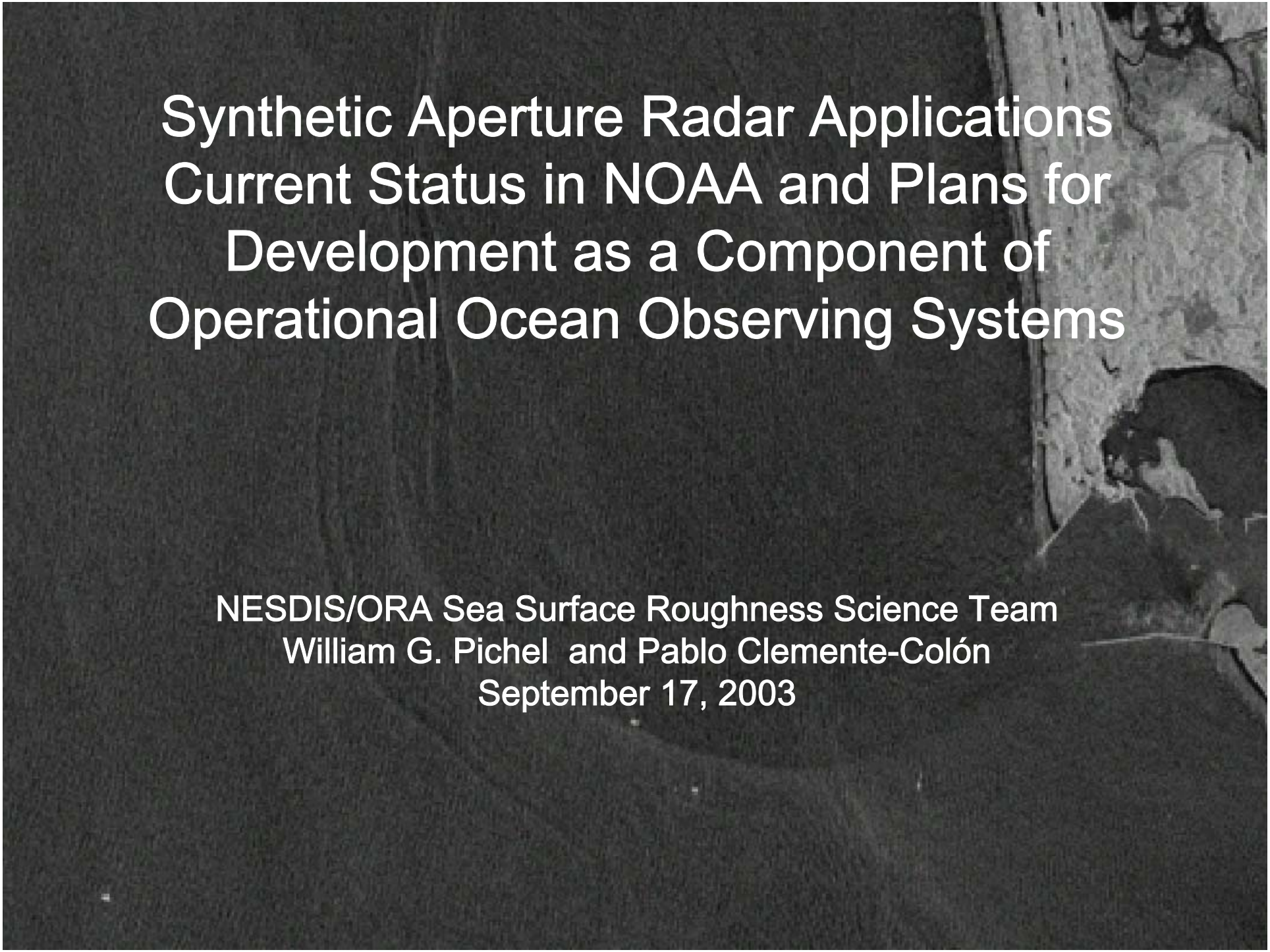
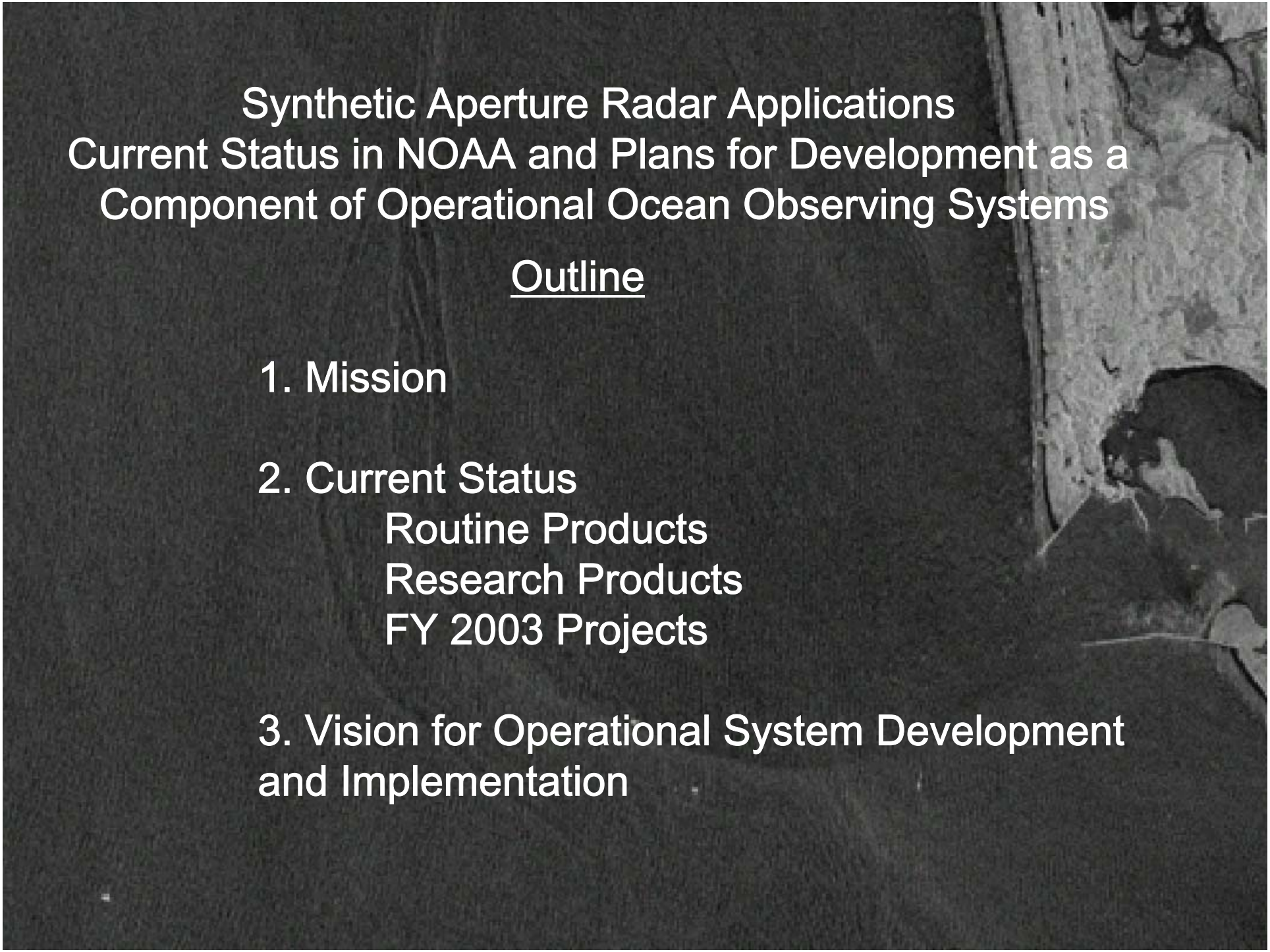


Synthetic Aperture Radar Applications Current Status in NOAA and Plans for Development as a Component of Operational Ocean Observing Systems

NESDIS/ORA Sea Surface Roughness Science Team
William G. Pichel and Pablo Clemente-Colón
September 17, 2003



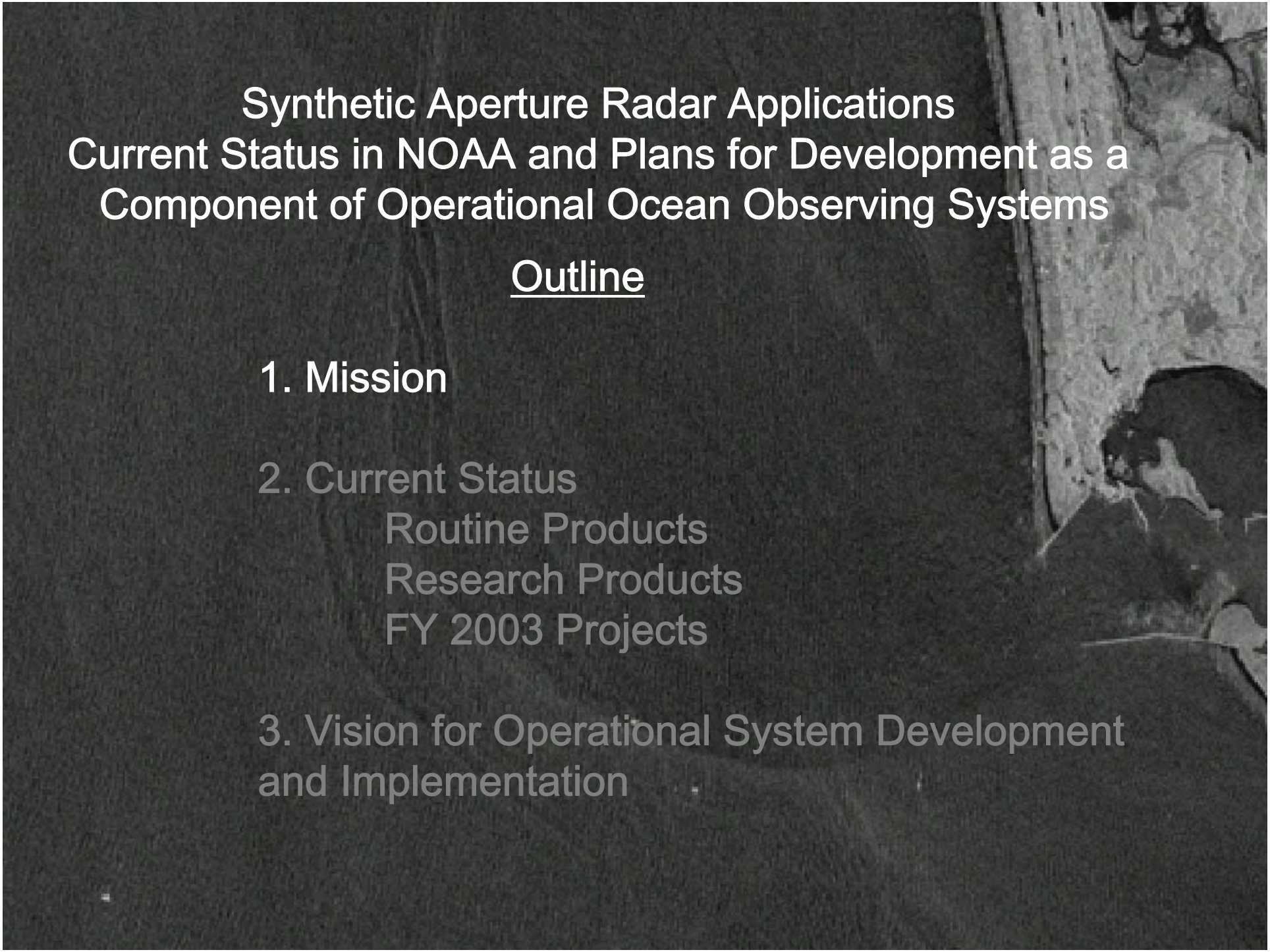
Synthetic Aperture Radar Applications
Current Status in NOAA and Plans for Development as a Component of Operational Ocean Observing Systems

Outline

1. Mission

2. Current Status
   - Routine Products
   - Research Products
   - FY 2003 Projects

3. Vision for Operational System Development and Implementation



Synthetic Aperture Radar Applications
Current Status in NOAA and Plans for Development as a Component of Operational Ocean Observing Systems

Outline

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Sea Surface Roughness (SSR) Science Team

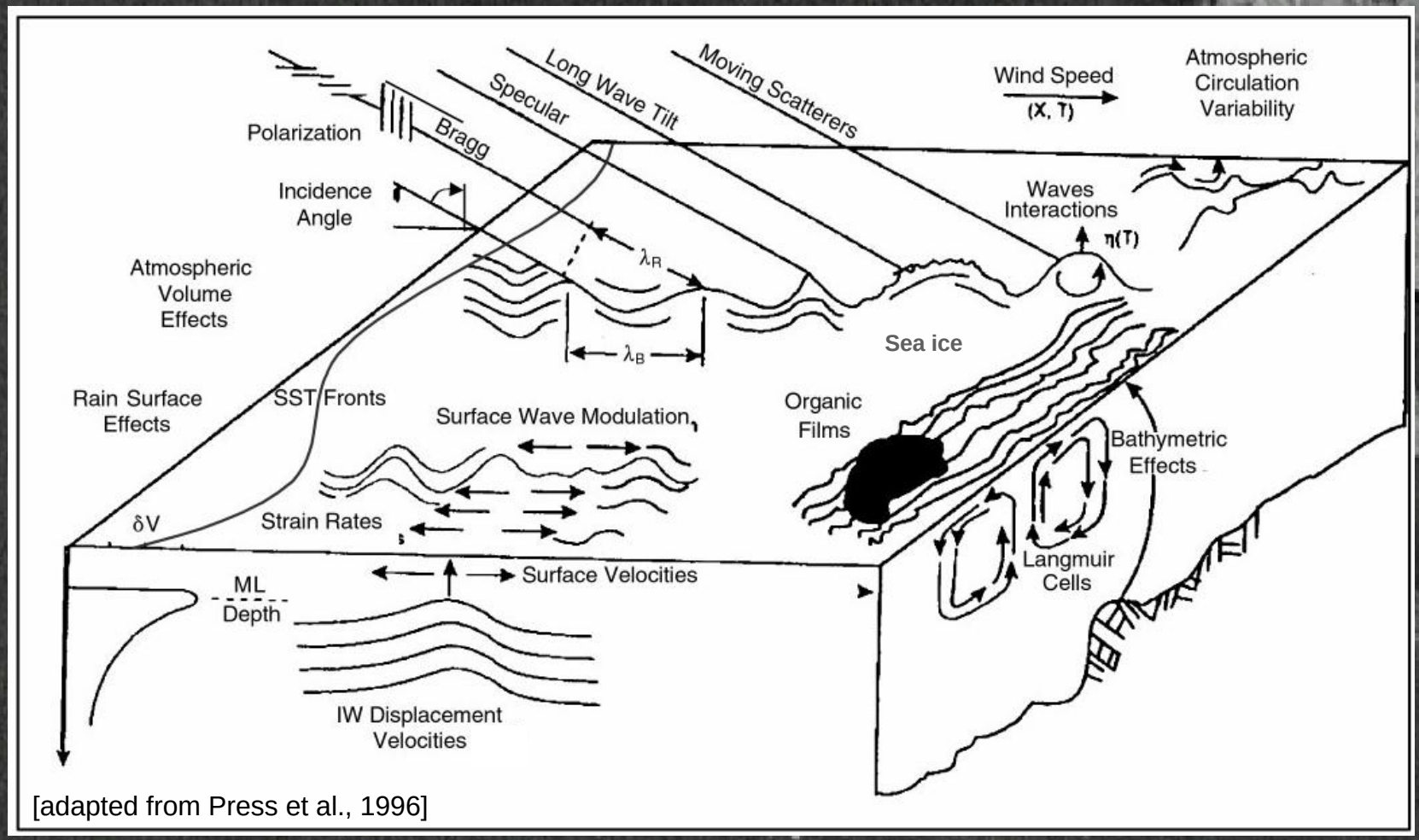
Mission

Develop an integrated end-to-end product system for operational generation of the sea-surface roughness products specified in the NPOESS Integrated Operational Requirements Document (IORD) II and the Ocean Observer User Requirements Document (URD).

Mission-Related Activities

- Requirements development
- Research
- Collaboration with academic, Government, and commercial partners
- Product development and validation
- User base development - including training
- Applications demonstration
- Operational code development, documentation and implementation.

Processes Involved in SAR Ocean Imaging



[adapted from Press et al., 1996]

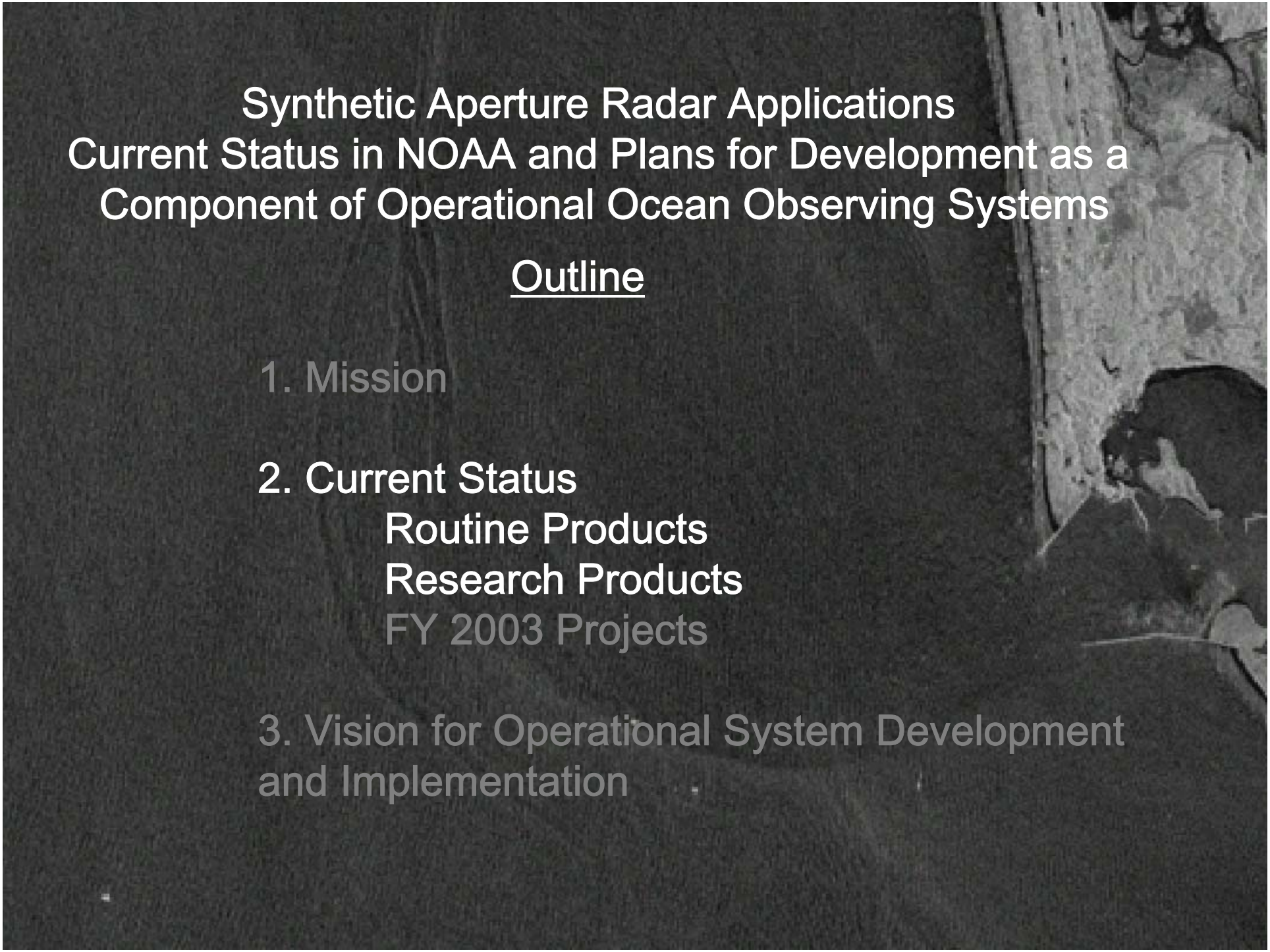
Main SAR response from the ocean is from resonance of the radar microwaves with capillary and small gravity surface waves (i.e. Bragg Waves), as well as modulation by longer waves. $k_B = 2 k_R \sin \theta$

SAR Satellites
Past
Present
Future

Satellite System	Country	Operational Dates (month and year)	SAR Band(s)
Seasat SAR	USA	6/78 - 10/78	L
SIR-A (Shuttle)	USA	11/81 - 11/81	L
SIR-B (Shuttle)	USA	10/84 - 10/84	L
KOSMOS 1870	Russia	7/87 - 7/89	S
ALMAZ-1	Russia	3/91 - 9/92	S
ERS-1	EU	7/91 - 3/00	C
JERS-1	Japan	2/92 - 11/98	L
SIR-C/XSAR (Shuttle)	USA	4/94- 4/94 and 10/94-10/94	L,C,X
ERS-2	EU	4/95 - present	C
RADARSAT-1	Canada	11/95 - present	C
SRTM (Shuttle)	USA	2/00 - 2/00	C,X
ENVISAT ASAR	EU	3/02 - present	C
ALOS PALSAR	Japan	2004	L
RADARSAT-2	Canada	2005	C
TerraSar-X1	Germany	2005	X
TerraSar -L1	Germany	2005	L
COSMO/SkyMed	Italy	2005	X
SAOCOM	Argentina	2006	L
TerraSar -L1	Germany	2005	L
RADARSAT-3 (?)	Canada	2007	C
NASA InSAR (?)	USA	2009	L
NPOESS Ocean Observer Operational SAR (?)	USA	2012	L,C or L,X

Legend

Current Satellites



Synthetic Aperture Radar Applications
Current Status in NOAA and Plans for Development as a Component of Operational Ocean Observing Systems

Outline

1. Mission

2. Current Status
   - Routine Products
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SAR-Related Environmental Data Requirements

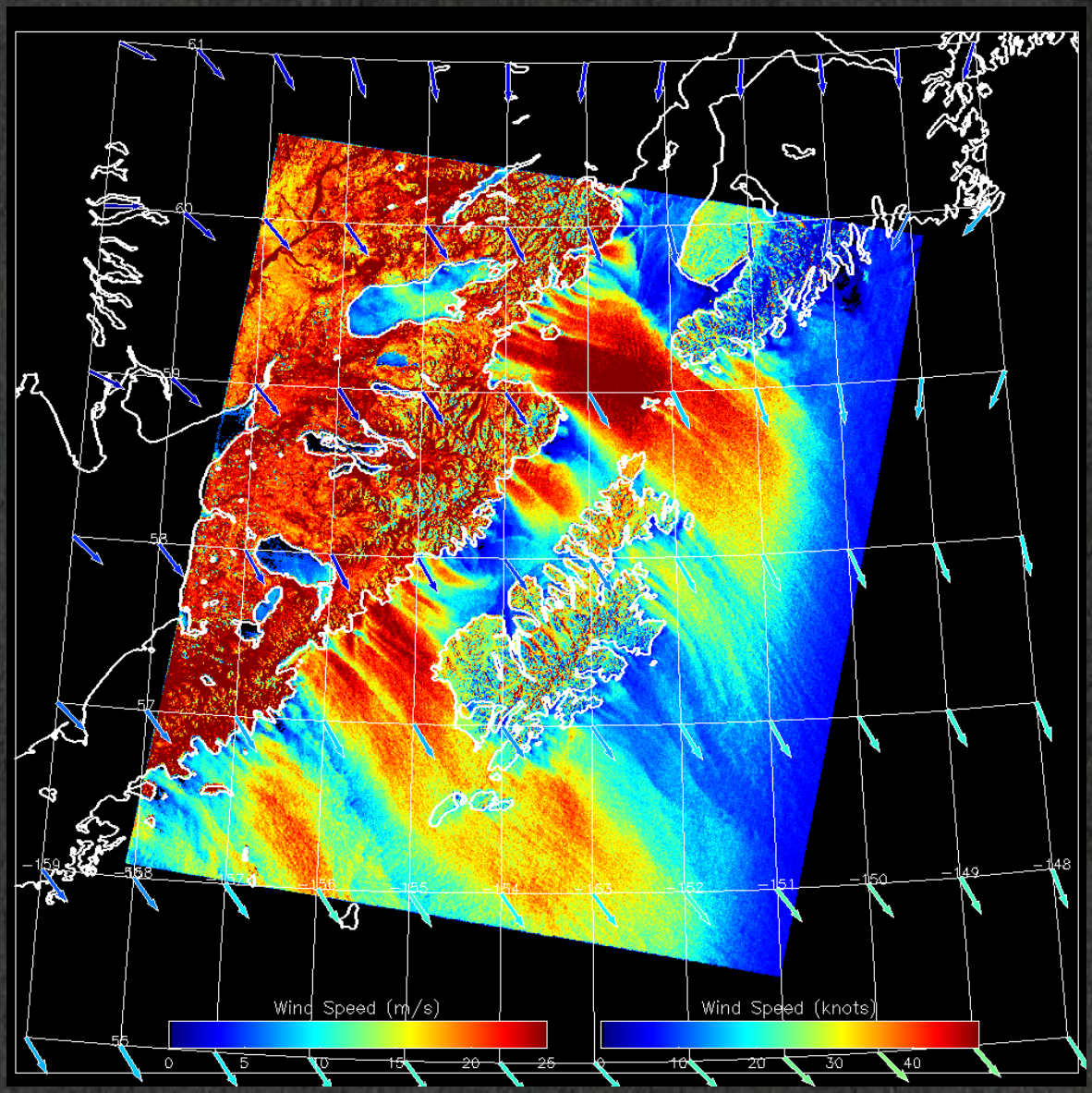
#	EDR TITLE	IORD II Requirement	OO URD Requirement	ORAD Interest
	OCEANIC			
1	Coastal Sea Surface Winds & Wind Stress	4.1.6.8.8.5	2.1b, 2.2b	X
2	Wave Characteristics - Significant Wave Height	4.1.6.6.8	2.4a	X
3	Wave Characteristics. - Ocean Wave Dir./Wavelength	4.1.6.8.8.8	2.4b	X
4	All Weather Day/Night Imagery	4.1.6.8.6	2.5c	X
5	Oil Spill Location	4.1.6.8.8.12	2.6	X
6	Vessel Positions		2.7	X
7	Bathymetry (Near Shore)	4.1.6.8.8.10	2.8	X
8	Littoral Currents	4.1.6.8.8.1	2.16c	X
9	Surf Conditions	4.1.6.8.8.9	2.18	X
10	Ocean Mesoscale Features (Fronts/Eddies)		2.19	X
11	Mixed Layer Depth			X

Note: IORD = Integrated Operational Requirements Document
OO URD = Ocean Observer User Requirements Document
ORAD = Oceanic Research and Applications Division

