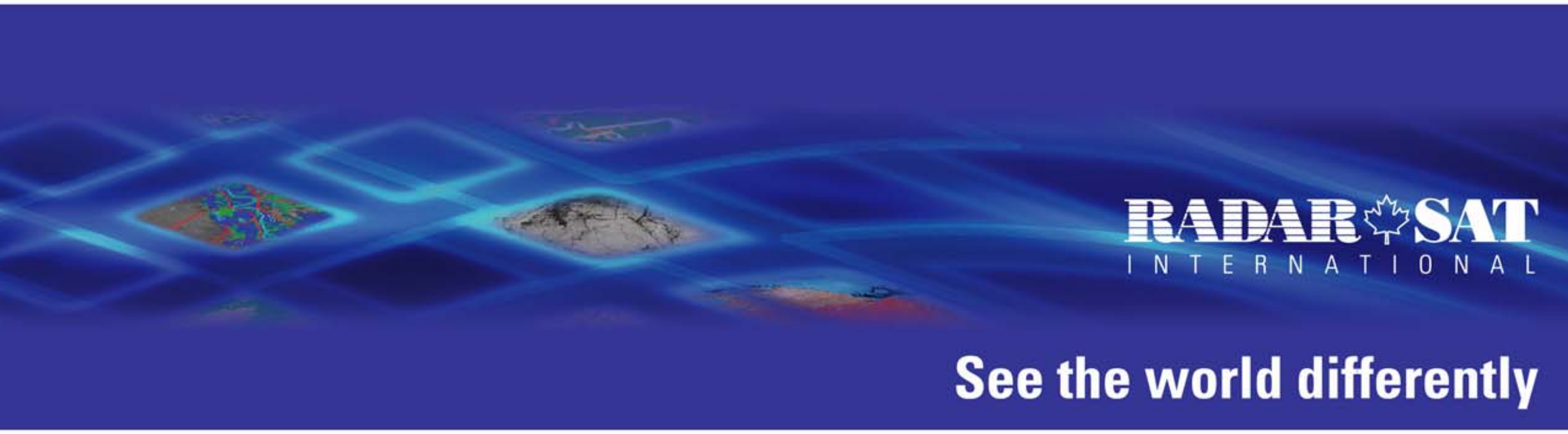
Final Report

California Pollution Watch and Target Detection

California Coastline



SUBMITTED TO:
California Department of Fish and Game
Office of Spill Prevention and Response
1700 "K" Street
Sacramento, CA 95814 Address

Tel: 916-324-3411 Email: jmuskat@dfg.ca.gov
Attn: Judd Muskat

SUBMITTED BY:
RADARSAT International
13800 Commerce Parkway
Richmond, BC, V6V 2J3

Contact: Jeff Hurley, Senior Project Manager
Tel: 819-827-8427 Fax: 819-827-1955
Email: jhurley@rsi.ca

Trademarks
All brand or product names are trademarks or registered trademarks of their respective companies or organizations.

Document Information

Document Name:	Final Report - California Pollution Watch and Target Detection
Document Number:	RSI-RP-52-2543
Date:	18 March 2005

Table of Contents

INTRODUCTION **6**

BACKGROUND **7**

REVIEW OF ACQUISITIONS **8**

DELIVERY STATISTICS **10**

- Data Transfer 10
- Processing and Initial Data Availability 11
- Analysis 12
- Total Delivery Times 13

REVIEW OF ANALYSIS **15**

- No Oil Detected 15
  - December 7, 2004 15
  - December 18, 2004 16
  - December 21, 2004 17
  - January 7, 2005 17
  - January 14, 2005 18
  - January 21, 2005 19
  - January 24, 2005 20
  - February 14, 2005 21
  - March 10, 2005 22
- Possible Oil Detections 23
  - December 4, 2004 23
  - December 11, 2004 26
  - December 24, 2004 29
  - December 28, 2004 31
  - January 28, 2005 33

TARGET DETECTION **35**

COMMENTS AND CONCLUSIONS **37**

APPENDIX A – TECHNOLOGY BACKGROUND .... **A**

APPENDIX B – RECENT NEWS STORY .... **D**

APPENDIX C – REFERENCES .... **F**

Figures and Tables

Figure 1. Imaging Coverage 9

Figure 2. Data Acquisition and Transfer 10

Figure 3. Transfer Times 11

Figure 4. Processing Times (ScanSAR Mode indicated by light blue bars) 12

Figure 5. Time required for Analysis by RSI Staff 13

Figure 6. End-to-End Process Times (From Acquisition to Analysis) 14

Figure 7. December 7 Wind Speed 15

Figure 8. December 18 Wind Speed 16

Figure 9. Low Wind Area (Shadow) Caused by Local Topography 16

Figure 10. December 21 Wind Speed 17

Figure 11. January 7 Wind Speed 18

Figure 12. January 14 Wind Speed 18

Figure 13. Wind Shadow and Platforms 19

Figure 14. January 21 Wind Speed 19

Figure 15. Possible Natural Oil Seeps 20

Figure 16. January 24 Wind Speed 21

Figure 17. February 14 Wind Speed 21

Figure 18. March 10 Wind Speed 22

Figure 19. Low Wind Area – March 10 22

Figure 20. December 4 Wind Conditions 23

Figure 21. December 4 Overview with 2 Events 24

Figure 22. Event “A” from December 4, 2004 25

Figure 23. Event “B” from December 4, 2004 26
Figure 24. December 11 Wind Speed 27
Figure 25. December 11 Overview with 1 Event 27
Figure 26. Event “C” from December 11, 2004 28
Figure 27. December 24 Wind Speed 29
Figure 28. December 24 Overview with 1 Event 30
Figure 29. Event “D” from December 24, 2004 30
Figure 30. December 28 Wind Speed 31
Figure 31. December 28 Overview with 1 Event 31
Figure 32. Event “E” from December 28, 2004 32
Figure 33. January 28 Wind Speed 33
Figure 34. January 28 Overview with 1 Event 33
Figure 35. Event “F” from January 28, 2005 34
Figure 36. Overview of all targets detected (December – March) 35
Figure 37. Detail Zoom – Target Detection with Shipping Lanes 36

Table 1. Acquisition Table 8

Introduction

This report will provide a detailed review of the recently completed Pilot Project for Oil Spill Detection that was undertaken for the California Department of Fish and Game.

Over approximately 3 months a total of 14 frames of spaceborne Synthetic Aperture Radar (SAR) imagery from the RADARSAT-1 platform were processed and analyzed for possible oil spills or releases, and also for maritime targets (e.g. ships, platforms, etc.). Images were collected along the California coast, from north of San Francisco to Los Angeles. All 14 frames of SAR imagery was processed and delivered in Near Real Time (NRT). There was possible oil detected on 5 of the scenes. The confidence of the oil detections were ranked based on the analysis by an expert image interpreter, and given one of the following codes:

1A – Probable Oil with source attached
1B – Probable Oil in region
2 – Probable Oil, no source (within approximately 30 miles)
3 – Possible Oil, lowest confidence

A review of all acquisitions will be provided in this report. A detailed analysis of the delivery chain for each acquisition will also be conducted and all relevant statistics supplied. An examination of the image interpretation will be provided, which will include wind information and comments on any potential oil that was detected. Supporting comments will be made in reference to the technology and techniques used for this application.

Final observations will highlight the achievements of the Pilot Project and establish where improvements can be made in future projects.

Background

SAR imagery is a proven technology for detecting oil on water, as oil dampens the capillary waves at the water's surface – which results in a low backscatter and other distinct characteristics (i.e. shape, tone, texture, and context). As such, it is possible to describe potential oil events accurately in terms of geographic location and extent. SAR images taken over the same area at different times are also useful in providing valuable contextual information that is not always evident in a single image.

Wind speed is one of the most critical elements to aid in the interpretation of this type of imagery. One of the best sources of historical wind speed conditions is also satellite imagery. For this report, the NASA/JPL's SeaWinds Scatterometer aboard the Quikscat satellite was the main source of wind data. While this information was not available in NRT for the analysis, it can be useful in a project review such as this.

A detailed collection of background material is contained in Appendices A - C of this document.

Review of Acquisitions

Based on input from CF&G, a comprehensive imaging plan was established for the December 2004 – February 2005 timeframe. Due to scheduling conflicts (i.e. holidays and satellite usage) the final image was captured in March 2005.

Table 1 details each acquisition (RADARSAT-1) acquired for this project. Three main offshore areas were imaged over the duration of the project; San Francisco (northern most region), Santa Lucia (area between San Francisco and Los Angeles), and the Santa Barbara Channel / LA (southern most region). The geographic distribution of the scenes can be seen in Figure 1.

Table 1. Acquisition Table

Date	Time (UTC)	Beam Mode	Event Detected?	Region
4-Dec-04	**13:58**	**SNA**	**YES**	**Santa Barbara Channel**
7-Dec-04	14:10	SNA	NO	San Francisco
11-Dec-04	**14:22**	**SNA**	**YES**	**Santa Barbara Channel**
18-Dec-04	14:06	S1	NO	Santa Barbara Channel
21-Dec-04	14:13	SNA	NO	Santa Lucia (Mid-Way)
24-Dec-04	**14:10**	**SNA**	**YES**	**San Francisco**
28-Dec-04	**14:06**	**S1**	**YES**	**Santa Barbara Channel**
7-Jan-05	14:17	SNA	NO	San Francisco
14-Jan-05	14:02	S2	NO	Santa Lucia (Mid-Way)
21-Jan-05	14:06	S1	NO	Santa Barbara Channel
24-Jan-05	14:06	W1	NO	San Francisco
28-Jan-05	**13:58**	**SNA**	**YES**	**Santa Barbara Channel**
14-Feb-05	14:10	SNA	NO	Santa Barbara Channel
10-Mar-05	14:22	SNA	NO	Santa Barbara Channel

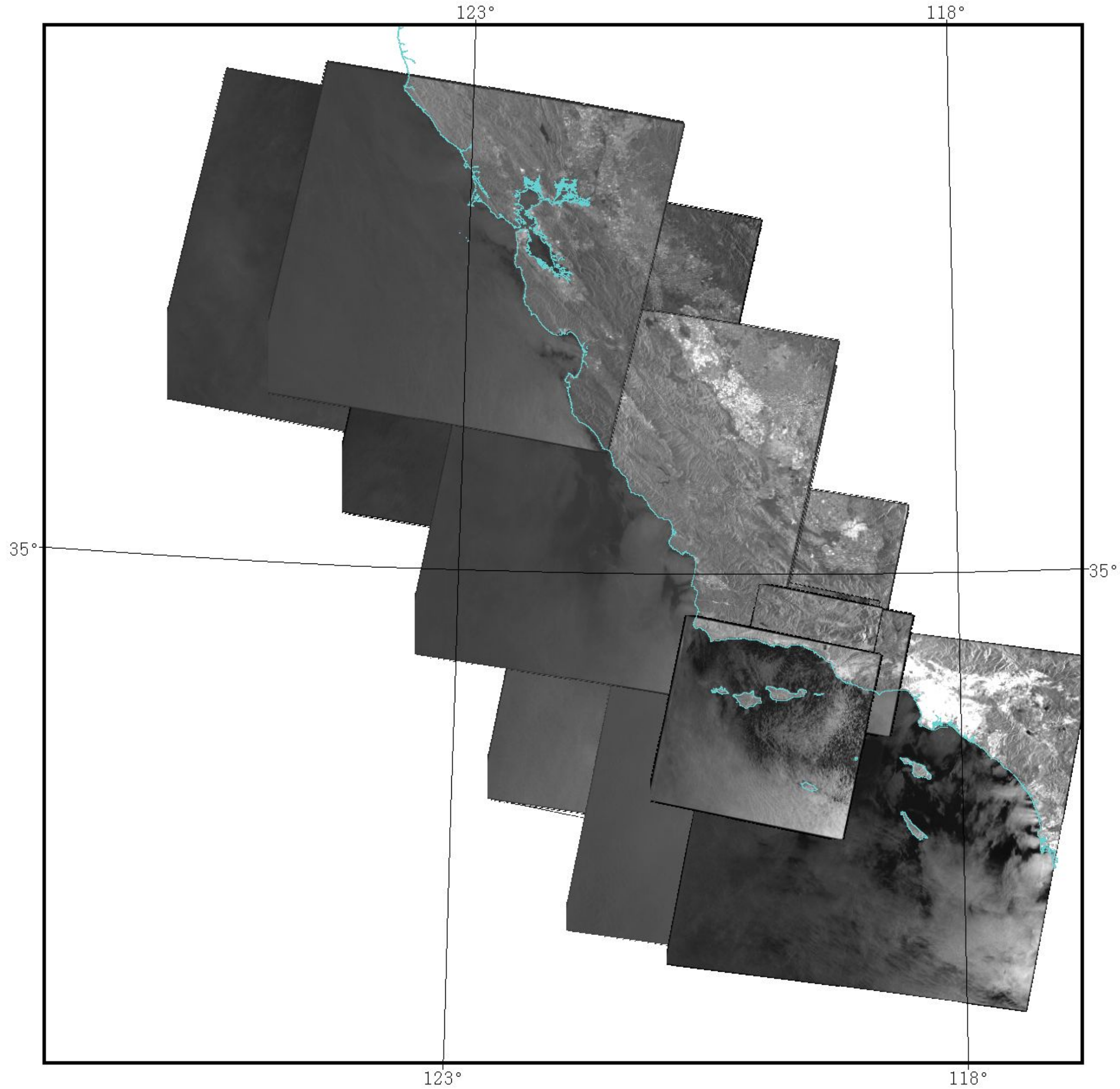


Figure 1. Imaging Coverage

Delivery Statistics

A useful and accurate interpretation of the imagery is the most important element in an Oil Spill Detection service. Second in importance to this is the turnaround time (from time of acquisition to time of report). As this was a Pilot Project, the intent was to test and/or identify the various means of providing the analysis as quickly and reliably as possible. The timeline for this service can be analysed in three distinct sections: Data Transfer Time, Processing Time, and Analysis Time.

Data Transfer

For each scene acquired over the California Coast, as series of events took place to deliver the data to the RSI analyst. Figure 2 is a graphical representation of the data flow. As the images were acquired the data were downlinked simultaneously to the Satellite Receiving Station located in Prince Albert, Saskatchewan, Canada (PASS).

