New England Shelf and the Gulf of Maine

Overview

The New England Shelf and the Gulf of Maine are located along Northeast coast of the United States. The New England Shelf extends from the eastern tip of Long Island to the southern end of Nova Scotia (Figure 1). The region includes the Nantucket Shoals, Georges Bank and Browns Bank; the latter two which mark the boundary between the Gulf of Maine and the Atlantic Ocean.

The Gulf of Maine is a semi-enclosed sea with a complex array of banks, ridges, gullies, and basins that extend as deep as 1,500 feet (500 meters) beneath the surface. These include, among others, Stellwagen Bank near Massachusetts Bay, Cashes Ledge, and Georges Basin.

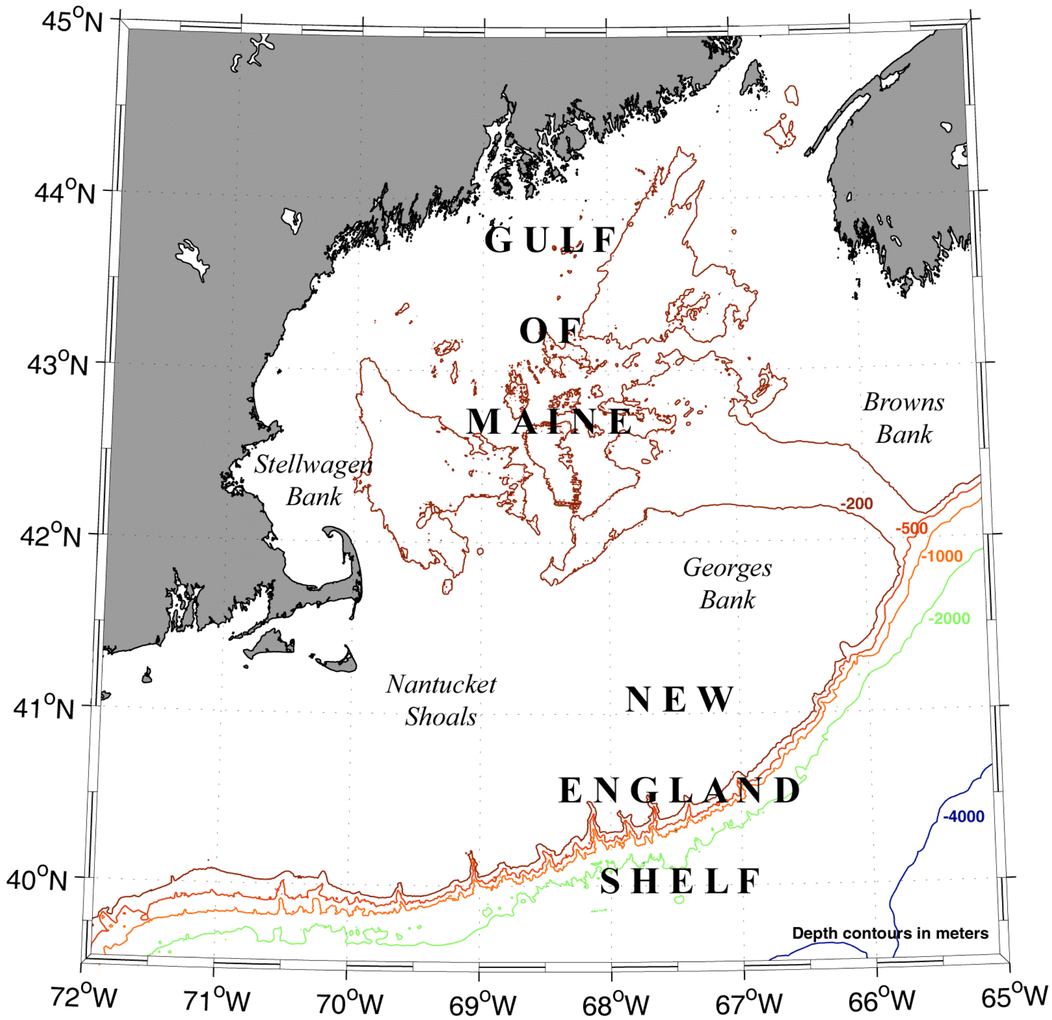


Figure 1. Bathymetry of New England Shelf and the Gulf of Maine

Observations

It has been more than 30 years since Halpern [1970, 1971] first published his observations of the internal tide and short period internal waves in Massachusetts Bay. Since that time there has been a considerable number of investigations into internal wave occurrences on the New England Shelf and Georges Bank and in the Gulf of Maine. [See Haury et al. 1979, 1983; Chereskin, 1983; Trask and Briscoe, 1983; Chang et al. 1998, Chang and Dickey 1999, 2001; Colosi et al. 2001; Porter et al. 2001]. The list most likely several hundred references short without taking into consideration the numerous cruise reports that have noted sightings of internal waves. The proximity of the Georges Bank and the Gulf of Maine to the Woods Hole Oceanographic Institute probably makes them some of the best studies oceanographic areas in the world.

The signatures of internal waves are typically observed in imagery acquired between May and October when summer heating of the upper layers in coastal waters enhances the stratification necessary for internal wave occurrences. In situ measurements taken during the winter months off Georges Bank also show the presence of internal waves [P. Weibe, personal communication, 2004]. These "winter" internal waves manifest themselves as waves of elevation propagating along the pycnocline close to the bottom. Table 1 shows the months of the year during when internal waves have been observed in this region.

Table 1 - Months when internal waves have been observed on the New England Shelf and the Gulf of Maine. (Numbers indicate unique dates in that month when waves have been noted)

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
				X	X	X	X	X	X		

The solitons along the New England Shelf are generated by tidal flow near the edge of the continental shelf and occur in groups separated by some 20 to 35 km, depending on their speeds of propagation, which are typically 0.5 to 1 m/s. Soliton amplitudes of 5 to 25 m have been measured, and wavelengths from 200 to over 1000 m. Table 2 presents a summary of internal wave characteristics for the region. The values have been reported in the literature and derived from remote sensing data sources. In the Gulf of Maine a similar generation mechanism is at work with tidal flow over one of the Gulf's many banks or ledges.