Routine NOAA Products

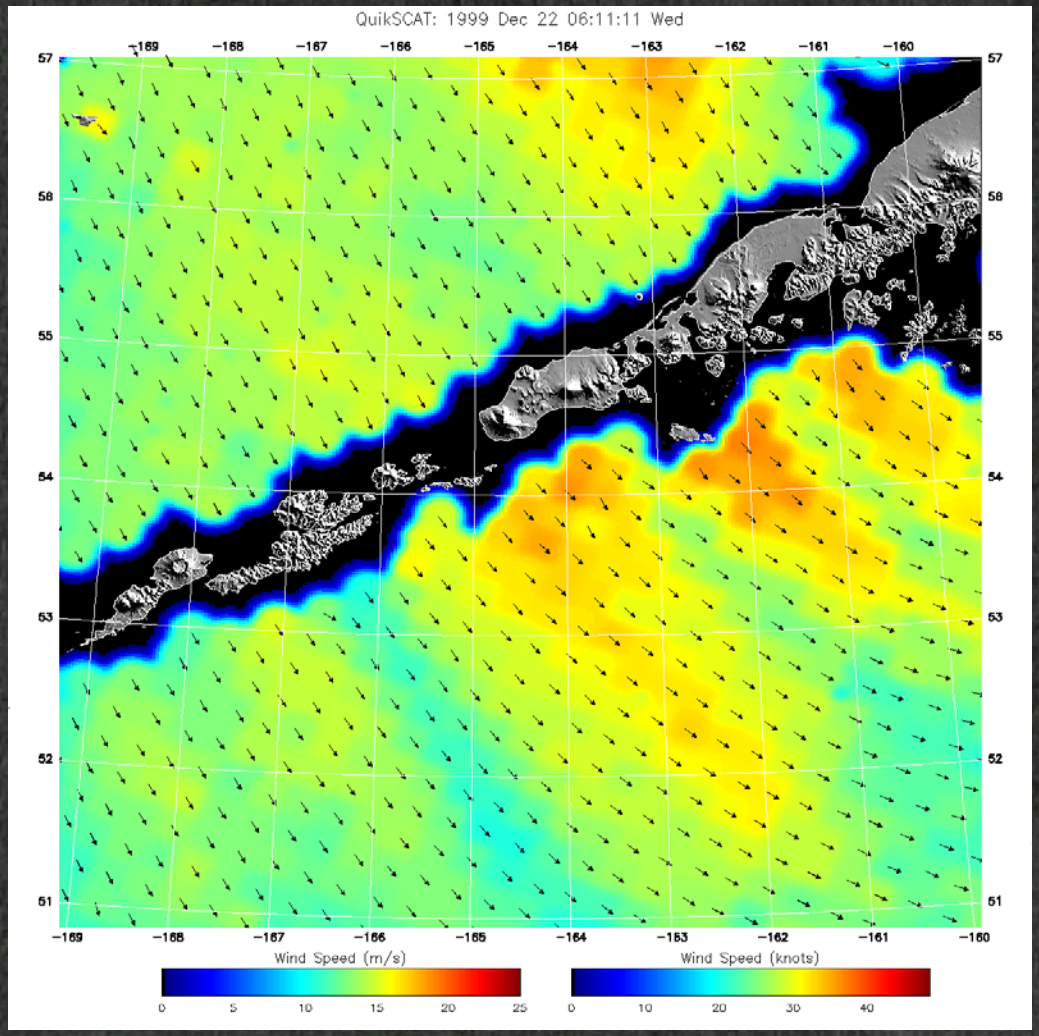
NESDIS Research Products

Oceanic SAR Products - High-Resolution Coastal Winds

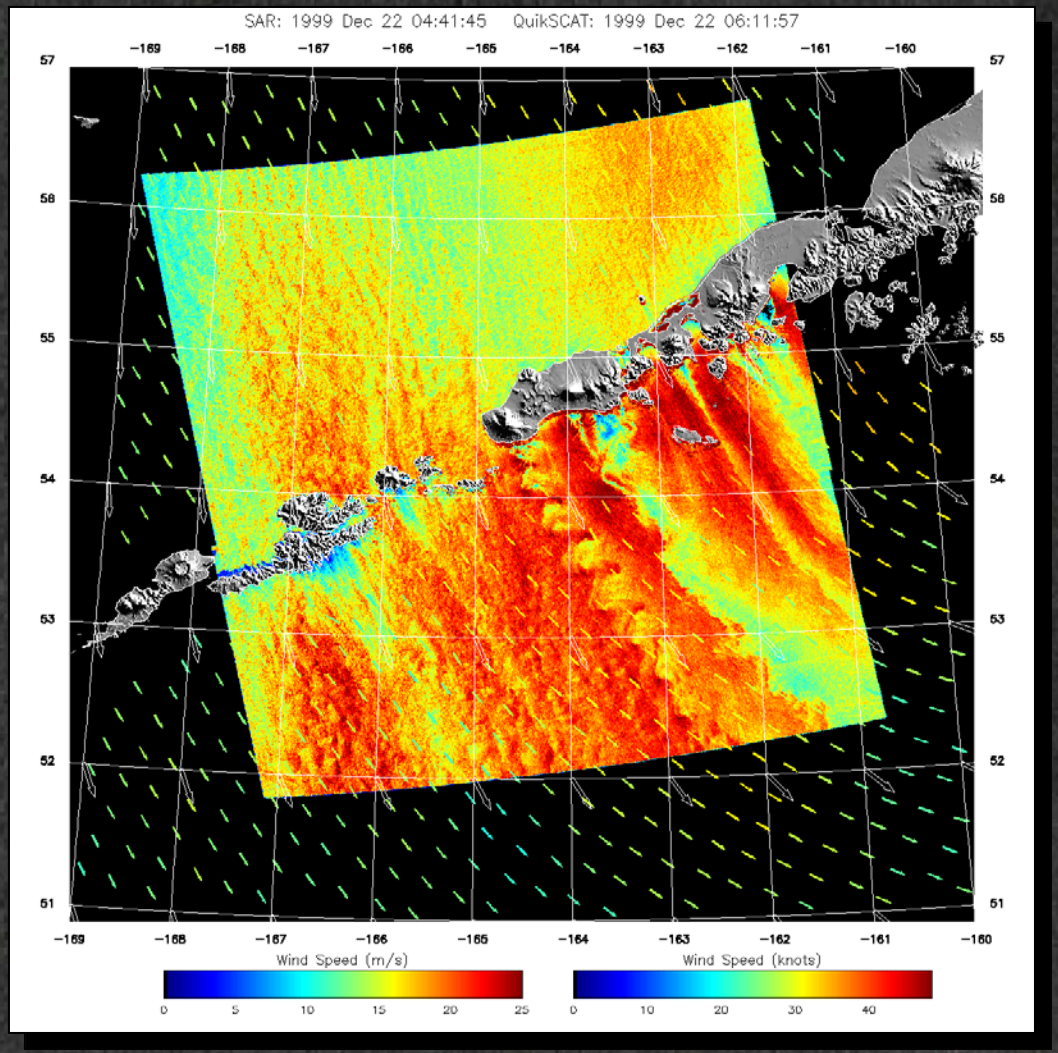


1 km Resolution Coastal Winds

Scatterometer/SAR Wind Comparison

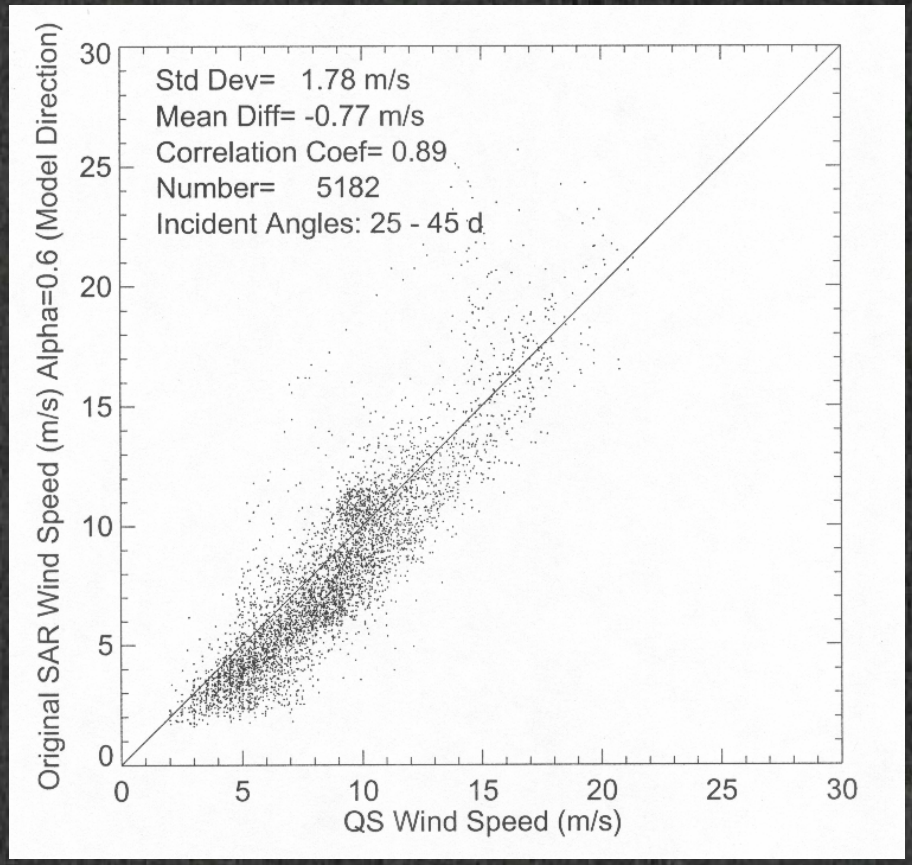


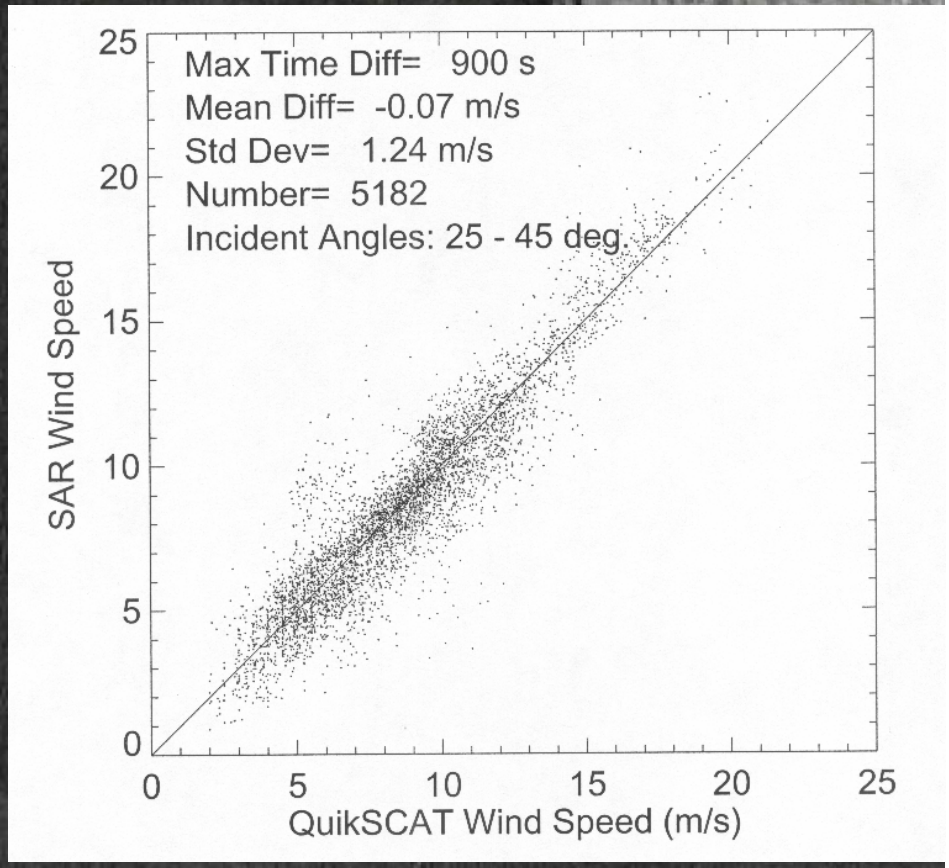
Scatterometer/SAR Wind Comparison



Scatterometer/SAR Wind Comparison

SAR Wind Versus QuikSCAT Wind (all comparisons within 15 min)

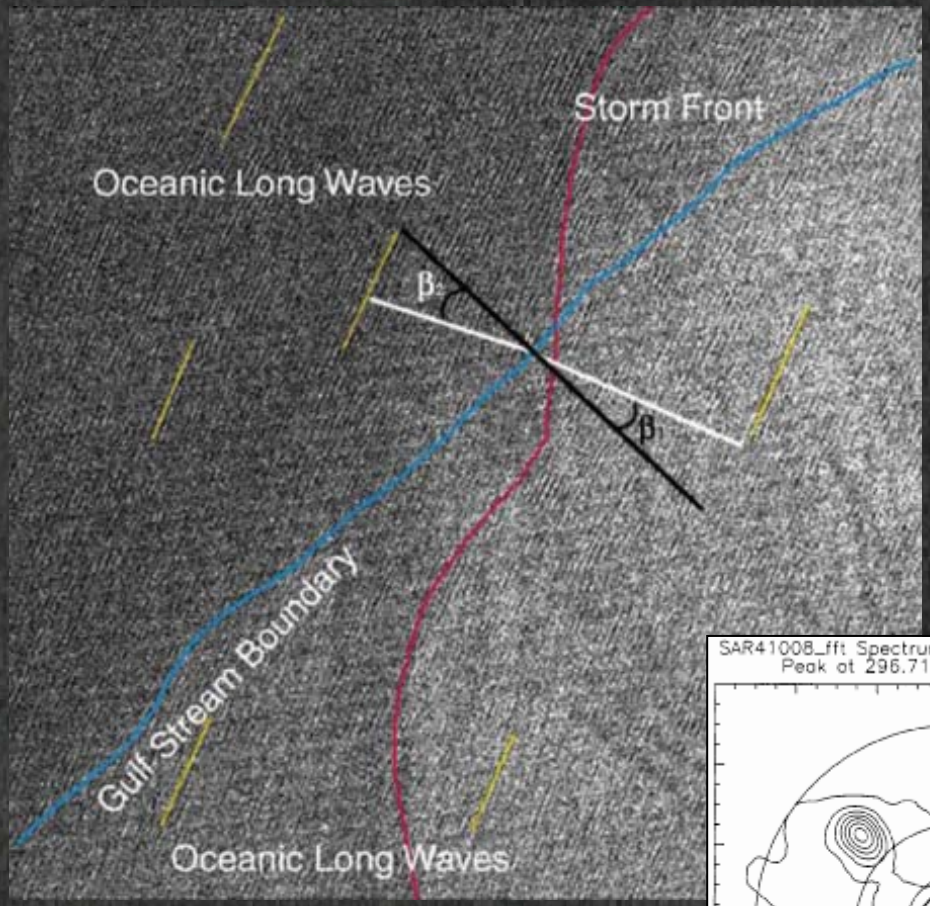


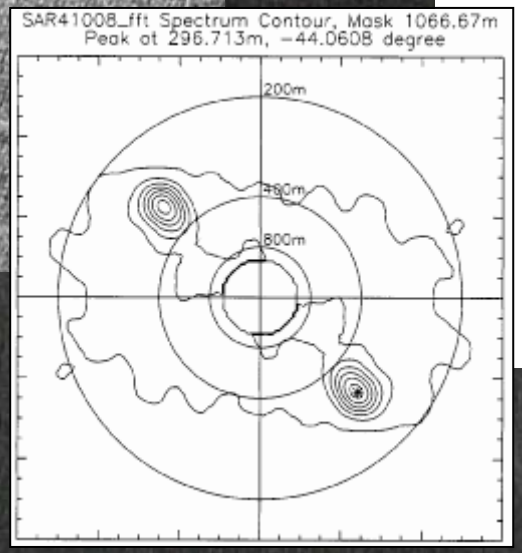


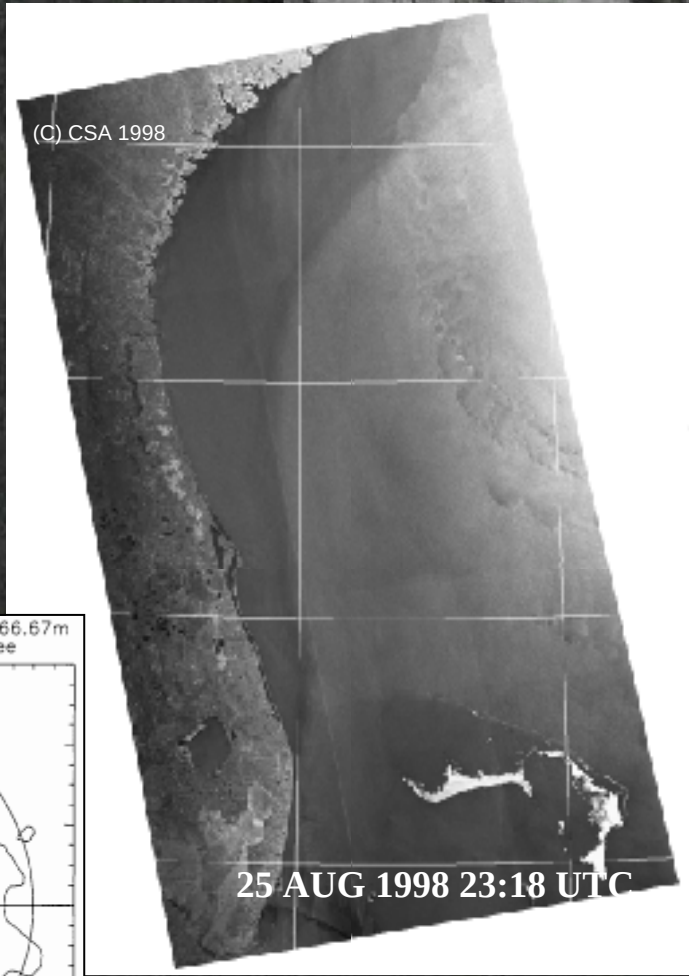
SAR winds with wind direction from NOGAPS

SAR winds with wind direction from QuikSCAT model function

Oceanic SAR Products - Ocean Swell Direction and Wavelength

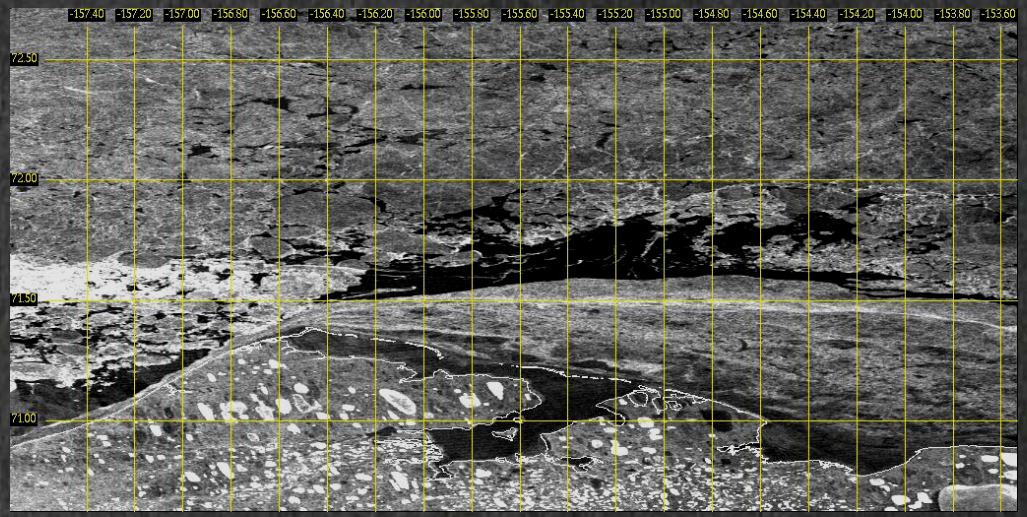






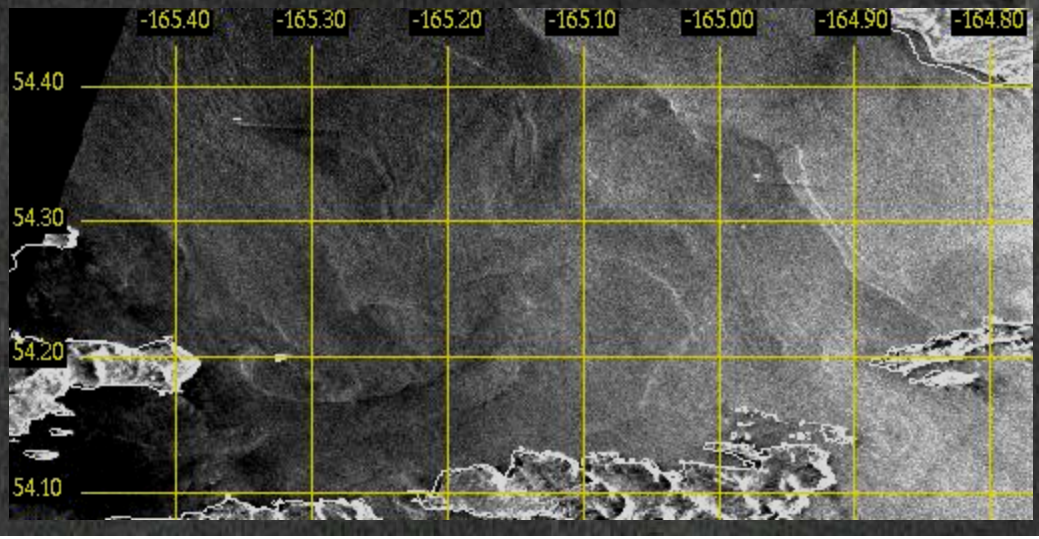
Dual SAR monitoring role for storm-generated swell and associated coastal flooding

Oceanic SAR Products - All-Weather Day/Night Imagery

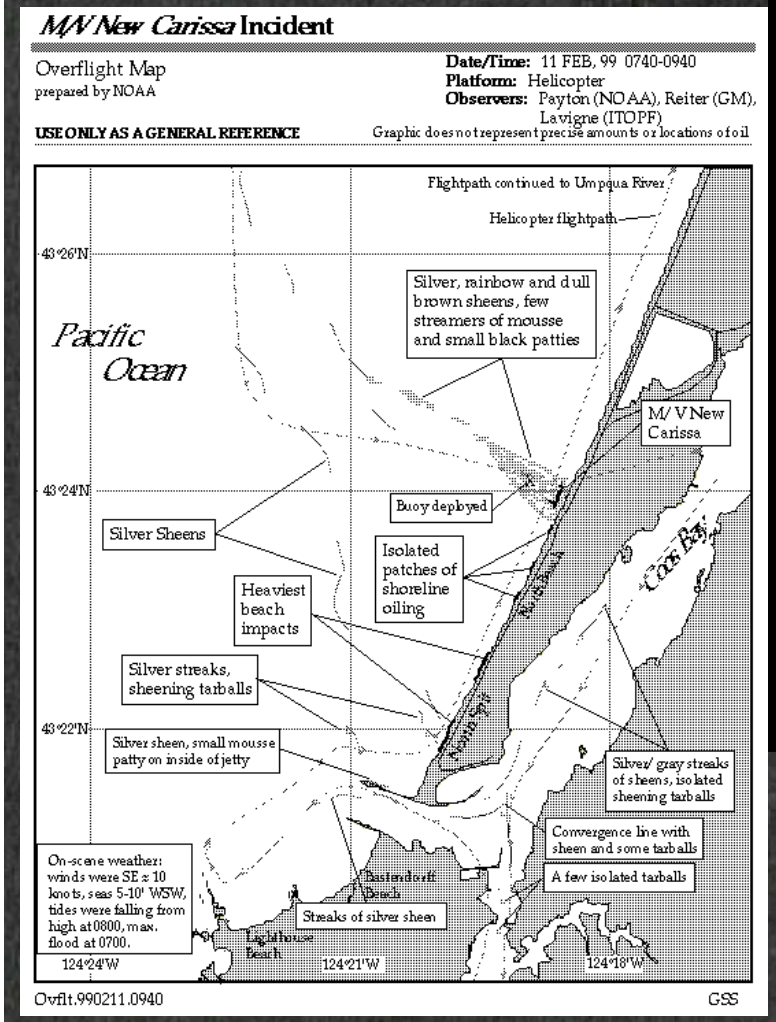


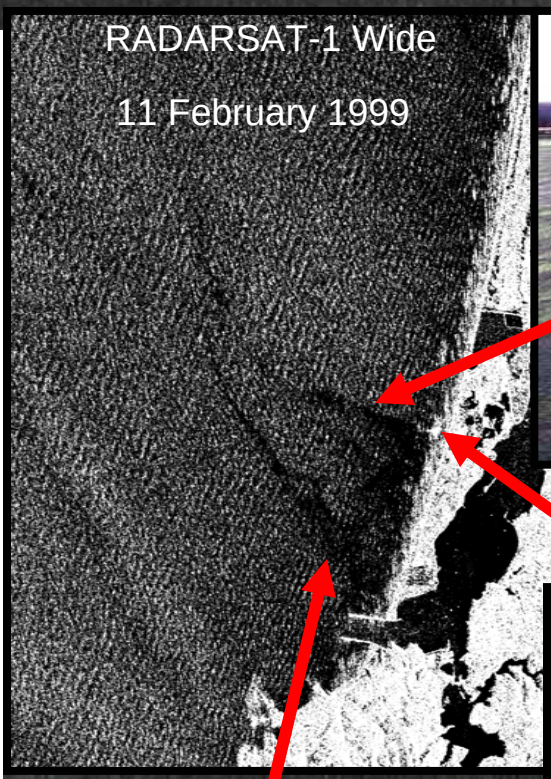
Radarsat-1 Ice Image
Pt. Barrow AK

Radarsat-1 Ocean Features - Aleutian Islands



Oceanic SAR Products - Oil Spill Location

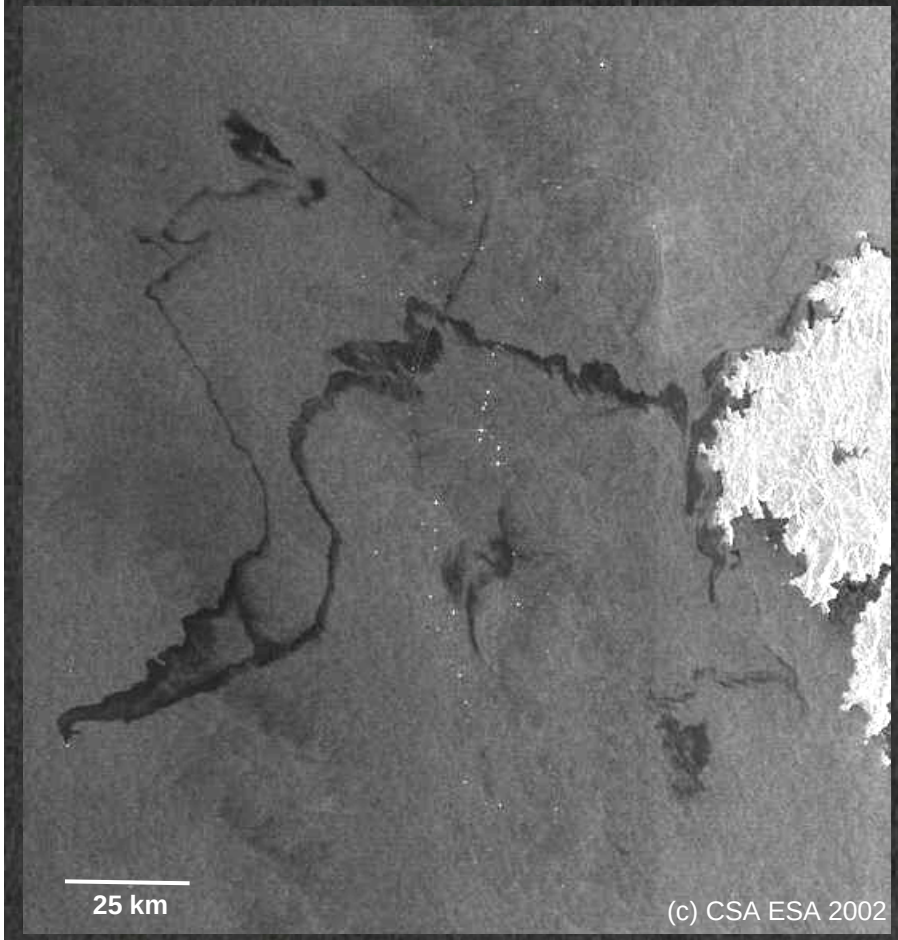




Biogenic slick

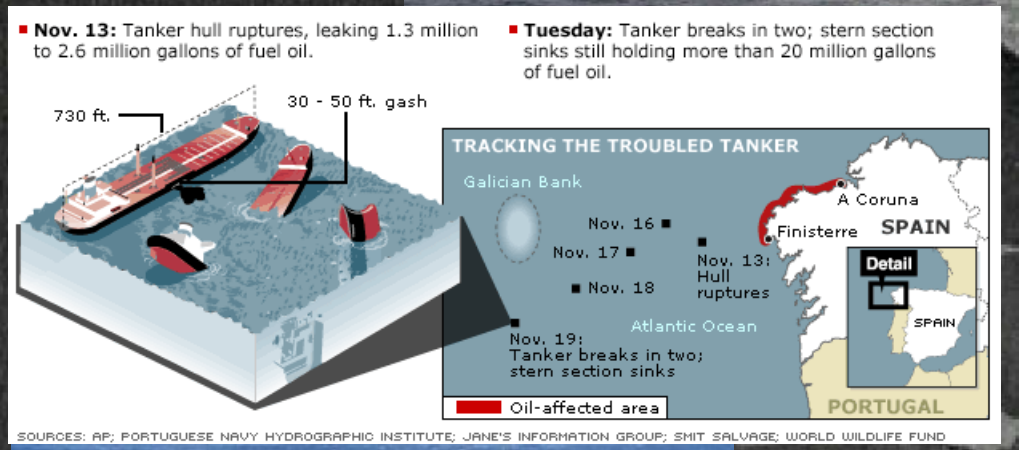
M/V New Carissa Spill - Coos Bay, Oregon

Prestige Oil Spill in La Coruña



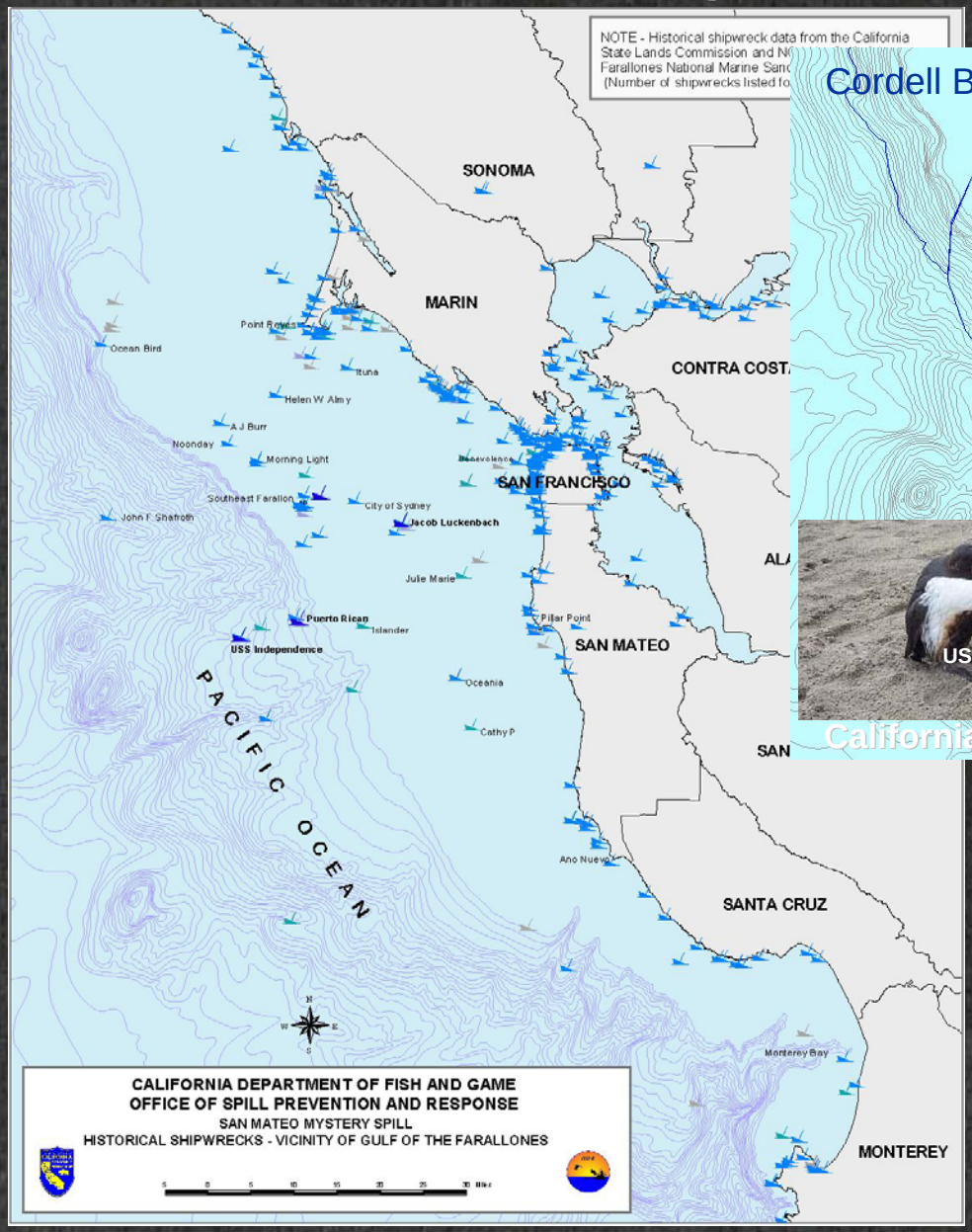
ENVISAT ASAR Wide Swath,
17 November 2002 10:45 UTC