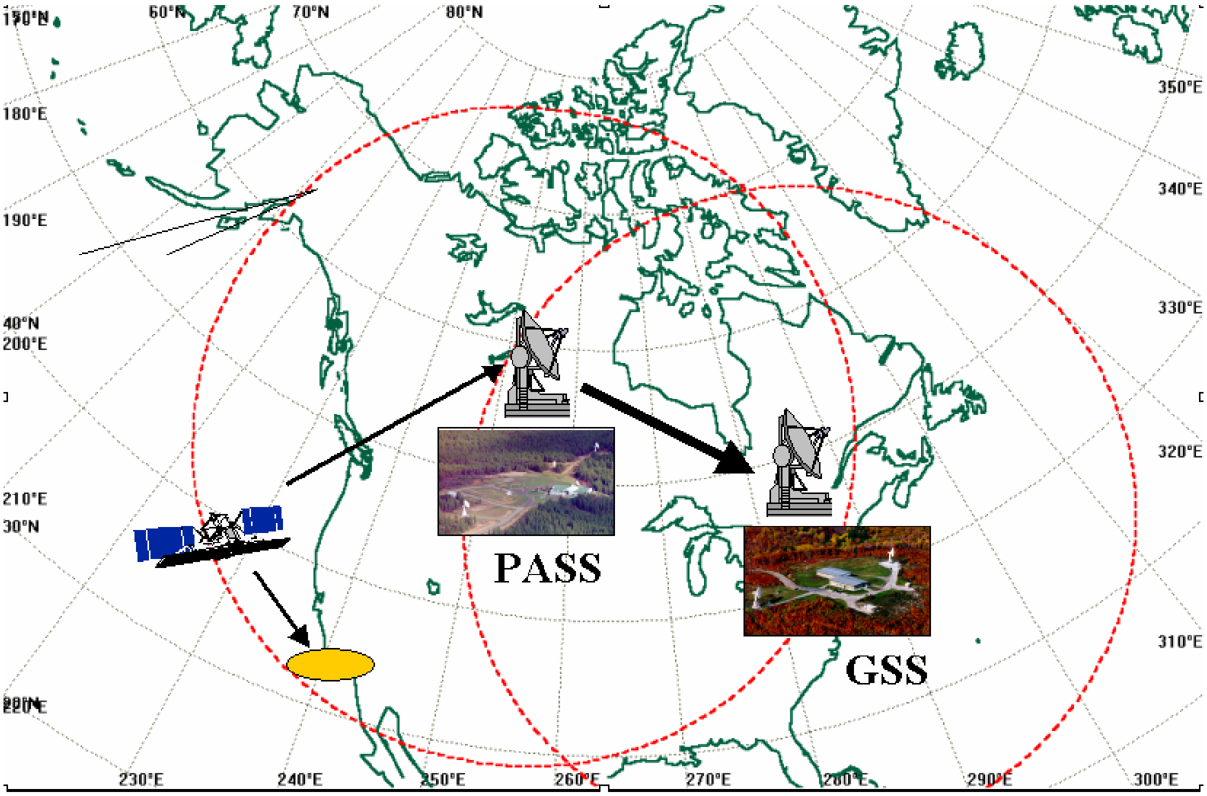


Figure 2. Data Acquisition and Transfer

The PASS facility acts a receiving station only, and at this point the data are not images. As such the digital file is then transferred via a Wide Area Network (WAN) to the Gatineau Satellite Station (GSS) located in Cantley, Quebec, Canada. At this facility is the Canadian Data Processing Facility (CDPF) where the data are processed into imagery.

The time required for this transfer is determined by several factors. File size, WAN traffic, image priority and reception all have an impact on total transfer time. The graph shown in Figure 3 represents the data transfer time achieved during this project. This time represents the total time from acquisition (i.e. when the image was taken) to delivery to CDPF.

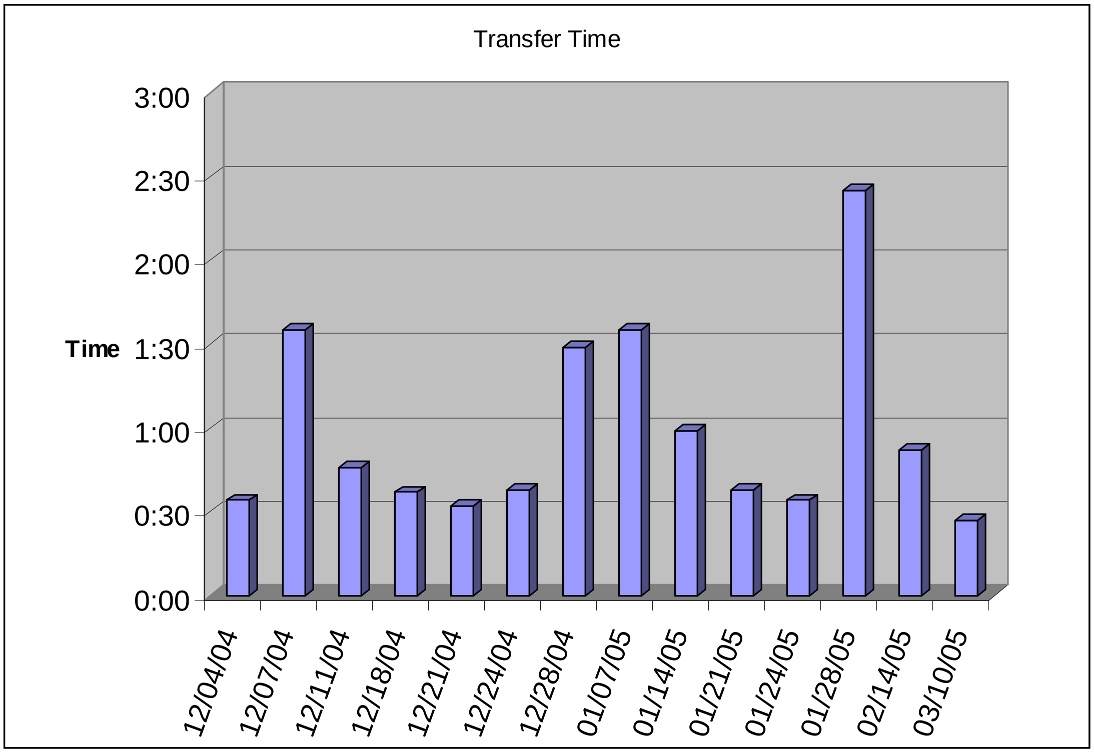


Figure 3. Transfer Times

The average data transfer time was 58 minutes. However, only 4 of the 14 dates had transfer times greater than this, and as such the median transfer time was 42 minutes. The major delays experienced were due to Priority Conflicts (Dec. 7 and 28, 2005) and reception problems, resulting in added delays (Jan. 7 and 28, 2005).

Processing and Initial Data Availability

The processing time is dependent on the type of product (or beam mode) being processed. Multi-beam products (i.e. ScanSAR mode) take longer to process than single beam (e.g. Wide 1) products. On occasion, an image quality issue requires reprocessing of the data to produce a suitable product for interpretation. For this project, a georeferenced MrSID compressed image was created and made available via FTP. A summary of processing times (time from data reception at CDPF to data placed on FTP site) for the pilot is shown in Figure 4.

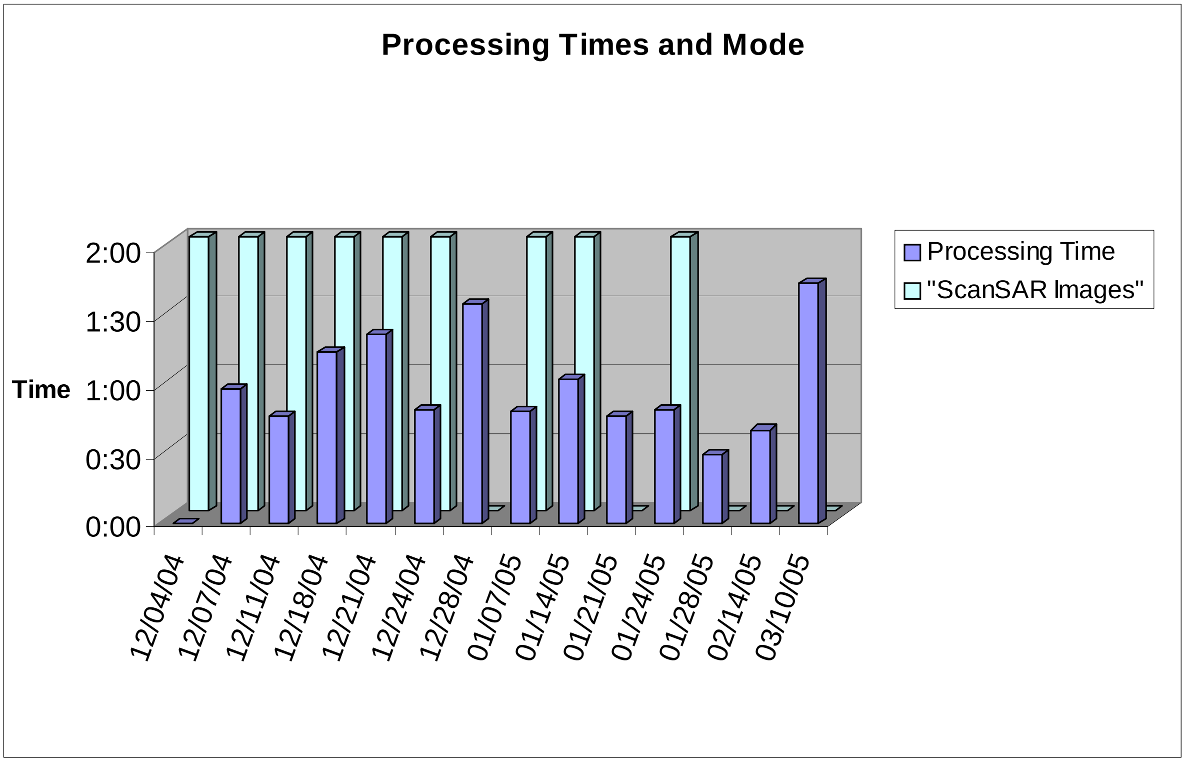


Figure 4. Processing Times (ScanSAR Mode indicated by light blue bars)

While there is not much variance in the processing times, the quickest times were achieved with the single beam (e.g. Standard 1) modes. The average processing time was 1 hour and 1 minute. Of the 2 single beam products that took over 1 hour, both had to be reprocessed due to image quality issues.

Analysis

After the data were processed, the final step was the analysis of the imagery for possible Oil Spill/Release information and generation of a target/ship report. The time represented here includes analysis of the image, and report generation and distribution. Analysis was considered complete once the email was sent (oil and target reports were sent separately). Figure 5 details the average time required to complete the analysis.

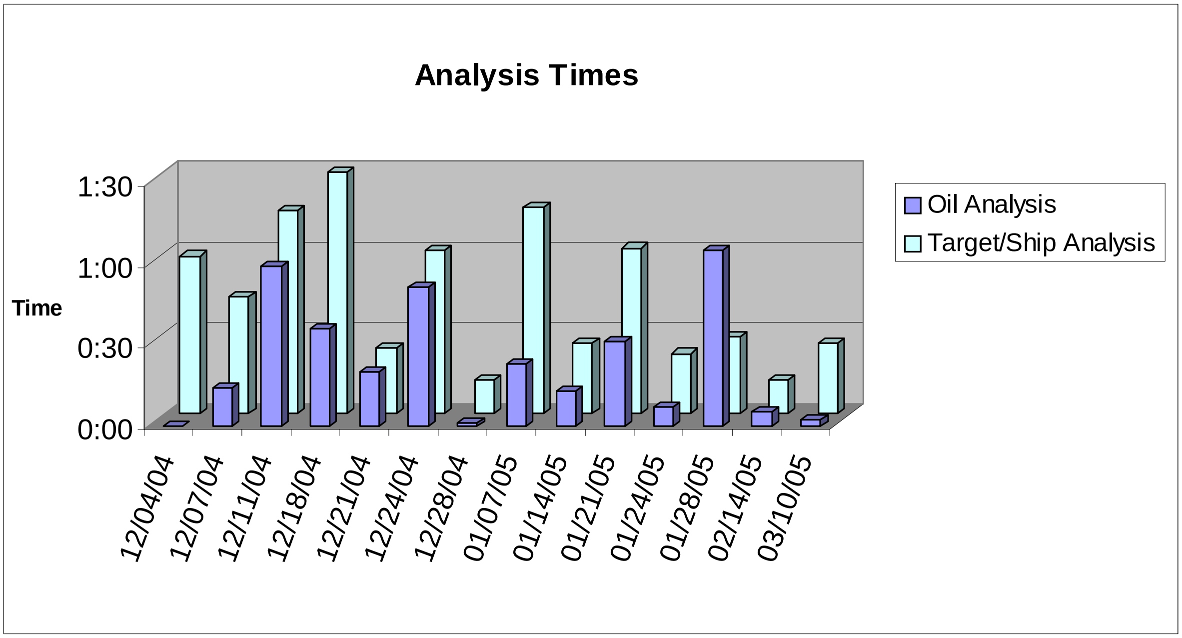


Figure 5. Time required for Analysis by RSI Staff

It is difficult to draw conclusions from this graph. As the interpretation and analysis process is completely manually and does require a certain degree of subjectivity, the complexity of the scene is the controlling factor over how long the process takes. The average analysis time for oil was 25 minutes, and for targets/ships, 43 minutes. It is important to note that RSI is currently evaluating automated ship detection tools, which will reduce the time for this analysis to less than 5 minutes per scene. It is not anticipated that the oil analysis will be automated for many years to come.

Total Delivery Times

The complete end-to-end process times were examined for all analysis that was completed for the project. Figure 6 captures the total time from acquisition to delivery for each scene in the project.

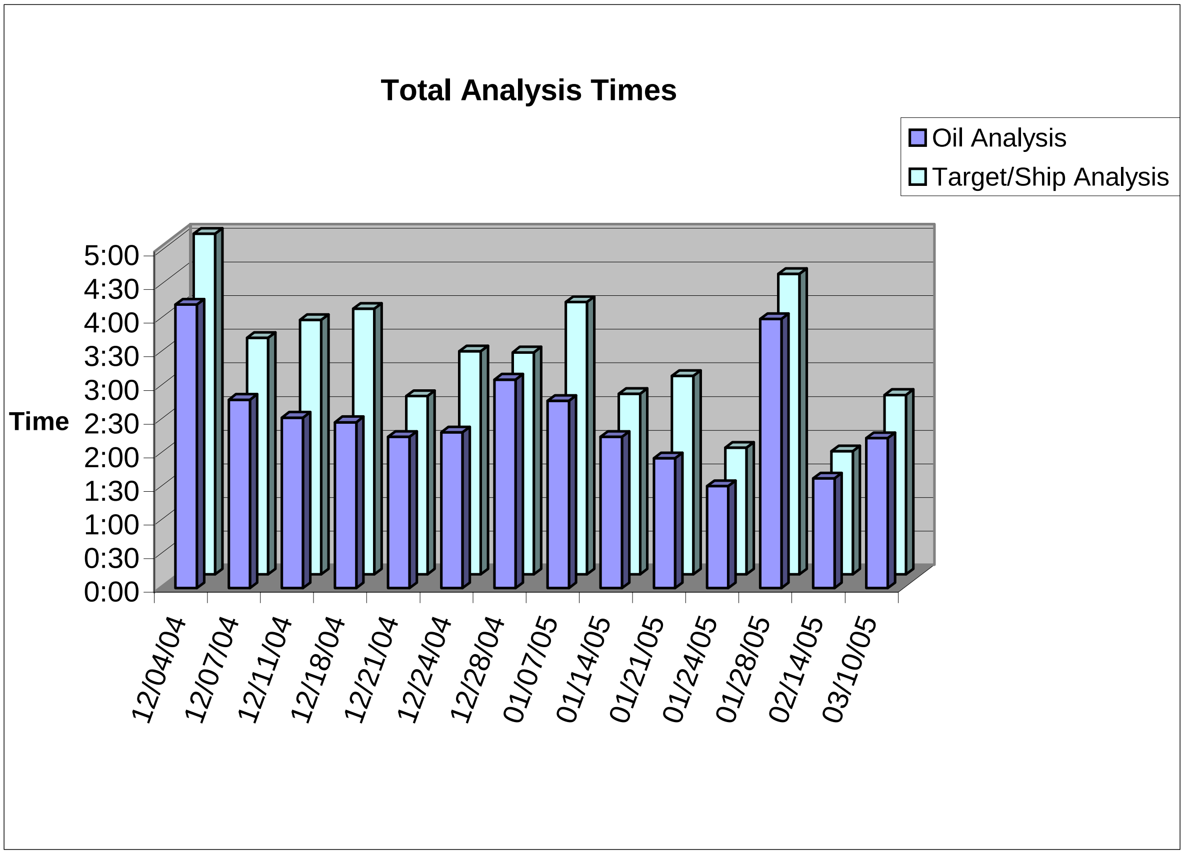


Figure 6. End-to-End Process Times (From Acquisition to Analysis)

The average time to delivery the Oil Analysis report was 2 hours 34 minutes. The average time to delivery both the Oil and Ship Analysis report was 3 hours 18 minutes. It is not shown on this graph, but it should be noted that the “data availability for FTP” time was 2 hours 11 minutes.

