Korea - Southeast Coast

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Overview

Continental shelf internal waves have been observed along the southeast coast of Korea between 35^o and 38^o N. latitude, 128^o to 130^o E. longitude) in in-situ measurements, Space Shuttle astronaut photography and synthetic aperture radar.

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. They observed non-linear internal waves with downward thermocline displacements of up to 26 meters, (from an initial depth of 20 meters) and wavelengths of approximately 600 m, with 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 1 presents a summary of internal wave characteristics from the southeast Korean shelf. The values have been taken from Kim et al. [2001] and derived from imagery.

Table 1. Characteristic Scales for southeast Korean Shelf Solitons

Packet Length L (km)	Along Crest Length C_r (km)	Maximum Wavelength λ_{MAX} (km)	Internal Packet Distance D (km)
2.7	> 30	1.5	40 - 45
Amplitude $2h_0$ (m)	Long Wave Speed c_0 (m/s)	Wave Period (min)	Surface Width l_1(m)
-20 to -26	0.5	3 - 10	180

Observations - 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). The data were taken using two thermistor chains and an Acoustic Doppler Current Profiler (ADCP). The observation site was located 8 km (Figure 2) 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 07:00 May 12 to 17:00 May 14, 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.

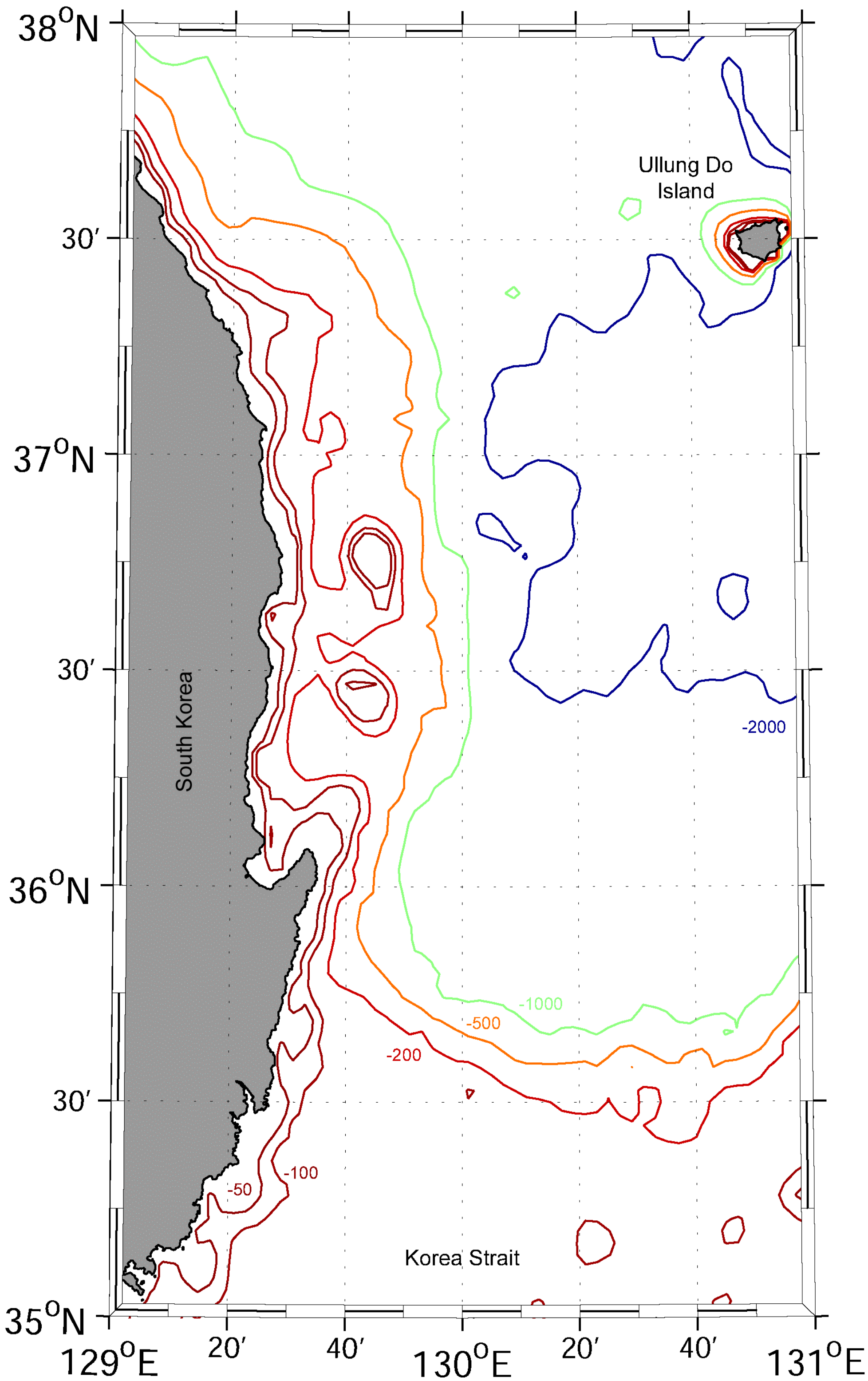

Figure 1: Bathymetry map of the southeast Korean Shelf. (Bathymetry derived from Smith and Sandwell version 8.2)

