Africa - South Atlantic Coast

Overview

Continental shelf internal waves have been observed along the southwest coast of Africa from the coast of Angola (~10^o S. latitude) to beyond the southern tip of the continent (36^o S. latitude). Figure 1 presents a bathymetry map of the continental shelf in this area.

Apel et al. [1975] reported the existence of solitons in this area based on ERTS (Earth Resource Technology Satellite) imagery collected in November 1972. They noted six packets off the south Atlantic coast, just north of Cape Town. The internal waves along the southwest African coast have been observed between the months of November to April, the austral summer. Just like the NY Bight, summer heating of the upper layers in coastal waters enhances the stratification for internal wave occurrences.

Table 1 presents a summary of internal wave characteristics from the southwest African Shelf. The values have been reported in the literature and derived from remote sensing data sources. Table 2 shows the months of the year during when these internal waves have been observed.

Table 1. Characteristic scales for Southwest Africa continental shelf solitons

Packet Length L (km)	Along Crest Length C_r (km)	Maximum Wavelength λ_{MAX} (km)	Internal Packet Distance D (km)
5 - 15	75 - 100	1.5 - 2.6	15 - 40
Amplitude $2h_0$ (m)	Long Wave Speed c_0 (m/s)	Wave Period (min)	Surface Width l_1(m)
-6 to -20	0.5 to 1.0	12 - 55	200

Table 2 - Months when continental shelf solitons have been observed off the South West Africa

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

Observations

Internal wave signatures off southwest Africa have been observed in space shuttle photographs, Landsat optical images, and synthetic aperture radar imagery from SIR-C and ERS 1/2.

Astronauts on board the Space Shuttle photographed internal waves off the coast of Namibia in March and December 1990. Figure 2 (STS035-074-019) was taken on December 3, 1990 and is one of a sequence of four images (STS035-074-016, 17, 18, and 19). The figure shows 4 internal

