# Yellow Sea

with contributions by John R. Apel

## Overview

The Yellow Sea is a shallow inland sea lying between northeastern China and the Korean Peninsula, with depths in its central north-south trough in excess of 60 to 80 m (Figure. 1). It serves as the oceanic outlet for the Yellow, Yalu, and Yangtze Rivers, which drain much of the north-central China landscape, caring large amounts of sediments into the ocean –hence its name. Lying in a range of latitudes between roughly 33°N to 40°N, its dynamics are those

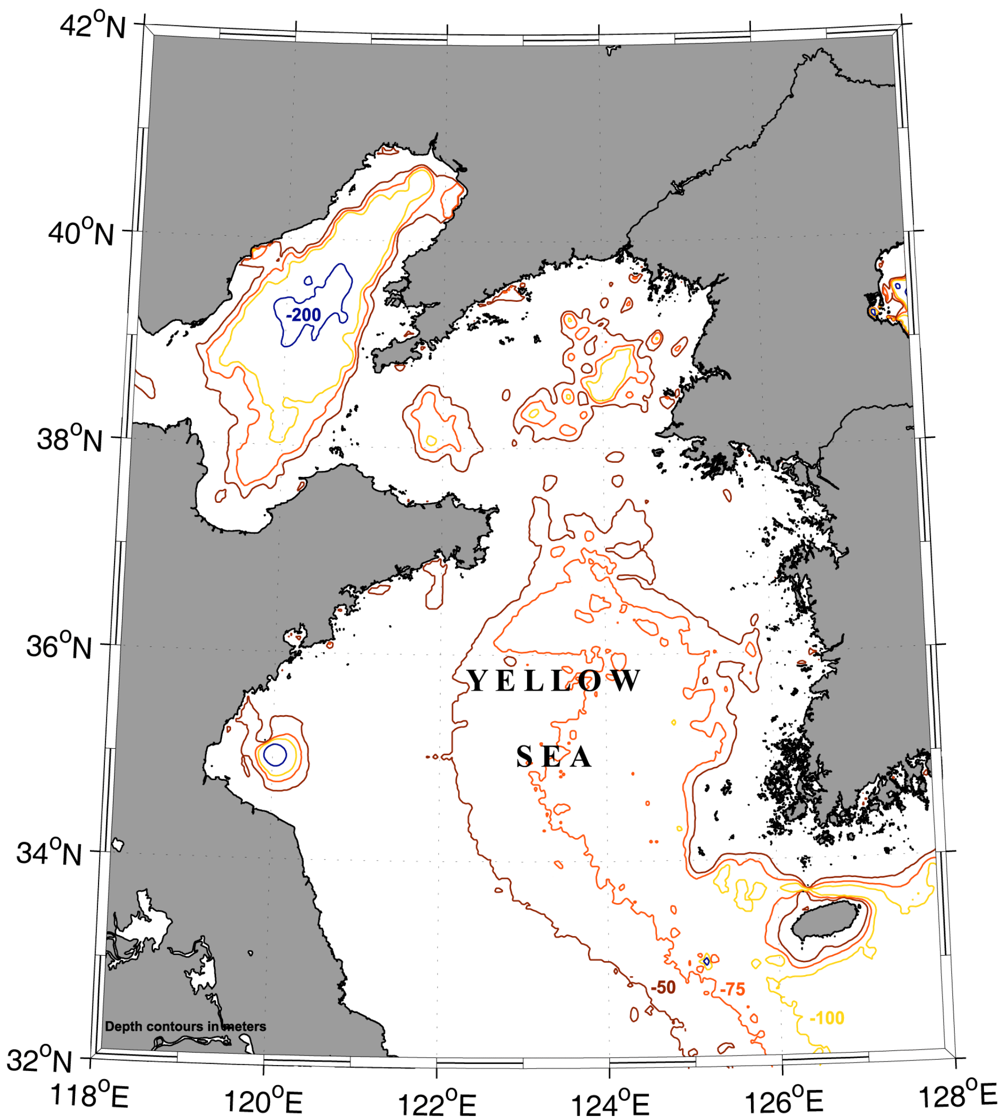



Figure 1. Bathymetry of the Yellow Sea. [Smith and Sandwell, 1997]

