Oil spill detection using radar data
Basic principles

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Overview

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- Oil characteristics
- Oil spill detection with radar remote sensing
- Examples
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Introduction

- The term “oil spill” refers to the release of a liquid petroleum hydrocarbon into the environment due to human activity.

- Most oil spills occur in open or coastal waters and correlate very well with the major shipping routes. Only few occur in inland waters.

- Causes for oil spills: Tanker accidents comprise only 5% of all pollution entering into the sea (Fingas, 2001)! Other sources: leaking pipelines, oilrigs, bottom seepages, etc.

- The majority of oil spill occur “deliberately” – 45% comes from operative discharges from ships. Much less as a direct result of ship accidents.

- Types of oil: 48% fuel oil, 29% crude oil, 23% other types of oil
Environmental impacts of oil spills

- Birds and marine mammals:
  - Penetrates and opens up the structure of the plumage of birds, reducing its insulating ability. Impairs flying ability (no foraging, starvation)
  - Oil ingestion: kidney damage, altered liver function and digestive tract irritation
  - Most birds affected die unless there is human intervention

- Fauna:
  - limits photosynthesis of marine plants and phytoplankton since less light penetrates into the water → less fauna populations → affects food-chain

- Air pollution due to oil evaporation
  (depends on the type of oil)
Introduction

Possibilities for cleaning

- Booms that float on the water to prevent further dispersal
- Oil skimmers: machine that can separate and remove oil floating on water
- Bioremediation: microorganisms or biological agents to break down or remove oil
- Controlled burning (disadvantage: causes air pollution)
- ...
Introduction

Largest oil spills

<table>
<thead>
<tr>
<th>Spill / Tanker</th>
<th>Location</th>
<th>Date</th>
<th>Tons of crude oil</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gulf War oil spill</td>
<td>Persian Gulf</td>
<td>January 23, 1991</td>
<td>780,000–1,500,000</td>
</tr>
<tr>
<td>Ixtoc I oil well</td>
<td>Gulf of Mexico</td>
<td>June 3, 1979–March 23, 1980</td>
<td>454,000–480,000</td>
</tr>
<tr>
<td>Atlantic Empress</td>
<td>Trinidad and Tobago</td>
<td>July 19, 1979</td>
<td>287,000</td>
</tr>
<tr>
<td>Fergana Valley</td>
<td>Uzbekistan</td>
<td>March 2, 1992</td>
<td>285,000</td>
</tr>
<tr>
<td>Nowruz Oil Field</td>
<td>Persian Gulf</td>
<td>February 1983</td>
<td>260,000</td>
</tr>
<tr>
<td>ABT Summer</td>
<td>700 nautical miles (1,300 km) off Angola</td>
<td>May 28, 1991</td>
<td>260,000</td>
</tr>
</tbody>
</table>
Oil characteristics

“Oil” is a very broad term may be a variety of different materials: crude oil, refined petroleum products (such as gasoline or diesel fuel) or by-products, ships' bunkers, oily refuse or oil mixed in waste.

The various types of oil differ from each other in their viscosity, volatility, and toxicity.

- Viscosity: how resistant the oil is to flow
- Volatility: how quickly oil evaporates into the air
- Toxicity: how poisonous/toxic the oil is to organisms/people

Based on these characteristics, oil types can be classified into different categories.
## Oil characteristics

### Oil types

<table>
<thead>
<tr>
<th>TYPE 1: Very Light Oils (Jet Fuels, Gasoline)</th>
<th>TYPE 3: Medium Oils (Most crude oils)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Highly volatile (evaporates within 1-2 days)</td>
<td>About 1/3 may evaporate within 24 hours</td>
</tr>
<tr>
<td>High concentrations of toxic compounds</td>
<td>Oil contamination can be severe and long-term</td>
</tr>
<tr>
<td>Localizes, severe impacts to water/intertidal resources</td>
<td>Impacts to waterbirds and fur-bearing mammals can be severe</td>
</tr>
<tr>
<td>No cleanup possible</td>
<td>Cleanup most effective if done quickly</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>TYPE 2: Light Oils (Diesel, No. 2 Fuel Oil, Light Crudes)</th>
<th>TYPE 4: Heavy Oils (Heavy Crude, No. 6 Fuel, Bunker C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moderately volatile; will leave residue</td>
<td>Heavy oils with little or no evaporation or dissolution</td>
</tr>
<tr>
<td>Moderate concentrations of toxic compounds</td>
<td>Heavy contamination of intertidal areas</td>
</tr>
<tr>
<td>Long-term contamination potential for intertidal resources</td>
<td>Severe impacts to waterbirds and fur-bearing mammals</td>
</tr>
<tr>
<td>Cleanup can be very effective</td>
<td>Long-term contamination of sediments</td>
</tr>
<tr>
<td></td>
<td>Weathers very slowly</td>
</tr>
<tr>
<td></td>
<td>Shoreline cleanup difficult under all conditions</td>
</tr>
</tbody>
</table>

Source: NOAA, 2009

Oil types 3/4 can be detected on SAR data more easily than types 1/2.
Oil spill detection with radar remote sensing

- Waves and roughness on the water surface can reflect radar energy back to the sensor, which may result in a certain "brightness" of the ocean surface.

