Sea of Japan – Korea Strait

based in part on the article *Observations of highly nonlinear internal solitons generated by near-inertial internal waves off the east coast of Korea*, by H. R. Kim, S. Ahn, K. Kim [2001] with permission of the authors

Overview

The Sea of Japan (or East Sea) is a semi-enclosed sea located in the western Pacific Ocean bounded by Japan (at the east and south) and Asia (at the north and west)(Figure 1). It is connected to the Sea of Okhotsk via the Tartarskiy Strait and La Perouse Straits (in the north); the north Pacific Ocean by the Tsugaru Strait (in the east) and to the East China Sea though the Korea Strait (in the south). Continental shelf lies under approximately 20% of the Sea. The region is influenced by the Tsushima Current, (a small branch of the Kuroshio) that enters through the Korea Strait and flows out through the northern and western straits. [LME, 2004]

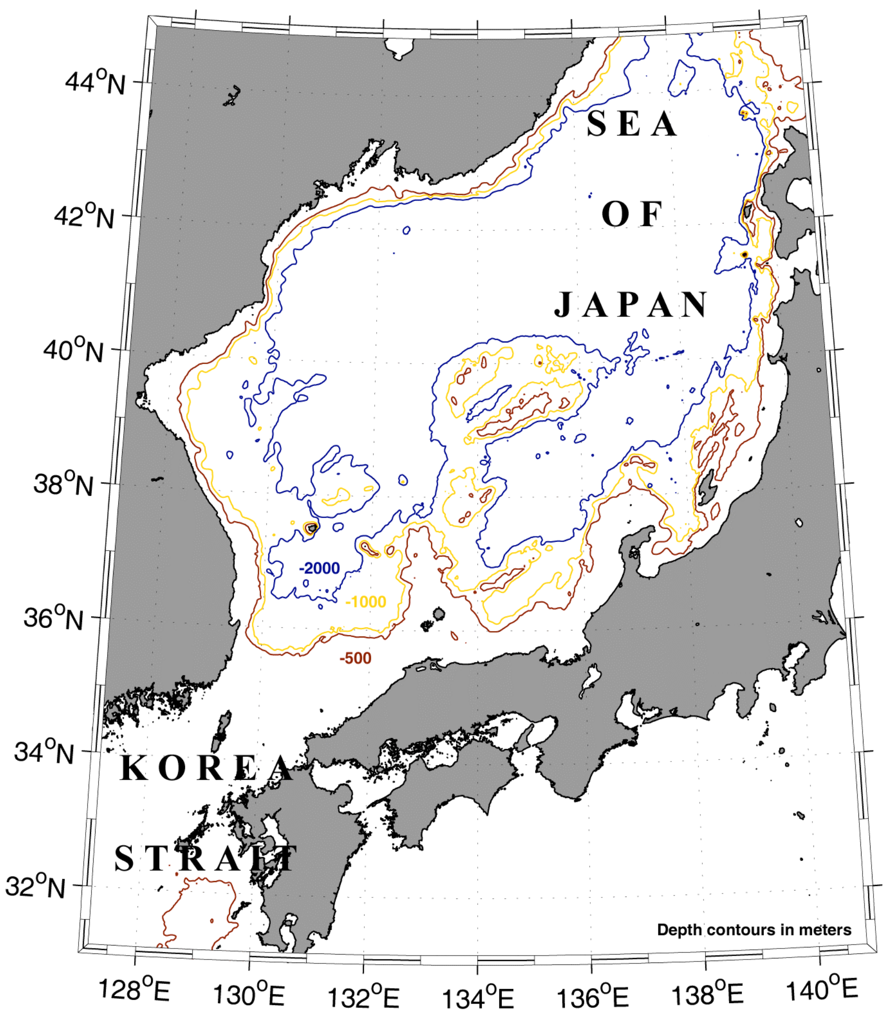

Figure 1. Bathymetry of Sea of Japan and the Korea Strait [Smith and Sandwell, 1997]

Overview

There has been some scientific study if internal waves in the Sea of Japan. In May 1999, Kim at al. [2001] carried out Acoustic Doppler Current Profiler (ADCP) measurements on several packets of internal waves 8 km off the Korean coast. These occurrences had an observed time period between wave packets of 19 hours, a period close to the local inertial frequency on the East Korean shelf, indicating a generation source other than tidal forcing.

Satellite imagery shows internal wave occurrences in the Korea Strait (Figures 6-7) and along the coast of North Korea (Figure 10) and Russia (Figure 12). Table 1 shows the months of the year when internal waves have been observed.

Table 1 - Months when internal Waves have been observed in the Sea of Japan and Korea Strait.
(Numbers indicate unique dates in that month when waves have been noted)