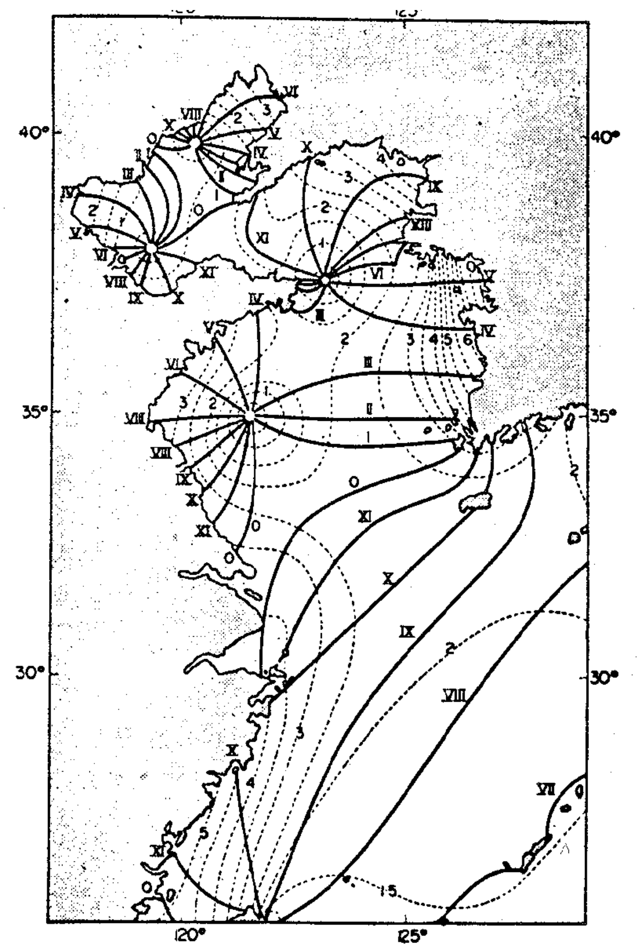



Figure 2. Co-tidal lines of the $M_2$ tide and range of the semidiurnal tide in the Yellow Sea and East China Sea. Phases refer to the 135°E longitude meridian and co-range $2(M_2 + S_2)$ in meters. Co-range lines off the Korean west coast show tidal ranges in excess of 8 m. Three amphidromes, or loci of zero tidal elevation, exist within the greater Yellow Sea Basin. [After *Ogura*; from *Defant*, 1961]

expected of a large, shallow, mid-latitude estuary on the eastern boundary of a continent. The tides are dominantly semidiurnal. Tidal forcing is variable in space and time, but is significant. Peak tidal currents among the shores of western Korea are often 1 to 1.5 m/s and reach a maximum in the passage off the southwest tip of the peninsula of 4.4 m/s. In the central basin, the speeds are of order 0.5 m/s. Tidal ranges along the Korean coast are 4 to 8 m; while along the China coast, they are 1 to 2 m [*M. Uda*, 1966].

Figure 2 is a map of the semidiurnal lunar $M_2$ co-tidal (constant phase relative to the passage of the Moon overhead) and co-range (constant range in meters) lines. The currents circulate counterclockwise around the amphidromes indicted by the small circles.

In the winter, northerly winds from the Asian mainland are strong and the resultant convention and wave mixing render the water column isothermal and isohaline to the bottom, with essentially no density gradients. In the late spring, summer, and early autumn, the southwesterly monsoon brings warm, wet air to the region with attendant rainfall and riverine runoff of fresh water. Solar heating combines with the fresh water outflow from the rivers to strongly stratify the upper layers of the water column. This results in strong temperature, salinity, and density gradients near depths of approximately 25 to 30 meters depending on wind mixing. Under such conditions, internal waves can be supported with the necessary generation mechanism. The most pervasive of such mechanisms is tidal forcing over shallow regions, followed by impulsive wind bursts. Typical wave amplitudes are 5 to 10 m, periods are 10 to 30 min, and wavelengths 100 to 1000 m. Very often they are soliton-like, which is to say they have strongly nonlinear characteristics that allow them to be readily identified in time-series data obtained by in-situ (in-water) measurements and by remote sensing data.

