Internal Solitary Waves Generated at *Banco Engaño*, Mona Passage

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Summary

Satellite images of MODIS/Terra/Aqua sensor and photos taken by NASA astronauts from the ISS (International Space Station) during fortuitous sunglint conditions in the waters of the Mona Passage reveal the surface signal associated with a packet of internal solitary waves (**ISW**), also called internal solitons (Alfonso-Sosa, 2013). The ISW packets are generated in a narrow and shallow sill of *Banco Engaño* (Figure 1). This bank is located in the western margin of the Mona Passage, east of the Dominican Republic. Specifically, the southern edge of the narrow sill is located near 18° 30.742'N 68° 10.010'W position, about 12.01 NM East of Cap Cana Marina, True Heading 86.73°. The sill depth is about 300 m, and its narrowest part is about 6 km wide (N-S direction) (Figure 2). The strong semidiurnal meridional tidal flow over this ridge that is the source of the waves observed in the MODIS and ISS images. The ISW packets are generated on May-June and August. This strong seasonality is possible due to changes in the stratification near the sill depth (300 m). Increases in the Brunt-Vaisalla frequency at 300 m generally occur on May-June and August-September at the Caribbean Series Time Series (CaTS) station located about 160 km SE (129°) from the sill (Figure 4). Only during these periods when the B-V frequency is near 3.71 CPH, the characteristic slope of the semidiurnal (M2) tidal beam matches the topographic slope (1.17°) of the narrow sill (Figure 3). During this critical condition, when the slope parameter γ equals one, the semidiurnal flow can generate internal solitary wave packets. The semidiurnal barotropic tidal flow at 304 m in the ADCP2 station-located about 7 km south of the sill-has been described by semidiurnal tidal ellipses parameters (Rosario-Llantin, 2000). The semimajor axis of the tidal ellipses during one deployment (SEP-DEC 1997) was 10.02 cm/s oriented 182.3° from North, and on the second deployment (JUL-DEC 1998) was 22.4 cm/s oriented 203.36° from North. Both flows cross nearly perpendicular the ridge. For both cases the semiminor axis was less than 1 cm/s. The value of the tidal excursion parameter is 0.75 during a barotropic current speed of 10 cm/s. This speed at 300 m is enough to generate ISWs. Figures 5 to 9 show the ISWs departing from Banco Engaño. Close to the source region, the separating distance between each soliton wavefront is less than 1 km. But it can increase up to 3 km when the soliton is located more than 30 km away from the source region (Figure 9).

