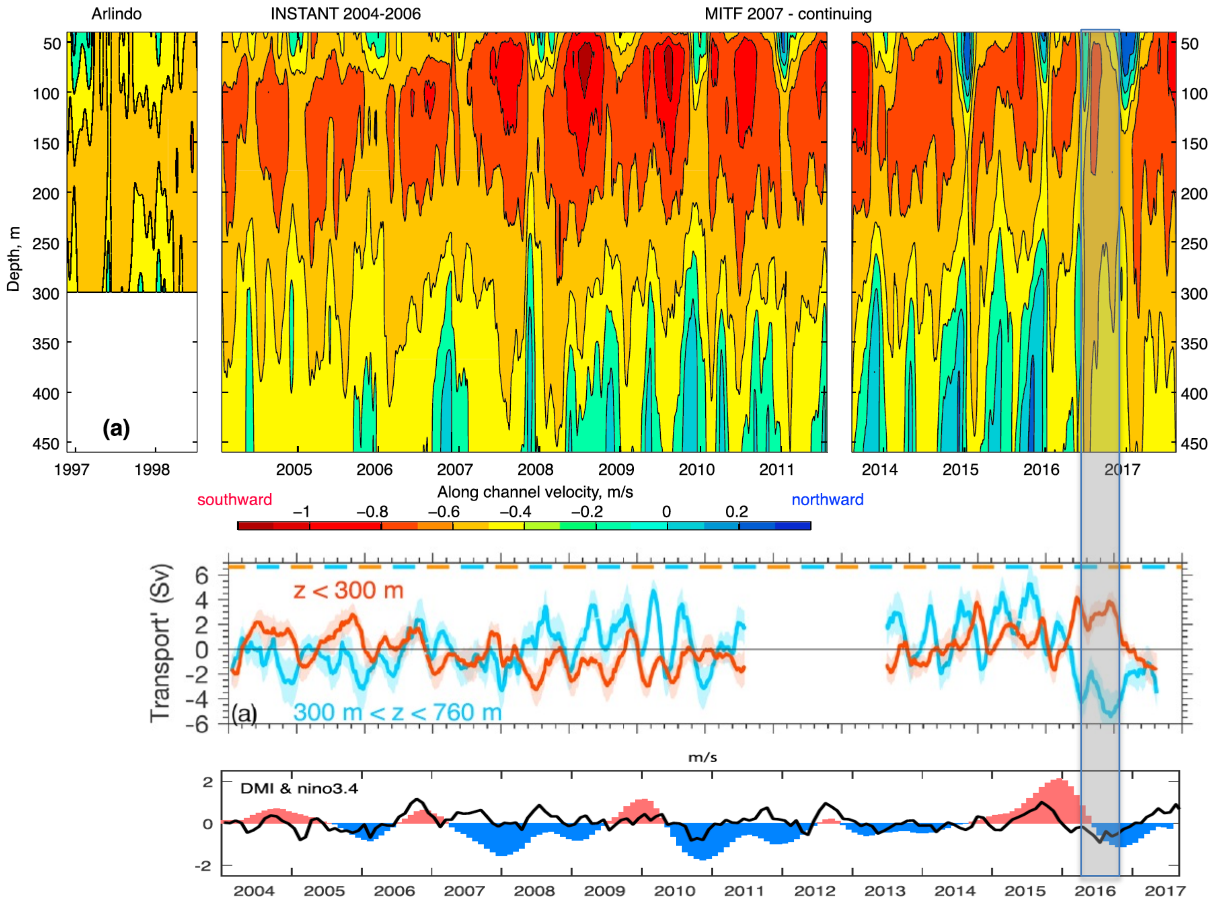
- Southward in summer, northward in winter with a mean northward transport between 60 and 315 m
- variability >> mean
- There is southward SPW(AAIW) below.

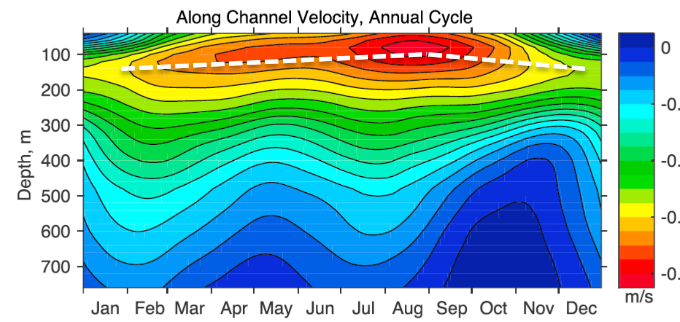


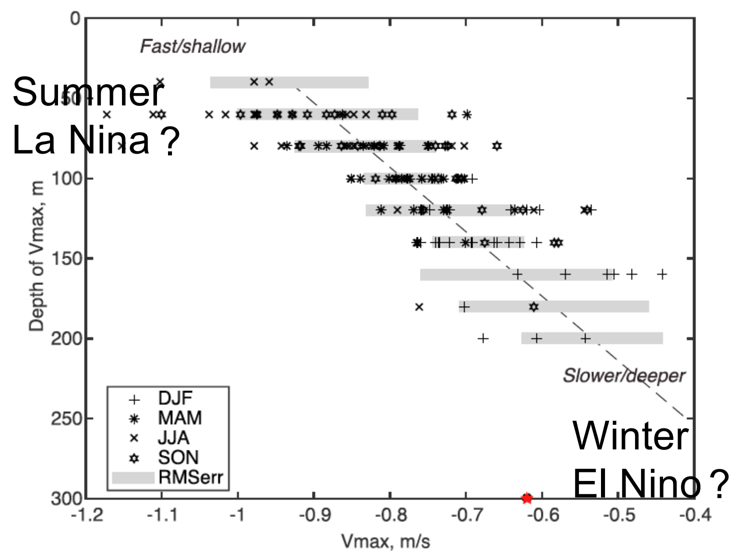
The Halmahera Sea (Li et al., 2020):

- 2.44$\pm$0.42 Sv toward the Indonesian seas
- apparent seasonal variations
- small year-to-year differences.