Bottom conditions in the Yellow Sea vary greatly. While very large sediment input from the major rivers might be expected to deposit mud and fine grained sediments, however, the very energetic tidal flows have scoured the mud down to sand and rock outcroppings along he shorelines, while leaving the deeper central basin with significant depths of sediments.

## Observations

There has been some scientific study of internal waves in the Yellow Sea. In-situ measurements of internal waves have been made in August 1981 [Zhou et al. 1991] and August 1996 ['96 joint China--U.S. internal wave/acoustic wave experiment in the Yellow Sea. Hsu et al. [2000] used ERS SAR data acquired the same time to compile a distribution map (Figure 3) of wave occurrences. Internal waves in the region are primarily generated along the west coast of Korea (between 33$^o$ and 39$^o$ N) and propagate into the Yellow Sea. This area along the Korean coast is the region of strongest currents as evidenced by the map in Figure 2.

Most of the waves are located off the southwestern coast of Korea. All internal waves appear to be generated by the interaction of the tidal current with shallow bathymetric features between the many small islands located off in that area. The internal waves have been noted to extend out to almost 122$^o$ E [*Hsu et al.*, 2000]. A branch of the Kuroshio Current (the Pacific Ocean's equivalent to the Gulf Stream), called the Tsushima Current, breaks off well to the south and penetrates into the Sea of Japan between Korea and Kyushu; some of this current finds its way up the east side of the sea. It may well be that these currents play a role in the generation of the profusion of internal waves seen in this image.

Farther to the north, in the vicinity of the narrows of 37$^o$ – 38$^o$ N, the shallow shelf break along the west coast of Korea, typically near the 50-m depth contour, is quite steep and such bathymetry is known to be prone to generate internal waves when strong currents are present. Here the internal waves appear to propagate both offshore into the Yellow Sea as well as ashore toward the Korean mainland. (Figure 5)

Table 1 shows the months of the year during when internal wave observations have been collected.

Table 1 - Months when internal waves have been observed in the Yellow Sea.
(Numbers indicate unique dates in that month when waves have been noted)

| Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sept | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | 6 | 4 | | | | |

Figures 3 through 7 show the internal wave activity along the eastern side of the Yellow Sea during July. The imagery shows a large number of wave packets and fronts propagating in a variety of directions away from the Korean Coast. This indicates that there is large number of internal wave sources in and among the small islands and shoals in the area. The waves, at least in the southern Yellow Sea extend out over more than 100 km from their generation point to almost 122$^o$E. While the majority of waves propagate into he Yellow Sea, the imagery also