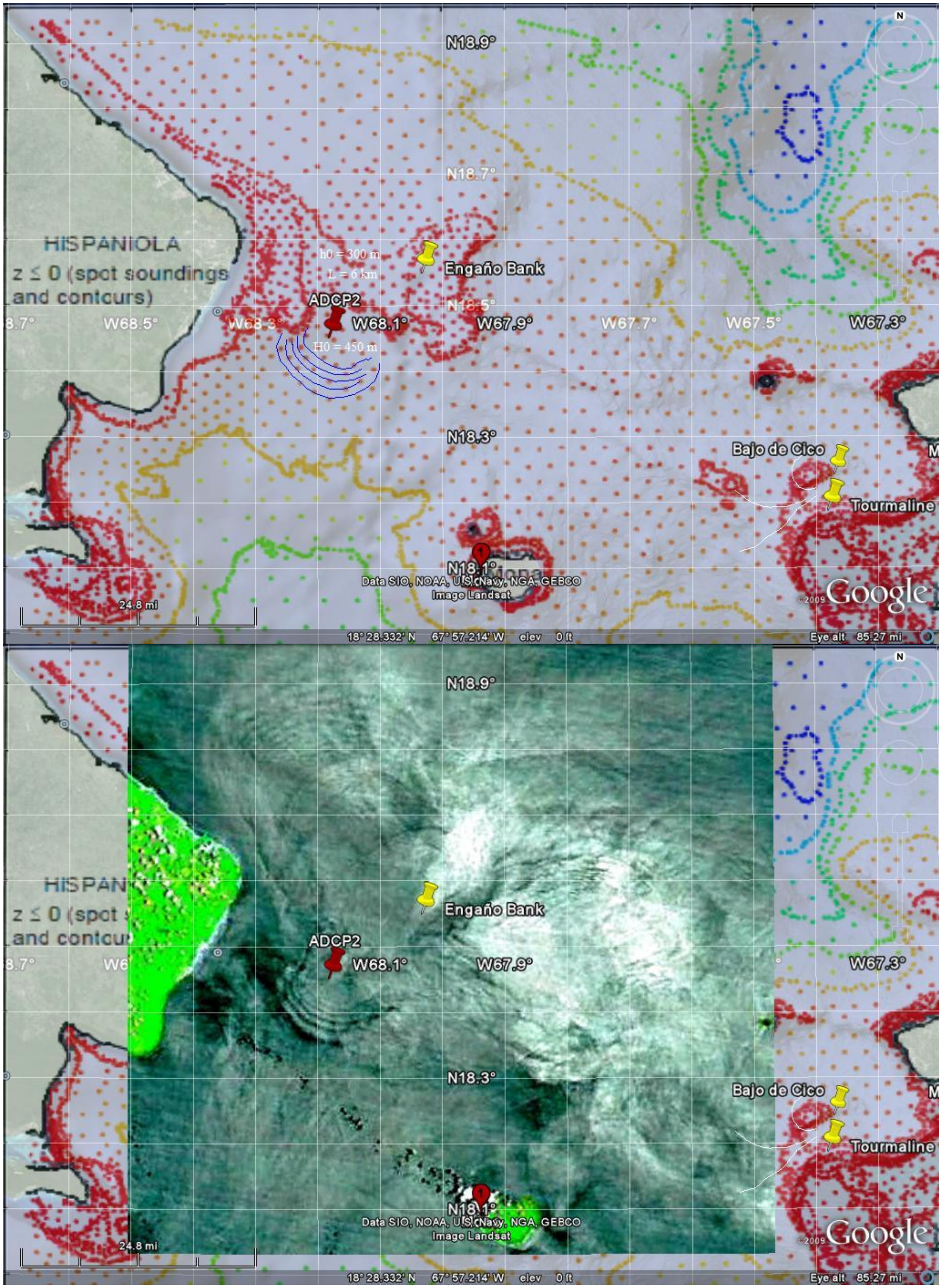


Figure 1. Top: Bathymetry of Mona Passage shows the location of Banco Engaño. Bottom: A MODIS image overlaid on the bathymetry shows an ISW packet moving away from Banco Engaño in a SW

direction and a second one in a NW direction.

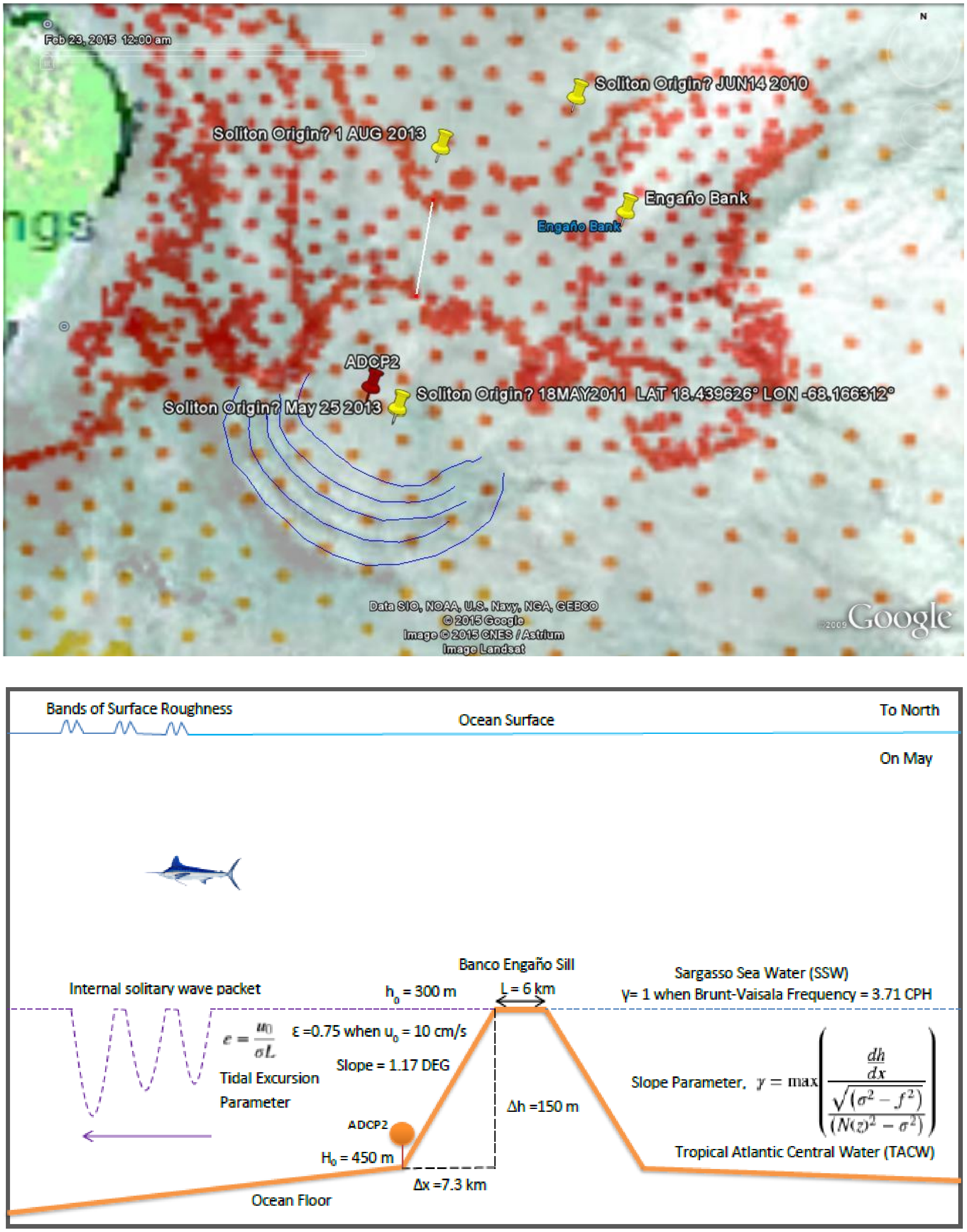


Figure 2. Top:Bathymetry of Engaño Bank. The narrowest section of the sill, signal by a white line, about 6 km wide. The blue lines mark the position of the ISW fronts. The yellow pins mark soliton origin approximate positions (SOAP) estimated from satellite images. The red pin marks the position of the ADCP2 mooring, located about 7 km from the southern edge of the sill. Bathymetry map is from

Mercado and Justiniano (2000). Bottom: A longitudinal profile across the narrow sill of Banco Engaño. The sill depth is about 300 m along a 6 km wide plateau. The topographic slope is about 1.17 degrees.