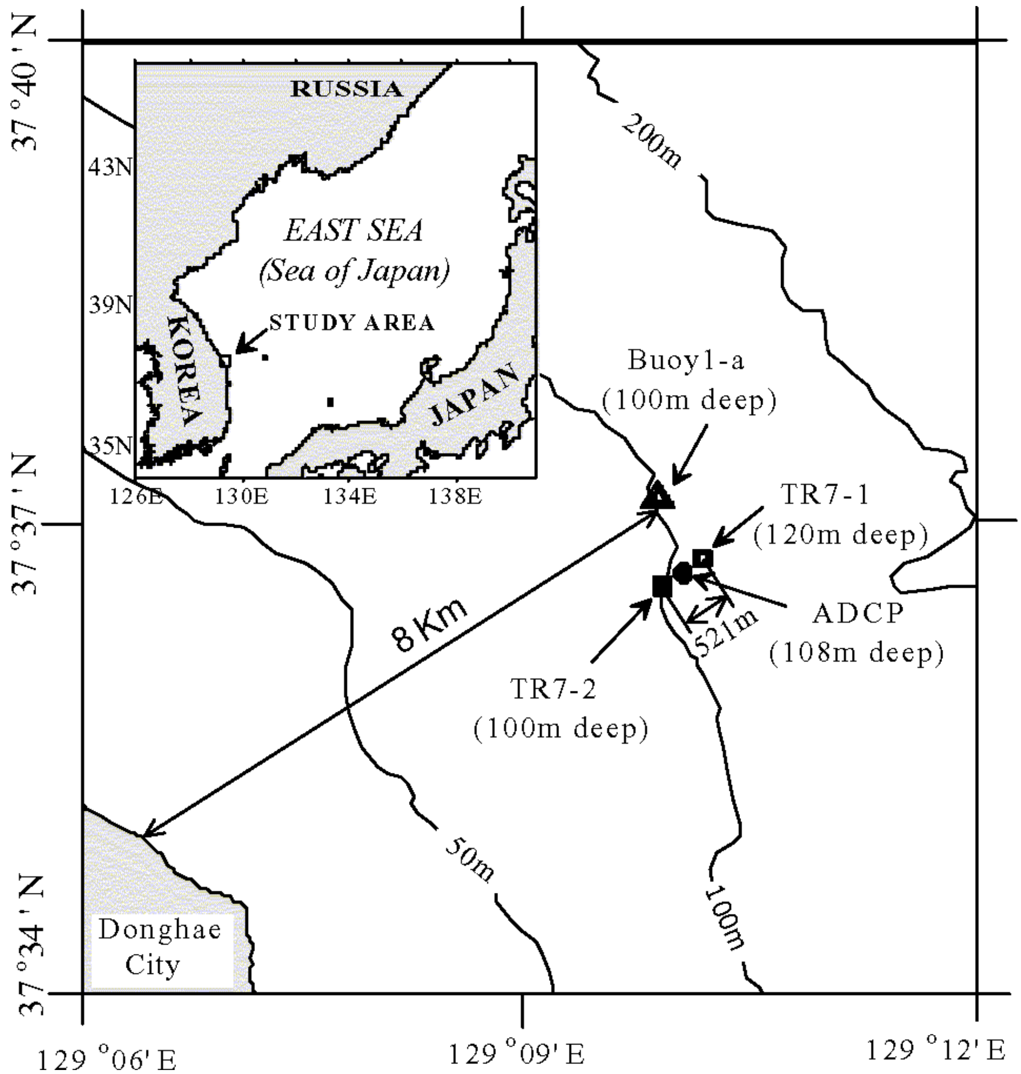

Figure 2. Area map of an internal wave experiment (IWES) off the east coast of Korea on May 12-14, 1999.

Large temperature fluctuations indicating solitary internal wave packets appeared three times (A, B, and C in Figure 3a) 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

A closer inspection of the time series for 2 hours (Figure 3b) 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 3c shows the temperature data converted to vertical displacements of isotherms. The maximum displacement of the solitary internal wave reached about 21 m downward.

