論文の内容の要旨

論文題目 Nonlinear internal wave generation around islands in stratified shear flow
（成層シア流が通過する島周辺における非線形内部波の生成）

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Abstract

Synthetic Aperture Radar (SAR) has the potential to provide an immense amount of oceanic information. Previous studies have revealed that SAR images have manifested nonlinear oceanic internal waves (Alpers and Hennings, 1984). We found more than 10 SAR images that show parabolic patterns around the Miyake and Mikura Islands. The parabolic signature (Fig.1) is reminiscent of a detached shock wave around obstacle in a compressible fluid. The islands are located in the pathway of the Kuroshio, and the flow speed was comparable to the propagation speed of the internal waves. So, the pattern was estimated to have been a manifestation of the nonlinear internal waves generated by a near critical stratified shear flow, the Kuroshio. It has not been studied even with the simplified topography and the topic is quite novel in the field of physical oceanography and fluid mechanics. In addition, if the SAR images exhibit nonlinear oceanic internal waves, it means that the SAR image provides information of small-scale oceanic process around the islands. Clarification of the small-scale processes around the islands is necessary for improvement of ocean modeling and a better understanding of ocean dynamics related to the Kuroshio. This study aims to clarify the nonlinear internal wave generation around the island in the Kuroshio and to better understand its generation mechanism.

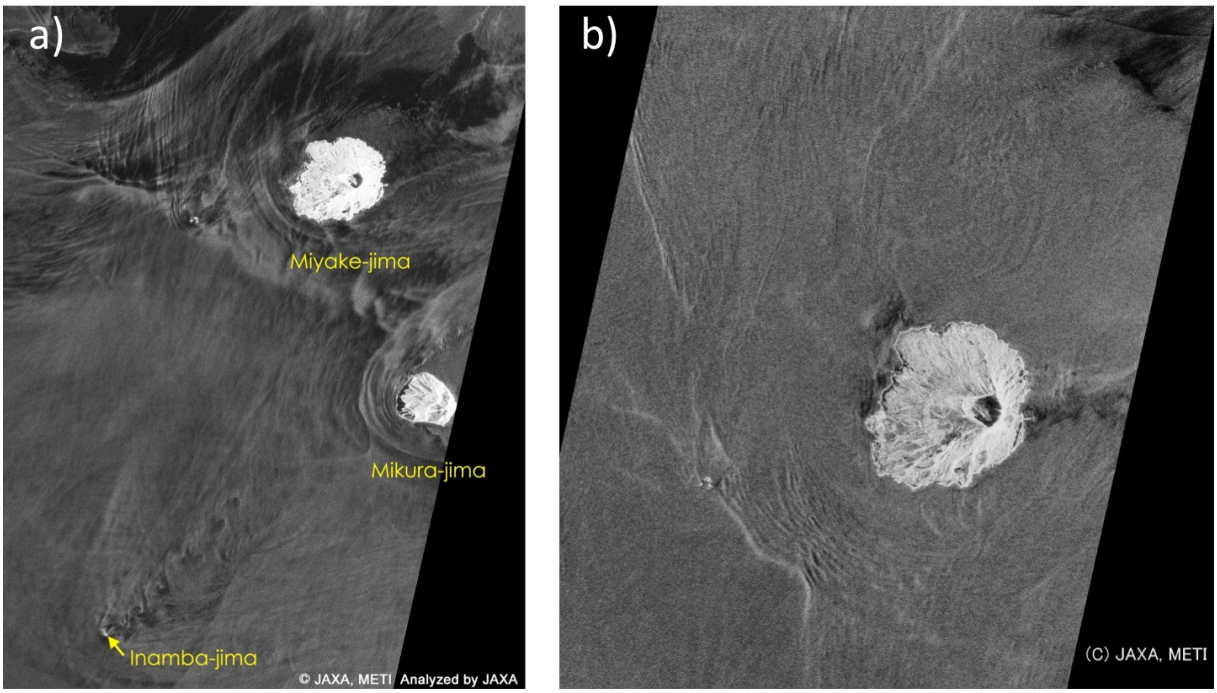

Fig.1 SAR images with parabola patterns obtained by ALOS/PALSAR at 19th of July 2006 (left, a), source: http://www.eorc.jaxa.jp/ALOS/img_up/l_pal_060612.htm,) and at 30th of August 2010 (right). Courtesy of JAXA/METI.