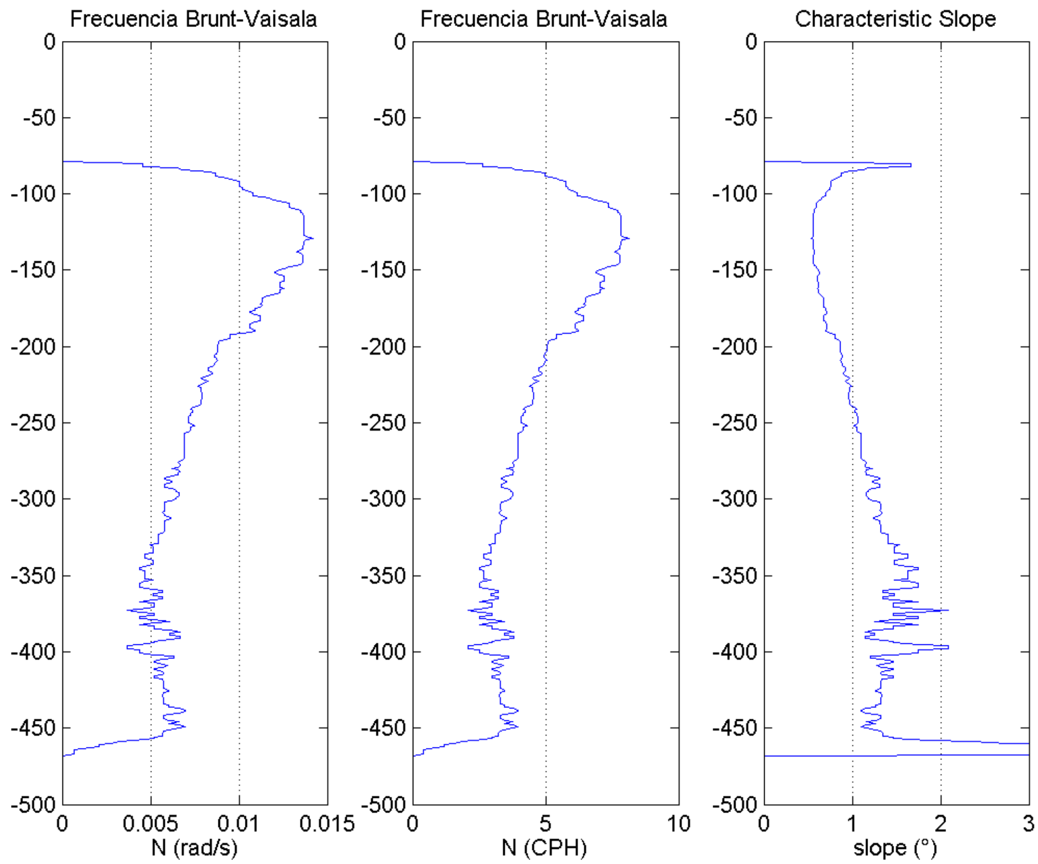


Figure 3. The Brunt-Vaisala frequency profile on May-11-1999 for ocean waters near Puerto Rico. The left and middle panels are expressed in radians per second (rad/s) and in cycles per hour (CPH), respectively. The right panel shows a profile of the characteristic slope of the semidiurnal tidal beam.