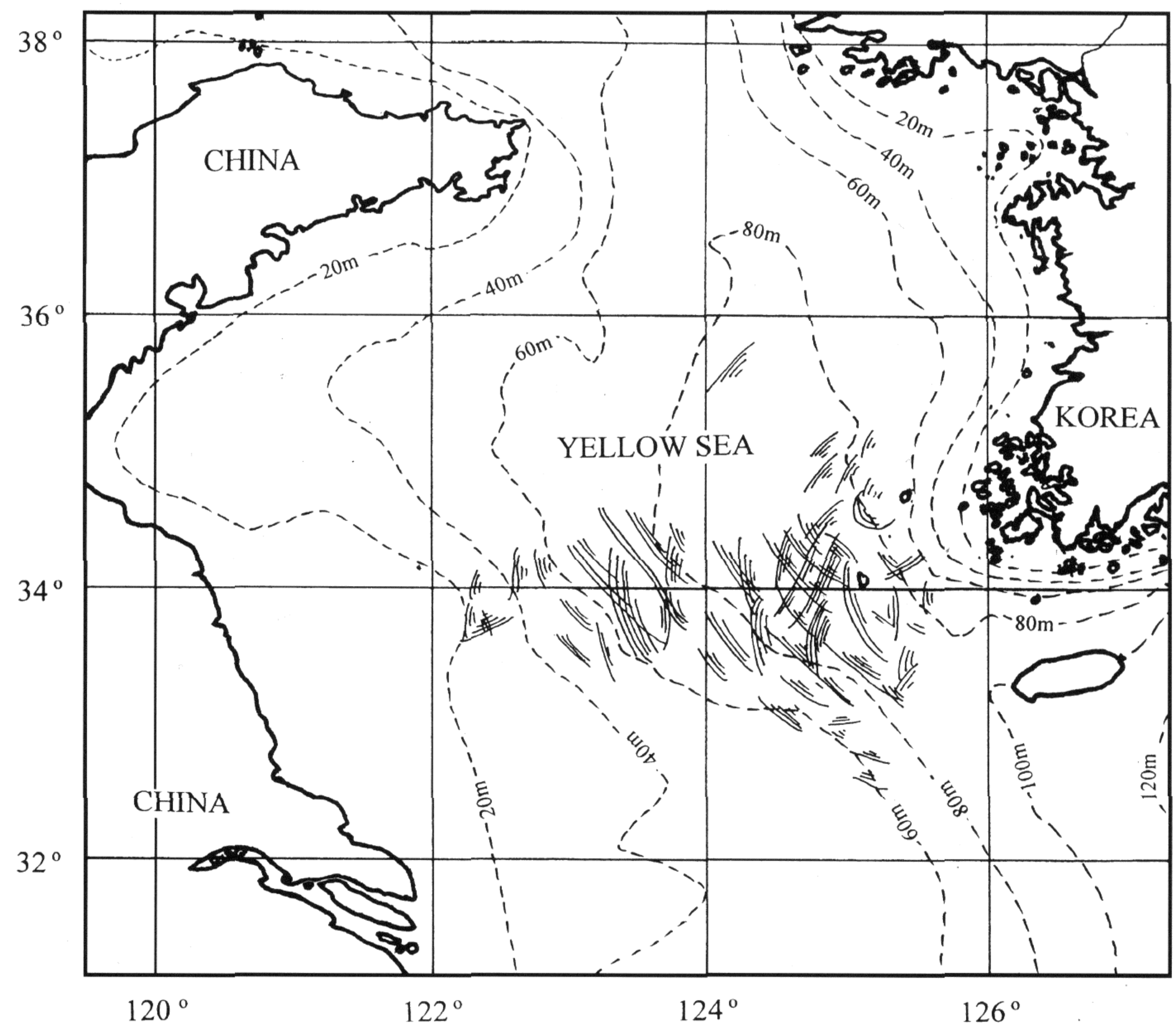
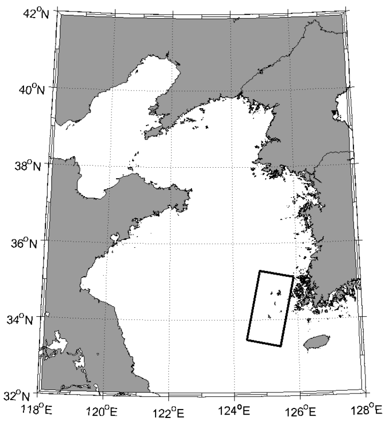



Figure 3. Location of internal wave packets observed off the southwest coast of Korea in the Yellow Sea during August 1996. In this figure all the wave packets are propagating away from the coast and extend as far west as 122° E [After *Hsu et al,* 2000]

contains a small number of waves propagating toward the Korean Peninsula, indicating that the at the shelf break internal waves are generated.