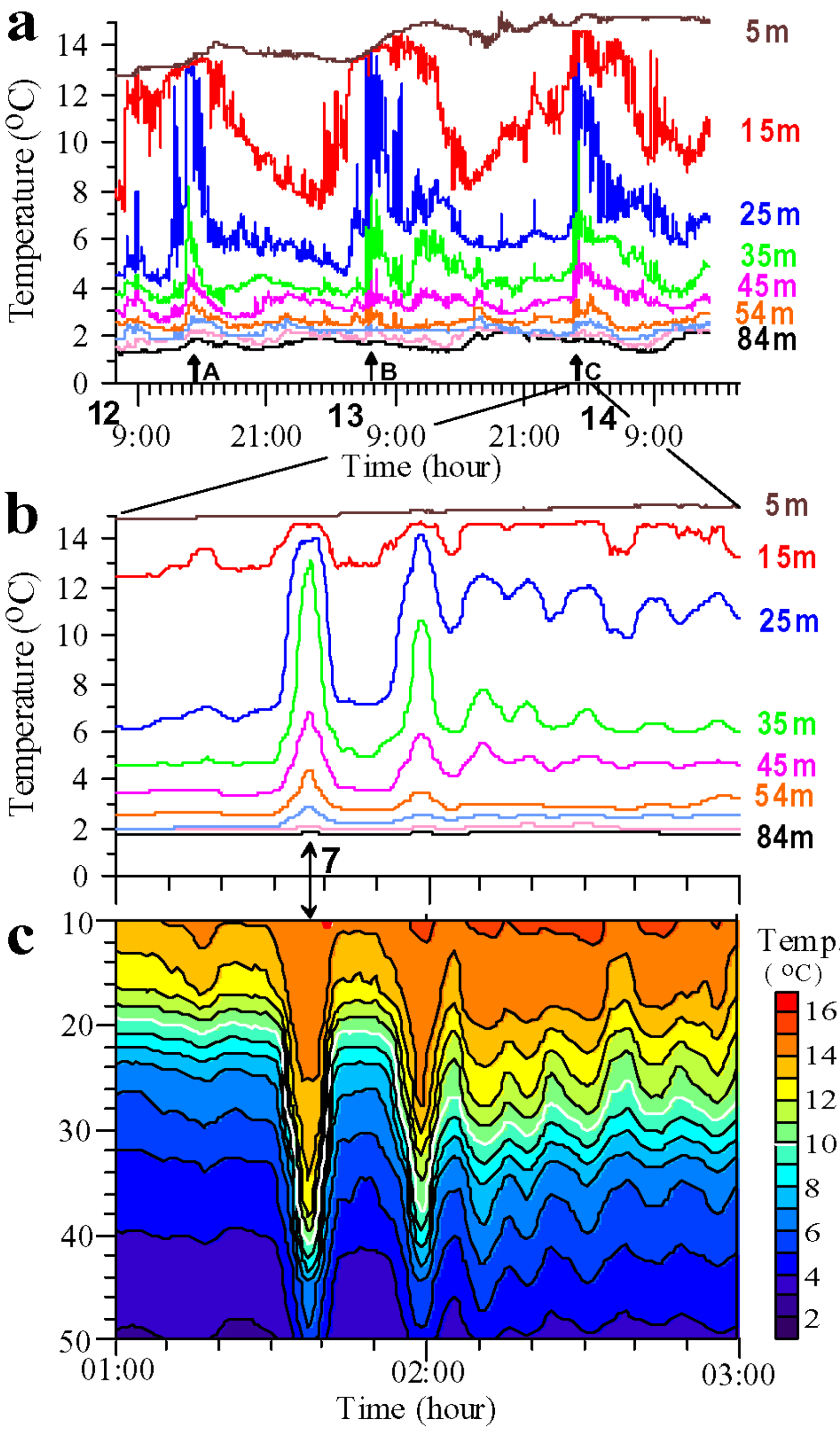

Figure 3a. (**a**) A time temperature time series. Three cycles of steep leading edges at an interval of about 19 hours can be seen, mostly visible at the 25 m and 35 m. (**b**) A 2-hour time series of the temperature from 1:00 am to 3:00 am, shows the solitary wave packet C. (**c**) A time series of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

Figure 4 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 3c and 4, 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.

