P2.16 SEA-SURFACE ROUGHNESS RESEARCH AT NOAA/NESDIS

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1. INTRODUCTION

The Office of Research and Applications (ORA) of the National Environmental Satellite, Data, and Information Service (NESDIS) of the National Oceanic and Atmospheric Administration (NOAA) has been involved in research and applications development using synthetic aperture radar (SAR) since the launch of the L-band Seasat SAR in 1978. Since 1992, research projects have been conducted with C-band SAR data obtained from The European Space Agency's (ESA's) European Remote Sensing (ERS-1/2) satellites, the Canadian Space Agency's RADARSAT-1 satellite, and more recently ESA's ENVISAT satellite. Measurement algorithms developed in this research activity are now being tested and evaluated within a number of applications demonstrations. A Sea Surface Roughness (SSR) Science Team was formed in 2003 to coordinate the research and development of an operational system to derive a suite of ocean products from SAR data. The development of this system will be the focus of activities for at least the next five years. This paper will present the goals of this effort, the current status of SAR product development and demonstration within NOAA and plans for development of an operational SAR ocean products system.

2. SEA-SURFACE ROUGHNESS RESEARCH GOALS

The mission of the SSR Science Team is to develop an integrated end-to-end product system for operational generation of the sea-surface roughness products specified in the National Polar-orbiting Operational Environmental Satellite System (NPOESS) Integrated Operational Requirements Document (IORD) II and the Ocean Observer User Requirements Document (OOURD). These documents contain specifications of environmental parameters required primarily by various government agencies. Some of these requirements can be best met or can only be met through the use of SAR instruments. Table 1 lists the SAR-derivable parameters included within the NPOESS requirements documents. It is the goal of the SSR Science Team to develop, demonstrate, and eventually produce these parameters operationally. To do this requires: (1) securing SAR data access for research and operations, (2) conducting SAR product research, (3) providing applications demonstrations and user outreach/education, and (4) development of a SAR ocean products system.

3. CURRENT CAPABILITY

The development of SAR applications in NOAA is currently about midway from the first experiences with obtaining research SAR data regularly from the ERS-1 satellite in 1992 to the operational availability of U.S. SAR data forecast for approximately 2012. Ice applications are essentially operational in the National Ice Center (NIC) with RADARSAT-1; however, data availability restrictions constrain geographic coverage so that all areas are not covered as frequently as desired, and some areas (such as Antarctic waters) usually receive no coverage. Development of automated ice classification algorithms for SAR imagery is underway, but have not reached the point that these can be used operationally. The NOAA Great Lakes Environmental Research Laboratory (GLERL) is providing SAR imagery of the Great Lakes in winter to the Coast Guard for aerial ice reconnaissance and icebreaker operations, as well as conducting research in lake ice classification with SAR. A near-real-time SAR demonstration (the Alaska SAR Demonstration, or AKDEMO) is underway within the NOAA/NESDIS Office of Research and Applications (ORA), Oceanic Research and Applications Division (ORAD), providing access to imagery, and generating coastal sea surface winds, vessel positions, and

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#	EDR TITLE	IORD II Requirem	OO URD Requirem	ORAD Interest
1	Coastal Sea Surface Winds & Wind Stress	4.1.6.8.8.5	2.1b, 2.2b	X
2	Wave Characteristics - Significant Wave	4.1.6.6.8	2.4a	X
3	Wave Characteristics. - Ocean Wave	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	4.1.6.8.8.1	2.6	X
6	Vessel Positions		2.7	X
7	Bathymetry (Near Shore)	4.1.6.8.8.1	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		2.19	X
11	Mixed Layer Depth			X
12	Sea & Lake Ice	4.1.6.8.7	3.1	X
13	Ice of Land Origin (Icebergs)		3.2	X
14	River Ice Location/Condition		3.5	X
15	Glacier Volumetric Change		3.6	
16	Continental Ice Sheet Melt Zone		3.7	
17	Ice-Sheet Motion		3.8	
18	Ice-Sheet Grounding Line Position		3.9	
19	Flood Mapping		4.1	X
20	Snow Water Equivalent Mapping		4.2	
21	Regional Soil Moisture		4.3b	
22	Coastal Wetland Mapping		4.4	X
23	Land Surface Topography		5.1	
24	Land Surface Deformation		5.2	
25	Land Surface Freeze/Thaw State		5.3	
26	Vegetation Classification/Biomass		5.4	
27	Coastal Change		5.5	X
28	Wetland Mapping			X
29	Mesoscale Atmospheric Features		6.1	X
30	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