Table 2. Characteristic Scales for solitons along the New England Shelf and the Gulf of Maine

Characteristic	Scale
Amplitude Factor	-5 to –25 (m)
Long Wave Speed	0.5 to 1.0 (m s^{-1})
Maximum Wavelength	0.6 to 1.5 (km)
Wave Period	8 to 25 (min)
Surface Width	100 (m)
Packet Length	1 to 10 (km)
Along Crest Length	10 to 30 (km)
Packet Separation	15 to 40 (km)

Figure 2 is an ERS-2 (C-band, VV) SAR image acquired August 1996 during ONR's Coastal Mixing and Optics (CMO) Experiment. The image shows the signature of a large internal wave field propagating shoreward. Figure 3 shows a temperature history collected via a thermistor string during the Shelfbreak Primer Study in July 1996. Solitons appearing as spikes on top of the internal tidal modulation.

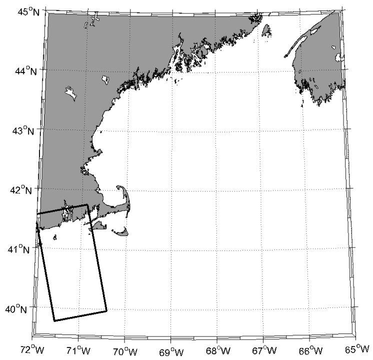
Figure 4 is a RADARSAT SAR image over Cape Code and Massachusetts Bay acquired in September 1998. The image shows the signatures of large continental shelf generated solitons east of Cape Cod. The signature of smaller internal waves can be seen in Massachusetts Bay and the Gulf of Maine generated by localized bathymetric variations. Figure 5 is a MODIS 250-m resolution visible image acquired over the Northern Gulf of Maine. The image shows a variety of internal wave signatures (many near the resolution limit of the sensor) southwest of Nova Scotia. The complex bathymetry of the Gulf of Maine providing for the large number of internal wave sources

Figure 6 is a density profile for the Massachusetts Bay near Stellwagen Bank acquired on 17 August 1999 at 42.31^{0}N, 70.42^{0}W during Cruise NAGL-98-01B. The normalized Mode 1 and Mode 2 eigenfunctions have been evaluated for $\lambda = \frac{2\pi}{k_0} = 400m$, with H = 77 m. For long waves ($k \to 0$) the maximum first mode wave speed (c_0) is computed to be 0.57 m/s without the effect of current shear. Figures 6e and 6f give the phase velocity and dispersion relations for the data. Table 3 presents the environmental coefficients and KDV parameters evaluated at wavenumber k_0 for U_0= 0.

The data in figure 5 were taken contemporaneously with the 120 kHz acoustic survey transect between Scituate, Massachusetts and Stellwagen Bank acquired 14 August 1999. The survey began slightly to the west of Stellwagen Bank (top panel – at right) and the ship moved from east to west (right to left). The evolution of the internal wave packet is clearly visible.

Figures 8 and 9 show the internal waves generated over and near Georges Bank. Not surprisingly, the characteristics of these internal waves are similar to those observed in the New York Bight, since the outer New England Shelf has similar bathymetry and is subject to the same tidal forces.

One theory of internal wave generation suggests that the operative process is formation of a lee wave down-current of a sharp change of bathymetry. Figure 10 is a short portion of a 120 kHz acoustic survey between the Northeast Peak (42.1^{o}N, 66.9^{o}W, 66 m water depth) and Georges Basin (42.3^{o}N, 66.9^{o}W, 295 m water depth) illustrating what appears to be a large lee-wave (the layer which runs along the bottom topography and then swoops up to near the surface). In the section further out into Georges Basin, small dense patches of scatterers occurred in a zone centered about 140 meters. These patches may have been herring schools.



