MAKARA, SAINS, VOL. 8, NO. 1, APRIL 2004: 35-38

A NUMERICAL EXPERIMENT OF 50-DAY RESONANCE INDUCED BY INDIAN OCEAN KELVIN WAVE IN THE SULAWESI SEA

Fadli Syamsudin

Center for Research and Development of Technology for Natural Resources Inventory,
Agency for the Assessment and Application of Technology (BPPT), Jakarta 10340, Indonesia

E-mail: fadli@ocean.hiroshima-u.ac.jp

Abstract

A numerical ocean modeling study using spectral element method is used to simulate the Indian Ocean Kelvin wave propagation along the Makassar Strait and the Sulawesi Sea by giving a-prescribed-50-day Kelvin wave forcing in the northern mouth of the Lombok Strait. The least square fit analysis is employed to extract a-50-day-resonant signal from the interface height data simulation. The results indicate that the 50-day Kelvin wave propagates northward along the Makassar Strait. One part of this wave turns back at the Labani channel and makes southward propagation along the eastern coast of the Makassar Strait. The rest part is going further to enter the Sulawesi Sea and makes 50-day resonance within the basin. This finding will have important implication on the intra-seasonal time scale variability of the Indonesian throughflow transport entering the Indonesian Seas and needs further investigation as well as comparison with observational data.

Keywords: A-50-day resonance of Indian Ocean Kelvin wave, Spectral Element Ocean Model (SEOM), the Least-square fit extraction, Indonesian throughflow.

1. Introduction

Sprintall *et al.* [1] observed the passage of the Indian Ocean Kelvin wave in pressure gauge records downstream in the Lombok Strait and in two moorings within the Makassar Strait (Sprintall *et al.* [2]). The evidence indicates that the Indian Ocean Kelvin wave (IOKW) enters the internal Indonesian Seas through the Lombok Strait and affects the flow in the downstream (poleward) straits. The most conclusive study using both numerical and observation shows that 55% of the Indian Ocean Kelvin wave (IOKW) energy intrudes into Lombok Strait and propagates along the Makassar Strait and reach the Sulawesi Sea with the intra-seasonal wave periods of 35 to 90 days (Syamsudin *et al.* [3]).

The intra-seasonal signals of Kelvin and Rossby waves showed frequent evidences observed by current meter mooring in several straits within the Indonesian Seas (eq. Qiu *et al.* [4]). Susanto *et al.* [5] used spectral and time frequency analysis of the sea level and current meter mooring data in the Makassar Strait reveal clear intra-seasonal signals with wave periods in the range of 48 – 55 days and 85-100 days. They noted that the peak period of those signals to be approximately 48 days.

For the case in the Sulawesi Sea basin, Qiu *et al.* [4] performed numerical experiments and found that Rossby wave coming from equatorial Pacific Ocean could make 50-day resonance as well within the basin. Masumoto *et al.* [6] using the Princeton Ocean Model (POM) with a resolution of 1/6º also found this intra-seasonal variability associated with the meso-scale eddies in the Sulawesi Sea.

This paper is interested in examining the intra-seasonal Indian Ocean Kelvin wave signal make same resonance phenomena as observed previously by Qiu *et al.* [4] and Masumoto *et al.* [6]. We employ a numerical experiment using the Spectral Element Ocean Model (SEOM) in order to investigate the possible resonant signal.

2. Spectral Element Ocean Model

The Spectral Element Ocean Model (SEOM) is an *h-p* type finite element model that approximates the solution within an unstructured grid of quadrilateral elements. A given spatial resolution can be achieved with any combination of number of elements and order of spectral interpolation within an element. SEOM accurately simulates dynamical features such as waves and currents within complex geometries (irregular coastlines, islands) owing to its combined use of unstructured grids and high-order interpolation. A more complete description of SEOM can be found in Iskandarani *et al.* [7], Haidvogel *et al.* [8], and Haidvogel and Beckmann [9].
This study uses one-and-a-half layer, reduced gravity physics to simulate the Kelvin wave propagation from its source in the northern mouth of the Lombok Strait, within the Makassar Strait, and Sulawesi Sea. Diagnostics are done on the Kelvin wave propagation within the Sulawesi Sea. The interface height in this basin is extracted to get 50-day signal of Kelvin waves, and then is examined whether this signal makes a resonance in the Sulawesi Sea.

