Iberian Peninsula – Atlantic Coast

Overview

The Iberian Atlantic coast extends from the Gulf of Cadiz to Galicia Bank off the northwest edge of the Iberian Peninsula (Figure 1). The continental shelf along the coast varies in width from 15 to nearly 400 km [LME, 2004]. The region is influenced by Atlantic eastern boundary currents as well as by upwelling in spring and summer (April to August).

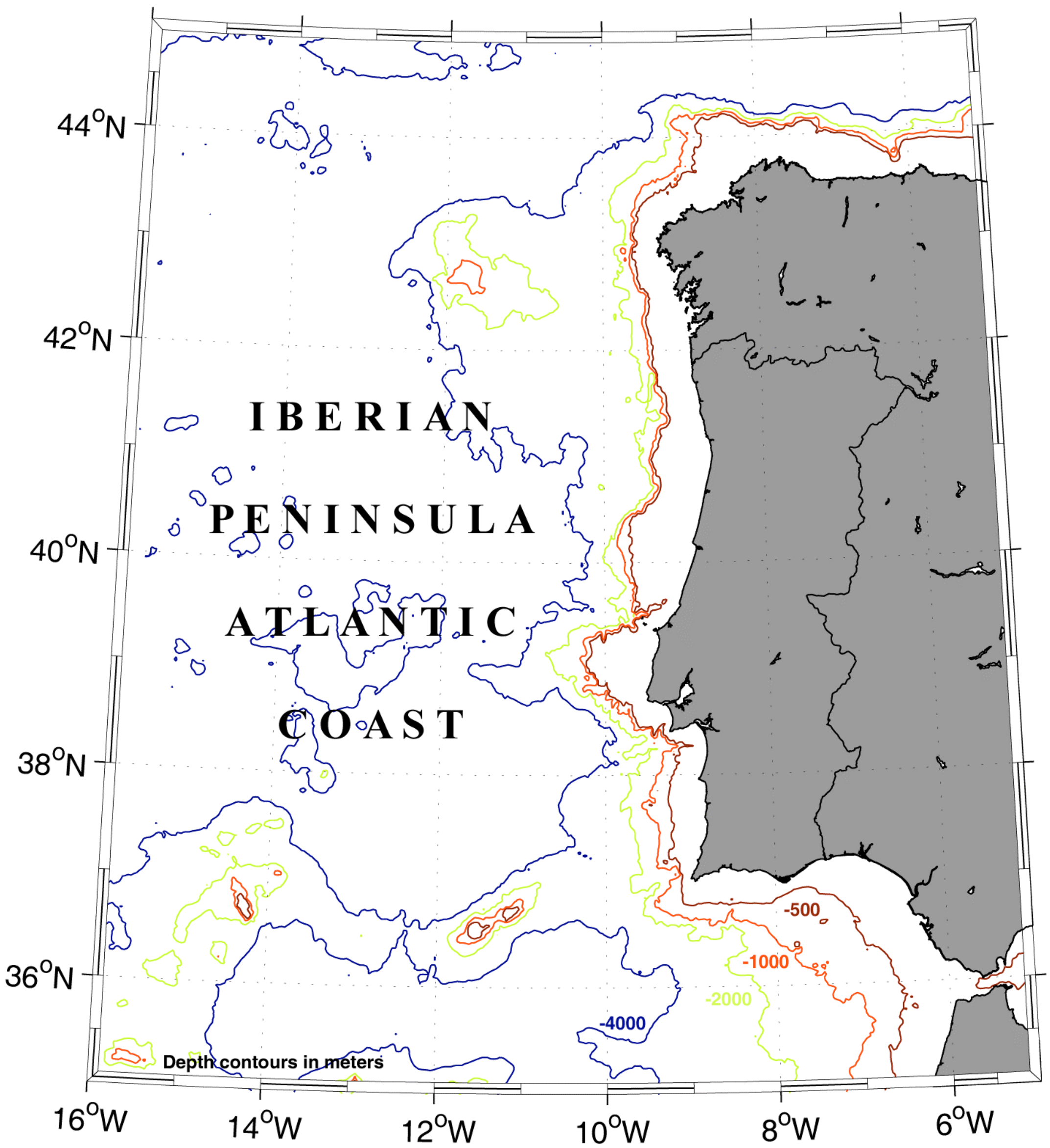


Figure 1. Bathymetry of Atlantic Coast of the Iberian Peninsula. [Smith and Sandwell, 1997]

Observations

There has been considerable scientific study of internal waves along the Atlantic coast of the Iberian Peninsula, both via satellite and in situ observations. Table 1 shows the months of the year when internal wave observations have been made.

Table 1 - Months when internal waves have been observed along the Atlantic coast of the Iberian Peninsula
(Numbers indicate unique dates in that month when waves have been noted)

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
					1	5	5	1	2		

Apel [1979] examined an astronaut photograph (AST-27-2367) showing two internal wave packets in the Gulf of Cadiz. Intersoliton separation was approximately 2 km and wave packet spacing 25 km (with an implied phase speed of 0.56 m/s). Figure 2 shows an ERS-1 SAR image of the Gulf of Cadiz acquired on 18 August 1995 showing very similar internal wave signatures.