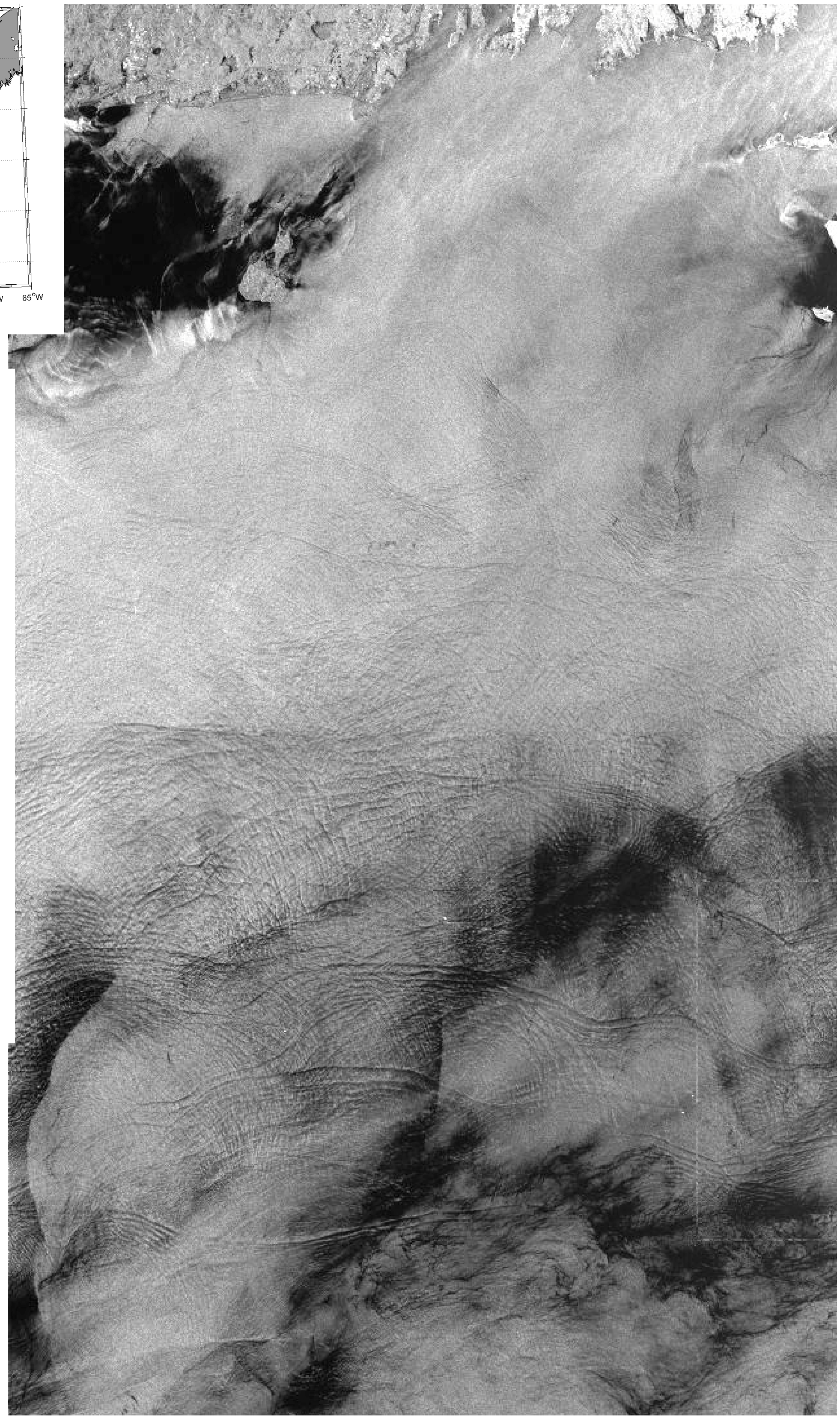
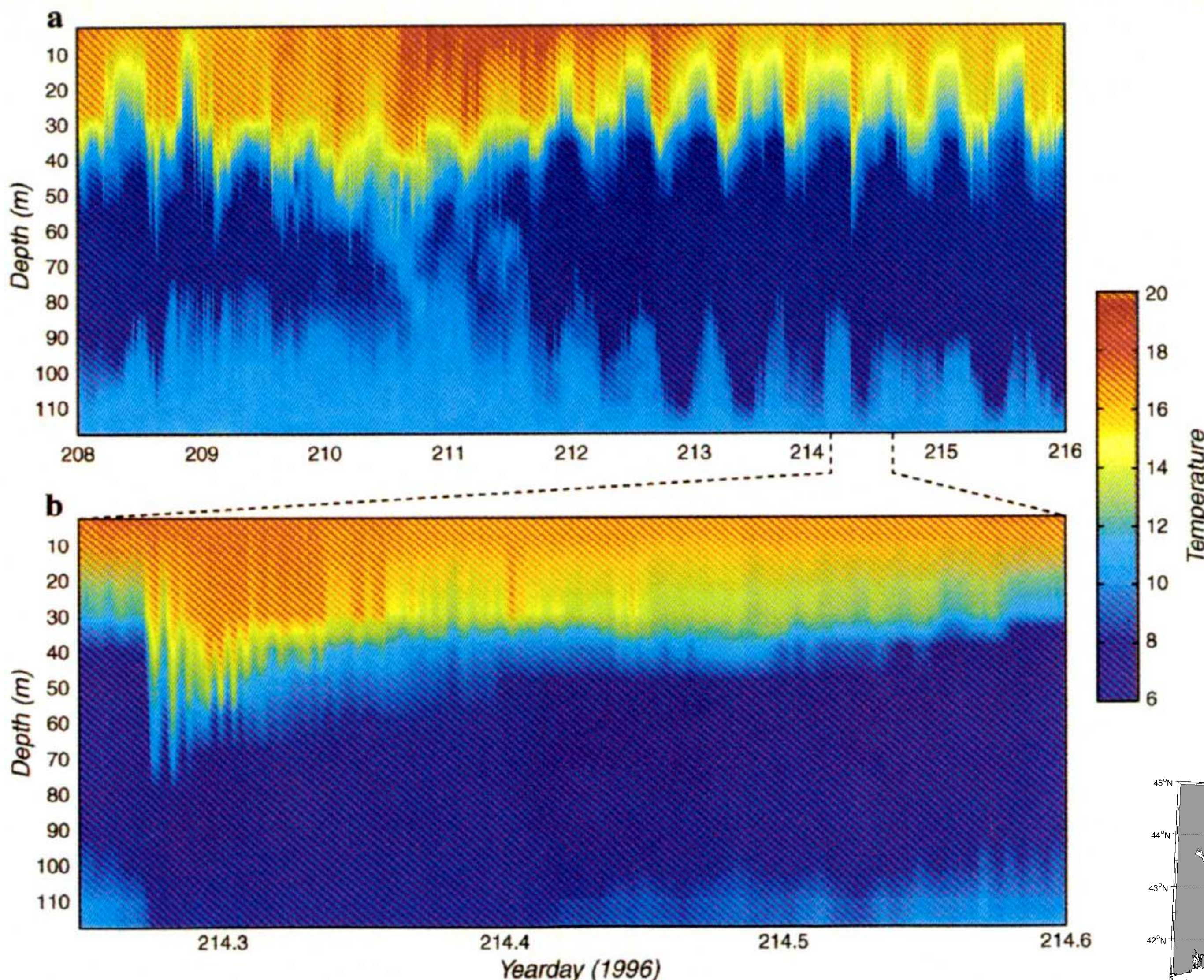


Figure 2. ERS-2 (C-Band, VV) SAR image over the New England Shelf acquired on 8 August 1996 at 2342 UTC (orbit 6800, frames 0801, 0819). A large number of continental shelf solitons can be seen south of the coast of Rhode Island. A uniform wind condition helps to highlight the internal wave signatures. Imaged area is 100 km x 200 km. ©ESA 1996. [Figure Courtesy of Don Thompson JHU/APL]