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
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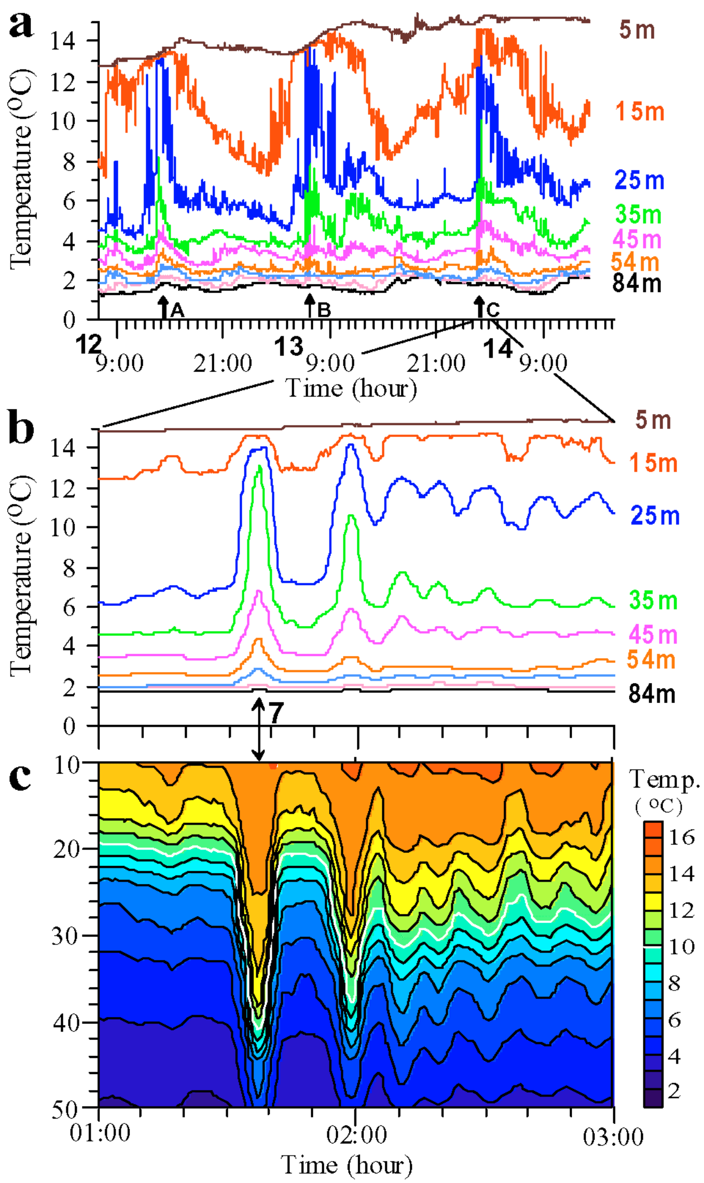
Internal Waves in the East Sea (IWES) Experiment: In situ observations of internal wave packets on the Korean Shelf were performed in May 1999 as part of an internal wave experiment dubbed "IWES" (Internal Waves in the East Sea). Non-linear internal waves were observed with downward thermocline displacements of up to 26 meters, (from an initial depth of 20 meters), wavelengths of approximately 600 m, and speeds of 0.5 m/s. However, the observed time period between wave packets was 19 hours, a period close to the local inertial frequency on the East Korean shelf. These waves represent the first known example of internal waves generated by near-inertial internal waves.

Table 2. Characteristic Scales for the solitons along the southeast coast of South Korea

Characteristic	Scale
Amplitude Factor	-20 to –26 (m)
Long Wave Speed	0.5 (m s^{-1})
Maximum Wavelength	1.5 (km)
Wave Period	3 to 10 (min)
Surface Width	180 (m)
Packet Length	2.7 (km)
Along Crest Length	> 30 (km)
Packet Separation	40 to 45 (km)

The IWES data were collected using two thermistor chains and an Acoustic Doppler Current Profiler (ADCP). The observation site was located 8 km (Figure 4) from the coast close to the continental shelf break near the 100 m isobath. Temperature and current data were recorded at 10 second intervals from 0700 on 12 May to 1700 on 14 May 1999. A CTD was used to measure temperature and salinity profiles three times during the experiment. Oceanographic and meteorological variables such as current and wind were also observed near the site of IWES using a buoy called ESROB1-a (East Sea Real-time Ocean Buoy1-a) at 10-minute intervals from 25 April to 27 June 1999.

Large temperature fluctuations indicating solitary internal wave packets appeared three times (A, B, and C in Figure 2a) at both sites of thermistor chains. A steep temperature rise led three events followed by gradual settling to its ambient level of about 8°C at 25-m depth. The observed interval between sudden temperature rise is about 19 hours, which is strong evidence that solitary internal waves are due to near-inertial waves