The internal waves observed in the Yellow Sea are apparently typical of waves observed in mid-latitude seas during the summer. They may be somewhat more energetic than average along the Korean west coast because of the higher speed tidal flows and the strong stratification there. They will certainly be reduced in amplitude and extent as the fall sets in by the processes of convective overturning and wind mixing. By late autumn they will be mostly absent in the main portion of the sea, although the input of warmer water form the Kuroshio will most likely maintain some stratification in the south and southeast, as will Yangtze River water.



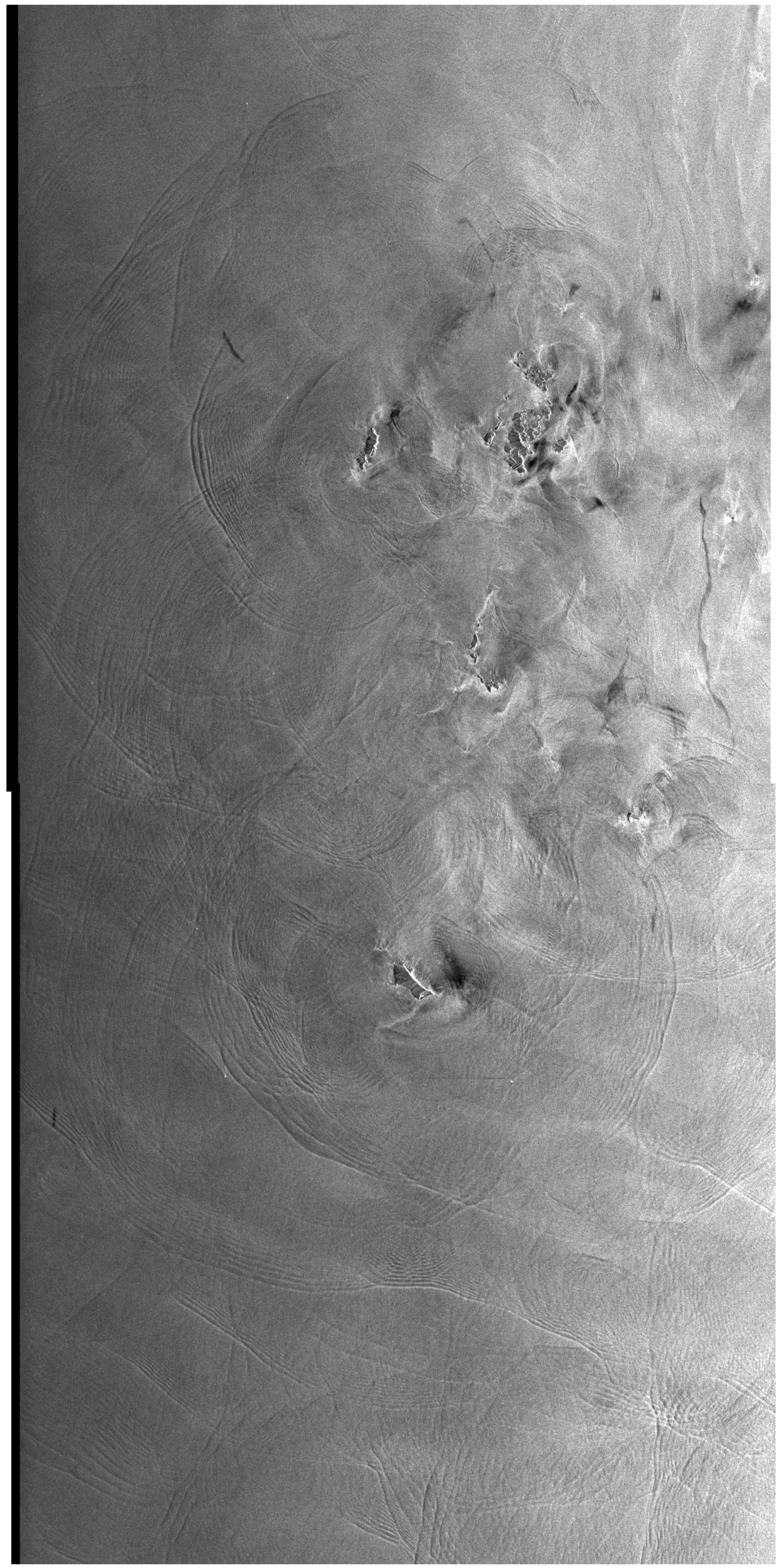