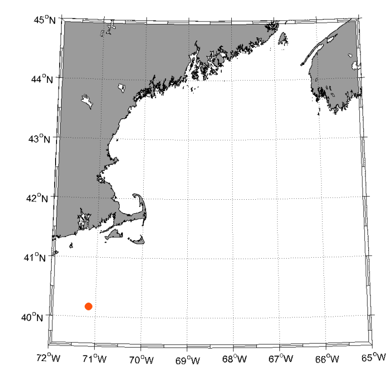


Figure 3. a) Temperature time series from a thermistor mooring near 40.17^0 N. 71.15^0, deployed as part of the Shelfbreak PRIMER study in 1996. b) An expanded view of the strongest bore event [Image from Colosi et. al 2001]

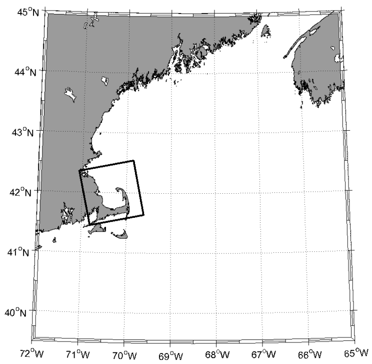
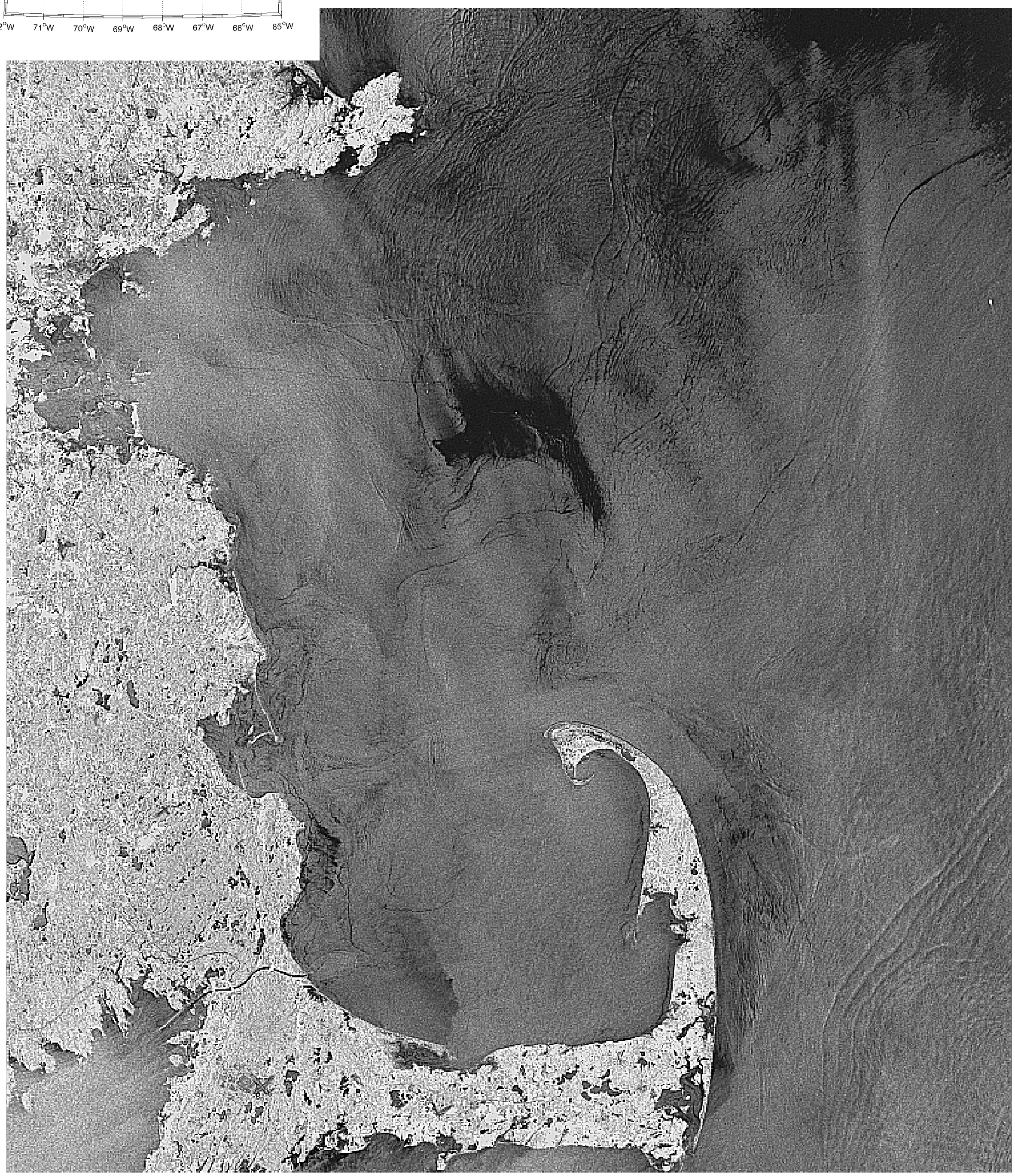


Figure 4. RADARSAT-1 (C-Band, HH) SAR image over Cape Cod and Massachusetts Bay acquired on 13 September 1998. Signatures of large continental shelf generated solitons are visible east of Cape Cod. Smaller internal wave signatures can be seen in Massachusetts Bay and the Gulf of Maine generated by localized bathymetric variations. Imaged area is approximately 100 km x 100 km. ©CSA 1998. [Figure Courtesy of Don Thompson JHU/APL]