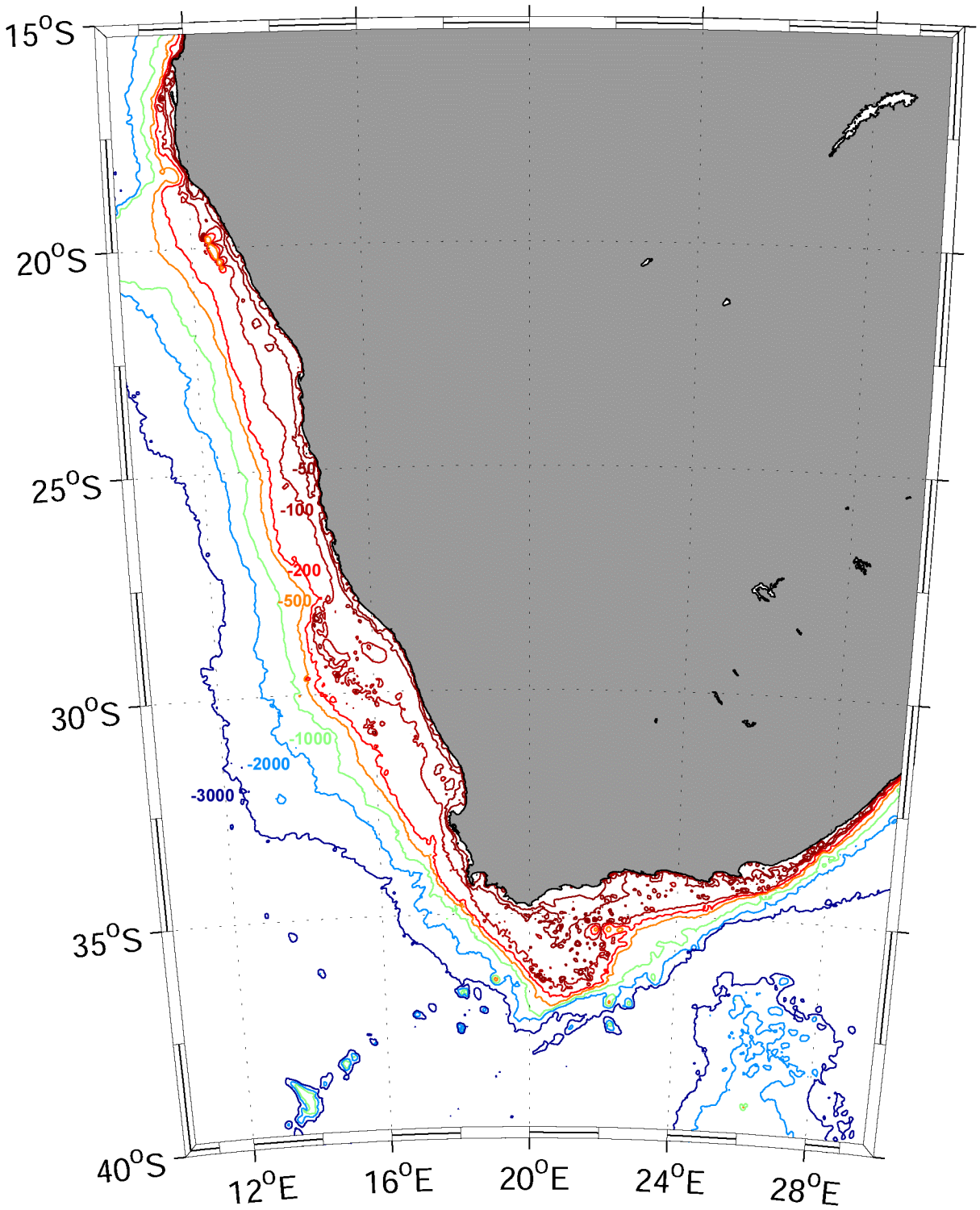

Figure 1: Bathymetry map of the southwest coast of Africa (Derived from Smith and Sandwell version 8.2)

wave packets propagating shoreward, each created during the last four semi-diurnal tidal cycles. The packets have separations of between 17 and 21 km with an implied propagation speed of around 0.4 - 0.5 m/s with the waves aligned parallel to the bottom topography. The waves in the packet closest to shore are difficult to see near the top of the image because they are being dissipated due to bottom interaction.

In March 1990 four images (STS036-082-075, 76, 77 and 78) were sequentially taken during mission STS-036 of space shuttle Atlantis passing over the western coast of Africa. These four photographs show several internal wave packets off the Namibia coast. Figure 4 shows two groups of internal waves propagating in two different directions. Zheng et al. [1997] analyzed this imagery and noted that all of the internal waves were in water depth less than 500 m with crest to crest wavelength variations between 1.08 and 2.27 kilometers and crest lengths between 50 km to 100 km. Both wave groups were propagating toward shore with one group propagating toward the northeast, the other toward the southeast. As waves from the two groups meet they under go complex soliton - soliton interaction. Examination of the bathymetry in the area (figure 5) shows a sharp variation in the distance of the 500-m isobath near $18^{o}30^{'}$ S. latitude and $11^{o}30'$ E. longitude. This "edge" is most likely the source of the southeast propagating solitons. Since they are not aligned parallel to the underlying shelf topography, these southeast packets will begin to refract towards the shore due to bottom interaction.

Zheng et al. [1997] also noted the patch of light blue water in the central part of the STS036-082-076, believed to be a plankton boom. Phytoplankton growth influenced by internal wave activity has been reported in eastern North Atlantic Ocean.

Figure 6 is a SIR-C (Shuttle Imaging Radar - C) image off the Atlantic coast of South Africa acquired on April 11, 1994. This image is taken in the same geographic area as the ERTS presented in Apel et al. [1975]. Three distinct leading crests are visible strongly oriented along the isobaths, with crest lengths in excess of 60 km. Figure 7 shows the ERTS image overlaid with the SIR-C image and a local bathymetry map. The waves appear to form just inside the 200-m isobath, with a possible very weak signature visible just outside the 200 isobath. Interpacket separation is approximately 35 km, which implies a propagation speed of around 0.75 m/s on the shelf. The distinction between packets disappears as they approach shore since the phase velocities of the waves are reduced by both the shoaling and (usually) by the decreasing pycnocline depth. The result is that the leading waves in one packet over take the tailing waves in the previous packet and the interpacket boundary disappears.

Figure 8 is also a SIR-C image taken on April 11, 1994 but off the southern coast of South Africa. A negative print of the image is presented to enhance the wave signatures. The figure shows the internal waves propagating along, rather than towards the visible coast. The most pronounced wave signatures are those at the middle left of the image. The direction of propagation (approximately east) indicates that the waves were probably generated at the western edge of the Agulhas bank. The left most soliton has an along crest length greater than 60 km.

The second set of internal waves signatures can be seen across the lower half of the image (lower right to left across on the image) implying an approximately westward propagation. The signatures are faint but more then a dozen waves are visible with wavelengths on the order of 3.5

km stretched out over more than 40 km. The weak signature and long uniform wavelengths are characteristic of solitons after several days of propagation. This life span means that the waves were generated a few hundred kilometers to the east. The most likely source is the continental shelf break near the southeast corner of Africa. The generation region may be associated with the Agulhas current which runs near the continental shelf break in that area [Apel, 1999; Grundlingh 1982].

KDV Parameters

Figure 9 shows a typical density profile for the southwest African shelf derived from temperature and salinity data taken from the NODC World Ocean Atlas 1998 at 30.5^0 S. latitude, 16.5^0 E. longitude. The normalized Mode 1 and Mode 2 eigenfunctions have been evaluated for $l = \frac{2}{pk_0} = 1852m$, with H = 250 m. For long waves ($k \rightarrow 0$) the maximum first mode wave speed (c_0) is computed to be 0.76 m/s without the effect of current shear. This agrees well with the SIR-C data in Figure 6. Figures 9e and 9f give the phase velocity and dispersion relations for the data. Table 2 presents the environmental coefficients and KDV parameters evaluated at k_0.

