COASTWATCH SAR APPLICATIONS DEMONSTRATION -- DEVELOPMENT PHASE

W. Pichel[1], P. Clemente-Colon[1], G. Hufford[2], G. Leshkevich[3], G. Wohl[2], F. Kniskern[4], J. Sapper[1], R. Carey[1]

[1]National Environmental Satellite, Data, and Information Service; [2]National Weather Service; [3]Great Lakes Environmental Research Laboratory; [4]National Ice Center

ABSTRACT

An applications demonstration of the use of synthetic aperture radar (SAR) data in an operational setting is being conducted by the NOAA CoastWatch program. The first phase, the development phase, of this demonstration has been completed. Case studies have been carried out to assess the utility of SAR data for monitoring (1) coastal ice, (2) river ice jams and flooding, (3) ocean fronts, current boundaries, and eddies, and (4) lake ice in straits and channels. The all-weather, day/night viewing capabilities of the SAR make it a unique and valuable tool for monitoring coastal, river, and lake ice as well as ice-free coastal ocean features.

Keywords: SAR, CoastWatch, AVHRR, Ice, Eddy

1. INTRODUCTION

The launch of the First European Remote-Sensing Satellite (ERS-1) in July 1991, marked the beginning of a wealth of satellite-borne synthetic aperture radar (SAR) data which will be available in the 1990's. With the promise of added SAR coverage from the Japanese Earth Resources Satellite (JERS-1, launched in January 1992), the Canadian RADARSAT, and ERS-2, it is now feasible to prepare for the operational use of SAR data for practical environmental applications. In order to develop expertise in SAR applications and the capability to handle SAR data in an operational setting, an applications demonstration of the use of ERS-1 data for coastal environmental systems management is being carried out within the CoastWatch theme of the National Oceanic and Atmospheric Administration (NOAA) Coastal Ocean Program. The development phase of this applications demonstration began in June 1992, and is the topic of this report.

2. COASTWATCH

2.1 CoastWatch Goal and Structure

CoastWatch is a relatively new activity within NOAA, with limited operations first achieved at one user site in 1990. The goal of CoastWatch is to provide data and products for near real-time monitoring of U.S. coastal waters in support of environmental science and management (Ref. 1). Satellite, in situ, and weather-model data and products are now being distributed electronically via the NOAA Ocean Products Center, seven NOAA field offices, and the NOAA National Oceanographic Data Center (NODC) to a diverse user community of Federal and state environmental managers and university researchers. The field offices, called CoastWatch Regional Sites (CRSs), are located in coastal states of the contiguous U.S. as well as in Hawaii and Alaska (see Figure 1). By 1993, all the CRSs were operational, providing products routinely to over 80 user agencies.

Coastwatch Regional Sites

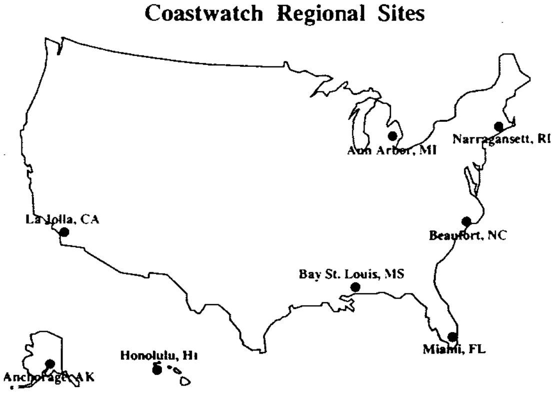

Fig. 1. CoastWatch Regional Sites (CRSs) are located at NOAA facilities and provide access to CoastWatch satellite imagery and other products. The CRSs at Narragensett, Beaufort, Bay St. Louis, La Jolla and Honolulu are located at National Marine Fisheries Service Laboratories. The Anchorage CRS is located at the Anchorage Weather Service Forecast Office. The CRS in Miami is at the National Hurricane Center. The CRS at Ann Arbor is at the Great Lakes Environmental Research Laboratory.