A combined in situ and satellite SAR observation experiment (INTIFANTE 99) was conducted off Cape Sines in July 1999. Small [2002] describes the observations of large amplitude internal waves of 50-m amplitude in 250-m water depth, and 40-m amplitude in 100-m depth. RADARSAT-1 SAR imagery (Figure 3) was used to show that the position of leading wave signatures was linked to the phase of the semi-diurnal tide (Figure 4). Individual wave packets contained up to seven waves with intersoliton separations of 500 to 1500m. Successive packet separations were typically 16-20 km, yielding an implied phase speeds of 0.35 to 0.45 m/s. The crest lengths ranged between 15 km and 70 km, the longer wavefronts being due to the merging of packets

Jeans [1998], Sherwin and Jeans [1999] and Jeans and Sherwin [2001] have examined in situ observations made on the Portuguese Shelf off Oporto carried out in August 1994 as part of the EU MAST II MORENA project, whose aim was to study mixing and exchange processes at the shelf edge. The internal waves had intersoliton separations of 500-1000 m, peak-to-trough amplitudes of 30-40 m and phase speeds around 0.57 m/s. These waves were imaged by the ERS-1 SAR (Figure 7)

ERS SAR imagery was used by Correia [2003] and Azevedo et al. [2004] to study the distribution of internal waves over the Galicia Bank located northwest of the coast of the Iberian Peninsula.]. Azevedo et al. [2004] attribute the existence of internal waves observed in the deep ocean west of the Galicia Bank to semi-diurnal internal tides emanating from the bottom slopes. New and Pingree [1992] and New and da Silva [2002] argue that this generation mechanism is also responsible for the generation of internal waves in the central Bay of Biscay.

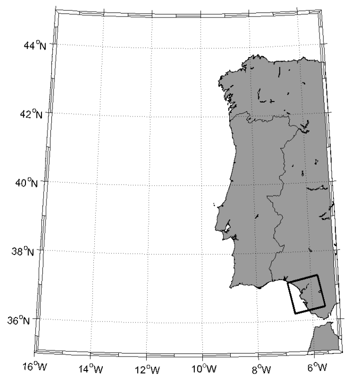
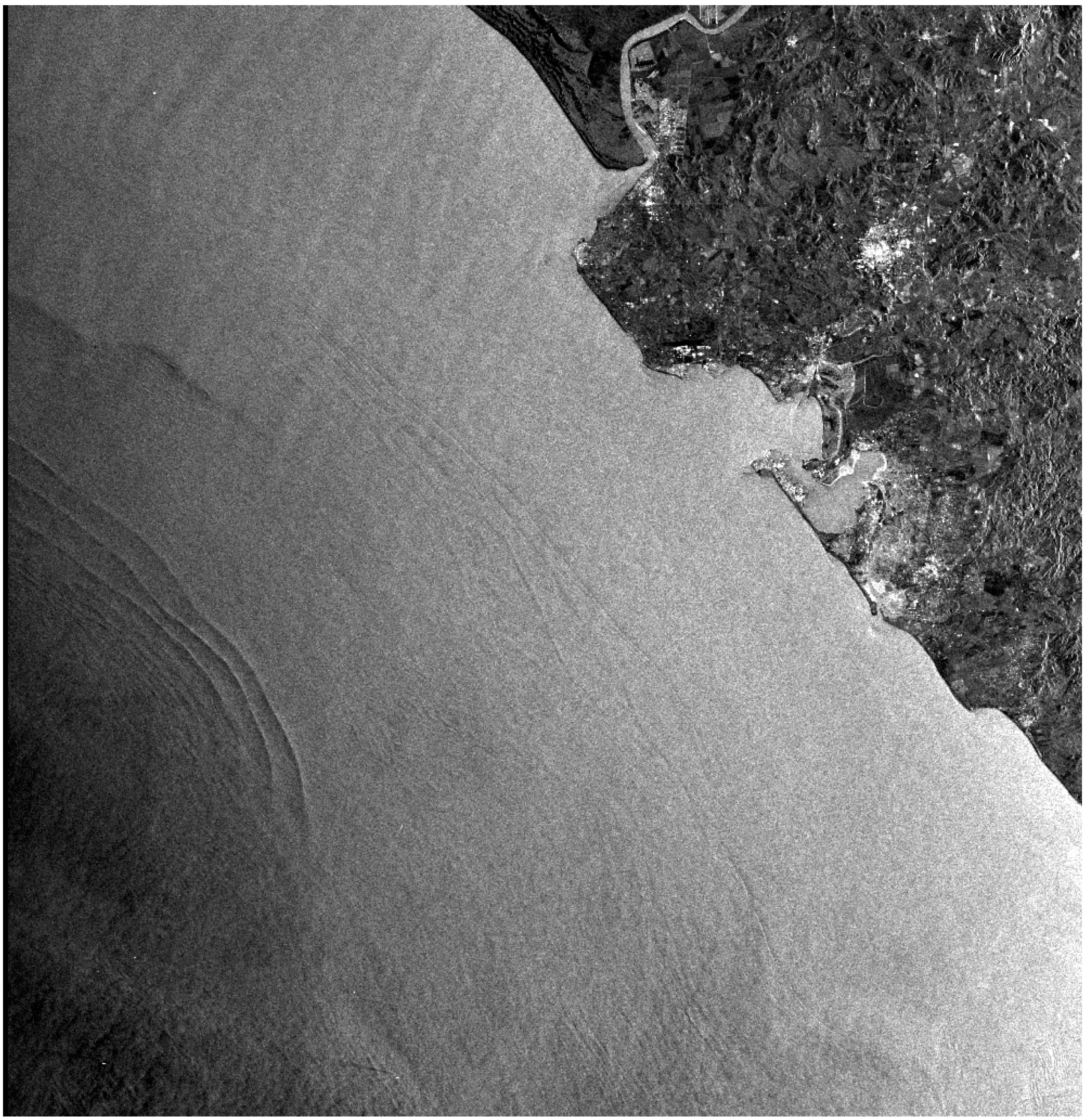
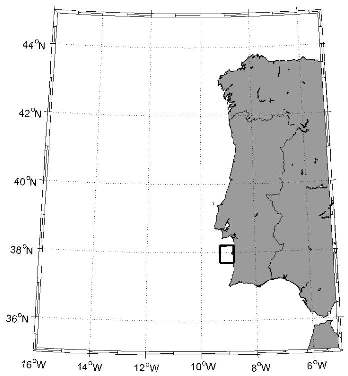


