South China Sea

Overview

The South China Sea is a marginal sea in the western Pacific Ocean extending from the Taiwan Strait to the Java Sea where the distance between Borneo and Sumatra is smallest. It is bounded by the southeast Asian continental coast (to the west) and by the Philippines and Borneo (to the east). It includes deep basins as well as large shelf regions.

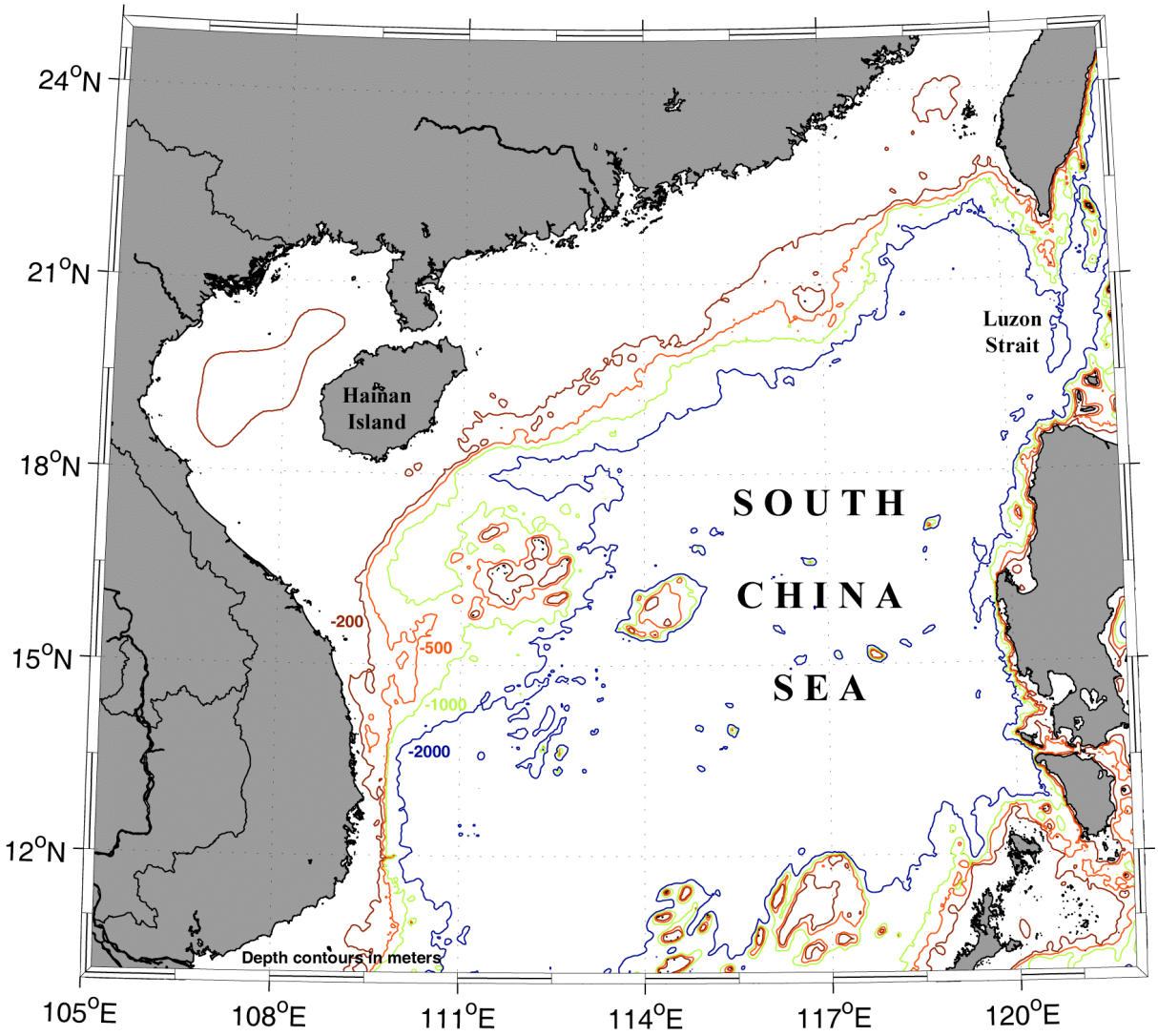

Figure 1. Bathymetry of the South China Sea. [Smith and Sandwell, 1997]

Observations

There has been some scientific study of internal waves in the South China Sea; initially by satellite imagery [Liu et al. 1998; Hsu and Liu 2000] and more recently by in situ observation during the ASIAEX campaign. Internal waves in the South China Sea occur in three regions; a) between the Luzon Strait and Hainan, b) along the Vietnamese coast and c) between Vietnam and Borneo. Internal waves are observed most frequently during summer, but in some regions activity is observed almost all year round.

Table 1 - Months when internal waves have been observed in the South China 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
1	3	1	7	9	13	18	7	2	2		

Region 1: Luzon Strait to Hainan Island

Internal solitary waves are found in the northern section of the South China Sea in the region between the Luzon Strait and Hainan Island. There are two categories of internal solitary waves: a) transbasin waves that are generated at shallow topography in the Luzon Strait under the influence of the tide and the Kuroshio Current, and b) internal waves that are generated at or near the continental shelf break by either the incident transbasin waves and / or the diurnal tide. [Duda et al. 2004]

The transbasin waves are large amplitude (>100 meter) solitary waves of depression that propagate from the Luzon Strait westwards, refract at Dongsha Island and its surrounding coral reef, and eventually impinge onto the continental shelf where they change amplitude, horizontal length scale and energy [Duda et al. 2004]. These waves can have crest lengths in excess of 200 km, they propagate with speeds up to 1.9 m/s [Hsu and Liu, 2000], and appear to occur in fortnightly groups. Figures 3 through 6 show examples of transbasin internal wave throughout their life cycle. A geographic distribution map of these transbasin waves was compiled by Hsu and Liu [2000] from "hundreds" of ERS-1/2 and RADARSAT synthetic aperture radar images acquired from 1993 to 1998 and is depicted in Figure7. KDV parameters derived from ASIAEX CTD casts are shown in Figure 2 [Liu et al. 2004].

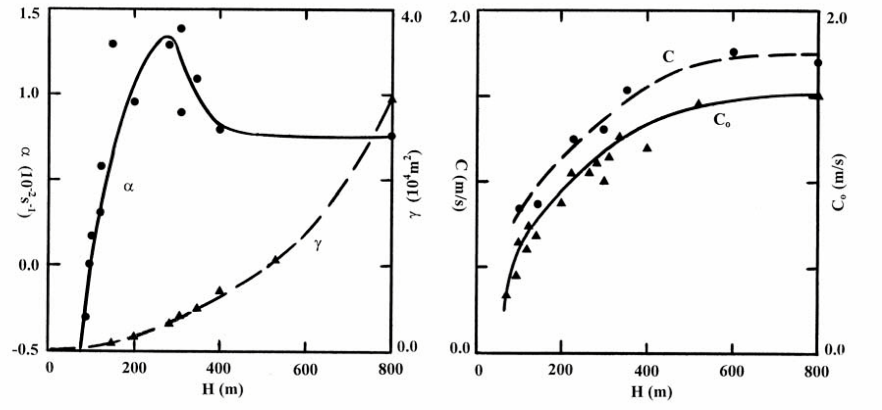

Figure 2. Environmental parameters α and γ as a function of depth derived from ASIAEX CTD cast data. (See Background and Theory Section 5.1.2). The nonlinear parameter α crosses zero at depth of 100 m and peaks at approximately 300 m. The difference between C and C_0 is caused by nonlinear effects.

Once the transbasin waves reach the area of the continental shelf break (inside the 500-m isobath) the transbasin solitons of depression first disintegrate into dispersive wave trains and then evolve into a packet of solitons of elevation in the shallow water area after they pass through a "turning point" of approximately equal layer depths. This was first noted in the change of the waves signatures in SAR imagery [Liu et al. 1998] and more recently via high frequency acoustics [Orr and Mignerey, 2003] collected as part of the ASIAEX program.

Internal waves generated at the shelf are shorter-scale and become ubiquitous in the region inside the 200-m isobath. Examples are shown in Figures 4 (top), 8 and 9 as observed by SAR and in Figure 10 as measured by in situ temperature sensors during ASIAEX [Duda et al. 2004]. In addition, there are a kind of internal wave generated at the shelf break by the diurnal tide that were observed during ASIAEX in areas where the shelf slope is near a "critical" value, i.e., where the slope has values between 0.16 and 0.3 degrees [Duda et al. 2004].

ASIAEX: In April and May 2001 several moorings were deployed around the continental shelf break area in the northern section of the South China Sea (SCS) as part of the Asian Seas International Acoustics Experiment (ASIAEX). RADARSAT-1 SAR images were also collected during this time to integrate with the in-situ measurements from moorings, shipboard sensors, and CTD casts. The goal was the study of the local ocean physics and direct comparison of temporal and spatial variability of acoustical and environmental signals. Details of the experiment and its findings are given in Beardsley et al. [2004] Chiu et al. [2004] Duda et al. [2004a,b], Liu et al. [2004] and Ramp et al. [2004].

