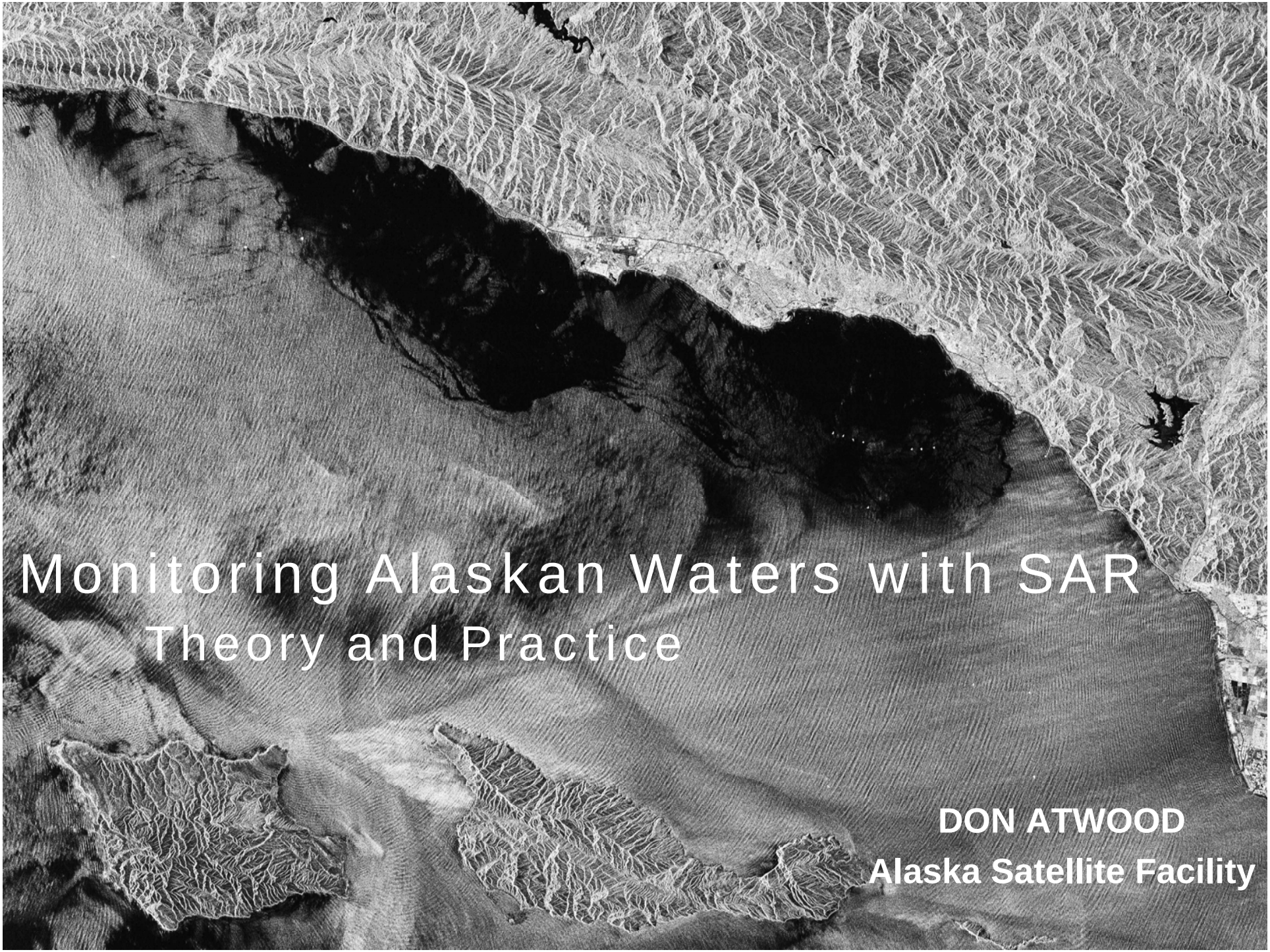


Monitoring Alaskan Waters with SAR

Theory and Practice

DON ATWOOD
Alaska Satellite Facility

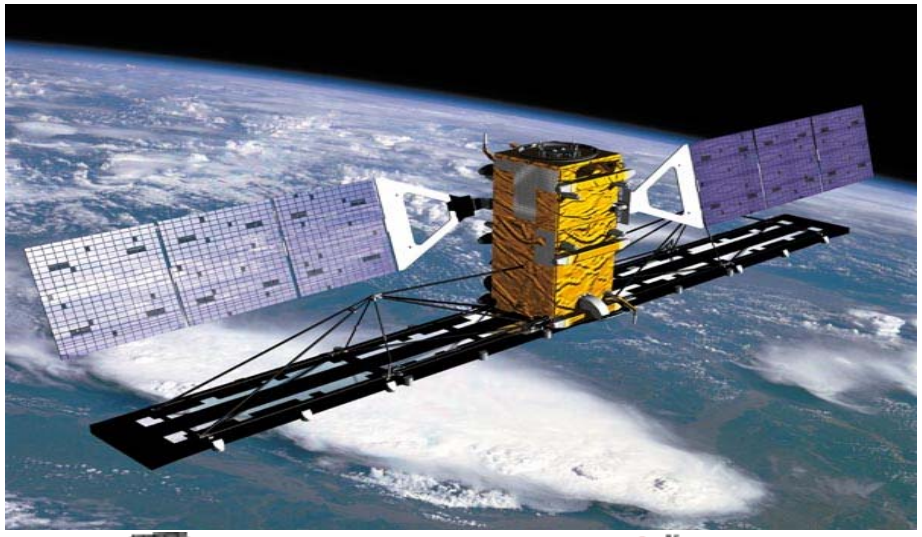
Presentation Outline

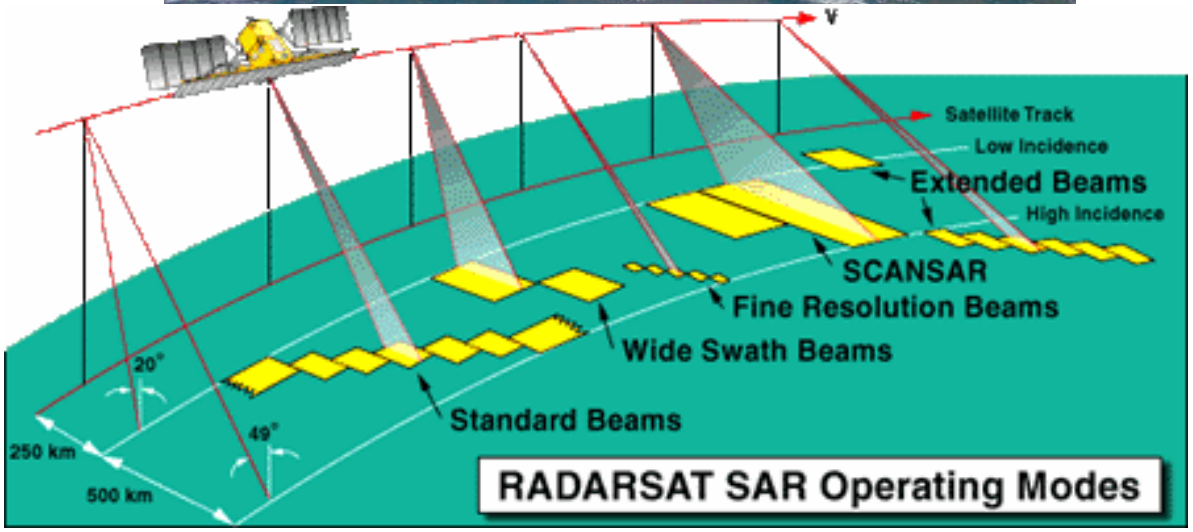
- Alaska Satellite Facility
- ERS-2 and RADARSAT-1
- NRT for NIC and NOAA
- SAR Fundamentals
- Marine Monitoring
    - Ice Analysis
    - Wind Retrieval
    - Atmospheric Effects
    - Ocean Features
    - Oil Spill Detection
    - Ship Detection
- Future Sensors

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



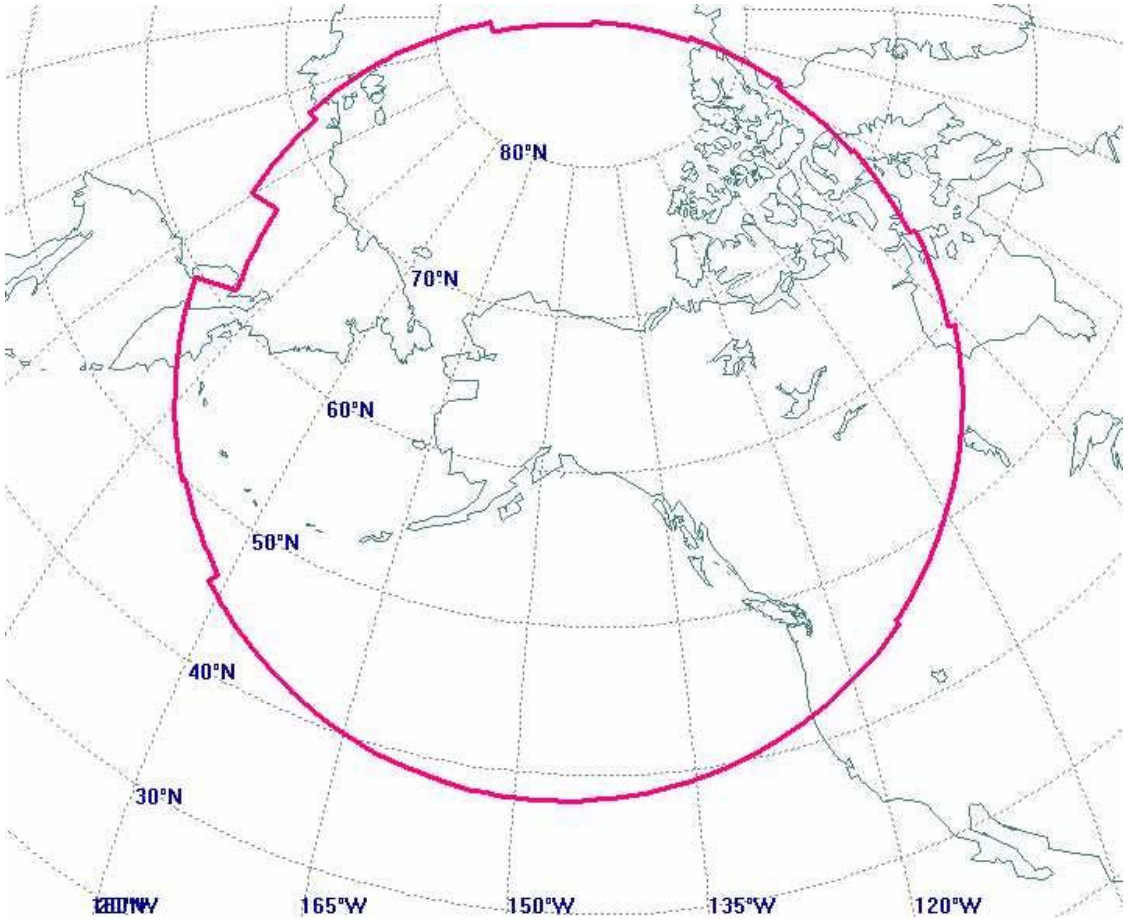


- Canadian Space Agency
- Launched 1995
- 3200 kg
- 5.66 cm (C-Band)
- HH Polarization
- 50 – 500 km swath
- 24 day Repeat Cycle
- 28min/orbit On-time
- On-board recorder
- 14.3 orbits/day
- Dawn/Dusk Orbit

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

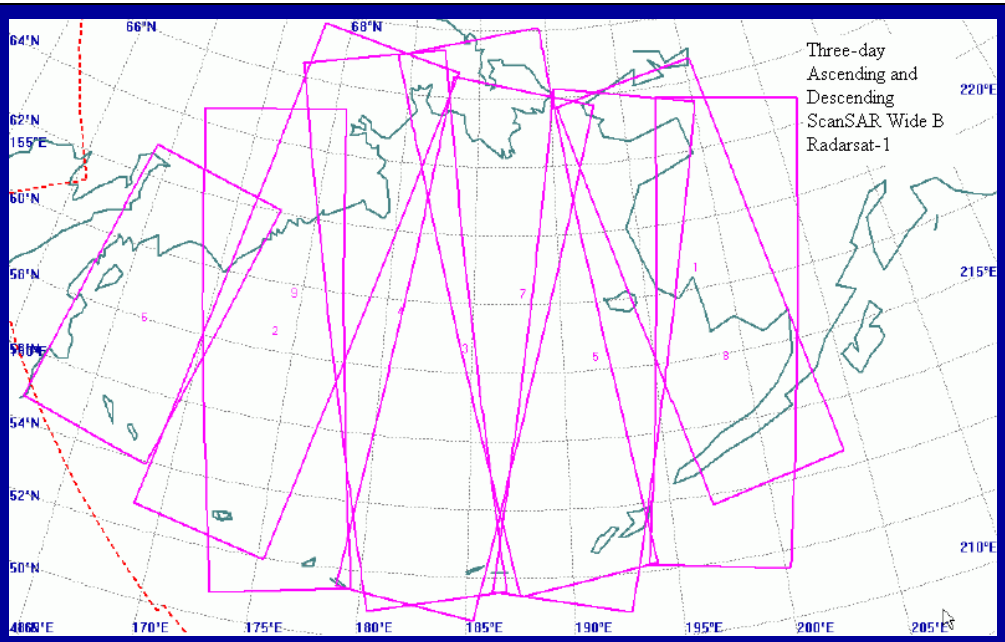


ASF Receiving Mask

Coverage:

- **Gulf of Alaska**
- **Bering Sea**
- **Chukchi Sea**
- **Beaufort Sea**

SAR Coverage of the Bering Sea



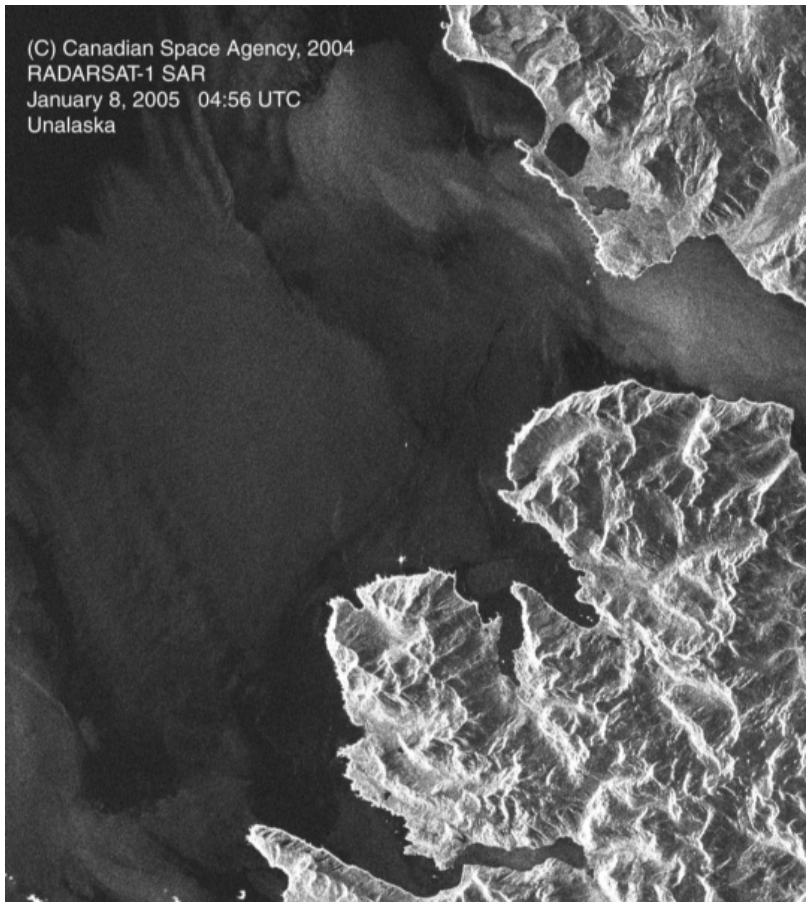
Three-Day, RADARSAT-1 Coverage

- Ascending and Descending Swaths
- ScanSAR Wide B (460 km swaths)