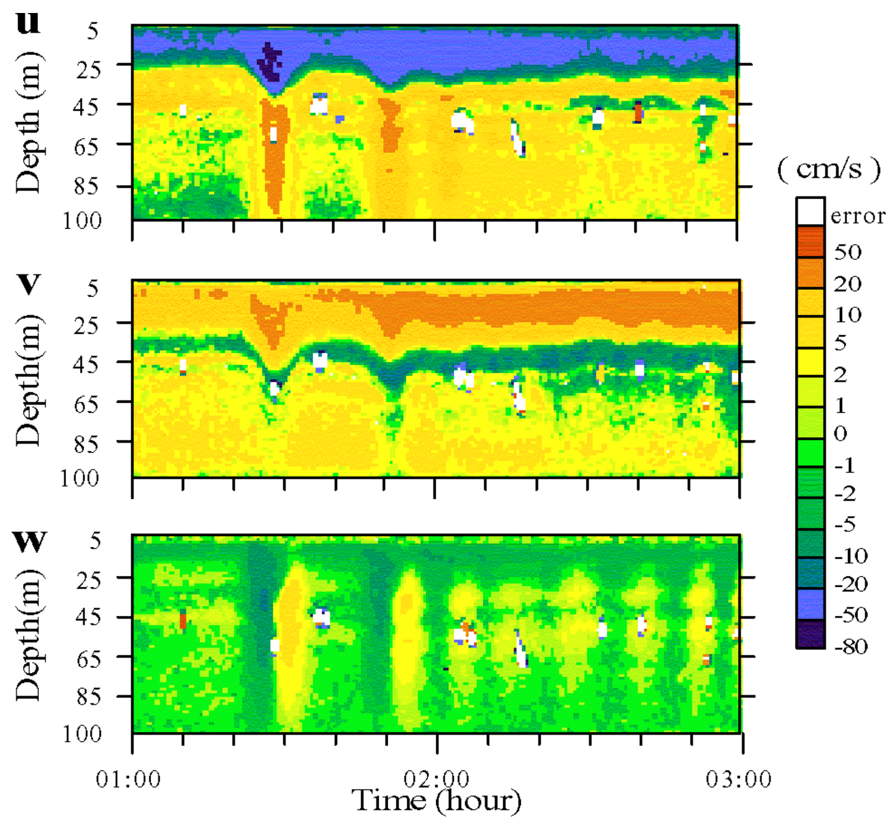


Figure 2a. (a) A time temperature time series. Three cycles of steep leading edges at an interval of about 19 hours can be seen, mostly visible at the 25 m and 35 m. (b) A 2-hour time series of the temperature from 1:00 am to 3:00 am, shows the solitary wave packet C. (c) A time series of isotherm depths from the temperature data for the same period as (b). The isotherm of 10°C represents the thermocline.

Figure 3. Horizontal and vertical components of the current velocity measured by a bottom-mounted ADCP for the same time as Figure 2b. U, V, and W are positive eastward, northward, and upward, respectively.

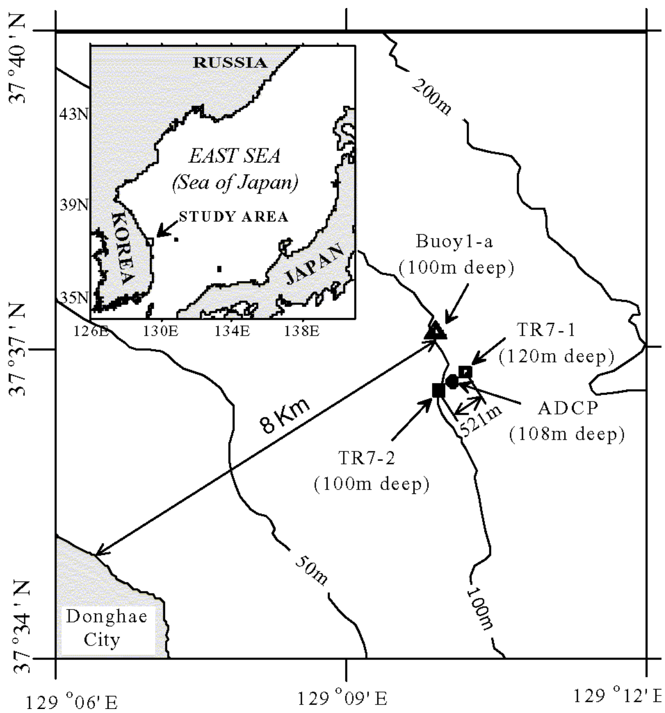


Figure 4. Area map of an internal wave experiment (IWES) off the east coast of Korea on 12 – 14 May 1999.

A closer inspection of the time series for 2 hours (Figure 2b) shows the first fluctuation at 25 m began with a sharp rise and lasted about 10 minutes as its temperature changed from 7°C to 14°C. The next fluctuation in the packet occurred 20 minutes later. The temperature fluctuated in phase vertically for the entire water column. Figure 2c shows the temperature data converted to vertical displacements of isotherms. The maximum displacement of the solitary internal wave reached about 21 m downward.

Figure 3 shows the ADCP data of the bottom-mounted workhorse for the same time span with the Figure 3b. The direction of the horizontal velocity changed with depth, northwest in the upper column, southeast in the middle and northeast in the lower water column. The high shear zone was undulated as large as 21 m in association with the temperature fluctuations. The speed of the current was as large as 70 cm/sec horizontally and 10 cm/sec vertically in the leading part of the wave packets and gradually decreased with time. For the solitary internal waves in Figure 2c and 3, the downward vertical motion drives the depression of the isothermal surface. The horizontal velocity reaches its maximum at the time of the maximum depression and the upward motion drives the isotherm back to its initial depth.

Internal wave packets have traditionally appeared with a period of 12.42 hours (or its multiples) due to generation process where surface tides interact with the shelf break topography [Halpern, 1971; New and Pingree, 1990; Sandstorm and Oakey, 1995]. The May 1999 internal wave packets were observed at the interval of about 19 hours, and were led by the highly nonlinear solitary waves (Figure 2a). The observed 19-hour interval between the packets is close to the local inertial period. This interval clearly indicates that the generation source is other than tides. Near-inertial internal waves have been frequently recorded in the East Sea.

The solitary internal waves recorded during the IWES experiment in May 1999 had a downward displacement of up to 26 m. This displacement is approximately the same as the depth of the quiescent pcynocline. This large variation cannot be described by the ordinary Korteveg-de Vries (KDV) equation, which derived under an assumption of weak nonlinearity, requiring the displacement of isopycnals to be smaller than their equilibrium level. For displacements as large as the equilibrium depth, such as this, the "CombKDV" model must be applied which accounts for a higher degree of nonlinearity [Stanton and Ostrovsky, 1998].