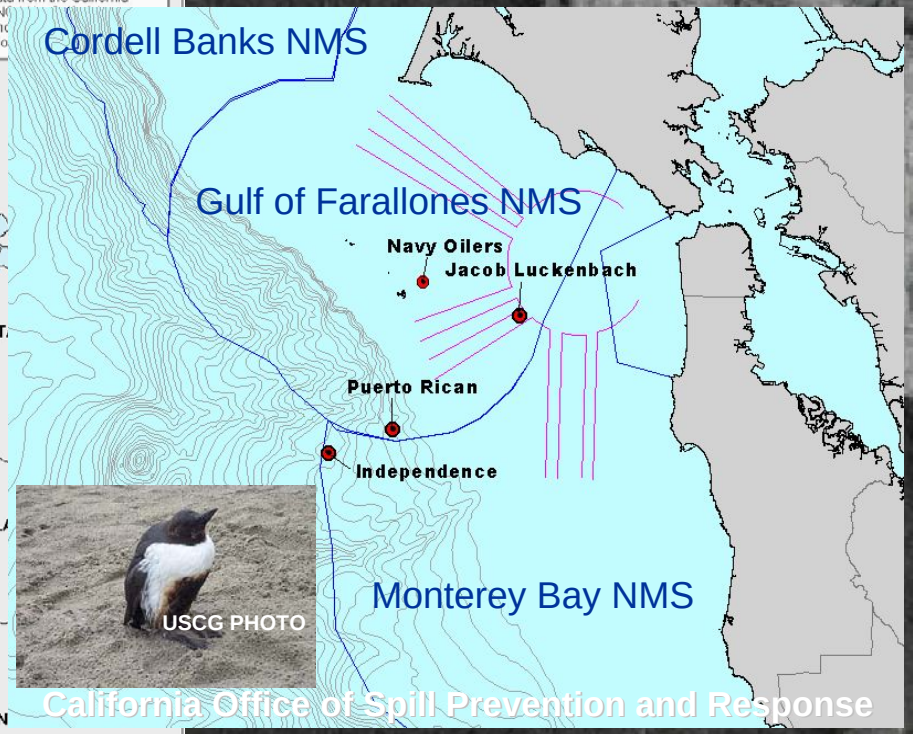
14 NOV



19 NOV

San Francisco Bay Oiled Birds Mystery

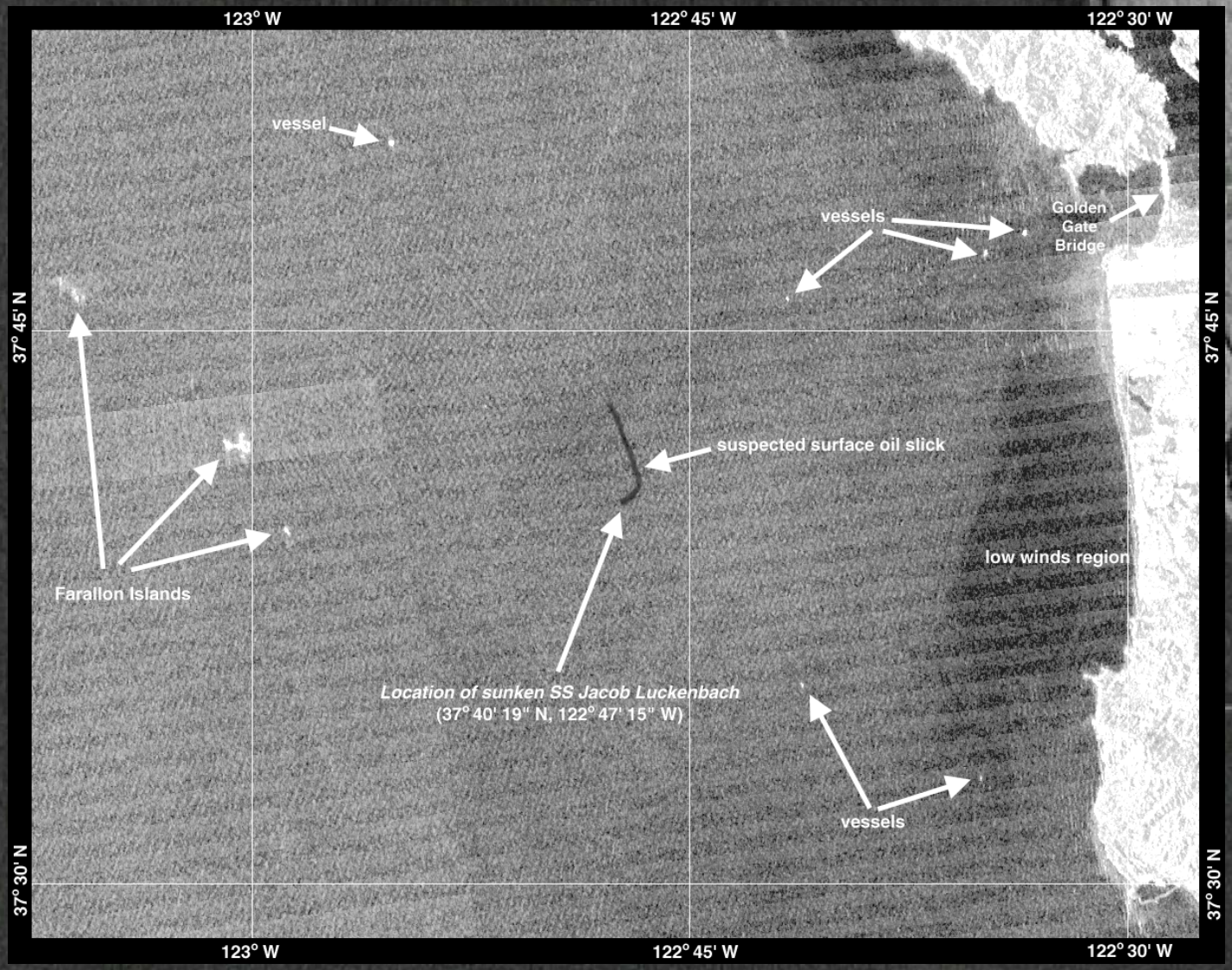




About 1500 sunken vessels Statewide

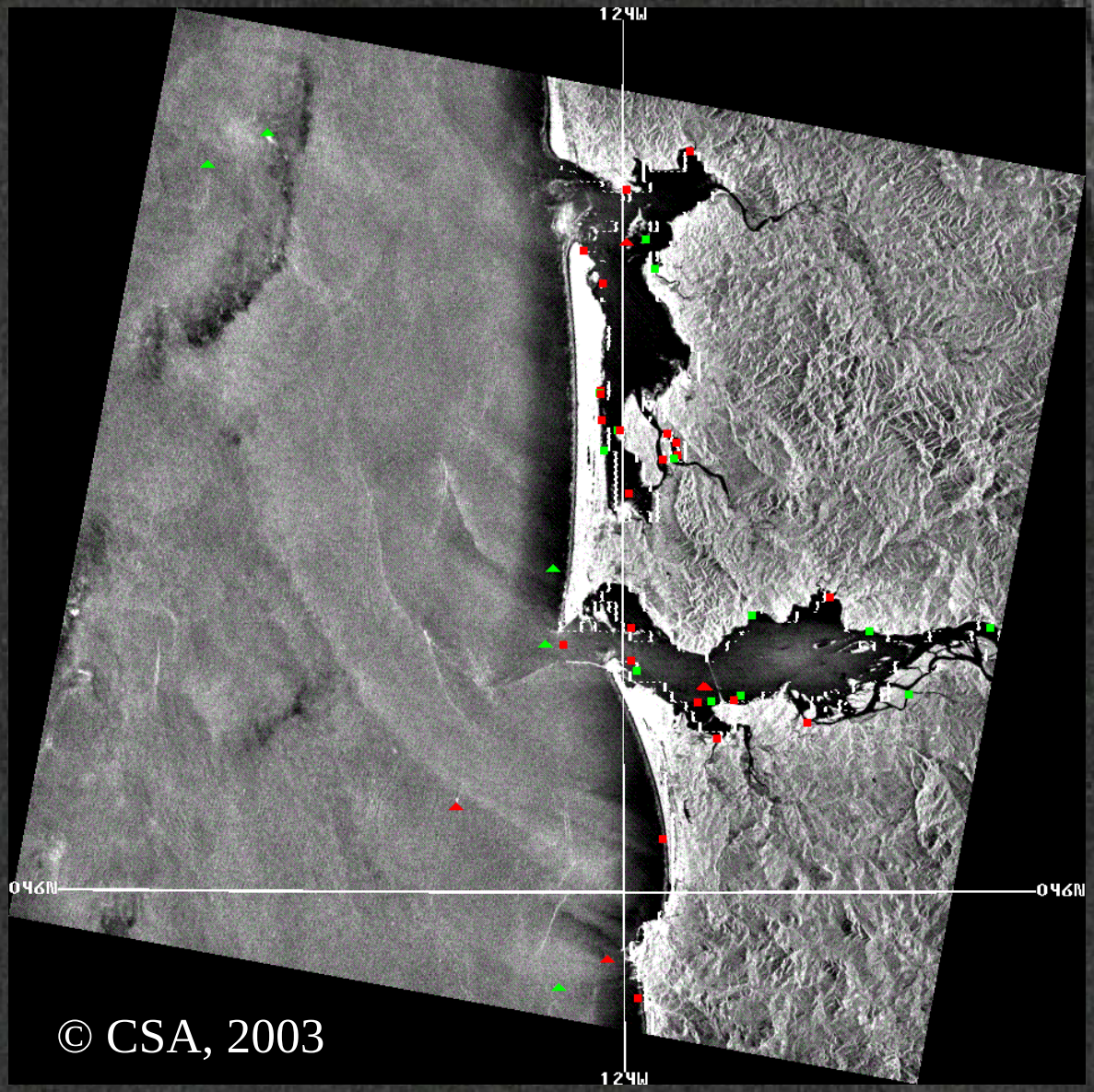
Oil from the Jacob Luckenbach 1953 shipwreck confirmed as responsible for recent oiled bird incidents

San Francisco Bay Oiled Birds Mystery



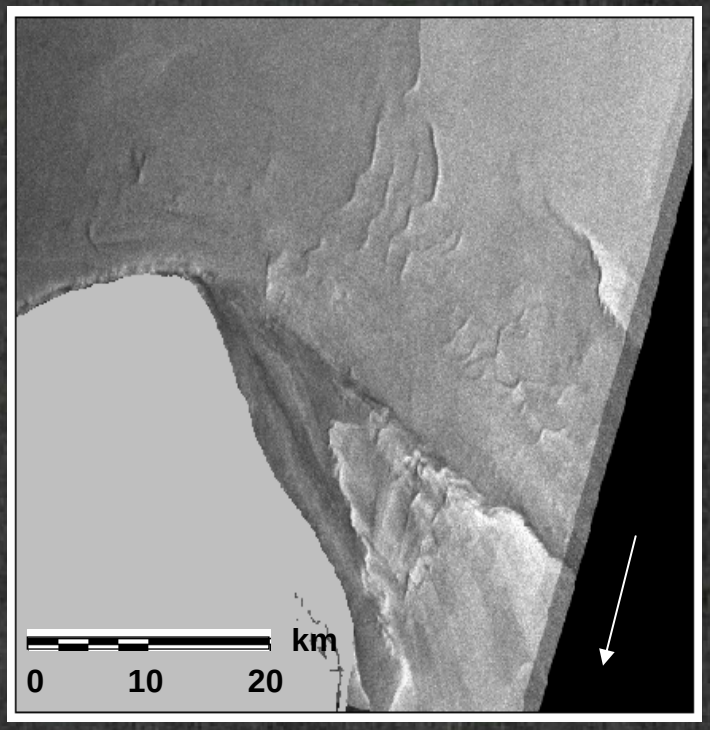
RADARSAT-1 ScanSAR Wide, 9 January 2002 02:09 UTC

Oceanic SAR Products - Vessel Positions



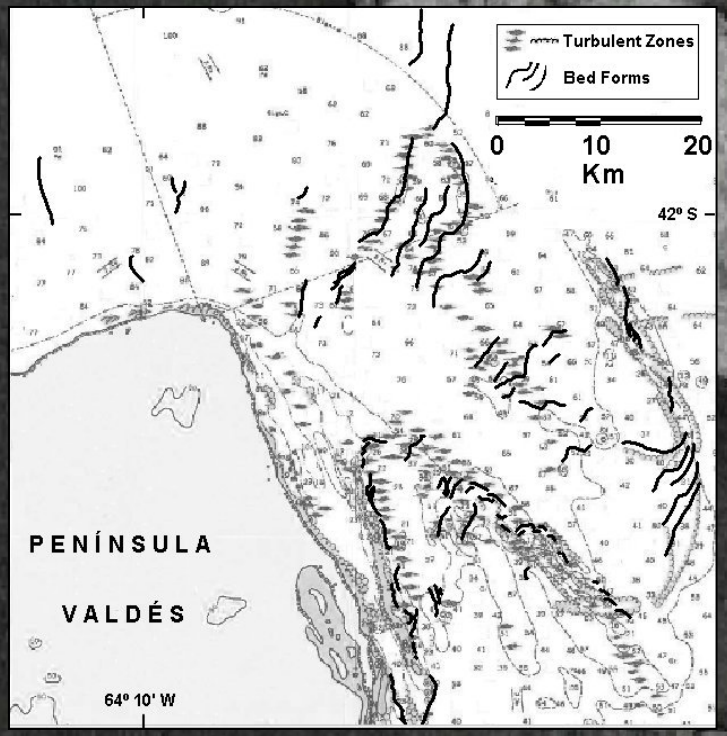
Ship Detection Product April 27, 2003 14:25 UTC

Oceanic SAR Products - Near Shore Bathymetric Features



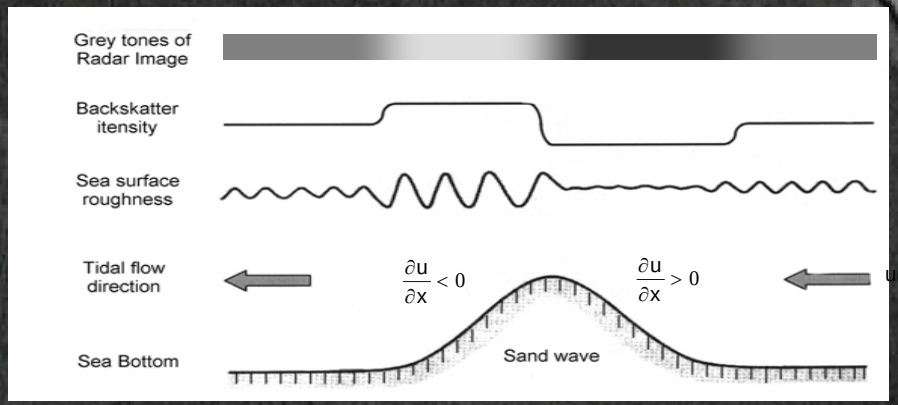
• Multitemporal ERS1/2 SAR composite image (July 9, 1992, February 22, 1998, and September 5, 1999)

• Identified bed forms in SAR imagery of the southern area of the San Matías Gulf entrance overlaid on the Argentine Navy Hydrography Service standard nautical chart

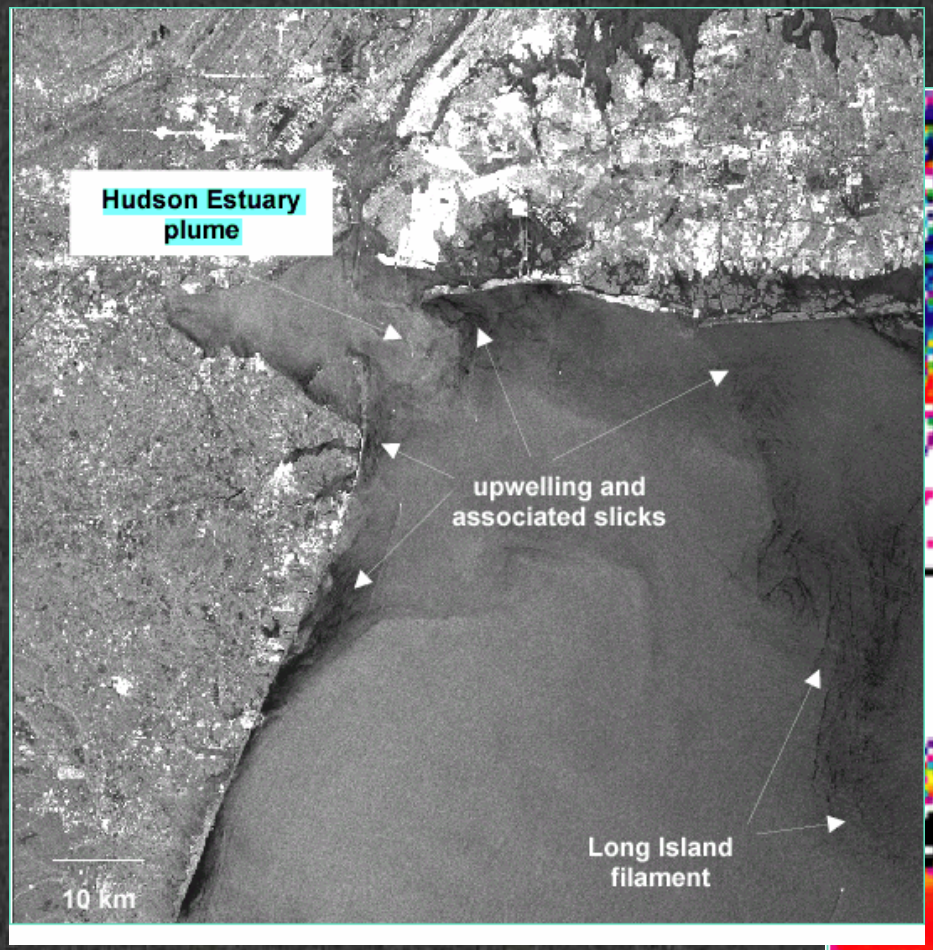


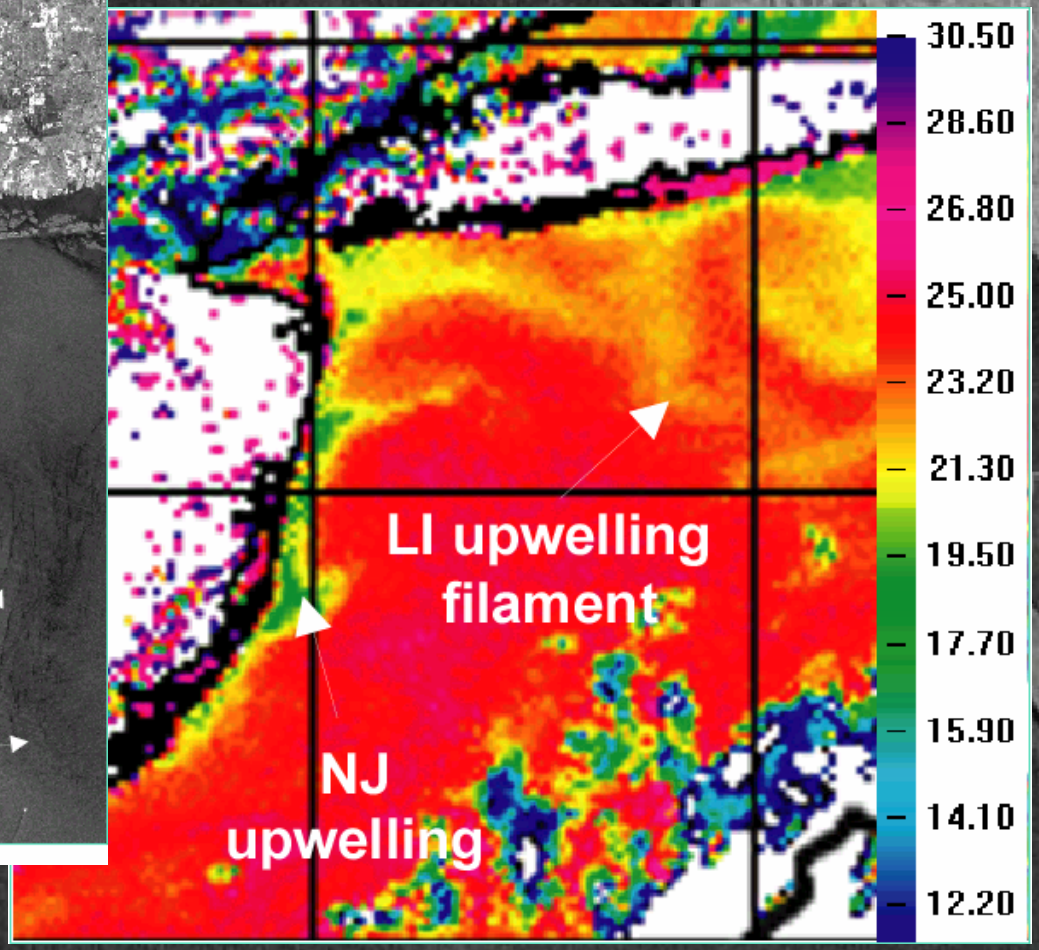
[adapted from Kasischke (1983)]

• Modulations generated when tidal currents encounter an obstacle.



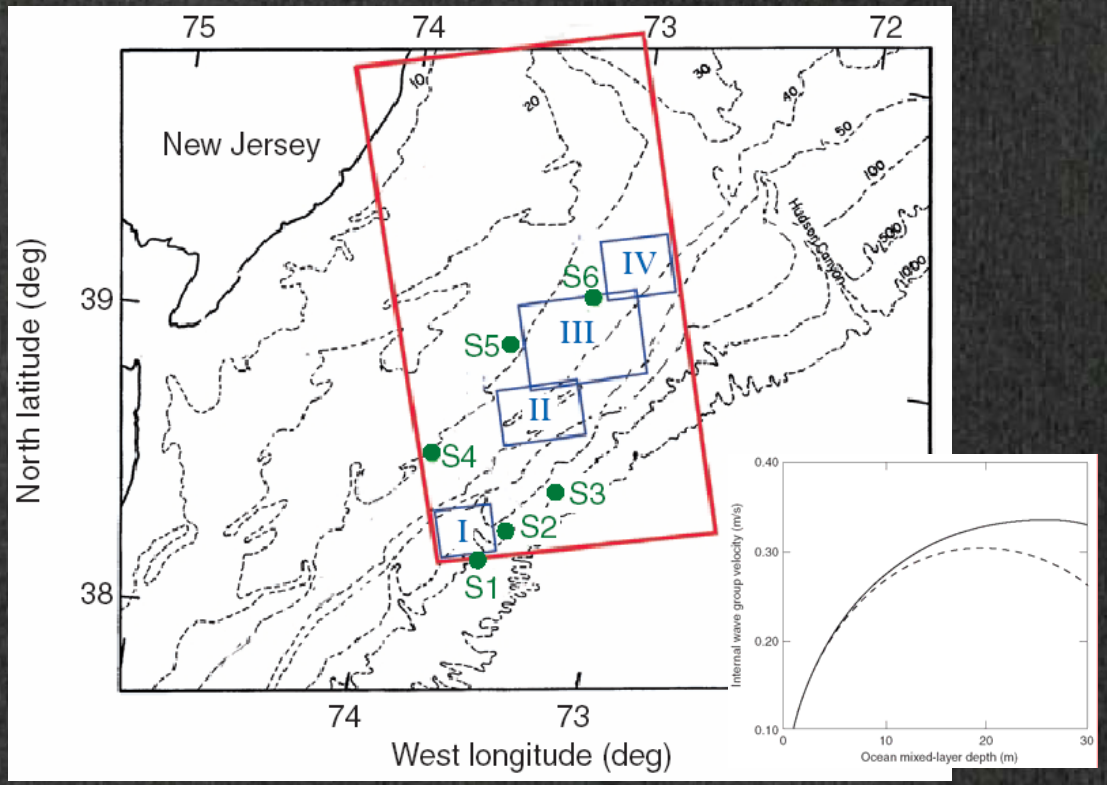
Oceanic SAR Products - Ocean Mesoscale Features

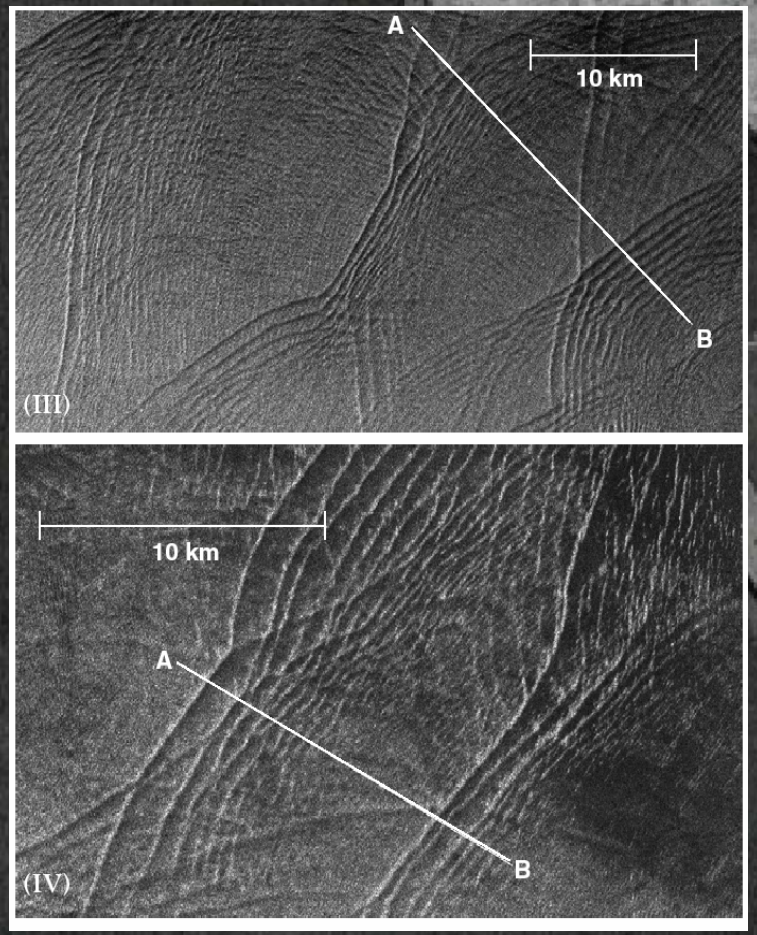




RADARSAT-1 Standard SAR frame and near-coincident AVHRR SST showing upwelling conditions off New Jersey, the Hudson River Estuary, and Long Island on 30 July 1998.

