Intraseasonal Variability of the Indonesian Throughflow Associated with the Madden-Julian Oscillation

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Abstract

Previous studies indicate significant intraseasonal (20-90 days) variability on the Indonesian Throughflow (ITF) transport produced by the Madden-Julian Oscillation (MJO). These studies, however, mostly focus on the transport through each individual strait, especially Makassar strait, and overall impacts of the MJO on ITF transport are not well understood. This study examines the intraseasonal variability of ITF transport associated with the MJO, including the transport through multiple major straits (Makassar, Lombok, Ombai, Timor) in the Indonesian Seas using a new 1/12° global HYbrid Coordinate Ocean Model (HYCOM) reanalysis. The composite analyses of oceanic and atmospheric variables are performed for the period January 2004-December 2015, in which eighteen well-defined MJO events were identified. Consistent with previous studies, large intraseasonal variability of the Makassar Strait Throughflow is identified from the analysis. In addition, the contribution of anomalous ITF transport through other straits during both active and suppressed phase of the MJO for the total transport is quantified based on the composite analysis.

INTRASEASONAL VARIABILITY OF THE INDONESIAN THROUGHFLOW

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I. Motivations

The Indonesian Throughflow (ITF) is a major part of the global thermohaline circulation, carrying about 15 Sv of waters from the Pacific to the Indian Ocean. It is well known that the ITF varies on several different time scales, including the intraseasonal variation associated with the Madden-Julian Oscillation (MJO). However, the ITF transport variations through most major straits in the Maritime Continent (MC) over the life cycle of the MJO have not been quantified. Here, a high-resolution ocean reanalysis is employed to investigate the impact of the MJO on ITF transport, including the influence during the suppressed phase of the MJO and its net effect.

II. Data & Method

- Hybrid Coordinate Ocean Model (HYCOM) reanalysis for 2004-2015

Horizontal resolution: 1/12º

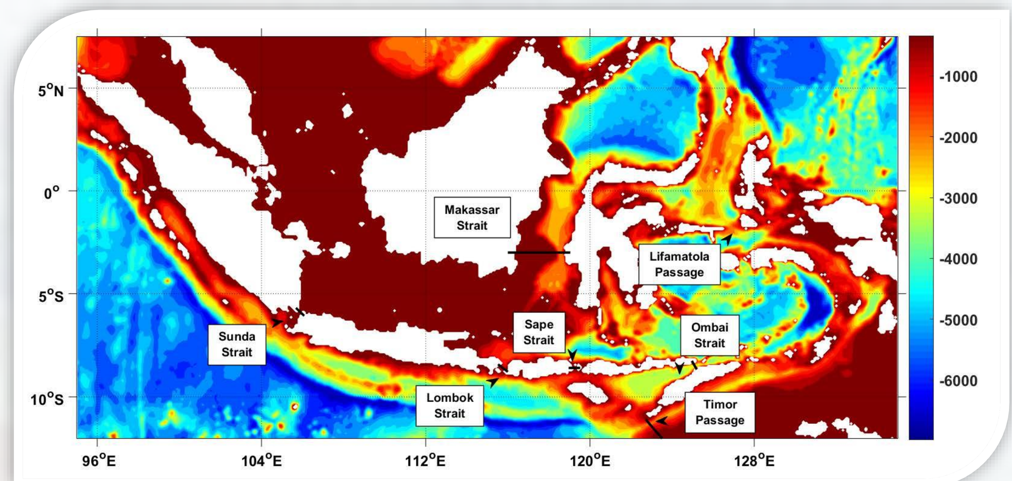


Fig. 1. The 1/12° global HYCOM topography (m) for the Indonesian Seas.

- Composite analysis based on the Real-time Multivariate MJO (RMM) Index (Wheeler and Hendon, 2004):

MJO event:
RMM amplitude > 1 for 30 consecutive days or more.

III. Results

- **ITF transport associated with the MJO**

Mean transports through major straits in the HYCOM reanalysis agree well with INSTANT observations (not shown).

Based on 18 MJO events for the 2004-2015 period, the amplitude of the fluctuation of ITF transport anomaly (Fig. 2a) and total transport (Fig. 2b) for all ITF exit passages due to the MJO is about 2.5-4 Sv (~20 to 33% of the mean ITF transport).

