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FINAL REPORT
MARKETING REMOTE SENSING DATA
FOR NORTH PACIFIC FISHERIES
DEVELOPMENT AND MANAGEMENT

PROJECT NAS13-513

PREPARED BY:
NATURAL RESOURCES CONSULTANTS, INC.
SEATTLE, WASHINGTON

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Final Report

Project NAS13-513

Marketing Remote Sensing Data for North Pacific Fisheries Development and Management

Executive Summary

The project, Marketing Remote Sensing Data for North Pacific Fisheries Development and Management, sought to link the fisheries and market awareness of Natural Resources Consultants, Inc. (NRC) with the technical abilities of other vendors and NASA. This union was intent on penetrating the marine industry for value-added remotely sensed data. The launching of two commercial products, *SeaStation*, a vessel information system capable of direct-to-vessel satellite image acquisition and processing and *OmniVision*, a shoreside vessel detection system using space-based radar assets, is a measure of our success. A further metric can be found in the formation of Ocean and Coastal ENvironmental Sensing, Inc. (OCENS). OCENS mission is to develop and market software, equipment, and information services that put to use data acquired from space-based sensors and improve the operations of marine and coastal zone users. The company was founded in 1994 and obtained private sector financing to aggressively carry forward the products and services begun within EOCAP.

OCENS current development and marketing activities include:

- 1) Software development;
- 2) Device driver development;
- 3) Development of **OCENS** Marine Forum HomePage: This site will offer a diversity of commercial fishing, sport fishing, yachting, and satellite services in segregated marine forums. **OCENS** products and services relevant to each market segment will be highlighted and/or demonstrated in each forum;
- 4) Production of user sheets and user handbooks describing how marine users can use the data acquired and processed by *SeaStation* to improve their fishing, route planning and vessel safety decisions;

- 5) Development of communications protocols necessary to forward data between shoreside and at-sea vessels;
- 6) Product sheet design and editing; Preparation of advertisement copy;
- 7) Application of new data compression procedures to image and other data
OCENS will be forwarding from its shoreside offices to ships at-sea;
- 8) Market assessment for *SeaStation* products and services.

As mentioned above, **OCENS** will be producing two primary products, *SeaStation* and *OmniVision*. *SeaStation* is a Windows™-based ocean and weather reconnaissance system released in two versions. *SeaStation* Standard is an exceptionally easy-to-use yet powerful system for the acquisition and processing of satellite imagery directly on-board fishing vessels and yachts. *SeaStation* Professional incorporates additional software and a communications system that permits the integration of shore-sourced environmental and, eventually, economic data. Both versions will be available for laptop and desktop PCs and target the commercial fishing, sport fishing, and blue water cruising markets.

OmniVision is a software/hardware system that uses space-based radar data to determine the location of vessels at-sea. Since radar can cut through clouds and mist, *OmniVision* provides an opportunity for nearly all-weather coverage. Furthermore, because the space-based radar systems act independently of any on-vessel transponders, these systems can be used to monitor the position of any vessel, not just those that agree to cooperate with the management process. These attributes should permit *OmniVision* to penetrate foreign markets for fisheries monitoring and surveillance.

Several new developments influence the markets that **OCENS** will be pursuing. Not the least of these developments is the heightened awareness of the applicability of computers to marine tasks. This awareness has trailed that associated with shore-based applications largely for reasons associated with processing power, data compression and communications, and hardware footprint. Significant progress has been made in all of these areas in recent years and **OCENS** will seek to capitalize on the rising tide of interest in computer applications in this market by providing powerful, yet easy-to-use software tools.

Another attitude that is affecting markets for both of **OCENS** current products is the increasing attention received by fisheries worldwide. With the persistent demand for seafood, the limited availability of those resources, and the existence of heavily capitalized fisheries worldwide, there is great pressure on fishermen to find fish quickly and cost effectively. *SeaStation* addresses this need. There is also pressure to operate illegally in prohibited areas or during closed times. *OmniVision*'s vessel monitoring capabilities target this market. As such, **OCENS** will bring new tools to the fish harvesting and fisheries enforcement and management practices of the next century.

Other developments that will increase our ability to penetrate target markets in the marine environment include the decline in services to fishermen offered by the National Marine Fisheries Service (NMFS) due to budget cuts, new sensor launches that will provide ocean color, radar, very high spatial resolution data, or hyperspectral information, and new types of environmental data made available by the military's interest in better serving civilian needs.

Primary sources of uncertainty that **OCENS** faces include the concern that planned sensors are actually launched on schedule, that the government does not change its policy regarding the access to NOAA AVHRR data, and that adjustments be made to high-resolution image pricing by image vendors so as to reflect the realities of the monitoring market. Trends in hardware costs and processing power have contributed greatly to our ability to penetrate marine software markets. While we anticipate that this trend will continue, we, of course, cannot guarantee it. Adequate financing, sales and marketing expertise, and insurance are all sources of business uncertainty that **OCENS** has recognized and is seeking to ameliorate.

Post-EOCAP activity will focus on the development and expansion of **OCENS** business opportunities. In the near-term, this will consist primarily of the continued development and marketing of *SeaStation* to the commercial fishing industry, recreational fishing boats and blue water cruisers and yachters. Mid-term activity to be pursued in the next two to four years includes continuing upgrades to *SeaStation* products to allow its integration with other electronic systems on-board the vessels and oceanographic data. **OCENS** marketing of the *OmniVision* vessel detection system will become much more aggressive during

this phase. **OCENS** intends to take advantage of advances in data compression and marine communications by developing the capability to supply a wide variety of data to vessels at-sea. **OCENS** also intends to expand the application of Geographic Information Systems in the marine environment by packaging marine environmental information as data layers for use in spatial information systems that can improve fishing performance and/or eliminate waste.

In the long term, **OCENS** strategy is to capitalize upon technological developments and its in-house expertise to broaden its business base. Revenues in later years will be enhanced by **OCENS** taking advantage of emerging space technology by applying it to aquaculture and new wild-capture fisheries applications, and becoming more intimately involved with the expanding marine telecommunications industry.

NRC will also be involved in post-EOCAP activity. Whereas most of **OCENS** near-term activities will be focused on product development and product and service marketing, remote sensing activities at NRC will be associated primarily with research investigations. These near-term investigations will, however, complement the mid- and far-term applications development of **OCENS** by focusing on fisheries and vessel monitoring and aquaculture applications.

The project team takes away several lessons from its three year EOCAP activity. Some of these issues include:

- An admonishment to NASA to evaluate the project team as much as the technology when evaluating proposals;
- A note of disappointment that NASA seems to be awarding more EOCAP contracts to large companies with already substantial R&D budgets, actions that, by default, preclude access to EOCAP funds by smaller companies without such R&D budgets;
- A reminder, gained from first hand experience, that technical feasibility does not necessarily translate into commercial application and success. We also learned from such experience, however, that the greatest attribute of the EOCAP program is its flexibility that allowed the project team to adapt to this reality and produce commercially viable products.

A recommendation to NASA to place a much stronger emphasis on if not the pre-project start presence, then the first year development, of a meaningful, business plan for the company and proposed project.

We suggest to future projects that they get as much of the data stream under their own control as is reasonably possible and to not depend upon government-sourced software.

Lastly, we encourage NASA to work towards becoming an objective clearinghouse for private-sector industry software and hardware. Not as a competing vendor but instead as an entity towards which businesses could turn when information is needed about the latest advances in private sector technology in the array of industries associated with the remote sensing field.

The EOCAP program has been a terrific opportunity for NRC and OCENS that we intend to leverage into successful business expansion in the marine computer software industry. All told, EOCAP II has contributed to an 8% increase in revenues at NRC over the twelve months ending May, 1995. It has also led to the development of OCENS and related activities that now involve ten subcontractors, \$70,000 of direct investment, and \$40,000 of new contracts at the time of this writing. Key innovations include those related to the SeaStation system involving its Windows 3.1 and Windows95 interface, PCMCIA receiver and converter cards, system integration with Geographic Positioning Systems (GPS), and new antennae designs for specific target markets. The geolocation algorithm and XCASS software used in our *OmniVision* product represent important enabling technologies co-opted by the project team to develop the *OmniVision* system. Finally, the project has contributed five papers to the scientific literature and been responsible for an additional four presentations in the US and overseas.

Much of EOCAP's success is based on the program's willingness to work with private business to develop a successful commercial product. Unlike other government programs in which several of the project members have participated, within EOCAP we have never felt like we were mired in bureaucratic quicksand. Instead, EOCAP represents firm ground to which other agencies and programs should look for counsel on how government/private sector cooperation should work together.

Introduction

Fish poaching, drug trafficking, ocean dumping, and other illegal activities are important problems on the high seas and in national economic zones. The primary thrust of the EOCAP II project, "Marketing Remote Sensing Data for North Pacific Fisheries Development and Management", was to use space-based sensors to improve the effectiveness of marine monitoring, control, and surveillance (MCS). Our initial objectives were to concentrate on the development of MCS tools using Advanced Very High Resolution Radiometry (AVHRR) and Synthetic Aperture Radar (SAR) data. Although we have successfully completed development of an initial version of our SAR-based monitoring tool (*OmniVision*), project activity has resulted in a much broader application of space-based assets to marine applications. Based in part on work commenced within EOCAP II, a new company, Ocean and Coastal Environmental Sensing, Inc. (OCENS), has been launched and the development of several new software products outside of the MCS arena initiated. One of those products, *SeaStation*, is near completion with a Fall, 1995 release date. Equity investment in OCENS now totals \$70,000 with an additional amount being sought in the first round of financing.

One of the pre-eminent objectives of EOCAP II is to make contributions to the US economy and job growth through the expansion of commercial uses of remotely sensed data. OCENS and the software products it is introducing into marine and coastal zone markets responds to this primary objective. EOCAP II funding leveraged the market and technical know-how of OCENS founders into smart products that benefit marine and coastal zone users. Although technical difficulties and geopolitical shifts damaged the commercial feasibility of initial project objectives, the flexibility of the EOCAP II program now permits long-term business success. This in no small part stems from the fact that the EOCAP program recognizes the realities of small and start-up businesses and does not attempt to force these conditions to fit the apparent needs of big government. Instead, EOCAP works with those who know their market best in order to produce successful products and expanding businesses.

Approach to Commercialization

This project has taken two noteworthy shifts in its approach to commercialization since its inception. As the primary contractor, Natural Resources Consultants, Inc. (NRC) initially planned to develop technical ship tracking expertise and market these products directly to US government fisheries enforcement interests operating in the North Pacific. However, with the shift in geopolitical conditions following the demise of the former Soviet Union, NRC recognized that it could very well end up competing with US military assets (namely the SOSUS North Pacific sonar net) for US fisheries enforcement markets. Given the amount and expertise of US military assets that could be directed at the fisheries enforcement problem, NRC shifted its emphasis from a focus on US markets to overseas markets. Primary overseas markets were those identified in developed and developing nations possessing significant fisheries within their exclusive economic zones but without the financial and technical resources to effectively patrol them with conventional means. Some forty nations around the globe matched these criteria:

The second shift in commercialization approach followed recognition by the project team that midway project results indicated that AVHRR-based ship track monitoring would not provide a level of coverage necessary for a reliable vessel monitoring service. At this stage, NRC revisited other market opportunities for AVHRR data in the marine and coastal zone markets. One such opportunity was the provision of APT-level data on weather and sea surface temperature directly to at-sea fishing vessels and yachts. To further investigate this market, NRC placed existing off-the-shelf APT systems on-board selected fishing vessels operating in the North Pacific fisheries. Skippers of these vessels were asked to comment on their interest in the acquired data and the usefulness of the software/hardware systems that provided it to them. Responses reflected an interest in the information but a frustration with the reliability of the software, the complexity of the user interface and the inability of the software to perform certain tasks of use to the fishing and boating sectors.

The market's assessment of the deficiencies of existing direct-to-vessel satellite reception and image processing systems spurred NRC's interest in the development of its own software to address them. Outside contractors were retained to begin software development within the framework of a streamlined, easy-to-use, Windows-based interface. Market comments associated with software features particularly relevant to the commercial and sport fishing and yachting markets have been incorporated into software and hardware development. This market has been revisited time and time again for critiques of the extant version and adjustments that would further enhance marketability. The result of this development activity and market research will be introduced formally to the marine fishing and boating markets in the Fall of 1995 as *SeaStation* Version 1.

Marketing research quickly indicated that the successful penetration of the market for direct-to-vessel satellite image acquisition and processing products would require a different focus than deliverable by NRC.

Although a leader in the delivery of reliable consulting services to the fishing industry worldwide, NRC had no experience in the sales and marketing, indeed the production, of software/hardware products.

Recognizing this deficiency, principals within NRC formed a new business, incorporated as Ocean and Coastal Environmental Sensing (OCENS) in November, 1994, focusing on software development, production, marketing, and sales. Business formation occurred only after the completion of an exhaustive five-year business plan detailing market opportunity, business strategies, product and service offerings, marketing and distribution plans, risk factors and five year cash flow and income statement analyses.

Business Results

Business results can be grouped into three primary categories:

Expanded business opportunities for NRC in interpretation of remotely sensed data;

Use of remotely sensed data and Geographic Information Systems (GIS) to augment fisheries services provided by NRC

Revenue and job creation associated with the formation and growth of
OCENS.

Evidence of progress in all three categories is available. Remote sensing and GIS service opportunities for NRC which have grown out of our EOCAP involvement have totaled just under \$50,000. An additional \$21,000 of activity is related to NRC contracts where remotely sensed data and GIS has been used to augment NRC's more conventional fisheries analysis. This \$71,000 total represents roughly 8% of NRC's non-EOCAP related billings in the twelve month period ending in May, 1995.

OCENS

As of summer, 1995, **OCENS** can report no revenues and has hired no employees. These conditions emerge from two realities, 1) The SAR-based software product developed with EOCAP funding and NASA technical support will use RadarSat data not available until January, 1996 (presuming a September, 1995 launch of the RadarSat instrument); and 2) Given the mid-project repositioning necessitated by the technical deficiencies of the AVHRR ship tracking module and shifts in global geopolitical circumstances, *SeaStation* development is now at mid-project levels.

Although **OCENS** has not yet hired any employees, this is no indication of the level of activity the company is putting forward to bring its initial products to market in Fall, 1995. Rather than assume the labor-related overhead levels that all too often crush start-up firms, **OCENS** has instead chosen to conduct much of the early development work on a subcontract basis. These contracts cover nearly all phases of product and business development and include:

- 1) Software development;
- 2) Device driver development;
- 3) Development of **OCENS** Marine Forum HomePage: This site will offer a diversity of commercial fishing, sport fishing, yachting, and satellite services in segregated marine forums. **OCENS** products and

services relevant to each market segment will be highlighted and/or demonstrated in each forum;

- 4) Production of user sheets and user handbooks describing how marine users can use the data acquired and processed by *SeaStation* to improve their fishing, route planning and vessel safety decisions;
- 5) Development of communications protocols necessary to forward data between shoreside and at-sea vessels;
- 6) Product sheet design and editing; Preparation of advertisement copy;
- 7) Application of wavelet and vector quantization data compression procedures to image and other data **OCENS** will be forwarding from its shoreside offices to ships at-sea;
- 8) Market assessment for *SeaStation* products and services.

All told these services involve ten individuals, approximately \$70,000 of private investment by **OCENS** principals, and \$40,000 of new contracts. In addition, **OCENS** has reached agreement with marketing representatives active in the tuna industry in the Atlantic Ocean and the fishing industries of Southern Europe and South America. As the company matures, more of these services will be brought into the company on a full-time basis. Software development and marketing responsibilities will be the first of the activities moved in-house.

Market Assessment

In the near-term (one-year), **OCENS** anticipates producing two primary products: *SeaStation* and *OmniVision*. *SeaStation* is a Windows™-based ocean and weather reconnaissance system released in two versions. *SeaStation* Standard is an exceptionally easy-to-use yet powerful system for the acquisition and processing of satellite imagery directly on-board fishing vessels and yachts. *SeaStation* Professional incorporates additional software and a communications system that permits the integration of shore-sourced environmental and, eventually, economic data. Both versions will be available for laptop and desktop PCs and target the commercial fishing, sport fishing, and blue water cruising markets.

Each industry's interest in *SeaStation* type products was assessed with a market survey. Survey forms included a flow chart of *SeaStation*

capabilities for each market sector, sample *SeaStation* screens, and image products. After mailing the survey packet to representatives of each market segment, telephone and, when possible, in-person interviews of each representative were conducted.

Survey results indicated a positive reaction to the *SeaStation* interface crafted by OCENS and a solid interest in the data product. Small modifications of the software were suggested along with the idea that user handbooks describing application potential be crafted for each market segment. Each of these suggestions has been adopted by OCENS in the product to be delivered to market this fall. Primary initial markets were identified in the low to mid-latitude fisheries and cruising markets with high-latitude fisheries representing a growth option when direct-to-vessel satellite image data could be augmented by shore-sourced information.

OmniVision is a software/hardware system that uses space-based radar data to determine the location of vessels at-sea. Since radar can cut through clouds and mist, *OmniVision* provides an opportunity for nearly all-weather coverage. Furthermore, because the space-based radar systems act independently of any on-vessel transponders, these systems can be used to monitor the position of any vessel. These attributes should permit *OmniVision* to penetrate foreign markets for fisheries monitoring and surveillance. As such, primary markets for the workstation system are in the public sector (i.e., marine monitoring or fisheries enforcement agencies). *OmniVision* will primarily rely upon data collected by the Canadian RadarSat sensor following its launch in Fall, 1995.

The first fully-functional version of *OmniVision* has been completed and the system now functions on any UNIX-based platform. *OmniVision* development has not, however, ceased. We continue to improve the user interface, geographic overlay and land masking routines, and wake detection algorithms. Aggressive marketing of *OmniVision* has not begun, in part due to the delays imposed by the RadarSat launch schedule but also due to the necessity of focusing OCENS near-term marketing dollars on our flagship product, *SeaStation*. OCENS anticipates a much more aggressive marketing effort for *OmniVision* in 1996. In the meantime, we are working

closely with RadarSat to have the system approved as a RadarSat-compatible bundle, approval that should be reached in October, 1995.

New Developments Affecting Market

Geopolitical Shifts

With the Soviet threat removed, many US military assets whose *raison d'être* had depended on that threat began to look for other markets. One of these assets was the US hydrophone net in the US North Pacific, SOSUS. Voluntary application of this technology and accompanying expertise to fisheries monitoring in the North Pacific would categorically preempt the commercialization of any alternative private sector monitoring service.

On the more positive side, previously classified military weather satellite data are now or will soon be available and the military is actively promoting their use. These sensors will augment the coverage of *SeaStation*. Furthermore, the Navy through NOAA is now releasing global weather and ocean data analyses and forecasts through its Naval Oceanographic Data Distribution System (NODDS). Lastly, the end of the cold war has resulted in the release of high resolution data from the world intelligence community that may offer limited business potential in the coastal zone.

Heightened Awareness of Applicability of Computers to Marine Applications

A second major development in our markets is the growing computer literacy and relevance of computers to the marine industry. Electronics have always been a big part of commercial fishing--sonars, net transponders, radars, and the like. But the changes we have seen in the last five years have been more associated with the use of the personal computer for shipboard activities. Increasingly, personal computers are evident on small and big vessels. Along with this hardware has come more and more digital charting, automated report generation and filing, on-vessel inventory management, and other software. Laptop and handheld GPS units are now commonplace. The trend is several years out of step with that happening shoreside and is probably, at least

in part, a function of the improving effectiveness and reduced cost of communication from ship to shore and visa versa. As such, we believe we are early in the upswing of this trend in the marine industry and significant market opportunity awaits in future.

Increased Attention on Fisheries

In general, fisheries worldwide are now receiving much more attention than they were in the late 1980s. Whereas tuna/dolphin interactions, sea turtles, and driftnets were the focus of a great majority of the global attention on fisheries in the late 1980s and early 1990s, attention has now expanded to the larger concern over sustainable fishing. A key component of the sustainable fishing platform is that of bycatch and its avoidance. Bycatch occurs when species other than those being targeted are taken by the fishing operation. One means of dealing with the bycatch problem is to fish at times, areas, or depths when and where more "pure" schools of your target species are located. These locations are often identified by temperature and other oceanographic conditions. In the handbooks being written by OCENS to accompany its *SeaStation* systems, a great deal of attention is being placed on how the data OCENS is providing to fishermen through its space-based sensors and shore-sourced NODDS data can help fishermen identify these low bycatch zones in their fisheries.

Lower Hardware Costs

Hardware and software costs have decreased by a factor of ten. This broadens the market base that can afford to have a computer on-board their vessel and contributes to higher levels of computing power and performance at affordable prices.

Improved Data Distribution Pathways

An increasing number of hardware, software, and value-added vendors are entering the remote sensing market. This competitive environment is creating the needed distribution systems and improved product quality. The more widespread use of the Internet will also contribute significantly to communication and data exchange.

Anticipated Future Changes Affecting Markets

Short-Term (Less than one year)

Decline in National Marine Fisheries Service services to fishermen: Budget concerns are cutting deeply into the number of personnel and level of services available from the US National Marine Fisheries Service in particular and NOAA in general. The anticipated shift of more of these support services to the private sector could spell opportunity for **OCENS**.

New Sensor Launches: The launch of RadarSat, SeaWiFS (hopefully), and high resolution sensors will increase the level of services **OCENS** is able to offer to existing and potential clients.

Naval Oceanographic Data Distribution System (NODDS) Improvements: While a wealth of data is available through NODDS, the user interface is a cumbersome beast that impedes more widespread use. **OCENS** will seize this opportunity in 1996 and apply its software talents to develop a more user-friendly interface. The interface will then be offered to **OCENS** customers as a unique gateway to the Navy/NOAA ocean and meteorological data.

Long-Term (One to Five Years)

Improvements in Shore-to-Ship Communication and Data Relay:

Shore-to-Ship and visa versa communication has always been unreliable and costly. However, the movement of new players (e.g. American Mobile Satellite) into the marine communication market not only offers the potential for new means of communication it also spurs existing vendors to become more responsive to marine user needs. As such, significant improvements in at-sea communication are expected between now and the year 2000. **OCENS** recognizes this as a valuable opportunity for growth in the late 1990s.

More Aggressive Monitoring Programs: As overfishing problems have become more pervasive in the last five years, the attention to improvements in catch monitoring has increased as well. To date, this monitoring has been implemented largely through the use of on-board

observers and transponders. Such coverage addresses those vessels that agree to "play by the rules" but neglects true pirates, poachers, or renegade vessels that can cause serious damage to ocean resources. Space-based radar and optical sensors have the potential to address this gap if efficient data distribution pathways can be developed and cost factors reduced.

Sources of Uncertainty

Launch of RadarSat and SeaWiFS instruments: Although **OCENS** has no direct dependencies on the SeaWiFS data stream in the short term (i.e., *SeaStation* relies upon AVHRR instruments already in orbit), it does anticipate valuable derivative markets for that data in fisheries, aquaculture, and on-line services. The delay of the SeaWiFS launch would jeopardize those markets. **OCENS *OmniVision*** product will depend upon radar data provided by RadarSat. Launch delay will harm cash flow in 1996 and later years that is associated with sales of *OmniVision* hardware/software bundles and information services. Launch failure would preclude **OCENS** entry into this market segment;

Change in government policy regarding access to and/or structure of AVHRR data: AVHRR data through US satellites have always been freely available if users invest in the necessary hardware and software to acquire the data stream directly from the satellite. Should the data stream be encrypted to require purchase of a decoding key as a prerequisite to data receipt, **OCENS** cost structure will be affected. If such changes occur, whether these costs are entirely transferable to the end user of the data will depend upon the nature of data access changes.

Trends in availability of very high spatial and spectral resolution data: Private sector interests are moving rapidly toward launches of very high, 1 to 3 meter spatial resolution instruments as well as instruments capable of recording in hundreds of spectra. Such space-based data have never before been available to private sector interests. Should these launches not go forward in the mid- to late-

1990s, **OCENS** will not be able to exploit new markets for these data in aquaculture and coastal zone management.

Pricing of private sector data sources: Although the new private sector data sources have a great many potential applications, the diversity of such applications will be limited if data pricing restricts access.

Trends in hardware costs: Order of magnitude reductions in hardware costs in recent years permit the movement of more and more computing power to the end user. This transformation has allowed **OCENS** to put new information products at the disposal of fishermen in near-real time. Should reductions in hardware costs slow down or stagnate, **OCENS** ability to continue the movement of high level information products to the end user will be impaired.

Restriction on foreign sales of high technology equipment: **OCENS** has identified important markets for its ocean monitoring technology in second and third world countries. Should the US government restrict the release of **OCENS** oceans products and services to these markets, business performance will be affected.