Variability in the Makassar Strait



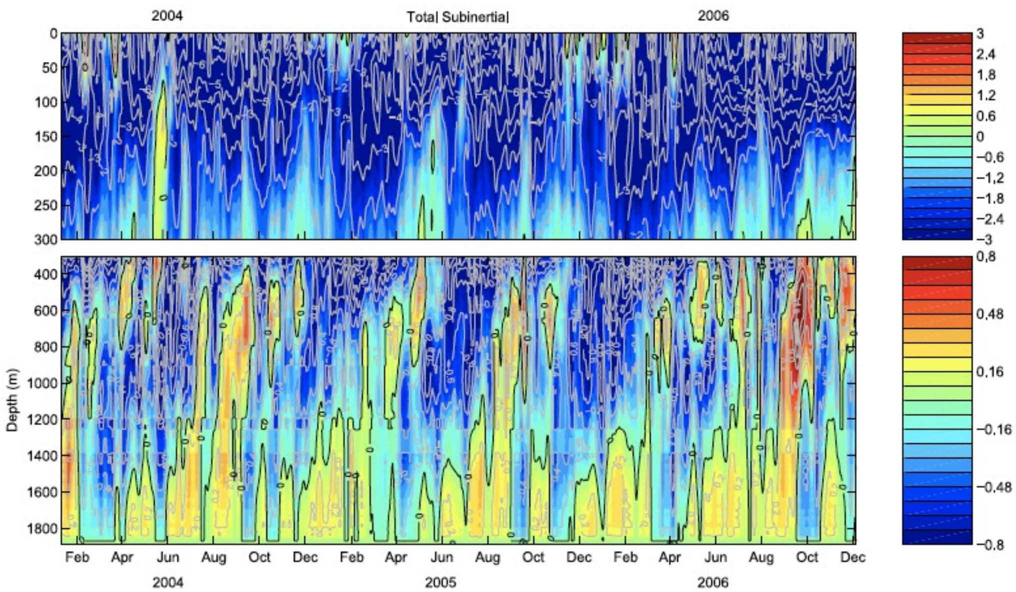




Gordon et al., 2012, 2019; Pujiana et al., 2019; Li et al., 2020

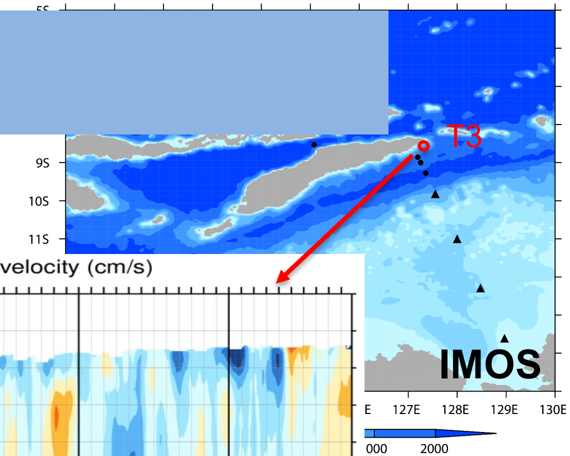
Outflow Straits

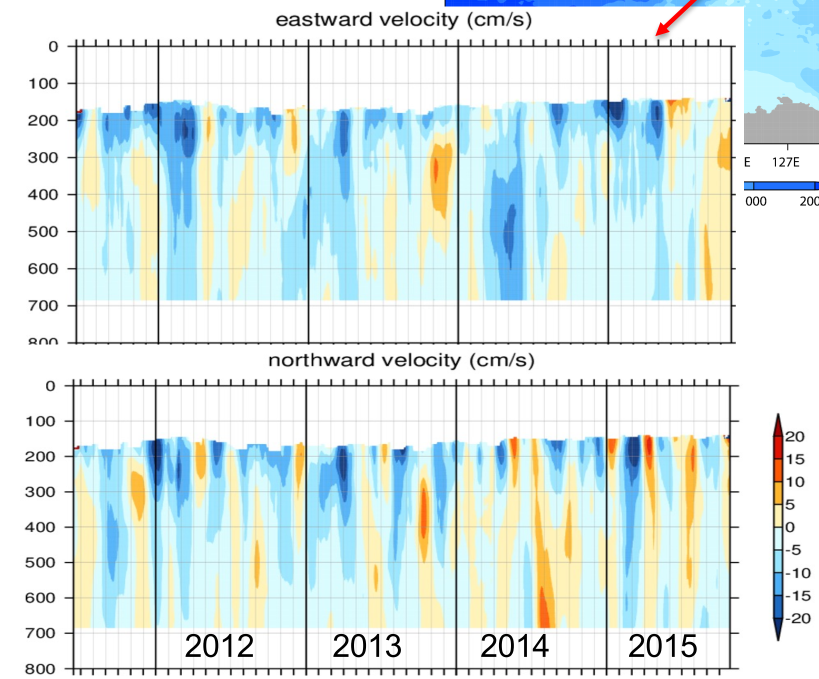
L + O + T transport



Sprintall et al., 2009:
Relatively strong semi-annual period with upward propagation.
Inflow dominates below 1200 m with another core around 500-600 m.

Timor Passage





IMOS observations:
Intraseasonal variability
Relatively stronger northeastward flow in the 2nd half of the years

Questions

- What is the (interannual) variability of the circulation in the Indonesian seas as manifested in the throughflows?

- What is the primary factor, local versus remote, in driving the interannual variability?

PIOM Setup

Liang, Xue & Shu
2019, JGR Oceans

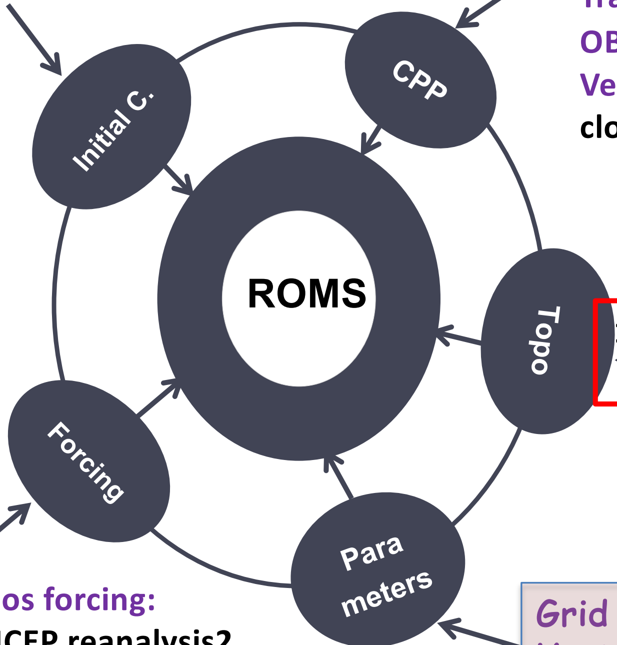
WOA13: winter T/S

Momentums:
  3rd order upstream for 3D eqs.
  4th-order center for 2D eqs.