Review of Analysis

All 14 frames of imagery were fully analysed for oil spill and target/ship detection. Possible oil slicks/releases were detected on 5 of the images (35.7% ‘hit’ rate). This is a relatively high rate of detection, especially for such a small sample of images.

There is a very strong link between wind speed and the detectability of oil on the ocean surface. The nominal wind speed “detection” window is generally accepted to be 5 – 25 knots (2.5 – 12.8 m/s). Oil is unlikely to be detected therefore in areas where there are very low or very high winds.

No Oil Detected

Out of all the images collected, 9 scenes had no apparent oil release/discharge from vessels or platforms. For some of these images, wind conditions made oil detection difficult. Below are the nearly coincident QuikSCAT wind data reports for the same area as the RADARSAT-1 image on that day.

December 7, 2004

The ScanSAR Narrow image on this day covered the region near San Francisco. Acquisition time was 14:10 UTC, while the wind data was collected at 13:45 UTC. As Figure 7 shows, winds were at the upper range for oil detection (15-25 knots, with rain in the area).

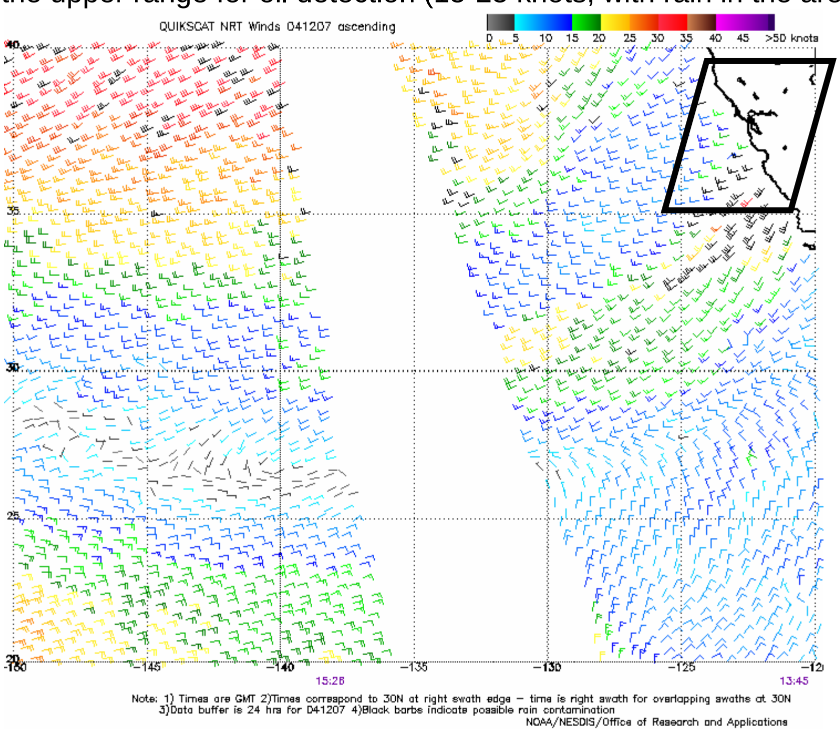


Figure 7. December 7 Wind Speed

December 18, 2004

This Standard 1 image covered the Santa Barbara Channel area, collected at 14:06 UTC with wind data at 14:00 UTC. Figure 8 indicates that winds were low in the Channel area (5 knots) and from the north.

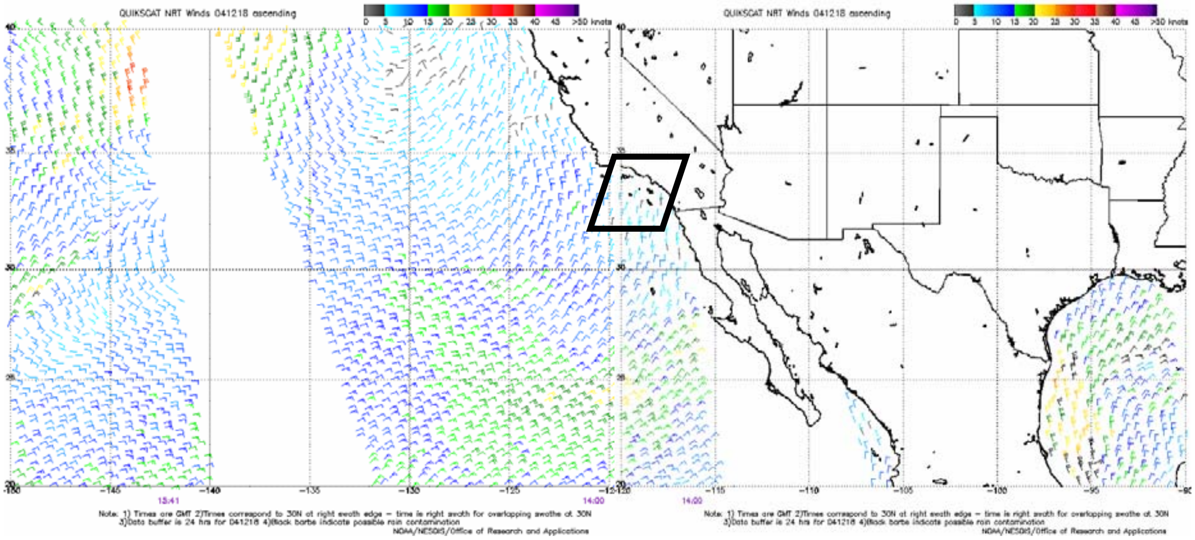


Figure 8. December 18 Wind Speed

It became evident during this pilot that winds from north caused large regions of "wind shadow" in the Channel. The Santa Ynez, San Rafael, and Sierra Madre Mountains are clearly responsible for this when the winds are from the north. Figure 9 is a detail zoom from the image on the 18th. It shows the mountain range along the coast, and the area of low wind (low backscatter, or dark tone) that makes oil detection very difficult.

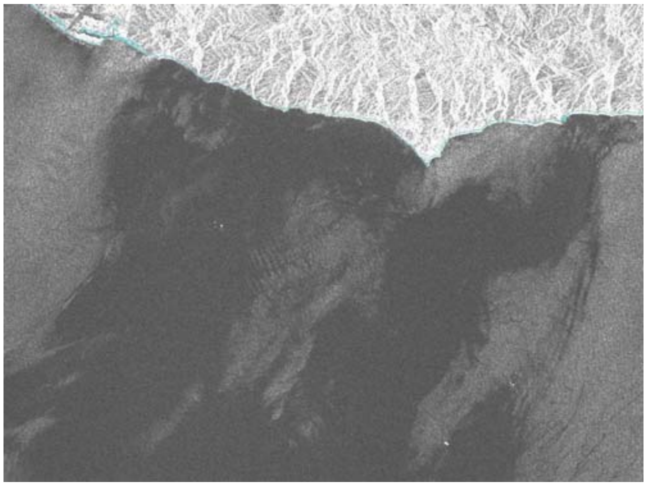


Figure 9. Low Wind Area (Shadow) Caused by Local Topography

December 21, 2004

This image was a ScanSAR Narrow over the Santa Lucia region of the coast. Image acquisition was at 14:13 UTC however the wind data was not available as is shown in Figure 10. The area close to the image was receiving high winds (20+ knots) from the North however. It is assumed high winds in the imagery would have made oil detection difficult.

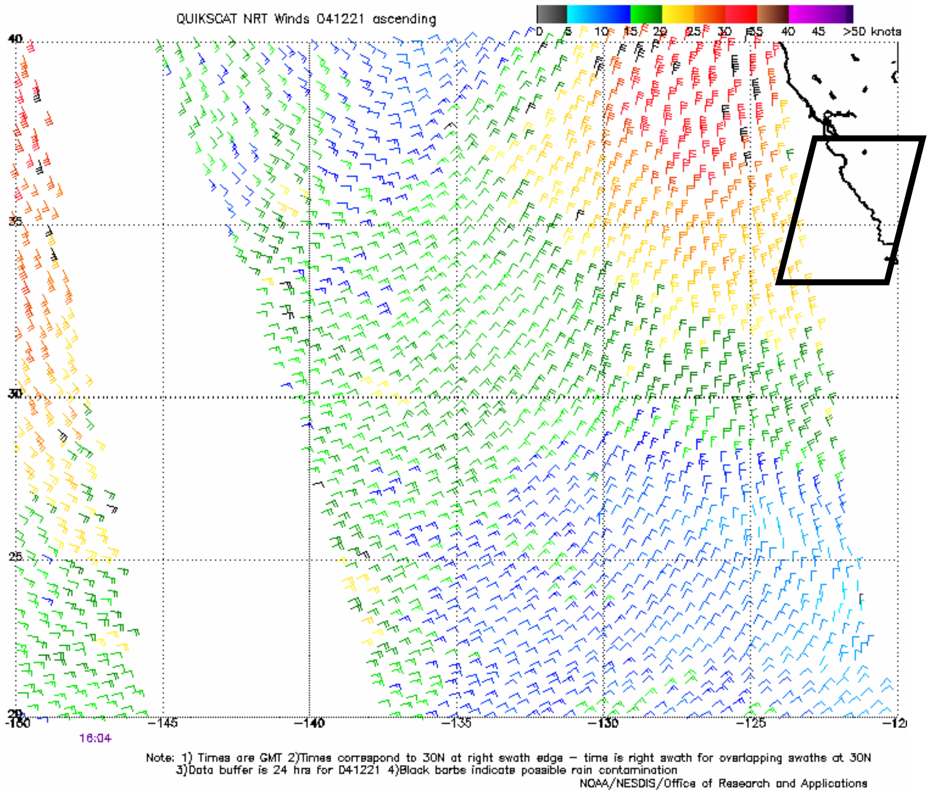


Figure 10. December 21 Wind Speed

January 7, 2005

This was a ScanSAR Narrow image of the San Francisco area, collected at 14:17 UTC. Wind data was collected at 13:43 UTC, and indicated (Figure 11) the presence of a major weather disturbance with precipitation and high winds (30+ knots). Again, oil detection is difficult in these conditions.

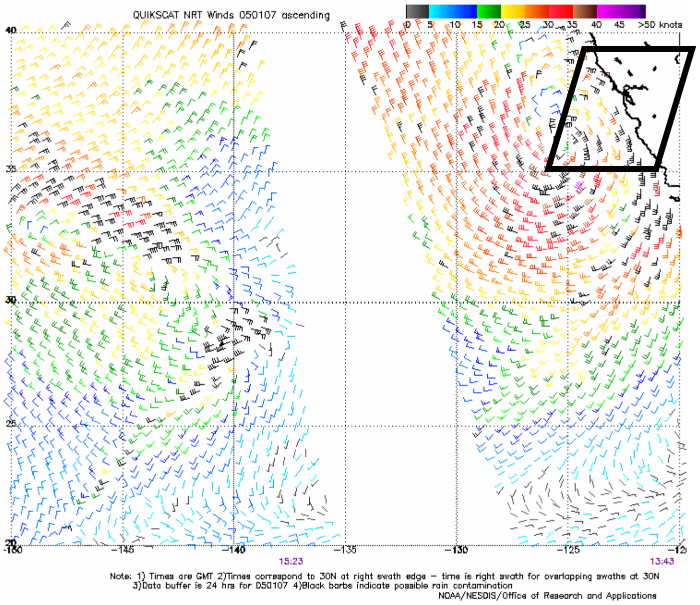


Figure 11. January 7 Wind Speed

January 14, 2005

This Standard 2 image collected at 14:02 UTC covered the Santa Lucia region. Wind data (Figure 12) was collected at the exact same time (14:02) and showed light wind (5-10 knots) from the north.

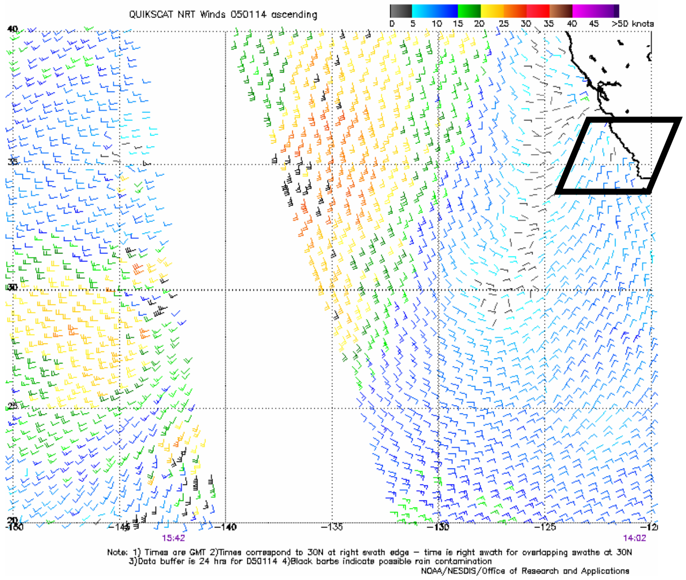


Figure 12. January 14 Wind Speed

The southern edge of this image did cover the Channel region partially. Once again, the wind shadow effect was evident. As Figure 13 shows, the platforms (shown in Blue) were effectively 'hidden' in the wind shadow caused by the local topography that can be seen along the coast.

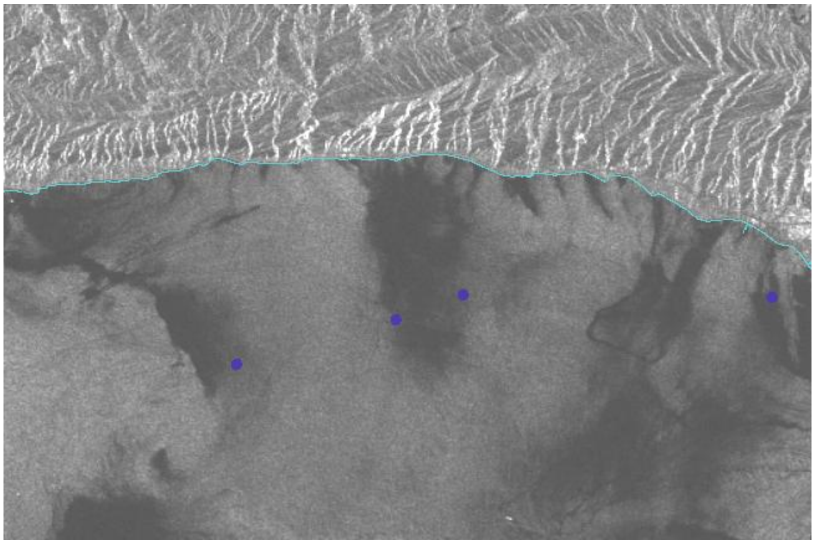


Figure 13. Wind Shadow and Platforms

January 21, 2005

The image on this day was a Standard 1 acquired at 14:06 UTC over the Santa Barbara Channel. No wind data was available as Figure 14 indicates, though low winds were prevalent nearby.