2.2 CoastWatch Products

Current CoastWatch satellite products include satellite sea surface temperature (SST) and visible-channel (i.e., cloud and turbidity) images at 1.2 km resolution derived from the

*Proceedings Second ERS-1 Symposium — Space at the Service of our Environment, Hamburg, Germany, 11 - 14 October 1993
ESA SP-361 (January 1994)*

Advanced Very High Resolution Radiometers (AVHRR) carried on the NOAA polar-orbiting satellites (see Figure 6; Ref. 2,3). Planned for the near future are ocean-color products from the SeaWiFS instrument on the SeaStar satellite, ocean model output from the planned NOAA Coastal Forecast System, ocean surface wind speed data from the Defense Meteorological Satellite Program (DMSP) Special Sensor Microwave/Imager (SSM/I) and SAR images and derived products from RADARSAT.

2.3 <u>CoastWatch Product Distribution</u>

CoastWatch products are produced centrally at the National Environmental Satellite, Data, and Information Service (NESDIS) and the Ocean Products Center (OPC) in Maryland and distributed via Internet by the OPC to the CRSs. Other products are generated at the CRSs from locally processed data. All products are obtainable from the CRSs in near real-time or from NODC retrospectively.

3. SAR APPLICATIONS DEMONSTRATION

3.1 <u>General Description</u>

The CoastWatch SAR Applications Demonstration has the goal of assessing the utility of SAR imagery for CoastWatch purposes. The applications demonstration has two phases, a development phase and a demonstration phase. Beginning in June 1992, the development phase had the goal of developing a capability to access and display ERS-1 SAR data and to accomplish a limited number of coastal application case studies. Although some capability development is still ongoing, enough infrastructure is in place to carry out applications demonstrations in the fall of 1993 and during the winter and spring of 1994. The ultimate goal of these activities is to prepare for operational use of SAR data in the RADARSAT era. Two CRSs are participating in the applications development and demonstration: (1) the Weather Service Forecast Office (WSFO) in Anchorage, Alaska (the CRS for Alaska), and (2) the Great Lakes Environmental Research Laboratory (GLERL) in Ann Arbor, Michigan (the CRS for the Great Lakes).

3.1 <u>SAR Communications</u>

The CoastWatch SAR applications demonstration is being accomplished by leveraging the SAR data capture, communications, and analysis system developed for the National Ice Center (NIC). Selected scenes of ERS-1 SAR data acquired at the Alaska SAR Facility (ASF) on the campus of the University of Alaska in Fairbanks are processed within six hours (quick-look processing) and stored in a special-purpose SAR Communications (SARCOM) computer. These data, along with selected retrospective data are then sent at prearranged times via a Government-leased ground and satellite communications system to the NIC and to computers operated by the National Environmental Satellite, Data and Information Service (NESDIS) of NOAA, both located in Suitland, Maryland (see Figure 2 and Ref. 4). SAR data received in Canada at Gatineau (near Ottawa) are also being sent to the NIC over a communications link between the U.S. and Canadian ice centers.