Sales and marketing expertise: **OCENS** founders recognize that for the company to succeed, high-quality marketing and sales expertise must be added to the team. To do so, **OCENS** plans to add to management a high level sales person in the first twelve months of operation and work in cooperation with marketing firms to develop and implement specific marketing strategies. Considerable sums are appropriated for each of these areas throughout all years of the business.

Financing: Should the financing needs of **OCENS** not be obtained, a scaled-down version of the business would be necessary. Such a scale-back would impair competitiveness, corporate growth, and the time horizon associated with expectations of return on investment. If severe enough, these threats could harm overall business viability.

Insurance: **OCENS** will carry full product and service insurance.

Nevertheless, defense of claims could be costly and damage cash flow as well as reputation.

Need for capital: The development of new, as yet unanticipated, products/services or the faster than expected growth of markets for existing products/services may require additional capital inputs beyond those identified in this business plan.

Competition: **OCENS** will be producing and aggressively marketing *SeaStation* and other products at affordable prices that may attract responses from competitors. A key to **OCENS** success will be its ability to stay ahead of these responses by continuing to anticipate user needs and upgrade its products in advance of competitive releases by other firms. **OCENS** will invest heavily in R&D and marketing to accomplish this objective.

Productivity Gains

EOCAP II has contributed to an 8% increase in revenues at NRC over the twelve months ending May, 1995. It has also led to the development of **OCENS** and related activities that now involve ten subcontractors, \$70,000 of direct investment, and \$40,000 of new contracts.

Other Developments

Articles and Conference Presentations

Articles

- Freeberg, M.H., R.W. Wrigley, K. Dunlop, & G. Staples. 1995 Application of Space-Based Radar Systems to Conventional Approaches to Fisheries Monitoring and Enforcement. Proceedings, Third Thematic Conference, Remote Sensing for Marine and Coastal Environment, Seattle, WA, September 18 - 20, 1995.
- Freeberg, M.H. 1994. Subpixel analysis of small water body temperature. Submitted to University of Washington Geological Remote Sensing Laboratory.
- Freeberg, M.H., R.C. Wrigley, G.C. Staples, and G. Klock. 1994. Fisheries enforcement through vessel localization using AVHRR and SAR

technology. Proceedings, OCEANS '94 Conference, Brest, France. September, 1994.

- Wrigley, R.C., D.V. Sullivan, and M. H. Freeberg. 1993. Detection of ship tracks using ERS-1 SAR Data. SAR Users Group Meeting, Seattle, Washington.
- Freeberg, M.H., E.A. Brown, and R. Wrigley. 1992. Vessel localization using AVHRR and SAR technology. Proceedings Marine Technology Society, Washington D.C., October, 1992.

Conference Presentations

Third Thematic Conference, Remote Sensing for Marine and Coastal Environment, Seattle, WA, September 18 - 20, 1995. Presentation Title: Application of Space-Based Radar Systems to Conventional Approaches to Fisheries Monitoring and Enforcement.

Third Thematic Conference, Remote Sensing for Marine and Coastal Environment, Seattle, WA, September 18 - 20, 1995. Poster Title: Application of remotely-sensed data to salmon harvest management and operation planning of the salmon industry in Alaska.

OCEANS '94 Conference, Brest, France. September, 1994. Presentation Title: Fisheries enforcement through vessel localization using AVHRR and SAR technology.

SAR Users Group Meeting, Seattle, Washington, July, 1993. Presentation Title: Detection of ship tracks using ERS-1 SAR Data.

Marine Technology Society, Washington D.C., October, 1992. Presentation Title: Vessel localization using AVHRR and SAR technology.

Key Innovations

SeaStation Windows Software (Windows 3.1 and Windows95): No APT groundstation and image processing software has ever been crafted from the ground up for the Windows environment, let alone the new release of Windows95. Furthermore, the manner in which development has been conducted will permit straightforward adaptation of the software to other data streams and, more importantly, markets. As such, **OCENS** completion of this software represents a key difference between *SeaStation* and its competition and sets the stage for broad business opportunities in the next five years.

PCMCIA Cards: Although not a development from within the company, EOCAP support permitted identification by OCENS of hardware vendors producing PCMCIA cards for NOAA AVHRR and GOES data reception. These small cards permit extension of *SeaStation* to the laptop computer market. Given that space often is a limiting factor on-board fishing vessels and yachts, this laptop architecture will be an important factor in successfully penetrating these markets.

GPS Integration

Developed software allows the user to integrate the *SeaStation* system with on-board GPS equipment. This innovation permits the user to overlay their vessel position directly on the navigated satellite image. Rather than inferring position relative to ambient weather systems or ocean conditions, vessel position is explicitly delineated.

Antennae Evaluation

Most APT groundstation vendors offer helix antennas as the primary pieces of hardware used to receive AVHRR APT data. These antennae offer fine technical performance. OCENS market research indicates, however, that they do not address the esthetic requirements of the blue-water cruising and yachting markets which OCENS intends to penetrate with its *SeaStation* product. As such, OCENS, in conjunction with a local but nationally respected antennae manufacturer, has successfully completed development of three new antennae that meet performance and esthetic requirements of the fishing and yachting markets. Any one of these three antennae will be available to the customer as part of the base *SeaStation* package.

OmniVision: The development of *OmniVision* as a rapid means of supervised and unsupervised SAR data analysis will permit OCENS to penetrate ocean monitoring markets in the US and overseas. Its recent extension to all UNIX-based platforms enhances market potential significantly.

Enabling Technologies

SAR Geolocation Algorithm: Developed in conjunction with the Alaska SAR Facility, this algorithm permits rapid geolocation of SAR data for use in the OCENS *OmniVision* system.

USDA XCASS Software: NASA personnel working in conjunction with OCENS in the development of *OmniVision* adapted the XCASS interface for use in the *OmniVision* system. XCASS presents an intuitive and relatively easy-to-use interface for the *OmniVision* system.

Technical Results

AVHRR Ship Track

A total of 163 NOAA 10 and 11 HRPT AVHRR images centered over the area of the Bering Sea around Unimak Pass were obtained during the months of January through April 1993 and processed during the summer of 1993. An additional 188 NOAA 11 images covering the northwest coast of North America and the northeastern part of the North Pacific Ocean were acquired for the period from May through November, 1993. All images were analyzed for the purpose of identifying and cataloging all of the ship tracks in the images.

In the winter imagery, five images contained ship tracks that were confirmed with seatruth data while an additional 19 images contained likely ship tracks. Ship tracks were observed with a greater frequency in the summer imagery. Of the 170 summer 1993 images, 55 contained evidence of ship tracks with an additional 21 with suspected, but unconfirmed, ship tracks. In only a few short periods did ship tracks persist for more than 24 hours. Occasionally, ship tracks visible during daylight images also appeared during ensuing nighttime images.

In many images a case for finding a ship track(s) could be made. Unfortunately, confirming that a given signature is indeed a ship track is a much more difficult matter. Ship tracks appear to exhibit more curvature than aircraft contrails because winds are more variable closer to the

surface. In addition, they exhibit a zig-zag pattern at their edges, perhaps due to local mixing with the adjacent cloud.

A number of attempts were made to enhance the images in order to improve the identification of the ship tracks. Spatial and radiometric enhancements were applied to the images using the ERDAS Algebra program. Most of the functions written within ERDAS Algebra had the effect of increasing the contrast in a specific range of the image where the tracks were found. Most of the functions that were written contained constants taken from an examination of the DN values in the raw image. These constants corresponded to an approximate "dividing-line" between tracks and the surrounding clouds in channels three and four. The best function took the natural log of the image value divided by the constant for each channel.

Although several of the functions effectively enhanced the ship tracks, several difficulties were encountered. While the specific DN values of a ship track may be unique relative to the surrounding clouds, there are usually other aspects of the image with similar DN values. The lack of a spectral signature unique to ship tracks confounds image analysis.

Another complexity uncovered during the work is the lack of consistency of ship track DN values from image to image. On channel three a track may range from DN 840 to 875 in one image, but in another image the range may be from DN 860 to DN 900. Consequently, mathematical functions to identify ship tracks must be written on a channel and image-specific basis and depend on an initial inspection of the image by the analyst. Given such a requirement, automated ship detection algorithms become very difficult.

Approaches outside the ERDAS Algebra sub-routine were also used to attempt to identify ship tracks in the imagery. One such technique was based upon principle component analysis (PCA). This method reconfigures a multi-band image based on its variance. With PCA the clearest ship tracks usually appeared in the third principle component, which typically represent about three percent of the image variation. Unfortunately, results were not consistently successful.

No enhancement approach revealed tracks that were not at least faintly apparent to the analyst in the original images. This suggests that the success of finding ship tracks depends on their likelihood of formation given ambient meteorological conditions and the sensors ability to record them if they do form. As an example, during the first half of June, 1993 there were many high, thick clouds associated with the passage of synoptic storms. No tracks were observed during that period. In the second half of the month, stratus decks favorable to ship track formation were visible and a few tracks were identified. July, 1993, conversely, was a very good month for tracks. They could be seen every day during the first half of the month. When a storm arrived around July 20, 1993, however, tracks become more scarce.

MAST Experiment

The June 1 to June 30, 1994 MAST experiment at the Naval Postgraduate School was a focused, at-sea experiment designed to identify the processes responsible for ship track formation. Ships of opportunity and dedicated US Navy ships were used as signature generating platforms while research aircraft, an airship, and a research vessel sampled vessel plumes and ambient conditions. Dr. Klock and/or Ms. Lynde from WRA, Inc. were present during the bulk of the experiment period with the purpose of evaluating the operational feasibility of ship track detection.

Unseasonably clear weather during the experiment and the lack of stratus clouds limited the number of days in which usable data could be collected. From the point of view of our EOCAP team, however, this result was informative in and of itself because it provided additional evidence that ship track detection in AVHRR imagery is ineffective as an operational enforcement mechanism. Given the existing body of knowledge, track formation is simply not a consistent enough phenomena upon which to base an operational enforcement system. For example, MAST results indicate that conditions for ship track formation were present during 50% of the days in June and that on those days approximately 10% to 20% of the boats known to be in an area covered by a specific image were actually detected in that image. Considered together, only 5% to 10% of the universe

of vessels trafficking the Monterey area in June could be detected via ship tracks.

Given the results of our analysis of the AVHRR and ship-of-opportunity data collected during MAST, a decision was made to terminate the AVHRR ship track component of the project. Efforts were redoubled on the development of SAR-based ship detection routines and shifted to programming of the Windows-based direct-to-vessel APT receiving and processing station.

SAR Activity

SAR activity proceeded in three significant phases during the course of the project. Phase 1 consisted of a thorough review of the existing SAR processing literature and processing algorithms. This phase and the subsequent delivery by Mr. Wrigley of the paper entitled, "Detection of ship tracks using ERS-1 SAR data" at the ERS-1 Users Conference in Seattle, WA in late July 1993. This presentation and ensuing communication resulted in a greatly improved understanding of the phenomena associated with ships and their wakes. Most helpful was the work conducted by a group at the Norwegian Defense Research Establishment (NDRE) suggesting that the most robust feature for detection of ships and their wakes was the ship itself and not its wake.

According to the NDRE, ships over 125 meters in length should be detectable in most sea states while ships between 50 and 125 meters have a variable probability of detection depending upon sea state. Ships less than 50 meters would be detected only rarely. If wakes are searched for, the wake feature with the highest probability of detection (~35%) is the so-called dark, turbulent wake directly behind the ship which flattens the sea state and can do so for quite some time. The V-wakes normally associated with ships have a low probability of detection (~5-10%).

These results re-oriented our approach in Phase II of the SAR development activity during Year 2 from trying to find "ship tracks" to finding ships themselves. Rather than pre-process the data to enhance linear features, SAR data were processed to enhance locally bright objects by converting

saturated pixels to a conspicuous pseudo-color. The image was then examined for groups of saturated pixels bigger than 2x2 pixels (25x25 meters).

Following this approach, data acquired by the Alaska SAR Facility were searched for scenes containing fishing vessels participating in the Bering Sea fishery during the January through March, 1993 period. A total of 16 scenes were ordered. A program that used information included on the SAR data tape to calculate geographic position in the image from image coordinates and vice versa was acquired from the Alaska SAR Facility and implemented at NASA Ames. Ship positions reported during the experiment could be converted into image coordinates and any objects located in the image coordinates could be expressed in latitude/longitude. Tests showed it to be sufficiently accurate for our purposes (100 meters in one case and 1 km in another).

Ten of the sixteen known fishing vessels supposed to be within acquired SAR images actually were identified in the imagery. Ten other vessels were also found in the imagery. Of the six vessels missed, four were in areas with high sea-states, and one had a reported position within 100 pixels of the edge of the image. The remaining undetected vessel was the smallest in the fleet at 155 feet (47 meters).

The second objective of our SAR efforts in Phase II was to begin the process of converting analyst-based search procedures to machine-based, unsupervised algorithms. This objective was pursued in two ways, incorporation of the ship detection algorithm developed by the NDRE and use of a low pass filter, level slicing algorithm. Development activity has culminated in the *OmniVision* product that will be marketed during 1996 following RadarSat's Fall, 1995, launch. Phase III activity focused on the evaluation of the *OmniVision* system using seatruth data collected off of the west coast of Vancouver Island.

This site was chosen because of the high amount and variability of vessel traffic passing into or out of the Strait of Juan de Fuca, the presence of inshore and offshore fishing grounds in the region, and the availability of vessel position data from the Canadian Coast Guard tracking station at

Ucluelet, Vancouver Island, British Columbia. The majority of vessels trafficking this area are transiting southeast into or northwest out of the Strait of Juan de Fuca, heading due west out to sea or northward up the British Columbia coast. Occasionally, vessels moved along a curved path out of the Strait, around Cape Flattery and down the coast (or northeast into the Strait around Cape Flattery). The Mt. Ozzard shore-based radar sensor is used to track this vessel traffic. The sensor is an 'S' band radar (2860 MHz to 2900 MHz) that provides coverage out to a seaward distance of 60 nautical miles (nm) from Mt. Ozzard.

The Alaska SAR Facility's archive of SAR imagery was searched for candidate scenes of the Ucluelet area in 1994 using their geographic search capability. The search area corresponded closely to the range of the Ucluelet radar. Any 100 km by 100 km SAR scene that intersected the search area was identified. Such scenes with more than 10 percent of their area intersecting the search area were plotted using the Alaska SAR Facility's routines to show the actual area of coverage of the scene on a map. These plots were then used in conjunction with knowledge of vessel positions at time of overpass to select the subset of images for full analysis.

Vessel position estimates at time of ERS-1 overpass were determined and plotted as point data over a map template of Vancouver Island and the candidate satellite pass footprints. Candidate ERS-1 footprints with multiple vessel hits were selected for further analysis. A total of fourteen such scenes were ordered from the Alaska SAR Facility on computer compatible tapes. Seven of these scenes overlapped the Mt. Ozzard radar mask significantly and were used as the basis for the bulk of image analysis. To preserve objectivity, image analysts were not shown the seatruth locations of vessels in the Mt. Ozzard database prior to image processing and "vessel" identification in the SAR imagery.

The *OmniVision*® vessel detection software system was used to process the SAR imagery. A 1280 x 1024 pixel display is configured with two working areas, with system functions appearing in pop-up menus along the leftmost 256 pixels, leaving the rightmost 1024x1024 pixels for imagery. A frame buffer contains a 2048 x 2048 array for temporary storage of image data

which is roamed by the 1024 x 1024 image display area. High resolution ERS-1 SAR imagery fills an 8192 x 8192 array with 8-bit pixels so *OmniVision*® must subsample the imagery in order to display areas larger than the frame buffer (2048x2048). An additional feature of the *OmniVision*® system is the ability to write user defined screen areas to disk as standard format files to be imported into other analysis or viewing packages.

Visual analysis of a given scene begins with an image subsampled by a factor of four (every sixteenth pixel is sampled) to fit the entire scene in the frame buffer. Since ships tend to saturate ERS-1 SAR pixels, a convenient visual analysis tool is to pseudocolor the saturated pixels (level 255) in a vibrant color (i.e. red). Large vessels over 200-300 meters are often apparent as saturated, thin shapes even at a subsampling of four. *OmniVision*®'s geolocation algorithm incorporates information extracted from both the window file header and control point files to convert row and column from the 8192 x 8192 array into latitude and longitude so simple point and click motions can reveal the vessel's position. Scanning the entire subsampled image proceeds by roaming the frame buffer and noting any candidate vessel's position. Higher resolution images, using either a subsampling of two (every fourth pixel) or no subsampling (every pixel is inspected), require examining multiple images for each SAR scene: four images for a subsampling of two and sixteen images for full resolution. Higher resolution images reveal smaller vessels and more detail of the larger vessels as well as better geolocation, but the analysis proceeds in the same way by roaming the frame buffer and noting candidate vessel positions. At full resolution an estimate of the number and arrangement of the saturated pixels obtained by zooming in on the ship is a useful estimate of the size of the vessel (i.e. 10 x 3 pixels would indicate a vessel size of approximately 125 meters long by 38 meters wide). If the vessel appears elongated, its heading can be estimated with a 180° uncertainty. Wakes appear only rarely in SAR imagery, but, when they do, the 180° uncertainty in heading can be resolved.

Unassisted, automated ship detection and geolocation by *OmniVision*® proceeds similarly to the manual procedure. Analysis is at full resolution,

so 16, 2048 x 2048 scenes are analyzed. Land areas are removed (masked) using a variety of techniques and unexpected ocean features are flagged for later interpretation by the system operator. Potential targets are examined through the application of a succession of linear two dimensional convolution templates, and, where applicable, further analysis based on a version of the Hough Transform is conducted. The Hough transform linearly remaps geometric patterns into their parametric forms, allowing the extraction of heading information from wake data when water is visible.

The fourteen scenes selected off the Ucluelet surface radar station during the April- July, 1994 period were all subjected to visual analysis on the *OmniVision*® system as described above. Land areas were simple to discriminate visually and exclude from the analysis. Various kinds of wind and wave effects were apparent almost everywhere. Typically, swells were more apparent on the near-range side of the images (the side closest to the satellite), most likely due to the stronger illumination there, and often caused saturated pixels along their crests. Internal waves and colder water leads were more subtle but extensive as well. The rare wakes observed were most likely to be dark turbulent wakes which could be confused with the colder water leads which were also dark. For the six SAR scenes included in this study, only two wakes were observed unambiguously out of 95 candidate vessels. Another nine wakes were considered possibles. On a few occasions dark, turbulent wakes behind vessels were contorted as if the vessel were turning back and forth.

Vessel detection passed through two stages. Within the first stage, clusters of spectrally saturated (DN at 255) pixels were identified in the image. Clusters were defined as any target 3 or more pixels long and 2 or more pixels wide. Once clusters were identified, seastate conditions were assessed. Smaller clusters were accepted as vessels under low sea state conditions but not under high sea state conditions. At high local seastate conditions, even large clumps (e.g.. 18 x 4 pixels) could be classified as questionable vessels.

Six ERS-1 images that had a significant degree of overlap with the Mt. Ozzard station mask (and thus offered the highest level of confidence for seatruth position projections) were evaluated against groundtruth data acquired from the Canadian Coast Guard, Ucluelet Station, Vancouver Island. The days evaluated were April 14, 1994 at 1215 PDT, June 10, 1994 at 1114 PDT, June 30, 1994 (2 scenes) at 1111 PDT, June 30, 1994 at 2228 PDT, and July 21, 1994 at 2228 PDT. Weather on all of the above days was mild at the time of the satellite passes. Winds at Ucluelet ranged from 11 kts on April 14 to dead calm on July 21, while wave height varied from 2 ft to less than 1 ft. The foreign fishing fleet was operating in the area five out of the six days--no foreign fishing activity took place on April 14.

Seatruth data were imported into TNTmips, a mapping and image processing software tool that allowed the layering of projected groundtruth vessel positions and target "vessel" coordinates extracted from the radar imagery. Both data sets were imported as vector point data with attached attribute data. Attribute data associated with the Mt. Ozzard data points included vessel identification, vessel type and time of siting while attributes linked to the radar image coordinates included pixel size and original column and row position in the raw satellite imagery. Plotting of each corresponding pair of data sets over a map template permitted an assessment of the space-based radar imagery's ability to detect vessels projected to be at a given point at a certain time.

Under certain fishing conditions, the Ucluelet radar station has difficulty accurately tracking fishing vessels operating on the West Vancouver Island fishing grounds. When the fleet becomes excessively commingled or vessel behaviors particularly erratic (e.g., during the summer hake fishery), radar operators "beach" the vessel positions and ignore Mt. Ozzard radar reports of their positions. These tracking difficulties and beachings precluded the acquisition by the project team of accurate position reports for these fishing vessels. What was known, however, was the location of the fishing grounds, the number and size of foreign fishing vessels expected to be operating on those grounds, and the size of the domestic fishing vessels likely to be on the grounds on each day of ERS-1 overpass. This information, when compared to the actual number and size

of vessels observed on the fishing grounds by the ERS-1 sensor, provided a coarse assessment of the ability of the space-based radar to detect fishing vessels.

A total of 49 foreign fishing vessel targets were operating on the fishing grounds over the course of the five June/July ERS-1 images analyzed in this study (Table 1). Foreign fishing vessels operating in the West Vancouver Island hake fishery in June and July are factory trawler operations. Because of the type of fishing in which they are involved and the great distance from their home ports from which they operate, these foreign, "distant water" trawlers tend to be large (>50 to 60 m length overall (LOA). Consequently, distant water fishing vessels should, at a minimum, saturate four pixels in the long direction and three pixels in the short direction. The number of 4x3 or large pixels observed in the SAR imagery and on the West Vancouver Island fishing grounds totaled 42. Although the clustering of these vessels is tight, the space-based radar was still able to discriminate individual targets, something the Mt. Ozzard station could not consistently accomplish. From these results, we estimate that the SAR imagery was discriminating 86% of the foreign fishing vessels actually on the grounds.

Some fishing vessels traffic through the West Vancouver Island area and are tracked by the Ucluelet station on their way to or from fishing grounds in Alaska. These fishing vessels are designated as Tracked Other Fishing vessels in Table 1. 100% (6 of 6) of these vessels were found in the SAR imagery.

Table 1. Number of Fishing Vessels Expected to be and Actually Found in ERS-1 SAR Imagery.

Image Date	Vessel Class	Number Expected	Number Found	% Found
14-Apr	All vessels on April 14 were non-fishing vessels			
10-Jun	Foreign Fishing	5	3	
	Tracked Other Fishing	2	2	
				71%
30-Jun North	Foreign Fishing	12	11	
	Tracked Other Fishing	1	1	
				92%
30-Jun South	Foreign Fishing	7	7	
	Tracked Other Fishing	0	0	
				100%
1-Jul	Foreign Fishing	12	10	
	Tracked Other Fishing	0	0	
				83%
21-Jul	Foreign Fishing	13	11	
	Tracked Other Fishing	3	3	
				88%
Total: Foreign Fishing		49	42	86%
Total: Foreign and Tracked Other Fishing		55	48	87%

Exclusive of the foreign fishing fleet, twenty-three vessels were projected to be detected within the selected ERS-1 images (Table 2). Of these twenty-three vessels, sixteen were detected in the ERS-1 imagery (70%). One vessel class, bulk carriers, accounted for six of seven "misses". As these boats are large and move in a consistent path not unlike other vessels observed in the imagery, a basis for their being missed is not readily apparent. Exclusion of the bulk carrier class from the database increased detection efficiency to 93% (14 out of 15).

Table 2. Number of Non-Fishing Vessels Expected To Be and Actually Found by *Omnivision* in ERS-1 SAR Imagery, By Image Date and Vessel Class.

Image Date	Vessel Class	Number Expected	Number Found	% Found
14-Apr	Tug w/ barge	1	1	86%
	Roll On/Roll Off	1	1	
	Tanker	1	1	
	Container Freighter	2	2	
	Vehicle Carrier	1	0	
	Bulk Carrier	1	1	
10-Jun	Bulk Carrier	2	0	60%
	Tanker	2	2	
	Container Freighter	1	1	
30-Jun North	Bulk Carrier	1	0	80%
	Scientific Research	1	1	
	Roll-On/Roll-Off	1	1	
	Government	1	1	
	General Cargo	1	1	
30-Jun South	Tug w/ barge	1	1	33%
	Bulk Carrier	2	1	
1-Jul	All vessels on July 1 imagery were fishing vessels			
21-Jul	Bulk Carrier	2	1	67%
	Container Freighter	1	1	

Total: All Days, All Vessel Classes

Total: All Days, All Non-Bulk Carrier Vessel Classes

Results suggest that space-based ERS-1 data provide a good means of augmenting conventional and transponder-based MCS systems. A total of 78 vessels (fishing or other) were expected to be found in the radar imagery. 64 of these vessels (82%) were found in the ERS-1 data using the *Omnivision*® vessel detection system. A total of 11 vessel classes other than fishing vessels were encountered in the seatruth data. Table 2 summarized the detection of vessels in each of these classes by the SAR data. Performance was worst for the bulk carrier class with only two of the eight vessels (25%) in this class detected in the radar imagery. This is perplexing since these vessels are large, with transit behaviors not unlike those of other vessel classes for which detection was good, and sometimes in the vicinity of similar vessels that were detected.

