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Satellite SAR ship detections from PMAR in support of Cutlass Express

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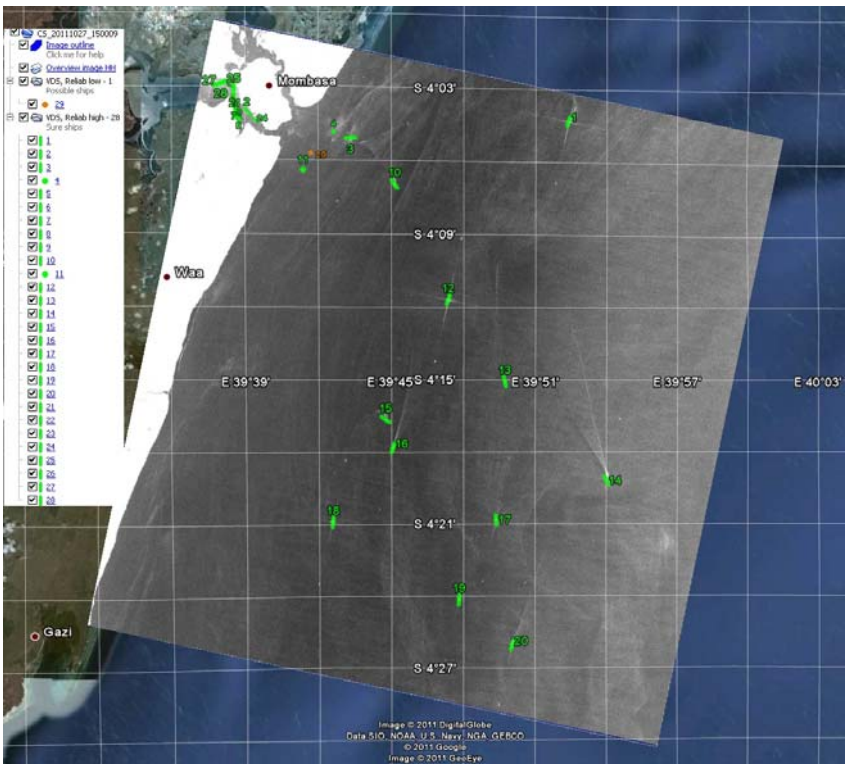

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Summary

Cutlass Express is a naval exercise on maritime interdiction and counter-piracy, to which a number of East African countries participate. It is organised by the US Navy for the purpose of regional maritime capacity building. JRC has been invited to join, based on its activities in the PMAR ("Piracy, Maritime Awareness and Risks") project. The at-sea operations in Cutlass Express took place 25-27 Oct 2011, and during those days, JRC had satellite SAR (Synthetic Aperture Radar) images collected and analysed. The resulting ship detections were fed into MSSIS / SeaVision, a system to enable international sharing of the maritime picture. In this way, PMAR results were made available to African operational maritime authorities in near-real time. The activity has succeeded in its goals to explore and demonstrate regional sharing of maritime surveillance data in the Horn of Africa, to bring PMAR results to African maritime authorities, to explore how satellite SAR can contribute to the maritime awareness, and to collect a part of the data needed for further work in the PMAR project.

Contents

Acronyms

AIS	Automatic Identification System
CSK, CS	Cosmo-Skymed
EUNAVFOR	European Union Naval Force Somalia – Operation Atalanta
IMO	International Maritime Organisation
JRC	Joint Research Centre of the European Commission
LRIT	Long Range Identification and Tracking
MSSIS	Maritime Safety and Security Information System
NATO	North Atlantic Treaty Organization
NRT	Near-Real Time
OTHTTS	Over The Horizon Tactical Tracking System
PMAR	Piracy, Maritime Awareness and Risks
RS2, R2	Radarsat-2
SAR	Synthetic Aperture Radar
SUMO	JRC's ship detector for SAR images
TSX, TX	TerraSAR-X
VDS	Vessel Detection System
VMS	Vessel Monitoring System

Background

1. JRC is running the PMAR ("Piracy, Maritime Awareness and Risks") project to explore technical possibilities to increase the maritime domain awareness with authorities in Africa. The project investigates which data sources and tools can be used to build up maritime situational awareness; the sources include ship reporting systems (coastal AIS, satellite AIS, LRIT, VMS) and observation systems (mainly satellite SAR). During certain periods in the project, large amounts of ship traffic data are collected in certain test regions, in order to enable the evaluation of different types of data, and of test methods to combine them.

2. Cutlass Express is a maritime interdiction / counter-piracy naval exercise. It is organised off East Africa by the US Navy, with a number of maritime operational authorities in the region participating. These include: Djibouti, Kenya, Mauritius, Mozambique, Seychelles, Tanzania, Uganda, Yemen, East African Standby Force, EUNAVFOR, IMO and NATO. The at-sea activities were taking place 25-27 Oct 2011. Maritime situational awareness during the exercise is obtained by using coastal AIS, satellite AIS, coastal and ships' radar, sightings and special systems (OTHTTS). The Cutlass Express exercise plan, including operation areas and temporal scenarios, has been fixed in detail during a one-year preparation phase.

3. During contacts in 2010 and 2011, JRC with its PMAR project was invited by US Naval Forces Africa to join the Cutlass Express exercise. Considering that this would positively contribute to fulfilling the PMAR objectives, and that timewise it could fit in the PMAR planning, JRC accepted this invitation at the occasion of the Cutlass Express table-top exercise held in Mombasa, Kenya, in the week of 18 July 2011. JRC scheduled a part of its PMAR data collection campaign to coincide with the Cutlass Express at-sea exercise times and locations, which were 25-27 Oct 2011, in two operation areas, in front of Dar Es Salaam and Mombasa. The contribution of PMAR to Cutlass Express is the provision of ship detections from satellite SAR images, also known as VDS, a data source that was not yet used in Cutlass Express, thereby adding to the maritime situational awareness.

4. From its own experience with VDS, JRC is well aware that its nature is quite different from most other ship detection or tracking systems. In particular, VDS has clear shortfalls for operational use, related to data content, data quality and timeliness. These are issues of current R&D.