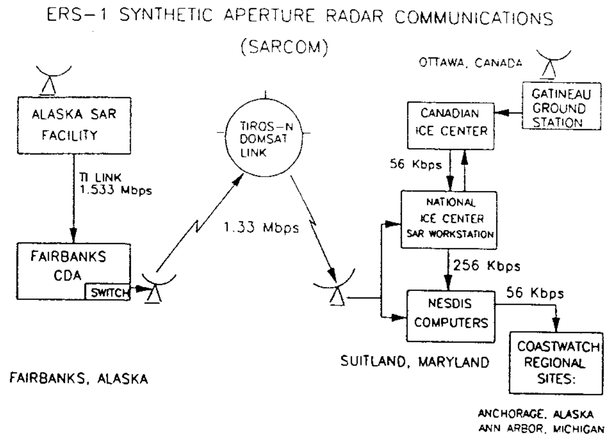

Fig. 2. SAR data from ERS-1 reaches the CoastWatch Regional Sites by first going via ground and microwave links from the ASF to the NOAA Command and Data Acquisition (CDA) station near Fairbanks. The data are sent from the CDA to Maryland via a domestic satellite (DOMSAT) communications link used for the NOAA polar orbiting satellite (i.e., TIROS-N) data. In Maryland, the data reach the National Ice Center SAR workstation and the NESDIS mainframe computers which are accessible to the CRSs via Internet. SAR data acquired in Canada are obtained via a link used to exchange products between the Ice Center Environment Canada in Ottawa and the U.S. National Ice Center.

3.2 <u>SAR Data Display and Processing</u>

Currently, hard-copy and electronic copies of coastal images are being made in the SAR Workstation at the National Ice Center and forwarded to the co-investigators for the CoastWatch SAR Applications Demonstration. A data base is under development on the NESDIS computers which will allow storage of the Alaska images and selected Canadian scenes for electronic access by NOAA PIPOR researchers, particularly those at the CRSs in Anchorage and Ann Arbor. Until recently, most SAR image display and analysis has been done on the SAR Workstation at the NIC (Ref. 5); however, commercial and government-developed SAR data display systems have been tested by the co-investigators, and will be used during the demonstration phase.

4. DEVELOPMENT OF ALASKA DEMONSTRATION

4.1 <u>CoastWatch Alaska SAR Applications</u>

In Alaska, SAR data are being assessed in eleven coastal and riverine areas as to their utility for CoastWatch applications. Table 1 lists the areas of interest.

Table 1: Alaska CoastWatch SAR Applications Demonstration Areas of Interest.

Areas of Interest	Applications
Prudhoe Bay Point Barrow Yukon Delta Kivalina	Monitoring Ice Conditions for Coastal Transportation
Cook Inlet	Monitoring Ice Hazards to Oil Activities
Yukon River	Monitoring Flooding due to Ice Jams
Prince William Sound	Monitoring Glacial Breakup
Shelikof Strait Bristol Bay	Monitoring Ocean Fronts and Eddies for Fishery Studies
Yakutat Bay Fairweather Ground	Monitoring Wave Conditions for Coastal Transportation and Fishing

4.1.1 Alaska ice applications development. During 1992 and early 1993, low resolution (100 m pixel spacing, 240 m resolution) SAR data from the ASF were collected for case studies from most of the above regions. For coastal applications involving ice, SAR data are clearly superior to other available remote sensing data. The combination of high resolution, all-weather day and night viewing capability, and the ability to discriminate between first year and multi-year ice, make the SAR a unique tool for coastal ice monitoring. The recent discovery of another major oil field in Cook Inlet with the potential of nearly one billion barrels of oil has increased the activity in the Inlet year around. Since the Inlet is ice covered from late November through April, knowledge of sea ice distribution and concentration are critical elements to safe vessel transportation (including oil platform support vessels) in the Inlet waters. When compared to coincident correlative data such as AVHRR imagery, Defense Meteorological Satellite Program (DMSP) imagery, ship reports, oil platform reports and aircraft overflights, it is evident that the high resolution SAR data provide a superior ice remote sensing capability.

The state of Alaska contains approximately 54% of the nation's coastline, and about 78% of the state's population lives on or near the coast, usually located close to a large river. Coastal and river transportation of goods is the major means of supply to these communities (less than 1% of Alaska has roads). These waters are typically ice covered from November through May (into July for the Northslope waters). This ice becomes not only a hinderance to vessel traffic, but presents the potential for flooding due to river ice jams, especially in the spring.