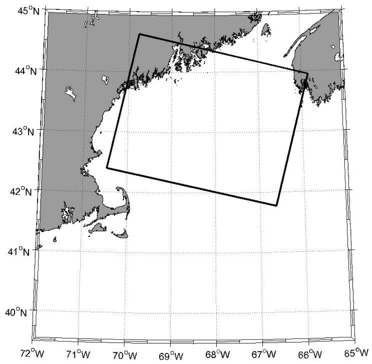
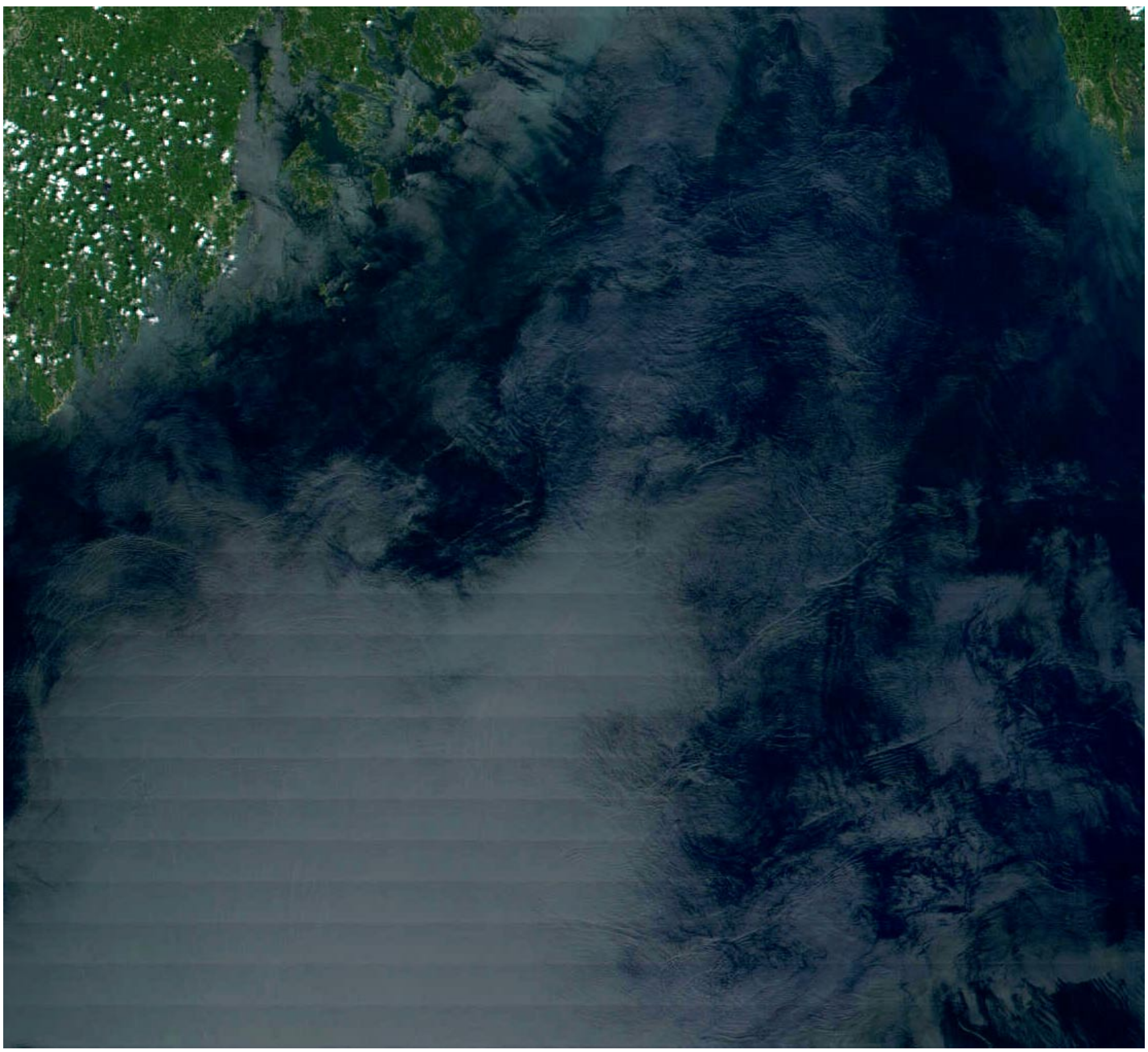
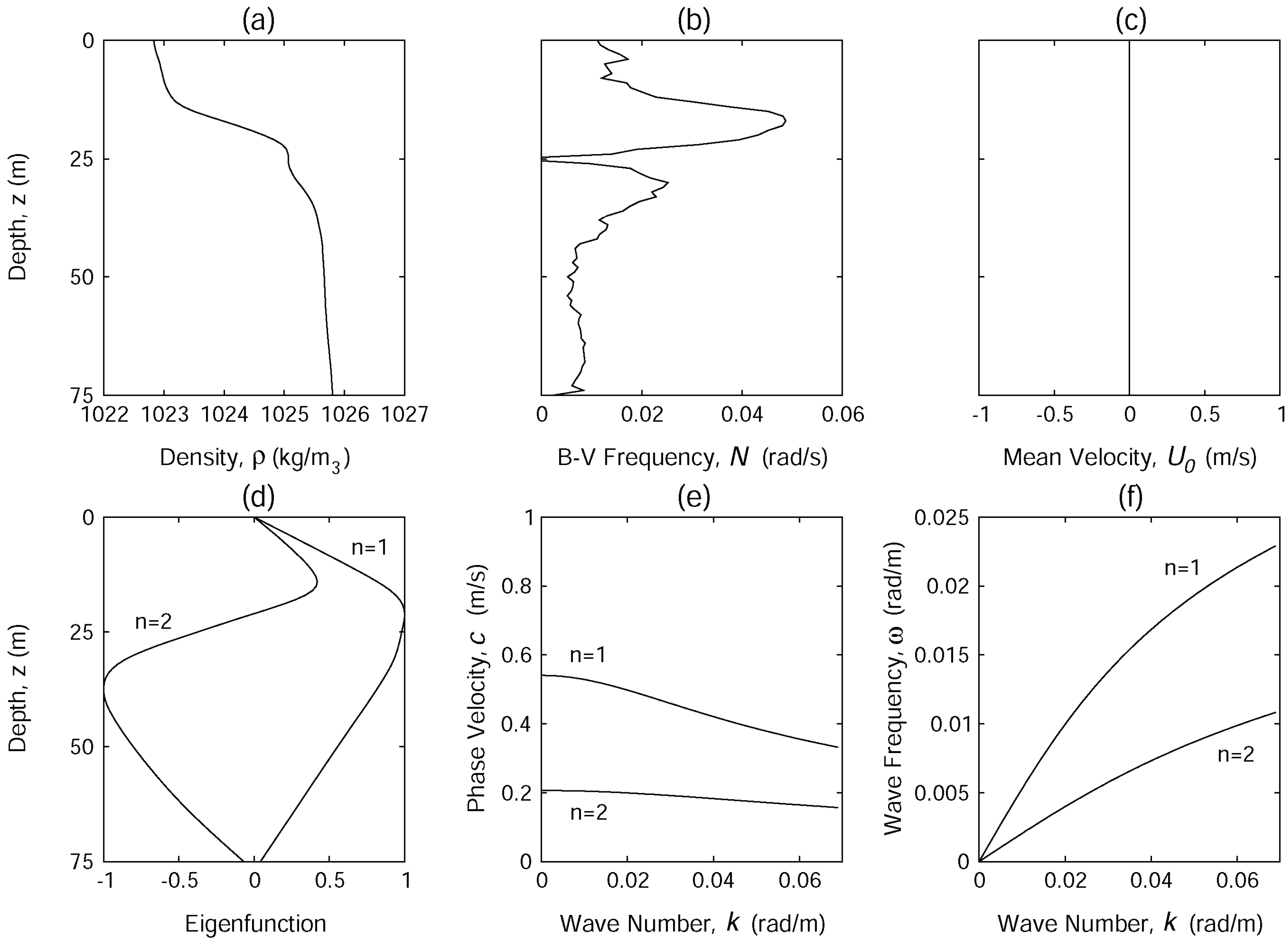