Oceanic SAR Products - Mixed Layer Depth from Internal Wave Measurements





SAR-Related Environmental Data Requirements

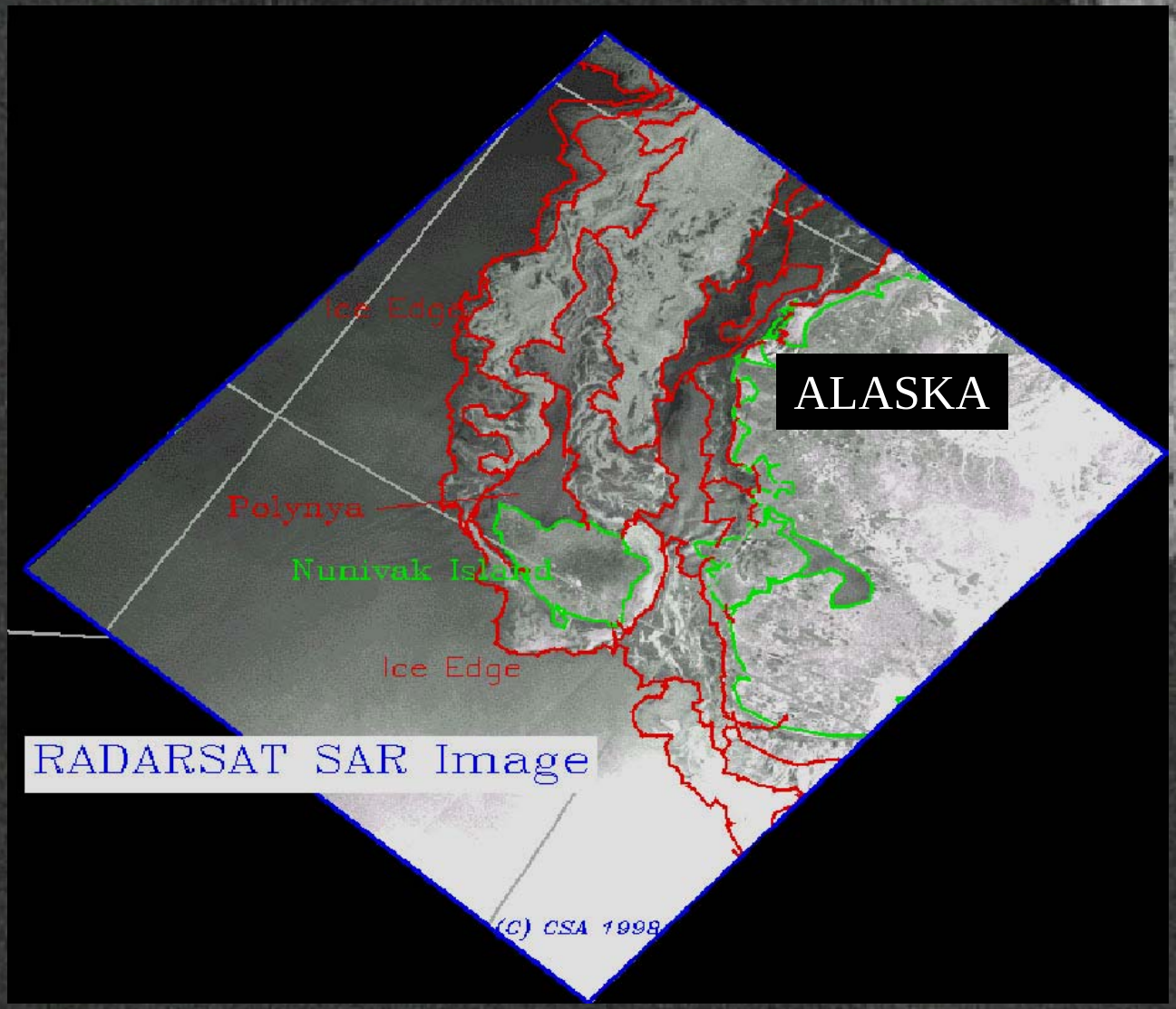
#	EDR TITLE	IORD II Requirement	OO URD Requirement	SOD Interest
	CRYOSPHERIC			
11	Sea & Lake Ice Concentration/Age/Motion/Edge Location	4.1.6.8.7	3.1	X
12	Ice of Land Origin (Icebergs)		3.2	X
13	River Ice Location/Condition		3.5	X
	HYDROLOGIC			
14	Flood Mapping		4.1	X
15	Coastal Wetland Mapping		4.4	X
	LAND			
16	Coastal Change		5.5	X
	ATMOSPHERIC			
17	Mesoscale Atmospheric Features		6.1	X
18	Microscale Atmospheric Features		6.2	X

Note: IORD = Integrated Operational Requirements Document
OO URD = Ocean Observer User Requirements Document
ORAD = Oceanic Research and Applications Division

Routine NOAA Products

NESDIS Research Products

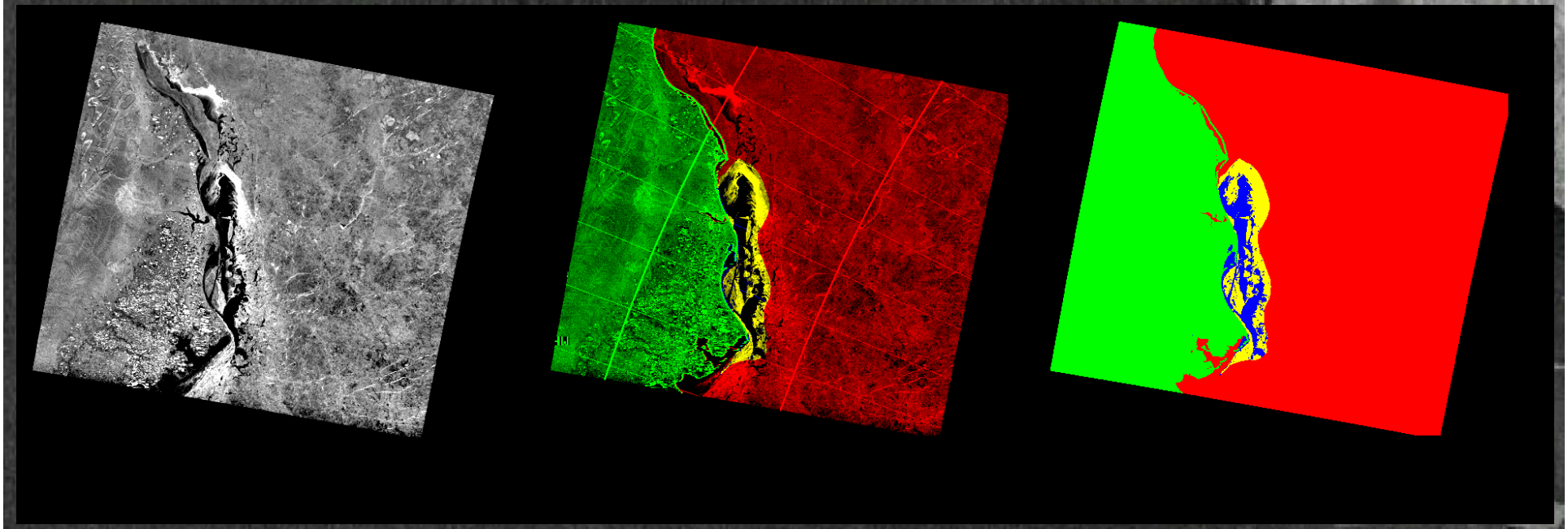
Cryospheric SAR Products - Sea Ice



National Ice Center Alaska Ice Analysis

Cryospheric SAR Products - Ice Mask

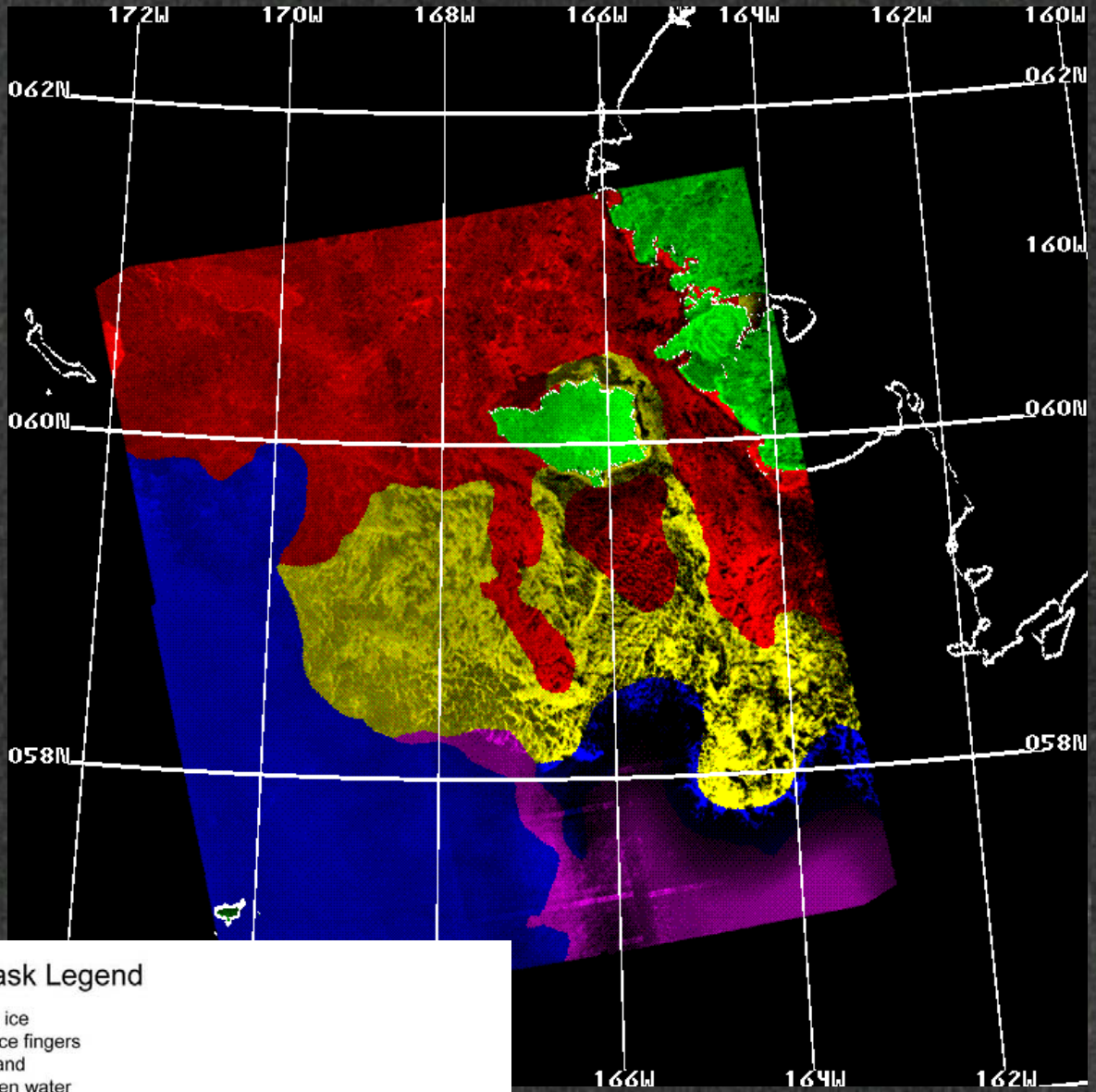
SAR Image **Ice Map Image** **Ice Map Mask**



Ice Mask is used to filter out ice in ship detection and coastal winds products in the Alaska SAR Demonstration

Red = solid ice
Yellow = ice filaments
Blue = water
Green = land

Ice Mask Product - January 2003



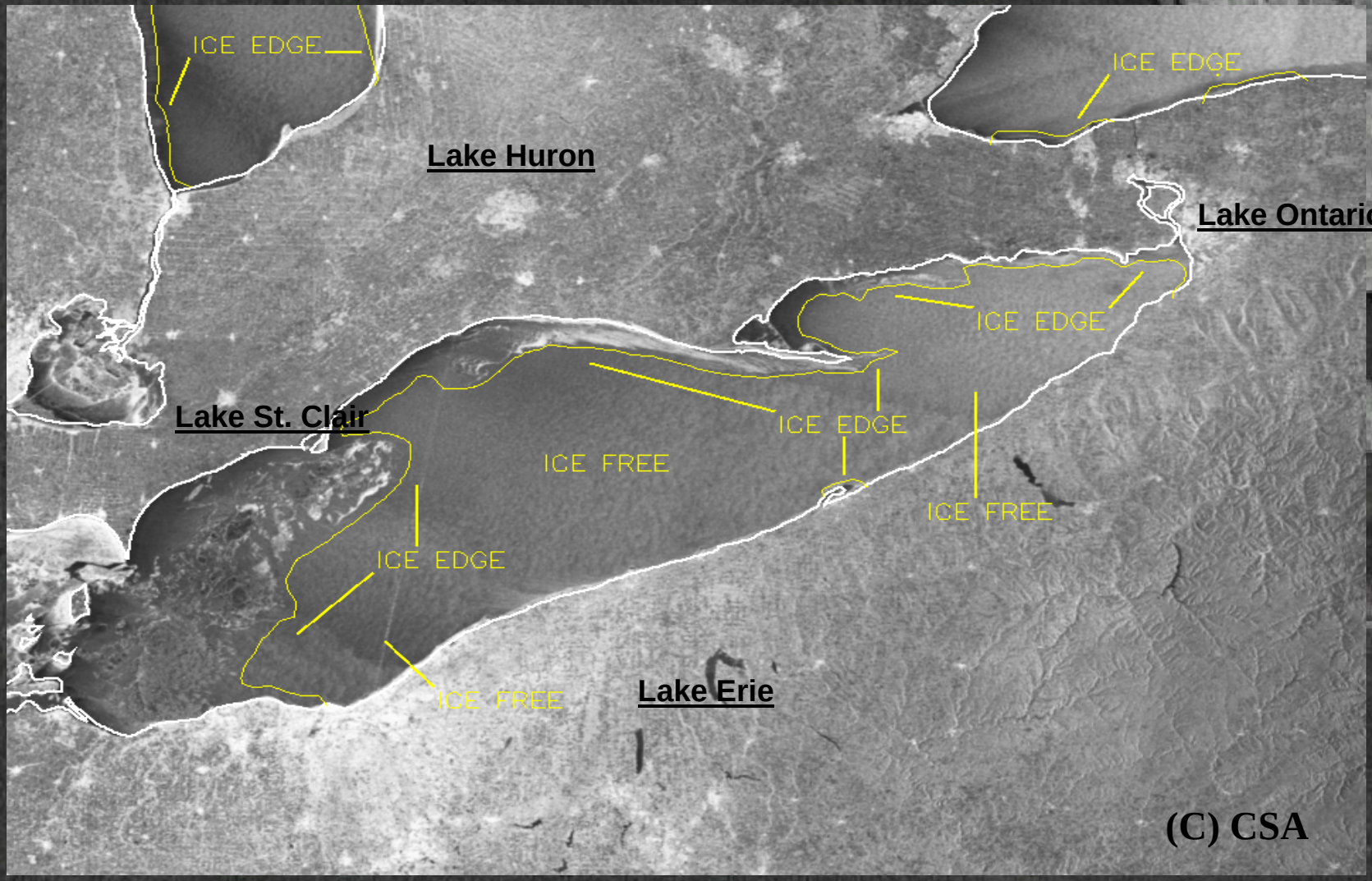
Ice Mask Legend

- red = sea ice
- yellow = ice fingers
- green = land
- blue = open water
- purple = rough open water (due to high winds and/or currents/fronts)

Veridian Ice Mask 3/29/03 0445Z

VERIDIAN

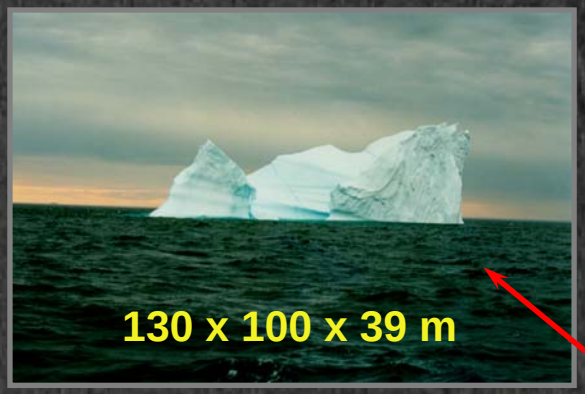
Cryospheric SAR Products - Lake Ice

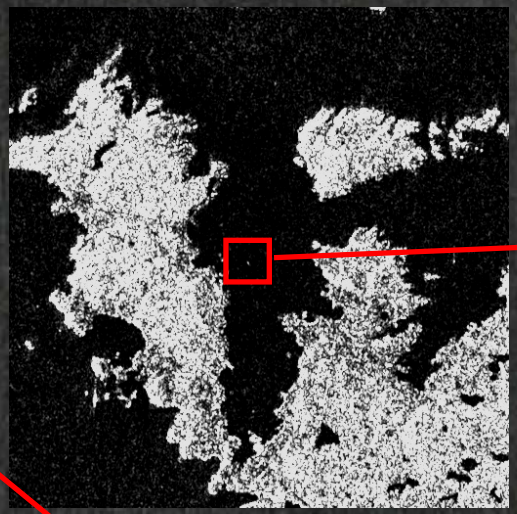


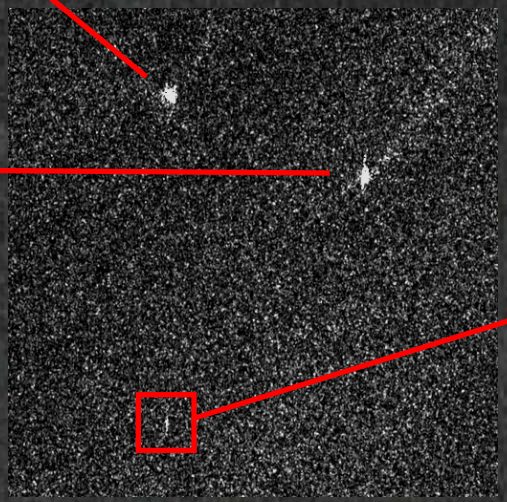
National Ice Center Great Lakes Ice Analysis

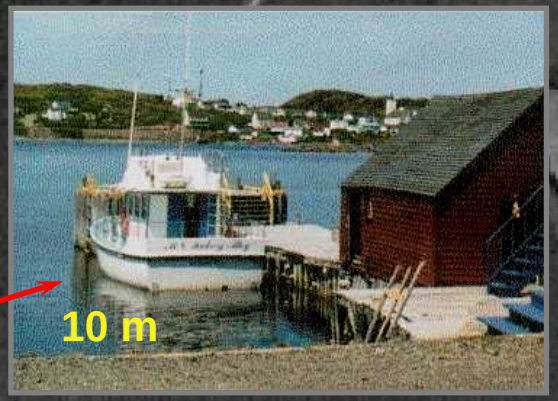
Cryospheric SAR Products - Icebergs

RADARSAT-1 Wide 3: Swath: 150 km - Resolution: 25 m



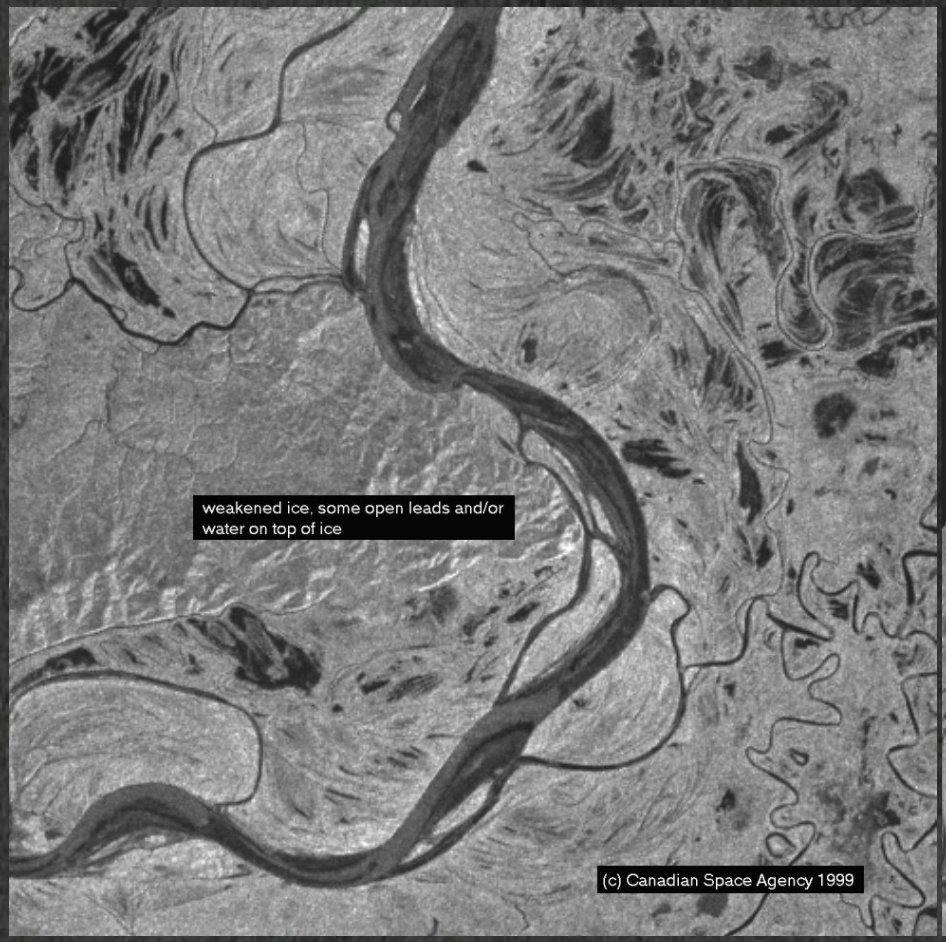




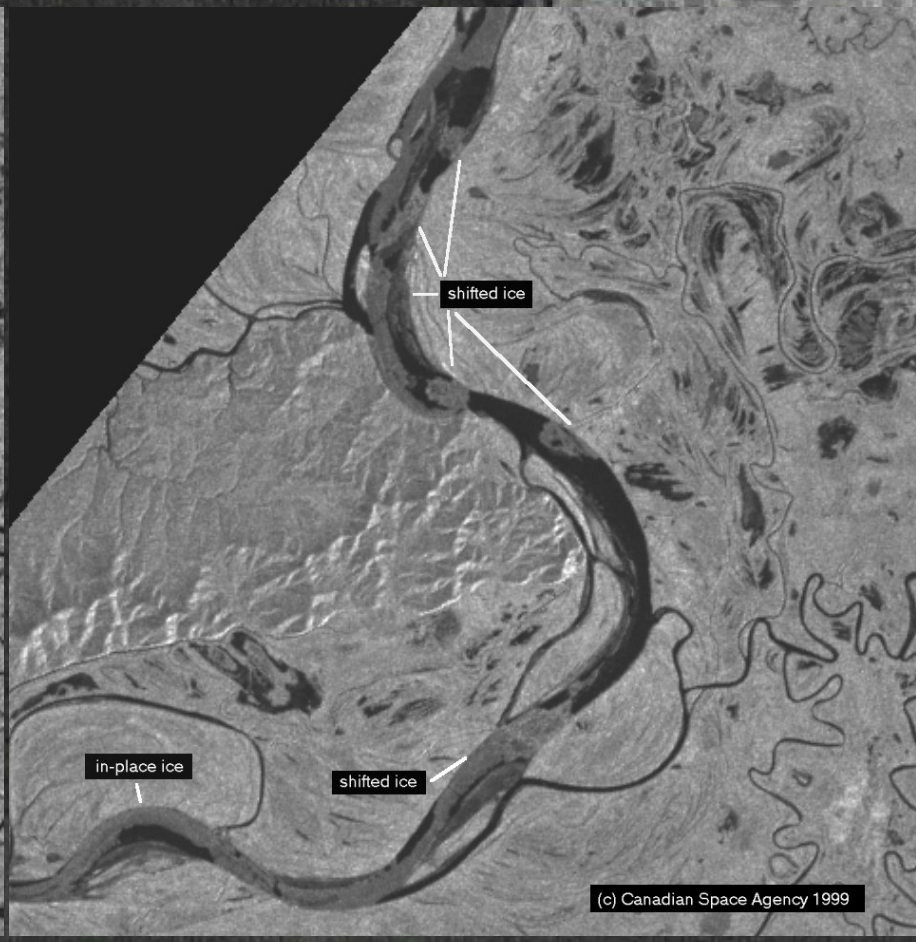


Cryospheric SAR Products - River Ice

Lower Yukon River
16 May 1999

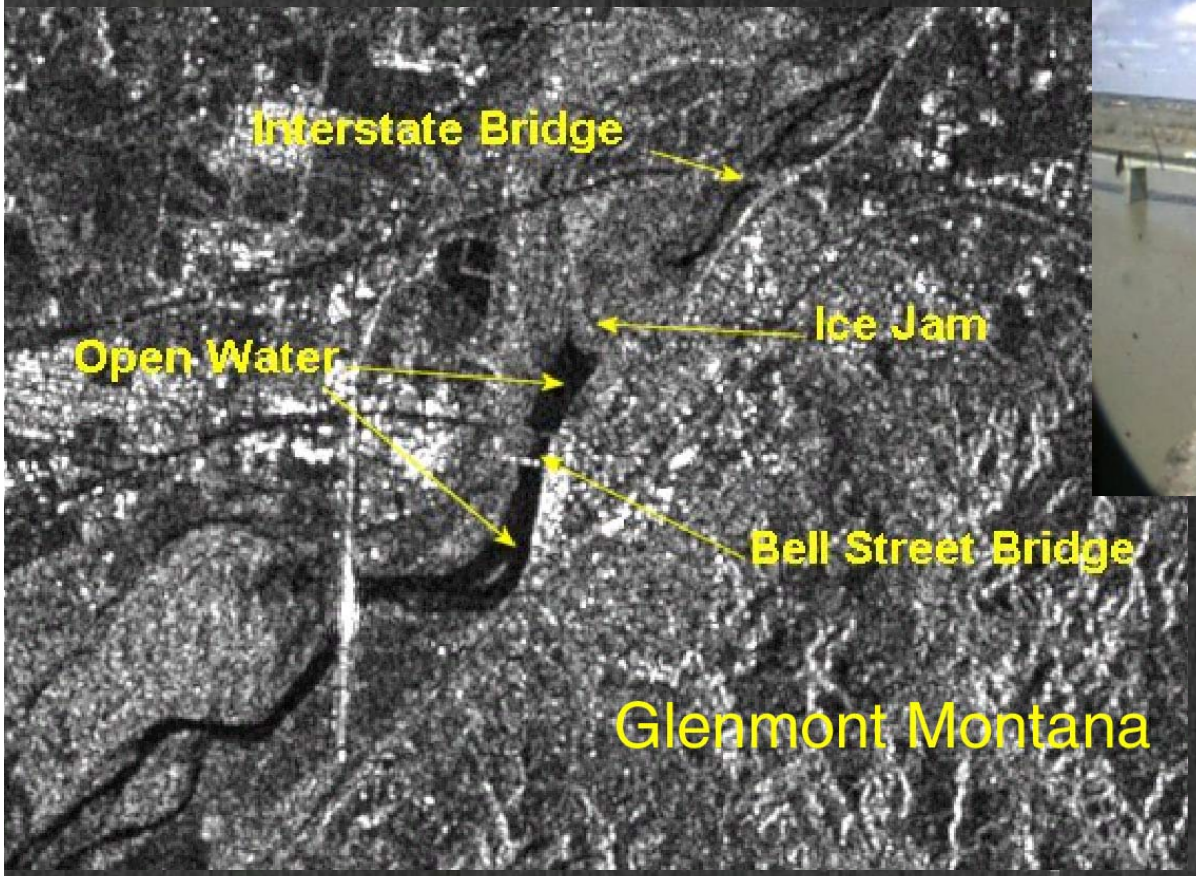


Lower Yukon River
19 May 1999



River ice breakup and jamming is routinely monitored for the development of potential flooding conditions