Figures 3, 4, and 5 illustrate the potential of SAR data as an aid in monitoring coastal ice conditions for vessel transportation guidance. For ice analysis, the National Ice Center utilizes predominantly AVHRR data. These data are supplemented when possible by aircraft and ship reports and by SSM/I ice information. Figure 3 is an example of the type of AVHRR imagery normally employed for ice analysis. It is a full-resolution (1.1 km) image of visible reflectance in AVHRR Channel 1 (0.58 - 0.68 μm) from an afternoon pass at 0104Z, May 29, 1992. The region depicted is the Bering Sea coastline of Alaska in the vicinity of Norton Sound. Although late in the ice year, fast ice still hugs the coast, particularly around the Yukon River Delta (area enclosed by black square). Seaward of the fast ice is a ribbon of low ice concentration, then a broader region of higher concentration including large flows, and then finally open water (in most cases hidden by clouds).

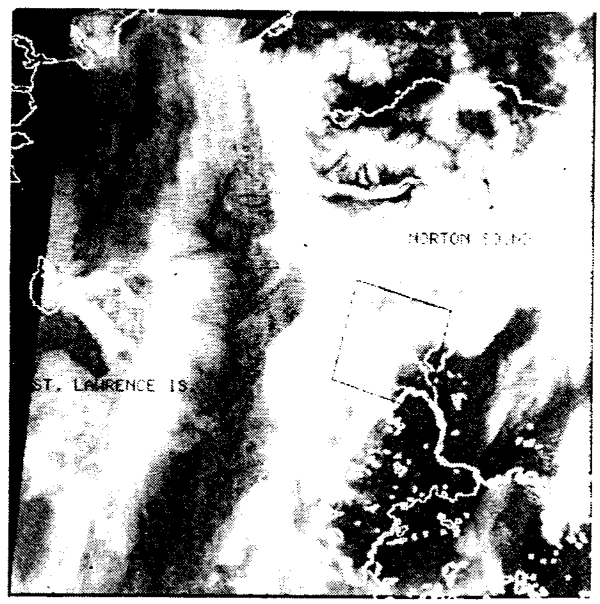

Fig. 3. NOAA AVHRR Channel 1 mapped image of the Bering Sea and Alaska Coast in the vicinity of Norton Sound, 0104Z, May 29, 1992. The black square encloses a portion of the Yukon River Delta. Brighter areas have greater reflectivity in the visible wavelengths.

Figure 4 is an enlargement of the Yukon Delta region, in which the AVHRR data has been remapped to coincide with the SAR image shown in Figure 5. Even though the SAR image is low resolution (100 m pixels, 240 m resolution), there is a wealth of detail here which is only hinted at in the AVHRR image; for example, the open water (or thin ice) right along the shore in the northwest corner of the Delta. The fast ice, although highly reflective as seen from the AVHRR image, has a relatively low radar cross section, indicating low salinity ice, perhaps with a wet surface. Likewise, the large round dark ice flows (probably wet) seen in the left edge of the SAR image are highly reflective in the visible image. The dark band seaward of the fast ice in the AVHRR image can be seen to be made up of a string of small open-water or thin ice regions. The information on ice flows and ridging or rafting (areas of greater radar cross section in the SAR) are particularly valuable in vessel guidance. The National Ice Center has successfully used SAR data to do near real-time ship routing in the vicinity of Point Barrow, Alaska.

Fig. 4. NOAA AVHRR Channel 1 image, 0104Z, May 29, 1992 -- an enlargement of the portion of Figure 3 enclosed in the black square. This image has been remapped to be coincident with the SAR image shown in Figure 5. The Yukon Delta is the darker region in the lower right quadrant. Fast ice shows as a bright band paralleling the shore; drifting ice fills the left and top of the image. Brighter areas have greater reflectivity in visible wavelengths.

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Fig. 5. ERS-1 SAR image in the region indicated by the black square in Fig. 3 and coinciding with the AVHRR image in Fig. 4, for 2213Z, May 28, 1992. Brighter areas have greater radar backscatter.