The ability of the radar data to discern fishing vessels was extremely encouraging. The nature of fishing operations off coastal Vancouver Island, indeed in most fishing operations worldwide, is one of transiting,

fishing, retrieving, and repositioning. When a group of co-mingled fishing boats exhibit this behavior, individual vessels become difficult to track with high look angle (low depression angle) radar. This is because the vessel signal of one vessel can be confused with that of another as they cross and re-cross their respective fishing paths. This trait becomes so problematic on some of the fishing grounds off Vancouver Island that shore-based radar reports of the position of actively fishing vessels are ignored by radar operators. In general, the Mt. Ozzard radar is unable to track and project vessel positions for fishing vessels during times of intensive fishing when large number of boats operate in a small area.

It does not appear that the space-based ERS-1 radar data is confused by such fishing behavior. 87% of fishing vessels known to be in the imagery were detected in the space-based radar data (Table 1). This performance includes the operations of the foreign factory fishing trawlers that operate in a tight cluster off coastal Vancouver Island. Operationally, this performance is important. Although it would appear that fishermen on-board vessels with transponders would have strong incentives to report the illegal operations if they know they are not similarly equipped with transponders, they may not. In the face of increasing limitations on license number and yet strong demand for high value fish, crustaceans, and cephalopods, it is not unreasonable to expect some fleets authorized for x number of transponder-equipped vessels to actually fish in an area with y number of vessels, most with transponders but some without. Since these areas are often remote or perhaps close to jurisdictional boundaries, the odds of detection of this strategy by random conventional searches may be low, especially since authorities "expect" all the boats in the area to have transponders on them. Space-based radar data appears capable of addressing this scenario because it can discriminate the full complement of vessels in an area. Illegal vessels without transponders could not "hide" amongst other fishing vessels carrying transponders or under cover of non-fishing vessels in the vicinity of the grounds.

On each of the days where radar imagery overlapped the radar mask of the Ucluelet station, more vessels were found in the ERS-1 imagery than were actually logged in the vessel position database. After exclusion from the

radar imagery of questionable vessel targets, detected vessel numbers more closely matched numbers expected based on the seatruth data. This brings up an important question: Is the space-based ERS-1 radar detecting vessels that were either unobserved by the shore-based radar or ignored by the radar operators or is it easily confused by seastate conditions and consequently producing bogus target information?

Although a definitive answer cannot be provided to this question at this time, ancillary vessel count data collected by coastal observers suggests that the ERS-1 data is indeed identifying more real targets than tracked by the shoreside system. The largest discrepancy between total, solid, and questionable vessel hits occurred on June 10 when eight out of a total of 21 targets were considered questionable. The June 10 SAR pass occurred at 11:14 AM local time, just three hours after a fishery opening in which 78 small fishing vessels were counted by coastal observers. Although most of the fleet would have left the grounds by mid- to late-morning, it is not unreasonable to expect that some remained and were detectable in the SAR imagery. This reasoning is supported by the fact that sea conditions on June 10 were relatively calm (5 knot winds with 1 foot wave heights) and that most of the questionable "vessels" represented small targets and were inshore.

Clear insights into the effect of environmental conditions on system performance were not obtained from these data. This is largely due to the fact that conditions were remarkably consistent across the image dates. Wave heights never exceeded 2 feet and wind speeds were 12 knots or less on all days. On the four days with 2 foot waves, 11 of the 33 (33%) detected vessels were classified as questionable. This is not substantially different than the 32% (45 of 147) figure associated with those days with 1 foot wave heights. July 21, a day with dead calm conditions in the study area, did, however, have the lowest ratio of questionable to total hits (2 out of 22, 9%).

The absence of wakes in the imagery is noteworthy. Several authors cite the relevance of wake detection to ship detection (Vesecky et al., 1982, Shemdin, 1990, Griffin et al., 1992). Such a paradigm applied to the ERS-1 imagery reviewed in this study would be an ineffective tool for ship

detection. This is particularly true for fishing MCS systems. Most fishing vessels actively fish at very low speeds (trawling) and in some cases may operate from fixed (crabbing, purse seining) or drifting (gillnets) positions. Only during periods of transit could they be expected to consistently produce wakes and, as long as fishing gear are not in the water, such transits may be considered acceptable, legal behavior. Consequently, space-based monitoring components of an effective fisheries MCS system must focus on ship, rather than wake, detection. Wake detection would provide bonus information about vessel direction and speed but would not be relied upon for vessel location.

Given the near-real time nature of a meaningful MCS system and the large size of most space-based radar images, automated image evaluation and vessel detection is an attractive goal. Because of seastate variability and the economic costs associated with a vessel or plane sortie to a suspected violator, however, it is doubtful that any system, even an expert one, would be allowed to carry the analysis from point of image acquisition to an enforcement action without some level of operator involvement. A more likely scenario is one in which an automated system would inventory the entire image, identify those targets that could be vessels, and point the system operator to these targets so that verification or rejection of the targets as vessels could be rapidly accomplished.

It is the latter scenario that was tested within this study by comparing *OmniVision*®'s automated detection performance of an image frame to the visual inspection of the same frame by a system operator. In automated mode, *OmniVision*® detected 83% (10 out of 12) of the vessels detected visually by the system operator. These results suggest that the automated mode is capable of augmenting the vessel detection process.

On-board APT System for Commercial Fishermen, Sport Fishermen, and Professional Navigators and Skippers

In late 1993, hardware and software were assembled from independent suppliers and used to construct a low-cost APT station for reception of AVHRR data on-board commercial fishing vessels. Software, APT antennae, and receiver card were acquired from Quorum

Communications, Inc. in Irving, Texas. Other hardware included a SVGA graphics card and monitor, 386 computer, cabling, and antennae mounting hardware. The computer and computer monitor were supplied by Arctic Alaska fisheries.

The assembled system was installed aboard Arctic Alaska's Kodiak Enterprise, a 275 foot commercial surimi/fillet trawler. Dockside testing was successfully completed in Fall, 1993 and at-sea testing was conducted during the fall pollock fishery in the Bering Sea. Key refinements to the software and hardware that would permit better penetration of the commercial fishing market were identified by vessel skippers and engineers.

The list of software/hardware adjustments suggested by the fishermen were compiled and forwarded to Quorum, Inc. in Irving, Texas, a potential software/hardware vendor. Several weeks thereafter, **OCENS** representatives traveled to Texas to meet directly with Quorum to discuss the needed changes and instigate discussions concerning a collaborative effort to develop, package, and market bundled, low-cost APT systems to the fishing industry and secondary markets.

The slow response to the product specifications outlined by **OCENS** encouraged us to move software development from an outside vendor to an 'in-house' programmer. In that vein, a software programmer was added in April, 1994 to begin to develop a Windows-based version of the software package. Two versions of the product, marketed under the *SeaStation* product name, have since been developed. The basic product will provide full satellite tracking, image acquisition and processing capabilities in a fashion that is tailored to the operating conditions of the commercial fishermen, sport tournament fisherman, and ocean mariner. *SeaStation* Professional offers all of the features of the standard version plus a communications engine that can receive data forwarded from **OCENS** shoreside offices through INMARSAT to the at-sea vessel. Forwarded data will include a wide range of environmental data including present condition or forecast estimates of wind speeds, wave heights, surface

pressure readings, mixed layer depth levels, ice edge locations, storm warnings, and, in certain areas, subsurface temperature readings.

Both systems use PCMCIA hardware supplied by an outside vendor that permits the operation of *SeaStation* on laptop as well as desktop computers. Given the fact that space is often a limiting factor on-board cruising and fishing vessels, the laptop option is an important system selling point.

OCENS has reached an agreement with this vendor that provides to **OCENS** exclusive and world-wide rights to that hardware for sales into the marine and coastal zone markets for a period of two years. **OCENS** has also responded to market survey responses from yacht skippers and vessel owners who called for modifications to our antennae package for esthetic reasons. **OCENS** and a local antennae manufacturer have completed development and testing of three antennas for the marine market that have a much lower profile than the standard helix quadrifilar antennae. These new antennas have been received very favorably by the market. Antennae design will no longer impede system sales in this market sector.

To better identify marketing strategies, **OCENS** founders approved a pre-launch market survey in 1995. Potential users in the commercial fishing, recreational fishing, and yachting/blue water cruising industries were sent market surveys and then interviewed in-person or via telephone by a private marketing consultant working in tandem with an **OCENS** representative. Results of the survey confirmed the importance of the laptop option, identified the aforementioned concern over antennae design, promoted the development of user handbooks documenting how space-based data can be used to improve fishing performance, trip planning, and vessel safety, and suggested that initial marketing efforts should focus on the yachting/blue water cruising and low- to mid-latitude tuna fisheries sectors. The survey also indicated that high latitude fisheries should not be pursued until the Professional version of *SeaStation* is launched. The concern was that cloud cover problems in these geographic regions would damage the credibility of a product dependent solely on satellite-based data. Professional's augmentation of that space-based data with information from other sources would address such a deficiency.

OCENS is marketing *SeaStation* through three channels; marine distributors/resellers, catalog sales, and location or fishery-specific representatives. **OCENS** has reached agreement with local Seattle marine electronics retailers and a handful of non-local retailers for distribution rights to the package. **OCENS** is currently demonstrating the product at boat shows in the Northwest region in conjunction with the local distributors (**OCENS** product sheet for the standard version is attached). In terms of catalog sales, **OCENS** has reached agreement with Capt. Jack's Nautical Software catalog to be carried as the exclusive weather and ocean temperature imaging system in that catalog. Capt. Jack's is mailed to approximately 25,000 homes and businesses. **OCENS** is negotiating with product representatives active in the Atlantic tuna fleets and fishing industries in Southern Europe and South American fishing industries to carry the product in those regions. **OCENS** also is presently negotiating with product representatives covering the North American and Pacific Basin markets. To assist with marketing efforts in all areas, **OCENS** has developed user sheets and user handbooks that spell-out how sea surface temperature information can be combined with other information available to the professional skipper to improve fishing effectiveness or trip execution. A second handbook offers insights into how information collected by space-based sensors and augmented with other data can be used to better gauge weather conditions, improve trip planning and increase vessel safety. User sheets are being distributed as marketing instruments. User handbooks will be packaged with each *SeaStation* bundle that **OCENS** sells. Even more refined application guides targetting locations or areas of interest to specific *SeaStation* users will be crafted for a fee on an as-needed basis.

Post-EOCAP II Activities

Post-EOCAP activity will focus on the development and expansion of **OCENS** business opportunities. In the near-term, this will consist primarily of the continued development and marketing of *SeaStation* to the commercial fishing industry, recreational fishing boats and blue water cruisers and yachters. With development of version 1.0 complete, major efforts will now be expended on marketing and the establishment of a widespread distribution network in the US. Other near-term activity will

include the marketing of *OmniVision*, **OCENS** Synthetic Aperture Radar-based vessel detection and ocean monitoring system and the penetration of broader markets for Sea Surface Temperature (SST) and ocean color information. **OCENS** will launch its own HomePage services in October, 1995 and offer forums on the HomePage in Commercial Fishing, Sport Fishing, Boating, and Satellite Remote Sensing. A major part of **OCENS** on-going activity is the evaluation of the feasibility of new products that take advantage of ocean productivity data (when the SeaWiFS sensor is finally launched) and high resolution weather data. **OCENS** will also address data compression questions through cooperative work with the University of Washington. This work is focusing on the application of new compression algorithms to the image and ocean data **OCENS** commonly encounters and must forward to vessels at-sea. On another front, **OCENS** has retained expertise in the field of wireless communications to design a state-of-the-art paradigm for the movement of compressed weather and ocean data from **OCENS** shore-based offices in Seattle to vessels at-sea on any of the world oceans.

Mid-term activity to be pursued in the next two to four years includes continuing upgrades to *SeaStation* products to allow its integration with other electronic systems on-board the vessels and oceanographic data. **OCENS** marketing of the *OmniVision* vessel detection system will become much more aggressive during this phase. Primary targets will be coastal state fisheries enforcement agencies and ocean monitoring authorities as well as high latitude fishing companies and insurance firms. **OCENS** will also explore other business relationships exploiting **OCENS** space-based vessel location monitoring capabilities, active vessel tracking techniques, and emerging United Nations requirements for comprehensive vessel surveillance capabilities. These low-cost, comprehensive detection networks will augment the conventional ocean surveillance capabilities of developed or developing countries. Communication services to the marine industry are rapidly improving. **OCENS** intends to take advantage of these advances by developing the capability to supply a wide variety of data to vessels at-sea. **OCENS** also intends to expand the application of Geographic Information Systems in the marine environment by packaging much of the above information as data layers for use in spatial information systems that

can improve fishing performance and/or eliminate waste. Lastly, **OCENS** will in this mid-term phase begin to aggressively attack overseas markets for its products and services.

In the long term, **OCENS** strategy is to capitalize upon technological developments and its in-house expertise to broaden its business base. Whereas **OCENS** cash flow in its first five years will be largely a function of sales of versions of its *SeaStation* and *OmniVision* systems, revenues in later years will be enhanced via **OCENS** taking advantage of emerging space technology by applying it to aquaculture and new wild-capture fisheries applications, and becoming more intimately involved with the expanding marine telecommunications industry.

NRC will also be involved in post-EOCAP activity. Whereas most of **OCENS** near-term activities will be focused on the product development and product and service marketing, remote sensing activities at NRC will be associated primarily with research investigations. These near-term investigations will, however, complement the mid- and far-term applications development of **OCENS** by focusing on fisheries and vessel monitoring and aquaculture applications:

Lessons Learned

The project team appreciates the opportunity to raise several EOCAP issues that we believe are important to the continuing success of the EOCAP program. These issues include:

Evaluate the team as much as the technology when awarding proposals. In doing so, solid teams should consist of individuals with business and technical status, innovators with a small business person's/entrepreneur's mentality, a corporate or business strategist, scientific knowledge and marketing savvy. We suggest that such a team represents the appropriate blend of science and business backgrounds to not just right a good proposal but also move those ideas to a successful business venture.

There seems to be a trend to offer more EOCAP awards to larger companies. While we understand that this may increase the likelihood of EOCAP success stories, we believe such large company awards move EOCAP away from, in our eyes, its more appropriate mission--assisting small firms without substantial financial assets with the often risky process of moving sound products and services to market. Larger companies with substantial R&D budgets lie outside of this risk curve and should not need to rely upon EOCAP-level funds to push a product to market. Failure to acquire EOCAP funding will probably not mean the termination of the targeted activity within the larger firm. On the other hand, EOCAP funds to a smaller company make a world of difference. Without access to such funds, proposed projects may never get off of the ground. If the activity proposed by the small business has sound business and technical merits, being left out of a limited EOCAP budget by awards to larger firms, while perhaps an appropriate political decision, runs counter to what we believe to be the appropriate EOCAP mission.

We have also learned first-hand that technical feasibility does not translate into commercial application. This statement emerges from our experience with the AVHRR ship track work. Yes, ship tracks could be observed in some AVHRR images but no, they could not be found in enough of those images for a wide enough range of vessels to offer a reliable monitoring service.

We found that the greatest attribute of the EOCAP program also emerged from our experience with the ship track activity. This attribute is a flexibility of approach that permitted the project team to adapt to the technical and geopolitical circumstances it encountered. Such adaptation has now resulted in two new products, a new company, private sector investment totaling \$70,000 to-date, and the retention of ten individuals to work on various aspects of continuing business and technical development. Throughout our project, EOCAP employees and contractors recognized the realities of small business development in the 1990s and helped us address those realities in whatever way possible. We strongly encourage EOCAP

principals to retain their philosophy of working with the businessman to develop commercial applications of remote sensing technology and avoid becoming another entity that attempts to force fit private business into the mold of a government bureaucracy.

The project team did not have a business plan in place when the original proposal to EOCAP was submitted. In retrospect, we now know that this was an important deficiency. The process of business plan preparation, review, refinement and rewrite sorted the business wheat from the notion chaff. It also lays on the table current activities in the context of future direction and objectives and surrounds all of this with business and marketing strategies. We understand that the EOCAP program has revised their proposal process to require business plan submission in conjunction with future EOCAP proposals. We think this is a fine idea but remind EOCAP that some small business persons and probably most scientists have no idea what a business plan is or what should go in it. As such, although we concur that proposals should be accompanied by a business plan, we suggest that good teams (see above) with solid technical ideas but a poor business plan be told that Year 1 activity should include a heavy emphasis on business plan refinement. To encourage such attention, we believe it appropriate that Year 2 and later funding be made contingent upon the delivery by the third quarter of Year 1 of a business plan that is considered *bona fide* by EOCAP business professionals.

All of the AVHRR data used in our project was sourced from outside of the project team. As such, we found that data interfaces used up a great deal of our time during Year 1 and 2. We encourage future EOCAP participants to attempt to get as much of the data stream that they will be using under their own control as possible.

During the first project year we spent some time reviewing existing government software to see if it would address our needs. Few pieces of software did so and those that did seemed poorly supported as the individual who had written them had moved on to different pastures.

We appreciated access to the government software files but, frankly, would not encourage future EOCAP contractors to spend a lot of within them. The software industry changes so quickly that state-of-the-art software created by a government contractor one year may be, if not out of date, well behind the leading edge the next year.

The remote sensing industry is a rapidly expanding one. Couple this with all of the changes going on in the telecommunications field, data compression, image processing and GIS, and it is very difficult for a small business to stay abreast of everything that is happening. We see an important role for NASA in this regard. Could not NASA serve as an objective clearinghouse for software and hardware for our industry? We do not intend that there be any advocacy associated with this endeavor but simply an honest effort to coalesce in one spot a compendium of private sector data, hardware, and software tools. This would serve two ends. For one, it would provide for small businesses (or any business for that matter) a way point that could be regularly inspected for information on cutting edge applications. Secondly, it would, if done well, keep NASA actively aware of what is happening in private sector product development. Of course, to be successful NASA would have to be committed to the undertaking. To launch such a system without the commitment to aggressively stay on top of on-going developments would end in a lack of service credibility and minimal effectiveness.

Our project was approved in late-1990. We did not receive a go-ahead until mid-1992. At the time, we looked at this as a significant obstacle to success. In retrospect, the delay was probably fortuitous. Had we not been delayed, we would have found ourselves launching products designed for a world with much different geopolitical realities than could have been expected at project start. Given the delay, our ability to adapt to these changes, and EOCAP's flexibility in allowing us to do so, we were able to adjust in mid-stream and set out on a course that is now culminating in two commercial products. We can only hope that if such delays are necessary for other project teams in the future, they can effectively adapt to them. If such adaptation is more

the exception than the norm, we encourage NASA to avoid the type of delay experienced by our project team.

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Appendices

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Appendix 1: OCENS Corporate Brochure and Product Sheets

Appendix 2: Vessel localization using AVHRR and SAR Technology

Vessel Localization using AVHRR and SAR Technology

Mark H. Freeberg¹, E.A. Brown², Robert Wrigley³

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¹Natural Resources Consultants, Inc. 4055 21st Avenue West, Seattle, Washington 98199

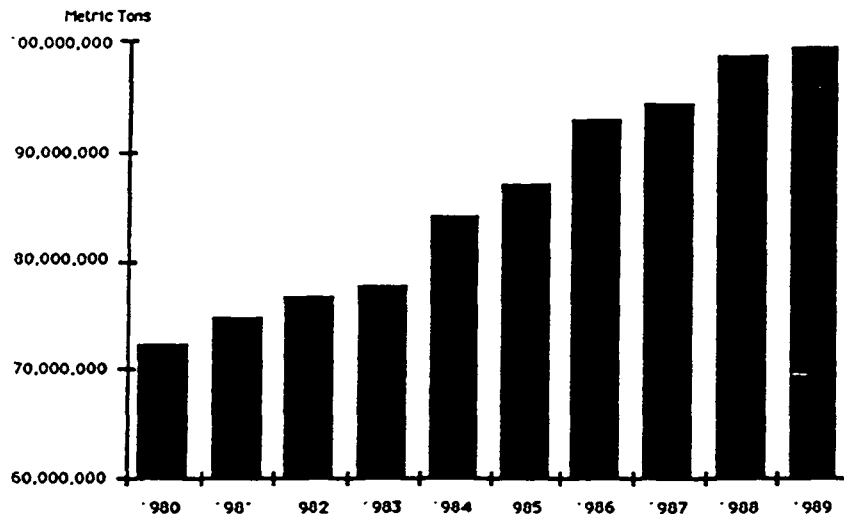
²Pacific Remote Sensing Alliance, 1978 Harvard Avenue East, Seattle, Washington 98102

³NASA/Ames Research Center, Moffett Field, California 94035

Introduction

World fisheries harvests have risen by almost 30 million metric tons since the early 1980s (Exhibit 1). Current landings of around 100 million metric tons now provide 20 kilograms or 44 pounds of protein for every person on earth. Unfortunately, this increase in harvest has not come without some expense. The number of over-exploited stocks has more than doubled from the 23 listed in 1983 to the 51 documented in 1989. In the Atlantic, more than half of the stocks for which data are available are now over-exploited. The heavily exploited Central Eastern Atlantic region contains 16 major stock groups, 11 of them are over-fished. Eight of the 17 stocks in the Southeast Atlantic are fished too heavily⁴. While fewer Pacific stocks are over-fished, their future status is also uncertain as fisheries expand unchecked and unmonitored.

Exhibit 1: Growth in world commercial fisheries harvests since 1980.



While several factors can be associated with the excessive fishing and over-exploitation of some of the world's key fishery resources, one of the most important is the lack of effective fisheries monitoring and enforcement (M/E) systems. Without adequate M/E, legal fisheries harvest quantities of target fisheries in excess of allocated quotas and discard large quantities of non-

⁴Alverson, D.L. and P. Larkin. 1992. Fisheries: Fisheries Science and Management, Century 21. World Fisheries Congress, Athens, Greece. May, 1992.

target individuals. Vessels from one nation encroach illegally into the national waters of other nations. Pirate vessels harvest species in prohibited areas or during closed seasons with little fear of apprehension.

Clearly, conventional M/E systems are stretched beyond their capacities. M/E is difficult for several reasons, including the fact that the ocean expanses that are home to the large, distant water fleets are immense. The North Pacific alone accounts for a surface area of 22 million square kilometers while the Bering Sea covers an additional 2.3 million square kilometers. This great size, when coupled with the hazardous weather conditions of many regions and the very limited enforcement budgets (only one Coast Guard cutter and one or two airplanes are available to cover the Bering Sea region), makes effective enforcement with conventional measures a difficult, if not impossible, task.