Figure 2. ERS-1 (C-band, VV) SAR image of the Gulf of Cadiz, Spain acquired on 18 August 1995 at 2242 UTC (orbit 21396, frame 2871). The image shows two internal wave packet signatures (one strong, one weak) on the continental shelf propagating shoreward. Packet separation is approximately 25 km shoreward and the distances between the lead solitons in the packets are approximately 2 km. Imaged area is 100 km x 100 km. © ESA 1995. [Image courtesy of Werner Alpers, University of Hamburg, Hamburg, Germany]





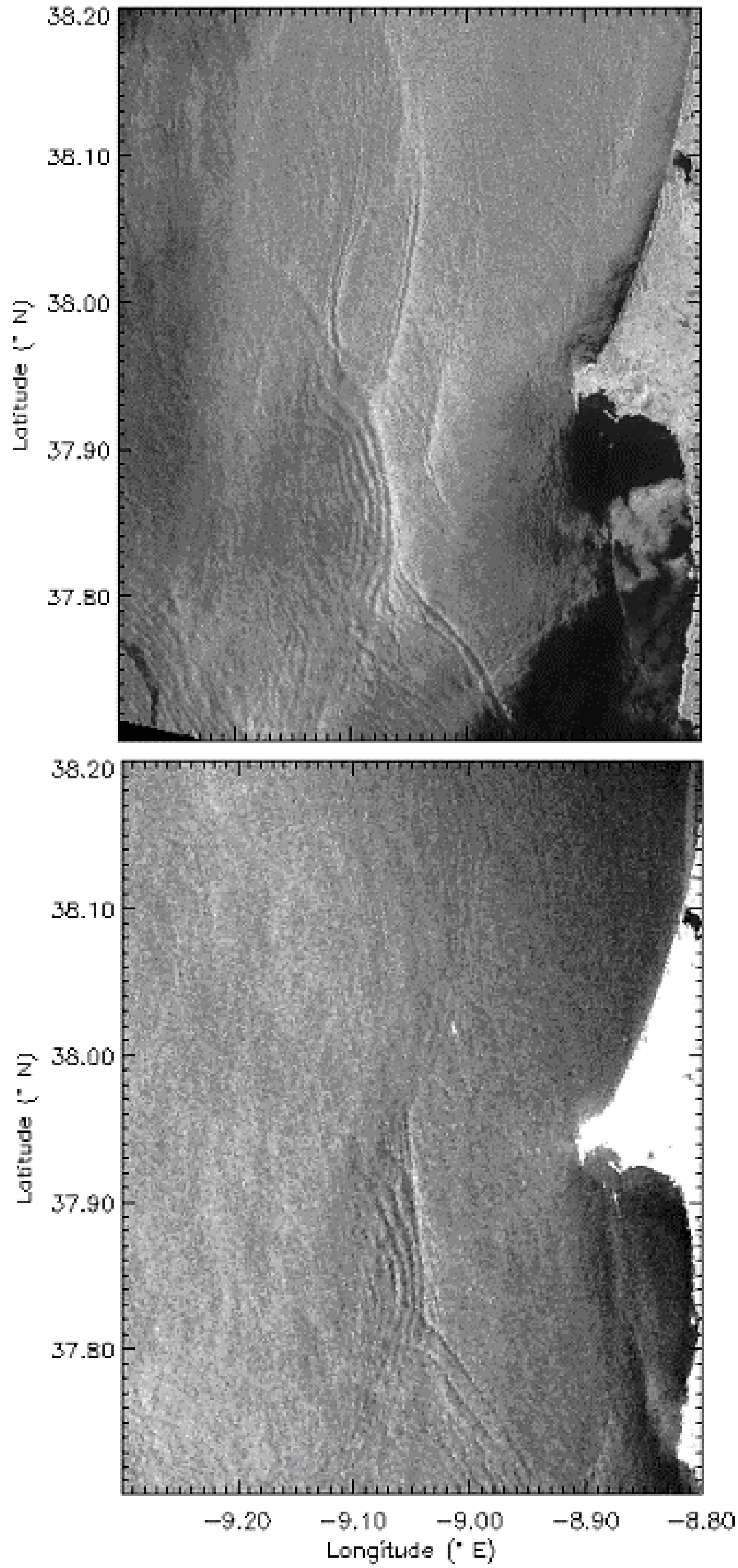


Figure 3. RADARSAT-1 (C-band, HH) SAR images over the coastal waters off Cape Sines, Portugal. (Top) Image acquired on 6 July 1999 at 1832 UTC, 6 days after spring tide and 1 hour 33 minutes before high water at Sines. (Bottom) Image acquired on 7 July 1999 at 0647 UTC, 7 days after spring tide and 2 hours 2 minutes before high water at Sines. The images were acquired 12 hours 15 minutes apart. ©CSA 1999. [After Small, 2002. Courtesy of Justin Small, School of Ocean and Earth Science and Technology, University of Hawaii, Honolulu, Hawaii]