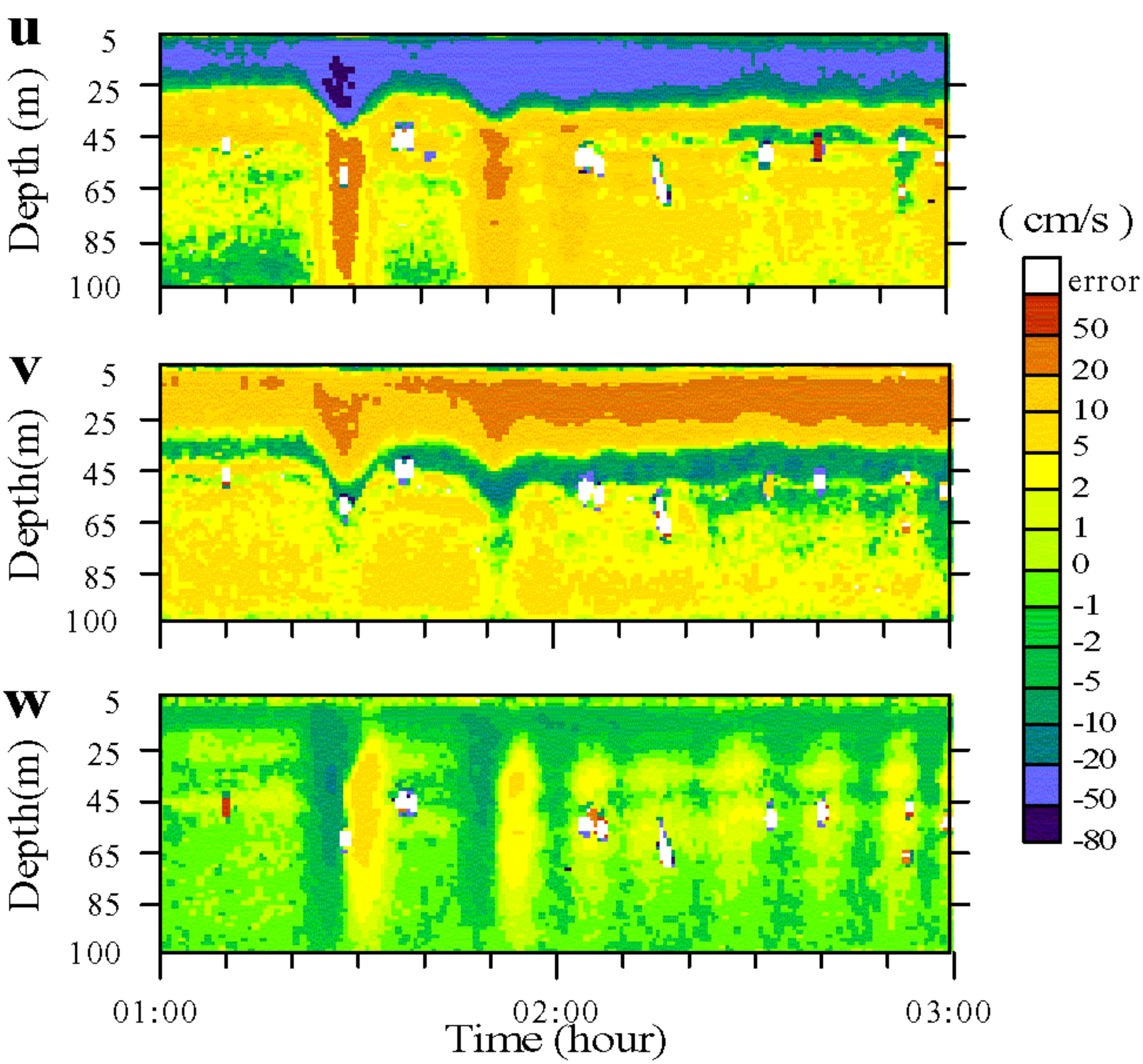

Figure 4. Horizontal and vertical components of the current velocity measured by a bottom-mounted ADCP for the same time as Figure 2b. U, V, and W are positive eastward, northward, and upward, respectively.

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.

Observations - Imagery

Figure 5 is one of three photographs (STS106-720-10, 11, 12) of internal waves off the southeast coast of Korea taken on September 20, 2000 by astronauts on board the Space Shuttle Atlantis. It is a complex picture, showing a large number of internal waves, as well as soliton-soliton interactions.

Four strong distinct linear crests are visible propagating west toward the shore in the upper right portion of the image. The traditional rank ordered sequence is difficult to detect, with the exception of the second group from shore. The separation between lead crests is 11 km, 9 km and 9 km respectively. This is a spacing much smaller then traditionally observed and is the result of the bottom topography. (This is also seen in ERS data shown in Figure 7).

A second set of weaker curved wavefronts is visible closer to the center of the image, north of the peninsula tip. The separation between crest is consistent with that observed in the previous group, but the direction of propagation (northwest) suggests a second-generation location on the shelf. The curvature is most likely the result of the bathymetry (Figure 6).

The picture is further complicated by a third set of smaller waves propagating due north, at nearly right to the linear wavefronts. The waves appear to originate just north of the seamount feature near 36^{o}30' N. and 129^{o}40' E. and help to produce the soliton-soliton interference pattern visible near the top right.

The bright filaments seen throughout the image are surface slicks reflecting sunlight in the sunglint region of the photograph.