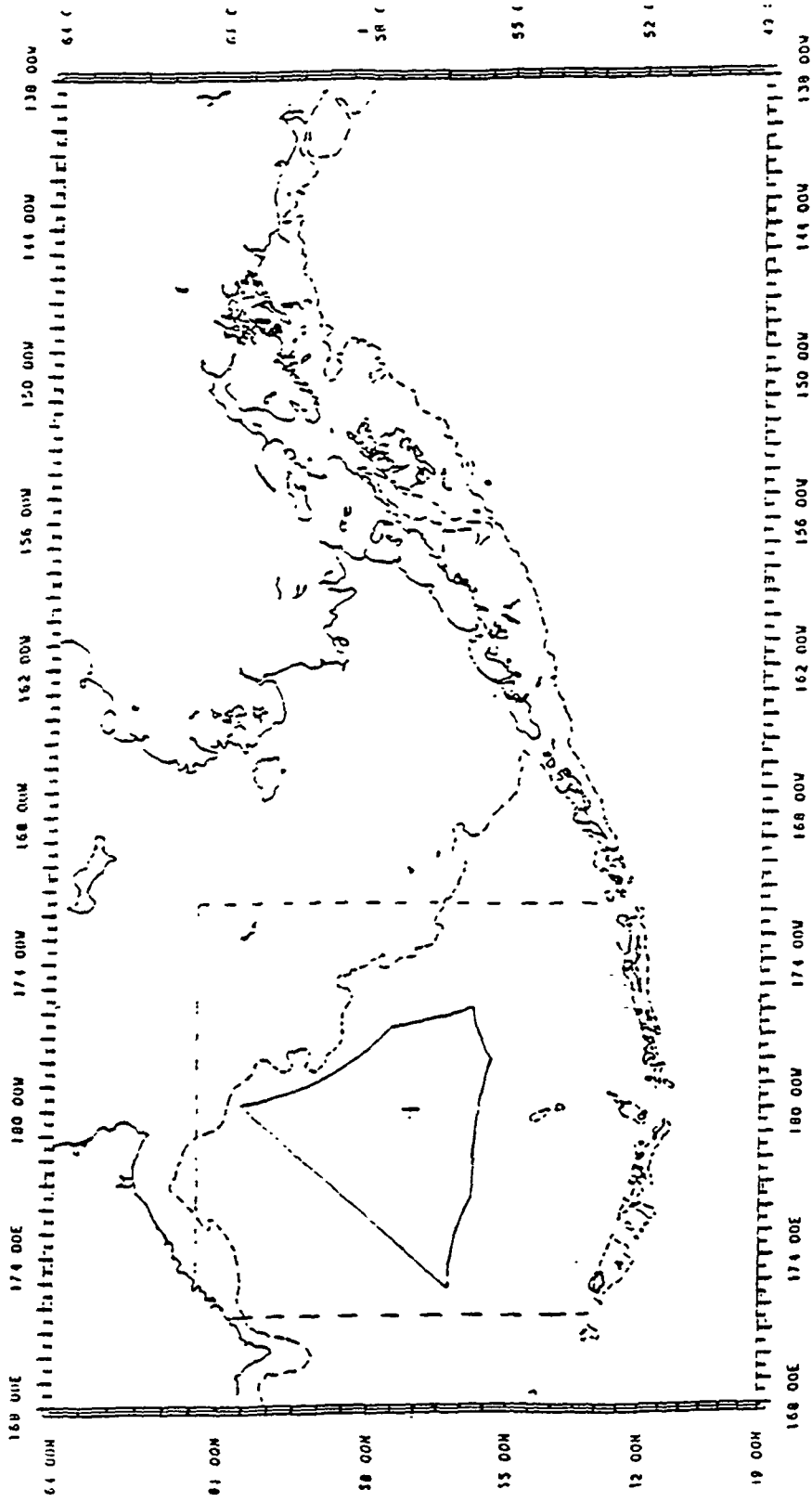
The admitted ineffectiveness of conventional monitoring/enforcement measures and the continuing trend of heavy exploitation of the ocean's resources encourages searches for alternative approaches. One such approach is the use of space-based technology to meet new demands for ocean monitoring. Our work is now focussing on the application of two such technologies, Advanced Very High Resolution Radiometry (AVHRR) and Synthetic Aperture Radar (SAR), to M/E enforcement problems in the North Pacific and Bering Sea.

Problem Description and Objectives

The M/E problems of the North Pacific and Bering Sea are not unlike those of other regions. In the Bering Sea, the large groundfish resource occupies shelf and slope waters under the national jurisdictions of the United States and the Commonwealth of Independent States (CIS). Centered between these national jurisdictions is a large window of international water with depths reaching down to 2,000 to 3,000 meters (Exhibit 2)⁵. While the fishery

⁵The borders of the "Donut Hole" parallel the shorelines of the US (Alaska) and the CIS at a distance of 200 miles from these shorelines. Following the United Nations Law of the Sea conference in the early 1970s, most nations expanded their national jurisdiction to a distance of 200 miles offshore.

Exhibit 2: Alaska, the Aleutian Islands, and the "Donut Hole".



resources of this deep-water area, often called the 'Donut Hole', are not prolific, the area serves as a convenient staging ground for forays into neighboring national waters. Foreign vessels can operate legally in this area, then move into the more productive slope and shelf waters nearby where large quantities of groundfish can be quickly harvested. In 1990, harvests from vessels based in the Donut Hole exceeded 1 million metric tons, almost one-third of the legal harvest documented by the US and CIS fleets. A large portion of these harvests is thought to have occurred in US and CIS waters. Such additional harvests threaten not only the groundfish stocks in the region but also compete directly on world markets against whitefish products harvested legally by US fishermen.

A different problem plagues the North Pacific region. Here, driftnet fisheries for squid and other species have recently been banned by the UN. Nevertheless, the driftnet ban has not effectively dealt with concerns that driftnets were being fished illegally in areas where large numbers of salmon of US origin could be intercepted. This inadequacy emerges from the fact that the UN ban can apply only to those boats which agree to conform to its prohibitions. Given the lack of effective M/E countermeasures, pirate boats can operate in the region with relative impunity and, in so doing, recognize sizable profits from the illegal harvest of driftnet-caught salmon. Illegal harvests by these boats may decrease salmon returns to US inshore commercial and recreational fisheries and damage already stressed West Coast salmon stocks.

In addition to concerns with effective fisheries enforcement, dangerous weather conditions confront fishermen on every ocean. On average, 50 vessels valued at over \$24 million are lost each year in conjunction with fishing operations in the North Pacific. Violent winds coupled with heavy seas claim many of these victims. Icing conditions can quickly overturn boats in a matter of hours, in some instances minutes, as tons of ice coat vessel superstructures. On the North Pacific and other oceans, such difficult conditions are exacerbated by the fact that the regions are so remote that weather forecasts can be unreliable.

Our objectives are thus two-fold: pursue new means of locating fishing vessels to improve fisheries M/E and investigate ways to refine the accuracy of weather forecasts for specific areas and fishing fleets. With limited time and resources, the bulk of our efforts will be focussed on the former objective. Success will be measured by our ability to produce a commercially-viable M/E product. The commercial product should be capable of localizing vessel positions in near real time under a variety of weather conditions and at a cost that does not prohibit the system's use by fisheries enforcement agencies around the world.

Technological Background

The Tools

As already mentioned, our quest for improvements to extant fisheries M/E focusses on satellite-based applications of AVHRR and SAR technologies. AVHRR image data consists of four or five spectral bands. Band 1 is visible (0.58 to 0.68 μm), band 2 is reflected infrared (0.725 to 1.00 μm) while bands 4 and 5 are thermal (10.3 to 11.2 μm and 11.5 to 12.5 μm , respectively). Band 3, the channel most frequently used for ship track analyses, is between the reflected and thermal infrared (3.55 to 3.93 μm).

AVHRR satellites (NOAA 9, 10, 11, and 12) orbit at a nominal altitude of 833 kilometers. The AVHRR imagery is in a 2,048 pixel format with a resolution of approximately 1.1 kilometer per pixel at nadir. In comparison to other satellite image sources, AVHRR trades relatively coarse resolution and an inability to peer through cirrus or heavy cumulus cloud cover for a field of view of roughly 3,000 square kilometers, good viewing in the stratus and stratocumulus conditions often associated with the major fishing regions of the world, and the ability to measure sea surface temperature to within a few tenths of a degree. AVHRR's wide field of view also provides overlapping coverage on subsequent orbits.

The recent launch of the ERS-1 provides an opportunity to evaluate its SAR sensor system to deal with various weather conditions. The ERS-1 SAR imagery provides high resolution (30 meters) viewing within a narrow, 100 kilometer wide swath. Given these characteristics, AVHRR data depicting ship tracks will be used to select SAR scenes for higher resolution analyses of

the ship tracks, ship wakes, and/or ships themselves. In addition, the narrow swath width would not impede M/E of specific areas of interest, such as Exclusive Economic Zone boundaries.

As neither the NOAA satellites or the ERS-1 are geo-stationary vehicles, around-the-clock coverage of specific areas is not possible. Because of the polar-orbiting nature of these satellites, this problem is less troublesome in northern latitudes than it is farther south since re-visit frequencies increase as we move northward. In the Bering Sea, for example, the presence of four satellites with AVHRR capabilities (NOAA 9, 10, 11, and 12) provides a pass every two to three hours over the region. Farther south off of Oregon, at least four passes per day are usable. SAR re-visits are still more infrequent.

The Process--AVHRR

The AVHRR work centers around the identification of cloud lines associated with stack emissions from ocean-going marine vessels. Anomalous cloud lines in satellite imagery were first noted by Conover⁶ in 1965. Because the cloud lines were very low, formed over warm and cold water, and, in some cases, crossed over one another, Conover eliminated aircraft and ocean conditions as possible sources of the lines and concluded that the lines distinguished ship effluents. Based on very limited atmospheric data, Conover suggested that cloud lines formed in conjunction with very clean marine air and a thermal structure permitting weak convection from the surface to a stable layer located at 0.5 to 1.0 kilometer. Stratocumulus or stratus clouds typically formed underneath the stable layer, temperatures ranged from 3C to 18C and apparent winds (wind relative to the moving vessel) reached 16 meters per second (31 knots) in images associated with cloud lines. Conover also inferred that the ship contrails formed from the addition of cloud nuclei, probably sulfate particles produced by combustion, and not moisture, as typical with the formation of aircraft contrails.

⁶Conover, J.H. 1965. 1966. Anomalous cloud lines. *Journal of Atmospheric Sciences*. 23: 778-785.

In connection with some of the initial research into global warming and the earth's radiation budget, Coakley, et. al.⁷ expanded the work of Conover. Coakley's work focussed on the effect that man-made aerosols could have on cloud reflectivity and the extent to which this effect might counter increases in global carbon dioxide. While such aerosols are too small to interact with radiation themselves, they could serve as nuclei for the formation of cloud droplets with strong interactive effects.

Using 1 km² AVHRR data, Coakley observed ship tracks at 3.7 μm (Channel 3). Tracks were difficult to observe at 0.63 μm and 11 μm . At 11 μm , water is a strong absorber and there is little to distinguish a cloud contaminated with aerosols from an uncontaminated cloud. The reverse is true at 0.63 μm as at this wavelength, liquid water is non-absorbing. Meanwhile, at 3.7 μm , water droplets both scatter and absorb radiation with scattering (relative to absorption) and reflectivity increasing as droplet radius decreases. High reflectivity at 3.7 μm is thus presumed to be associated with shifts to smaller droplet radii that is accompanied by increases in the number of cloud particles.

Radke, et.al.⁸ confirmed the association of small droplet size and high droplet count to ship tracks during *in situ* measurements off of the coast of southern California in 1987. Using satellite data and aircraft flights through the ship tracks, Radke documented an increase in reflectivity that was coupled with sharp increases in droplet concentration and 12% to 33% reductions in droplet radius within the ship track. Radke also noted that tracks could be distinctly identified by using the radiance ratio between absorbing and non-absorbing wavelengths. High liquid water contents also provided track signatures.

Inconclusive results have been obtained from investigations attempting to determine the contribution to cloud formation made by heat released by

⁷Coakley, J.A. Jr., R.L. Bernstine, and P.A. Durkee. 1987. Effect of ship-stack effluents on cloud reflectivity. *Science*: 237: 1020 - 1022.

⁸Radke, L.F., J.A. Coakley, Jr., and M.D. King. 1989. Direct and remote sensing observations of the effects of ships on clouds. *Science* 246:1146 - 1148.

vessel power plants. Numerical models developed by Porch et. al.⁹ suggest that the buoyancy input from heat present in the ship stack may be as important a factor in track formation as the latent heat produced during the nucleation process. More detailed work with vessel power plants will be necessary to clarify this role in the phenomena.

Porch's models did demonstrate that the impact of a vessel power plant heat source decreases as the height of the boundary layer and depth of the mixed layer increase. As supported by the work of Scorer¹⁰, this finding helps to explain why ship trails are seldom seen in air which has considerable convection and, consequently, a deep mixed layer.

Using high resolution (14 meters) data from the Apollo-Soyuz mission, Porch was also able to provide some ship track morphometrics. Tracks grew from their origin to widths of three to six kilometers over approximately 40 kilometers of length. Magnification of the origin of the ship track indicated that the track began as a brightening of the background clouds and not as the formation of new clouds. Given the limited amount of such high resolution data, it is difficult to determine whether such generation is the norm or the exception. SAR imagery collected in our project may provide further clues.

The work of Durkee and his graduate students at the Naval Post-Graduate School in Monterey has advanced considerably the understanding of the ship track phenomena and means of detecting it. In a 1992 paper, Nielson and Durkee¹¹ described their attempts to construct a computer algorithm to distinguish tracks. Also in 1992, a thesis by Salvato¹² presented analyses of ship tracks formed under subtropic and arctic conditions. Salvato discovered that while subtropic tracks are brighter, longer, and wider than arctic tracks, the Arctic ship tracks were brighter relative to their surrounding environment than their counterparts in the subtropic. This higher contrast

⁹Porch, W.M., C. J. Kao, and R.G. Kelley, Jr. 1990. Ship trails and ship induced cloud dynamics. *Atmospheric Environment* 24A (5): 1051-1059.

¹⁰Scorer, R.S. 1987. Ship trails. *Atmospheric Environment*. 21:1417-1425.

¹¹Nielson, K. and P. Durkee. 1992. A robust algorithm for locating ship track cloud features using 3.7 micron satellite data. Preprints to the Papers on the 6th Conference on Satellite Meteorology & Oceanography, January 5 - 10, 1992. Atlanta, Georgia.

¹²Salvato, G. 1992. Comparison between Arctic and subtropic ship exhaust effects on cloud properties. Masters thesis, US Naval Postgraduate School. 54 pp.

suggests that tracks formed in the Arctic may be more readily detectable than those in the subtropic.

In summary, what do we presently know about the ship track phenomena and the identification of ship tracks:

- Tracks form from the addition of cloud condensation nuclei (CCN) in low CCN areas. The contribution to the phenomena of vessel power plant heat emissions or sea salts from the ship wake is still unknown;
- Ship tracks are distinguished by smaller droplet radii, an increase in the number of cloud particles, and elevated liquid water concentrations relative to ambient conditions outside of the track;
- Ship tracks appear to form best in clean, marine air conditions. Intrusions of continental air masses provide numerous CCN that impedes the use of the CCN provided by the ship exhaust for cloud formation;
- Stratus or stratocumulus cloud layers are most often associated with ship tracks. Tracks are seldom found in conjunction with cumulus or cirrus formations;
- Tracks form more readily with a shallow mixed layer and a low marine boundary layer. Strong convection accompanied by a deep mixed layer appears to dampen the generation of ship tracks;
- Subtropic tracks tend to be brighter, longer, and wider than those formed in the Arctic. Arctic tracks are brighter relative to the background than subtropic tracks, however.
- Due to the high reflectivity of tracks at 3.7 μm , tracks are especially noticeable on AVHRR channel 3;

• Ratios calculated by dividing nonabsorbing wavelength radiance by absorbing radiance appear to distinguish ship tracks from environmental conditions;

Of course, if ship tracks occur infrequently (an assertion suggested in the early papers prepared by Conover¹³, Coakley¹⁴, Scorer¹⁵ and Radke¹⁶) then an understanding of the phenomena and how to identify it may be useful in studies of global climate but of little application to fisheries M/E. Coakley¹⁷, for example, estimated that ship tracks may appear in only 5% to 10% of all orbital passes. At these frequencies, the detection of ship tracks would be of little tactical significance since vessels operating illegally would face little threat of detection.

The work of Durkee and his students suggests, however, that ship track signatures appear in a much higher percentage of orbital paths than was earlier thought. In research off the California/Oregon coast, for example, high percentages of the AVHRR images contain ship tracks¹⁸. If such percentages are typical of other areas fished by the large distant-water fleets, ship track identification could indeed emerge as a useful M/E tool. Fortunately, many of the most productive fishing grounds in the world¹⁹ which, not surprisingly, are also those with some of the greatest M/E concerns, are associated with consistent stratus or stratocumulus layers. Given that most of the conditions conducive to the formation and identification of ship tracks are associated with stratus/stratocumulus layers, we expect that high percentages of the images acquired for these areas will contain ship tracks. As such, while our area of immediate interest is the

¹³Conover, J.H. 1965. 1966. Anomalous cloud lines. *Journal of Atmospheric Sciences*. 23: 778-785.

¹⁴Coakley, J.A. Jr., R.L. Bernstine, and P.A. Durkee. 1987. Effect of ship-stack effluents on cloud reflectivity. *Science*: 237: 1020 - 1022.

¹⁵Scorer, R.S. 1987. Ship trails. *Atmospheric Environment*. 21 (6): 1417-1425.

¹⁶Radke, L.F., J.A. Coakley, Jr., and M.D. King. 1989. Direct and remote sensing observations of the effects of ships on clouds. *Science* 246:1146 - 1148.

¹⁷Coakley, J.A. Jr., R.L. Bernstein, and P.A. Durkee. 1987. Effect of ship-stack effluents on cloud reflectivity. *Science*: 237: 1020 - 1022.

¹⁸Personal communication, Dr. Philip Durkee, August 5, 1992

¹⁹The North Pacific, Gulf of Alaska, and Bering Sea, the eastern Pacific along the coasts of the US, Canada, Chile, and Ecuador, the North Atlantic, and off of west and southwest Africa.

North Pacific, we envision ready application of this technology to other fishing areas.

The Process--SAR

As already mentioned, SAR data provides high resolution images of 100 kilometer swaths of the ocean. The high resolution available with SAR data is not without liabilities--the chief of which concerns the handling of the vast amounts of SAR data downloaded from the satellite. For example, each 100 kilometer by 100 kilometer SAR scene contains approximately 160 megabytes of data. As ships and ship wakes are readily distinguished within the SAR data²⁰ and since manual attempts to visually review the imagery would be time intensive and cost prohibitive, recent work pertinent to ship feature detection has thus focussed on ways to computerize SAR image analysis.

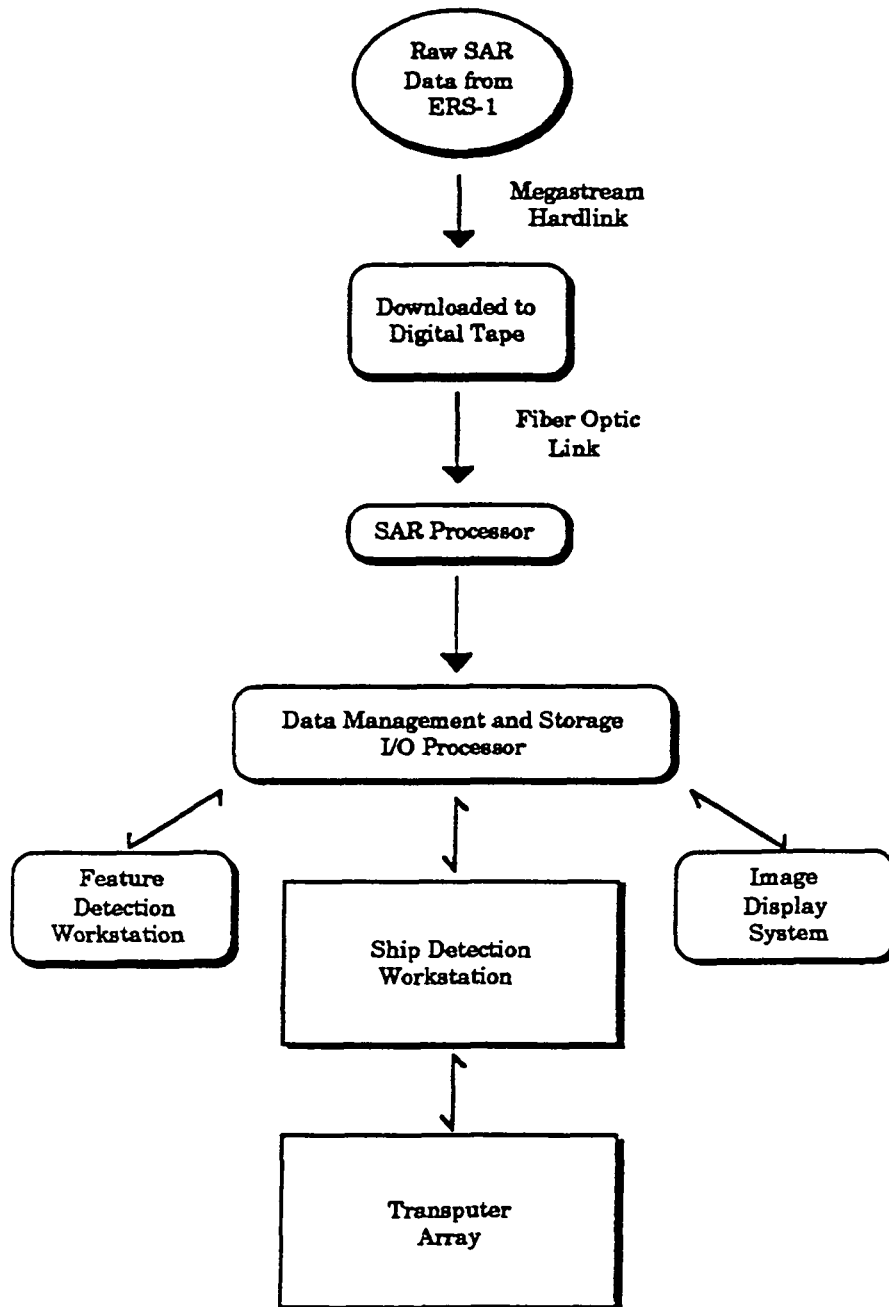
Rye, et.al²¹ presents an overview of the development of a workstation for the fast processing of ERS-1 SAR data. Since effective detection presumes fast detection, Rye's work was conducted under the premise that processed results would have to be available within three hours of the satellite overpass. With this limitation in mind, Rye describes a process whereby data is downloaded to a groundstation, recorded onto a high density digital tape, then transmitted via groundlink to the SAR processor (Exhibit 3). After the raw image is processed into an image usable by the Ship Detection Work Station (SDWS), approximately two of the three hours available for acquisition, transmission, processing and detection have been consumed.

Once processed images are passed from the SAR processor to the SDWS through a fiber optic link, SAR images are further analyzed for ships and ship wakes. Before ship feature detection algorithms attack the image, two other algorithms are applied, one of which geo-locates the image and masks coastal features and a second which removes large scale structures from the

²⁰Vesecky, JF and RH Stewart. 1982. The observation of ocean surface phenomena using imagery from the SEASAT Synthetic Aperture Radar: An Assessment. J. Geoph. Res. 87 (C5): 3397 - 3430.

²¹Rye, A.J., F.G. Sawyer, and R. Sothinathan. 1990. A workstation for the fast detection of ships. IGARRS Proceedings, 1990.

Exhibit 3: SAR processing workstation described by Rye, 1990.



scene. The latter achieves a homogenous background and preserves linear features in the SAR image by dividing each pixel by the mean of a larger local window within the image of up to 30 x 30 pixels.

Ship detection algorithms rely upon a thresholding technique for their success. Ships are identified when a predetermined percentage of pixels are above a threshold level for a given area or when adjacent pixels are above threshold. If two thresholds are used, pixels above the second threshold denote a ship while those above the first threshold indicate features which could be ship targets.

Alternative wake detection algorithms work either from the point of view of using an identified ship position to detect a wake or finding wake features in order to locate a vessel. The latter approach is accomplished by using the Hough Transform to detect linear fragments which are then linked to form wake lines. A last step establishes wake vertices and, presumably, ship location.

Since some 'ships' may instead be bright features on a wave crest, an alternative wake detection algorithm can be applied to questionable vessel detections. This algorithm searches in the vicinity of the 'ship' for linear features which suggest a ship wake. Finding such a feature confirms the target as a ship.

Following application of the ship and wake detection algorithms, detections are exposed to several post-processing algorithms. These algorithms associate ships with wakes and provide estimates of ship position, heading, and speed. The reliability of the detection is also derived. Results are superimposed on a map of the subject area at image display terminals networked with the workstation.

Application

Given the body of knowledge concerning the presence and identification of ship tracks in AVHRR imagery as well as emerging capabilities for the rapid detection of ships in SAR imagery, an investigation of the capacity of these two technologies to deal effectively with fisheries M/E concerns in the North Pacific was initiated in 1989. Consequently, in 1990 a group of private and public sector interests completed a pilot project which successfully demonstrated that ship tracks could be observed in North Pacific AVHRR

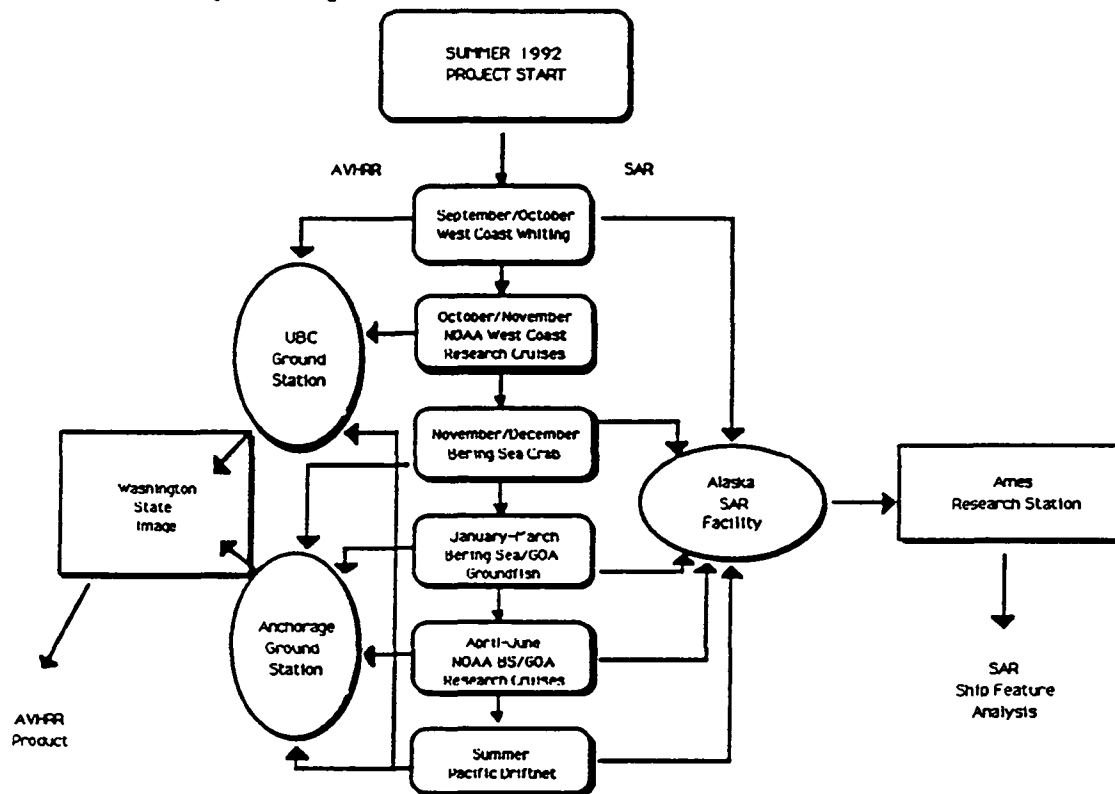
imagery. This success led to a more comprehensive project begun in 1992 that seeks to fully develop AVHRR and SAR applications for fisheries M/E, first in the North Pacific and Bering Sea, and thereafter in other ocean areas.

