Available online at www.sciencedirect.com
ScienceDirect
Remote Sensing of Environment 107 (2007) 256–263
Remote Sensing of Environment
www.elsevier.com/locate/rse

Multi-angle Imaging SpectroRadiometer (MISR) time-lapse imagery of tsunami waves from the 26 December 2004 Sumatra–Andaman earthquake

Michael J. Garay [a,b,*], David J. Diner [b]

[a] University of California, Los Angeles, Los Angeles, CA, United States
[b] Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA, United States

Received 15 May 2006; received in revised form 14 September 2006; accepted 7 October 2006

Abstract

On 26 December 2004, a few hours after a massive earthquake occurred off the western coast of Sumatra in the Indian Ocean generating a major tsunami, the Multi-angle Imaging SpectroRadiometer (MISR) instrument on NASA's Terra satellite captured unique, time-lapse evidence of extremely large waves occurring along the eastern coast of India. The MISR imagery provides information on the location and characteristics of tsunami waves in near-shore waters, along with estimates of the wave speed.

Keywords: Multi-angle remote sensing; Terra; MISR; Asian tsunami; Sumatra–Andaman earthquake

1. Introduction

At 00:58:53 UTC on 26 December 2004, the largest earthquake in over 40 years occurred in the Indian Ocean with its epicenter to the west of the Indonesian island of Sumatra. Details of the earthquake and the rupture process can be found in Lay et al. (2005), Ammon et al. (2005), and Bilham et al. (2005). The earthquake caused a sudden uplift of the ocean floor, triggering a major tsunami that resulted in catastrophic devastation and loss of life in the surrounding coastal regions.

In this paper we present unique observations made by the Multi-angle Imaging SpectroRadiometer (MISR) instrument on NASA's Terra-EOS satellite on the day of the earthquake, a few hours after the initial tsunami waves impacted the eastern Indian coast. Besides providing a new perspective on the tsunami event, the MISR observations allow estimates of the speed of the tsunami wave fronts in the near shore environment.

In the next section we will describe the MISR instrument and how tsunami information was obtained from the MISR imagery. After this, we present examples of tsunami wave speeds determined in two different regions along the eastern coast of India where features associated with large, breaking waves were observed. Finally, the MISR observations are compared with coincident tide gauge measurements of the tsunami waves.

2. Observations

MISR is one of five instruments onboard NASA's Terra Earth Observing System (EOS) satellite, launched in December 1999 into a near-polar orbit that crosses the equator at approximately 10:30 local time, on its descending portion. A detailed description of the MISR instrument is given by Diner et al. (1998), so only a brief summary is provided here. MISR makes measurements in four spectral bands, 446 nm (blue), 558 nm (green), 672 nm (red), and 866 nm (near infrared), using an array of nine cameras. The cameras are oriented along the direction of the satellite motion in pairs at angles of ±70.5°, ±60.0°, ±45.6°, ±26.1°, with the remaining camera pointing in the nadir (0°) direction. MISR "global mode" data are processed so that the red band has a ground resolution of 275 m × 275 m in all nine cameras. To reduce data volume, all but the nadir camera blue, green, and near infrared spectral bands are resampled to a resolution of 1.1 km × 1.1 km. MISR's image swath is approximately 400 km wide, acquiring data over the

* Corresponding author. University of California, Los Angeles, Los Angeles, CA, United States.
E-mail address: Michael.J.Garay@jpl.nasa.gov (M.J. Garay).

0034-4257/$ - see front matter © 2006 Elsevier Inc. All rights reserved.
doi:10.1016/j.rse.2006.10.022

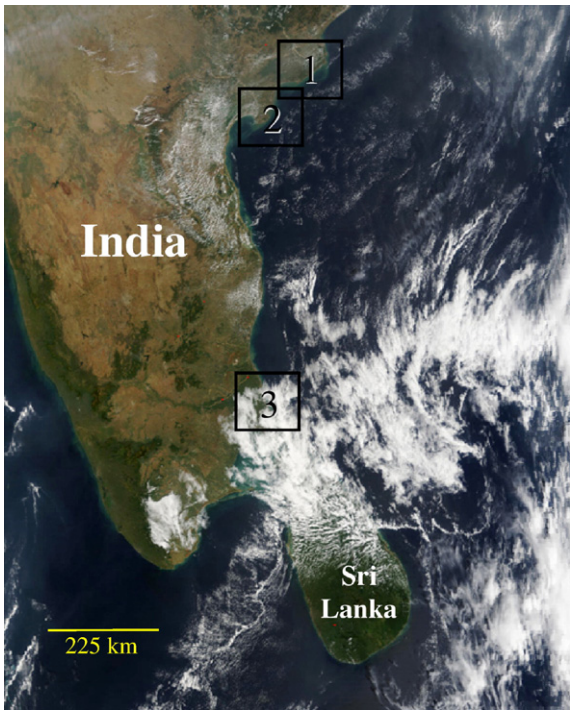

Fig. 1. MODIS Terra satellite visible image of India and Sri Lanka from 26 December 2004. The MISR swath extends down the center of this MODIS image. Numbers indicate regions where tsunami-related observations were made by MISR. Region 1 is the Godavari River Delta. Region 2 is the Krishna River Delta. Region 3 is the Nagapattinam District in the Indian state of Tamil Nadu.