The 8 to 10 km spacing of the linear wavefronts observed in the space shuttle photograph (Figure 5), is also observed in the wavefronts visible in an ERS-2 image (Figure 7) of the same area acquired on September 30, 2000. The separation between wave crests can be seen to decrease in the right center of the image. This decrease is the result of the bottom topography, which corresponds to the position of King Rock, a part of Hupo Bank (Figure 8).

KDV Parameters

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 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.

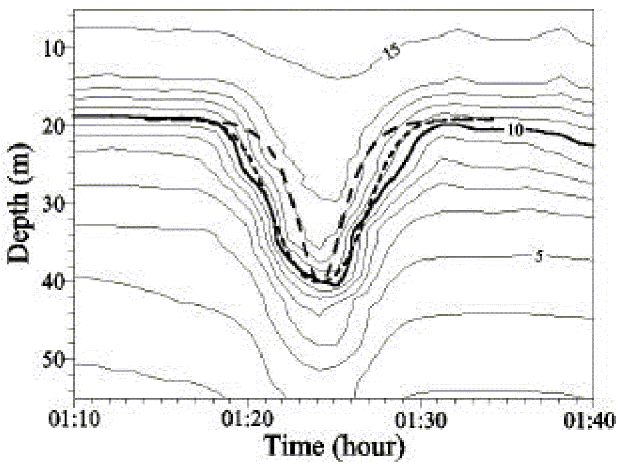

Figure 8. Isotherm displacements for soliton 7 in the wave packet C shown in Fig. 2b and 2c are fitted by the CombKdV equation (outer dotted line) better than the KDV solution (inner broken line).

Table 2. Environmental Coefficients and KDV parameters for the IEWS Korean Solitons

Depth Layer 1 - h_1 (m)	Density Layer 1 (Kg/m^3)	Depth Layer 2 - h_1 (m)	Density Layer 2 (Kg/m^3)
20	1025.5	80	1027.2

Long Wave Speed c_0 (m/s)	Nonlinear coefficient $1/\alpha$ (m)	Dispersion Factor $\gamma^{1/2}$ (m)	Amplitude (measured) $2h_0$ (m)	Non-Linear Phase Velocity V (m/s) for (v=.98)
0.51	-17.77	16.34	-23.9	0.62