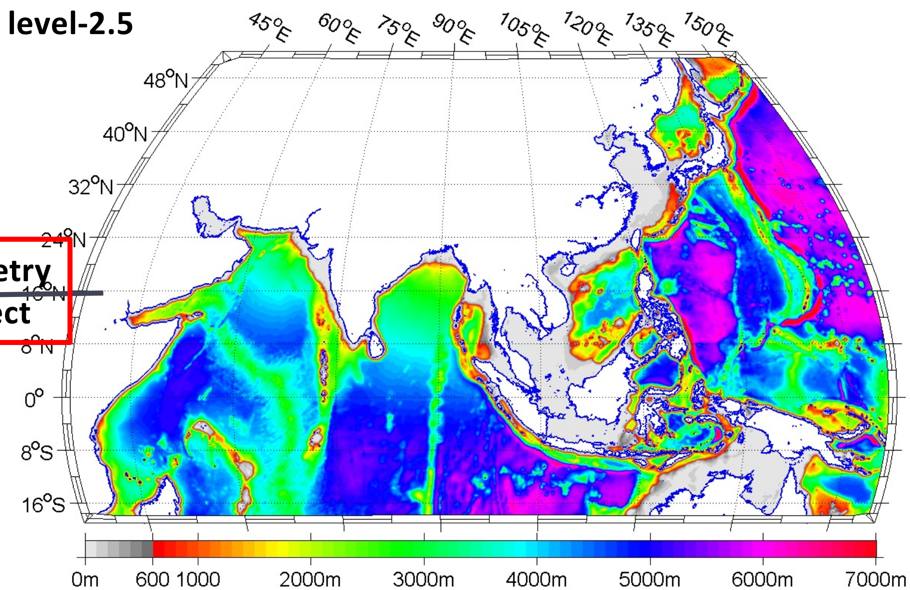
Tracers: 4th-order center

OBCs: modified radiation

Vertical mixing: MY level-2.5 closure



1/30 deg bathymetry
by OCCAM project



Atmos forcing:
  NCEP reanalysis2

Boundary forcing:
  OFES monthly climatological

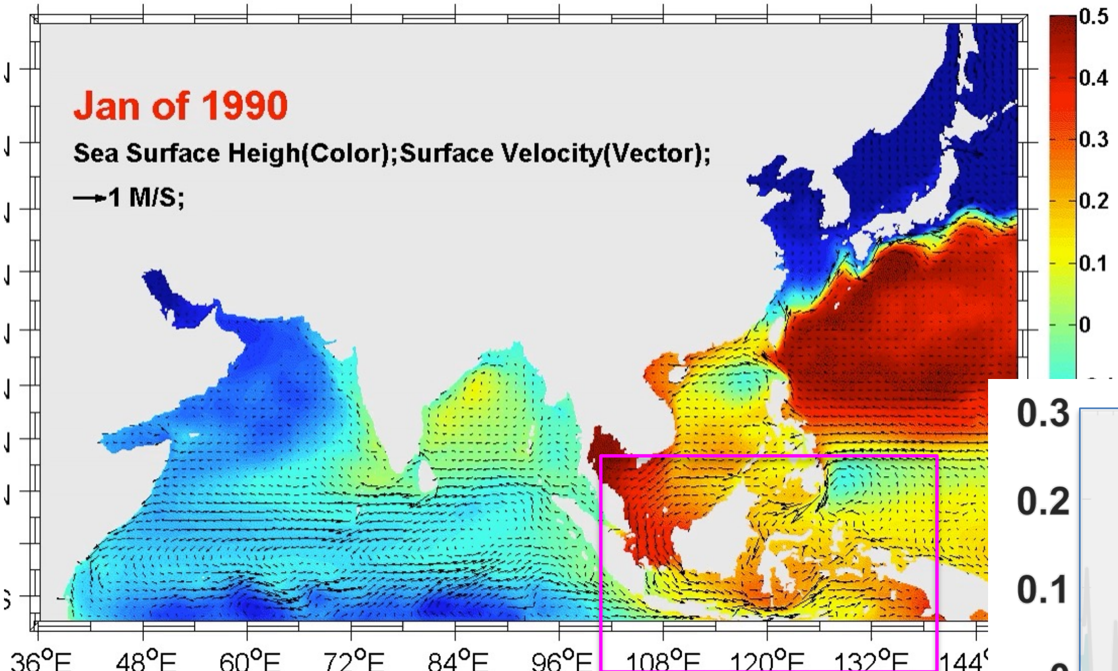
Rivers: monthly climatological

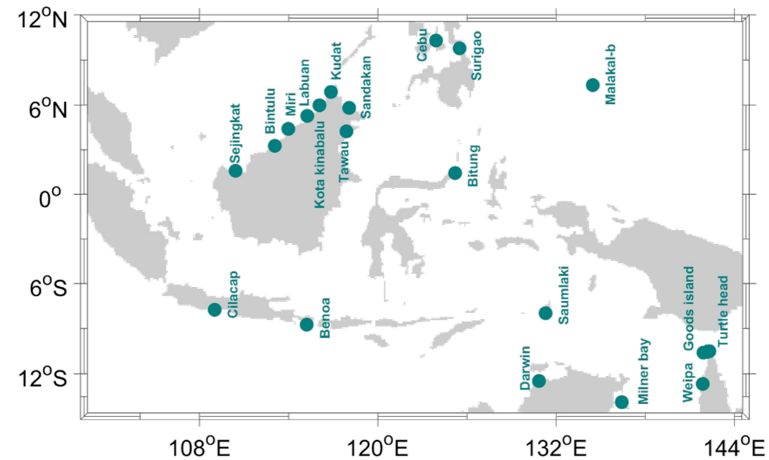
Tides: M_2, N_2, S_2, K_2, K_1, O_1, P_1, Q_1

