Monitoring Alaskan Waters with SAR
Theory and Practice

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Presentation Outline

- Alaska Satellite Facility
- ERS-2 and RADARSAT-1
- NRT for NIC and NOAA
- SAR Fundamentals
- Marine Monitoring
  - Ice Analysis
  - Wind Retrieval
  - Atmospheric Effects
  - Ocean Features
  - Oil Spill Detection
  - Ship Detection
- Future Sensors
Alaska Satellite Facility (ASF)

- Operated by the Geophysical Institute (University of Alaska Fairbanks)
- NASA Ground Network Station and member of the NASA DAAC Alliance
- ASF operates on a 24x7 schedule
  - 3,000 Level 0 products per year
  - 45,000 Level 1 products per year
- U.S. Order Desk for customers of RADARSAT-1 and ERS-2
- Operational SAR support for NOAA and the National Ice Center (NIC)
  - 40 NRT products daily
RADARSAT-1

- Canadian Space Agency
- Launched 1995
- 3200 kg
- 5.66 cm (C-Band)
- HH Polarization
- 50 – 500 km swath
- 24 day Repeat Cycle
- 28min/orbit On-time
- On-board recorder
- 14.3 orbits/day
- Dawn/Dusk Orbit
ERS-2

- European Space Agency
- Launched 1995
- 2400 kg
- 5.66 (C-Band)
- VV Polarization
- 100km swath
- 35 day Repeat Cycle
- No On-board recorder
- 14.3 orbits/day
- 10:30AM Orbit
ASF Receiving Ground Station

Coverage:
- Gulf of Alaska
- Bering Sea
- Chukchi Sea
- Beaufort Sea

ASF Receiving Mask
SAR Coverage of the Bering Sea

Three-Day, RADARSAT-1 Coverage
- Ascending and Descending Swaths
- ScanSAR Wide B (460 km swaths)

Frequency for complete coverage of the Bering Sea

Three times per week
14 passes per cycle

Five times per week
15 passes per cycle

Six times per week
20 passes per cycle
Close coordination with the U.S. Coast Guard
• Acquisition Planning
• NRT processing
• Conversion to GeoTIFF
• Push to ftp site
• ASF’s NRT SAR images assist ship navigation

• Annotated RADARSAT-1 image from NIC identify fuel-saving ice leads
But for other applications, we need some Physics......
Microwave Interactions

What does SAR see?

Hurricane Ivan
Microwave Interactions

What does SAR see?

• surface roughness of the water

Fortunately, oceanographic and atmospheric phenomena modulate the surface roughness

Hurricane Ivan
Smooth Surfaces: Angle of incidence equals the angle of reflection (specular reflection)

Rough Surfaces: Reflection diminishes with increasing Incidence Angle
SAR Fundamentals
- Scattering Mechanisms -

Diffuse Reflection  Specular Reflection  Corner Reflector
SAR Fundamentals
- Scattering Mechanisms -

- Waves
- Smooth Water
- Hard Targets
Primary source of Ocean surface roughness:
Gravity-capillary Waves

Wind generated
Wavelength - order of 1 cm
Waves get modulated by:
  • tilt modulation,
  • hydodynamic modulation
  • velocity bunching

Modulation can indicate:
  • Changing wind speed
  • Oil spill
  • Other surfactants
  • Upwelling
  • Currents
  • Bathymetry
SAR Fundamentals
- Bragg scattering

Primary mechanism for backscattering SAR:
Bragg Scattering off wind-generated gravity-capillary Waves

\[ \lambda_s = \frac{\lambda_r}{2 \sin \theta} \]

where:
- \( \lambda_r \): radar wavelength
- \( \lambda_s \): sea surface wavelength
- \( \theta \): incidence angle
SAR Fundamentals
- Polarization -

Horizontal Transmit
Horizontal Receive

Vertical Transmit
Vertical Receive

HH
HV
VV
VH
C Band Microwaves
- ERS-1,2, RADARSAT-1, EnviSat
- 5 cm wavelength
- Good for Bragg scattering
- Choice for ocean monitoring
- Shallow penetration into ice

L Band Microwaves
- JERS-1, ALOS
- 20 cm wavelength
- Poor Bragg scattering match
- Choice for land monitoring
- Deeper penetration into ice
Observing Sea Ice with SAR

- To date: C-band, HH polarization deemed best
- Incidence Angle dependence should be corrected (Ice Look-up Table)
- Low wind conditions permit better water/ice discriminations
- Signal Strength and Context provide clues to ice classification
- Analysis yields information on Ice concentration and age
- Attempts at automation have not been successful
  - However, dual polarization may change this
- Ice Analysis remains an Art as much as a Science
Sea Ice

Sea Ice and Grease Ice

Bering Sea
Sea Ice

Polyna and Sea Ice

St. Lawrence Is.