4.1.2 <u>Alaska coastal ocean applications</u>. The detection of fronts and eddies is quite important for fishing activities and for fishery studies. In another case study, AVHRR and SAR data were analyzed to detect fronts and eddies in Shelikof Strait for use in studies of fishery egg and larvae survival. Under moderate wind conditions, there is an excellent correspondence between AVHRR thermal features and signatures of these features in the SAR data. Figure 6 is an AVHRR Channel 4 (10.3 -11.3 μm) image of the Gulf of Alaska in the vicinity of Kodiak Island. Shelikof Strait is the strait between Kodiak Island and the Alaska Peninsula to the northwest. A large eddy is apparent close to the Alaska Peninsula at the southern end of Shelikof Strait. Wavelike undulations in the temperature front in Shelikof Strait (as a result of baroclinic instability - see Ref. 6) and indications of smaller eddies in the Strait are also evident. There is an ongoing investigation in this region (Fisheries Oceanography Coordinated Investigations -FOCI) studying physical oceanographic mechanisms which affect walleye pollock egg and larvae transport. As a result of these studies, there is growing evidence suggesting that eddies may play an important role in transporting and retaining eggs and larvae in the nursery areas along the Alaska Peninsula, leading to increased recruitment (Ref. 7).

Fig. 6. AVHRR Channel 4 (thermal infrared) image of surface temperature in the Gulf of Alaska in the vicinity of Kodiak Island for 2343Z on May 1, 1992. Darker grey tones represent warmer surface temperature. Shelikof Strait lies between Kodiak Island and the Alaska Peninsula. The lower portion of the image has some cloud cover. There is no sea ice in this region.

Although eddies on scales of 30 or more kilometers with large thermal signatures are readily apparent in AVHRR imagery, smaller eddies and those with low thermal contrast are not routinely detectable. However, on SAR imagery, like that shown in Figure 7, smaller eddies are clearly visible. Currents, wave/frontal interactions, and wind speed variations all modulate the amplitude of the small-scale ocean surface waves which influence the SAR backscattered signal. This is the mechanism which allows frontal boundaries, eddies, and current meanders to be imaged (Ref. 8). Two eddies with scales of about 20 km and a jet with a dipole vortex are evident in Figure 7. In this case, there is a good correspondence between the circulation and frontal features seen in the SAR imagery with those features evident in the AVHRR imagery. Dark lines of lower backscatter from the SAR imagery have been mapped to the AVHRR image and are shown as white lines on the AVHRR enlargement in Figure 8. The "hook-like" thermal pattern in the AVHRR image can now be seen to be an indication of an eddy which is readily apparent in the SAR image. As for the dipole vortex so apparent in the SAR image, there is only a faint thermal signature in the AVHRR image.

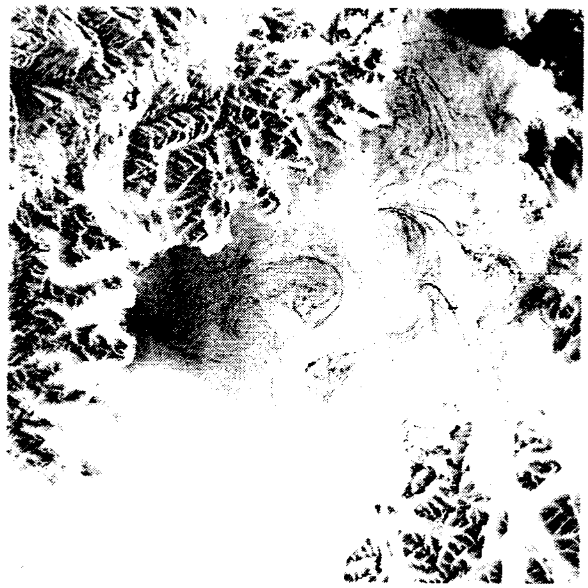

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Fig. 7. ERS-1 SAR image of Shelikof Strait from 2221Z, May 1, 1992. Kodiak Island is in the lower right corner of the image with the Alaska Peninsula on the left side of the image. Two distinct eddies are shown, one near Kodiak Island and another in the center right of the image. The mushroom-shaped feature in the center of the image is a dipole vortex.