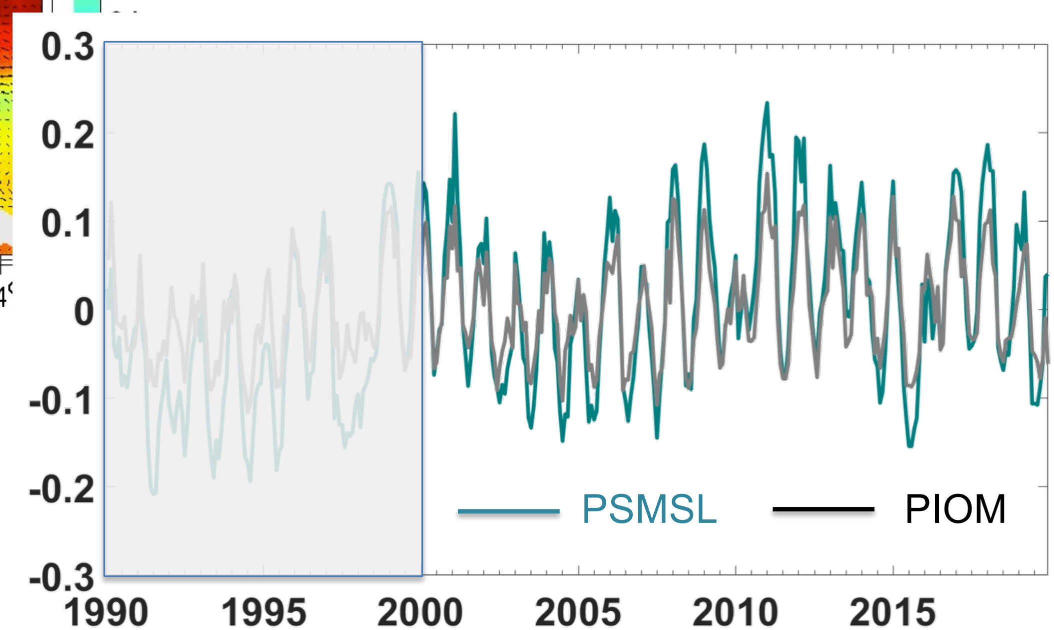
Grid size: 1/12°
Vert levels: 30

H. h. mixing coef.: 5;
Bk. potential temp:14;
Bk. salinity:35
Bk. mean density:1025

Real-time Simulation

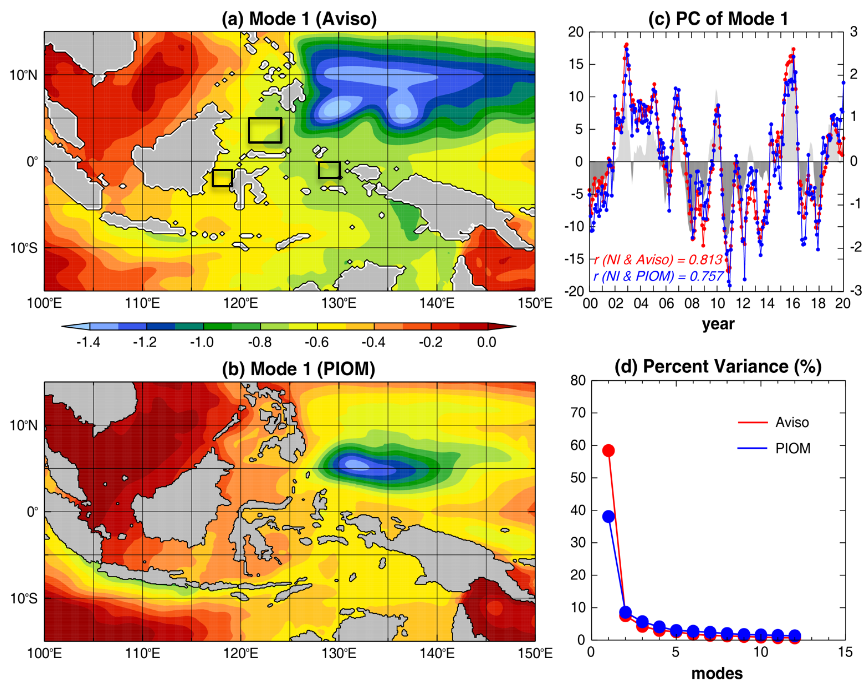


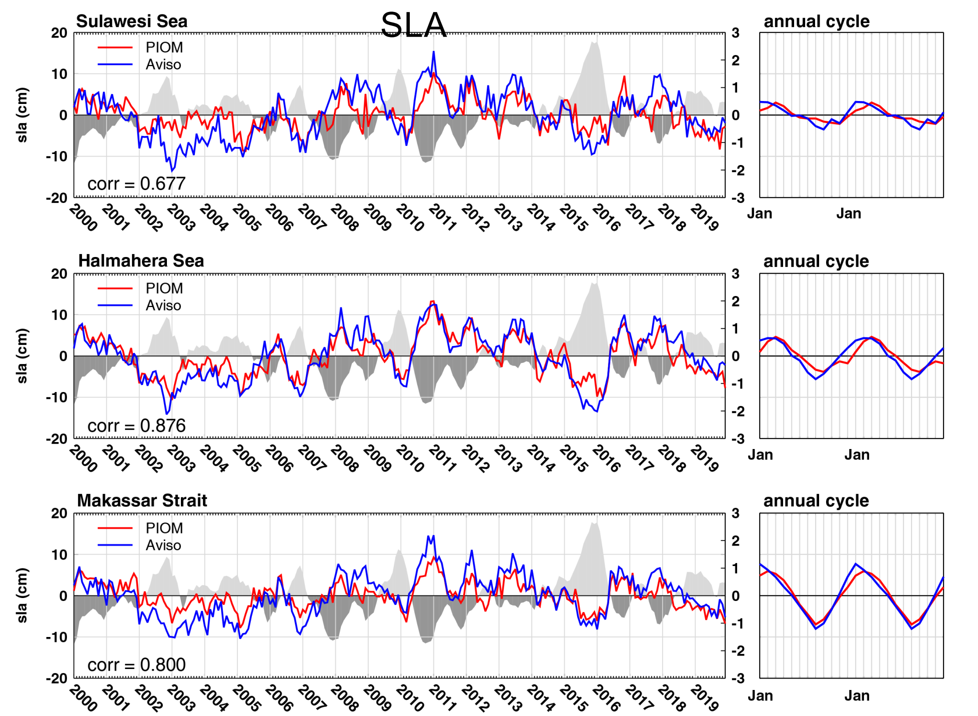


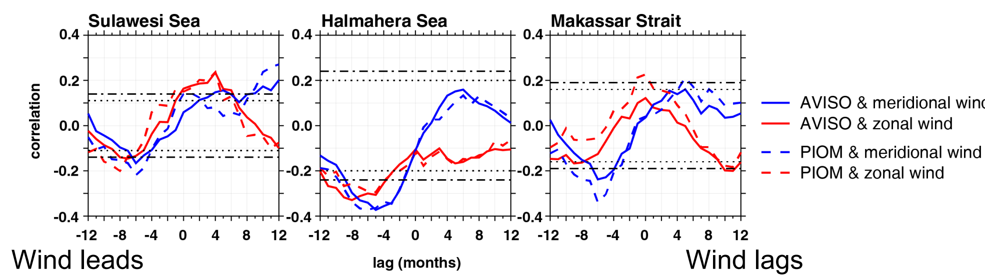


Interannual Variability in PIOM

Hu, Xue, & Liang (submitted)

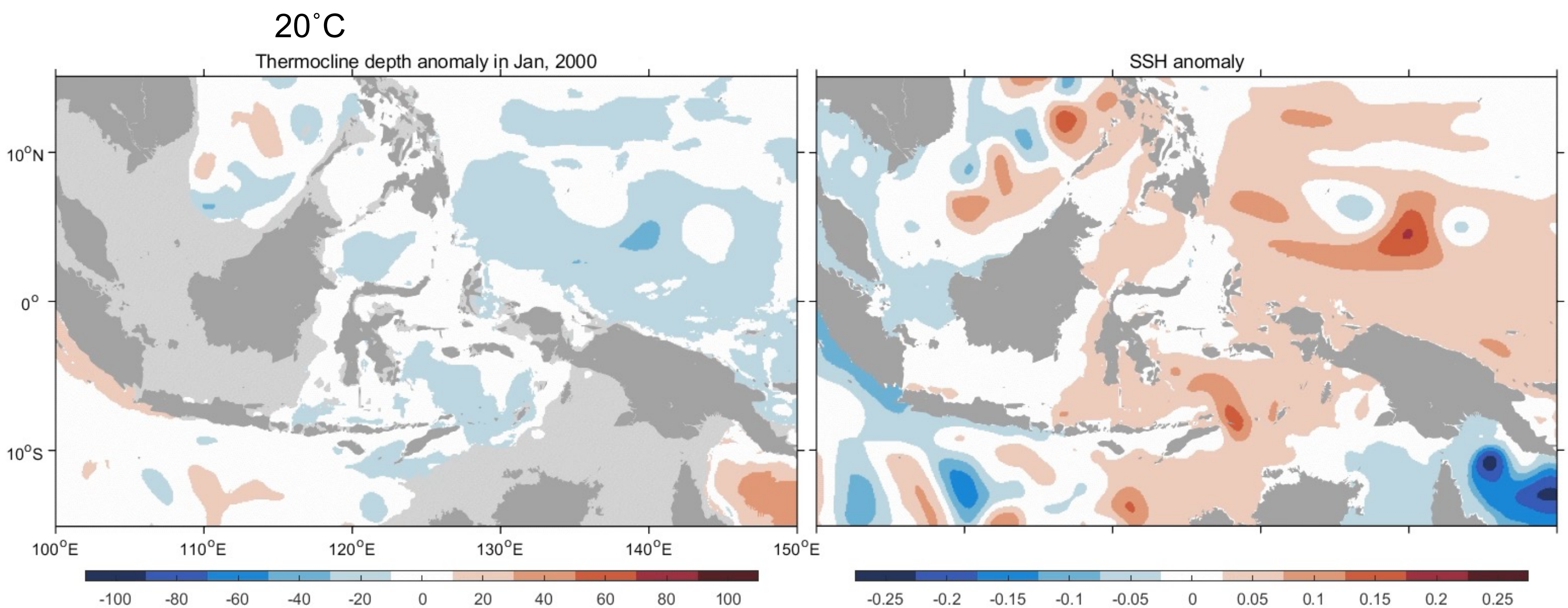






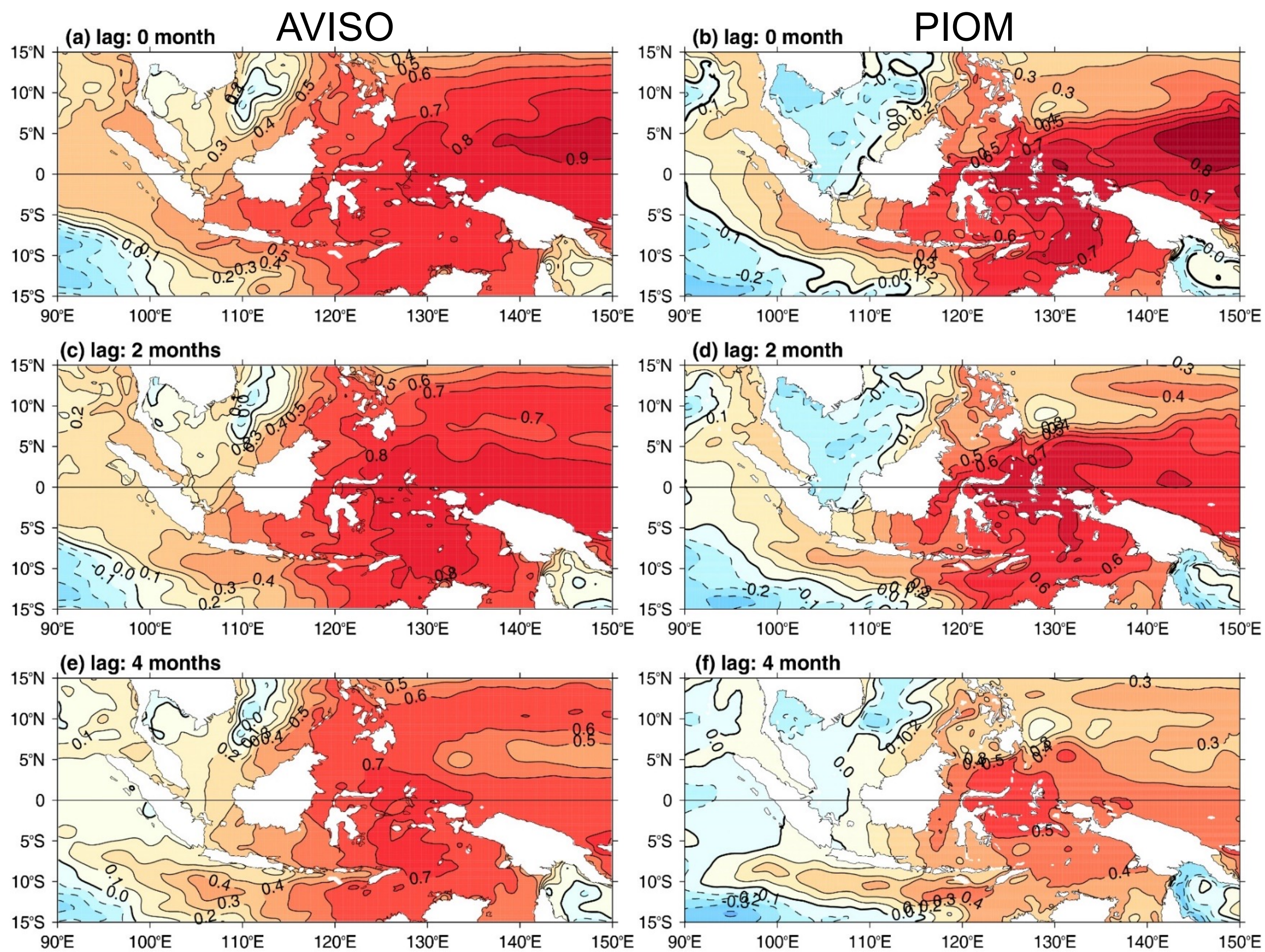
- Interannual variations of the SLA in the Indonesian seas, which are well reproduced by PIOM, correlate strongly with Nino3.4.
- Interannual variations of the SLA don't seem to be driven by the local winds as the zero-lag correlations are mostly insignificant.