Prudhoe
Sea Ice

Ice Edge

Bering Sea near Aleutians

Sea Ice Leads

Arctic Ocean
Ice Charts

Representative Ice Charts Produced by NIC and NWS

http://www.natice.noaa.gov/

http://pafc.arh.noaa.gov/ice.php
Wind Retrieval

- Wind increases surface roughness, surface roughness increases radar backscatter

- Wind retrieval utilizes a semi-empirical formula (CMOD5) to yield high resolution ocean surface wind fields with sub-km resolution

- Scatterometers yield 25 km resolution, limited to open ocean
Wind Retrieval

- Retrieval of wind speed requires knowledge of:
  - Wavelength and polarization
  - Image geometry
  - Incidence angle
  - Normalized Radar Cross Section (NRCS)
  - Wind direction from:
    - analysis of Wind Streaks
    - weather model such as NOGAPS or MM5

- Wind retrieval valid for wind speeds of 3 - 35 m/s
- Wind speed accuracy (from buoy validation) is +/-1.6 m/s
- Wind retrieval accuracy limited by wind direction errors
Wind Retrieval

Quasi-Operational program developed under NOAA/NESDIS-sponsored Alaska SAR Demonstration (AKDEMO)

APL/NOAA SAR Wind Retrieval System (ANSWRS) now operates at NOAA/NESDIS, JHU/APL, ASF, and U of Miami CSTARS
Wind Retrieval

- ASF web page for wind products
- NRT winds
- Archive Data
- Updated software from JHU Applied Physics Laboratory
- Google .kmz files now available

http://wind.asf.alaska.edu/windspeed/sar_web/
Wind Retrieval

Google .kmz files support wind data on Google Earth

- Intuitive geospatial tool
- Available free to public
- Provides wind in geographic context

But, as with all SAR winds, results are confounded by ice!
Wind Retrieval
Most atmospheric phenomena that extend to the ocean surface can be observed with SAR. Only requirement is that the phenomena modulate the surface roughness.
Atmospheric Effects

Atmospheric Fronts

Gulf of Alaska

Bering Sea

CSA © 1998

CSA © 1998
Atmospheric Effects

Atmospheric Lee Waves

St. Lawrence Is.

Vortex Streets

Aleutians
Atmospheric Effects

Polar Low

Convection Cells

Gulf of Alaska

Bering Sea
Atmospheric Effects

Wind Rows

Bering Sea

Wind Shadows

Cook Inlet
Observing Ocean Features With SAR

- Observation of ocean features limited to wind regime of 3-13 m/s
  - Limited return from lower wind speed
  - Ocean features dominated by wind at higher wind speeds

- Modulation of the surface roughness via “stretching of waves”, tilt modulation, hydrodynamic effects, and velocity bunching can highlight:
  - Long surface waves
  - Internal waves
  - Upwelling
  - Currents and Eddies
  - Current changes caused by changing bathymetry

- Ocean features can confound wind speeds during wind retrieval
Ocean Features

Long Surface Waves from Local Winds and Storm Events

Middleton Is.  
San Francisco Bay
Ocean Features

Diffraction and Refraction of Surface Waves

Santa Barbara Is.  Point Reyes Beach
Ocean Features

Dipole Eddies

Oceanic Eddy

St. Matthew Is.