This larger three year study funded through NASA's Earth Observation and Commercial Applications Program (EOCAP) is now entering its fifth month. Work within the development project will proceed along two principle pathways. Within the first, AVHRR data covering the Bering Sea, Gulf of Alaska, and central Northern Pacific will be downloaded and analyzed for ship tracks. Imagery will be processed principally with ERDAS software and algorithms will be written to use this software in an automated fashion. Our goal is to download, process, and detect ship trails and estimate ship position in the AVHRR imagery within two hours of satellite overpass.

Several test periods are planned for this element of the study. Each of these test periods coincides with the prosecution of fisheries for crab or pollock, cod, whiting and other groundfish in the region (Exhibit 4). Beginning in the fall, AVHRR data will be downloaded in conjunction with the September/October whiting fishery along the US West Coast, the November/December crab fisheries in the Bering Sea, and the January through March groundfish (largely pollock) and crab fisheries in the Bering Sea and Gulf of Alaska. Attention will shift to the central North Pacific during the summer months and will focus on areas where pirate driftnets could still be intercepting US and Canadian-origin salmon.

In test periods associated with the groundfish and crab fisheries, important contributions to the study will be made by US fishing vessels. These vessels will groundtruth the AVHRR scenes by providing known vessel positions against which to check the vessel tracks detected in the imagery. Once verified, cooperating vessels will also provide information on speed, direction, engine size, fuel type, and anecdotal weather and sea surface conditions. Since many of these boats are similar in size and design to those illegally penetrating the US EEZ, documenting their presence in the AVHRR imagery will tell us much about the M/E effectiveness of the system in the Bering Sea and Gulf of Alaska.

Exhibit 4: Flow chart of EOCAP test periods, image sources, and image analysis responsibilities



NOAA research vessels have also agreed to cooperate with the study during sampling cruises off of the US West Coast in October and November and in the Bering Sea and Gulf of Alaska during the spring and summer. These vessels will be valuable in that they will be monitoring a number of weather and sea surface parameters on a routine basis. Such a large dataset should contribute to an improved understanding of the meteorological conditions which are or are not associated with ship track formation.

AVHRR data will be accessed through one of two sites depending on the area of interest. For work off of the US West Coast, ten bit AVHRR imagery will be transmitted via high speed modem from the groundstation at the University of British Columbia in Vancouver, BC to image processors in Washington. Groundstations at either Anchorage or Fairbanks, Alaska will

be the source of AVHRR data for activity in the Bering Sea and Gulf of Alaska.

The second major component of the study involves SAR image acquisition and analysis. Since work by other scientists has indicated that ships and ship features can be detected with SAR data, activity in this project will de-emphasize testing under a variety of conditions and locations and concentrate on the development of fast detection software similar to that described by Rye, et.al.²². As a further check on AVHRR ship track detections, a small number of SAR scenes which overlap with the AVHRR imagery will be downloaded during each AVHRR test period. Furthermore, since the eastern boundary of the "Donut Hole" in the Bering Sea provides a finite area susceptible to the swath width of the SAR, SAR data for this region will be downloaded on a regular basis during the fall, winter, and spring months.

Raw SAR data will be downloaded and processed into a SAR image at the Alaska SAR Facility in Fairbanks, Alaska. Processed images will be shipped on eight-track tape to the NASA Ames Research Center at Moffett Field, California for ship feature analysis. Ship and wake detection algorithms similar to those described by Rye will be written and applied to these imagery on a Sun 4 workstation at the Ames facility. An automated process whereby analysis is complete and ship features discriminated within one hour of receipt of the processed SAR image is the ultimate goal of this element of the development project.

Automation is necessary to address concerns with the cost and timeliness of the final product. Obviously, ship detection is of little use if it cannot be completed within a matter of a few hours. As mentioned earlier, our target for AVHRR data acquisition and shiptrack detection is two hours and thus near real-time M/E is feasible for this element of the study. In regards to the SAR data, SAR image analysis is the only portion of the SAR data acquisition, processing, and analysis sequence which is under our control. Recognizing the existing realities of SAR data acquisition and processing at the SAR facility in Alaska, it is doubtful that we will be able to achieve near

²²Ibid

real-time performance within this element of the project. This is not to say, however, that successes will not breed new opportunities we cannot now count upon.

Since comparable AVHRR/SAR systems do not exist, the question of cost effectiveness is a difficult one to informatively address. Active systems which rely upon transponders carried aboard each vessel cost from \$1,000 to \$5,000 per vessel per year but have no application to situations where boats wish to hide themselves while fishing illegally. Given what we know about the inability of AVHRR data to provide track 'fingerprints' specific to particular vessels, it also appears that the use of AVHRR will not completely alleviate the need for M/E vessels and aircraft. These platforms will still be necessary to confirm potential violators and apprehend actual ones. Thus, we are left with evaluating the cost effectiveness of this approach for US applications through improvements in the efficiency of existing search, detection, and deterrence procedures. Such an increase in efficiency would be accomplished by a reduction in the number of aircraft overflights or an increase in the percentage of successful sorties. Quantification of the value of stepped improvements in existing M/E efficiencies is necessary.

Status

At this writing we are in the midst of our West Coast test period involving groundtruth boats fishing for whiting. Two large factory trawlers and five to ten smaller catcher boats are cooperating with this phase. In addition, we have obtained positions and vessel characteristics for a handful of deep draft cargo vessels bound for or leaving from the ports of Portland and Seattle.

AVHRR imagery for the Oregon/Washington coast has been downloaded from the NOAA 11 satellite at the UBC groundstation from August 24 through September 15, October 1 through October 8, and October 16 through November 3. Imagery was then modemed from the Vancouver groundstation to Seattle. Processing of images obtained during the August/September period is underway.

SAR orbits provided good coverage our region of interest off of the West Coast on August 29 and September 4. Datatakes from the appropriate orbits for these two dates were downloaded at the Alaska SAR facility and are now being processed into SAR images. Images should be available for analysis in early October.

NDB

Appendix 3: Detection of ship tracks using ERS-1 SAR data

DETECTION OF SHIP TRACKS USING ERS-1 SAR DATA

Robert C. Wrigley*, Donald V. Sullivan**, and Mark H. Freeberg***

*MS 242-4, NASA, Ames Research Center, Moffett Field, CA 94035-1000,
(415)604-6060

**Johnson Controls World Services, Inc.,
Ames Research Center, Moffett Field, CA 94035, and

***Natural Resources Consultants, Inc.,
4055 21st Avenue West, Seattle, WA 98199

INTRODUCTION

While several factors can be associated with excessive fishing and over-exploitation of some of the world's key fisheries, one of the most important is the lack of effective monitoring and enforcement systems. Without such systems, vessels from one nation can encroach illegally into the national waters of another and pirate vessels can harvest species in prohibited areas or during closed seasons with little fear of apprehension. This situation encourages searches for alternative approaches; one approach is the use of space-based imagery to meet the demands for monitoring fisheries. We are concentrating now on the use of imagery from the Advanced Very High Resolution Radiometer (AVHRR) to detect persistent plumes emanating from exhaust stacks of larger vessels (70-350 feet), but we are examining also the use of synthetic aperture radar (SAR) data from the first European Remote Sensing satellite (ERS-1) to detect vessels and their wakes. Among others, Vesecky and Stewart (1982) noted ship wakes in Seasat SAR data and we anticipated they would be present in ERS-1 SAR data even though the frequency and polarization were different. The station mask of the Alaska SAR Facility for the ERS-1 SAR covers the so-called Donut Hole in the Bering Sea, an area of international waters between Russian and U.S. boundaries, where all nations can fish legally but which can also be used as a safe haven for illegal forays into U.S. (or Russian) waters. The Donut Hole was a focus of our AVHRR investigation and it was a natural extension of our AVHRR effort to include ERS-1 SAR data in our examination. In this paper we describe initial attempts to detect ships in ERS-1 SAR data acquired by the Alaskan SAR Facility (ASF).

INITIAL EXPERIMENT

During August-September 1992, an initial opportunity to test ship plume and ship wake detection was planned in conjunction with activity by seven vessels fishing for whiting off the coast of Oregon. Three orbital passes of SAR data were requested based on the ASF's future data prediction and plotting capabilities. Two passes were acquired: orbit 5855 on August 28th provided data along the coast that included land area around the mouth of the Columbia River and some 30 km offshore while orbit 5898 on August 31st provided data beginning 40 km offshore and continuing for the full 100 km swath width offshore. The two southernmost SAR scenes from both dates were requested and received as high resolution data.

Each SAR scene was examined using the IDIMS image processing system at Ames Research Center. Preliminary examination showed no ships or ship wakes in any scene. Many interesting features were observed, particularly in the scene containing the mouth of the Columbia River which is shown in Figure 1: the river plume, internal waves, the surf zone, a breakwater at the river mouth, and two bright objects off the breakwater suspected to be sea bouys. Although all scenes contained the expected speckle, many subtle features were clearly present (e.g. internal waves). The absence of ships and ship wakes was puzzling since at least one of the participating vessels, the 85 foot Cape Falcon, was reported to have been in the area covered by the Columbia River scene. No vessels were reported to be in the August 31st scenes offshore. A 4X4 pixel average was computed at each pixel in the Columbia River scene and both offshore scenes in an attempt to reduce speckle and bring out ships and wakes. The averaged scenes brought out still more subtle details such as swells better, but no ships or wakes.



Fig. 1. SAR image from ERS-1 of the area around the mouth of the Columbia River, Oregon/Washington on August 28, 1992 (orbit 5855). Scene number 35275100.

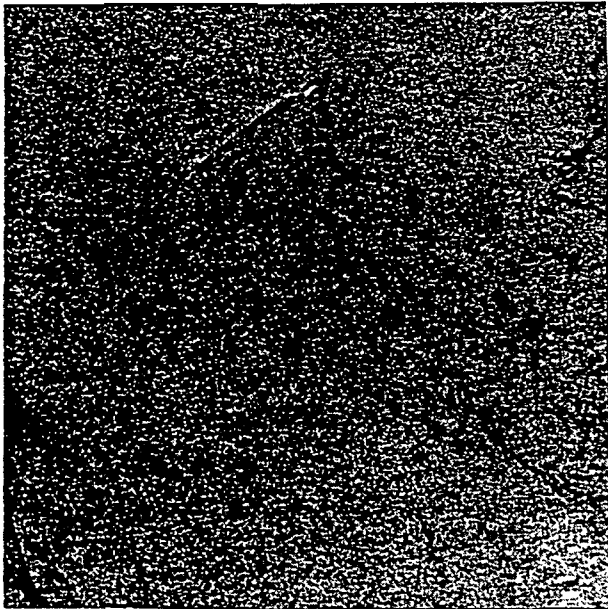


Fig. 2. SAR image of large vessel (~1,000 feet long) and its wake in Prince William Sound south of Valdez, Alaska on June 9, 1992. Scene number 21310100.



Fig. 3. SAR image of two small vessels and their wakes 40 km south of Valdez Alaska on June 9, 1992. Scene number 21310100.

The three scenes were converted into hard copy output by a High Resolution Film Recorder at Ames' Central Computer Facility. Upon examining the 8"X10" prints, two small ships and dark wakes behind them were observed in the southern portion of the Columbia River scene. The two ships are together and headed north. Note the abundance of internal waves at the shelf break, the lobate waves north of the river mouth, the breakwater south of the mouth, and the two bright objects seaward of the breakwater. The image consists of 8192 lines and 6144 elements covering an area of 100 km by 75 km. Re-examination of the digital scenes on IDIMS revealed the ships and wakes but they were not as obvious on the display screen as in the prints. Subsequently, the print was shown to the captain of the Cape Falcon. He identified the two bright objects off the breakwater as a sea buoy used as a weather station and a pilot ship. He also identified the two ships headed north as his and a similar 70-80 foot vessel. We did not anticipate detecting such small ships or the sea buoy.

ADDITIONAL SHIP TRACKS

Due to the paucity of ships and wakes in the SAR data we received, we contacted the ASF for other examples. They indicated Dr. Omar Shemdin spent some time examining their archive for ship wakes and suggested we contact him. Shemdin gave us three scene numbers and we ordered them. One scene south of Valdez in Prince William Sound revealed three wakes. One wake was caused by a very large vessel covering ~25 pixels (or 1000 feet long) itself; Figure 2 shows this vessel with a wake that curves outward initially before becoming straight. Note that only one side of the wake is visible; we assume this is controlled by the illumination geometry. Figure 2 contains 1024 lines by 1024 elements representing a 13 km by 13 km area. Figure 3 shows two wakes from much smaller vessels closer to Valdez; it also contains 1024 lines with 1024 elements. Both vessels are visible and their wakes are very persistent. Note that the wakes are apparent in both calm (dark) and rougher (brighter) water.

APPLICATION OF THE HOUGH TRANSFORM

Rye *et al.* (1990) described the development of a system for rapidly processing ERS-1 SAR data to detect and locate ships using the Hough transform (Hough, 1962) which maps line segments from the same line to a single point in conjunction with end-of-line algorithms. Using this as a starting point, we applied the transform to a number of images after pre-processing with various types (low-pass, gradient, Laplacian). With this combination of algorithms we detected the large vessel in Figure 2 but missed its wake, and missed both vessels and their wakes in Figure 3. We concluded that a detection methodology based solely on linear feature recognition was overly simplistic. We are now focussing on the definition of clues the eye-brain combination uses to delineate ship tracks.

SUMMARY

In summary of our initial activities using SAR data to locate ships, 1) we examined SAR data from the August-September 1992 whiting experiment and found two 70-80' ships participating in the experiment but no others, 2) we examined other SAR data containing ship tracks and found a wider variety of ship tracks, 3) we developed and applied the Hough transform with unsatisfactory results, and 4) we decided to reevaluate the approach for detecting ship tracks.

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**Appendix 4: Fisheries enforcement through vessel localization using
AVHRR and SAR technology**

Fisheries Enforcement through Vessel Localization using AVHRR and SAR Technology

Mark H. Freeberg
Natural Resources Consultants, Inc.
4055 21st Avenue West, Suite 200
Seattle, WA 98199
M.Freeberg@Omnet.com

Robert C. Wrigley
MS 242-4
NASA Ames Research Center
Moffett Field, CA 94035

Gordon C. Staples
RADARSAT International
200-3851 Shell Rd.
Richmond, BC
Canada V6X 2W2

Dr. Glen Klock
Western Resources Analysis
2113 Sunrise Circle
Wenatchee, WA 98801

Abstract - Natural Resources Consultants, Western Resources Analysis and NASA are investigating the application of Advanced Very High Resolution Radiometer (AVHRR) and Synthetic Aperture Radar (SAR) technology to fisheries enforcement concerns. The goal of the project is to develop and market a surveillance system that can passively monitor fishing vessel locations in near real time. Work has been conducted along the US West Coast and in the Bering Sea. Vessel tracks were observed with regularity in the West Coast AVHRR data but were less detectable in the more complex meteorological conditions found in the Bering Sea. ERS-1 SAR data did reveal 50 m to 100 m fishing vessels operating on fishing grounds in the Bering Sea. The larger vessels were detected despite wind-roughened seas and the presence of speckle. The smaller vessels also had good returns and both vessel classes may be detectable with automated methods. Given the usefulness of AVHRR and SAR imagery in detecting vessels, and the potential for near-real time data provision from Canada's RADARSAT, commercialization opportunities are now being investigated.

I. INTRODUCTION

World fisheries harvests have risen by almost 30 million metric tons since the early 1980s. Current landings of around 100 million metric tons have occurred in concert with an increase in the number of over-exploited stocks, which have risen from 23 in 1983 to 51 in 1989. While several factors can be associated with the excessive fishing and over-exploitation of some of the world's key fishery resources, one of the most important is the lack of effective fisheries monitoring and enforcement (M/E). Without adequate M/E, allocated quotas are exceeded, vessels from one nation illegally encroach into international waters of other nations, and pirate vessels harvest species in prohibited areas.

M/E is difficult for several reasons, including the fact that the ocean expanses that are home to large distant-water fishing fleets are immense. Clearly, conventional measures of enforcement (ships and planes) are stretched beyond their capacity to respond effectively. The poor performance of conventional M/E measures and the continuing trend of heavy exploitation of the ocean's resources encourages searches for alternative M/E systems.

The goal of the subject fisheries enforcement project is to use space-based technologies as the basis for the development of a surveillance system that can passively monitor fishing vessels in near real time and which can be marketed to enforcement officials worldwide. Such systems would be directed at localizing 'unfriendly' vessel positions and could be integrated with conventional M/E approaches as well as active transponder-based systems monitoring the locations of known 'friendly' vessels.

The quest for improvements to extant fisheries M/E focuses on satellite-based applications of Advanced Very High Resolution Radiometer (AVHRR) and Synthetic Aperture Radar (SAR) technologies. AVHRR image data comprises five spectral bands (0.58 μm -12.5 μm), provides a swath width of around 2400 km, and has a resolution of approximately 1.1 km at nadir. In comparison to other spaceborne sensors, AVHRR trades relatively coarse resolution for a field of view of roughly 3,000 square km. In contrast to the AVHRR data, ERS-1 SAR imagery provides high resolution (30 m) viewing within a narrow, 100 km wide swath. The ERS-1 SAR sensor is weather-independent and provides imagery under all light conditions.

Ships or ship tracks identified in the SAR and/or AVHRR imagery were seatruthed via the use of known fishing and other vessel positions. Signatures were seatruthed using positions of fishing vessels participating in the West Coast Pacific whiting (*Merluccius productus*) fishery in September and October, 1992, and the Bering Sea groundfish fishery, January through March, 1993. Summer, 1993 imagery was also obtained for the US and Canadian West Coast and additional North Pacific seatruth positions were acquired from ship of opportunity

weather reports filed with the National Environmental Satellite, Data, and Information Service (NESDIS).

II. SHIP TRACK IDENTIFICATION -

A. AVHRR

AVHRR ship detection work centers around the identification of cloud lines associated with stack emissions from ocean-going marine vessels. Anomalous cloud lines in satellite imagery were first noted by [1]. In a later study by [2], ship tracks were observed in 3.7 μm (Channel 3) AVHRR imagery. Tracks were difficult to observe at 11 μm (Channel 4) since water is a strong absorber and there is little to distinguish a cloud contaminated with aerosols from an uncontaminated cloud. The reverse is true at 0.63 μm (Channel 1) as at this wavelength, liquid water is non-absorbing. Meanwhile, at 3.7 μm , water droplets both scatter and absorb radiation with scattering (relative to absorption) and reflectivity increasing as droplet radius decreases. High reflectivity at 3.7 μm is thus presumed to be associated with shifts to smaller droplet radii that is accompanied by increases in the number of cloud particles. Recent studies confirmed the association of small droplet size and high droplet count to ship tracks during *in situ* measurements off of the coast of southern California in 1987 [3].

Research at the Naval Post-Graduate School in Monterey has advanced considerably the understanding of the AVHRR ship track phenomena and means of detecting it. Computer algorithms have been developed that distinguish ship tracks in AVHRR imagery [4]. Recent work at the School also suggests that subtropic ship tracks are brighter, longer and wider than ship tracks formed in the Arctic. The Arctic ship tracks, however, were brighter relative to their surrounding environment than their counterparts in the subtropic [5].

B. SAR

SAR data provides high resolution images of 100 km swaths of the ocean. The high resolution available with SAR data does, however, have its drawbacks. Chief amongst these is the vast amount of SAR data downloaded from the satellite. For example, each 100x100 km SAR scene contains approximately 65 megabytes of data. Since manual attempts to visually review the SAR imagery would be time intensive and cost prohibitive, work on ship feature detection in the subject project has focused on ways to computerize SAR image analysis.

Most ship detection algorithms rely upon a thresholding technique for their success. Ships are identified when a predetermined percentage of pixels are above a threshold level for a given area or when adjacent pixels are above threshold. If two thresholds are used, pixels above the second threshold denote a ship while those above the first threshold indicate features which could be ship targets. Alternative wake detection algorithms work either from

the point of view of using an identified ship position to detect a wake or finding wake features in order to locate a vessel. The latter approach is accomplished by using the Hough Transform to detect linear fragments which are then linked to form a wake line, wake vertices and, presumably, ship position [6]. Since some 'ships' may instead be bright features on a wave crest, an alternative wake detection algorithm can be applied to questionable vessel detections. This algorithm searches in the vicinity of the 'ship' for linear features which suggest a ship wake. Finding such a feature confirms the target as a ship (Fig. 1).

III. RESULTS

A. AVHRR

During the fall 1992 Pacific whiting fisheries, a total of 28 8-bit images were acquired. Tracks or possible tracks were noted in 11 of the 28 images (39%). After determining that thermal calibration of the 8-bit imagery to a temperature range of 0 to 25 C was obscuring ship track information the study team shifted to the use of 10-bit rather than 8-bit imagery. An additional 31 10-bit images were subsequently obtained. In the 10-bit imagery, tracks were identified in only 5 images (16%, Fig.2).

The lack of ship tracks in the 10-bit imagery was puzzling until a review of the downloading process indicated that some data were lost when downloading the 10-bit imagery. The use of 10-bit data was discontinued, and the 8-bit data were recalibrated to allow for a higher temperature range in channel 3.



Fig.1. SAR image of large vessel (~1,000 feet long) and its wake in Prince William Sound south of Valdez, Alaska on June 9, 1992. Scene # 21310100



Fig. 2 Ship tracks observed in channel 3, NOAA 12 AVHRR imagery covering the Pacific Northwest coast.

To cover the 1993 fishing operations in the Bering Sea, AVHRR data were received from a ground station at Elmendorf Air Force Base near Anchorage, AK. Initial specifications called for the imagery to be navigated, calibrated, and analyzed for cloud type and percent coverage. More than 40 scenes were secured for the January 20 - 31 period.

Ship tracks (1 to 10 per scene) were noted on about one-third to one-half of the Bering Sea images. Ship tracks were only observed, however, on the un-navigated images, apparently indicating that the subtle linear ship track feature is lost when an image is rectified to a latitude/longitude map base (navigated). This creates obvious problems in trying to relate observed ship tracks to 'unfriendly' vessel positions in an operational setting and is the subject of continuing evaluation.

Our results confirm the findings of [7] that meteorological conditions play an important role in track formation and confirmation. Although the use of AVHRR data for ship track detection is not inhibited by cloud presence, its performance is influenced by the type of cloud. Stratus cloud conditions prevailed on two or three days during the late-January Bering Sea test period. It was noted that ship tracks were more prevalent in images for those days. Similar relationships between stable stratus-dominated systems and ship track occurrence were also observed during the Summer, 1993 West Coast study.

B. SAR

Two orbital passes of SAR data were acquired from the Alaska SAR Facility (ASF) to cover the Fall 1992 West Coast whiting fishery. Orbit 5855 on August 28th

provided data along the coast that included land area around the mouth of the Columbia River and some 30 km offshore while orbit 5898 on August 31st provided data beginning 40 km offshore and continuing for the full 100 km swath width offshore.