Region 2: Along the Vietnamese Coast

Several different types of internal wave signatures have been observed along the Vietnam Coast south of Hainan Island. These observations include a) signatures of internal waves similar to the ones generated at the shelf by the large transbasin waves coming from the Luzon Strait, b) signatures of a "disorganized" internal wave field, and c) signatures well ordered and organized wave packets similar to the ones associated with internal waves generated at the continental shelf waves by the tide. All of these signatures reveal that the internal waves propagate to the northwest, roughly perpendicular to the continental shelf break. An example of the first type (a) of internal wave generated at the continental shelf can be seen in Figure 11 (top-right). Two packets are visible with a packet structure and orientation similar to packet structures observed on the image depicted in Figure 4 (upper section corresponding to the shelf region). Also visible, close to Hainan Island, are a number of less well-organized surface signatures. Figure 12 shows a more detailed view of these surface striations. By contrast, Figure 13 shows several well-organized wave packets propagating near the Hainan coast northeastwards The packet structure and the separation of the solitons within the packets are characteristic of solitons which are tidally generated at the he continental shelf. A similar set of well ordered packets south of Hainan Island propagating towards the Gulf of Tonkin is shown in Figure 14.

Figure 15 shows at least four well-defined internal wave packets with rank ordered solitons propagating southwestwards toward the Vietnamese coast. Figure 16 shows a large circular internal wave packet propagating to the southeast off the shelf into the South China Sea. The packet has a crest length in excess of 240 km. Its shape seems to be affected by the local bathymetry. The western edge of the packet can be seen to impinge on the Vietnam coast. Thus these seaward propagating wave packets are possibly the source of the wave approaching Vietnam. Figure 17 shows a high-resolution image from an area further south along the coast that was acquired at the same time as the image depicted in Figure 16.

Region 3: South Vietnam to Borneo

Internal wave dynamics in the southern South China Sea are influenced by both the outflow of the Mekong River and by the broad continental shelf between Vietnam and Borneo. In Figure 18 an ERS SAR image showing the Mekong River plume fronts. In some parts along these fronts very fine scale internal wave packets can be delineated Note, however, that the internal wave signatures in this image are partly contaminated by signatures associated with low wind speed (dark area) and atmospheric convective cells.

Figure 19 shows three fine scale, well ordered soliton packets propagating to the southwest over the continental shelf between Vietnam and Borneo. Packet separation is approximately 60 km. The packet structure, separation between the solitons in the packets, and the orientation of the wave crests suggest that they are tidally generated at the shelf break.

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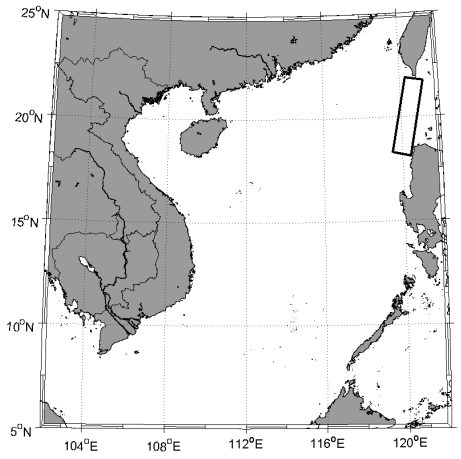


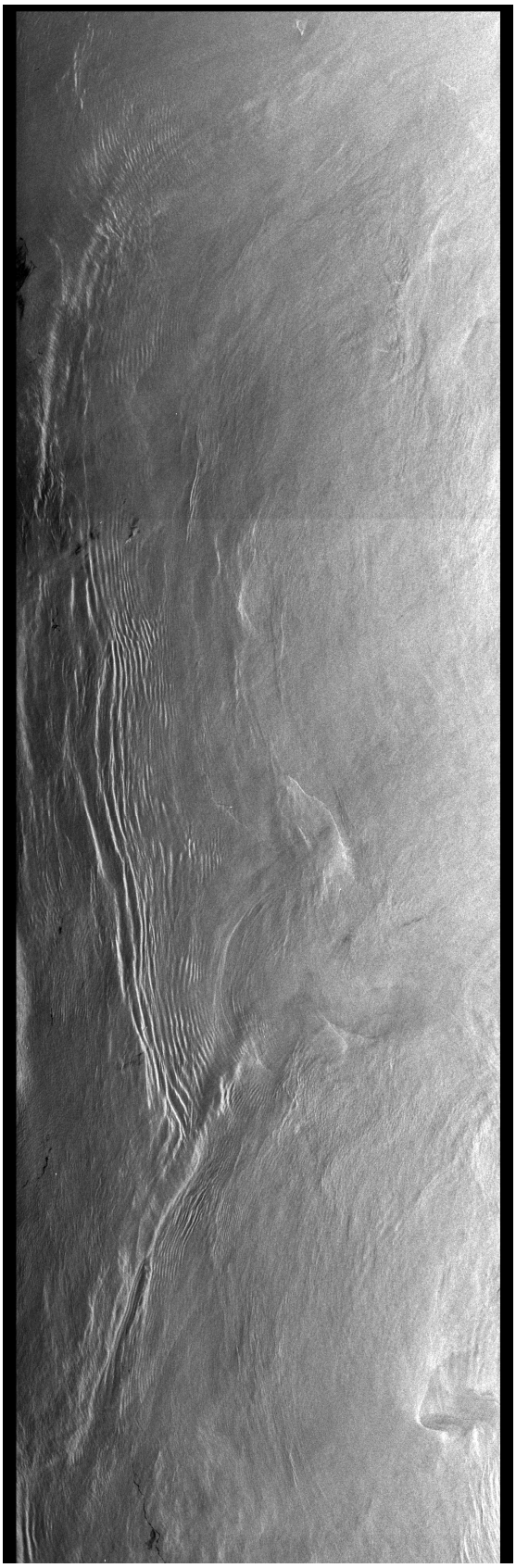


Figure 3. (Right) ERS-1 (C-band, VV) SAR image of the Luzon Strait in the South China Sea acquired on 16 June 1995 at 0229 UTC (orbit 20489, frames 3177, 3195, 3213). The image shows the signature of a large soliton packet propagating westwards. Imaged area is 100 km x 300 km [Hsu and Liu, 2000]. ©ESA 1995 [Image courtesy of Werner Alpers University of Hamburg, Hamburg, Germany.] (Below) An enlargement showing the details of the internal waves [Apel 1999].

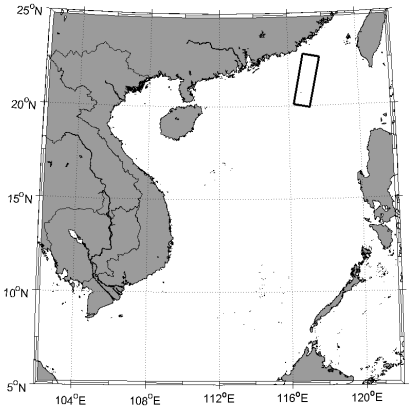
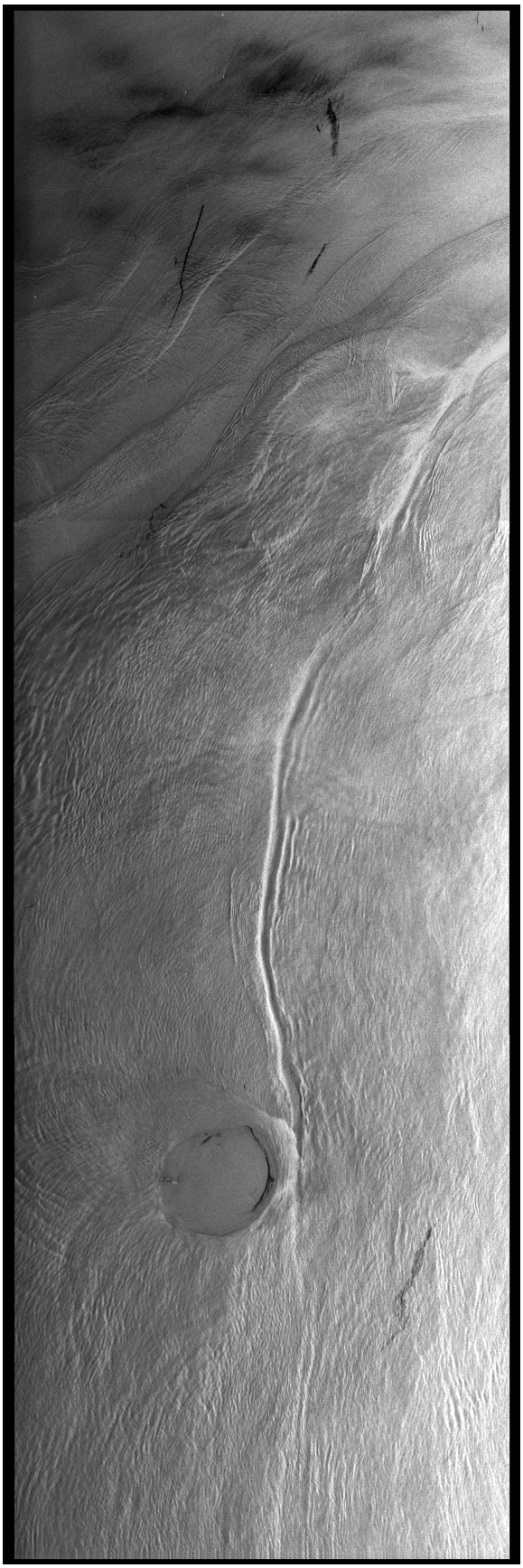


Figure 4. ERS-2 (C-band, VV) SAR image of Dongsha Island and the China shelf break acquired on 26 April 2000 at 0243 UTC (orbit 26224, frames 3117, 3159, 3195). The image shows the signature of a large soliton generated in the Luzon Strait impinging on Dongsha Island. Wave refraction and interference can be seen west of Dongsha Island. Near the top are visible much finer scale internal waves that are believed to be generated near the shelf break. Imaged area is 100 km x 300 km. (Below) An enlargement of a 100 km x 100 km section highlighting the finer scale shelf solitons. ©ESA 2000 [Image courtesy of Werner Alpers University of Hamburg, Hamburg, Germany.]