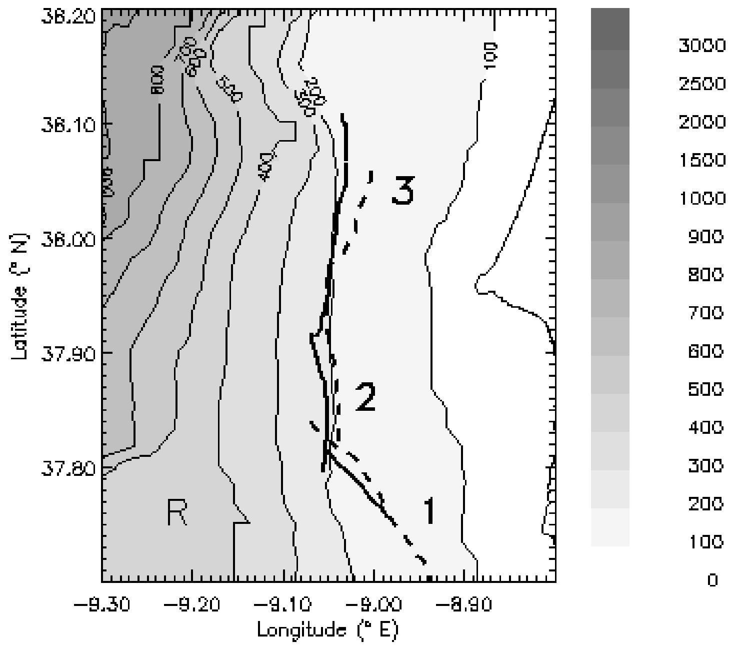
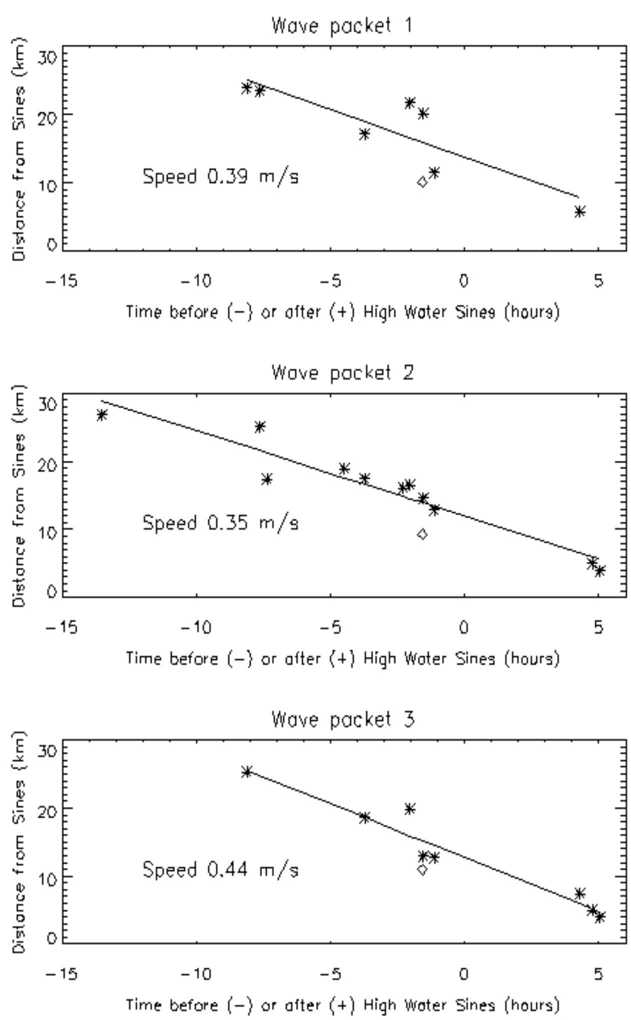


Figure 4. (Top) Position of the leading solitons of the three main wave packets observed in RADARSAT-1 images. Thick lines show the positions taken from the 7 July 1999 at 0647 UTC, dashed lines show the positions taken from the 6 July 1999 at 1832 UTC [see Figure 2]. The coastline is taken from GEBCO and water depth (in m) is taken from the Instituto Hidrografico Lisbon, 1-minute bathymetry database. (Right) Distance of the leading internal soliton in the wave packets from Cape Sines as a function of the phase of the tidal cycle (at the port of Sines). Images from June to August are included only. Data points are shown as asterisks, except for 8 August 1999, which are shown as diamonds. The propagation speed of the leading soliton in the wave packets is obtained from a least-square fit of the data points and is marked on each plot. The times of high water for the port of Sines has been taken from the Portuguese and the UK Admiralty Tide Tables. [After Small, 2002. Courtesy of Justin Small, School of Ocean and Earth Science and Technology, University of Hawaii, Honolulu, Hawaii]