Each SAR scene was examined using the IDIMS image processing system at Ames Research Center. Preliminary examination showed no ships or ship wakes in any scene which was puzzling since the 85 foot Cape Falcon fishing vessel was reported to have been in the area covered by the Columbia River scene. Many interesting features were observed, however, particularly in the scene containing the mouth of the Columbia River including the river plume, internal waves, the surf zone, a breakwater at the river mouth, and two bright objects off the breakwater suspected to be sea buoys (Fig. 3). Computation of a 4 x 4 pixel average in the images reduced speckle, brought out still more subtle details such as swells but still did not reveal any ships or wakes.

The three scenes were converted into hard copy output by a High Resolution Film Recorder at Ames' Central Computer Facility. Upon examining the 8" x 10" prints, two ships and dark wakes behind them were observed in the southern portion of the Columbia River scene. Re-examination of the digital scenes on IDIMS revealed the ships and wakes but they were not as obvious on the display screen as in the prints.

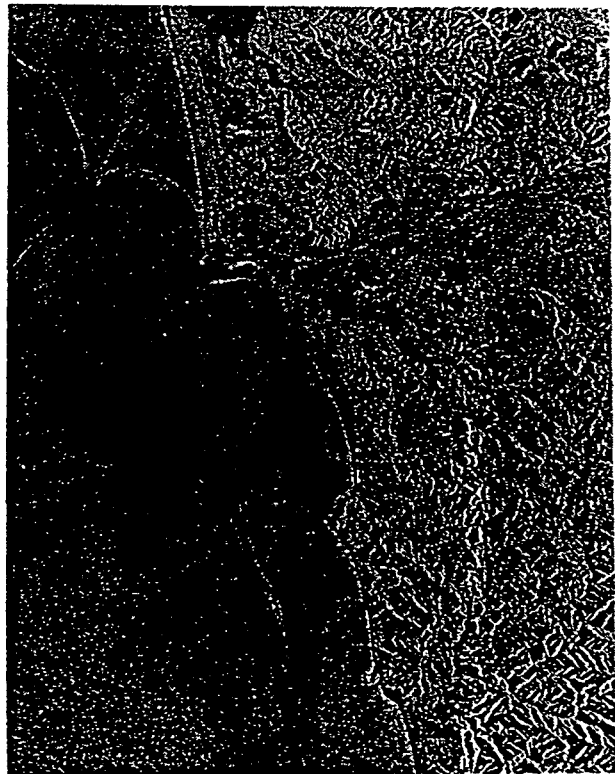


Fig. 3: SAR image from ERS-1 of the area around the mouth of the Columbia River, Oregon/Washington on August 28, 1992 (orbit 5855). Scene number 35275100.

SAR scenes were also received from the ASF covering the 1993 groundfishing operations in the Bering Sea. During this time period, twelve vessels ranging in size from 50 m to 100 meters in length had recorded their positions at NOAA 9 -12 and a portion of the ERS-1 overpass times. Examination of a scene from February 4th revealed four small, bright objects in an area where three vessels had reported their positions (Figure 4, arrows highlight two vessels). In each case, a number of contiguous pixels had saturated the sensor (i.e. the digital numbers were 255) while the background pixels were less than half those values. No wakes were observed nor was a 50 meter vessel which was reported to be approximately 20 km away. The lack of observed wakes may be due to the low trawling speed of the vessels while they were fishing.

Four other SAR scenes, each with a single vessel reported to be in it, showed contiguous, saturated pixels near reported ship positions. On the other hand a scene with two vessels reported to be in it showed none in the area, but two large vessels were observed some 70 km away indicating conditions were not completely unfavorable for ship siting. It proved to be more difficult to locate vessels in scenes with observable swells, or high sea state, because of the general brightness of the scene and because the tops of the swells were often 255. Fig. 5 depicts this problem and shows the sea around one of the Pribilof Islands with a vessel in the swells to the south of it (arrow).

The ASF has developed an algorithm to transform geographic coordinates into image coordinates and vice versa based solely on the satellite ephemeris data (TWOWAY_CEOS). The algorithm proved very useful in locating the recorded vessel positions in image coordinates. In the February 4th scene mentioned above the vessels recorded their positions only at the AVHRR overpasses so a direct comparison of searuth position at time of ERS-1 overpass and ship targets in the SAR image was not possible. However, it appeared the TWOWAY_CEOS predictions were off by only a few kilometers from the expected vessel positions calculated from vessel-provided speed and heading information. In cases with single vessels in the scene, the predictions approached kilometer accuracy. Such accuracy should be sufficient for M/E purposes due to the time lag required to receive, process and report results from SAR data, i.e. a few hours for a dedicated system.

The above experience with known fishing vessels indicated it would be appropriate and very useful operationally to concentrate on the use of thresholding technique (including local filtering to reduce speckle) to locate the vessels. Once a target is identified by thresholding, it would be useful to search the local area around it for any associated wake pattern. This approach would limit the application of the computationally intensive wake recognition routine to those targets already identified by thresholding.

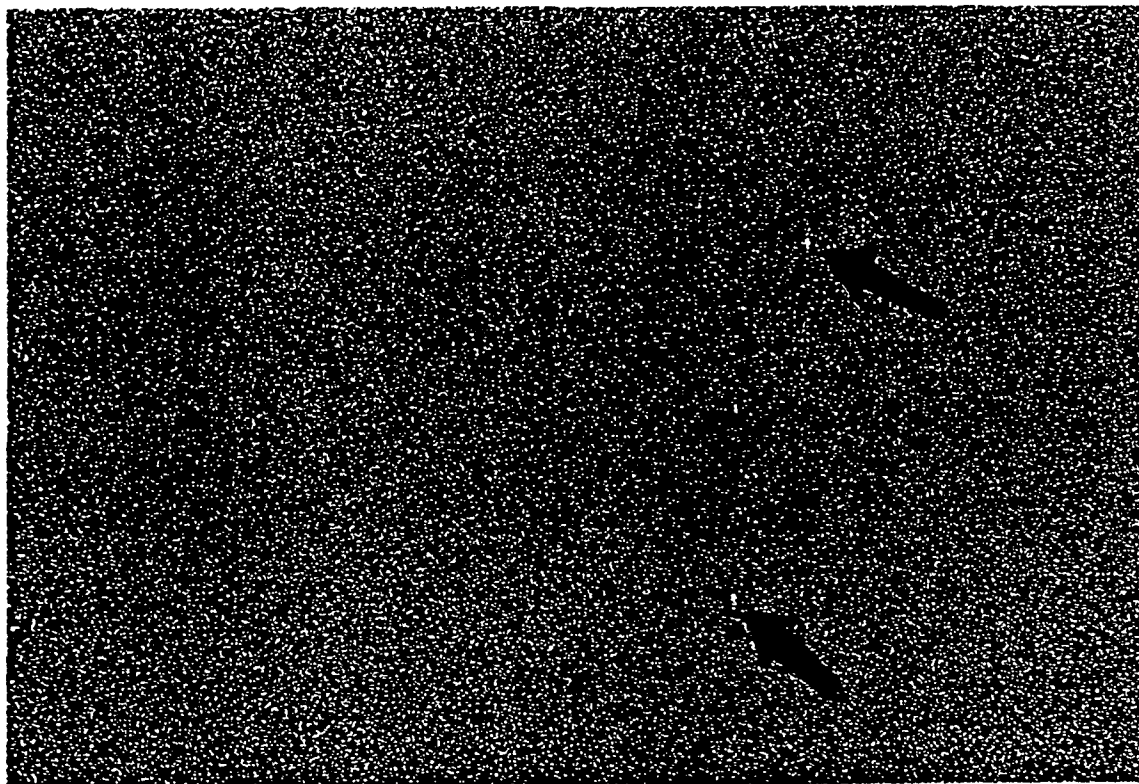


Fig. 4: Searuth vessels identified in a Bering Sea SAR image.

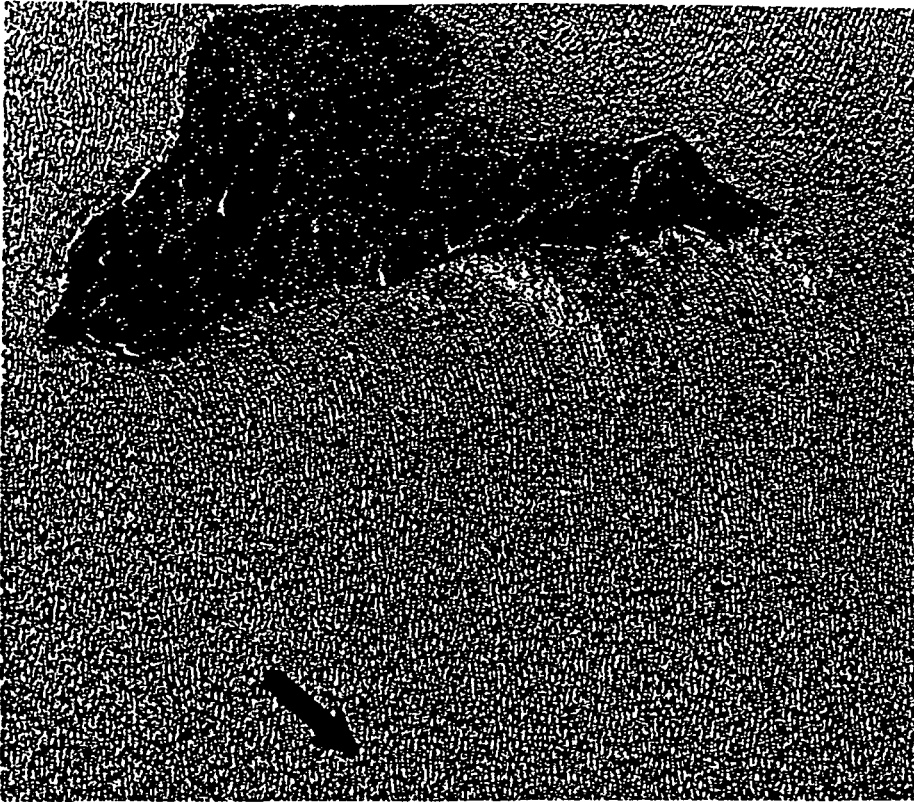


Fig.5. Seatruth vessel in ocean swells to the south of the Saint Paul, Pribilof Islands

IV. COMMERCIAL OPPORTUNITIES

With the pending launch of Canada's RADARSAT in 1995, commercial opportunities for vessel detection should be readily available. RADARSAT is equipped with a C-band (5.6 cm wavelength) HH polarized SAR. Unlike the ERS-1 SAR which has a fixed incidence angle of 23° (nominal), RADARSAT will have the ability to acquire data in multiple beam modes over a range of incidence angles (Fig. 6).

The Standard Mode Beam, with a scene size of 100 x 100 km, will have approximately 25 m resolution, 12.5 m pixel spacing, and incidence angles that range from 20° (near range) to 49° (far range). Other beam modes (ScanSAR and Wide Swath), encompassing a similar range of incidence angles, will offer an increased scene size at a reduced resolution. In addition, a Fine Beam Mode (10 m resolution), with variable incidence angles between 37° and 48° will compliment the other modes. The Standard Beam and Fine Beam Modes will likely be the

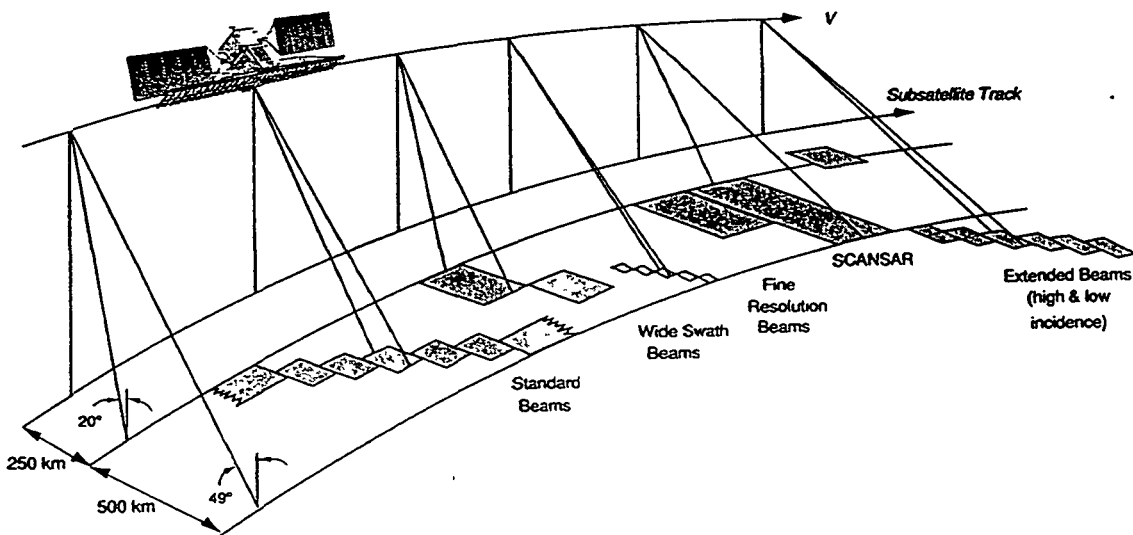


Fig.6. RADARSAT beam modes, resolutions and incidence angles

most effective for vessel detection, since most fishing boats are typically under 150 m in length.

In addition to RADARSAT's beam modes, the HH polarization and variable incidence angles should increase the probability of vessel detection. Compared to VV polarization, HH polarization is less sensitive to surface roughness, which should allow better discrimination between a noisy background (wind roughened water) and the vessel [8]. However, as the sea surface roughens with higher wind speeds, discrimination (based on imagery with HH or VV polarization) will become increasingly difficult. Independent of the SAR polarization, radiation incident on a surface will tend toward specular reflection as the incidence angle increases. At large incidence angles, the probability of vessel detection will increase since most of the radiation is reflected away from the SAR by the surrounding water, but strongly backscattered when the radiation hits a vessel [9].

V. CONCLUSION

Attention to the limitations of conventional means of monitoring and enforcing fishing regulations is increasing. New approaches which can address problems of illegal fishing and overfishing must be developed. In this regard, the United Nations Food and Agricultural Organization has recently released a set of Standards and Guidelines covering the use of remote sensing systems for the monitoring of fishing operations.

Active transponder-based vessel monitoring systems will be an important component of future approaches to fisheries monitoring and enforcement. Regulations requiring the presence of such transponders on all fishing vessels will permit identification of 'friendly' vessels in any region of interest. With this tool, fisheries enforcement officials will be able to monitor the position of all vessels that agree to carry the transponders and not disrupt their unique signatures.

Unfortunately, active transponder-based systems do not address the fisheries M/E problems associated with 'unfriendly' vessels who choose not to 'play by the rules'. As such, passive systems are needed to identify and alert management officials to the position of these vessels.

We anticipate that meaningful fisheries M/E systems will in the future integrate conventional aircraft and vessel monitoring platforms, active transponder-based systems, and passive surveillance. It is encouraging to see work progressing on the technical fronts in each of these areas and to observe the recognition by policy makers of the importance of each. With the launch of RadarSat, the growth of private sector high resolution multispectral instruments, the continuing availability of AVHRR data, and satellites to be launched in conjunction with EOS, opportunities to obtain data associated with passive vessel monitoring will likely expand in the next five years. Use of these data will help move the global community towards effective management and monitoring of our ocean ecosystems.

ACKNOWLEDGMENTS

AVHRR imagery: Satellite Oceanography and Meteorological Lab. Dept. of Oceanography, University of British Columbia, Vancouver, Canada

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**Appendix 5: Application of space-based radar systems to fisheries
monitoring, control and surveillance**

APPLICATION OF SPACE-BASED RADAR SYSTEMS TO
FISHERIES MONITORING, CONTROL AND SURVEILLANCE*

Mark H. Freeberg
Natural Resources Consultants, Inc.
4055 21st Avenue West, Suite 100
Seattle, WA 98199
markfreeb@aol.com

Robert C. Wrigley
MS 242-4
NASA Ames Research Center
Moffet Field, CA 94035

Karma Dunlop
Natural Resources Consultants, Inc
4055 21st Avenue West, Suite 100
Seattle, WA 98199
nrc@wln.com

Donald V. Sullivan
Johnson Controls World Services
Ames Research Center
Moffet Field, CA 94035

Gordon Staples
RADARSAT International
200-3851 Shell Road
Richmond, BC
Canada V6X 2W2

ABSTRACT

The use of space-based radar to augment conventional approaches to fisheries monitoring, control, and surveillance (MCS) was investigated. Using ERS-1 imagery obtained through the Alaska SAR Facility, algorithms were developed to detect vessels in the Synthetic Aperture Radar (SAR) data. Vessel detection performance across a range of sea conditions, vessel types, and vessel sizes was evaluated by comparing known vessel locations provided by the Canadian Coast Guard's Ucluelet tracking station. Vessels included foreign fishing trawlers, inshore fishing vessels, freighters, tankers, tugs, military and government research vessels. The nature of emerging fisheries MCS programs is presented in conjunction with space-based radar's responsiveness to these conditions. The paper closes with a discussion of the steps that can be taken to ameliorate those characteristics of space-based radar that most inhibit its incorporation into the fisheries MCS paradigm of the next century.

1.0 INTRODUCTION

Effective fisheries monitoring in the next century will emerge from the integration of conventional (ie. vessel and aircraft platforms), transponder-based, and space-based radar surveillance approaches. In the 20th century, fisheries monitoring, control and surveillance (MCS) has relied most heavily on conventional platforms. Given the deteriorating condition of many of the world's fish stocks, the rate of increase in fishing power and technological capacity of the world's fishing fleets, and the emergence of severe budget and personnel restrictions in the last decade, conventional MCS approaches are now stretched to, if not well beyond, their limits.

Considerable attention has been paid to transponder-based, MCS systems in the last five to seven years as a means of filling in many of the gaps left by extant conventional approaches. Transponders permit the detection of illegal, closed area fishing by equipped vessels, offer improvements in vessel safety as a result of the accurate position information that they make available, and provide a basis for more secure ship-to-shore communications. Recent work has demonstrated that knowledge of vessel operational characteristics and the careful study of vessel position "footprints" provided through the transponder vessel monitoring systems can distinguish between vessel transit, active fishing, and repositioning behaviors (NMFS, 1993). Some of the systems now in place include those in place in the Western Pacific (DOC, 1994a), Australia (Marshall, 1995), and New Zealand and under evaluation by the European Economic Community (European Commission, 1994), Taiwan (Anon, 1995) and the Maldives.

Transponder-based monitoring methodologies cannot, of course, address the MCS of vessels that are not equipped with transponders. Such boats slip through the surveillance net and go undetected. Authorized and legally operating vessels that are so missed are perhaps of little concern. If, however, illegal or pirate activities are the intent of the

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undetected vessels, serious resource consequences may result. Because space-based radar surveillance systems act independently of vessel-resident equipment, supplementation of conventional and transponder-based MCS systems with space-based radar approaches could address existing surveillance gaps.

Space-based radar fisheries surveillance technique development has lagged that occurring in the other areas. The following paper presents the results of an analysis of the effectiveness of space-based radar data as a monitoring tool. More specifically, the detection of vessels in ERS-1 radar data is compared to seatruth data specifying the exact location, bearing, speed and type of vessels known to be at-sea at time of ERS-1 overpass. Vessel detection through manual and automated, user-independent approaches using the *OmniVision*® vessel detection system is also investigated. Lastly, the operational realities confronting the integration of space-based radar monitoring approaches into a cost-effective MCS system is discussed.

2.0 METHODS

2.1 STUDY AREA AND SENSOR DESCRIPTIONS

Seatruth data and SAR imagery focussed on a study site off of the west coast of Vancouver Island. This site was chosen because of the high amount and variability of vessel traffic passing into or out of the Strait of Juan de Fuca, the presence of inshore and offshore fishing grounds in the region, and the availability of vessel position data from the Canadian Coast Guard tracking station at Ucluelet, Vancouver Island, British Columbia. The majority of vessels trafficking this area are transiting southeast into or northwest out of the Strait of Juan de Fuca, heading due west out to sea or northward up the British Columbia coast. Occasionally, vessels moved along a curved path out of the Strait, around Cape Flattery and down the coast (or northeast into the Strait around Cape Flattery). Figure 1 depicts the location of the Mt. Ozzard shorebased radar sensor used to track this vessel traffic by the Canadian Coast Guard. The sensor is an 'S' band radar (2860 MHz to 2900 MHz) that provides coverage out to a seaward distance of 60 nautical miles (nm) from Mt. Ozzard.

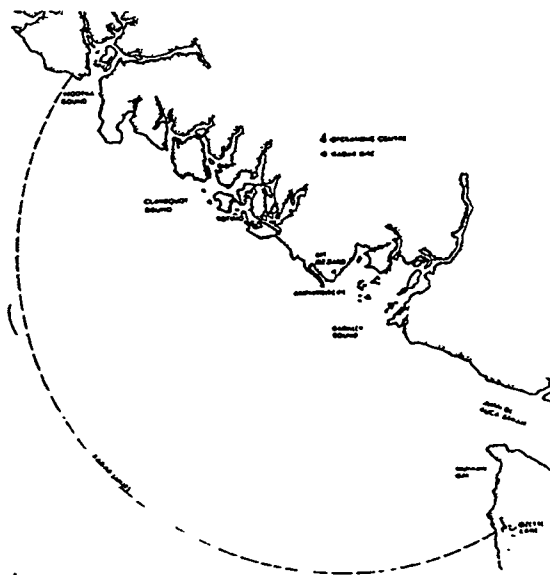


Figure 1: Location of Canadian Coast Guard Vessel Tracking Station at Mt. Ozzard, Ucluelet, Vancouver Island, British Columbia

Space-based radar was obtained from the European Remote Sensing satellite ERS-1 through the Alaska Synthetic Aperture Radar (SAR) Facility. ERS-1 is a C-band (5.7 cm), VV-polarized sensor that was launched in 1991. Other characteristics of the ERS-1 and RadarSat space-based radar systems are summarized in Table 1. Figure 2 is a graphic explaining nomenclature for imaging radar geometry.

Table 1: Characteristics of ERS-1 and Radarsat SAR Systems.
Source: Lillesand and Kiefer, 1994

Characteristic	ERS-1	Radarsat
Launch	7/17/91	1995
Altitude (km)	785	798
Period of orbit (min)	101	101
Orbit inclination	98.5°	98.6°
Orbits per day	14	14
Distance between orbits	25°	25°
Orbit repeat period (days)	35	24
Look angle	23°	20° to 59°
Swath width (km)	100 (right)	45 to 500
Revisit period (days)	35	3+
Wavelength (cm)	5.7 (C band)	5.6 (C band)
Polarization	W	HH
Resolution (m)	30	10 to 100

*Repeat cycle depends on operational mode but is generally 35 days.

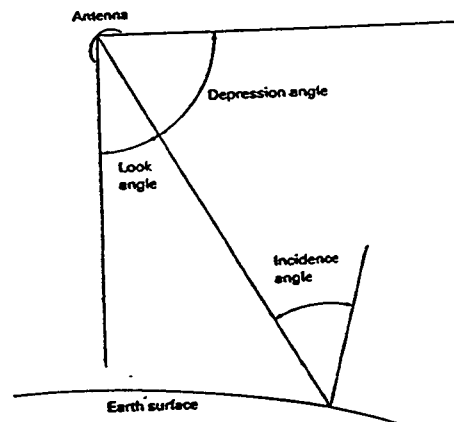


Figure 2: Nomenclature for Imaging Radar Geometry. Source: Lillesand and Kiefer, 1994.

2.2 SAR DATA SELECTION

The Alaska SAR Facility's archive of SAR imagery was searched for candidate scenes of the Ucluelet area in 1994 using their geographic search capability. The search area corresponded closely to the range of the Ucluelet radar (see Figure 1). Any 100 km by 100 km SAR scene that intersected the search area was identified. Such scenes with more than 10 percent of their area intersecting the search area were plotted using the Alaska SAR Facility's routines to show the actual area of coverage of the scene on a map. These plots were then used in conjunction with knowledge of vessel positions at time of overpass to select the subset of images for full analysis.

2.3 SEATRUTH DATA ACQUISITION AND PROCESSING

Vessel traffic along the west coast of Vancouver Island is archived by the Mt. Ozard/Ucluelet radar station on an hourly basis. The Ucluelet vessel database includes 24-hour military time, vessel identification including vessel class, and vessel latitude and longitude position in degrees/minutes/seconds at each hour.

Acquired Ucluelet tabular radar data was entered into a Microsoft Excel spreadsheet. Latitude and longitude positions were converted from degrees/minutes/seconds to decimal degrees for easier manipulation and to be consistent with map template units and *Omnivision*® datasets. Once vessel positions had been converted to decimal degrees, the heading and speed for each vessel was calculated based on two known coordinates. Since the satellite pass times did not coincide exactly with the hourly Mt. Ozzard vessel database records, vessel positions at time of satellite pass needed to be projected.

