SPATIAL AND TEMPORAL VARIATIONS OF INTERNAL WAVES IN THE NORTHERN SOUTH CHINA SEA

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1 Introduction

- Extensive studies have been made of IWs recently in the northern South China Sea by field measurements, remotely sensed observations and numerical modeling.
- Studies include information on the spatial distributions of the IWs, characteristics and generation mechanisms.
- Satellite observations show that IWs in the northern South China Sea have significant spatial and temporal variations.
- The IWs are thought to be generated via tide-topographic interaction, lee-wave formation and shear flow instability.
- The spatial and temporal variations of the IWs have not been fully explained by these generation mechanisms.
- It is the purpose of this paper to study the spatial and temporal variations of the IWs using SAR images and to look for new explanations of the IW distributions observed by SAR in the study area.
2 Data and methods

The study area:

The study area is the northern South China Sea which extends from 110°W to 122°W longitude and from 18°N to 23°N latitude.
The SAR images:

- ERS-1/2, ENVISAT and RADARSAT-1 SAR images
- 344 images taken over 13 years between 1995 and 2007
- provided by the Remote sensing Ground Station (RSGS) of China and the ESA-MOST Dragon Programme

ENVISAT ASAR on 21 June 2005
Radarsat-1 SAR on 24 April 2001
The thermocline:

Calculated from the Letvitus data which was downloaded from http://www.nodc.noaa.gov
The wind speed:

- Over each internal wave image estimated from the BlendQscat data (downloaded from [http://dss.ucar.edu/datasets/ds744.4/data](http://dss.ucar.edu/datasets/ds744.4/data))
- The monthly mean wind speed have been downloaded from [http://www.remss.com](http://www.remss.com)
3 Observations of the IWs

Internal waves are imaged by SAR and have signatures in alternating bright and dark bands on SAR images. The Fig. shows an example of such SAR images of internal waves in the region of the Dongsha Island. The image was taken by ENVISAT ASAR on 21 June 2005.
The internal wave parameters including the wavelength, propagating speed, direction, location and imaging time can be retrieved from SAR images.
It can be seen that most of the internal waves are propagating northwestwards. They have crest lengths ranging from about 100 to 250 km. The internal waves are concentrated within a latitudinal band from 19°N to 22°N.
It can be seen that the propagating speeds of IWs range from about 0.3 m/s to 3.0 m/s.
It can be seen that the internal wave amplitudes range from about 2 m to 150 m.
This is a histogram of latitudinal distribution of the IWs with a resolution of 1 degree longitude. It is shown that there is an obvious longitudinal distribution of the IWs. The IWs are mainly distributed between 114°E to 120°E with a high percentage of 73. About 26% of IWs are concentrated within a range from 110°E to 114°E while the other 1% of IWs appear within an area from 120°E to 123°E.
Seasonal distribution:

This presents the seasonal distributions of the IWs. It can be found that there exits a seasonal variation.
This presents the seasonal variations of the IWs. The occurrence of the IWs reaches its seasonal maximum with a percentage of 70 in summer and has its seasonal minimum with a percentage of 1 in winter. Spring and autumn appear to be transit periods with percentages of 18 and 11 respectively.
Caused by the generation mechanisms? However, the spatial and temporal variations of the IWs have not been fully explained by these generation mechanisms.

Are there any decisive factors and external factors related to the spatial and temporal variations of IWs in the study area? **Thermocline? Wind?**

We will examine the relationships between the variations of the IWs and the thermocline and wind.
4 Variations of IWs with thermocline

Studies have shown that the ocean vertical stratification is a decisive factor for IW generation and propagation. The variations of the IWs with the thermocline estimated from the Levitus data is investigated.
The thermocline in the South China Sea is modulated by the seasonal reversing monsoon as well as the intrusion of the Kuroshio through the Luzon Strait. This presents the monthly mean thermocline along the 20.5°N latitude between 115.5°E and 122.5°E. It can be seen that the thermocline exits all year round. The thermocline ranges from 80 m to 123 m. It becomes deeper in winter due to the great loss of heat on the surface. This indicates that it is possible to form internal waves all the time.
Monthly mean strength of the thermocline:

It shows the monthly mean strength of the thermocline. As one would expect, the strong thermocline occurs from June to August, corresponding well with the high occurrence probability in summer.
Correlation between the monthly mean thermocline and the spatial variation of the internal waves:

Important information obtained is the correlation between the monthly mean thermocline and the spatial variation of the internal waves. The thermocline from April to September has a strong upwards from 119°E to 115°E where there is a high occurrence probability of IWs. This might suggest that the strong shallowing of the thermocline provides the boundary condition for the IW generation and propagation.
5 Variations of the IWs with wind

Sea surface wind is an important factor for internal wave imaging according to SAR imaging theories. For example, for ERS-1/2 SAR the threshold wind speed which is needed to generate the resonant Bragg waves is about 3.2 m/s. For the high wind speed condition, the internal wave signal may be too weak to be observed by SAR due to low signal-to-noise ratio.

The variations of the internal waves in the study area with wind is discussed.
The variation of the IWs with wind over each SAR image:

This fig. presents the internal wave distributions with wind. It can be seen that 96% of internal waves are observed by SAR under wind speeds of 10 m/s while only 4% of internal waves are imaged above wind speeds of 11 m/s. This result supports that low and middle wind conditions are favorable for SAR imaging of internal waves. High wind condition is unfavorable for SAR imaging of internal waves.
The variation of the IWs with winds over the study area:

This shows the monthly mean wind field from Qscat data over the study area. Winds are dominated by the East monsoon. In summer the southwesterly winds with an average wind speed of 6 m/s dominate. In winter the wind direction totally reverses, northeasterly winds with an average speed of 9 m/s prevail.
This fig. shows the monthly mean wind speed over 8 years between 2000 and 2007 over the study area. It can be seen that monthly mean wind speed from October to March is higher than the wind speed from April to September. The monthly averaged wind speed from October to March is about 6.5 m/s while the monthly averaged wind speed from April to September is about 9.3 m/s. This is due to that the winter monsoon is much stronger than the summer monsoon.
This fig. (left) is the monthly mean internal wave occurrence in the study area. It is found that there is a strong correlation between the monthly mean wind speed and monthly mean internal wave occurrence. The higher wind speeds in autumn and winter, the lower probability of internal waves observed by SAR. This may indicate that the lower occurrence of the internal waves in autumn and winter is partly due to the instrument used to observe the internal waves.
6 Conclusions

In this paper the spatial and temporal variations of the IWs in the northern South China Sea and their relationships with thermocline and wind are discussed.

The results show that the IWs are mainly distributed between 114°E to 120°E with a high percentage of 73. About 26% of IWs are concentrated within a range from 110°E to 114°E while the other 1% of IWs appear within a range from 120°E to 123°E.

The occurrence of the IWs reaches its seasonal maximum with a percentage of 70 in summer and has its seasonal minimum with a percentage of 1 in winter. Spring and autumn appear to be transit periods with percentages of 18 and 11 respectively.
The thermocline exits all year round indicating that it is possible to form IWs all the time. The strong upwards of the thermocline from 119°E to 115°E where there is a high occurrence probability of IWs might suggest that the strong shallowing of the thermocline provides the boundary condition for the IW generation and propagation.

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Thanks