The density field at the IWES observation sites could be approximated as a two-layer system because the pycnocline was very sharp during the experiment. The thickness of the upper layer was 20 m before the first solitary internal wave. The IWES observations were fitted to this CombKDV model, using a nonlinearity parameter, v, as a free parameter as done in Stanton and

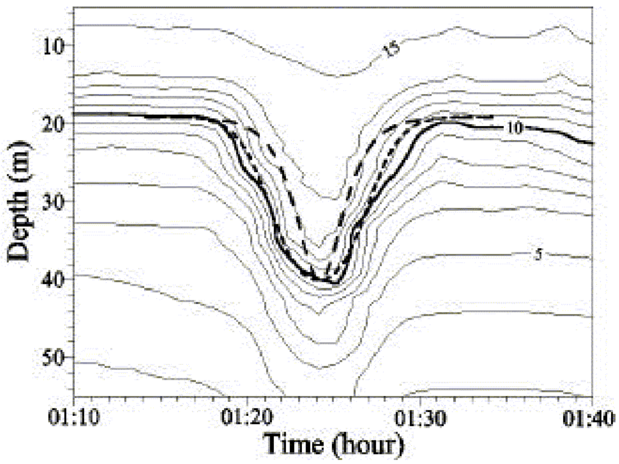


Figure 5. Isotherm displacements for soliton 7 in the wave packet C shown in Fig. 2b and 2c are fitted by the CombKdV equation (outer dotted line) better than the KDV solution (inner broken line).

Ostrovskey [1998]. Table 2 summarizes both the environmental variables and the resulting model variable estimates for these internal waves. A representative fit is shown in Figure 8 for the 10°C isotherm of the solitary internal wave 7 in Figure 3b. The broader wave shape of the CombKdV equation fits better than the KDV solution.

Table 3 – CombKdV Parameters

Environmental		CombKdV Model	
h_1 = 20 m	ρ_1 = 1025.5 kg m^{-3}	α = -0.0287 s^{1}	c = 0.51 m/s
h_2 = 80 m	ρ_2 = 1027.2 kg m^{-3}	α_1 = -0.0012 m^{-1} s^{-1}	V_{max} = 0.62 m/s

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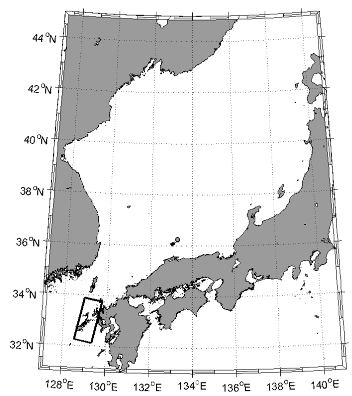
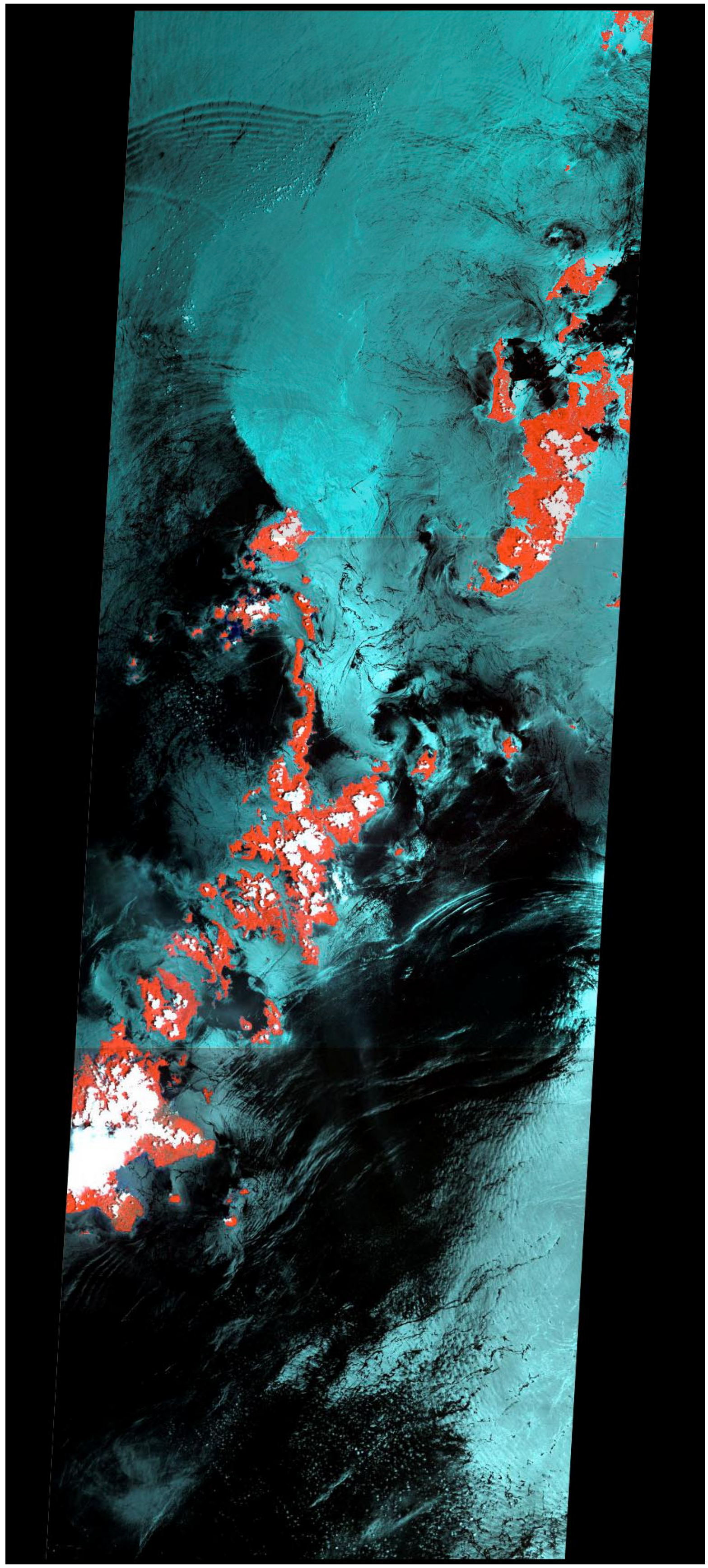
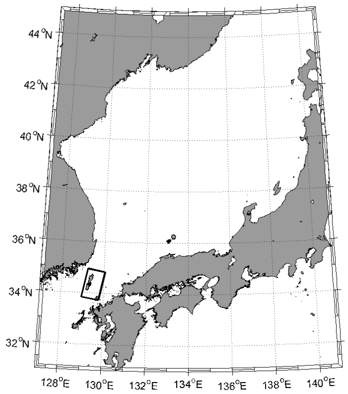