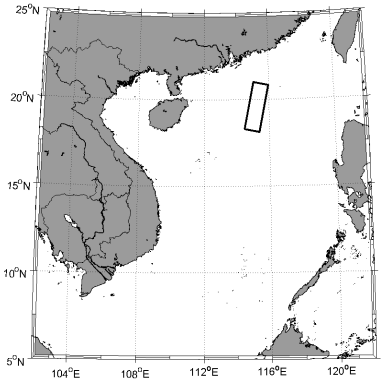
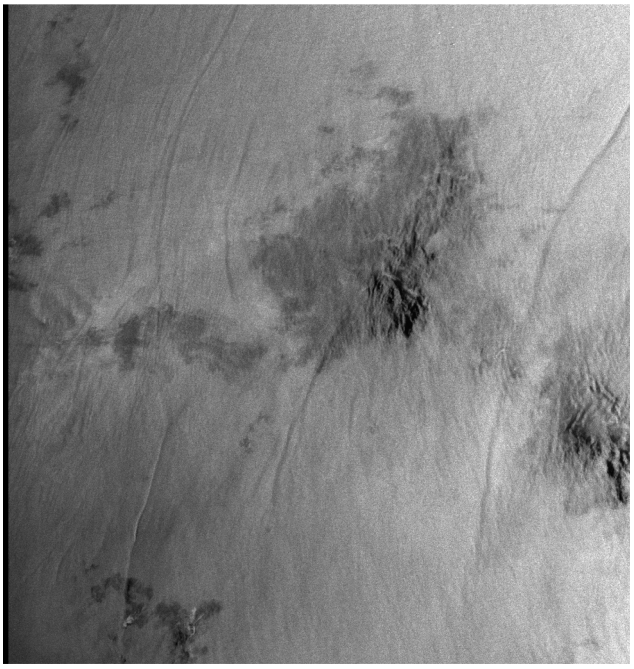
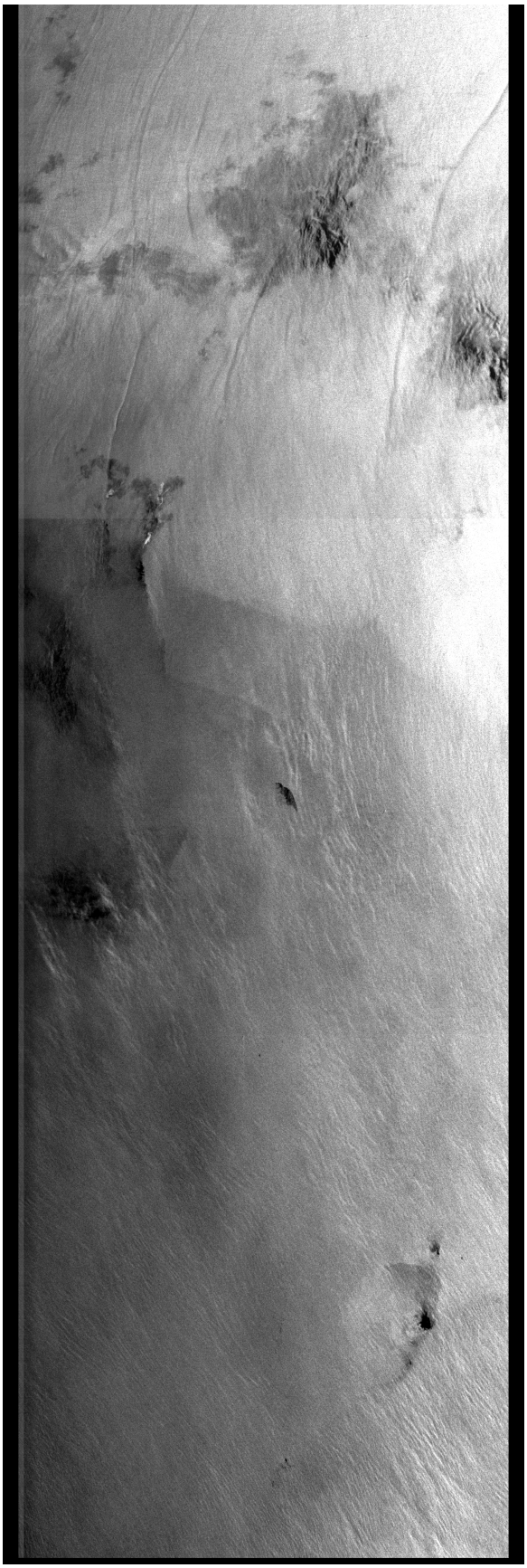


Figure 5. ERS-2 (C-band, VV) SAR image of the South China Sea acquired on 30 May 1998 at 0249 UTC (orbit 16247, frames 3195, 3213, 3231). The image shows how the internal waves generated in the Luzon Strait evolve after more than two days. The origin of the dark patches in the image is not known. They could result from oil pollution or from atmospheric effects. Imaged area is 100 km x 300 km. (Below) An enlargement of a 100 km x 100 km section highlighting the dark patches. ©ESA 1998 [Image courtesy of Werner Alpers University of Hamburg, Hamburg, Germany.]





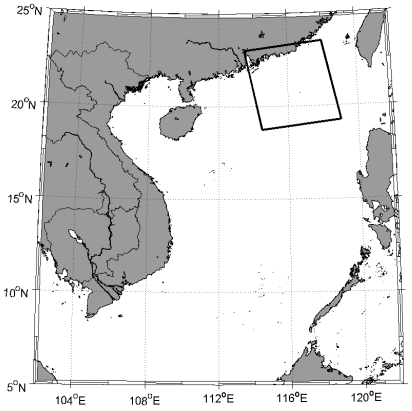
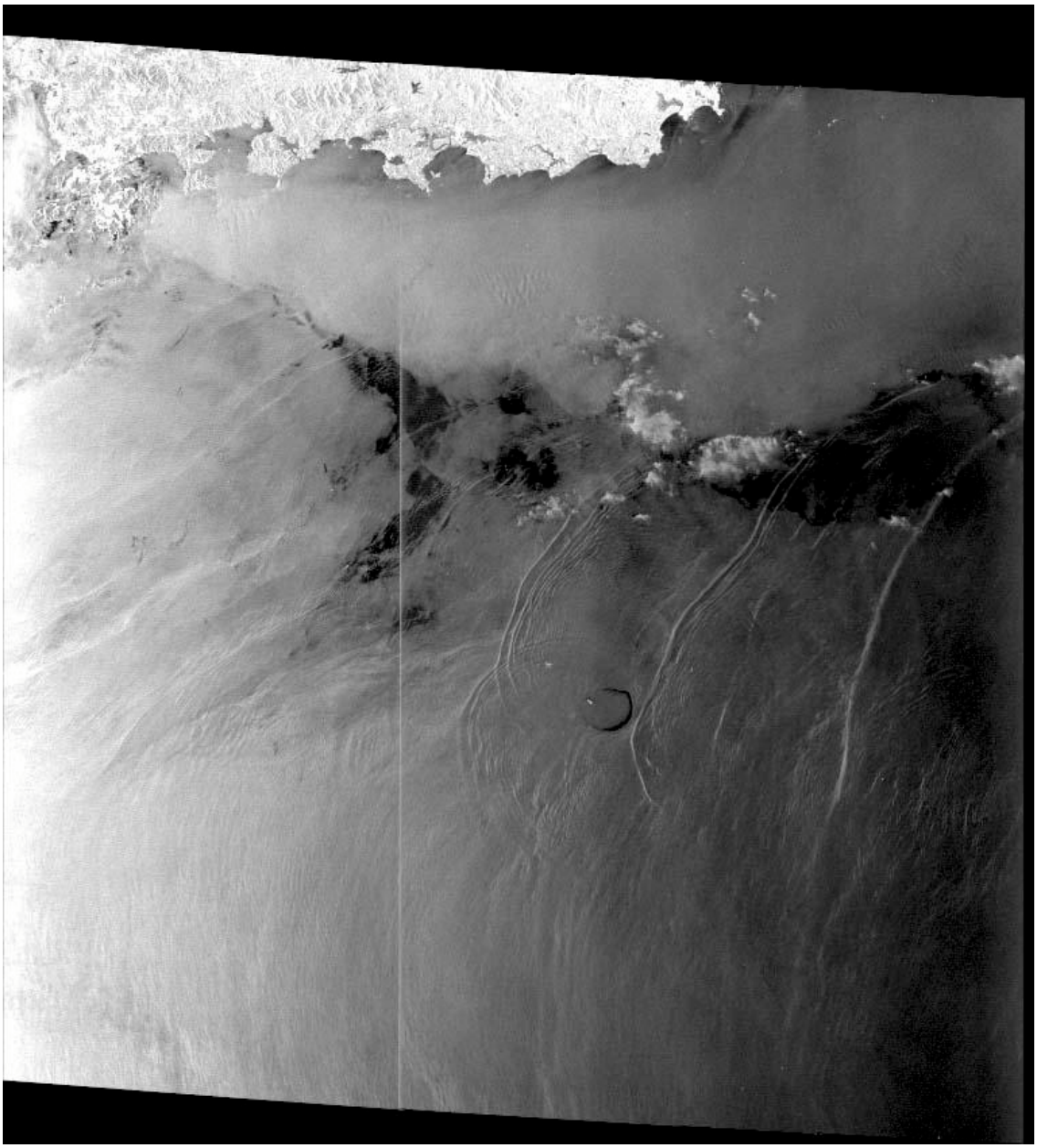