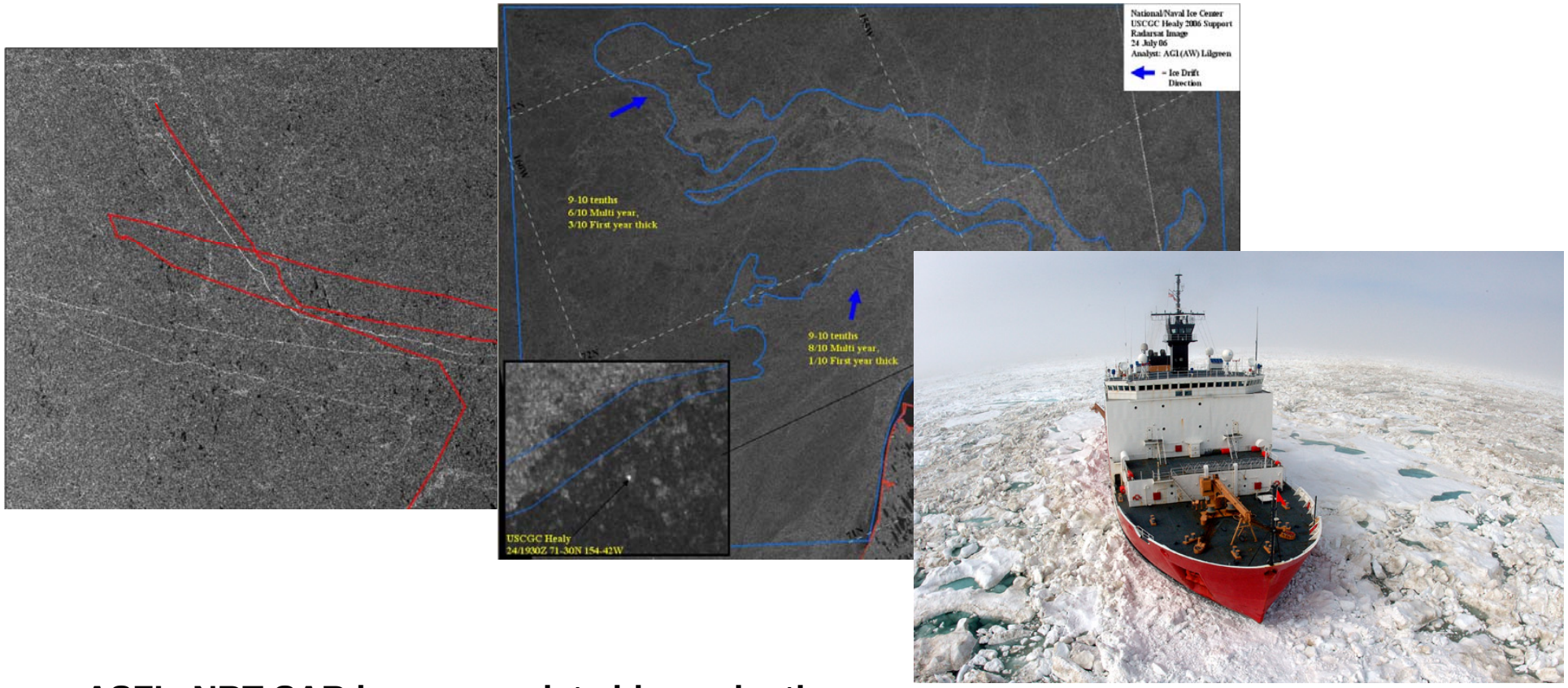
Frequency for complete coverage of the Bering Sea

Emergency Response
Selendang Ayu Incident

Close coordination with the U.S. Coast Guard
- Acquisition Planning
- NRT processing
- Conversion to GeoTIFF
- Push to ftp site

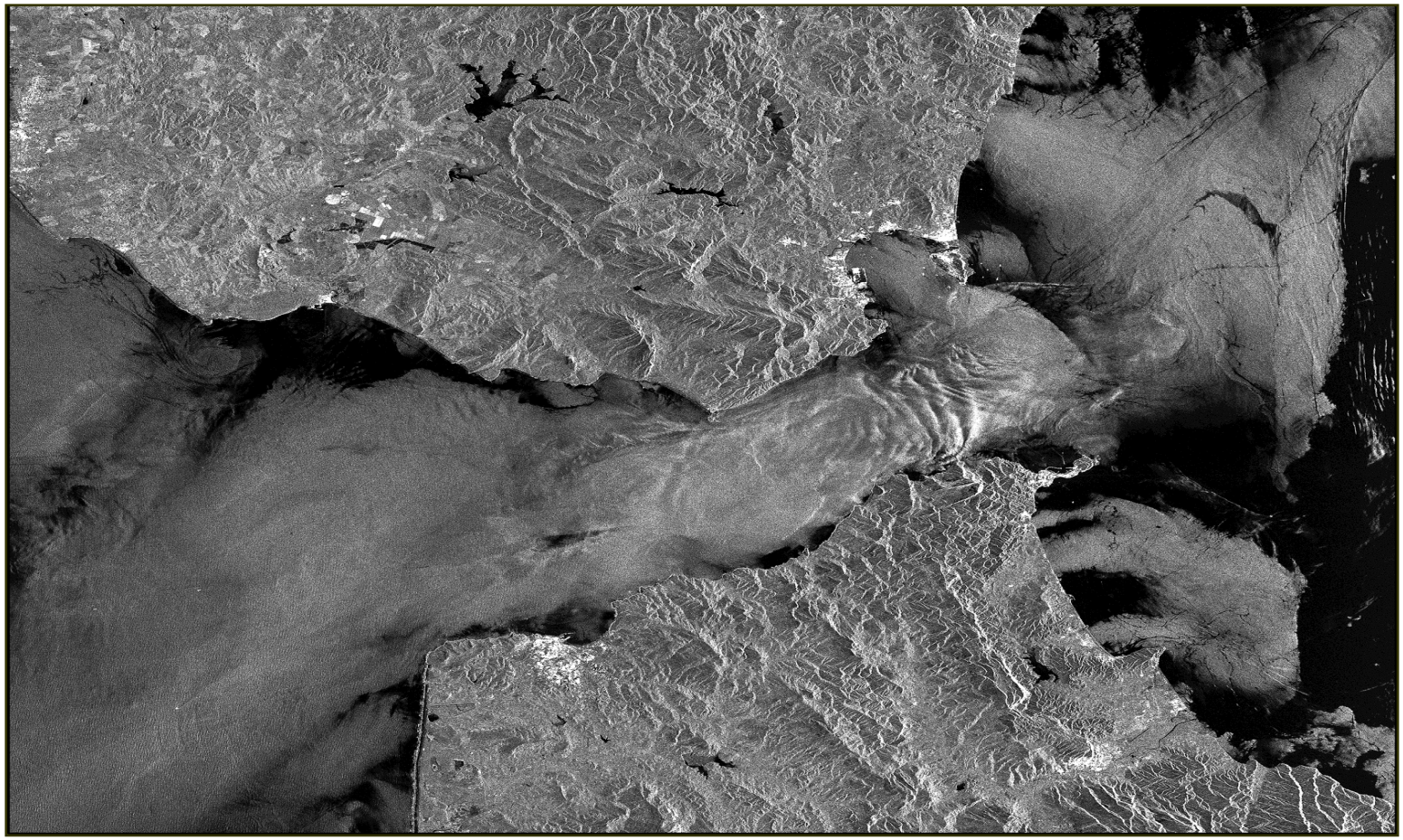


NRT Support
USCG Healy



- **ASF's NRT SAR images assist ship navigation**
- **Annotated RADARSAT-1 image from NIC identify fuel-saving ice leads**

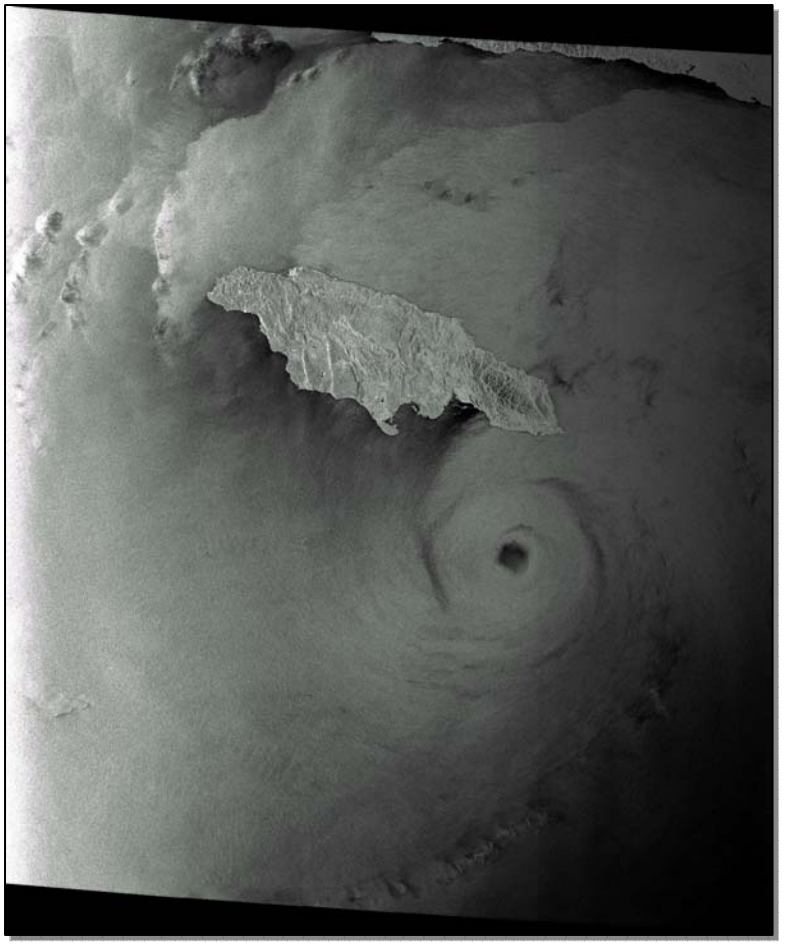
But for other applications, we need some Physics…….



Strait of Gibraltar

Microwave Interactions

What does SAR see?



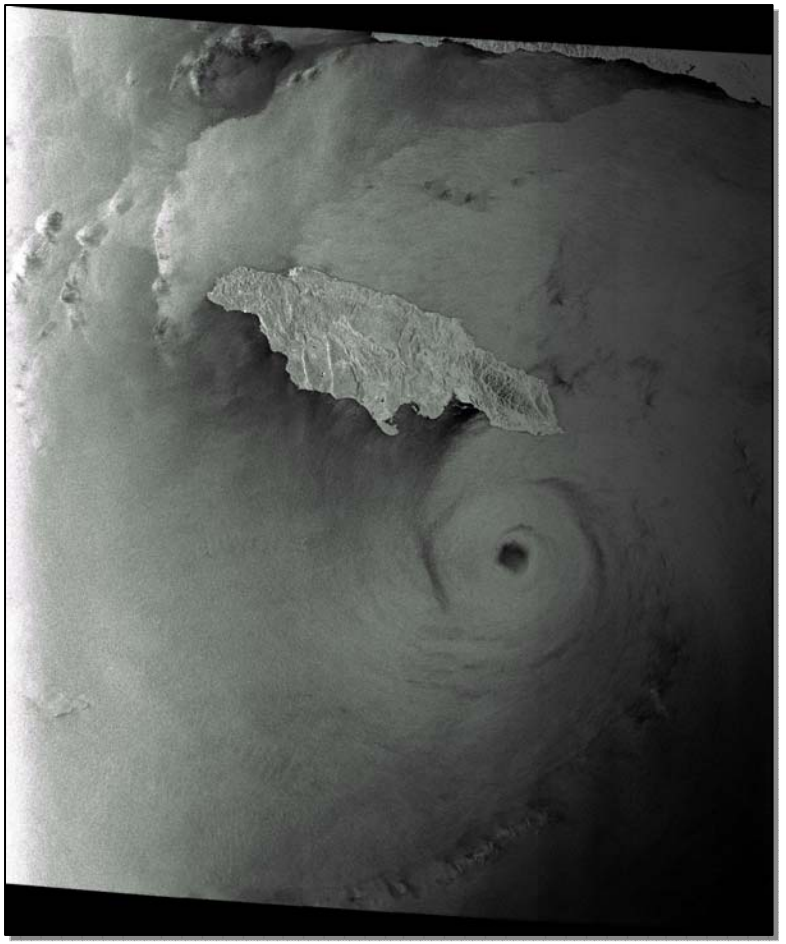
Hurricane Ivan

Microwave Interactions

What does SAR see?

- **surface roughness of the water**

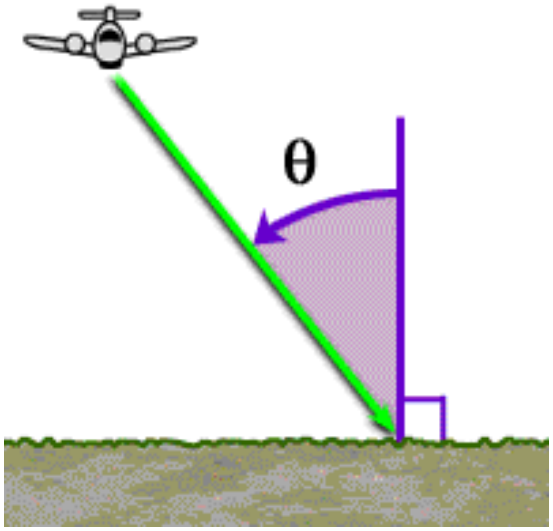
Fortunately, oceanographic and atmospheric phenomena modulate the surface roughness