To demonstrate the idea that the Kuroshio traps the nonlinear internal wave, the relationship between SAR images within the Kuroshio must be investigated. We collected the SAR images showing parabolic patterns around the Miyake and Mikura Islands, and the patterns are shown in 13 days of 138 days among the published images from 2006 to 2011. Every image was taken when the Kuroshio approached the island based on the distance between the Miyake Island and the Kuroshio axis as reported in Quick Bulletin of Ocean Conditions. The maximum separation distance was 30 miles. For some cases, tidal flow might have increased the flow speed of the Kuroshio since the images were taken when the tidal gauge record was at a minimum. To discriminate the wind effect, in situ wind measurements were also studied, and we found that, when the images were taken, the average speeds were 2.8 m/s and 4.1 m/s at two observation stations in the Miyake Island. The gentle wind speed indicated that the parabolic patterns were not induced by wind, but rather the wind would enable the oceanic internal wave to be manifested in SAR images. These results support the idea that the Kuroshio plays a central role in creating the parabolic surface signatures by exciting internal waves. The analysis of JCOPE2 oceanic reanalysis data showed the Froude number did not change considerably between the seasons and the values indicate that mode-2 waves were likely to be trapped, while mode-1 waves were not. It was also found that internal waves with particular amplitude induce a greater velocity at surface, and the nonlinearity is larger in the summer season. As a result of analysis of the environmental condition, it can be said that both the summer season wind and oceanic stratification improve detection of mode-2 internal waves in SAR images.

To examine the idea that the Kuroshio induced trapped nonlinear internal waves around the islands, non-hydrostatic numerical simulations were conducted with horizontal grid resolution of

200 m. The initial and boundary conditions were set with vertical profiles of the Kuroshio axis reproduced in JCOPE2. As a result, a mode-2 internal wave was trapped and the parabolic pattern was observed in surface convergence field (Fig.2). The comparison between the simulations with stratification for summer and winter season revealed that mode-2 internal waves were trapped in both seasons, but the surface manifestation was more prominent in the summer season. This was consistent with the analysis of oceanic reanalysis data. Although the numerical simulations reproduced trapped internal waves around the Miyake Island which created a parabolic pattern in surface convergence field, the amplitude was small and the nonlinear characteristic was not clearly observed. Because of the possible shortcomings of observation and reanalysis, the density profile and the incoming flow speed of the Kuroshio was artificially modified in the numerical experiment. The simulation indicated that nonlinear internal waves can be generated and be trapped around the islands under certain conditions, which warrants further observational studies. In addition to the mode-2 nonlinear internal waves, mode-1 nonlinear internal waves were also generated under extreme conditions. As a result of data analysis and numerical simulations, we conclude that, at the least, mode-2 internal waves were trapped around the islands. Further observational study is needed to verify the nonlinearity of mode-2 internal waves and possible trapped mode-1 waves.

We further studied the possible generation mechanism of nonlinear internal waves around the island topography in stratified shear flow. The forcing effect of shear flow and topography on the internal waves was examined, respectively, with two configurations. Configuration (1) was linearly sheared flow past a circular cylinder, and configuration (2) was vertically uniform flow past Gaussian bell topography. Both of the results showed a resonant generation of nonlinear internal waves in near critical flow, and indicated that both shear flow and the island topography force the nonlinear internal wave. The case of linearly sheared flow past Gaussian bell topography showed that internal waves were less generated with the broader Gaussian Bell topography. The result is inconsistent to the ones with realistic numerical simulation where trapped internal wave often appears around the Miyake Island whose topography is broader than Mikura Island. The discrepancy indicated that actual topography around Miyake Island was important for the background flow to create critical situation. It is also suggested that background shear effect was important for nonlinear internal wave generation around the Mikura Island.

[References]

[1] Alpers, W., & Hennings, I. (1984). A theory of the imaging mechanism of underwater bottom topography by real and synthetic aperture radar. Journal of Geophysical Research: Oceans (1978–2012), 89(C6), 10529-10546.