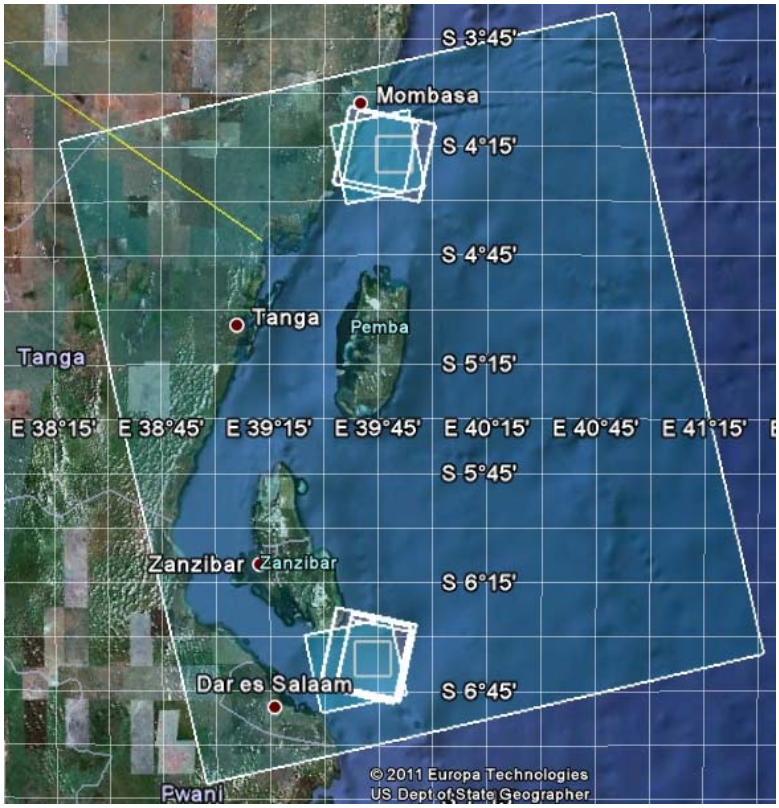
5. A key system to exchange and share the maritime situational picture is MSSIS, a global ship tracking system operated by the Volpe Center of the US Department of Transportation. The maritime picture in MSSIS can be visualised by the add-on SeaVision, designed by the US Navy for maritime domain awareness in Africa. MSSIS / SeaVision was one of the main tools used in Cutlass Express to share maritime awareness between all exercise participants.

Objectives

6. The objectives of JRC's contribution to Cutlass Express were:
- Explore and demonstrate how VDS (satellite SAR ship detections) can contribute to the maritime situational and domain awareness for the operational scenarios of Cutlass Express (counter-piracy, maritime interdiction, maritime law enforcement – carried out in multi-national cooperation);
- Explore and demonstrate how VDS data can be shared among operational partners;
- Show activities and results of PMAR to an audience of maritime operational authorities in East Africa;
- Collect a part of the test data needed for the PMAR project.

Activities

7. Based on the Cutlass Express exercise plan, potential satellite SAR image acquisitions were checked. (The satellites pass over the Earth in a fixed orbit pattern, so if a certain area needs to be imaged, it has to be checked at which times this is possible.) There are three satellite SAR systems that give useful and reliable results for ship detection: Cosmo-Skymed, provided by e-Geos; Radarsat-2, provided by KSAT; and TerraSAR-X, provided by InfoTerra and DLR. JRC has set up purchase contracts with these providers for PMAR. During the 3 days of the exercise, a total of 16 satellite image acquisitions were possible over the two operation areas. Of those, 11 were selected. Also the imaging mode and product type of the SAR data were selected (swath width, resolution, incidence angle, polarisation, detected/complex, geographic projection). The selection was based on optimal performance for ship detection, and matching to the operation area sizes. The selected acquisitions were communicated to the satellite providers. The figure below shows the operation areas (the two smallest boxes, in front of Mombasa and Dar Es Salaam) and the requested satellite SAR images (the tilted boxes enclosing the operation areas, plus the one large tilted box).



8. Although JRC is very well capable to perform ship detection on SAR images, with its SUMO ship detector, the satellite providers (mentioned above) were asked to perform the ship detection. This is because the results needed to be available as fast as possible, many images were taken in the night, and JRC does not support 24/7 operations as it is a research centre, not an operational centre. Taking into account (a) the time needed for the satellite to orbit between the position where it acquired the image and the ground station in Europe where the data can be downlinked, (b) the time to process the downlinked SAR data to an image, and (c) the time needed to do the ship detection on the image, the results could be made available to JRC 1-4 hours after the acquisition of each image. This is considered as Near-Real Time (NRT).

9. Software was set up at JRC to automatically download the ship detection results from the ftp sites of the three providers. As a second step, this software converted the (three different) formats of the ship detection reports from the providers into one single format, the PVOL format (for MSSIS). As a last step, the software uploaded the PVOL results file to MSSIS. In

this way, it was aimed that the satellite SAR ship detections were visible in MSSIS / SeaVision within a few hours after acquisition. Although this is much further from real-time than coastal AIS, for satellite SAR this is very fast, at the state-of-the-art, and it is not much slower than the delivery of satellite AIS.

10. The US Navy's SPAWAR research centre and the Volpe Center have given essential support to JRC on the aspect of interfacing with MSSIS, through the mediation of US Naval Forces Africa. The Volpe Center of the US Department of Transportation, who run MSSIS, had already before provided JRC with access to the MSSIS and SeaVision, and with the software to read and upload data (TV32). SPAWAR provided JRC with software to write PVOL files.

11. In addition to the PVOL upload of the ship detections that was designed to function automatically, some time later an email was sent to a list of addressees with information about the detections: overview jpg images, total number of detections and list of detections, still based on the detection results from the satellite image providers.

12. After that, the satellite SAR images themselves were downloaded from the providers' ftp sites, and analysed with JRC's SUMO ship detector. The results of this are more reliable, because the automatic results are quality-checked by hand, which leads to a significant improvement. These results were sent by email to the same list as above, as kmz files (for viewing in Google Earth) and jpg images.

13. All the while, contact was maintained via email with the Cutlass Express operations centres in Dar Es Salaam, Tanzania, and Naples, Italy, and with SPAWAR, San Diego.

Results

14. In total, 9 satellite SAR images were obtained and analysed, see table below.

Date (Oct 2011)	Time (UTC)	Area	Satellite	Mode	# Detections by provider	# Detections by JRC-SUMO
25	03:05:18	Mombasa	TSX	Strip	16	13
25	03:05:54	Dar Es Salaam	TSX	Strip	0	0
26	14:42:48	Dar Es Salaam	CSK	Strip	4	3
26	15:24:44	Dar Es Salaam	CSK	Strip	3	3
26	15:45:06	both areas	RS2	Scan	43	38
27	03:30:21	Dar Es Salaam	CSK	Strip	1	2
27	03:30:57	Mombasa	CSK	Strip	10	14
27	15:00:09	Mombasa	CSK	Strip	21	29
27	15:00:46	Dar Es Salaam	CSK	Strip	0	0

Images in Stripmap mode have a higher resolution but a smaller swath; they are the smaller ones in the figure under point 7. Images in ScanSAR mode have a lower resolution but a wider swath; it is the one large image in the figure under point 7. Only 9 instead of the 11 requested images were obtained, because in two cases the satellite operators could not honour the scheduling request.