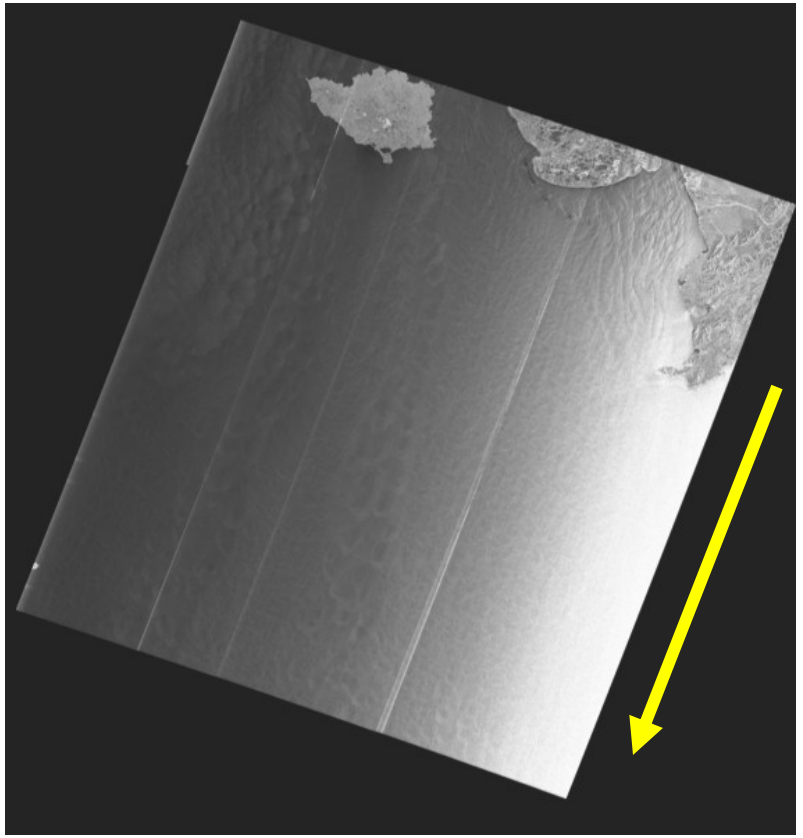


Hurricane Ivan

SAR Fundamentals
- Incidence Angle -

Incidence Angle

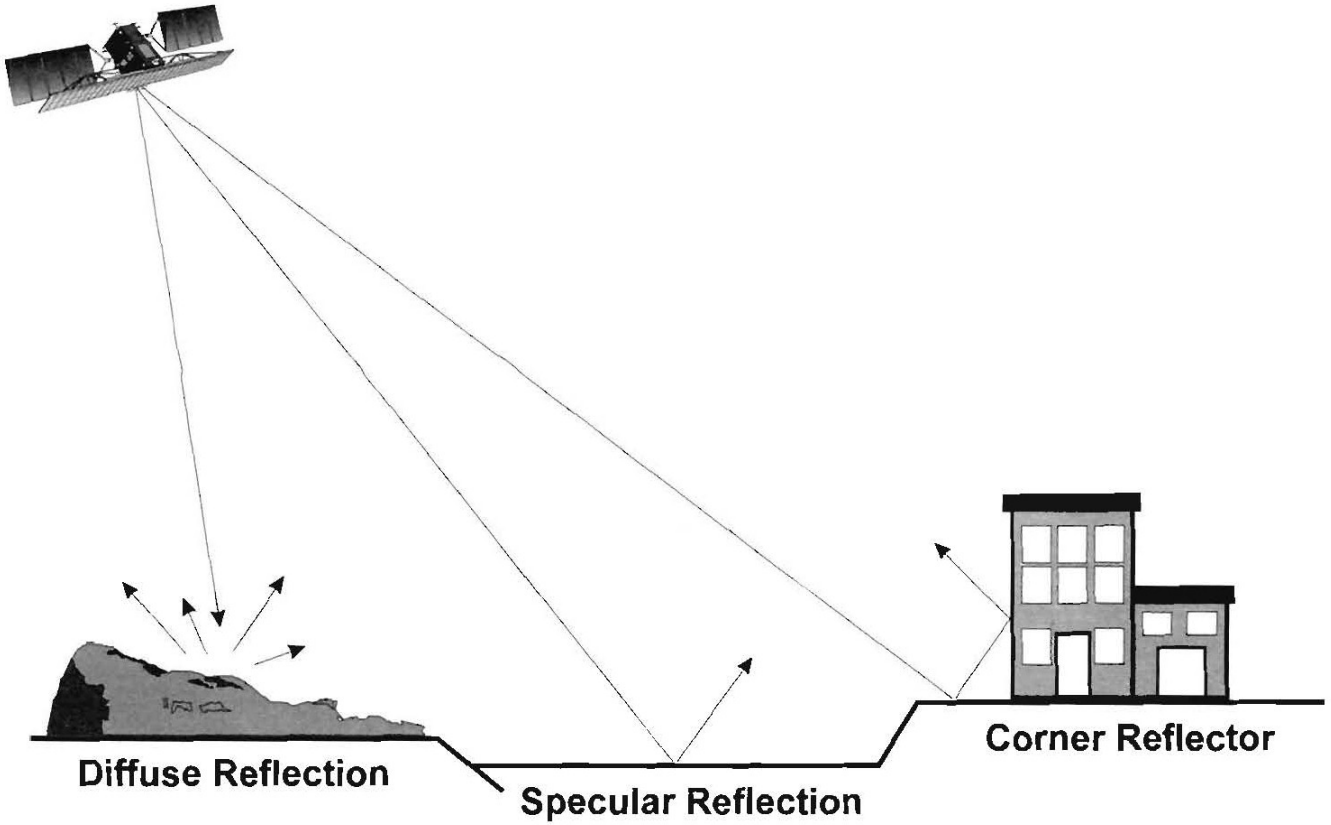




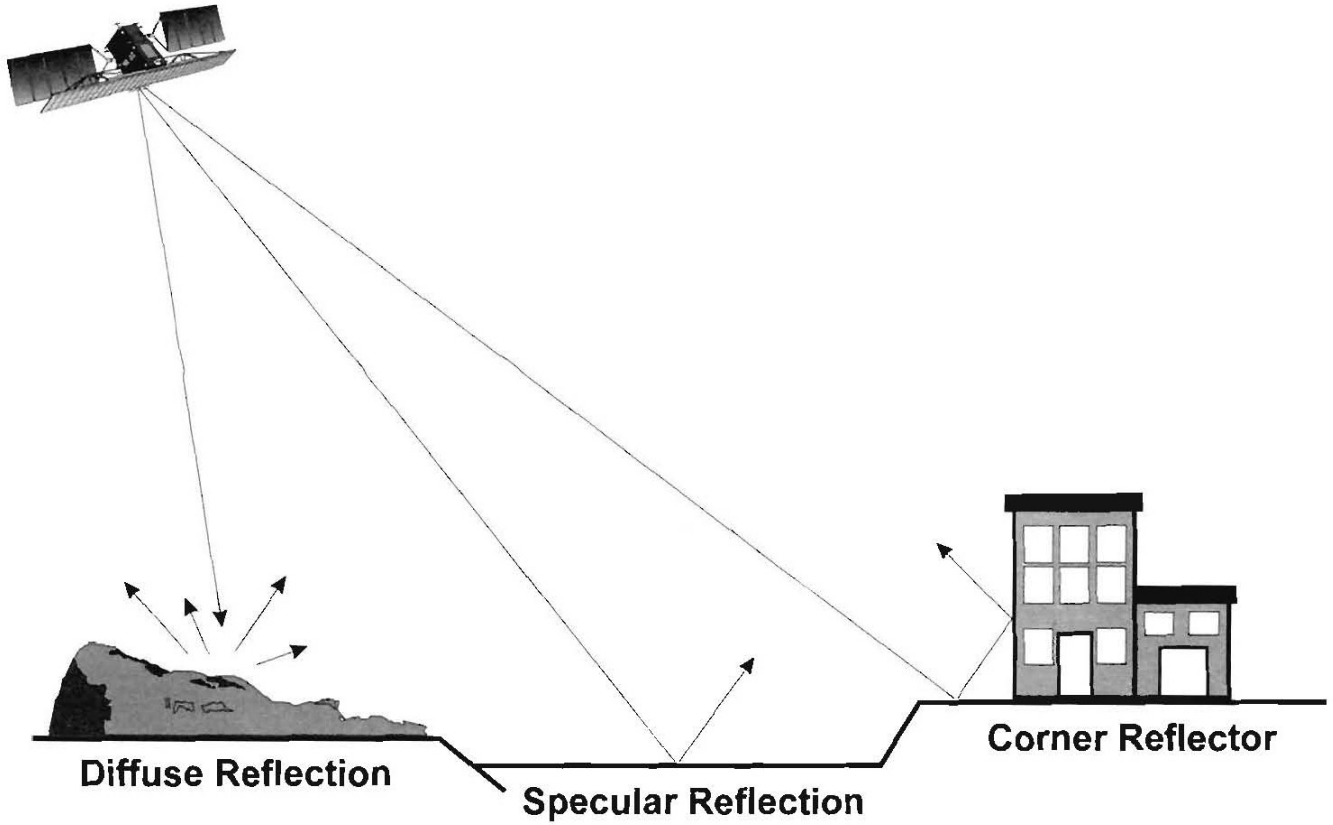
Smooth Surfaces: Angle of incidence equals the angle of reflection (specular reflection)

Rough Surfaces: Reflection diminishes with increasing Incidence Angle

SAR Fundamentals
- Scattering Mechanisms -



SAR Fundamentals
- Scattering Mechanisms -



Waves **Smooth Water** **Hard Targets**

SAR Fundamentals
- Surface Roughness

Primary source of Ocean surface roughness:
Gravity-capillary Waves

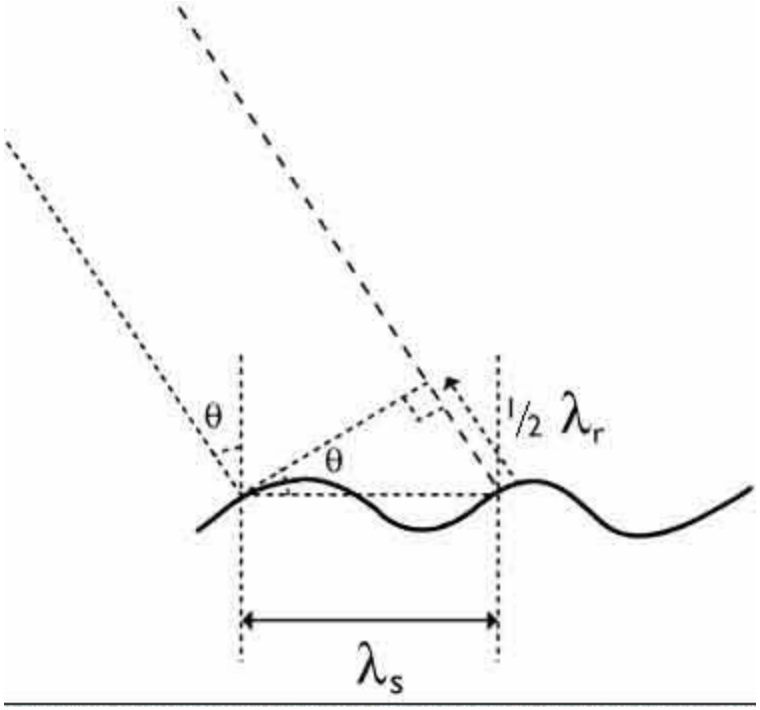
Wind generated
Wavelength - order of 1 cm
Waves get modulated by:
- tilt modulation,
- hydodynamic modulation
- velocity bunching

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:

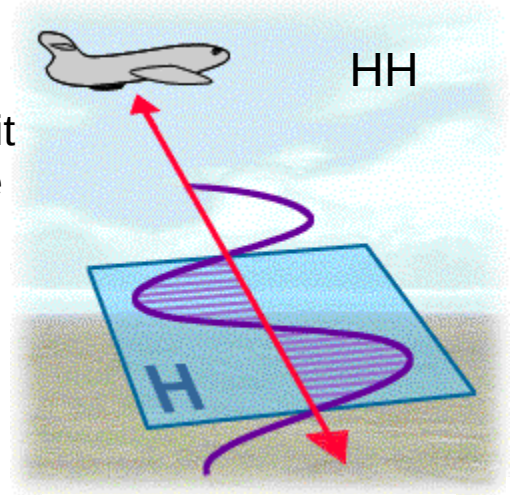
λ_r radar wavelength

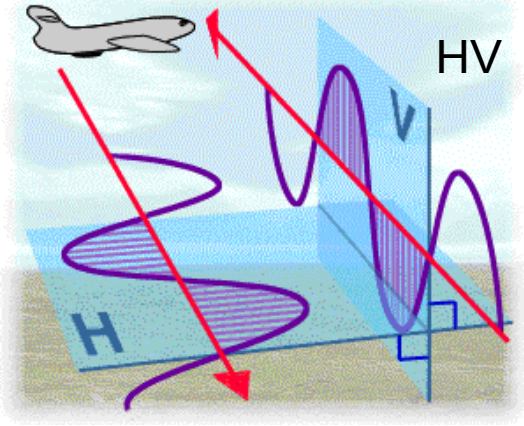
λ_s sea surface wavelenght

θ incidence angle

SAR Fundamentals
- Polarization -

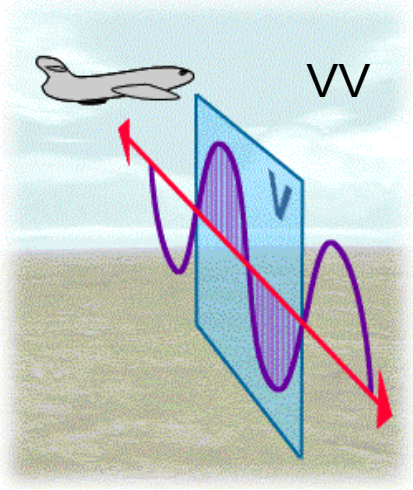
Horizontal Transmit
Horizontal Receive

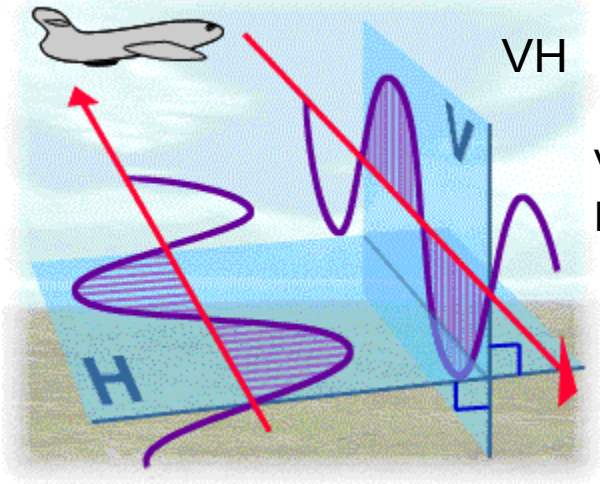




Horizontal Transmit
Vertical Receive

Vertical Transmit
Vertical Receive





Vertical Transmit
Horizontal Receive

SAR Fundamentals
- Wavelength -

C Band Microwaves

- ERS-1,2, RADARSAT-1, EnviSat
- 5 cm wavelength
- Good for Bragg scattering
- Choice for ocean monitoring
- Shallow penetration into ice

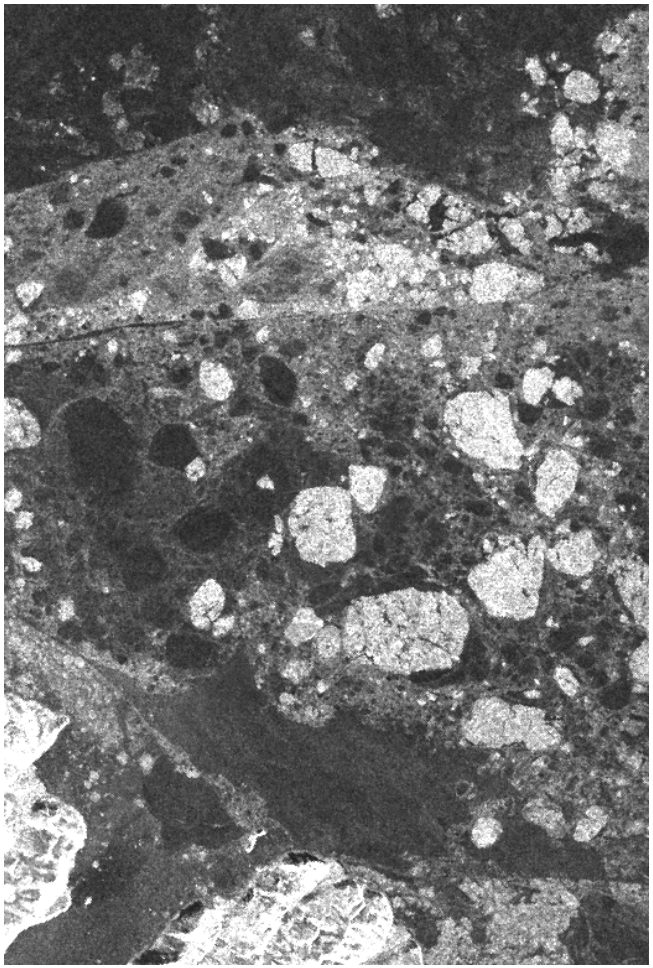
L Band Microwaves

- JERS-1, ALOS
- 20 cm wavelength
- Poor Bragg scattering match
- Choice for land monitoring
- Deeper penetration into ice