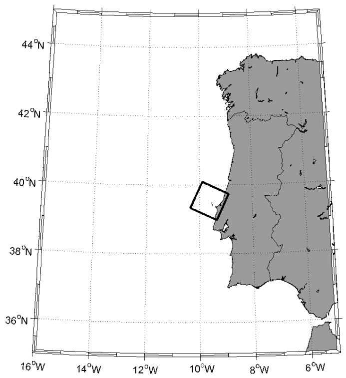
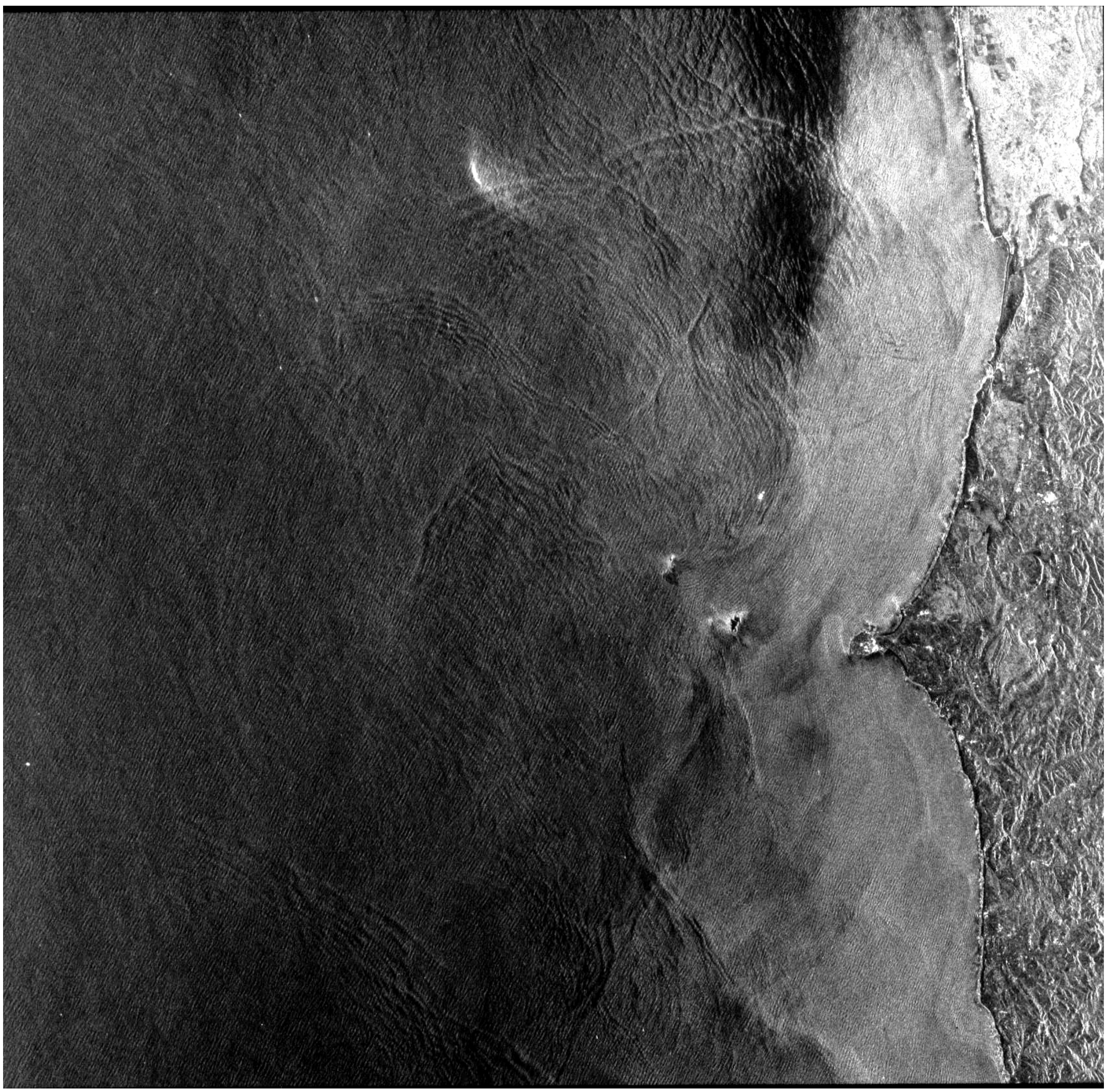


Figure 5. SEASAT (L-band, HH) SAR image of internal waves off the coast of Portugal acquired on 20 August 1978 at 2143 UTC (Rev 785). Imaged area is approximately 100 km x 100 km. [Image courtesy of NASA JPL]



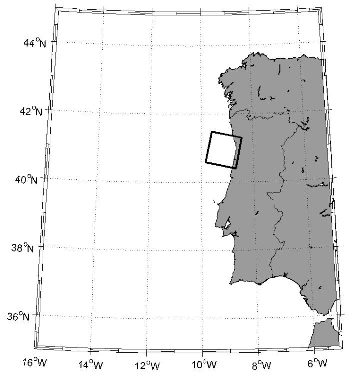


Figure 6. ERS-1 SAR (C-band, VV) image over the coastal waters off Oporto, Portugal showing significant internal wave activity on the continental shelf. Image was acquired on 8 August 1994 at 1122 UTC (orbit 16020, frame 2781). Internal wave signatures extend more than 200 km along the coast. Imaged area is 100 km x 100 km. ©ESA 1994. [Image courtesy of José da Silva, Instituto de Oceanografia, Lisbon, Portugal]