SAR data collected from SEASAT in 1978 have been used to demonstrate the potential of these data for use in examining ocean wave spectra. Alaska continues to lead the nation in deaths of commercial fishermen and transportation personnel due to inclement weather and waves. For instance, waves exceeding 45 feet are common in the Gulf of Alaska in the Winter months. SAR data provides a large aerial view of the ocean wave spectra that cannot be collected by a few isolated buoys in the Gulf. Wave data from the buoys and from ship reports will be used however to validate the SAR estimates. In a joint project between the Anchorage WSFO and the Civil Engineering Department of the University of Alaska at Fairbanks, waverider buoys will be placed in late 1993 at the mouth of Cook Inlet and perhaps near Yakutat Bay. Data from these buoys will be compared with wave spectra measurements from the ERS-1 SAR.

The value of SAR to coastal ocean applications derives from the wide range of phenomena to which it is sensitive (e.g., internal waves, fronts, eddies, surface waves, wind variations, current interactions), and the all-weather, day/night sensing capability. In Alaska, where the surface of the ocean is so often obscured by clouds, the value of this capability cannot be overstated.

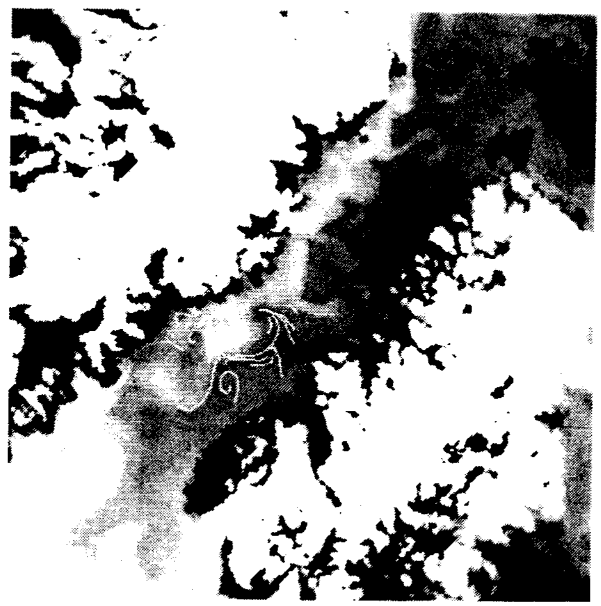

Fig. 8. AVHRR Channel 4 image of Shelikof Strait from 2343Z May 1, 1992. Kodiak Island is in the lower right, the Alaska Peninsula is in the upper left. This is a thermal image with surface temperatures depicted in shades of grey. Warmer temperatures are darker grey. The white lines in Shelikof Strait are lines of low backscatter traced from the SAR image (dark lines in Figure 7). These lines coincide with frontal and eddy features in both images.

5. DEVELOPMENT OF GREAT LAKES DEMONSTRATION

The first SAR data for the Great Lakes SAR applications demonstration were received in February 1993 from the Gatineau readout station in Canada. The primary application to be studied in the Great Lakes is ice analysis; i.e., ice identification and mapping, and ice jam monitoring in straits, connecting channels, bays, and harbors. During the period February 17-24, a data set was collected over Lakes Erie, Huron, and Superior. This data set consists of ERS-1 SAR data, AVHRR imagery, U.S. Coast Guard Side Looking Airborne Radar (SLAR), and still pictures and video taken from a Coast Guard helicopter. These data are now being analyzed to understand the ice patterns seen in the SAR data. Preliminary results of the analysis are presented in a companion paper entitled: "Great Lakes SAR Ice Research Applications Demonstration."

6. DEMONSTRATION PHASE

The next phase of this applications demonstration, the demonstration phase, began in June 1993. During this year-long phase, routine monitoring of selected coastal regions will be periodically conducted using SAR data in Alaska and the Great Lakes. The 3-day repeat coverage offered by the ERS-1 Ice Orbit during January-March 1994 will be exploited in the demonstration phase in coastal regions of interest to CoastWatch.