Table 1 - Environmental Parameters Derivable from SAR

ice masks for selected areas in Alaska waters. A retrospective applications demonstration for the Gulf of Mexico is being conducted, examining algal bloom monitoring, river plume and ocean current identification, and oil seep/spill applications. A near real-time project called GhostNet is also underway with the goal of using multi-platform remote sensing data to find areas of convergence which might collect derelict fishing nets. Research is also on-going for mapping of oil spills, monitoring river ice breakup, detecting ocean features including river plumes and upwelling, measuring mixed layer depth, and measuring atmospheric features including storm signatures.

4. Ocean Products Research and Development

NOAA, via the SSR Science Team, is engaged in a wide variety of research and development activities covering the full range of necessary functions from working with users to obtain product specifications to the development of near real-time data and product systems. It has become

clear that just concentrating on research is not sufficient to fulfill the SSR Science Team mission.

4.1 Securing SAR Data Access for Research and Operations

Since the U.S. does not have its own SAR satellite, access to available foreign SAR data must be acquired by access agreements, barter, or data purchase. Data access is crucial to applications demonstrations and for operational use of the data. Currently, the principal satellite being used for SAR data in the U.S. is the Canadian Space Agency's (CSA) RADARSAT-1 satellite (see Table 2). Some access to the European Space Agency's ENVISAT Advanced SAR (ASAR) data is also possible, predominately for approved research projects. Access to RADARSAT-1 data is via a Memorandum of Understanding with NASA, NOAA, and the Canadian Space Agency (CSA) as signatories. NASA provided the launch for RADARSAT-1, and in exchange the U.S. has access to 15.82% of the satellite on-time. Of this data, about 6000 frames per year are available from the Alaska Satellite Facility (ASF) at he University of Alaska, Fairbanks in near real-time for ice and ocean applications. NOAA is entering into an agreement with Japan to become the America's Node for data from the Advanced Land Observing Satellite (ALOS). This satellite has an L-Band SAR instrument called the Phased Array L-band SAR (PALSAR). The ASF will receive and process the data for NOAA. RADARSAT-2 will be a commercial mission and most current and planned SARs have a commercial aspect to them. Data purchase negotiations are underway and buying consortia are being formed by the users; however it is uncertain at this time what the prices will be and where near real-time data will be obtained. In addition to the data-access arrangements described above, NESDIS has submitted or participated in a number of research proposals with the goal of securing data access for research and applications demonstrations. These have been the key to NOAA access to ERS-1/2, RADARSAT-1, ALOS, and ENVISAT SAR data. With the data provided to these projects, NOAA has been able to develop the capability to provide near real-time products from RADARSAT-1 to users of the Alaska SAR Demonstration.