Interannual Variability in PIOM



- Opposite responses between SSH and thermocline depth anomalies with lower SSH and shallower thermocline during El Nino and vice versa during La Nina;
- Westward propagation in the western Pacific; some penetrations into the Indonesian seas and continuation to the eastern Indian Ocean;
- The exit area has mixed signals.

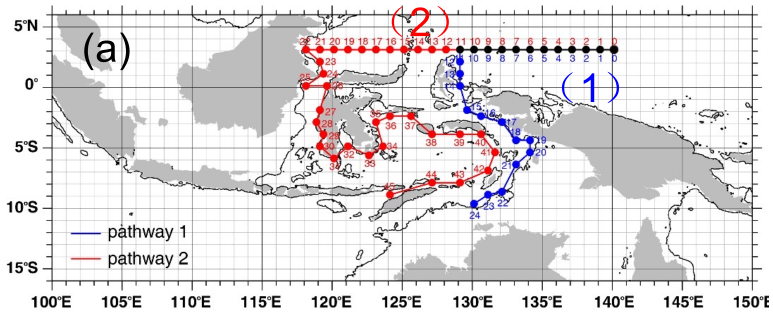
Interannual Variability in PIOM



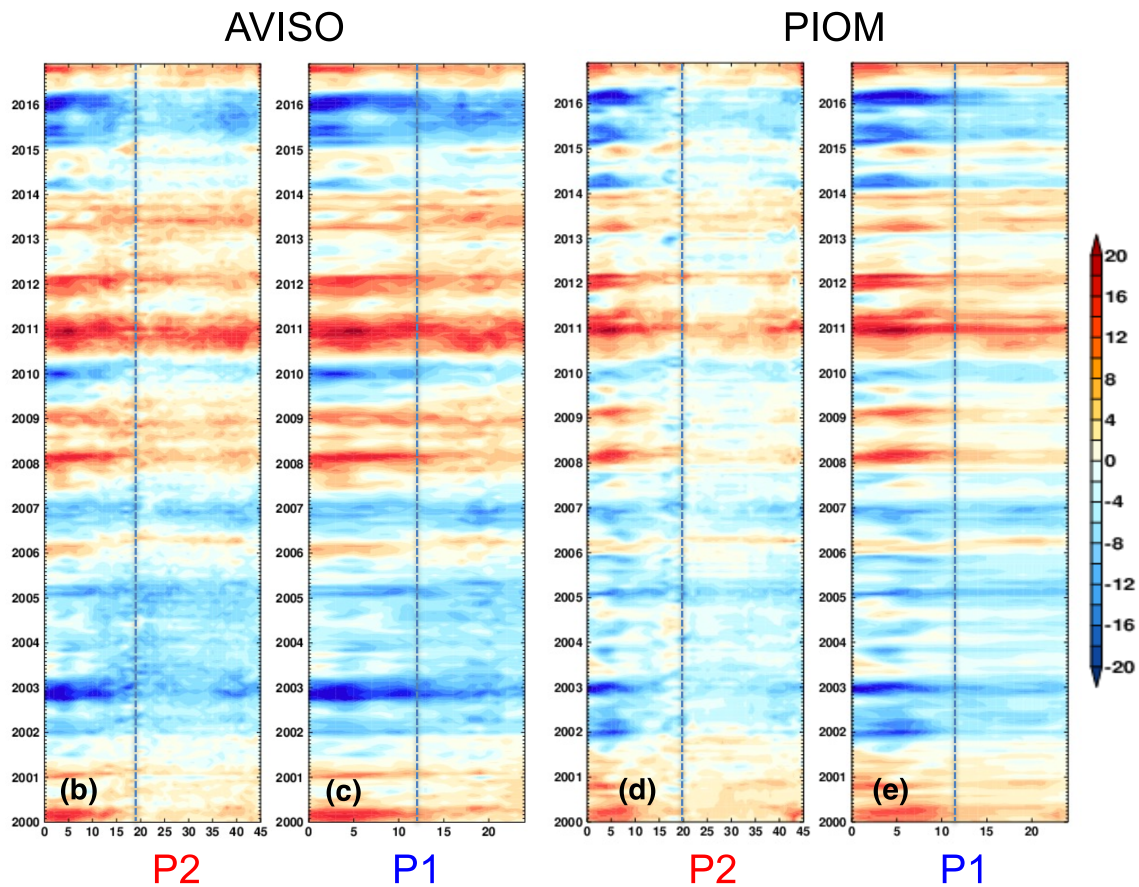
Although the correlation is somewhat lower in PIOM, but the interannual sea level anomaly signal through the Indonesian seas to the ITF exit in the eastern Indian Ocean can be traced back to (2°-6°N, 145°-155°E) for a time lag up to 4 months, suggesting the remote forcing mechanism from the equatorial Pacific.

Hu, Xue, & Liang (submitted)

Interannual Variability in PIOM



Two possible pathways of oceanic wave propagation (a) as seen from the evolutions of the SLA (cm) along pathway 1 (c, e) and pathway 2 (b, d) observed by Aviso altimeter (b, c) and simulated by PIOM model (d, e).



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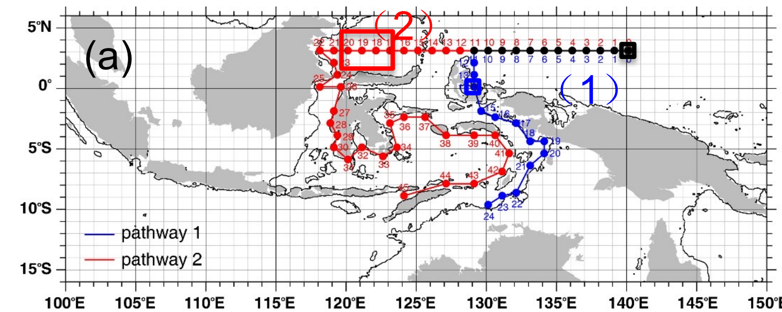
Interannual Variability in PIOM

	Event	Period	Sulawesi Sea AVISO/PIOM	Halmahera Sea AVISO/PIOM
El Niño events	2002/2003	2002-05 to 2003-03	37/23	55/58
	2009/2010	2009-07 to 2010-04		
	2015/2016	2014-10 to 2016-05		
La Niña events	2000/2001	2000-01 to 2001-02	47/29	47/45
	2007/2008	2007-07 to 2008-06		
	2010/2011	2010-06 to 2011-05		
	2016/2017	2016-08 to 2016-12		



- The magnitude is comparatively smaller in the Sulawesi Sea than in the Halmahera Sea.
- The difference between the Sulawesi Sea and the Halmahera Sea becomes smaller during La Nina periods.