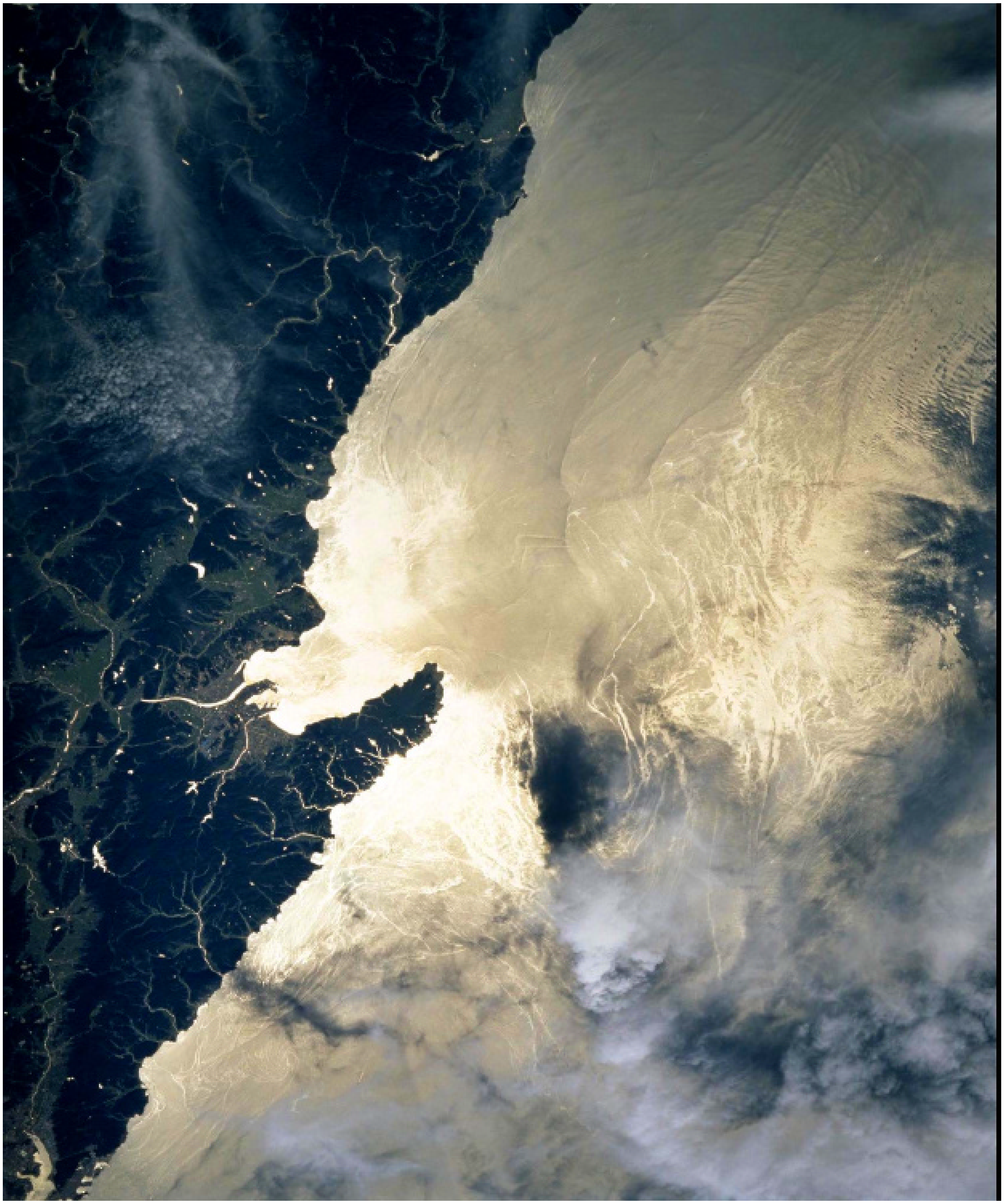

Figure 5. Space Shuttle Photograph (STS106-720-11) acquired September 20, 2000, 02:00 GMT. Image is centered near 36^o N., 129.5^o E. with approximate dimensions of 124 km x 102 km. Image Courtesy of Earth Sciences and Image Analysis Laboratory, NASA Johnson Space Center (http://eol.jsc.nasa.gov).