Monitoring Spring Ice Break-up on the Yellowstone River, Montana

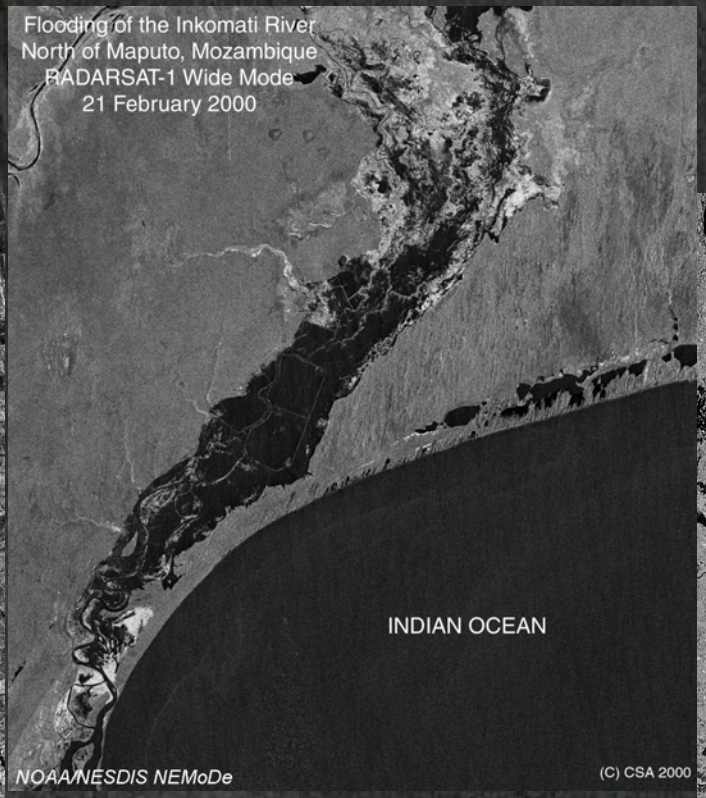


Ice Jam North of Bell Street Bridge Glenmont, Montana

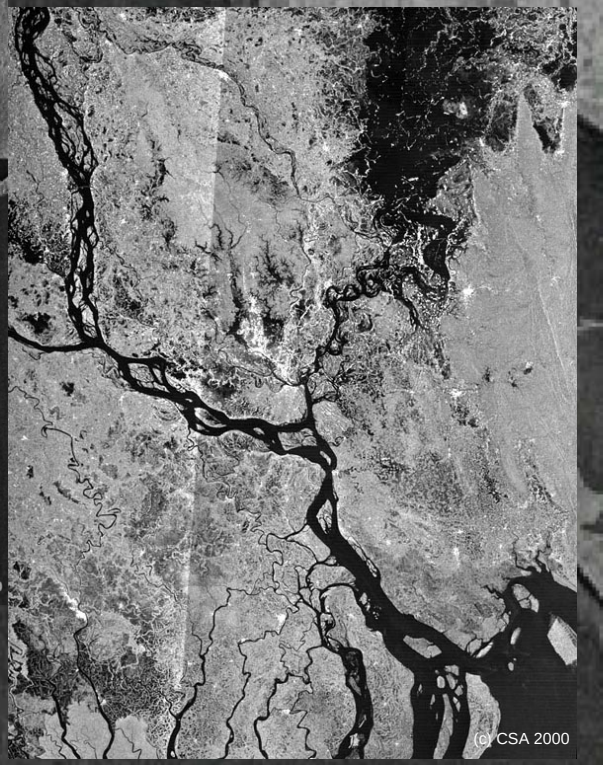
Hydrologic SAR Products - Flood Mapping

Red River – 4 MAY 97

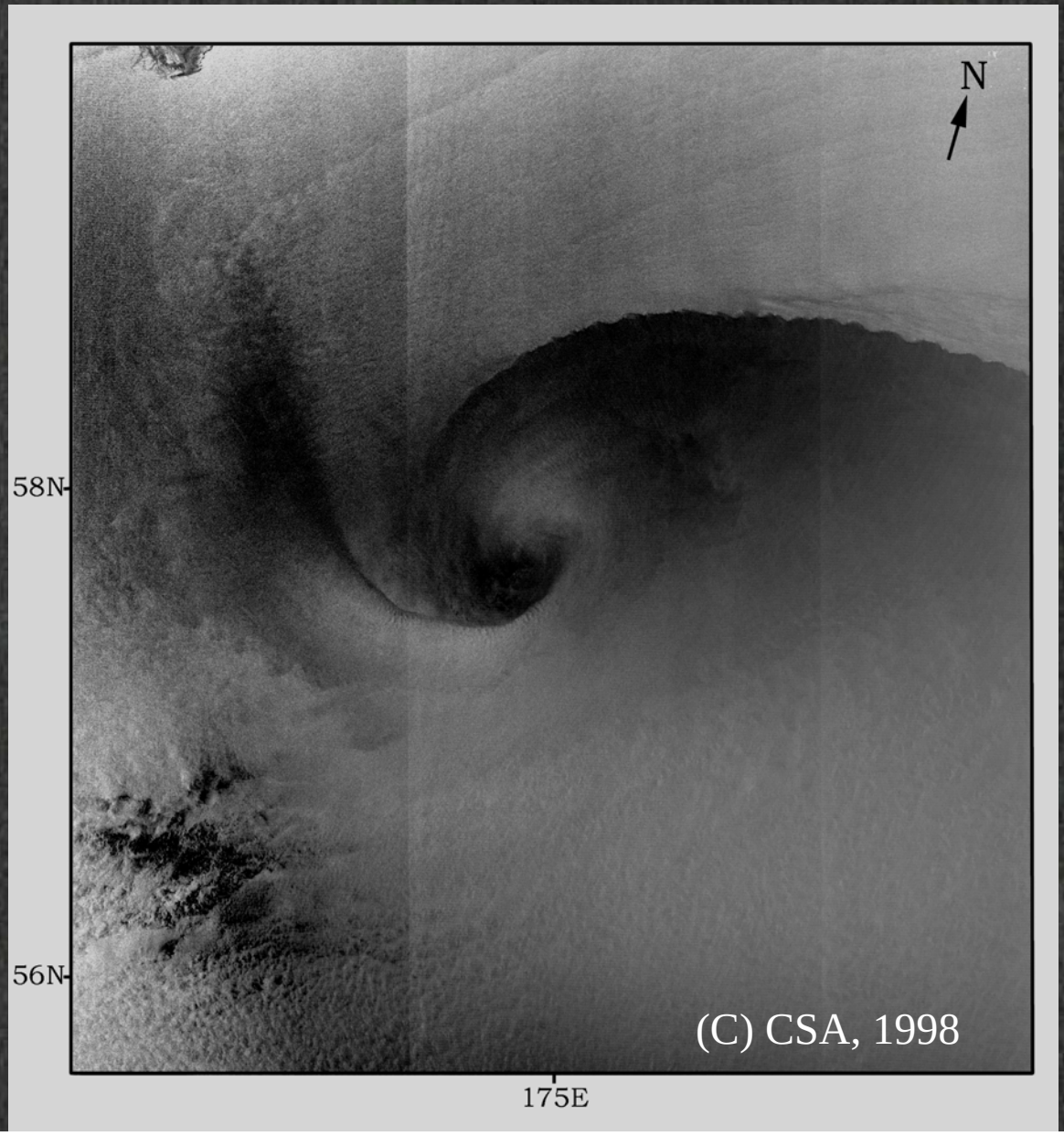
Inkomati River – 21 FEB 00



Ganges River – 21 AUG 00

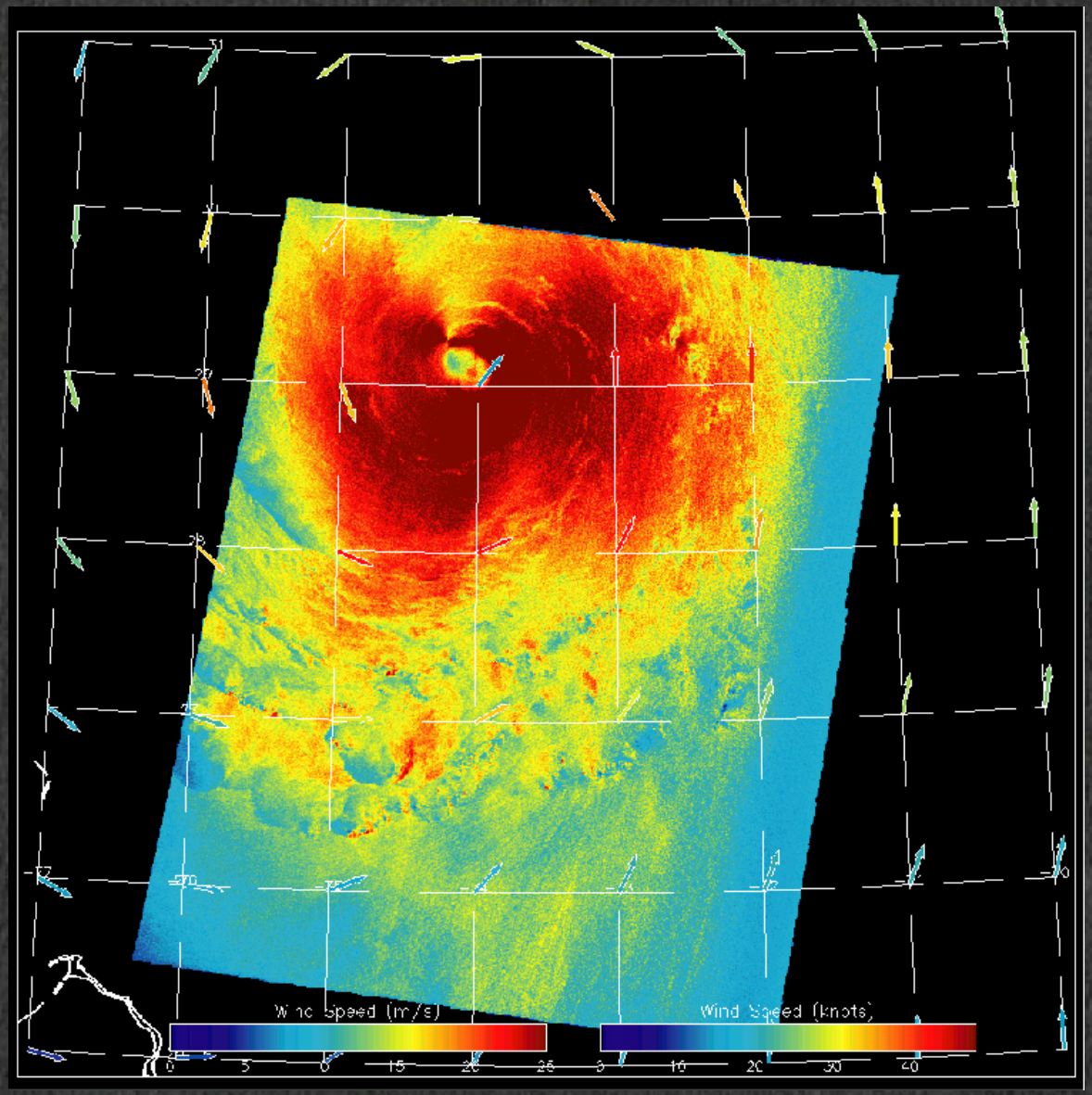


Atmospheric SAR Products - Atmospheric Mesoscale Features



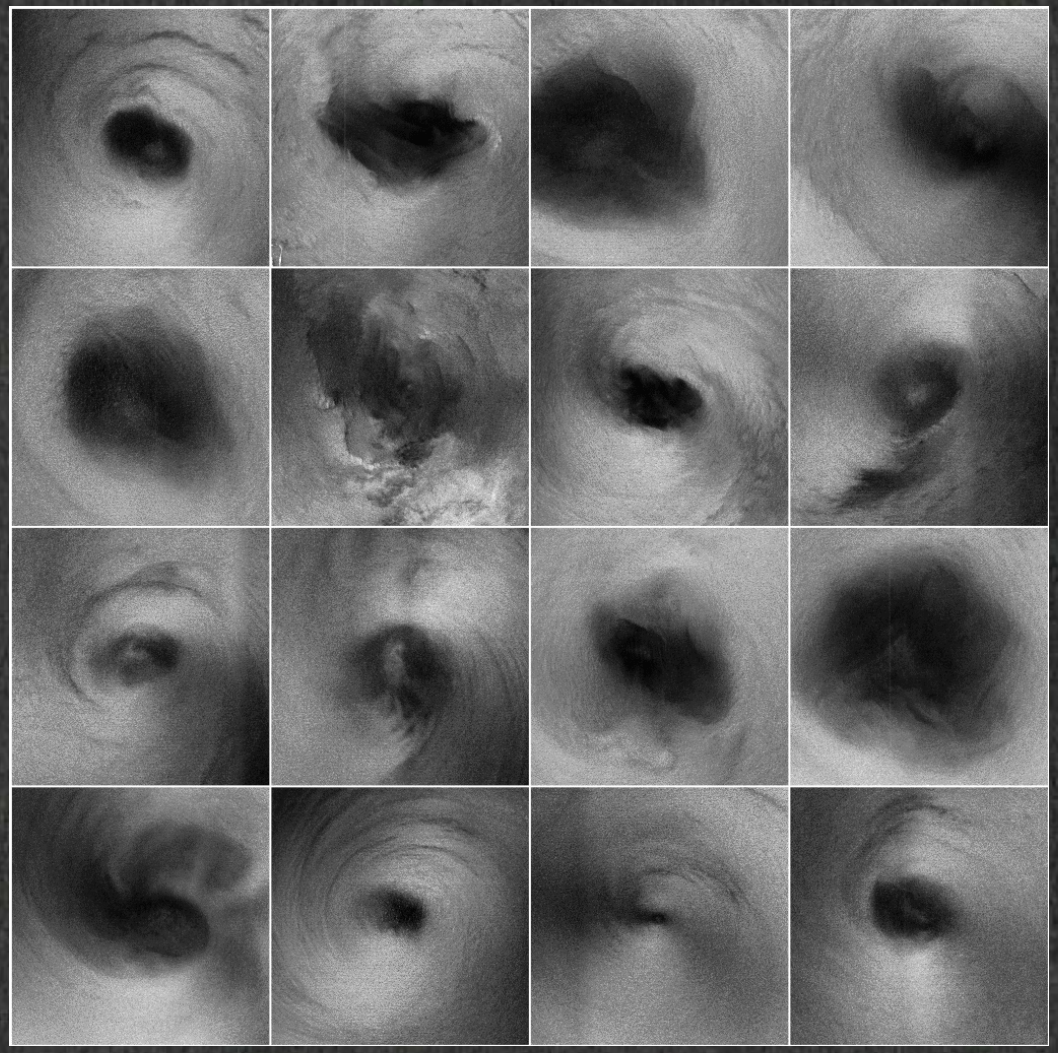
Polar Mesoscale Cyclone in Bering Sea February 5, 1998

Hurricane Studies



RADARSAT-1 SWB wind image capturing Hurricane Danielle on 31 August 1998.

Atmospheric SAR Products - Atmospheric Mesoscale Features



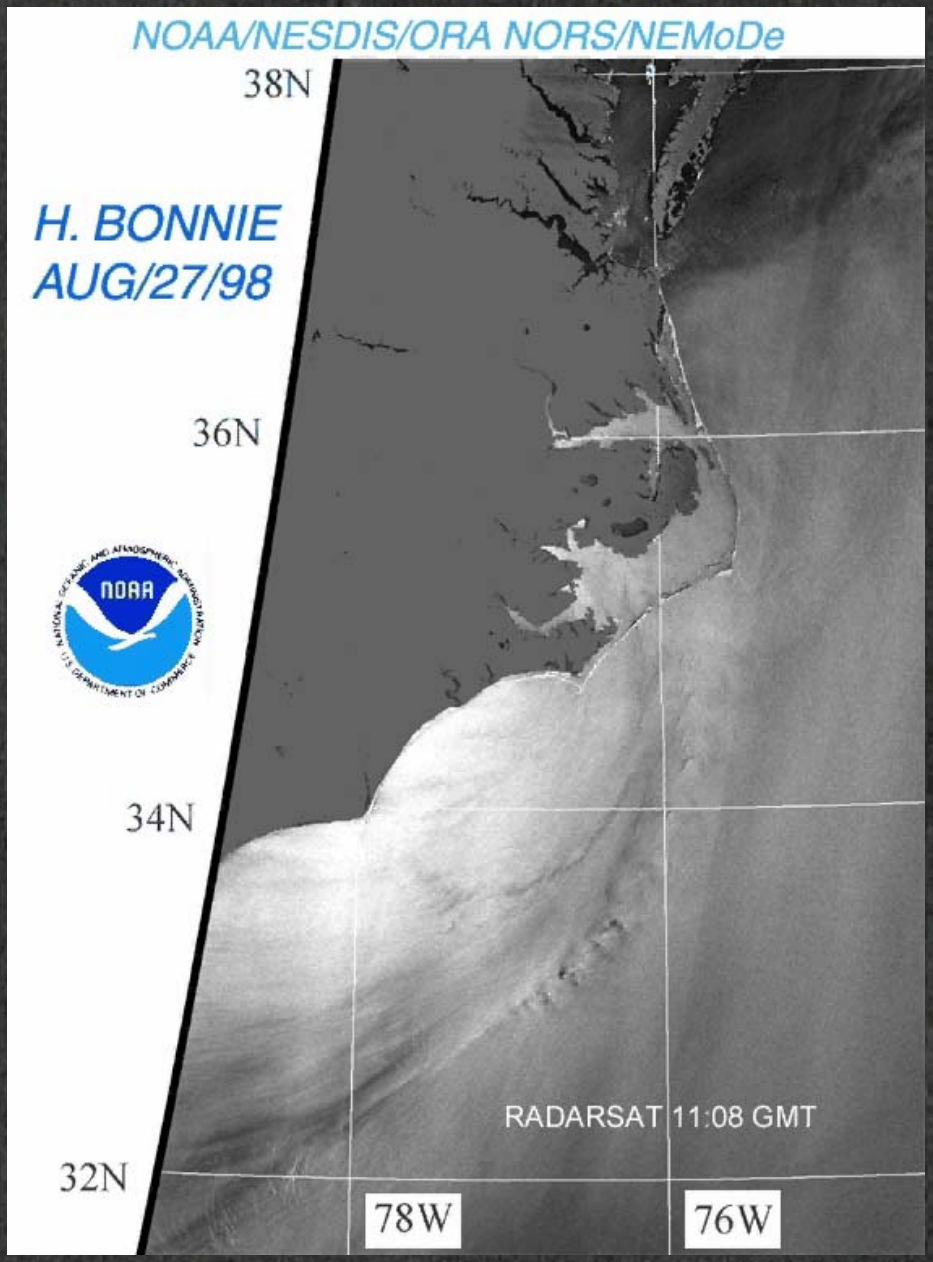
100 km

[CSA Hurricane Watch Project]

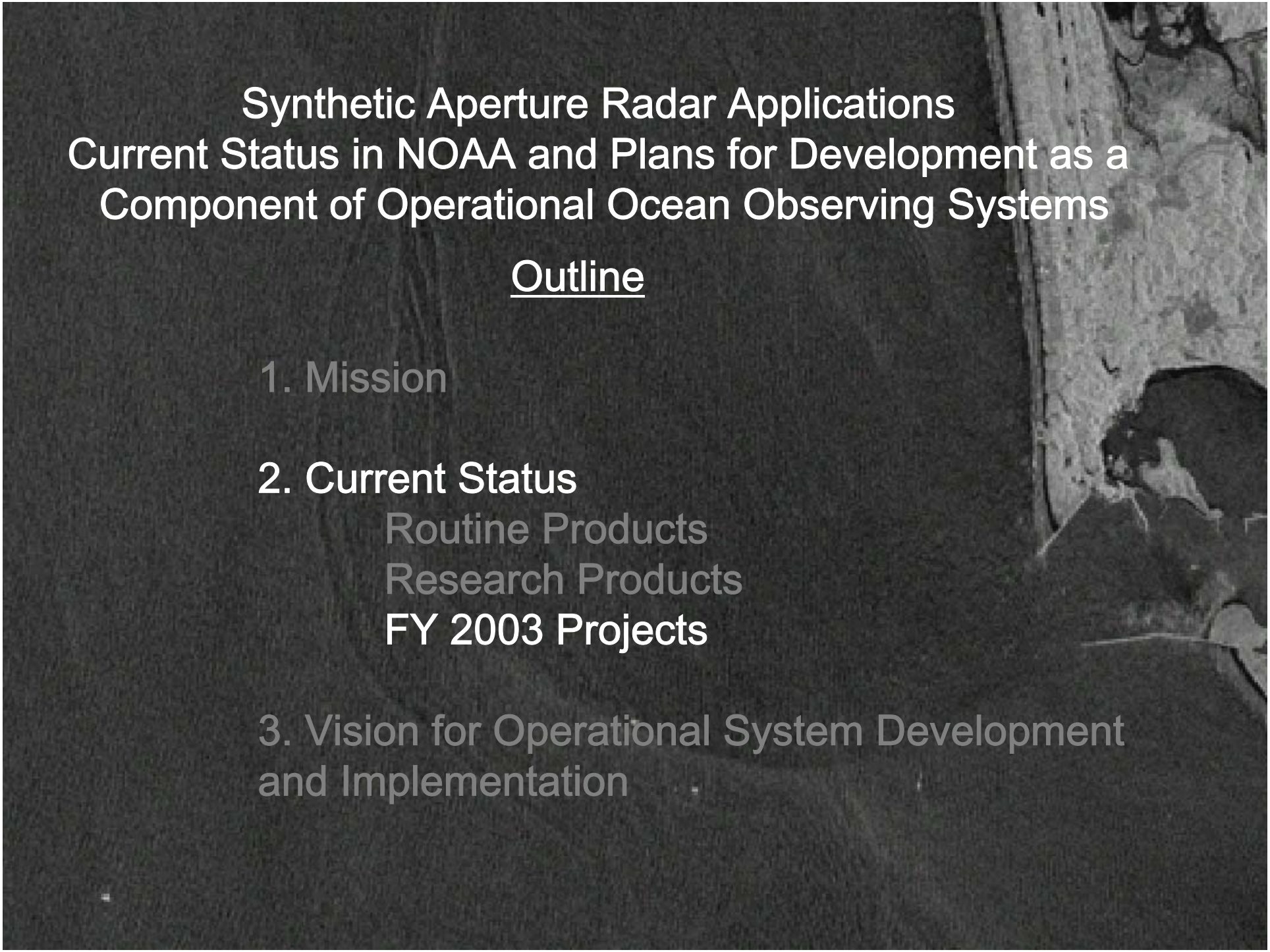
Danielle 31 Aug ‘98	Dennis 27 Aug ‘99	Dennis 29 Aug ‘99	Dennis 31 Aug ‘99
Floyd 15 Sep ‘99	Alberto 17 Aug ‘00	Florence 13 Sep ‘00	Dalila 26 Jul ‘01
Flossie 29 Aug ‘01	Flossie 1 Sep ‘01	Erin 11 Sep ‘01	Erin 13 Sep ‘01
Felix 17 Sep ‘01	Humberto 26 Sep ‘01	Juliette 27 Sep ‘01	Olga 28 Nov ‘01

Hurricane Eye Wall Studies

Atmospheric SAR Products - Atmospheric Mesoscale Features



Hurricane Precipitation Studies



Synthetic Aperture Radar Applications
Current Status in NOAA and Plans for Development as a Component of Operational Ocean Observing Systems

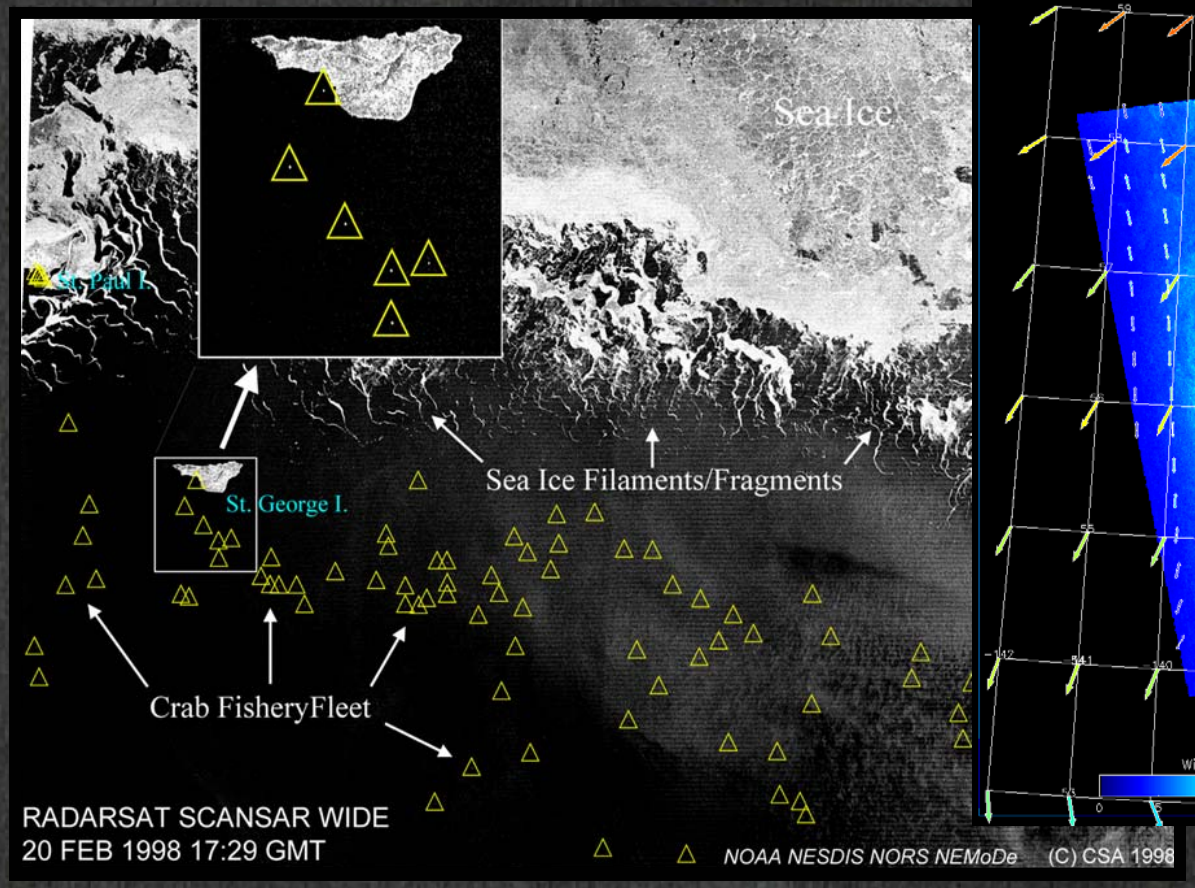
Outline

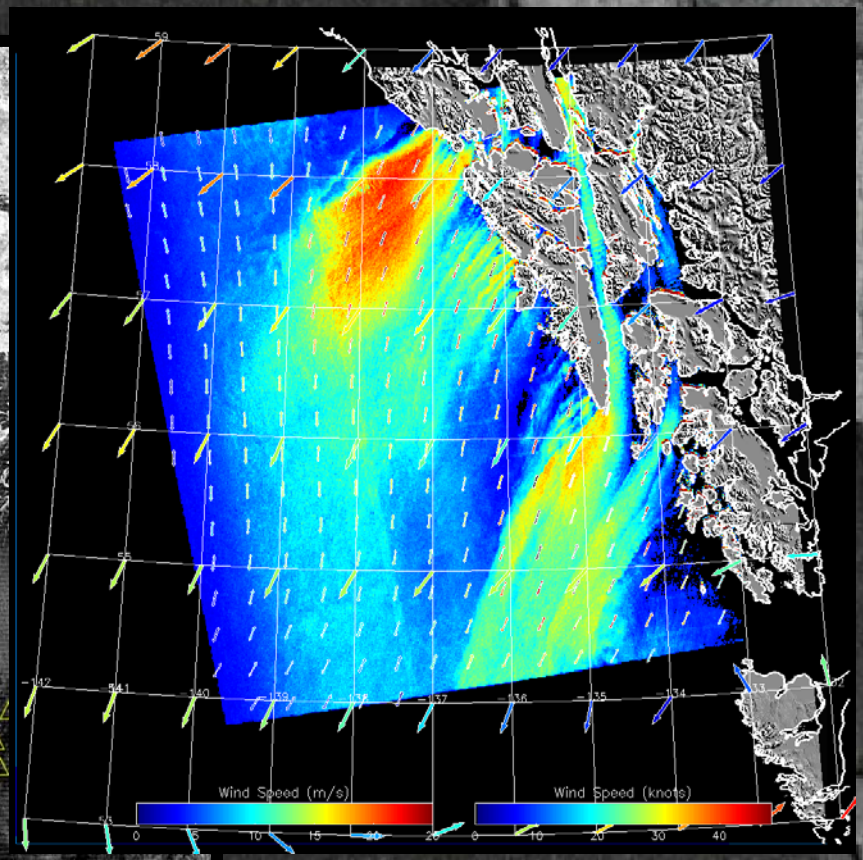
1. Mission

2. Current Status
   - Routine Products
   - Research Products
   - FY 2003 Projects

3. Vision for Operational System Development and Implementation

SSR Project 1 - Alaska SAR Demonstration





March 19, 2001 02:48 GMTB

GOAL: Applications Demonstration of Automated SAR Applications in Alaska Waters for Operational Agencies

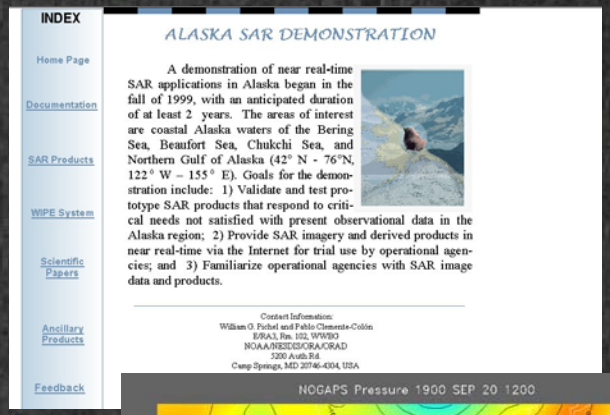
COLLABORATORS: JHU/APL, Veridian, ACT

PRODUCTS: Coastal Winds, Vessel Positions, Ice Masks, SAR Imagery (used for Sea Ice and River Ice Analyses)

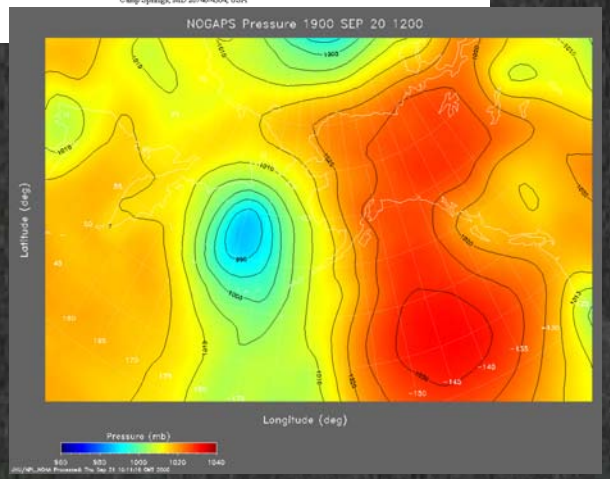
Alaska SAR Demonstration

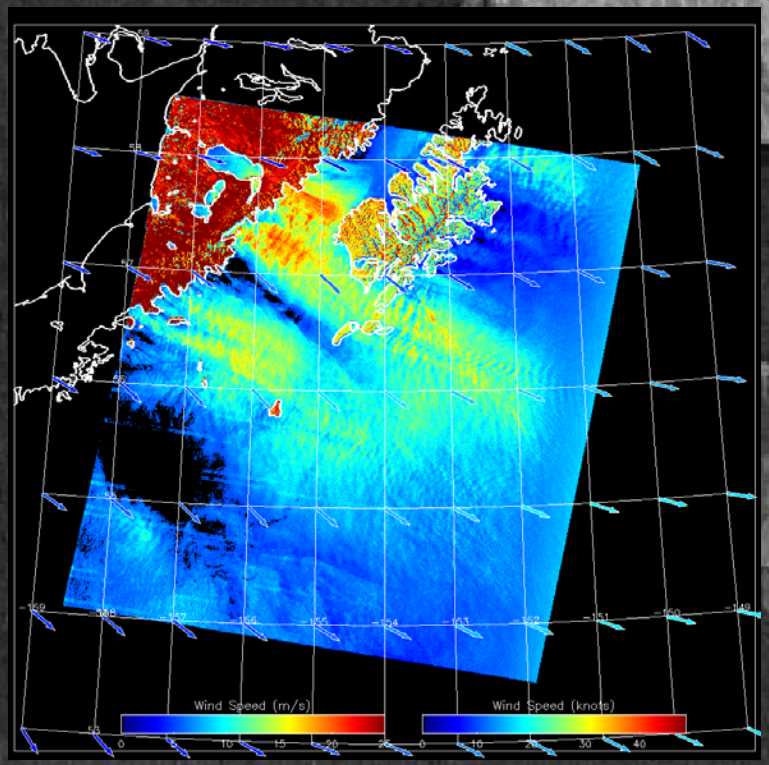
Initial Product Implementation - October 1999

