Dragon's Mouth Outflow Plume as a source of nonlinear internal waves

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18-AUG-2013

Introduction

Nonlinear internal waves are known to be generated by tidal currents over abrupt ocean bottom topography. Strong semidiurnal currents over a shelfbreak, bank or ridge generate a trapped lee wave at the opposite side of the flow, and then when the currents slack; it can be liberated as a soliton, solibore or as a non-linear wave packet. These waves travel long distances. But recent STS-034 Astronaut Photography and NASA MODIS images reveal another scenario or mechanism for the generation of nonlinear internal waves. The low salinity waters of the Gulf of Paria are rushed through the narrow passage, known as the Dragon's Mouth, as a huge buoyant plume into the Caribbean Waters North of Trinidad. Their low salinity is due to the discharge of Orinoco River Delta waters that are advected by the Guiana Current through the Serpent's Mouth Passage into the Gulf of Paria. These colored waters deeply contrast with the clear blue Caribbean Waters, allowing the easy delimitation of the Dragon's Mouth Outflow Plume (DMOP) boundaries. Soon after the waters are discharged by the Dragon's Mouth the plume interacts with a strong westward flowing current, a branch of the Guiana Current entering the Caribbean Sea North of Trinidad. Only the plume boundaries perpendicular to the East-West Guiana Current are sources of nonlinear internal waves. The DMOP East boundary seems to be a more active generation zone.

Generation Mechanism for DMOP Internal Waves

In 2005, Jonathan D. Nash and James N. Moum explained the generation mechanism of large amplitude internal waves in the coastal ocean by the Columbia River Plume: "*Internal waves can be generated from a river plume that flows as a gravity current into the coastal ocean. The convergence of horizontal velocities at the plume front causes frontal growth and subsequent displacement downward of near surface waters. Individual freely propagating waves are released from the river plume front when the front's propagation speed decreases below the wave speed in the water ahead of it*." In other words if the Froude Number $F = u_f/c$, defined as the ratio of the frontal propagation speed (u_f) and the wave speed (c), transitions from supercritical ($F > 1$) to subcritical ($F < 1$), the wave depression originally trapped in the plume front is released as a free propagating wave. The time of release will depend on the wave amplitude because it controls the wave speed. Once the wave speed is larger than the front speed it will be free to propagate.

In the case of DMOP, we propose a slightly different mechanism. Soon after the DMOP exits the Dragon's Mouth Passage, the low density plume serves as an obstacle to the westward flowing Guiana Current. The Guiana westward velocities cross perpendicularly the DMOP eastern front. In the eastern front, the cross-frontal velocity of the DMOP gravity current pushes against the westward flowing Guiana Current. The collisions of the two cross-frontal currents allowed grow of a trapped internal wave in the frontal boundary. In the eastern front, the trapped wave acquires a sufficient large amplitude and wave speed (c) to move against the Guiana Current. After being released, fissions into a non-linear internal wave packet. This packet moves slowly toward the East, along the offshore waters of Trinidad's Northern Coast. Some of the images show that in the southern tip of the wave packet (nearer to Trinidad's Northern Coast) the waves lag probably due to the shallower depths. But it's still unclear if the wave packet refracts toward the coast.

For the DMOP western front, the cross-frontal velocities are parallel. The frontal propagation velocity and the Guiana Current velocity point toward the west. In this case the value of the cross-frontal propagation speed (u_f) must be larger than the Guiana cross-frontal speed in order to operate the frontal wave growth. In this particular case, we have to consider the modulation of the ambient current due to strong semidiurnal currents in that region.

References

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Nash, J.D. and J.N. Moum, 2005: River plumes as a source of large-amplitude internal waves in the coastal ocean, Nature 437, 400-403 (15 September 2005) | doi: 10.1038/nature03936, (500 kB pdf).