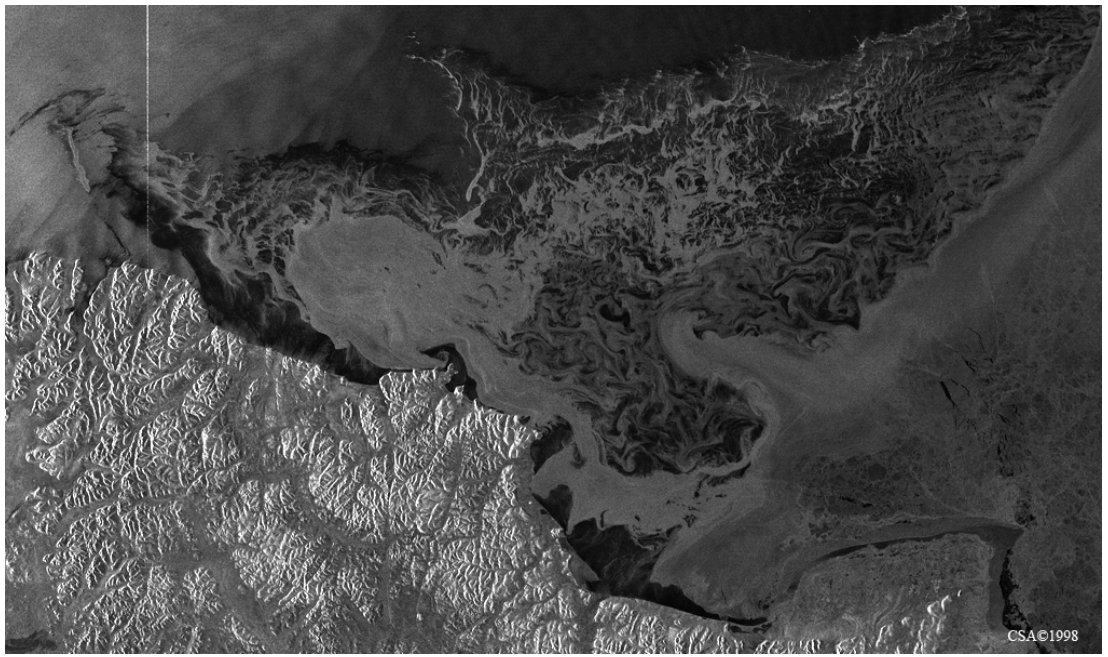
Observing Sea Ice with SAR

- 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



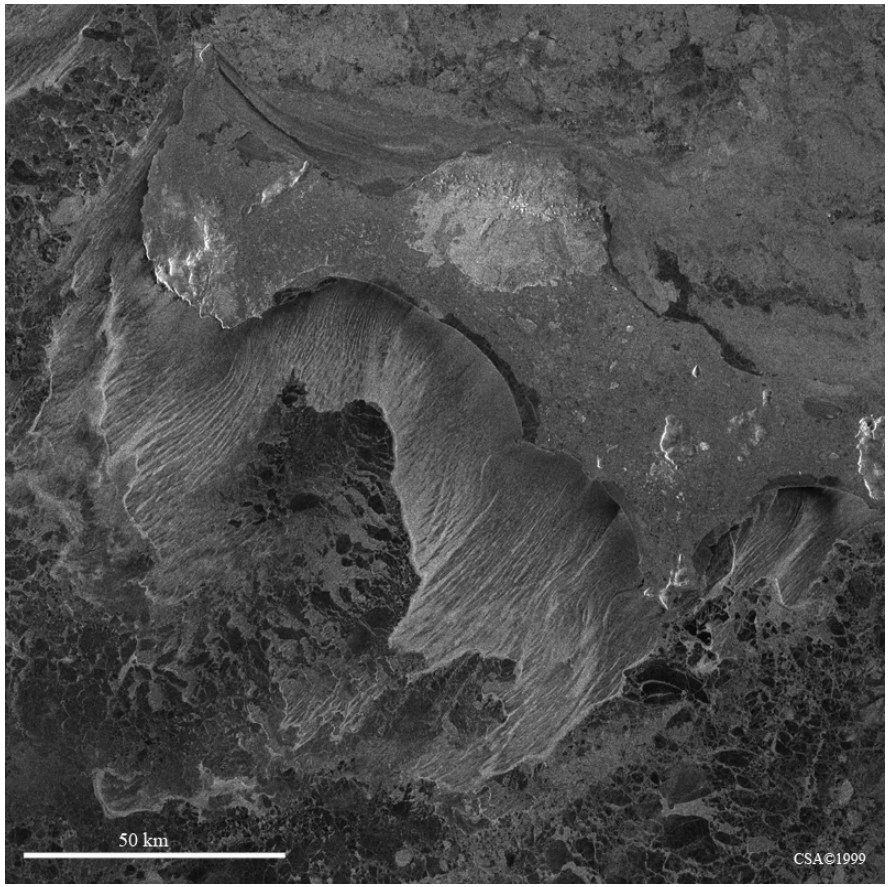
Sea Ice and Grease Ice



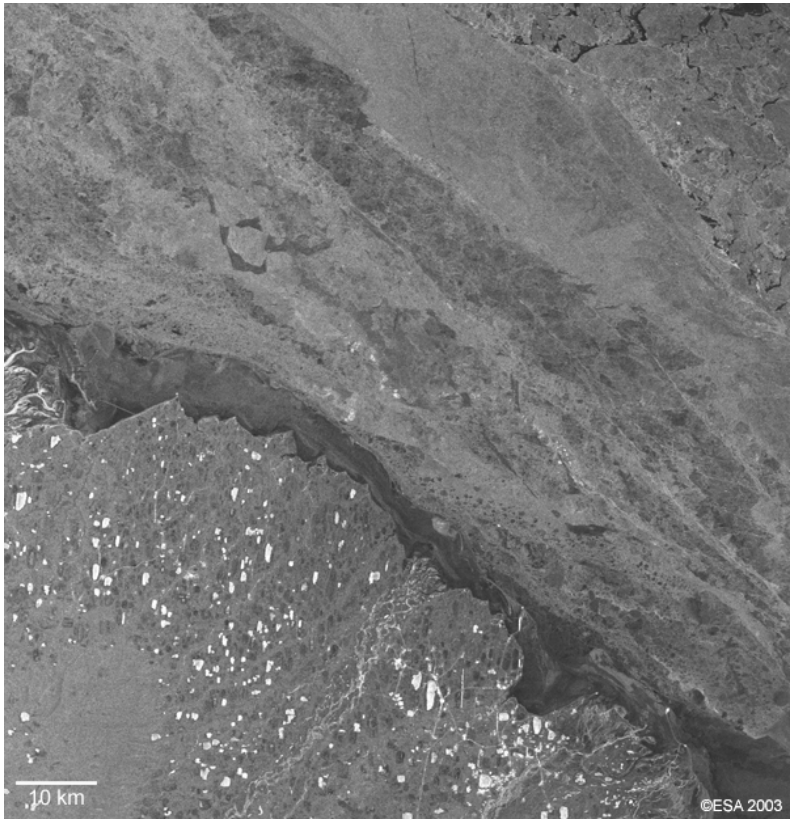
Bering Sea

Sea Ice

Polyna and Sea Ice



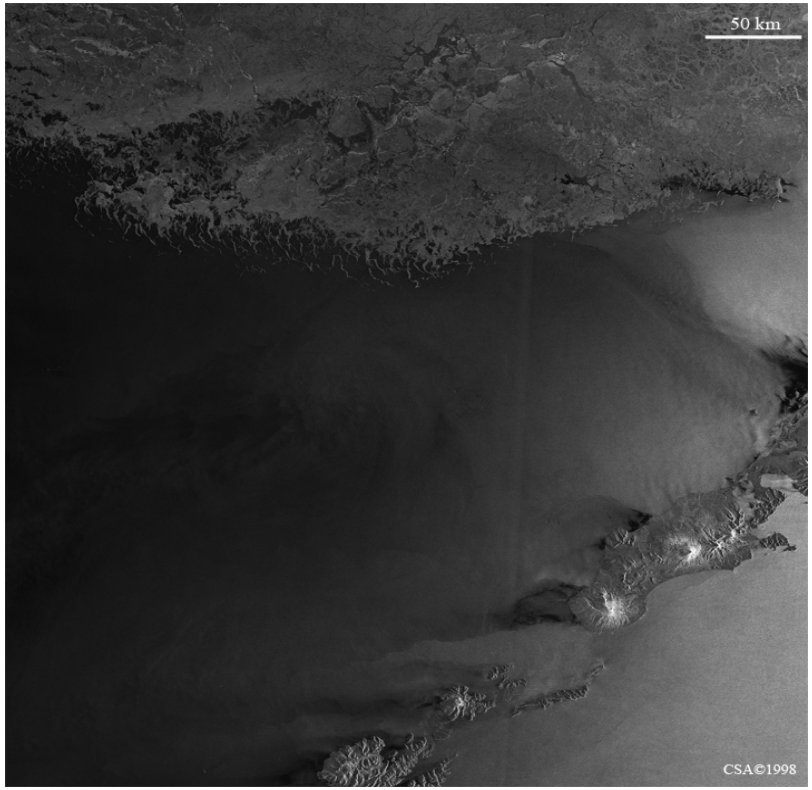
St. Lawrence Is.



Prudhoe

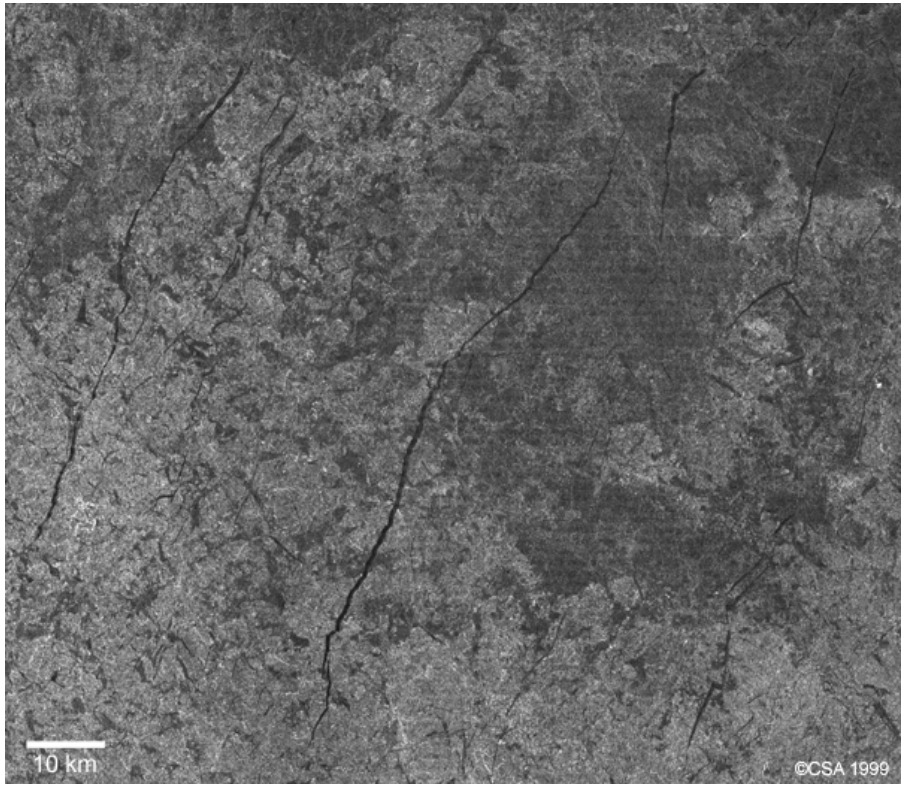
Sea Ice

Ice Edge



Bering Sea near Aleutians

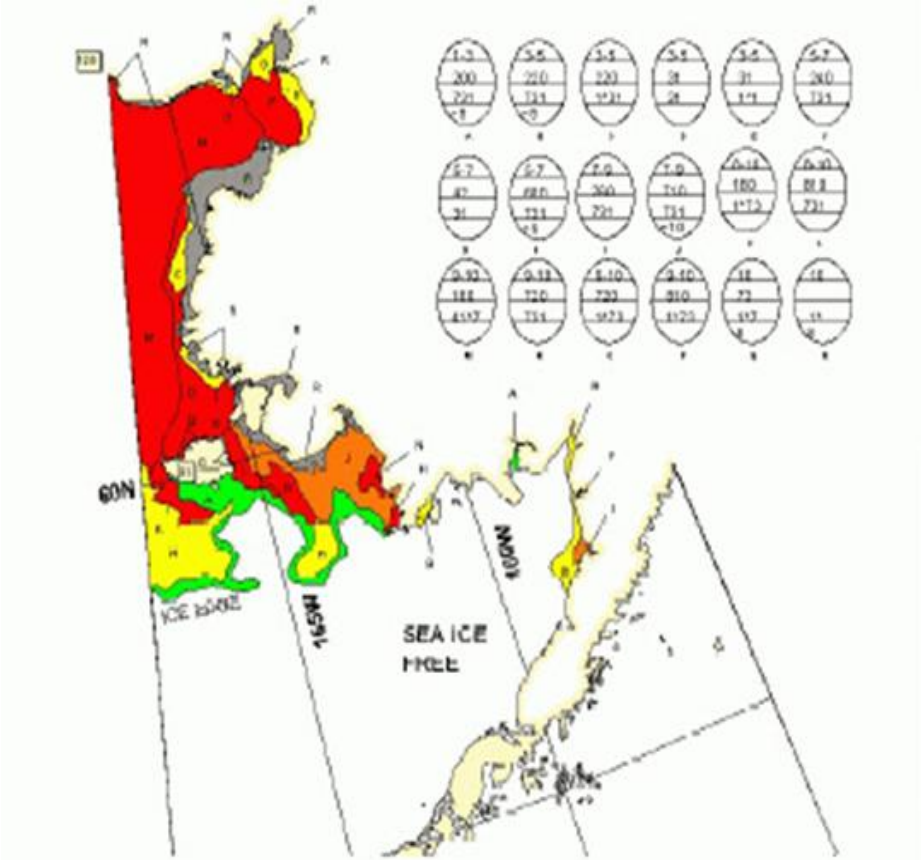
Sea Ice Leads



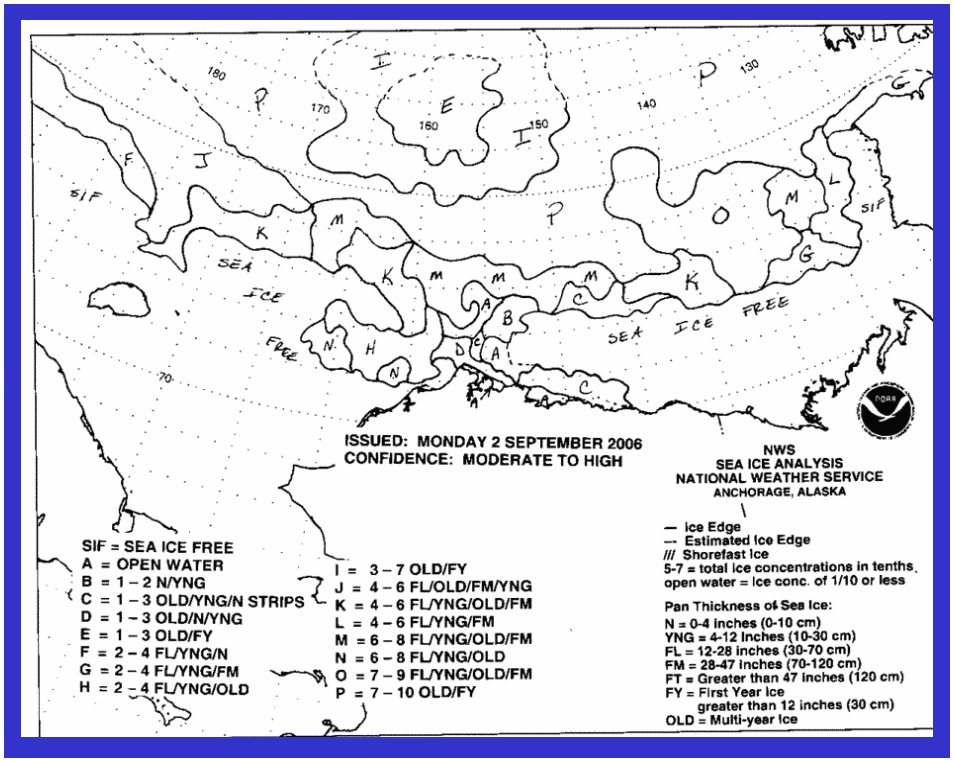
Arctic Ocean

Ice Charts

Representative Ice Charts Produced by NIC and NWS



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



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

Wind Retrieval

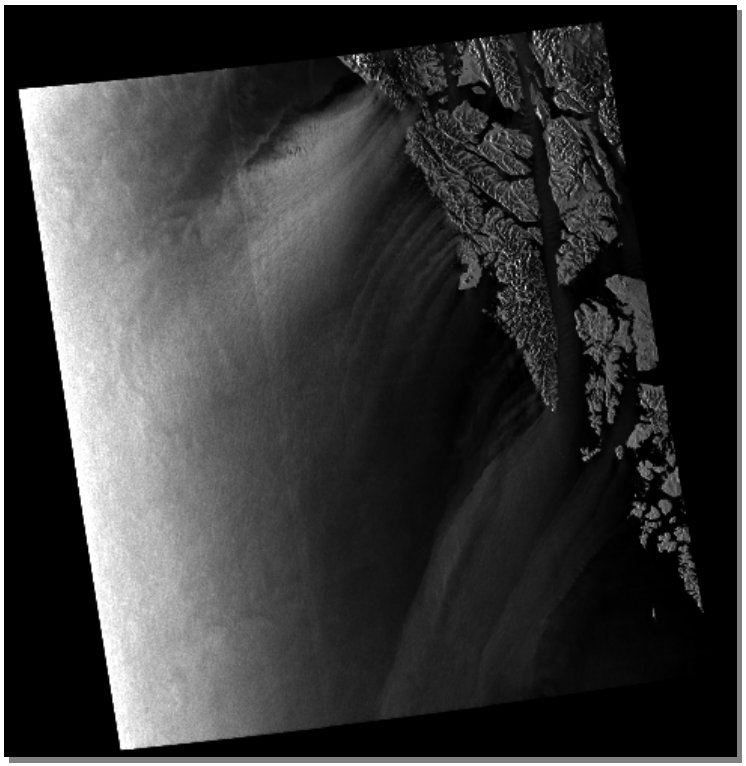
- Wind increases surface roughness, surface roughness increases radar backscatter
- Wind retrieval utilizes a semi-empirical formula (CMOD5) to yield high resolution ocean surface wind fields with sub-km resolution
- Scatterometers yield 25 km resolution, limited to open ocean

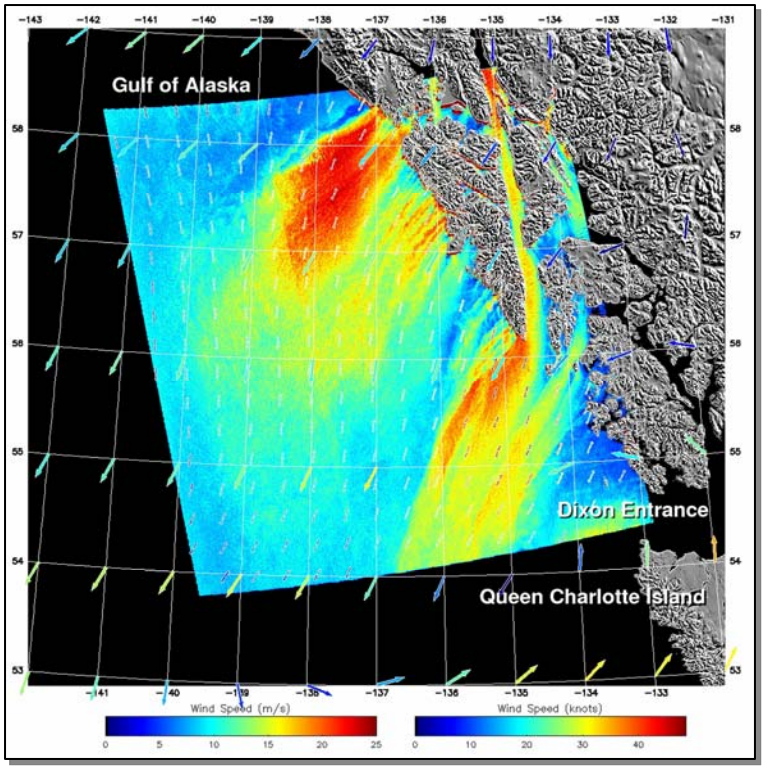
Wind Retrieval

- 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

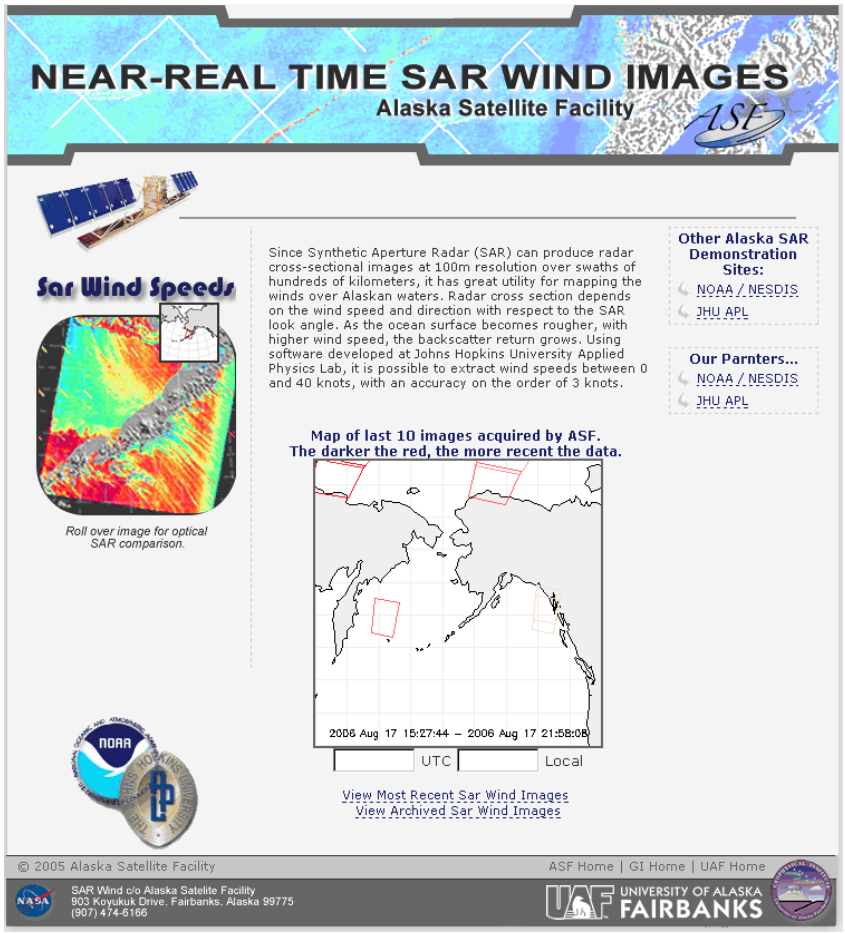




Quasi-Operational program developed under NOAA/NESDIS-sponsored Alaska SAR Demonstration (AKDEMO)