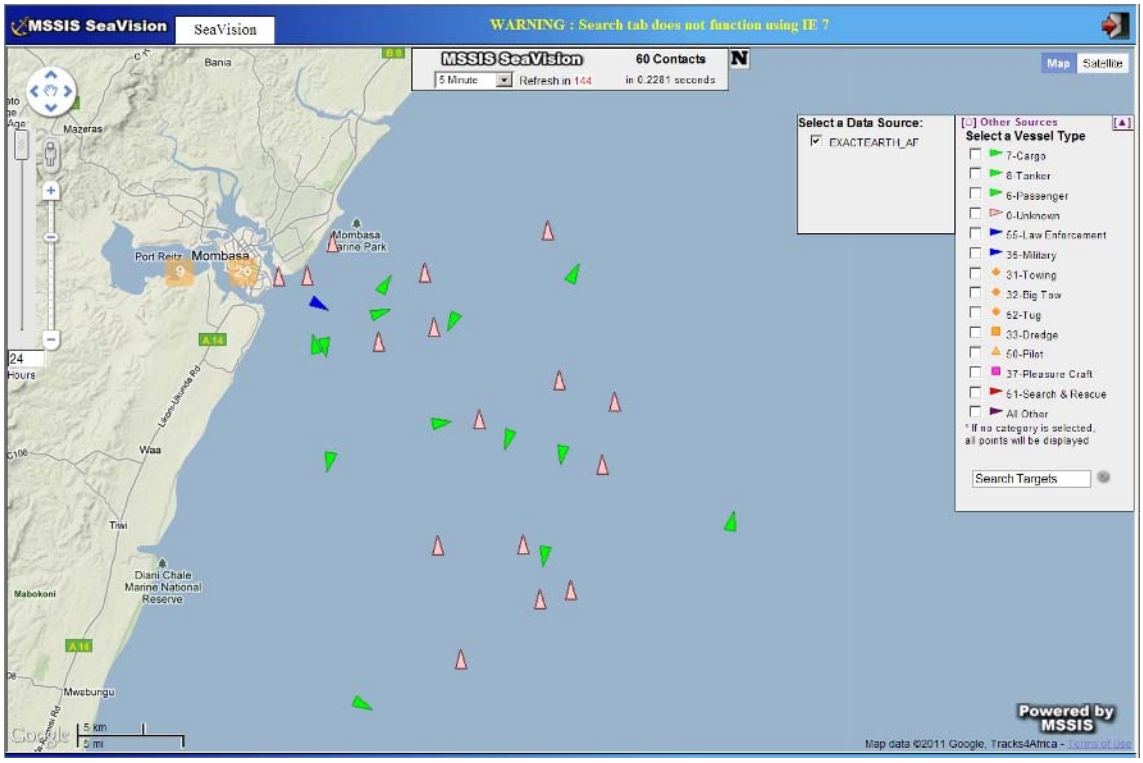
15. Appendix A shows all satellite images with their detected ships as Google Earth screen dumps from the SUMO kmz files.

16. On the first day of the exercise, it was announced that the Kenya Navy unfortunately had to withdraw from the exercise. This meant that there was no activity in the Mombasa operations area. On the second day, the Tanzania Navy announced that they would change the operations area. As the satellite images have to be planned at least 3 days in advance, the image locations could not be changed. This meant that many of the collected satellite images did not contain

exercise activities.

17. The automatic software at JRC to read data from the providers' ftp sites and upload them to MSSIS, being run for the first time during the week of the experiment, had many problems. During the week, many steps had to be corrected by hand. By the end of the week, however, the automatic software was functioning well, except for the final ingestion of the PVOL data into MSSIS. This step had to be done by emailing to SPAWAR, who ingested the data into MSSIS. It is still being examined why this step did not work at JRC.

18. All VDS positions (satellite ship detections) from JRC were eventually present in MSSIS and visible in SeaVision. MSSIS / SeaVision is designed to show the most recent AIS position of each ship, which is for coastal AIS normally a few minutes old. But in order to handle satellite AIS, which can become available with a delay in the order of hours, ship positions can be shown with an age of up to 24 hours. The same approach was now used for the satellite SAR ship detections; they became visible immediately after upload, when they were a few hours old, and remained visible up to 24 hours after original image acquisition. The figure below shows an example (as viewed in SeaVision on 25 Oct, 17:18 UTC); the pink symbols are JRC's input, the ships detected from satellite SAR (here, from the TSX overpass at 03:05 UTC that day).



Evaluation

19. Regarding timeliness, the NRT VDS results were available to the Cutlass Express participants either by email or in SeaVision in most cases within 4-6 hours after satellite acquisition. The best possible automatic upload of VDS results into MSSIS in the current configuration is 45 minutes.

20. Regarding the quality of the VDS results, the control using SUMO with manual verification showed that the NRT results from the providers contained at least 3 false alarms (3 % of the total number of 98 ship detections). It is inherent to satellite SAR imaging that there may be a small percentage more of false alarms which are not as such recognised. It is also inherent to SAR imaging that the smallest ships remain undetected, with the minimum detectable ship size

depending on image mode (i.e., resolution and swath width), met/ocean conditions and several other parameters. Areas near the coast (out to some 3 nm) are prone to false alarms due to contamination from bright reflectors on land and physical features such as human constructions, reefs, shallows, outflows, etc. The difference in the number of ship detections between the provider results and the SUMO results listed under point 14 is (apart from the mentioned 3 false alarms) mostly due to the inclusion or exclusion of such uncertain detections.

21. The well-known inflexibility of the tasking of satellite observations (fixed orbit pattern, several days advance scheduling) was again shown to be a problem for operational use.

22. In spite of these intrinsic shortfalls, satellite SAR ship detection is nonetheless valuable, because it is the only way to know about the presence of medium and large ships that do not show up in the maritime picture constructed from the ship reporting systems (AIS, LRIT, VMS). To make best use of this capability, is it needed to correlate VDS detections with ship positions from reporting systems, so as to pinpoint and display only the additional non-reporting ships. This correlation functionality, which has been demonstrated before by JRC in the context of fisheries control, is still under development in the PMAR project. Concerning the display of VDS targets in SeaVision, it is believed that displaying only the non-reporting ships, avoiding to add VDS targets that are already present in SeaVision from the reporting systems, would be less confusing. It is hoped that feedback about the VDS targets in SeaVision will be provided by those who have used it during the exercise.

23. The three providers of satellite images and derived NRT VDS results all used a different format for their VDS reports, both regarding contents (attribute set with each detection) and formatting. A standardisation would be most desirable. Possibly this can be reached under the ESA-funded MARISS project, aimed at professionalising earth observation services, in which all three providers participate.

Conclusions

24. All objectives (point 6) have been reached. First, it has been explored and demonstrated how VDS data (satellite SAR ship detections) can be shared among operational partners – namely, in the first place by uploading the VDS results into the MSSIS / SeaVision system, and additionally by email with attachments that visualise the results. Second, it has been explored and demonstrated how VDS can contribute to the maritime situational and domain awareness for the operational scenarios of Cutlass Express. Considering the VDS delay of a few hours, the more valuable contribution was probably to the domain awareness. Under different operational scenarios, however, the VDS, even with that delay, can contribute significantly to the situational awareness. Third, activities and results of the PMAR project have been shown to an audience of maritime operational authorities in East Africa – namely those who have been actively involved in or passively following the Cutlass Express exercise. Fourth, a part of the test data needed for the PMAR project has been collected.

25. Considering the above, the activity has been a success, and even the issues mentioned under point 16 (last minute cancellation and change of operations) do not detract from that.

26. Based on this experience, it is now seriously considered to join the “Obangame Express” exercise that is planned for end February 2012 in the Gulf of Guinea. This is a similar exercise, involving Ghana, Togo, Nigeria, Cameroon, Equatorial Guinea, Gabon, Republic of Congo and Sao Tomé & Principe. It would fit very well in JRC’s PMAR-Gulf of Guinea project.