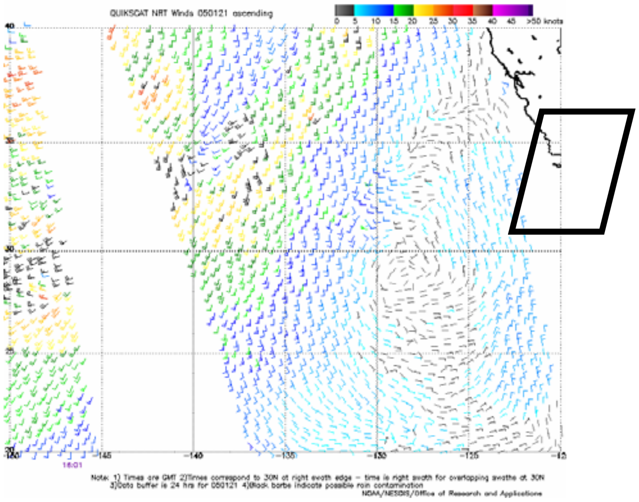


Figure 14. January 21 Wind Speed

Low wind speed and wind shadow were unmistakable on the image from this day. As Figure 15 shows, the area close to shore and around the platforms appears very calm (dark signature). Of interest is the region slightly farther from the shore, and just south of the platforms. As the image chip details, several dark curvilinear signatures occur just outside the very low wind area. It is possible these are the result of natural oil seepage. Contextually, they are quite different from vessel or platform discharges of oil in their shape and pattern.

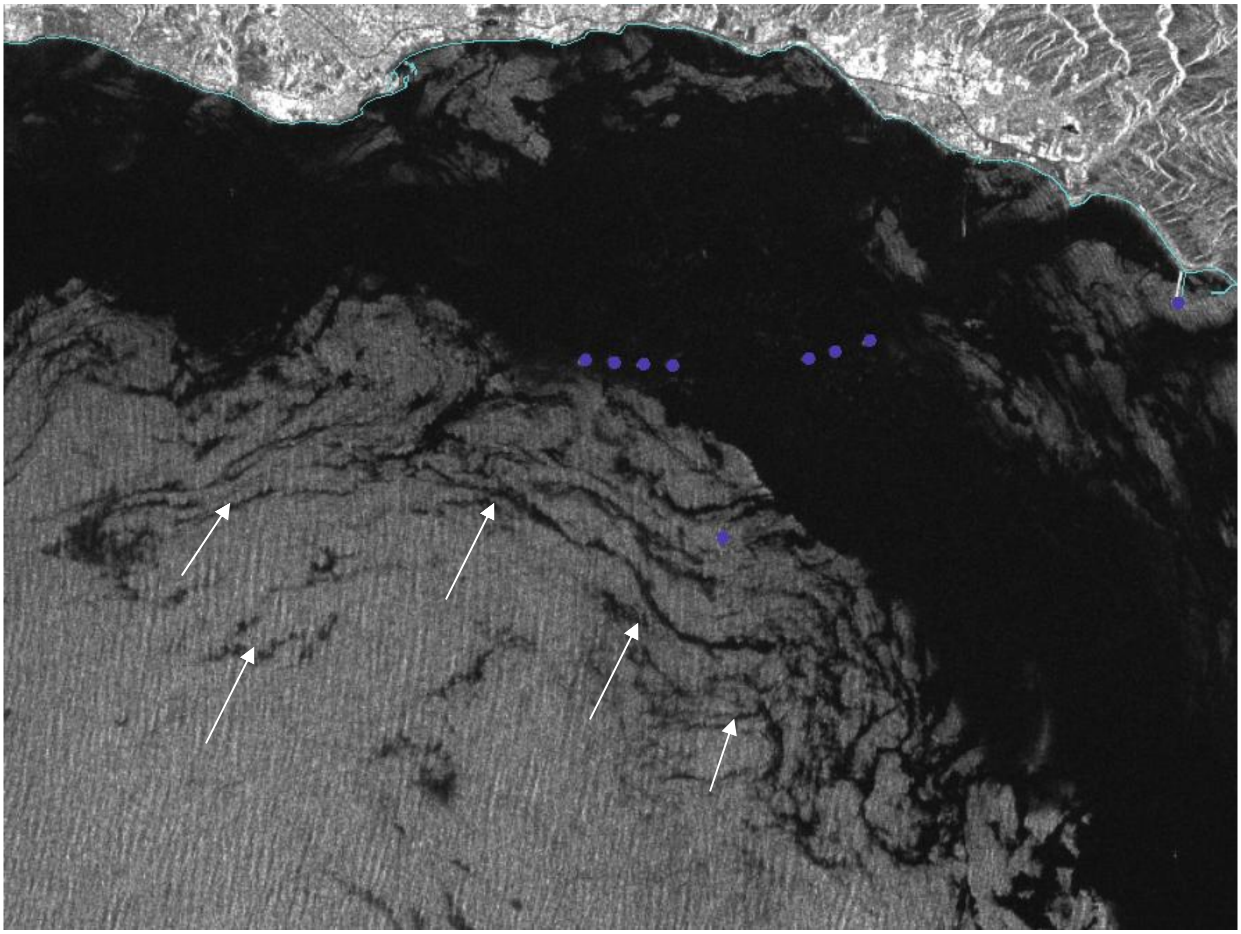


Figure 15. Possible Natural Oil Seeps

January 24, 2005

This image was a Wide 1 over the San Francisco area acquired at 14:06 UTC. Wind speed at 14:43 was light (5-10 knots) from the South (Figure 16). No oil was detected, though conditions were favourable.

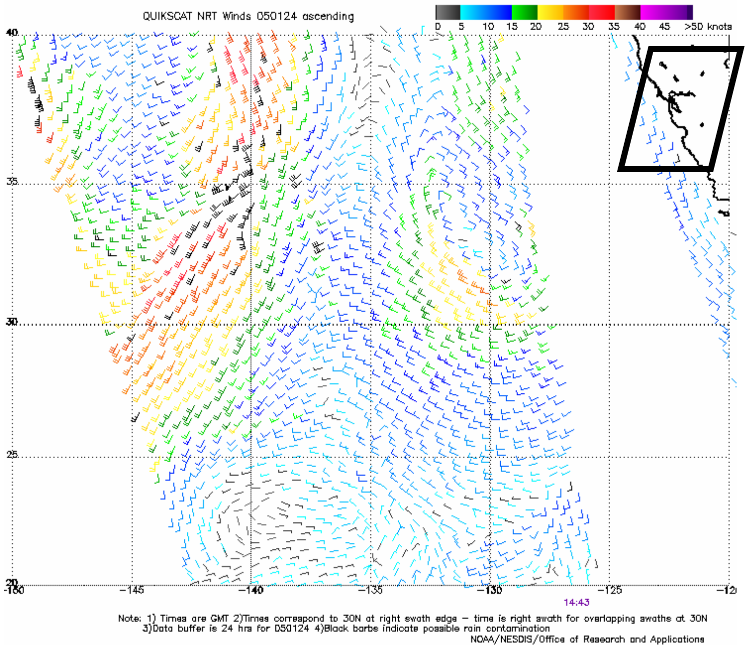


Figure 16. January 24 Wind Speed

February 14, 2005

This ScanSAR Narrow image of the Santa Barbara Channel was acquired at 14:10 UTC, and wind was near coincident at 13:59 UTC. Unfortunately, precipitation seems to have 'contaminated' the wind information, though close to the area seems to be very low wind.

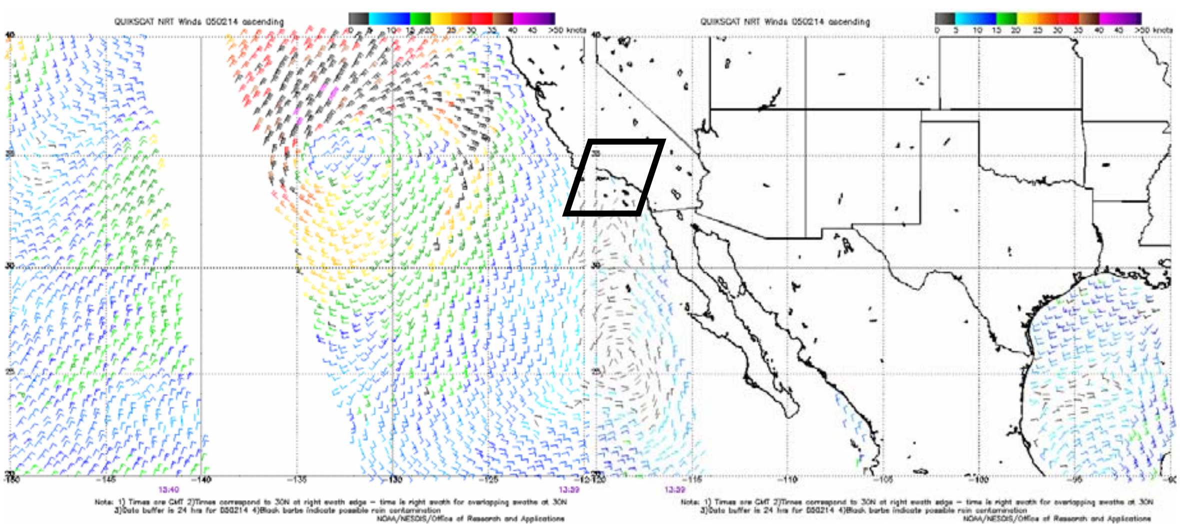


Figure 17. February 14 Wind Speed

As was seen in Figure 15, the February 14th scene had several areas of likely natural oil seeps, with large regions of low wind as well.

March 10, 2005

This image was a ScanSAR Narrow over the Santa Barbara Channel at 14:22 UTC. The nearest wind information was collected approximately 1 hour before the RADARSAT image. Winds were light (5 – 10 knots) and from the north-west (Figure 18) at that time.

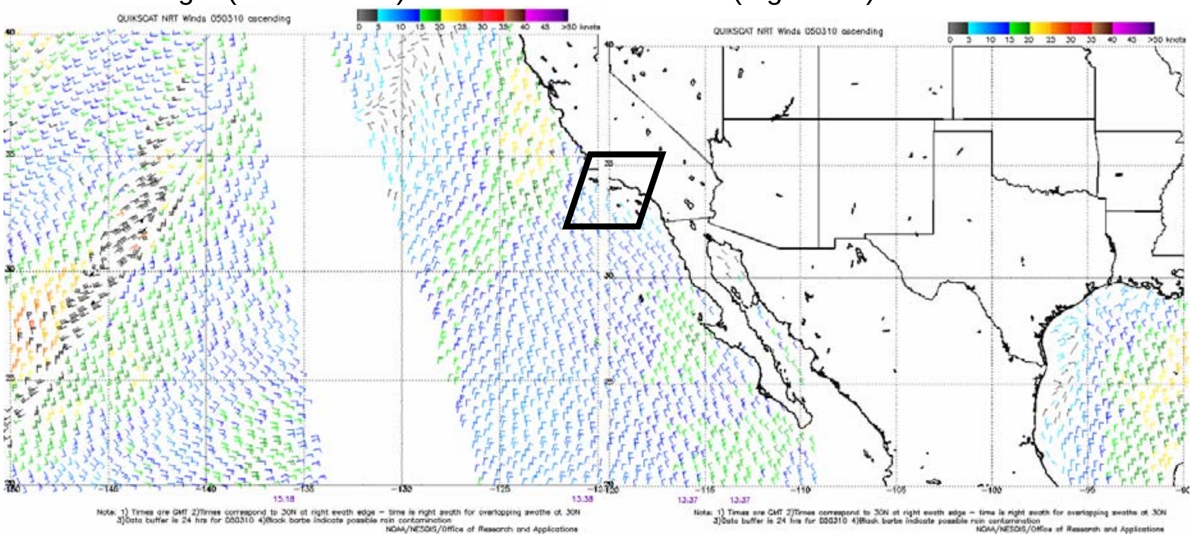


Figure 18. March 10 Wind Speed

The wind shadow effect mentioned several times in this report was once again evident, with large areas between the mainland and the Channel Islands having low backscatter (dark tones). This results in an image that is difficult to interpret strictly for oil releases from ships or platforms.

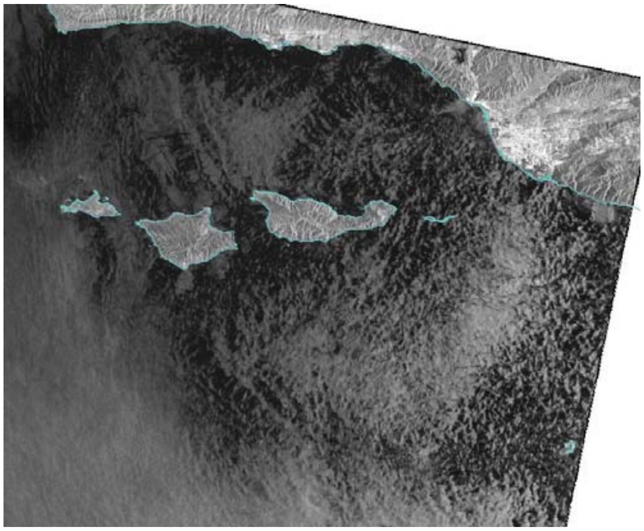


Figure 19. Low Wind Area – March 10

Possible Oil Detections

There were 5 scenes with possible oil, and a total of 6 possible oil events detected. Of these 6 events, 3 were closely associated to known oil production platforms. Each scene is examined in detail below.

December 4, 2004

This image was collected over the Santa Barbara Channel region at 13:58 UTC. Wind conditions depicted in Figure 20 were collected at 13:23 UTC, and show an unclear wind pattern. The region seems to have winds around 5 – 10 knots.

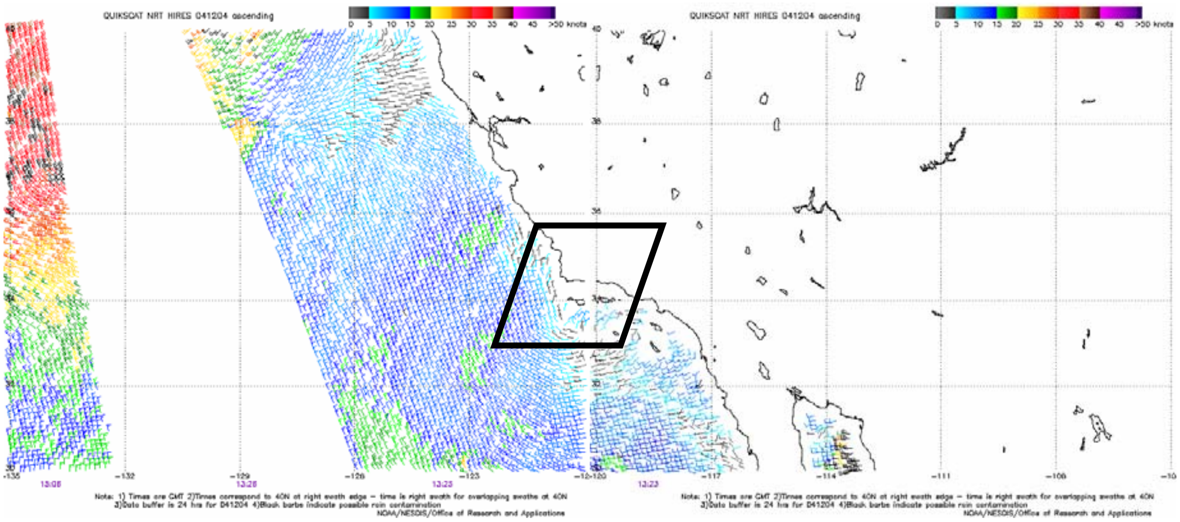


Figure 20. December 4 Wind Conditions

There were 2 possible oil events detected on this image. The overview of the complete scene is shown in Figure 21.