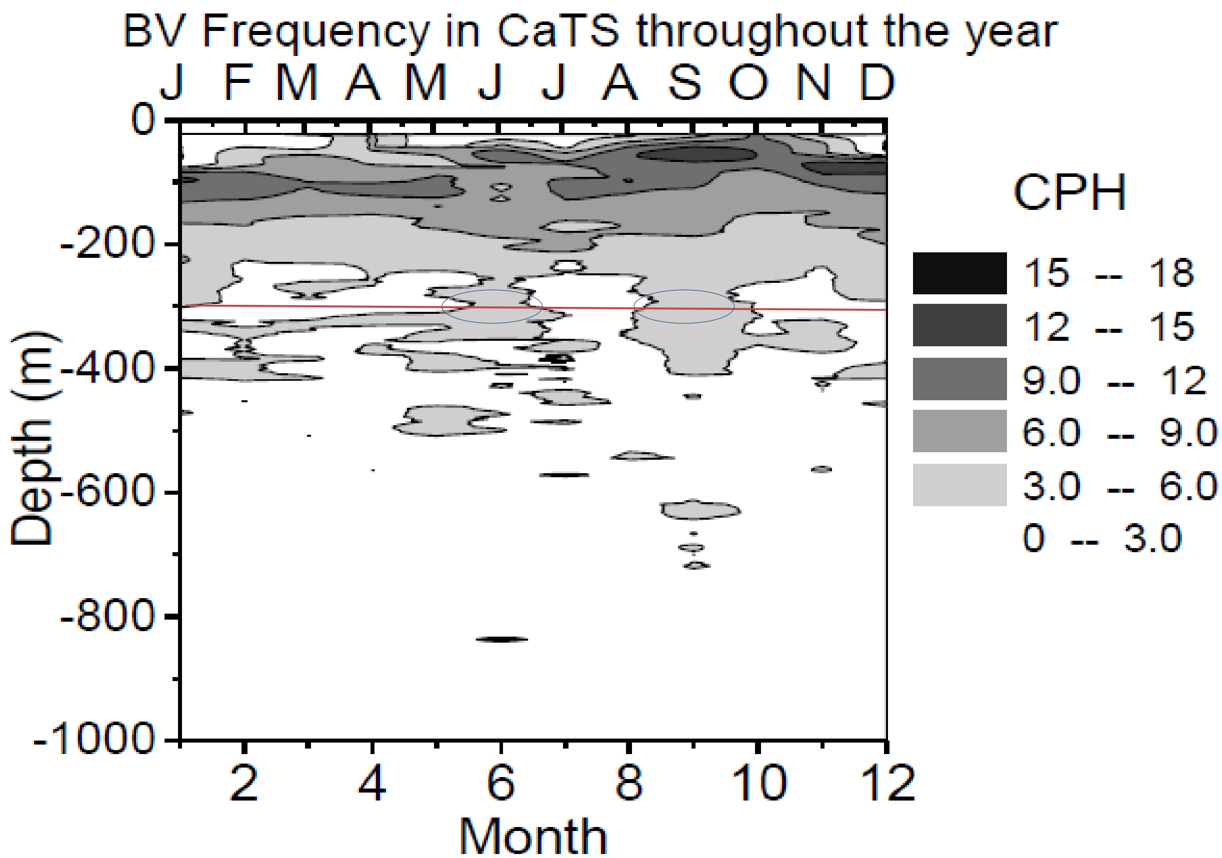


Figure 4. The annual cycle of Brunt-Vaisala frequency in the Caribbean Time Series Station (CaTS). A red line marks the 300 m depth. Blue ellipses mark the increases of BV frequency on May-June and August-September. This is Figure D.11 (top) from Alfonso-Sosa et al. (2002).

Three different MODIS images (See Below) show the packets moving south and southwest. Two of the images, corresponding to 2011 and 2013, indicate the same point of origin. The three MODIS images correspond to the following dates: 18-MAY-2011 15:15 UTC, 23-MAY-2013 15:20 UTC, 25-MAY-2013 15:05 UTC.

Event	Date	Date3	Date2
Mayaguez High Tide	5/23/2013 10:30	5/25/2013 12:30	5/18/2011 13:00
Max. Northward Speed V at 18.4 N 68.2 W	5/23/2013 8:00	5/25/2013 10:00	5/18/2011 10:00
Max. Southward Speed V at 18.4 N 68.2 W	5/23/2013 13:00	5/25/2013 15:00	5/18/2011 16:00
Departure Lee Wave	5/23/2013 11:00	5/25/2013 12:50	5/18/2011 13:45
MODIS Image	5/23/2013 15:20	5/25/2013 15:05	5/18/2011 15:15
Time Interval (h)	4.33	2.25	1.50
Lead Soliton Travel Distance (km)	14.0	9.8	9.8
Speed (m/s)	0.90	1.20	1.81
			Edwin Alfonso-Sosa, 2013

The photo taken from the ISS (International Space Station) on day JUN-14-2010 14:23 UTC and the image of MODIS/Aqua on AGO-01-2013 17:45 UTC shows a generation point of the packet inside a circle of about 6 NM around Banco Engaño (POS 18.55 N 68.03 W). These packets move north unlike previous events.

Banco Engaño is a source of alternating bipolar internal solitons packages (see images below). The direction of outbound packets alternates with the tidal current that initially generated them. Consider the following example, if there is a strong tidal semidiurnal northward current in Banco Engaño at 0800 GMT, about three hours later (1100 GMT) the magnitude of the tidal current approaches zero (slack water), then the packet is released from the generation area and begins to move southward. The tidal current changes direction towards the south, reaching its highest magnitude about two hours later, at (1300 GMT). Another two hours later, (1500 GMT), the package already was about 14 km away from the generation area. If in the previous example, the initial tidal current pushes the water off to the south then the soliton packet would head north. These events indicate the mechanism of generation may be a "lee wave" generated by a turn in the strong spring tide currents near Banco Engaño, during conditions of lunar perigee and syzygy.

The speed range of the leading soliton in each package goes from 0.90 m s^{-1} to 1.81 m s^{-1}. These velocities are near the generation area (<14 km) (see table).