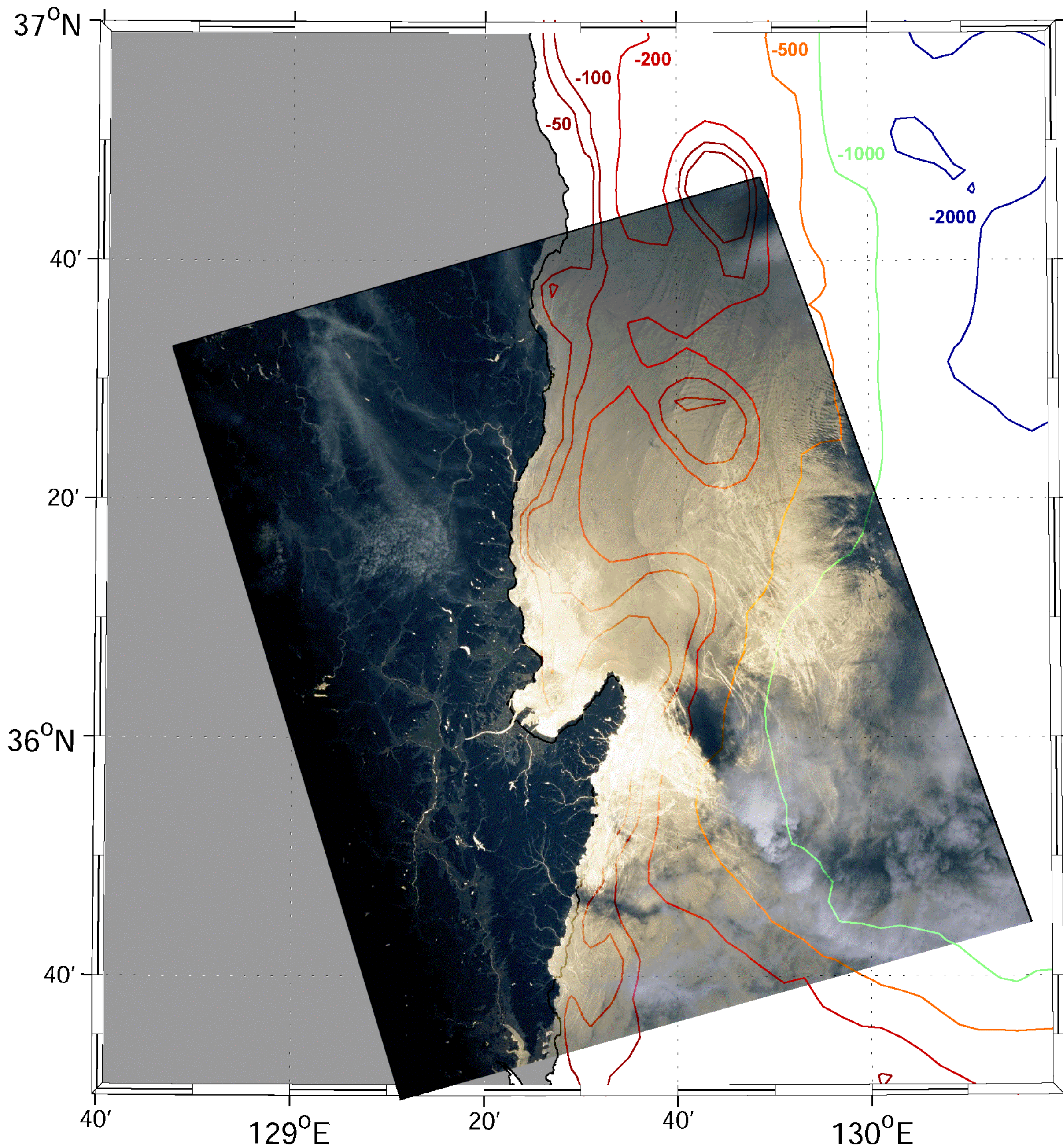

Figure 6. Space Shuttle Photograph (STS106-720-11) shown with a map of the local bathymetry. (Bathymetry derived from Smith and Sandwell version 8.2)

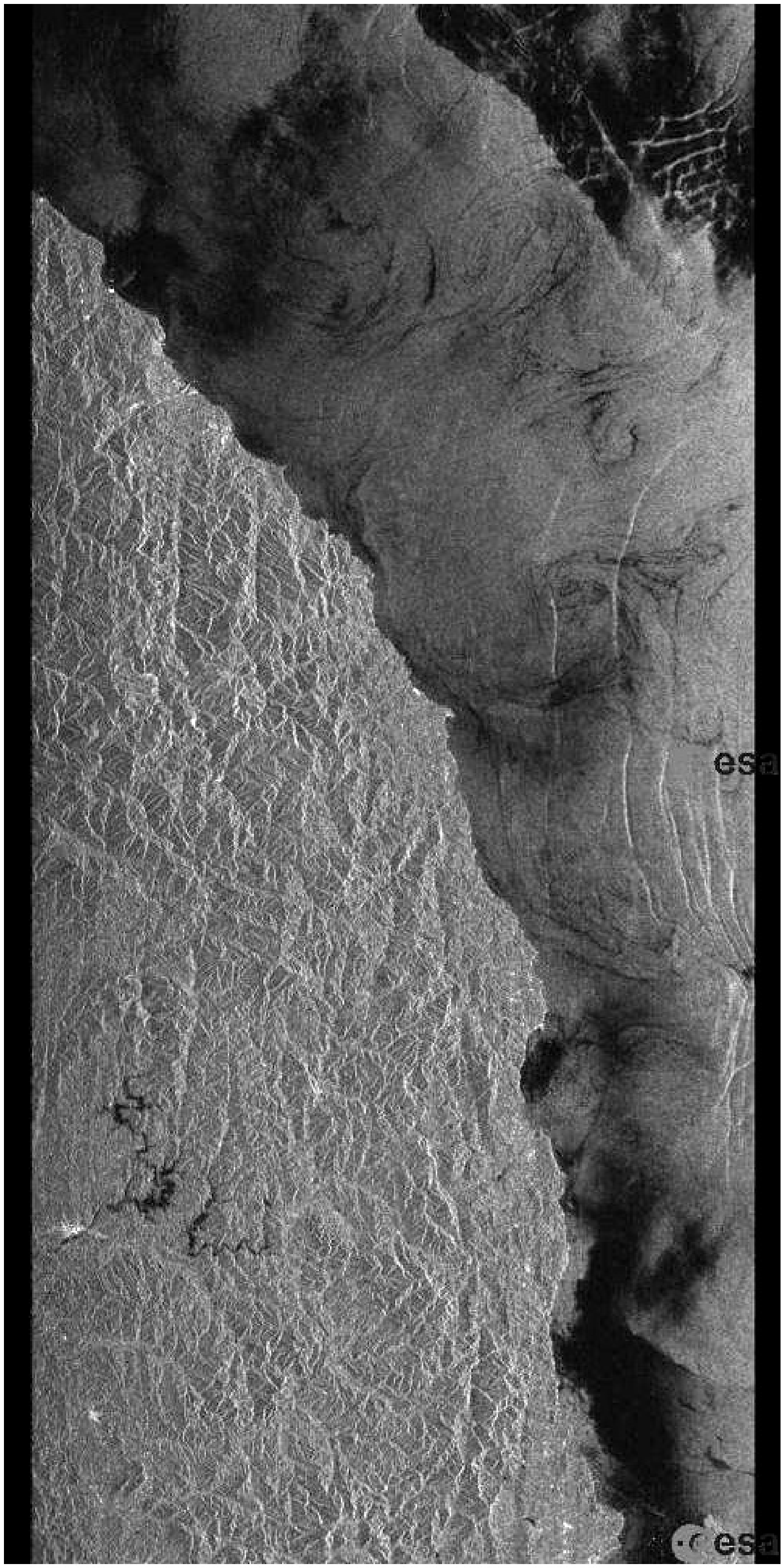

Figure 7 ERS-2 C-Band SAR survey image acquired September 30, 2000 at 02:05 GMT over the southeast Korea, (Orbit: 28471, Frames: 2853, 2871). Image is centered near 36.94° N., 129.40° E. Image is 200 km x 100-km. ©ESA 2000.