Figure 6. RADARSAT-1 (C-band, HH) ScanSAR image of the South China Sea collected on 26 April 1998. The image shows the evolution of the internal waves generated in the Luzon Strait as they propagate westward across the South China Sea. The internal waves are refracted as they pass Dongsha coral reef (near image center) and then recombine [Hsu and Liu, 2000] Imaged area is 450 km x 450 km. ©CSA 1998



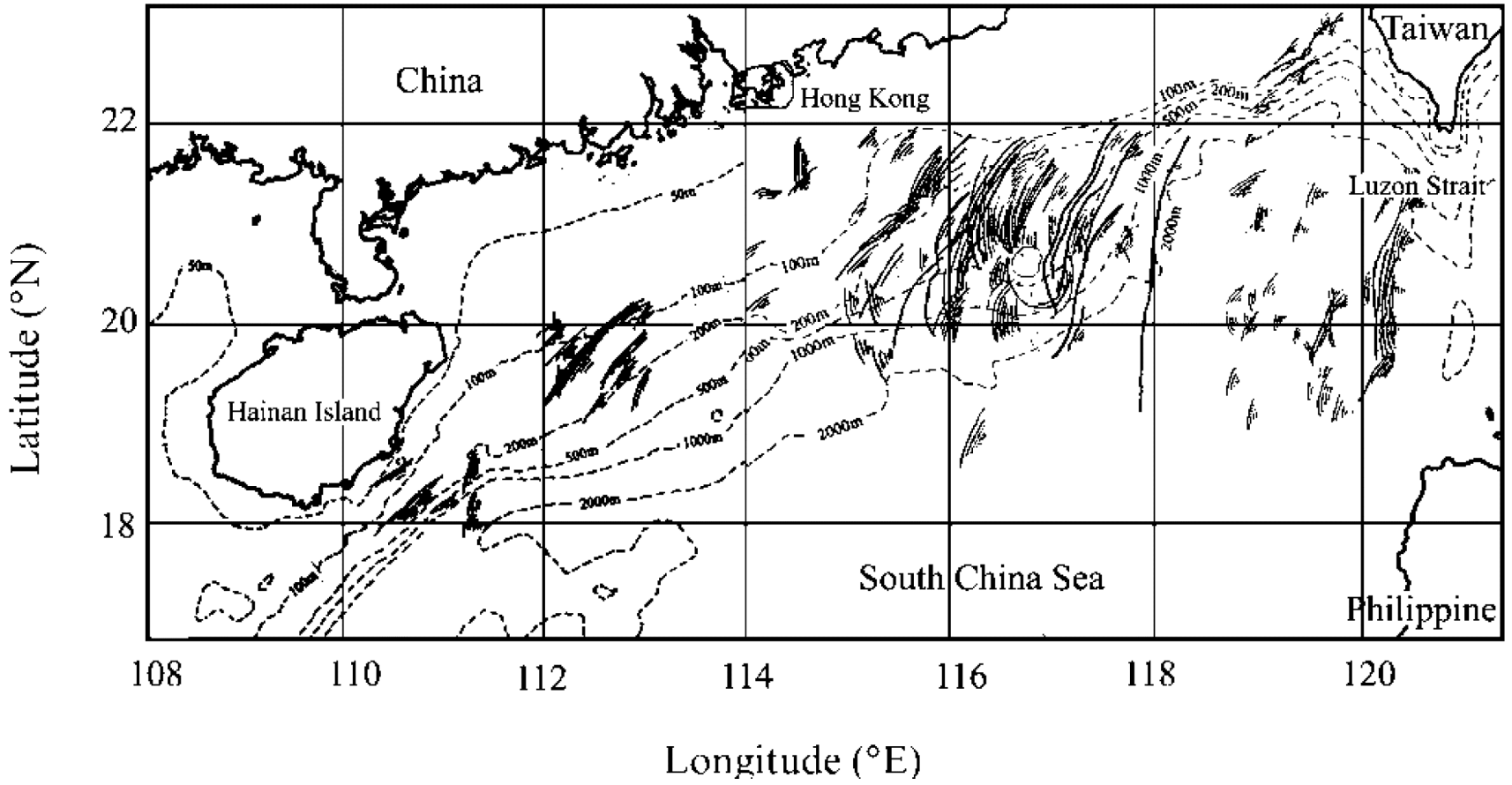


Figure 7. Map showing the geographic distribution of transbasin internal waves between the Luzon Strait and Hainan Island. The image was compiled from "hundreds" of ERS1/2 SAR images of acquired from 1993 to 2000. [After *Hsu and Liu* 2004]

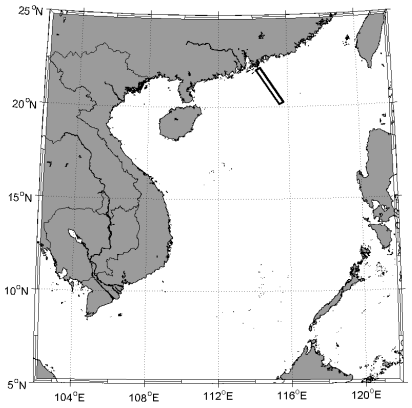


Figure 8. (Left) SIR-C SAR image over the continental shelf off Hong Kong acquired on 20 April 1994 at 0331 UTC (Seg. 9-11). The image shows a very large number of internal wave signatures inside the 200-m isobath (near image bottom). Imaged area is 18 km x 250 km. (Above) An enlargement of the top 60-km section highlighting the large number of wave and their complex interactions.