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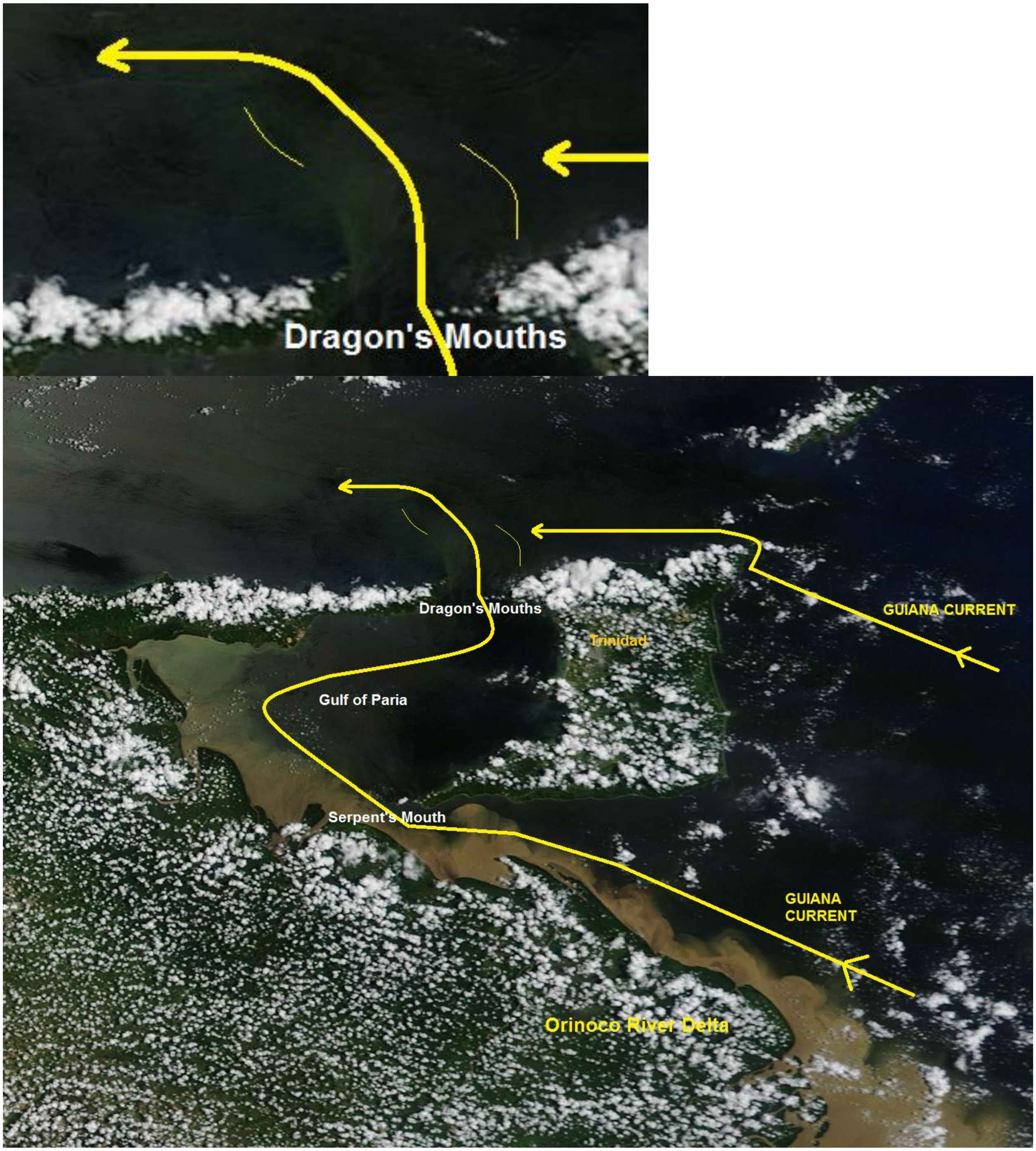
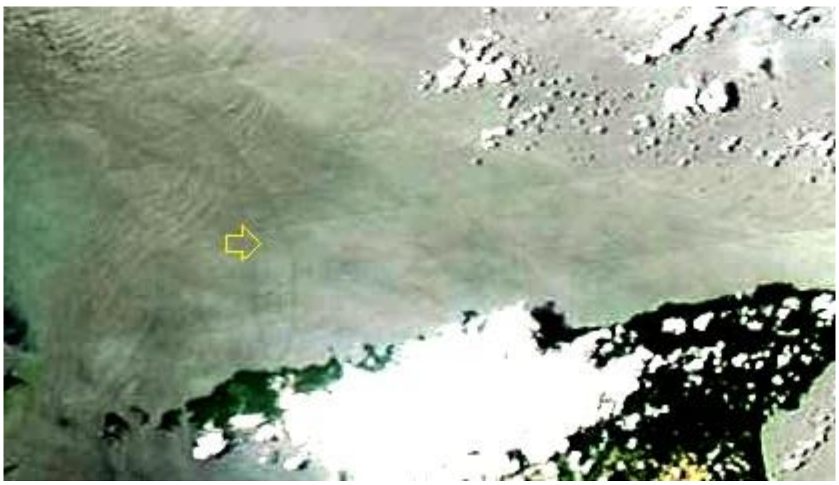
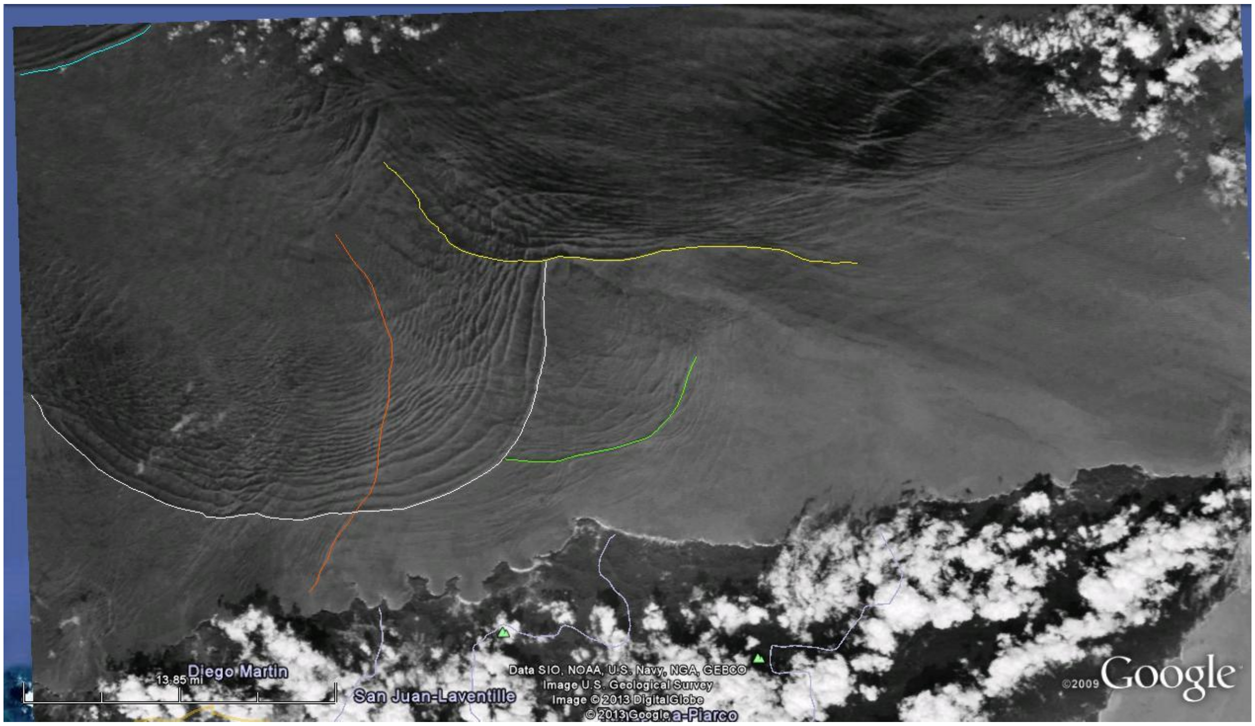