entire globe in a period of nine days, with a repeat cycle of 16 days. Although MISR's nine cameras instantaneously image different points along the satellite ground track, the cameras are registered to a common reference after processing so that each point is viewed from nine different directions during an interval of approximately 7 min. The data used in this analysis are projected to the World Geodetic System 1984 (WGS84) ellipsoid (Diner et al., 1998). Stationary features lying essentially at sea level will be found at the same location in all nine camera images. The speed and direction of moving features near the surface can be measured due to the known time interval between successive camera views.

On 26 December 2004, at approximately 03:35 UTC, tide gauge records indicate that the eastern coast of India was struck by the initial wave of the tsunami generated by the Sumatra–Andaman earthquake (Bilham et al., 2005; Fine et al., 2005; Hirata et al., 2006; Nagarajan et al., 2006). The Terra satellite passed over the eastern coast of India and the western coast of Sri Lanka slightly more than 90 min later, allowing MISR to obtain images of some of the regions affected by the tsunami between approximately 05:10 and 05:18 UTC.

Animations were constructed from the sequence of red band (275 m, highest resolution) images of the area. These animations revealed unique, time-lapse sequences of what appear to be the fronts of breaking tsunami waves moving toward the Indian coast. Due to its coarse resolution relative to the small scale of the wave breaking phenomenon, MISR does not typically observe breaking ocean waves, implying that the waves observed on 26 December 2004 were of an exceptionally large and unusual character.

While the animations provided important qualitative information about apparent tsunami wave features, quantitative information was obtained through careful analysis of the images from individual cameras. Because the georectification of MISR

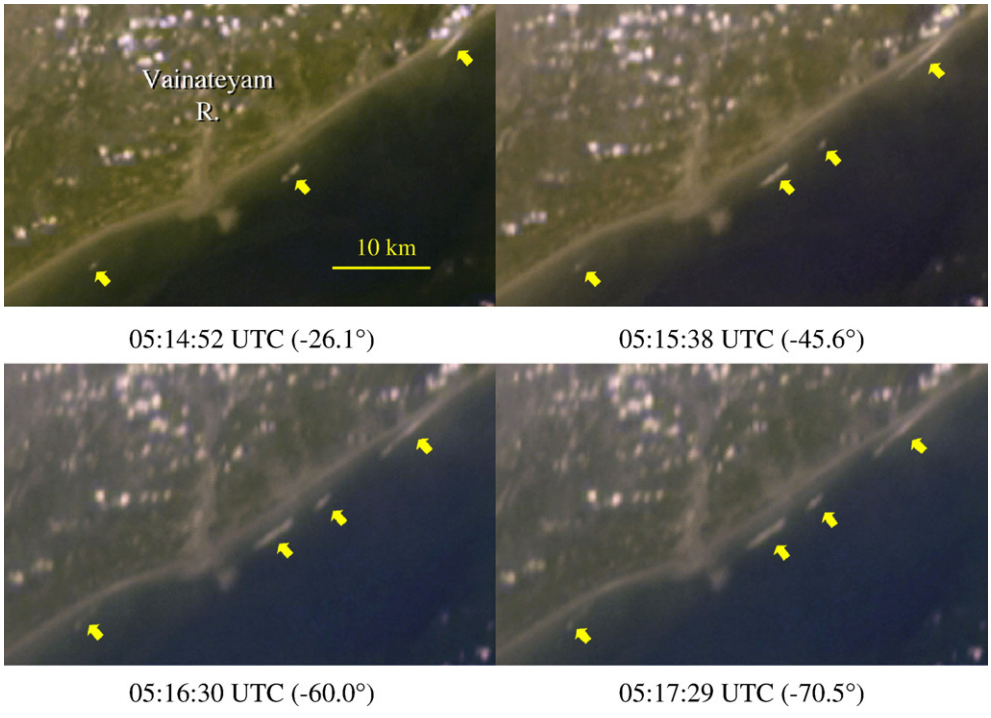

Fig. 2. MISR image sequence of tsunami wave features along the Godavari River Delta. Times and MISR viewing camera zenith angles are indicated below each panel. Arrows indicate positions of tsunami features along the coast.