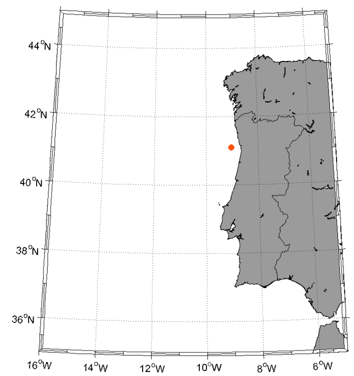
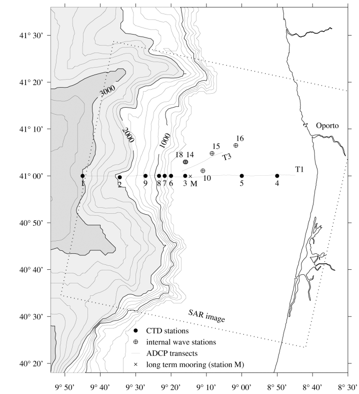
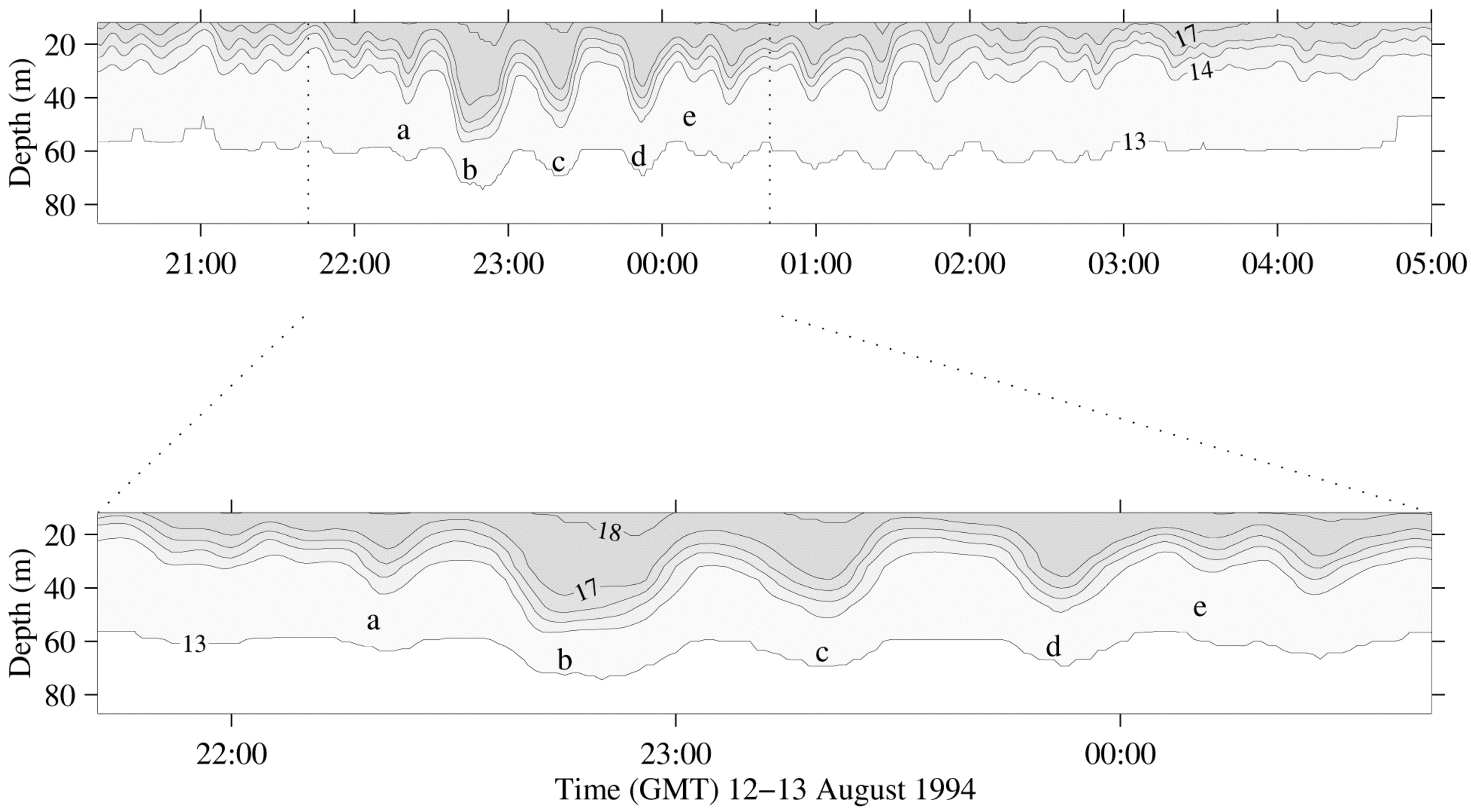


Figure 7. Thermistor chain observation of a non-linear internal wave train passing Station 16 located off the coast of Portugal in August 1994 (map at right). The letters a to e in the lower figure indicate different troughs in the internal wave train. [After Jeans and Sherwin, 1998, 2000]