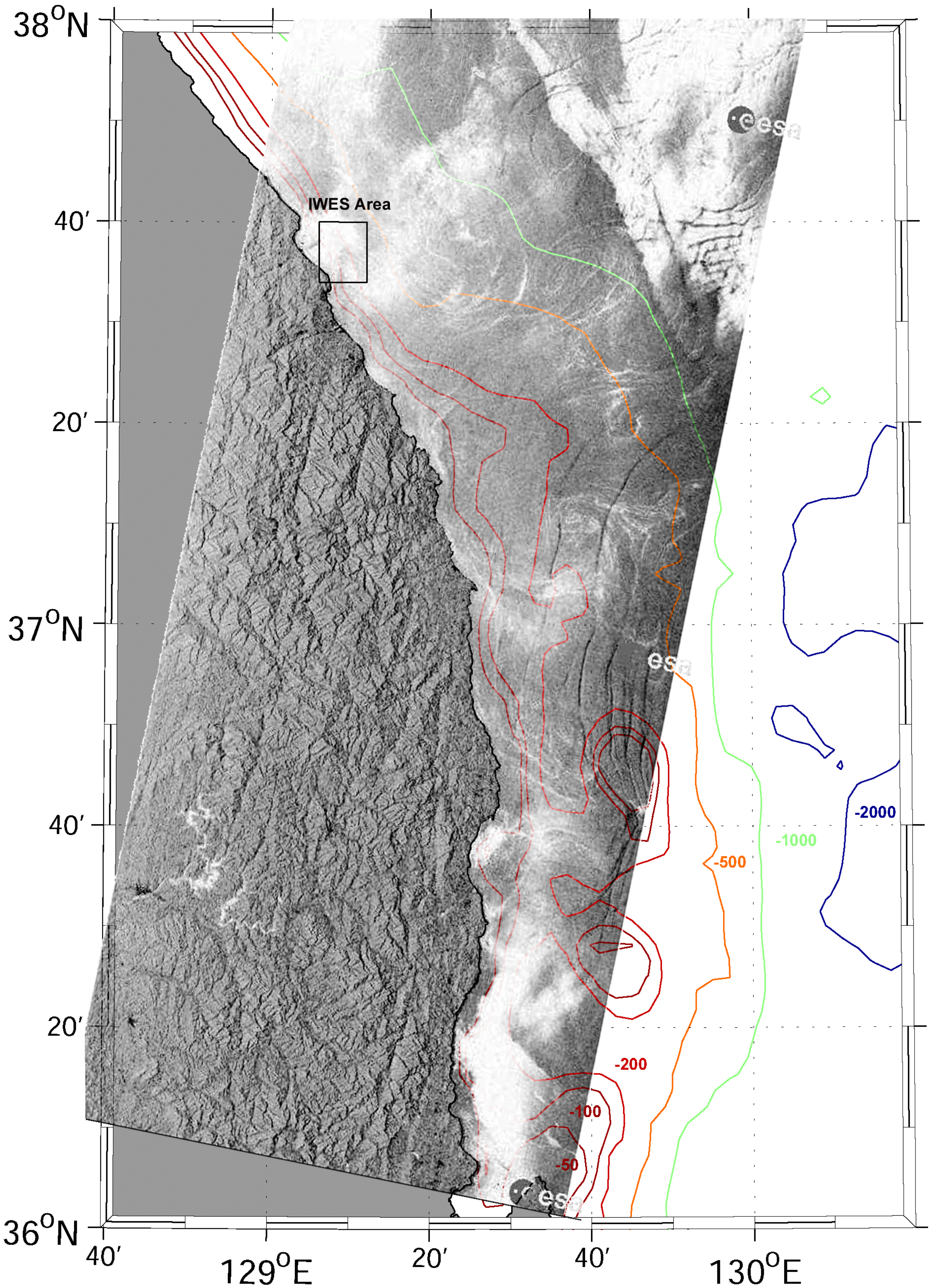

Figure 8. ERS-2 image shown with a map of the local bathymetry. The effects of bathymetry in the area of Hupo Bank (shallow water) can be seen in the wavefront.

References

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