Figure 4. ERS-2 (C-Band, VV) SAR image of the Yellow Sea off southwest Korea acquired on 8 July 1998 at 0219 UTC (orbit 16805, frames 2907, 2925). The image shows a large number of internal wave packets propagating away from the islands in a variety of directions. Imaged area is 100 km x 200 km. © 1998 ESA [Courtesy of Werner Alpers University of Hamburg, Hamburg, Germany]

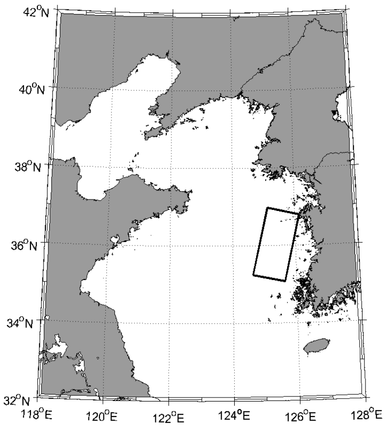



Figure 5. ERS-2 (C-Band, VV) SAR image of Yellow Sea off the west coast of South Korea acquired on 23 July 1997 at 0219 UTC (orbit 11795, frames 2871, 2889). The image shows a large number of internal wave signatures propagating away from the islands and into the Yellow Sea. One eastward propagating packet can be seen in the bottom left quadrant. Imaged area is 100 km x 200 km. ©ESA 1997. [From The Tropical and Subtropical Ocean Viewed by ERS SAR http://www.ifm.uni-hamburg.de/ers-sar/]