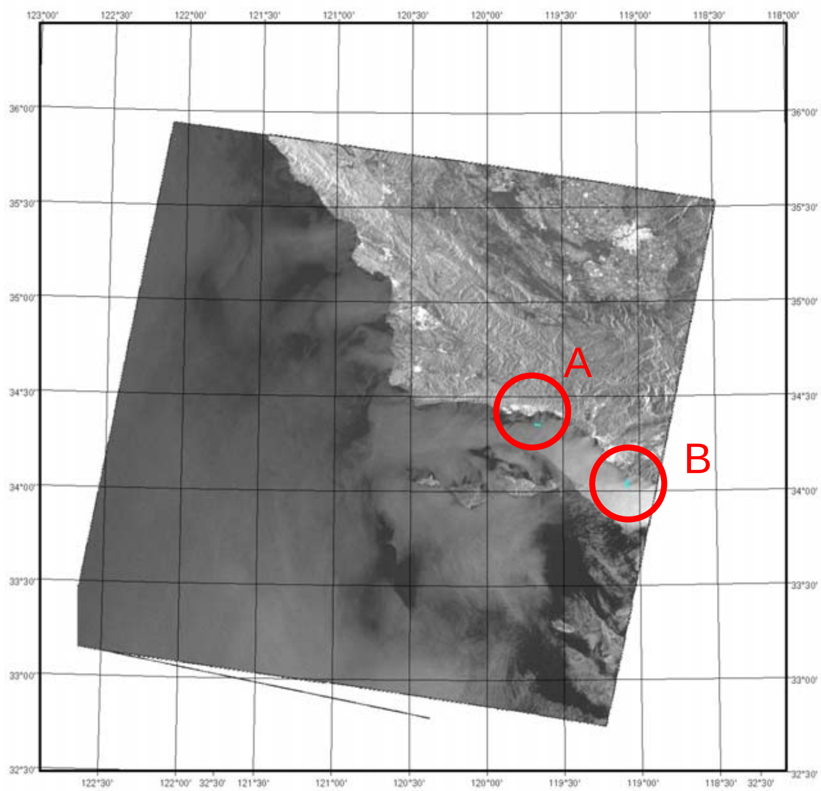


Figure 21. December 4 Overview with 2 Events

Marked “A” in Figure 21 is the first event, shown in greater detail in Figure 22. This potential slick, while indicated as a category 3, does have most of the traits of a point source pollution event. With more accurate wind direction information, and a more clearly defined oil polygon (i.e. higher contrast), this would have been categorized as a high confidence “1A” event. This is likely a release from the ‘Hillhouse A’ Platform with some hydrocarbons present. The signature is not extremely strong (high contrast between water / oil), hence the lower confidence ranking.

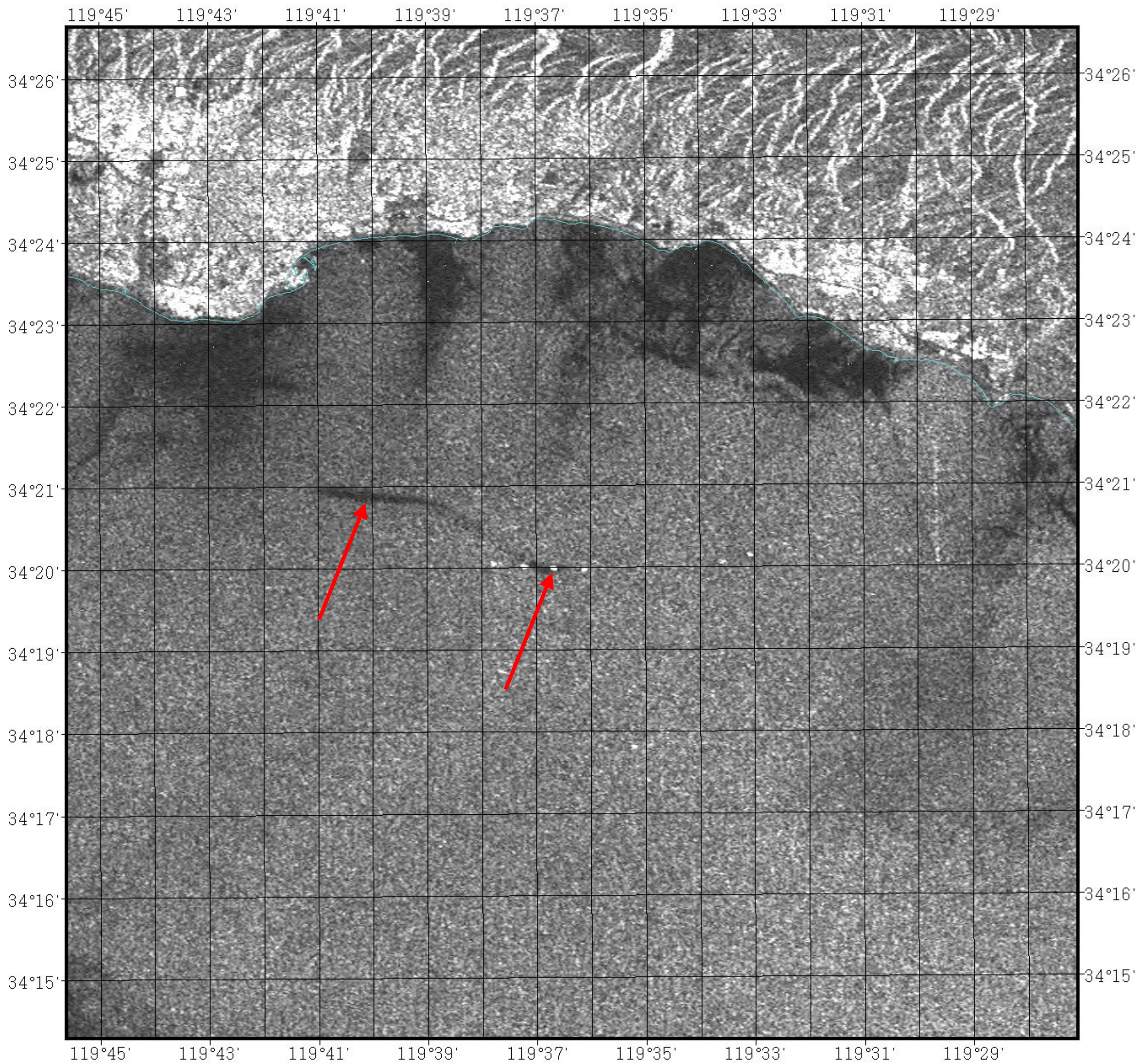


Figure 22. Event "A" from December 4, 2004

The second event on the December 4th scene is indicated in Figure 21 as Event B. Shown in Figure 23, this category 3 event was only 8.5 miles from shore. The orientation, and location near what appears to be a fresh water outlet make this a low confidence detection.

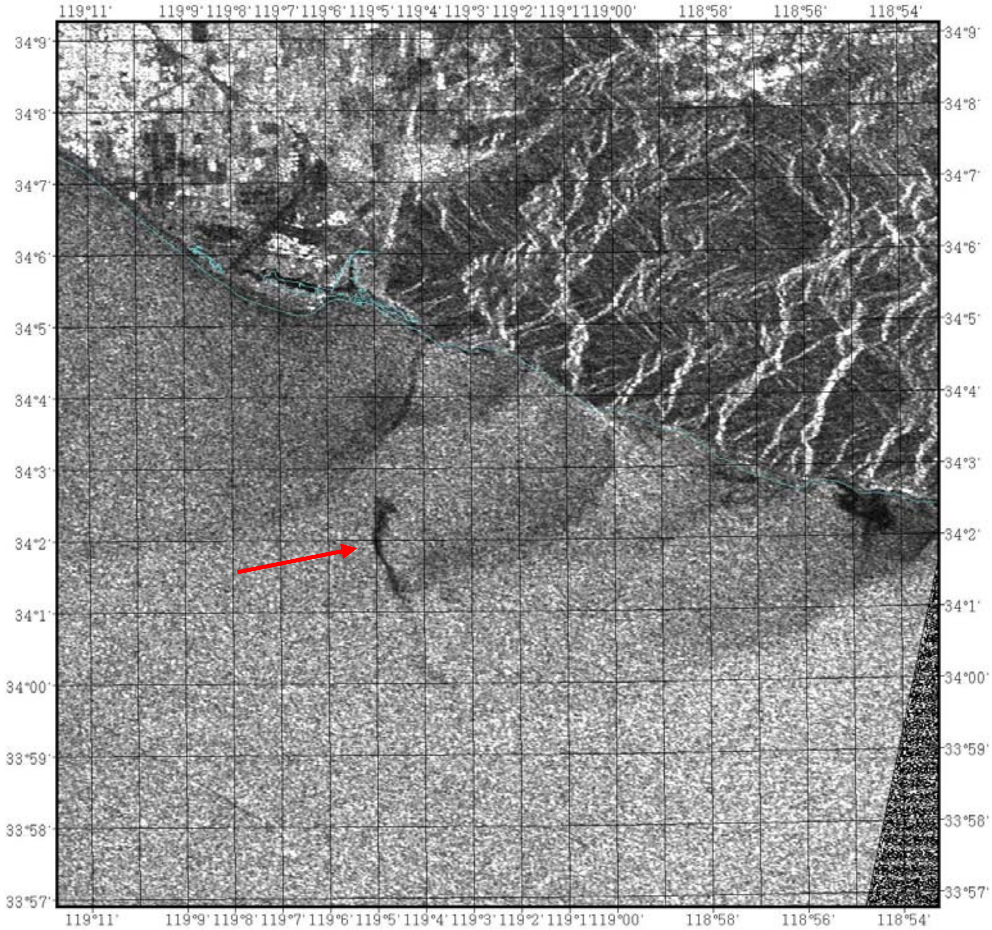


Figure 23. Event "B" from December 4, 2004

December 11, 2004

This ScanSAR Narrow image was also collected over the Santa Barbara Channel, at 14:02 UTC. Wind data, shown in Figure 24, was collected at 13:41 UTC, and shows winds from the north-north-west and are light near the coast and pick up to 10 knots farther from shore.

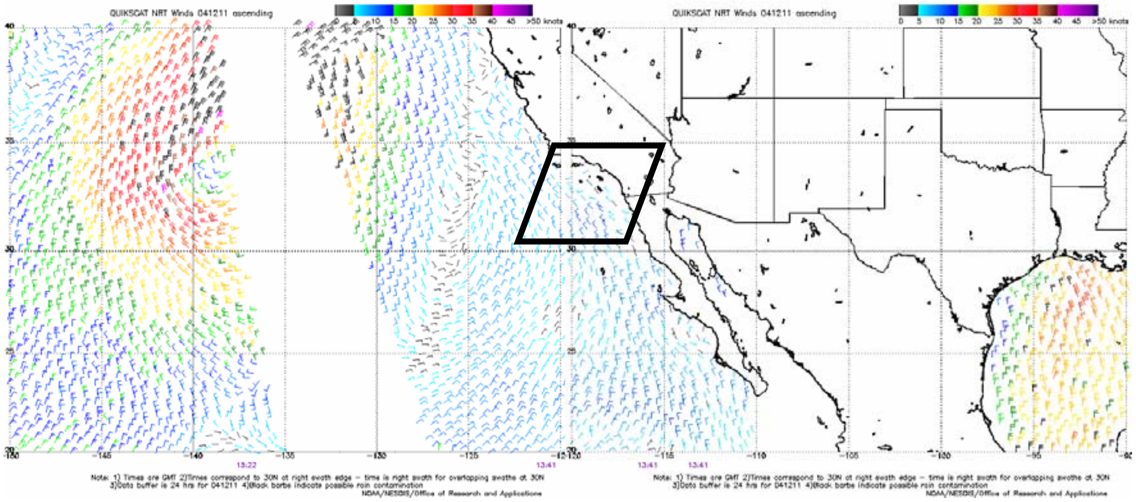


Figure 24. December 11 Wind Speed

One category 3 event was detected south of the channel islands, and is shown in Figure 25.

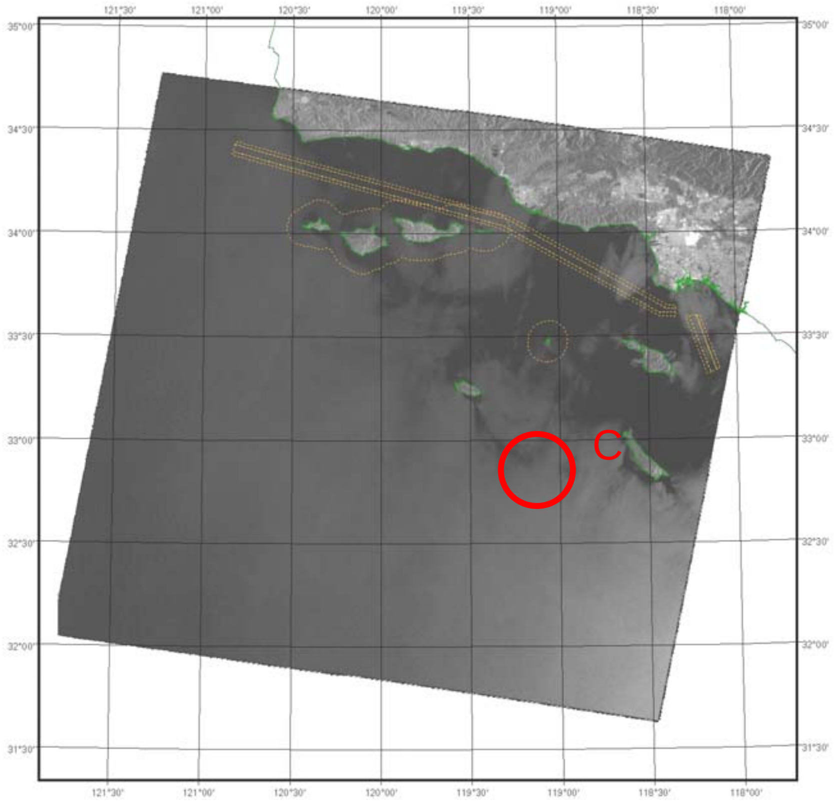


Figure 25. December 11 Overview with 1 Event

While relatively small in size (approximately 1 mile in length) the shape of this polygon is typical of a moving ship release of oil. With no targets in the area though, there was not enough contextual evidence to give this a more confident ranking. The detail zoom for event "C" is shown in Figure 26.