The model formulation is based on momentum and continuity equations for shallow water in a two-dimensional region Ω with a boundary Γ, as follows:

$$\mathbf{u_t} + \mathbf{u} \cdot \nabla \mathbf{u} + f \times \mathbf{u} + g' \nabla\eta + (\gamma\, \mathbf{u})/\mathbf{h} - [(\nu)/h]\nabla\cdot (h \nabla \mathbf{u}) = 0 \quad (1)$$

$$\eta_t + \nabla \cdot (h\, \mathbf{u}) = 0 \quad (2)$$

where $\mathbf{u} = (\mathbf{u,v})$ is the horizontal velocity vector; h is upper layer thickness (H (resting depth) + η (interface height)) ; **f** is the Coriolis parameter; g' is the reduced gravity; γ is the bottom drag coefficient; ν is the diffusion or lateral viscosity coefficient; ρ is the density of the fluid; $\mathbf{u_t}$ is the first derivative of **u** with respect to time; and ∇ is the two-dimensional gradient operator.

The boundary conditions are Dirichlet conditions on **u**,

$$\mathbf{u} = 0 \text{ on } \Gamma_D \quad (3)$$

and the sidewall inflow of mass transport is given by the Neumann condition

$$h\,(\mathbf{u} \cdot \mathbf{n}) = V_{inflow/outflow}\,(\mathbf{x},t) \text{ on } \Gamma_N \quad (4)$$

where Γ_D and Γ_N are the boundaries where Dirichlet and Neumann conditions are applied respectively; **n** is the unit normal to the boundary; V is the boundary mass flux per unit length. The reader can refer to Bernardi and Pironneau [10] for further details on appropriate boundary conditions for the shallow water equations.

The least square fit method applied to the harmonic analysis will be used to extract the 50-day period of the Kelvin wave signal from the interface height data simulation using the SEOM.

3. Numerical Experiment

Figure 1 presents the unstructured grid system used in this study. This grid is designed to simulate the Kelvin wave propagation within the channel. It consists of 289 elements, where each element has a 7x7 and a 5x5

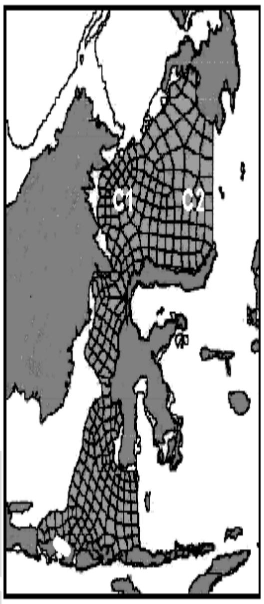

Figure 1. Spectral element of unstructured grid SEOM in the Makassar Strait and Sulawesi Sea. The location of Indian Ocean Kelvin wave forcing at the northern mouth of the Lombok Strait (white bar). The C1 and C2 are the control location for the velocity magnitude in the Sulawesi Sea basin. The grid boundary taken to be constant at 200 meters.

spectral expansion for velocity and pressure. The resulting average grid resolution on the pressure grid is 10 km (~1/11º).

A-50-day Kelvin wave signal is produced by opening one element (~50km, close to the width of Lombok Strait) at the northern mouth of the Lombok Strait and using velocity forcing at the inlet. A simulation for several cycles (1cycle/50 days) is performed to see the Kelvin wave propagation within the Makassar Strait and the Sulawesi Sea.

We continue the setting up forcing given by Syamsudin *et al.* [3] for the 50-day period of the Indian Ocean Kelvin wave signal in the northern mouth of the Lombok Strait (see the white bar crossing the channel in the Fig. 1). In order to generate a Kelvin wave signal, we give a transport forcing of 4 Sv (1 Sv = 10^6 m^3/s) in this experiment.

4. Results

Harmonic analysis is performed to extract a-50-day Kelvin wave signal using the least-square fit method applied to the interface height data.

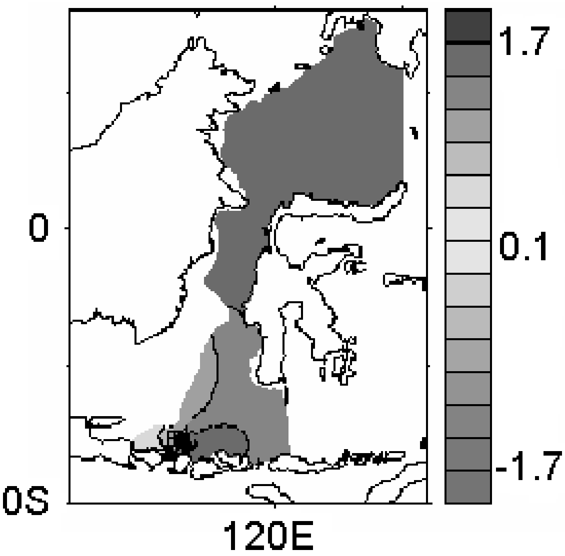

Figure 2. The least-square fit extraction for the phase of 50-day Indian Ocean Kelvin wave period. The gray scale bar is in radians.