Table 2. Environmental Coefficients and KDV parameters (λ_0= 1852 m) for the Southwest African Continental Shelf Solitons

Long Wave Speed c_0 (m/s)	Nonlinear coefficient $1/\alpha$ (m)	Dispersion Factor $\gamma^{1/2}$ (m)	Amplitude (KDV theory) h_0 (m)	Non-Linear Phase Velocity V (m/s) for (s^2=1)
0.76	-99.08	54.14	-5.00	0.81

References

Apel, J.R., H.M. Byrne, J.R. Proni, and R.L. Charnell, 1975b: Observations of oceanic internal and surface waves from the Earth Resources Technology Satellite. J. Geophys. Res., 80 (6), 865-881.

Apel, J.R , 1999: Are Strongly Sheared Baroclinic Currents Sources for Internal Solitons? IOS/WHOI/ONR Internal Solitary Wave Workshop Papers 6th Edition, WHOI Technical Report number WHOI-99-07, http://www.whoi.edu/science/AOPE/people/tduda/isww/text/

Grundlingh, M. L. Eddies in the Southern Indian Ocean and Agulhas Current, in *Eddies in Marine Science,* edited by A. Robinson, Chap. 12, Springer-Verlag, New York, 1982

Zheng, Q., Klemas, V., Yan, X.-H., Wang, Z., and Kagleder, K., 1997, Digital orthorectification of space shuttle coastal ocean photographs. Int. Journal of Remote Sensing, vol. 18, no. 1, 197-211.