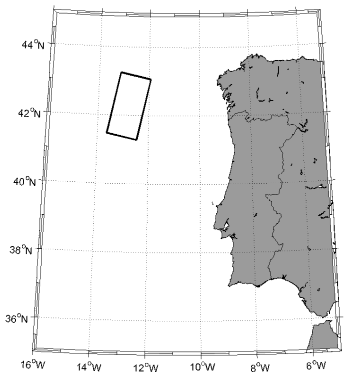
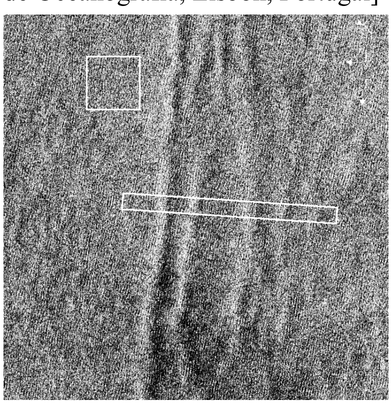
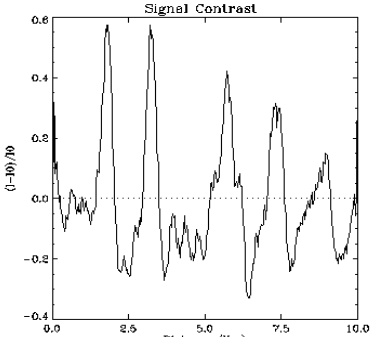
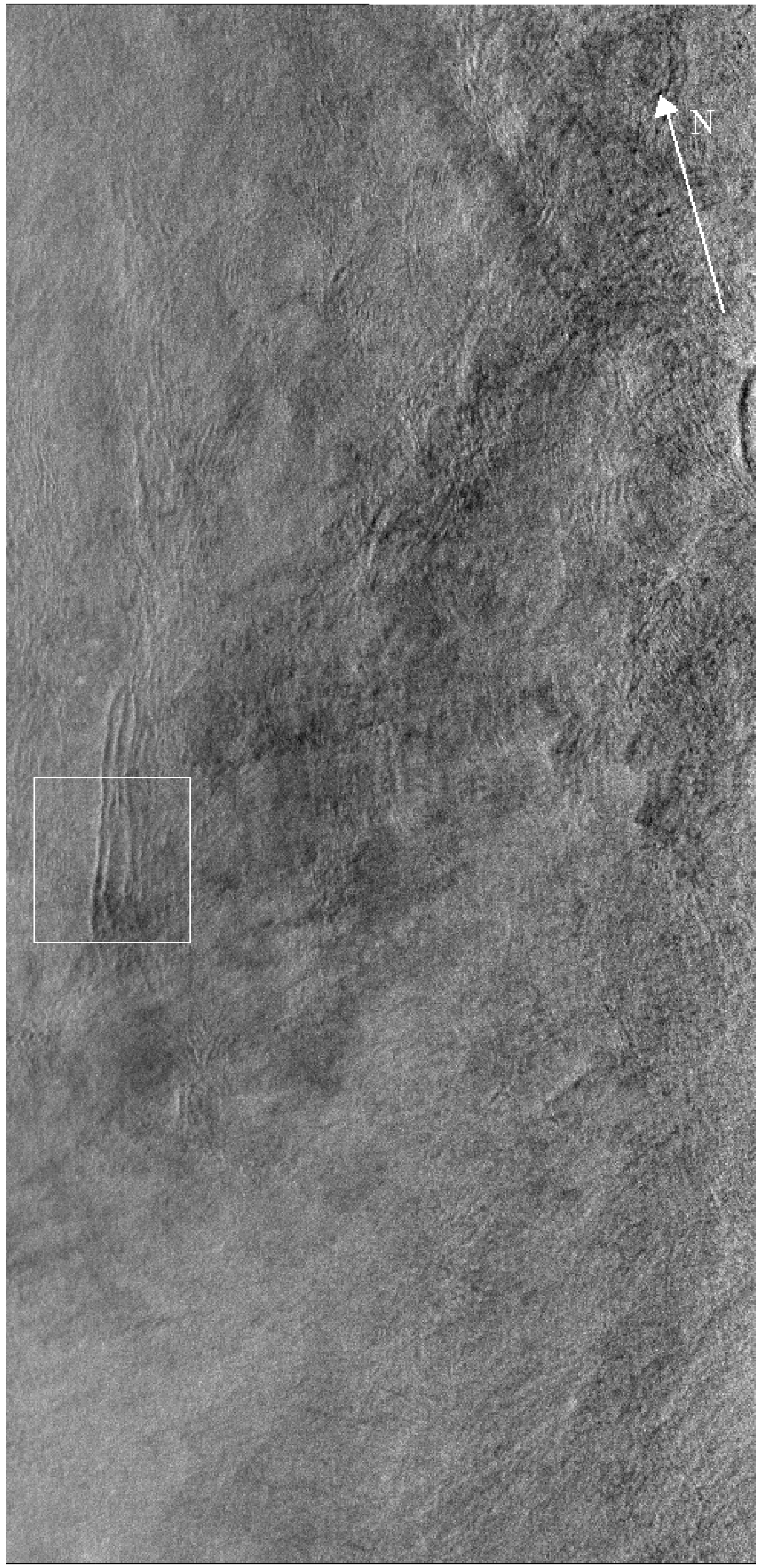
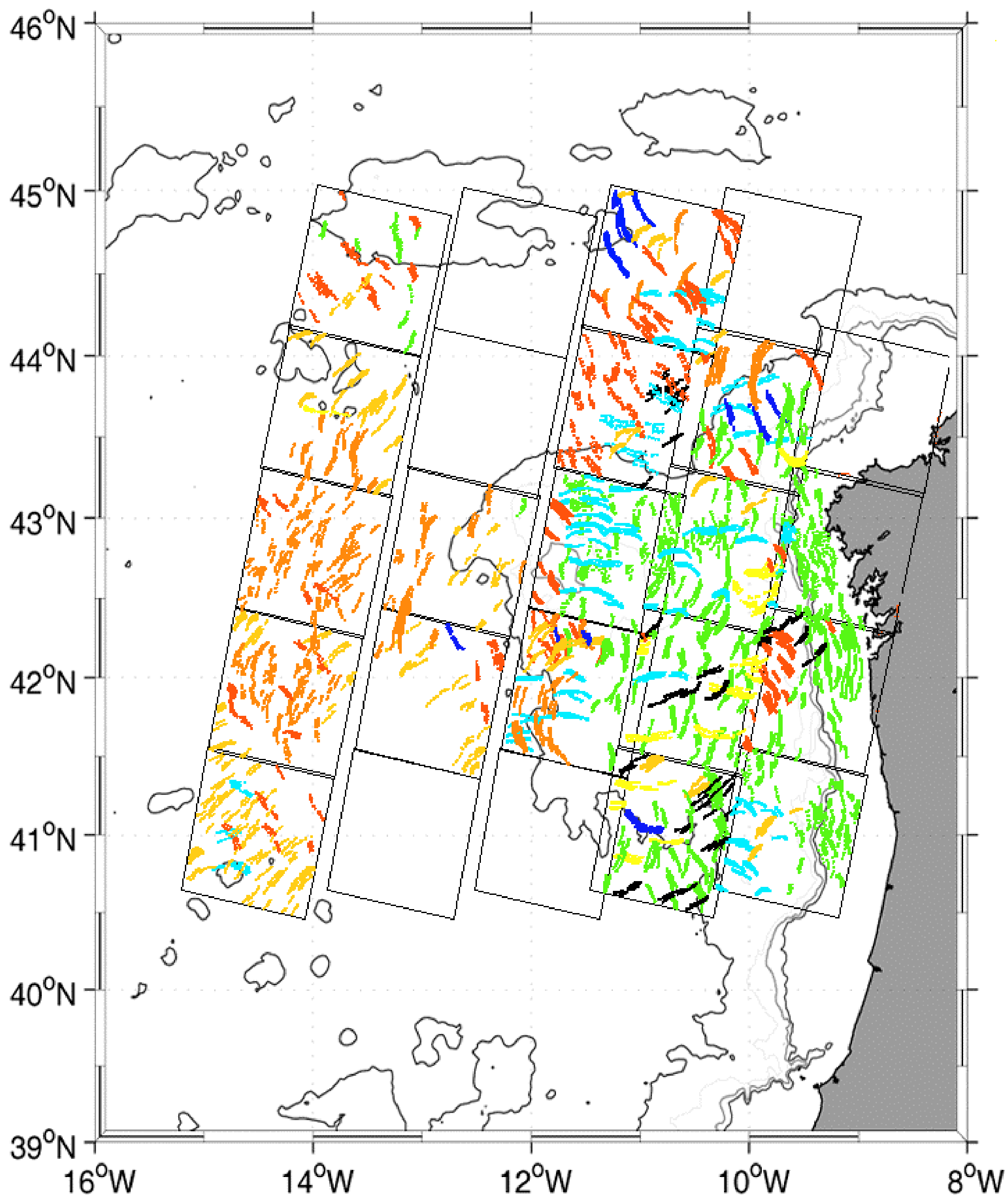


