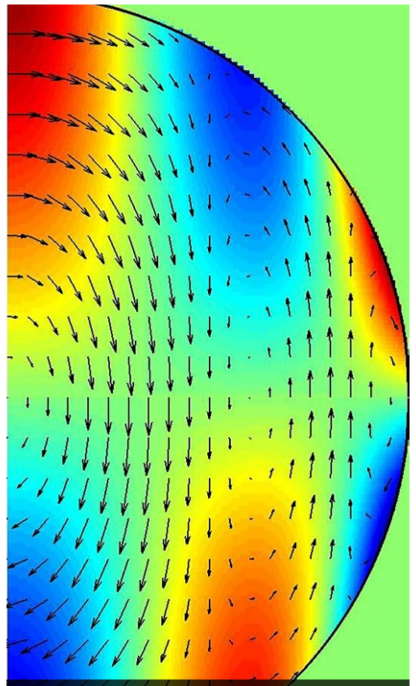
Internal wave generation and interaction processes observed in the East Sea (Japan Sea)

A first for the region

Internal ocean waves form underneath the surface of the ocean, where lower density water overlies denser water, and frequently occur over continental shelves. Prof SungHyun Nam and PhD student Suyun Noh at Seoul National University have observed and analysed deep internal waves, far off the shelves, in the southwestern East Sea (also known as the Japan Sea) between Japan and Korea. They found evidence of high-frequency internal waves being generated as a result of the interaction of two types of lower-frequency waves (near-inertial waves and semidiurnal internal tides).


Inertial and near-inertial waves flow through the interior of a fluid, not at the surface.

Ocean waves are not just limited to the ocean surface. Waves also form within the ocean where there is a density gradient: a significant increase in density with depth. This means they frequently occur over continental shelf regions near freshwater output, such as outlets of major rivers. Oceanographers study internal waves because they transport heat, energy and momentum (a measure of mass multiplied by velocity for solid body or density multiplied by flow speed for fluid) in the ocean. They ultimately break, generating turbulence (chaotic motion) – a process which plays a role in the large-scale ocean circulation.

Large-scale computational ocean models are sensitive to the amount of ocean mixing driven by internal waves. Internal waves are not explicitly modelled in large-scale ocean models, but they are parameterised, meaning the models include a representation of their effect even though the waves themselves are too small and complex to be modelled in the larger-scale models. The study of internal waves is therefore important to improve our understanding of mixing and circulation processes in the ocean, and ultimately to improve larger-scale ocean models that are so important to our understanding of weather and climate.

INTERNAL WAVES IN THE EAST ASIAN MARGINAL SEAS

Prof SungHyun Nam and PhD student Suyun Noh at Seoul National University have focused on two kinds of low-frequency internal waves, known as near-inertial waves (NIWs) and semidiurnal internal tides (SDITs). These waves interact with each other and the mesoscale ocean circulation (the mesoscale circulation occurs on scales of less than 100 km and is considered the 'weather' of the ocean), cascading into high-frequency internal waves.

These particular waves and their interaction processes have rarely been reported in the East Asian marginal seas despite their importance in ocean mixing and transferring energy and materials. When we talk about material transport in the upper (mixed) layer of the ocean, we mean both natural (e.g. gas bubbles, plankton, and nutrients) and human-made (e.g. microplastics and oil) materials.

The researchers collected measurements of the ocean currents and water characteristics via subsurface mooring.

In their recent work, Prof Nam and Noh observed high-frequency waves generated from NIWs and SDITs on five occasions in the southwestern East Sea (Japan Sea). The enhanced high-frequency waves are closely related to NIWs and SDITs, mesoscale circulation, and their interactions. The NIWs were amplified due to wind forcing on the ocean surface. The SDITs were generated in a remote place and propagated into the observational site.

Prof Nam and Noh's observations suggest that the five episodes of high-frequency waves are the result of enhanced NIWs and/or SDITs and their wave-wave interaction, rather than local generation. This suggests that the mesoscale ocean circulation and wave-wave interaction processes have a significant impact on the energy cascade of oceanic internal waves from low to high frequencies.