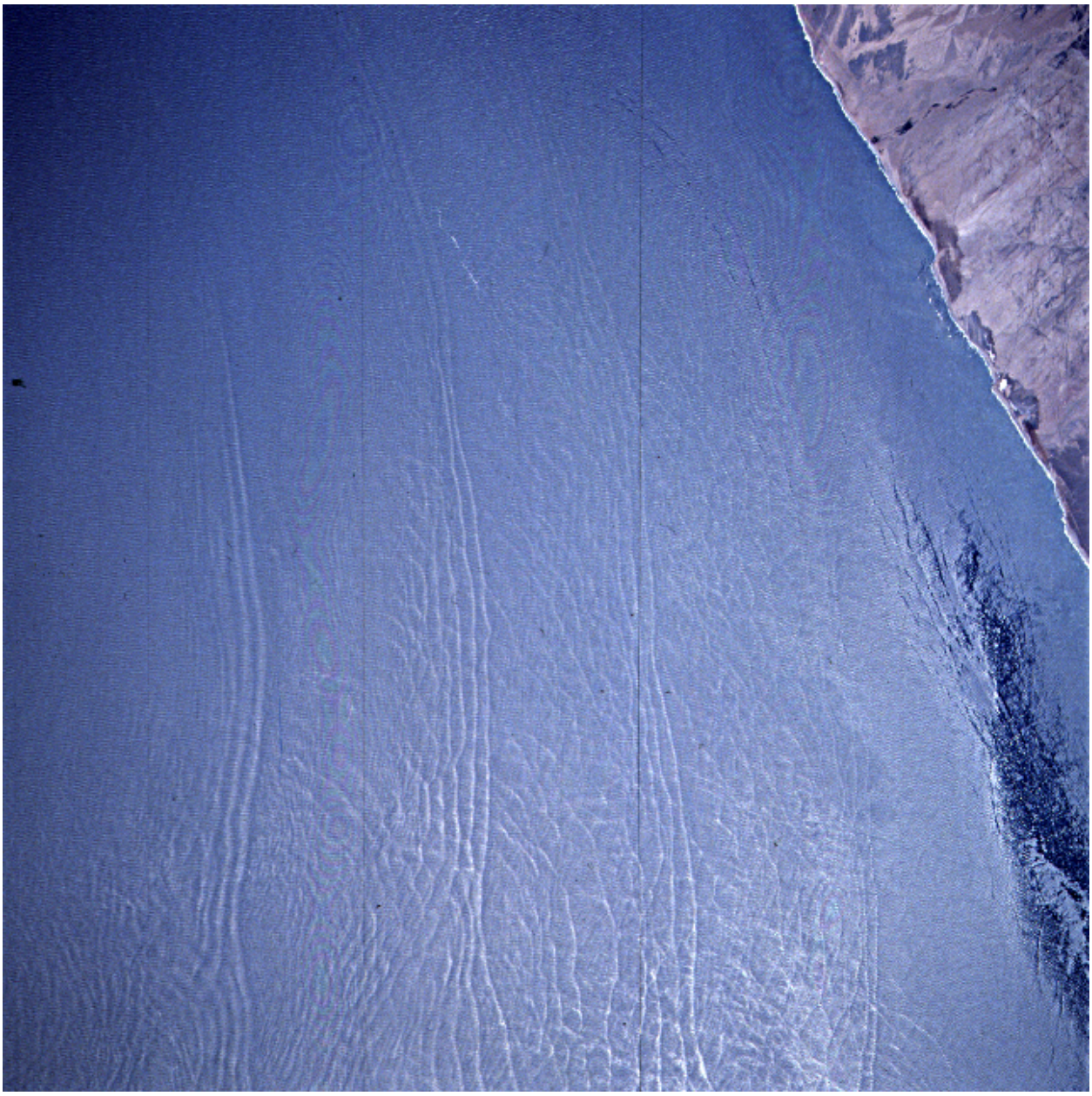

Figure 2. Space Shuttle Photograph (STS035-074-19) acquired December 3, 1990, 09:23 GMT and centered at 23.0° S, 14.0° E. Image dimensions are approximately 100 km x 100 km. Image Courtesy of Earth Sciences and Image Analysis Laboratory, NASA Johnson Space Center (http://eol.jsc.nasa.gov).

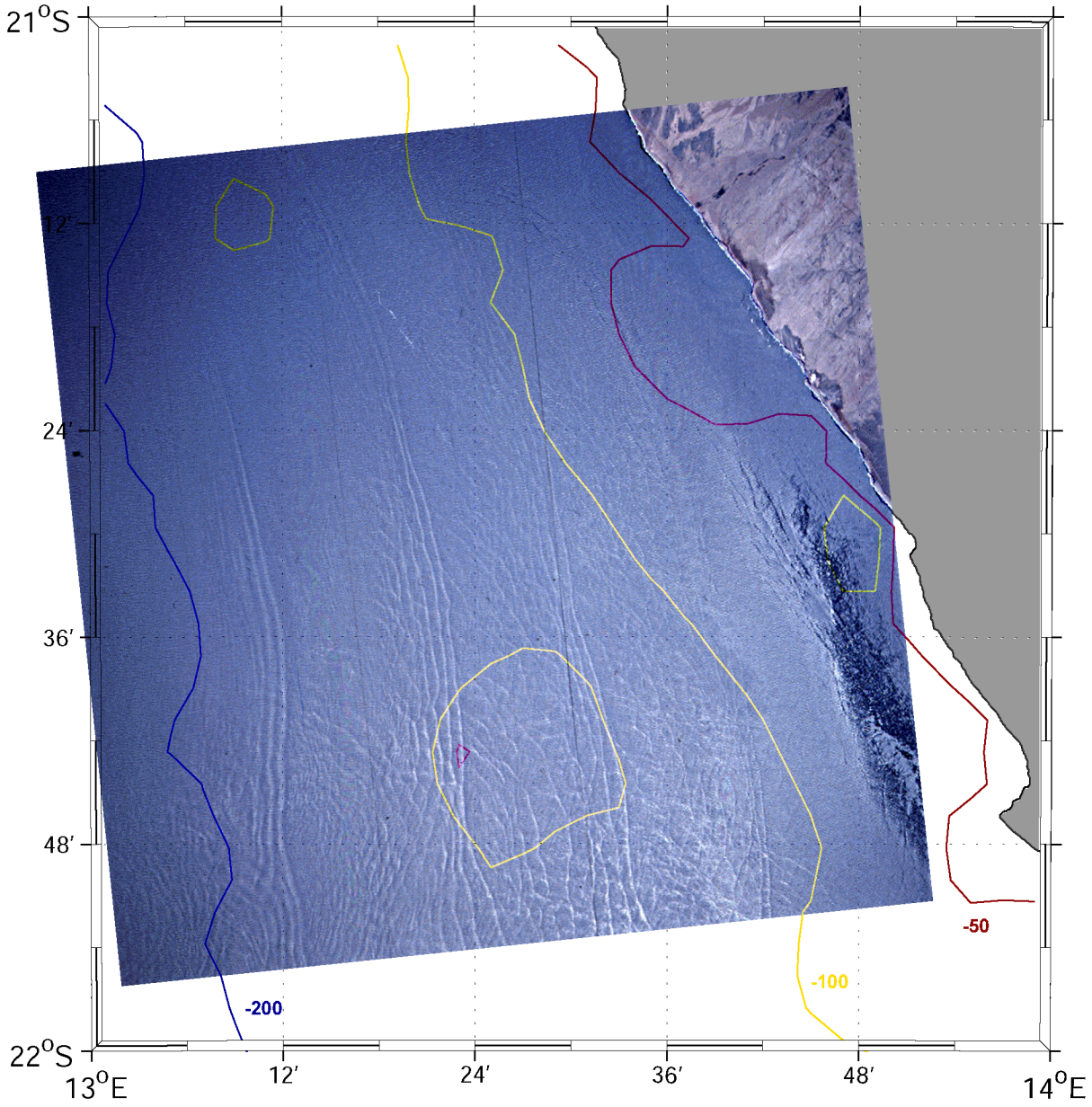

Figure 3. Space Shuttle Photograph (STS035-074-19) shown with local bathymetry. Bathymetry derived from Smith and Sandwell version 8.2.