WEB SITE



ANCILLARY FIELDS



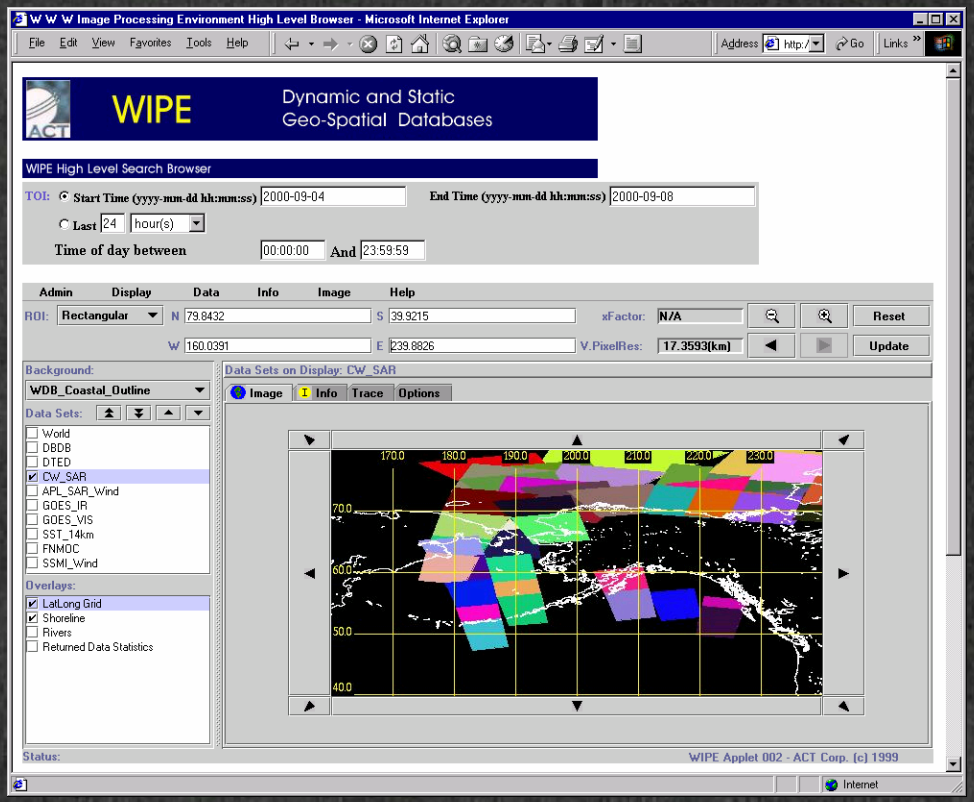


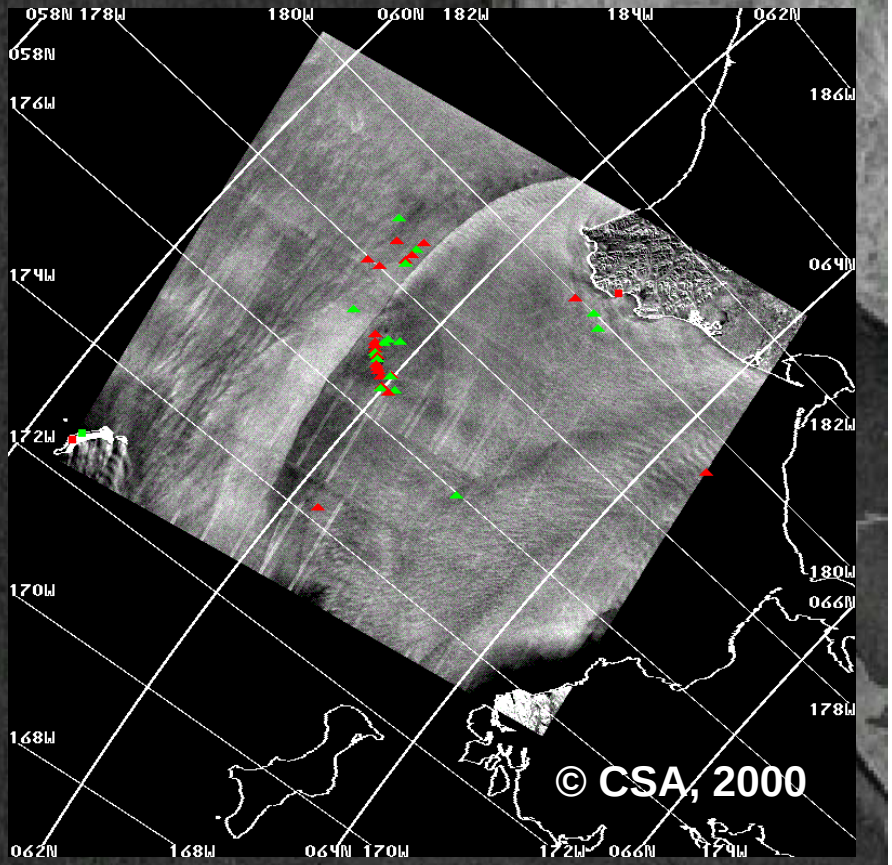
JHU/APL WIND IMAGES **8/8/00 16:37 GMT**

http://radarsatpc3.wwb.noaa.gov/akdemo/index.html

Alaska SAR Demonstration

Additional Products - March 2000





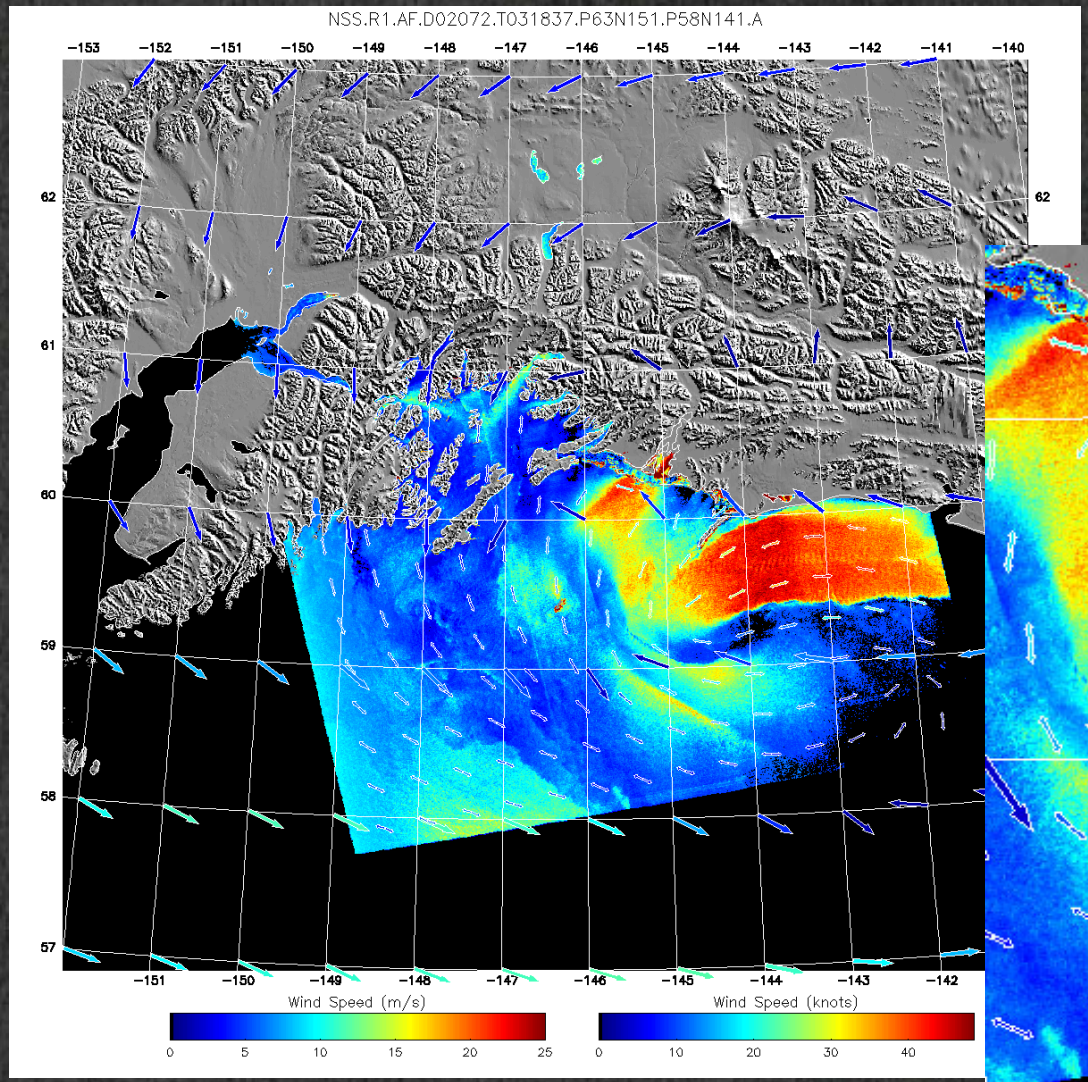
APPLIED COHERENT TECHNOLOGY CORP.
WWW IMAGE PROCESSING ENVIRONMENT (WIPE)

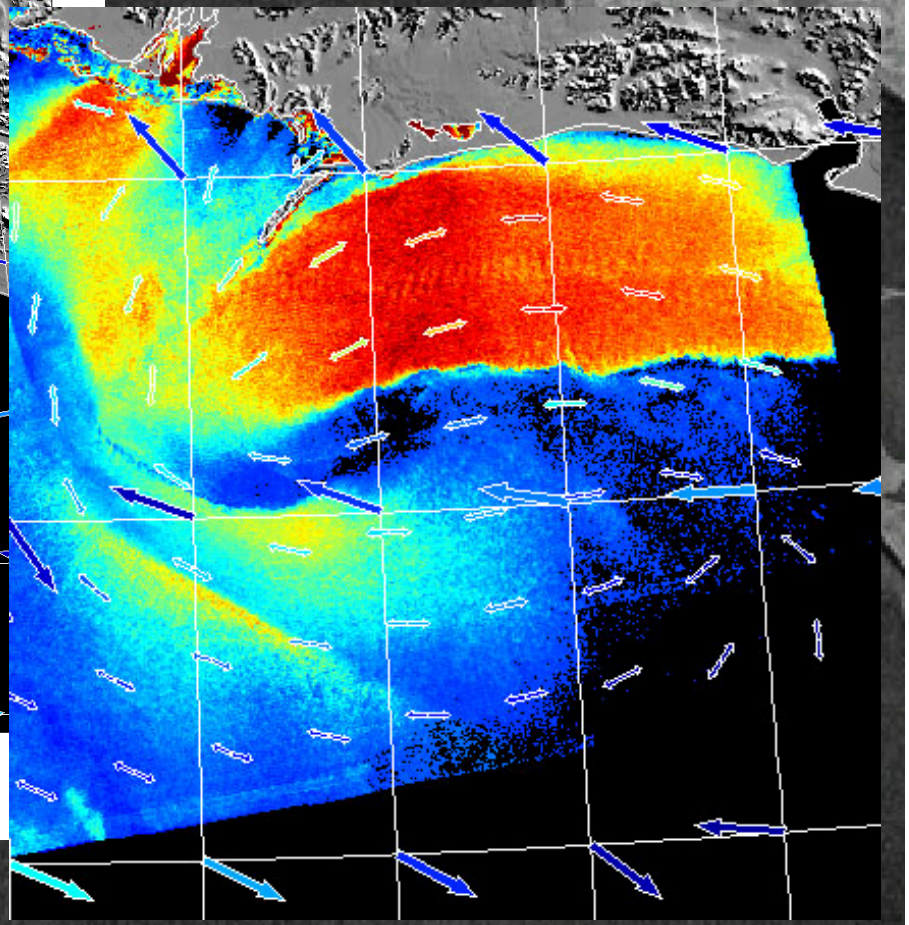
VERIDIAN
VESSEL DETECTION PRODUCTS
WIND VECTOR PRODUCTS
ICE IMAGERY

Alaska SAR Demonstration

New Formats - 2001

Fusion of Both Wind Products



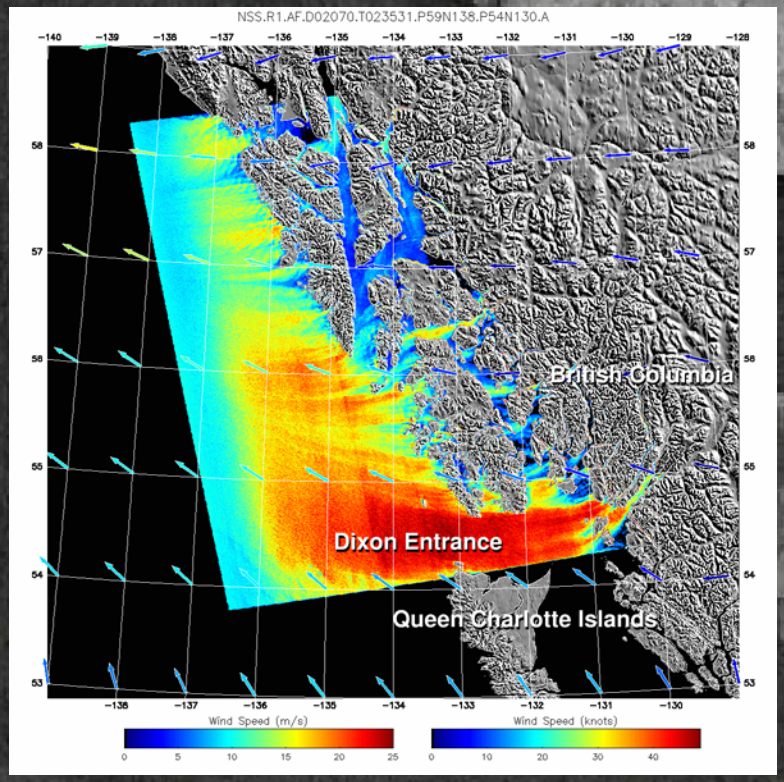


Barrier Jet March 13, 2002

Alaska SAR Demonstration

Major AKDEMO Upgrade - January 2003

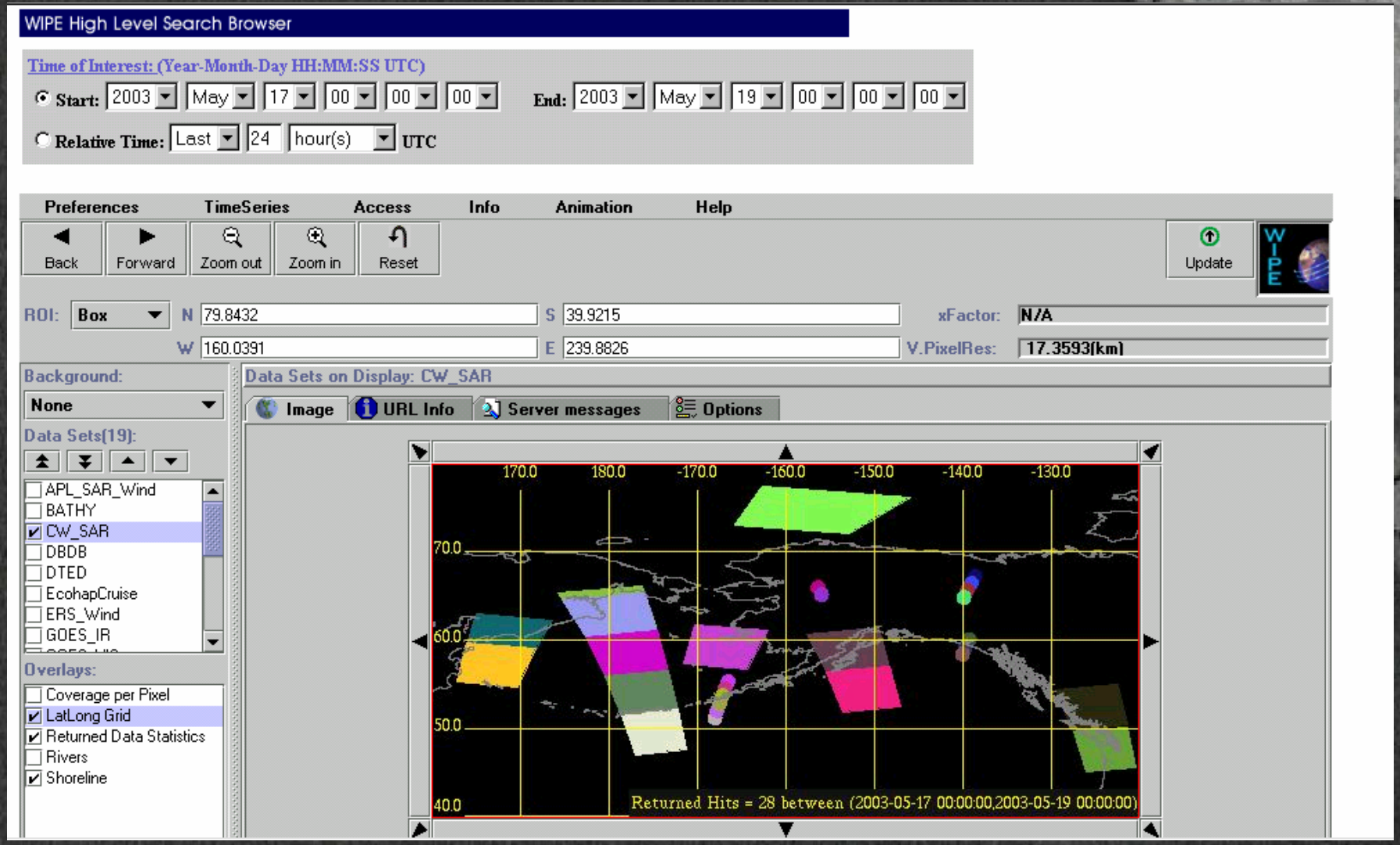
- Data timeliness improved to 2-3 hours down from 4-6
  - Migration to faster Linux product processors
  - New WIPE server PCs
  - Faster SAR processing at ASF
- Experimental Wind Merged Product
- New Ice Mask Product
- Product Scheduling Graphics
- WIPE Upgrade
- AWIPS formatted wind images available