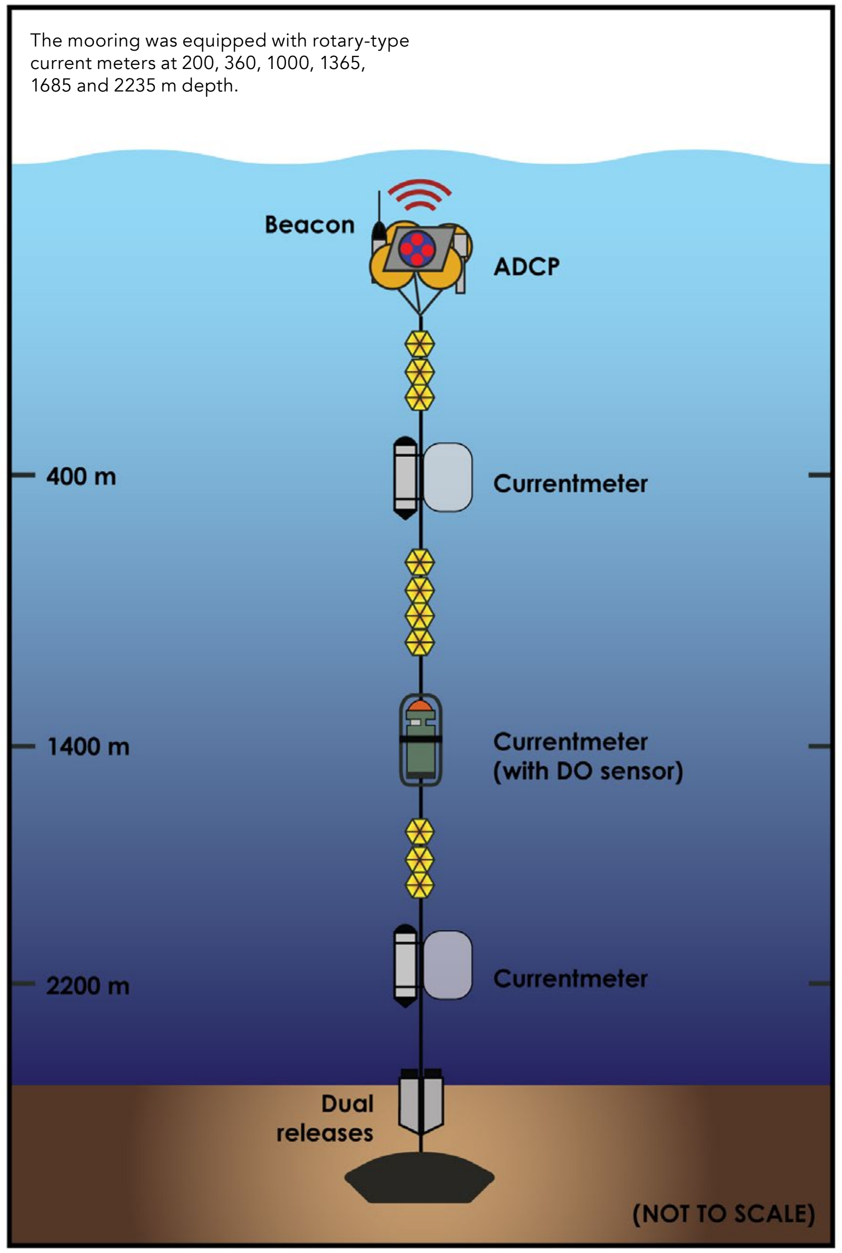
HOW WAS THE RESEARCH CARRIED OUT?

Prof Nam and Noh used measurements of the ocean currents and water characteristics collected via a subsurface mooring, which was deployed in the southwestern East Sea between Ulleungdo and Dokdo, far from the continental shelves, at a depth of 2200 m from November 2002 to April 2004. The mooring was equipped with six single-point rotary-type current meters (rotary current meters measure the ocean current by counting the rotations of a propellor) at 200, 360, 1000, 1365, 1685 and 2235 m depth, and an upward-looking acoustic Doppler current profiler (a current profiler that uses the speed of sound waves in the water to measure the current) at 160 m depth (covering the upper 160 m with a depth interval of 4 m). Measurements of water temperature were also taken at 160 m as well as other depths. This data was considered together with observations of the ocean mixed layer depth from the World Ocean Database and satellite derived measurements of sea surface height and wind vector.