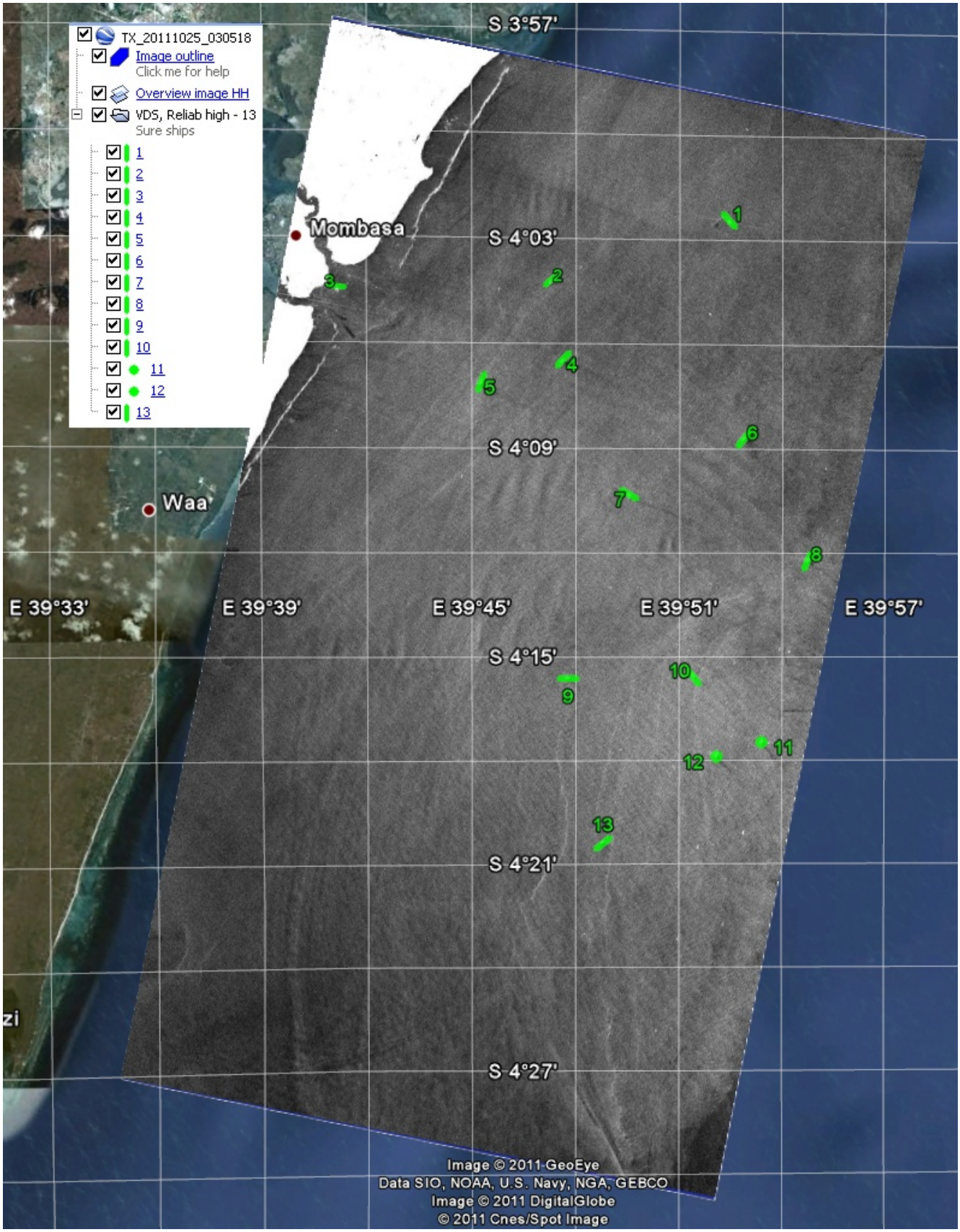
Acknowledgements

This work was done in cooperation with and/or using inputs from: US Naval Forces Africa, SPAWAR San Diego, the Volpe Center of the US Department of Transportation, DLR, InfoTerra, e-Geos and KSAT. Cosmo-Skymed images are © e-Geos 2011. TerraSAR-X images are © InfoTerra/DLR 2011. Radarsat-2 images are © MDA 2011.

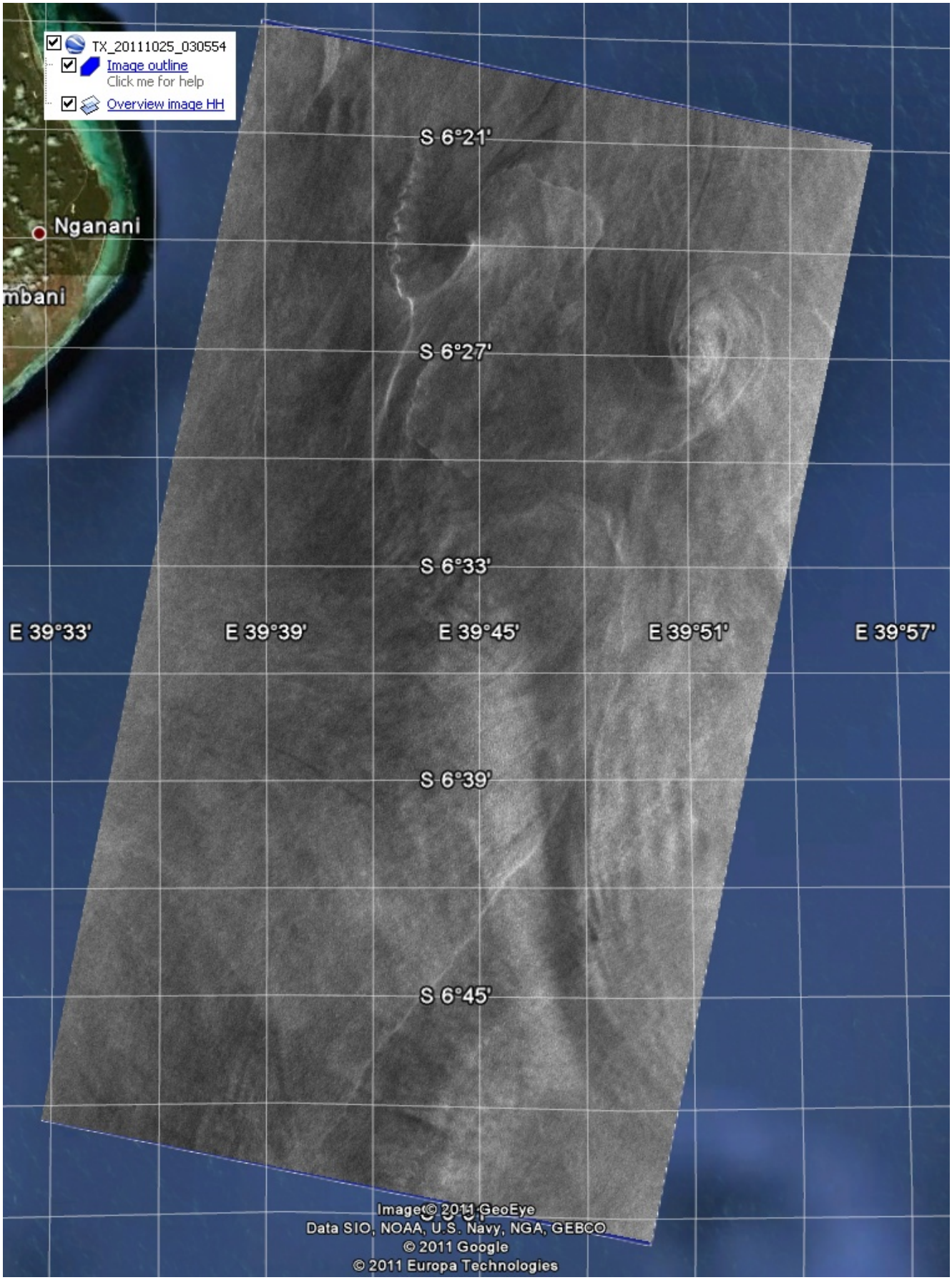
Appendix A – All satellite images with their detected ships using SUMO with manual verification