AWIPS Formatted Wind Images

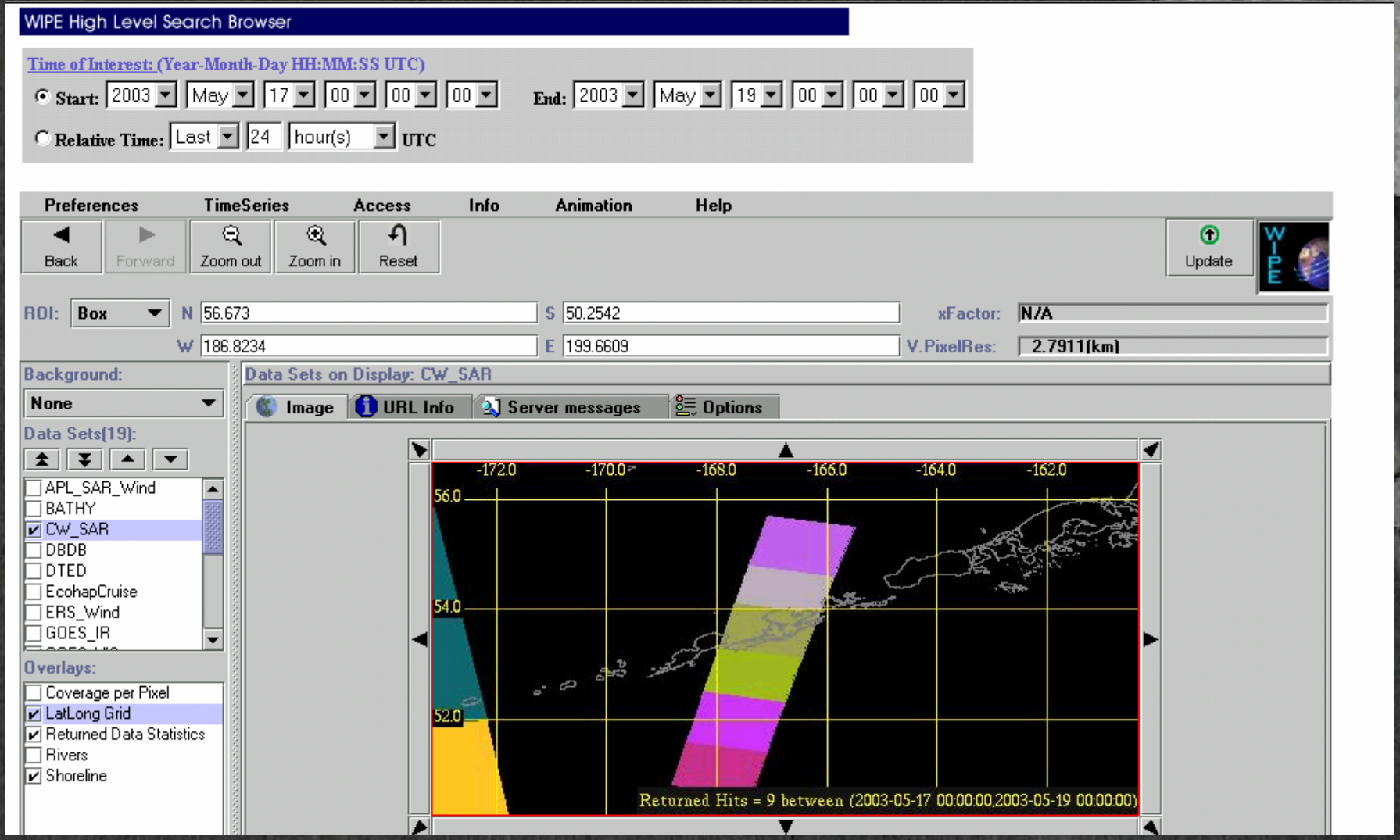
Alaska SAR Demonstration

WIPE Upgrade - January 2003



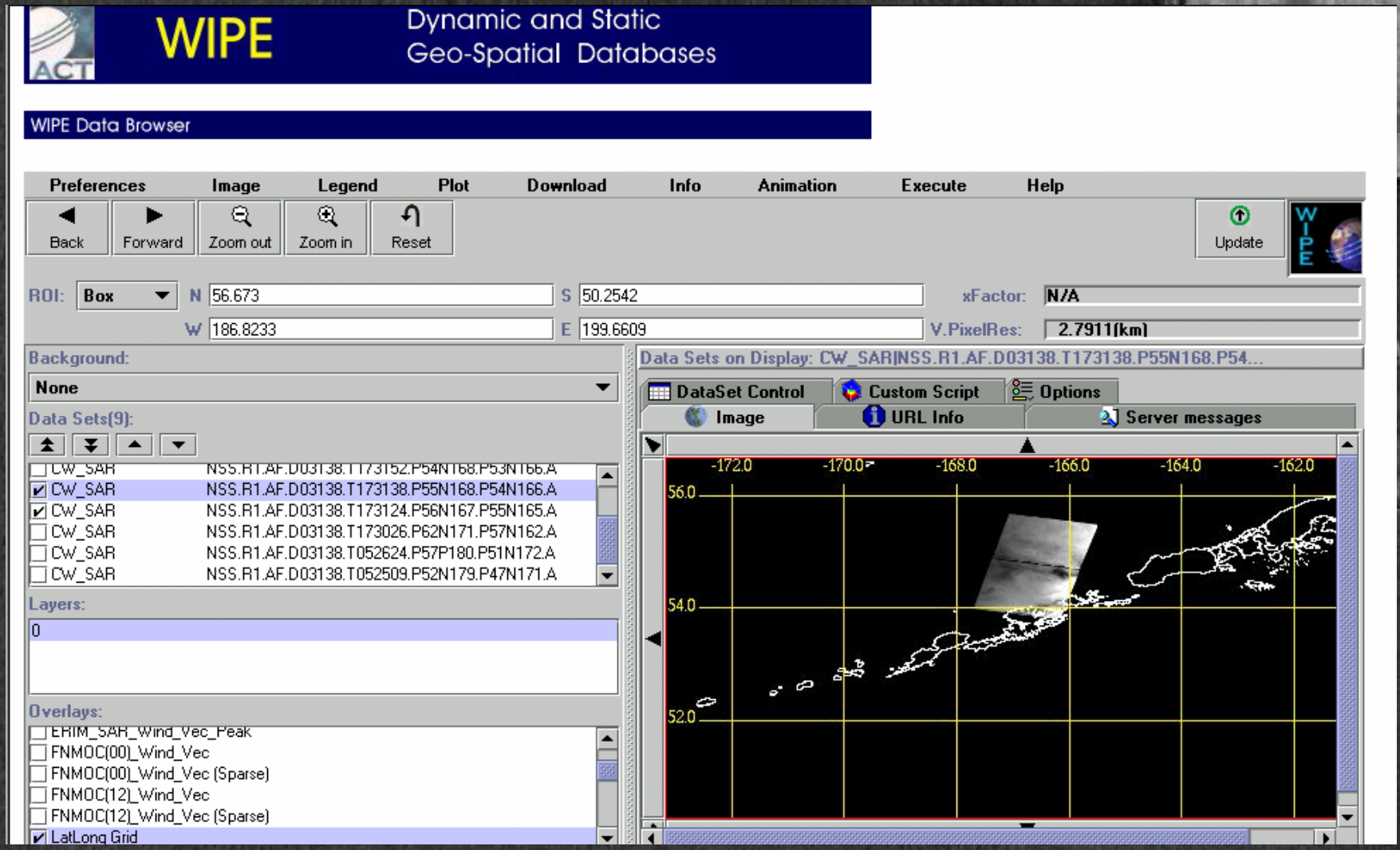
Alaska SAR Demonstration

WIPE Upgrade - January 2003



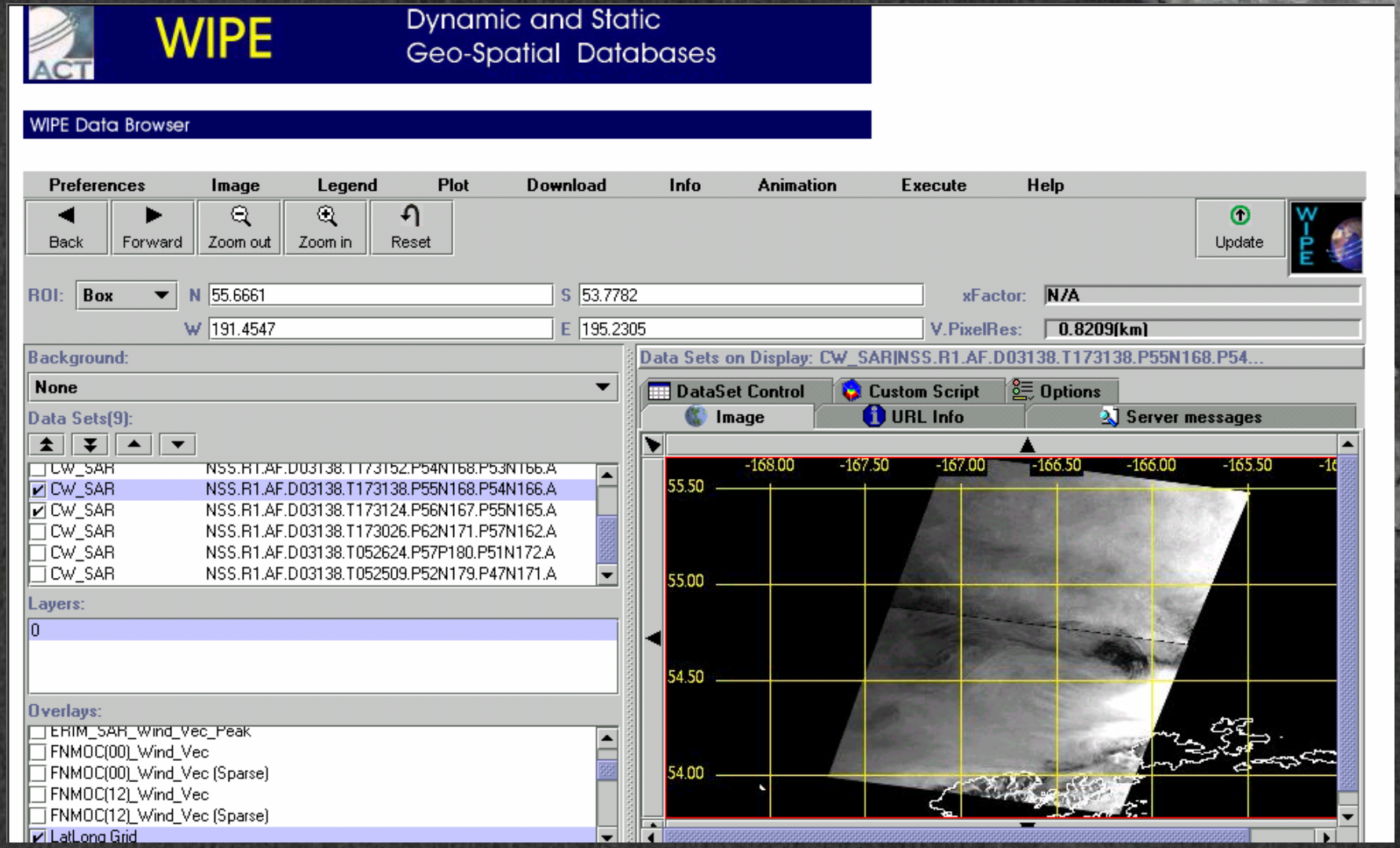
Alaska SAR Demonstration

WIPE Upgrade - January 2003



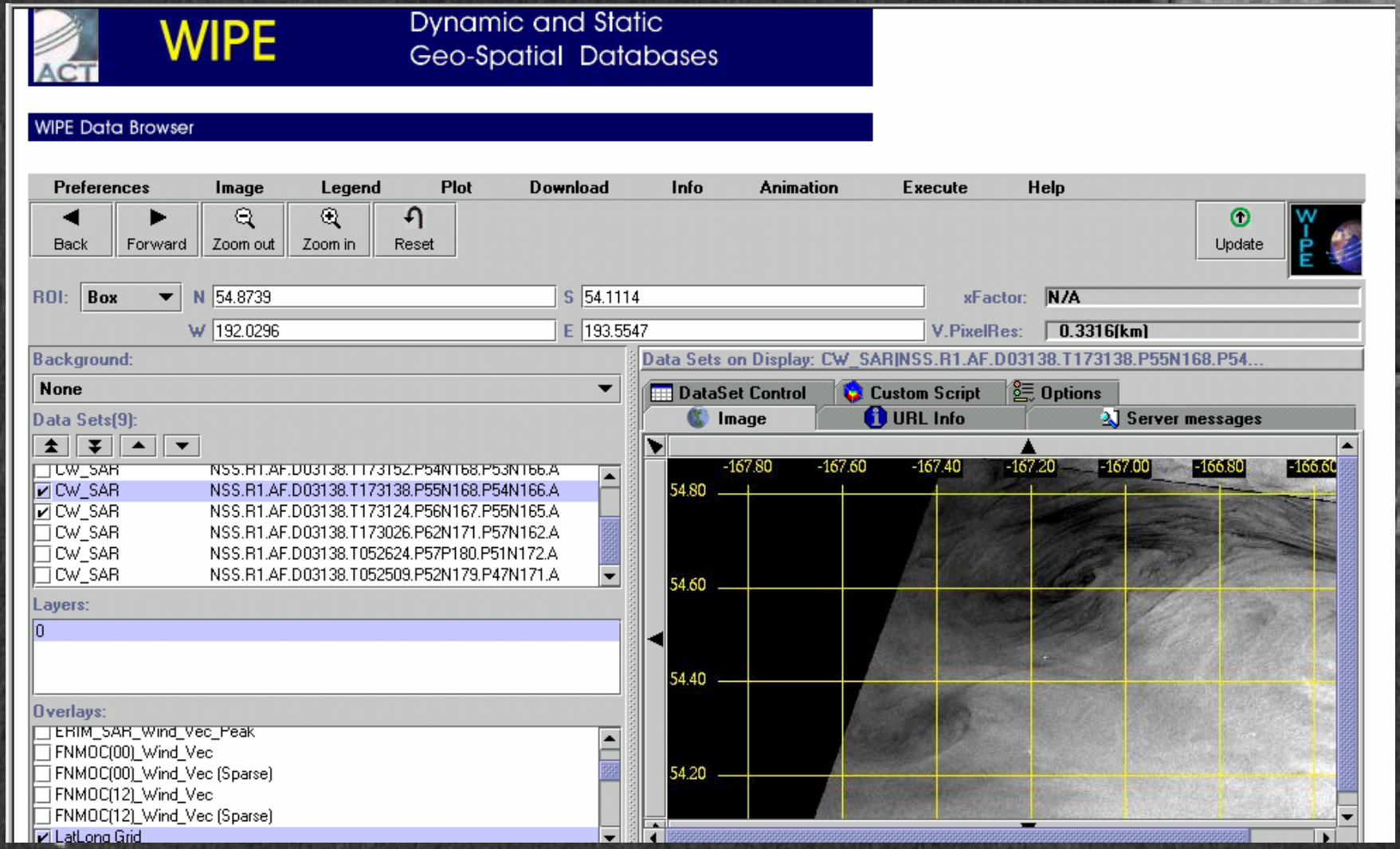
Alaska SAR Demonstration

WIPE Upgrade - January 2003



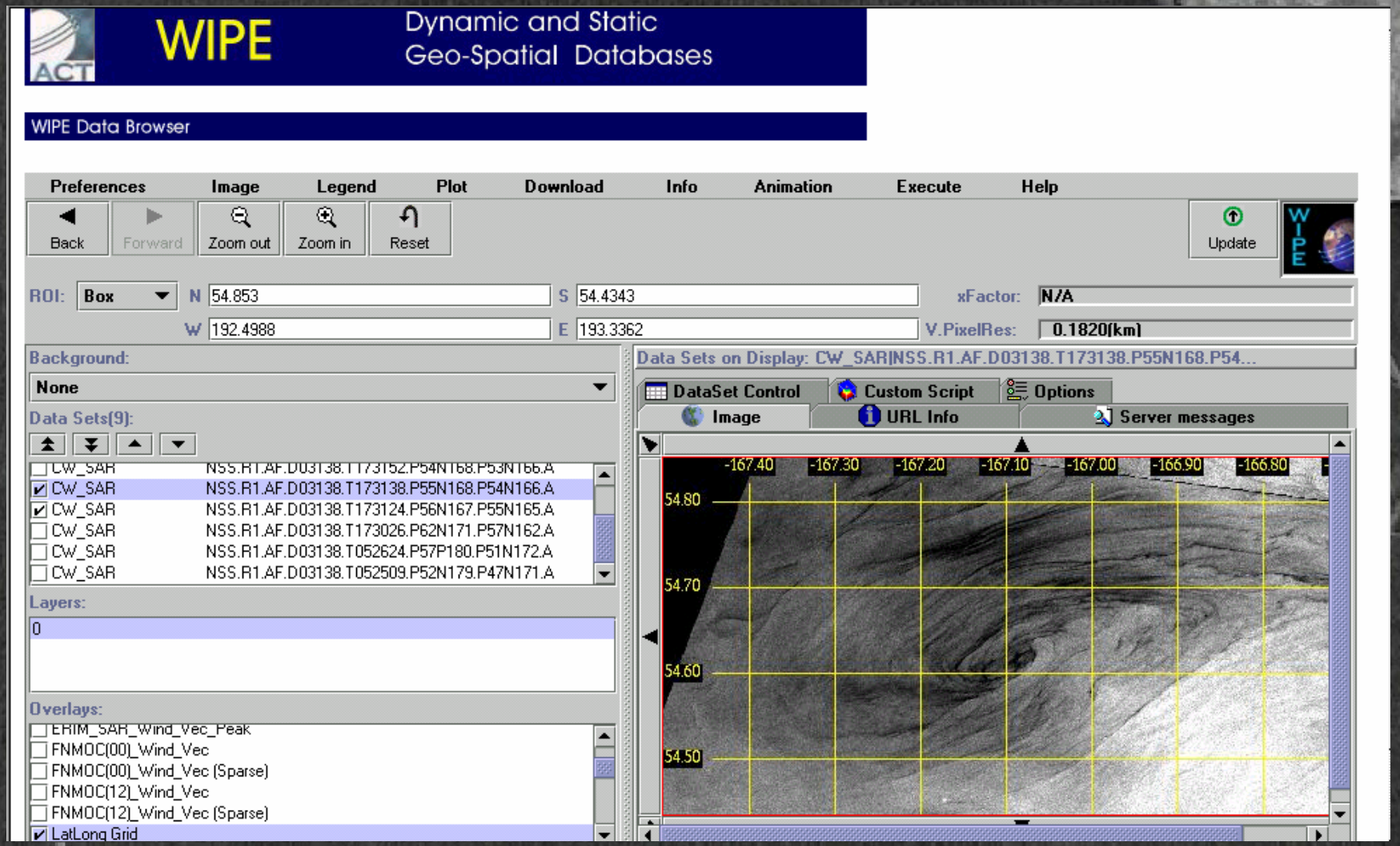
Alaska SAR Demonstration

WIPE Upgrade - January 2003



Alaska SAR Demonstration

WIPE Upgrade - January 2003

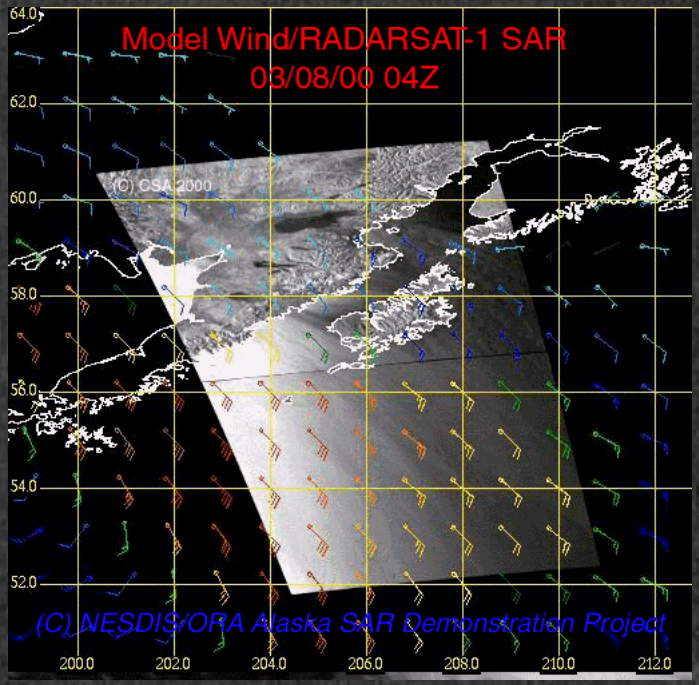


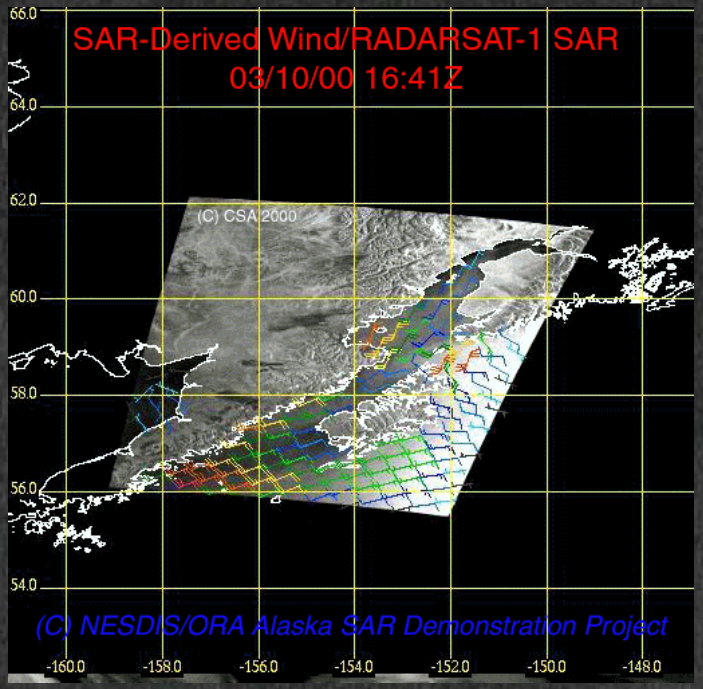
Alaska SAR Demonstration

WIPE Upgrade - January 2003

WIPE Output - JPEG Format

Alaska SAR Demonstration





WWW Image Processing Environment

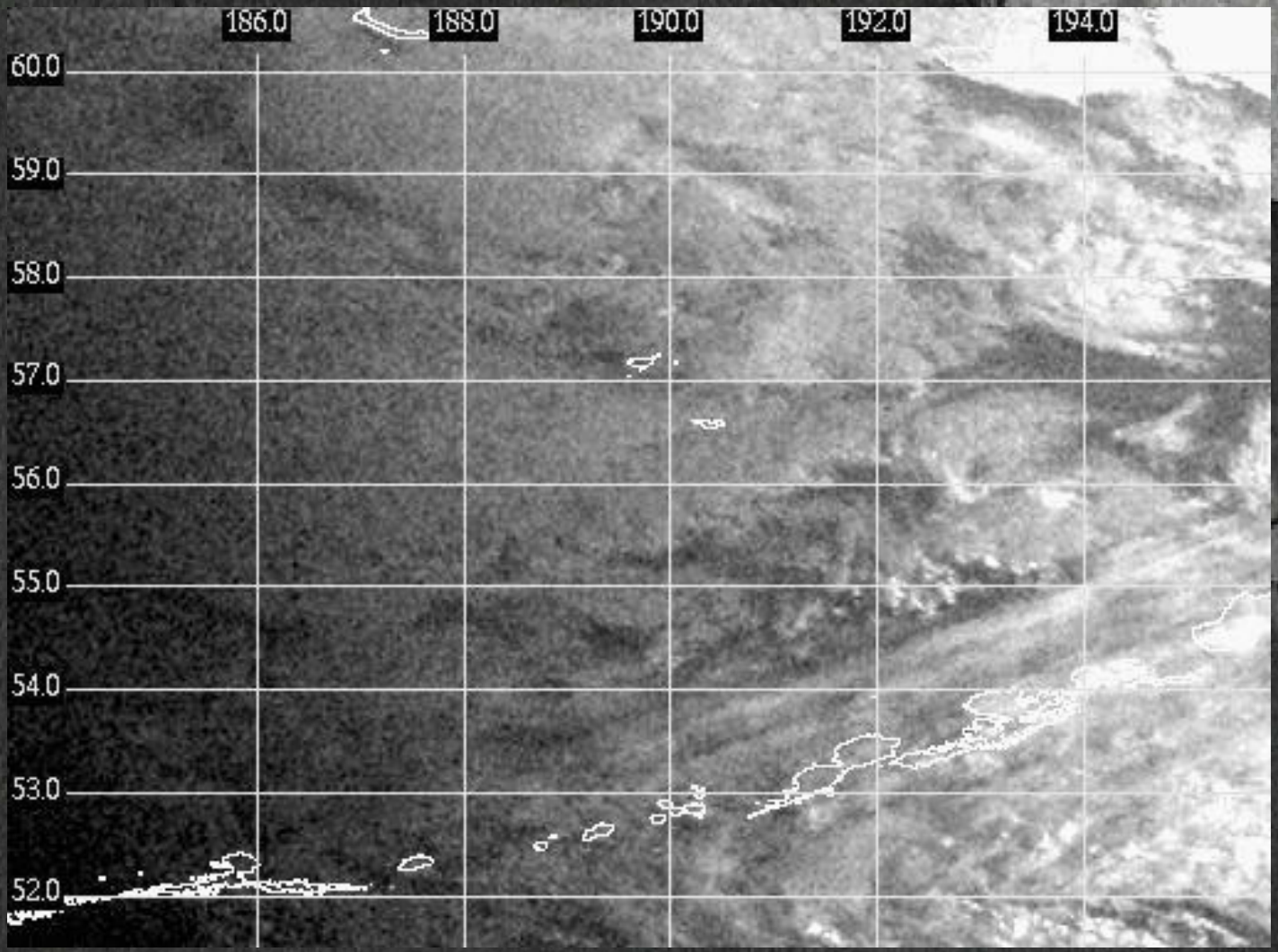
- Display of coincident image and overlay products
- On-line analyses
- Data output into scientific and GIS formats

WIPE ACT

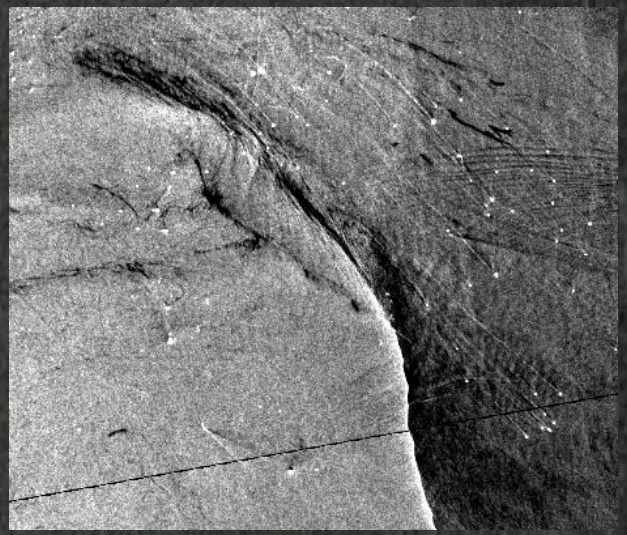
NESDIS

WIPE Animation

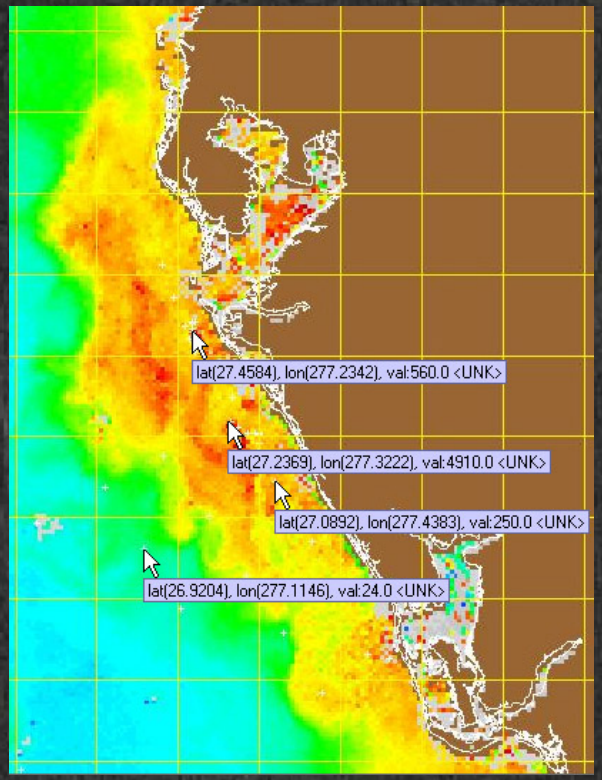
Animation of Mesoscale Cyclone in the Bering Sea GOES West 1 km Visible 4/8/00 1700Z - 4/9/00 0600 Z RADARSAT ScanSAR Wide B 100 m 4/8/00 1807Z & 4/9/00 0503Z

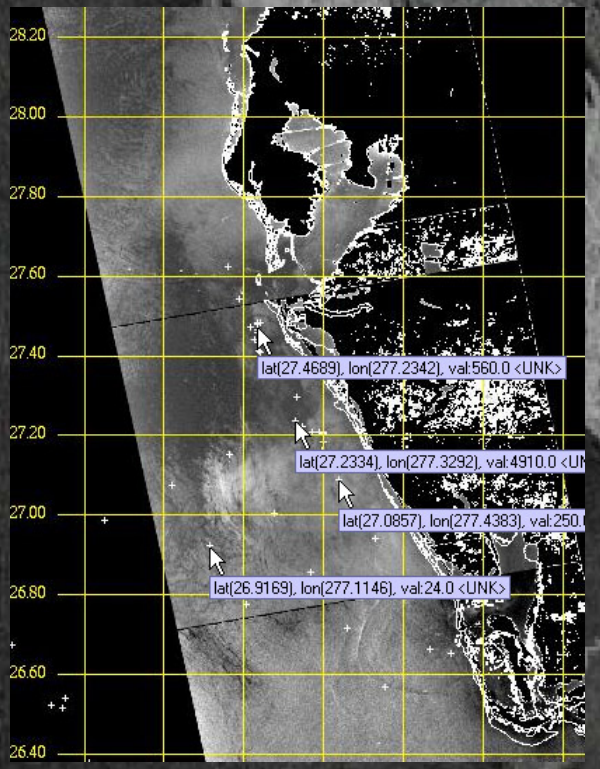


SSR Project 2 - Gulf of Mexico Experiment



Mississippi plume front
R-1 Standard Mode
6/3/02





HAB West Florida Shelf

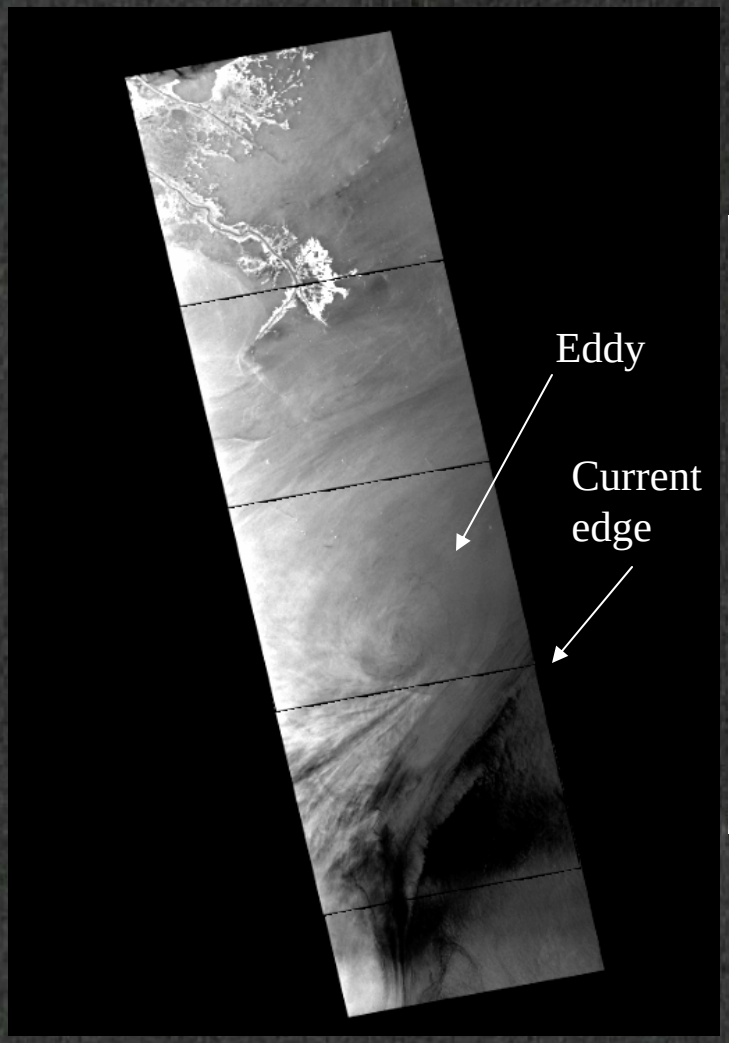
***GOAL*: Retrospective Applications Demonstration of SAR applications in the Gulf of Mexico**

***COLLABORATORS*: LSU Coastal Studies Institute, NOS Beaufort Laboratory**

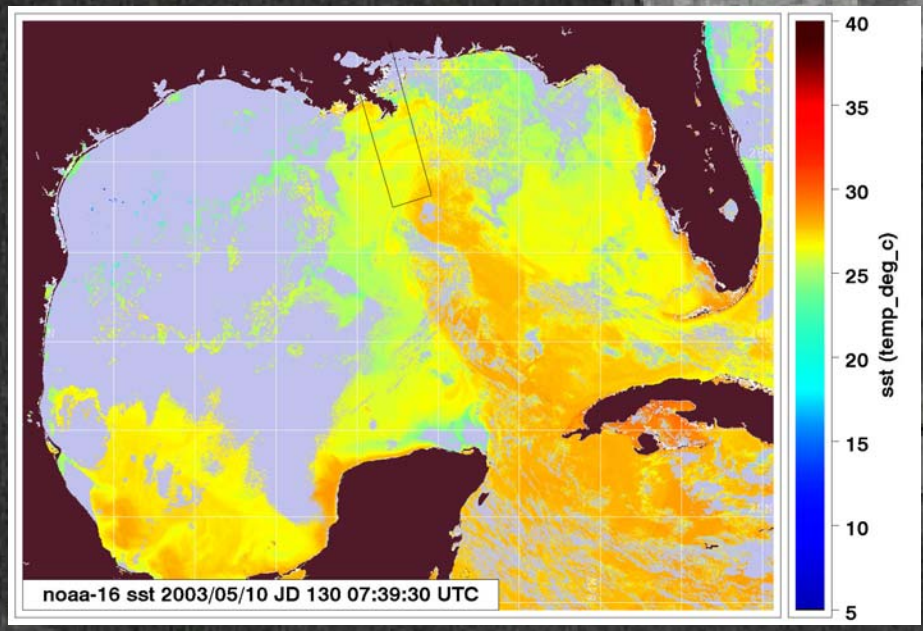
***PRODUCTS*: Hazardous Algal Blooms, Current Features, Spills and Seeps**

SSR Project 2 - Gulf of Mexico Experiment

SAR 5/11/03 23:52:33 GMT

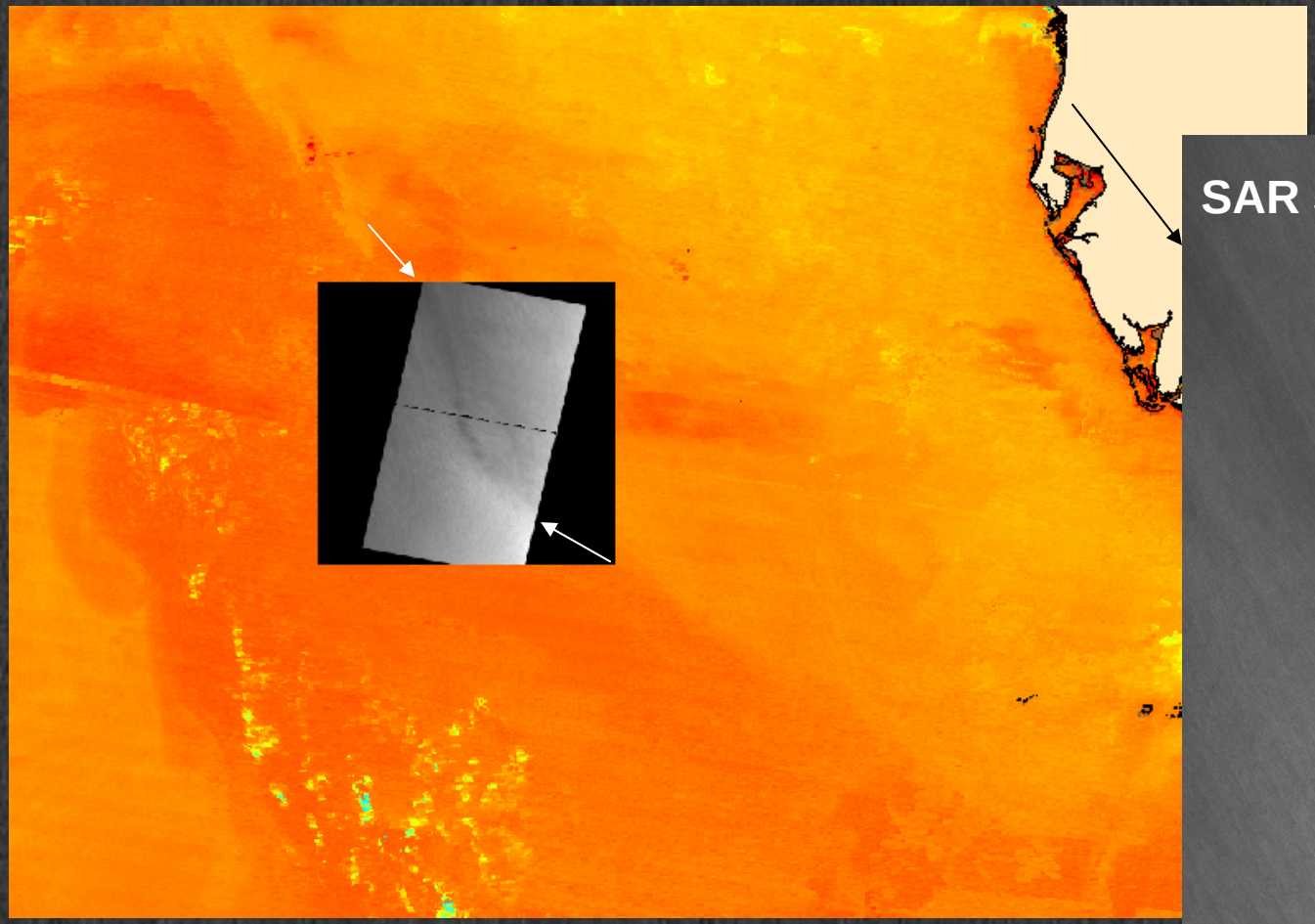


AVHRR



SSR Project 2 - Gulf of Mexico Experiment

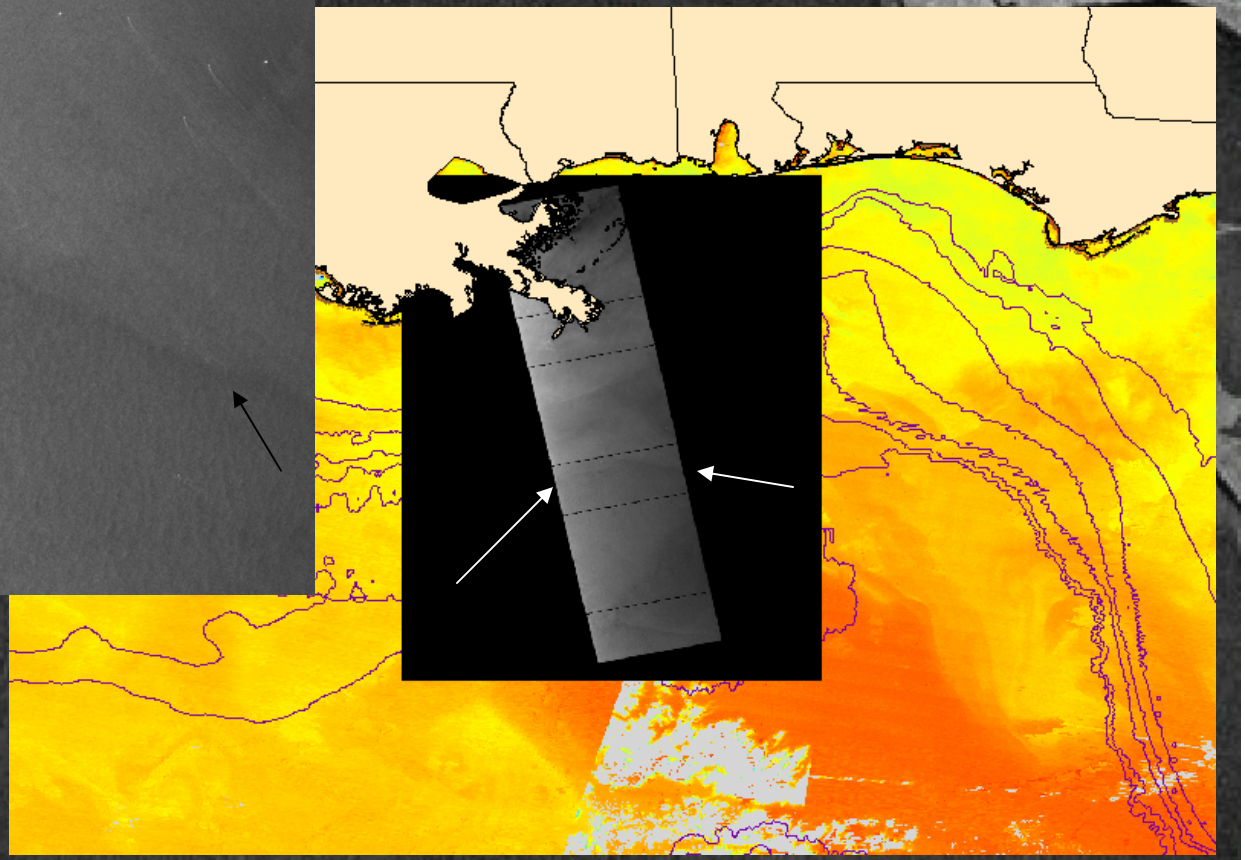
SAR and MODIS Terra SST week 18 composite