Figure 6. ASTER false-color VNIR image over the islands off the southwestern tip off Japan acquired on 20 July 2000 at 0232 UTC. The image shows the signatures of several internal wave packets among the islands, indicating a northern propagation direction. Imaged area is 60 km x 180 km.





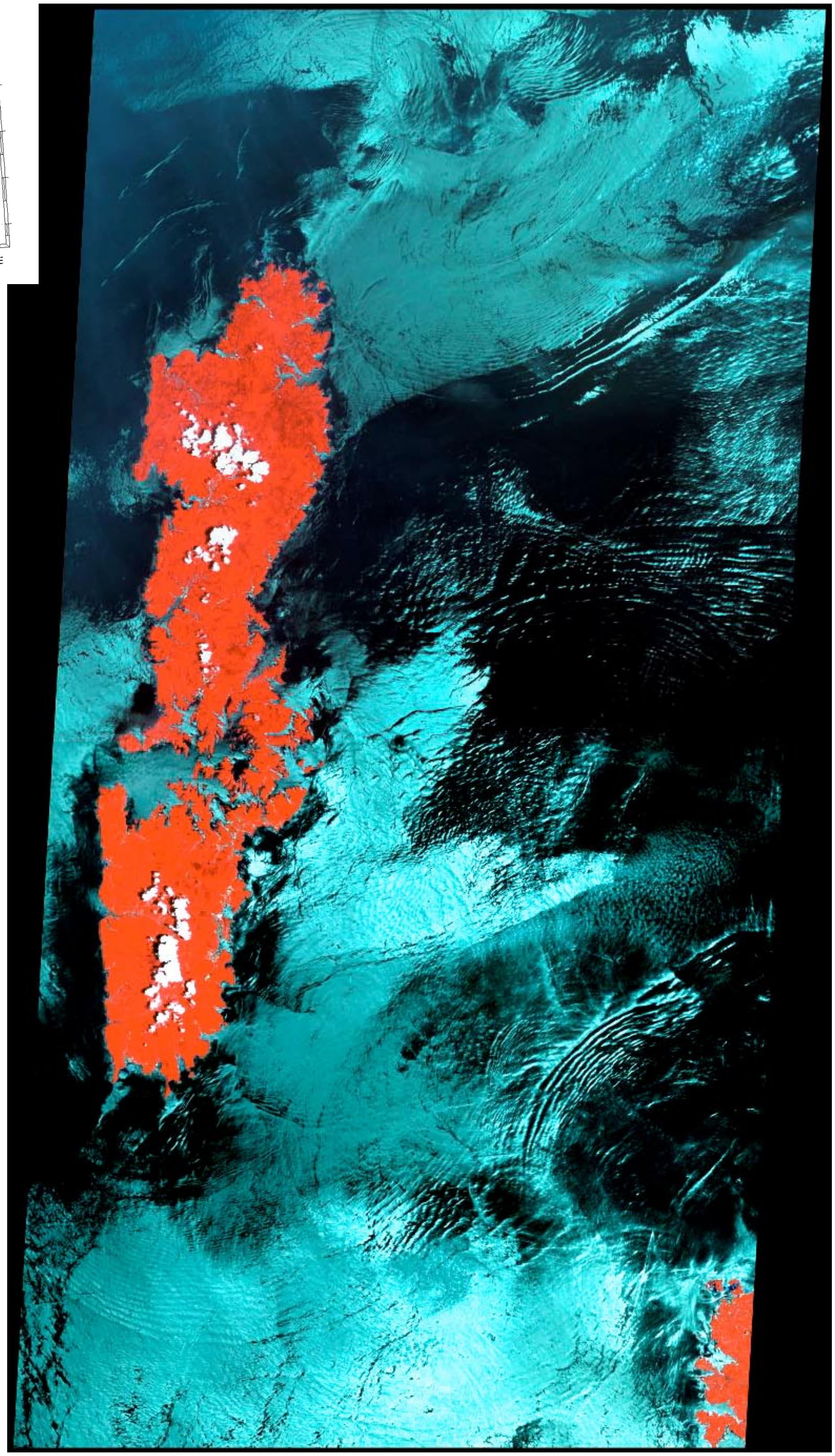
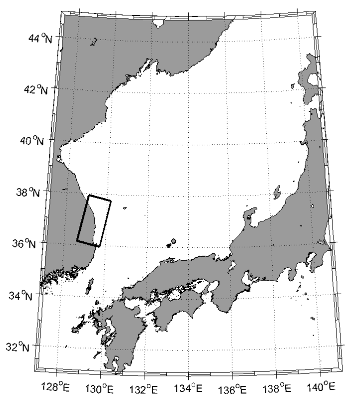