4.2 Conducting SAR Product Research

SAR research in NOAA began with the Seasat satellite in 1978, but the short lifetime of this satellite and the lack of digital processing capabilities (the data were initially processed optically) led to slow progress toward any operational use of SAR data. With the initiation of the ESA ERS-1 mission and the follow-on ERS-2 mission, research and case studies began within NESDIS. There was a long learning curve, but by 1995 a number of studies had been completed, related to sea ice analysis (Leshkevich et al., 1995), but as experience grew applications were expanded to include oil spills, river ice, lake ice, vessel detection for fishery studies, and icebergs. ORA work with ERS-1/2 was mostly qualitative in nature, with image analysis predominating. With the launch of Radarsat-1 in 1995, efforts were underway to make use of SAR data on a more operational basis, especially in the NIC. Research work intensified and more papers were published on the results of NESDIS SAR research (Yan et al., 1997; Clemente-Colón et al., 1998, Pichel et al., 1998). In 1997, ORA entered into a two-year cooperative agreement with the Johns Hopkins University Applied Physics Laboratory (JHU/APL) for quantitative SAR coastal winds development. This project was very successful, leading to a validated SAR winds algorithm which provided 1 km resolution winds with an accuracy approaching that of scatterometer winds. In 1998, Robert Winokur, then Associate Administrator of NESDIS, tasked ORA with doing an operational demonstration of quantitative coastal ocean applications of SAR with funding provided first in FY 1999. This effort became the Alaska SAR Demonstration (AKDEMO). After about 9 months of planning and talking to users in Alaska, ORA began an intensive year of applications development with JHU/APL and the Environmental Research Institute of Michigan (ERIM - which became Veridian, and is now General Dynamics). The SAR winds product was developed into a routinely produced product available via a new AKDEMO web site (Pichel and Clemente-Colón, 2000; Monaldo et al., 2000; Thompson and Beal, 2000). Access to routine products via the web site began October 1999. In April 2000, a ship detection product was developed by General Dynamics (Wackerman et al., 2001), and a web-based interactive data access and analysis tool called the World Wide Web Interactive Processing Environment (WIPE) was developed by Applied Coherent Technologies (ACT) Corporation (Pichel et al., 2000). The AKDEMO also included imagery used by the Anchorage Weather Service Forecast Office for ice analysis, weather analysis, and analyses of spring ice break-up for the large Alaskan rivers (and associated flooding), and

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

Table 2 - Past, Present, and Future SAR Satellites

imagery used by the National Ocean Service for monitoring ice hazards to oil operations in Cook Inlet. An ice mask product was added in January 2003. Although, the AKDEMO has been the focus of ORA research efforts, there are other research projects underway. Table 3 gives the status of development for the various applications being considered for operational implementation.

4.3 Providing Applications Demonstrations and User Outreach/Education

Currently, a number of applications demonstrations are underway to give users quasi-operational experience in the use of SAR for real world applications. The first of these is the Alaska SAR Demonstration (AKDEMO), initiated in October 1999 and still running. This is a demonstration of near real-time SAR product derivation, dissemination, and utilization in Alaska. SAR-derived products include high-resolution wind speed and direction, vessel positions, ice masks, and SAR imagery for ice, hydrologic, and meteorological analyses. These are being used and evaluated for hazardous coastal wind analysis, fisheries management and monitoring, monitoring of river ice break-up, flood monitoring, oil spill monitoring, polar mesoscale cyclone

#	EDR TITLE	Lead in NOAA	Research	Product Dev.	App. Demo.	Operations
	OCEANIC					
1	Coastal Sea Surface Winds & Wind Stress	ORAD	Since 10/97	Since 10/98	Since 10/99	
2	Wave Characteristics - Significant Wave Height	ORAD	Since 5/03			
3	Wave Characteristics. - Ocean Wave Direction/Wavelength	ORAD	Since 5/02			
4	All Weather Day/Night Imagery	NIC	12/92-6/96	12/92-6/96	12/92 - 6/96	Since 6/96
5	Oil Spill Location	ORAD	Since 6/96	Since 6/96		
6	Vessel Positions	ORAD	Since 10/97	Since 10/98	Since 3/00	
7	Bathymetry (Near Shore)	ORAD	Since 5/02			
8	Littoral Currents	?	Not started			
9	Surf Conditions	?	Not started			
10	Ocean Mesoscale Features Fronts/Eddies, Upwelling, Harmful Algal Blooms	ORAD	Since 12/92	Since 10/97	Since 12/01	
11	Mixed Layer Depth	ORAD	Since 5/01			
	CRYOSPHERIC					
12	Sea & Lake Ice Concentration Age or Type Motion Edge Location	NIC (GLERL Participating in lake ice studies) ORAD	Since 12/92	12/92-6/96	12/92 - 6/96	Since 6/96
13	Ice of Land Origin (Icebergs)	?	?	?	?	?
14	River Ice Location/Condition	NWS Anchorage & Glasgow MT	Since 10/94	Since 10/96	Since 10/98	
15	Glacier Volumetric Change Tidewater glacier change Glacier Dammed Lake Change	 ORAD NWS Anchorage	 10/97-10/99 Not started			
16	Continental Ice Sheet Melt Zone	-	-	-	-	-
17	Ice-Sheet Motion	-	-	-	-	-
18	Ice-Sheet Grounding Line Position	-	-	-	-	-
	HYDROLOGIC					
19	Flood Mapping	ORAD	Occasional			
20	Snow Water Equivalent Mapping	-	-	-	-	-
21	Regional Soil Moisture	-	-	-	-	-
22	Coastal Wetland Mapping	?	Not started			
	LAND					
23	Land Surface Topography	-	-	-	-	-
24	Land Surface Deformation	-	-	-	-	-
25	Land Surface Freeze/Thaw State	-	-	-	-	--
26	Vegetation Classification/Biomass	-	-	-	-	-
27	Coastal Change	?	Not started			
28	Wetland Mapping	?	Not started			
	ATMOSPHERIC					
29	Mesoscale Atmospheric Features Polar Mesoscale Cyclones Hurricanes Atmospheric Boundary Layer Processes	 ORAD AOML ORAD	 Since 10/97 Since 6/98 Since 1/98	Since 10/98	Since 10/99	
30	Microscale Atmospheric Features	?	Not started			