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

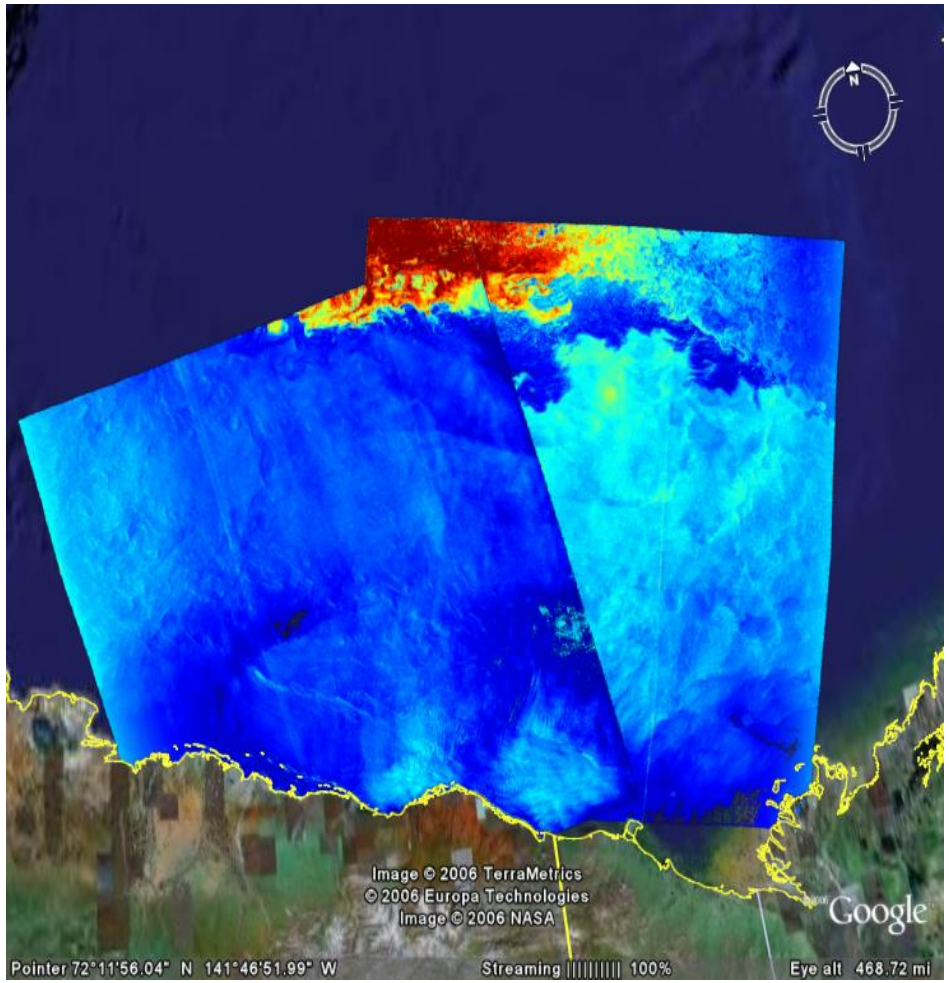
Wind Retrieval



- 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

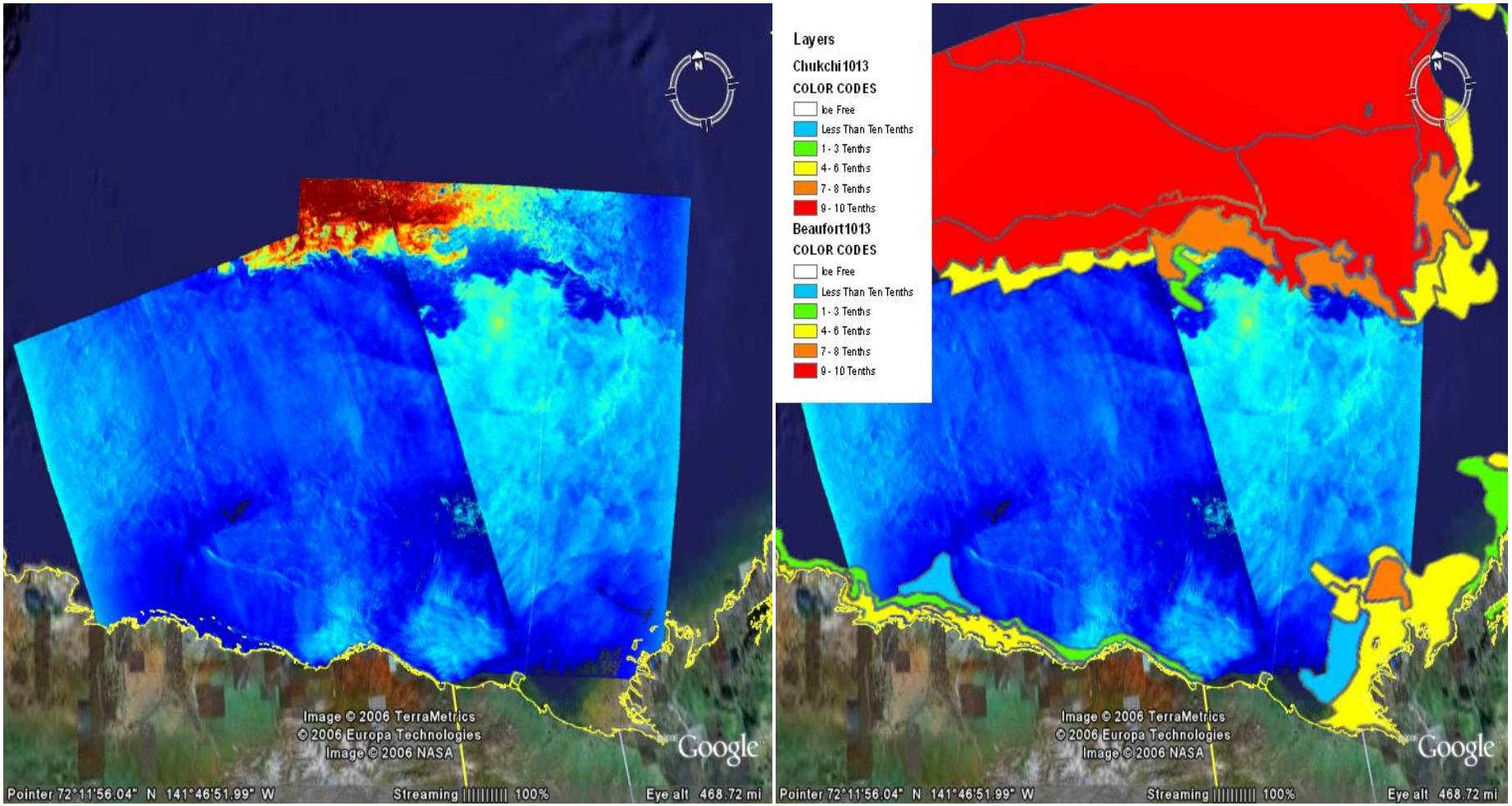


Google .kmz files support wind data on Google Earth

- 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



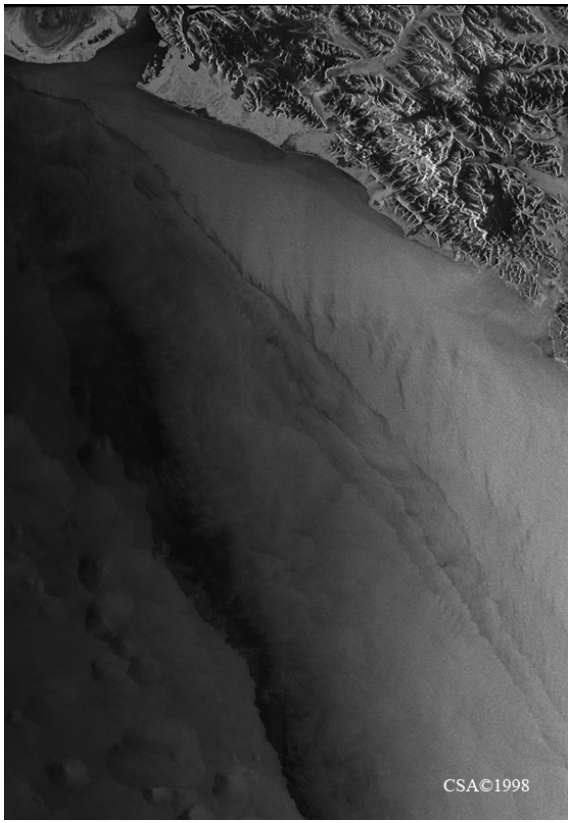
Observing Atmospheric Effects with SAR

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

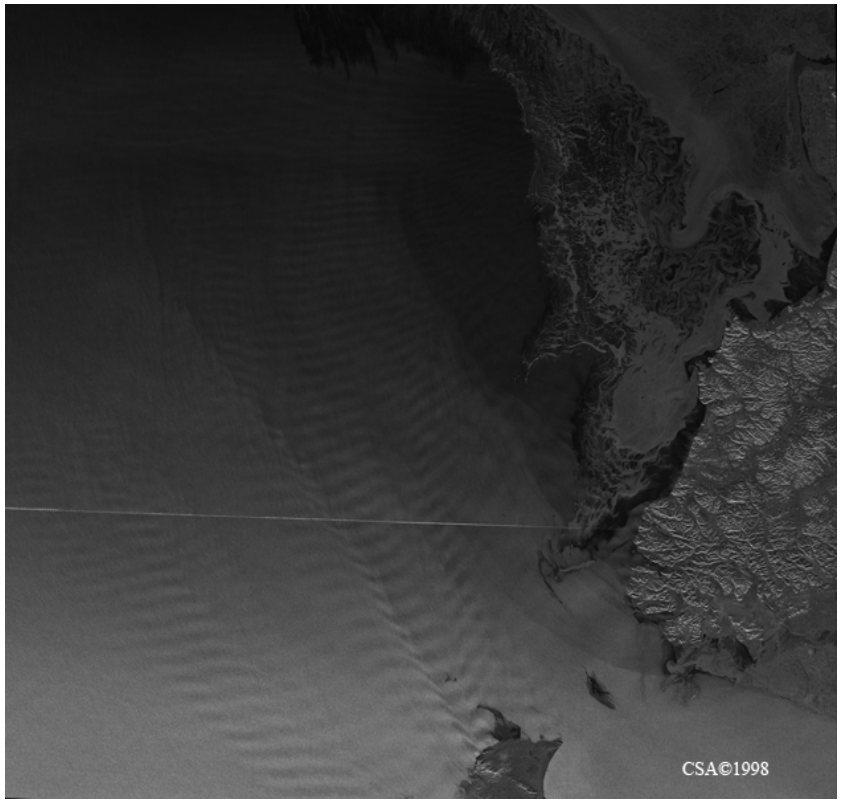


Gulf of Alaska

Bering Sea

Atmospheric Effects

Atmospheric Lee Waves



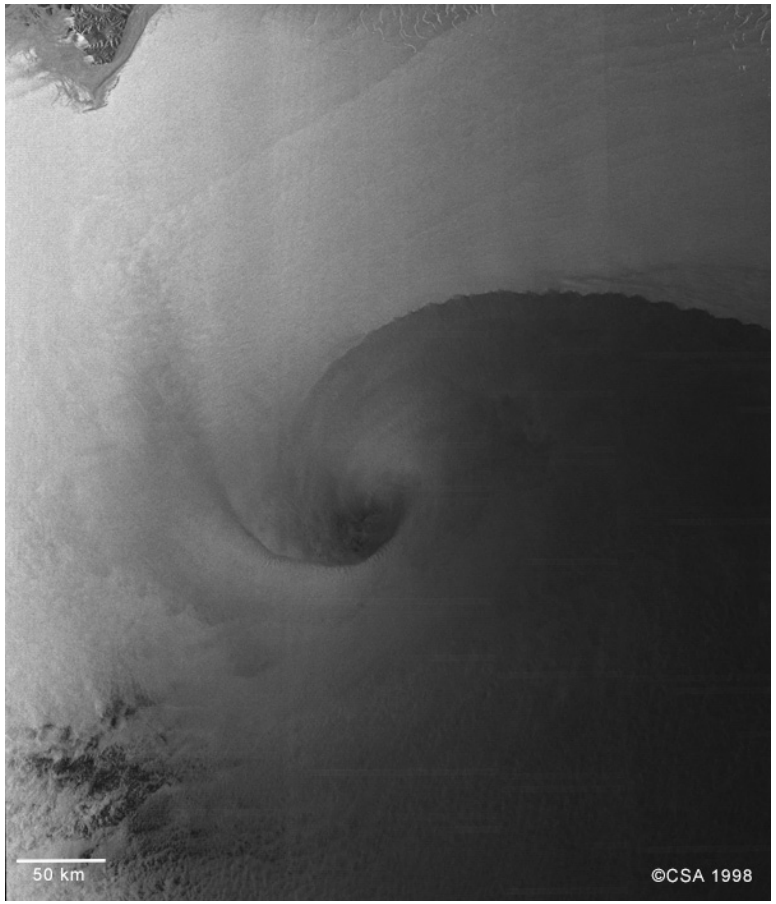
St. Lawrence Is.

Vortex Streets

Aleutians

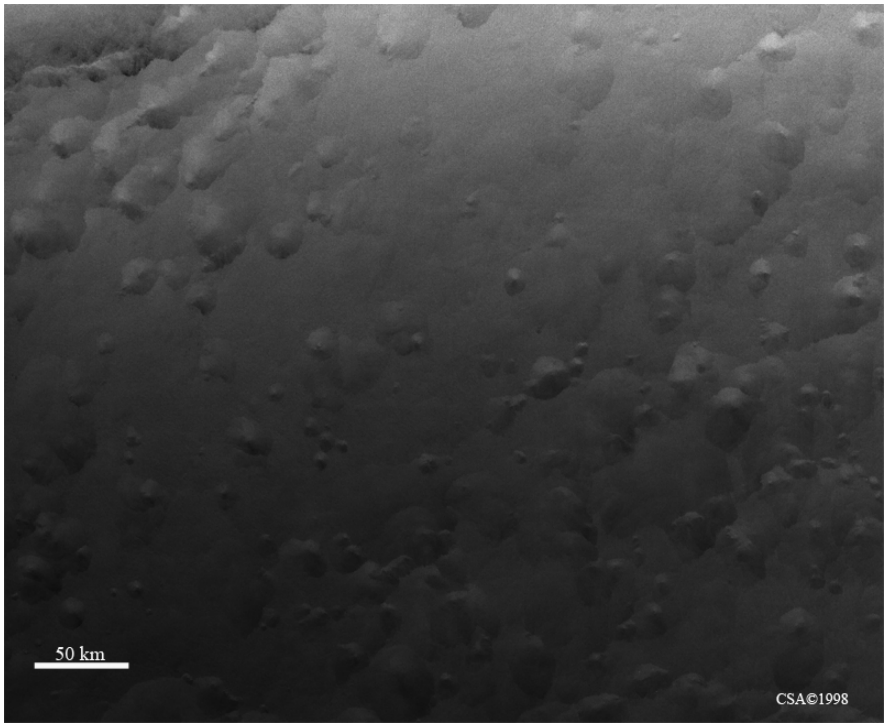
Atmospheric Effects

Polar Low



Bering Sea

Convection Cells



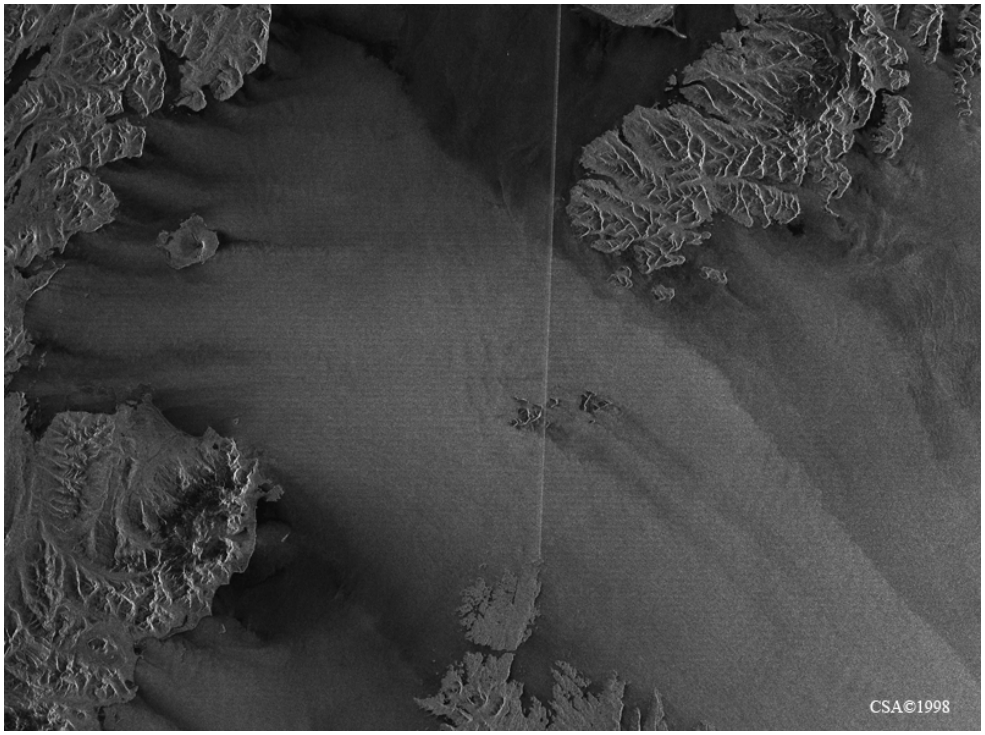
Gulf of Alaska

Atmospheric Effects

Wind Rows

Bering Sea

Wind Shadows



Cook Inlet

Observing Ocean Features With SAR

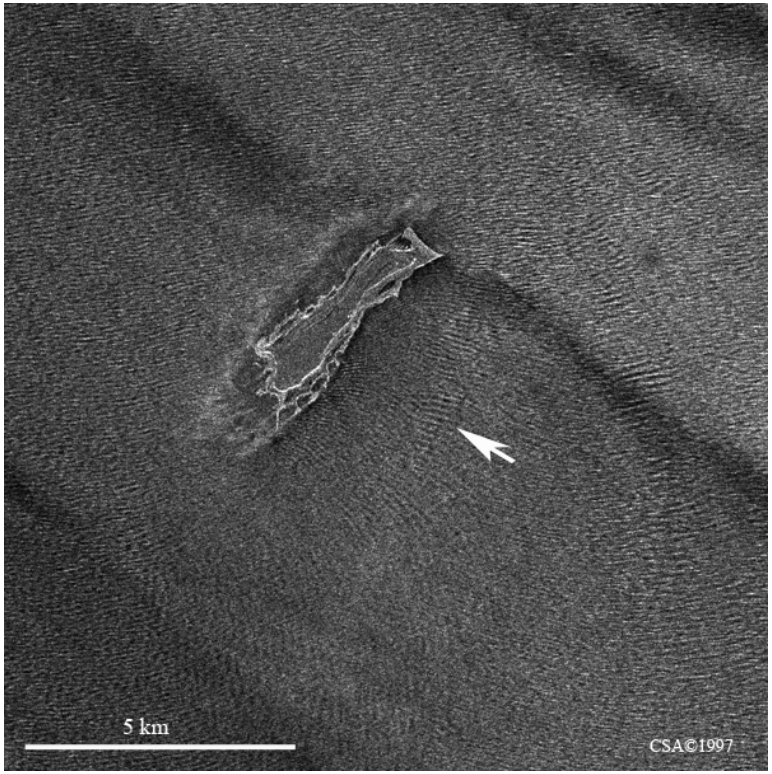
- Observation of ocean features limited to wind regime of 3-13m/s
  - Limited return from lower wind speed
  - Ocean features dominated by wind at higher wind speeds