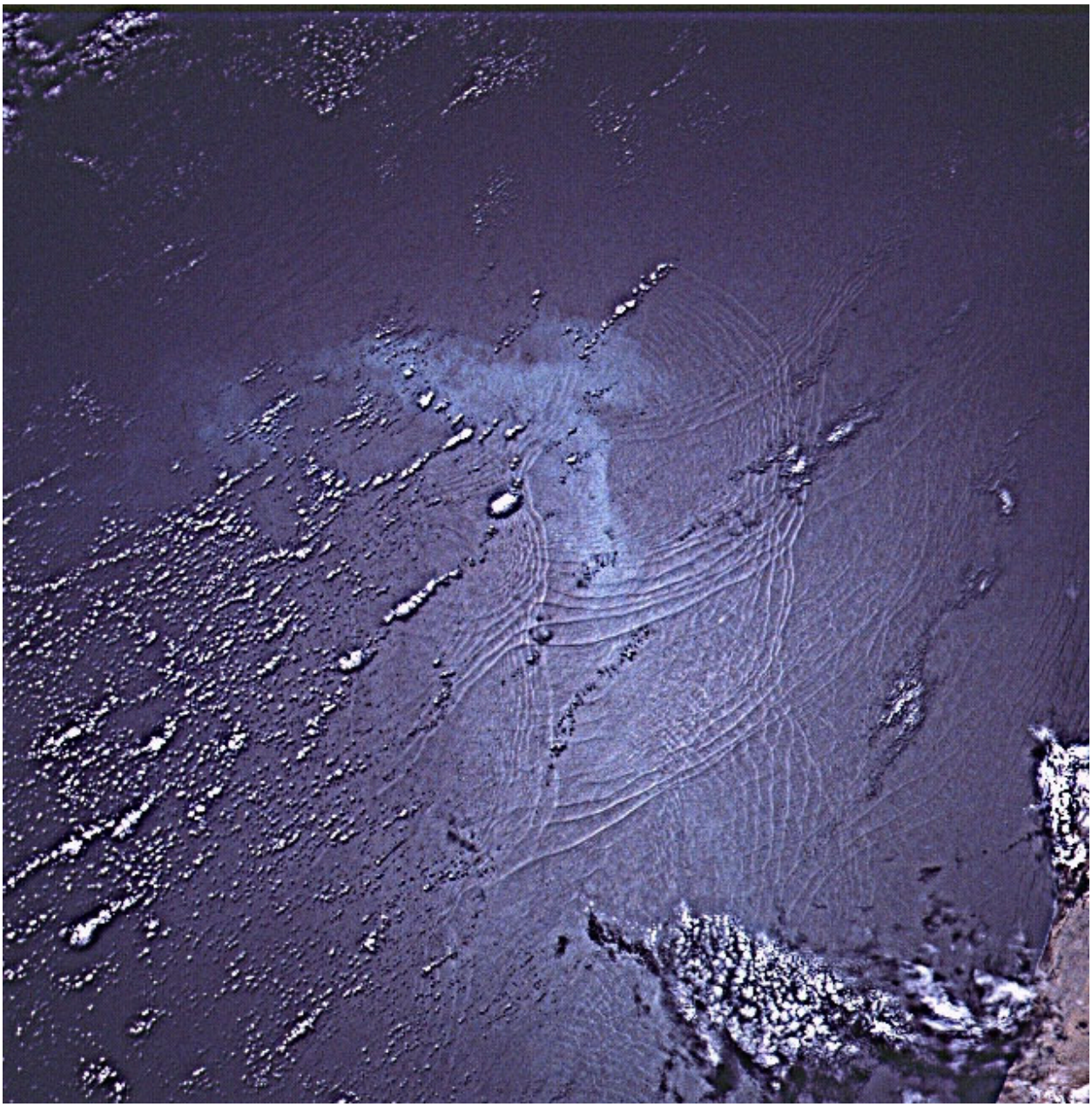

Figure 4. Space Shuttle Photograph (STS036-082-76) acquired March 1, 1990, 12:54 GMT centered at 19.5^{o} S, 11.5^{o} E. Image has been processed for digital orthorectification of geometric distortions by researchers at Center for Remote Sensing, College of Marine Studies, University of Delaware. Image dimensions are approximately 102 km x 102 km. Original image courtesy of Earth Sciences and Image Analysis Laboratory, NASA Johnson Space Center (http://eol.jsc.nasa.gov).