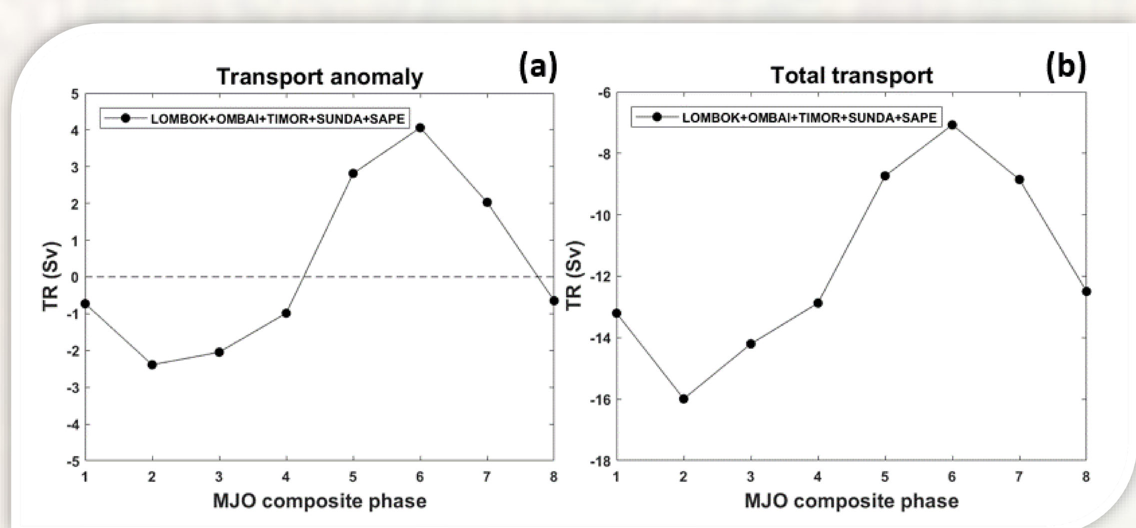


Fig. 2. MJO composite of anomalous (a) and total (b) transport for the summation of transport through all exit passages of ITF.

IV. Results. Continued

A significant reduction of the ITF transport in all major straits is found during the MJO active phase (phases 4, 5 and 6 of Fig. 3), consistent with previous studies.