The above vessel projection approach operates on the premise that the "projected" vessel is travelling in a straight line. This is generally true for the relatively short distances travelled by the subject vessels compared to the 100 km x 100 km SAR scene and the curvature of the earth and especially so for large ocean-going vessels such as the oil tankers and freighters operating in well-specified shipping lanes off of the coast. However, these vessels change their course dramatically as they navigate into the Strait of Juan de Fuca. Moreover, other vessels such as scientific research vessels, government regulatory vessels and fishing vessels operate off the coast of Vancouver Island and change their course and speed frequently. Fishing vessels also move at varying speeds depending on their activity. They can be travelling as much as 10-12 knots if steaming to fishing grounds or to the beginning of a tow. When towing trawl nets, fishing vessels typically travel at 2-4 knots, and become almost stationary when retrieving the net. Recognizing these operational characteristics, vessel projections for fishing and other erratically moving vessels were treated with great caution by the project team. The fishing vessel seatruth data did, however, permit determination of the general location and size of each subject fishing fleet and the size of specific fishing vessels, information which was adequate to address study objectives relevant to this vessel class.

Using the above approach, vessel position estimates at time of ERS-1 overpass were determined and plotted as point data over a map template of Vancouver Island and the candidate satellite pass footprints. Candidate ERS-1 footprints with multiple vessel hits were selected for further analysis. A total of fourteen such scenes were ordered from the Alaska SAR Facility on computer compatible tapes. Seven of these scenes overlapped the Mt. Ozzard radar mask significantly and were used as the basis for the bulk of image analysis. To preserve objectivity, image analysts were not shown the seatruth locations of vessels in the Mt. Ozzard database prior to image processing and "vessel" identification in the SAR imagery.

2.4 ERS-1 SYNTHETIC APERTURE RADAR PROCESSING AND ANALYSIS

The *OmniVision*[®] vessel detection software system developed by Ocean and Coastal Environmental Sensing, Inc. (OCENS) and NASA was used to process SAR imagery. *OmniVision*[®] consists of specialized display and analysis modules and support routines. The system converts raw SAR data into modern, portable file formats, all running under X-Windows on a high performance workstation, currently a Hewlett-Packard Model 9000/720, with 64 Megabytes of RAM and 2.4 Gigabytes of disk storage.

A 1280 x 1024 pixel display is configured with two working areas, with system functions appearing in pop-up menus along the leftmost 256 pixels, leaving the rightmost 1024x1024 pixels for imagery. A frame buffer contains a 2048 x 2048 array for temporary storage of image data which is roamed by the 1024 x 1024 image display area. High resolution ERS-1 SAR imagery fills an 8192 x 8192 array with 8-bit pixels so *OmniVision*[®] must subsample the imagery in order to display areas larger than the frame buffer (2048x2048). An additional feature of the *OmniVision*[®] system is the ability to write user defined screen areas to disk as standard format files to be imported into other analysis or viewing packages.

Visual analysis of a given scene begins with an image subsampled by a factor of four (every sixteenth pixel is sampled) to fit the entire scene in the frame buffer. Since ships tend to saturate ERS-1 SAR pixels, a convenient visual analysis tool is to pseudocolor the saturated pixels (level 255) in a vibrant color (i.e. red). Large vessels over 200-300 meters are often apparent as saturated, thin shapes even at a subsampling of four. *OmniVision*[®]'s geolocation algorithm incorporates information extracted from both the window file header and control point files to convert row and column from the 8192 x 8192 array into latitude and longitude so simple point and click motions can reveal the vessel's position. Scanning the entire subsampled image proceeds by roaming the frame buffer and noting any candidate vessel's position. Higher resolution images, using either a subsampling of two (every fourth pixel) or no subsampling (every pixel is inspected), require examining multiple images for each SAR scene: four images for a subsampling of two and sixteen images for full resolution. Higher resolution images reveal smaller vessels and more detail of the larger vessels as well as better geolocation, but the analysis proceeds in the same way by roaming the frame buffer and noting candidate vessel positions. At full resolution an estimate of the number and arrangement of the saturated pixels obtained by zooming in on the ship is a useful estimate of the size of the vessel (i.e. 10 x 3 pixels would indicate a vessel size of approximately 125 meters long by 38 meters wide--ERS-1 pixel spacing is 12.5 m). If the vessel appears elongated, its heading can be estimated with a 180° uncertainty. Wakes appear only rarely in SAR imagery, but, when they do, the 180° uncertainty in heading can be resolved.

Unassisted, automated ship detection and geolocation by *OmniVision*® proceeds similarly to the manual procedure. Analysis is at full resolution, so 16, 2048 x 2048 scenes are analyzed. Land areas are removed (masked) using a variety of techniques and unexpected ocean features are flagged for later interpretation by the system operator. Potential targets are examined through the application of a succession of linear two dimensional convolution templates, and, where applicable, further analysis based on a version of the Hough Transform is conducted (Hough 1962). The Hough transform linearly remaps geometric patterns into their parametric forms, allowing the extraction of heading information from wake data when water is visible.

3.0 RESULTS

3.1 RADAR IMAGE PROCESSING AND ANALYSIS

The fourteen scenes selected off the Ucluelet surface radar station during the April- July, 1994 period were all subjected to visual analysis on the *OmniVision*® system as described above. Land areas were simple to discriminate visually and exclude from the analysis. Various kinds of wind and wave effects were apparent almost everywhere. Typically, swells were more apparent on the near-range side of the images (the side closest to the satellite), most likely due to the stronger illumination there, and often caused saturated pixels along their crests. Internal waves and colder water leads were more subtle but extensive as well. The rare wakes observed were most likely to be dark turbulent wakes which could be confused with the colder water leads which were also dark. For the six SAR scenes included in this study, only two wakes were observed unambiguously out of 95 candidate vessels. Another nine wakes were considered possibles. On a couple of occasions dark, turbulent wakes behind vessels were contorted as if the vessel were turning back and forth.

Vessel detection passed through two stages. Within the first stage, clusters of spectrally saturated (DN at 255) pixels were identified in the image. Clusters were defined as any target 3 or more pixels long and 2 or more pixels wide. Once clusters were identified, seastate conditions were assessed. Smaller clusters were accepted as vessels under low sea state conditions but not under high sea state conditions. At high local seastate conditions, even large clumps (eg. 18 x 4 pixels) could be classified as questionable vessels.

Table 2 lists the images by date of acquisition and gives the number of vessels detected at full resolution, subsampling by two and subsampling by four. Questionable detections are generally those associated with higher seastate conditions

Table 2: Target Detection in ERS-1 SAR Imagery of Coastal Vancouver Island.

Image Date	Questionable	Total Targets	Wave Height (ft)
	"Vessel" Targets		
<i>14-Apr South</i>	2	10	2
14-Apr North	2	5	2
1-May	3	9	2
4-May	3	5	2
21-May	3	6	1
24-May	1	3	1
7-Jun	3	9	1
10-Jun	7	23	1
27-Jun	4	6	1
30-Jun North	7	40	1
30-Jun South	12	31	1
1-Jul	8	20	1
20-Jul	1	5	2
21-Jul	2	22	1
Total	58	194	
Total Cross-checked to Seatruth Data	38	146	

Rows in italics refer to those images cross-checked against seatruth data.

3.2 COMPARISON TO SEATRUTH INFORMATION

Six ERS-1 images that had a significant degree of overlap with the Mt. Ozzard station mask (and thus offered the highest level of confidence for seatruth position projections) were evaluated against groundtruth data acquired from the Canadian Coast Guard, Ucluelet Station, Vancouver Island. The days evaluated were April 14 at 1215 PDT, June 10 at 1114 PDT, June 30 (2 scenes) at 1111 PDT, July 1, and July 21 at 2228 PDT. Weather on all of the above days was mild at the time of the satellite passes. Winds at Ucluelet ranged from 11 kts on April 14 to dead calm on July 21, while wave height varied from 2 ft to less than 1 ft. The foreign fishing fleet was operating in the area five out of the six days—no foreign fishing activity took place on April 14.

Seatruth data were imported into TNTmips, a mapping and image processing software tool that allowed the layering of projected groundtruth vessel positions and target "vessel" coordinates extracted from the radar imagery. Both datasets were imported as vector point data with attached attribute data. Attribute data associated with the Mt. Ozzard data points included vessel identification, vessel type and time of siting while attributes linked to the radar image coordinates included pixel size and original column and row position in the raw satellite imagery. Plotting of each corresponding pair of datasets over a map template permitted an assessment of the space-based radar imagery's ability to detect vessels projected to be at a given point at a certain time.

3.2.1 Fishing Vessels

Under certain fishing conditions, the Ucluelet radar station has difficulty accurately tracking fishing vessels operating on the West Vancouver Island fishing grounds. When the fleet becomes excessively commingled or vessel behaviors particularly erratic (eg. during the summer hake fishery), radar operators "beach" the vessel positions and ignore Mt. Ozzard radar reports of their position. These tracking difficulties and beachings precluded the acquisition by the project team of accurate position reports for these fishing vessels. What was known, however, was the location of the fishing grounds, the number and size of foreign fishing vessels expected to be operating on those grounds, and the size of domestic fishing vessels likely to be on the grounds on each day of ERS-1 overpass. This information, when compared to the actual number and size of vessels observed on the fishing grounds by the ERS-1 sensor, provided a coarse assessment of the ability of the space-based radar to detect fishing vessels.

A total of 49 foreign fishing vessel targets were operating on the fishing grounds over the course of the five June/July ERS-1 images analyzed in this study (Table 3). Foreign fishing vessels operating in the West Vancouver Island hake fishery in June and July are factory trawler operations. Because of the type of fishing in which they are involved and the great distance from their home ports at which they operate, these foreign, "distant water" trawlers tend to be large (>50 to 60 m length overall (LOA)). Consequently, distant water fishing vessels should, at a minimum, saturate four pixels in the long direction and three pixels in the short direction. The number of 4x3 or larger pixels observed in the SAR imagery and on the West Vancouver Island fishing grounds totalled 42. Although the clustering of these vessels is tight, the space-based radar was still able to discriminate individual targets, something the Mt. Ozzard station could not consistently accomplish. From these results, we estimate that the SAR imagery was discriminating 86% of the foreign fishing vessels actually on the grounds.

Some fishing vessels traffic through the West Vancouver Island area and are tracked by the Ucluelet station on their way to or from fishing grounds in Alaska. These fishing vessels are designated as Tracked Other Fishing vessels in Table 3. 100% (6 of 6) of these vessels were found in the SAR imagery.

Table 3: Number of Fishing Vessels Expected To Be and Actually Found in ERS-1 SAR Imagery.

Image Date	Vessel Class	Number Expected	Number Found	% Found
14-Apr	All vessels on April 14 were non-fishing vessels			
10-Jun	Foreign Fishing	5	3	
	Tracked Other Fishing	2	2	
				71%
30-Jun	North Foreign Fishing	12	11	
	Tracked Other Fishing	1	1	
				92%
30-Jun	South Foreign Fishing	7	7	
	Tracked Other Fishing	0	0	
				100%
1-Jul	Foreign Fishing	12	10	
	Tracked Other Fishing	0	0	
				83%
21-Jul	Foreign Fishing	13	11	
	Tracked Other Fishing	3	3	
				88%
Total: Foreign Fishing		49	42	86%
Total: Foreign and Tracked Other Fishing		55	48	87%

Canadian fishing vessels also participate in the West Vancouver Island summer hake fishery. The majority of these vessels are catcher boats which, after harvesting the fish, return to port and offload their catch at shorebased processing plants. Because these vessels are designed for shorter trips and do not conduct on-board processing they tend to be smaller (≤ 50 m) than the typical foreign factory trawler. Such a size should saturate no more than 3 pixels in the long direction and 2 pixels in the short direction. A total of up to 50 targets matched these saturation criteria and were observed on the fishing grounds in the five summer SAR scenes (Table 4). Unfortunately, these vessels are not tracked by the Ucluelet station so there was no seartruth data against which this assessment could be checked. Nevertheless, the spatio-temporal location and size of these vessels suggests that they are likely participants in the summer offshore fishery.

Table 4: Untracked "Fishing Vessels" Found on the Fishing Grounds in ERS-1 SAR Imagery.

Image Date	Vessel Class	Number Expected	Number Found
14-Apr	All vessels on April 14 were non-fishing vessels		
10-Jun	Untracked Other Fishing	0	12
30-Jun	North Untracked Other Fishing	0	19
30-Jun	South Untracked Other Fishing	0	16
1-Jul	Untracked Other Fishing	0	0
21-Jul	Untracked Other Fishing	0	3
Total:			50

3.2.2 Other Vessels

Exclusive of the fishing fleet, twenty-three vessels were projected to be detected within the selected ERS-1 images (Table 5). Of these twenty-three vessels, sixteen were detected in the ERS-1 imagery (70%). One vessel class, bulk carriers, accounted for six of the seven "misses". As these boats are large and move in a consistent path not unlike other vessels observed in the imagery, a basis for their being missed is not readily apparent. Exclusion of the bulk carrier class from the database increases detection efficiency to 93% (14 out of 15).

Table 5: Number of Non-Fishing Vessels Expected To Be and Actually Found In ERS-1 SAR Imagery, By Image Date and Vessel Class

Image Date	Vessel Class	Number Expected	Number Found	% Found
14-Apr	Tug w/barge	1	1	
	Roll-On/Roll-Off	1	1	
	Tanker	1	1	
	Container Freighter	2	2	
	Vehicle Carrier	1	0	
	Bulk Carrier	1	1	
				86%
10-Jun	Bulk Carrier	2	0	
	Tanker	2	2	
	Container Freighter	1	1	
				60%
30-Jun North	Bulk Carrier	1	0	
	Scientific research	1	1	
	Roll-On/Roll-Off	1	1	
	Government	1	1	
	General cargo	1	1	
				80%
30-Jun South	Tug w/barge	1	1	
	Bulk Carrier	2	0	
				33%
1-Jul	All vessels on July 1 imagery were fishing vessels			
21-Jul	Bulk Carrier	2	1	
	Container Freighter	1	1	
				67%
Total: All Days, All Vessel Classes		23	16	70%
Total: All Days, All Non-Bulk Carrier Vessel Classes		15	14	93%

4.0 DISCUSSION

Results suggest that space-based SAR data provide a good means of augmenting conventional and transponder-based MCS systems. A total of 78 vessels (fishing and other) were expected to be found in the radar imagery. 64 of these vessels (82%) were found in the ERS-1 data using the *OmniVision*[®] vessel detection system. A total of 11 vessel classes other than fishing vessels were encountered in the seartruth data. Table 5 summarizes the detection of vessels in each of these classes by the SAR data. Performance was worst for the bulk carrier class with only two of the eight vessels (25%) in this class detected in the radar imagery. This is perplexing since these vessels are large, with transit behaviors not unlike those of other vessel classes for which detection was good, and sometimes in the vicinity of similar vessels that were detected. We are currently exploring whether discrepancies in the seartruth data could account for these misses.

The ability of the radar data to discern fishing vessels was extremely encouraging. The nature of fishing operations off of coastal Vancouver Island, indeed in most fishing operations worldwide, is one of transiting, fishing, retrieving, and repositioning. When a group of commingled fishing boats exhibit this behavior, individual vessels become difficult to track with high look angle (low depression angle) radar. This is because one vessel can be confused with that of another as they cross and re-cross their respective fishing paths. This trait becomes so problematic on some of the fishing grounds off of Vancouver Island that shorebased radar reports of the position of actively fishing vessels are ignored by radar operators. In general, the Mt. Ozzard radar is unable to track and project vessel positions for fishing vessels during times of intensive fishing when large number of boats operate in a small area.

It does not appear that the space-based ERS-1 radar data is confused by such fishing behavior. 87% of fishing vessels known to be in the imagery were detected in the space-based radar data (Table 3). This performance includes the operations of the foreign factory fishing trawlers that operate in a tight cluster off coastal Vancouver Island. Operationally, this performance is important. Although it would appear that fishermen on-board vessels with transponders would have strong incentives to report the illegal operations if they know they are not similarly equipped with transponders, they may not. In the face of increasing limitations on license number and yet strong demand for high value fish, crustaceans, and cephalopods, it is not unreasonable to expect some fleets authorized for

x number of transponder-equipped vessels to actually fish in an area with y number of vessels, most with transponders but some without. Since these areas are often remote or close to jurisdictional boundaries, the odds of detection of this strategy by random conventional searches may be low, especially since authorities "expect" all the boats in the area to have transponders on them. Space-based radar data appears capable of addressing this scenario because it can discriminate the full complement of vessels in an area. Illegal vessels without transponders could not "hide" amongst other fishing vessels carrying transponders or under cover of non-fishing vessels in the vicinity of the grounds.

On each of the days where radar imagery overlapped the radar mask of the Ucluelet station, more vessels were found in the ERS-1 imagery than were actually logged in the vessel position database. After exclusion from the radar imagery of questionable vessel targets, detected vessel numbers more closely matched numbers expected based on the seatruth data. This brings up an important question: Is the space-based ERS-1 radar detecting vessels that were either unobserved by the shorebased radar or ignored by the radar operators or is it easily confused by seastate conditions and consequently producing bogus target information?

Although a definitive answer cannot be provided to this question at this time, ancillary vessel count data collected by coastal observers suggests that the ERS-1 data is indeed identifying more real targets than tracked by the shoreside system. The largest discrepancy between total, solid, and questionable vessel hits occurred on June 10 when seven out of a total of 23 targets were considered questionable. The June 10 SAR pass occurred at 11:14 AM local time, just three hours after a fishery opening in which 78 small fishing vessels were counted by coastal observers. Although most of the fleet would have left the grounds by mid- to late-morning, it is not unreasonable to expect that some remained and were detectable in the SAR imagery. This reasoning is supported by the fact that sea conditions on June 10 were relatively calm (5 knot winds and 1 foot wave heights) and that most of the questionable "vessels" represented small targets and were inshore.

Clear insights into the effect of environmental conditions on system performance were not obtained from these data. This is largely due to the fact that conditions were remarkably consistent across the image dates. Wave heights never exceeded 2 feet and wind speeds were 12 knots or less on all days. On the four days with 2 foot waves, 11 of the 33 (33%) detected vessels were classified as questionable. This is not substantially different than the 32% (45 of 147) figure associated with those days with 1 foot wave heights. July 21, a day with dead calm conditions in the study area, did, however, have the lowest ratio of questionable to total hits (2 out of 22, 9%).

The absence of wakes in the imagery is noteworthy. Several authors cite the relevance of wake detection to ship detection (Vesecky et al., 1982, Shemdin, 1990, Griffin et al., 1992). Such a paradigm applied to the ERS-1 imagery reviewed in this study would be an ineffective tool for ship detection. This is particularly true for fishing MCS systems. Most fishing vessels actively fish at very low speeds (trawling) and in some cases may operate from fixed (crabbing, purse seining) or drifting (gillnets) positions. Only during periods of transit could they be expected to consistently produce wakes and, as long as fishing gear are not in the water, such transits may be considered acceptable, legal behavior. Consequently, space-based radar monitoring components of an effective fisheries MCS system must focus on ship, rather than wake, detection. Wake detection would provide bonus information about vessel direction and speed but would not be relied upon for vessel location.

Given the near-real time nature of a meaningful MCS system and the large size of most space-based radar images, automated image evaluation and vessel detection is an attractive goal under certain operational conditions. Given seastate variability and the economic costs associated with a vessel or plane sortie to a suspected violator, however, it is doubtful that any system, even an expert one, would be allowed to carry the analysis from point of image acquisition to an enforcement action without some level of operator involvement. A more likely scenario is one in which an automated system would inventory the entire image, identify those targets that could be vessels, and point the system operator to these targets so that verification or rejection of the targets as vessels could be rapidly accomplished.

It is the latter scenario that was tested within this study by comparing *OmniVision*®'s automated detection performance of an image frame to the visual inspection of the same frame by a system operator. In automated mode, *OmniVision*® detected 83% (10 of 12) of the vessels detected visually by the system operator for this frame. These results suggest that the automated mode is capable of augmenting the vessel detection process.

5.0 OPERATIONAL CONSIDERATIONS

5.1 EFFICACY OF OTHER MCS APPROACHES

Undoubtedly, conventional approaches will always have an MCS role. With the development and implementation of transponder-based and space-based radar MCS technologies, this role will likely shift from that of active, broad-area surveillance to directed response within local areas or to specific targets of interest. Such a shift would permit more efficient use of human and technological resource limitations associated with the fiscal belt tightening that is likely to continue into the next century. In fact, would it be surprising if these budgetary realities led to MCS programs self-funded through vessel fines and forfeitures?

Transponder-based systems will carry increasing amounts of the MCS load in the next century. Their use around the world to-date has led to higher levels of compliance with quota restrictions, permitted the detection of illegal fishing actions, enhanced vessel safety, and improved ship-to-shore communications (Marshall, 1995). The on-vessel equipment is small and relatively unobtrusive and, so far, system costs have been borne by the regulatory authority and not the individual vessel owner. To date, they are the most cost-effective and least burdensome system of fishery MCS available.

Although many applications of transponder-based MCS systems have been experimental or voluntary, more programs will become mandatory in the future. Transponder installation will become a *de facto* condition for licensing or quota use. Standardization of the transponder equipment and software would contribute to the effectiveness of the tool as an international MCS tool. In 1994, the US NMFS released system performance specifications that are to be applied within any fishery determined to have a need for a vessel monitoring system (DOC, 1994b).

The DOC's transponder-based system specifications serve as a reasonable set of criteria for space-based radar MCS system design. Unless we witness the emergence of stealth fishing vessels in the next century, space-based radar MCS systems are tamperproof. Although not blocked by clouds, high winds and sea conditions might impede vessel detection by space-based radar systems. Consequently, space-based radar systems are largely, but not completely, immune to weather conditions, perhaps not unlike transponder-based systems disrupted by storms or electromagnetic interference. Position accuracies for space-based radar systems like RadarSat are on the order of tens of meters for coastal imagery but deteriorate in the open ocean to 1 km (because of the lack of ground control points for georeferencing). The coastal accuracies are clearly within the 400 meter specification for acceptable transponder-based approaches. Although the open ocean accuracies do not meet the NMFS criteria, they are accurate enough so that if identified targets are without transponders, conventional overflights or patrols can be sorted to a very discrete locale for closer inspection. Space-based radar MCS systems have the capacity to delineate vessel location, size, speed, bearing, and date/time. By themselves they do not yet have the capacity to determine vessel identity. Efforts to explore the uniqueness of certain vessel or vessel class radar signatures would be an important contribution to a holistic vessel MCS paradigm. The existing fleet of space-based radar MCS sensors also cannot provide continuous vessel positions. Position reports are instead a function of satellite overpass times. Lastly, shoreside processing software associated with space-based MCS systems can readily meet the transponder-based system software specifications designated by the DOC/NMFS. In fact, the *OmniVision*® software package already provides these features.

5.2 SPACE-BASED FISHERIES MCS CONSIDERATIONS

Results of this study and the comparison to existing NMFS standards for transponder-based MCS systems suggest that space-based radar approaches can play a role in improving the management and monitoring of our global fisheries resources. This role would be further enhanced by dealing with the three of the most troubling characteristics of space-based approaches: data delivery, data coverage, and data cost.

5.2.1 Data Delivery Characteristics

From the point-of-view of an operational vessel MCS system, old data is useless data. This is one of the beauties of transponder-based approaches—position fixes are where the boats are right now, not yesterday. Space-based radar systems must strive to approach that level of response if they are to be accepted as a useful part of any nation's MCS system. For nations that can afford their own groundstation, this problem is minimized. For those that must depend upon the acquisition and relay of data from a remote site it becomes a bigger concern. Consequently, the consistent commitment of RadarSat International to the delivery of space-based radar to vessel detection and

monitoring and interests in a near-real time framework (≈ 6 hours) is welcomed. Other entities responsible for space-based radar system operation are encouraged to take the steps necessary to make these data available sooner for those applications that are time-sensitive. Improvements in data transmission relays, data compression algorithms, and processing hardware should make a near-real time data delivery goal more achievable.

5.2.2 Data Coverage and Development of Integrated Space-based Monitoring System

Even if data are quickly supplied to the value-added or end-user, the dependence upon one or two space-based radar systems for all of our space-based monitoring needs will leave huge temporal gaps in coverage. Whereas transponder systems can provide a position report on command, days may go by before a RadarSat or ERS sensor revisits the site of interest to a specific management authority. By this time, violators are hundreds of kilometers away, if not safely in port.

It is encouraging to note the recent launch of ERS-2 and the launches of other space-based radar systems planned for the near future (RadarSat and ENVISAT). These sensors should greatly increase coverage capabilities. As we consider a new paradigm for future fisheries MCS, what should not be neglected is the suite of high resolution visible wavelength sensors already in orbit or planned for launch in the next few years. Table 6 itemizes the set of satellites with the spatial resolutions currently thought capable of addressing the MCS problem. A total of 13 systems are in the list, 5 in orbit now and 8 set for launch before the turn of the century.