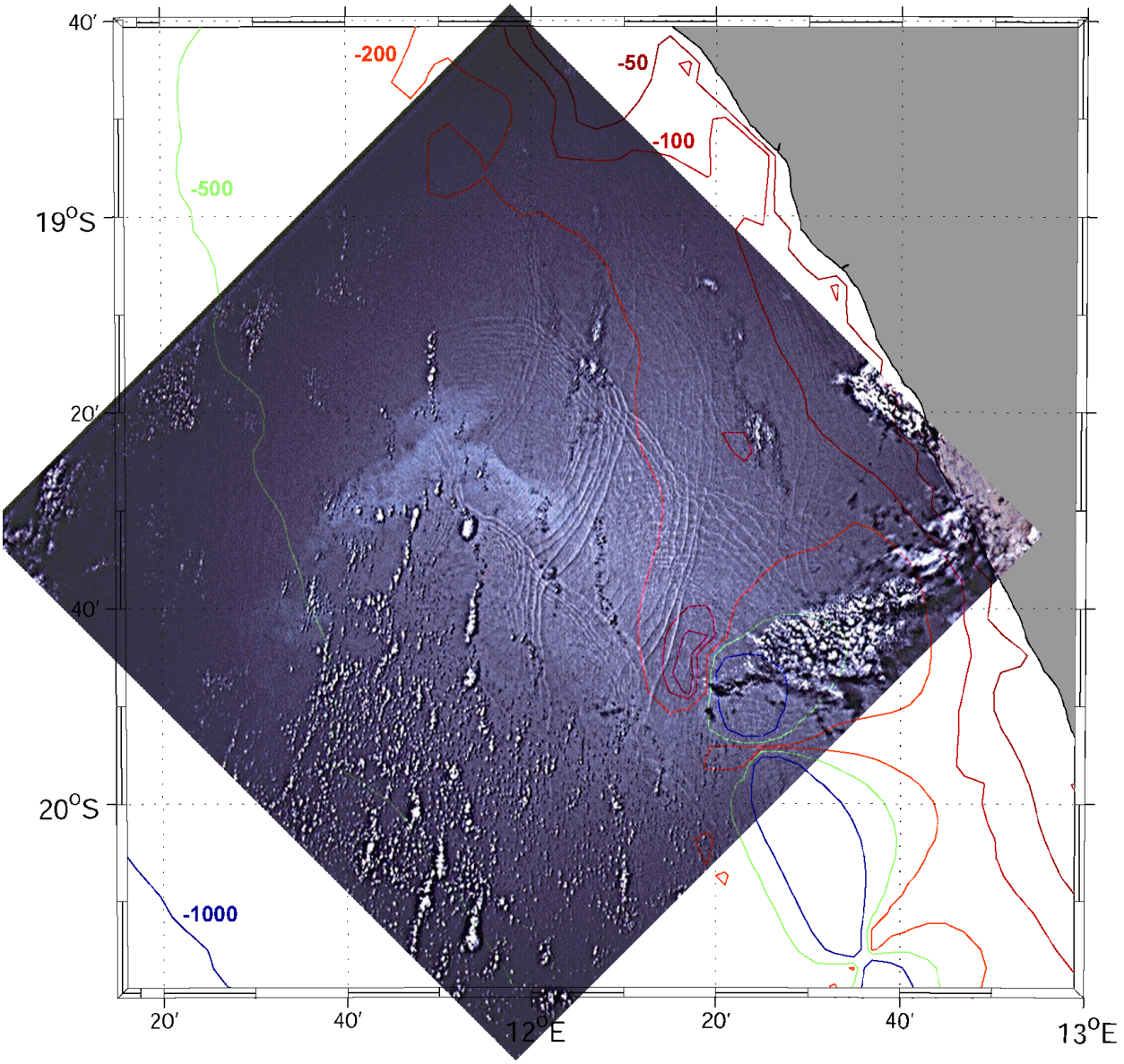

Figure 5. Space Shuttle Photograph (STS035-074-19) overlaid with local bathymetry. Bathymetry derived from Smith and Sandwell version 8.2.