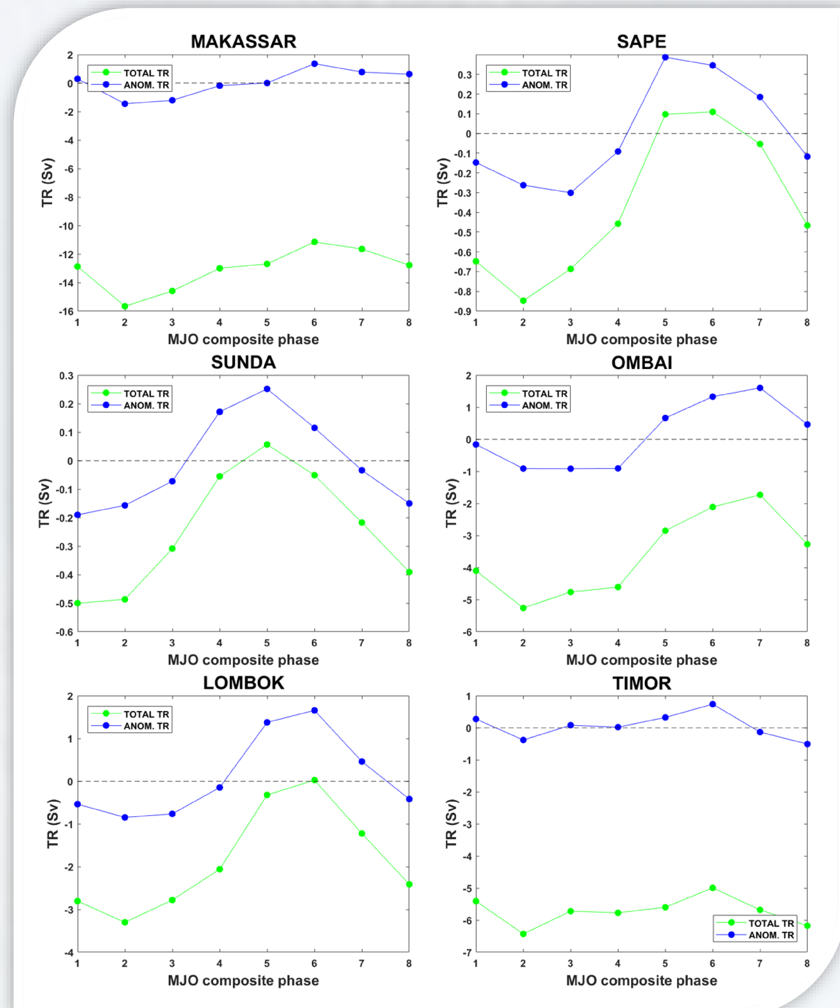


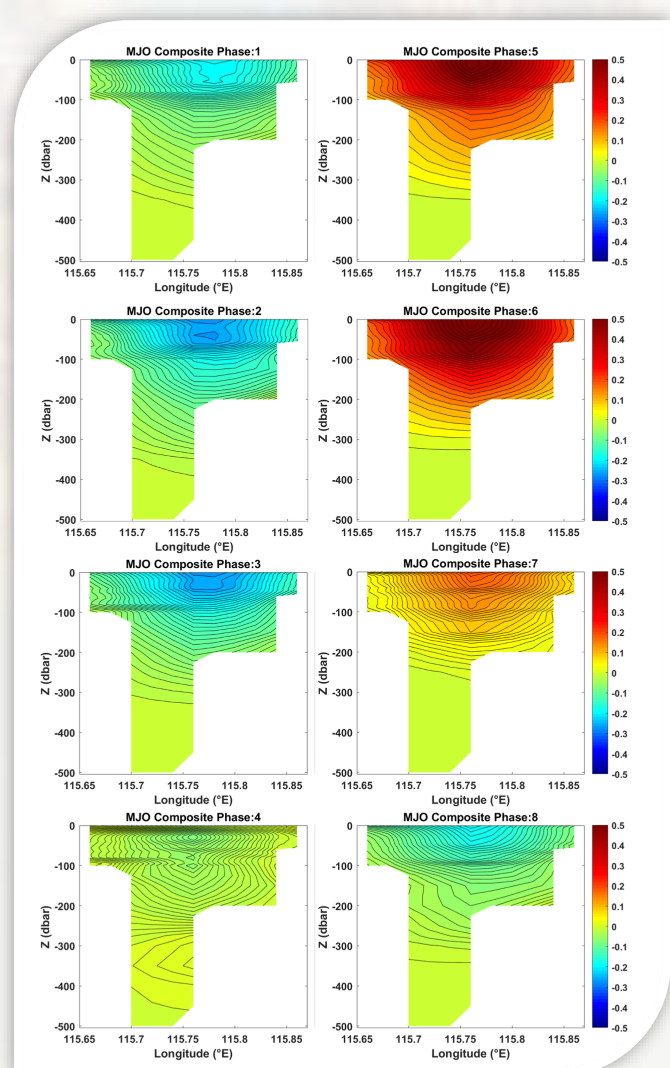
Fig. 3. MJO composite of total (green line) and anomalous (blue line) transport through the MC main straits and passages. See Fig. 1 for their locations.

A significant enhancement of the ITF transport during the MJO suppressed phase over the MC (phase 1 and 2) is evident. As the magnitude of the enhancement is comparable to that of the reduction, the net effect of the MJO on the ITF transport is nearly zero (Table 1).

Strait / Passage	Makassar	Sunda	Lombok	Sape	Ombai	Timor
Av. anomalous transport	0.03	-0.01	0.10	0.00	0.15	0.05

Table 1. Average anomalous transports (Sv) associated to the MJO in the MC major straits based on the composite of Fig. 3.

- **Vertical structure of MJO-induced ITF current fluctuation**



The vertical section of the along-strait velocity across the Lombok Strait (Fig. 4) shows strong anomalous southward currents (MJO phase 2) which vertical extent is less than the one of the northward anomalies (phase 6). Similar results were found for Ombai Strait and Timor Passage (not shown).

Fig. 4. MJO composite of along-strait velocity anomaly (m/s) across the Lombok Strait. Positive values indicate northward currents.