In this appendix, each satellite SAR image is shown overlaid on Google Earth. The image gray scaling is adapted to show radar backscatter details on the sea surface, so the land is mostly saturated (white). The ship detections, as found by SUMO, are indicated, and divided into high, medium and low reliability, in the colours green, yellow and orange, respectively. The lower the reliability, the higher the possibility that the detection is a false alarm. If a heading can be recognised from the ship outline, the detection is indicated on the image as a bar. There is 180 degree ambiguity as to the heading. If the ship outline does not show a clear heading, the detection is indicated with a dot.

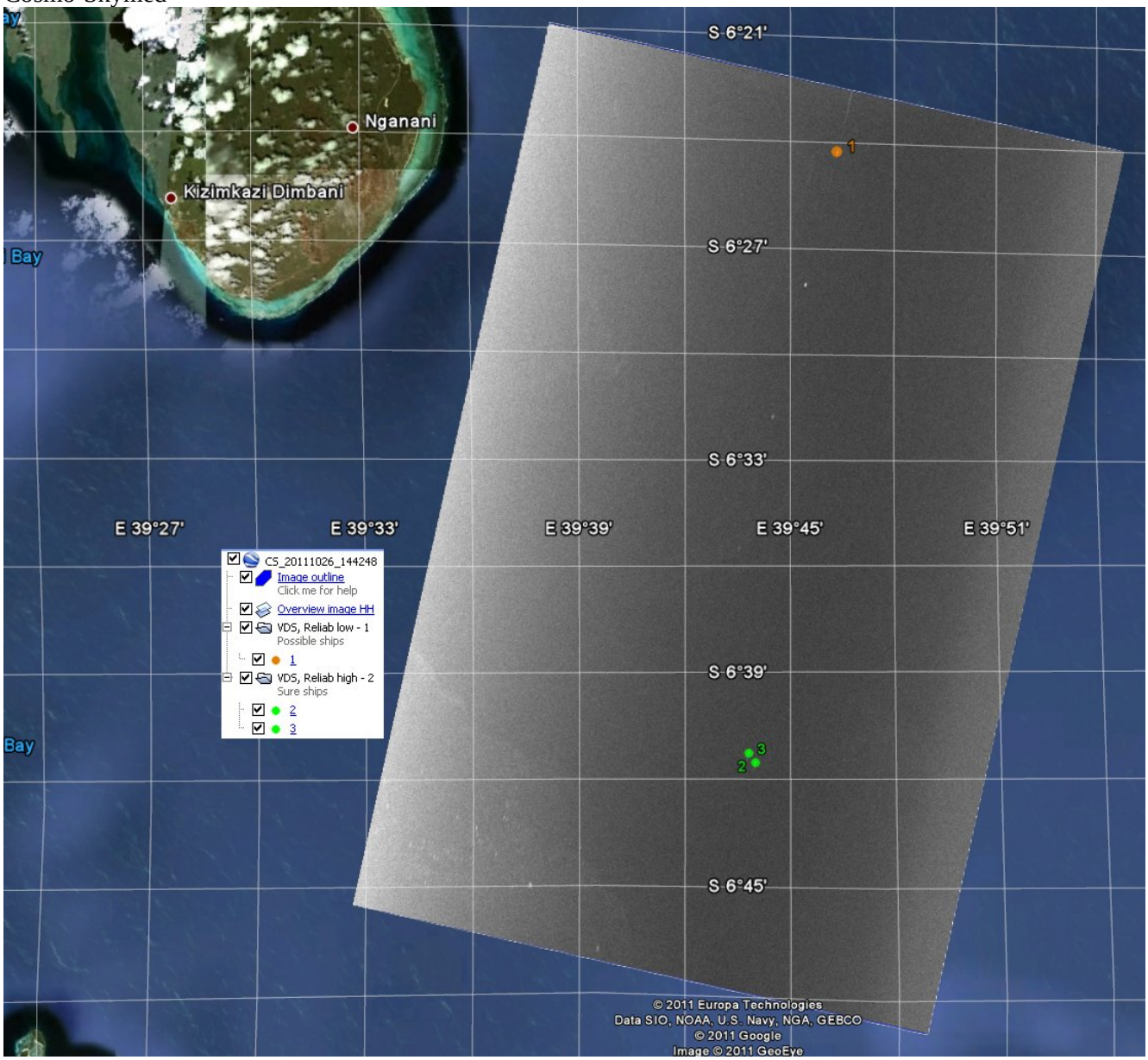
2011-10-25 03:05:18 UTC
TerraSAR-X



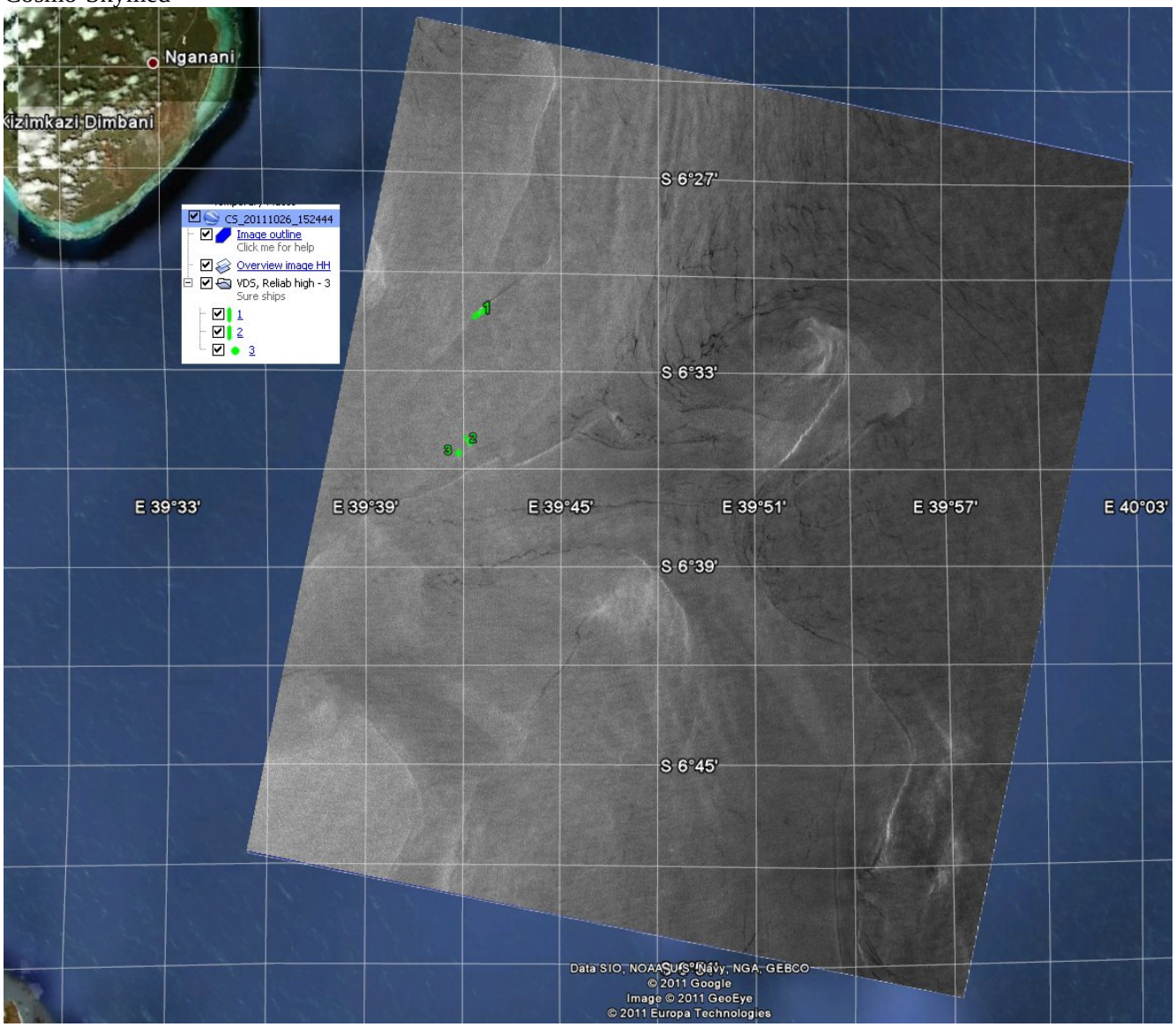
2011-10-25 03:05:54 UTC
TerraSAR-X



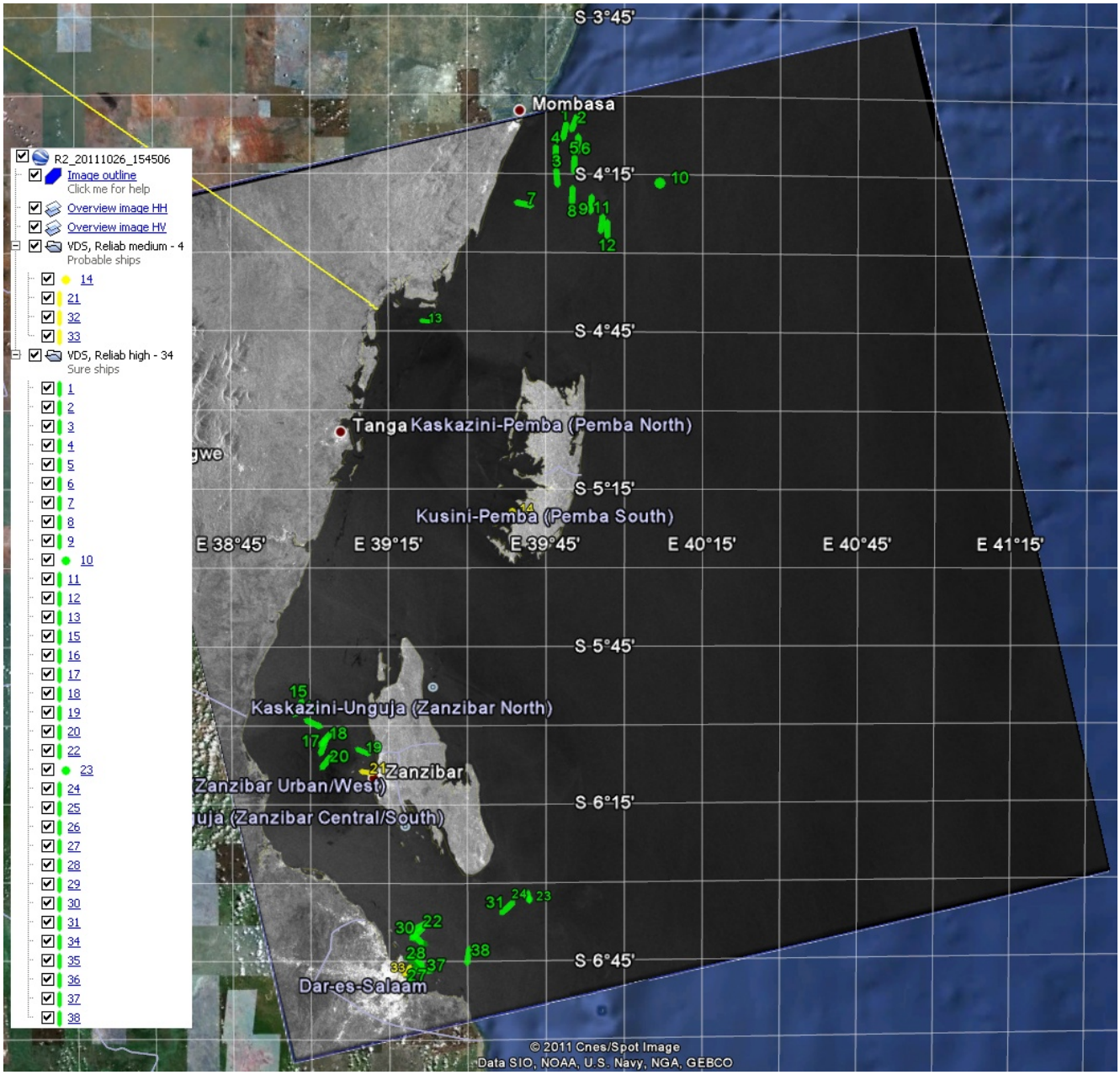
2011-10-26 14:42:48 UTC
Cosmo-Skymed



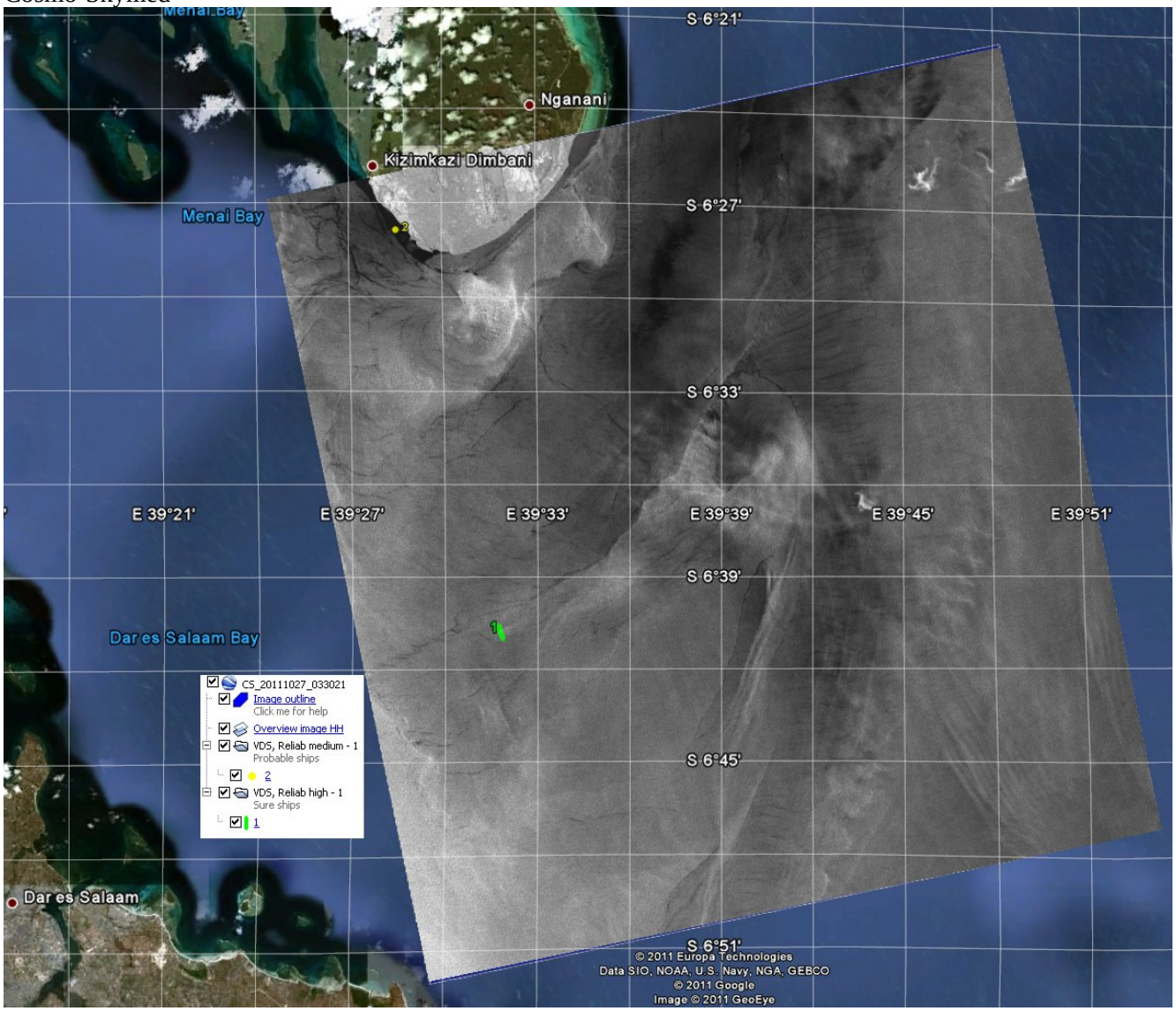
2011-10-26 15:24:44 UTC
Cosmo-Skymed



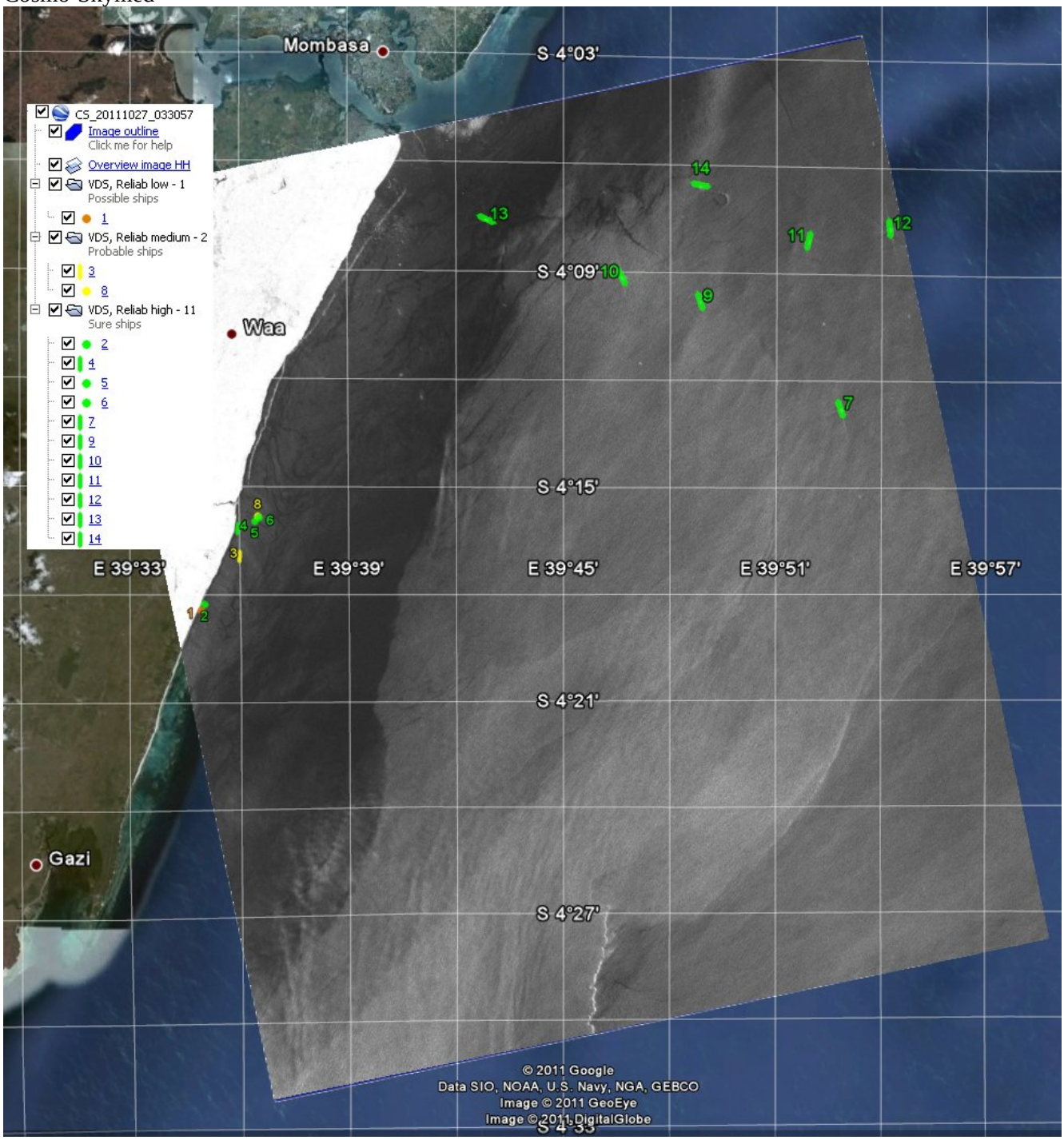