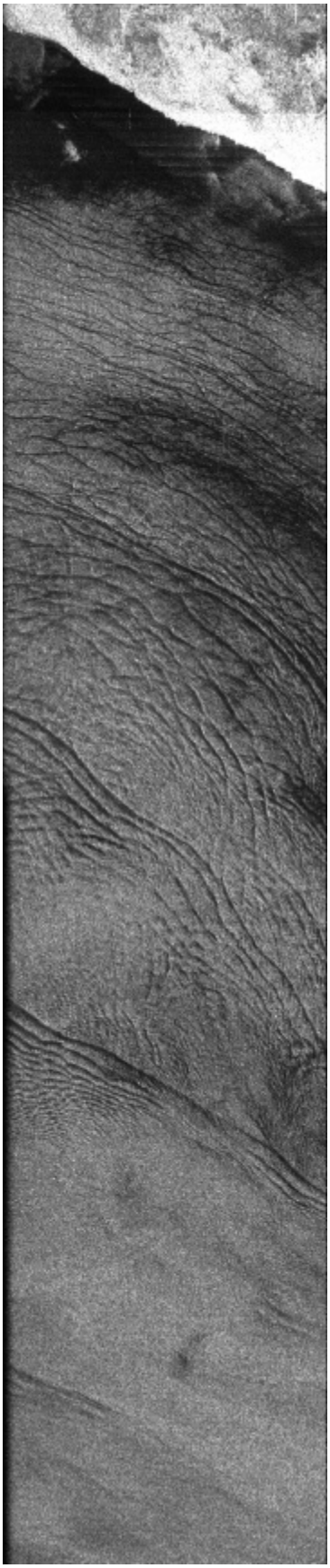

Figure 6. SIR-C data of internal waves off the Atlantic coast of South Africa collected on April 11, 1994 1:22 GMT (Data Take 26.7). The image is 300 x 60 km., centered at 31°39.7' S latitude, 16°53.1' E. longitude

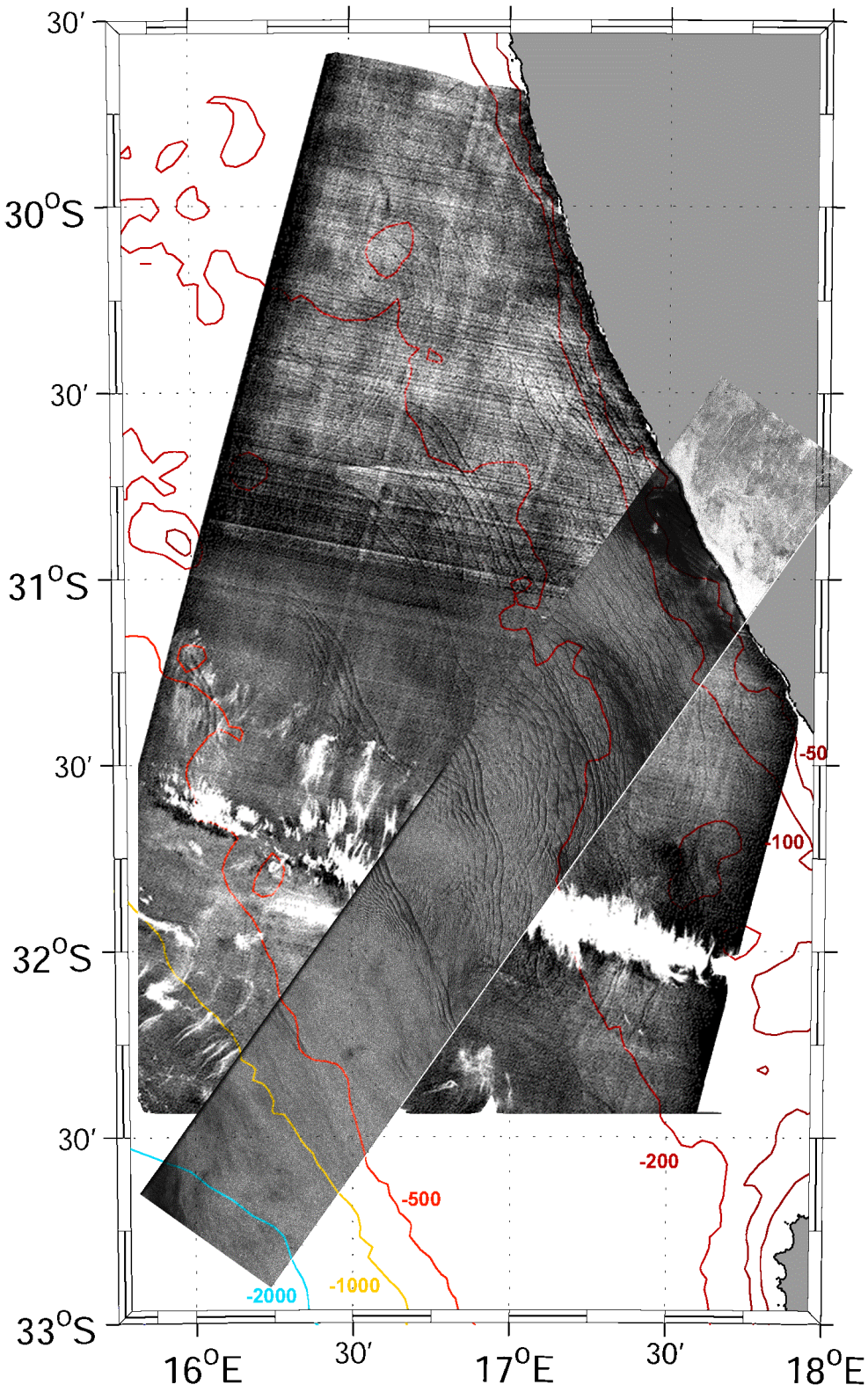

Figure 7. SIR-C data with the 1972 ERTS image from Apel et al. [1975] shown with the local bathymetry. The strong agreement in wave signatures between the two images, taken over 22 years apart, attest to the reproducibility of the generation process.