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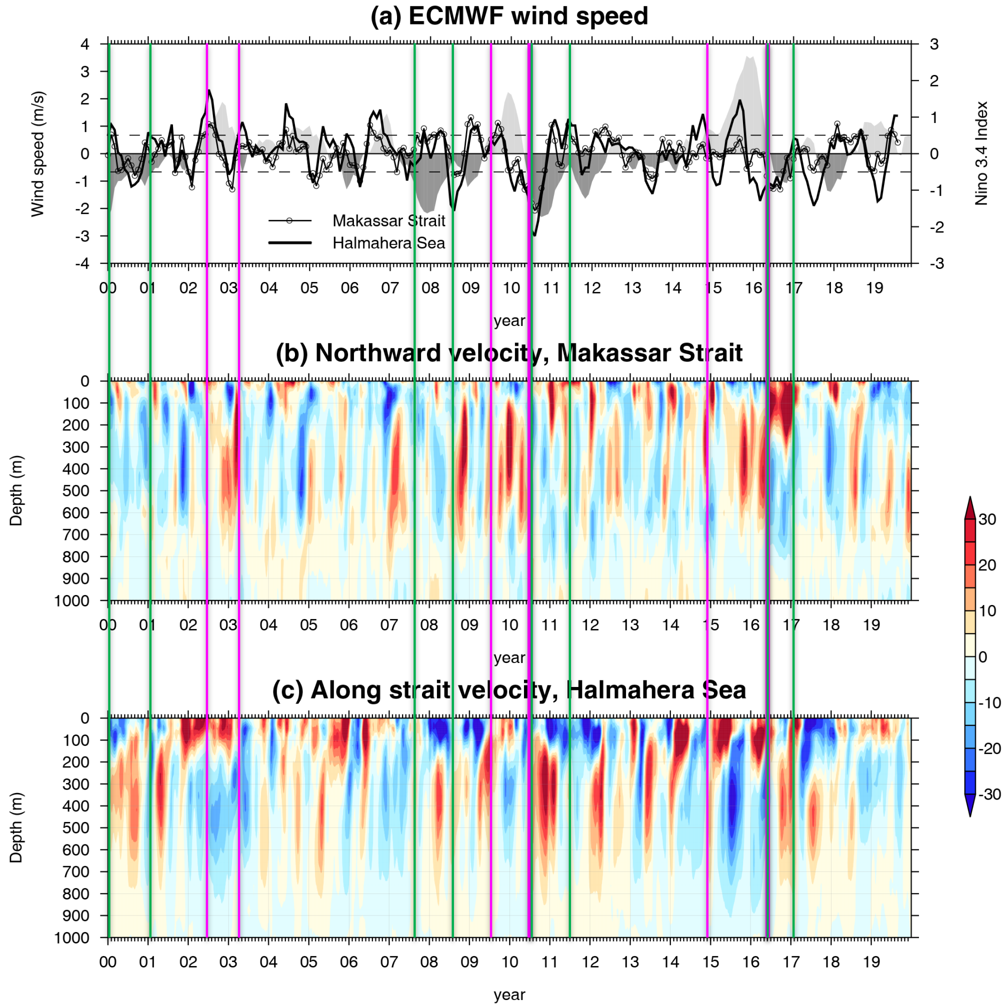
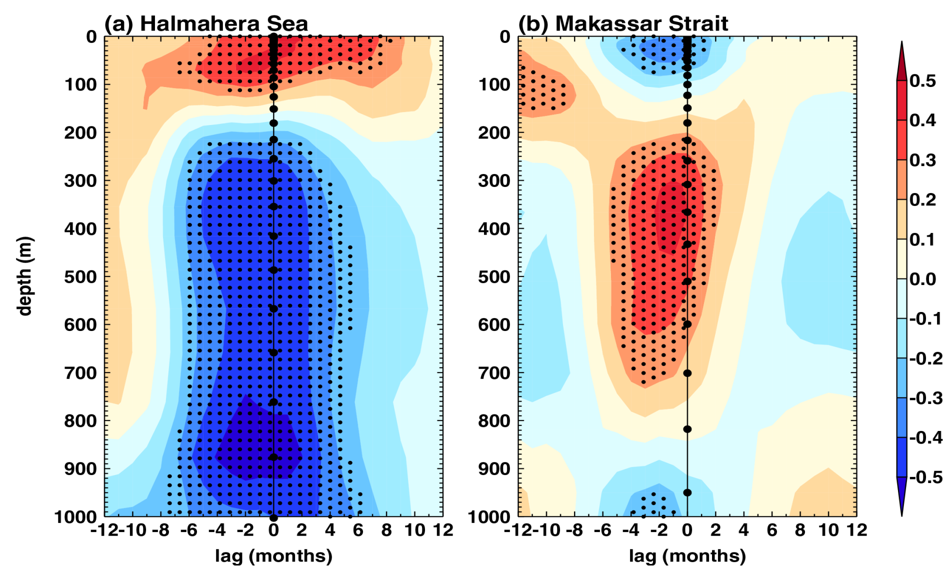
Interannual Variability in PIOM



Lead-lag correlations with Nino3.4



- Negative (positive) anomalies, i.e., increase (decrease) of southward velocity in the upper layer (subthermocline) during El Niño, and vice versa during La Niña.
- Opposite responses between the Makassar Strait and the Halmahera Sea.