- Oil on the sea surface dampens waves and roughness on the water surface of the ocean. The energy reflected back to the sensor is therefore lower and the amount of specular reflection higher.

- The presence of an oil spill can be detected as an area which appears "darker" than the surrounding water surface.
Oil spill detection with radar remote sensing

Factors that influence the detection of oil spills:

- SAR-related factors:
  - wavelength
  - polarization
  - revisit interval
  - incidence angle

- Environmental factors:
  - type of oil (Type 1 < Type 4)
  - presence of wind/waves
  - size/ dispersion of oil spill
  - presence of look-aikes
Oil spill detection with radar remote sensing

**SAR-related factors:**

- **Polarization:** Contrast between oil spills and surrounding water usually higher in VV-polarization than in HH-polarization (note: Radarsat-1 is only HH)

- **Wavelength:** C-band (e.g. Envisat ASAR) and X-band primarily suitable for oil spill detection. L-band less suitable.

- **Temporal resolution:** New X-band sensors (TerraSAR-X, Cosmo-SkyMed) provide up to daily revisit capabilities
Oil spill detection with radar remote sensing

- Look-alikes – phenomena easily confused with oil spills:
  - low wind situations
  - wind sheltering by land
  - natural films (e.g. by planctonic species)
  - algae
  - rain cells
  - grease ice (depends on wavelength)
  - ...

- additional parameters or expert knowledge required to separate oil spills from look-alikes
UKRAINE - Oil Spill in the Kerch Strait - November 16, 2009

Interpretation:

A ship is reported to have polluted the Kerch Strait with an oil spill. The image shows the extent of the pollution as of November 16, 2009. The spill has spread along the coast, affecting a significant area.

Data Sources:

Temple Bar Imaging Services (MBM) 2009

For more information visit:
http://www.templebar.de
Ship accident in Antarctica: MV Ushuaia runs aground - Situation on December 6/7, 2008

Small oil spill (300x50m) reported on December 4, 2008.
Ship could be detected on TerraSAR-X data of 6 December, but no oil spill.

Possible reasons:
> type of oil (light marine gasoil)
> quick dispersal through wind and waves
Oil spill caused by MV Explorer, which hit an iceberg on 23/11/07.

Two days after the sinking, a 5 km² area of sheen was observed in the vicinity of the sinking location.

→ Slow and steady release of fuel from tanks onboard the vessel.
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Antarctic mainland, wind shelter on ocean

TS-X, Stripmap, VV, 29/11/07
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low backscatter areas less wind/waves due to iceberg?

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Oil spill found near location of sunken vessel.

Size: approx. 0,3 x 2 km

Separation from other dark patches not possible through backscatter alone, but by its shape, relatively clear border and contextual information

TS-X, Stripmap, VV, 29/11/07
Methods for oil spill detection using radar data

- Strategies for separating oil spills from look-alikes:
  - Expert knowledge: human interpreter assigns confidence level to potential oil spill
  - Acquire additional parameters of external conditions and incorporate them in the algorithm:
    - wind speed and direction
    - contextual features (e.g. distance to coastline, distance to other dark features)
    - features of the “dark spot”: geometry and shape, texture (e.g. homogeneity)
Methods for oil spill detection using radar data

Core modules of an oil spill detection and classification algorithm

- SAR image
- Region selection / dark spot detection
- Feature extraction
- Oil spill and look-alike classification
- Warnings on suspicious slicks

Thresholding/Segmentation (bimodal histogram?), wavelets (edge detection), fuzzy clustering (for unsharp boundaries), etc.

Compute object features for each slick: area, geometry, textural/statistical information, contrast to background, number of neighboring spots, distance to other detected spots or features, etc.

Used to distinguish oil spills from other dark areas by combining extracted features and ancillary data (wind speed, etc.):
  - Statistical classifiers/probability models, ANN, etc.

after Brekke & Solberg 2005 (modified)
Thank you for your attention!

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