Figure 7. ASTER false-color VNIR image over the Korea Strait acquired on 4 July 2000 at 0232 UTC. The image shows a variety of internal wave signatures in the Eastern Channel. The signatures indicate a region of complex internal wave activity with a number of source locations. Imaged area is 60 km x 120 km.



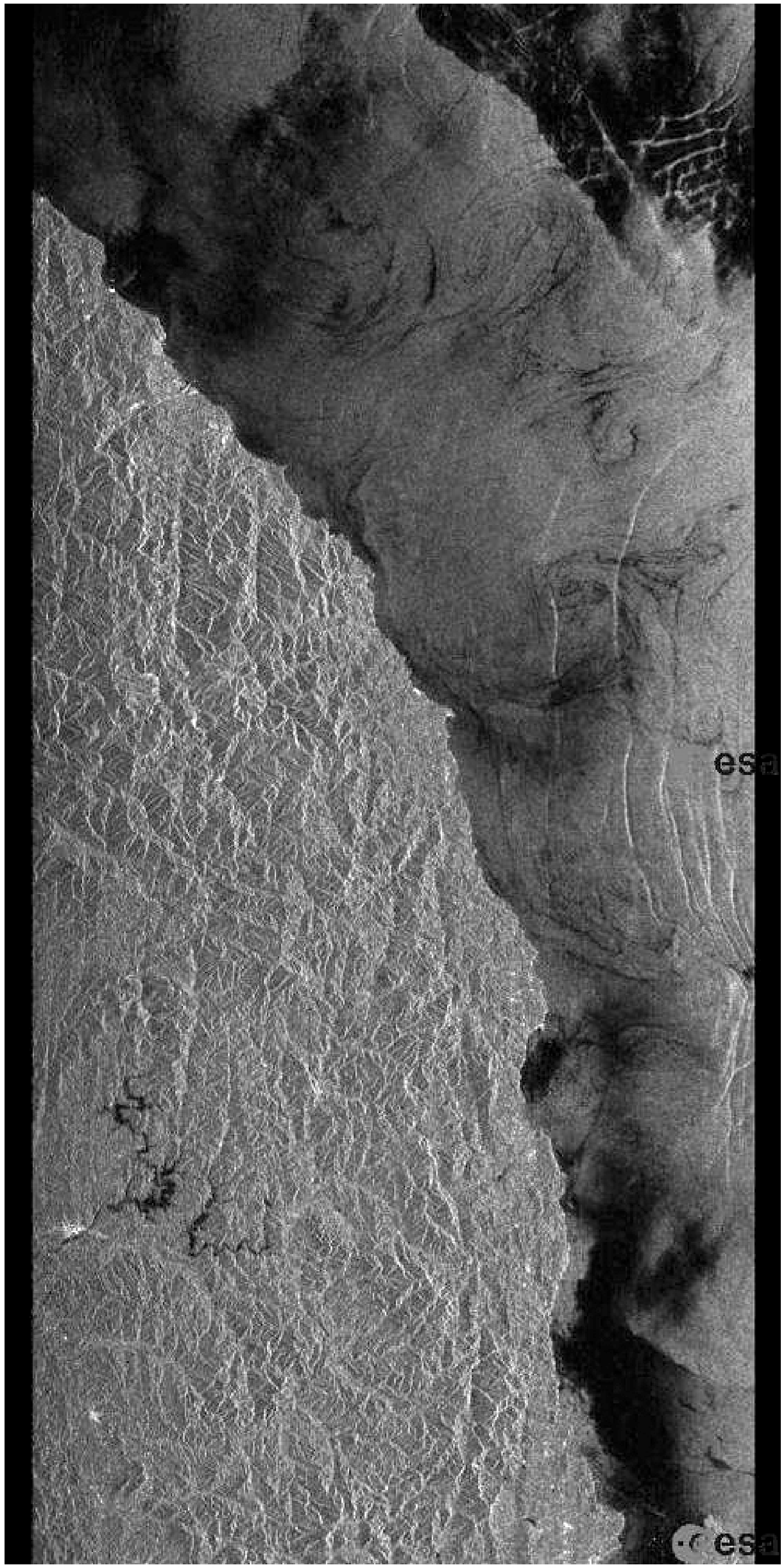


Figure 8. ERS-2 (C-Band, VV) SAR survey image over the southeast Korea acquired on 30 September 2000 at 0205 UTC (orbit 28471, frames 2853, 2871). The top of the image is contiguous with the bottom of Figure 9. Imaged area is 100 km x 200-km. ©ESA 2000.