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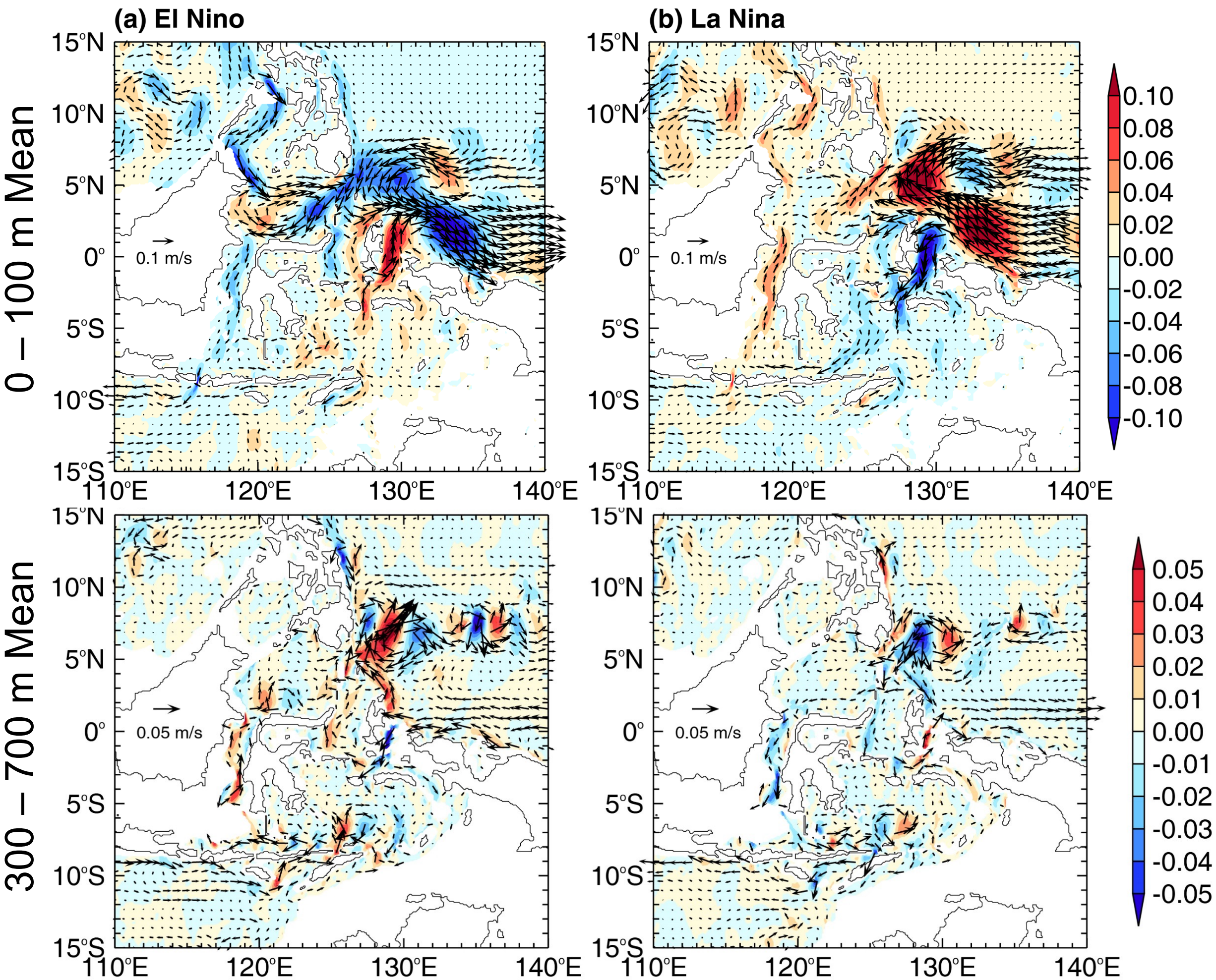
Interannual Variability in PIOM



The velocity anomaly composites (vectors, m s^{-1}); red/blue represent northward/southward anomalies.

- The southeastern and northwestern half of Indonesian seas respond in opposite phases
- Variations all linked to the changes of NECC, which is stronger and shifts southward during El Niño, accompanied by strengthened ME and HE.
- In narrow passages, the anomalies are north- or southward, but in the wider Sulawesi Sea and Banda Sea, they are eddies and often counter-rotating eddy pairs.

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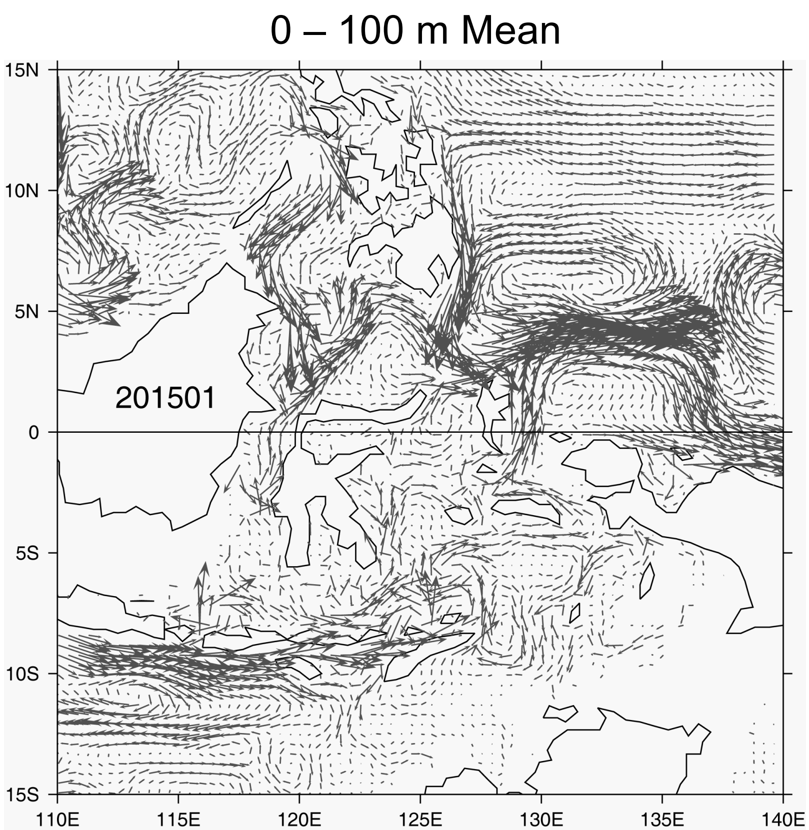
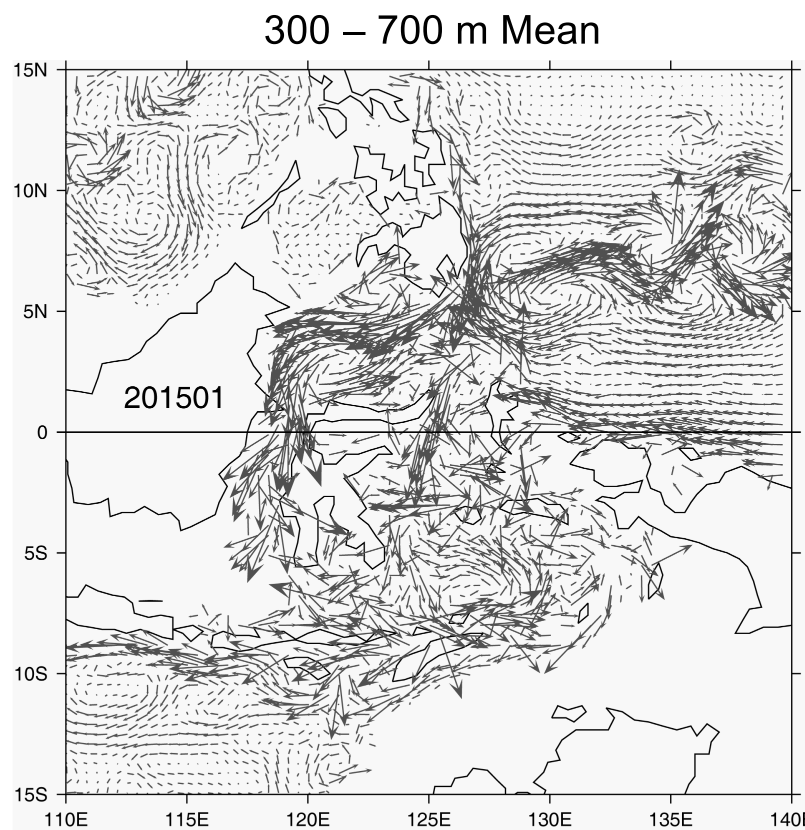
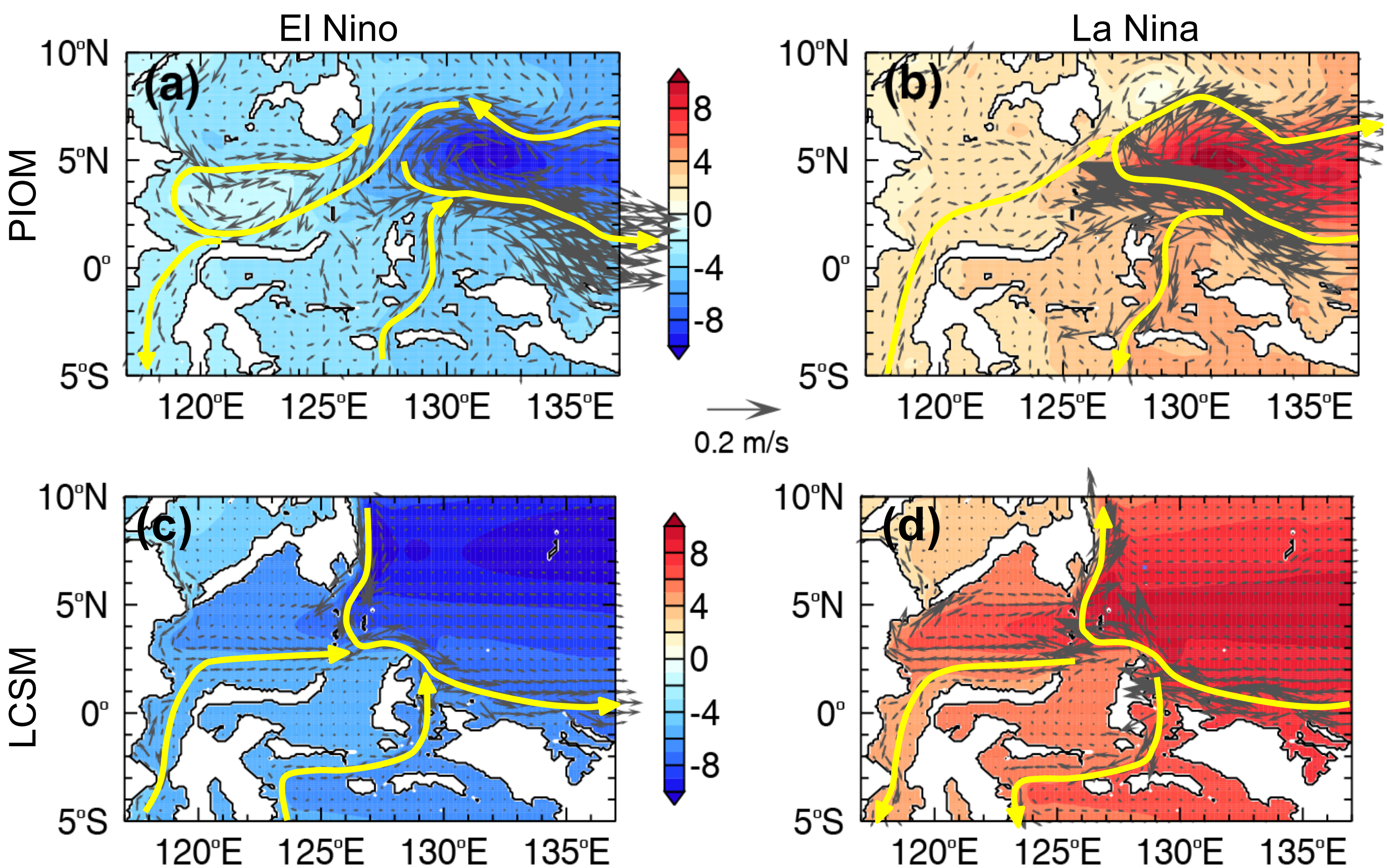
Interannual Variability in PIOM