Figure. 8. ERS-1 (C-band, VV) SAR image west of Galicia Bank acquired on 30 July 1994 at 1138 UTC (orbit 15891, frames 2745, 2763). The image shows several trains of ISWs propagating seaward. The image shown below is a zoom (full resolution) of the section of the image marked by a white box in the image at right. The variation of the relative image intensity across the internal wave signature (rectangle), normalized to the background backscatter (square box), is shown in the lower figure [After Azevedo et al. 2003, courtesy of Jose da Silva Instituto de Oceanografia, Lisbon, Portugal]









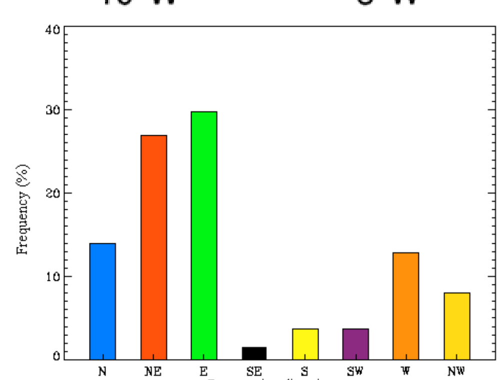


Figure 9. Distribution map of internal wave occurrences along the northwestern coast of the Iberian Peninsula and around the Galicia Bank. The map, compiled by Correia [2003], was generated from 18 ERS SAR frames acquired in September 1991(4), July 1994 (7), August 1994(4), and July 2000(3). The wave propagation direction is color keyed. A histogram of the wave propagation direction is shown in the figure to the right. [Map courtesy of José da Silva Instituto de Oceanografia, Lisbon, Portugal]

References

Apel, J.R., 1979; Observations of internal wave surface signatures in ASTP photographs, Apollo-Soyuz Test Project II, F. El-Baz and D.M. Warner eds., NASA SP-412

Azevedo, A., S. Correia, J.C.B. Da Silva and A.L. New, 2004; Hot-spots of internal wave activity off Iberia revealed by multi-sensor remote sensing satellite observations – Spotiwave, 2nd Workshop on Coastal and Marine Applications of SAR, Longyearbyen, Spitsbergen, Norway, 8-12 September 2003. To be published in ESA Special Publication Series SP-565.

Correia, S.M.L., 2003; "Observation of internal waves using multisensor satellite data off the Iberian Peninsula", 164 pp, University of Lisbon, Institute of Oceanography, Lisbon December 2003, (in Portuguese).

da Silva J. C. B., Ermakov S. A., Robinson I. S., Jeans D. R. G., Kijashko S. V. (1998). 'Role of surface films in ERS SAR signatures of internal waves on the shelf 1. Short Period Internal Waves' *J Geophys. Res*., 103(C4), 8009-8031.

Jeans D. R. G., 1998; A nonlinear internal tide on the Portuguese shelf', PhD Thesis, University of Wales, Bangor.

Jeans D. R. G., T. J. Sherwin, 2001; The evolution and energetics of large amplitude waves on the Portuguese shelf. *Journal of Marine Research*, Vol 59 (3) 2001**,** 327-353

Jeans, D.R.G. and Sherwin, T.J. 2001; The variability of strongly non-linear solitary internal waves observed during an upwelling season on the Portuguese shelf. *Continental Shelf Research*, 21, 1855-1878.

Large Marine Ecosystems of the World: LME 25: Iberian Coastal Ecosystem, January 2004 http://na.nefsc.noaa.gov/lme/text/lme25.htm

New, A.L., and R.D. Pingree, 1992: Local generation of internal soliton packets in the central Bay of Biscay. *Deep-Sea Re*s., **39A (9**), 1521-1534.

New, A.L., and J.C.B. DaSilva, 2002: Remote-sensing evidence for the local generation of internal soliton packets in the central Bay of Biscay *Deep-Sea Re*s., **49,** 915-934

Sherwin, T.J., and D.R.G. Jeans, 1999: An investigation of the temporal variability of a non-linear internal wave field on the Portuguese Shelf. *Woods Hole Oceanographic Institution Technical Report* WHOI-99-07, ed. by T. Duda and D. Farmer

Small, J. 2002; Internal tide transformation across a continental slope off Cape Sines, Portugal. *Journal of Marine Systems*, 32:43-69.

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

THIS PAGE INTENTIONALLY LEFT BLANK