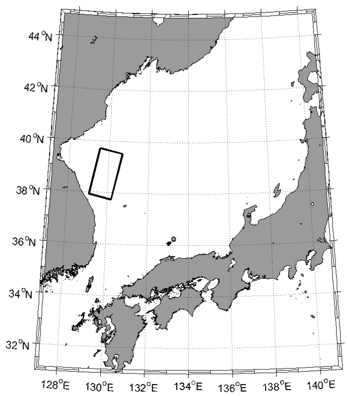
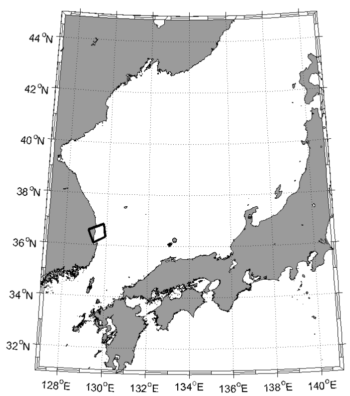


Figure 9. ERS-2 (C-Band VV) SAR survey image off the east coast of North Korea acquired 30 September 2000 at 0204 UTC. (orbit 28471, frames 2817, 2835). The bottom of the image is contiguous with the top of Figure 8. Imaged area is 100 km x 200-km. ©ESA 2000.



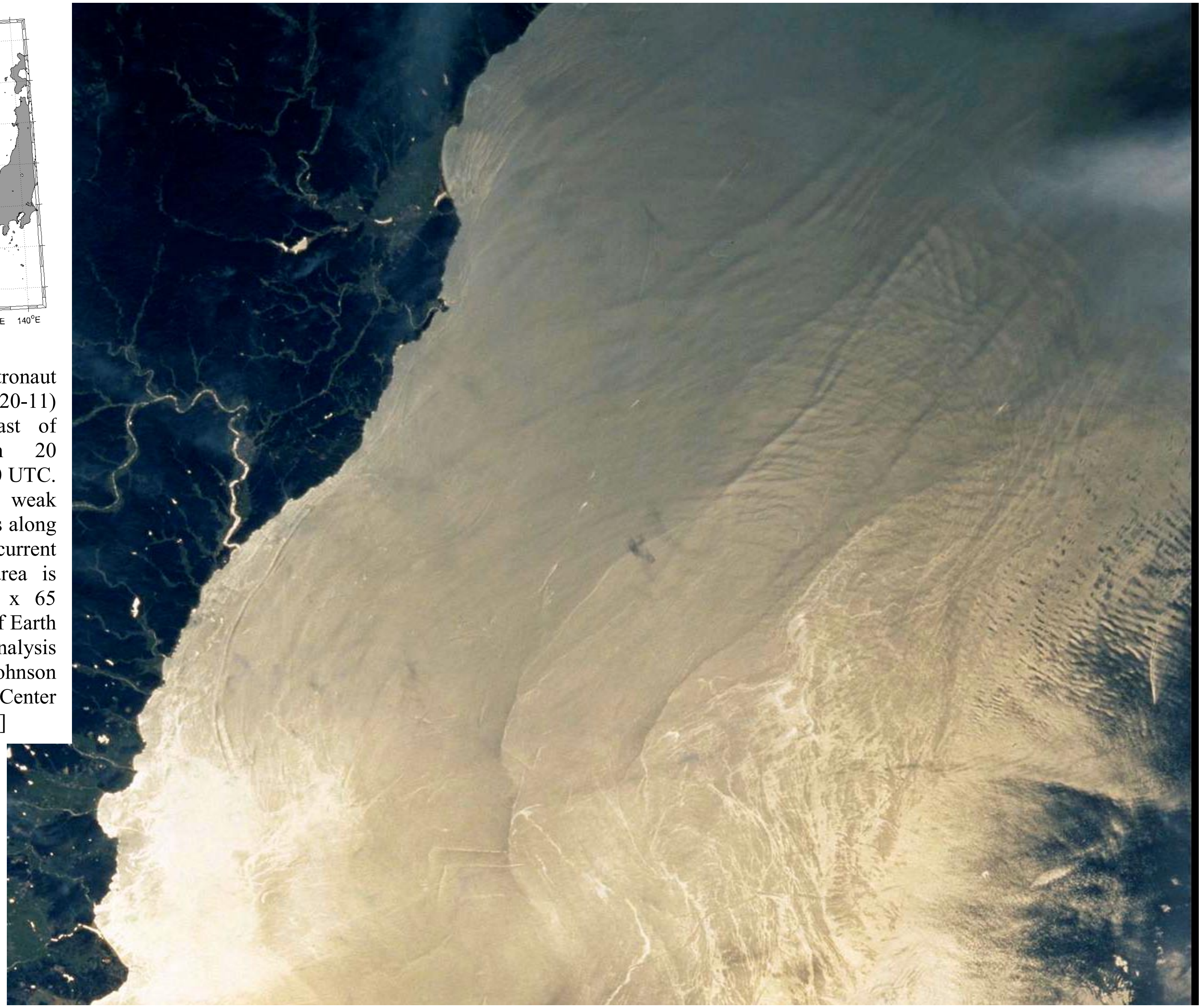


Figure 11. Astronaut photograph (STS106-720-11) off the southeast coast of Korea acquired on 20 September 2000 at 0200 UTC. The image shows weak internal wave signatures along with surface slicks and current signatures. Imaged area is approximately 75 km x 65 km. [Image Courtesy of Earth Sciences and Image Analysis Laboratory, NASA Johnson Space Center (http://eol.jsc.nasa.gov).]