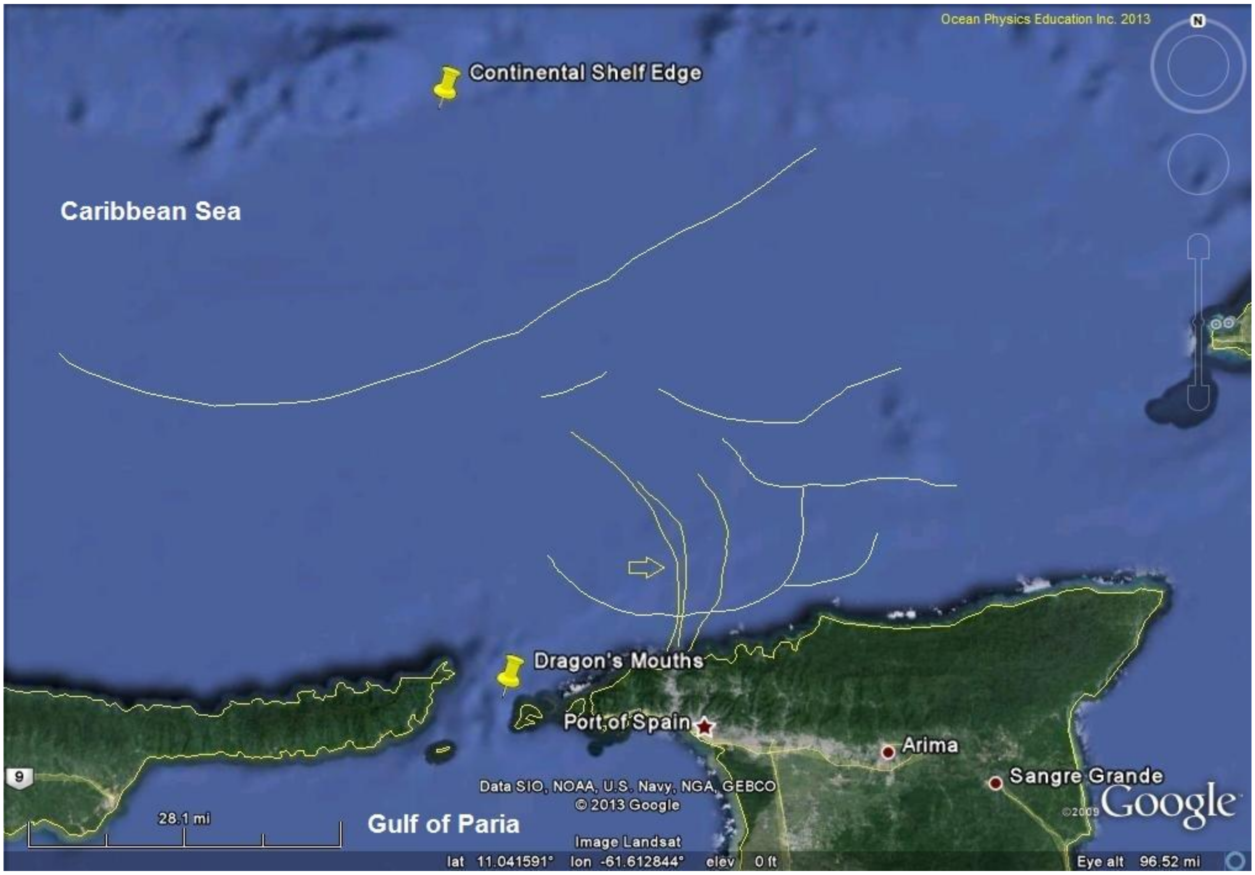
A closer view of Dragon's Mouth Outflow Plume (DMOP). The two yellow arcs represent the position of the internal waves in the plume East and West boundary. The Guiana Current (long yellow line) advects the Orinoco River Plume waters into the Gulf of Paria. Then the low salinity Paria waters cross the Dragon's Mouth to be discharged into the Caribbean Sea. MODIS/Terra image taken on AUG 6 2013.