2011-10-26 15:45:06 UTC
Radarsat-2



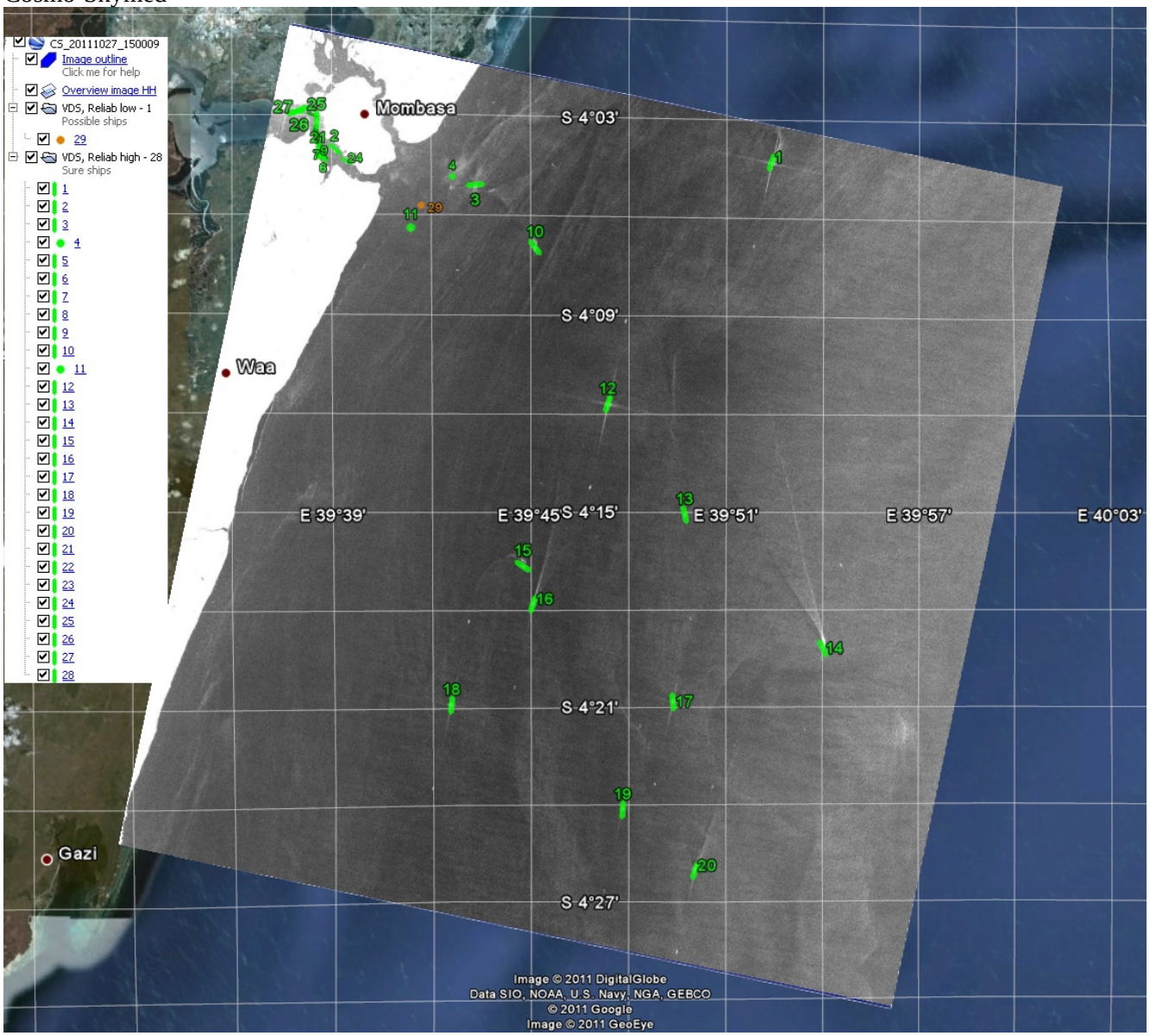
2011-10-27 03:30:21 UTC
Cosmo-Skymed



2011-10-27 03:30:57 UTC
Cosmo-Skymed



2011-10-27 15:00:09 UTC
Cosmo-Skymed



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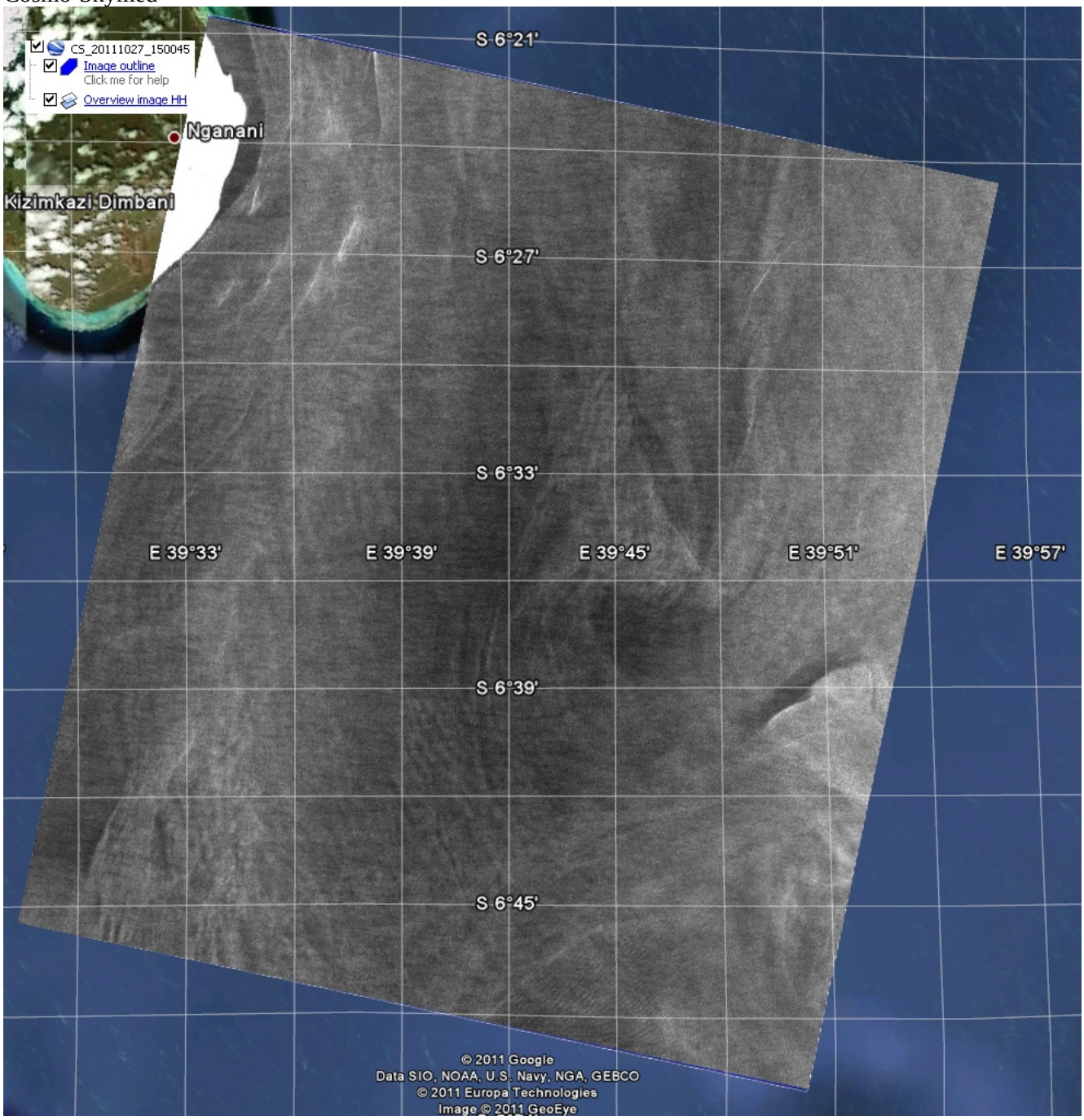
Cosmo-Skymed



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