- 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

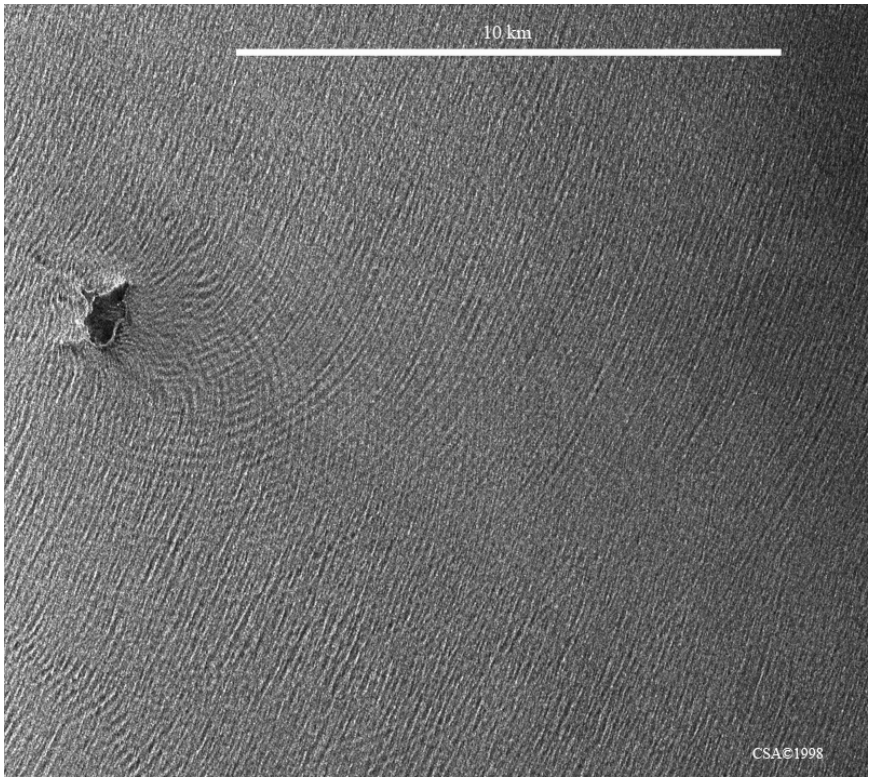


Middleton Is.

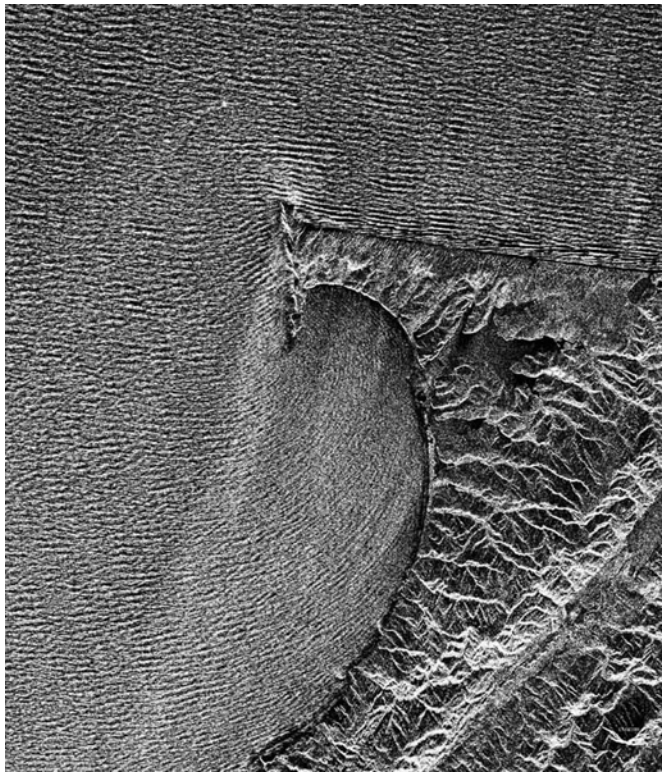
San Francisco Bay

Ocean Features

Diffraction and Refraction of Surface Waves



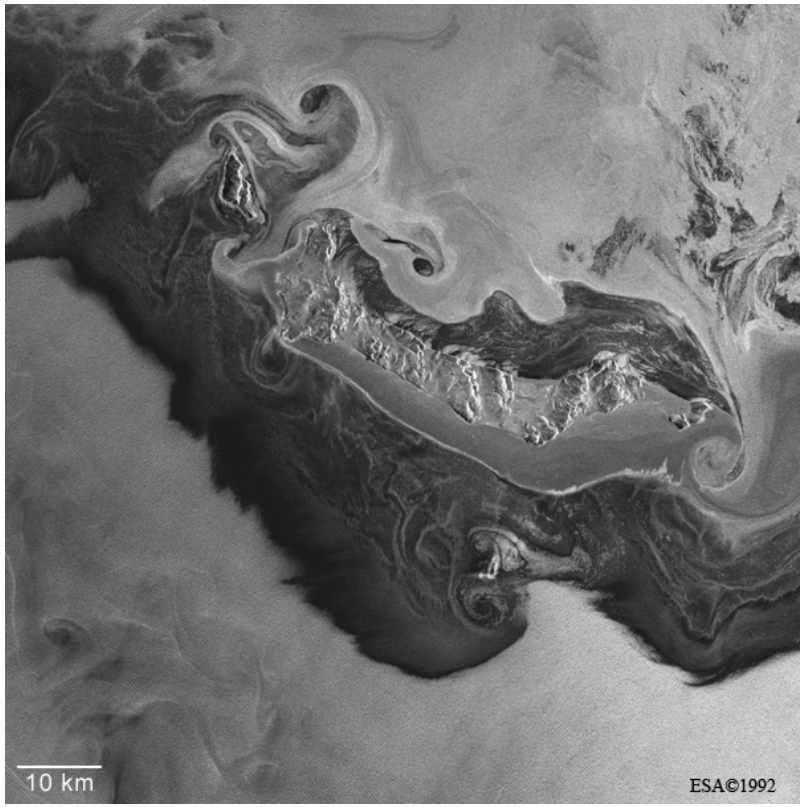
Santa Barbara Is.



Point Reyes Beach

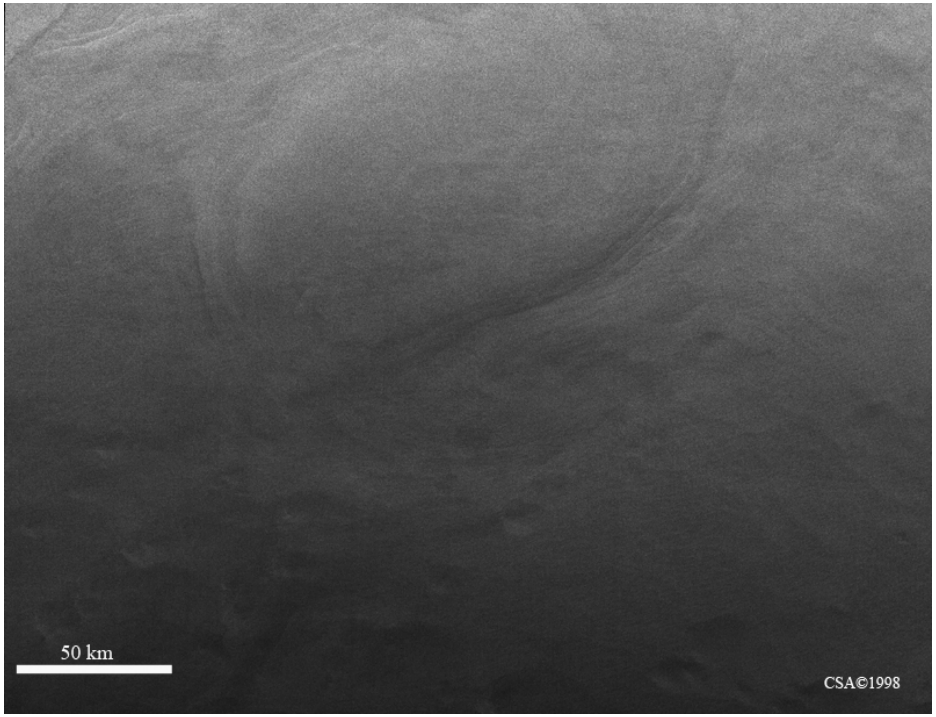
Ocean Features

Dipole Eddies



St. Matthew Is.

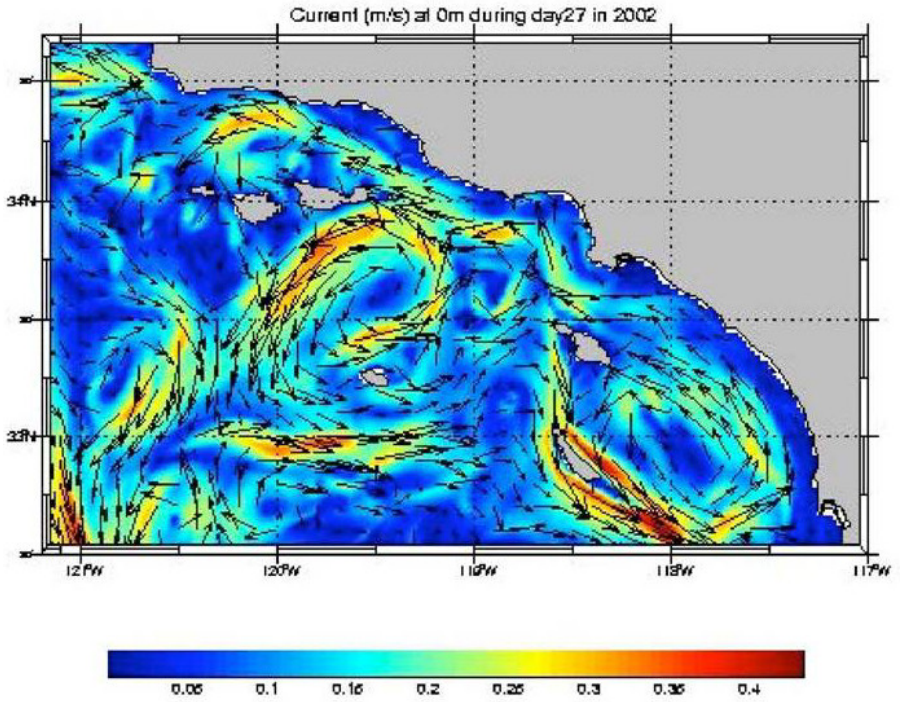
Oceanic Eddy



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

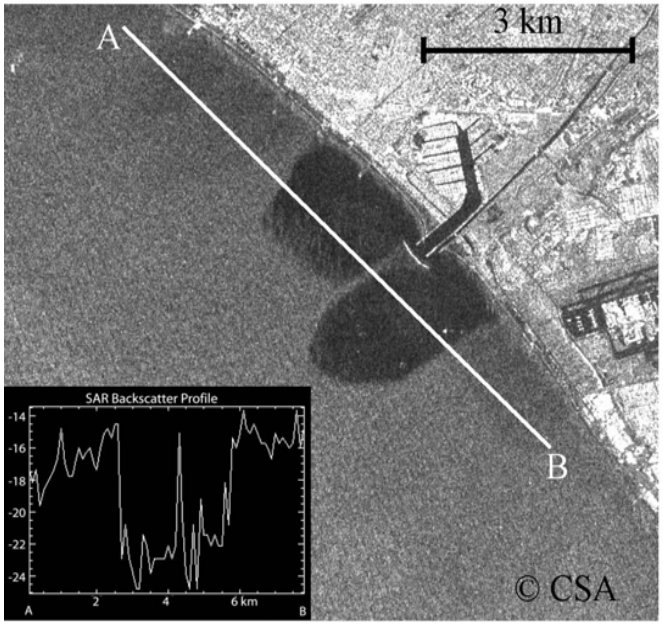
- Optimal detection requires:
  - Wind speed of 3-12 m/s
  - Small incidence angle
  - VV polarization