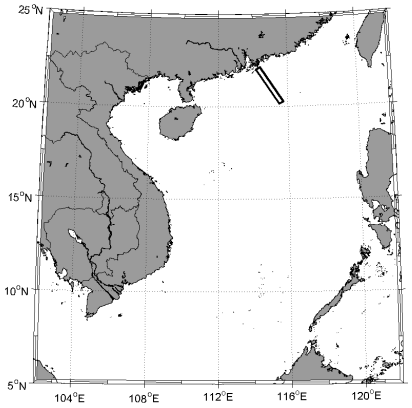
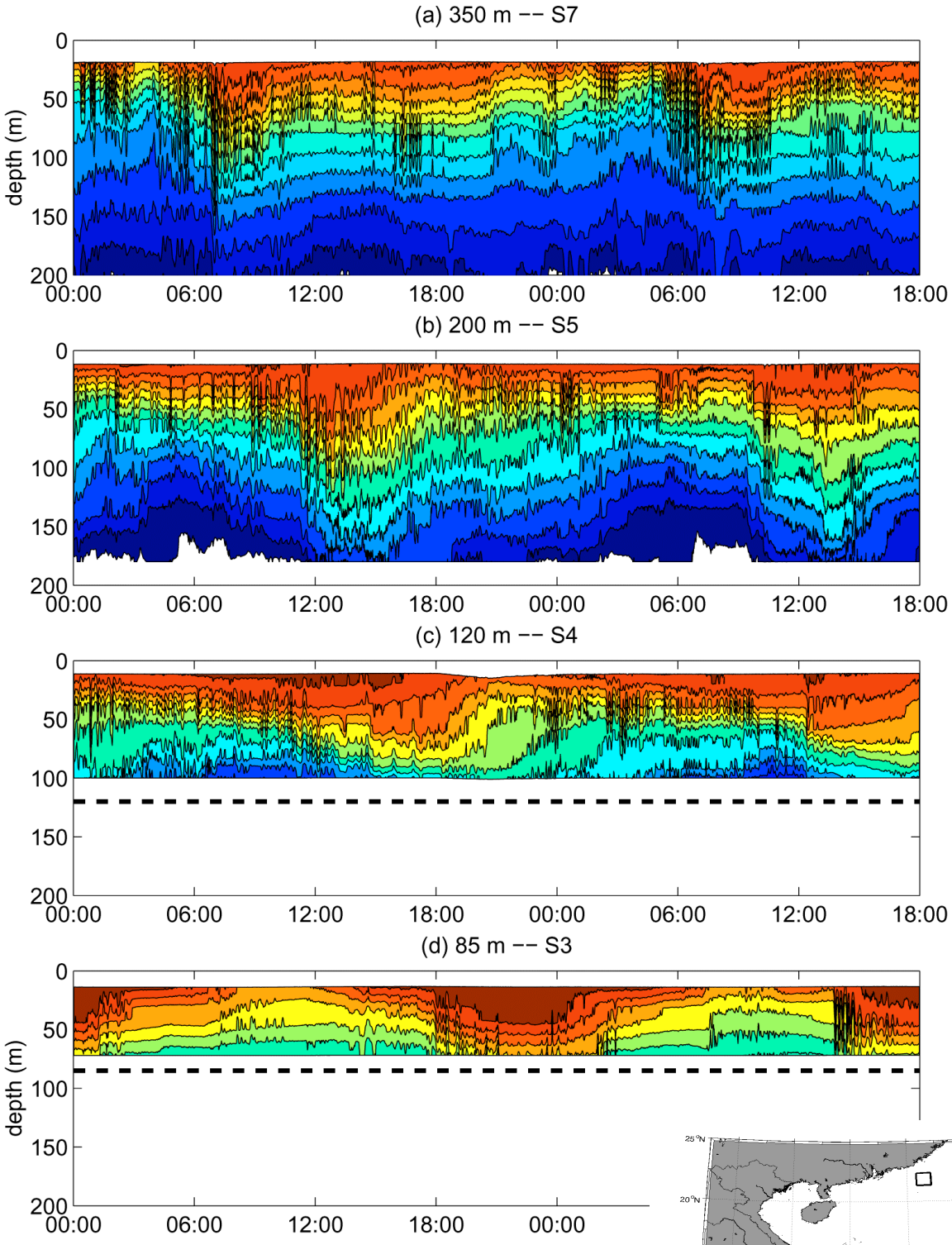


Figure 9. (Left) SIR-C SAR image over the continental shelf off Hong Kong acquired on 20 April 1994 at 0331 UTC (Seg. 9-11). The image shows a very large number of internal wave signatures inside the 200-m isobath (near image bottom). Imaged area is 18 km x 250 km. (Above) An enlargement highlighting the area around the 100 meter isobath (near image center). Imaged area is 18 km x 60 km.



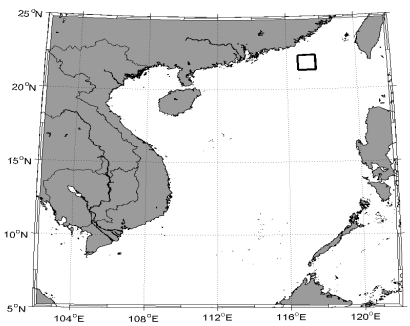


Figure 10. Forty-two hours of temperature data collected at four mooring sites on 2 and 3 May 2001 as part of the ASIAEX campaign. The data show transbasin solitons moving toward shore from 350 through 85-meter depth. When the waves reach 200-m, the temperature record includes a large number of small-scale shelf generated internal waves. [After Duda et al. 2004]

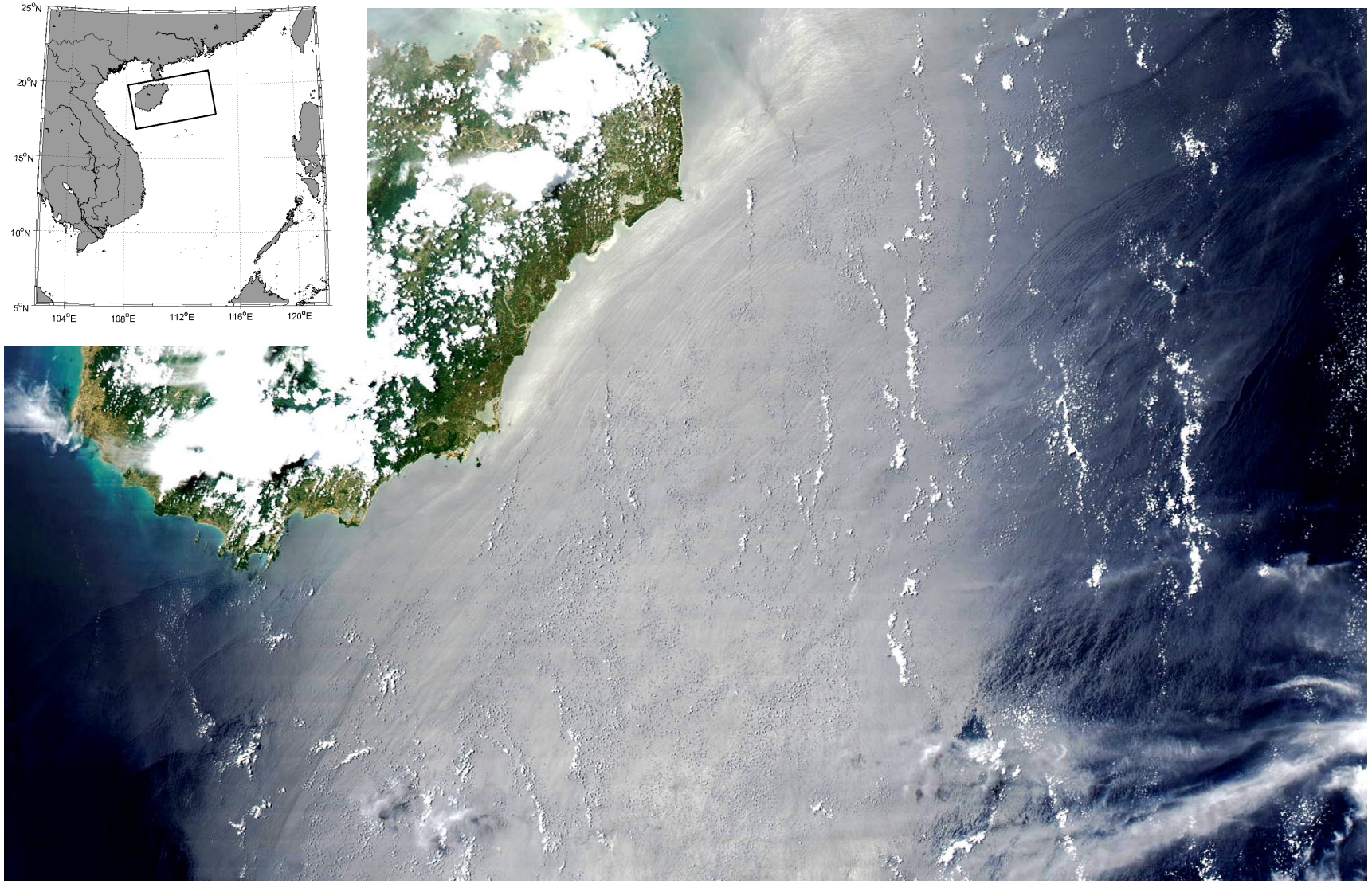


Figure 11. MODIS (Bands 1,3,4) 250-m resolution visible image over Hainan Island in the South China Sea acquired on 9 July 2003 at 0545 UTC. The image shows internal wave packets east (top right) and south (bottom left) of Hainan Island propagating to the northwest. Less well organized surface signatures are visible immediately east of the island. Imaged area is approximately 500 km x 325 km.