V. Results. Continued

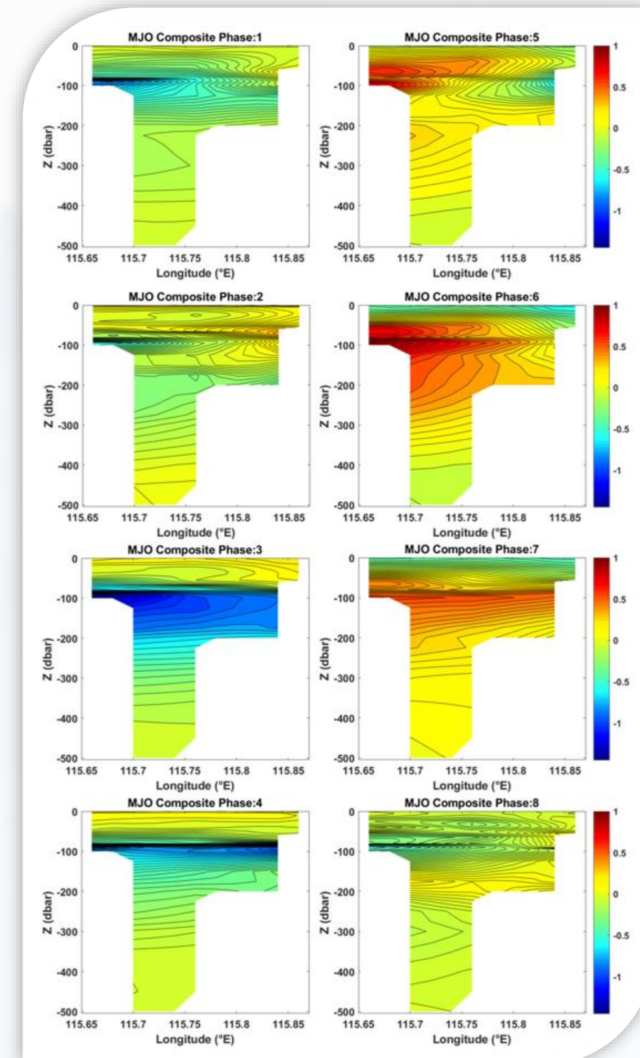


Fig. 5. MJO composite of temperature anomaly (°C) across the Lombok Strait.

The composite of the temperature along the same section in Lombok Strait (Fig. 5) presents large cold anomalies around the thermocline depth (~100 m) during the suppressed phase that suggest strong upwelling, which can decrease the along-shore current vertical extent.

Similarly, the warm anomalies around the thermocline depth indicate downwelling during the active phase, which may cause the increase of the surface current vertical extent.

- **Influence of oceanic Kelvin waves generated by MJO forcing on the ITF**

During the MJO active phase over the MC (phases 4 and 5 of Fig. 6), when westerly winds are found in the equatorial Indian Ocean, eastward currents along the equator generate positive SSH anomalies at the eastern boundary that propagate along the coast. During the suppressed phase over the MC (phases 8 and 1 of Fig. 6), negative SSH anomalies with the magnitude and time evolution like those during the active phase are also present.