Table 3 - Status of SAR Product/Application Development in NOAA - September 2003

detection, and coastal and open-ocean sea ice analysis. Products are accessible to authorized users and in some cases to the general public via the Alaska SAR Demonstration web site (http://fermi.jhuapl.edu/sar/stormwatch/index.html) and also via a web-based interactive data analysis tool called the World Wide Web Interactive Processing Environment (WIPE). In addition to the AKDEMO, there are four other applications demonstrations underway within NOAA/NESDIS. These are: (1) the Gulf of Mexico Experiment (GoMEx), a retrospective study of oil spill, ocean feature, and hazardous algal bloom detection in the Gulf of Mexico, (2) GhostNet, a study of the use of multi-platform satellite data in the location of convergence areas to aid in the search for derelict nets in the Northeast Pacific and Alaska waters (3) Hurricane Watch, a study of the use of SAR imagery in hurricane research, and (4) near real-time monitoring of the Columbia River plume for use in salmon fishery studies. As a result of supporting these applications demonstrations, members of the SSR Science Team at NESDIS have been gaining experience in the full range of activities related to the long-range development and maintenance of operational systems for SAR product production.

User training and education has been a particular emphasis from the beginning of NOAA involvement in SAR. A number of workshops and symposia have been sponsored by NOAA/NESDIS to help foster the development of operational applications of SAR and to educate the public on the use of this emerging technology. The latest of these is the 2nd Workshop on Coastal and Marine Applications of SAR held in Svalbard Norway in September 2003. Nearing publication is a SAR Marine Users Manual, containing comprehensive explanations of the many applications of SAR data in the marine environment. This publication, sponsored by NOAA/NESDIS/ORA, has been authored by the international SAR research community.

5. PLANS FOR DEVELOPMENT OF A SAR OCEAN PRODUCTS SYSTEM

NOAA is now embarked on a new phase of involvement in SAR applications; i.e. operational ocean products system development. The goal is to take the algorithm and product production experience gained in recent research and applications demonstration work and apply it to the development of a fully operational SAR ocean products system that can become part of the NPOESS central data processing systems or installed at acquisition stations worldwide for production of products from data received by individual acquisition stations.

5.1 History and Current Status of Near Real-time SAR Data System and Ocean Products System

With the initiation of the European Space Agency (ESA) ERS-1 mission in 1991, NOAA/NESDIS, the Navy, and the National Ice Center (NIC) began developing a capability to handle ERS-1 SAR imagery in near real-time for ice applications. Building on the ASF that NASA established at the University of Alaska, Fairbanks, a data system to capture and process SAR in near real-time and send it through dedicated land lines and the NOAA TIROS-N DOMSAT link from the NOAA Fairbanks Command and Data Acquisition (CDA) station to Suitland, Maryland was developed to bring the first operationally useful SAR data to the NIC. Besides the NIC use of the data, ORA began its first SAR research since Seasat by participating in a project to look at coastal ice applications in Alaska and the Great Lakes, partnering with the NOAA Pacific Marine Environmental Laboratory and the NOAA Great Lakes Environmental Laboratory. This project also began with the launch of ERS-1.