The arrows point to two nonlinear internal wave packets at the DMOP East and West boundaries. The white arrow points to a Soliton Packet generated at the Continental Shelf Break and moving Southeast to Trinidad. Below only the DOMP East Margin shows and internal wave moving East. MODIS/Terra images taken on AUG 17 2013 and AUG 5 2013, respectively. We acknowledge the use of data products or imagery from the Land Atmosphere Near-real time Capability for EOS (LANCE) system operated by the NASA/GSFC/Earth Science Data and Information System (ESDIS) with funding provided by NASA/HQ. http://earthdata.nasa.gov/data/nrt-data/rapid-response/



Five distinct wave packets were distinguished in this image. The leading wave front of each group was colored. The orange colored wave packet velocity is perpendicular to the other four packets. This suggests a different origin mechanism for the orange packet. The image was red filtered and contrast stretched to enhance the surface signal of the internal waves. At least 10 internal wave groups can be seen in this image. Astronaut photograph ISS034-E-32377 was acquired on January 18, 2013 16:16:48 GMT, with a Nikon D3S digital camera using a 180 millimeter lens, and is provided by the ISS Crew Earth Observations experiment and Image Science & Analysis Laboratory, Johnson Space Center. The image was taken by the Expedition 34 crew. The image can be downloaded from the NASA/JSC Gateway to Astronaut Photography of Earth.



The white arcs represent the position of the leading wave fronts of the soliton packets generated at the continental shelfbreak. The yellow arcs are the leading wave fronts of the internal wave packets moving East (yellow arrow), that were generated at the DMOP eastern front. The last one shows signs of refraction toward the Trinidad's Northern Coast.