Figure 5. MODIS (Bands 1,3,4) 250-m resolution visible image over the central and northern Gulf of Maine acquired on 28 July 2001 at 1545 UTC. The image shows a variety of internal wave signatures (many near the resolution limit of the sensor) in the northern Gulf of Maine soutwest of Nova Scotia. The complex bathymetry of the Gulf of Maine provides and large number of internal wave sources. Imaged area is 250 km x 275 km.

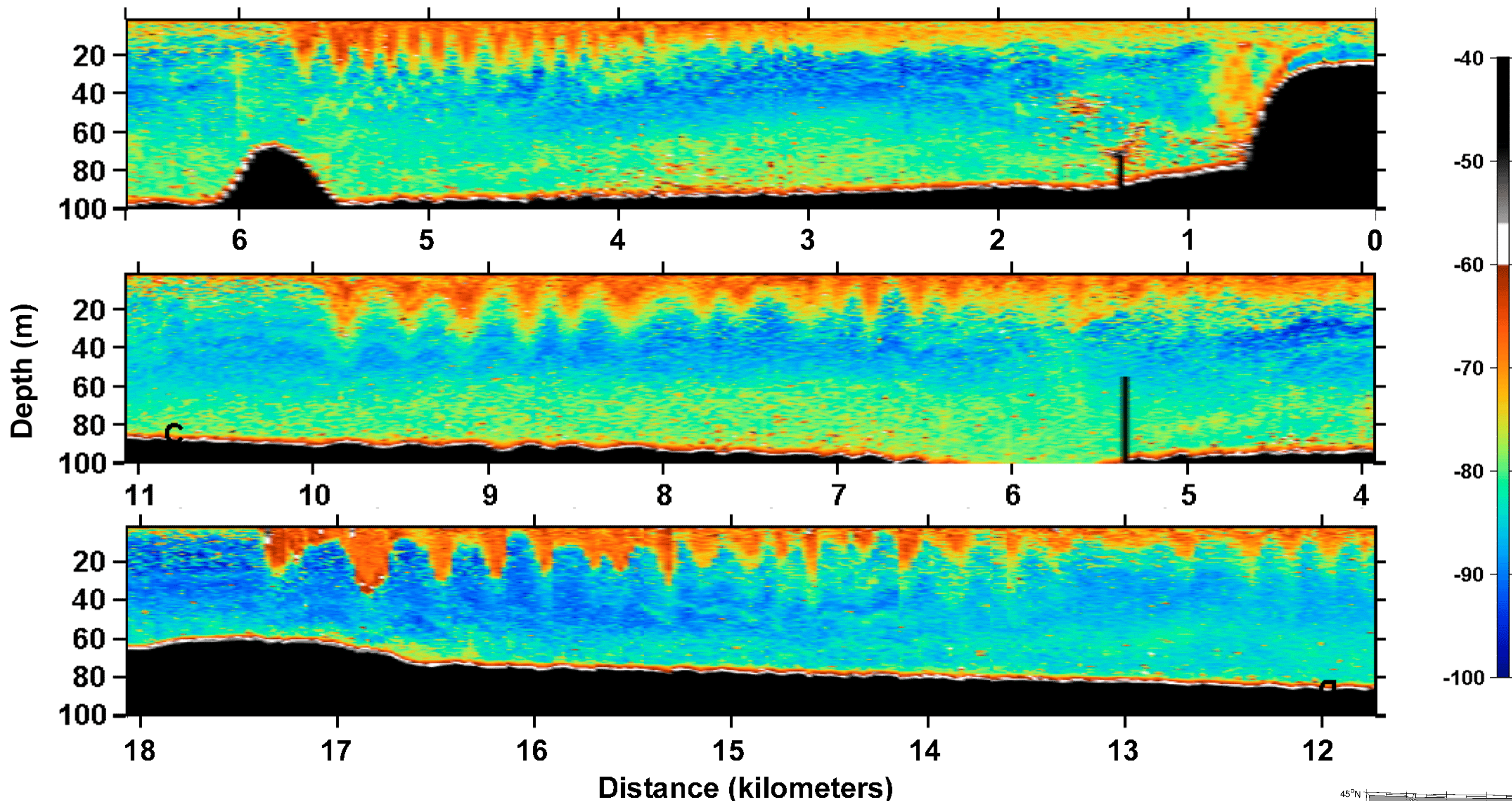




KDV Parameters
Mode 1

Wave Speed (k = 0) c_0 (m/s) 0.54
Nonlinear coefficient $1/\alpha$ (m) -18.5
Dispersion Factor $\gamma^{1/2}$ (m) 14.9
Amplitude (KDV theory) η_0 (m) -1.5
Non-Linear Phase Velocity V (m/s) for (s^2=1) 0.57