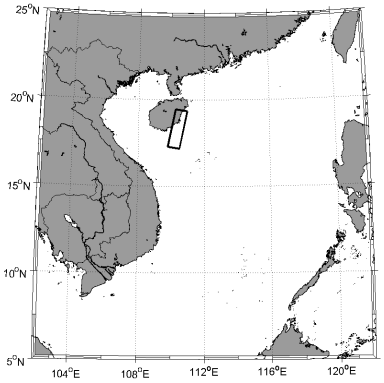
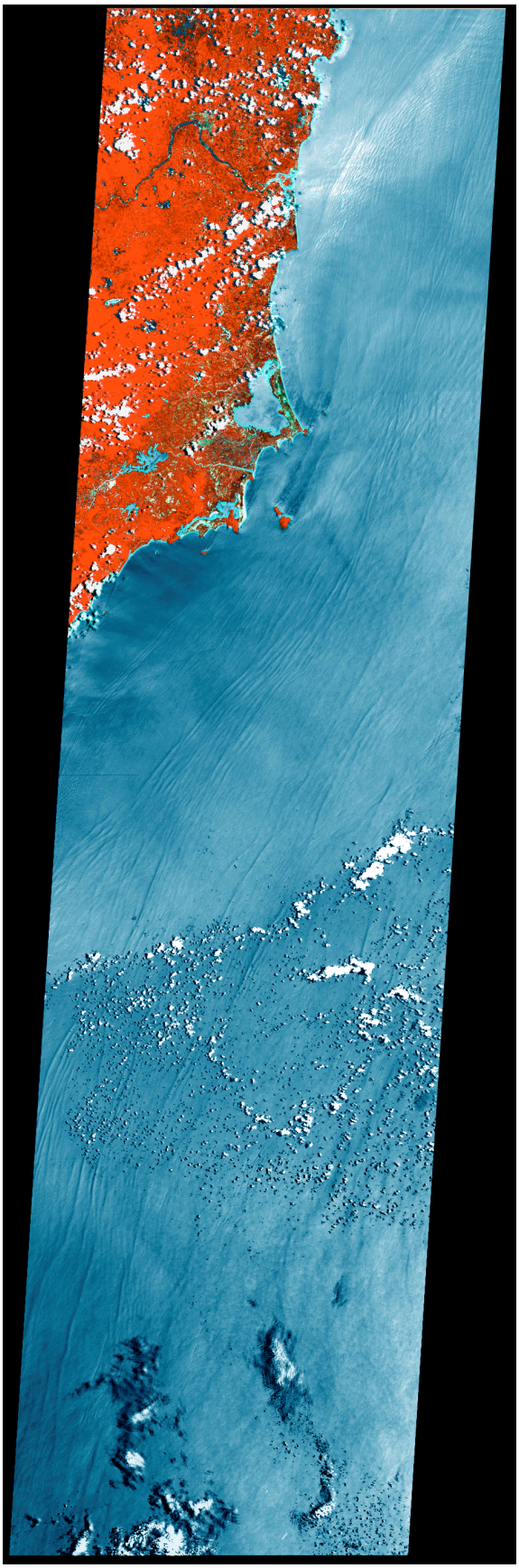


Figure 12. ASTER false-color VNIR image over the coastal waters east of Hainan Island acquired on 26 July 2000 at 0338 UTC. The image shows a variety of surface signatures. Imaged area is approximately 60 km x 180 km.



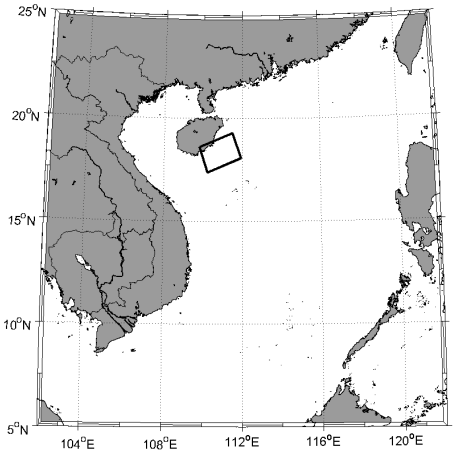
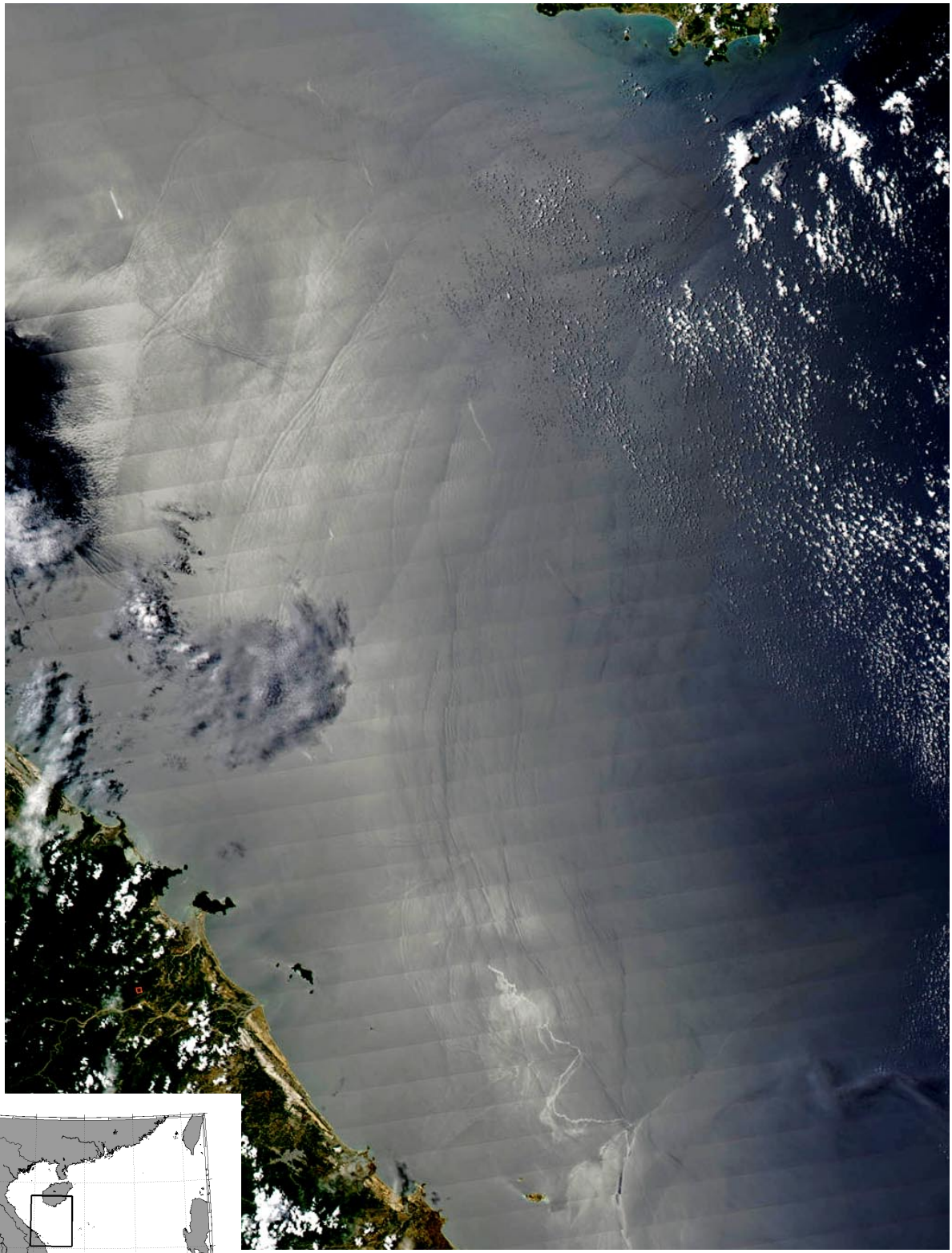


Figure 13. Astronaut photograph (STS007-05-245) acquired on 23 June 1983 showing well organized internal wave packets off the southeast coast of Hainan Island. Imaged area is approximately 100 km x 100 km. [Image courtesy of Earth Sciences and Image Analysis Laboratory, NASA Johnson Space Center (http://eol.jsc.nasa.gov)]



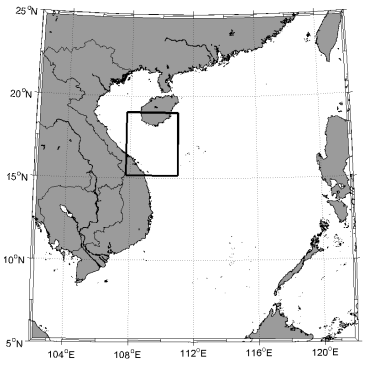


Figure 14. MODIS (Bands 1,3,4) 250-m resolution visible image over Hainan Island and the coast of Vietnam acquired on 7 July 2003 at 0600 UTC. The image shows internal wave packets south (middle) of Hainan Island propagating to the northwest. Additional waves can be seen propagating toward the Vietnamese coast. Imaged area is 255 km x 340 km