Table 6: Existing and Planned Environmental Sensors with Spatial Resolution Attributes Permitting Ship Detection Applications.

Existing Satellites/Sensors	Operated by:	Revisit	Spatial Resolution (m)
SPOT	France Private (Spot Image)	16 - 26	10 to 25
IRS	India Public	16 - 26	10 to 25
LANDSAT	USA Public	16 - 26	10 to 25
ERS-1 Synthetic Aperture Radar	EEC	35	30
JERS-1 SAR	Japan	44	30
<u>Future Sensors (Anticipated Launch Date)</u>			
RADARSAT/SAR (Fall, 1995)	Canada/US	1 to 24	10 to 100
ERS-2/SAR (1995/1996)	EEC	35	30
Worldview/Optical sensor (1996)	US Private (Worldview)	2	3
Eyeglass/Optical (1996/1997)	US Private (Orbital Sciences)	2	1
SPOT 4	France Private (Spot Image)	16 - 26	10 to 25
Lockheed/Optical (1997)	US Private (Space Imaging)	2	1 & 4
ENVISAT/Advanced SAR (1998)	EEC	35	30
SPOT 5	France Private (Spot Image)	16 - 26	10 to 25

Two main obstacles stand in the way of the effective use of these sensors as fisheries MCS tools. The first of these is the lack of an efficient means of cross-platform data collection and processing specific to the fisheries MCS application. It is not unlike the type of problem NMFS has tried to avoid in its publication of standards for transponder-based vessel monitoring systems. Many different sensors have many different owners with many different stated and unstated interests. Furthermore, data from one sensor is often stored, compressed, transmitted, and processed quite differently than data from another sensor. Consequently, unless there emerges an expressed interest in coalescing these disparate data types into a meaningful whole, which in our context is a new fisheries MCS paradigm, they likely will remain separate, and much less informative, pieces. Recognition that the value to fisheries MCS of the assembled whole is much greater than that of any of the separate pieces is perhaps the first step along the pathway to the more effective application of these data to fisheries management and monitoring problems.

5.2.3 Data Cost

The second major obstacle to a broader use of high resolution visible and microwave sensors for fisheries MCS is data cost. Costs of \$1,000 to \$5,000 per image are prohibitively expensive for most second and third world countries where space-based systems could otherwise provide the greatest boost to fisheries MCS capabilities. Here again, transponder-based systems have probably set the benchmark towards which space-based system marketers must look if they expect to seriously crack the vessel detection market nut. Including system hardware, software, infrastructure, and data transmission costs, transponder-based systems cost, on average, \$100 per day per area

(includes multiple boats) of coverage (R.G. Lovingfoss, pers. comm, April 1995). One coverage "day" for the least expensive space-based system is, at a minimum, an order of magnitude higher than these costs.

Data costs become trivial, of course, if just one boat is confiscated because of an illegal intrusion detected by the radar vessel detection system. Furthermore, they represent a small fraction of the annual expenditures on the conventional approaches that would be necessary to replace them. Nevertheless, the low cost of transponder-based systems is a relevant reference point. If such a system can keep track of 90% of the boats in my EEZ for \$100 per day, is it cost effective to pay \$3,500 per day to identify the final 10%? Such a question really can only be answered by the decision maker actually responsible for that EEZ. However, vendors of high resolution space-based radar and optical data can make the answer more obvious by better considering the product they are offering, the operational and economic realities of the market they are targetting, and the reference points to which they are being compared, in their pricing decisions. If they do, the future for the use of space-based radar and optical remote sensing data as a tool in effective fisheries MCS systems is bright.

6.0 ACKNOWLEDGEMENTS

The authors wish to thank the Canadian Coast Guard and Mr. Larry Pokeda for providing access to their Ucluelet vessel position database; the European Space Agency for ERS-1 data used in the study, and the Alaska SAR Facility in Fairbanks, Alaska for their cooperation throughout the project. The work was funded in part by funds provided by the NASA Earth Observation and Commercial Applications Program.

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OCENS

▼ About the company

Ocean and Coastal Environmental Sensing, Inc. (OCENS) was founded to develop and market affordable high technology equipment and information services that use remotely sensed satellite data. Its business interests are located primarily in the marine and coastal zone markets.

New sensors, reduced hardware costs, expanded processing capacities and a maturation of data access and distribution systems are now breaking down many of the barriers that in the past impeded broad use of remotely sensed data in those markets.

Through product innovation, the expertise of its professionals, and applications development initiated in collaboration with NASA, OCENS is taking advantage of these new opportunities. OCENS is a leader in its field: we'd like to help you become a leader in yours. We invite you to read on and discover how OCENS capabilities can meet your specific needs.

▼ Glossary of Terms

Global Positioning System (GPS): The GPS is a data stream providing high-accuracy location information.

Vessel Detection System (VDS): As implied, the VDS is a system specifically designed to determine vessel locations.

Monitoring, Control and Surveillance (MCS): An integrated approach to zone enforcement and management utilizing each of the three areas in concert.

Remote Sensing: A term used to describe the acquisition of earth information using sensors on board aircraft and/or space-based satellites.

NASA's EOCAP: EOCAP (Earth Observation Commercialization/Application Program) matches sound product/business opportunities identified by private sector firms with NASA's technical expertise and development funds.



OCENS

▼ Proven expertise

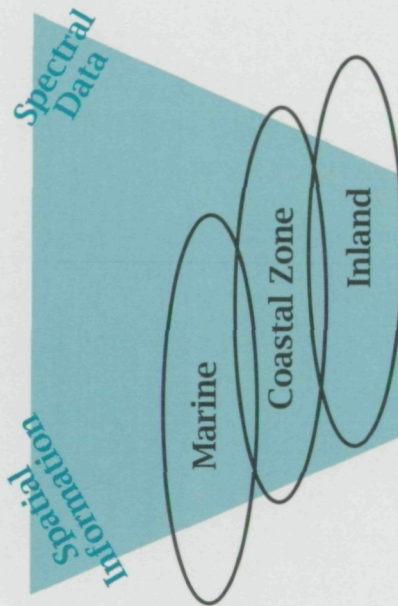
OCENS was founded on the expertise of leading professionals in software development, natural resource management, fisheries, image analysis, and remote sensing technology. Several of these founders are principals of the world-renowned fisheries consulting firm, Natural Resources Consultants (NRC).

NRC was established in 1980 to meet the need for a comprehensive consulting service dealing with all aspects of the marine and inland fishing industries and their related resource base. Since its formation, NRC has undertaken more than 900 projects concerned with the assessment, conservation, utilization, valuation, and commercial development of marine, coastal zone, and inland resources.

The core of OCENS weaves together this access to NRC's unique resource and market awareness along with leading edge software development and hardware systems. This combination of proven expertise and cutting edge development makes it possible for OCENS to offer you products addressing the specific needs of marine and coastal zone users.

The OCENS logo is a reflection of our operating philosophy and business interests. Remote sensors collect color, temperature and other spectral data that can help define targets of interest to end-users in marine, coastal or inland markets. Spatial information provides size, shape and location insights that further clarify these features.

OCENS recognizes that activities of the three environmental zones are closely intertwined. This is symbolized by the three interconnected rings that lie within the OCENS data acquisition and application development triangle. That these rings are at the center of the triangle further reflects OCENS' belief that application of data collected by remote sensors should be driven by real needs defined by users in each of these markets. Available data that fail to pass through the filter of customer requirements do not emerge as OCENS applications.



Application Development

OCENS

SeaStation and OmniVision product descriptions, including hardware and software specifications, may be obtained by contacting OCENS.

OCENS Products

▼ *SeaStation*

SeaStation targets users in the commercial fishing, sport fishing and yachting markets. It provides an easy-to-use, Windows-based, graphical interface permitting rapid, direct-to-vessel acquisition and processing of environmental data originating from space-based sensors. The point and click simplicity of *SeaStation's* interface means that anyone who can operate a PC can now access valuable remotely sensed data.

SeaStation algorithms reflect the latest advances in image processing and navigation and offer a wide range of powerful analytical tools. Imagery acquired directly from orbiting satellites is linked to the Global Positioning System (GPS) data stream to provide real-time relationships between vessel position and environmental data such as sea surface temperature, weather conditions, and ice edge location. Two versions of the software, *SeaStation Professional* and *SeaStation Standard*, permit you to match software capabilities to your individual information needs.

OCENS has further recognized user interests in compactness and portability by crafting its *SeaStation* hardware/software bundle for use on either notebook or desktop computers.

▼ *OmniVision*

The *OmniVision Vessel Detection System (VDS)* responds to the need for improvements in fisheries monitoring, control, and surveillance (MCS) capabilities. *OmniVision* is a sophisticated hardware/software bundle developed in collaboration with NASA that analyzes space-based radar data and uses that information to detect vessels and vessel wakes. Because radar cuts through mist and cloud cover, *OmniVision* is able to identify vessel locations, wake directions, and speeds when other sensor systems cannot.

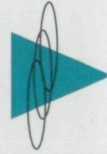
OmniVision is available through OCENS as either a stand-alone hardware/software bundle or as a system integrated with radar data purchase, relay, ingestion and processing services. As a part of this latter approach, OCENS works with you to set up comprehensive, yet cost-effective, services that may draw upon radar and other sources of vessel traffic, position, and identification information in order to meet the MCS needs of marine resource managers, enforcement agencies, coastal vessel traffic controllers and large-scale fleet managers.

Looking Ahead

Current versions of *SeaStation* act as the core of OCENS' *SeaStation* vessel information system. As new space-based sensors and data sources are deployed in the future, modules permitting easy integration of these data with the base environmental information or, in fisheries applications, with the environmental/catch system will be added. A complete package places a powerful tool for environmental data collection and analysis at a skipper's fingertips.

Existing and emerging sensor launches and improving data relay capacities provide technical opportunities for unprecedented insights into marine and coastal zone processes. OCENS recognizes, however, that end-user needs must drive technology utilization, not the other way around. We take great pride in our industry and global market awareness and our commitment to listening to what you, the customer, want. OCENS believes that such a philosophy best permits us to harness the capabilities of remote sensing technologies for your practical benefit.

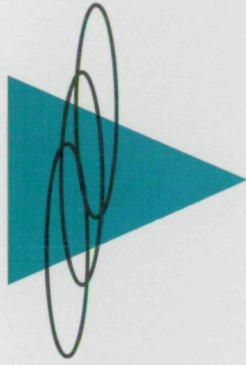
We welcome your interest in OCENS...and the future of remote sensing technology.



OCENS

Ocean and Coastal Environmental Sensing

4055 21st Avenue West ▼ Seattle, WA 98199
▼ Phone: 206/285-3480 ▼ Fax: 206/283-8263



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Ocean and Coastal
Environmental Sensing, Inc.

The OCENS Mission

To develop and market software, equipment, and information services that utilize data acquired from aircraft and earth orbiting satellites, and improve the operations of marine and coastal zone users.

OCENS

Windows 3.1 or Windows95
for laptop or desktop users

SeaStation[®]

Automated Satellite Image Reception for Ocean and Weather Data

"...simply the best."

Overview

To achieve the goal of making weather and ocean data available with mouse-click ease, a new standard had to be set. *SeaStation is that standard.*

So now, no matter where you are on the world's oceans, SeaStation brings real-time satellite weather and ocean data directly to the desktop or laptop computer on your vessel. Use it to save time, save fuel and save lives.

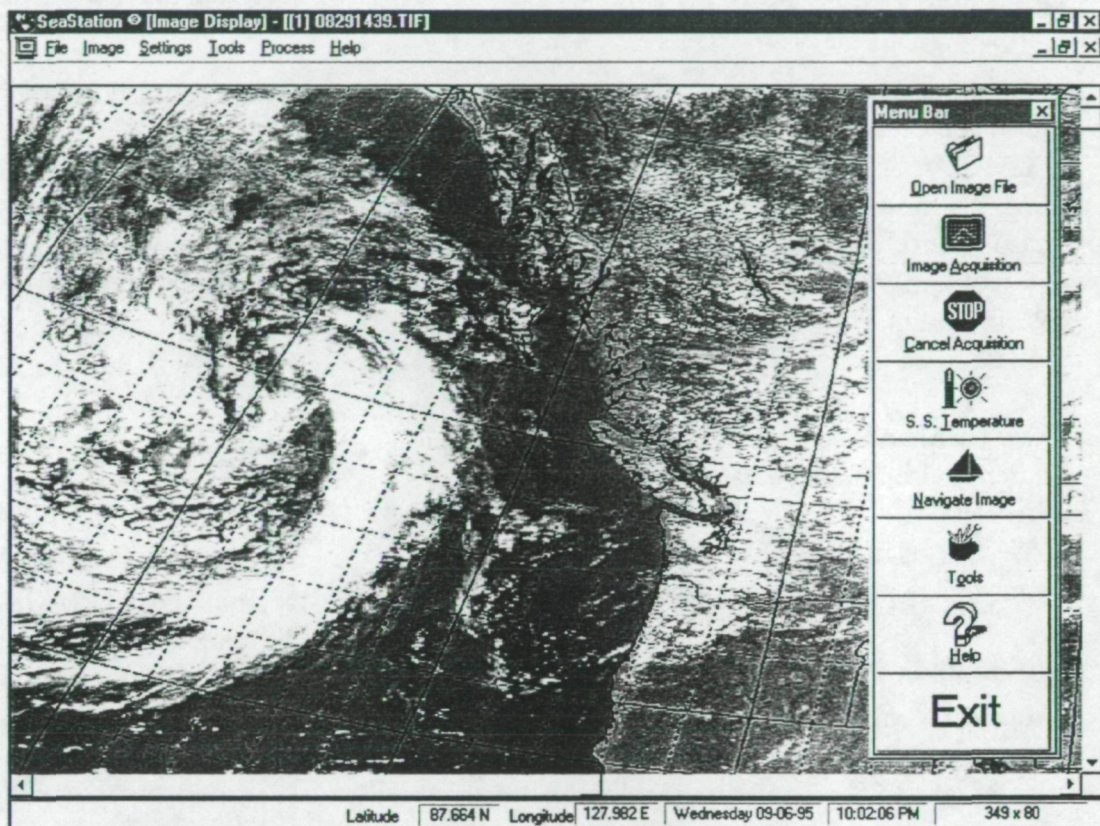
Easy to Set Up, Easy to Use

Simply install the SeaStation software, hook up the SeaStation antennae to the satellite receiver and SeaStation converter card, and start receiving satellite imagery.

Automatic Acquisition Once you click start, SeaStation begins satellite tracking and download functions automatically. As satellites come within range of your vessel, SeaStation locks onto their signal, downloads the imagery to your computer screen, all the while monitoring on-going satellite traffic in the background.

Powerful Processing State-of-the-art image processing routines are applied to the acquired image with one click of your mouse. In a matter of seconds, raw satellite data are converted to the weather and temperature information important to you.

GPS Interface SeaStation successfully integrates your vessel's Global Positioning System with the downloaded satellite image. With this capability your vessel's position is plotted dynamically on top of the on-screen image. Add latitude and longitude grids, coastlines, and political boundaries to provide further context to your position and the ambient weather conditions.



Trip Planning Point and click your mouse on trip waypoints, weather systems, and ocean features of interest to you in the image. SeaStation automatically reports to you the bearing and distance from your present position to those targets.

Sea Surface Temperature A simple but flexible interface for the analysis of sea surface temperature obtained from satellite imagery was one of the key inputs OCENS received from fishermen during the SeaStation development process. OCENS has ported those insights into versions prepared for professional skippers, navigators and cruisers.

Image Annotation Add notes to the image about your passage and the ocean and weather conditions affecting it. Inspect these notes in the months ahead as you review your trip and plan for the next one.



OCENS

SeaStation[®]

SeaStation System Includes

- SeaStation software
 - Satellite receiver
 - PCMCIA converter card
 - ISA Bus card (for installation of the PCMCIA card in desktop computers)
 - 10 feet (3m) of cabling
 - Whip antennae
 - WeatherFax port
- Two user handbooks describing how satellite and other environmental data can augment your maritime skills.
- One year of free monthly updates of e-data to keep your image navigation accurate.

Additional Options

- Alternative antennae designs
 - Longer cable lengths
 - Laptop or desktop configurations of the system
- Detailed handbooks tailoring the use of satellite and other environmental data to the specific geographic area that your next cruise will carry you.

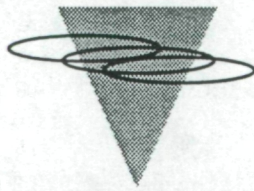
System Requirements:

- 486 or higher PC compatible (desktop or laptop)
- Microsoft Windows 3.1 or Windows95
- A mouse or other pointing device
- Minimum 8MB RAM
- Minimum 20MB hard drive
- Minimum 640x480 color video
- Type 2 PCMCIA slot (laptop)
- 2 ISA Bus card slots on motherboard (desktop).

OCENS' Mission

Ocean and Coastal Environmental Sensing, Inc. (OCENS) was founded to develop and market affordable high technology equipment and information services that use remotely sensed satellite data. Through product innovation, the expertise of its professionals, and applications development initiated in collaboration with NASA, OCENS has become a leader in its field. *We'd like to help you become a leader in yours.*

Ask for your authorized local representative by contacting:



OCENS

Ocean and Coastal Environmental Sensing, Inc.
 4055 21st Avenue West, Suite 100
 Seattle, WA 98199
 Tel. 206-285-3480, Fax 206-283-8263



OCENS

OMNIVISION

Q: What does the Norwegian Defence Research Establishment have to do with your vessel detection needs?

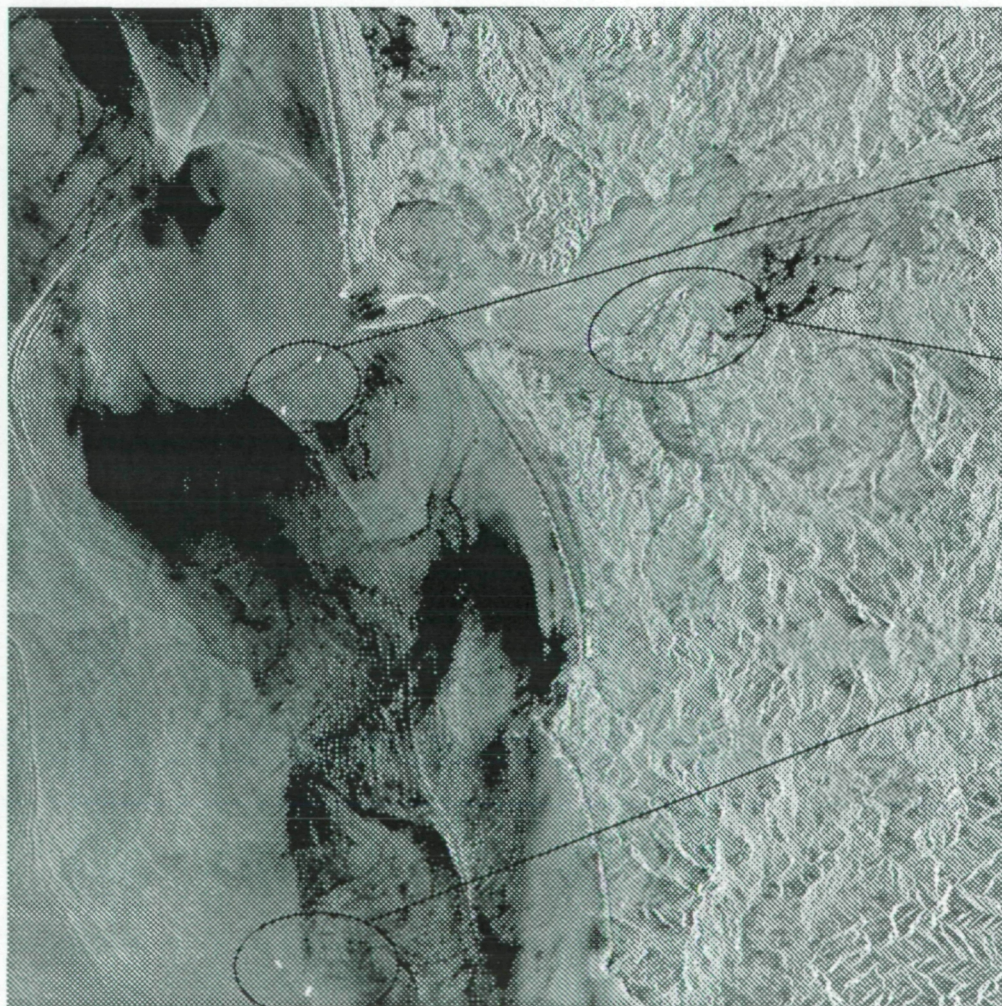
*A: Since 1991, the Norwegian Defence Research Establishment has been relying on an advanced radar technology to help monitor Norway's 2 million sq. km economic ocean zone. A similar eagle eye detection system known as **OMNIVISION** is now available for your vessel monitoring needs through Ocean and Coastal Environmental Sensing (OCENS).*

From your keyboard, **Omnivision** gives you access to near real-time satellite images allowing you to identify vessel location, speed and heading.

Omnivision's computer-based vessel detection system (VDS) offers umbrella coverage of your region-of-interest. Because it allows you to rapidly pinpoint the location

of vessels through each 100 km swath of satellite imagery, your agency's monitoring and enforcement effectiveness can increase substantially. Rather than having to patrol your entire economic zone with planes and ships, **Omnivision** enables you to deploy such assets directly to specific troublespots.

The **Omnivision** VDS utilizes data from Radarsat International's orbiting SAR (synthetic aperture radar) instrument to cut through mist and cloud cover that block monitoring by other types of satellite data or piloted craft. **Omnivision** identifies vessel location, wake direction and speed, and allows instant access to a geopolitical overlay. The system can also identify a number of other oceanographic features that are of use to the fisheries manager, enforcement officer and scientist.



Sea buoy and pilot ship seaward of Columbia River Breakwater

Vessels moored near Astoria Harbor, OR

Northbound shipping traffic

Photo rendition of ERS-1 SAR image of southern Washington/northern Oregon coastline, including the mouth of the Columbia River. Image supplied by the Alaska SAR facility and processed with OCENS's **Omnivision**.

OmniVision

Product information
continued...

Simply put, **OmniVision** is a sophisticated Hewlett-Packard workstation which runs software that analyzes radar data and uses that information to detect vessels and vessel wakes.

The **OmniVision** package includes all the hardware, software and training required for installation of the system.

OmniVision is ideal for agencies and individuals responsible for monitoring vessel movements in territorial waters. Interested parties may include fishery agencies, Port Authorities, Coast Guard, Navy or individuals with a particular ocean monitoring concern.

For further information, please contact OCENS at the address below for a list of relevant publications and references.

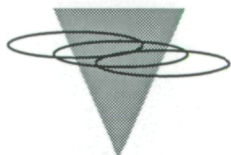
About OCENS:

OCENS is a company developed to revolutionize marine and coastal zone usage through affordable uses of satellite remote sensed data. The Company is founded by professionals with expertise in natural resource management, fisheries, image analysis, and remote sensing technology. OCENS is managed by current and former executives of Natural Resources Consultants, a world-renowned fisheries consulting firm; the National Oceanic and Atmospheric Administration; the University of Washington; and The Boeing Aerospace Company.

Through product innovation and the expertise of its founders, OCENS has positioned itself to be the leading supplier of remotely sensed information to the marine and coastal zone markets.

Some of these products and services are used to:

- Improve fishing effectiveness and reduce waste;
- Optimize navigation decisions;
- Reduce loss of life and equipment due to ice and weather hazards;
- Increase aquaculture production;
- Monitor use conflicts and encourage sustainable use policies and regulations.



OCENS

Ocean and Coastal Environmental Sensing
4055 21st Avenue West
Seattle, WA 98199
Telephone: 206/285-3480
Telefax: 206/283-8263

OmniVision System Specifications:

- ▼ Memory: 64 MB
- ▼ Mass Storage: ≥2 GB
- ▼ Display Size: 20"
- ▼ Processor Speed: ≥80 SPECfp,
≥80 SPECint

The **OmniVision** workstation is based on any of several Hewlett Packard workstations (i.e., the 700 series models of the HP 9000 workstations). **OmniVision** runs under X Windows and utilizes HP's native graphics language STARBASE where required for maximum power. The **OmniVision** system is based on a software package developed by NASA for the USDA.

The SAR software on the workstation ingests SAR data, performs geolocation based on header information, performs any of a number of speckle filters to preprocess the data, highlights candidate target ships, tests for any wakes, displays their positions in latitude/longitude, and indicates wake direction.

The **OmniVision** software can rapidly overlay geopolitical boundaries on the SAR image from digital line graph files at a number of scales.

The OCENS Mission

To develop and market software equipment and information services that utilize data acquired from aircraft and earth orbiting satellites, and improve the operations of marine and coastal zone users.



Natural Resources Consultants, Inc.
4055 21st Avenue West, Suite 200
Seattle, Washington 98199
U.S.A.