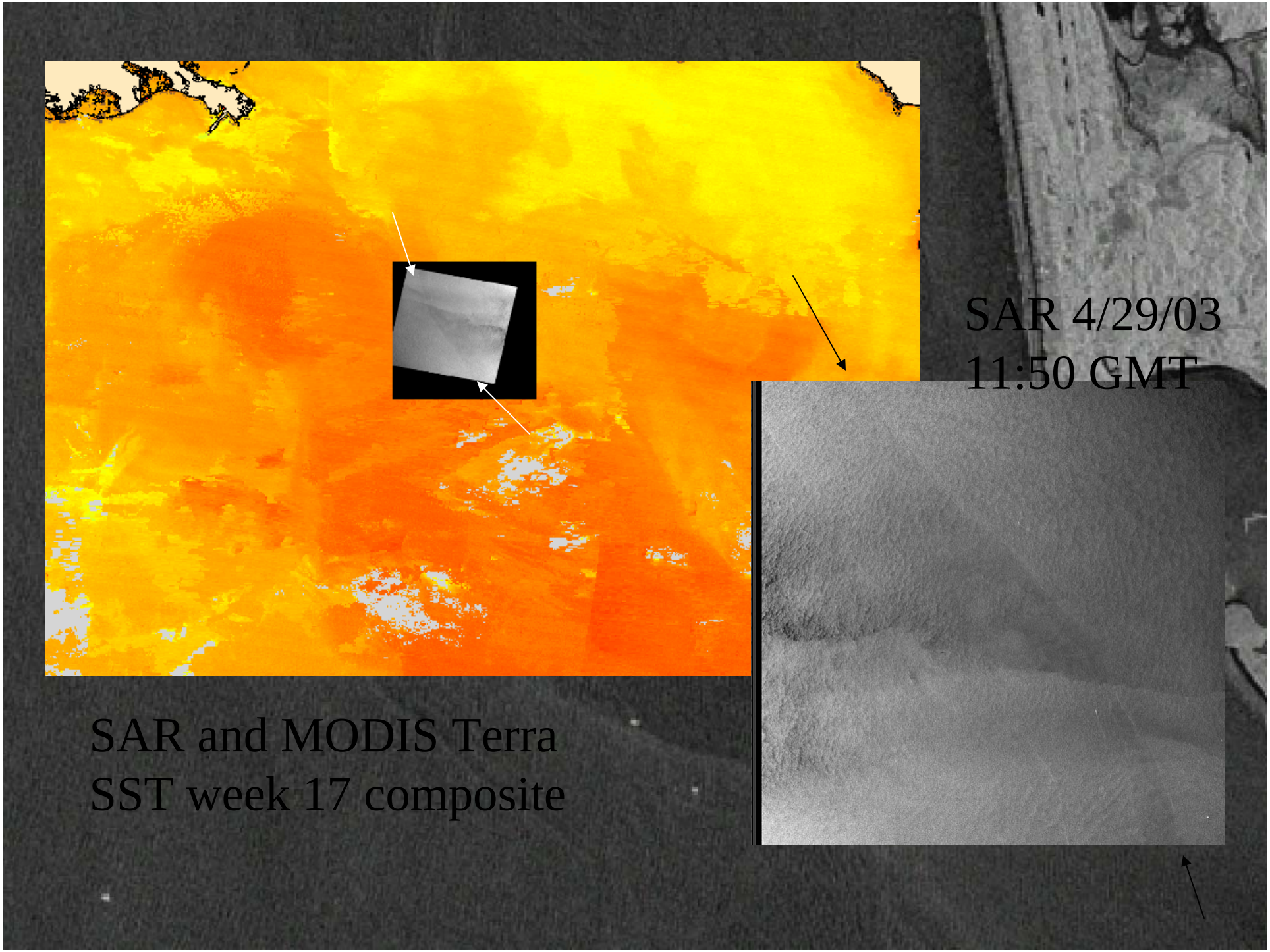
SAR 5/6/03 11:46 GMT

SSR Project 2 - Gulf of Mexico Experiment

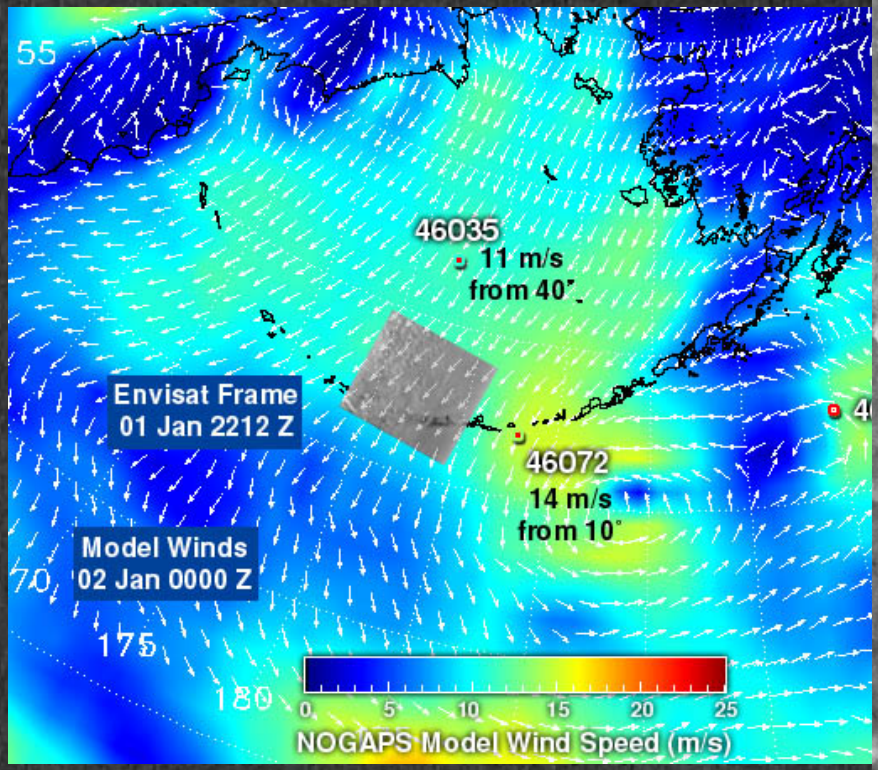
SAR and MODIS Terra SST
week 15 Composite



Northern Boundary
of Loop Current


SAR 4/29/03
11:50 GMT
SAR and MODIS Terra
SST week 17 composite

SSR Project 3 - ESA ENVISAT Project

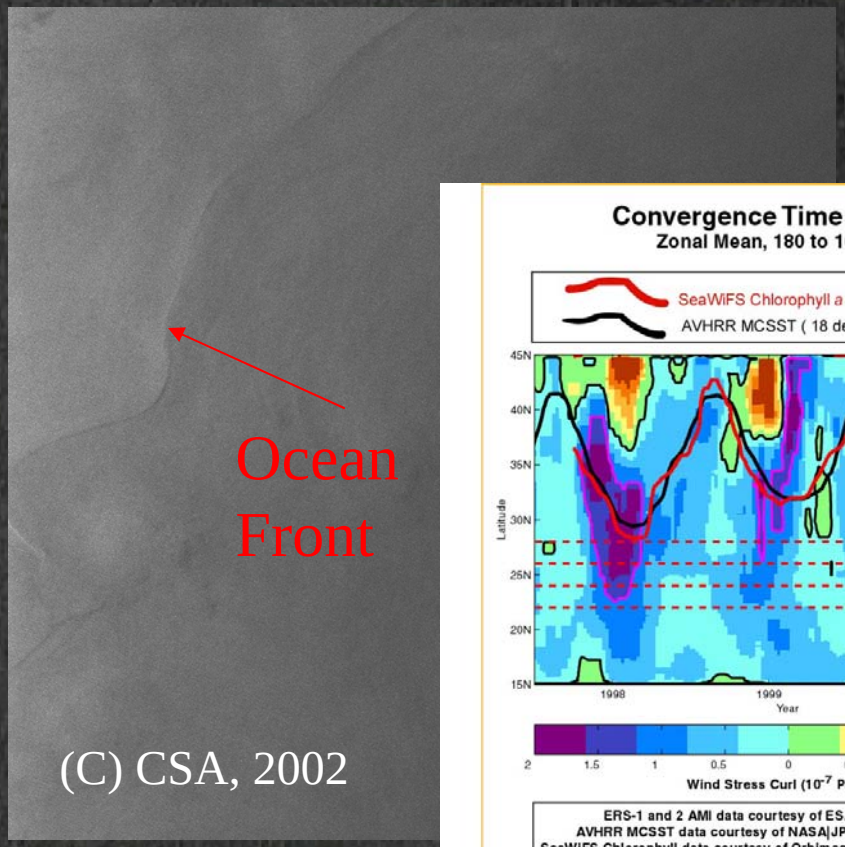


GOAL: **Operational Demonstration of CoastWatch Coastal Oceanographic and Hydrologic Applications of ENVISAT ASAR Imagery.**

COLLABORATORS: **JHU/APL, SSARGASSO, Veridian, ACT**

PRODUCTS: **Winds, Vessels, Ocean Features**

SSR Project 4 - GhostNet Project



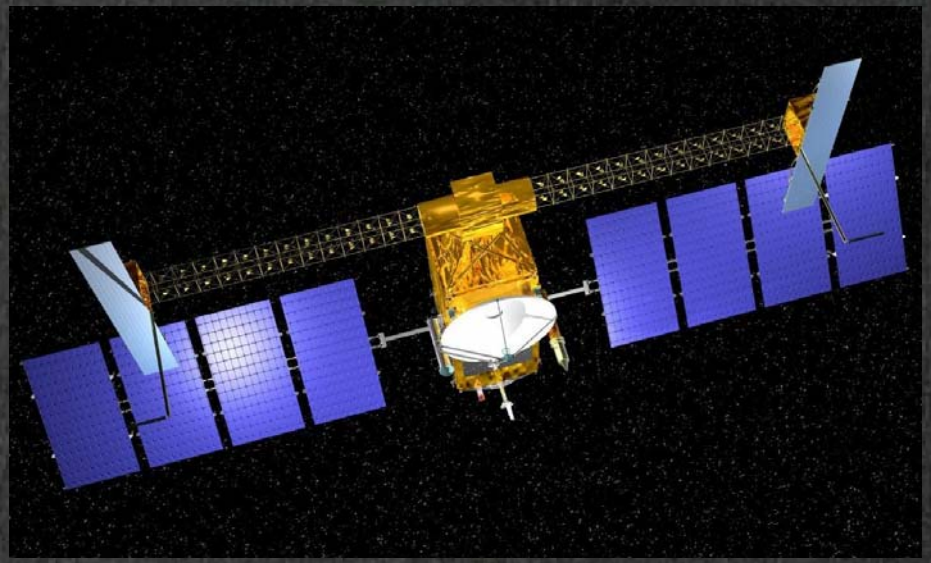
R-1 10April 2002

***GOAL*: Detection of Derelict Nets at Sea using Airborne LIDAR and Satellite Remote Sensing**

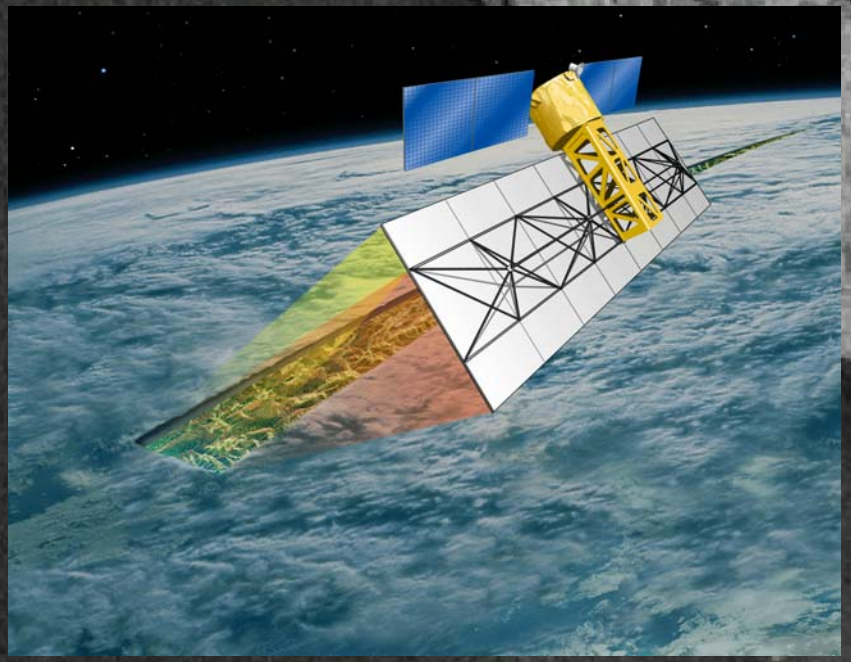
***COLLABORATORS*: Airborne Technologies, NOAA ETL, NMFS, ASF, USC**

***PRODUCTS*: Convergence Zones, LIDAR signatures, buoy network**

SSR Project 5 - Ocean Observer Study



Wide Swath &
Delayed Doppler Altimeters



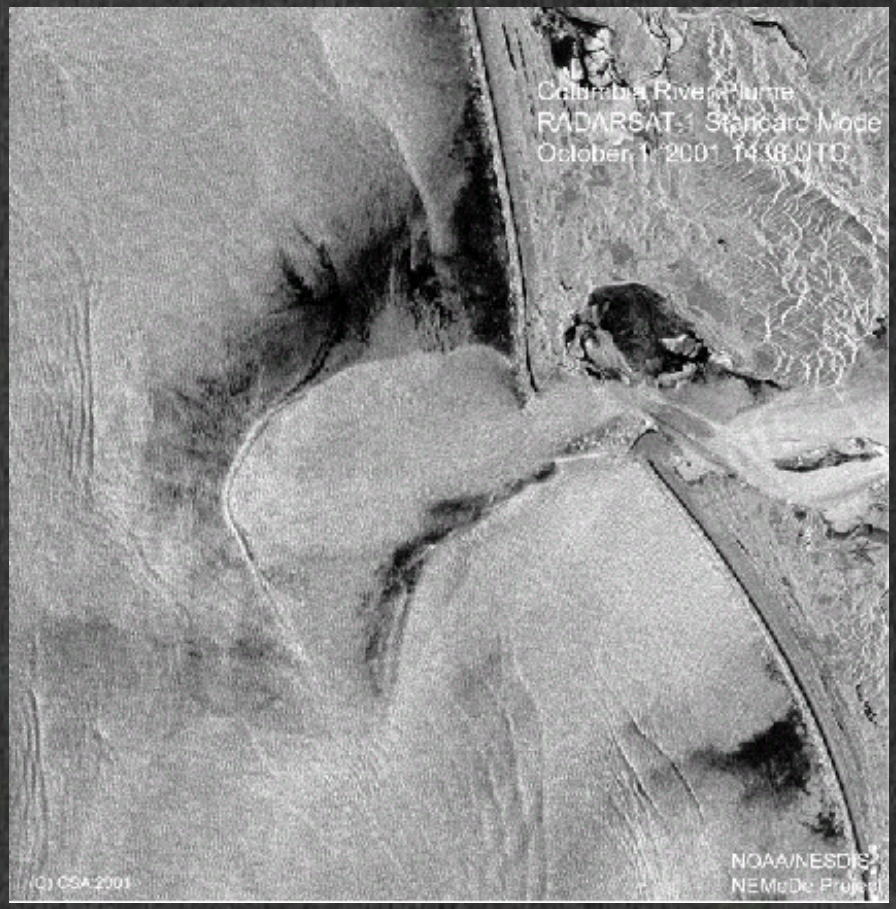
L & C Band Interferometric SAR

***GOAL*: Define and Develop Cost Estimates for U.S. Operational Satellite System to meet U.S. Ocean Data Requirements**

***COLLABORATORS*: IPO, NASA/JPL**

***PRODUCTS*: Ocean Observer User Requirements Document, Ocean Observer Instrument and Satellite Study**

SSR Project 6a - NeMoDe:
Grant to Oregon Health and Science University



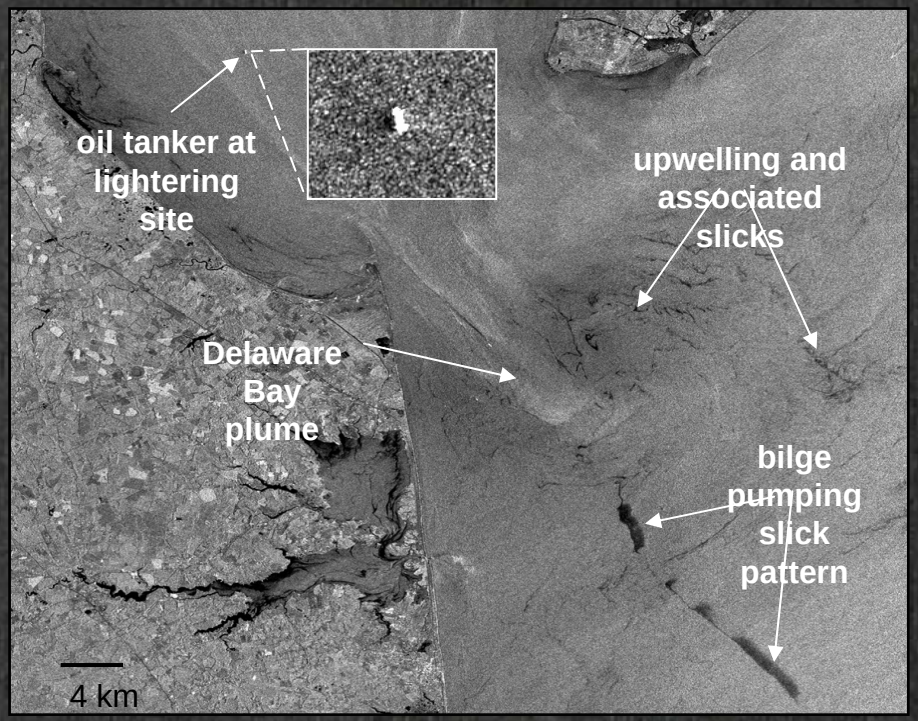
RADARSAT-1 Standard SAR subimage showing the Columbia River plume and coastal ocean conditions on 1 October 2001.

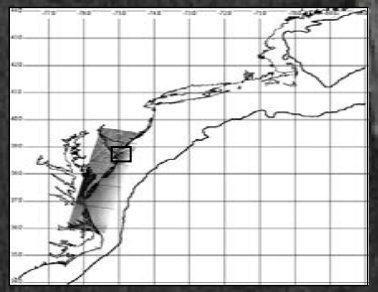
***GOAL*: Satellite Ocean Front Mapping in Support of Salmonid Resource Management (David Jay and Todd Sanders)**

COLLABORATORS: **Oregon Health and Science Univ., NMFS, Univ. of RI**

***PRODUCTS*: Field support, Plume front maps**

SSR Project 6b - NeMoDe: Grant to University of Delaware





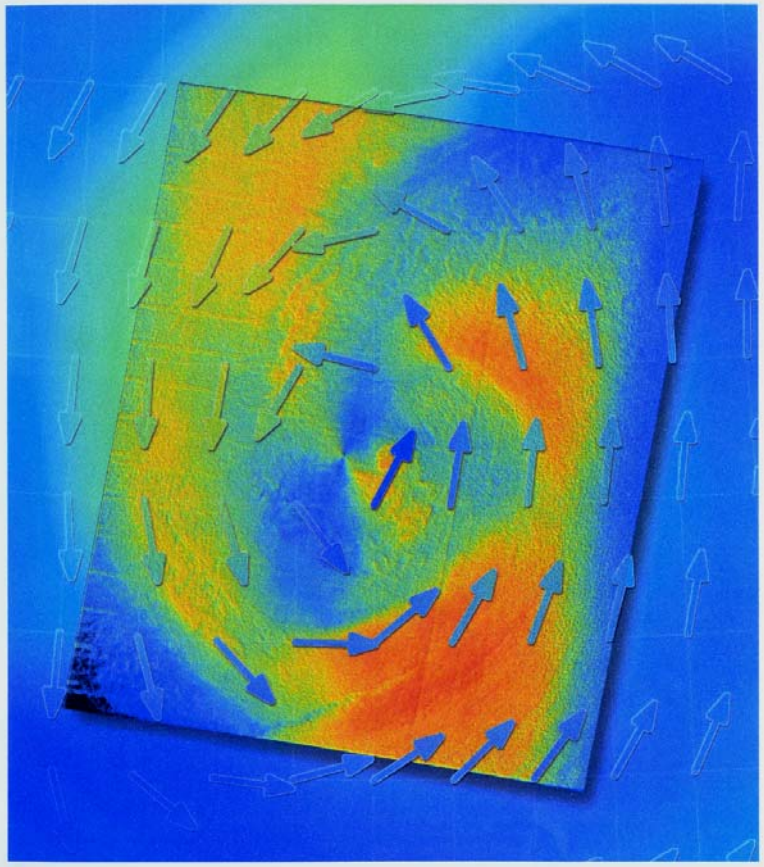
RADARSAT-1 Standard Mode
13 August 1998 11:15 - ebb tide

***GOAL*: Using satellite imagery for modeling and monitoring the circulation in Delaware Bay and adjacent coastal ocean (Richard Garvine and Xiao-Hai Yan**

***COLLABORATORS*: Univ. of Delaware, NRL, State of Delaware, Delaware Bay and River Cooperative**

***PRODUCTS*: Public web site of coastal imagery, circulation model, Model/ocean feature studies**

SSR Project 6c - NeMoDe:
Grant to SSARGASSO Associates



High Resolution Wind Monitoring with Wide Swath SAR: A User's Guide

Section I, Version 02c
27 August 2002

http://fermi.jhuapl.edu/sar/stormwatch/user_guide/

R. C. Beal
SSARGASSO Associates
Ellicott City, Maryland

F. M. Monaldo
D. R. Thompson
N. Winstead
The Johns Hopkins University
Applied Physics Laboratory
Laurel, Maryland

G. S. Young
Pennsylvania State University
State College, Pennsylvania

C. Scott
National Weather Service
Anchorage, Alaska

Major funding through
NOAA/NESDIS Grant No. NA06EC0243

Draft Version (limited distribution)

***GOAL*: User Guide to SAR Wind Field Interpretation (Robert Beal)**
***COLLABORATORS*: SSARGASSO Associates, JHU/APL, NWS Alaska**
***PRODUCTS*: User Guide to SAR Wind Field Interpretation**

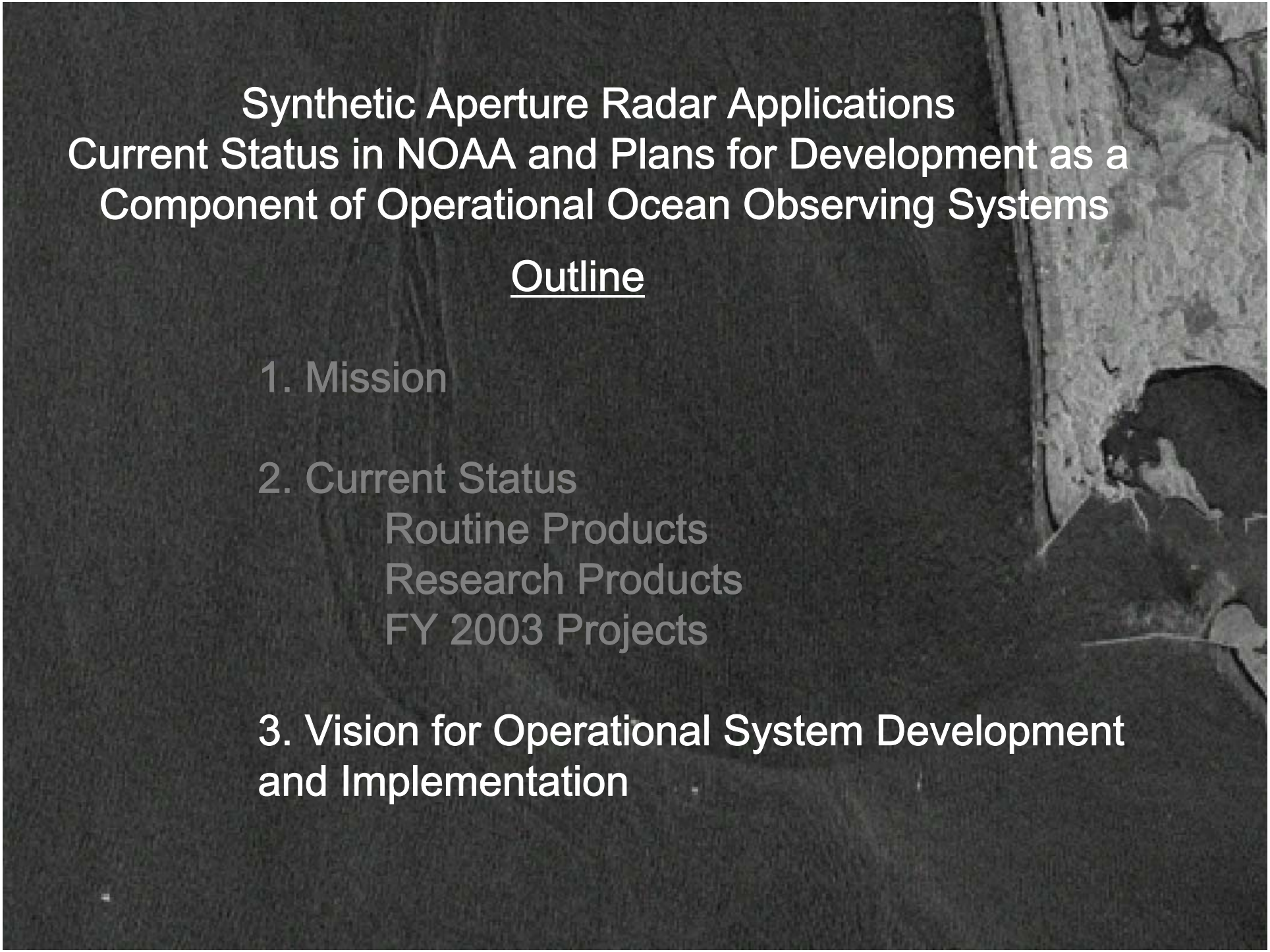
SSR Project 6d - NeMoDe:
Contract to Global Ocean Associates

Synthetic Aperture Radar
Marine User's Manual

***GOAL*: Synthetic Aperture Radar Marine User's Manual (Chris Jackson Editor)**

***COLLABORATORS*: Global Ocean Associates , Chapter Authors**

***PRODUCTS*: SAR Marine User's Manual (20 Chapters)**



Synthetic Aperture Radar Applications
Current Status in NOAA and Plans for Development as a Component of Operational Ocean Observing Systems

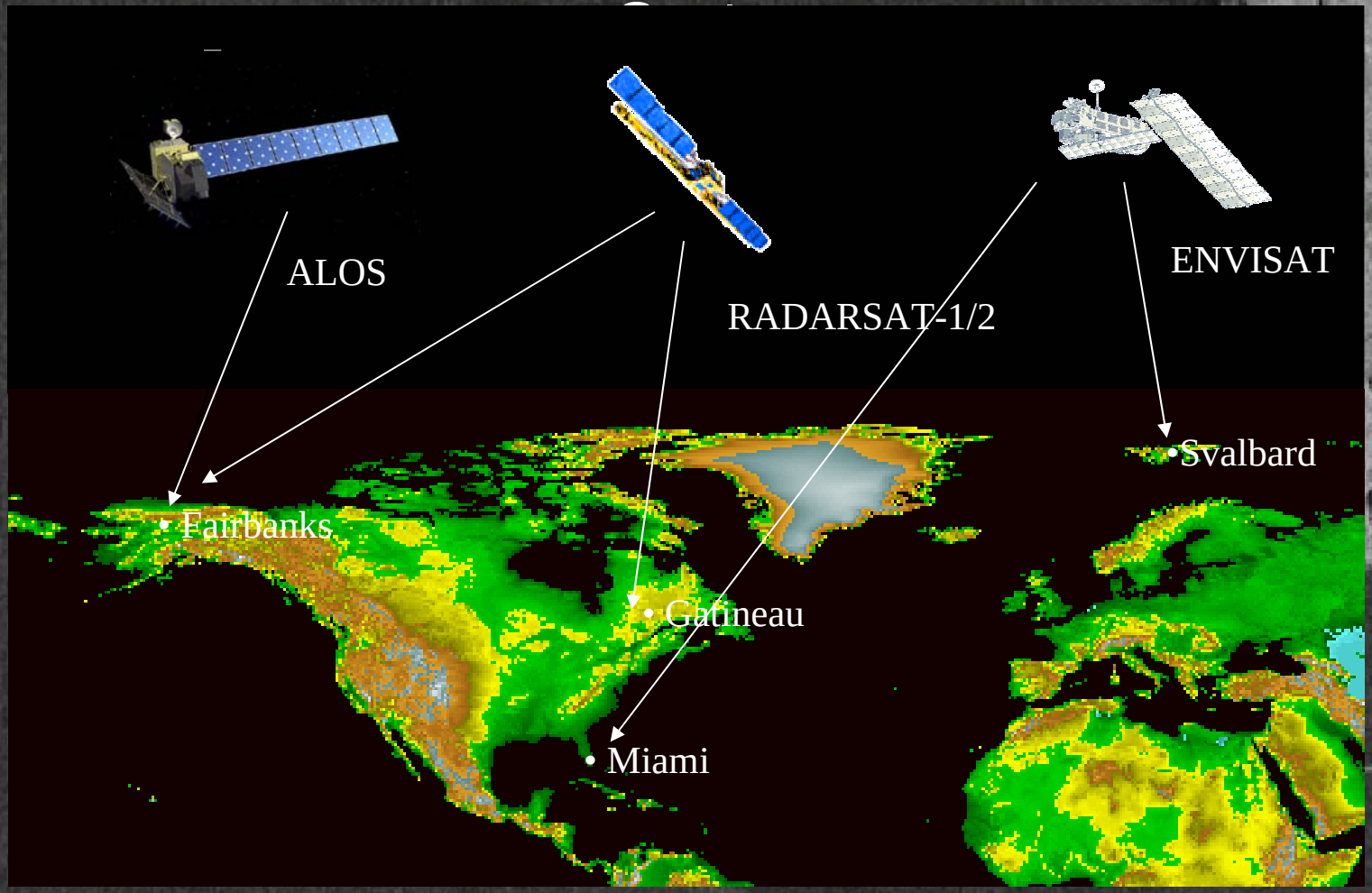
Outline

1. Mission

2. Current Status
   - Routine Products
   - Research Products
   - FY 2003 Projects

3. Vision for Operational System Development and Implementation

SSR Project 7 - International SAR Ocean Products



***GOAL*: Develop international SAR ocean products processor to be installed at readout stations to produce near real-time SAR products for the operational community**

***COLLABORATORS*: NERSC, NSA, Veridian, JHU/APL, RSI, ASF, RSMAS**

***PRODUCTS*: Multiple - winds, waves, vessels, features, etc.**

1st Step – Svalbard Workshop
2nd Workshop on Coastal and Marine Applications of SAR

September 8-12, 2003
Longyearbyen,
Spitzbergen, Norway

GOAL: Assess operational readiness of algorithms for winds, waves, current features, and sea ice

SAR Products System Development Vision/Strategy

1. Decide on best algorithms at Svalbard conference
2. Work with Norwegians, Canadians, and ASF to refine automated versions of these algorithms
3. Continue wind product development with JHU/APL and Veridian - merge SAR winds with scatterometer and passive polarimeter winds for validation and improved direction information
4. Extend existing algorithms to ENVISAT & ALOS
5. Prototype a portable automated operational SAR wind system for CSTARS
6. Based on CSTARS wind system and Alaska SAR Demo, work with international partners to develop fully automated operational SAR ocean products system
7. Install this system at acquisition stations and/or centrally

Sea Surface Roughness Web Sites

1. Alaska SAR Demonstration - NOAA site:
   http://radarsatpc3.wwb.noaa.gov/akdemo/index.html

2. Alaska SAR Demonstraton - The Johns Hopkins Univ. Applied Physics Lab site: http://fermi.jhuapl.edu/sar

3. GhostNet Home Page:
   http://www.highseasghost.net

4. SAR Marine Users Manual - Global Ocean Associates site: http://sarusermanual.com

5. User Guide to SAR Wind Field Interpretation - SSARGASSO site:
   http://fermi.jhuapl.edu/sar/stormwatch/user_guide/