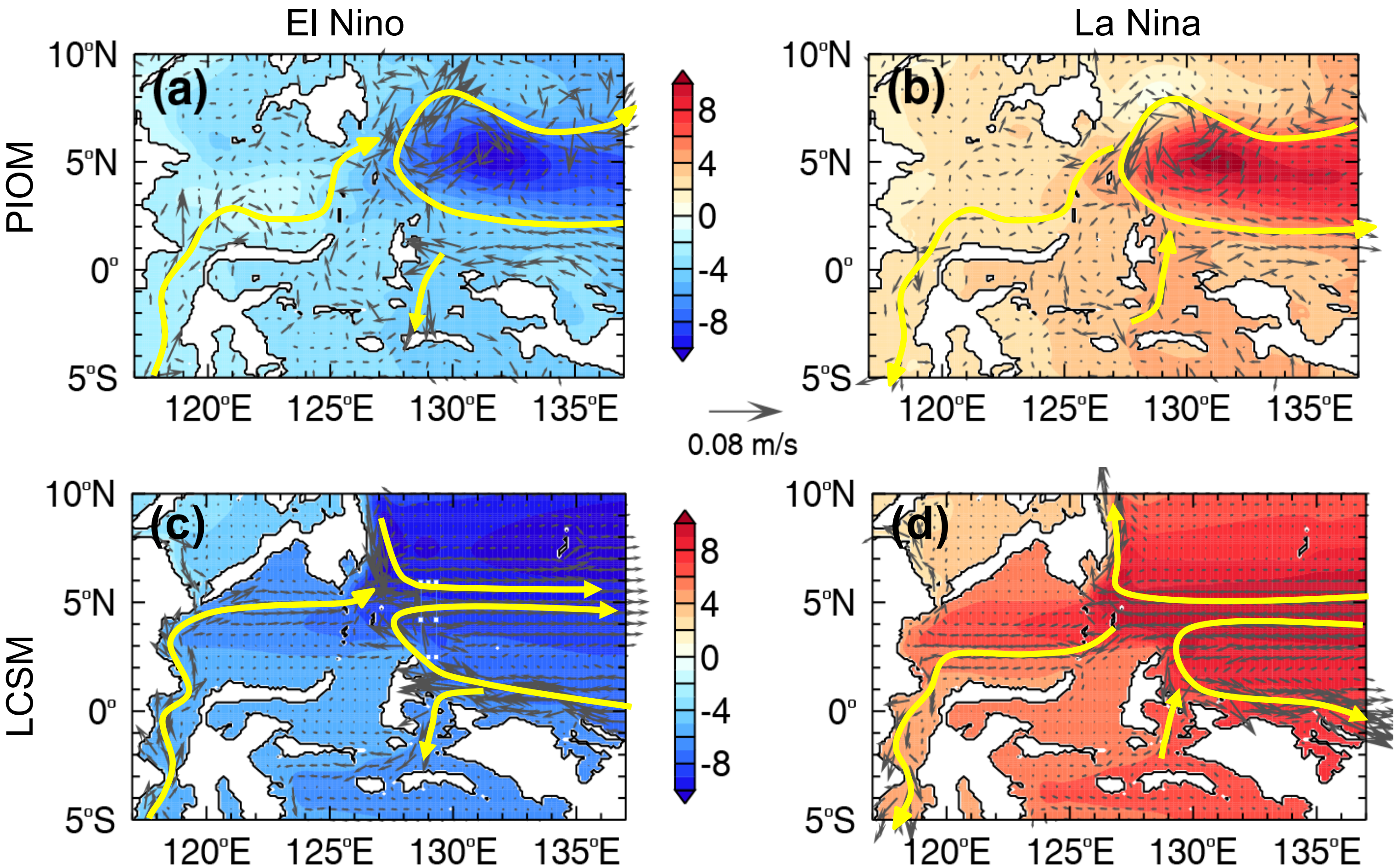
Interannual Variability in PIOM & LCSM – surface layer



Flow anomalies in the Makassar Strait are in **opposite** directions between LCSM and PIOM, while they agree in the Halmahera Sea.

Flow anomalies in the Makassar Strait are strongly affected by eddies, while those in the Halmahera Sea are governed by linear dynamics.

Interannual Variability in PIOM & LCSM - subthermocline



Effects of the nonlinearity weakened below the thermocline, and flow anomalies in the LCSM generally agree with those in PIOM.

Summaries

- The interannual variations of sea level in the Indonesian seas, which are strongly correlated with Nino 3.4.
- Lag correlation analyses suggest that these interannual signals do not seem to be driven by the local wind, but they can be traced back to the equatorial Pacific.
- The oceanic waves from the Pacific move into the Indonesian seas via not only the previously known eastern waveguide, but also the Makassar Strait via the Sulawesi Sea.
- Despite the largely coherent SLA throughout the Indonesian seas, flows in the Makassar Strait and those in the Halmahera Sea respond in opposite phases. Moreover, opposite responses are also found above and below the thermocline in both passages.
- LCSM is able to produce the opposite flow anomalies above and below the thermocline in the Halmahera Sea, but it fails in the Sulawesi Sea and the Makassar Strait because there above the thermocline flow anomalies are strongly affected by nonlinear eddies.