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

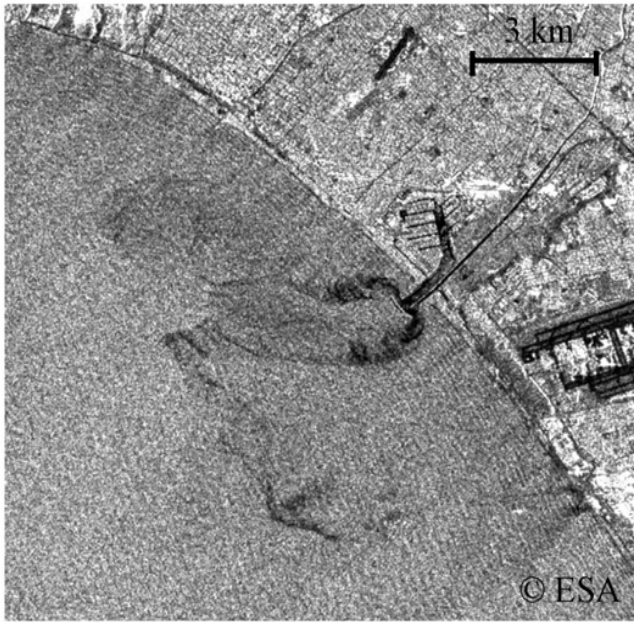
Slick Detection

Storm Water Discharge

RADARSAT-1, 8 November 1998



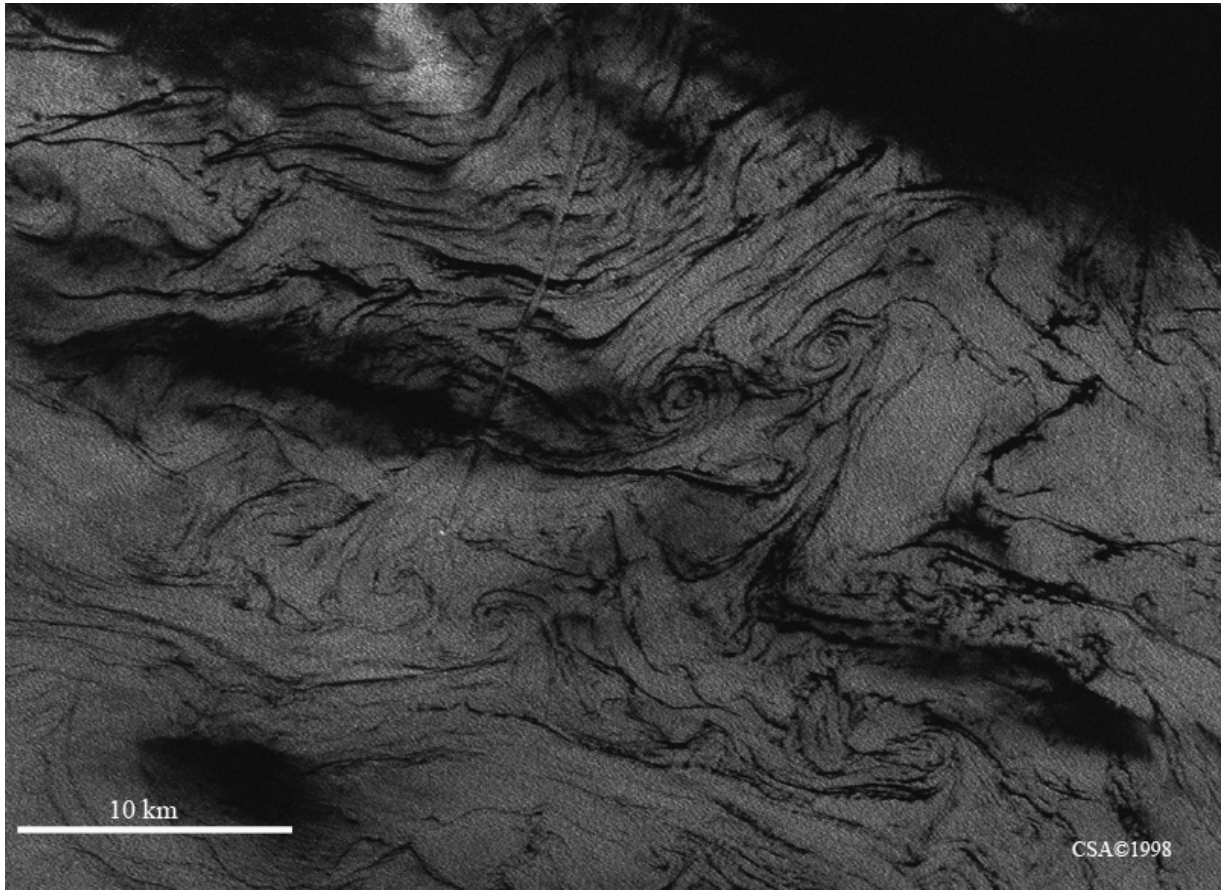
ERS-1 SAR, 28 December 1992



Southern California

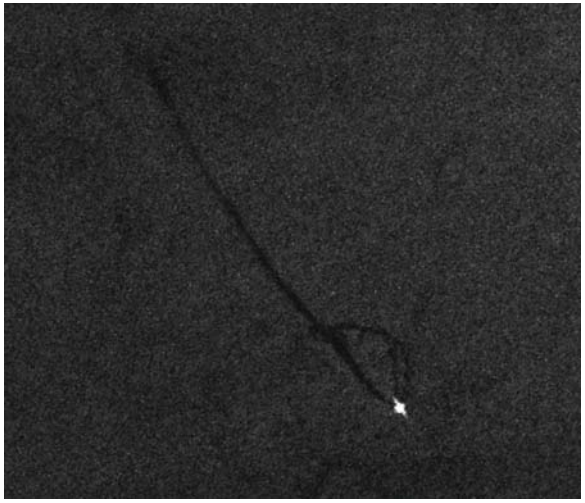
Slick Detection

Biogenic Slicks

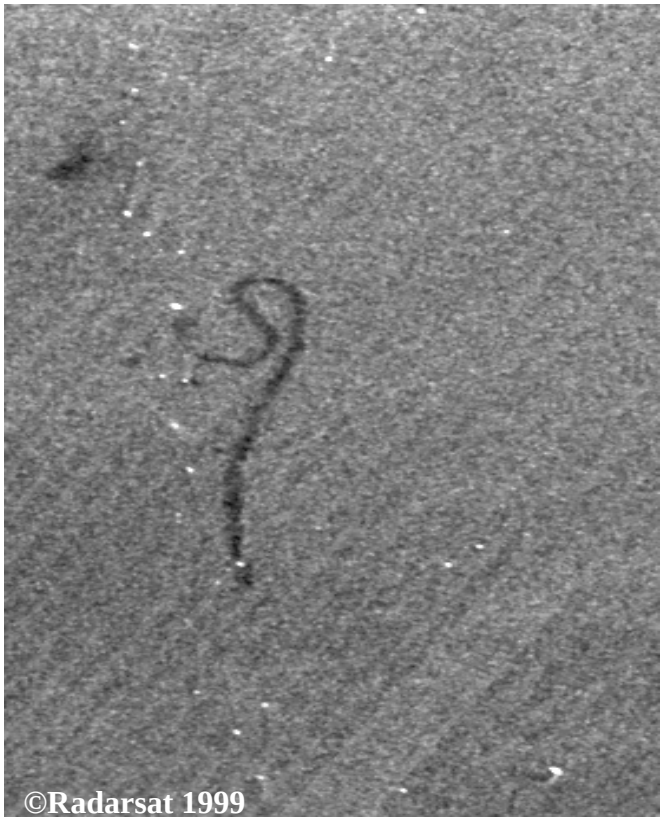


Gulf of Alaska

Slick Detection

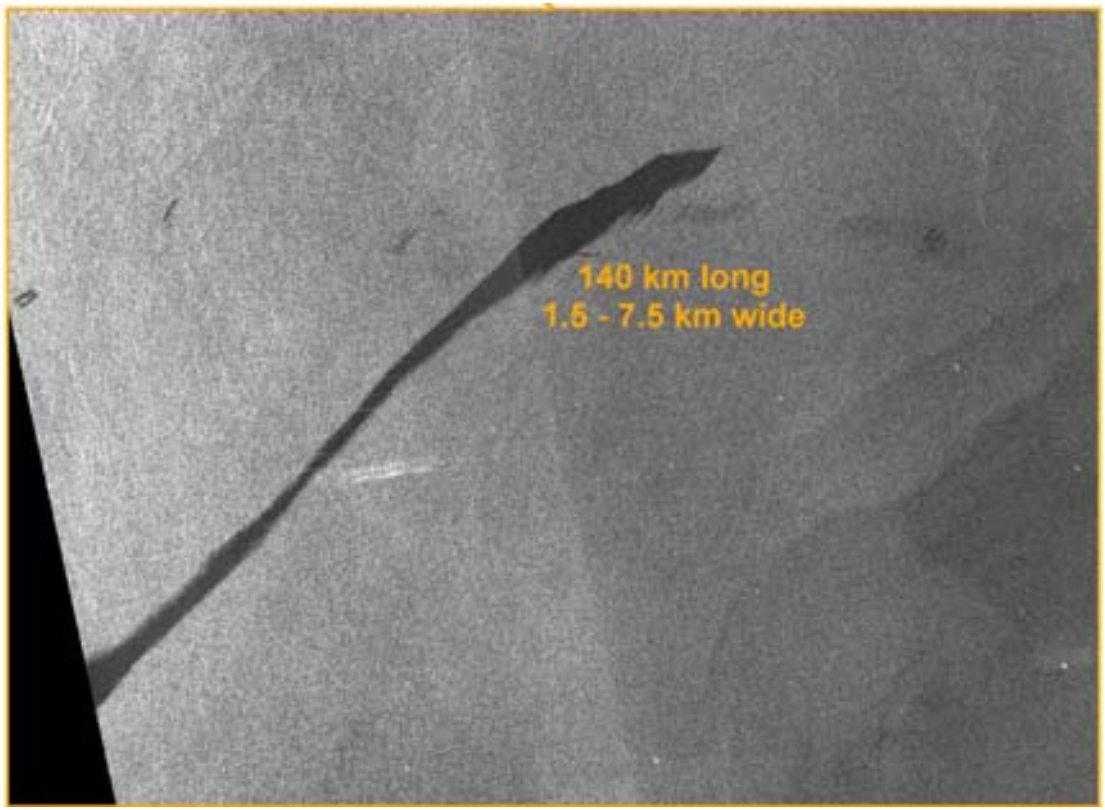


Illegal Bilge Dumping



Slick Detection

Accidents

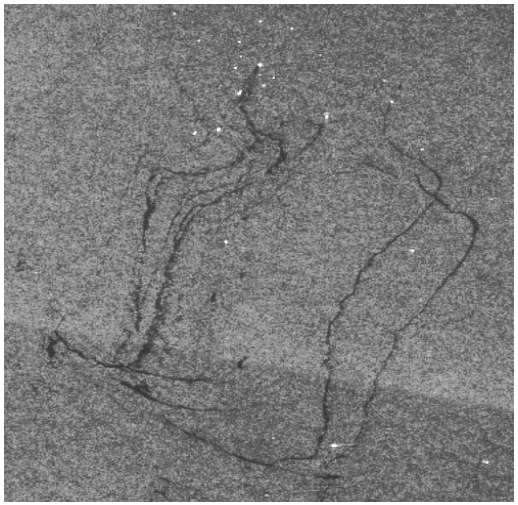


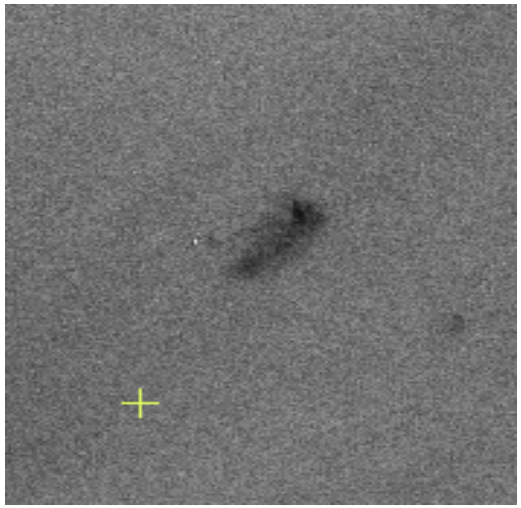
Ship Collision off Sri Lanka

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

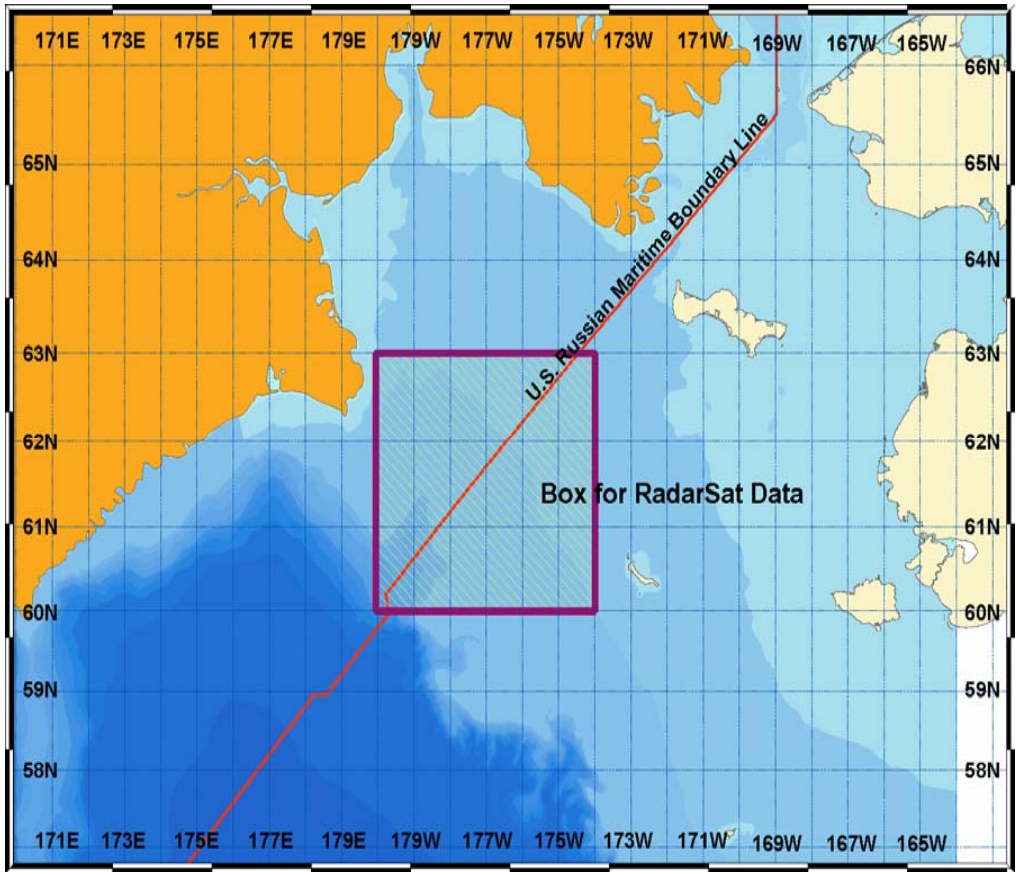
Oil Spill Detection

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

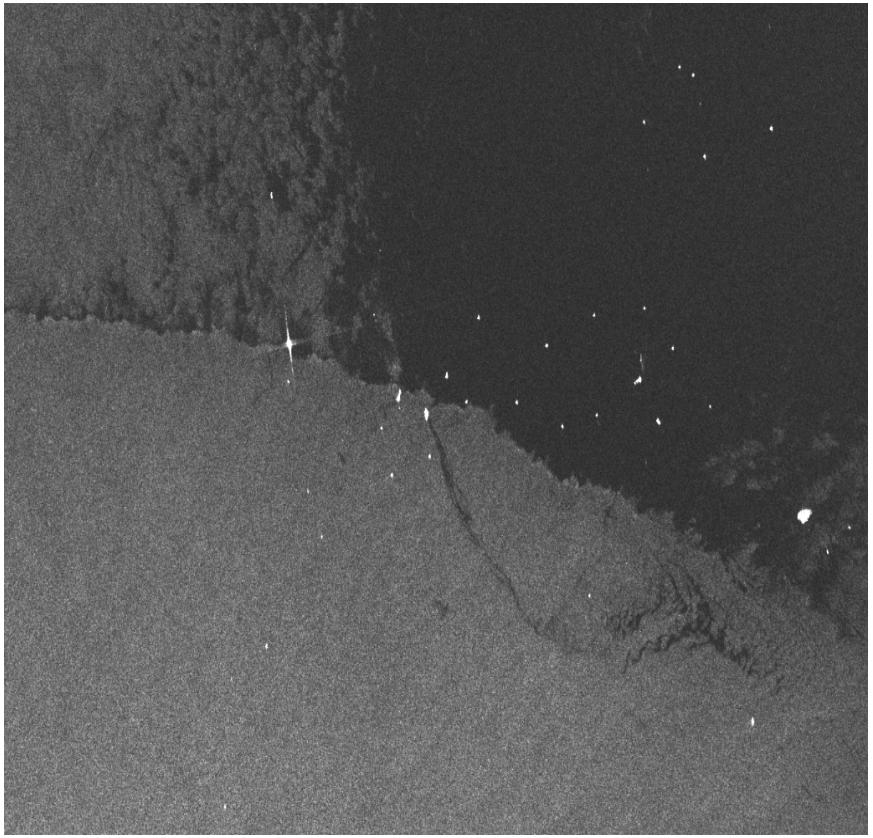
Illegal Fisheries Monitoring

Monitoring illegal fisheries is
a ship detection problem

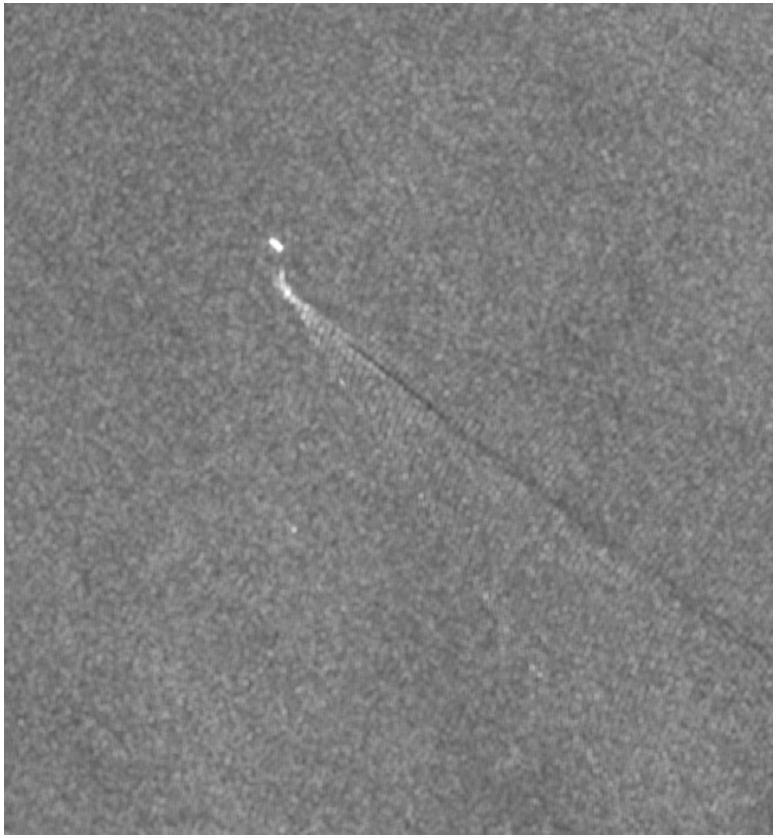


Ship Detection

Fishing Fleet



Ship associated with wake



Ship Detection

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

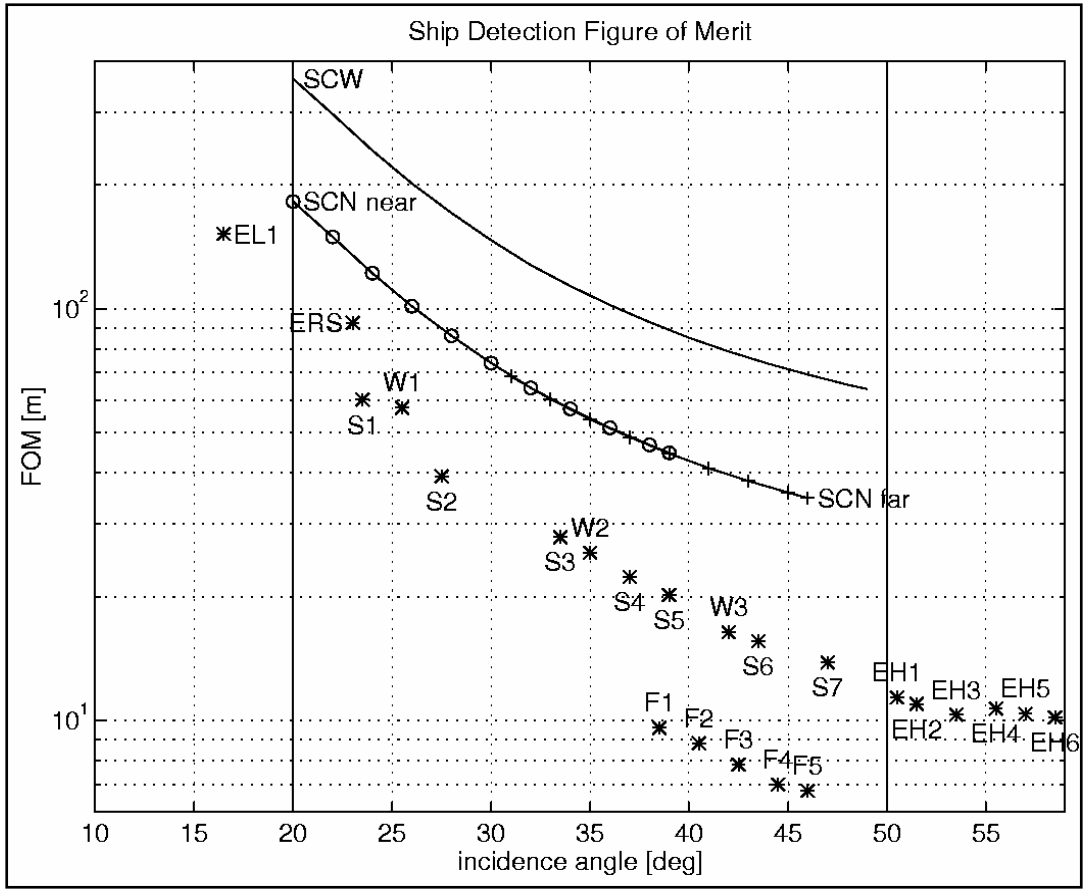
Detection algorithms apply a pixel-based threshold according to clutter statistics and desired Constant False Alarm Rate (CFAR)