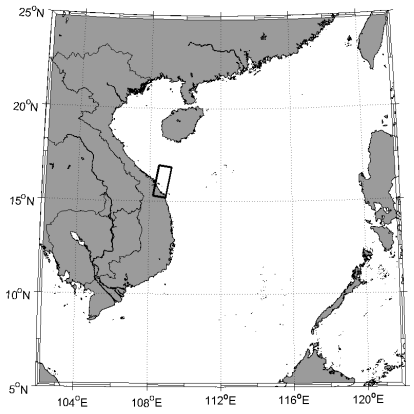
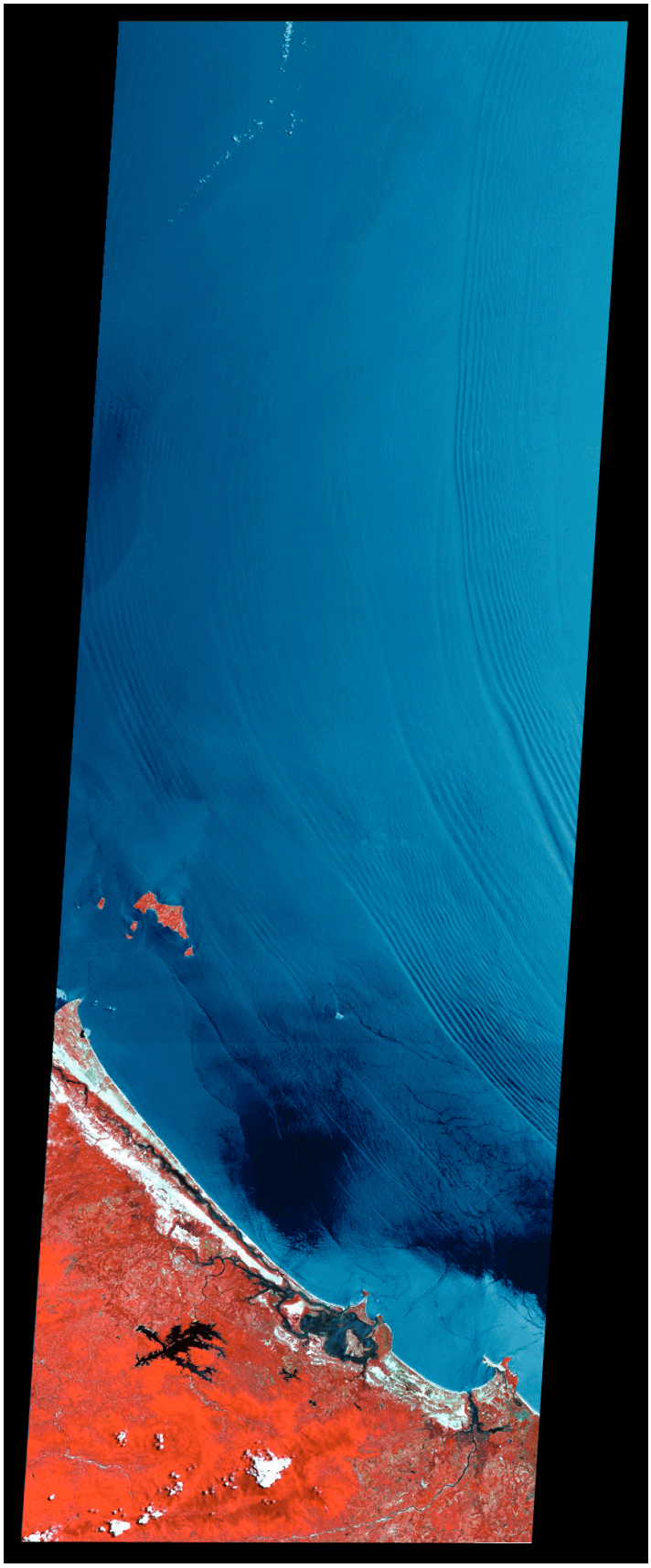


Figure 15. ASTER false-color VNIR image along the coast of Vietnam acquired on 29 July 2001 at 0331 UTC. The image shows at least four well-defined internal wave packets with rank ordered solitons propagating toward Vietnamese coast. Imaged area is 60 km x 180 km.



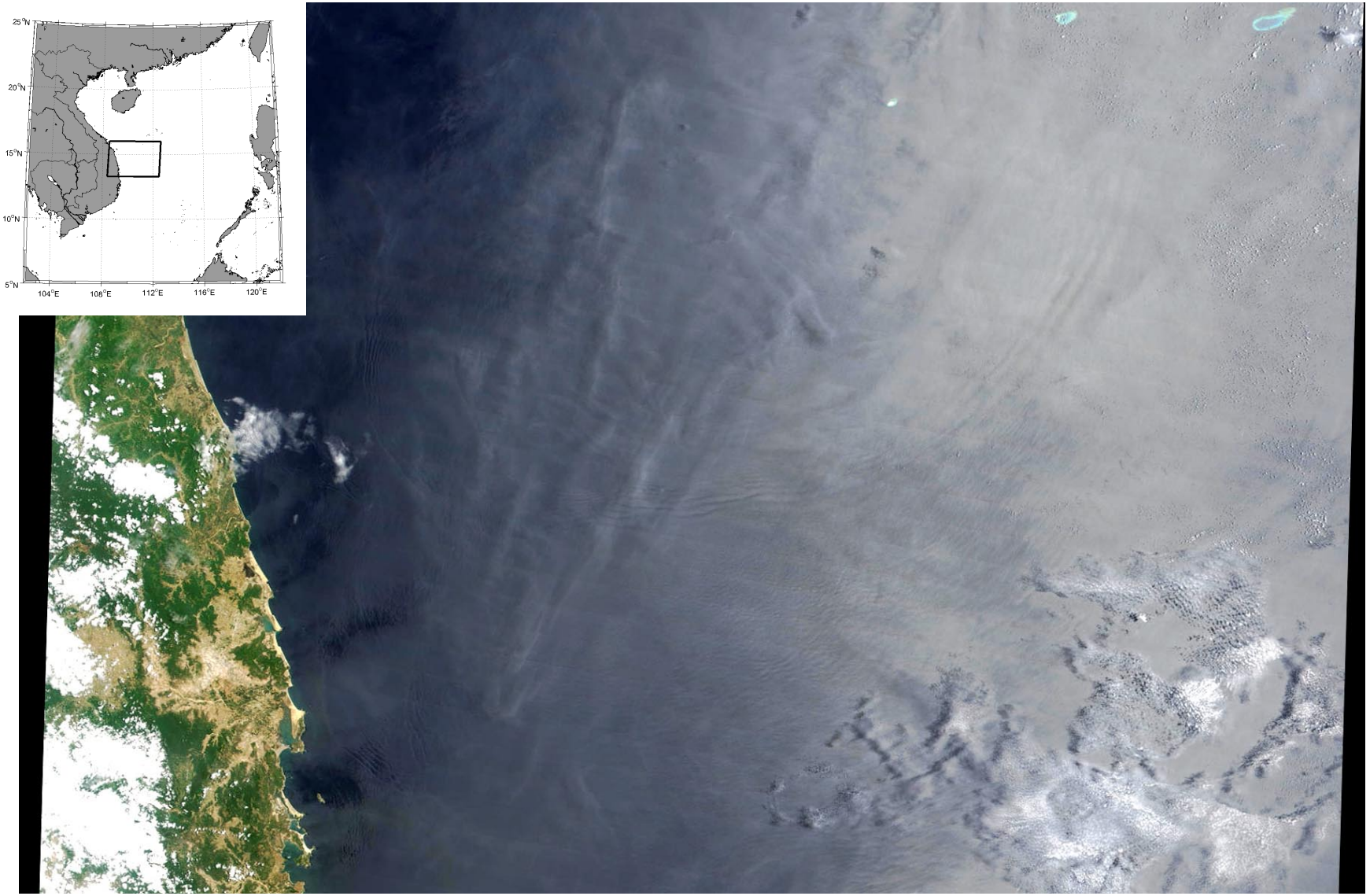
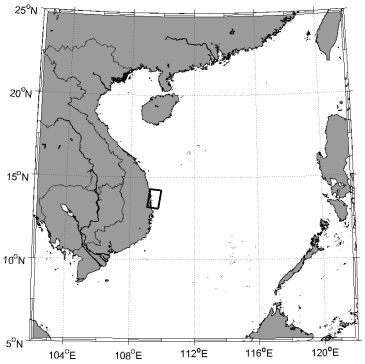


Figure 16. MODIS (Bands 1,3,4) 250-m resolution visible image off the coast of Vietnam acquired on 10 August 2002 at 0315 UTC. The image shows the faint signature of large circular internal wave packets propagating to the southeast. The west edge of the packet propagates towards the Vietnamese coast. The wave appears to originate between Hainan Island and Vietnam near the continental shelf. Imaged area is 435 km x 300 km.