Figure 8. SIR-C data of Internal waves off the south coast of South Africa collected on April 11, 1994 15:43 GMT (Data Take 36.8). The image is 110 x 60 km., centered at 34°21.7' S latitude, 22°03.3' E longitude. A negative print of the image is presented to enhance the wave signatures.

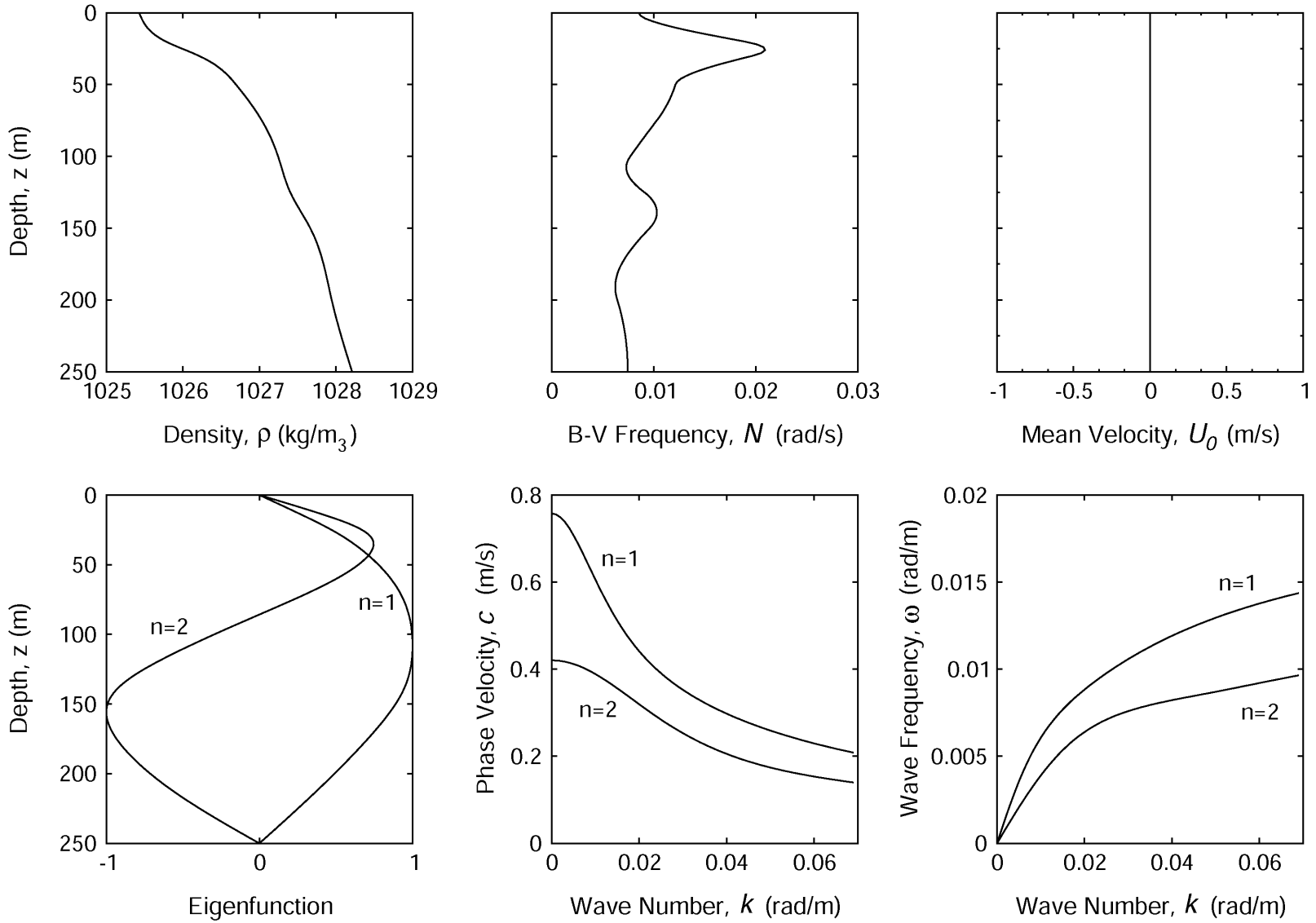

Figure 9. a) Density Profile derived from NODC World Ocean Atlas 98 Seasonal (Jan - Mar) temperature and salinity data at 30.5^0 S. latitude, 16.5^0 E. longitude b) derived Brunt-Väisälä frequency *N*(z) c) zero flow current profile d) Normalized vertical eigenfunctions (mode 1 & 2) for $2\pi/k_0$ = 1854m, H = 250 m for density and velocity profiles shown e) Phase Velocity f) Dispersion relation.