THE SEASONAL CYCLE OF TRANSPORT FROM THE PACIFIC TO THE INDIAN OCEAN VIA THE INDONESIAN THROUGHFLOW

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Abstract

A series of numerical model experiments were run to investigate the annual cycle of mass transport between the Pacific and Indian Oceans via the Indonesian throughflow (ITF). The reduced-gravity model developed for and used in this study was forced only by climatological winds and incorporated only hydrodynamic processes. The model may not provide an accurate estimate of long-term mean throughflow transport, but the suite of model experiments provides insights into annual variations of the throughflow.

The $1\frac{1}{2}$-layer, reduced-gravity model used in this study, forced by climatological wind stress (from *Hellerman and Rosenstein* [1983]), produces a mean Indonesian throughflow which has an annual range of more than 8 Sv (an annual harmonic of amplitude 4.2 Sv and a smaller semi-annual harmonic amplitude of 0.5 Sv). The peak throughflow occurs from mid-April through July, and the minimum is in November and December. The partitioning of the annual mean transport through the three straits resolved in the model (Lombok, Ombai and Timor) is about equal. A linear version of this model gives a similar result indicating that the annual, wind-driven response of the throughflow is primarily linear.

Experiments with time varying wind forcing only in specific regions show that most of the annual throughflow signal is due to equatorial winds (from $10°S$ to $10°N$). ITF transport anomalies generated by off-equatorial winds account for less than $1Sv$ and are out of phase with the baseline throughflow signal. The effects of remote wind forcing in the equatorial Indian Ocean cancel those due to winds in the Indonesian seas. The annual cycle of throughflow derived from the model forced only by equatorial Pacific winds is nearly equivalent to that of the baseline run.

In this model, annual Rossby waves are formed in the eastern Pacific by Ekman pumping. These Rossby waves propagate to the western boundary of the Pacific then form coastal Kelvin waves that propagate through the Indonesian seas. In northern spring, a downwelling wave brings elevated sea level to the Pacific side of the Indonesian seas, and the ITF is maximum. In northern fall an upwelling wave reduces the sea level on the Pacific side, and the ITF is minimum. In the Indian Ocean, monsoon winds produce equatorial Kelvin waves which propagate east and form coastal waves along the southern coasts of Sumatra and Java. In this case, a downwelling (upwelling) wave increases (decreases) sea level on the Indian Ocean side of Indonesia in northern spring (winter), thus acting in opposition to the baseline ITF variability. The model forced by winds varying only in the Indian Ocean has an ITF which is five months out of phase with the baseline run (maximum in northern winter and minimum in northern spring). The effect of winds in the Indonesian seas on the model upper layer thickness is opposite to the effects of the remotely forced Kelvin waves from the Indian Ocean. In northern winter, when the Indian Ocean winds cause a upwelling coastal wave, the local wind stress provides downward Ekman pumping. In northern spring, locally-forced, upward Ekman suction counters the downwelling Kelvin wave.

The similarity of the linear and nonlinear model runs is consistent with the idea of equatorial wave dynamics playing a significant role. Additional experiments varying the grid size and coastline geometries also confirm this. Eddy activity in the western Pacific causes fluctuations in the model's North Equatorial Current (NEC) and the latitude at which it bifurcates into the Mindanao Current and Kuroshio. Changes in the ITF appear to be independent of these changes since the linear and nonlinear runs give very different NEC/MC systems but similar ITF transport anomalies.

Finally, there is some indication that semi-annual variations of the ITF transport may originate from higher order (second) baroclinic modes due to decreased characteristic wave speed and a shorter Rossby radius of deformation. Approximating variability due to the second baroclinic mode by using different stratification, the model produced a throughflow transport with annual and semi-annual harmonics equal in magnitude.