Figure 2 shows the least-square fit extraction for the phase of 50-day Kelvin wave period and reveals a clear northward propagation along the western coast of Makassar Strait. One part of this Kelvin wave turns back at the Labani channel and makes southward propagation along the eastern coast of the Makassar Strait. Another part is going to enter the Sulawesi Sea basin with no further indication propagate along their coasts. Homogeneous positive phase propagation indicates a resonant phenomenon within the Sulawesi Sea basin.

In order to prove this evidence, we designate two control points in the western and eastern parts of the Sulawesi Sea basin which are represented by C1 and C2, respectively. Figure 3 shows the location of those control points.

The results show a clear evidence of resonance in the velocity magnitudes on both points. Interestingly, the resonance does not constantly have same magnitude. The eastern part of control point C2 has stronger velocity compare to the western part of control point C1. This means that the sea level in the eastern part of Sulawesi Sea basin is higher than the one in the western part, but both points make resonance at the same phase.

The 50-day Kelvin wave resonance in the Sulawesi Sea basin showed in this experiment has similar results with Qiu *et al.* [4] when simulating Rossby waves from its source in the Pacific Ocean, and also with a-50-day eddy shedding phenomenon as simulated by Masumoto *et al.* [6].

The similarity of those results above needs further investigation and comparison with the observation data

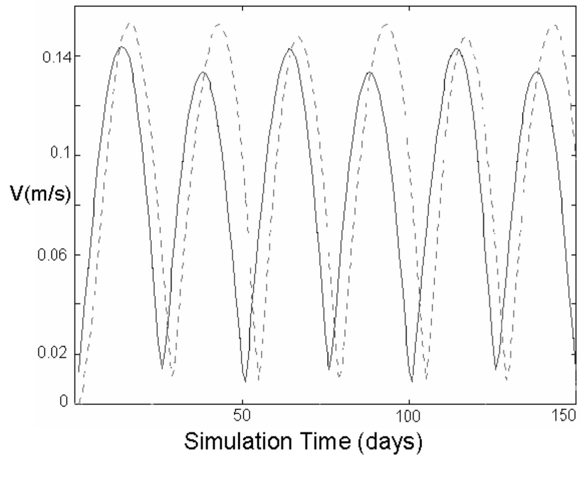

Figure 3. Velocity magnitude at control point C1 (solid line) and C2 (dashed line) in the Sulawesi Sea basin.

in order to have a better idea on how the Indonesian throughflow variability changes within the Indonesian Seas. This finding will have important implication on the intra-seasonal time scale variability of the Indonesian throughflow transport entering the Indonesian Seas.

5. Concluding Remark

The 50-day Kelvin wave propagates along the western coast of the Makassar Strait. One part of this wave turns back at the Labani channel and makes southward propagation along the eastern coast of the Makassar Strait. The rest part is going further to enter the Sulawesi Sea basin and makes a-50-day resonance within the basin.

This 50-day resonance in the Sulawesi Sea basin supports the previous modeling results in the regions as simulated by Qiu *et al.* [4] and Masumoto *et al.* [6]. Further studies are needed to elucidate this finding with the real observations.

Acknowledgements

The author thanks to the anonymous reviewer for his constructive comments that significantly reduced the grammatical errors in this manuscript.

References

[1] J. Sprintal, J. C. Chong, F. Syamsudin, W. Morawit, S. Hautala, N. Bray, S. Wijffels, Geoph. Res. Lett 26 (1999) 2493.
[2] J. Sprintal, A. L. Gordon, R. Martugudde, R. D. Susanto, J. Geophys. Res. 105 (2000) 17217.
[3] F. Syamsudin, A. Kaneko, D.B. Haidvogel, Geoph. Res. Lett. (2004) (in press).
[4] B. Qiu, M. Mao, Y. Kashino, J. Phys. Oceanogr. 29 (1999) 1599.
[5] R. D. Susanto, A. L. Gordon, J. Sprintall, B. Herunadi, Geoph. Res. Lett. 27 (2000) 1499.
[6] Y. Masumoto, T. Kagimoto, M. Yoshida, M. Fukuda, N. Hirose, T. Yamagata, Geophys. Res. Lett. 28 (2001) 1631.
[7] M. Iskandarani, D. B. Haidvogel, J. Boyd, Int. J. Num. Methods in Fluids 20 (1995) 393.
[8] D. B. Haidvogel, E. Curchitsher, M. Iskandarani, R. Hughes, M. Taylor, In: Numerical methods in atmospheric and oceanic modeling. The Andre J. Robert memorial volume, Canadian Meteorological Society, 1997, p. 505.
[9] D. B. Haidvogel, Aike Beckmann, In: Numerical Ocean Circulation Modeling, World Scientific Publishing Company Inc., Singapore, 1999.
[10] C. Bernardi, O. Pironneau, Communications in Partial Differential Equations 16 (1991) 59.