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

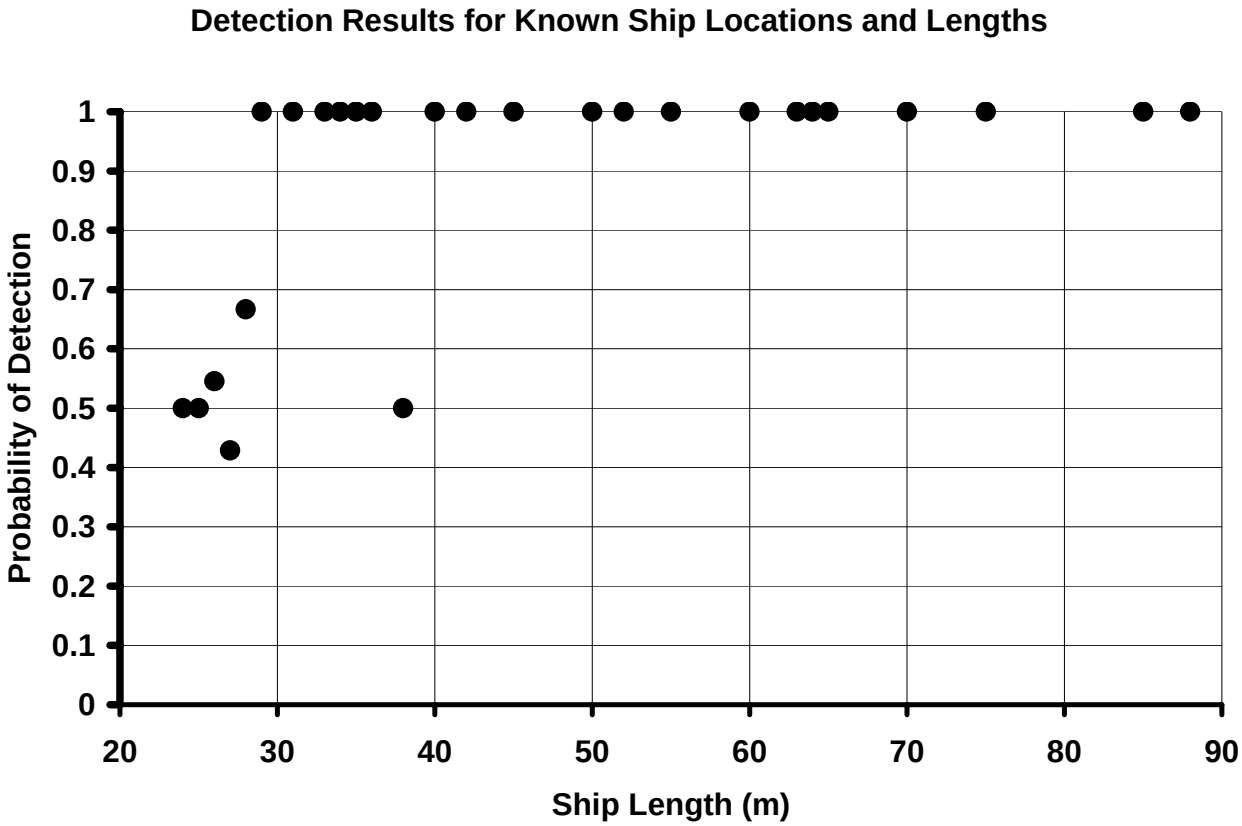
Automated Identification System (AIS) will permit correlation between detected targets and known ship data

Ship Detection

Impact of Resolution and Incidence Angle



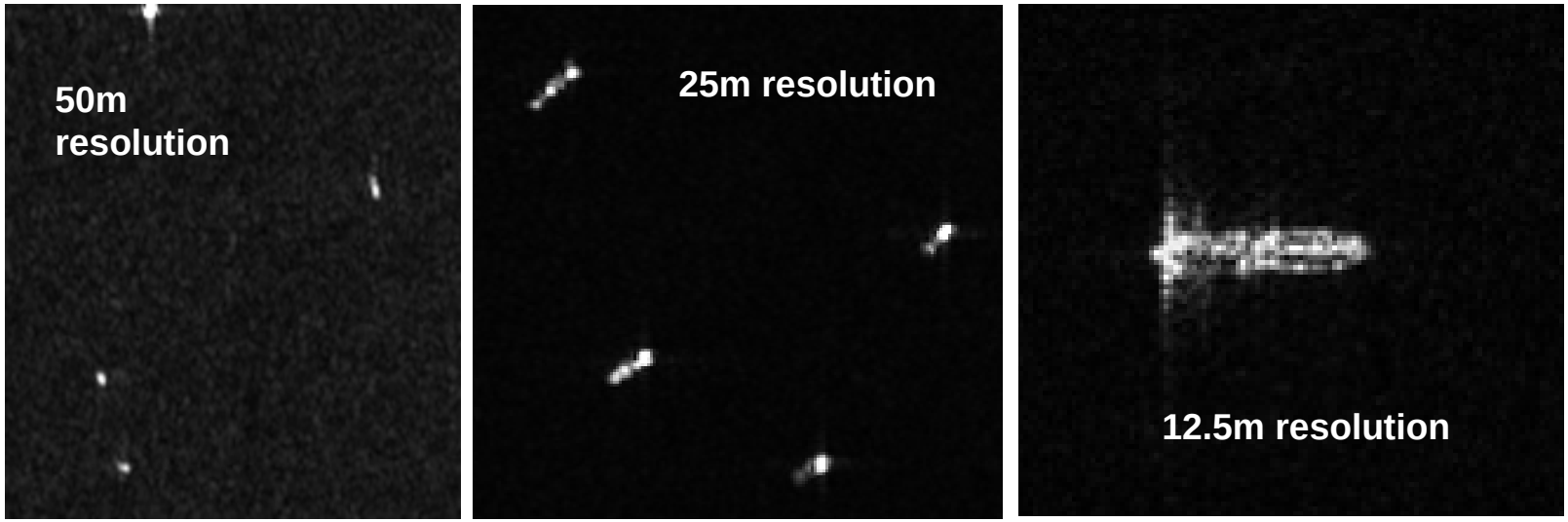
Ship Detection



Results for 25m pixels, 50m resolution

Ship must equal ½ the resolution – *Wackerman,et.al.*

Ship Detection

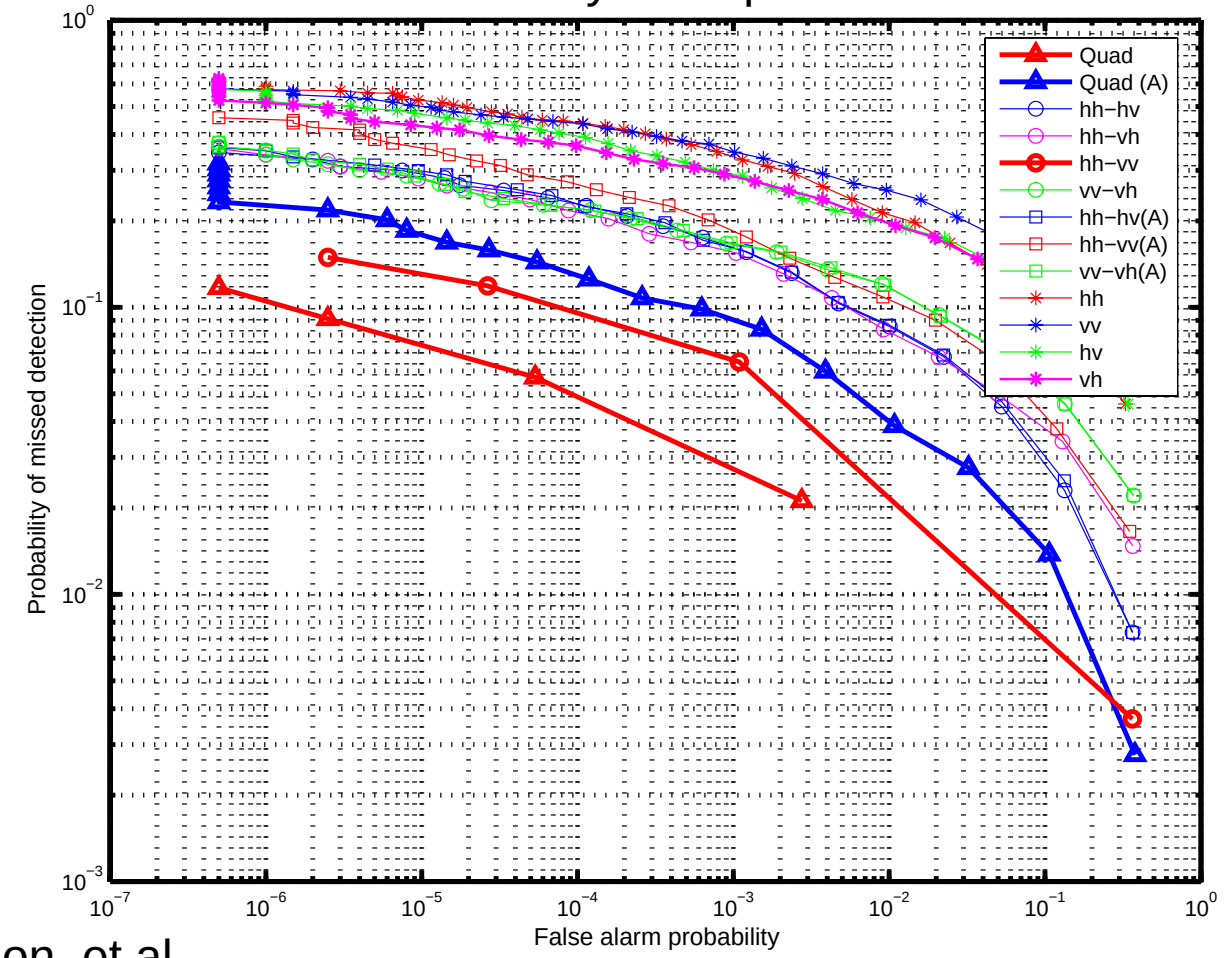


Improved Resolution permits Ship Identification

Wackerman,et.al.

Ship Detection

Role of Polarimetry in Ship Detection



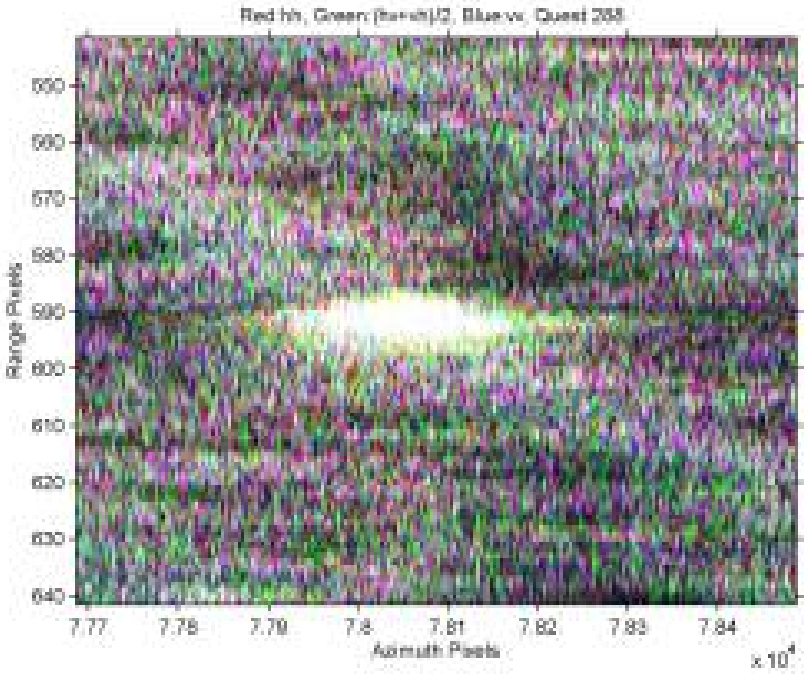
Paris Vachon, et.al.

Ship Detection

Red: HH

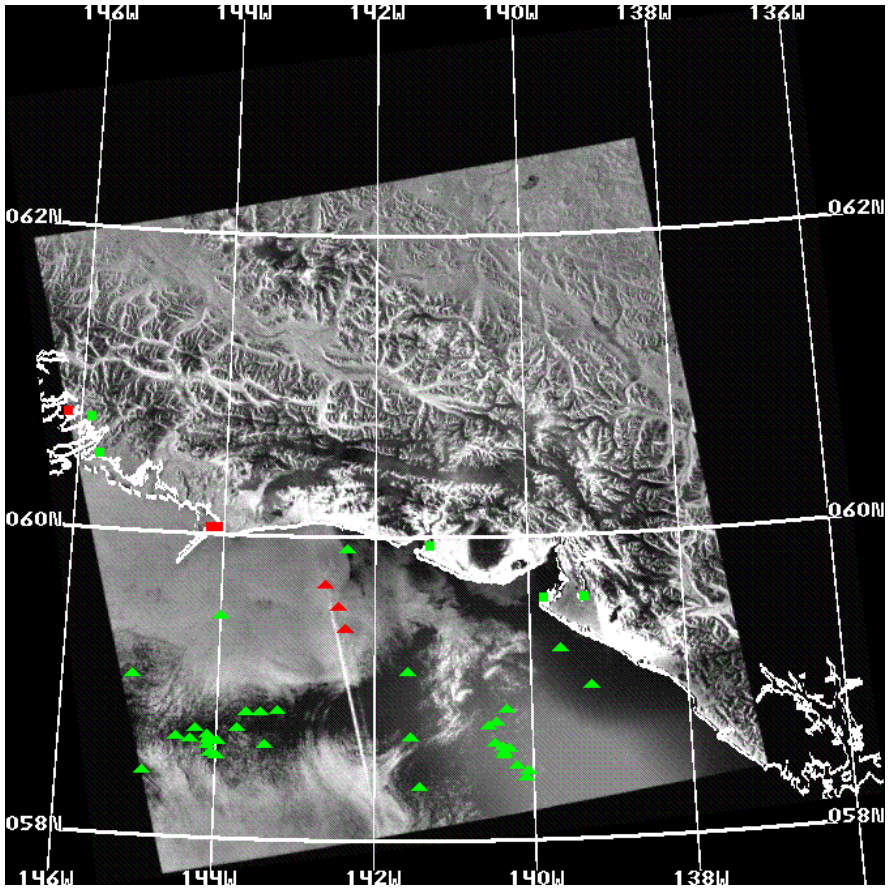
Blue: VV

Green: (HV+VH)/2



Paris Vachon, et.al.

Ship Detection



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

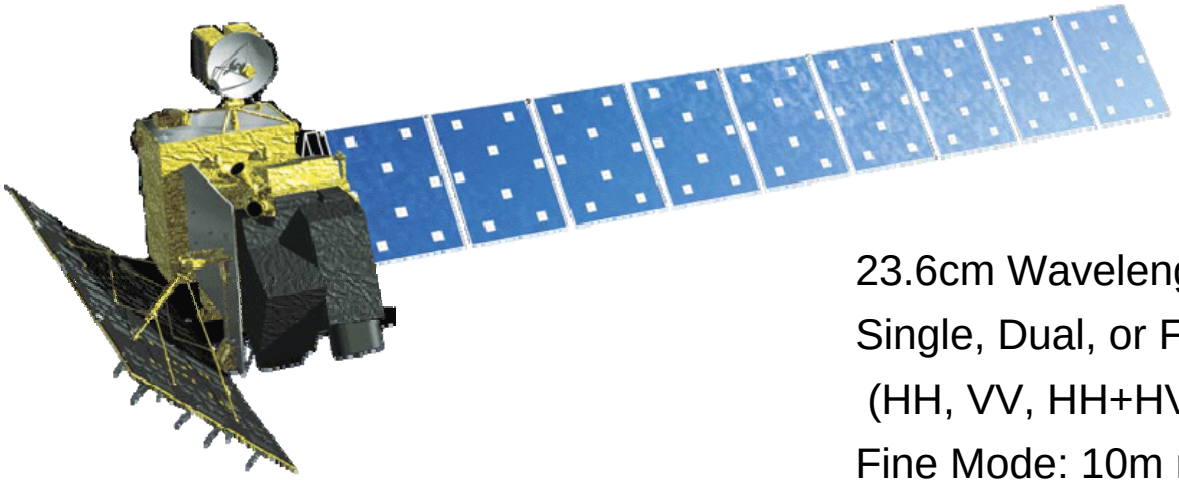
SAR-derived ship information:

- 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

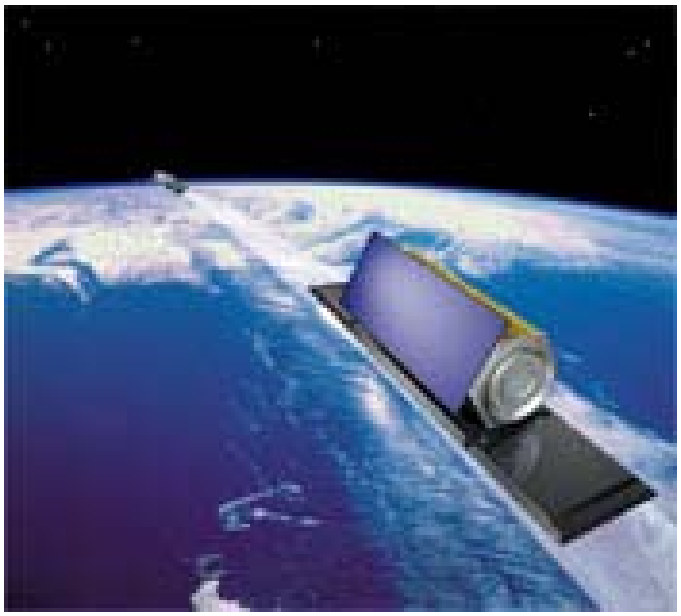
On-board recorder

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
- Launch in 2012, 2013, 2014
- 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?