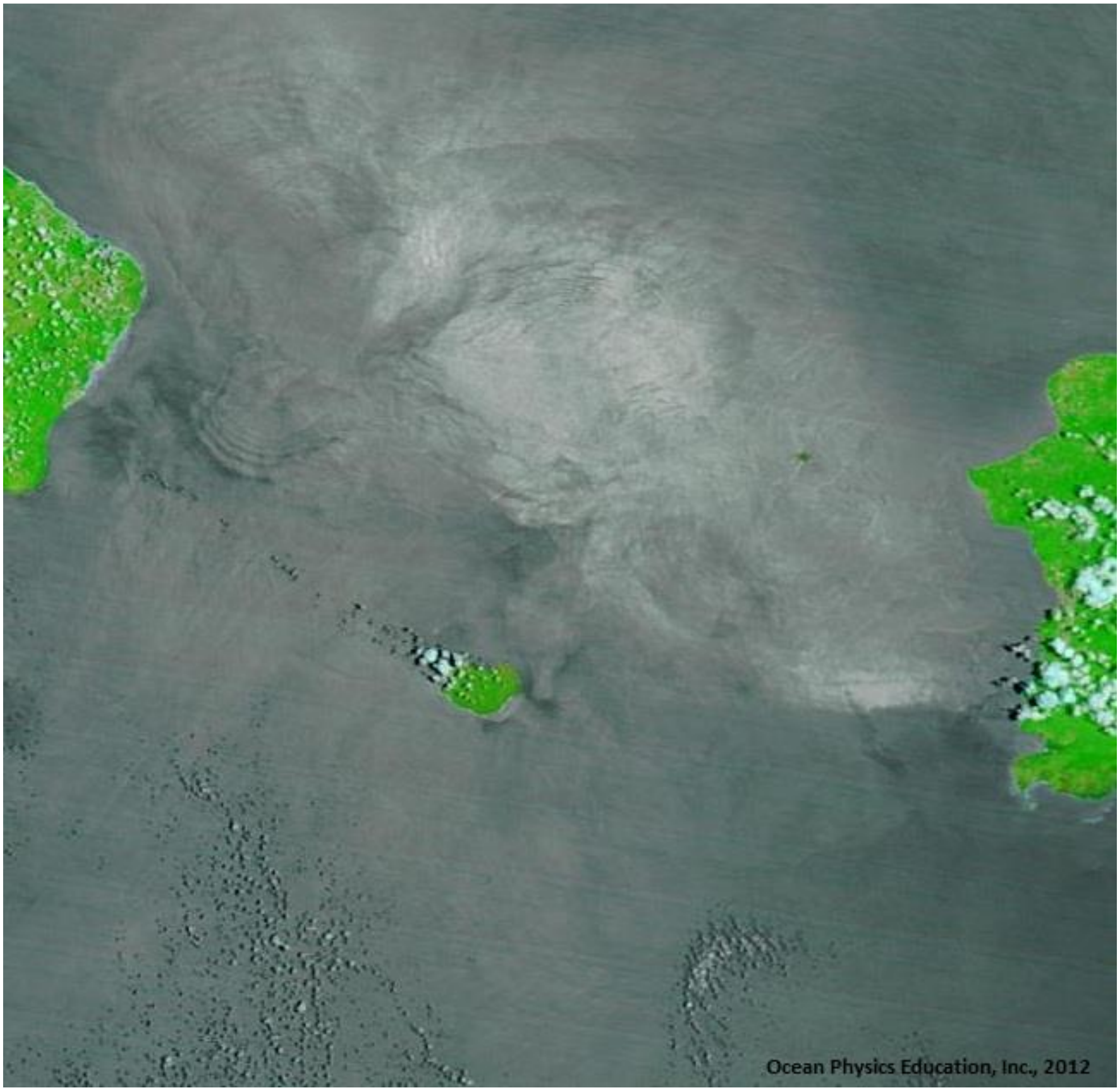


Figure 5. This image of the Mona Passage shows a newly generated soliton packet leaving *Banco Engaño* and moving to the south. Another package previously generated is moving to the north. Image MODIS/Terra on May-18-2011.

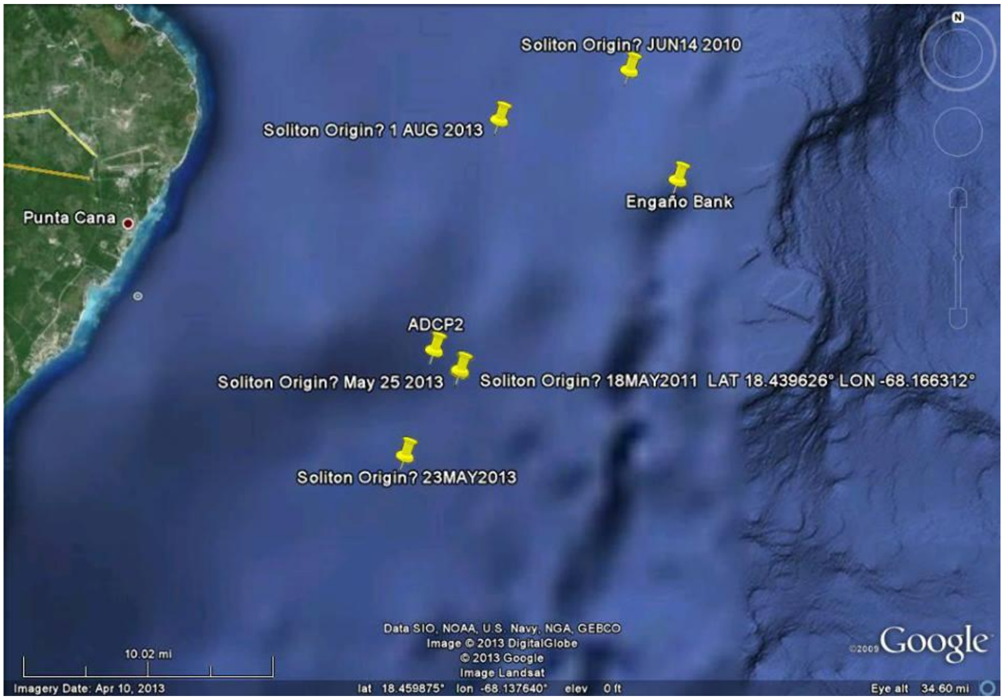


Figure 6. Soliton origin approximate positions (SOAP) in *Banco Engaño*.