Figure 6. a) Smoothed density profile derived from CTD cast acquired on 17 August 1999 at 12:35 (local) and 42.31^{0}N, 70.42^{0}W, depth = 100 m near the acoustic survey transect shown in Figure 7 (data courtesy of Mark Benfield) b) derived Brunt-Väisälä frequency N(z) c) zero flow current profile d) Normalized vertical eigenfunctions (mode 1 & 2) for $2\pi/k_0$ = 400m, H = 77 m for density and velocity profiles shown e) phase velocity f) dispersion relations.



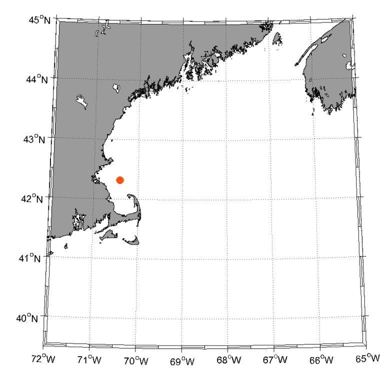
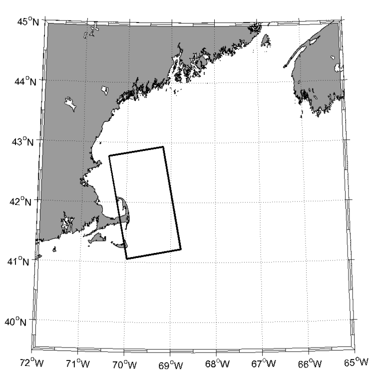


Figure 7. Part of the 120 kHz acoustic survey transect showing internal waves between Scituate, Massachusetts and Stellwagen Bank acquired on 14 to 15 August 1999 between approximately 2200 and 0500 local time. The internal waves were encountered slightly to the west of Stellwagen Bank (top panel – at right) with the ship moving from west to east (left to right). The evolution of the internal wave packet is clearly visible. [Data courtesy of Peter Weibe, WHOI, Woods Hole, Massachusetts]

Figure 8. RADARSAT-1 (C-Band, HH) SAR image of Cape Cod and the southern Gulf of Maine acquired on 13 August 1998. Continental shelf generated solitons can be seen east and southeast of Cape Cod. Internal wave signatures can be seen extending up into the Gulf of Maine. Imaged area is approximately 100 km x 200 km. ©CSA 1998. [Figure Courtesy of Don Thompson JHU/APL]