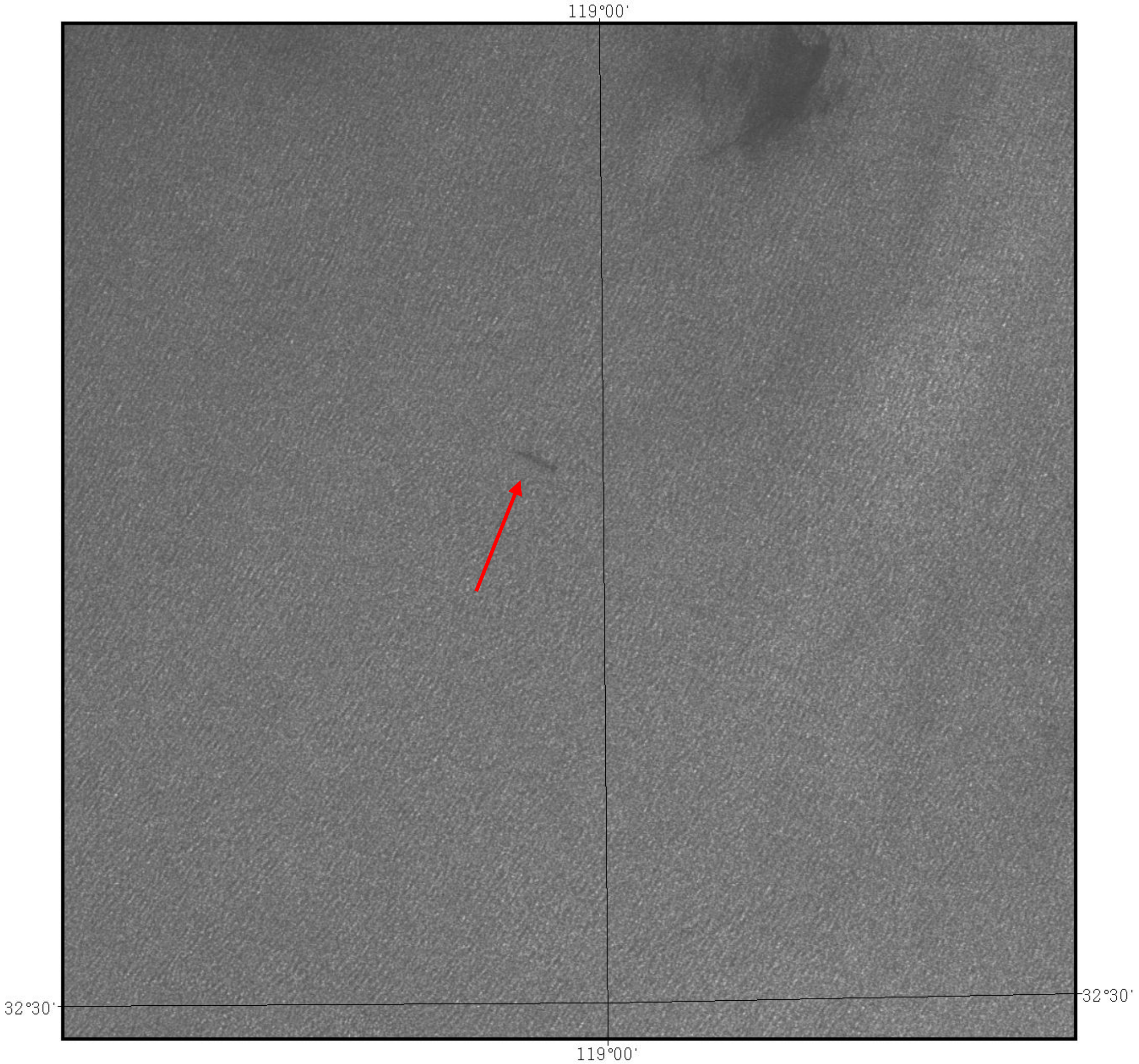


Figure 26. Event "C" from December 11, 2004

December 24, 2004

The image collected on this date was a ScanSAR Narrow in the San Francisco region. Image time was 14:10 UTC, and wind data, shown in Figure 27, was collected at 13:05 UTC. Direction and speed are unclear, but appear to be light with possible precipitation in the area.

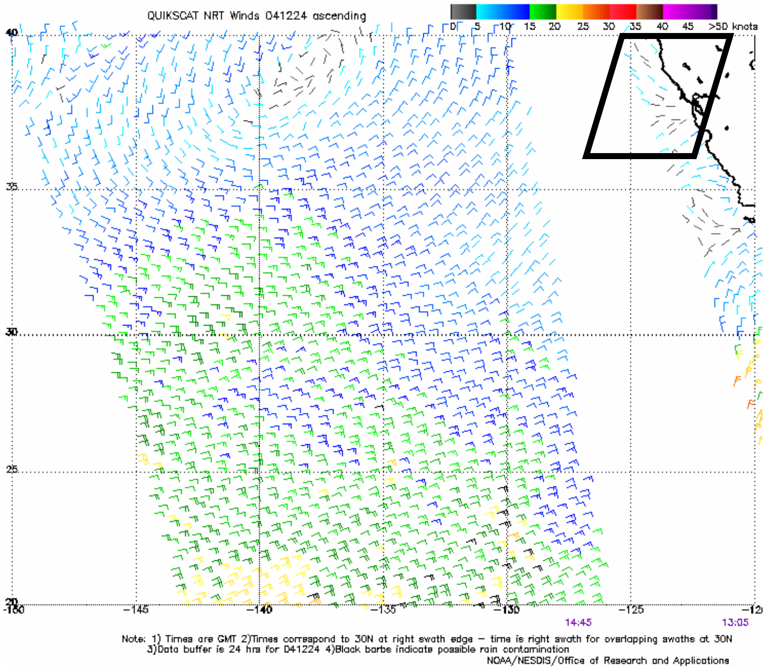


Figure 27. December 24 Wind Speed

Another small, low confidence detection was made on this image. Marked as event "D" on Figure 28, this polygon has a low backscatter response, but shape and context were such that it did not receive a higher confidence. This was possibly a weather related phenomena or an oil slick that had weathered significantly. A detail zoom of this detection is shown in Figure 29.

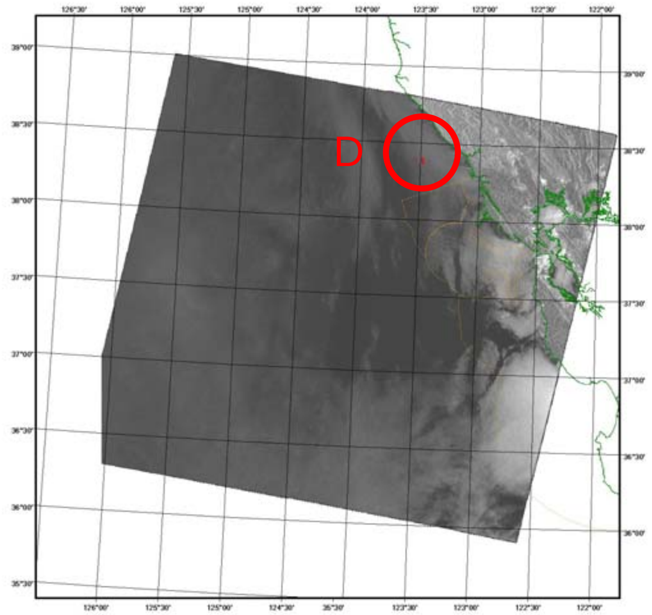


Figure 28. December 24 Overview with 1 Event

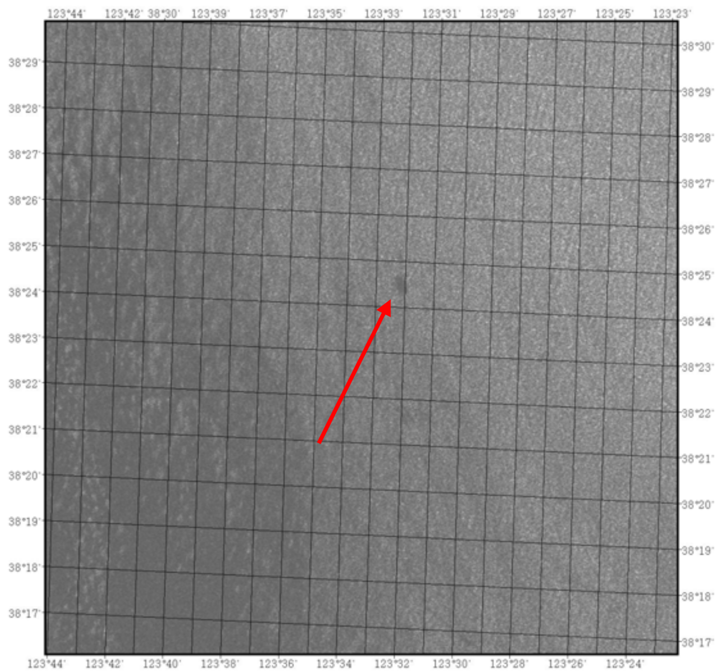


Figure 29. Event "D" from December 24, 2004

December 28, 2004

This image was one of the higher resolution Standard 1 collections made, in this case over the Santa Barbara Channel. Image collect was at 14:06 UTC, and the associated wind data, shown in Figure 30, was taken at 13:01 UTC. Precipitation was present and wind was from the south-west, at around 10 knots. Figure 31 is an overview of the scene coverage.

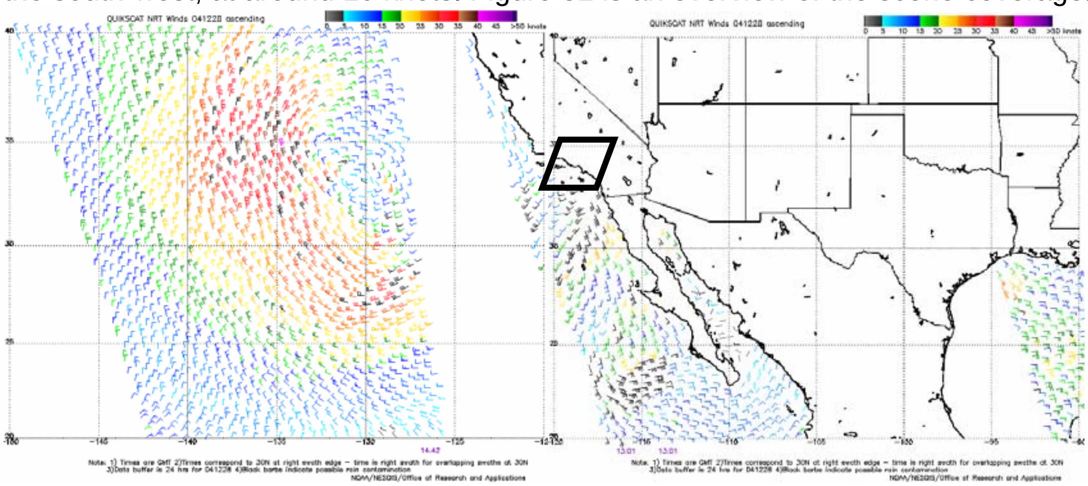


Figure 30. December 28 Wind Speed

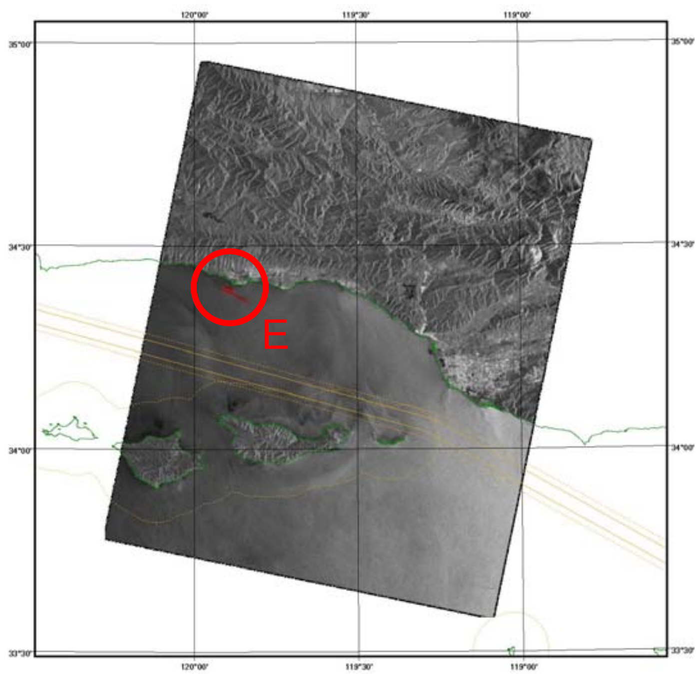


Figure 31. December 28 Overview with 1 Event

The event "E" is shown in detail below (Figure 32). Located within the low backscatter (i.e. dark) area is the platform "Holly". As a category 3 event, it is a low confidence detection. The distribution of the dark polygon is not consistent with a point source release (given the estimated wind direction). The contrast is also not very high, as would be expected for an oil release event.

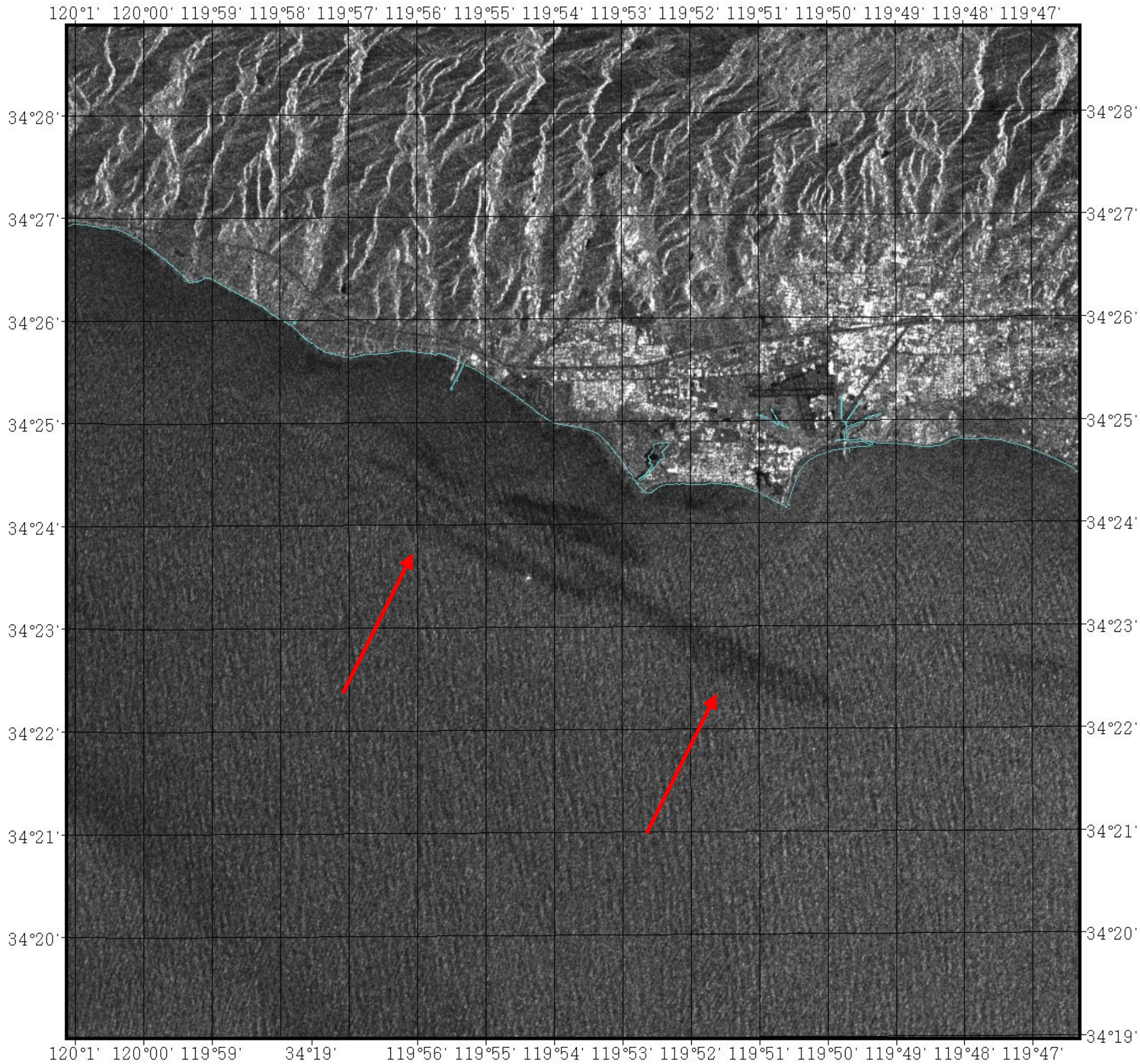


Figure 32. Event "E" from December 28, 2004

January 28, 2005

This Santa Barbara Channel image was a ScanSAR Narrow acquired at 13:58 UTC. Wind information available were at 12:50 UTC, and were 10 – 15 knots from the south (Figure 33). Image overview is shown in Figure 34.