When the Canadian RADARSAT program was established in the early 1990s, a project was started to bring RADARSAT-1 data to NOAA and the NIC in a much more operational fashion by establishing a more reliable data stream between ASF and Suitland. NOAA provided project leadership for this effort, again partnering with NIC and the Navy. The RADARSAT-1 SAR processing capability established by NASA Jet Propulsion Laboratory at ASF was augmented by NESDIS to handle near real-time operational data processing and communications (via a direct connection between ASF and Suitland which bypassed the unreliable connection through the Fairbanks CDA station). A direct T1 link was established between ASF and Federal Building 4 (FB4) in Suitland (constructed for the ADEOS-1 mission). A T1 link from FB4 to the Anchorage Weather Service Forecast Office (WSFO) is used

to send SAR imagery to the National Weather Service (NWS). A completely new system for handling the large RADARSAT-1 SAR data sets was built by the NESDIS Satellite Active Archive. This system was designed to handle data from ASF, from the Canadian processor in Gatineau, from the Norwegian Tromsø station, and from the Scotland station at West Freugh. The Satellite Active Archive SAR system was implemented in 1996 and has been running well ever since. Initially SAR data were available for use in the NIC and ORA within 6 hours after observation. Improvements implemented at ASF in 2002 have cut that time down to 2-3 hours. Further refinements may decrease this data latency time down to 1-2 hours. After this near real-time data handling system was developed at SAA, the Alaska SAR Demonstration was initiated and the data system was augmented to include a web server and a web-based data analysis tool (i.e. WIPE). Redundant processing systems in ORA and the Satellite Services Division (SSD) of the NESDIS Office of Satellite Data Processing and Distribution (OSDPD) are used to generate products served to users. This system, although not operational, is operated as if it were operational, both for NIC ice analyses and for the AKDEMO. Operational ice analyses for the Great Lakes, the waters around Alaska, and for the high Arctic are generated every week (in season) by the NIC using RADASAT-1 data when available along with other satellite data, *in-situ* data, and observer reports. Some of these analyses are updated twice or three times a week. For the AKDEMO, ORA and OSDPD generate high resolution sea surface winds, vessel detection products, ice masks, and mapped SAR imagery every day from about 15-20 images received in near real-time. These products are served via WIPE along with satellite visible and infrared imagery, and Fleet Numerical Meteorology and Oceanography Center (FNMOC) atmospheric model output.

5.2 Vision for the Future Development of a SAR Ocean Products System

Planning has just begun for an operational SAR ocean products system. The 2nd Workshop on Coastal and Marine SAR Applications held in Svalbard in September 2003 is helping to define what algorithms should be included in such a system. The concept is to partner internationally (with Norway, Canada, ASF, and others) to develop an international SAR ocean products processing system that can handle multiple SAR satellite input and generate a consistent set of ocean quantitative products. This system could then be deployed at multiple acquisition stations worldwide. In the U.S. this system would be installed at ASF and at the University of Miami Center for Southeastern Tropical Advanced Remote Sensing (CSTARS), and eventually at West Coast and Hawaii stations. It would be used as the NPOESS SAR product processing system, installed at one or more of the central data processing systems for NPOESS. Software would be developed according to NPOESS Integrated Program Office (IPO) standards. Level 0 complex SAR data would be brought from individual acquisition stations to the NPOESS processing centers via the NPOESS fiber optic communications system (i.e., the Safety Net).

6. CONCLUSION

NOAA is about halfway between elementary SAR applications research and case studies which started in earnest in 1992 and a fully operational automated ocean products system which is expected in the 2012 time frame. Routine near real-time use of SAR imagery from RADARSAT-1 in the National Ice Center and production of products in the Alaska SAR Demonstration have given NOAA considerable experience with the use of SAR imagery for quantitative and qualitative product production and application. New satellites like ENVISAT, ALOS, and RADARSAT-2 will be important for this effort for the next few years. It is hoped that international and domestic partnerships will lead to the development of an automated operational SAR ocean products system that can be installed at acquisition stations to provide a wide array of products to operational users.

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