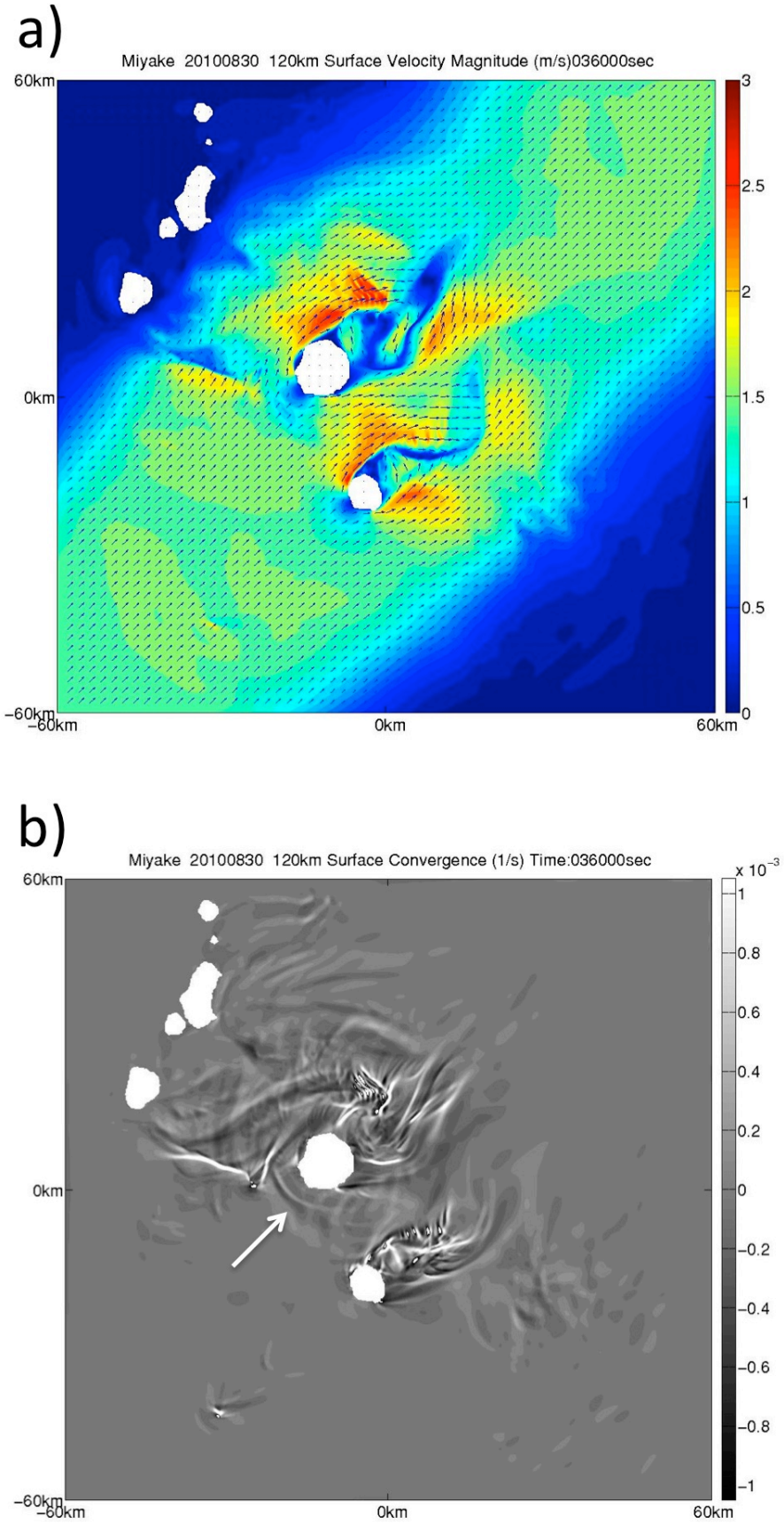

Fig.2 a) Surface flow field and b) surface velocity convergence field 10 hours after the numerical simulation for 30th in August 2010. The white allow indicates the parabola pattern responsible created by a mode-2 internal wave.