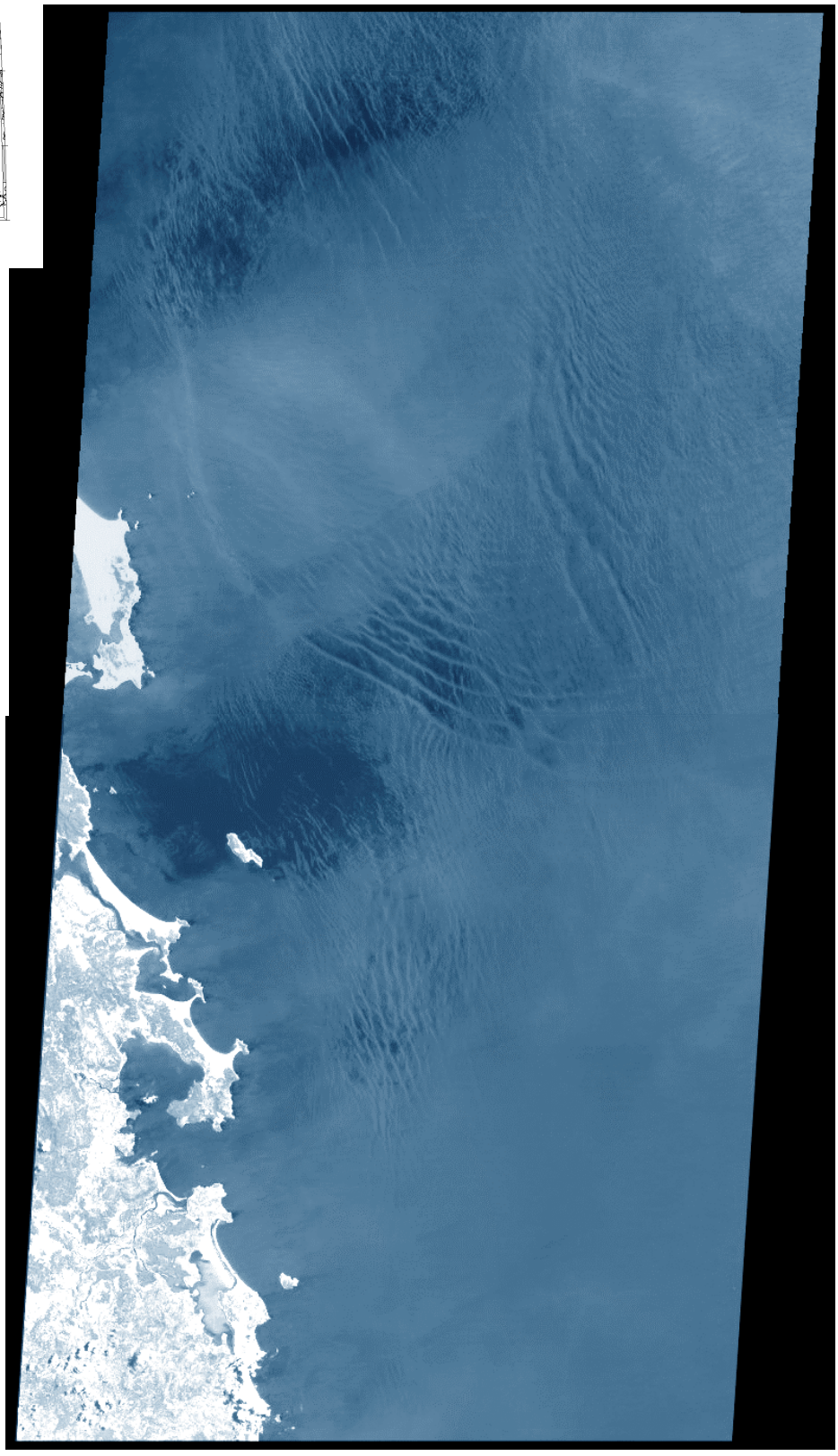


Figure 17. ASTER false-color VNIR image along the coast of Vietnam acquired on 10 August 2002 at 0320 UTC. The image shows several groups of internal waves propagating toward the coast. The signatures are also visible (at lower resolution) in Figure 15 (at bottom left) which was acquired simultaneously. Imaged area is 60 km x 120 km.

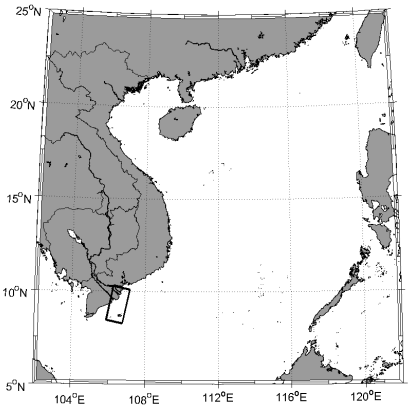
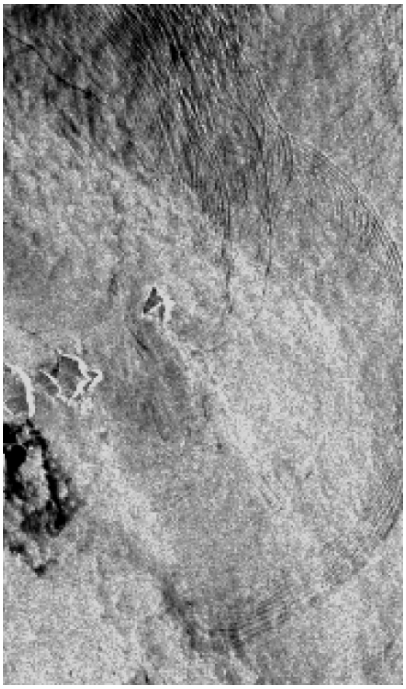


Figure 18. ERS-1 (C-band, VV) SAR image of the Mekong River outflow in the South China Sea acquired on 3 September 1996 at 0318 UTC (orbit 7172, frames 3411, 3429). The image shows several frontal boundaries associated with the river outflow. Internal wave packets are present along several of these outflow fronts. Also present are the signatures of atmospheric convection, and low wind speed (dark areas). Imaged area is 100 km x 200 km. ©ESA 1996 [Image courtesy of Werner Alpers University of Hamburg, Hamburg Germany]



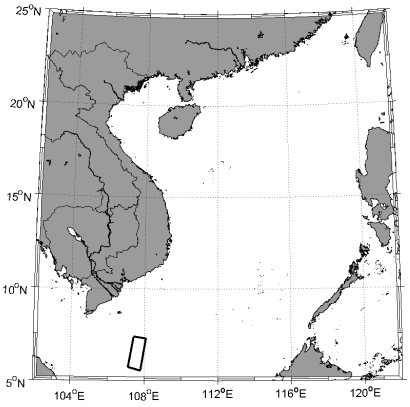
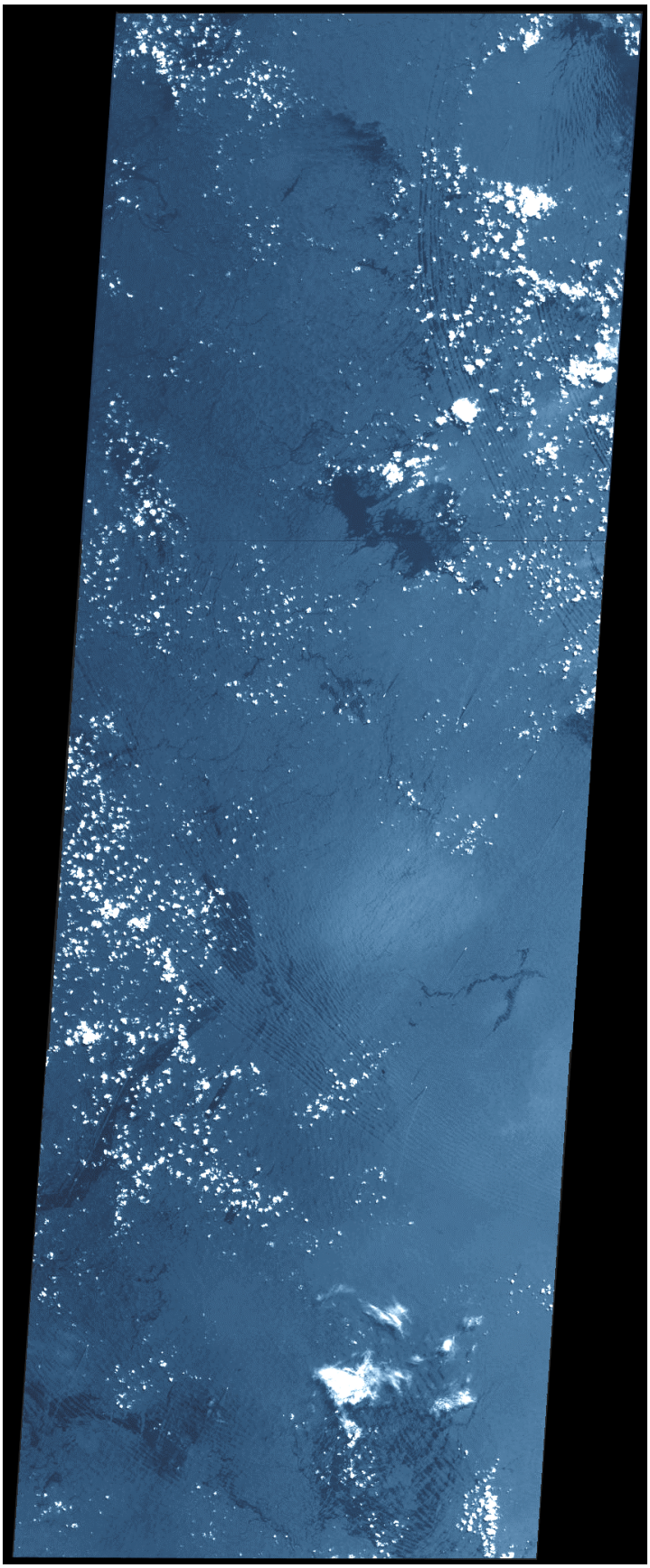


Figure 19. ASTER false-color VNIR image in the South China Sea between Vietnam and Borneo acquired on 3 May 2001 at 0330 UTC. The image shows three well defined internal wave packets with multiple solitons propagating to the southwest. Packet separation is approximately 60 km. Imaged area is 60 km x 180 km.



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