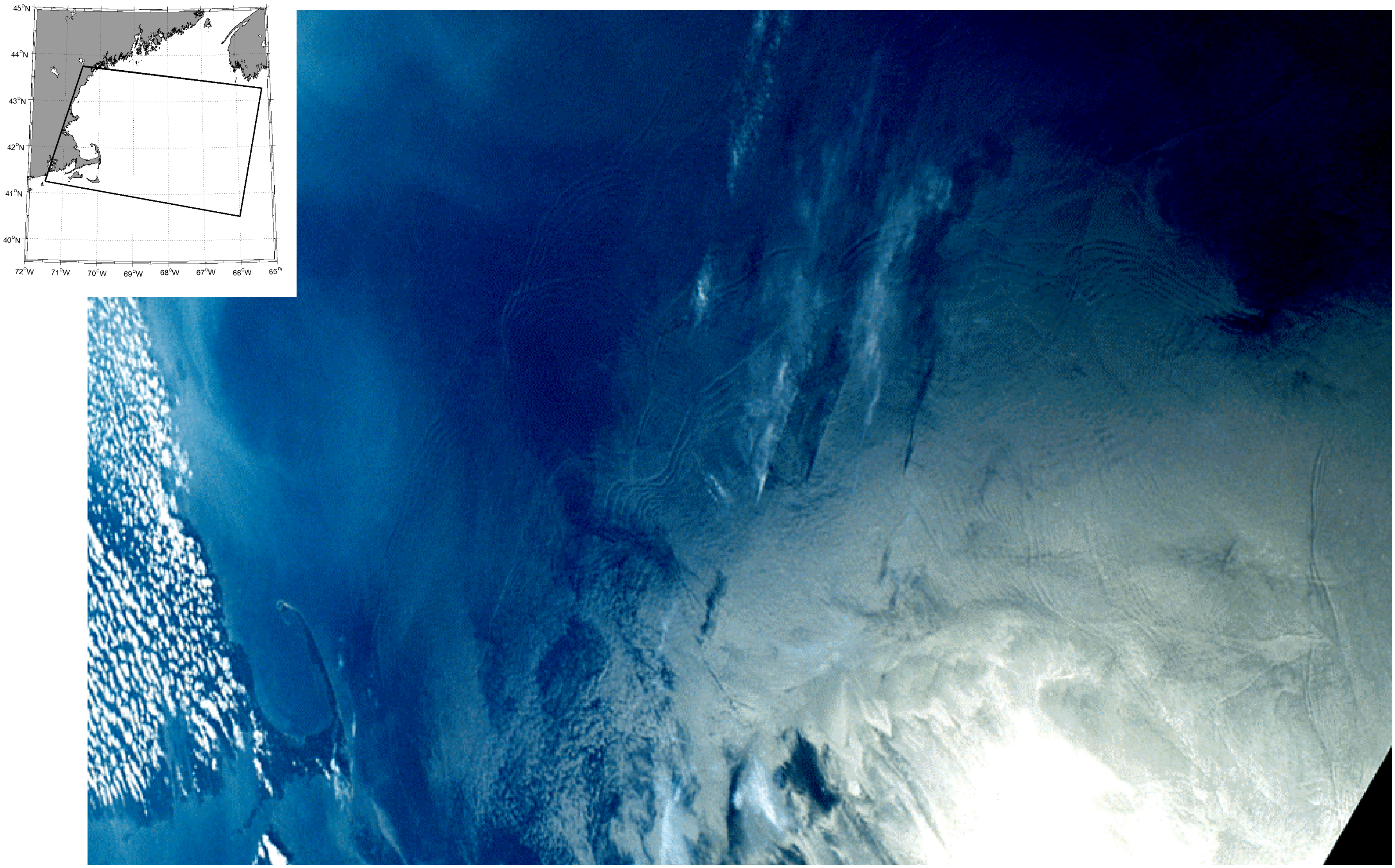
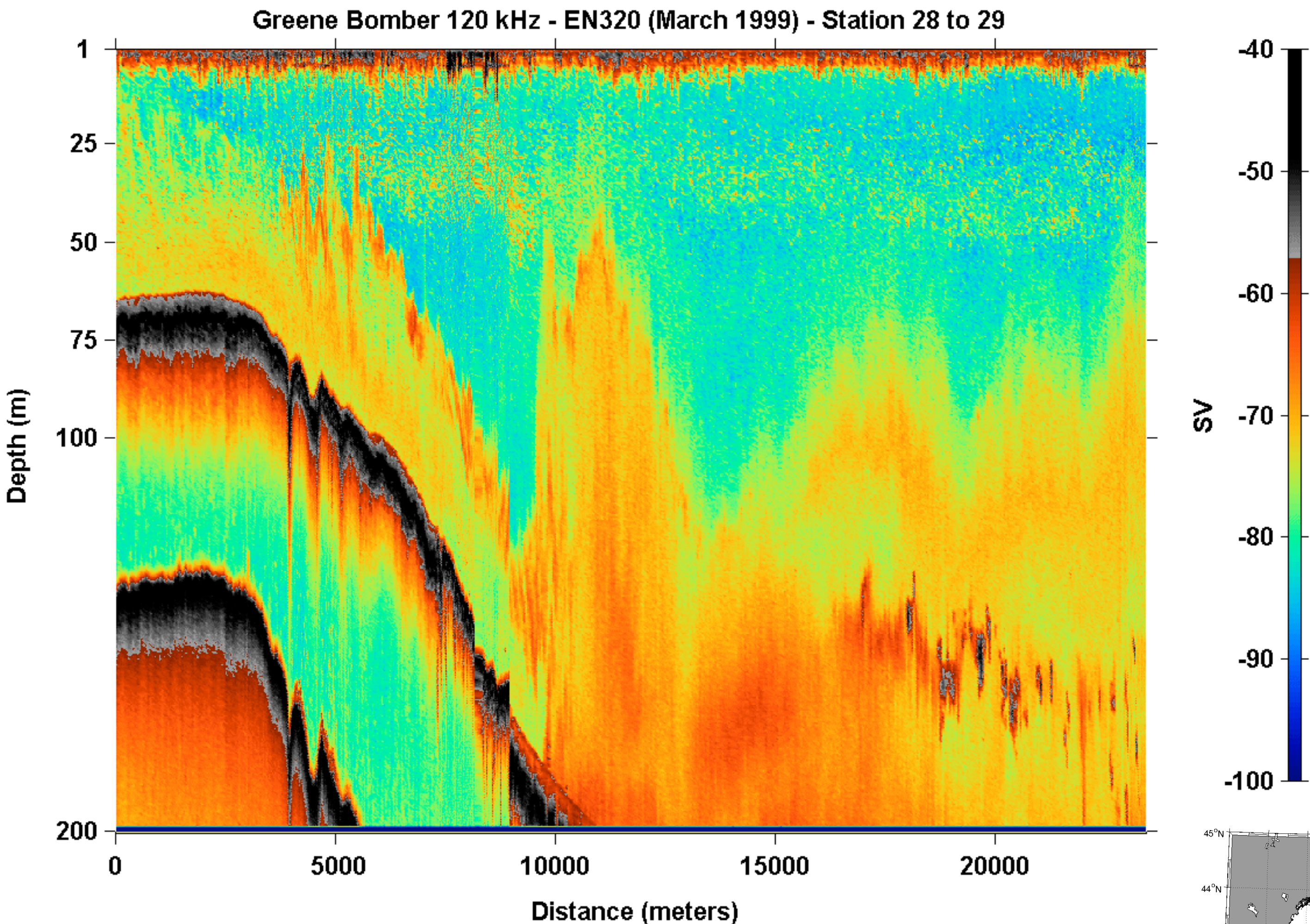
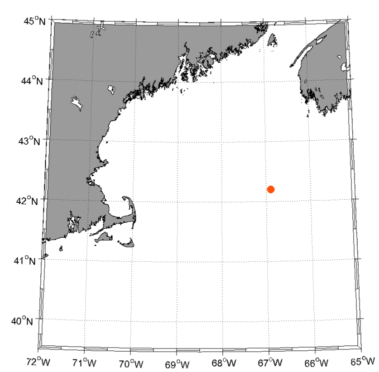


Figure 9. High oblique astronaut photograph (STS28-151-216) over the eastern tip of Georges Bank acquired on 9 August 1989. Sunglint highlights the signatures of internal wave generated along the eastern edge of the Gulf of Maine. [Image Courtesy of Earth Sciences and Image Analysis Laboratory, NASA Johnson Space Center (http://eol.jsc.nasa.gov)]





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