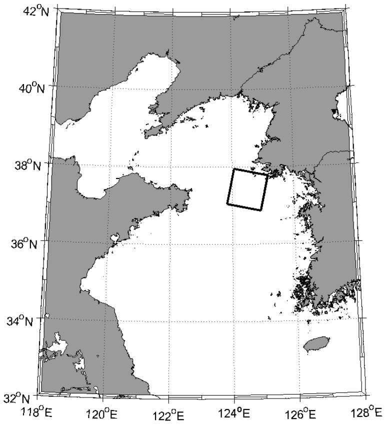
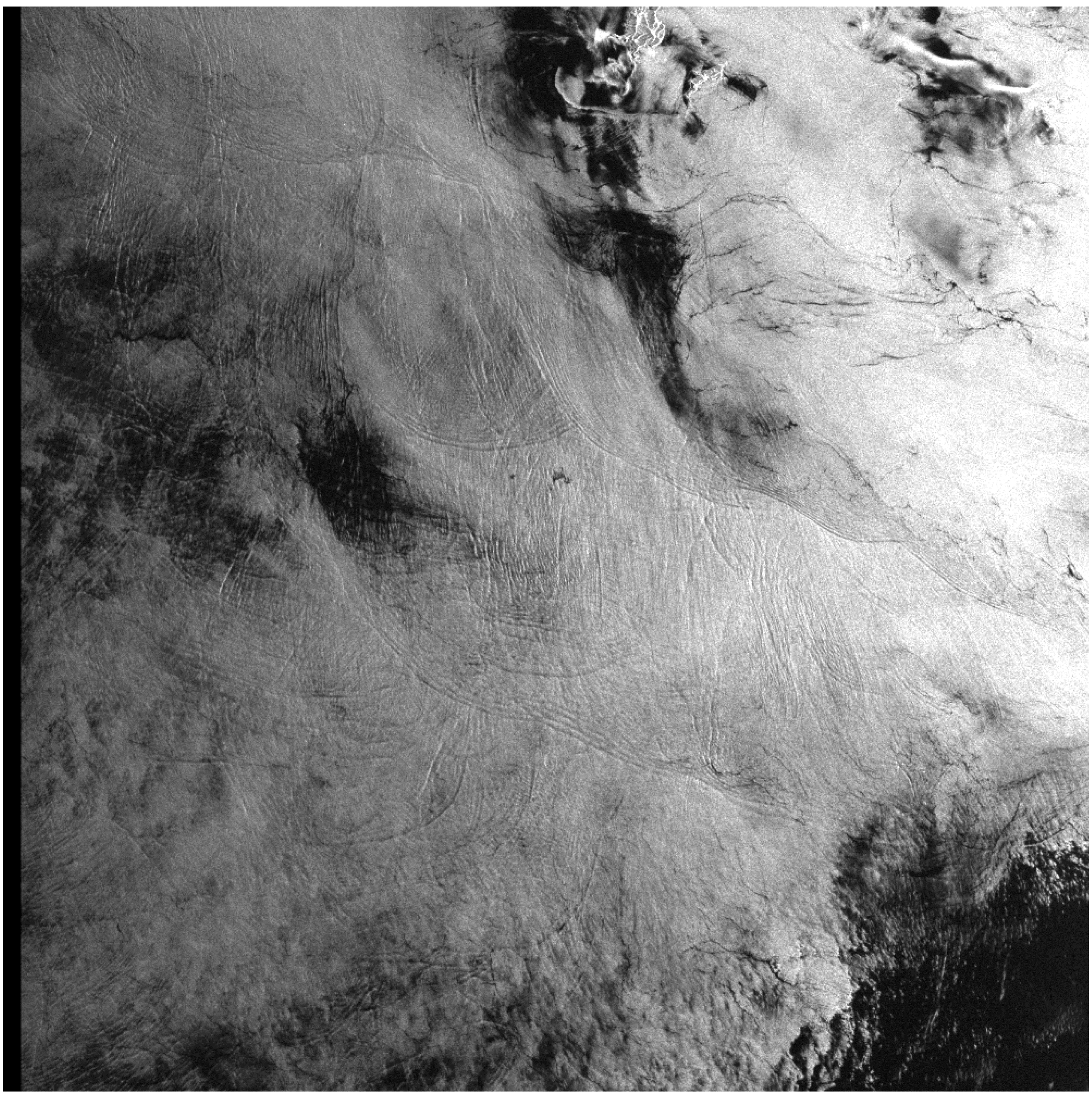



Figure 6. ERS-2 (C-Band, VV) SAR image of Yellow Sea off the west coast of North Korea acquired on 11 July 1998 at 0219 UTC (orbit 16848 frame 2853). The image shows a large number of internal wave signatures propagating both offshore (away from the islands) and toward shore from sources off the upper left corner of the image. Imaged area is 100 km x 100 km ©ESA 1998. [Courtesy of Werner Alpers University of Hamburg, Hamburg, Germany]