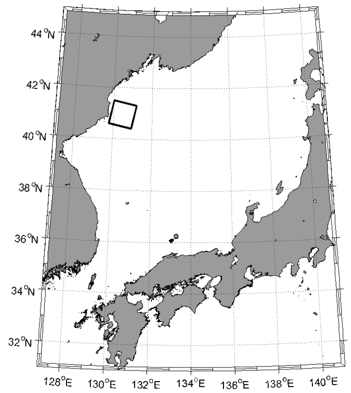
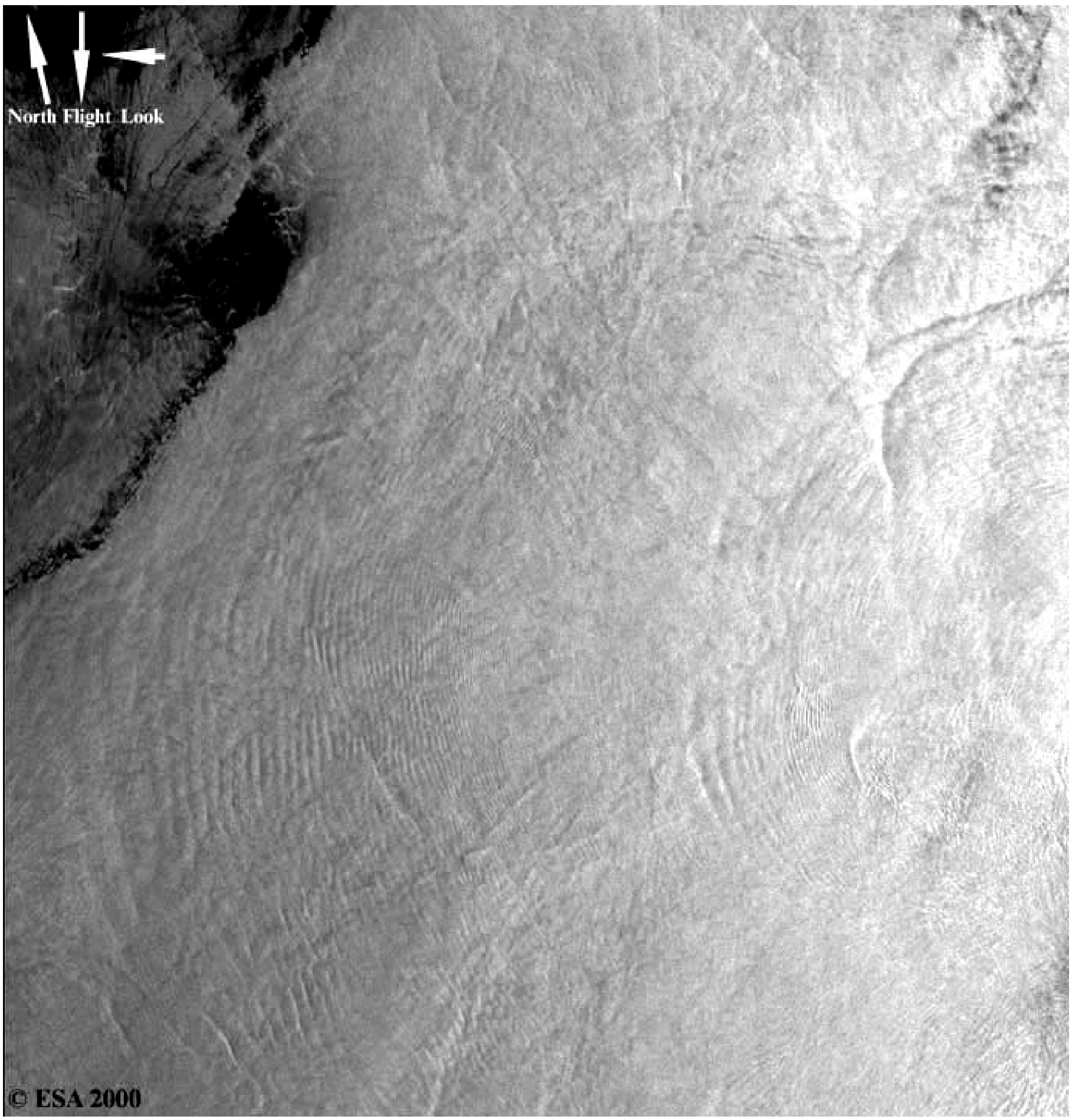


Figure 10 ERS-2 (C-Band, VV) SAR image along the northeast coast of North Korea acquired on 30 September 2000 at 0203 UTC (orbit 28471, frame 2781). Imaged area is 100 km x 100 km. ©ESA 2000.



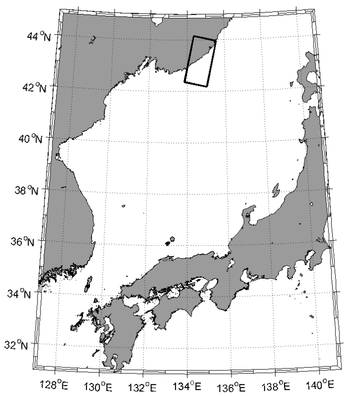


Figure 12 ERS-2 (C-Band, VV) SAR image of the coast of Russia acquired on 16 September 1997 at 0148 UTC (orbit 12582, frames 2727, 2745). Imaged area is 200 km x 100-km. ©ESA 2000.