During this demonstration phase, the Anchorage WSFO will be using a commercial software package to display and manipulate the SAR data into a viable product that can be readily used by the forecaster. The demonstration phase will focus on assessing the importance of SAR to many different monitoring, forecast, and warning problems in Alaska. A major effort during this phase will be to acquire high resolution SAR data to monitor river ice jams. Monitoring of Alaskan rivers for ice jams presents the opportunity to recognize the occurrence of jamming and issue flood watches and warnings to the communities affected. This can only be accomplished in an efficient manner with all weather, high resolution SAR data. It would take major resources and a fleet of aircraft to cover the rivers. The low resolution SAR data have been helpful in showing the presence of large jams on the Yukon, especially in the Fort Yukon area (here the Yukon is approximately 12 miles wide); however, higher resolution will allow a better understanding of what is happening at key locations, regardless of the width of the river. Video and visual observations to be taken during overflights by the Alaska River Forecast Center will be used to help interpret the SAR data.

7. SUMMARY

The NOAA CoastWatch Regional Sites at the Weather Service Forecast Office in Anchorage, Alaska and the Great Lakes Environmental Research Laboratory in Ann Arbor, Michigan have participated in the development phase of an applications demonstration of the utility of SAR data to coastal management and monitoring activities. In order to develop the ability to process and interpret SAR data and to begin to assess the value of SAR data, a number of case studies were accomplished in which SAR data were collected and compared to correlative data such as AVHRR thermal and visible data. It was found that for both ice monitoring and ice-free ocean monitoring, the all-weather day/night viewing capability of the SAR, its high resolution, and the physical phenomena to which it responds make the SAR a uniquely valuable tool for coastal environmental monitoring. Even though only low resolution SAR data have been examined to date, the wealth of ice information available in the SAR make it clearly superior to other data sources. However, other types of remote sensing data, when available, can complement the SAR data, each adding to the interpretation of the other. In ice-free coastal areas, case studies have shown good correspondence between SAR and thermal imagery of ocean features such as eddies and fronts. The higher resolution of the SAR allows the analysis of features at smaller scales than those possible using only lower-resolution thermal data.

8. ACKNOWLEDGEMENTS

SAR data for this demonstration were provided by the European Space Agency within the framework of the Programme for International Polar Oceans Research (PIPOR proposal PI/BCB12). Funding to support the demonstration was provided by the NOAA Coastal Ocean Program. The imagery used in this applications demonstration could not have been obtained and processed without the efforts of many at the Alaska SAR Facility (especially Greta Reynolds), the Ice Center Environment Canada (especially Robert Tessier and Terry Mullane), the Canadian Centre for Remote Sensing (especially Bonnie Harris), the National Ice Center (especially Salina Nauman, Mark Dunn, Jim Nolan, and Cheryl Bertoia), and the Naval Research Laboratory (especially Florence Fetterer and Conrad Johnson). Figure 1 was provided by Eileen Maturi and Paige Bridges of the NOAA Satellite Applications Laboratory. This manuscript was assembled by Gail Heddinghaus of the NOAA Satellite Research Laboratory.

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GEORGE LESHKEVICH

esa SP - 361
January 1994
Volume I

Proceedings of the Second ERS-1 Symposium

SPACE AT THE SERVICE OF OUR ENVIRONMENT

11-14 October 1993
Hamburg, Germany

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Published by: *ESA Publications Division*
ESTEC, Noordwijk, The Netherlands

Editor: *Brigitte Kaldeich*

Price: *Dfl 200.00 (2 volumes)*

ISBN 92-9092-286-9

Cover photo: courtesy D. Massonet, CNES, Toulouse
The photograph shows a detail of the area where the Landers earthquake occurred on 28 June 1992. It covers an area of 90 by 110 km and shows observed interferometric fringes which result from the slip of the Earth's surface during the earthquake. One cycle of grey shading represents 28mm of change in the range.