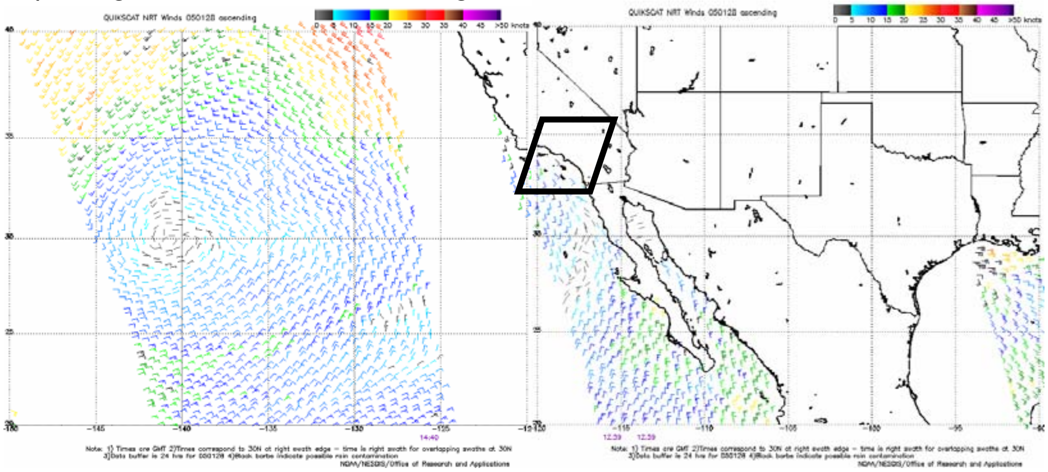


Figure 33. January 28 Wind Speed

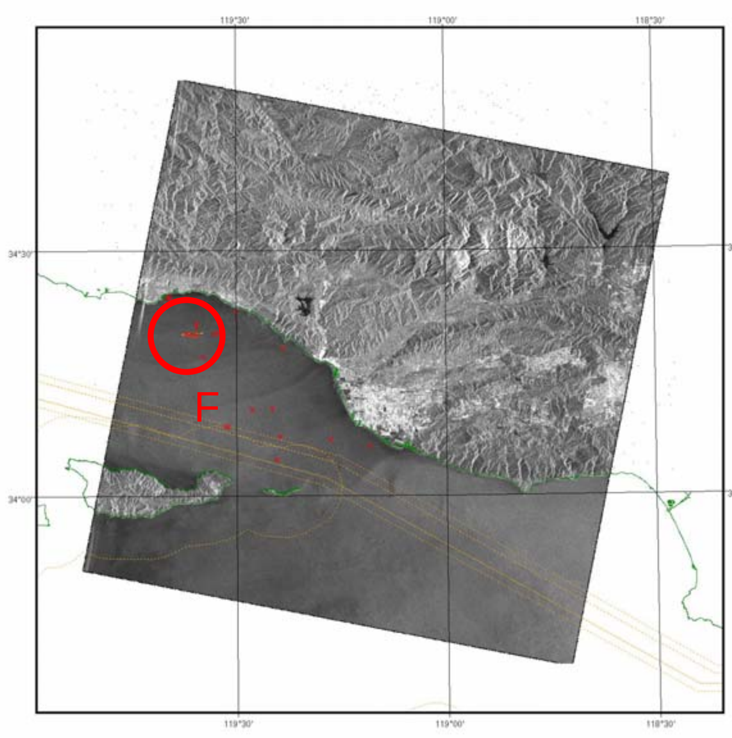


Figure 34. January 28 Overview with 1 Event

Once again, a category 3 detection was made and associated with the Hillhouse A platform. As Figure 35 indicates, a low backscatter region is present in and around the platforms. Contrast is not high, but does stand out from the surrounding maritime state.

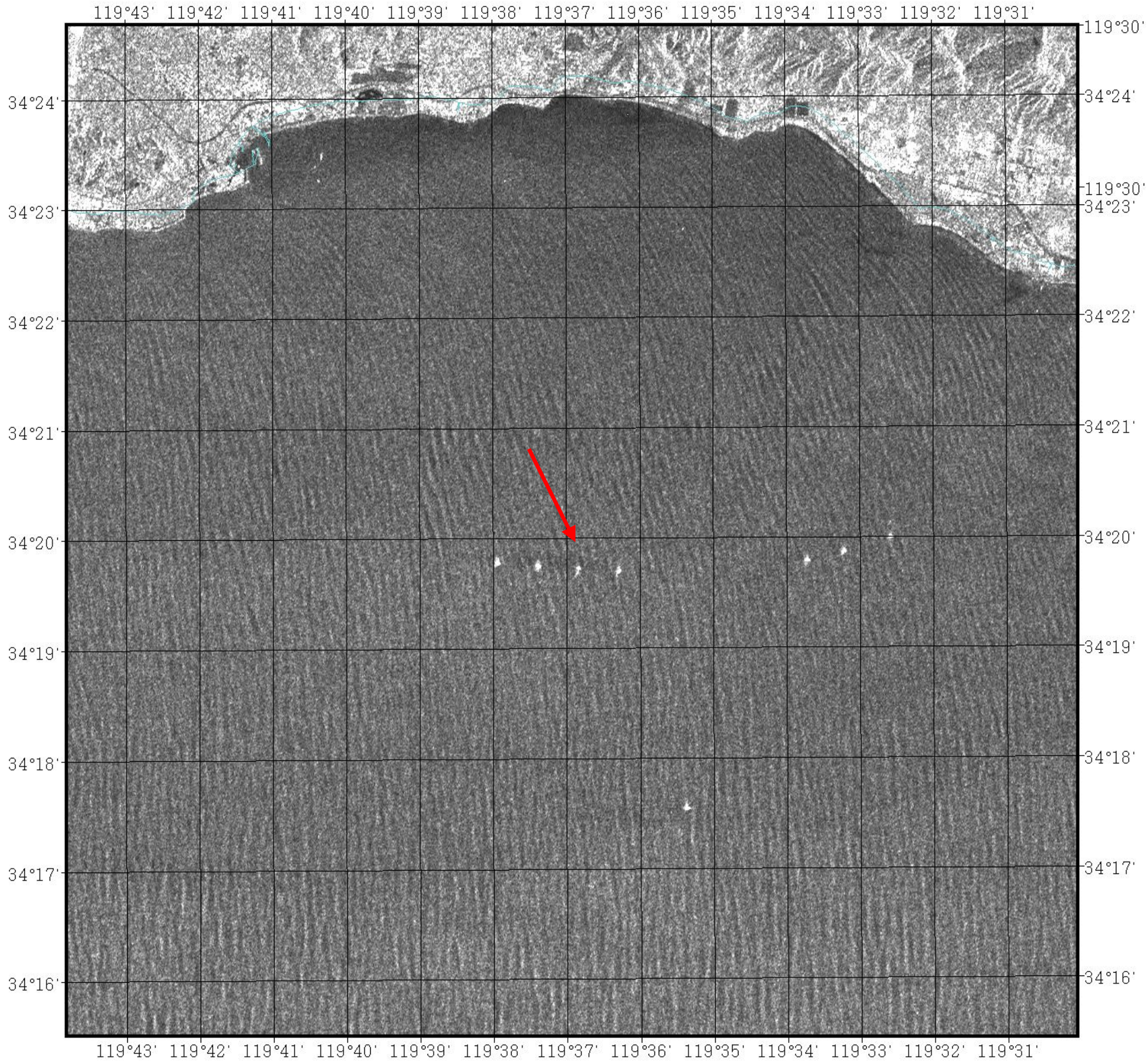


Figure 35. Event “F” from January 28, 2005

Target Detection

For each scene processed, a target (ship/platform) detection was also completed. This was secondary to the oil detection analysis, and as such was completed only after the oil analysis was complete. Just as the case with oil analysis, the target detection is done manually in a customized GIS environment. A confidence ranking was also used for the target information:

1 – Ship with visible wake
2 – Probable target
3 – Possible target (lowest confidence)
4- Known platform (from GIS layer provided)

Figure 36 shows the complete extent of all targets detected in the 14 scenes analyzed. A total of 458 targets were located (including known platforms). The range of detections was 15 targets (minimum) and 69 targets (maximum) and averaged 33 targets per scene.

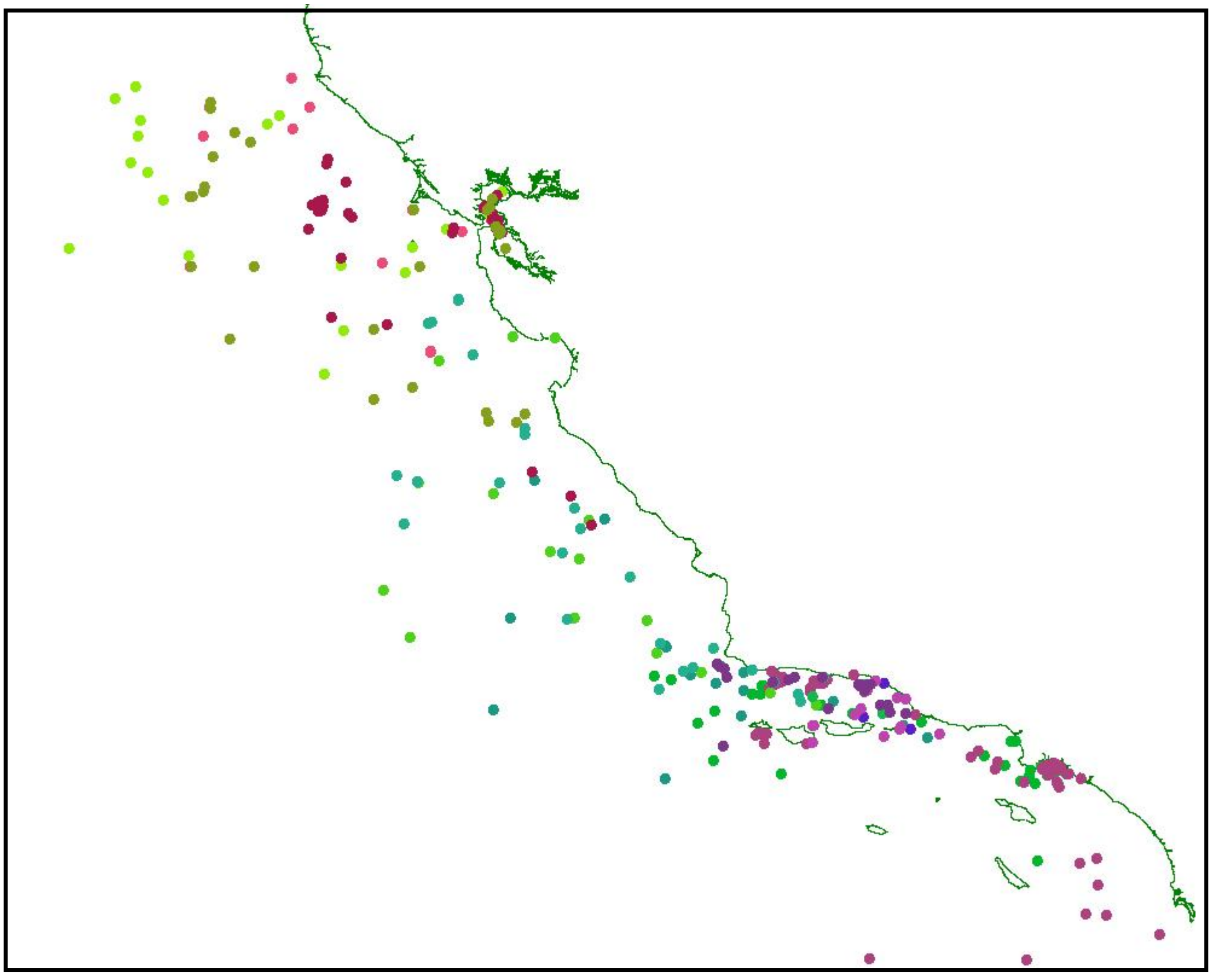


Figure 36. Overview of all targets detected (December – March)

Such information is most useful when used in conjunction with other sources of vessel data. It does provide contextual information for possible oil releases (from ships or platforms) and can also be used to monitor vessel movement over time. Figure 37 shows the Santa Barbara Channel region with the shipping lane vectors. Adherence to these boundaries is evident, as many of the point targets (i.e. ships) are located directly in the shipping lanes.

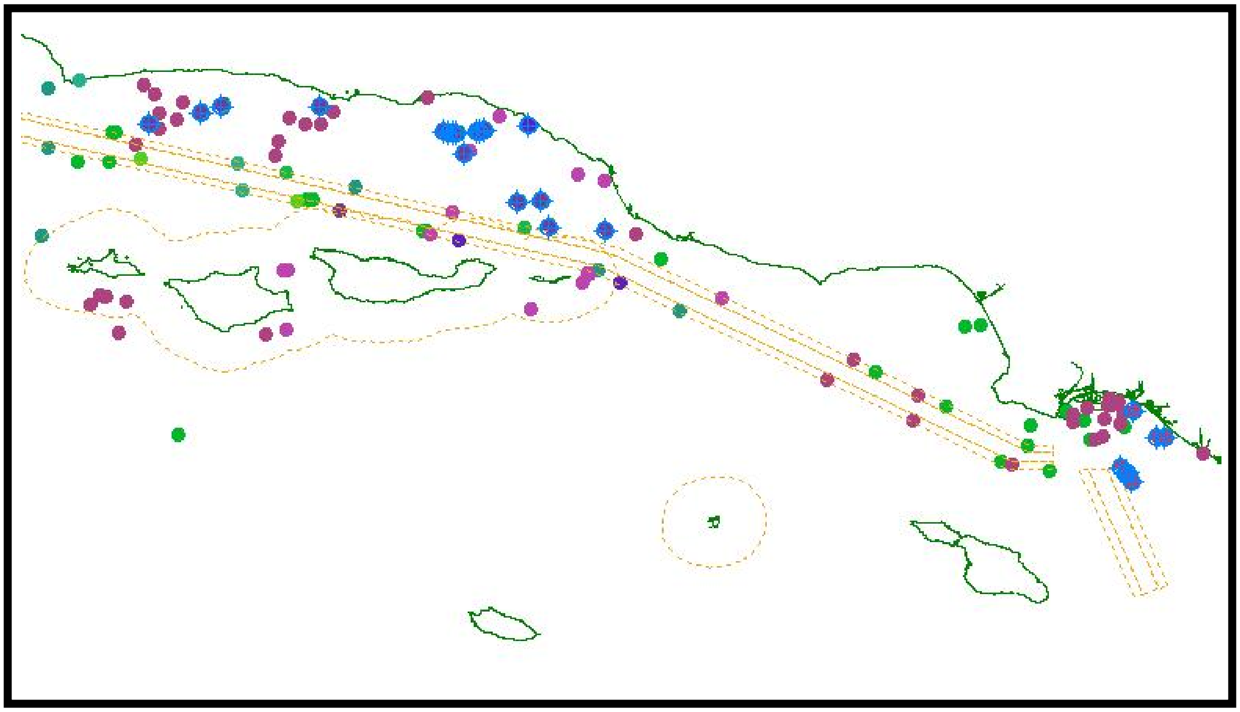


Figure 37. Detail Zoom – Target Detection with Shipping Lanes

Comments and Conclusions

This Pilot Project sought to explore two key aspects of a potential operational oil slick detection service. Firstly, the end-to-end process was demonstrated in every detail to get a complete understanding of the timeline involved to deliver a product to the client. Secondly, it was necessary to show that the technology has the capability to detect oil releases from vessels or platforms, and also provide associated target reports, along the California Coast

Overall delivery times were satisfactory for the pilot, with the oil analysis being available in just over 2.5 hours. Some improvements could be made in the end-to-end delivery time. RSI is currently undergoing WAN improvements that would overcome any delays from traffic in the system. Processing time will improve as the hardware and software are upgraded over time, but by utilizing only single beam products, overall processing time could be reduced by approximately 15 minutes. The generation of the target reports does add a considerable time to the analysis chain. With the establishment of an operational target detection software at CDPF, these reports could be generated in under 5 minutes. RSI intends to have such software installed in the immediate future at CDPF.