Soliton Origin Approximate Positions (SOAP) at Mona Passage.

Mona Passage SOAP Coordinates				
Date (UTC)	**LAT**	**LON**	**Bathymetric Feature**	**Sensor**
6/14/10 14:23	18.613636°	-68.062945°	Engaño Bank	ISS024-E-5967 Photo
8/1/13 17:45	18.584928°	-68.142481°	Engaño Bank	MODIS/Aqua
5/25/13 15:05	18.438716°	-68.166663°	10 NM SW of Engaño Bank	MODIS/Terra
5/18/11 15:15	18.439626°	-68.166312°	10 NM SW of Engaño Bank	MODIS/Terra
5/23/13 15:20	18.390042°	-68.200020°	10 NM SW of Engaño Bank	MODIS/Terra
5/10/12 17:45	18.536170°	-67.815671°	12 NM East of Engaño Bank	MODIS/Aqua
8/1/13 17:45	18.259309°	-67.695429°	Mona Passage Sill	MODIS/Aqua
6/14/10 14:23	18.242832°	-67.371562°	Bajo de Sico	ISS024-E-5968 Photo
6/14/10 14:23	18.187177°	-67.381599°	Tourmaline Bank	ISS024-E-5968 Photo
			Ocean Physics Education Inc., 2013	

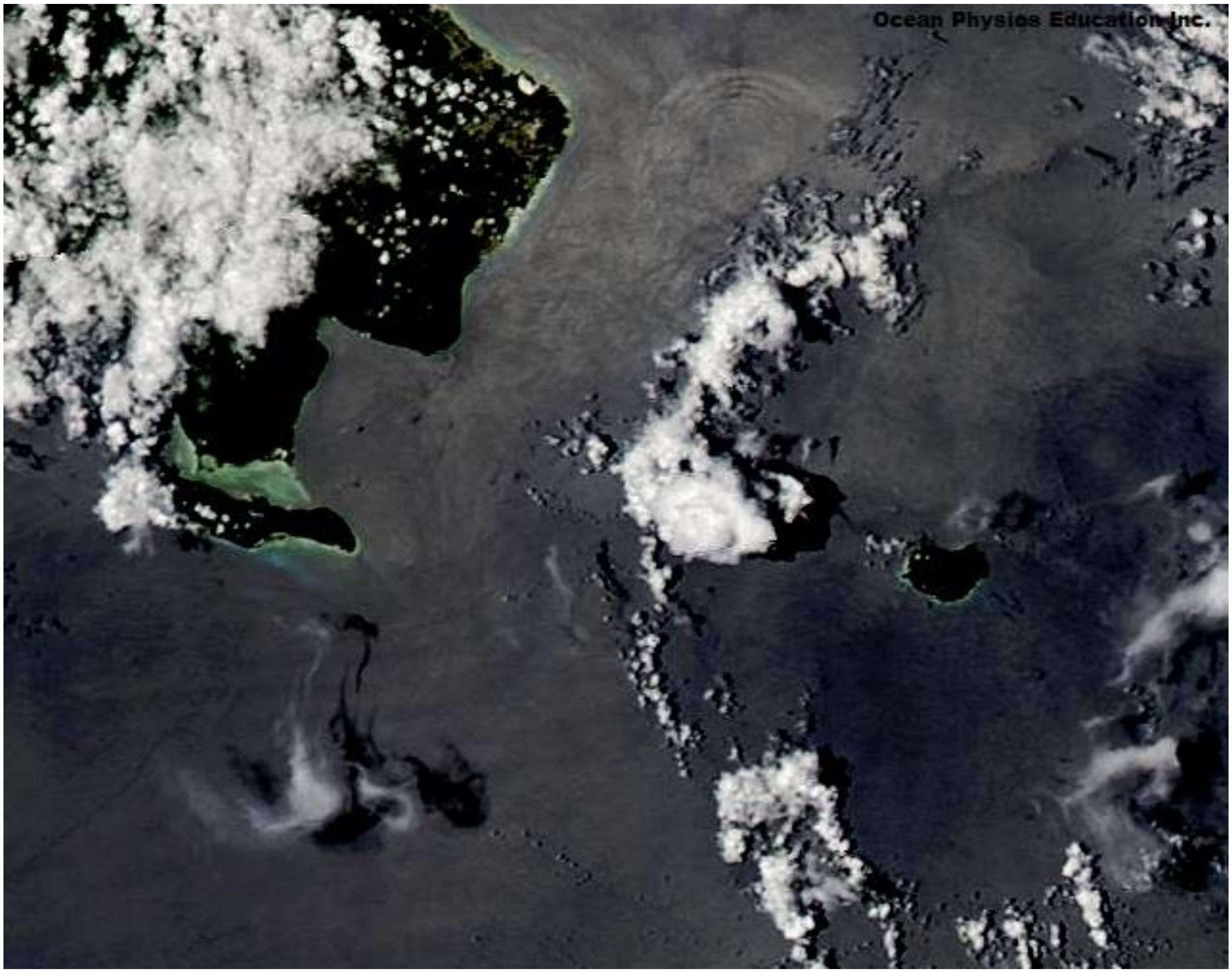


Figure 7. Soliton package leaves *Banco Engaño* and moves north. Image MODIS/Aqua on Aug-1-2013.