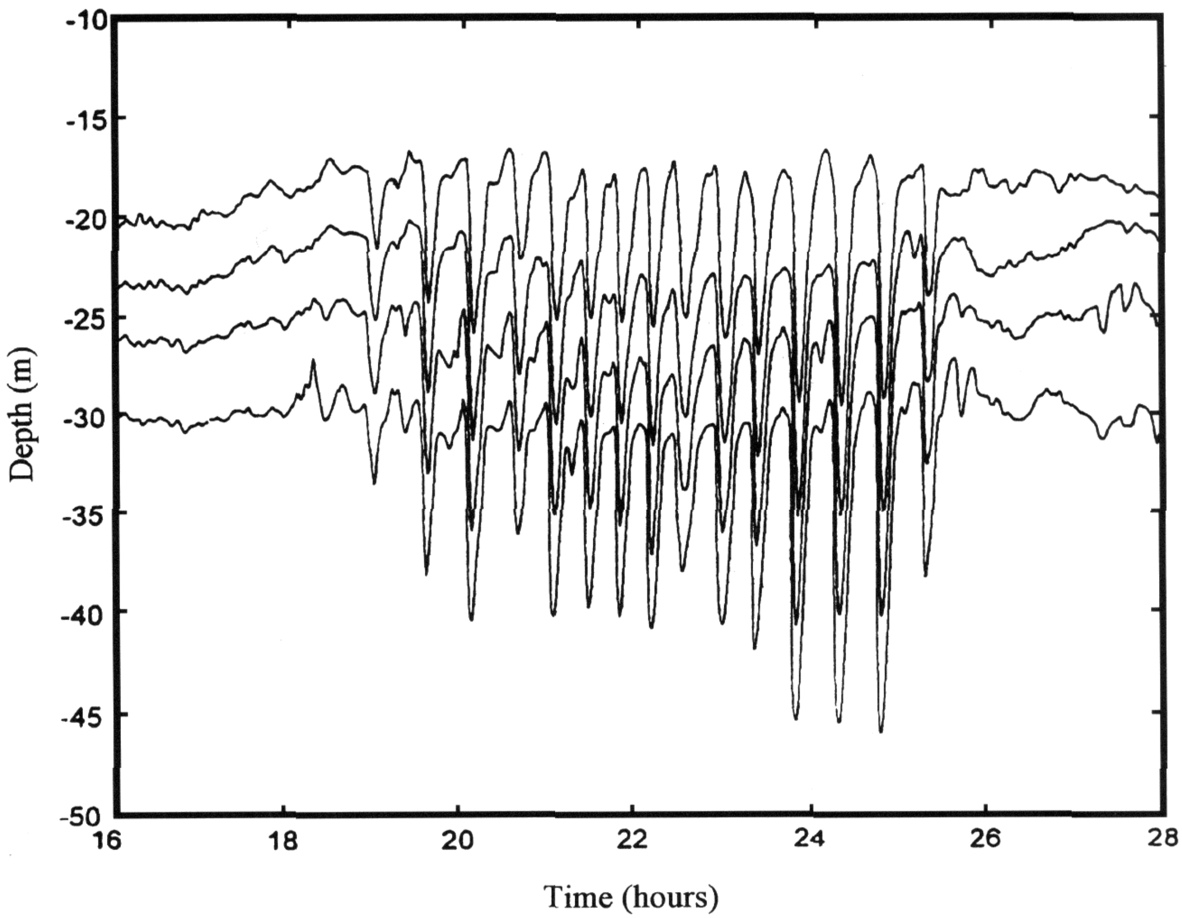



Figure 7. Isothermal depth versus time derived from the thermistor chain measurements of internal waves in the Yellow Sea on 22 August 1996. The data show an average soliton amplitude of 10m. The data were taken near 37°N, 124°E. The isotherms correspond to 22°C, 18°C, 14°C and 10°C temperatures. [After *Hsu et al* 2000]

## References

Defant, A., 1961. Tides in the Mediterranean and adjacent seas. Observations and discussion. *Chapter 12. Physical Oceanography. Vol. 1, 364 - 456.*

Hsu, M.-K., A.K. Liu, and C. Liu, 2000: A study of internal waves in the China Seas and Yellow Sea using SAR. *Continental Shelf Re*s., **2**0, 389-410.

Ogura, S., 1933. The tides in the seas adjacent to Japan. *Hydrog. Bull. Dep. Imp. Jap. Navy, 7, 1-189.*

Smith, W. H. F., and D. T. Sandwell, Global seafloor topography from satellite altimetry and ship depth soundings, Science, v. 277, p. 1957-1962, 26 Sept., 1997. http://topex.ucsd.edu/marine_topo/mar_topo.html

Uda, M, 1961: (?)

Zhou, J. X., X. Z. Zhang, and P. H. Rogers, 1991; "Resonant interaction of sound wave with internal solitons in the coastal zone," *J. Acoust. Soc. Amer*., vol. 90, pp. 2042–2054