Several detections of possible oil were made during the pilot, and 4 of the 5 scenes with oil were over the Santa Barbara Channel. While all 6 of the events were category 3 (the lowest confidence), half were also closely linked to known oil production facilities. Of those, 2 were likely associated to the same platform. It was also noted that north winds often adversely affected the Santa Barbara Channel region, causing wind shadows that hampered possible oil detections.

To conclude, the Pilot Project demonstrated that oil and target detection from a SAR satellite sensor is a feasible and effective application.

Questions or Comments…

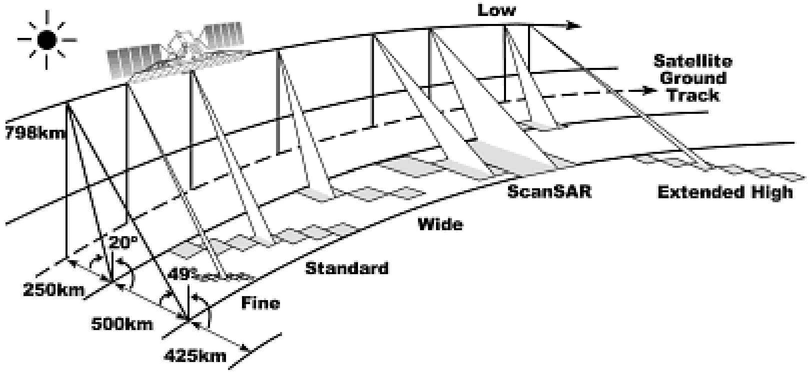
If you would like more information regarding this report, or have any comments, please contact:

Jeff Hurley
Senior Project Manager
RADARSAT International
75A McClelland Road 1.819.827.8427 (ph)
Cantley, QC, CANADA 1.819.827.1955 (fax)
J8V 2Y8 1.819.664.5784 (cell)
jhurley@rsi.ca / www.rsi.ca

APPENDIX A – Technology Background

Monitoring oceans for oil spills is a challenging task made more difficult by the vast regions to cover. For over 20 years, coastal and marine applications have benefited from the information derived from satellite imagery. While Earth observation using satellites makes the job easier because of broad area of coverage, passive optical sensors, which rely on reflected sunlight to image, are not effective at night or if there is cloud. In contrast, synthetic aperture radar (SAR) satellites, such as RADARSAT-1, can image regardless of weather and illumination conditions. As RADARSAT imagery has been used increasingly for detecting oil on ocean surfaces, its abilities have become well understood.

RADARSAT-1 does not continuously image, but is programmed to acquire imagery in a specific beam mode and position, according to client need. The steerable sensor allows the collection of data over a 1,175 km wide swath using seven different beam modes, as shown in the figure at below. This provides users with superb flexibility in acquiring images with a range of resolutions, incidence angles, and coverage areas. For synoptic studies, RADARSAT-1 ScanSAR Narrow imagery provides a clear view of a 300-km swath with 50-metre resolution, and the swath can be adjusted to fit any point in the target area under surveillance. For a more detailed analysis, RADARSAT Fine beam mode imagery provides 50 km wide swaths and 8 m resolution.



The ability to choose the beam and position is important because image characteristics vary with the incidence angle associated with each beam. When planning image acquisitions RSI ensures that the most appropriate beam position is selected for the application. For oil slick detection, the most appropriate beam positions are those with steep incidence angles.

For small monitoring areas the most common beam modes for oil detection are:

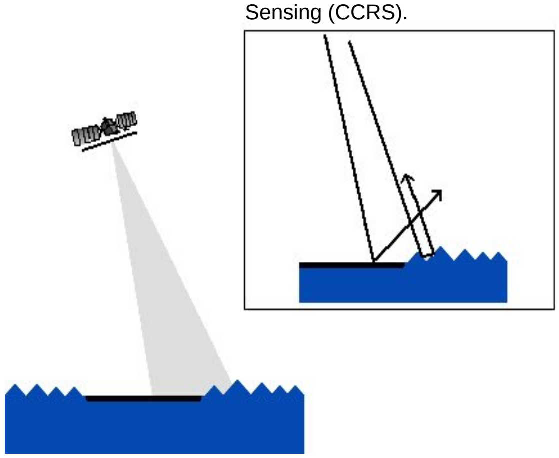
- Standard 1 (swath width: 100 km, nominal resolution: 25m)
- Standard 4 (swath width: 100km, nominal resolution: 25m)
- Wide 1 (swath width: 150km, nominal resolution: 30m)

For larger monitoring areas the most common beam mode is:

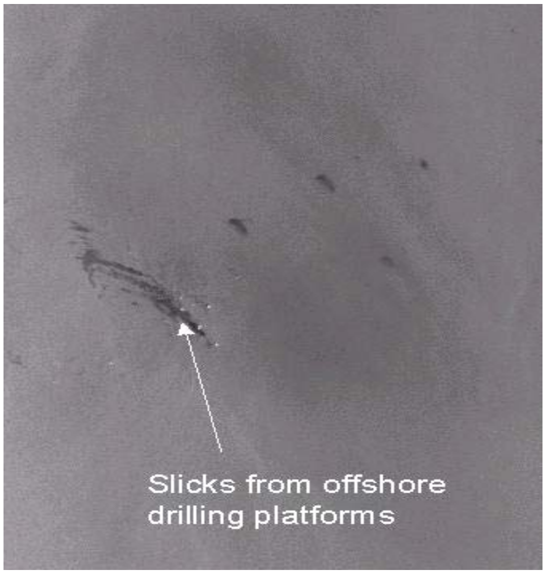
- ScanSAR Narrow A (swath width: 300km, nominal resolution: 50m)

The detection of oil on the ocean surface requires discrimination between the ocean-surface backscatter and the backscatter from the oil. Scattering from the ocean-surface at incidence angles larger than about 20° is predominantly due to Bragg scattering from capillary waves and short gravity waves. One of the effects of oil on water is to attenuate these waves, and hence reduce the SAR signal return (or backscatter) as shown in the diagram on the following page. Areas of reduced backscatter appear as dark tones on a SAR image, therefore on a processed RADARSAT image an oil spill will have a darker tone than the surrounding water.

RADARSAT-1 data © Canadian Space Agency 2000. Received by the Canada Centre for Remote Sensing (CCRS).



Oil suppresses surface waves, which SAR detects as reduced backscatter.



RADARSAT-1 image showing oil from offshore drilling platform.
(The oil appears as a dark tone, and the offshore platforms appear as bright targets)

Key parameters that define ocean-surface backscatter include wind speed and SAR incidence angle: the backscatter increases with increasing wind speed, and decreases with increasing incidence angle. The detection of oil is enhanced at small incidence angles and for wind speeds roughly between 3 m/s and 12 m/s (Staples and Hodgins, 1998).
Like any technological tool, SAR has limitations. The primary factor influencing the ability of SAR to detect oil slicks is surface wind speed. When wind speeds are low, the ocean-surface appears smooth relative to the SAR wavelength, and hence the backscatter from the water is similar to that from the oil. When wind speeds are high, oil-induced attenuation is dominated by wind-induced surface roughness. Therefore, oil detection is optimal at moderate wind speeds, but can be problematic at very low and high wind speeds.
It is also possible for other phenomena to produce regions of low radar backscatter, thus leading to potential misinterpretation or 'false positives'. These phenomena are: (a) slicks caused by fresh water intrusions (e.g., rivers); (b) regions of very weak or no wind; (c) shadow zones of waves behind structures, islands or land; (d) beds of underwater vegetation which calm the surface waters; and (e) biogenic oils. The turbulence in a ship's stern wake will temporarily dampen any capillary waves, thus also resulting in a low radar backscatter. These phenomena can all appear as darker tones in an image against the lighter surrounding water. By gathering and using information about the location of known sources or locations of these phenomena, however, the image interpretation specialist can reduce the probability of misinterpreting an oil slick.

While these issues may impact the chances of detecting some oil spills, RSI mitigates them by comparing scenes of the same area but acquired at different times, and through the experience of the analyst, who applies a variety of enhancement techniques, along with prior knowledge of the area, to further enhance the visibility of target of interest.

In March 2002, the European Space Agency launched Envisat, another SAR-equipped earth observation satellite. Envisat employs an Advanced Synthetic Aperture Radar (ASAR) imaging system operating in C-band. The capabilities of the ASAR sensor offer improvements over the ERS 1 / 2 missions in the categories of: coverage, range of incidence angles, polarization and modes of operation. But the Envisat sensor has the additional advantage of compatibility with the sensor operated on the ERS satellites. In this manner historical data from ERS missions over the last ten years can be compared with newly collected Envisat imagery to conduct time-series analysis.

RSI is part of the SARCOM consortium and therefore has rights to distribute Envisat products and services. Envisat is often incorporated into operational services. For an Oil Spill Detection Service, Envisat into. It is clear that the RADARSAT-1 and ENVISAT ASAR sensors offer comparable imaging qualities for oil slick detection. Using the two sensors in combination can provide benefit to oil slick surveillance and monitoring applications.

APPENDIX B – Recent News Story

NASA News
JET PROPULSION LABORATORY
CALIFORNIA INSTITUTE OF TECHNOLOGY

Alan Buis (818) 354-0474
Jet Propulsion Laboratory, Pasadena, Calif.

Gretchen Cook-Anderson (202) 358-0836
NASA Headquarters, Washington

News Release: 2005-048 March 17, 2005

NASA Researchers use Imaging Radar to Detect Coastal Pollution

A NASA-funded study of marine pollution in Southern California concluded space-based synthetic aperture radar can be a vital observational tool for assessing and monitoring ocean hazards in urbanized coastal regions.

"Clean beaches and coastal waters are integral to Southern California's economy and lifestyle," said Dr. Paul DiGiacomo, an oceanographer at NASA's Jet Propulsion Laboratory, Pasadena, Calif. He is lead author of the study recently published in the Marine Pollution Bulletin. "Using Southern California as a model system, we've shown existing high-resolution space-based radar systems can be used to effectively detect and assess marine pollution hazards. This is an invaluable tool for water quality managers to better protect public health and coastal resources," he said.

DiGiacomo and colleagues from JPL; the University of California, Santa Barbara; and the University of Southern California, Los Angeles, examined satellite radar imagery of the coastal waters of Southern California. The area is adjacent to 20 million people, nearly 25 percent of the U.S. coastal population. The imaging radar data from the European Space Agency's European Remote Sensing Satellites 1 and 2 and Canada's Radarsat were complemented by shore-based surface current radar data and other field measurements.

"The key to evaluating and managing pollution hazards in urban coastal regions is accurate, timely data," DiGiacomo said. "Since such hazards are usually localized, dynamic and episodic, they're hard to assess using oceanographic field sampling. Space-based imaging radar works day and night, regardless of clouds, detecting pollution deposits on the sea surface. Combined with field surveys and other observations including shore-based radar data, it greatly improves our ability to detect and monitor such hazards," he said.

The study described three major pollutant sources for Southern California: storm water runoff, wastewater discharge and natural hydrocarbon seepage.

"During late fall to early spring, storms contribute more than 95 percent of the region's annual runoff volume and pollutant load," said JPL co-author Ben Holt. "Californians are accustomed to warnings to stay out of the ocean during and after storms. Even small storms can impact water quality. Radar data can be especially useful for monitoring this episodic seasonal runoff," he said.

DiGiacomo noted a regional Southern California marine water quality monitoring survey is under way involving JPL and more than 60 other organizations, including the Southern California Coastal Water Research Project. Its goal is to characterize the distribution and ecological effects of storm water runoff in the region. Space radar and other satellite sensor data are being combined, including NASA's Moderate Resolution Imaging Spectroradiometers. The sensors provide frequent observations, subject to clouds, of ocean color that can be used to detect regional storm water runoff and complement the finer resolution but less frequent radar imagery.

The second largest source of the area's pollution is wastewater discharge. Publicly owned treatment works discharge daily more than one billion gallons of treated wastewater into Southern California's coastal waters. Even though it is discharged deep offshore, submerged plumes occasionally reach the surface and can contaminate local shorelines.

Natural hydrocarbon seeps are another local pollution hazard. Underwater seeps in the Santa Barbara Channel and Santa Monica Bay have deposited tar over area beaches. Space imaging radar can track seepage on the ocean surface, as well as human-caused oil spills, which are often affected by ocean circulation patterns that make other tracking techniques difficult.

Further research is necessary to determine the composition of pollution hazards detected by radar. "From imaging radar, we know where the runoff is, but not necessarily which parts of it are harmful," Holt said. "If connections can be established, imaging radar may be able to help predict the most harmful parts of the runoff."

While the researchers said environmental conditions such as wind and waves can limit the ability of space radar to detect ocean pollution, they stressed the only major limitation of the technique is infrequent coverage. "Toward the goal of a comprehensive coastal ocean observing system, development of future radar missions with more frequent coverage is a high priority," DiGiacomo said.

JPL is managed for NASA by the California Institute of Technology in Pasadena.

-end-

APPENDIX C – REFERENCES

Bentz, C.M., and Miranda, F.P., 2001, Application of Remote Sensing data for oil spill monitoring in the Guanabara Bay, Rio de Janeiro, Brazil. In IGARSS '01, Proceedings of the International Geoscience and Remote Sensing Symposium, 9-13 July 2001, Sydney, Australia IEEE, New York.

Fingas, M., and C. Brown, 1997, Remote sensing of oil spill: Sea Technology, v. 38, p. 37-46.

Fortuny-Guasch, J., Improved Oil Slick Detection and Classification with Polarimetric SAR, Proceedings PoLinSAR Workshop, Frascati, Italy, 2003

Freeberg, M.H., R. Wrigley, K. Dunlop, D. Sullivan, and G.C. Staples; "Application of Space-based Radar Systems to Fisheries Monitoring and Surveillance*," Proceedings ERIM Remote Sensing for Marine and Coastal Environments*, pp. 278 - 289, Vol I, Seattle, WA, September, 1995.

Fu. L.L., and B. Holt, 1982, Seasat views oceans and sea ice with synthetic aperture radar: JPL Publication 81-120, 200 p.

Kourti, N., I. Shepherd, D. Brock, S. Moesel, P. Griffith, D. Martin; Ship Detection for Fisheries Monitoring: a summary of workshop presentations; pp.16 – 20; *Backscatter*, Fall 2000.

Long, M., Radar Reflectivity of Land and Sea, Lexington Books, 1975.

Staples, G.C., J. Hornsby, Turning the Scientifically Possible into the Operationally Practical, In Proceedings, IGARSS'02, Toronto, Canada, June 2002.

Staples, G.C., and D.O. Hodgins, RADARSAT-1 Emergency Response for Oil Spill Monitoring, Proceedings Fifth Int'l. Conf. on Rem. Sens. for Marine and Coastal Environments, October, 1998.

Vachon, P.W., R.B. Olsen; Ship Detection with Satellite-based Sensors: a summary of workshop presentations; pp. 23 – 25; *Backscatter*, Fall 2000.

Vachon, P., P. Adlakha, H. Edel, M. Henschel, B. Ramsay, D. Fleet, M. Rey, G. Staples, and S. Thomas; Canadian Progress Toward Marine and Coastal Application of Synthetic Aperture Radar, *John Hopkins APL Technical Digest*, Vol. 21, No. 1, Jan – Mar 2000.

Vachon, P.W., J.W.M. Campbell, C. Bjerkelund, F.W. Dobson, and M.T. Rey; "Validation of Ship Detection by the RADARSAT SAR" submitted to *Proc. Pacific Ocean Remote Sensing Conference* (PORSEC'96), 13-16 Aug. 1996, Victoria, Canada.