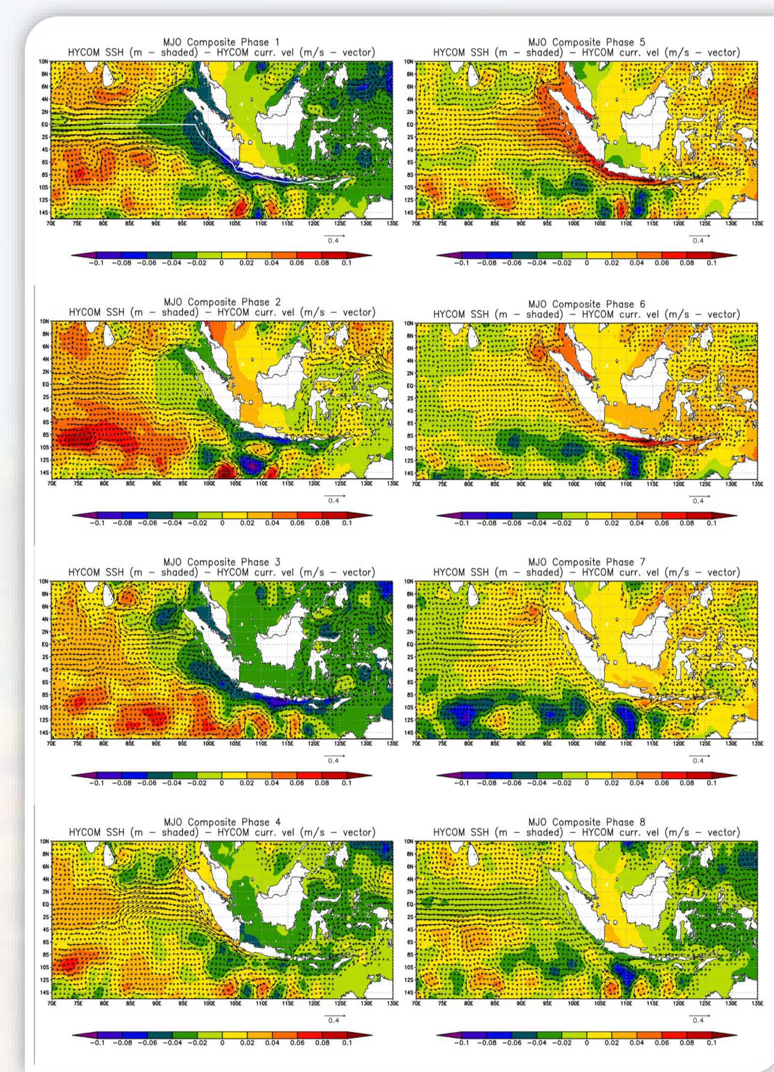


Fig. 6. MJO composite of upper-ocean (average over 0–150-m depths) velocity (m/s) and SSH anomalies (m) from the HYCOM reanalysis.

A Hovmöller diagram (Fig. 8) of composite SSH along the line shown in Fig. 7 shows a phase speed (~2.9 m/s) for the positive SSH anomalies that is consistent with MJO-induced first baroclinic mode Kelvin wave speed in this region. The propagation of negative SSH anomalies is not as clear as positive anomalies. However, the propagation of the negative anomalies is found for some of the MJO events (Fig. 9). In this case (DYNAMO period), during the MJO suppressed phase, negative SSH anomalies and the associated anomalous currents propagate eastward along the coastline, followed by positive SSH anomalies also propagating eastward during the subsequent active phase.

VI. Results. Continued

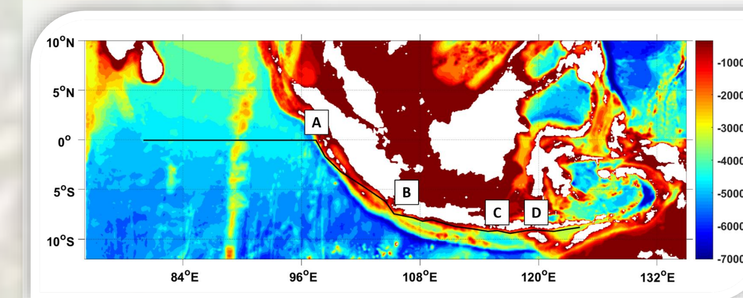


Fig. 7. Path (black solid line) used for the Hovmöller diagram. The shading indicates 1/12° global HYCOM topography (m).

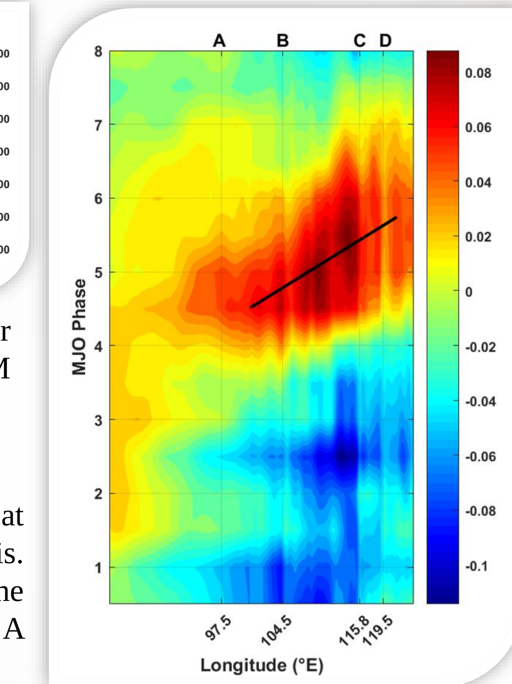


Fig. 8. Hovmöller diagram of SSH anomalies at different MJO phases from the HYCOM reanalysis. Locations A, B, C, and D are found on Fig. 7 and the black solid line indicates the phase line of ~2.9 m/s. A period of 65 days is used to calculate the phase speed.