Gulf of Alaska
Ocean Features

Currents and Small-scale Eddies

Southern California
Ocean Features

Bathymetric Effects

Kuskokwin Bay
Slick Detection

- Surfactants change surface tension and suppress capillary waves
  - Wind required for detection
  - Lower backscatter by 10dB

- Slick sources include:
  - Oil spills
  - Illegal bilge dumping
  - Natural hydrocarbon seeps – use to find oil
  - Storm water discharge
  - Biogenic sources
Slick Detection

- Optimal detection requires:
  - Wind speed of 3-12 m/s
  - Small incidence angle
  - VV polarization

- Automated Detection method includes:
  - Adaptive threshold detection
  - Feature Analysis (Linear or Blob)
Slick Detection

Storm Water Discharge

RADARSAT-1, 8 November 1998
ERS-1 SAR, 28 December 1992

Southern California
Slick Detection

Biogenic Slicks

Gulf of Alaska
Slick Detection

Illegal Bilge Dumping
Slick Detection

Accidents

Ship Collision off Sri Lanka

140 km long
1.5 - 7.5 km wide
Slick Detection

Oil Slick Shapes

Streaks

Blobs

Validating an oil spill:

- Probable shape and size
- Recurrence in images
- Proximity to shipping lanes or land
- Presence of feathering in edges
- Trajectory consistent with currents
- Identifiable source
Oil Spill Detection

Programs under development in U.S., Canada, Norway, Scotland

- ScanSAR acquisitions
- Oil Spill detection via:
  - full automation
  - semi-automated
  - visual inspection
- Initiate airborne surveillance
- Support prosecution of violators
Illegal Fisheries Monitoring

Monitoring illegal fisheries is a ship detection problem
Ship Detection

Fishing Fleet

Ship associated with wake
Detection of bright targets against ocean clutter:
- Improves with decreasing wind speed
- Improves with increasing incidence angle
- Improves with increasing ship length
- Improves with increasing resolution

Detection algorithms apply a pixel-based threshold according to clutter statistics and desired Constant False Alarm Rate (CFAR)

Impact of Polarimetry:
- Significant improvement in missed detects
- Possible improvement in ship classification

Automated Identification System (AIS) will permit correlation between detected targets and known ship data
Ship Detection

Impact of Resolution and Incidence Angle

Ship Detection Figure of Merit

![Graph showing the impact of resolution and incidence angle on ship detection.](image-url)
Ship Detection

Detection Results for Known Ship Locations and Lengths

Results for 25m pixels, 50m resolution

Ship must equal $\frac{1}{2}$ the resolution – Wackerman, et al.
Ship Detection

Improved Resolution permits Ship Identification

Wackerman, et. al.
Ship Detection

Role of Polarimetry in Ship Detection

Paris Vachon, et.al.
Ship Detection

Red: HH
Blue: VV
Green: (HV+VH)/2

CFAV Quest
76 m × 12.6 m

Paris Vachon, et.al.
Under NOAA/NESDIS, an automated system to detect ships in U. S. waters

SAR-derived ship information:
- Position
- Direction
- Length
- Speed
- Class

http://www.orbit.nesdis.noaa.gov/sod/mecb/sar/sarproducts.html
New Mission: ALOS

PALSAR: Phased Array type L-band Synthetic Aperture Radar

23.6cm Wavelength (L-Band)
Single, Dual, or Full Polarization
(HH, VV, HH+HV, VV+VH, HH+HV+VH+VV)
Fine Mode: 10m resolution/ 70km Swath
ScanSAR: 100m resolution / 350 km Swath
46 day Repeat Cycle
On-board recorder
14.6 orbits/day
10:30 AM Orbit

Available at: http://aadn.asf.alaska.edu/
New Mission: RADARSAT Constellation Mission

- Canadian Space Agency Mission
- 3+ Satellites in Constellation
- Goal of Operational Maritime Surveillance for detection of wind, oil, ships, icebergs

- Requirements:
  - Daily coverage of Canadian waters
  - 7 year lifetime
  - C-band, Dual polarization (HH and HV)
  - Low cost ($600M for three)

- Downlink to Svalbard, Esquimalt, Halifax, ASF?
New Mission: Sentinel Series

- European Space Agency Mission
- 2+ Satellites in Constellation
- First launch in 2011
- Support Operational Maritime Surveillance for detection of wind, oil, ships, sea ice
- Offer continuity for ERS and Envisat with enhanced revisit / coverage

- Requirements:
  - C-band
  - Selectable dual polarization (HH/HV or VV/VH)
  - Wide swath – 250 km
  - Daily coverage of Europe with 2 satellites
  - NRT in < 3 hours

- Collaborate with RADARSAT Constellation
Questions?