WHAT WERE THE MAIN CONCLUSIONS?

The researchers identified five episodic enhancements of high-frequency waves observed between July and December 2003 in the southwestern East Sea. This is significant because it is the first time that this phenomenon has been observed in the region. Prof Nam and Noh then went on to explore the

> ***The study of internal waves is important to improve our understanding of mixing and circulation processes in the ocean.***



Their observations "reveal that the high-frequency internal waves and forward energy cascading from low to high-frequency internal waves are enhanced through remarkable interactions among the internal waves."

process of formation of the enhanced high-frequency internal waves in relation to NIWs, SDITs and the local ocean properties.

According to the researchers, there are three possible mechanisms for the formation of enhanced high-frequency internal waves: "one is forward cascading [energy exchange between large and small scales of motion] occurring directly from either one of the enhanced NIWs or SDITs; the second is from nonlinear interaction between NIWs and SDITs; and the third is local generation of enhanced high-frequency internal waves from the interaction between currents and bottom topography [the shape of the ocean floor]."

The bathymetric features of the bottom topography do not support the third possibility; hence, it was ruled out by the researchers. The first and second possibilities were consistent with the observations; however, Prof Nam and Noh comment that their observations "reveal that high-frequency internal waves and forward energy cascading from low to high-frequency internal waves are enhanced not only by direct local and remote wind forcing or by remote tidal forcing, but also through remarkable interactions among the internal waves and mesoscale circulation field."

A computer model was used to help explain the observations. The mixed layer of the ocean is sometimes represented by a so-called slab model – a model mostly focusing on exchanges of energy between the ocean and atmosphere that does not model the ocean eddies and waves in detail. Prof Nam and Noh used a modified slab model to study the internal wave processes observed in the East Sea in order to investigate whether the high-frequency internal waves could be indeed formed as a result of the interaction of NIWs and SDITs.

They found that a slab model with wind forcing on the surface reproduced most of mixed layer NIWs supporting the theory that "well-known mechanisms of surface generation and downward propagation of NIWs" were at play, particularly during the passage of a typhoon, which occurred during one of the events the researchers analysed. Even when the wind forcing was weak, Prof Nam and Noh found that there was a mechanism involving interaction with the surrounding ocean that meant that the high-frequency internal waves would have been generated from the NIWs and SDITs.

These results are in line with the results of several previous studies, although "more and better observations are required to further deepen our understanding on how the internal waves extract energy from the mesoscale field and transfer the energy into a smaller scale and turbulence in the ocean."

Behind the Research

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Research Objectives

Prof Nam and PhD student Noh study two types of low-frequency internal waves generating high-frequency internal waves.

Detail

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Bio

Ms Suyun Noh is a PhD student at Seoul National University (SNU) working with Prof SungHyun Nam on the internal waves under various conditions.

Professor SungHyun Nam received a PhD from SNU in 2006, served at the Agency for Defense Development, South Korea from 2006 to 2008, and the Scripps Institution of Oceanography, USA from 2008 to 2014. He is now an associate professor at SNU (since 2014).

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References

Noh, S. and Nam, S. (2020). Observations of enhanced internal waves in an area of strong mesoscale variability in the southwestern East Sea (Japan Sea). *Sci Rep* 10, 9068. Available at: https://doi.org/10.1038/s41598-020-65751-1

Personal Response

What are your plans for future research on internal waves?

"We will continue to unravel the spatial and temporal variability in generation, propagation, evolution, and dissipation of internal waves of different types in the East Asian marginal seas. In spite of remarkable improvements of satellite remote sensing technologies, our ability to observe the deep interior of the ocean in a continuous manner is still largely limited in space. To address complex generation and interaction processes of deep oceanic internal waves and their energy cascading into a smaller scale and turbulent mixing, long and continuous *in-situ* observations are vital in necessary spatial and temporal resolutions. We will continue to service the subsurface mooring, among others, to collect the invaluable time series data in the future."