The Hovmöller diagram during these MJO events show both negative and positive anomalies propagate along the path with a phase speed similar to the composite.

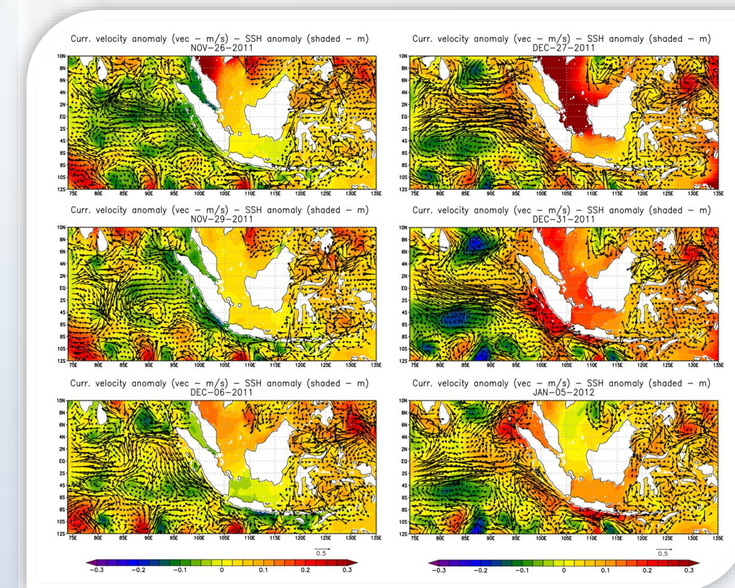


Fig. 9. SSH (shading; m) and upper-ocean (average over 0–150-m depths) velocity anomalies (vectors, m/s) for November 26, 29, December 06, 27, 31, 2011 and January 5, 2012 relative to the climatology for the 2004-2015 period from the HYCOM reanalysis.

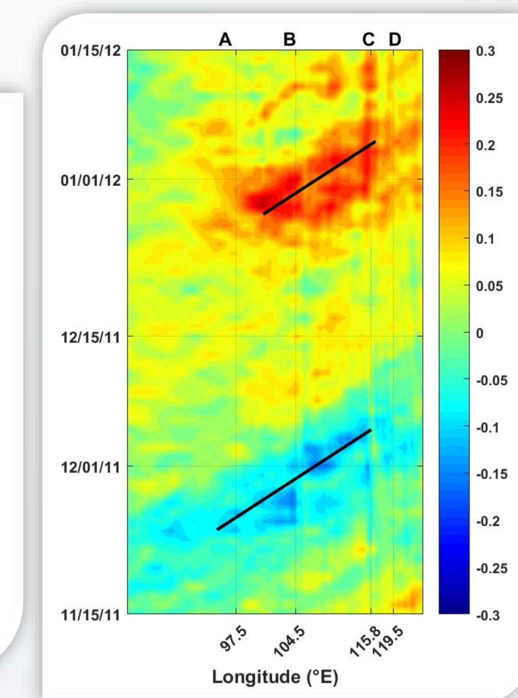


Fig. 10. Hovmöller diagram for the case study. Locations A, B, C, and D are found in Fig. 7. Black solid lines indicate the phase line of ~2.9 m/s.

VII. Conclusions

- **Impact of the MJO on the ITF transport: Amplitude of the ITF transport variation associated with the MJO is significant (~30% of total mean transport), but the net effect of the MJO on the ITF transport over its life cycle is nearly zero because of the cancellation of the reduction during the active phase and the enhancement during the suppressed phase.**

- **Vertical extent of the currents at ITF exit passages is largely influenced by strong upwelling (downwelling) during the MJO suppressed (active) phase.**

- **Coastal Kelvin waves associated with the MJO propagate eastward along the coast of Sumatra and Java islands during both active and suppressed phases, affecting the ITF transport through the major straits in the Indonesian Seas.**

Acknowledgements

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