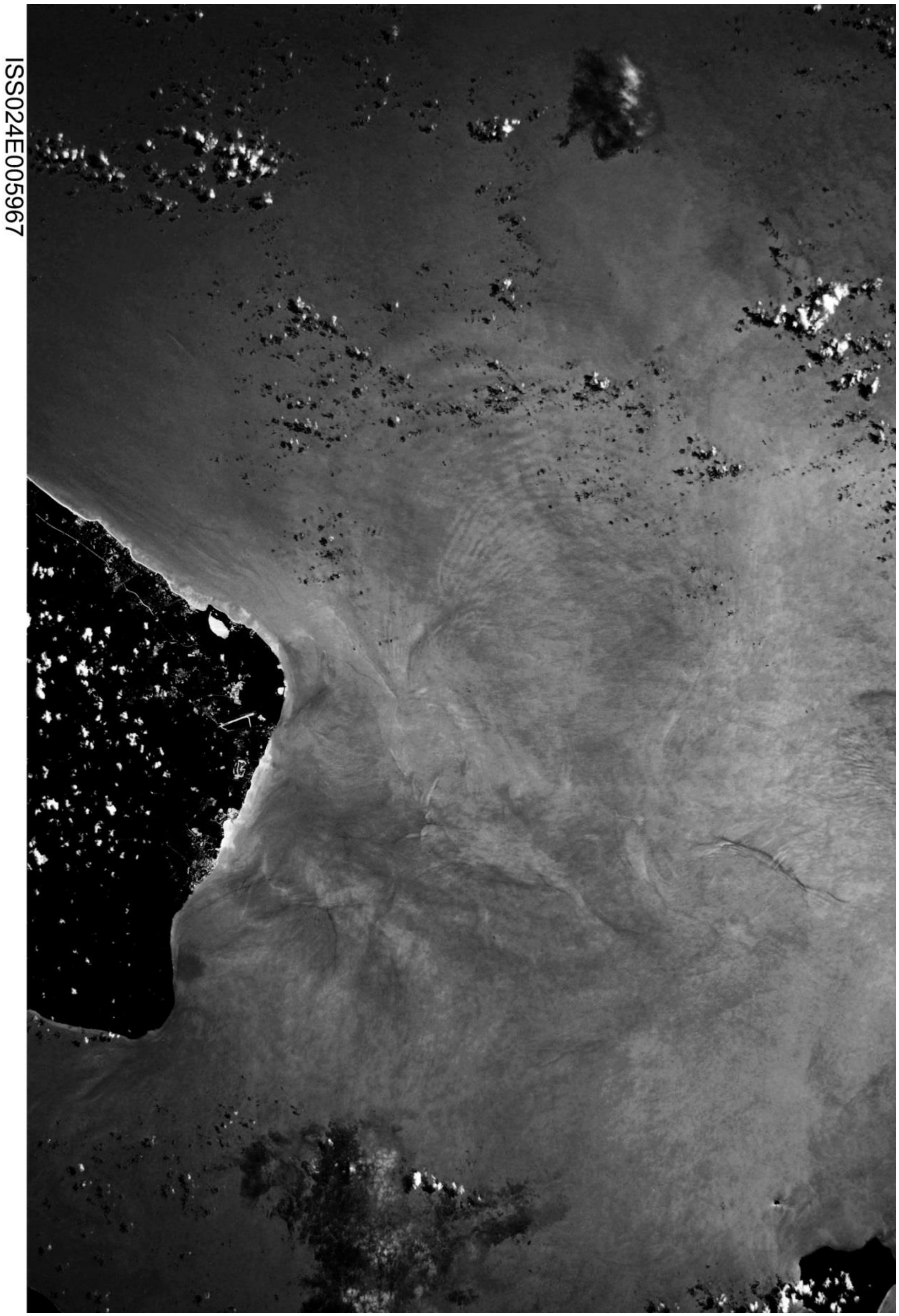
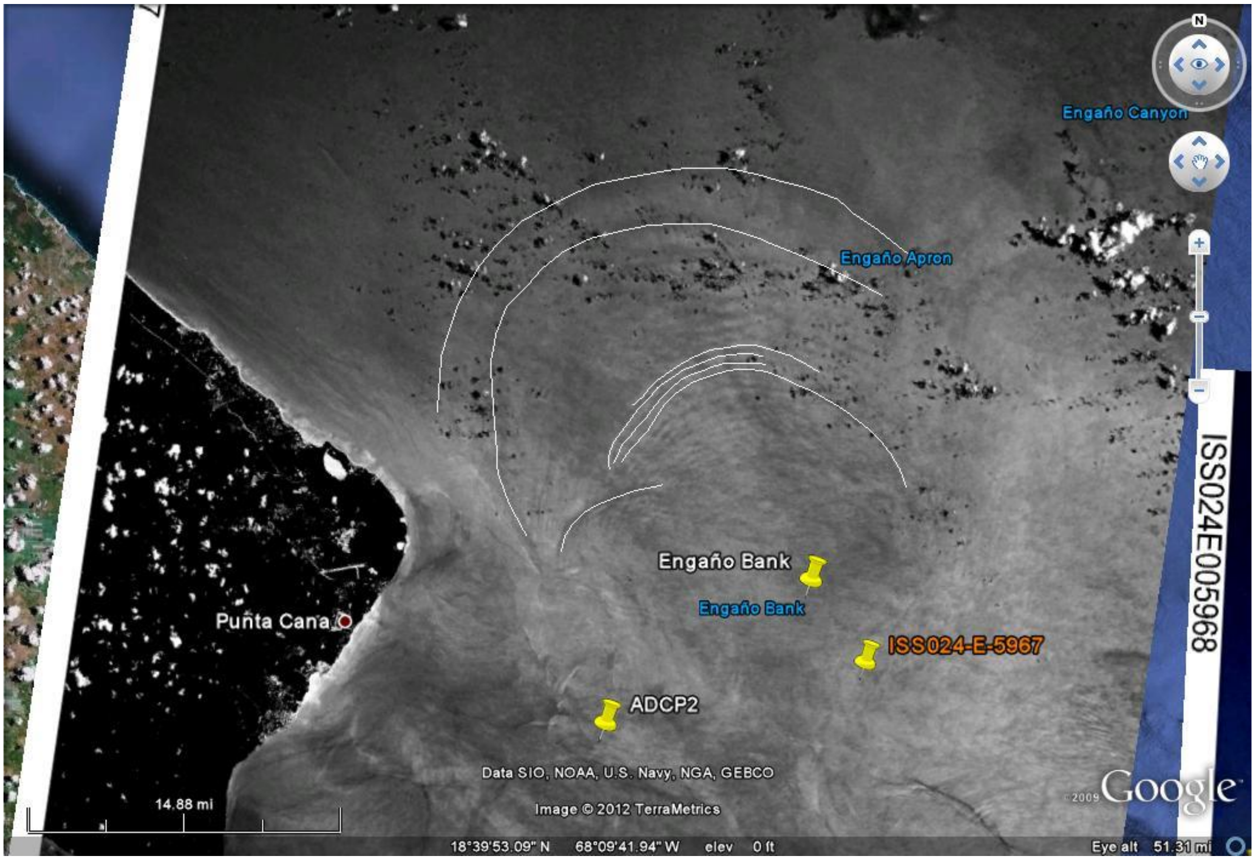


Figure 8. Photo taken by the ISS-024 on 14 June 2010. A soliton package fissions into multiple internal waves.



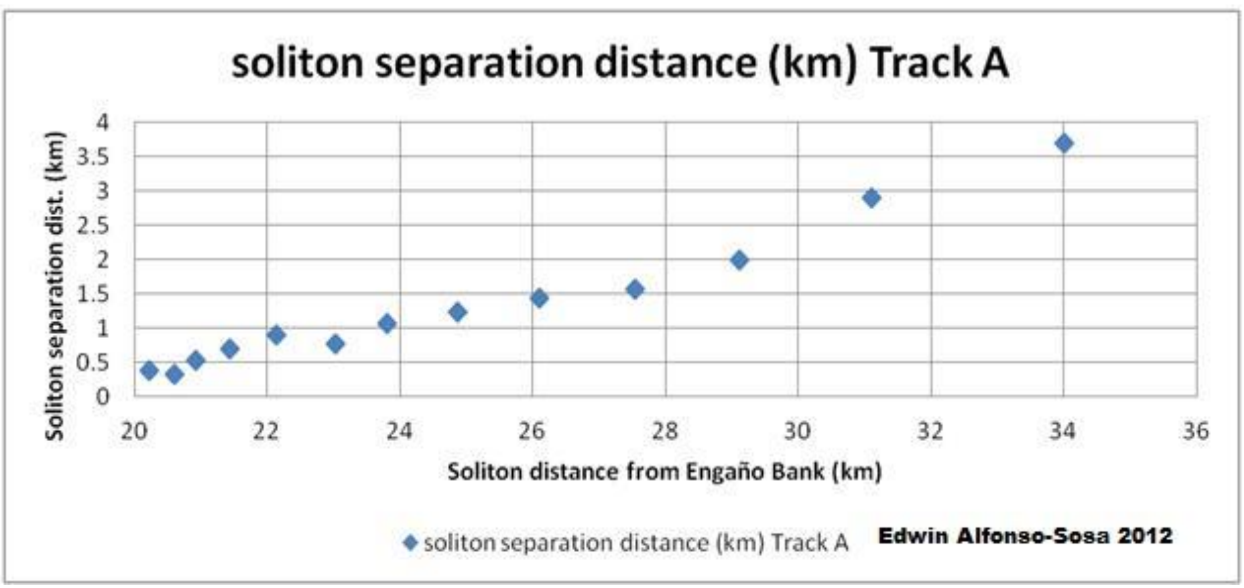


Figure 9. The separation of the solitons increases as they move away from *Banco Engaño*.

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